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Max Planck RESEARCH

The Science Magazine of the Max Planck Society 3.2015

Aging

RESEARCH POLICY
We Have to Refocus Excellence

INFORMATICS
Displays Straight from the Printer

BIODIVERSITY
Balance in the Biotope

HISTORY OF SCIENCE
The Master Plans of the Mandarins

Photo: IRAM/André Rambaud

The Peak of the Art of Observation

The backdrop is the stuff of a Hollywood film. At any moment, James Bond could ski around the corner to again save the world from some villain or other. In reality, the people who normally spend their time up here – at an altitude of 2,550 meters – have utterly peaceful intentions. In keeping with the spacey ambience, their attention is directed, not at the breathtaking beauty of the French Alps, but at the farthest reaches of the icy-cold universe. Astronomers use the radio antennas on the Plateau de Bure to study interstellar molecules and cosmic dust, observe the birthplaces of stars, travel to distant galaxies or catch sight of black holes at the edge of space and time.

The IRAM observatory currently consists of seven antennas, each measuring 15 meters in diameter. The facility is one of the best and most sensitive radio telescopes worldwide, but that's not enough for the researchers: in the years ahead, five additional 15-meter dishes will be built on the summit, new receivers will be designed and the track systems extended, allowing the telescopes to then be positioned up to 1.6 kilometers apart. The 45-million-euro project is called NOEMA: NOrthern Extended Millimeter Array. The facility is expected to open up a new window on space and scan the sky with ten times greater sensitivity and four times better spatial resolution than before.

To achieve all of this, the scientists plan to use the full extent of NOEMAs power. They will direct all of the antennas at an astronomical object and then superimpose the millimeter waves they receive. This will allow them to perceive details even from one ten-thousandth of the angle at which the full moon appears in Earth's firmament, guaranteeing deep insights into the cosmic machinery.

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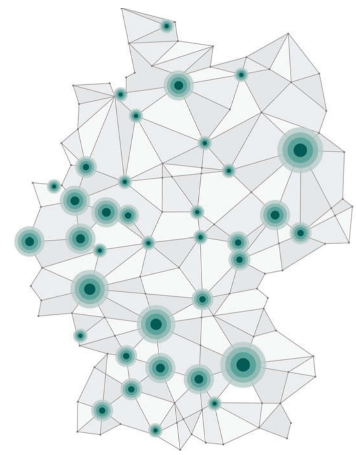


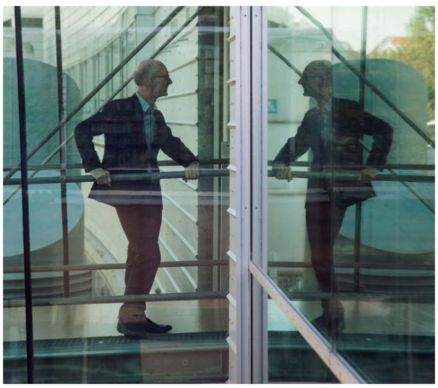
18 AGING

ON THE COVER Practically all organisms and living things must submit to the natural aging process. But how does it occur? The researchers whose work we report on here are studying fish or a freshwater polyp that has nearly achieved immortality. And they grapple with the social consequences of aging in humans – when an active working life ends and retirement begins.

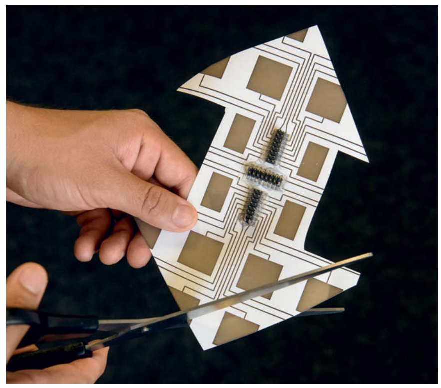
PERSPECTIVES

VIEWPOINT

FOCUS



46 Launched: Stuart Parkin is setting up a new department at the Max Planck Institute of Microstructure Physics.



54 Snipped: A pair of scissors can bring this sensor into nearly any shape and size.

60 Collected: In the Jena Experiment, researchers study how species diversity affects ecosystems.

SPECTRUM

PHYSICS & ASTRONOMY

MATERIALS & TECHNOLOGY

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CULTURE & SOCIETY

REGULAR FEATURES

Photos: Sven Doering, Oliver Dietze, Anna Schroll (from left to right)

Insights and Exchange in Berlin

Annual Meeting of the Max Planck Society with Nobel laureate Stefan Hell and 700 guests

In a celebratory mood: Max Plank President Martin Stratmann, Federal Minister of Research and Education Johanna Wanka and Nobel laureate Stefan Hell (from left) at the Annual Meeting.

The Plenary Assembly in the Great Orangery at Charlottenburg Palace marked the end and was also the highlight of the Max Planck Society's two-day Annual Meeting in mid-June. In his speech, President Martin Stratmann proposed the creation of new, nationwide education and research networks (the abridged version is printed in this issue, see page 10 ff.). Johanna Wanka, German Federal Minister of Research and Education, provided a positive assessment of the funding programs launched by the federal government. At the end of the event, Stefan Hell, the Max Planck Society's 18th and youngest Nobel Prize winner, provided insight into his extremely rocky career path in a podium discussion with science journalist Ranga Yogeshwar.

Beforehand, the Executive Committee and Senate, Directors and Supporting Members had met for their working sessions and a summer party at the Max Planck Society's newly renovated Harnack House. With a view to the conference venue's history, President Stratmann remarked: "The building underscores just how significant Berlin remains as a hub of exchange for international scientists." Max Planck Director Lothar Willmitzer was also presented with the Stifterverband 2015 Science Prize at the Annual Meeting.

Springer Takes Over Open Access Journals

Living Reviews to become part of major publishing group

The Max Planck Society launched a unique model of scientific publications in 1998 with its *Living Reviews*: The articles are updated by the authors when required, or in other words are "kept alive," and do not therefore don't become outdated like other review contributions. Springer is now taking over three of these Open Access journals: *Living Reviews in Relativity*, *Living Reviews in Solar Physics* and *Living Reviews in Computational Astrophysics*. From the publishing house's perspective, the journals will complement both its Open Access portfolio and other "living" publications.

Bruce Allen, Managing Director of the Max Planck Institute for Gravitational Physics, believes the *Living Reviews* stand to gain from integration into an important publishing house: "The journals will remain Open Access but at the same time will benefit from the latest developments in publishing and enjoy long-term success." The Max Planck Institutes will continue to be involved in the three journals, primarily through their right of nomination and the make-up of the editorial teams.

Photo: Amac Garbe/MPG

“Chaperones seal landfill sites”

Franz-Ulrich Hartl explains how protein deposits in the brain protect cells in old age

They were long regarded as harmful and the catalysts of age-related diseases, such as Alzheimer’s, Parkinson’s and Chorea Huntington. However, protein deposits in the brain can also slow down aging processes under certain circumstances. Franz-Ulrich Hartl, Director at the Max Planck Institute of Biochemistry in Martinsried, explains how this works.

Were you surprised that protein deposits in cells could also have a beneficial effect?
Franz-Ulrich Hartl: Yes, very much so, despite the literature containing indications that they are not generally harmful. Scientists originally assumed that neurodegenerative diseases were triggered by large, insoluble protein aggregates detected as deposits in the brain. The investigation of the brains of people who had died at a very old age nevertheless revealed significant protein deposits relatively frequently despite there being no dementia symptoms.

Which protein deposits are harmful?
Over the past five years, it has become increasingly evident that it isn’t large deposits in the brain that are generally toxic, but rather the smaller forms known as oligomers. If the cells fail to prevent the formation of protein aggregates at the outset – which appears to be the case during old age – these smaller forms are combined into larger, insoluble aggregates and deposited in certain locations in the cell. This bears comparison with a landfill site. In this way, the material that would otherwise have been left lying around is collected and rendered harmless to some extent.

To gain better insight into this process, you examined roundworms, which are short- and long-lived animals.
The roundworm *Caenorhabditis elegans* is extremely well suited as a model organism for the aging process. Its organism consists of many cells and it has clear organ structures, such as nervous, muscular and digestive systems. The researchers observed the animals over many generations and were easily able to conduct genetic experiments on them. We recorded over 5,000 proteins in short- and long-lived animals at several points in time during the aging process. This revealed that the long-lived animals, which survived for around 30 days on average, accumulated significant quantities of protein aggregates in insoluble form. In contrast, less aggregate was found in the short-lived control worms that stayed alive for around 14 days.

Did the composition of the protein deposits differ?
Yes, the protein aggregates of the long-lived animals was extremely rich in chaperones. They usually help cells to fold proteins correctly so that they can’t clump together. They also contribute to ensuring that misfolded proteins can be removed from the cells. We now assume that the chaperones also seal the existing landfill sites by attaching themselves to the active surface of the protein aggregates. If this is the case, the toxic processes taking place on the surface of the large protein deposits may be minimized.

What mechanism lies behind this?
We don’t know exactly. It is nevertheless likely that a special class of chaperone plays a part here: the small heat-shock proteins. Researchers previously assumed that their function was to prevent aggregation. However, the literature also contains indications that they could also instigate and even assist aggregation under certain conditions. As we found different small heat-shock proteins in the aggregates of the long-lived worms than those in the short-lived species, we assume that the properties of these heat-shock proteins could have something to do with this phenomenon.

How do you intend to investigate this mechanism?
One way is through a biochemical approach. We want to create extracts from the long-

Franz-Ulrich Hartl

lived worms and then put these with the extracts of short-lived or normal worms. It will be interesting to see whether we can trigger a stronger formation of aggregates in the test tube. We may then be able to isolate and identify the active substance from these extracts. As we suspect this may have something to do with the small heat-shock proteins, we will of course pay particular attention to them.

You are conducting research into chemical substances that may one day be suitable for use as drugs to combat Alzheimer’s, Parkinson’s and Chorea Huntington. If the protein deposits are broken up, couldn’t this prove counterproductive or even harmful?
The molecular chaperones could be deployed to prevent or slow down the formation of toxic aggregates. It’s not so much about breaking up the existing large aggregates. You have to be extremely careful here, otherwise there’s a risk of creating toxic forms again. Activating a process that increasingly amasses oligomers in larger-sized aggregates is also conceivable. If a medical treatment were to be produced one day, it would have to be applied at an early stage, as the protective cellular mechanisms become increasingly weak in old age.

Interview: Barbara Abrell

Photo: Axel Griesch

New Max Planck Centre in Canada

Cooperation in photonics and optics research

The Max Planck Society and the University of Ottawa have set the wheels in motion to establish the Max Planck-University of Ottawa Centre for Extreme and Quantum Photonics. The Centre will link up two of the world's foremost research teams in the field of photonics. Ferdi Schüth, Vice President of the Max Planck Society, and Allan Rock, University of Ottawa President, recently signed a memorandum of understanding.

The new Centre will be at the forefront of research in photonics and optics, in activities including the development of very high intensity laser sources, a quintessential technology for future advanced manufacturing processes, optical methods for quantum information science and the fabrication of devices for use in classical and quantum photonics. However, a cornerstone of this partnership will be to provide young researchers with the opportunity to explore different scientific cultures early on in their professional development.

The principal Max Planck researchers in the new Centre will include Professor Gerd Leuchs, Professor Philip Russell and Professor Vahid Sandoghdar, all from the Max Planck Institute for the Science of Light. The principal investigators from the University of Ottawa will be Professor Paul Corkum, Professor Robert Boyd, and Professor Pierre Berini.

Ambitious program of cooperation: Ferdi Schüth, Vice President of the Max Planck Society, during his speech at the University of Ottawa.

Physics Until You Drop

The Max Planck Society congratulates the winner of the Jugend forscht competition

Is it possible to construct a robot that can stand steadily on just one leg and hop? Anselm von Wangenheim from the Schülerforschungszentrum Kassel took up the challenge of finding out. Using complex simulations, the 18-year-old demonstrated that the construction of such a monopod is physically feasible. The student also enjoyed success experimentally: using skewers, wood glue and sensors, he constructed a duopod, a two-legged robot.

The jury of the 50th Jugend forscht federal competition was impressed by how the young researcher independently deployed sophisticated cybernetics. The laudation stated that his project illustrated how a theoretical concept can be fleshed out in detail and then coherently followed through to practical demonstration. The jury awarded Anselm von Wangenheim first prize in the physics category. Max Planck Society Vice President Ferdi Schüth presented the certificate in Ludwigshafen. The Max Planck Society has donated the prize money for the winners in the physics category for several years now.

Outstanding: Max Planck Vice President Ferdi Schüth (left) with Anselm von Wangenheim, the winner in the physics category.

