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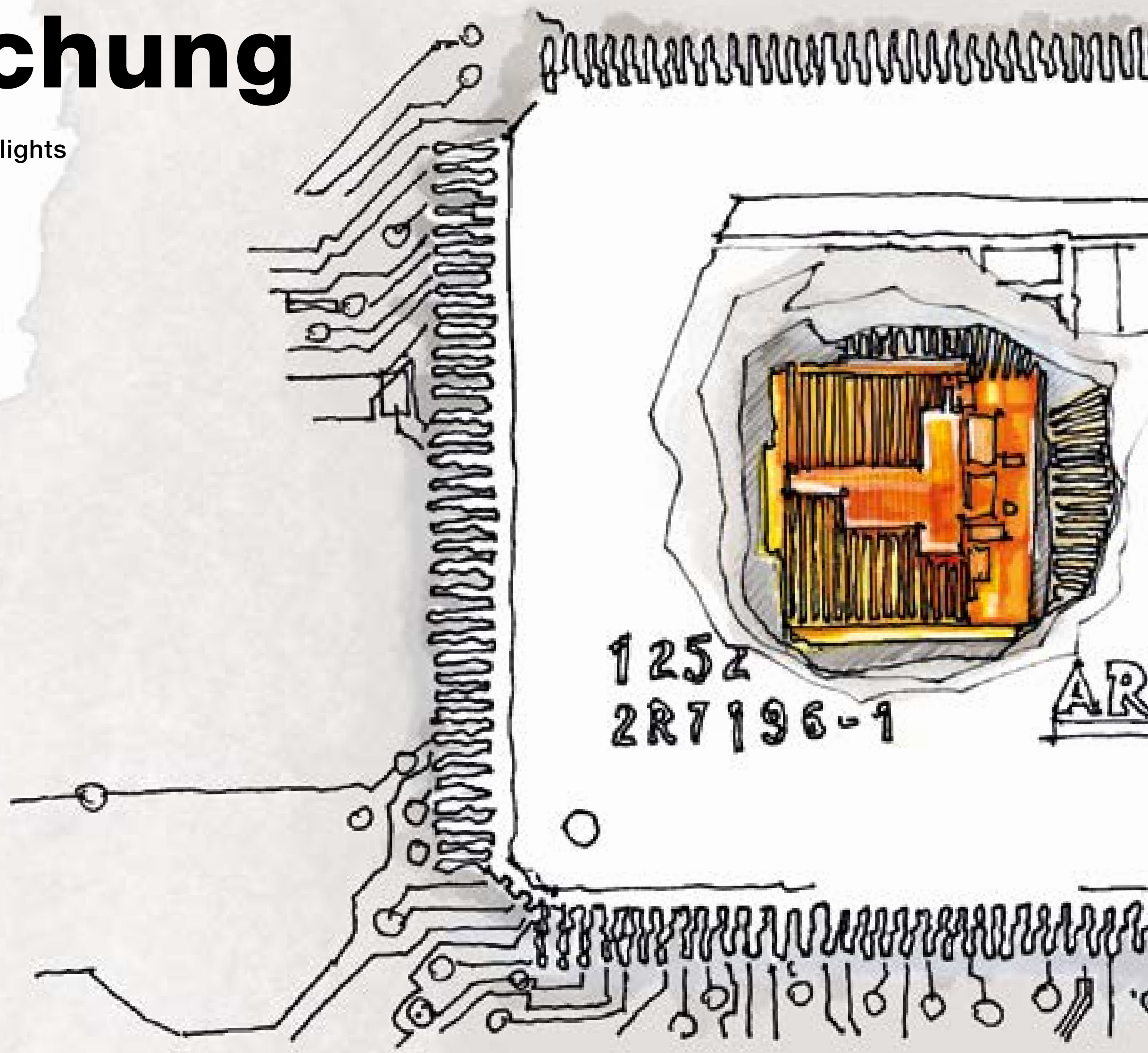
Faszination **Forschung**

TUM Research Highlights



One Step Ahead
of the Bad Guys

Proteomics: The First Maps of the Human Proteome
Virology: Lurking in the Liver
Nanoelectronics: Nano Sprays with a Spark

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Dear TUM friends and associates,

With painstaking precision and devotion to detail, good scientists challenge accepted ideas – bit by bit. They are motivated by the desire to improve the world around us and our everyday lives. In this edition of Faszination Forschung, we invite you to discover how years of work by TUM researchers can result in truly groundbreaking findings.

History was made on June 12, 2014, at the opening ceremony of the soccer World Cup in Brazil, when a paraplegic man took the first kick of the tournament using the power of his mind. Gordon Cheng, head of the TUM Institute for Cognitive Systems and an expert in robotics, worked with colleagues in the US to develop the “exoskeleton” that made this dream a reality.

On May 28, 2014, TUM Chair of Proteomics and Bioanalytics Bernhard Küster published one of two initial comprehensive maps of the human proteome. This achievement is on a par with the first complete sequencing of the human genome by Celera Genomics and the Human Genome Project in 2001. Mapping the proteome – in other words, all the proteins in the human body – is a second crucial key to unlocking the mystery of human life.
With her new research showing that it may be possible to cure hepatitis B, Ulrike Protzer has achieved a scientific breakthrough. Over 250 million people suffer from persistent hepatitis B infections. Until now, doctors were able to treat only the symptoms of this chronic viral infection, which can cause severe liver damage. Through her work in virology, Protzer has found a way to destroy the DNA of the hepatitis B virus, opening up new therapeutic possibilities.

The European Space Agency’s GOCE satellite mission provided the most precise measurements of the Earth’s gravitational field established to date. The satellite orbited the Earth 27,000 times, collecting more than five terabytes of data. Geodesist Roland Pail, coordinator of the GOCE Gravity Consortium, used the data to create today’s most precise gravity model of Earth. Researchers from a wide range of fields – from oceanography and climate studies through geophysics and geology to construction and civil engineering – can apply the GOCE data to their work.

There has long been a demand in industry for affordable gas sensors suitable for mass production. Paolo Lugli, Chair of Nanoelectronics at TUM, has come up with a solution using carbon nanotubes as sensors. He has developed a cost-effective process that allows these sensors to be sprayed or printed onto both small and large surfaces.
In his latest book on calculating the world, renowned philosopher and scientific theorist Klaus Mainzer explores the world of big data – where processes are used to comb through large amounts of data to establish contextual relationships. He also looks at the risks and restrictions associated with these processes. In an interview in this publication, Mainzer explains his main theses, based on many years of research into algorithms.
Big data is also important in networking technical systems that communicate with one another. Georg Sigl is responsible for uncovering security gaps in these systems and developing technologies to close these loopholes. As an IT security expert, he focuses mainly on controllers in machinery or industrial equipment – an area increasingly targeted by hackers.

In this issue you will discover more about our researchers and their ongoing search for the solutions of tomorrow. Enjoy!

Prof. Wolfgang A. Herrmann

Picture credit: Eckert

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Cover Story: **One Step Ahead of the Bad Guys**

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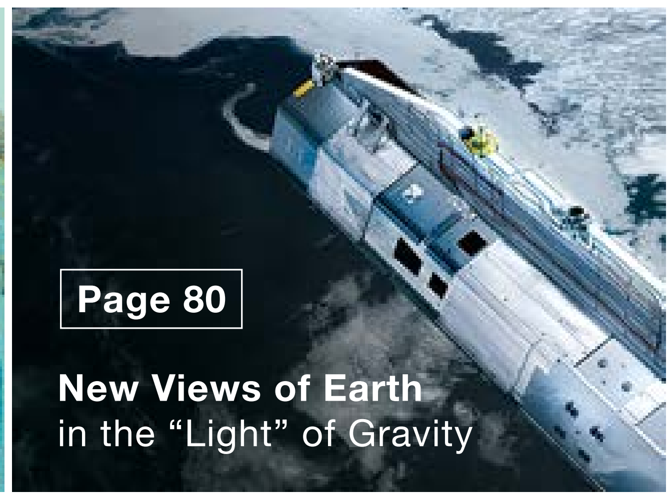
The First Maps of the Human Proteome



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New Views of Earth in the “Light” of Gravity

Cover Story

“We build the bridge between industry and university research in order to win the unending race against hackers.”

Georg Sigl

Research and Technology

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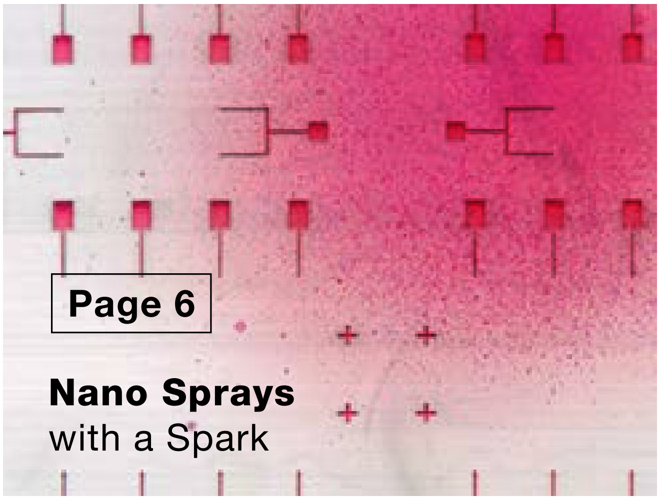
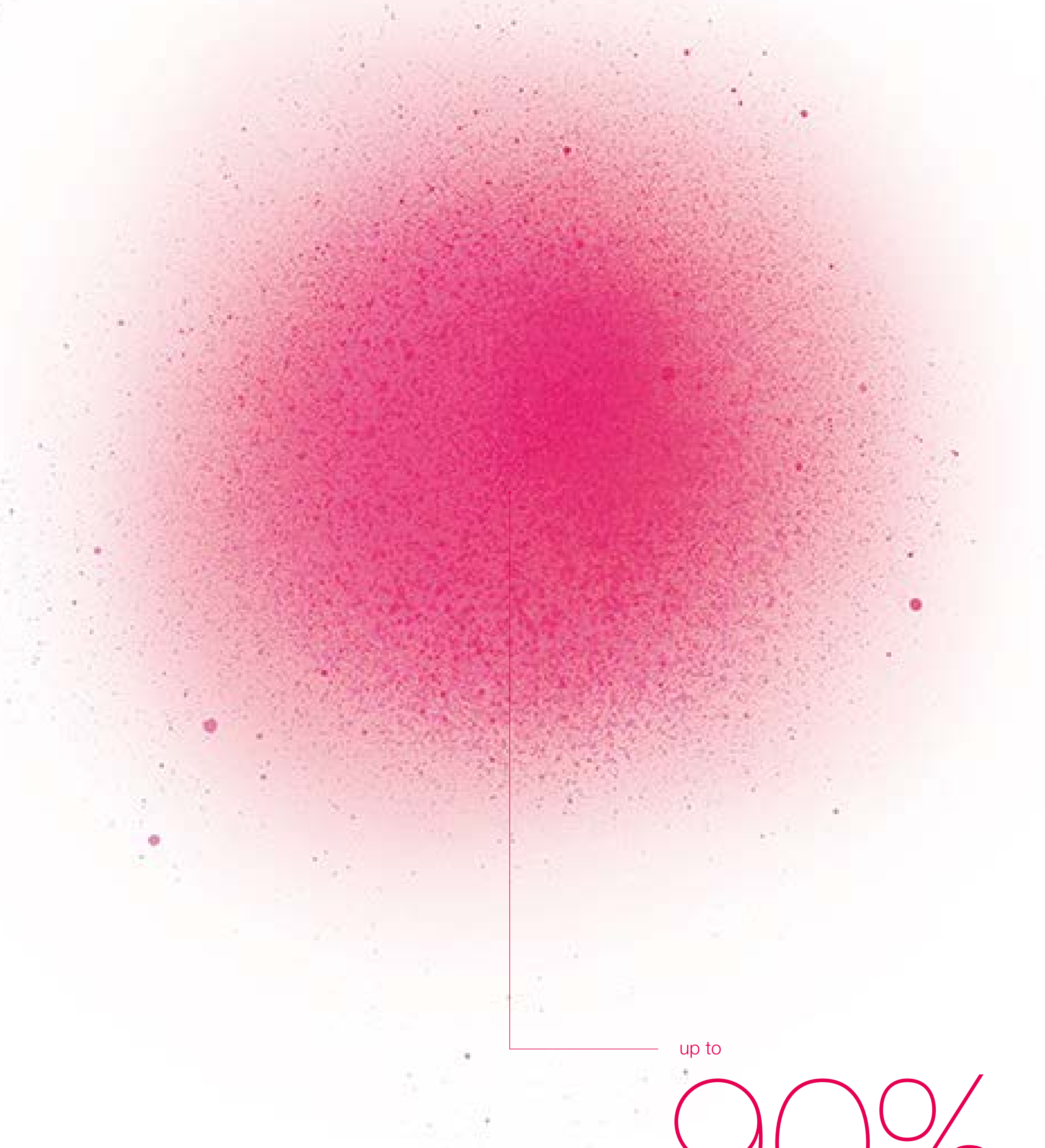


In Every Issue



up to

90%

transmittance

bendable

a few tens of
nanometers thick

Nano Sprays **with a Spark**

Why complicate something so simple? This was the question posed by researchers at TUM's Institute for Nanoelectronics. The group led by Prof. Paolo Lugli wanted to replace complex and expensive coating methods using exotic materials with common spraying and inkjet printing processes. With impressive results. The list of industrial applications that can use these innovative methods is long and growing all the time.

Link
www.nano.ei.tum.de

Picture credit: ediundsepp

Nano-Sprays mit Pfiff

Neu entdeckte Materialien versprechen neue Möglichkeiten: Nanoröhrchen aus Kohlenstoff, Graphen, leitfähige Polymere oder Silber-Nanodrähte können bei der Entwicklung einer Vielzahl elektronischer Produkte und Sensoren innovative Wege eröffnen. Prof. Paolo Lugli und seine Mitarbeiter am Lehrstuhl für Nanoelektronik der TUM haben dafür in den letzten Jahren die Sprühbeschichtung perfektioniert. Dabei werden mit Sprühköpfen hauchdünne Schichten auf die verschiedensten Oberflächen aufgetragen. Dies ist weitaus billiger und schneller als bisherige Verfahren wie Sputtering oder Epitaxie. Auch die Methode des Tintenstrahl-Druckens nutzen die Forscher, beispielsweise um die dazugehörigen elektronische Schaltungen schnell und billig herzustellen.

Intelligente Anwendungen für Alltag und Labor

Anwendungen gibt es viele, und täglich kommen neue Ideen dazu: Gassensoren sollen bald die Luft in Innenräumen überwachen oder messen, wann Fleisch verdorben ist; Sensoren für die Ionenkonzentration in Flüssigkeiten können ganze Labors ersetzen, die Forschung in der Pharmabranche erleichtern oder unser Trinkwasser überwachen. Andere Sensoren werden vielleicht bald in Küchenherden, Kühlschränken oder Waschmaschinen Temperatur und entstehende Gase detektieren. Transparente Schichten, die sich bei Anlegen einer Spannung erhitzen, könnten Windschutzscheiben abtauen und Windkraftanlagen eisfrei halten. Und in Zukunft könnte man dreidimensionale Objekte, die in 3D-Druckern hergestellt werden, mit aufgesprühten funktionalen Schichten kombinieren und auf diese Weise intelligent machen. *Brigitte Röthlein*

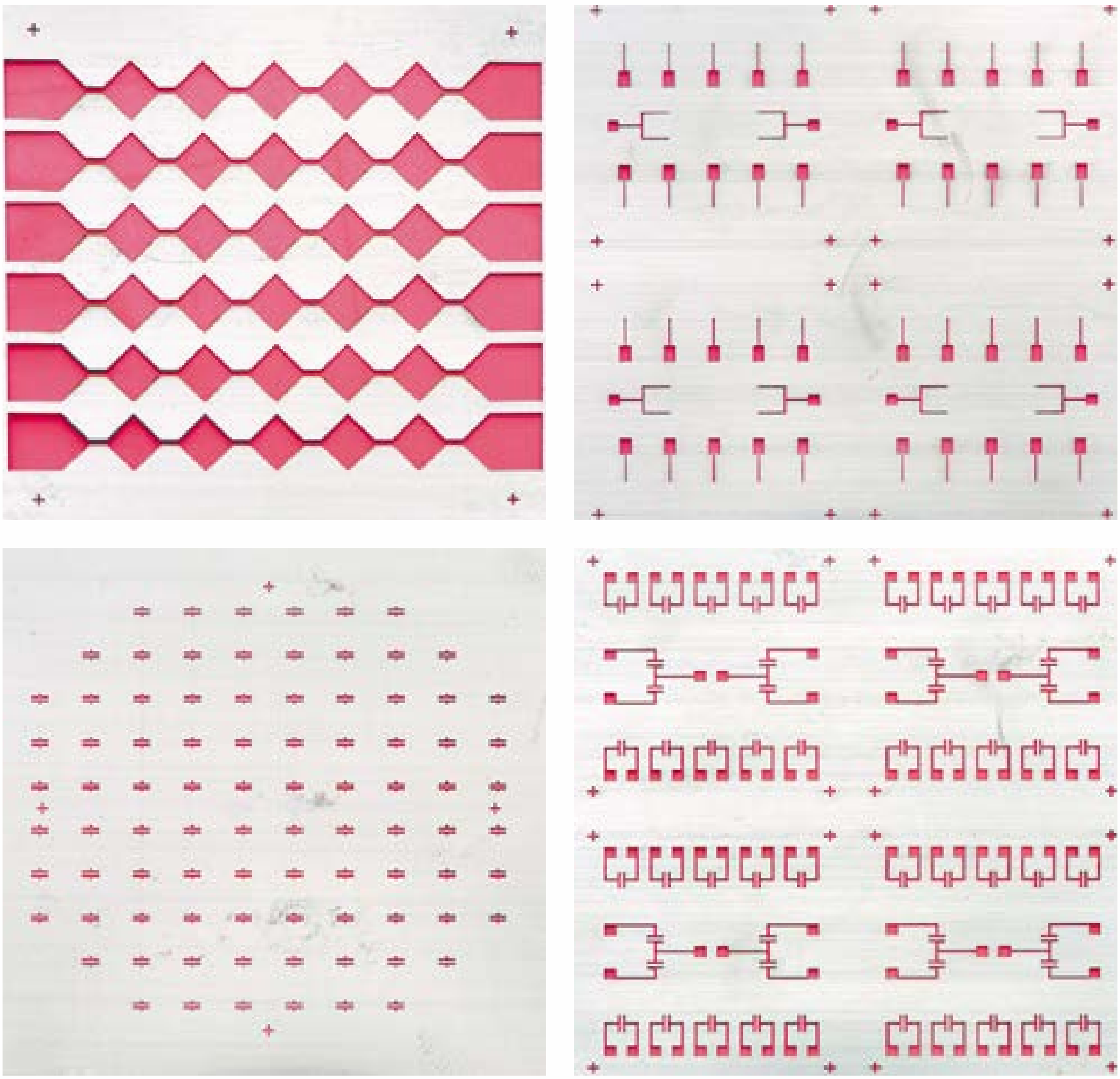
Science is still full of surprises. Numerous new materials have been discovered in recent years: carbon nanotubes, graphene, metal nanowires and conductive polymers. Methods have been developed to produce these exotic substances in greater quantities and with a sufficiently high level of purity, but researchers are still racking their brains about what they can actually do with them. “This is a rapidly growing field of technology,” comments Paolo Lugli, Chair of Nanoelectronics at TUM. He and his team are developing methods to apply ultra-thin layers of the materials onto a variety of substrates, thus making them useful for a wide spectrum of applications. At the forefront are spray deposition and inkjet printing. While already an industrial standard for many applications, these methods are now making their way into the world of electronics.

The arrival of the unbreakable cellphone

One example is transparent electrodes, found in touchscreens, television flatscreens and solar cells. Up to now, these have been made of indium tin oxide (ITO). This is an expensive and brittle material that tears easily when applied to flexible films, which means that the electrodes lose some of their electrical conductivity. Carbon nanotubes (CNT) provide a solution to this problem.

They form a dense mesh of conductive tubes when deposited on a surface. When bent, the mesh moves elastically, but does not tear. This opens the door to the development of cellphones with bendable, shatter-proof touchscreens. Another plus is that carbon is an abundant material, unlike the heavy metal indium, which occurs in the Earth’s crust as rarely as silver or mercury. “Electrodes made of CNT are 80 percent transparent,” explains Lugli, “which makes them highly suitable for optical applications.” His colleague Dr. Alaa Abdellah has developed a spray coating process that allows ultra-thin and very even layers to be applied over both small and large surfaces. “We have been working on this for over six years, so we have a lot of experience at this stage,” he affirms. “First of all, you need good spray heads, and then the right interplay between the ink, the spray parameters and the distribution.” Over this time, the researchers under Lugli and Abdellah have learned a number of tricks to help them achieve good results. They know how to produce the most homogeneous inks from exotic substances, how to make them adhere to the substrate, how to remove unwanted chemicals afterwards and how to achieve a perfectly even sprayed film. “All of this trial and development work required a great many bachelor’s, master’s and doctoral theses,” confirms Paolo Lugli. “And we are still a long way from the finish line. New challenges are always popping up for which we have to find clever solutions.”

For instance, there is the question of how to distinguish between gases using the CNT layers. The researchers have already proven that the carbon nanotubes, deposited on a foil, are able to detect gas molecules. The gas molecules attach themselves to the nanotubes and alter the conductivity of the layer. This change can be measured and used to determine the concentration of molecules in the environment. The challenge now is to detect the gases on a selective basis, for example distinguishing carbon dioxide (CO_2) from ammonia (NH_3), carbon monoxide (CO) or nitrogen oxides (NO_x). For each of these gases, there is huge demand for a low-cost sensor that can be mass-produced. These sensors could be used, for instance, to monitor CO_2 levels in indoor spaces, to detect NH_3 and thus spoilage in packaged meat, and to protect health and safety by monitoring toxic CO and NO_x levels. “We are on the brink of making the CNT films selective,” promises Lugli. “Right now we are looking at functionalizing the layers with nanoparticles, using palladium or gold for example.” These elements react with the individual gases in different ways and therefore alter the conductivity of the layer in a distinctive way. “If we are successful, then before long, every classroom, lecture hall or conference room could be equipped with a CO_2 meter to indicate when the room requires urgent ventilation. Air conditioning units could also be fitted with such sensors.” Besides gas concentrations, the nanolayers could also measure temperature. Manufacturers of household goods are already considering such applications in stovetops, washing machines and refrigerators. ▷



Picture credits: Filser

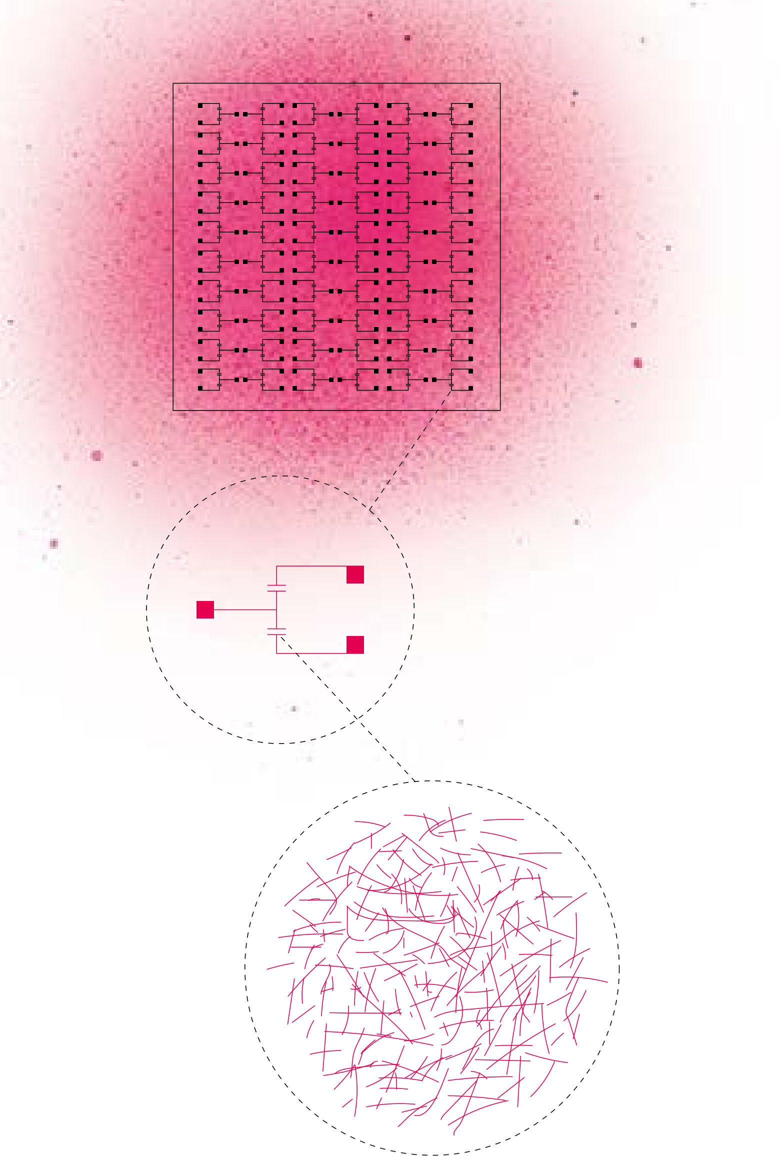
It all begins with simple shapes stamped onto templates. The researchers use these to see whether the exotic materials that they spray onto films will adhere properly and distribute evenly without running off. Later, when they are working on industrial applications, they must ensure that the spray coating has been applied precisely. This is the only way to ensure that the delicate sensor structures function correctly.

Integrated circuits by inkjet

The TUM researchers are by no means limiting their work to gas-related applications. They also have some interesting plans for liquids. For example, they have succeeded in covering CNT sensor fields with membranes that selectively allow only specific ions such as chlorine, magnesium or calcium to pass through. These in turn alter the conductivity, so their concentration can be measured with great accuracy using an electronic circuit. The group has submitted a patent application for its array of ion-sensitive sensors, rather like electronic noses analyzing different smells. “We tested the sensors on various mineral waters and were delighted to find that we were able to distinguish between them,” reports Lugli.

They are hoping to develop this idea further to create a “lab on a chip” capable of capturing and measuring multiple parameters in parallel on a miniature scale. This could be used to monitor drinking water quality, for example, or for the chemical analysis of blood and other organic liquids. A particularly interesting project is under way in cooperation with the University of Alberta in Canada. The researchers want to place living cells directly onto the sensors in the hope of being able to study the function of the cell membrane. How quickly are calcium, potassium or sodium absorbed or released through their ion channels, and under what conditions do the cells become healthy or diseased? “Finding answers to these questions is of huge importance for the development of new drugs,” points out Lugli.

While the sensors are highly intelligent, they cannot do it all. Some form of electronic device is needed to analyze the measurements, read them out or send them to a cellphone. Abdellah and his team are working on a fast and cost-effective way of producing such circuits using inkjet printing. “The ink we use is made from silver particles, which we print onto photographic paper or plastic foils and then sinter with a UV flash lamp,” explains the engineer. “We can then add standard electronic components, just like on a conventional printed circuit board.” The devices thus produced may be considerably larger than current microelectronic chips, but they ▷



When viewed under the microscope we can see that the structures of the sensors (center) are composed of extremely fine carbon nanotubes (bottom) that form a dense mesh when deposited onto a surface. With their spray method, the TUM researchers can layer them onto films in large quantities (top).

Picture credit: Filser / graphics: ediudsepp

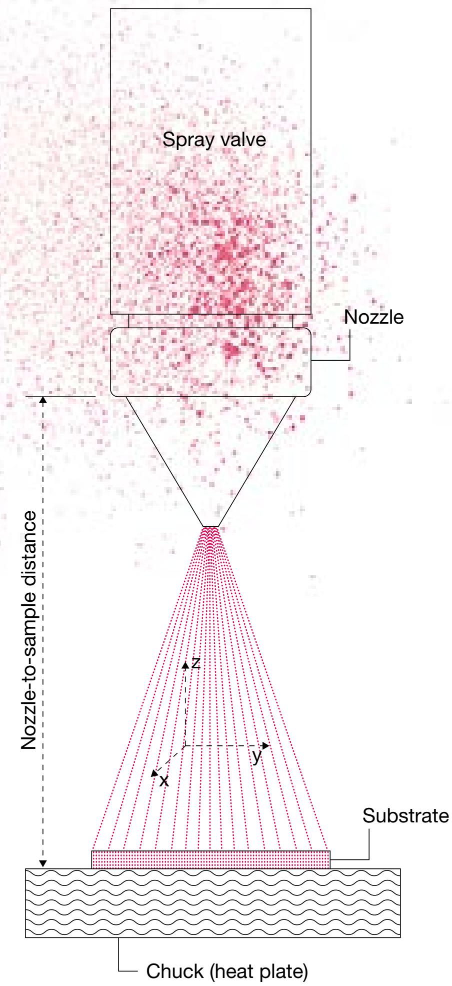
Patience and care are needed when developing the delicate structures. The TUM researchers use inkjet printing to manufacture the electronic circuits for the sensors. Here, Dr. Alaa Abdellah uses a microscope to connect one of the tiny transistors to a carbon-nanotube-coated sensor in order to test its electrical properties.

can be manufactured and tested quickly and at low cost. In everyday life, miniaturization is not always the most important driver; often it's about producing devices cheaply and on a large scale. A massive market could also be opened up for ultra-thin layers of silver nanowires. These are also transparent, and since they are made of metal wires, they conduct an electric current much better than semiconducting CNTs. At the same time, their electrical resistance is so high that the layers heat up quickly, which could make them ideal for coating car windshields, the blades of large wind turbines or airplane wings to keep them free of ice. Even the heating for car seats, which still relies on wires in the upholstery, could, in the future, simply be sprayed on to the material. "Our spraying technique is perfect for any application that requires such materials to be applied in an even layer over large surfaces," claims Abdellah. In principle, this is also possible with ITO, but it is far too expensive for the regular consumer sector.

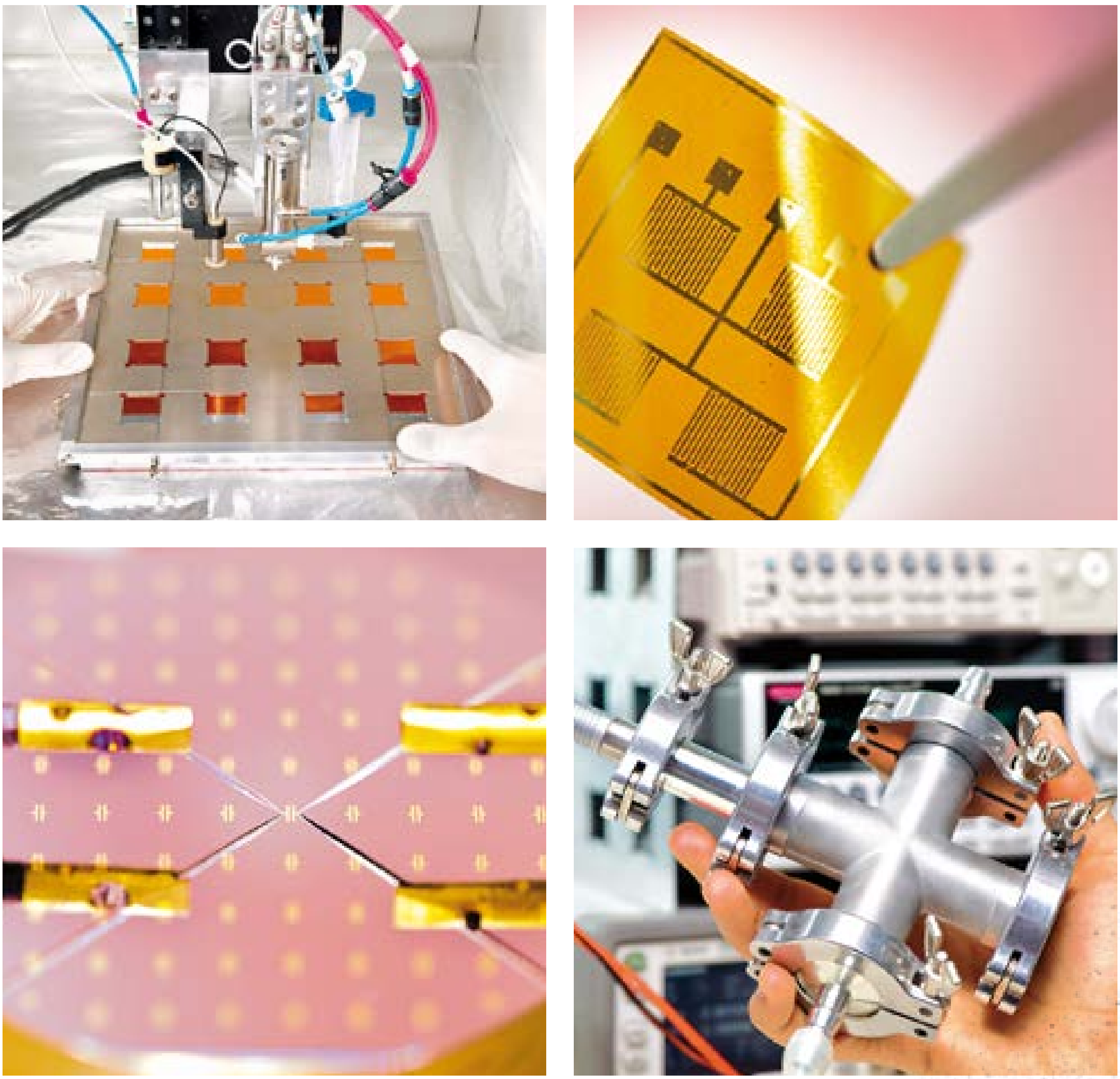
A glimpse into the future

In order to find suitable applications and keep ahead of the competition, the scientists must maintain a large network of contacts and stay up to speed on the latest developments. "We have to remain at the cutting edge of research, which requires us to be smarter and faster than our competitors," says Lugli. "We need to know what everyone else is doing, and do it better than them." Contact with companies is also important, whether on a one-to-one basis or at specialist conferences. Industrial contacts are now being sought to pursue an intriguing vision for the nano-researchers: "We could combine objects created with a 3-D printer with our coating technique," declares Paolo Lugli. "Currently, 3-D technologies are limited in the number of materials that can be printed, but we could make printed objects "smart" if we integrate them with functional conductive layers." The researchers are indeed now attempting to integrate their spray coating method in a 3-D printer, and are examining possible applications. "This is a relatively new field of technology, but I am absolutely convinced that it is going to bloom in the near future," Lugli concludes.

Brigitte Röthlein



The basic principle of the high-tech spray nozzle is not unlike conventional air brushing. But here, everything must be perfect to ensure that extremely thin layers can be applied evenly. The Munich-based researchers have become adept at producing homogeneous inks from the exotic substances, adhering them to the substrate and achieving a perfectly even spray film.



Picture credits: Filser/graphics: ediudsepp

Tried and tested: Coatings are applied to a film in the spray chamber (top left). The template ensures that the correct shape is maintained. The finished part – in this example, a prototype for a flexible gas sensor based on carbon nanotubes (top right) – will first be tested for its electrical properties (bottom left), followed by further testing for its sensing functionality with a variety of gases (bottom right).

Picture credit: Filser

Spraying for science: Prof. Paolo Lugli, Chair of Nanoelectronics at TUM, is working with his colleagues to apply ultra-thin layers of state-of-the-art materials onto a variety of substances. They have discovered that simple methods like spray deposition and inkjet printing – both tried-and-tested industrial processes for inks and paint – are also suited to innovative applications.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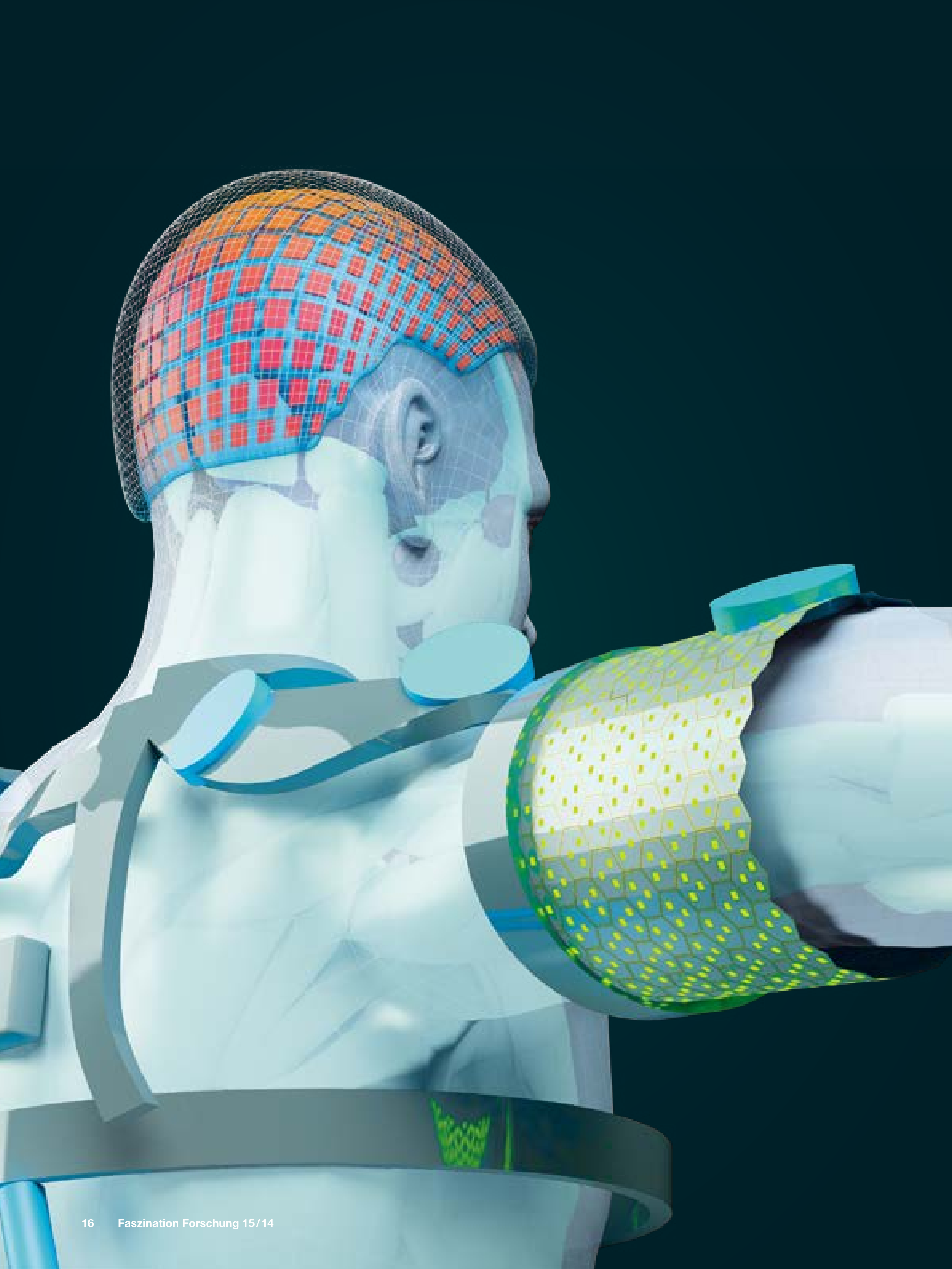


The Walk Again Project aims to overcome paralysis with the help of a phenomenal amount of smart technology. It utilizes an exoskeleton controlled by the thought of a paralyzed person. An electrode cap detects the brain signals, and a computer integrated into the suit converts these into commands for movement.

Exoskeleton Enables Paraplegic **Man to Walk**

Picture credit: ediundsepp

The first kick of the 2014 soccer World Cup in Brazil was taken by a paraplegic man wearing a mind-controlled robotic suit known as an exoskeleton. Prof. Gordon Cheng, head of the TUM Institute for Cognitive Systems, played a key role in this global premiere.

Exoskelett lässt Gelähmte gehen

Der 12.Juni, der Tag der Eröffnungsfeier der Fußballweltmeisterschaft 2014 in Brasilien, ist für Prof. Gordon Cheng, Leiter des Instituts für Kognitive Systeme an der TUM, etwas Besonderes. Erstmals hat ein gelähmter Mensch einen Roboteranzug, als Exoskelett bezeichnet, mit seinen eigenen Gedanken so gesteuert, dass das vom Exoskelett geführte Bein den WM-Fußball angestoßen hat. Die geglückte Mind-Machine-Kooperation ist das Ergebnis einer mehrjährigen internationalen Zusammenarbeit, an der Cheng mit seinem Institut maßgeblich beteiligt war. Die Steuerung des Exoskeletts durch die Gedanken des Patienten ist wegen des Prinzips des „erweiterten Körperschemas" möglich. Der Patient sieht das Exoskelett als Teil seines Körpers an. Der in das Exosklett integrierte Computer ist so programmiert, dass er die Gedanken des Patienten, die mithilfe einer Elektrodenhaube abgeleitet werden, in Befehle für das Exoskelett übersetzen kann.
An bestimmten Teilen wie den Fußsohlen ist das Exoskelett mit einer künstlichen Haut überzogen, die Tastsinn vermittelt. Sie wurde in Chengs Institut entwickelt. Jede ihrer 160 in flexiblen Kunststoff eingebetteten Basiseinheiten ist mit einem Mikroprozessor sowie mit sechs sich selbst organisierenden Sensoren bestückt. Sie erkennen, wenn sie beschleunigt, berührt, erwärmt werden oder sich zum Beispiel einem anderen Objekt wie dem Fußboden nähern. Dem Patienten wird dies in weniger als 300 Millisekunden anhand von Vibrationen an seinen Armen vermittelt, denn er muss wissen, welche Bewegung der Roboter gerade ausführt. Das Gehirn lernt diese Signale richtig deuten.
Die künstliche Haut eignet sich auch für Industrieroboter. Sie stellen derzeit für die in ihrer Nähe arbeitende Menschen eine Bedrohung dar und sind deshalb hinter Gittern und Laserschranken untergebracht. Eine auf der Roboteroberfläche aufgebrachte künstliche Haut könnte mithilfe ihrer Sensoren eine Kollision vorzeitig erkennen und vermeiden.

Gerlinde Felix

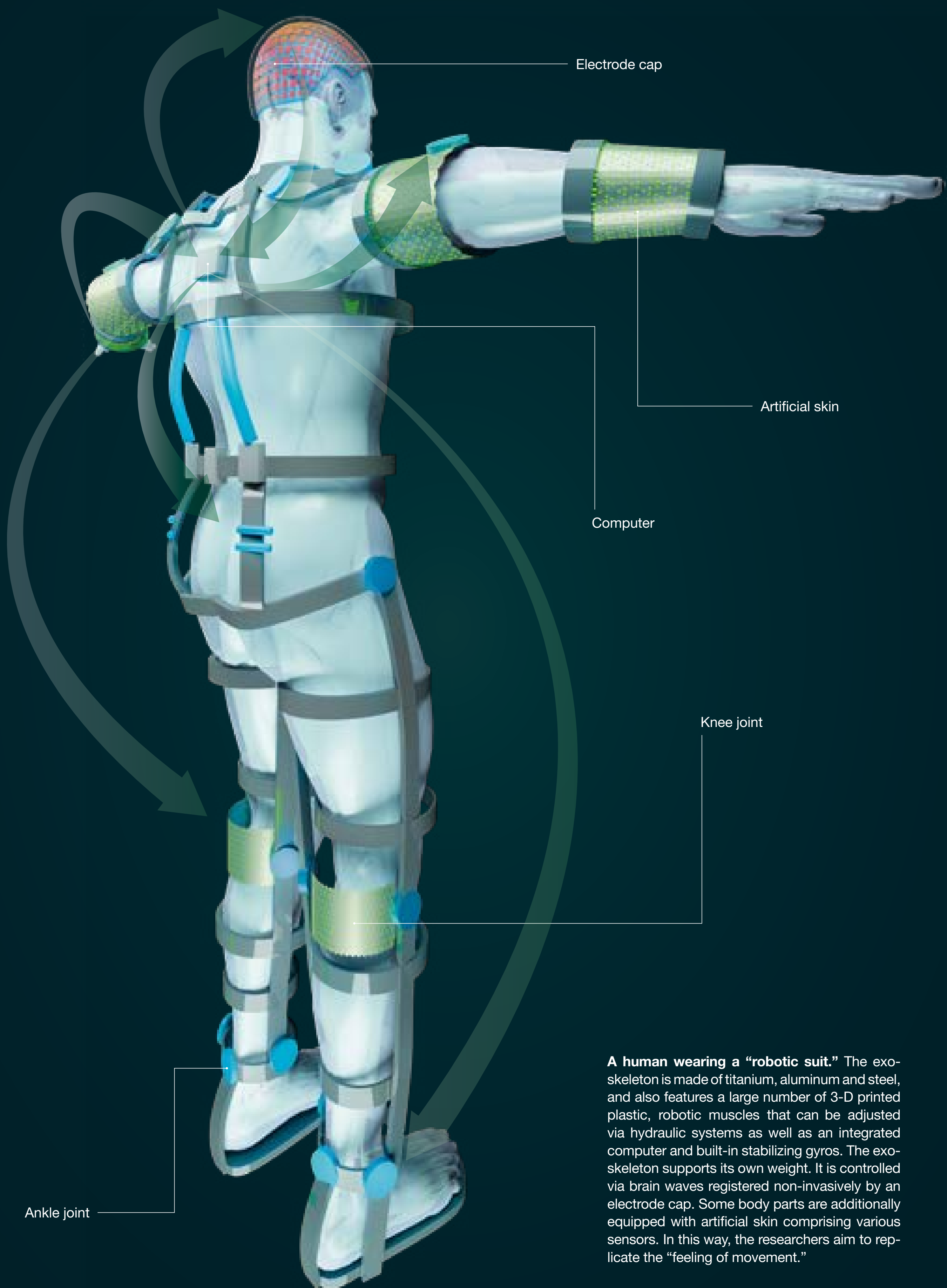
Link

www.ics.ei.tum.de

My interviewee's eyes shine with delight when the stadium in São Paulo, Brazil, appears in the huge digital photo frame in his office. The frame shows over a thousand images from more than four years' work. But this particular image is something special. It is "the" picture for Gordon Cheng, Professor of Cognitive Systems at TUM. And June 12, 2014, the day of the opening ceremony of the soccer World Cup in Brazil's São Paulo, is a day he will never forget. "Watching Juliano Pinto kick that World Cup ball was a fantastic and hugely satisfying feeling," explains Cheng with a smile on his face. In itself, kicking a soccer ball is nothing special. However, 29-year-old Pinto has been paralyzed for a number of years. The fact that he was able to independently kick the ball despite his paralysis is all down to the exoskeleton that he was wearing and controlling with his mind. The exoskeleton is a kind of robotic suit capable of supporting its own weight. It is made of titanium, aluminum and steel, and also features a large number of 3-D printed plastic, robotic muscles that can be adjusted via hydraulic systems, and an integrated computer and built-in stabilizing gyros. Parts of the exoskeleton are even covered by an artificial skin that transmits tactile signals to the user. "The skin provides the user with feedback, ▷

"When we drive a car, the car becomes an extension of our body schema. When we eat, it's the knife, fork or chopsticks. It's the same with the exoskeleton."

Gordon Cheng



Picture credit: ediundsepp

A human wearing a “robotic suit.” The exoskeleton is made of titanium, aluminum and steel, and also features a large number of 3-D printed plastic, robotic muscles that can be adjusted via hydraulic systems as well as an integrated computer and built-in stabilizing gyros. The exoskeleton supports its own weight. It is controlled via brain waves registered non-invasively by an electrode cap. Some body parts are additionally equipped with artificial skin comprising various sensors. In this way, the researchers aim to replicate the “feeling of movement.”

Fantastic footwork by an exoskeleton. Since January 2014, the Walk Again Project has trained eight paralyzed persons in Brazil to move with the exoskeleton. One of them used the suit to take the World Cup's first kick – just with the help of mind power and supported by innovative technology. Lead robotic engineer Gordon Cheng and research assistant Philipp Mittendorfer were watching the training sessions and continuously worked to improve the system.

Picture credit: Eckert

Gordon Cheng holding parts of a robot with artificial skin on its surface. The artificial skin makes robots more sensitive and human-like. It will make it easier for humans to work or live with robots in a shared environment. One example is factory robots, which today work behind bars and laser barriers.

telling them indirectly, for example, that the robotic leg – and therefore the patient's own leg – has touched the ground," adds Cheng.

Tactile stimulation for robots

The mind-controlled exoskeleton is the product of many tough years of international collaboration between experts in the fields of neuroscience and cognitive technology. Gordon Cheng at TUM has been a key player in this initiative together with project leader Miguel Nicolelis, neuroscientist and physician at Duke University in Durham, North Carolina, in the US. The battery-powered exoskeleton is the result of collaboration between all project participants. However, the artificial skin that transmits tactile signals was developed primarily by scientists in Munich. Cheng came to Munich to hold a lecture just over four years ago. The university was so impressed by his work that it offered him a professorship in cognitive systems. He was very tempted by the offer but would not commit without consulting his wife. Luckily, she said yes. The university created a new chair for Cheng, the Institute for Cognitive Systems (ICS). One of the ICS's core goals was the creation of artificial skin for robots. Cheng was unfamiliar with the German system, so he had no idea how much work was waiting for him in Munich. He started from scratch with just eight employees at the beginning. Later, in the critical phase of the project, he was flying back and forth between Munich and São Paulo to tailor the exoskeleton and artificial skin to the requirements of the patients in São Paulo. It was a herculean task to have everything ready by June 12, 2014. Today he has more than double the number of employees with new people joining all the time. Yet Cheng still has time for visitors – whether it's preschoolers or school children looking to find out more about science, or the French prime minister and his entourage. In fact, he can't help smiling when he talks about that visit, when more than a dozen limousines and two buses full of people brought Karlsstraße in Munich to a standstill. "We like what we are doing and are always happy to show it to other people. Luckily, we didn't have to deal with the chaos caused by our guests."

Humanoid robots and neuroscience

Cheng is a true globetrotter. He was born and spent his first years in Macau, when it was still a Portuguese colony. Later, he went on to study information sciences and complete a PhD in systems engineering in Australia. From 2003 to 2008, Cheng founded and headed up the Department for Humanoid Robotics and Computational Neuroscience at the Institute for Advanced Telecommunications Research in Kyoto, Japan. During this time, he was also responsible for the neuroscientific "Computational Brain" project. It was during a symposium in Kyoto that he met Miguel Nicolelis. Both scientists were impressed with each other's work. Before taking the professorship in Munich in 2010, Cheng worked as a visiting professor in the US and France, and also at the Edmond and Lily Safra International Institute of Neuroscience in Natal, Brazil. The institute was founded by Nicolelis in 2005. He specifically chose to locate it in one of the poorest regions in Brazil. In addition to the actual research ▷

Picture credit: Eckert

Prof. Gordon Cheng is director of the Institute for Cognitive Systems at TUM. The passionate robotic engineer believes that, in the future, robots and smart machines will better assist especially older and disabled people in their daily lives. Cheng is convinced that research must give something back to society.

Picture credit left: Eckert, right: KUKA Systems GmbH institute, the site also houses a clinic that offers free, prenatal check-ups and a science school for 1,500 children. Cheng taught at the school for one month.

The first step toward an exoskeleton

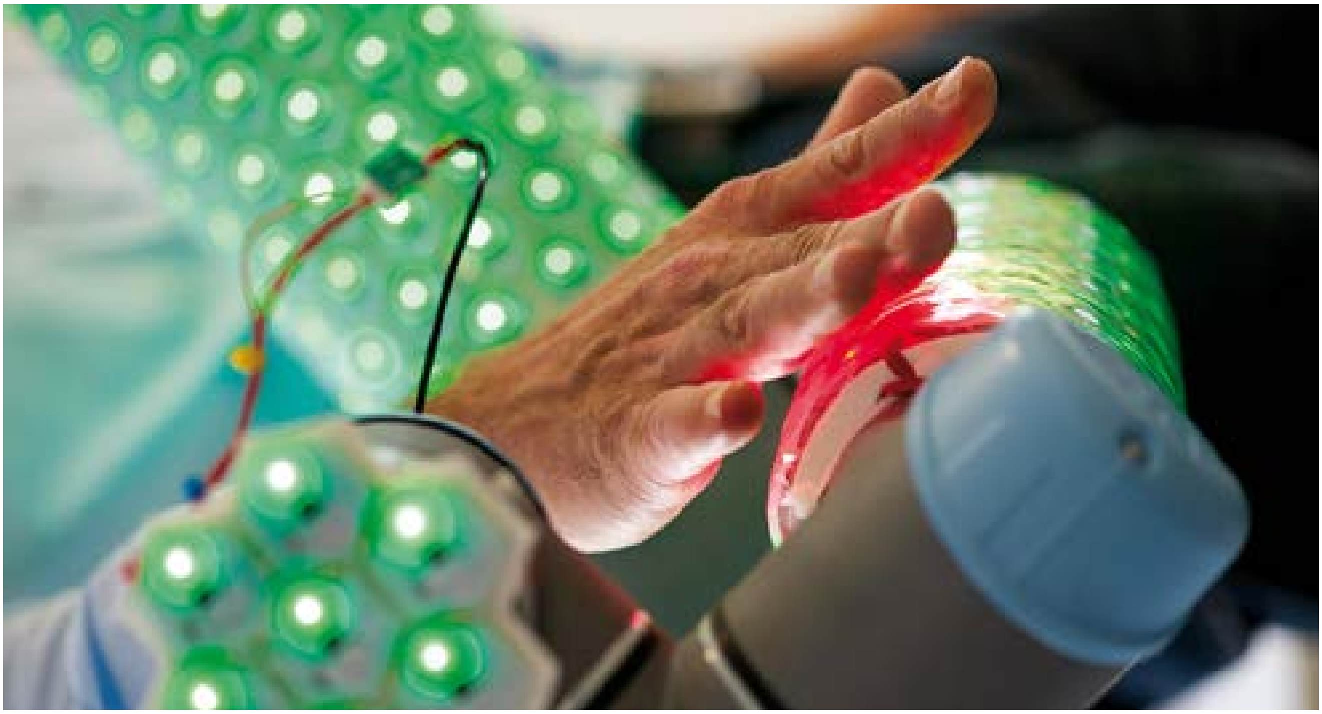
Cheng and Nicolelis started carrying out initial trials for the Walk Again Project back in 2008 in North Carolina. The first steps were made by a female rhesus macaque monkey called Idoya. Nicolelis and his team implanted electrodes into her brain. As soon as Idoya was able to walk upright on a treadmill, the team recorded the signals emitted by her brain and mapped them against slow motion recordings of her movements. The scientists were able to use this data to identify the commands associated with leg movement. The commands from the monkey's brain were transmitted in real time to Japan. There, Cheng fed them into a humanoid robot, which started to imitate Idoya's steps. The robot's leg movements were then played back live to Idoya, who learned to control and improve them. When Nicolelis's treadmill stopped, Idoya also stopped moving, but kept her eyes firmly fixed on the monitor. The robot in Japan kept walking for another three minutes. This could only have been done by Idoya herself. She regarded the robot's movements as her own and was able to control its steps just by using her mind. "This was possible only because the robot had become part of her body schema," Cheng enthuses, clearly still impressed by the rhesus macaque's intelligence. "When we drive a car, the car becomes an extension of our body schema. When we eat, it's the knife, fork or chopsticks. It's the same with the exoskeleton."

Mind and body working together

Eight paralyzed Brazilians aged between 20 and 40 made it through to the final selection for the Walk Again Project in São Paulo. For these eight people, the exoskeleton became a part of their body. But it took a long time to learn how to deal with the new technology. The learning process started on a treadmill. The participants were placed in a harness and their legs supported by a frame. Their brain activity was measured noninvasively along the scalp using electrode caps on their heads and electroencephalography (EEG). The mechanical frame was used to walk the patients' legs. While this was happening, the participants were asked to concentrate hard on wanting to walk. The resulting brain wave pattern was similar in all eight patients. In the next phase, the patients had to wear the electrode cap and start training with a virtual computer simulation. Instead of their own legs, the participants saw animated legs below their waists. Whenever they thought about walking, standing or kicking in the right way and imagined making the corresponding movements, ▷

Keeping robots on their feet with artificial skin

Heavy-duty, walking industrial robots currently pose a risk to people working in their immediate vicinity. They have the potential to cause serious injuries, for example to an individual's head or chest. Most industrial robots therefore work behind bars and laser barriers. However, this takes up space in production halls, and limits the ways in which robots can be used. Covering the surface of robots with artificial skin could change this. The artificial skin is made up of self-organizing sensors that can detect and prevent collisions before they happen, making interaction between humans and machines safer. For this to become reality, however, the industrial robots have to be given information on the position of the sensors. This is not done manually, but by using self-organizing algorithms. "The robot then knows what it looks like within just a short time," explains Philipp Mittendorfer, a researcher who is writing a PhD thesis about artificial skin. The algorithms automatically determine the position of sensors on the robot's surface. Other algorithms determine structural dependencies between the robots' joints and body parts, reconstruct the shape of body parts in 3-D and investigate the robot's kinematics. The robot can use its own sensors to get to know itself. "The exoskeleton requires only part of the functionality possible with artificial skin. With industrial robots, however, we will be able to unlock the technology's full potential," continues Mittendorfer. The skin can be used to quickly integrate industrial robots into production sites – a concept that is being investigated in the EU-funded "Factory-in-a-day" research project.



Touching the artificial skin of a robot part. The multimodal-cellular skin is named CellulARSkin. It consists of several hexagonally shaped unit cells, each featuring multiple sensor modalities. The artificial skin makes it possible to enrich robot interactions through a multimodal sense of touch.

their virtual legs made the exact same movements. "The patients were more or less learning a new language. We can do this only because our brains are unbelievably adaptable," explains Cheng. From January 2014 on, the participants started training using an exoskeleton with an integrated computer. The signals from the brain are translated into specific commands that the computer sends to the exoskeleton. "An incredible amount of data was collected, decoded and translated into movement commands for the exoskeleton. This all had to be categorized and the computer programmed correspondingly," continues Cheng.

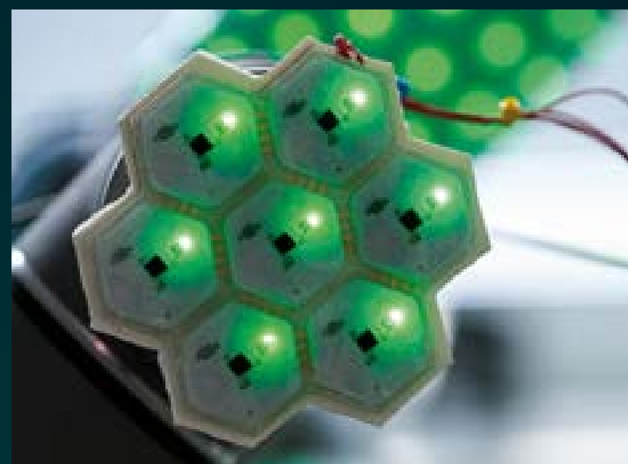
Artificial skin stabilizes exoskeleton

As far back as 2008 however, the researchers realized that something was missing. The participants need continuous feedback on the current position of the robotic legs and, during training on the treadmill, with virtual legs. They have to know what movement the robot is making at all times; otherwise the exoskeleton could fall over. What they needed were sensory receptors. This is where CellulARSkin comes in. The artificial skin was developed at the ICS to provide tactile sensations. It comprises a large number of hexagonal printed boards approximately the size of a two-euro coin. Each one features an energy-saving microprocessor and six sensors. Four of these have separate functions to detect changes in speed, temperature and touch and to sense proximity to other objects in three-dimensional space, for example when they are close to or moving away from the ground. The exoskeleton is currently equipped with around 160 of these elemental cells. And since they are not available on the market, the cells had to be developed at the ICS. The hexagonal elemental cells are embedded in flexible plastic and can be connected to form honeycomb-like mats. What makes the skin so revolutionary and exciting is that each cell works locally. The sensors organize their network themselves and pre-process data at this level, which significantly reduces the data transfer load to the central computer. This is made possible by a set of algorithms developed specifically for this application. This localized approach means that the sensors are resistant to external influences and component failure – if one component malfunctions, the rest of the artificial skin will continue to work. CellulARSkin is also placed on the soles of the exoskeleton's feet. The sensors here send information to a central control unit when the sole of the foot is just about to touch the ground, when it makes contact with the ground and when it is just leaving the ground. The participants feel these signals via small motorized metal cylinders attached to their arms. When the virtual foot touches the treadmill or the robotic

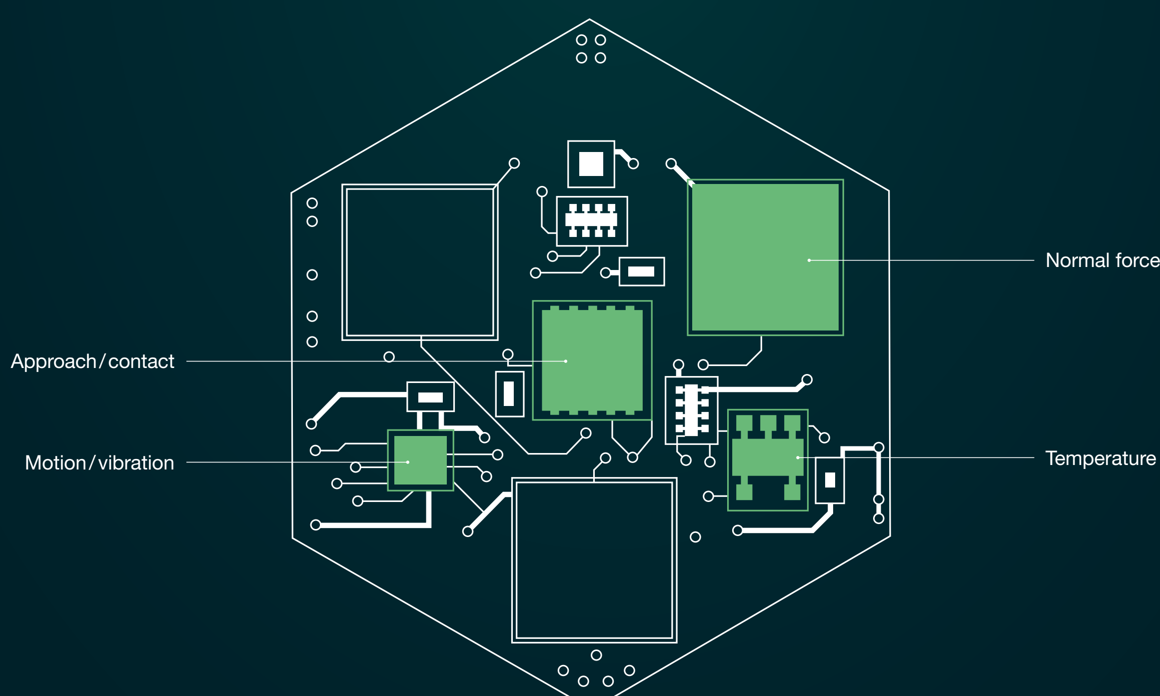
Picture credits: Eckert / graphics: ediundsepp (source: TUM) foot touches the ground, the cylinders start to vibrate less than 300 milliseconds after contact. “The delay cannot be any longer. Otherwise the brain would not be able to cope, and this could be very stressful for the participants. Our brains learn very quickly and can interpret these signals correctly within a very short time,” explains the Munich-based researcher. The artificial skin enabled the participants’ brains to learn more effectively while moving on the treadmill and in the exoskeleton. Around 80 of the 160 elemental units are used to make sure that the 42 kg exoskeleton is not pressing down too hard on any part of the users’ bodies.