Photos: Luc Gauthier / University of Ottawa (top); Jugend forscht

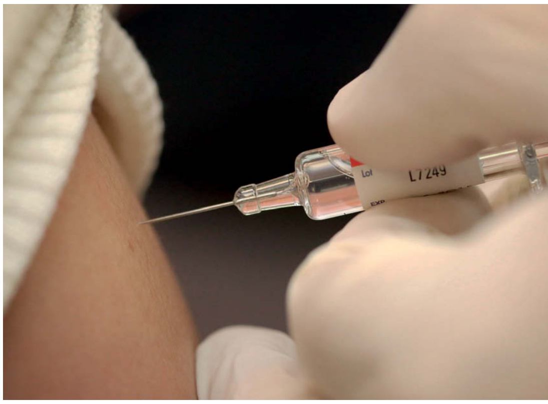
Sweet Vaccines on Track for Application

Start-up is set to make research results ready for market

Vaxxilon is the name of the new enterprise founded by the Max Planck Society together with the Swiss pharmaceutical company Actelion. It will carry out research into, develop and market vaccines based on glycans – natural polysaccharides that play an important role in many cellular processes. Such glycans for vaccines were previously produced from cultured bacteria – a process that complicates production and often makes it unfeasible.

The team headed by Peter Seeberger, Director at the Max Planck Institute of Colloids and Interfaces, has established the scientific foundation for the manufacture of glycans on a completely synthetic basis. This enables the production of new vaccines, including against bacteria, that cannot be cultured or whose sugar cannot be isolated. Vaxxilon is seeking to exploit this potential. With a financing commitment of up to 30 million euros, Actelion is the main investor and principal shareholder in Vaxxilon. The first studies on humans involving the application of a new vaccine are scheduled to take place within the next three years.

For an interview on the topic, visit:
www.mpg.de/9317940/interview-erselius-vaxxilon



Protective jabs: Sugar not only makes inoculations sweet – some vaccines owe their effect to so-called polysaccharides.

On the Net

Everybody is from Somewhere
How can people live together with an increasing number of diverse characteristics in the world's rapidly expanding cities? What are the similarities and differences in social and spatial patterns that arise when new diversity meets old diversity? The documentary film "GlobaldiverCities" by Dörte U. Engelkes provides insight into the large-scale multidisciplinary, international and comparative research project of the same name conducted by Max Planck Director Steven Vertovec between 2011 and 2015. Pay a visit to the website of Max Planck Institute for the Study of Religious and Ethnic Diversity, Göttingen, for more information:
www.mmg.mpg.de/de/subsites/global-divercities/about

Career in Science
The Max Planck Society offers junior scientists the possibility to apply for a position as a Max Planck Research Group Leader. Over 80 research institutes conduct basic research in Biology and Medicine, Chemistry, Physics and Technology, as well as in the Humanities, Social Sciences and Law. The MPG particularly addresses new, innovative and interdisciplinary research areas. To achieve this, we need you: outstanding postdocs in all of the research fields pursued in our organization. We invite you to work with us and apply for a position as a Max Planck Research Group Leader. Application deadline is October 28, 2015.
www.mpg.de/career/max-planck-research-groups/applications

Vaccines with Cookie Monsters
Junior scientists at the Max Planck Institute for Dynamics of Complex Technical Systems in Magdeburg show what makes their day in the lab. Udo Reichl's Bioprocess Engineering Research Group uses the capabilities of microorganisms to produce viral vaccines. This is amusingly demonstrated with a hungry Cookie Monster (virus) diving into a bunch of cookies (cell substrate) in order to grow and multiply. The Monster's mouth is then taped over with a red band to illustrate his inactivation (vaccine). Enjoy!
www.youtube.com/watch?v=PZItz6BHtzo

Photo: dpa

We Have to **Refocus Excellence**

How can we better use the potential for excellence we have in Germany to further advance German cutting-edge research vis-à-vis international competition? Cutting-edge research and good basic education are not a contradiction – even if, in the opinion of our author, the President of the Max Planck Society, the two still do represent conflicting priorities in Germany.

TEXT **MARTIN STRATMANN**

Education is the foundation upon which research is built. A successful education and science system must thus fulfill two tasks: First, it must guarantee access to the best possible university education for the broad public. Second, it must ensure that particularly gifted students and aspiring scientists find themselves in an environment that allows their skills to flourish to the benefit of society. This results in the proliferation of cutting-edge research.

Conflicting priorities between a broad base and excellence must be dealt with productively

Broad base and excellence – this is a concept we're familiar with from the realm of sports, and we as a society have accepted it as such. Recreational sports and high-level competitive sports are not opposites, they are mutually dependent. Leading Germany to a gold medal in rowing in the men's eight competition isn't something that can be achieved under the conditions experienced in recreational sports. It requires dedicated training centers, which, in turn, rely on the pool of talent coming out of recreational sports.

Broad base and excellence – every science system is familiar with these conflicting priorities, as well, and must deal with them productively in order to be successful. And just as in sports, that requires structural diversity and differentiation.

Access to university education for the broad public is something that countries like the United States realized very early on with the vertical diversification of its university system: almost 80 percent of universities and colleges have almost no right to award doctorates, while slightly more than 20 percent of universities have this right. Of these rough-

A network of the best: In Germany, scientific excellence – in this image, the top one percent of the most frequently cited scientists – is spread across a wide area. This has positive consequences: output is generated in numerous locations, and scientific education is very good in many places, also by international comparison. To create visibility, Martin Stratmann recommends bundling the geographically dispersed excellence into cross-regional networks, and embedding the hubs of these networks in the locations where excellent science is practiced in Germany.

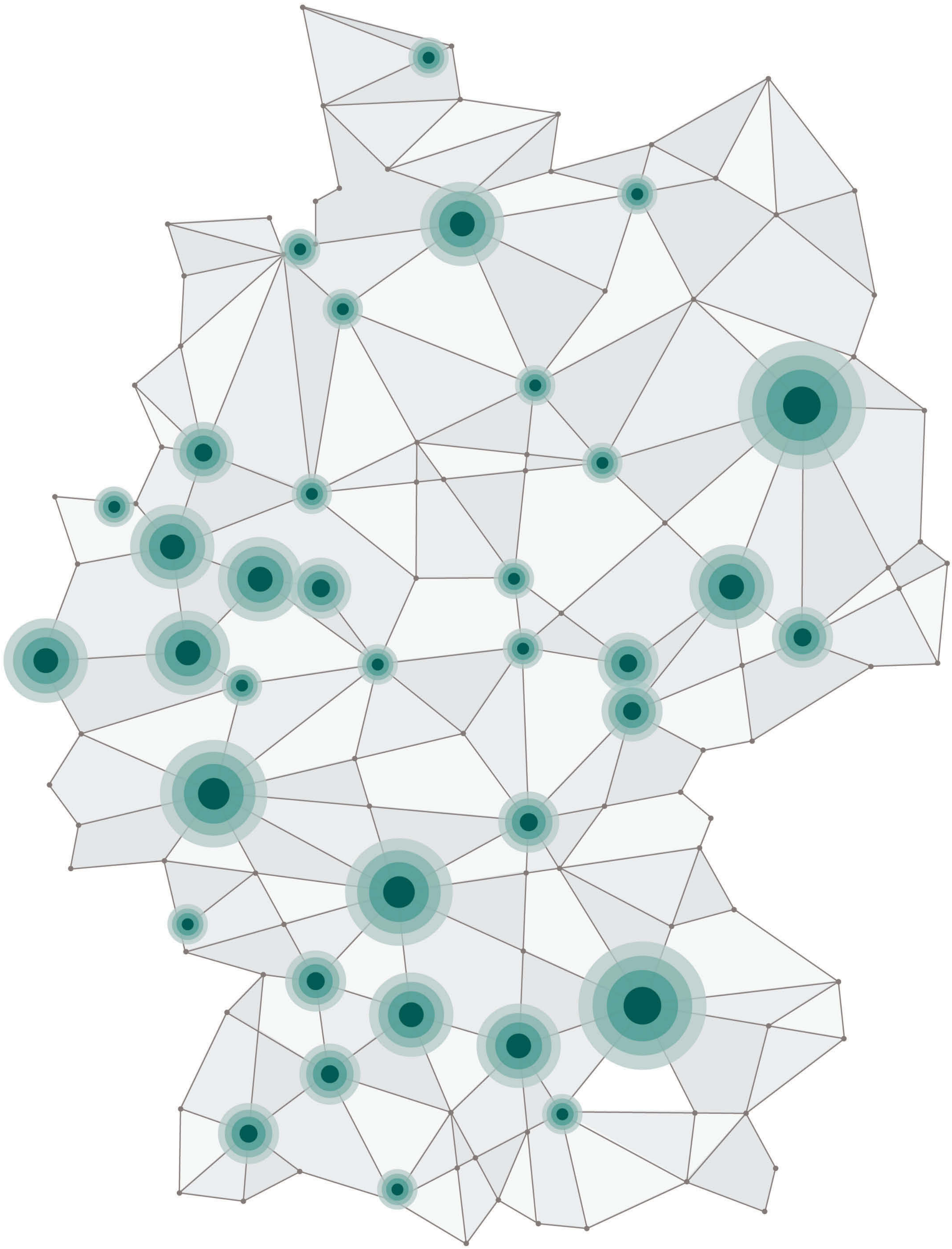


Photo: designergold, based on original material from the MPG

ly 1,000 universities in the US, a small group of research universities emerges where the vast majority of Ph.D.'s are completed and that simply do not provide a broad-based university education. This elite cluster manages to provide exclusive teaching while successfully concentrating on excellent research and attracts students and scientists from across the entire globe. But in the overall system of 4,600 institutions, this cluster makes up just slightly more than two percent.

The German system, too, has faced the challenge since the 1960s, if not before, of opening up access to a university education for a huge number of students while still remaining internationally competitive in terms of research performance.

Unlike the US, Germany extended access to a university education through a massive horizontal expansion of the university system. A large number of universities were created based on the same model, with the result that there are now more than 100 universities that are entitled to confer doctorates, all structured much the same and all having to cope with accepting large numbers of students.

What Germany failed to do is ensure broader access to a university education through greater diversity of the institutions, and perhaps also by expanding universities of applied sciences. Broad-based and

There is a diverse non-university research infrastructure

top-level education – Germany only really began to try to bring these two conflicting priorities into alignment in the course of the Excellence Initiative.

Research, on the other hand, offers a somewhat different picture. Alongside traditional universities, there is a diverse non-university research infrastructure. With its declared mission of advancing cutting-edge research, the Max Planck Society is an essential component of this structural diversity. Within our organization, outstanding scientists find working conditions that only leading international universities can otherwise offer.

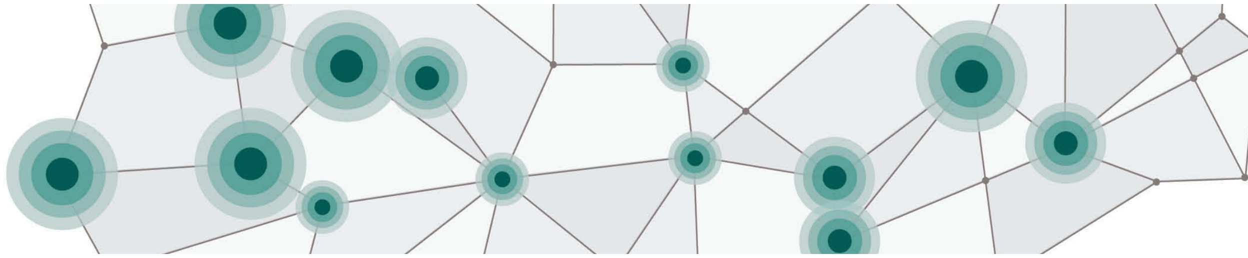
But how does German research fare internationally? To answer this question, I will first analyze Germany as a research hub and compare it with the US, the UK and the Netherlands. The four countries vary in size. To be able to compare the specific performance factors that set a country apart from the global average, I will standardize the parameters. The basis is always the country's share in the global population. Using this as a premise, the question is: by which factor is a country's performance greater than would be expected given its share of the global population? I'm going to call this factor the "performance indicator".

Since good research requires a sound financial foundation, I will begin with a few economic figures. The US accounts for about 4.5 percent of the global population and 22 percent of the world's gross national product. With a performance indicator of 5, the US is economically five times as successful as its share of the global population would indicate. At the same time, the country supplies some 30 percent of the globally available resources in research and development. In terms of America's share of the global population, that's six times the global average.

The German figures are similar: With a performance indicator of 4.5, we are four and a half times as successful as our share of the population would indicate. And like the US, we invest about six times more in research and development.