Affordable technology

For Cheng, June 12 was not the end of his work, but just the beginning. “We still have a long way to go,” he adds. And he has many new ideas to try out. “We will be improving the exoskeleton even more and harnessing new technologies to bring down production costs.” Cheng would like to see the exoskeleton used by as many paralyzed people as possible. He also believes it can help patients with other movement disorders. “Science can really give something back to society here.” Cheng and Nicolelis are very much on the same track here. With all this going on, it’s hard to see how Cheng finds the time to watch football with his eight-year-old daughter, an ardent fan of FC Bayern and goalkeeper Manuel Neuer. But he is a pioneer in the truest sense of the word: “It’s something completely new for me,” he says. And new is something he is always willing to try. *Gerlinde Felix*



Each hexagonal cell of the artificial skin comprises four sensors that measure pressure, proximity, temperature and vibration as indications for touch. The interconnected cells pass electrical signals via varied pathways through the entire skin to and from the central computer.



The First Maps of the **Human Proteome**

A group of researchers led by Prof. Bernhard Küster has published one of two initial comprehensive maps of the human proteome. Following the first complete sequencing of the human genome in 2001, a second key to unlocking the mystery of life has now been found with the mapping of the proteome – in other words, all the proteins in the human body.

Die ersten Karten des menschlichen Proteoms

Eine Gruppe der TUM um Prof. Bernhard Küster hat im Mai 2014 zeitgleich mit einer Gruppe von US-Forschern eine der beiden ersten wirklich umfassenden Karten des menschlichen Proteoms vorgelegt – der Gesamtheit aller Eiweiße, die unser Körper bilden kann. Gene liefern den Bauplan für Proteine und die Münchener haben den Nachweis für 92% oder 18.097 der aus dem menschlichen Genom abgeleiteten Eiweißgrundformen erbracht. Diese Grundformen sind allerdings erst der Anfang, da Menschen über eine Vielzahl von Mechanismen verfügen, um Proteine verschiedenen Bedürfnissen entsprechend abzuwandeln. Dennoch konnten die Forscher bereits eine Reihe fundamentaler Erkenntnisse aus den vorliegenden Proteinkarten gewinnen. So wurden offensichtlich hunderte Gene im Lauf der Evolution stillgelegt da für sie keine Proteine mehr zu finden sind. Gleichzeitig scheinen neue Proteine im Entstehen begriffen zu sein, die bislang gänzlich unbekannt waren.

Die Arbeit wurde vor allem durch zwei methodische Fortschritte möglich: Zum einen erlaubt die Massenspektrometrie heute Spezialisten, binnen weniger Tage das Proteom menschlicher Gewebe zu analysieren und dies zu Kosten von wenigen 1.000 Euro. Zum anderen ermöglicht eine von der Küster-Gruppe zusammen mit der Firma SAP entwickelte Datenbank der internationalen Forschergemeinschaft, ihre bislang in vielen Einzeldateien verstreuten Analyseergebnisse zusammenzutragen und gemeinschaftlich auszuwerten.

Im Fokus steht auch der medizinische Nutzen. So konnten Bernhard Küster und sein Team anhand ihrer Daten bereits die Wirksamkeit von Medikamenten aus dem Proteinprofil von Krebszellen vorhersagen.

Langfristig wollen die Forscher über das biologische Verständnis des Proteoms und des Genoms die personalisierte und zielgerichtete Therapie von Patienten weiter voranbringen.

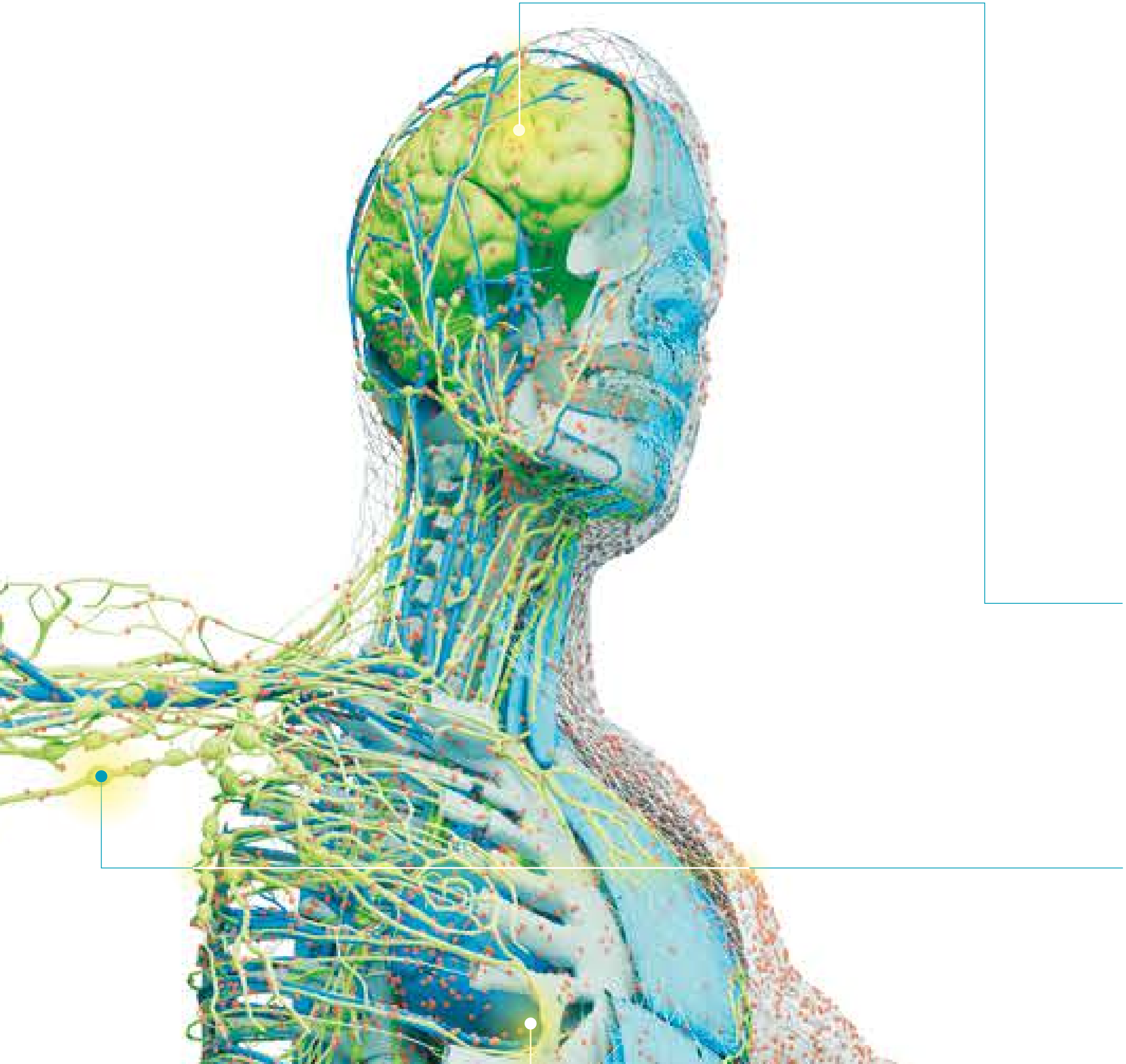
Link

www.wzw.tum.de/proteomics
https://www.proteomicsdb.org/

Picture credit: RCSB Protein Data Bank

The protein p53 is encoded by the TP53 gene and functions as a tumor suppressor. It is also known as the "guardian of the genome" because it is intimately involved in repairing damaged DNA. In most human cancers, TP53 is mutated, rendering it functionless.

Decoding the Human Proteome



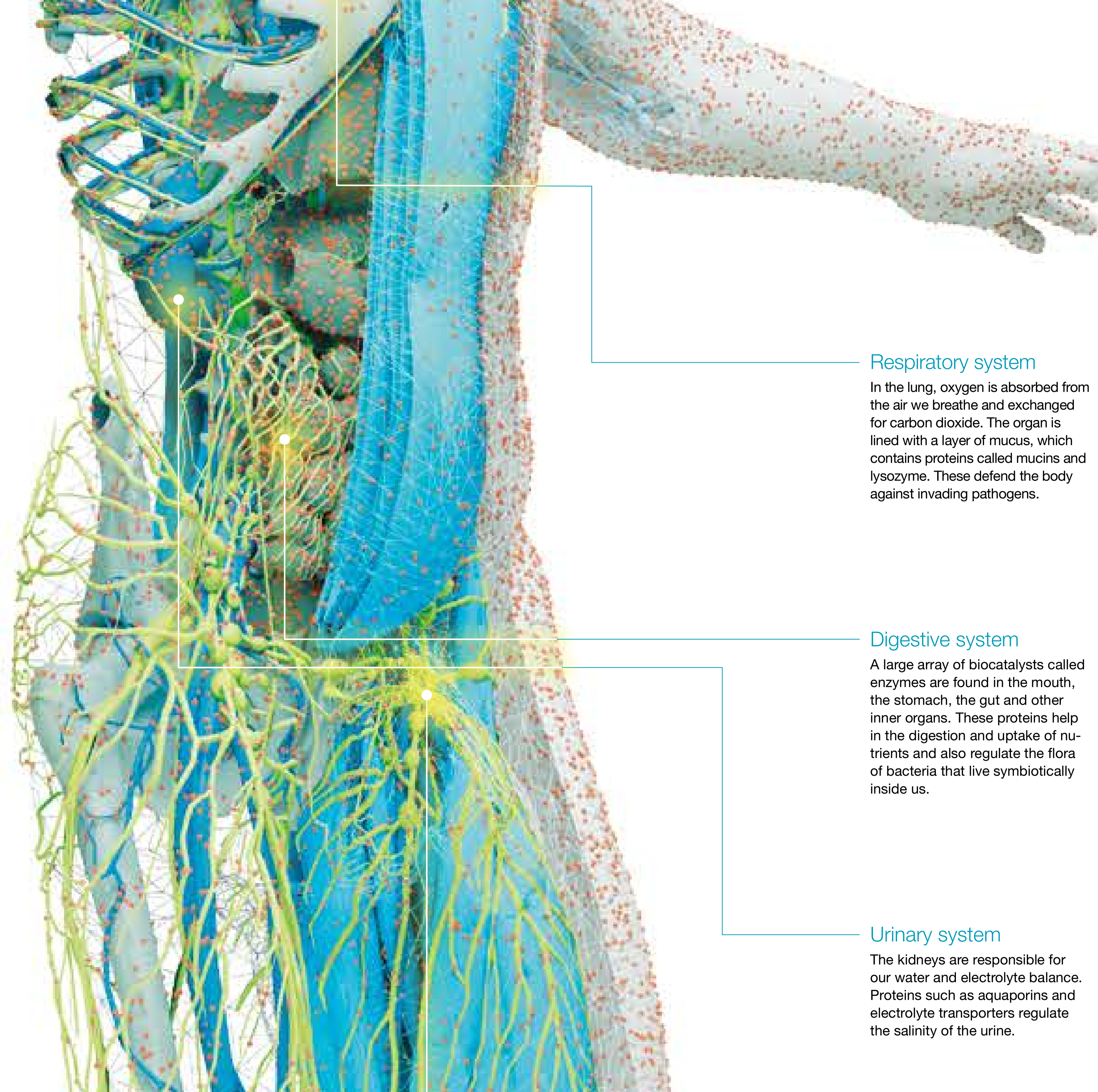
Each human cell contains the same genetic information, including 20,000 protein coding genes. It is the repertoire of expressed proteins – the proteome – that gives the many different cell types in our body the specific characteristics required to perform their diverse functions.

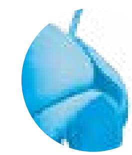
Nervous system

Nerve cells are wrapped in a blanket of myelin, which is required for the efficient transmission of neural signals. Myelin contains mainly lipids, but also proteins, such as the myelin basic protein.

Lymphatic system

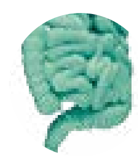
Lymph nodes are a reservoir for immune cells and contain a spectrum of antibodies and immune proteins that guard human beings from pathogens, such as viruses and bacteria.





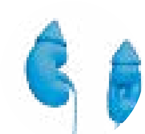
Respiratory system

In the lung, oxygen is absorbed from the air we breathe and exchanged for carbon dioxide. The organ is lined with a layer of mucus, which contains proteins called mucins and lysozyme. These defend the body against invading pathogens.



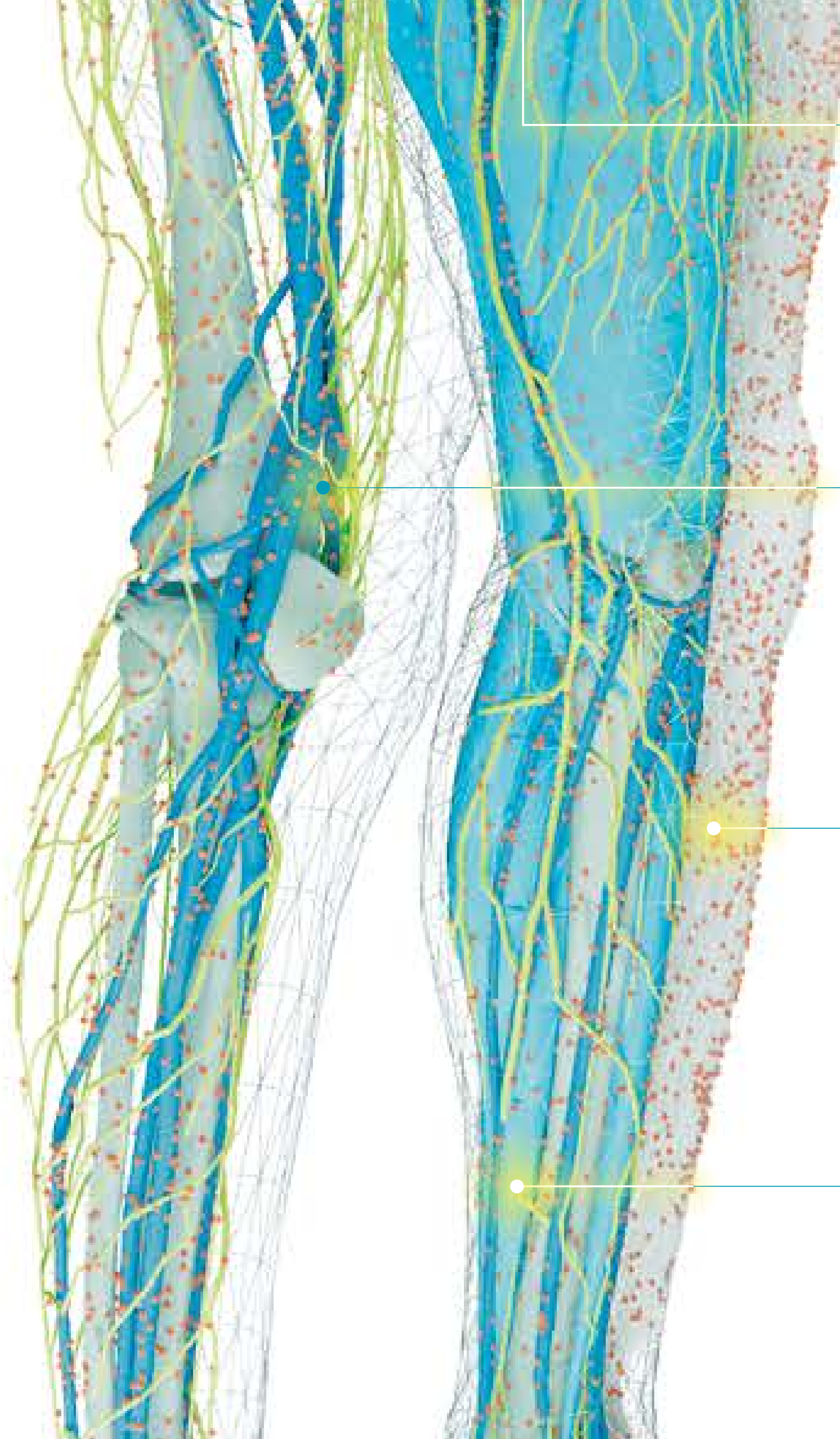
Digestive system

A large array of biocatalysts called enzymes are found in the mouth, the stomach, the gut and other inner organs. These proteins help in the digestion and uptake of nutrients and also regulate the flora of bacteria that live symbiotically inside us.



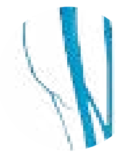
Urinary system

The kidneys are responsible for our water and electrolyte balance. Proteins such as aquaporins and electrolyte transporters regulate the salinity of the urine.



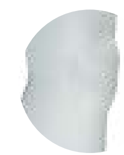
Reproductive system

Important hormones such as estrogen and testosterone are produced in the ovaries and testes. Interestingly, these two organs also show the broadest spectrum of protein expression of all organs in the body.



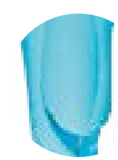
Circulatory system

Hemoglobin is the protein that transports oxygen from the lungs to every cell of the body. There are about 5 liters of blood in adults, and oxygenated hemoglobin gives blood its distinctive red color.



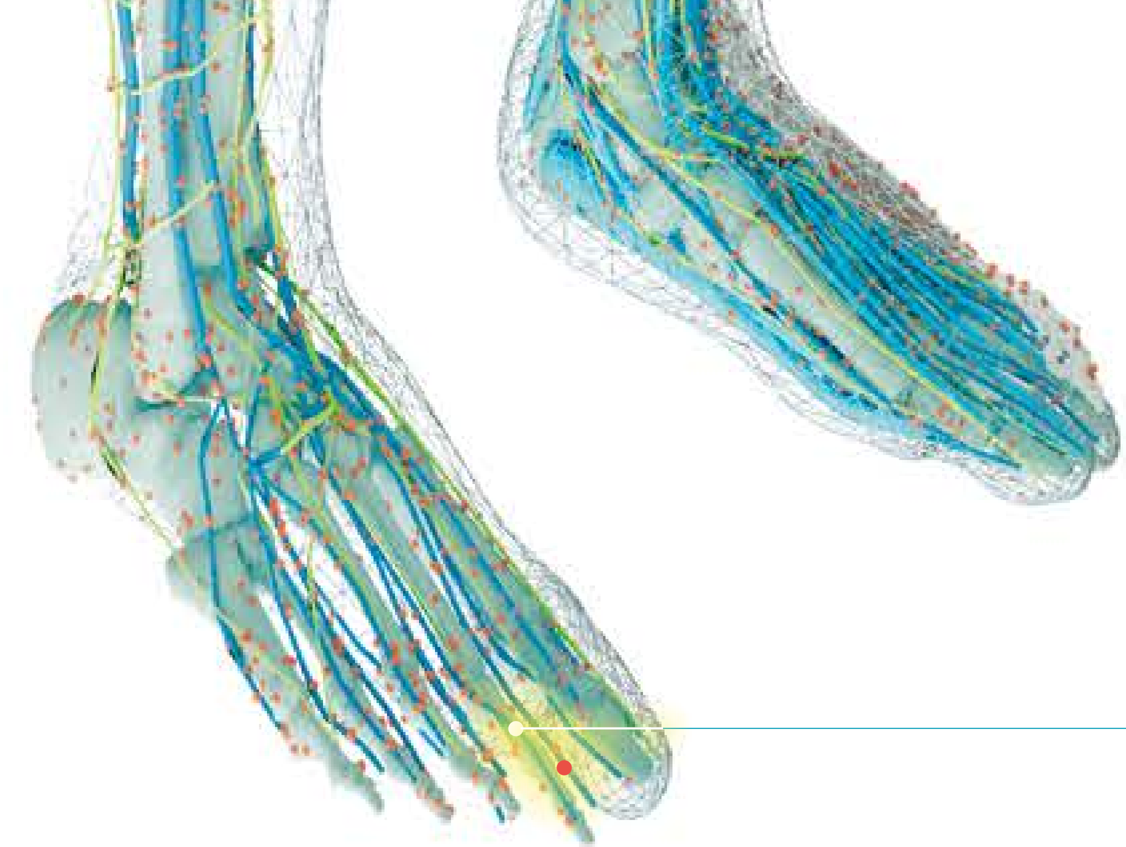
Integumentary system

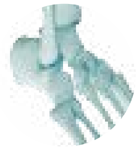
The skin is the largest organ in the body and contains large quantities of fibrous and waterproof proteins called keratins, which provide protection against all kinds of damage, including mechanical force or rain. Keratins are also the major constituents of hair and nails.



Muscular system

Actin and myosin are proteins that constitute a large part of the 5-6 kg of muscle proteins in the human body. These proteins give muscles the ability to contract and thus create movement.

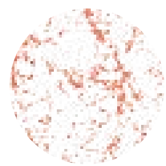




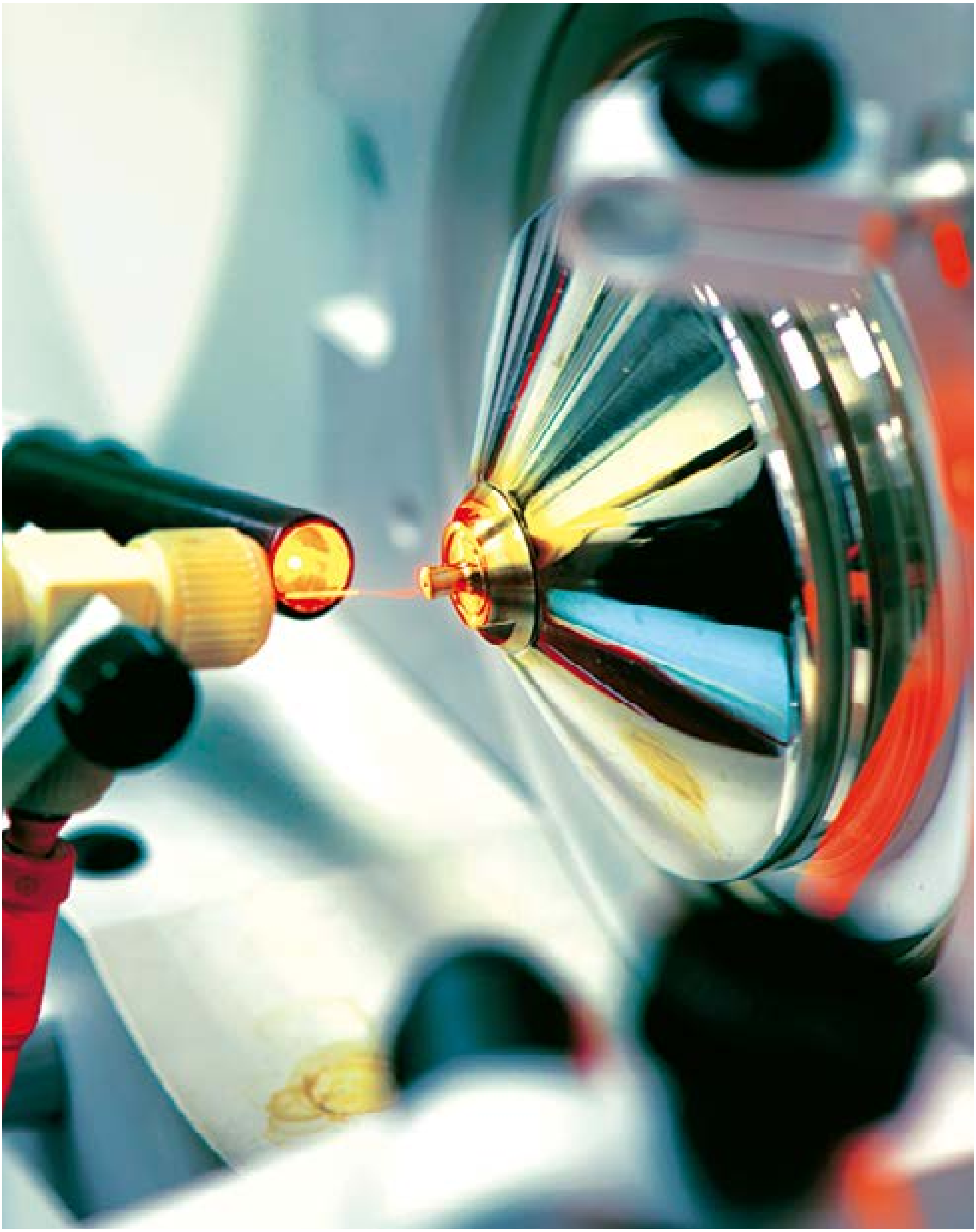
Skeletal system

Collagen is a structural protein that provides strength and flexibility to bones, tendons, ligaments and skin. A staggering 25 percent of all the body's proteins are collagen.

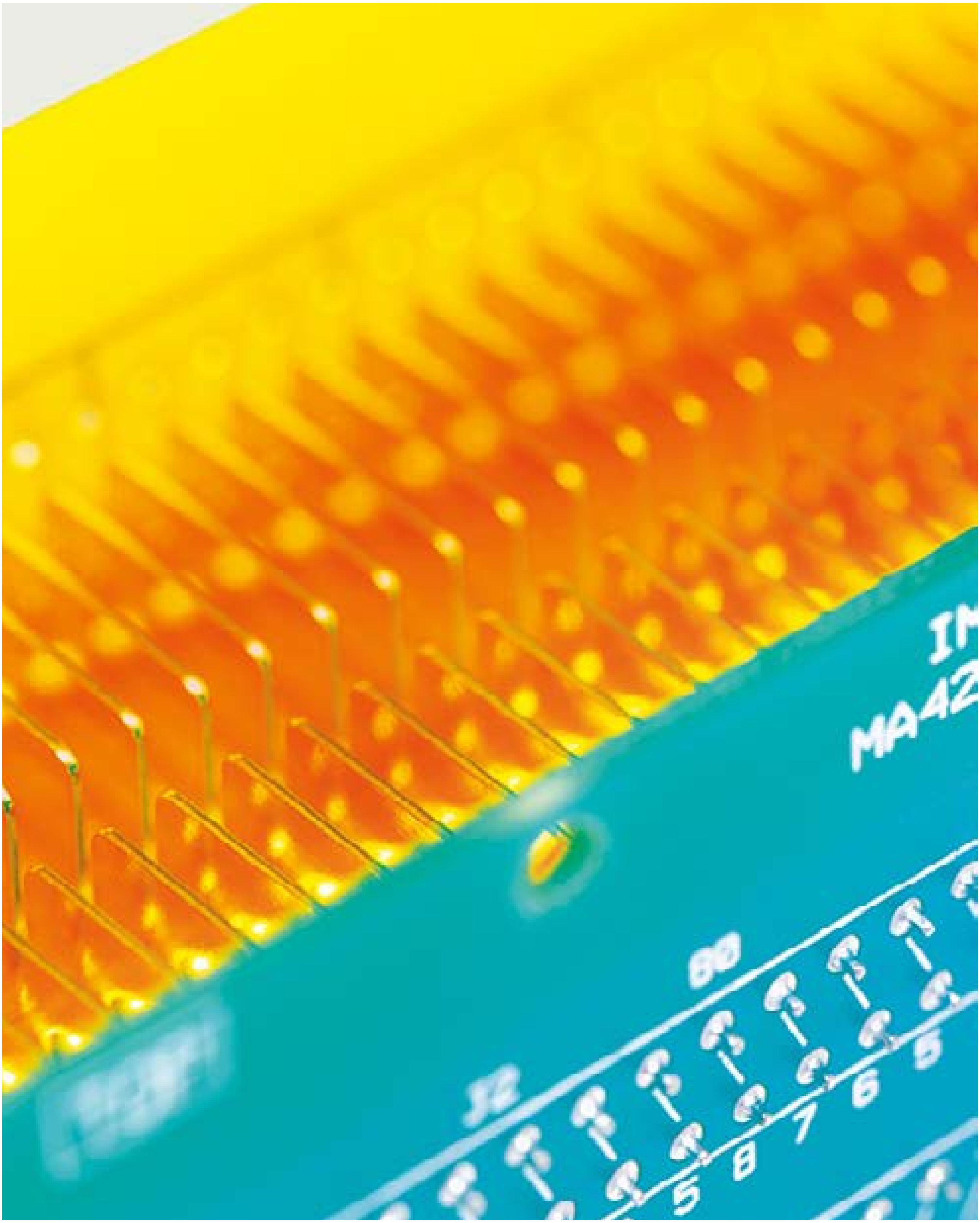
18,097 proteins



Picture credit: ediundsepp



Ionizing peptide samples for mass spectrometry. Guided via a thin glass capillary (left), the samples encounter high electric voltage and are transferred into an aerosol (electrospray ionization). The resulting ions enter the metal capillary (right) leading into the vacuum of the mass spectrometer.