The UK and the Netherlands follow suit. So what we notice is that, measured in relation to their population figures, these four countries are about equally successful in economic terms and invest disproportionately large amounts of money in research and development. As such, they are deliberately investing in scientific and, ultimately, economic competition.

The crucial question is then: What do the countries achieve with the money they invest? How successful are they, from a scientific vantage point, compared with the others? A detailed answer to this general question would, of course, require an extensive analysis for which there is not enough space here. I will therefore answer the question regarding the German science system's performance by focusing on publication figures – in the knowledge that such an analysis cannot properly accommodate all disciplines. Nevertheless, an analysis of this sort



does provide sufficient insight to reflect the importance of German cutting-edge research by international comparison.

How good are the four cited countries at converting their investments into scientific output?

Let us begin by analyzing the total number of publications. The US produces about 22 percent of all scientific publications globally. If we relate this to the number of inhabitants, then the US is about five times more successful than its share of the global population would indicate. The UK is slightly more successful, Germany is somewhat less successful and the Netherlands, measured in terms of its size, is surprisingly successful. One might conclude that the quantity is determined by the amount of available funds.

Let us now take a look at the share of publications that are in the top 10 percent of the most frequently cited publications in their field. The US has a performance indicator of 7, as does the UK, while Germany manages an indicator of 6. And the Netherlands leads the pack with an indicator of 10.

If we look at the share of publications that are among the top one percent of the most frequently cited publications, the US manages a performance indicator of 8.4, and the UK is just slightly behind. Germany has an indicator of 5.7. The Netherlands – once again with an indicator of 10 – shows that much can be achieved even with less money.

This “pyramid” of publication excellence becomes all the steeper the more successfully a country concentrates on the quality of its scientific output, and the more well known and influential the country’s leading scientists are.

Ultimately, the top indicates the number of scientists who have published the largest number of the top one percent of publications in their discipline. This is a particularly significant number, given that science is still performed by individuals with smart minds, and a country that can attract these smart minds has a genuine locational advantage.

This small global elite currently numbers 3,215 scientists, and more than half of them (1,701) do their research in the US – a substantial share of whom, incidentally, are originally from outside the States. Relative to the size of its population, the US is therefore home to 11.5 times more cutting-edge scientists than it should have based on its share in the global population. The UK has a performance indicator for cutting-edge scientists of 10, and the smaller Netherlands also manages a 10. And what about Germany? Our country is well and truly beaten on this score, with a performance indicator of 4.5. Despite its size, Germany has a total of just 164 scientists of this caliber, compared with 303 in the UK and 76 in the Netherlands.

Thus, based on very similar raw data, Germany shows signs of weakness at the top. The Excellence Initiative was and is therefore the right choice and very much needed. It must tackle the point where our biggest deficit lies: in our lack of excellence compared with our toughest international competitors. That is why the Excellence Initiative must prove itself to be what its name suggests: an initiative to improve the excellence of German research.

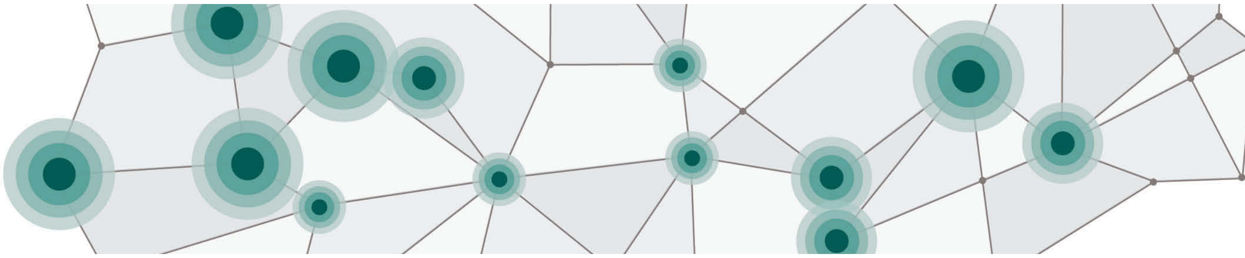
But the advancement of cutting-edge research in Germany also has some successes to show for itself.

By international comparison, Germany shows signs of weakness at the top

One of the things that demonstrates this is the development of the individual levels of the excellence pyramid over time. Germany succeeded in raising its performance indicator in the area of one percent of the most frequently cited publications by 16 percent in the past ten years, while our biggest competitors lost momentum: the UK’s indicator fell by 5 percent, and the United States’ even by 24 percent. In absolute figures, however, both countries remain far ahead of Germany.

The Excellence Initiative’s programs should therefore be continued. This will strengthen the universities and make them more effective. It will permanently stabilize what they’re successful at rather than ending it at an early stage. On this point, the German Research Foundation and the Science Council have already made specific proposals regarding the Initiative.

Photo: designergold, based on original material from the MPG



But beyond that, it is important not to lose sight of the structural evolution of the universities. As the comparison with our Dutch neighbors shows, Germany not only has a problem endowing universities with basic funding, it also has an efficiency problem.

Currently, there is also a lot of talk about additional personnel for universities. Indeed, additional personnel can appear to be beneficial. However, if we want to couple additional personnel with keeping an eye on the strengthening of cutting-edge university research, we need to take into account that genuine excellence is rare. At the moment, the Max Planck Society manages to appoint about 15 elite scientists per year, and even this modest number keeps us all pretty much in suspense.

So we must take care not to award too many permanent posts in great haste while ultimately doing nothing more than consolidating mediocrity. That would be hard on our universities in the long term. To be visible internationally, our universities need some outstanding minds. Top scientists are highly mobile and go where the conditions and the reputation are right. Conditions are more than just financial resources, they also include a large pool of outstanding students – the basis for any scientific success.

If we want to continue taking the Excellence Initiative seriously, we will need to provide these conditions in Germany, and also selectively create new positions at the top — the very place where we are currently lacking them. This takes time – and it may also require new concepts. Establishing excellence at the top of our pyramid demands that we not let our best scientists relocate to other countries and that, at the same time, we attract outstanding minds to Germany from other countries.

In the current Excellence Initiative (ExIn), the best minds at the Max Planck Society are already working very successfully with the best minds at the universities: almost half of our Directors are now involved in an ExIn graduate school as Principal Investigators; almost two thirds are involved in excellence clusters. Yet still, these predominantly local networks do not fully leverage the potential of excellent German research. How can we work together to achieve even more?

To find an answer to that question, it pays to take a look at the institutional and geographical distribution of the most frequently cited scientists in Germany. Where do these scientists, who are at the peak of the excellence pyramid in their discipline, work? Half are at German universities (81), and one third are at the Max Planck Society (52). The remainder are split among various other organizations.

In terms of geographical distribution, the greater Munich area leads with 27 most frequently cited scientists, followed by the greater Berlin area and Heidelberg, each with 16. However, none of these regions alone can match scientific hotspots like the Boston area.

Specialist excellence in Germany is spread across different regions and not concentrated in a single place. Were we to superimpose the geographical distribution of the most frequently cited scientists of all disciplines one on top of the other, we would be right back at the beginning and would be able to pick out locations of particularly great performance density. This is where the hubs between the scientific disciplines lie. This realization results not only from this very specific publication analysis: the German Research Foundation's Funding Atlas paints a very similar picture of this cross-regional distribution and the regional interdisciplinary concentration.

We can't let the best scientists relocate to other countries

How can we bring together this geographically dispersed excellence that already exists in Germany in a productive way? How can we cleverly bundle the individual visibility of the best German scientists so that the resulting structure attracts not only the world's best scientists but also the world's best doctoral students to Germany? How do we establish the right conditions for outstanding appointments at German universities?

When leading scientists from the Max Planck Society get together with leading scientists from the universities in future-oriented fields, the result is cross-regional education and research networks – let's call them schools – that can compete with the top institutions in the world. The hubs of these networks

Photo: designergold, based on original material from the MPG

would be embedded in the places where excellent science is practiced in Germany and would integrate them. This would mean a further strengthening of university towns; the best professors, as the key players in cutting-edge university research, would have even greater international visibility in these schools.

Such cross-regional, topic-centered Max Planck Schools could offer outstanding graduate education by global standards. Interdisciplinary hot topics of the future wouldn't necessarily need to be tied to university disciplines. I firmly believe that schools like these would attract the best graduate and Ph.D. students from Germany and abroad – and they would keep them in our country, too.

This can happen through tenure track pathways within the schools I have described, through which we create attractive positions for the best young scientists in Germany beyond the doctoral student level. Doing so would achieve something fundamental: new staff posts for junior scientists, combined with high standards of excellence.

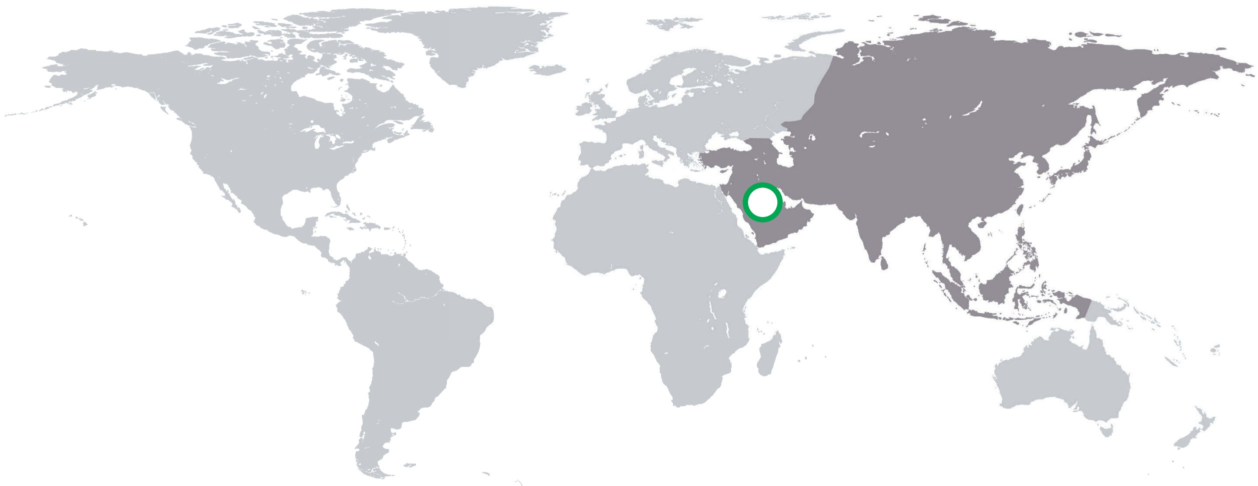
The key to strengthening excellence at the top is, I believe, ultimately the creation of a sustainable environment for successful new appointments from abroad through the cross-regional network of a Max Planck School; and not only for the Max Planck Society but also for the universities working with us. The Alexander von Humboldt Chair is already attractive now – how attractive would it be if it were in the same town as a school at the international cutting edge?

International competition – be it in business or in science – is first and foremost a competition for minds. We need to remain compatible here with attractive offers and an excellent environment. If we take modern cognitive research as just one example, we see that it spans everything from brain research, linguistic research and psychology to robotics and computer science. These are areas that are going to determine our country's economic future. Only those who succeed in bringing the best professors and the best students into their country and giving them chances of advancement there will be able to share in the resulting economic success. ◄

THE AUTHOR

Martin Stratmann, born in 1954, studied chemistry at Ruhr-Universität Bochum (RUB). He completed his Ph.D. at the Max-Planck-Institut für Eisenforschung (iron research) in 1982. Following a postdoctoral position in the US, he became a Group Leader at the Max-Planck-Institut für Eisenforschung. He earned his German postdoctoral lecturing qualification at the University of Düsseldorf and subsequently taught at the University of Erlangen-Nuremberg from 1994 to 1999. In 2000, he accepted the appointment as Scientific Member and Director at the Max-Planck-Institut für Eisenforschung. He has received many awards, including the U. R. Evans Award of the British Institute of Corrosion in 2005. Martin Stratmann has been President of the Max Planck Society since June 2014.

This article is an abridged version of the speech Martin Stratmann gave at the General Meeting of the Max Planck Society in Berlin in June 2015.



Old Traditions in a New World

Max Planck scientists cooperate with partners in around 120 countries worldwide. Here they relate their personal experiences and impressions. During a visit to the laser laboratory in Riyadh, quantum physicist Nora Kling got to know a new, fascinating world.

Normally I would never in my life have considered going to Saudi Arabia for my research. Nearly everything I knew about the country had come from media reports. That made me somewhat afraid initially; life there appeared to be so different. But even in my first week at the newly established laser laboratory at King Saud University, which collaborates with the Max Planck Institute of Quantum Optics and Ludwig Maximilian University, I noticed how respectful and polite the people are. In fact, they're so polite that I hardly ever spoke with other students on campus during my stay there. While it's perfectly natural for people from Western countries to approach strangers and ask them questions, in Saudi Arabia, that's considered pushy.