Picture credits: Filser

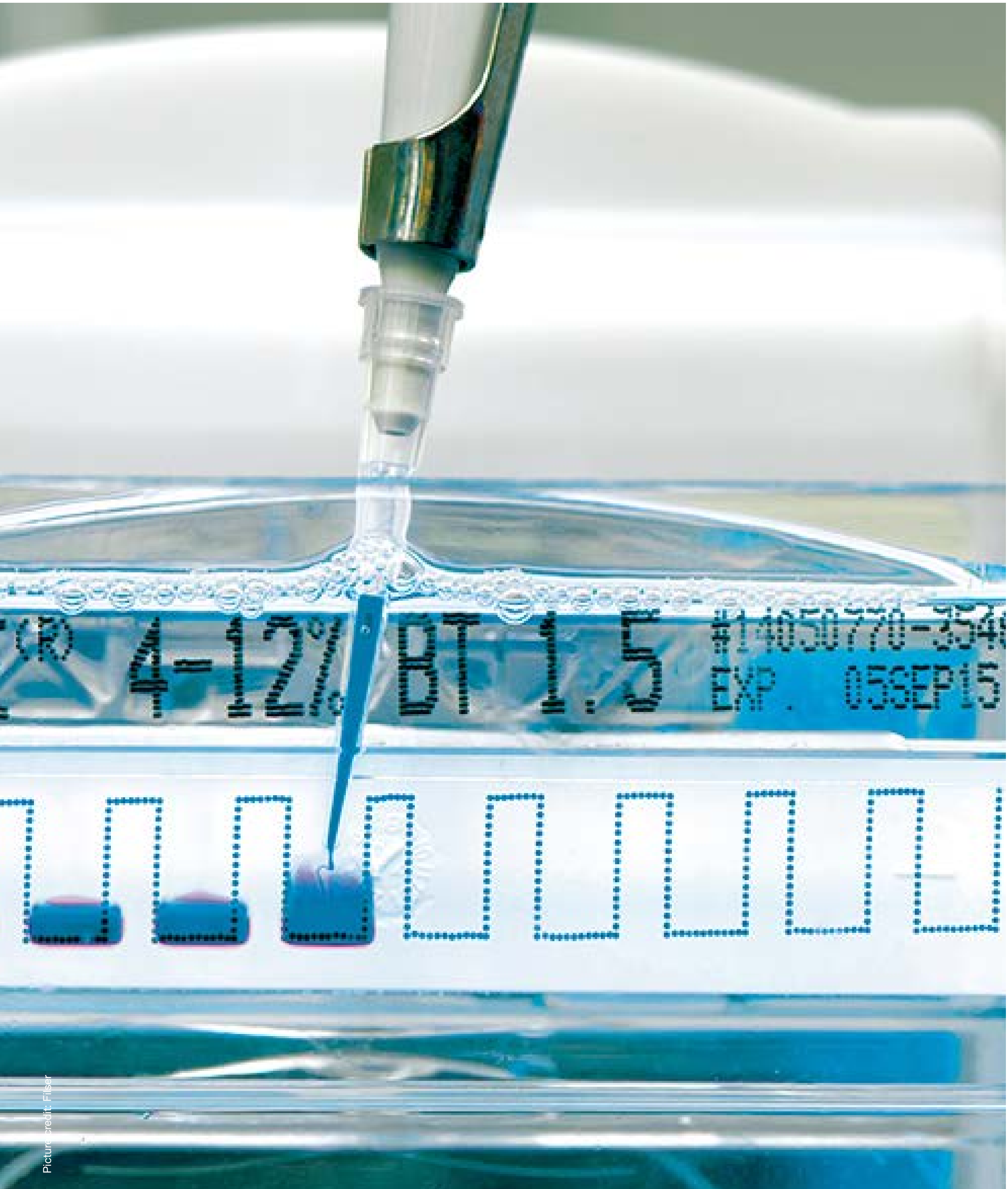
Inside the mass spectrometer, the ions are accelerated. The resulting ion beam enters a magnetic field, which deflects the individual ions according to their mass and charge. The above image shows a so-called stacked electrode, which is part of the optics that focus the ion beam.

Complex projects call for dogged determination – and Bernhard Küster, TUM Professor of Proteomics and Bioanalytics, has what it takes; his work is more complex than most people can imagine. At the end of May, the results of his research were announced to the world. According to Küster's article published in the scientific journal "Nature," the human organism is made up of at least 18,097 different proteins. A study published at the same time by a team led by Akhilesh Pandey from Johns Hopkins University in the US arrived at the slightly lower figure of 17,294 proteins. The two teams have produced by far the most comprehensive map of the human proteome to date. Bernhard Küster's group maintains that they have so far accounted for 92 percent of all proteins in the human body. "Nature" dedicated its front cover to the finding, confirming the human proteome as one of the great scientific discoveries of the year.

The human genome codes for the proteome

The term proteome, coined in 1994 by Australian Marc Wilkins, describes the entire set of proteins in an organism and is based on a more well-known word ending in "ome": the genome, or the genetic blueprint of an organism. As far back as the 1990s, the sequencing instruments of genome researchers were already running at full speed. By 2003, the DNA sequence of humans was more or less correctly decoded. Geneticists soon announced that they had also solved the human protein puzzle. In simple terms, they calculated that each gene encodes a protein, so the number of genes corresponds to the number of proteins. Based on this interpretation, the human proteome would comprise 19,629 proteins, all stored and named in freely accessible databases. Many, however, are just predictions derived from computer analysis of the human genome. Now, 15 years after the decoding of the genome, 2014 could well become known as the year the human proteome was decoded. Scientists have mapped the proteome and, as a result, arrived at a more solid and accurate prediction for the number of human proteins. ▷

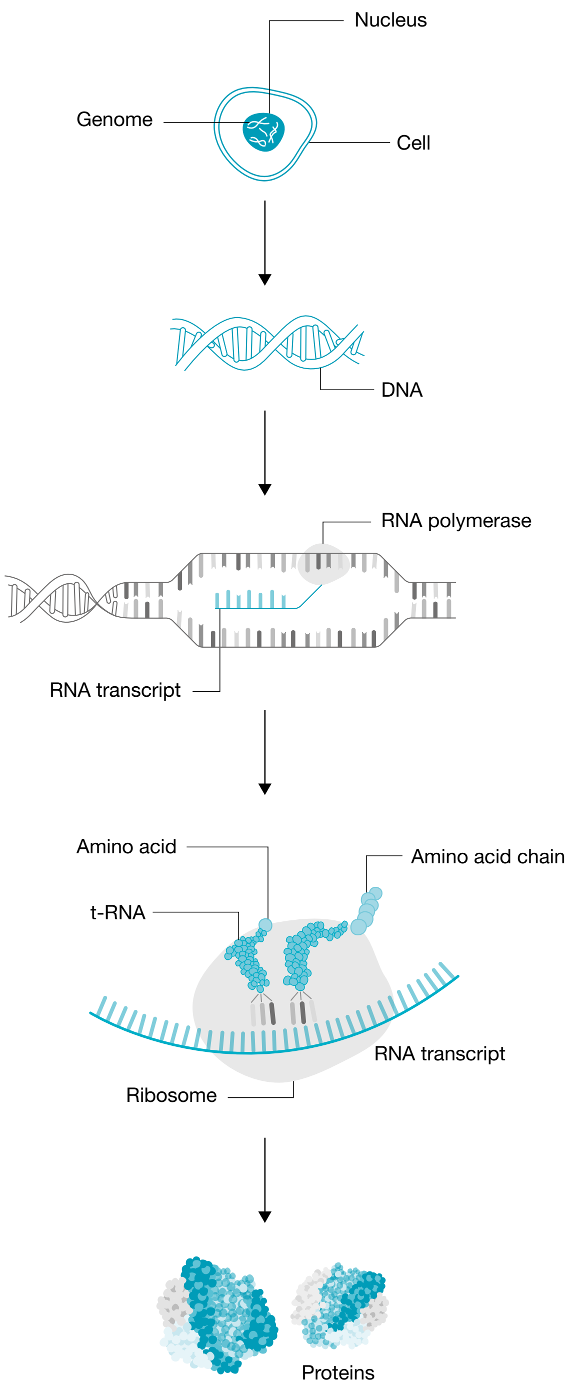
Bernhard Küster's group collected protein samples from 60 different tissues, 13 bodily fluids and 147 cancer cell lines. Here, a gel electrophoresis apparatus is being loaded with protein samples to separate them according to size.



Picture credit: Fiser

Genes and Proteins

Our genes contain the blueprint for the production of proteins. The process starts with the unpacking of the DNA of the chromosomes and its transcription into messenger RNA. At the level of the ribosomes – the protein factories of the cell – many individual amino acids are linked together to form a protein following the blueprint of the messenger RNA, but with all kinds of chemical modifications, if required.



The catch is that, unlike the genome, which barely changes in the course of a person's life, the proteome is highly dynamic. Proteins are constantly generated, transformed and broken down, depending on the organism's exposure to stimuli, environmental factors, diseases and drugs. The proteome is highly complex, as it reflects all facets of our life and our environment.

Back in 2001, an international research project called the Human Proteome Organization (HUPO) was set up along the same lines as the genome research project. The ultimate target is to analyze every protein in every tissue – including their changes over time and variants of the basic form. This undertaking would mean analyzing 500,000, possibly even a million proteins. "That is a lot of proteins," noted the journal "Nature," skeptical of the hugely ambitious plan in 2001. The researchers are still a long way off their ultimate target, but now two research groups have at least reached the first milestone. The basic number of human proteins has been determined, the variants of which will be identified in further research.

Mapping the human proteome

Progress in mapping the human proteome was aided by advances in mass spectrometry (MS). This method is as important to proteome researchers as sequencing instruments are for genome researchers. Küster has five mass spectrometers available at his chair, each one worth some EUR 750,000.

Over the last 18 months, these machines were tasked with drawing a map of the human proteome. Bernhard Küster's team analyzed 60 different tissues, 13 bodily fluids and 147 cancer cell lines. Most of the tissue samples were provided by TUM's pathology labs, and as Küster confirms, laughing: a number of saliva and even ear wax samples were acquired from his own people for analysis. After that, the researchers followed a straightforward work flow. First of all, the proteins from any biological source were broken down using a protease, an enzyme that cuts all proteins into pieces called peptides at precisely defined positions within the amino acid sequences. After a few hours of lab work, the reaction tube contains an impressive 100,000 peptides instead of the original approximate number of 19,000 proteins.

The next step is pre-separation. "Even the most modern mass spectrometers are not able to handle the complexity of 100,000 peptides all at once," stresses Küster. So a liquid chromatography technique is used to send around 50 different peptides every second to the measurement chamber of the directly connected mass spectrometer. "Modern MS devices can properly identify five to ten peptides per second in a repetitive process along the liquid chromatographic time frame of several hours," he explains. A mass spectrometer needs ions – it cannot measure neutral particles. To generate ions from peptides,

Picture credit left: ediundsepp, right: Filser the scientists use electrospray ionization, a technique for which John B. Fenn won the Nobel Prize for Chemistry in 2002. Bernhard Küster explains, “That was a very important development because it allows us to ionize even large proteins and peptides without destroying them.” Subsequently, and through controlled manipulation of the trajectory of the ions in electrical fields under high vacuum, the ionized peptides are separated in the mass spectrometer according to their ratio of mass to charge. At the end, the detector records a huge spectrum of signals from which the mass and quantity of each peptide can be determined. In a second analysis step, the device determines their amino acid sequence, and within one hour, the instrument can churn out data for over 20,000 peptides.

But what can be done with this huge volume of data? What goes together? Which peptides belong to which protein? The next step is to complete a giant jigsaw puzzle aided by information from the genome. “Our work would be much more difficult without the decoded genome. We need the amino acid sequences that can be derived from genes to piece together our peptide analysis data efficiently,” explains Küster. For this, a computer must first virtually reproduce the protease breakdown of all of the predicted 19,629 proteins and, if needed, of other sequences present in the genome. Next, a mathematical algorithm compares the amino acid sequences determined in the measurements with those of the theoretically calculated peptides. One by one, the machine checks which puzzle pieces it can and cannot combine and assemble into proteins.

The biggest coherent data set of the human proteome

In this way, the Munich-based scientists identified some 80 percent of all human proteins. This work thus comprises the largest single data set of the human proteome. In addition, the team re-analyzed several dozen individual MS data sets on tissues and cell lines that other groups had uploaded to public databases. “The main starting point for our study was the idea that we could use the world’s existing knowledge by bringing it all together,” emphasizes Küster. Examples of such internationally available databases include PeptideAtlas and ProteomeXchange. The problem is the lack of software and computer architectures capable of performing comparative analyses of the terabyte-scale data volumes. Hence, some databases are currently little more than data dumps. Just over two years ago, therefore, Küster hit on the idea of collaborating with SAP to develop a new database and software. The result is ProteomicsDB – an all-in-one database and software system running on computers at SAP’s headquarters in Walldorf to perform a comprehensive analysis of the human proteome. Küster sees the platform as a tool for all scientists engaged in human proteome research: “It’s available to anyone.” New data sets are continuously being added to ProteomicsDB – the Pandey group’s sets have already been loaded – and in mid-September 2014, updated results were made public. At that stage, 18,248 of the 19,629 predicted human proteins were actually available, or 93 percent of the number forecast by the genome researchers. ▷

“If we knew the protein profile of, for instance, a tumor, we might be able to administer drugs in a more targeted way.”

Bernhard Küster

18,097

human proteins were published by Bernhard Küster in May 2014. New data sets are continuously being added, and in mid-September, updated results were made public. At that stage, 18,248 of the 19,629 predicted human proteins were actually available.
Using proteins to develop cancer therapies: Küster and his team were able to show that the efficiacy of 24 cancer drugs on 35 cancer cells bore a clear correlation with their protein profiles. The photo shows cancer cells being removed from the liquid nitrogen tank in which they are stored.

Missing proteins

Some details in the huge trove of data confirm previous expectations. For instance, a core set of 10,000 to 12,000 proteins can be identified in most cell types and tissues. In addition, many tissues are characterized by the presence of specific proteins.

The proteome map also raises some fundamental questions for scientists, such as how to find the seven percent or so of all predicted proteins that have remained elusive until now. This is undoubtedly due, in part, to the detection limits of mass spectrometry, as proteins with just 100 molecules per cell or even fewer remain under the radar. Detecting highly insoluble proteins is also proving to be a challenge. To identify this last seven percent, the TUM scientists are appealing to the world's experts in the field for help – one of the sections in ProteomicsDB is called “Adopt a protein”. “There are very good labs out there doing in-depth research on a small region of the map, and we invite them to add their data to ProteomicsDB,” explains Küster.

It may turn out that some of the currently gray areas in the proteome map don't even exist. A number of genes are permanently inactive, having been switched off as humans evolved. One such inactive area can be found in the human nose. In order to smell, organisms from mice to

Picture credit: Filser

men need special receptors on the surface of sensory cells in the olfactory epithelium located far back in the nose. Based on the predictions, we should have 853 of these olfactory receptors. But Bernhard Küster and his group have been able to account for only one in four of these. Perhaps this is one reason why our sense of smell is much less well developed than that of, say, mice and dogs.

Previously unknown proteins

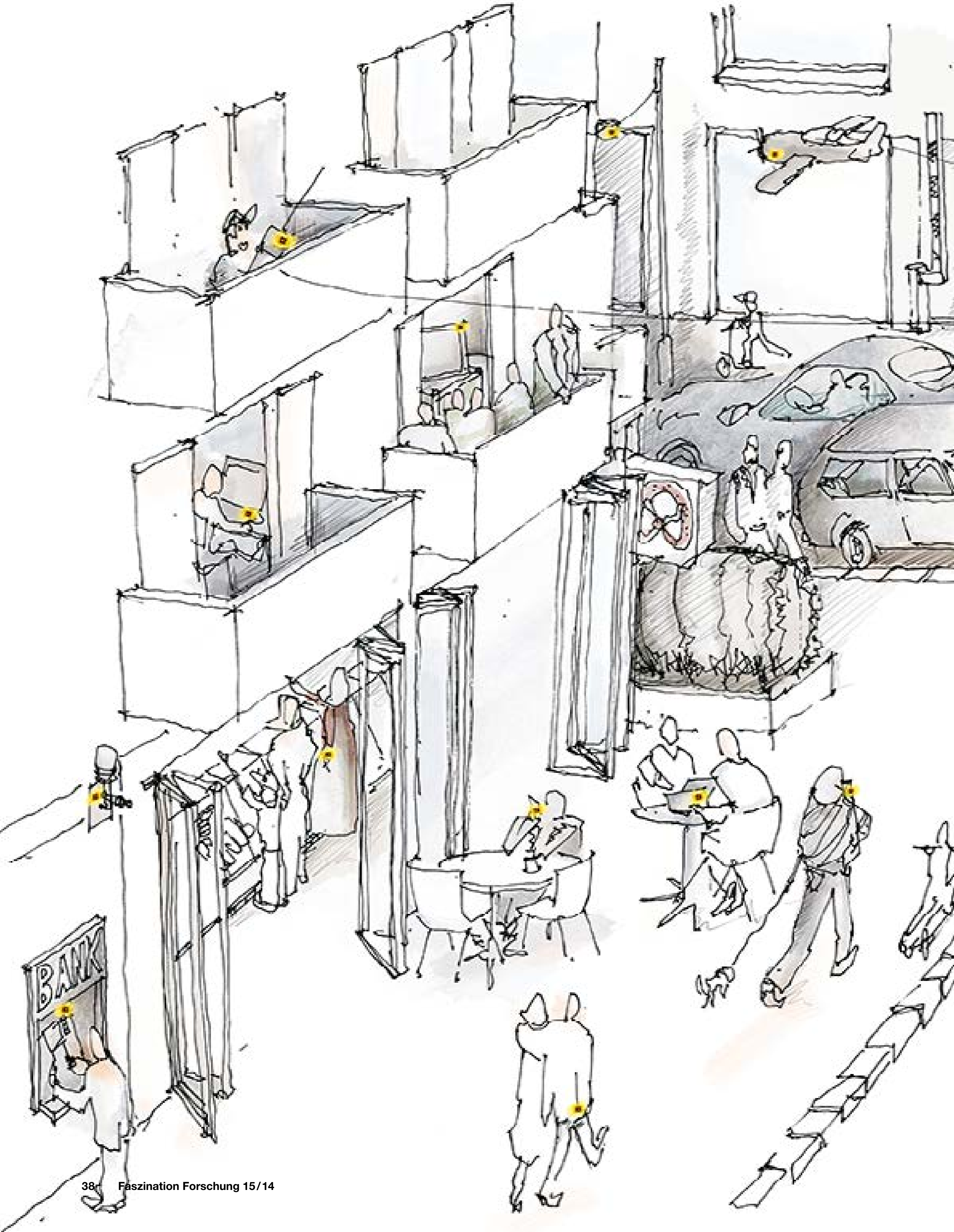
Another surprising finding is that the term "gene" might have to be interpreted more broadly than it has been to date. It is clear that our bodies create proteins whose genes have not yet been recognized by the genome researchers.

Our cells are home to some 10,000 large RNA molecules with functions that remain unexplained. Some are referred to as transcripts of unknown coding potential (TUCP). Others are called long intergenic non-coding RNAs (lincRNA). Some play a role in the regulation of stem cell properties and cell differentiation, for example. The attribute "non-coding" is not quite accurate, however, because the TUM team has identified 430 proteins originating from such non-coding lincRNA sequences. They were able to assign these by comparing the proteins found with amino acid sequences that can be derived from the lincRNAs. At present, no one knows why these "genes" are translated into proteins, but they may well represent evolutionary processes in which nature "tries out" new proteins with perhaps novel properties.

Protein patterns can determine drug efficacy

"Our map is only the starting point," says Küster. Scientists are sure to find more surprises while filling in the remaining spaces on the human proteome map and asking questions of the database. But what is the point of proteome research, apart from gaining a better understanding of basic biological principles? According to Küster, there are already indications of possible medical implications, as proteins are the targets for almost all medicines. It seems that certain protein patterns influence the effectiveness of such drugs. Küster and his team were able to show that the efficacy of 24 cancer drugs on 35 cancer cell lines bore a clear correlation with their protein profiles.

Says Küster, "This edges us a bit closer to even more individualized treatments for patients. If we knew the protein profile of, for instance, a tumor, we might be able to administer drugs in a more targeted way. This would also create a rationale for investigating new drug combinations and, generally, aligning treatments more closely with a patient's individual needs." *Bernhard Epping / Barbara Wankerl (TUM)*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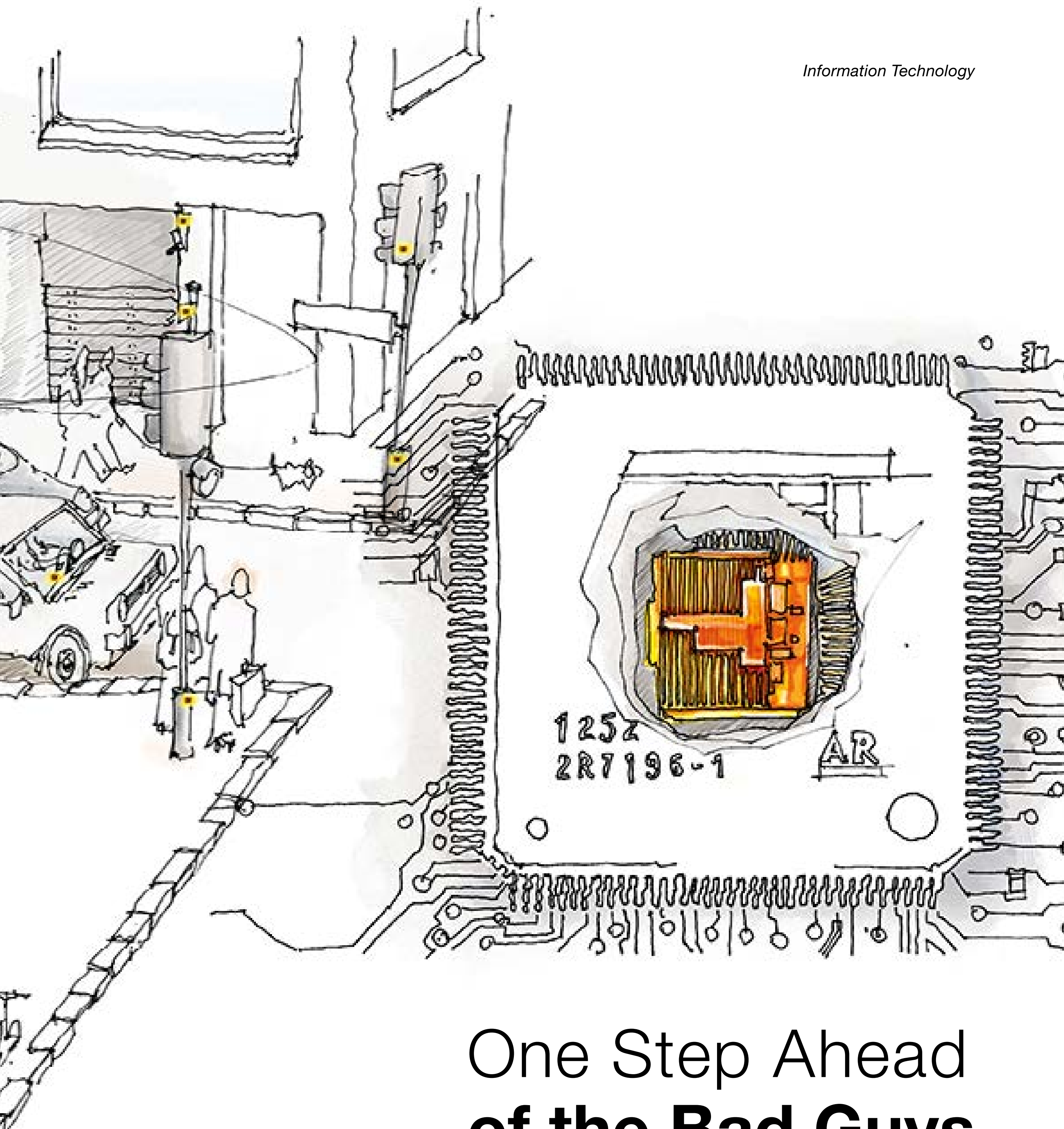
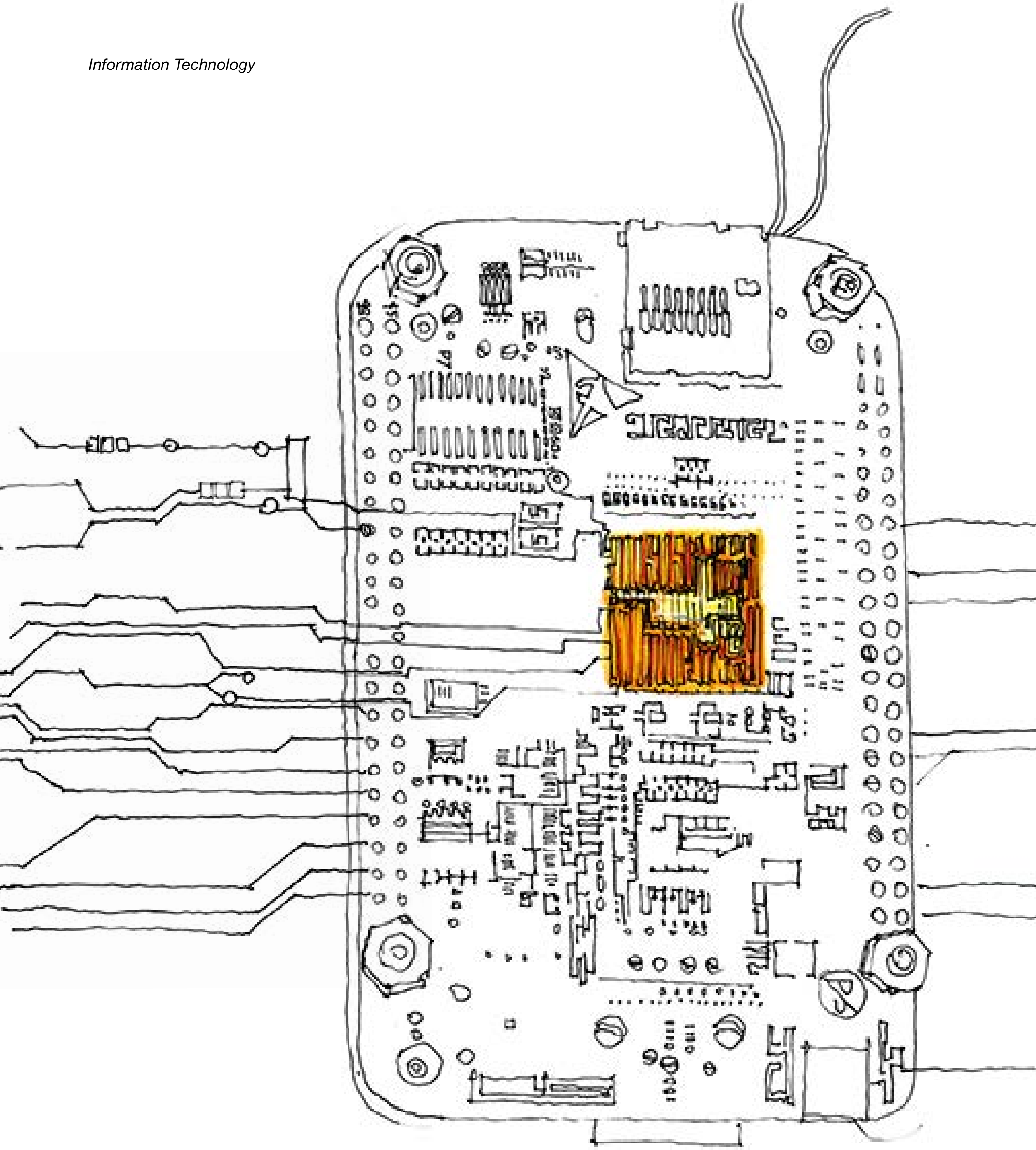


One Step Ahead **of the Bad Guys**

Georg Sigl is a professor of IT security. His job is to uncover security gaps in technical systems, particularly, control systems embedded in machines and production units. These embedded systems are increasingly being targeted by hackers, and Sigl leaves no stone unturned to identify weak spots, whether it's listening in on how cell phones compute or dropping acid on processors.