Having grown up on a farm in South Dakota, I was raised to be very down-to-earth and independent. I always experienced an open atmosphere during my university studies in the natural sciences, and also later at the Max Planck Institutes. I was able to develop my research skills completely independently of gender roles. Coming from this background, for me, the separation between men and women in Arabic society is rather disconcerting. The fact that women aren't allowed to drive is something I find especially strange.

The separation of the sexes also pervades everyday life. Some restaurants have special "family areas" with private booths closed off by velvet curtains. There, women can remove their face veils undisturbed and sit together with family and friends to enjoy the food – which, incidentally, is really fantastic. Hospitality has a long tradition in Saudi Arabia and plays a very significant role in the culture. Attentive university staff built a new restroom in line with Western standards especially for us, the cooperation partners from Germany.

Graphic: iStockphoto

Nora Kling, 32, is studying ultrafast, light-induced movements of electrons and atomic nuclei within molecules. Born in the US, she studied chemistry and mathematics, but she also took physics courses, which enabled her to obtain a Ph.D. in physics at Kansas State University. She wrote her dissertation on the development of an imaging method that analyzes the ultrafast interactions between laser light and ions in molecules. As an external Fulbright scholar and visiting scholar of the Max Planck Society, she was already able to spend two years working on her Ph.D. project at the Max Planck Institute of Quantum Optics before returning to Ferenc Krausz at the MPI and to the LMU Laboratory for Attosecond Physics in Garching as a postdoc in 2014.

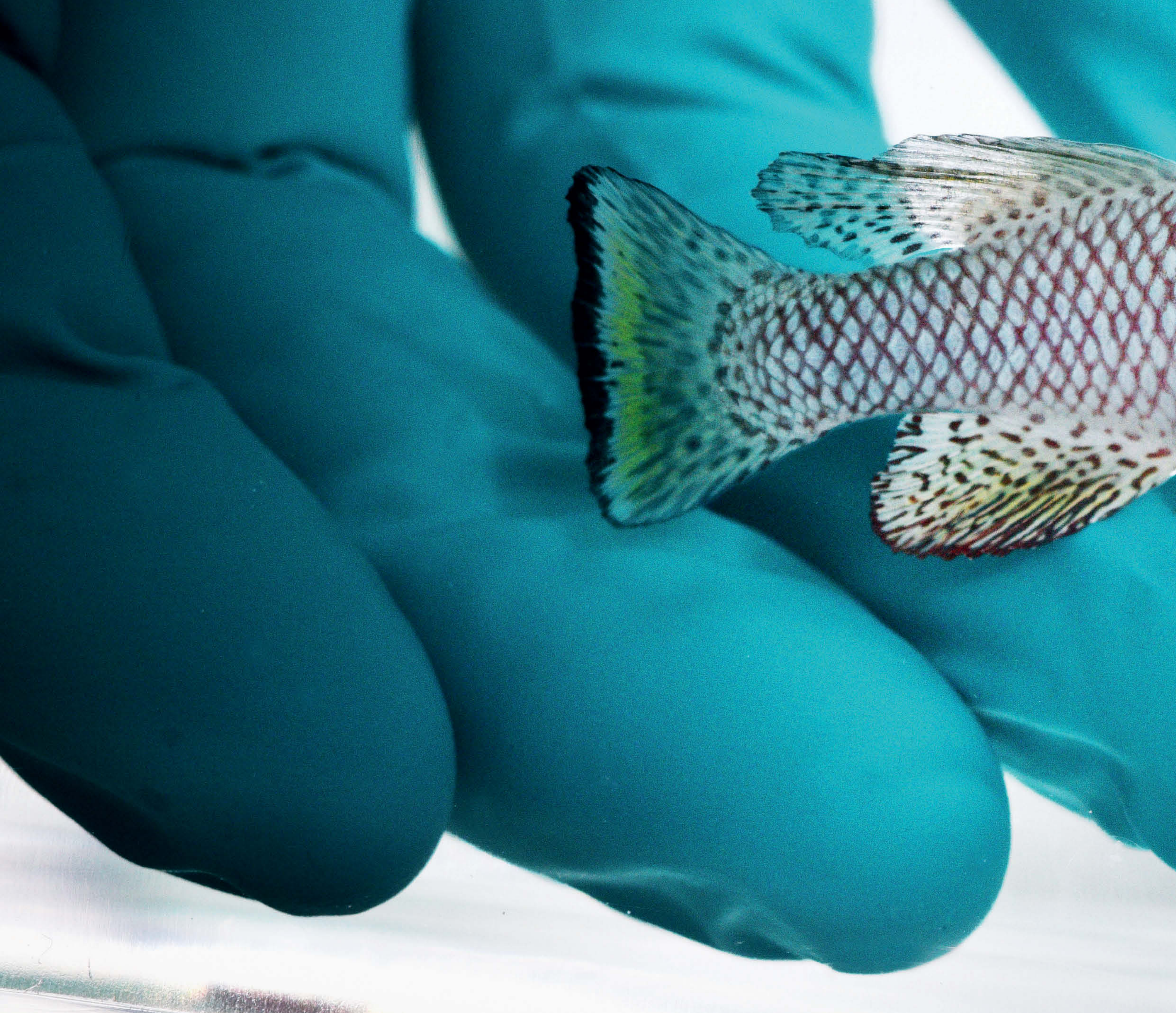
Since the lab is located on the men's part of the campus, I never saw a single female student during my stay at the laser lab in Riyadh. But I also didn't have a lot of time, as I was fully focused on my work.

Science is my greatest strength – what I'm best at. And I would like my work to contribute to overcoming cultural barriers, and to show that women, too, can work in science. The women's part of the campus is completely separate from ours, but actually it is precisely basic research in physics and engineering that is so interesting for the young, highly educated women of Saudi Arabia. Their male colleagues prefer the better paying jobs in the finance sector or the oil industry, anyway.

Our lab is unique: it's located in the middle of the desert, where it's exposed to the merciless heat and sun. The special location offers us the opportunity to bring leading-edge technology to this part of the world and to create new synergies with existing research projects. For instance, one of our first cooperation partners is a biophysicist who can use our equipment to study the ultrafast internal conversion of melanin – the pigment that protects us against the sun.

I find it incredibly exciting to help initiate such interesting and interdisciplinary projects that might not exist otherwise. And I hope our lab not only offers a shared research platform, but can also build up greater understanding for cultural diversity among scientists.

Photos: Private collection



Living in **Fast Motion**

Life is short, especially for the turquoise killifish, *Nothobranchius furzeri*: it lives for only a few months and then its time is up. During that short life span it passes through every phase of life, from larva to venerable old fish. Its brief life expectancy – unusual for a vertebrate – has long fascinated **Dario Valenzano** of the **Max Planck Institute for Biology of Ageing** in Cologne. In just ten years, he has turned it into a model organism for research on aging.

With its red net-like pattern and black-and-yellow-patterned fins, the turquoise killifish doesn't really look turquoise. But the name refers to the blue-green base coloration of its scales. After just a few months, the vibrant colors of the young fish begin to fade. The fish's rapid physical decline has piqued the interest of researchers on aging worldwide.

TEXT **HARALD RÖSCH**

"Wow, that's a really old fish!" Valenzano can barely hide his astonishment in the fish facility of the Max Planck Institute in Cologne, where aquariums are lined up end to end on long shelves.

However, anyone expecting to find a date of birth in the distant past will be surprised to read "September 2014" on the birth certificate affixed to the aquarium pane. The presumed Methuselah was just nine months old on the day of the visit to the fish facility – a positively biblical age for a member of this *Nothobranchius* species. Most of its relatives are already dead at that age.

Valenzano encountered the fish – named after its discoverer, Richard Furzer – in 2002, as a student in the laboratory of his mentor Alessandro Cellerino in Pisa. Together with his mentor, he set up a small aquarium stocked with fish. They had been given the fish by an acquaintance, a hobby aquarist who had bred killifish for many years. The fish buff drew the two researchers' attention to the phenomenal rate at which the fish ages.

The young student had no specific interest in fish at the time. He was mostly focused on the behavior and evolution of primates and humans. For his master's thesis, he observed capuchin monkeys in captivity for months and analyzed their facial expressions. Nevertheless, the ephemeral fish piqued his interest and soon became his passion. Out of curiosity, he looked for signs of aging in the brains of the fish and found the same protein deposits that are typical of aging in the human brain.

From then on, Valenzano wanted to solve the puzzle of the short life span of *Nothobranchius* and make it a model organism for research into aging. Several models already existed: for example, the nematode *C. elegans*, the fruit fly *Drosophila* and the mouse. The latter lives just two to three years. That may not sound like much, but that's also how long researchers have to wait before they can examine a mouse in advanced age. Nematodes and fruit flies, in contrast, live just a few weeks, but as non-vertebrates, they differ significantly from humans. "I wanted to develop the vertebrate equivalent of *Drosophila*

Photo: Frank Vinken

to study the biology of vertebrate aging," explains Valenzano.

Nothobranchius would thus fill a gap: it has an extremely short life span and, as a vertebrate, is closely related to humans. In just a few months, *Nothobranchius* undergoes the entire aging process that in other vertebrates takes years or decades. But why, of all fish, has this one not been blessed with a long life? After all, some fish live to be very old. Koi carp, for example, can live for several decades. One species of rockfish in the North Pacific even has a life span of over 200 years.

The short life span of the killifish could be related to the climate of southern Africa, the habitat of the turquoise killifish, as it is also called. Water is present there for only a few months of the year; some bodies of water dry up completely after just two months. This probably isn't the most auspicious situation for fish longevity. Only fish that are able to develop and reproduce while water is still available are able to survive. Under such conditions, there is nothing to be gained from longevity genes, so selection doesn't favor them. For Valenzano, this could be the reason for the extremely short life span of *Nothobranchius*.

Due to the short rainy season, *Nothobranchius furzeri* has evolved to mature quickly: The fish grow into adults capable of reproduction just three to four weeks after hatching. Then the shimmering colors of youth pale, the fins fray, and the spine becomes progressively curved. The fish passes through every phase of aging, including dotage, rapidly, as if in a time-lapse film.

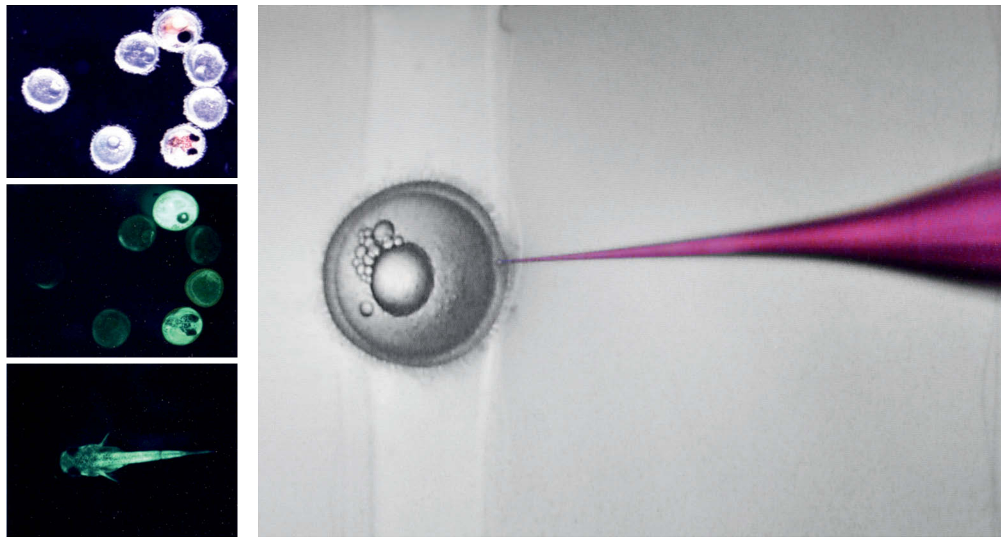
Nature seems indifferent to this; after all, the arrival of the next fish generation is ensured. The eggs are resting at the bottom of the pond. When the pond dries up, the embryos are safe, lying in a sort of dormant state. This allows them to survive the months of drought.

In advanced age, *Nothobranchius* is rather inflexible. It ages even when – as in the lab – there is no threat of early death due to desiccation. That's what Valenzano found so fascinating about

Photo: Frank Vinken

Left page: The key to age: Using the killifish, *Nothobranchius furzeri*, Dario Valenzano wants to find out why organisms age.

This page: Successful gene transfer: Researchers use a fine glass needle to transfer the gene for the green fluorescent protein GFP to a fertilized fish ovum (large image). In the maturing embryos (small image, top), the fluorescent gene is active (center) and causes the animals to fluoresce (bottom, five-day-old larva).



the fish: "*Nothobranchius* could provide an answer to the question of why aging occurs at all. Does aging confer an advantage on plants and animals? Or was there simply no reason to prevent the inevitable process of decay once successful reproduction has taken place?"

Although aging can't be halted in *Nothobranchius*, it can be slowed. A number of factors influence the life expectancy of the fish, one being temperature: the cooler the water, the longer the fish live. Food supply also plays a role. If there is a scarcity of food, the fish live longer – a phenomenon that researchers have also observed in fruit flies, nematodes and rodents. Why this is so hasn't been fully explained. "Perhaps the temperature and food supply give the fish cues as to whether the environmental conditions are favorable. When temperatures are low and food is scarce, it makes sense to wait awhile before reproducing. Consequently, the fish must stay alive longer in order to reproduce," suspects Valenzano.

He studies these relationships with the aim of gaining a general understanding of aging. Many of the signs of aging in killifish also occur in other organisms: they develop cancer, show cognitive decline, become less fertile, lose their pigmentation and become more fragile. "*Nothobranchius* thus allows us to study in a short time how these biological mechanisms work," explains Valenzano.

GLOBAL KILLIFISH BOOM

Many characteristics must coincide for a species to serve as a model organism for science. *Nothobranchius furzeri* is a success story in this respect. Valenzano has elevated it to an object of global scientific interest. Some 40 laboratories around the world are now working with this species. "Every two weeks or so we receive inquiries from scientists to send them *Nothobranchius* eggs so that they can breed the fish in their labs," Valenzano says. There is now even a biannual international scientific conference on the turquoise killifish.

The road leading to this point was rocky, and Valenzano's project didn't always evoke enthusiasm. Some members of his doctoral thesis committee in Pisa were cautious and warned him about the risk of developing something completely new. Nevertheless, they all supported him. Particularly Stanford University, where he went to do his postdoc work, gave him the opportunity to develop genetic tools to study aging in killifish.

First, he investigated whether *Nothobranchius* simply dies young without first aging appreciably. He also wanted to shed light on precisely how the fish ages. He discovered protein deposits and damage in the brain that became increasingly common with advancing age. He also found learning deficits: older killifish learn less quickly to associate a harmless light stimulus with a frightening mechanical disturbance in the water. As in humans, aging affects multiple organs in killifish. The animals become more sluggish and lose weight. Also, their spine begins to curve. The kidneys become less efficient, and tumors grow in the liver. "Cancer is the most common cause of death in laboratory killifish," Valenzano says.

He also had to draw up instructions for keeping and breeding the fish. Although *Nothobranchius* is undemanding and quite easy to keep, the fish must live under similar conditions to allow the findings from different research labs to be compared. Valenzano therefore developed detailed protocols for the chemical composition of the water, and for temperature, light

Photos: Frank Vinken (4)

» Does aging confer an advantage, or was there simply no reason for evolution to prevent the inevitable process of decay once successful reproduction has taken place?

Male killifish at five (top) and twelve weeks of age (bottom). The colors fade with age, and the fins become frayed. Since the eyes don't stop growing, older fish also have larger eyes.

and food. After all, the aging process is affected by numerous environmental factors.

To serve as a model for aging research, an animal must have a sequenced genome that allows researchers to study specific genes and design strategies to manipulate them. Valenzano has therefore gone to great lengths to develop suitable molecular biological methods, for example the transfer of DNA to *Nothobranchius* eggs. The eggs are covered by a tough outer sheath to prevent them from drying out. "At first, the sheath caused us a lot of headaches. We were unable to penetrate it to inject genes using conventional microneedles. We weren't successful until we used shorter, harder needles and a few other tricks, mostly discovered by trial and error," Valenzano explains.

Through his needle, he injected a "jumping gene" into the eggs. The gene produces an enzyme that snips the genome at specific locations. In this way, Valenzano introduced a foreign gene into the genome of *Nothobranchius furzeri* for the first time. Without proof that *Nothobranchius* can be genetically modified, its model career wouldn't have made it out of the starting blocks. In the process, Valenzano discovered chromosome segments that control aging in the killifish. He plans to study these regions in detail to determine which genes are responsible. He also identified genes for the color of the fish's tail, and others that determine the sex of the fish.

In the meantime, Valenzano and others have built up a set of tools that allow them to analyze the killifish genome as precisely as that of fruit flies and mice. Recently, the entire genome of *Nothobranchius furzeri* was decoded. Its sequence will soon be available to the scientific community.

Scientists are now even able to switch off *Nothobranchius* genes using the CRISPR/Cas9 method. Using this technique, which has recently revolutionized the biological sciences, US researchers were able, in the space of just two to three months, to breed genetically modified *Nothobranchius* strains that show typical signs of aging, such as reduced fertility and susceptibility to tumors, at the tender age of just two months. The trigger for these changes is a dysfunctional gene for the telomerase protein. This enzyme normally prevents the end caps of chromosomes, the telomeres, from becoming progressively shorter over time. Shortened telomeres also occur in humans in advanced age.

But Valenzano is interested in more than just the killifish genome. He hypothesizes that the intestinal flora holds another key to understanding the aging process of many organisms, including the killifish. As in humans and most other animals, myriad bacteria help their host digest food and contribute to metabolic processes that influence predispositions to such diseases as diabetes. Every fish species has its own resident bacterial community, the composition of which can even differ from one fish to another within a species.

MICROBES IN FISH INTESTINES

Valenzano characterized which bacteria occur in the fish intestines by analyzing the genomes of the microorganisms. "We now know that older fish have different intestinal flora than younger fish, more associated with pathological states," Valenzano says. As a next step, he wants to determine whether fish that live to be particularly old have different microorganisms than their short-lived counterparts, and whether he can prolong the life span of a fish by altering its intestinal flora. To do so, he first purges the intestinal flora with an antibiotic and then transplants microbes from an old fish by adding its intestinal content to the aquarium water. In this way, he can study whether the old fish can live longer and remain healthy with the bacteria from young fish intestines.

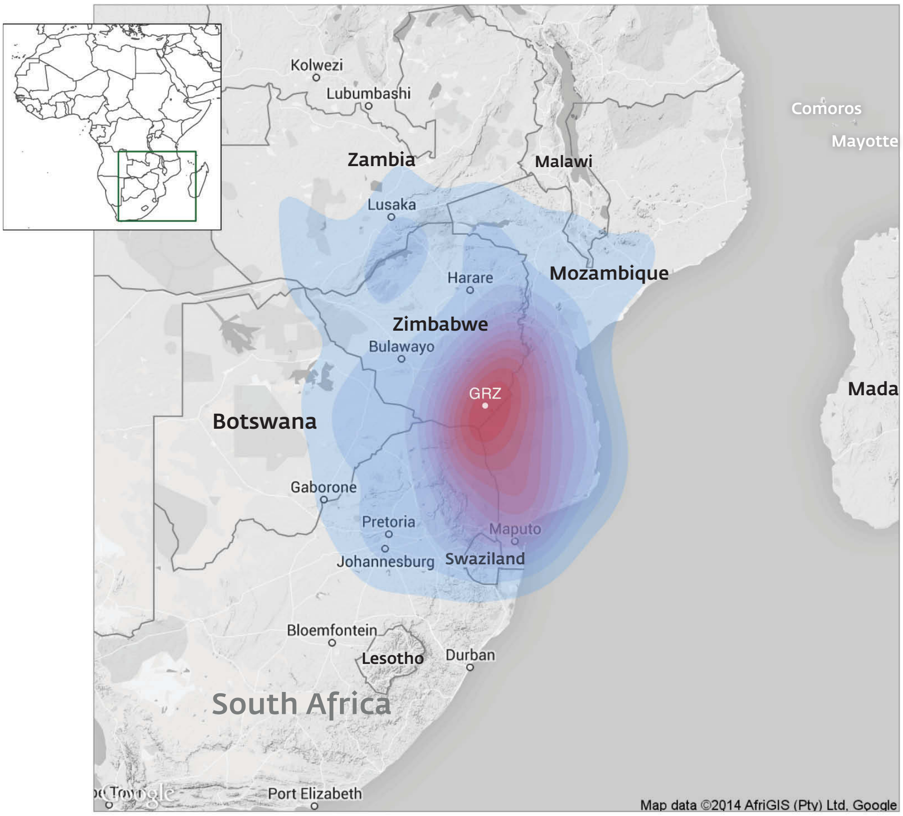
Photos: MPI for Biology of Ageing – Dario Valenzano (2)

In the future, Valenzano, together with colleagues in his research group at the Max Planck Institute, wants to take the experiments out of the laboratory. He is bent on studying the fish in the wild. After all, evolution has spent millions of years devising ways to help animals cope successfully in habitats with fluctuating environmental conditions. *Nothobranchius furzeri* has made a virtue out of necessity: it simply lives faster and dies sooner. >

Right: When scientists have to improvise … a simple folding table – and an ironing board – serve Valenzano and his colleagues as the base for genetic and intestinal analyses in the savanna.

Below: Typical habitat of *Nothobranchius furzeri* in Gonarezhou National Park in Zimbabwe during the dry period. Most bodies of water dry up completely during this season. The killifish eggs wait in the desiccated ground for the next rain.

Photos: MPI for Biology of Ageing – Dario Valenzano (2)



The researchers working with Valenzano have found *Nothobranchius furzeri* in various locations in Mozambique, and recently also in Gonarezhou National Park in Zimbabwe (GRZ). The climates at these various locations differ considerably: a tropical monsoon climate in the lowlands (blue), a desert climate in the highlands (red). The drier the climate, the faster the ponds dry up again, which could explain the particularly short life span of the killifish living in Gonarezhou Park.

Other fish, in contrast, wouldn't dream of sacrificing their longevity. Lungfish, for example, which live in the same ponds as *Nothobranchius*, burrow deep into the mud and wait there for the drought to end. Some lungfish can reach the ripe old age of 50 years or more. Related species of *Nothobranchius* in the New World found yet another solution to the problem: some North American killifish jump out of drying ponds and survive the dry period on land in damp wood.

OUT OF THE LAB AND INTO THE SAVANNA

"Evolution is one big experiment in which gene variants are constantly being tested and the most suitable are selected," says Valenzano. He hopes that these naturally occurring variants will tell him why nature causes *Nothobranchius* to age rapidly and what happens in the process.

To do so, he must study the fish as they occur in nature. However, until the turn of the millennium, science labs held only the progeny of the fish originally introduced by Richard Furzer. Furzer had captured the hitherto unknown *Nothobranchius* species in eastern Zimbabwe near the border with Mozambique in 1968 and brought specimens to Europe. Since then, hobby aquarists have bred the offspring – and the offspring of the offspring – in their aquariums over a period corresponding to around 80 fish generations.

Because individuals of the *Nothobranchius* strain, known as GRZ (after the park in which they were found, Gonarezhou National Park in Zimbabwe), have bred only with individuals of the same strain during this whole time, the fish have become extremely similar genetically. Their genes are almost all the same variants – an ideal situation for genetic investigations. Having an inbred line is a luxury that not all model systems have. The zebrafish community, for instance, lacks a well-established inbred line, which is part of the reason why it was quite hard to assemble the zebrafish genome.

Fish of the GRZ strain have the shortest life expectancy of all vertebrates that can be bred in captivity: 9 weeks on average to 13 weeks at most under controlled laboratory conditions. For a long time, it remained unclear whether the short life span of the GRZ strain was a consequence of decades of inbreeding or whether *Nothobranchius furzeri* has a similarly short life span in the wild.

In 2004, Valenzano and several colleagues thus travelled to Mozambique in search of the killifish. Although many of the ponds have been transformed into rice paddies in recent years, the researchers found the killifish in several locations. The fish live under various climatic conditions there: regions at higher altitudes in the interior of the country are relatively dry compared with the coastal lowlands, which receive more rain. The coastal areas thus don't dry out as quickly, and *Nothobranchius* has more time to develop there before finding itself stranded on dry land.

The scientists captured several dozen fish in four habitats and took them back to the laboratory, where they bred them. Now Valenzano was able to compare the life expectancy of *Nothobranchius furzeri* taken from the wild with that of the GRZ strain from the laboratory. He was also able to examine whether

Map: Map data ©2014 AfriGIS (Pty) Ltd, Google

» Cancer is the most common cause of death in laboratory killifish.

different natural climatic conditions affect the aging process.

The wild fish live for 25 to 32 weeks, significantly longer than the GRZ fish from the laboratory. However, they still have a very short life expectancy for a vertebrate. What's more, the highland fish do, indeed, age more quickly and die sooner than the fish from the wet coastal region. In addition, harmful protein deposits accumulate more slowly in the brains of the lowland fish.