Picture credit: ediundsepp



Link
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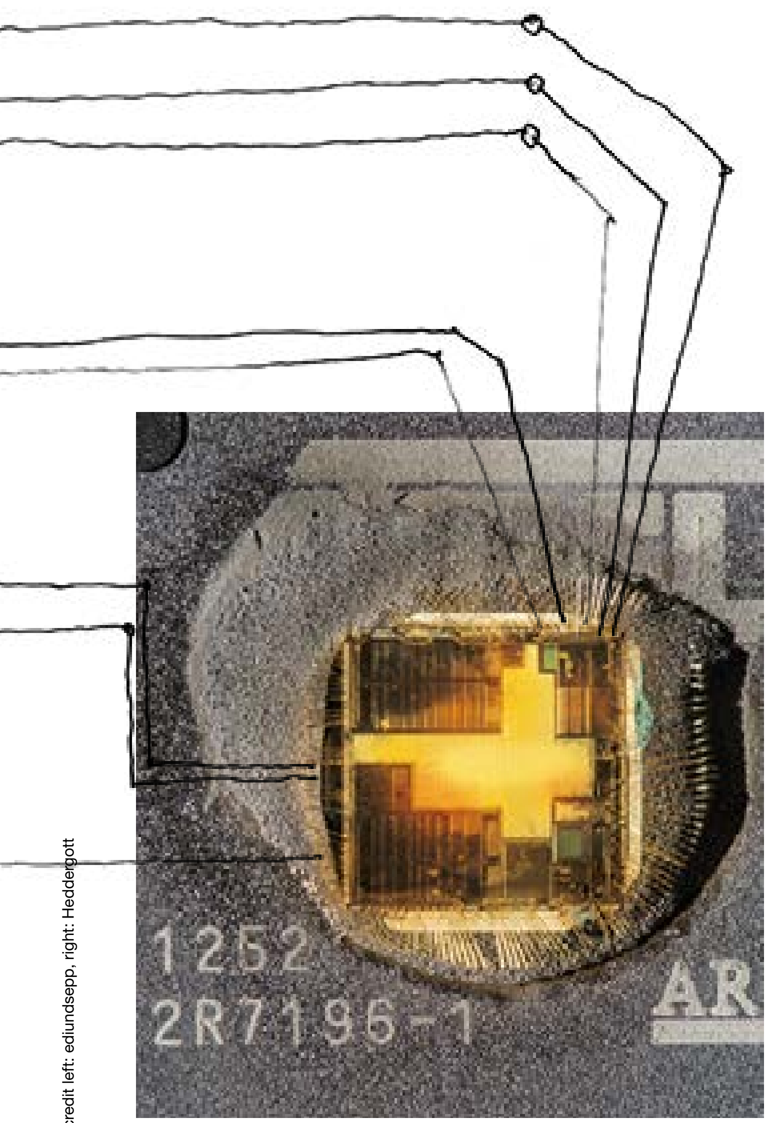


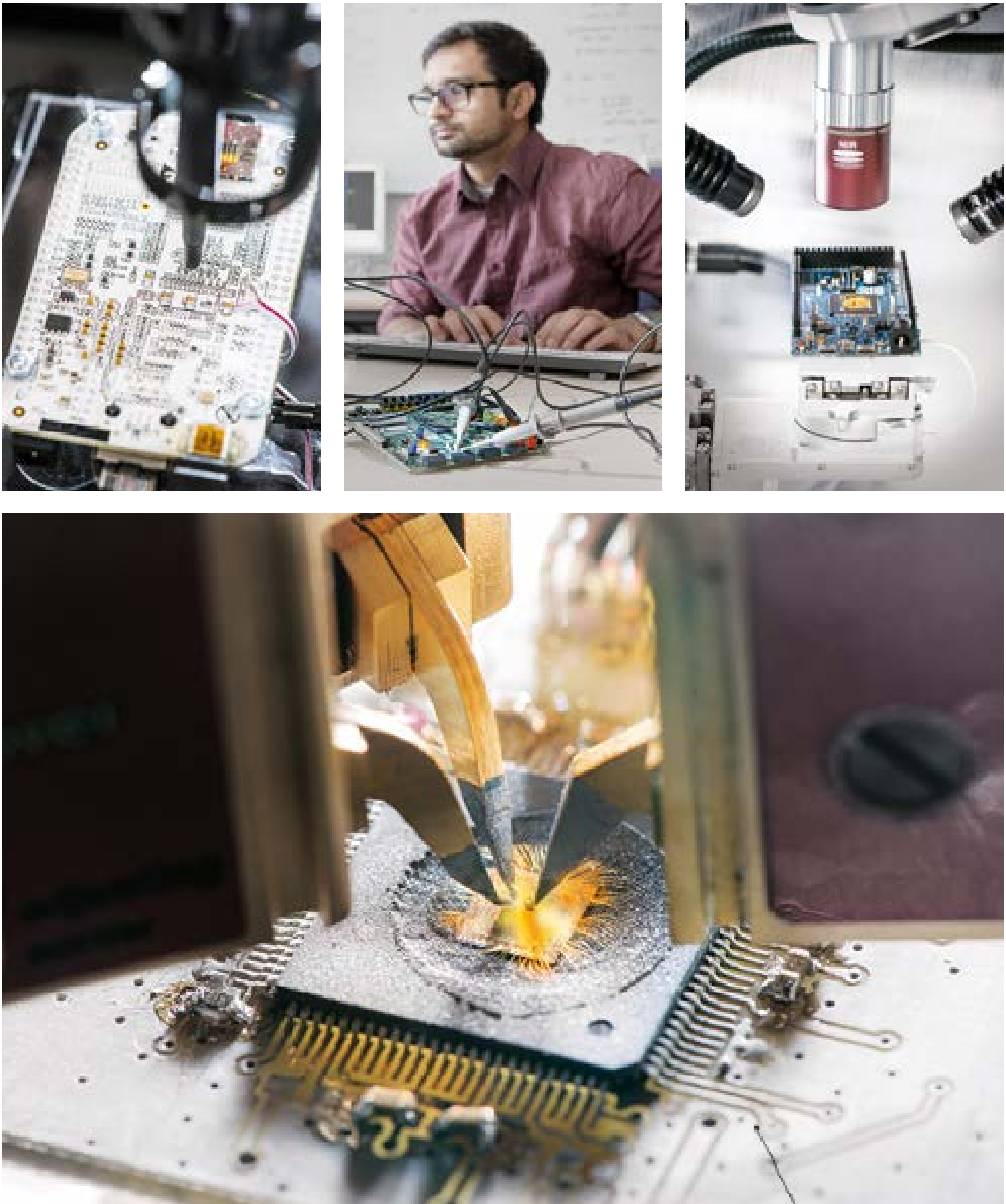
Picture credit left: ediundsepp, right: Heddergott

A microcontroller opened with the help of chemicals in order to find out about the composition of the processor.

Den Bösen einen Schritt voraus

Georg Sigl, Professor für Sicherheit in der Informationstechnik an der TUM, entwickelt Sicherheitstechnologien, um Steuerungs-Hardware für die Industrie, sogenannte Embedded Systems, zu schützen. In Deutschland wird derzeit unter dem Schlagwort „Industrie 4.0“ die Vernetzung von Maschinen vorangetrieben. Maschinen und andere Komponenten einer Produktionsanlage werden zunehmend mit Steuergeräten, sogenannten Embedded Systems, ausgestattet und an das Internet angebunden. So ist es möglich, alle Maschinen miteinander intelligent zu vernetzen. Mit der Vernetzung steigt aber auch das Risiko, dass Hacker über das Internet in Fabriken eindringen, Produktionsdaten aus Maschinen stehlen und Fertigungsstraßen zum Stillstand bringen. Um das zu verhindern, entwickelt Georg Sigl Sicherheitstechnologien, die die Embedded Systems vor Angriffen schützen.
Sigl gehört auch der Leitung des Fraunhofer-Instituts für Angewandte und Integrierte Sicherheit (AISEC) in München an. Er simuliert in seinen Labors unter anderem Hackerangriffe auf Hardware, mit denen er die Sicherheitscodes, sogenannte Schlüssel, von Computerprozessoren knackt. Dafür nutzt er unter anderem sehr empfindliche Messverfahren, mit denen er den Stromverbrauch oder die elektromagnetischen Abstrahlungen der Prozessoren analysiert. Ein Schwerpunkt der Arbeit liegt derzeit auf der Entwicklung robusterer Verfahren für die Verschlüsselung von Hardwarekomponenten. Dazu gehören sogenannte PUFs, Physical Unclonable Functions, nicht kopierbare, physische Eigenschaften. Dabei verwendet man äußere, physische Merkmale von Prozessoren oder anderen elektronischen Bauteilen, um sie fälschungssicher zu machen. So lässt sich beispielsweise der individuelle Ladungszustand, den ein Prozessor mitsamt seiner Tausenden von Transistoren beim Einschalten des Computers hat, als fälschungssicheres individuelles Merkmal des Prozessors nutzen. Sigls Arbeit zeichnet sich dadurch aus, dass sie informatische, mathematische und elektrotechnische Expertise vereint und damit umfassende Schutzkonzepte liefert. *Tim Schröder*

There are many theories regarding the origins of Stuxnet. Some experts believe that hackers developed the computer worm for industrial espionage. Others think it was created by the Israeli secret service to disable Iran’s nuclear capabilities. Whatever the reason, the developers behind Stuxnet had one clear target in mind: a Siemens controller used to regulate electronic components in industrial systems. Stuxnet was designed to sabotage these facilities, or at least significantly disrupt production. Numerous companies across the globe reported that they had come under attack from Stuxnet. Even today, the extent of damage to systems in Iran and elsewhere in the world is unclear. What we do know, however, is that this computer worm – which was discovered roaming the globe four years ago – is one of the most high-profile examples of professional malware designed to attack industrial facilities. It revealed just how vulnerable sophisticated technology can be if manufacturers do not implement sufficient protective measures.
There are a lot of computer controllers in the world today. Just one car alone can contain several dozen minicomputers used to control engine valves or power windows. The number of these embedded systems is set to rise by billions in the near future. The German government, for example, is currently promoting the transition to smart factories ▷



Chips under attack in Georg Sigl's laboratory: Measuring electromagnetic radiation to prepare for side channel attacks (top left); fault injection with power glitches in order to perform fault attacks (top center); firing laser beams at an open processor chip while it carries out calculations. The laser causes calculation failures, which can be used to extract secret information (top right). Side channel attack by means of three highly sensitive measuring probes (bottom).

Picture credit left: Heddergott, right: ediundsepp under the banner of its "Industry 4.0" initiative. More and more machines and components in production facilities are being equipped with embedded systems and linked to the Internet. In other words, all machines are being connected in smart networks. When a company receives an order, it can then use this intelligent network to send commands to its different production sites via the Internet. Embedded systems enable machines to activate themselves and components to organize their own transport. A malware attack could therefore have devastating consequences, allowing criminals to steal blueprints from machines or bring entire production lines to a halt. Yet these systems harbor an alarming number of security gaps.

It is Georg Sigl's job to close these gaps before they can be exploited by criminals. Sigl is a professor of IT security at TUM and one of the heads of the Fraunhofer Institute for Applied and Integrated Security (AISEC) in Munich. In his labs, he fires laser beams at computer processors and measures electromagnetic radiation from smartphone chips in a bid to decode the secrets of computers, chip cards and embedded systems, crack codes and break into secure systems. He does this to discover and close security gaps before hackers strike. Sigl spent many years at Siemens and later Infineon, working on secure chip cards and developing a number of groundbreaking security technologies. Today, he applies this expertise to a number of tasks, including the protection of embedded systems.

Finding and closing security gaps

"Identification and – even more importantly – authentication are crucial when it comes to protecting technical applications," explains Sigl. "During an identification process, I only have to enter a unique identifier. With authentication, however, I have to prove that I really am the person I claim to be." This can be done by entering a PIN, for example at an ATM. Users can also use unique characteristics such as a fingerprint to authenticate themselves. Bank accounts, protected computers and machines can be accessed only by individuals who know the right password or have a specific characteristic – theoretically at least. In reality, security systems repeatedly reveal that they are vulnerable to attack. In 2008, researchers at the Ruhr-Universität Bochum (RUB) were able to decode an encoded signal for a garage door opener by intercepting the radio signal with a sensitive antenna and duplicating the key. Once they had done this, they were able to open and close the garage door at will. This was a sensitive experiment, as the security gap affected the entire product range of a renowned manufacturer. "This is what we call a side channel attack," explains Sigl. "Chips and computer processors generate electromagnetic radiation when they compute. This can easily be picked up by sensitive antennas and used to clone a key." Mobile devices such as smartphones are particularly vulnerable to side channel attacks, as they are constantly being carried around in public.

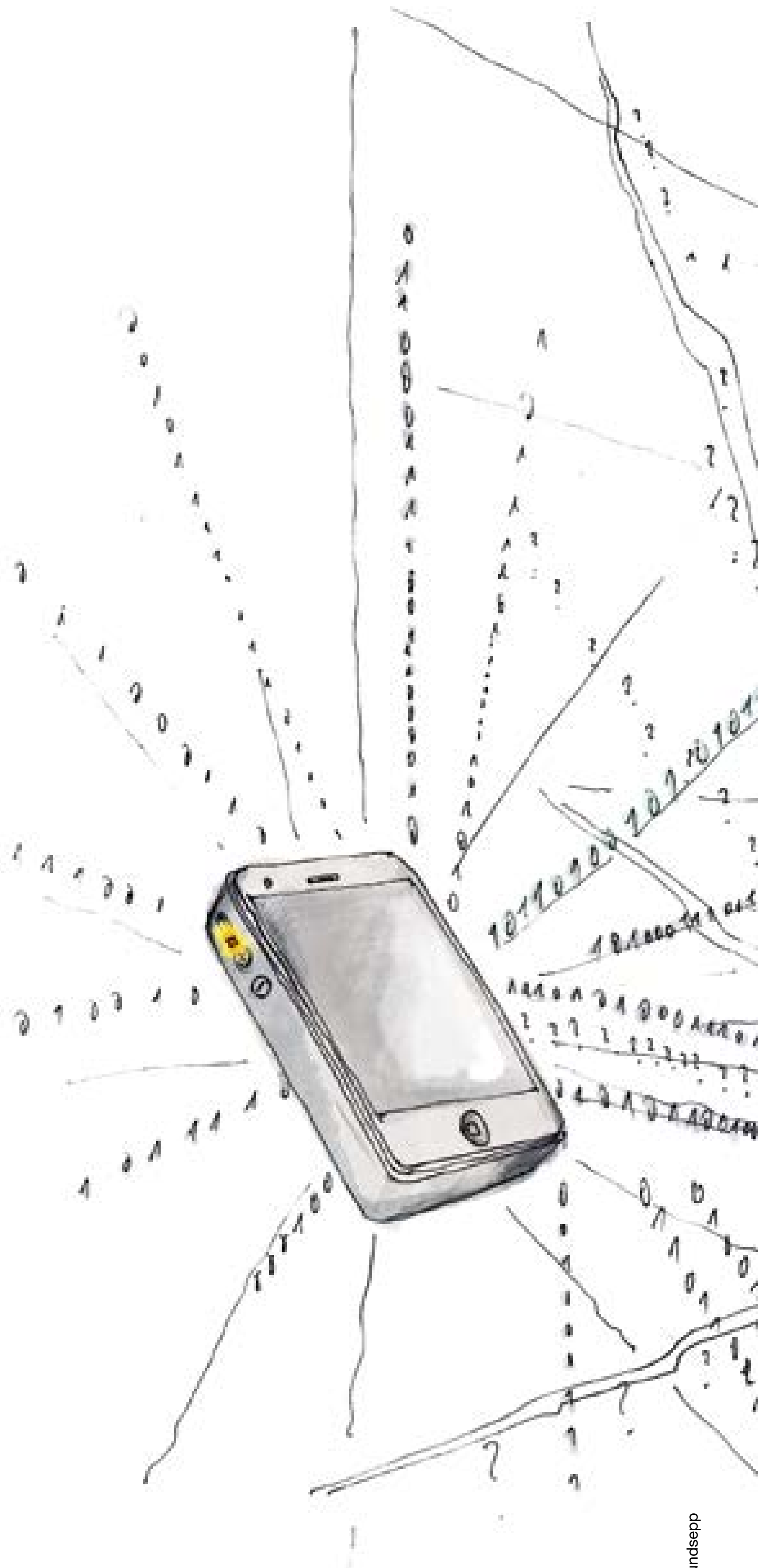
Cloning keys in this way requires sensitive equipment. And Sigl has it all in his labs. In fact, Sigl and his team even go so far as to burn away processor casing with nitric acid to uncover the circuit paths inside. After all, this is something that could well happen in real life if industrial spies were to steal hardware. Once the processor is exposed, Sigl and his employees use a probe measuring just one tenth of a millimeter in size to eavesdrop on the faint electromagnetic signals – in much the same way as a doctor uses a stethoscope to listen to the human body. The researchers are listening for the security key. Almost every secure technology system has a key of this kind. Experts differentiate between symmetric and asymmetric encryption. In the case of symmetric encryption, the transmitter and receiver use the same key. When children create a secret language, for example, they are using symmetric encryption and use the same key to encrypt and decrypt messages. In contrast, asymmetric encryption uses a public and a private key. Here, users can encrypt (or sign) a message using a private key. This happens automatically when you transfer money, for example, during online banking. The bank then uses a public key to check whether the signature is correct. With this method, the sender and the receiver do not need to send the key to each other – a clear benefit over a secret language, as the act of exchanging the key is a potential threat to security. ▷

Protecting keys

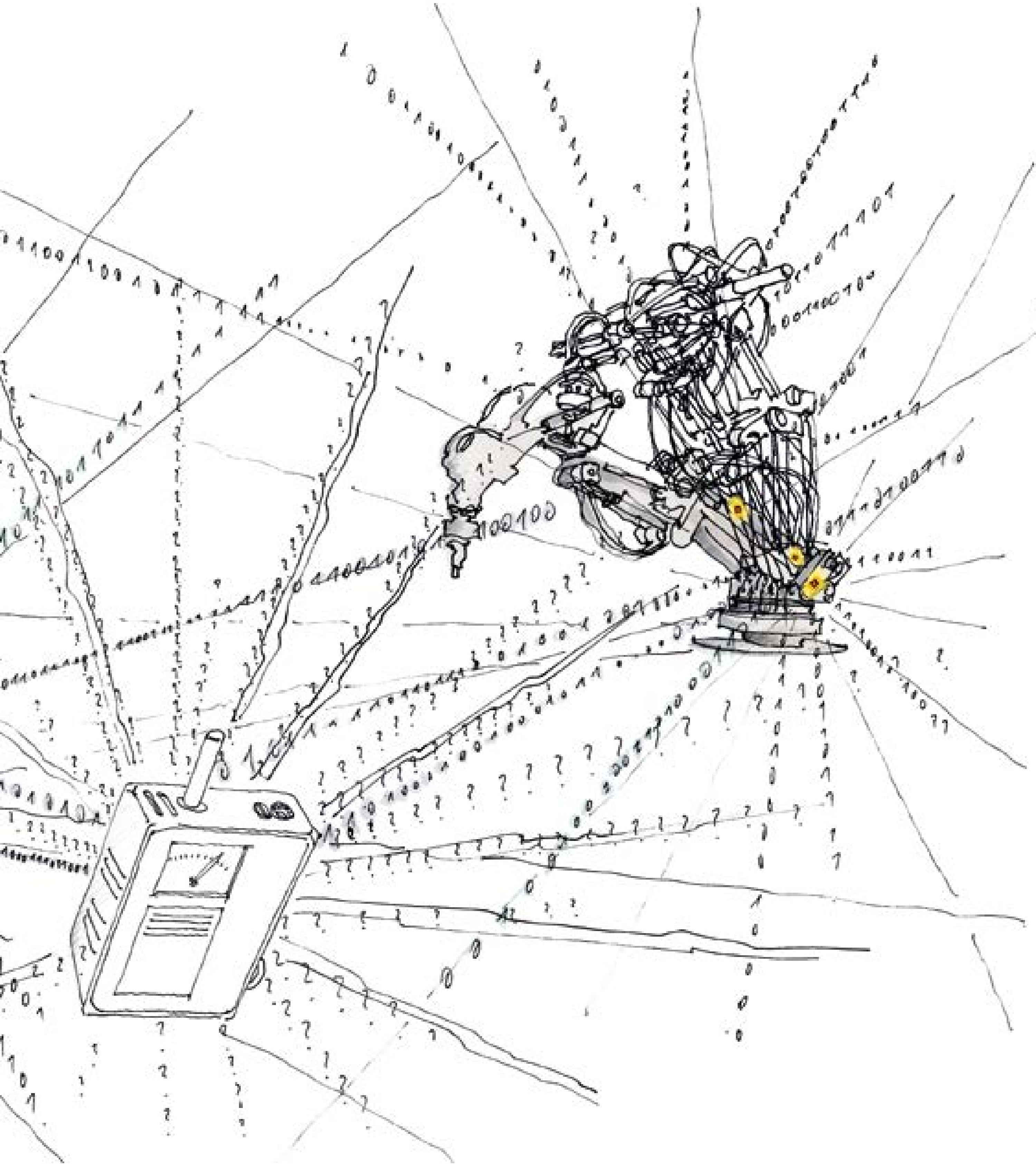
In cryptography, a secret number is used to encrypt the data to be sent. This private key protects the message from outside attack. Hacking is all about decoding this key. And there are different ways of doing this for different applications. Sigl is familiar with these methods from his time in the chip card industry. One way is to measure the duration of a computing operation. If the process takes a long time, for example, this could indicate that the key is using more ones than zeros. Measuring a chip's power consumption can also be used to capture security keys, as complex computational operations require more power. Sigl uses the differential power analysis (DPA) principle to outline how this method works. In this case, a hacker feeds random data many thousands of times into a chip that uses an unknown key to encrypt it and measures the power consumption during these cryptographic operations. This consumption depends on every single key bit. The hacker then guesses one bit of the key and calculates an internal bit, which depends on the data and the guessed key bit. Then he assigns the thousands of power consumption measurement values into two groups, using the internal bit for the decision. If the statistical distribution of these values can be separated into two groups of high and low power, he has guessed the key bit correctly. If no statistically relevant distinction of the power values is possible, the guessed bit is wrong. In this way, a long key with many bits can be determined bit by bit.

Yet there is a way of countering this. "Engineers can incorporate random numbers that change the computing operation and make it impossible for an attacker to map regularities during DPA," explains Sigl. "However, you have to be very careful when doing this to ensure that you do not incorporate any leaks that allow information to be captured via a side channel attack."

For Georg Sigl, the move to security came very much by chance in the 1990s, when he switched departments while working at Siemens. "I was an experienced microprocessor designer, but cryptography was a completely new area for me," he says. "It was a secretive world that I knew nothing about, and it wasn't until I moved departments that I found out how fascinating it is." Today, the electrical engineer is primarily interested in fostering an interdisciplinary approach to cryptography that incorporates mathematics, IT and electrical engineering. "Electrical engineers are, above all, hardware specialists, whereas mathematicians and IT engineers have in-depth insights into the mathematics of cryptography. We bring these areas of expertise together to provide a multi-disciplinary approach to study." This integrated approach is crucial, as today's hackers are already combining mathematical, physical and engineering methods to uncover new channels of attack. "The challenge for researchers in our field is to become so proficient in these areas that we can cross-link them and come up with new ideas for counteractive measures." ▷



Picture credit: ediundsepp

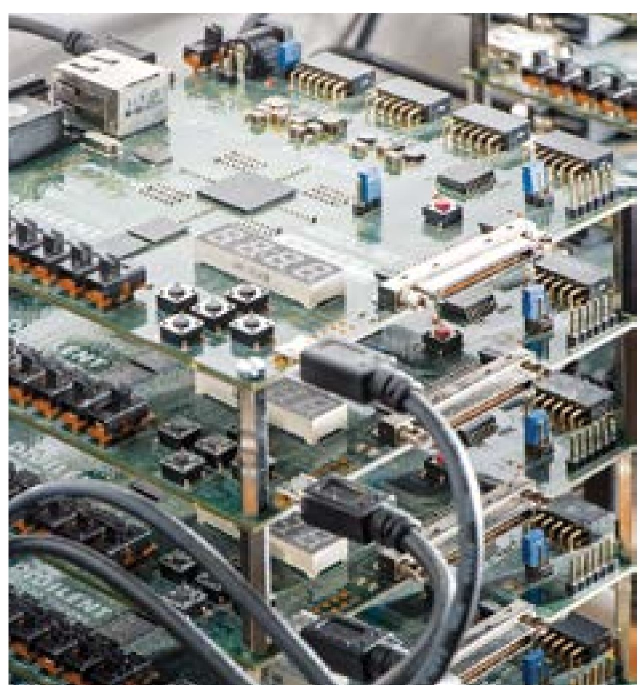


In the future, smart factories, machines and other components will be equipped with embedded systems to be controlled via the Internet. These systems are prone to security gaps. Georg Sigl and his group continuously develop new technologies to protect the industry‘s control hardware from any such attack.

Georg Sigl is a professor of IT security at TUM and one of the heads of the Fraunhofer Institute for Applied and Integrated Security (AISEC). Before that he spent ten years at Infineon developing technologies for secure chip cards. “Germany has a world wide leading position in this high-end hardware security technology,” he says, “The two leading chip card companies have their main R&D sites here, and we build the bridge between this industry and university research in order to win the unending race against hackers.”

Unclonable chip functions

A relatively recent technology known as the physical unclonable function (PUF) underscores the importance of this approach. PUF uses the external, physical properties of processors and other electronic components to make them uncopiable or incapable of generating security keys. Georg Sigl and his team are working intensively in this field. PUFs can also be used to protect embedded systems. The risk of malware being introduced to technical systems via counterfeit hardware is a major concern for manufacturers. Being able to uniquely identify security-relevant hardware would help close this security gap. PUFs can be used to do this. The technology usually harnesses the unique properties that a hardware component is given during production. Every computer processor, for example, differs slightly from all other seemingly identical microprocessors – even if they are produced in the same series. When a device is switched on, the many thousands of transistors in a processor’s memory often have different states. Some are switched to represent 1, and others 0. This state pattern is almost exactly the same every time a chip is switched on. It can therefore be used as a kind of individual key to encrypt data on the component or to make it uniquely identifiable. Another type of PUF uses properties that are created during production and stored for the customer in much the same way as a TAN list. This can include specific electronic properties. To identify a processor or other component at a later date, the chip is fed predefined computing operations saved on the PUF list. If the chip responds with a characteristic PUF pattern, the customer can be sure that it is an original component. The real challenge for Sigl is to always be one step ahead of the attackers. “Staying ahead of the curve is not just a question of carrying out research in secret in companies. We also need to develop and implement new ideas at universities and research institutes.” This was one of the main reasons why Georg Sigl moved into research in 2010. And with the two working groups at the TUM and the Fraunhofer Institute AISEC, he is certainly in the best possible position to make life difficult for hackers, even in this increasingly networked world. *Tim Schröder*



Connected evaluation boards with field programmable gate arrays are used to test out ideas for new PUFs.

Picture credits: Heddergott

Study Highlights Forest growth

Trends from 1870 to the Present

TUM scientists showed that trees have been growing significantly faster since the 1960s. The typical development phases of trees and stands have barely changed, but they have accelerated – by as much as 70 percent. The study is based on long-term data from experimental forest plots that have been continuously observed since 1870.

Picture credit left: Häberle, right: Steinacker (TUM)

Cynthia Schäfer and Eric Thurm, doctoral candidates at the Chair for Forest Growth and Yield, take a growth ring sample from an experimental plot tree.

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Three decades ago, "forest dieback" was a hot topic, with the very survival of large forest ecosystems seemingly in doubt. But instead of a collapse, the latest studies indicate that forests have actually been growing at a faster rate. Whether, how and why forest stands have changed their growth patterns over the last century are still hotly disputed questions. The current study provides some answers. It is based on data from experimental forest plots that have been observed systematically since 1870. This makes them among the oldest forest study sites in the world. The forested areas are also representative of the typical climate and environmental conditions found in Central Europe. "Our findings are based on a unique data pool," maintains Prof. Hans Pretzsch from TUM's Chair for Forest Growth and Yield, who headed up the study.

Accelerated growth

In the cases of spruce and beech, respectively the dominant species of coniferous and deciduous trees in Central Europe, the scientists noted significantly accelerated tree growth. Beechtrees exhibited a growth rate that was 77 percent faster than in 1960, while the figure for spruce was 32 percent. The stand volume growth for beech was 30 percent, and 10 percent for spruce. "The stands as a whole had a lower growth rate than the individual trees essentially because larger trees require more space. Hence, each stand will have fewer trees," explains Pretzsch. The scientists are putting the growth acceleration down to rising temperatures and the extended growing season. Carbon dioxide (CO_2) and nitrogen are other factors contributing to the faster growth. The concentrations of these gases in the atmosphere have been rising steadily over the last century. "Interestingly, we observed that acid rain had only a temporary slowing effect on the growth of our experimental plots. In fact, the input of pollutants started to fall off significantly from the 1970s," says Pretzsch. "It is true, though, that only a few of our experimental areas are located in the ridges of the highland mountains where the greatest damage was observed."

Change requires adaptation

While the trees both grow and age faster, the appearance of the forest does not change as a result. But the same tree and stand sizes are achieved significantly earlier than in the past. This could benefit the forestry industry in that target diameters and the optimal harvest rotation age will be reached sooner. Besides, more wood can be harvested without compromising the principle of sustainability. At the same time, the altered timescale has not yet been incorporated into traditional forestry yield models, which monitor growth merely as a function of age. The risk here is that the newly discovered benefits will not be exploited. Meanwhile, the accelerated growth and aging of trees is also significant for the forest ecosystem as a whole, as Pretzsch explains: "The plant and animal species that will be most affected are those living in habitats that depend on special phases and structures of forest development. These species may have to become more mobile to survive."

Long-term observation provides unique pool of data

The study was based on 600,000 individual tree surveys conducted since 1870. Over such a long timescale, it was possible to determine from the growth of the trees how they responded to changing environmental conditions. Pretzsch adds: "Even though the experimental areas varied in terms of climate and soil conditions, we were still able to discern an overall trend of faster growth." But it is not just the experimental plots and the long observation period that make the data so interesting. "We did not observe the trees in isolation, but rather always in interaction with their neighbors. This helped us understand how the dynamics of individual trees influence the stand as a whole. The growth trends at stand level are relevant for the forestry industry in terms of productivity, carbon sequestration and climate risks," concludes Pretzsch. *Barbara Wankerl (TUM)*

Lurking in **the Liver**

The hepatitis B virus is a silent killer. It can lie dormant in human liver cells for years and then eventually lead to cirrhosis and liver cancer. No cure has been found to date. But now Prof. Ulrike Protzer has discovered that it may be possible to eliminate this persistent virus from human cells.

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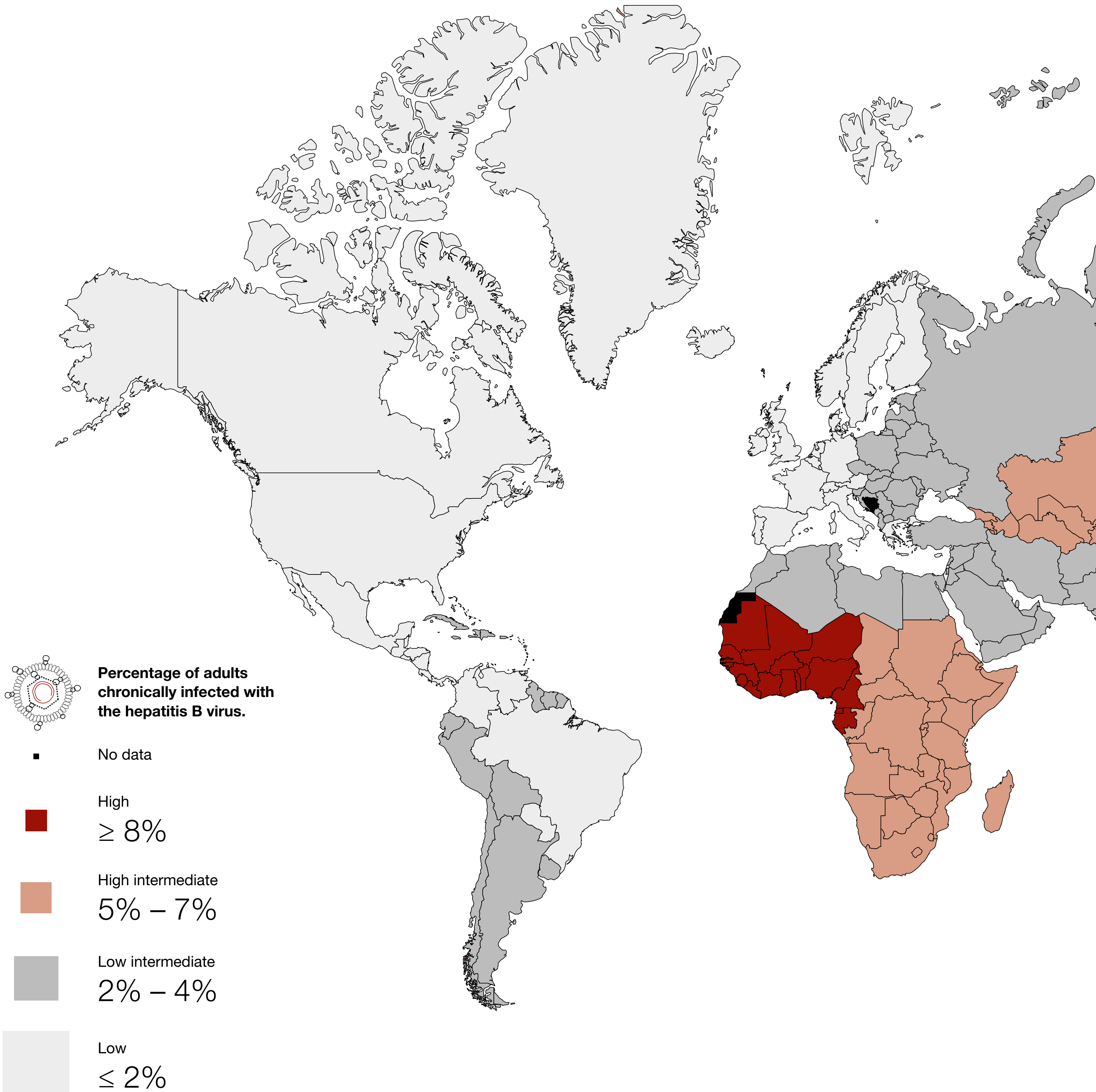
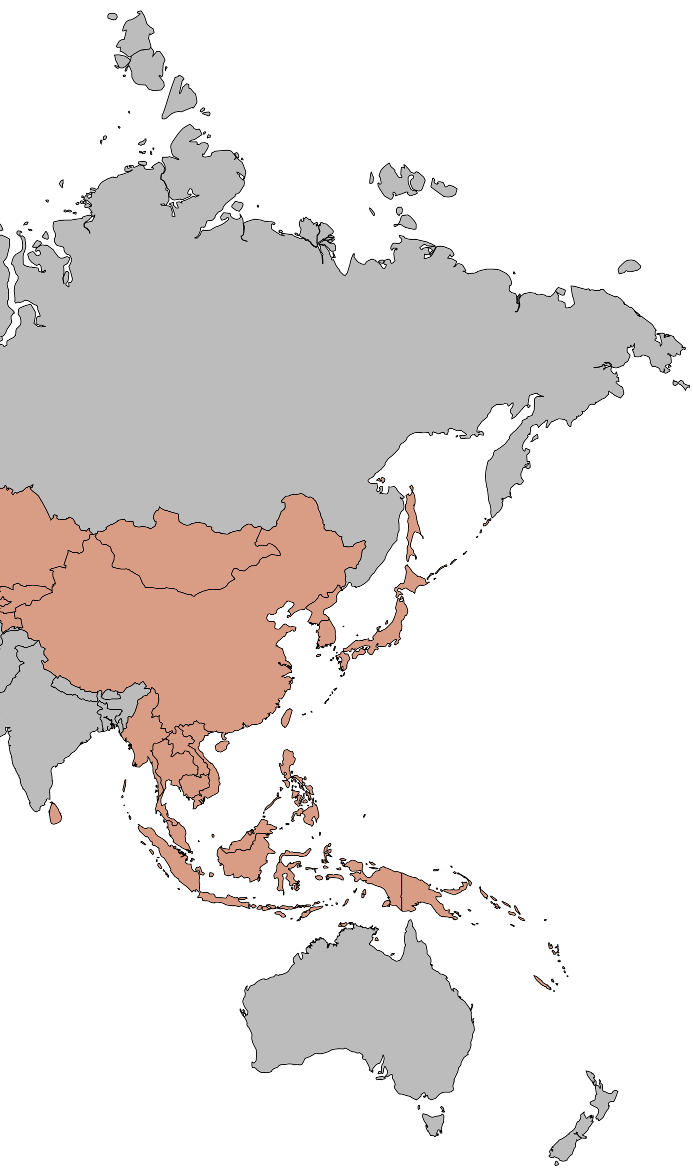
www.virologie.med.tu-muenchen.de

Picture credit: Bauer



Geographic distribution of chronic hepatitis B virus infection. With about 250 million carriers, hepatitis B virus infection is highly prevalent around the globe. This map shows the prevalence of hepatitis B surface antigen (HBsAg) as a marker of chronic HBV infection among adults in different countries.



Picture credit: ediundsepp (source: TUM)

Gefährliches Leben in der Leber

Das Hepatitis-B-Virus tötet aus dem Hinterhalt. Es befällt zunächst unbemerkt menschliche Leberzellen und führt Jahre später zu Leberzirrhose und Leberkrebs. Hepatitis B wird meist bei oder direkt nach der Geburt übertragen. Bei Säuglingen und Kleinkindern schafft das Virus es in 90 Prozent der Fälle, seine DNA dauerhaft in den Zellkernen der Leberzellen zu hinterlassen. Schätzungen gehen davon aus, dass insgesamt 250 Millionen Menschen dauerhaft mit dem Hepatitis-B-Virus infiziert sind. Eine Heilung gibt es bisher nicht. Doch die Virologin Prof. Ulrike Protzer hat gleich zwei Möglichkeiten entdeckt, das persistente Virus aus den Zellen zu verbannen.

Zerstörung der Virus-DNA
Jahrelang dachte man, dass nur eine Zerstörung der infizierten Leberzellen die Chance auf Heilung bringt. Ulrike Protzer hat herausgefunden, dass es auch anders geht. Stimuliert man spezielle Rezeptoren auf den Leberzellen, so stellen die Zellen sogenannte APOBEC-Proteine her. Diese greifen gezielt die Virus-DNA an, schneiden einzelne Basen kaputt und führen somit zum Abbau des viralen Erbguts. Die Methode ist faszinierend, hat jedoch einen Haken. Nur 40 bis 60 Prozent der Virus-DNA können auf diesem Weg vernichtet werden. Um das Virus ganz zu vertreiben, braucht man die Hilfe des Immunsystems.

T-Zell-Therapie
Die T-Zellen sind dafür verantwortlich, infizierte Körperzellen zu zerstören. Bei Patienten mit chronischer Hepatitis B attackieren aber die T-Zellen die infizierten Körperzellen nicht. Deshalb helfen die Forscher nach, indem sie T-Zellen mit speziellen Rezeptoren versehen, die das Oberflächenprotein des Hepatitis-B-Virus als gefährlich erkennen und sowohl infizierten Leberzellen als auch Leberkrebszellen zerstören. Für eine Therapie wäre es am besten, beide Methoden zu kombinieren.

Claudia Steinert

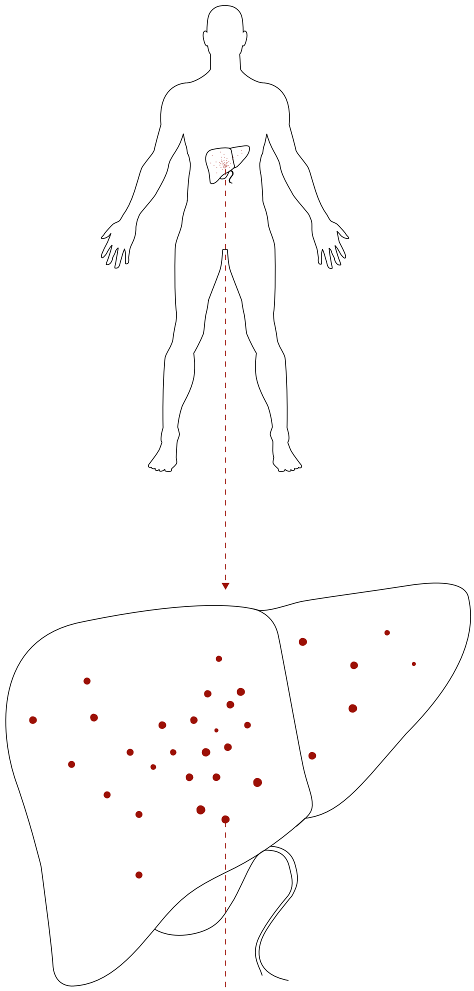
Anyone who has exchanged e-mails with Ulrike Protzer will have a fair idea of the long hours she works. She usually responds in the morning around seven or in the evening after the late-night news. In between, the professor of virology at TUM and Director of the Institute for Virology at Helmholtz Zentrum München is busy trying to develop a cure for chronic hepatitis B.

It is estimated that over 250 million people suffer from persistent hepatitis B virus infections. By way of comparison, the number of people infected with HIV currently stands at just 35 million. Hepatitis B is one of the world's most prevalent infectious diseases, responsible for around 500,000 deaths every year. This disease takes a particularly strong toll in Eastern Europe, Africa and Asia.

Ulrike Protzer knows all this from first-hand experience. She has worked in Africa and had to watch young people succumb to a virus that had been "hiding" in their liver for a long time. Even though most infections occur at the time of birth or shortly afterwards, there are no symptoms in the early stages. The virus keeps a low profile – it wants to be passed on to the next generation, so it needs its ▷

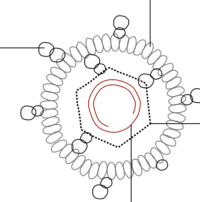
Picture credits: Bauer

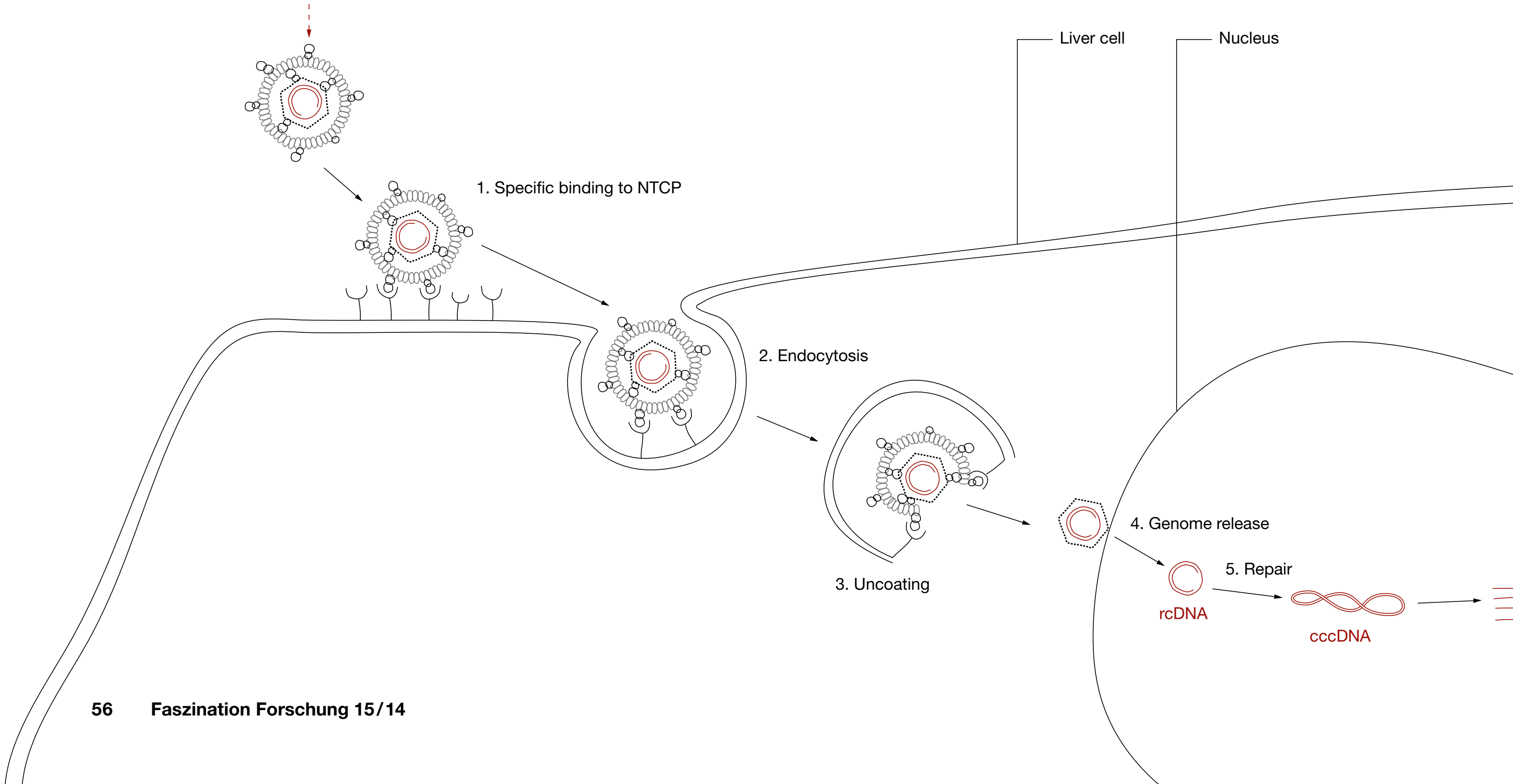
Diagnostics of virus infections. To allow correct diagnosis of viral infection, quality-assured modern diagnostics are essential. Patient material from the clinics is initially processed and prepared (top left) for analysis with standardized diagnostic assays (bottom left). Before reports are finalized, specialized medical virologists discuss the results (right).



A virus with unusual DNA

The hepatitis B virus is extremely host-specific – it can infect only humans and chimpanzees. It is characterized by its circular DNA, which is only partially double-stranded – one strand is shorter than the other. Only when this strand is completed in the liver cells does the virus assume its permanent form: covalent closed circular DNA (cccDNA), which persists as a minichromosome in the cell nucleus.





human host to remain healthy and capable of reproduction for as long as possible.

It is only when the infected person has become a young adult and passed the virus on to their own offspring that the damage caused to the liver becomes clear. Cirrhosis and liver cancer (known as hepatocellular carcinoma) are the most common long-term consequences. These conditions are untreatable in most cases, with 50 percent of patients dying within six months of diagnosis.

The virus is engineered to pass from mother to child. While the immune system of adults is well equipped to fight the hepatitis B virus, children can't efficiently eliminate the virus. In fact, 90 percent of all babies and small children who come into contact with the virus become chronic virus carriers. The figure for adolescents and adults is just 5-10 percent.

This complicates efforts to prevent infection in the first place. There is a vaccine, but it has to be administered prior to infection or – to stop the virus being passed on from mother to child – in the first 24 hours after birth. In rural China or remote African villages, this is simply not practical. "Wiping out this disease through vaccination alone will be very, very difficult," stresses Protzer. That is why her research is concentrating on ways to eradicate the virus from the liver cells. While the latest drugs are capable of controlling hepatitis B, they cannot eliminate it.

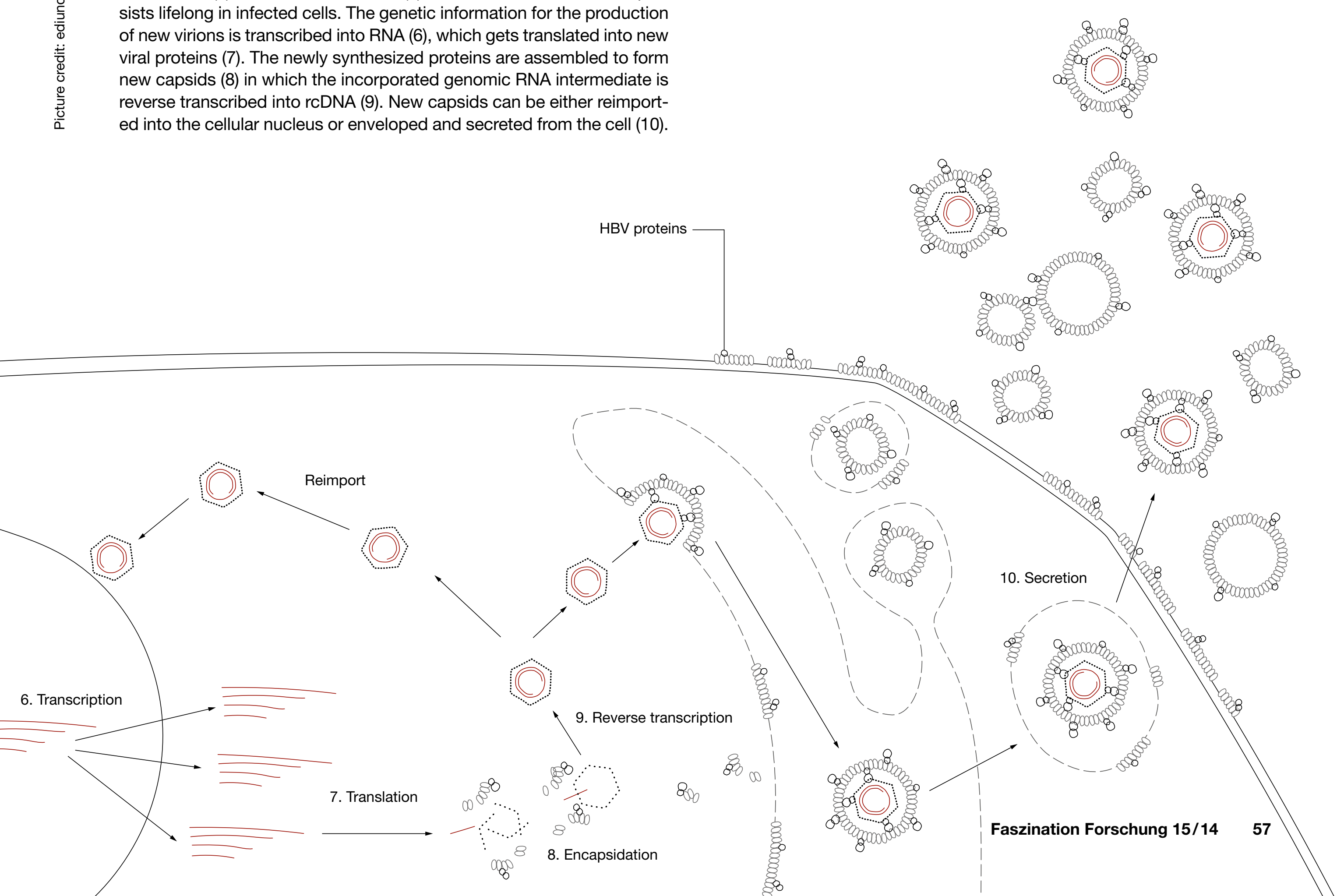
The virus uses the liver cells

The hepatitis B virus is amazingly small and unbelievably efficient. Its genome consists of just 3,200 base pairs containing all of four genes. "That this thing can survive at all is astonishing in itself," says Protzer. The human genotype is a million times bigger, and even the herpes viruses have 50 to 70 times more DNA than hepatitis B.

When a person becomes infected, the virus circulates in their blood until it reaches its target: the hepatocytes in the liver. A transporter with the job of conveying bile acid from the blood to the liver "smuggles" the hepatitis B virus into the cells unnoticed. The virus then latches on to the cell nucleus, opens its capsid and imports its tiny genome ▷

Picture credit: ediundsepp (source: TUM)

The hepatitis B virus uses liver cells (hepatocytes) for reproduction. The free virus (virion) recognizes hepatocytes via the NTCP receptor (1) and is taken up by invagination of the cell membrane (2). The virus is released into the cytoplasm (3) and its genome (rcDNA) is imported into the nucleus (4), where it is converted (5) into so-called cccDNA that persists lifelong in infected cells. The genetic information for the production of new virions is transcribed into RNA (6), which gets translated into new viral proteins (7). The newly synthesized proteins are assembled to form new capsids (8) in which the incorporated genomic RNA intermediate is reverse transcribed into rcDNA (9). New capsids can be either reimported into the cellular nucleus or enveloped and secreted from the cell (10).



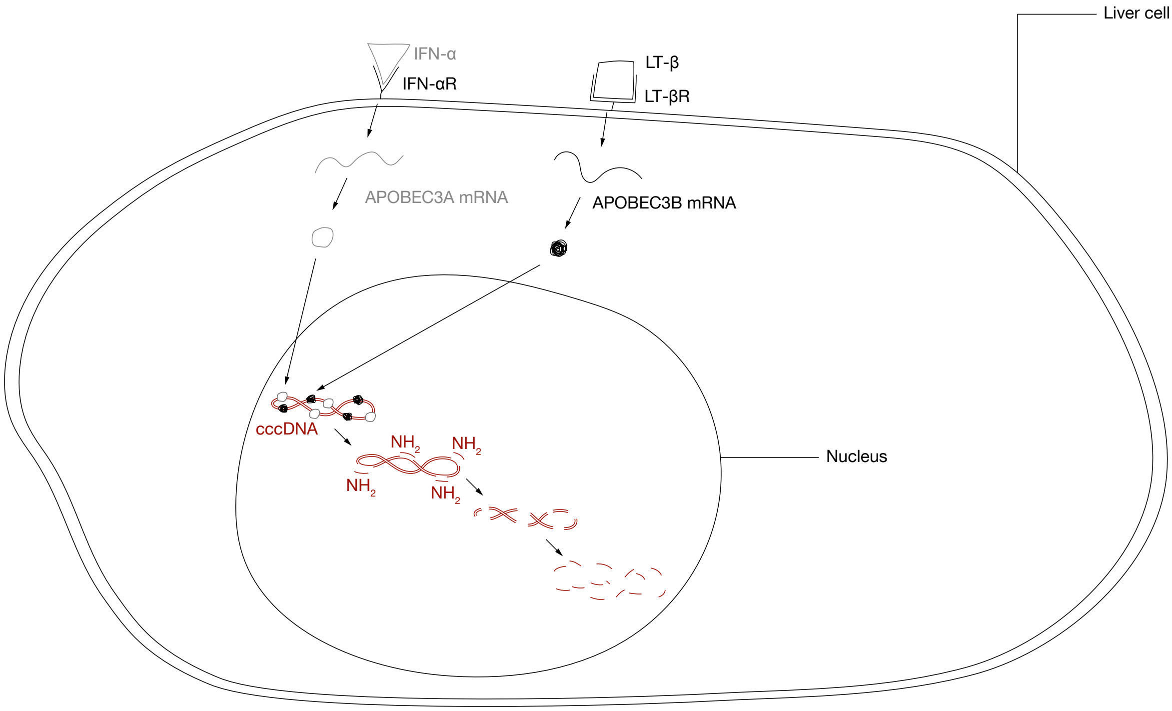
Picture credit: Bauer

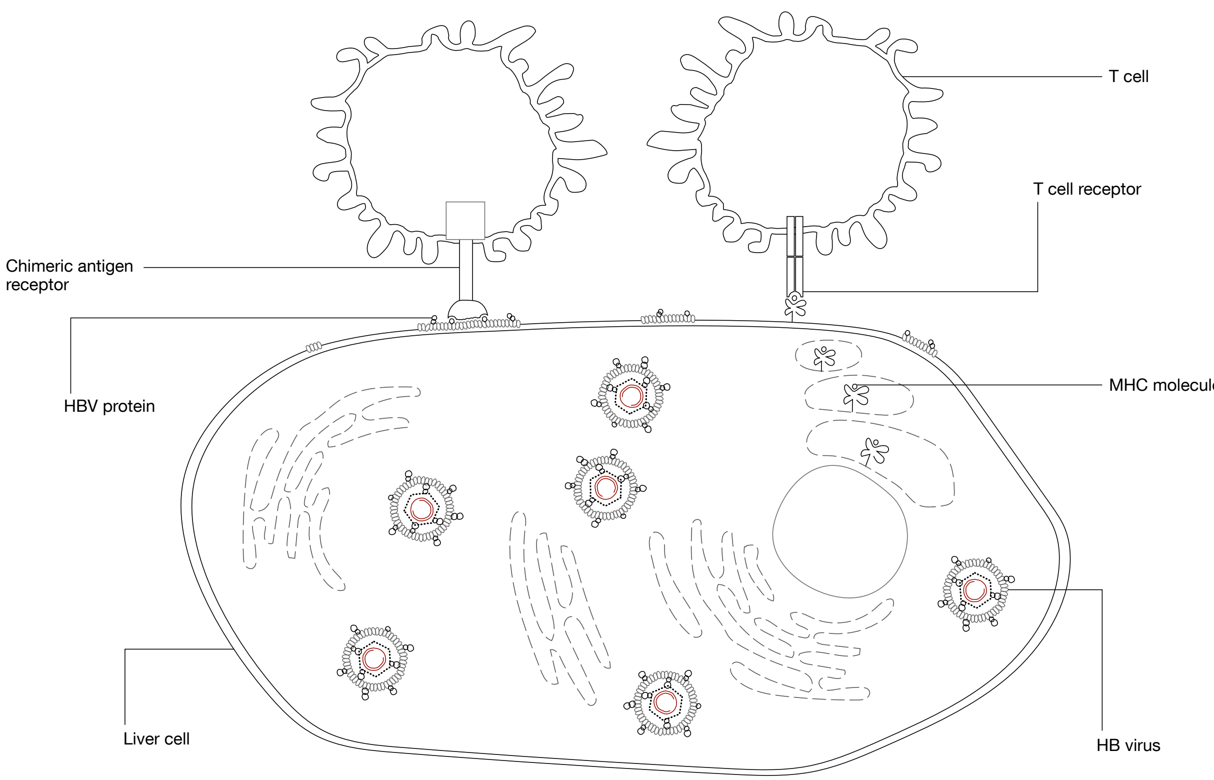
into the cell nucleus via a mechanism that is not yet fully understood. The cell is an active assistant in this process. “We are not sure how the virus DNA gets into the nucleus through the nuclear pores, but we do know that cellular proteins are involved,” affirms Protzer.
Once the virus has penetrated the cell nucleus, the cell does all of the work for the virus. First, it assists in converting the only partially double-stranded, circular virus DNA into its permanent form cccDNA. It does this by inserting the missing base pairs and fixing the loose ends. Only then can the virus genes be transcribed and proteins produced. Here too, the human cell lends a helping hand. Protzer explains the dilemma: “If we tried to disrupt the viral protein synthesis or the DNA transcription, we would end up damaging the cellular enzymes. Hepatitis B ensures that we have very few areas to target.”

Very few weak points
Recently, Ulrike Protzer succeeded in finding one of these rare weak points to target. Together with her research team, she discovered a way to degrade the cccDNA in the cells without damaging the liver cells. “It was fascinating to see that there are actually ways for the immune system to eliminate a particular DNA from the cell nucleus, because that can easily become critical for the cell,” she relates. The researchers used special immune mediators to stimulate receptors on the surface of the liver cells. Signal pathways are then triggered inside the cell, and these result in the formation of APOBEC proteins. These proteins belong to the large group of deaminases. They function rather like scissors, specializing in cutting off amino groups (nitrogen-containing side chains) from other molecules.
The APOBEC proteins bind to a virus protein and are thus conveyed to the cccDNA. There, they proceed to cut up one of the building blocks of DNA, the base cytosine. Dozens of amino groups detach the APOBEC proteins, making the virus DNA useless. Eventually, it is completely degraded. In theory, the cell could repair the faulty virus DNA, but luckily, it does not. “It could be that the cell simply capitulates in the face of too many faults,” reckons Protzer. The fact ▹

Picture credits left: Bauer, right: ediundsepp (source: TUM)

State-of-the-art technology enables sophisticated bench work and translation of basic findings into clinical applications. Confocal microscopy with an incorporated incubation chamber allows real-time imaging of virus infection and reconstruction of three-dimensional images of infected cells (left). Generation and cultivation of genetically modified T cells is being adapted to “good manufacturing process” guidelines (a regulatory requirement for clinical use) to enable a translation of this approach into clinical applications (right).





Different approaches to eliminate HBV-infected hepatocytes. Top: Upon treatment with cytokines like IFN-α or LT-β, infected cells upregulate APOBEC deaminases. These proteins enter the nucleus and remove amine residues from the viral cccDNA, finally resulting in fragmentation of the viral genome. **Bottom:** Infected cells can be recognized by T cells engrafted with genetically modified receptors. These are optimized either for recognition of HBV proteins on the MHC molecules produced by the cell (right) or for binding to HBV proteins incorporated into cellular membranes (left).

Working for twenty years in infectious diseases and infection research, Prof. Protzer has specialized in viral hepatitis. With recent advances in the field, including her own findings about novel ways to eliminate the virus from infected cells, she is driven more than ever by the goal to cure patients with hepatitis B.

Picture credit left: Bauer, right: Thomas Bock/Hanswalter Zentgraf, German Cancer Research Center

"I would love to see some improvement here, because there will always be some new infectious diseases to combat, whether it be flu or Ebola."

Ulrike Protzer

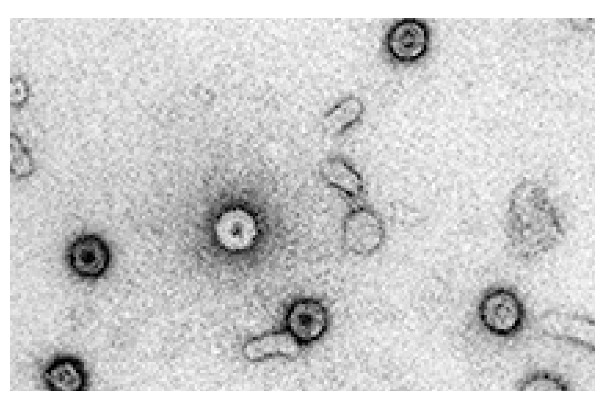
that Protzer and her team have found a mechanism to eliminate the virus DNA from liver cells without destroying them opens up exciting new therapeutic possibilities. For a long time, researchers thought that chronic hepatitis B could be treated only by completely destroying the infected cells.
There is one catch, however. In experiments carried out so far, it has never been possible to eliminate all of the cccDNA. The researchers were able to generally degrade 50 to 60 percent, or at most 80 percent, of the virus DNA in this way. "For the rest," says Ulrike Protzer, "we need the help of the immune system."