But Valenzano was still missing a piece of the puzzle: the wild relatives of the fish from which the GRZ strain originally developed. Furzer had captured the founding pair in the east of Zimbabwe, a region that is even drier than the habitats in Mozambique. "So the breeding conditions in the laboratory aren't necessarily what make the GRZ strain so short-lived. Perhaps the extreme shortness of their life span is due to the extreme dryness of their natural habitat," Valenzano says.

CAPTURING FISH IN A NATURE RESERVE

To clarify this point, Valenzano had to journey to Zimbabwe's Gonarezhou National Park, the original home of the GRZ strain. It took five years to gather the necessary papers from the national park authorities, despite the fact that he didn't want to capture any fish, but only take tissue samples for genetic and intestinal analyses. "Poaching in southern Africa has escalated out of control in recent years, so any activity in the park is carefully scrutinized," Valenzano says.

In the spring of 2015 he finally had all the necessary permits. Once again, he and a team of scientists set off on a journey to southern Africa. Before entering the national park, however, they made a quick stop in a hardware store to buy an ironing board. "It wasn't for our laundry, of course. We needed a flat surface on which we could collect our samples. A collapsible ironing board fit the bill perfectly," Valenzano remembers with a smile.

With the samples from Gonarezhou, Valenzano can now compare the genome of the GRZ strain with that of the fish from Mozambique. He hopes to glean further information about which genes control the aging process in *Nothobranchius furzeri*. He also aims to analyze how often the various alleles of aging-related genes occur in nature and how that frequency changes over time. This should tell him how evolution has adapted the life expectancy of the fish to the prevailing environmental conditions. His future investigations will also focus on differences in the intestinal flora of the wild fish.

To do that, he will have to travel to Africa often. "It's a long-term project stretching over a period of 20, maybe even 30 years." That's perfectly feasible for a young scientist. His aquariums will then contain fish of the 40th or 60th generation. Translated into human life spans, that corresponds to 1,000 to 1,500 years. Humans clearly can't hold a candle to the killifish as a model organism for aging research. ◂

TO THE POINT

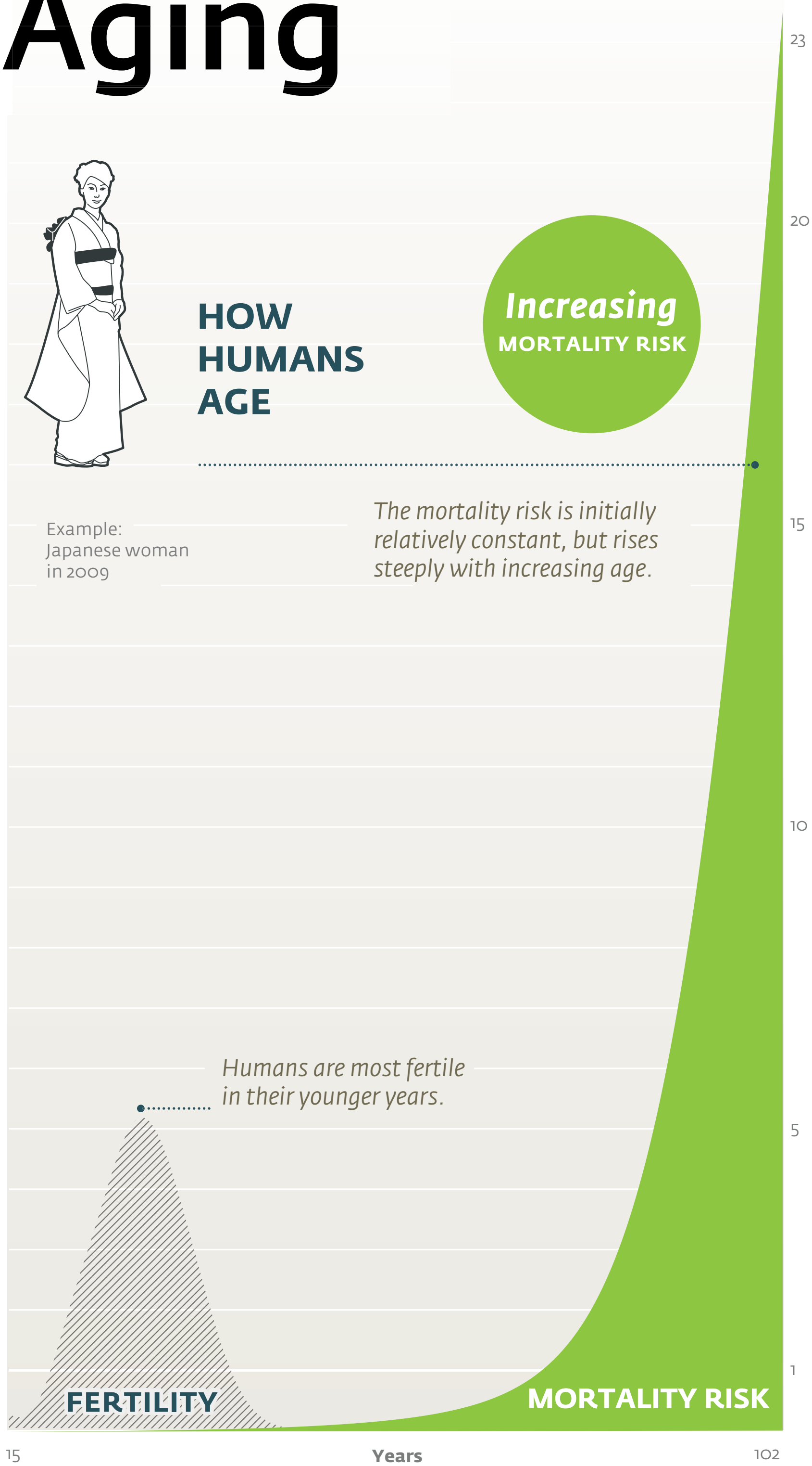
- **Thanks to the shortest life span of all vertebrates that can be bred in the laboratory, *Nothobranchius furzeri* is eminently suitable as a model organism for studying aging processes.**
- **Scientists around the world are studying which genes control the aging process in *Nothobranchius*. To this end, they artificially induce genetic mutations and study gene variants that occur in nature.**
- **The life span of *Nothobranchius* is also influenced by other factors besides genes, such as temperature and food availability. The composition of the intestinal flora also plays a role.**

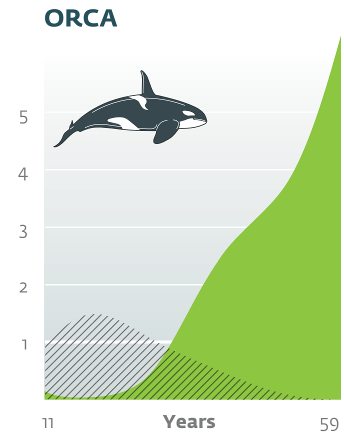
GLOSSARY

CRISPR/Cas9: A new molecular biological method that enables scientists to genetically modify organisms much more easily and inexpensively than before. The CRISPR/Cas system serves as a sort of immune system in bacteria, neutralizing viruses – so-called bacteriophages. Cas enzymes can cut DNA at repeating segments known as CRISPRs (clustered regularly interspaced short palindromic repeats). Researchers can then insert new DNA segments at these sites.

Killifish: They belong to the taxon of tooth-carps. The name stems from the Dutch word for drainage ditch (*kill*). The fish were discovered in such ditches in the Dutch colonies of North America. Killifish are the egg-laying species of tooth-carps. This classification is now scientifically obsolete, but the term is still commonly used by aquarists.

The Diversity of Aging



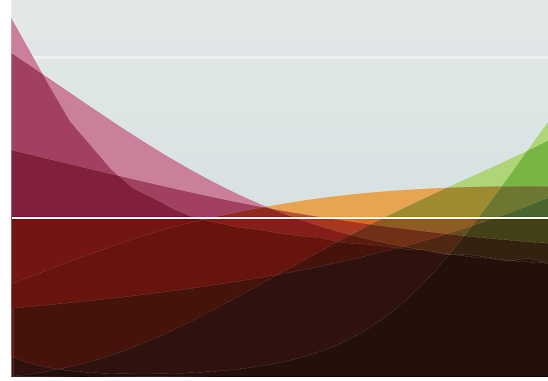


Many animals age similarly to humans

AGING CURVES

Relative mortality risk (colored areas) and fertility (gray hatchings) in relation to age, beginning with sexual maturity up to the age at which only 5 percent of adult individuals are still alive.

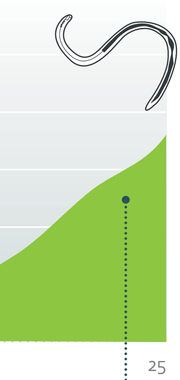
Mortality risk and fertility are shown in the remaining graphs in relation to the respective life average.



|← Age of sexual maturity

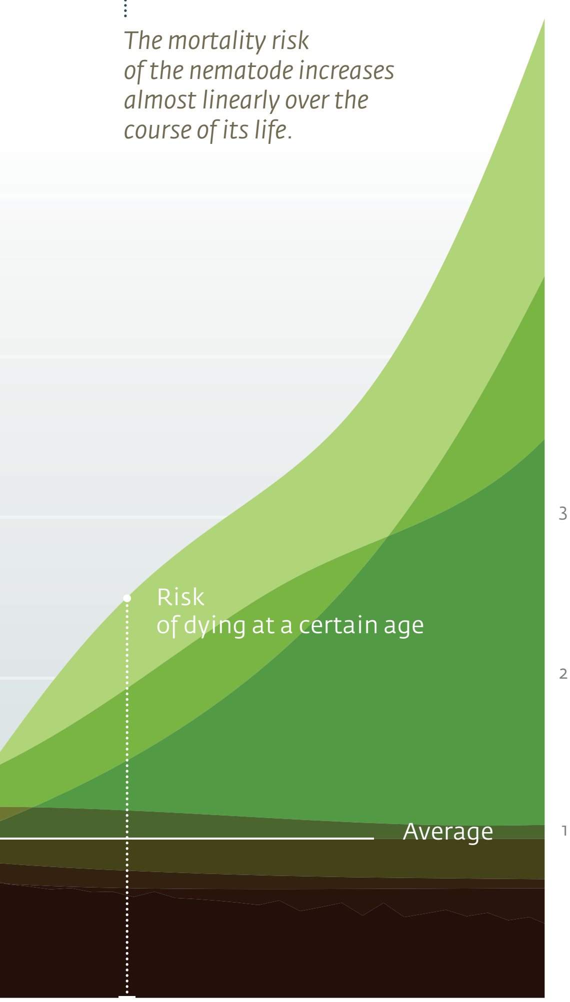
TYPICAL LIFE EXPECTANCIES

Data visualization and design: Moritz Stefaner. Illustrations: Sarene Chan



The mortality risk of the nematode increases almost linearly over the course of its life.

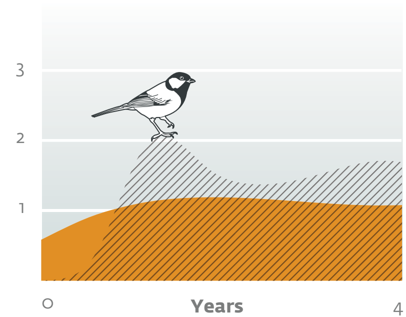
YELLOW BABOON



Age at which only 5 percent of individuals are still alive →|

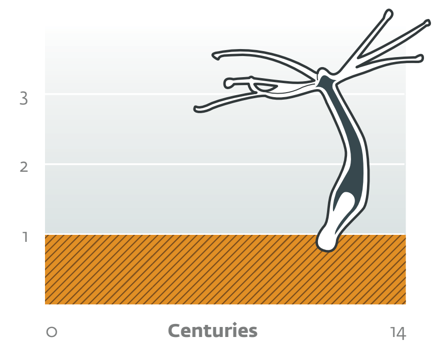
Constant MORTALITY RISK

GREAT TIT



The mortality risk of some animals doesn't change with age.

FRESHWATER POLYP

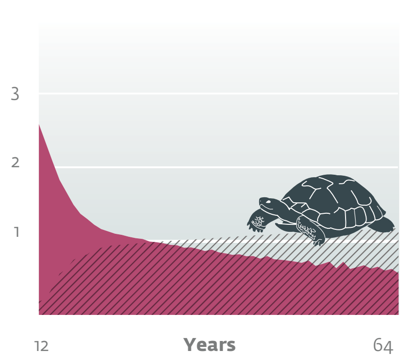


Freshwater polyps can live to be centuries old, and remain as vigorous and fertile as on their first day.

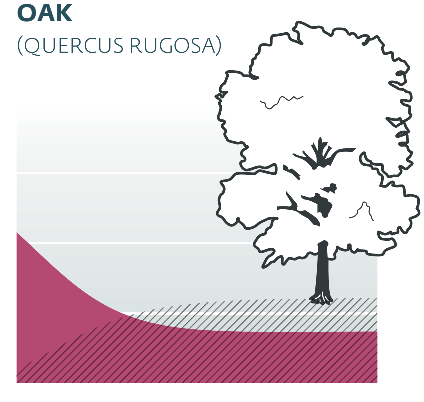
Decreasing MORTALITY RISK

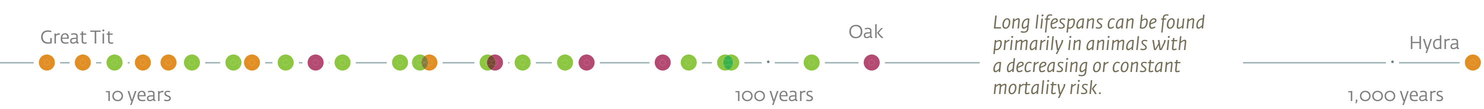
Some plants and animals die less frequently the older they become.

CALIFORNIA DESERT TORTOISE



OAK
(QUERCUS RUGOSA)





Long lifespans can be found primarily in animals with a decreasing or constant mortality risk.

Based on: Owen R. Jones, Alexander Scheuerlein et al. **Diversity of ageing across the tree of life** Nature, 505:7482, 169-173

To read more, visit http://bit.ly/ageing-diversity

A Hint of **Immortality**

Eternal life lasts a very long time. Nevertheless, **Ralf Schaible** from the **Max Planck Institute for Demographic Research** in Rostock can already affirm that the freshwater polyp *Hydra* comes quite close to this ideal. In a long-term experiment initiated by the institute's Director James W. Vaupel, he and his colleagues investigate why, under certain circumstances, *Hydra* doesn't age.

TEXT **KLAUS WILHELM**

The freshwater polyps at the Max Planck Institute in Rostock get absolutely everything they need for a long life. After all, "the experiment," as Ralf Schaible calls it, has no use for unhappy animals. That's why Schaible creates paradisiacal conditions for these tiny animals, which measure less than one centimeter in length and are as thin as a needle: "We pamper them with everything they could ever dream of." Several of his staff are tasked with feeding the nearly 1,800 polyps. Using extremely fine pipettes, they deposit the polyps' favorite food directly onto their tentacles: brine shrimps, small crustaceans. They get the same ration every time, delivered free of charge, three times a week – and that for nearly ten years now.

The *Hydra* seems to enjoy it. Under these conditions, the species has now revealed its secret: "*Hydra* doesn't age," says Schaible, summing up the experiment's spectacular findings, "it's had a constant mortality rate throughout all these years." Previously that seemed, from a scientific perspective, impossible.

THE BODY BREAKS DOWN WITH AGE

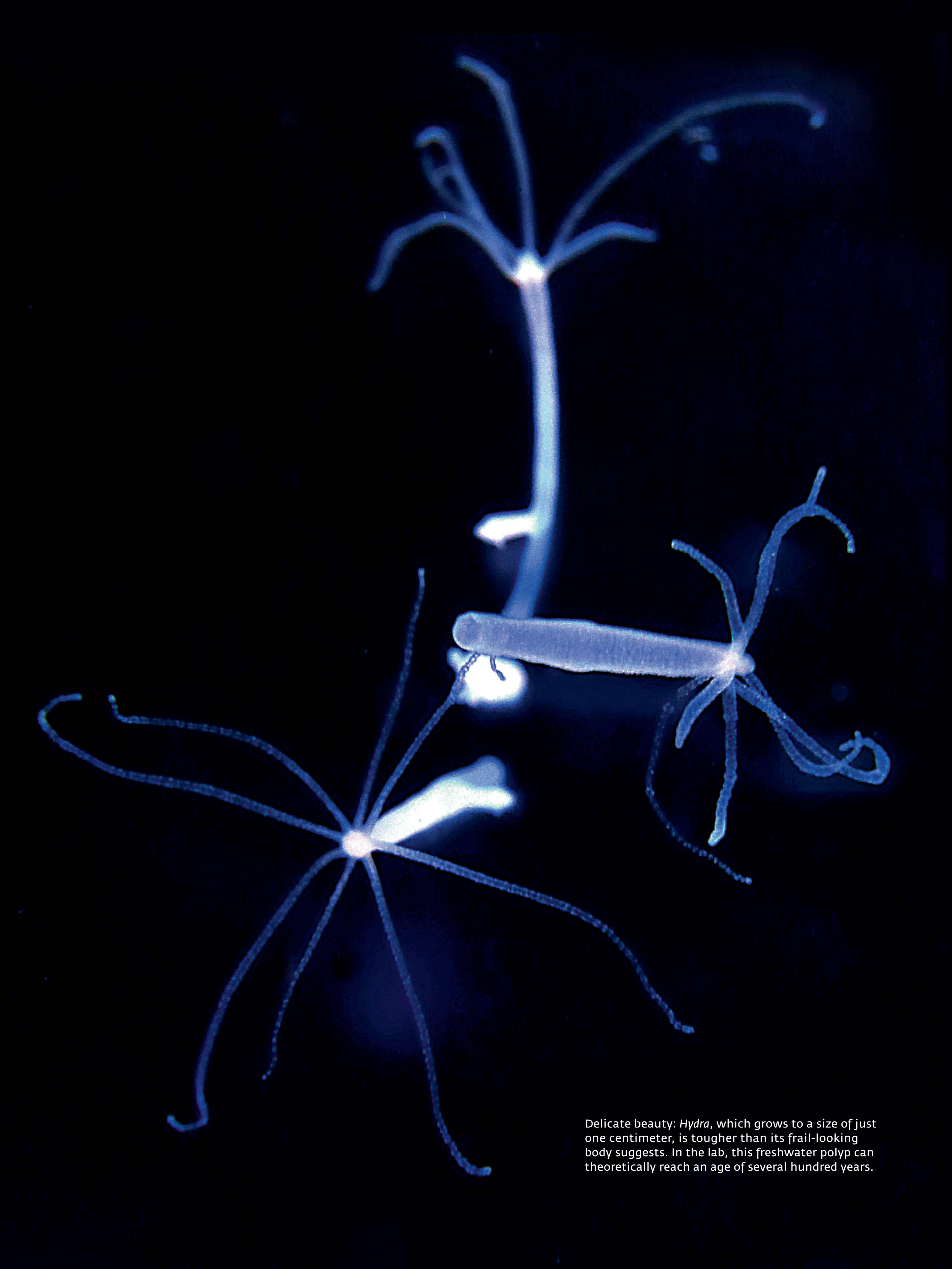
Aging, mortality, immortality – these topics have held a fascination for humans since well before the post-post-post-modern era. And for good reason: dark circles plow ever deeper furrows under our eyes. Our skin and connective tissues sag. Wrinkles cover our necks and faces. Reading glasses sit on our noses like a senior citizen ID card. Our minds aren't as quick as they once were. The sprint to the next bus stop becomes more like a tired trot.

No, aging is no fun, and with every passing day, the risk of dying increases. Some of us find the process frightening. Others confidently proclaim that they don't care – even though perhaps they, too, stand in front of the mirror each morning and furtively but meticulously examine their wrinkles. And who knows: maybe they also secretly hope that science will one day be able to halt this course of events, like the medieval alchemists who sought the elixir of eternal life. In Ralf Schaible's view, however, that was – and is – a vain hope: "I think immortality is impossible," he says, "even in an organism like *Hydra*."

Hydra possesses truly astonishing properties – just like the eponymous character in Greek mythology, the many-headed monster that grew two new heads for each one it lost. And the head in the middle of its body is immortal, besides.

Like its mythological role model, the freshwater polyp, too, replaces the body parts it loses. "But why can they

Photo: Fotostudio Hagedorn



Delicate beauty: *Hydra*, which grows to a size of just one centimeter, is tougher than its frail-looking body suggests. In the lab, this freshwater polyp can theoretically reach an age of several hundred years.

do that and others can't?" Schaible wonders. Does it have to do with *Hydra's* extreme longevity?

The longer the experiment continues, the more convinced the researcher becomes that it does. With an expected end date on December 31, 2017, the experiment began on March 1, 2006. That's when the scientists began to spoil *Hydra 1* from cohort number 1, as well as all the offspring it produced.

Each animal lives in its own dish of water with minerals at a constant temperature of 18 degrees Celsius. They always receive the same amount of food and follow the rhythm of a normal day with light and darkness. To round out this life of luxury, they live in their petri dishes without fish or other animals that might eat them.

Right after the start of the experiment, *Hydra 1* began to reproduce asexually. The researchers collected the offspring and gave each of them a "private room" as well – more than 1,800 times to date.

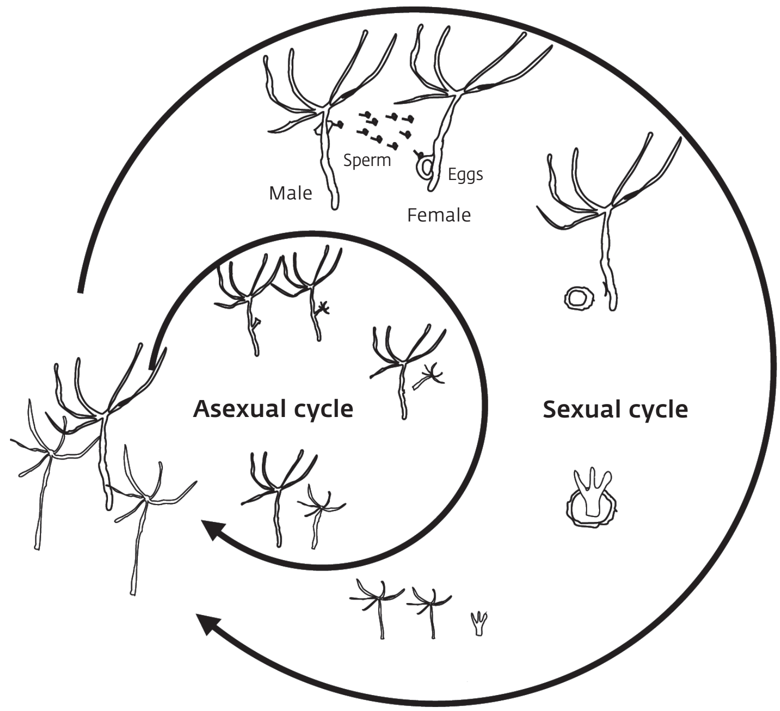
Nevertheless, there are some deaths. Most of them are due to lab accidents, for instance when individuals stick to the covers of their dishes and dry out, or fall on the floor. But the occasional *Hydra* also dies a natural death: it first stops eating and shortens its tentacles; next, the entire body begins to shrink; after one to two weeks, the animal dissolves into its component parts. "But so far," says Schaible, "we have rarely observed this kind of death."

The scientists also determine the asexual reproduction rate. For this, they count every new daughter organism. "To date, more than 30,000 genetically identical polyps have been created in this way," says Schaible. He has detailed data from more than 1,800 in-

LONG-LIVED CLAMS

The ocean quahog *Arctica islandica* is the longest-lived complex animal on Earth. One specimen of this shellfish verifiably made it to the ripe old age of over 500 years old – as evidenced by the lines on its shell. Populations of *Arctica islandica* also live, for example, in the Baltic Sea. There, however, they die between the ages of 40 and 60. A comparison of Icelandic, Irish and Baltic clams shows that all clam populations have the same aging pattern despite differences in their maximum lifespans. Thus, their mortality increases only slightly with increasing age. This doesn't appear to have anything to do with the telomeres, as there is no difference in these protective caps on the ends of the chromosomes. According to popular theories, the telomeres are considered to be the "bomb fuse of death," since they get a tiny bit shorter each time a cell divides, thus limiting the life of the cells, much like an hourglass.

Photo: Fotostudio Hagedorn



Left: Daily feeding routine: The researchers have to provide food to nearly 1,800 polyps every day. They use fine pipettes to dispense small crustaceans into the dishes.

Right: *Hydra* can reproduce both sexually and asexually. For sexual reproduction, an individual produces sperm and secretes them into the water. They are picked up by female individuals and fertilize their ova. The embryo detaches from the mother organism, falls to the ground and develops into an adult animal there. In this form of reproduction, the genetic material of the two individuals involved is mixed anew. More frequently, *Hydra* procreates asexually: stem cells migrate from the core of the body to a sort of bud, which develops into a complete animal, including foot and tentacles. In this type of vegetative reproduction, mother and daughter are, with the exception of mostly insignificant mutations, genetically identical, or clones.