T cell therapy to destroy infected or abnormal cells

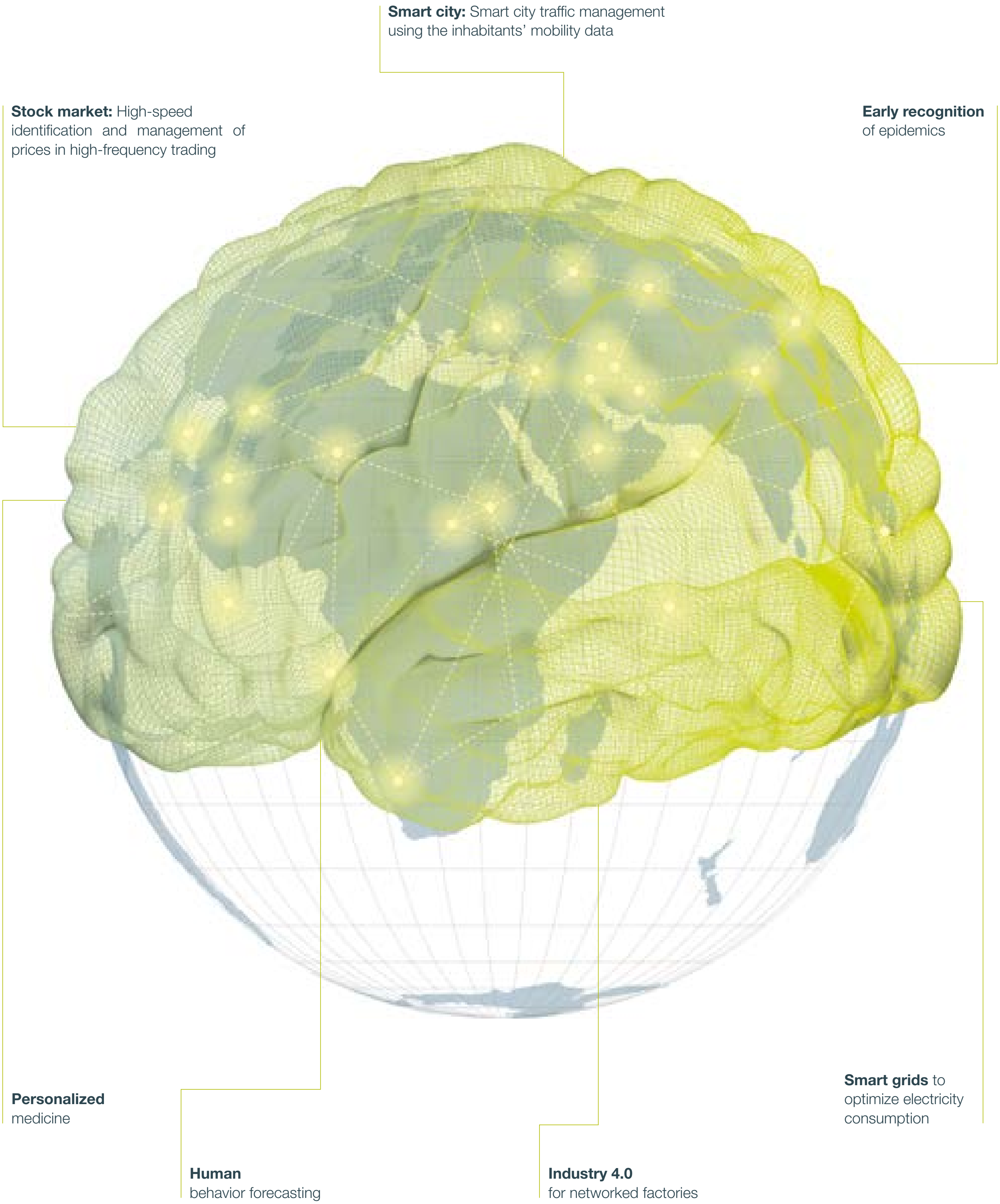
To be more exact, help is required from the T cells. As part of the immune response, T cells destroy infected or abnormal cells in the body. The diseased cells draw attention to themselves by presenting fragments of viral proteins, known as antigens, on their surface, thereby attracting T cells.
The fact that 90 percent of all adults who come into contact with the hepatitis B virus are able to clear the infection with their immune system shows that the body has its own defense mechanism. But in patients who are chronically infected, the immune system is not up to the task. Like a bloodhound unable to pick up the scent because of a cold, the killer cells aimlessly pass by the infected hepatocytes instead of attacking them.
"That is why we have to activate the T cells and specifically direct them toward the infected cells," explains Protzer. This approach has already worked in a mouse model. The scientists took blood from infected mice and added new receptors to the T cells. These chimeric antigen receptors were modified to recognize the surface protein of the hepatitis B virus and classify it as foreign and dangerous.
When injected back into the mouse, the modified T cells with their new receptors become immediately aware of diseased cells in the liver tissue. They latch on to them and release cytokines. With these semiochemicals, they prompt neighboring cells to search for virus DNA in their cell nuclei, too. Finally, the T cells destroy the infected somatic cells. Since both chronically infected cells and liver cancer cells display the surface protein of hepatitis B, infected and abnormal or cancerous cells can be destroyed with the same mechanism. This T cell therapy has made headlines in recent years in connection with the treatment of tumors in particular. Indeed, the journal "Science" declared it the breakthrough of the year in 2013. "I think that we will have to combine both methods to arrive at a treatment for chronic hepatitis B: destroying the cccDNA with the APOBEC proteins in conjunction with T cell therapy. We are currently investigating whether we can replace the modification of the T cells with specific antibodies, thus simplifying the therapy," relates Protzer. Her mission in life is to develop a treatment for chronic hepatitis B. Having now discovered more than one mechanism to eliminate the virus from the liver, she is a few steps closer to realizing her dream.
Ulrike Protzer hopes to see more medical professionals choosing the research avenue to search for treatments for dangerous infectious diseases. Even though Germany has an excellent basic research platform for hepatitis B, there is still a shortage of people who are able to bridge the gap between laboratory and clinical practice. "I would love to see some improvement here, because there will always be some new infectious diseases to combat, whether it be flu or Ebola," she concludes. And she already has her hands full with hepatitis B! *Claudia Steinert*

History

In 1964, physician Baruch Samuel "Barry" Blumberg found a new antigen in the blood of Australian aborigines. He named it the Australia Antigen. A few years later, the related hepatitis B virus was discovered. This virus causes acute and chronic liver infections and also plays a major role in the development of liver cancer. A hepatitis B vaccine was created in 1982, and it could be called the world's first anti-cancer vaccine. In 1976, Blumberg and Daniel Carleton Gajdusek jointly received the Nobel Prize in Physiology for their discovery.



Electron microscope image of hepatitis B viruses



The network structure of the World Wide Web is similar to the connections between the nerve cells and the different areas of the human brain. According to Klaus Mainzer, the modern IT world can be viewed as the next stage in the biological evolution of information. The end result would be a kind of superorganism consisting of our planet and its IT networks as the nervous system.

“Algorithms are powerful and useful. **But by themselves they are blind**.”

Algorithms, until recently strictly the preserve of computer enthusiasts and mathematicians, are now pushing their way center stage – quite simply because of the key role they play in the supercomputers that are digitalizing our lives. The dawn of the big data world is welcomed by some as a golden era, but feared by others as the realization of Orwell’s worst nightmare. But what are the economic, social and legal implications of big data? What are the potential opportunities and risks? We interviewed philosopher of science Prof. Klaus Mainzer, Chair of Philosophy of Science at TUM and Director of the Carl von Linde Academy, about his latest book on computing the world, “Die Berechnung der Welt. Von der Weltformel zu Big Data,” to find out more.

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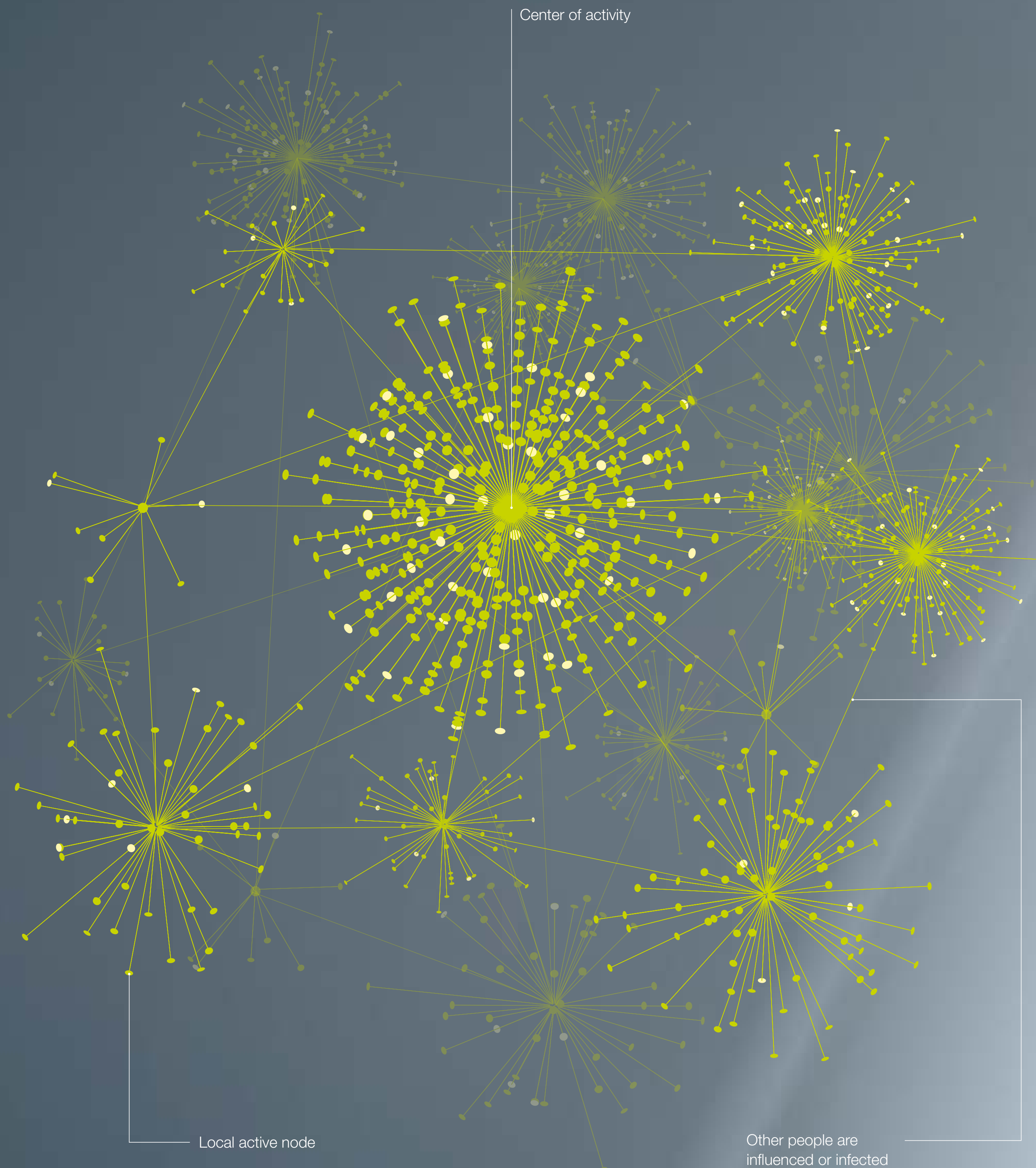
Picture credit: ediundsepp



The cascade-like spreading of an epidemic disease is represented as a cluster and a complex pattern in a network. Social infection works in a very similar way. An innovation catches on because people are influenced by the behavior of their neighbors.

Picture credit: Jooss/graphics: ediundsepp

“We depete natural resources by using them – but this is not the case with data. Data can always be reused in different contexts, creating new ways to make a profit.”

Klaus Mainzer

"Algorithmen sind mächtig und hilfreich. Aber alleine sind sie blind."

Algorithmen – vor nicht allzu langer Zeit eher Thema für Nerds und Mathematiker – sind inzwischen in den Feuilletons angekommen. Hintergrund ist die umfassende Digitalisierung mithilfe gigantischer Rechnerkapazitäten, die Grundlage einer neuen Welt ist: der Big Data-Welt, die gerade dabei ist, unser Leben zu revolutionieren.

Von den einen wird sie als ein Eldorado gefeiert, von den anderen als Realisation Orwell'scher Phantasien gefürchtet. Doch welche Perspektiven eröffnen sich tatsächlich damit für die Wirtschaft, das Recht und die Gesellschaft? Welche Chancen und Risiken bestehen? Prof. Klaus Mainzer, Inhaber des Lehrstuhls für Philosophie und Wissenschaftstheorie an der TUM und Direktor der Carl von Linde-Akademie befasst sich in seinem aktuellen Buch "Die Berechnung der Welt – Von der Weltformel zu Big Data" mit diesen Fragestellungen. Bei allen Vorteilen, die Big Data für Wirtschaft, Gesellschaft, aber auch für die Wissenschaften mit sich bringt, hält er es für riskant, sich allein auf eine datengetriebene Methode zu verlassen. Wer mit Tunnelblick auf Effizienz und schnelle Ergebnisse auf die Frage nach Ursache und Wirkung verzichtet, gerät auf dünnes Eis. "Wenn wir das nicht begreifen oder vergessen, fliegen uns am Ende die Algorithmen um die Ohren." Letztlich geht es nicht allein darum, teure Programmierfehler in der automatisierten Produktion zu vermeiden, sondern um größere Gefahren.

Wie er eindrucksvoll zeigt, bringen Big Data-Methoden in der Medizin wenig nachhaltigen Nutzen, wenn Kausalzusammenhänge nicht geklärt werden. Ähnliches gilt für das "Precriming" und andere Versuche, mithilfe der Mustererkennung Kriminalität und Terroranschläge vorherzusehen, um präventiv eingreifen zu können. Das weckt nicht nur ungute Assoziationen mit dem Film "Minority Report", sondern bedroht für ihn ganz klar unsere Gesellschaft in ihren Grundfesten. "Wenn staatliche Sicherheit in totale Überwachung umschlägt, ist die Demokratie verloren."

Birgit Fenzel

Picture credits: Jooss

Prof. Mainzer, the subtitle of your new book encompasses both "the theory of everything" and "big data." Basically these are two different ways of understanding the complex world we live in. How do they differ?

Mainzer: The search for a theory of everything is a very old idea. The great philosopher Plato was a mathematician who was convinced that everything in the world was made up of the accepted basic elements of the time: fire, water, air, earth and the celestial spheres. He believed that these elements were identical to the five regular solids of Euclidean geometry. These are the perfect symmetries of the Euclidean space. So he believed that the world was governed by mathematical laws. Even today, cosmologists are seeking to unite the known fundamental forces of physics and explain them using mathematical symmetry laws. But now, instead of Euclidean geometry, they are applying quantum physics and the differential geometry of the theory of relativity. There is one common idea behind all of this theory-led research: We need a good theory to know what it is we are looking for. Only then can we understand the complexity of the world. Big data, on the other hand, entails collecting data and writing algorithms to process this data. The algorithms recognize patterns, so this is a quicker method than the time-consuming search for laws. In essence, this is a data-driven science.

What are algorithms?

Mainzer: Algorithms are clear formal procedures for solving problems, just like the math we learned at school and the instructions in computer programs. Philosopher and mathematician Gottfried Wilhelm von Leibniz – after whom the supercomputing center in Garching, Germany, was named and who first used the binary numbers 0 and 1 for calculation, i.e., our modern bits – actually believed that all problems could be solved with algorithms if they were suitably encoded with numbers. In the 20th century, logician and mathematician Alan Turing defined a universal formal program allowing the simulation of all algorithms. Such a "Turing machine" could, in principle, simulate the supercomputer in Garching, as well as the program on your smartphone. With Turing's definition of computability, however, it is also possible to decide whether problems can even be solved algorithmically, how complex the solutions are and how long they will take. This has practical cost-benefit implications, because computing time costs money. Turing also considered the philosophical question of whether human thinking can be reduced to algorithms and computer programs. Logician Gerhard Gentzen, a contemporary of Turing, introduced formalisms that allowed the accuracy of algorithms to be verified. But what are the practical implications of all this? Well, take a computer program that controls a production process at BMW. The company would naturally like to rule out programming errors in advance and so avoid accidents and additional costs. What these examples show is that the problems of our ▷

modern big data world are rooted in fundamental questions of logic, mathematics and philosophy. If we fail to grasp this or forget its importance, then ultimately, algorithms could wreak havoc. This is what my book is all about, and this is what has interested me ever since my student days.

Algorithms are really nothing more than procedures or rules for solving mathematical problems – so nothing to get excited about. Yet now they are being spoken of in revolutionary terms. What is so special about big data algorithms?
Mainzer: Simply put: the sheer volume of data. The Internet and the World Wide Web heralded the first digital revolution: now people can communicate with each other anywhere in the world with small-scale technology like cellphones, smartphones and apps. The first digital revolution was the Internet of people – where people communicate with each other. A computer is no longer a mere computation device. While it continues to process its bits, its real function is as a means of communication. Right now we are embarking on the second digital revolution – the Internet of Things. This will go beyond the interpersonal level to encompass communication between "things." Modern technology in the form of sensors, RFID chips and software interfaces will allow various objects to communicate with each other, independently of human interaction.

That sounds like science fiction...
Mainzer: But we have been living with the Internet of Things for some time already. We experience the Internet of Things through the enormous volume of data and signals produced. To take one example: Google processes 24 petabytes of data per day – that's 6,000 times more than the content of the American Library of Congress. Just one company processing the entire memory of a nation in a single day. Special algorithms are needed to handle such huge quantities of data. They break down the massive volume into subpackages, process these in parallel and search for data correlations and patterns at lightning speed. So in order to find the needle, you need to go through a giant haystack with a fine-toothed comb.

In your book, you refer to the masses of data as the "crude of the future." But in some ways, the hype around big data also recalls the gold rush of the 19th century. But instead of panning for gold in the rivers of the Yukon, the fortune-hunters of the big-data age are now mining for data with algorithms. How do you explain the hype in the business world?
Mainzer: Mining big data and finding correlations can help to predict customer and product profiles with much greater efficiency than ever before. But the gold rush or oil metaphor fits only to some extent.

Picture credits: Jooss

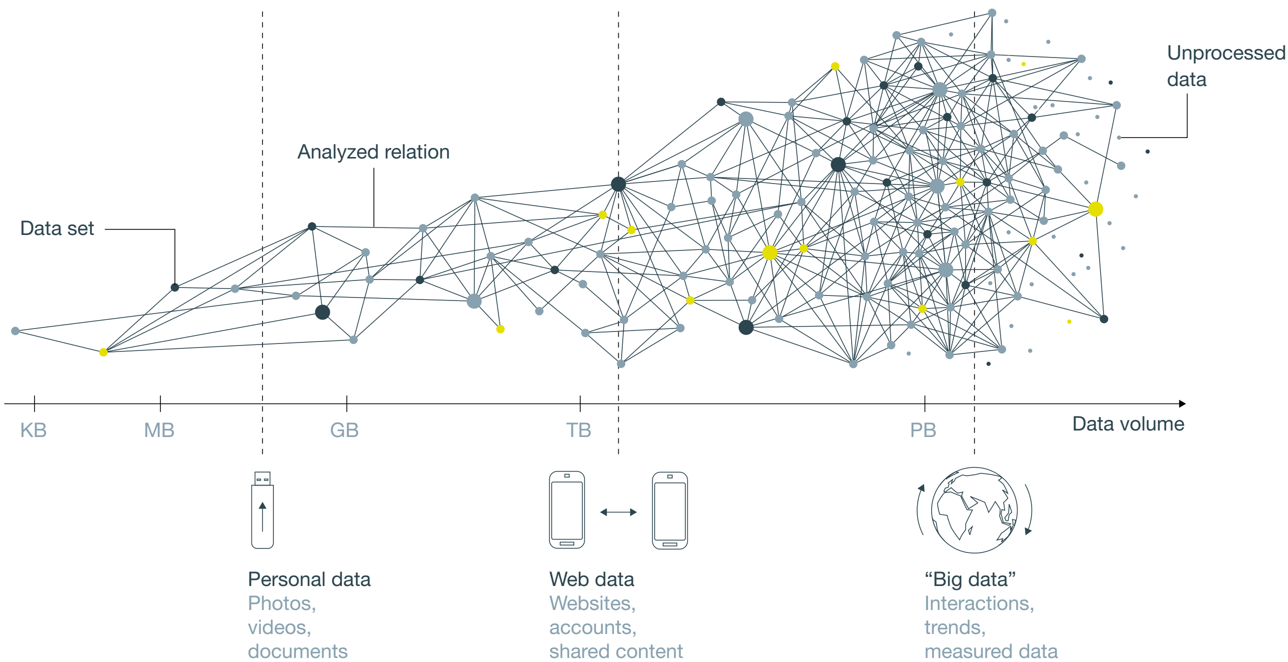
It certainly explains the upbeat mood in the business world – so where does it not sit comfortably?
Mainzer: We deplete natural resources by using them – but this is not the case with data. Data can always be reused in different contexts, creating new ways to make a profit. We will see new business models and value chains emerging. Data owners will earn money by licensing rights of use to their data, as will knowledge workers with skills in mass data management and entrepreneurs with new big data business ideas. The value chain will thus be completely transformed by big data.

How will this affect markets and consumers?
Mainzer: The impact will be huge. We are setting our sights on Industry 4.0, that is, the Internet of Things in the world of industry. Conventional mass production will be replaced by a new system of manufacture "on demand." Tailor-made instead of off-the-shelf. The ultimate vision of Industry 4.0 is made-to-measure suits as standard. In the automobile industry, many manufacturers are already operating on an on-demand basis, with their suppliers abandoning stockpiling. Another example of where the Internet of Things has been embraced is container ports, where many operations have been automated using robotic vehicles that engage with each other. This world is coming into being at an exponentially fast rate, but hardly anyone is aware of it. Some people are talking about exponential technology and exponential companies that are created with information technology.

The idea of a customer getting exactly what they want sounds great – what's the catch?
Mainzer: Well, there is a price to pay. An automated process requires trillions of sensors, and in some cases drones and cameras. Tons of data have to be collected, because the machines have to organize themselves. They interact with each other. This also means that the people who are integrated in this process are subjected to intensive scrutiny throughout the entire day. The controller computers know them better than they know themselves. And this is apart from the fact that the customer's data is also collected. In the end, you will have transparent employees and transparent customers. In this respect, this way of producing data presents a huge social challenge.

Your book also deals with the introduction of big data to science. You use medicine as an interesting example of how these new technologies can benefit the scientific community. What is the state of play here?
Mainzer: Big data will have a massive impact on medical science. Consider that 400,000 papers have already been written on diabetes alone. No one could read all of these in their lifetime. Even while they are reading, the knowledge is growing at an exponential rate. That is why we need intelligent software to filter the information and find the most suitable treatment for the patient.

But you also use medicine to illustrate the potential pitfalls. Where does the problem lie?
Mainzer: If I rely solely on finding efficient data correlations through data mining, then I have not necessarily understood the causes of the disease. Even Steve Jobs, once the ▷



The growing diversity and complexity of Web services is leading to a petabyte-scale data explosion. The term "big data" describes the rapidly growing volume of data on the one hand, but also the systems used to analyze this data.

icon of effective and smart computing, died of cancer, despite using his fortune to exploit all the computing capacity and big data analysis available at the time. Jobs had his cancer cells sequenced at frequent intervals because of the constant mutation of the tumors. His physicians could then continuously adjust his treatment. Ultimately, though, as long as we remain in the dark about the causes of cancer and the mechanism of cancer cells, the analysis of data on a massive scale and the calculation of correlations will be of limited use.

Your book is intended as an argument against the promises of big data and for the continued relevance of basic research and philosophical reflection. But given the growing complexity of data, isn't the search for explanations, causes, theories and laws completely outdated?

Mainzer: It is true that some of the biggest proponents of big data, like Chris Anderson, are talking about the "end of theory." Back in 2002, American computer scientist and software entrepreneur Stephen Wolfram proclaimed a "new kind of science," in which computer experiments would replace mathematical proofs and theories. Wolfram had simulated extensive pattern formations of cellular automata on high-performance computers, discovered some remarkable correlations, and classified the patterns based on his observations. Together with my UC Berkeley colleague Leon Chua, I wrote a book refuting this theory entitled "The Universe as Automaton," in which we proved that it is only the fundamental mathematical laws of cellular automata that allow accurate forecasting and classification of patterns. In our follow-up book "Local Activity Principle," we expanded this argument to examine the emergence of patterns in nature, taking in physics, chemistry, biology and brain research. Here too, we found that it was only when the basic equations were known that accurate declarations and forecasts could be made on the emergence of structure and patterns. What we can generally say about science is that theory is often the best way to solve a problem. How will a mountain of data help me if I don't know what I am looking for? At CERN, for example, a huge amount of data is produced during proton collisions, but only a fraction can be analyzed by the computers now in existence. I have to know what I am looking for. The best example of this is theoretical physicist Peter Higgs, who predicted the particle named after him on the basis of his mathematical model in the framework of quantum field theory. Once experiments had confirmed his model, he was duly awarded the Nobel Prize last year. The Higgs boson is key to explaining how the universe began. But it took Higgs' model to know exactly where to look in the enormous number of events and volumes of data.

Seen in that light, is big data no more than shadow puppetry, like in Plato's cave?

Mainzer: Yes, of course. That is the data landscape of big data. Plato asked what was actually behind the shadows. His answer was the ideas of truth, goodness and beauty. ▷

Picture credit: Jooss/graphics: ediundsepp

“Pythagoras’ theorem is correct not because it has been confirmed in countless surveys, but because it ensues from the axioms of Euclidean geometry. Logically consistent.”

Klaus Mainzer

Picture credit: Jooss

"Theory is often the best way to solve a problem. How will a mountain of data help me if I don't know what I am looking for?"

Klaus Mainzer

An inscription was said to hang above the entrance to the Platonic Academy: "Let no one ignorant of geometry enter here." Geometry stood for mathematics in those days. Why? Because Plato believed that, before reflecting on the eternal ideas of truth, goodness and beauty, he must first learn truths that do not rely on observation or changes in perception. And in his view, that is the world of mathematics. Pythagoras' theorem is correct not because it has been confirmed in countless surveys, but because it ensues from the axioms of Euclidean geometry. Logically consistent. For Plato, that was the first step into the world of unchangeable ideas. But one does not have to be a die-hard Platonist to understand his basic idea: that behind observed data lie structures and laws that must be recognized to understand certain facts. Finding patterns in data using algorithms is useful, but algorithms are blind without theory and laws. On the other hand, it must also be stressed that mathematical theories in the natural and social sciences remain empty without empirical data.

One of the chapters in your book deals with big data in the humanities and cultural studies. In the digital humanities, new automation methods are already in use. For example, metadata from old manuscripts is being algorithmically created to draw conclusions on the source, production conditions and context. This sounds like a very efficient and helpful approach at first, but is there a risk that it will take the "human" out of the humanities, as critics fear?
Mainzer: Here too, the critics have a point. Supercomputers cannot replace the appraisal and interpretation of a literary scholar. But software programs that automatically write standardized texts are already out there. I could easily foresee the same happening for scientific and engineering papers. They would follow certain standards. The software would write the article in the standard English of the particular discipline, and the human authors would add their findings. The citations would be perfectly executed. There would be no room for plagiarism, either, because the software could automatically trawl the Internet to see whether the findings existed elsewhere. There are already writing programs available that adapt themselves to the style of the author. We'll just have to wait and see if they're capable of producing Faust, Part 3.

As you have noted, it is practically impossible to predict social behavior, because there are no known equations of motion and evolution for individuals. But early indications from big data show that such predictions are indeed possible thanks to data analysis on a massive scale and the calculation of correlations. Why is that a double-edged sword?
Mainzer: With big data algorithms, we can predict not only product profiles, but also criminal profiles. In "pre-criming," profiles of criminals are created to prevent them from offending – along the lines of the film "Minority Report." But where big data differs from the movie is that you don't need to read minds – you just need the metadata, such as where and when an e-mail was sent, the names of the sender and recipient in conjunction with the criminal profiles, and other data.

The ethical and legal challenge is to protect democratic rights in the age of big data and digitalization. This was made very apparent through the recent controversy surrounding the NSA.
Mainzer: That episode provided further proof that whoever has the biggest search engines, the most storage capacity and the best algorithms rules the world. After the fall of the Iron Curtain, some people got the impression that the US was on the retreat – militarily, economically and politically. But the Snowden revelations showed us that they had reckoned without the NSA and the power of American IT.

One consequence of this is the parallel development of data protection and security technology. It begs the question: Can we safeguard and strengthen personal rights and rights of self-determination on the Internet without compromising freedom through over-regulation?
Mainzer: Europe is not just the birthplace of industry, technology, research and science. Europe is also where the concepts of state under the rule of law and democracy were born. These philosophical ideas originated in ancient Greece, as well as in England, France, Germany and Switzerland – the birthplaces of Kant, Locke, Montesquieu and Rousseau, among others. If we can develop an information technology package that incorporates our rule-of-law and democratic standards, and that is on a par with the Americans', then we could provide an example to the world along the same lines as we are currently endeavoring with our energy transition policy. It would be great if Germany could accomplish this in a good-hearted, respectworthy way, just like the national team at the World Cup. Also acting in partnership with the US, and not in opposition. Important negotiations on the trade agreement between the US and Europe are forthcoming. We must fight for our legal standards just as strongly as for our food standards, while at the same time demonstrating that we, too, are masters of technology and science. That would be my dream scenario at any rate. *Interview by Birgit Fenzel*

In order for humans and machines to communicate, brain waves of the pilots are measured using electroencephalography (EEG) electrodes connected to a cap.

Picture credit: Heddergott

Link
www.fsd.mw.tum.de

Using Thoughts **to Control Airplanes**

Pilots of the future could be able to control their aircraft by merely thinking commands. Scientists at TUM and TU Berlin have demonstrated the feasibility of flying via brain control – with astonishing accuracy.

The pilot is wearing a white cap with myriad attached cables. His gaze is concentrated on the runway ahead of him. All of a sudden, the control stick starts to move, as if by magic. The airplane banks and then approaches straight on toward the runway. The position of the plane is corrected time and again until the landing gear gently touches down. During the entire maneuver the pilot touches neither pedals nor controls.

This is not a scene from a science-fiction movie, but rather the rendition of a test at the TUM Institute for Flight System Dynamics. Scientists working for Prof. Florian Holzapfel are researching ways in which brain controlled flight might work in the EU-funded project "Brainflight."

"A long-term vision of the project is to make flying accessible to more people," explains aerospace engineer Tim Fricke, who heads the project at TUM. "With brain control, flying, in itself, could become easier. This would reduce the work load of pilots and thus increase safety. In addition, pilots would have more freedom of movement to manage other manual tasks in the cockpit."

Surprising accuracy

The scientists have logged their first breakthrough: They succeeded in demonstrating that brain-controlled flight is indeed possible – with amazing precision. Seven subjects took part in the flight simulator tests. They had varying levels of flight experience, including one person without any practical cockpit experience whatsoever. The accuracy with which the test subjects stayed on course by merely thinking commands would have sufficed, in part, to fulfill the requirements of a flying license test. "One of the subjects was able to follow eight out of ten target headings with a deviation of only 10 degrees," reports Fricke. Several of the subjects also managed the landing approach under poor visibility. One test pilot even landed within only a few meters of the centerline.

The TUM scientists are now focusing in particular on the question of how the requirements for the control system and flight dynamics need to be altered to accommodate the new control method. Normally, pilots feel resistance in steering and must exert significant force when the loads induced on the aircraft become too large. This feedback is missing when using brain control. The researchers are thus looking for alternative methods of feedback to signal when the plane's capabilities are pushed too hard, for example.

Electrical potentials are converted into control commands.

In order for humans and machines to communicate, brain waves of the pilots are measured using electroencephalography (EEG) electrodes connected to a cap. An algorithm developed by scientists from Team PhyPA (Physiological Parameters for Adaptation) at TU Berlin allows the program to decipher electrical potentials and convert them into useful control commands.

Only the very clearly defined electrical brain impulses required for control are recognized by the brain-computer interface. "This is pure signal processing," emphasizes Fricke. Mind reading is not possible. Stefanie Reiffert (TUM)

Authors

Dr. Bernhard Epping is a freelance science journalist and author for public relations and books. He also works at the Technology Transfer Office of the University of Tübingen. His focus subjects are medical and biological research and health policy.

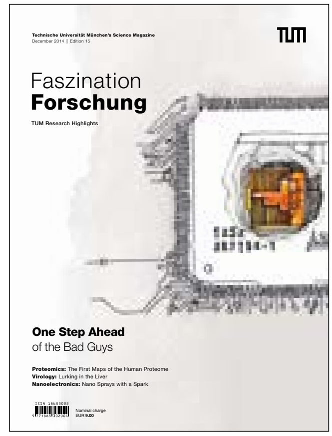
Gerlinde Felix is a freelance medical and science journalist. She studied physics and medicine. Gerlinde Felix works for newspapers, magazines and online publications, as well as for research institutions. In 2011, her book "The Healthy Liver" was published.

Birgit Fenzel studied German language and literature, philosophy and educational sciences before starting her career in journalism. After finishing university and completing a year of voluntary service, she worked as an editor for a daily newspaper, also completing freelance assignments for other public service broadcasters. She worked on scientific articles for the ddp news agency and was most recently employed as an editor at the Max Planck Society.

Dr. Brigitte Röthlein has been working since 1973 as a science author for magazines, TV and radio broadcasting and for newspapers. She holds a degree in physics and a PhD in communication science, education science and history of natural sciences.

Tim Schröder is a freelance science journalist based in Oldenburg, Germany. He works as an editor for the daily Berliner Zeitung newspaper, also regularly contributing to the Frankfurter Allgemeine (Sunday edition), Neue Zürcher Zeitung and Mare newspapers. His specialist areas are basic and applied research, energy and the environment.

Claudia Steinert studied biochemistry in Leipzig, Germany. Starting during her studies and continuing after she completed her degree, she worked in the press office of several branches of the Max Planck Institute. She has been a freelance science journalist since 2013. She is currently studying journalism, working toward a qualification as editor from the Deutsche Journalistenschule (German school for journalism). She focuses mainly on research, ecology and health.



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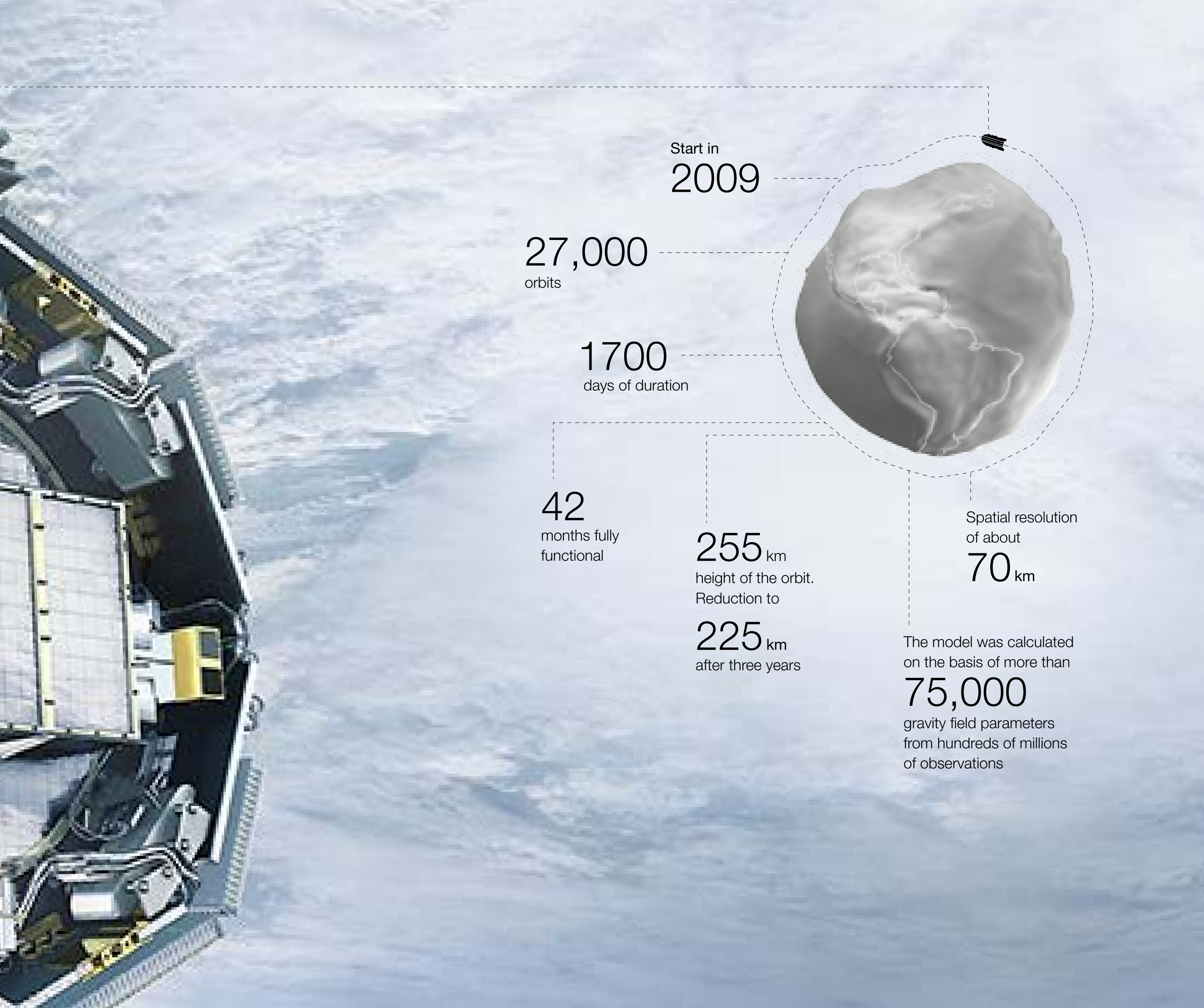

New Views of Earth in the **“Light” of Gravity**

The completion of ESA’s GOCE satellite mission is not so much an ending as a milestone in the ongoing exploration of Earth – as revealed by gravity. By providing the most accurate measurements and models yet of Earth’s gravitational field, GOCE is enabling researchers to sharpen the picture of our dynamic planet, from mantle convection to melting glaciers. TUM Prof. Roland Pail coordinates the international GOCE Gravity Consortium.

Picture credit: ESA - AOES Medialab

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Gravitationsmessungen zeigen ein neues Bild der Erde

Im November 2013 verglühte der Satellit GOCE (Gravity Field and Steady-State Ocean Circulation Explorer) bei seinem Wiedereintritt in die Atmosphäre. Die Satelliten-Mission der Europäischen Weltraumbehörde ESA hatte die Vermessung des Schwerefelds der Erde zum Ziel. Die im Juli 2014 vollständig veröffentlichten GOCE-Daten werden die beteiligten Forscher – mit dabei ein Team der TUM – über Jahre hin beschäftigen. Die vorliegenden Daten zeigen das Schwerefeld der Erde in nie dagewesenem Detail. Winzige Variationen in den Konturen des Felds entsprechen der ungleichen Massenverteilung, ob in der Kruste oder im Mantel, in den Ozeanen oder im Eis. Die Schwerkraftmessungen ermöglichen eine neue Sicht auf unseren Planeten – zusätzlich zu den bereits bekannten Beobachtungen, die auf Licht, Magnetismus oder seismischen Wellen basieren.

Prof. Roland Pail vom TUM Institut für Astronomische und Physikalische Geodäsie (IAPG) koordiniert das internationale GOCE Gravity Consortium. Das IAPG entwickelte das Schwerefeldmodell der Erde sowie die dazugehörigen, auf die Anforderungen unterschiedlicher Nutzergruppen zugeschnittenen Datenprodukte.

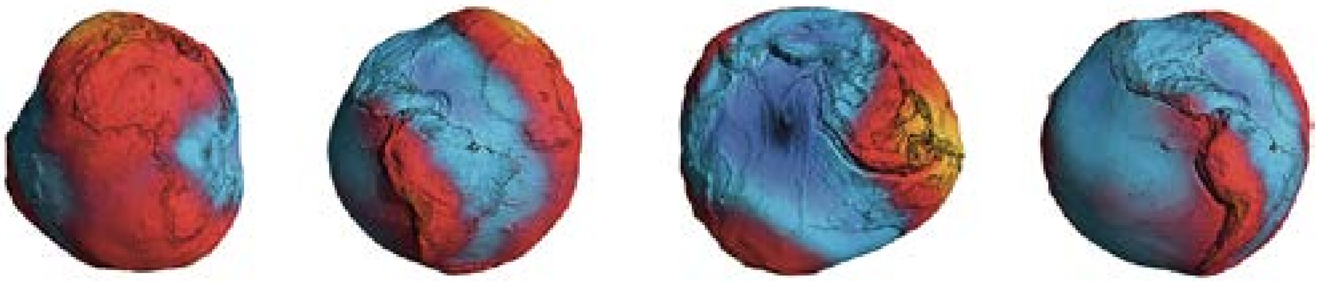
Die ersten Ergebnisse lassen auf neue Erkenntnisse in verschiedensten Bereichen hoffen – von Geophysik und Geologie bis hin zu Ozeanographie und Klimaforschung. GOCE-Datenprodukte werden genutzt, um Meeresströmungen, den Anstieg des Meeresspiegels sowie das Abschmelzen von Eisfeldern zu kartieren und zu beobachten. Die Messungen decken auch verborgene geologische Muster auf. Sie können künftig für die Erschließung natürlicher Ressourcen und zur Bewertung von Risiken von Interesse sein. Geophysiker erkennen aus den Satelliten-Schwerefeldmessungen Dichteunterschiede tief im Erdinneren und gewinnen daraus neue Erkenntnisse über die dynamischen Prozesse, die unsere Kontinente formen und für Erdbeben, Tsunamis oder Vulkanausbrüche verantwortlich sind. Mittlerweile nutzen Forscher aus dem Bauwesen das GOCE-Geoid, um ihr Projekt zur Vereinheitlichung nationaler Höhensysteme voranzubringen, denn die aus den Schwerefeldmessungen berechneten Höhen der Erdoberfläche bieten erstmals eine global einheitliche Bezugsgröße. *Patrick Regan (TUM)*

An artist's impression of GOCE in orbit: One key application of data from the GOCE satellite mission is to monitor signs of global warming in changing sea level, ocean circulation and ice cover.

Picture credit: ESA - AOES Medialab


BREEZE

Picture credit: ESA - AOES Medialab



Earth in the "light" of gravity: These four views show the height of the geoid — which corresponds to the mean ocean surface at rest — above or below a reference model for Earth's shape that is based not on gravity, but on the planet's rotation. Deviations above (red) or below (blue) the reference surface are caused by mass anomalies in Earth's mantle.

In November 2013, a satellite that had been flirting for years with Earth's gravity at the very edge of the atmosphere took its final, fiery plunge. The only known record of its last moments is a snapshot taken from the deck of a ship, by a passenger on a penguin-watching cruise. Any parts of the spacecraft that didn't burn up on re-entry splashed unseen and unheard into the South Atlantic.

The scientific impact, however, was evident long before the satellite known as GOCE fell from the sky. A series of four data releases had already begun enabling new views of our planet's deep interior and vast inaccessible areas of continental crust, as well as ocean currents and ice sheets. One result, the most accurate representation yet of the geoid – a gravity-derived figure of Earth's surface that serves as a global reference for sea level – is helping to advance the project of unifying height systems worldwide. While media headlines heralded the geoid's resemblance to a potato, researchers in a diverse range of fields celebrated the bonanza of new data.

A mission of the European Space Agency (ESA), the Gravity Field and Steady-State Ocean Circulation Explorer (GOCE) set out to measure Earth's gravitational field ▷

It is extremely rare to capture any record of a satellite's re-entry. This is the only known photo of the GOCE satellite burning up in the atmosphere, taken by a tourist on a cruise in the Falkland Islands.

Picture credit left above: IAPG/TUM, left below: Bill Chater, right: ESA - A. Le Floc'h

in unprecedented detail. Tiny variations in contours of the field correspond to uneven distributions of mass, whether in the crust or the mantle, ocean or ice. Thus, gravity offers a way to observe our planet that is complementary to approaches relying on light, magnetism, or seismic waves. Precise measurement and high-resolution modeling of the gravity field can yield insights into processes ranging from plate tectonics to climate change, and into hidden features that could guide resource exploration.

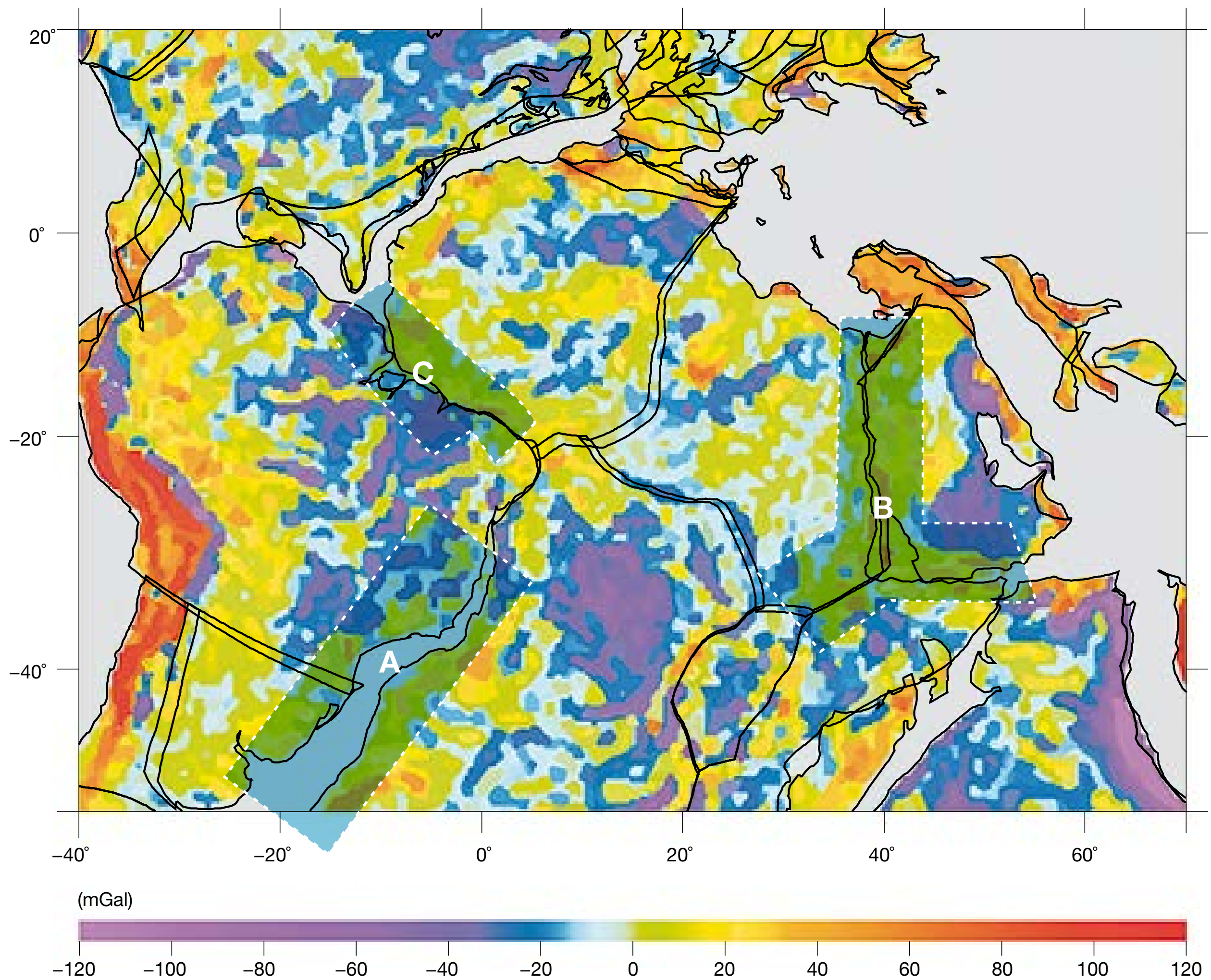
Mission complete – the work goes on

Every element of satellite and mission design, from GOCE's innovative gravitational gradiometers to its sleek aerodynamics and low orbit altitude, pushed the boundaries of engineering and operations. And it all worked beyond expectations. Launched in March 2009, the satellite orbited Earth 27,000 times during 1700 days in orbit, roughly three times longer than its nominal mission period, and was fully operational for 42 months. With the original mission goals being largely achieved after the first three years, a decision was made to further lower the orbit altitude from 255 to 225 kilometers. Flying 30 kilometers closer to the Earth would yield even more sensitive measurements, revealing detailed structures of the gravity field.

As coordinator of the international GOCE Gravity Consortium, the TUM Institute of Astronomical and Physical Geodesy (IAPG) has been responsible for developing the gravity model, as well as associated data products tailored to the needs of various user groups. The model, composed of more than 75,000 parameters describing the global gravity field with a spatial resolution of rough-

Prof. Roland Pail succeeded Prof. Reiner Rummel, a founding father of ESA's GOCE mission, as Director of the TUM Institute for Astronomical and Physical Geodesy and coordinator of the GOCE Gravity Consortium. He also serves as Dean of Civil, Geo and Environmental Engineering.

Picture credit left: Eckert, right: Prof. C. Braitenberg, Univ. of Trieste

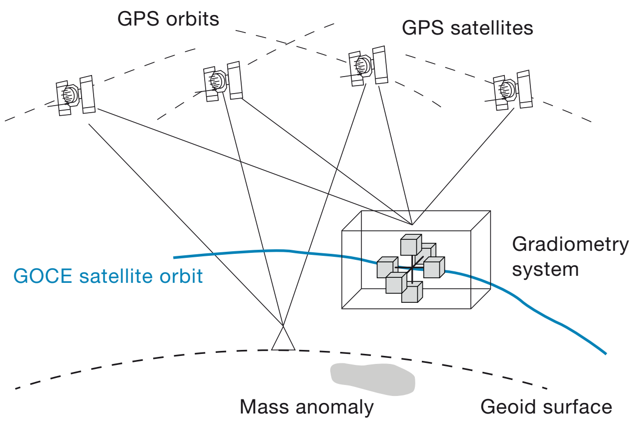


New light on geology and paleogeography: This figure highlights newly revealed features of the former supercontinent Gondwana (black lines), which began to break up around 184 million years ago. With the new high-resolution gravity data, reflecting mass anomalies in Earth's interior, researchers can directly measure continental structures and identify geological lines in greater detail than ever before. Symmetrical "gravity highs" due to magmatism can be clearly seen across the plate margins where the Atlantic Ocean (A) and the Red Sea (B) formed. The lack of symmetry in the margin between Brazil and West Africa (C) may contribute to solving open geological questions. Such insights can also be used to guide resource exploration.

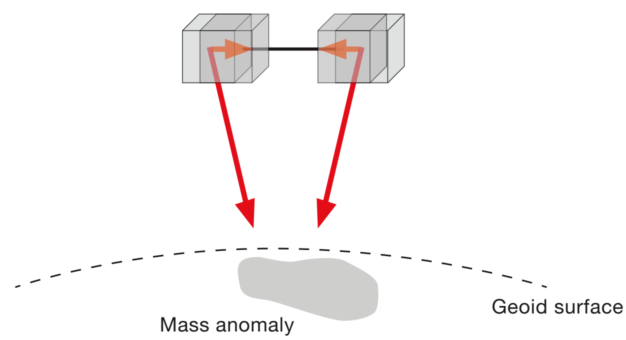
ly 70 kilometers, was computed from hundreds of millions of observations. This exercise in high-performance computing applied sophisticated processing algorithms to the rigorous solution of a very large equation system. Each time more data could be incorporated, the model improved.

The satellite's re-entry yielded an unexpected bonus. Much of the way down, the global positioning system (GPS) receiver continued reporting the satellite's position to an accuracy of two to three centimeters. Several of the main instruments kept on taking measurements even longer, failing only after the temperature on board rose above 90 degrees C. The final phase, from the time the satellite fell below 130 kilometers to the time it started burning, lasted roughly 90 minutes, or one full orbit. Now the record of GOCE's last day is being pored over by a separate community of scientists interested in atmospheric sciences, aerospace engineering and even space debris.

The fifth and final version of the GOCE gravity model – based on 800 million measurements and associated data from the entire mission period – was released to the scientific community in July 2014. "Once the final model and data products were placed on the public server, the GOCE mission could be considered complete, but this is by no means the end of satellite gravimetry," says Roland Pail, director of the IAPG. "At the same time users are applying the final GOCE data release to questions in geophysics, geology, oceanography, climate studies and civil engineering, follow-on satellite missions are in the works." ▷



The uneven distribution of mass in the Earth (represented here by a mass anomaly shown in gray) causes satellite orbits to be irregular. The GOCE satellite used GPS to track its own orbit precisely, and deviations from an ideal orbit revealed variations in Earth's gravitational field. The satellite's gravitational gradiometry system provided even more sensitive measurements of subtle contours in the field. At the heart of the system were six test masses (shown as gray cubes) mounted in pairs on perpendicular axes.



Since the gravitational field varies from point to point in space, it would exert a different force on each of the test masses, moving them slightly in different directions. Sensors recorded the acceleration of each test mass, allowing changes in force along each of the three axes to be measured. These gradiometric measurements provided the basis for computing the field.

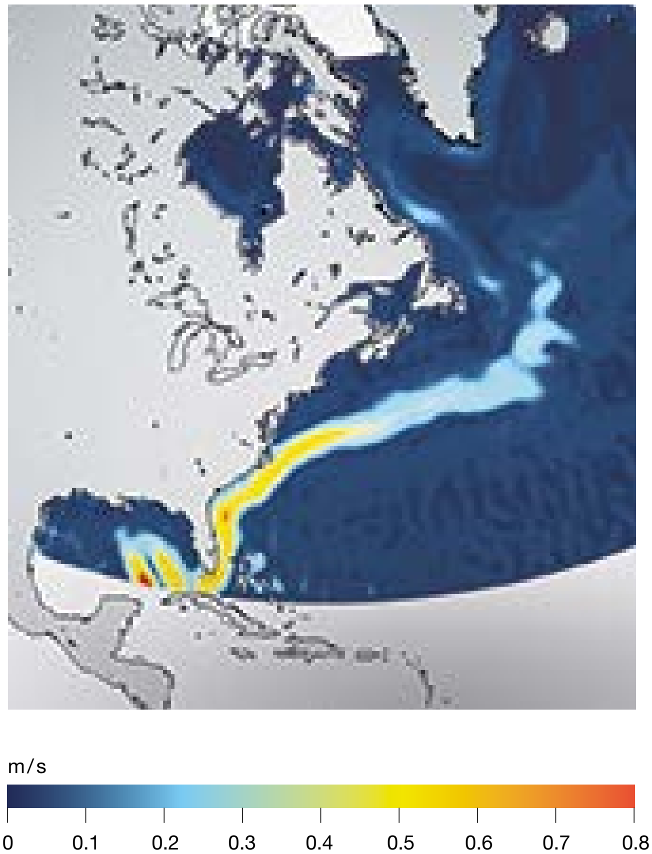
Results to date promise discoveries to come

Some of the earliest results based on GOCE data confirmed scientists' suspicions that previous models were marred by large inaccuracies. In regions such as the Himalayas, the Andes, and parts of Africa, for example, it had been difficult if not impossible to obtain gravity measurements by conventional means. Already by 2010, researchers were able to show that the GOCE satellite could provide adequate coverage and accuracy to correctly model continental areas where data had been lacking.

Similarly, by 2011, the world's oceans were coming into sharper focus. Scientists could now map ocean currents via gravitational variations in masses of water. For the first time, ocean circulation could be observed globally, from space. This is considered crucial for understanding heat transport and the dynamics of Earth's changing climate. Today, large-scale features including the Gulf Stream and the Antarctic Circumpolar Current can be clearly seen in gravity-derived maps; furthermore, even the current velocities can be determined. Also, with the GOCE geoid as a consistent reference, sea level rise due to global warming – caused both by thermal expansion and by melting of ice in the polar regions – can be more accurately measured and monitored.

More recent studies also show tremendous promise for expanding our knowledge of continental geology and deepening our understanding of the processes at work far below the surface. Researchers have found that GOCE data can be used to trace otherwise elusive borders between welded-together fragments of continental crust. Such areas are of interest for two reasons: they tend to be rich in mineral resources, and they can be the locus for earthquakes and other hazards. Previously, the patchy coverage and low resolution of gravity measurements made this impossible. With GOCE data, scientists can now, for example, clearly identify seemingly unconnected geologic units in Africa as being associated not only with each other, but also with formations in South America – recalling the time when the now separate continents were one. In time, this capability will provide new tools for both resource exploration and risk assessment. Satellite gravity measurements are also being used to map density variations in Earth's deep interior, which stem from variations in temperature and chemical composition. Scientists are developing three-dimensional images of mass distribution in the mantle. These static snapshots can in turn reveal more about dynamic processes, including the convection that drives plate tectonics ▷

Satellite assembly and testing: Pre-launch preparations were carried out at ESA's European Space Research and Technology Centre (ESTEC) in Noordwijk, the Netherlands.



This improved view of the Gulf Stream from space, based on the final release of the GOCE gravity model, charts current velocities in meters per second.

and intrudes into human life in the form of earthquakes, tsunamis and volcanic eruptions. Researchers have now identified large-scale gravity variations that follow former tectonic plate boundaries on both sides of the Pacific Ocean, as well as signals thought to correspond to so-called mantle plumes more than 2000 kilometers below the crust. Such findings suggest that deep views based on satellite gravimetry can be combined with independent insights from global seismic tomography, mantle flow models and reconstructions of tectonic plate history to address many unanswered questions.

A new initiative, under the auspices of the TUM Institute for Advanced Study (TUM-IAS), aims to further refine the GOCE gravity maps. As a TUM-IAS Fellow hosted by Pail, Dr. Christian Hirt of Curtin University in Australia is working toward a hundred-fold improvement in resolution, with implications for applications from climate studies to surveying. Hirt is creating a composite model incorporating the latest satellite and terrestrial gravity data, high-resolution topography, and mass-density models. Where data permits, he expects to achieve 100-meter spatial resolution, bringing out details on the scale of mountains and valleys. This is the first-ever effort to create local-resolution gravity maps with global coverage.

Prospects for future gravity missions

The trajectory of a space mission doesn't begin on the launching pad, but with the earliest formation of the constellation of ideas that will define and motivate it. In the case of the new approach embodied in GOCE, that goes back at least as far as the 1970s, when Pail's predecessor, TUM Emeritus Prof. Reiner Rummel, was a postdoctoral researcher at Ohio State University. "Already at that time this idea floated around in NASA documents," Rummel recalls, "and it stayed with me." It is not uncommon for a satellite or probe to take decades to get off the ground. By the 1980s, technology had advanced to the point where GOCE started looking practical; the first proposals encountered fierce competition before the project was approved by the European Space Agency in 1999. "And then," Rummel notes, "it took another ten years to build, because it is a very complicated satellite."

During this past decade, GOCE was not alone, but accompanied by two complementary gravity missions: the German project CHAMP (Challenging Minisatellite Payload) and the German-American collaboration GRACE (Gravity Recovery and Climate Experiment). To build on their successes, scientists worldwide are preparing for future missions, and TUM researchers are on board. Their main focus is on a prospective joint ESA-NASA mission in the time frame of 2025 to 2030, although they also are taking a close interest in the follow-on GRACE mission set to launch in 2017.

"From the users' point of view," Pail explains, "the most important thing is that we provide for continuity and extension of the observations and time series. They give this a higher priority than better accuracy." The upcoming GRACE follow-on mission addresses this concern, but it also incorporates modifications based on lessons learned during the first. In addition, it will carry an experimental instrument to test a new approach to ranging, with the potential for a fifty-fold improvement in accuracy. If the experiment proves successful, such instruments would likely be incorporated into new proposals.

Current ideas for the future ESA-NASA mission include technically ambitious requirements such as coordinating a constellation of satellites – not one pair, as in GRACE, but two pairs. In general, teams developing proposals are keeping the process open and the details more or less confidential, because competition will be tough: out of perhaps 30 to 40 proposals submitted, only one will be selected. Many members of the GOCE collaboration have already joined the race, forming a new team to hammer out a winning proposal. *Patrick Regan (TUM)*

Picture credit: IAPG/TUM

Prof. Dr. Dr. h.c. mult. Wolfgang A. Herrmann

After studying chemistry at TUM, Wolfgang Herrmann completed his PhD in chemistry (1973) and his lecturer qualification (1978) at the University of Regensburg. He did further research at Pennsylvania State University, USA. In 1982, he took up a professorship at Johann Wolfgang Goethe-Universität in Frankfurt am Main. He returned to TUM in 1985, and has served as its President since 1995.

Digitalization as a Means **of Economic and Social Empowerment**

The ability to unlock the opportunities of digitalization calls for new technologies and, above all, skilled professionals. To train them at the forefront of scientific progress is the task of a leading university.

The digital world is global, incredibly fast, irreversible, and full to bursting with opportunities. In the wake of steam engines, mass production and the first industrial robots, we are now approaching the fourth industrial revolution – manufacturing within an Internet of Things, often referred to as Industry 4.0, or the Industrial Internet. This new age sees robots communicating with one another, workpieces communicating with assembly lines, and assembly lines with logistics, while company data is accessible from anywhere via the cloud. The miniaturization of computing components and the growing affordability of storage, coupled with increasingly powerful data networks, are enabling more and more social, economic and industrial activities to be digitalized.

However, technical change is always a double-edged sword, presenting us with both risk and opportunity. We can already guess the risks: surveillance, data theft, the ability to log our every action and interest. Here we will need to define and implement new ethical guidelines, rules, standards and mechanisms to protect us from both intelligence services and other players.

The opportunities, on the other hand, are large: In my view, digitalization is also about empowering all people and companies to shape a common future, both socially and economically. Digitalization allows faster, easier, direct access to target markets worldwide – it is international by nature. It enables new and creative combinations of human talents, well beyond regular job activities. The older generation, people who have withdrawn from working life, can actively participate as long as they have access to fast data highways. And the decisive factor for success will no longer be the location of a factory – for instance in an urban area – but access to high-speed Internet and the availability of specialized staff to develop and implement new software innovations and business models with partners all over the world. Alongside new technologies and algorithms, the economy particularly needs well versed professionals tapping the potential of digitalization. And their training takes place at the universities. So to invest in our universities is to invest in the future of our economy. A good example of a strong alliance between higher education and business is the German state of Bavaria's new digitalization center (Zentrum Digitalisierung Bayern), in which TUM plays a leading role. The role of this alliance is to bundle, coordinate and advance all of Bavaria's digital activities in the fields of higher education, research, innovation and technology, and IT security. For the first time, a comprehensive and coherent competence network will be established in our state, which will also enhance the effectiveness of regional strengths.

Digitalization does not just have economic ramifications; it also requires us to keep ethical considerations in mind. The rapid and far-reaching developments in our society call for urgent action. TUM stepped up to its ethical responsibilities by establishing a dedicated interdisciplinary research facility: the Munich Center for Technology in Society (MCTS). Not only does digitalization have implications for data protection and personal rights, it also could rapidly escalate into a social issue if whole regions are excluded from the exponential growth in data traffic. That is why, irrespective of the costs, high-speed, nationwide data networks are an essential infrastructure measure – in Germany as elsewhere. As a representative of the scientific community in the "Network Alliance Digital Germany" initiated by the Federal Ministry of Transport and Digital Infrastructure, I am also mindful of our duty to address the societal challenges posed by digitalization. □

Picture credit: Eckert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Ich fahre fast täglich 32 km mit dem Fahrrad zur Arbeit. Das bringt mir die Power für meinen Job. Schließlich gilt es, gemeinsam mit den internationalen Kollegen die Serversysteme an annähernd 100 Standorten weltweit zu überwachen, zu administrieren und zu managen. Da hilft ein wacher Geist. Mein Name ist Walter Lauter und ich arbeite als IT-Spezialist. Mehr über mich, meine Arbeit und was ZF außer einer starken, internationalen IT-Familie noch zu bieten hat, gibt es unter www.ich-bei-zf.com.
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