Graphic: Ralf Schaible, MPI for Demographic Research

dividuals. The most productive animal has produced 341 offspring so far, others just 10 or 20.

The researchers' aim for their long-term experiment is to determine the animals' natural mortality over many years. From the number of annual deaths, they calculate the probability of death for each age. Demographers have always been interested in this factor. In humans, the probability of death changes continually, usually increasing. The change in the probability of death is what demographers call aging.

It is in this context that the scientists working with James Vaupel in the Laboratory of Evolutionary Biodemography have, for some time now, also been analyzing the probabilities of death in animals. For biologists like Schaible, this is an "entirely different world, and one that I first had to learn to understand," says the Rostock-based researcher. Natural scientists normally tend to look at aging from a physiological standpoint, and at the level of cells and molecules: muscle strength and metabolic rates decrease over the span of a life, the genetic make-up changes, and so on.

Schaible realized, however, that the *Hydra* experiment offered the chance to show that organisms age and die in very different ways. The team in Rostock has thus been keeping meticulous records for nine years now about when the polyps are born and when they die. Now they know that "*Hydra* has a constant mortality risk, and it doesn't age because its mortality doesn't change with increasing lifespan."

In other words, regardless of whether an individual is just one year old or nine, its risk of dying remains the same.

HARDLY ANY FATALITIES PER YEAR

Moreover, the mortality is surprisingly low, especially for such a small animal. Per year, only one in around 220 individuals dies. All the others continue on and on and on. The polyp thus has a life expectancy of several centuries (see page 26) – so it's not immortal, but almost. "One might think that for such a small, fragile organism, even ten years must be an eternity," says Schaible.

"The scientific community initially ridiculed our findings," concedes the scientist. The experiment was said to be simplistic. But the criticism gradually abated – the data was simply too conclusive. It supported the hypothesis that aging processes are extremely variable and are influenced by genes and by environmental conditions.

So living organisms age differently – a finding that contradicts the popular theory that, upon reaching sexual maturity, mortality increases while fertility decreases. The data on the probability of death and the reproduction of 46 species that James Vaupel and his colleagues at the Max Planck Institute in Rostock and the Max-Planck Odense Center on the Biodemography of Aging in Odense, Denmark, calculated (see page 26) shows the diversity of aging patterns in nature.

In primates, baboons and chimpanzees, the probability of death follows the standard curve and resembles that

Two weeks after *Hydra* was treated with UV light, the polyps changed visibly: In contrast to untreated animals (left), in some of the treated *Hydra*, two heads form, and the buds don't detach (center). In others, many tentacles grow in the bud zone (right).

of humans. In other species – such as the violescent sea-whip coral, the oak or the Californian desert tortoise – the mortality risk decreases continually even well into old age – probably because they grow ever larger and can thus withstand predators ever more successfully. In many birds, the risk of death initially increases and then remains constant. The constant and extremely low mortality of *Hydra*, however, is unique in the animal kingdom.

"But the aging processes also vary within a species or group of animals," explains Schaible. Japanese biologists, for instance, studied the species *Hydra oligactis*. At a water temperature of 18 degrees, the animals diligently produce buds and don't age. At 14 degrees, in contrast, the species begins to reproduce sexually. This means that the animals now produce only eggs and sperm, and die after five months. In this case, the probability of death increases with time – just as in humans. In other *Hydra* species, however, in the same experiment, mortality doesn't increase. So sexual reproduction doesn't reduce life expectancy in *Hydra* in general.

The researchers therefore don't yet know whether the difference in mortality is merely an adaptation to lower temperatures or a true aging effect. Apparently, however, the old notion that mutations and other damage accumulate in an organism's cells over the years and inevitably lead to its death is incorrect.

Thanks to its immense regenerative capacity, and under the luxurious conditions in the lab, *Hydra* is able to escape this decline. If a freshwater polyp is cut into two halves, in two to three days, two complete new individuals will grow. Even if the animal is cut into five pieces and only 500 cells remain, it can still regenerate quickly and precisely.

SELF-RENEWAL PRESERVES YOUTH

It owes this ability to renew itself to stem cells, which *Hydra* has more of than specialized somatic cells. These stem cells divide throughout their lives and produce all cell types needed to form or regenerate a body or individual body parts. Its body is thus constantly renewing itself, allowing *Hydra*, despite continuous reproduction, to grow ever older without decaying.

Through budding, *Hydra* continuously produces genetically identical offspring. Many genetically identical individuals reduce the probability that the genes of an individual organism will be wiped out by adverse environmental conditions. "Our *Hydra* apparently pays no price for its extended lifespan – its asexual reproduction is simultaneously its fountain of youth," says Schaible.

This quasi immortality in the lab may also be merely a by-product of adaptations that help the animals survive in nature. For example, the constant production of genetically identical offspring ensures the survival of the genetic material even when mortality is high due to environmental factors. Moreover, the extraordinary ability of the polyps to regenerate increases their survival rate, for instance when predators, such as snails, nibble on them.

In parallel with the long-term experiment, the researchers in Rostock launched a few shorter studies to find out why their polyps don't age. They subjected the polyps to minor stress, first feeding them normally, then letting them fast for 60 days, then giving them brine shrimps again. This resulted in the polyps reproducing more efficiently. They thus gained more life energy and used it more wisely, which may have further extended their lifespans.

In another experiment, the scientists irradiated the polyps with harmful UV light or treated them with aggressive hydrogen peroxide. Both caused considerable stress for the animals, and 30 percent died immediately following exposure. Some were deformed, growing multiple heads or slit tentacles, but most of them recovered and regained their previous appearance. Now the researchers wanted to know what happens with the damage when the polyps regenerate anew.

"*Hydra* seems to be able to distinguish intact stem cells from damaged cells. It then responds to the damage in different ways," explains Schaible. If few cells are damaged, they are sent to the foot and tentacles, where they specialize and, due to the short lifespan of somatic cells, eventually die.

Photos: Ralf Schaible, MPI for Demographic Research

What's the secret of longevity? Ralf Schaible is also looking for the answer to this question in the polyp's genes.

However, if too many maltreated stem cells flood the organism, the animals might choose one of two different strategies: some behave egotistically and deport the damaged cells. They collect them in the buds, from which new *Hydra* form. "In this way, the polyps get rid of the damaged cells and possibly live longer," says Schaible. Others sacrifice themselves in what appears to be a selfless act: they move the few intact cells into the buds, from which healthy offspring then grow. They themselves perish.

The scientists want to conduct further experiments to determine which molecules are behind the longevity of their animals. They are focusing primarily on the protein FOXO. That's the name of a so-called transcription factor that regulates the activity of many genes – "a sort of master switch for cell renewal and longevity," as Schaible puts it. Using special substances, the scientists can modify the aging process of *Hydra* and probably also the activity of FOXO and other genes, increasing the animals' mortality rate.

For Schaible and his colleagues, the extremely long-lived, non-aging polyp is a fascinating case of longevity. "If we were to find the genes for aging in such a non-aging organism, it would really be something special." ◂

Photo: Fotostudio Hagedorn

TO THE POINT

- **For the freshwater polyp *Hydra*, the probability of dying remains constant throughout its life – unlike with humans, whose mortality risk increases with age.**
- **Stem cells that are active throughout their lifespan give *Hydra* the ability to replace old somatic cells with new ones. This allows it to offload the cell damage that increases over time.**

GLOSSARY

***Hydra*:** The genus *Hydra* belongs to the *Cnidaria*, which also includes jellyfish. Biologists know of around twenty *Hydra* species, five of which are found in Germany. They live in ponds and lakes and in river sections where the water doesn't flow too rapidly. The animal consists of a foot with which it anchors itself to the ground, and a head with five to eight tentacles that it uses to capture prey. The tentacles are equipped with cnidoblasts, which shoot out poisonous cnidocytes when touched.

Retirement **Comes of Age**

Compulsory retirement for mayors at 65? Too old to embark on a career as a firefighter at 30? Age limits seem out of tune with the times – even virtually discriminatory. Yet there is one age limit that most people are happy to hold onto: retirement age. **Ulrich Becker**, Director at the **Max Planck Institute for Social Law and Social Policy** in Munich, studies the characteristics of age-specific regulations and their legal intricacies.

TEXT **MECHTHILD ZIMMERMANN**

No one may be discriminated against on the basis of age – this principle is enshrined in the Charter of Fundamental Rights of the European Union. Although this right is not yet included in Germany's Basic Law, the country's General Act on Equal Treatment expressly specifies age – along with race or ethnic origin, gender, religion or belief, disability and sexual orientation – as a characteristic that must not be used as a basis for discrimination.

However, age differs from all of the other criteria for discrimination in a variety of ways: age discrimination potentially affects all people, as everyone can be classed as old at some stage. What makes it even more difficult is that, "unlike discrimination on the grounds of religion or gender, there are justified reasons for discriminating on the basis of age," says Ulrich Becker, Director at the Max Planck Institute for Social Law and Social Policy. It's a fact that people's physical strength and intellectual capacities decline with increasing age. While Becker's Department deals with this topic and the associated phenomena on a normative level, the institute's Social Policy Department carries out empirical studies and investigates the resulting economic impacts.

A LEGAL MINEFIELD

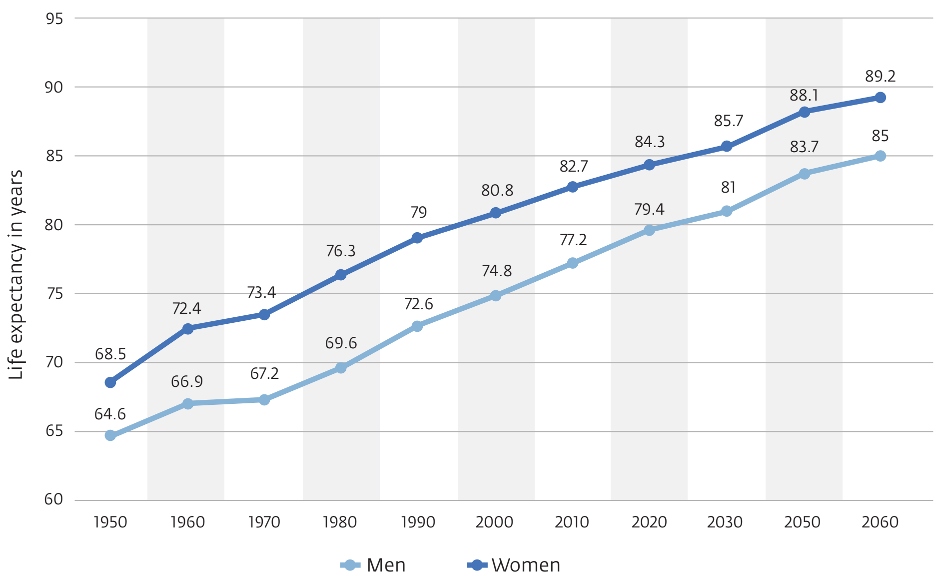
As a lawyer, Ulrich Becker has entered a legal minefield by focusing on the topic of age. He engaged in a comprehensive investigation of this area of the law in Germany by co-editing a book entitled *Recht der Älteren*, which was published in 2013. Whereas "elder law" has long been well established as a separate field of jurisprudence in the US, Becker was entering uncharted waters in Germany. The areas that specifically concern the elderly include the conditions associated with health insurance and nursing care, the question of self-determination and guardianship, inheritance law, and the legal framework for retirement provisions.

The complexity of this topic is demonstrated by the small sub-field of age limits alone. And what makes it even more difficult is that many of the factors that affect the age issue are in flux. Demographic change is creating major challenges for society and politics. The many factors that are transforming our image of the elderly include new insights into aging and the plasticity of the brain, and the knowledge that the differences between individuals in terms of their physical and mental capacities vary even more with advancing age. At the same time, many citizens would like to maintain the habits and entitlements they have grown to enjoy – despite the fact that the circumstances dictated by reality have long since changed.

Wherever we look – be it in the political, business, religious or cultural

Photo: Christopher Robbins/Thinkstock

The traditional age limit of 65 no longer seems appropriate in a society in which greater value is placed on individual capacity than formal criteria. However, the quest for alternative criteria is proving difficult.



Left: While the life expectancy of women (dark blue) and men (light blue) in Germany continues to rise, the age limits for public office and honorary positions have remained the same for years. People affected by these limits see them as discriminatory.

Right: Ulrich Becker (second from right) discusses the correlations between age, productivity and income with his colleagues Lorena Ossio and Michael Schlegelmilch.

arenas – we can observe people well past retirement age who hold important positions, set trends and assume key responsibilities. The visit of Britain's Queen Elizabeth II (89) to Berlin became a major media event due to, among other things, the large number of events in which she participated. German finance minister Wolfgang Schäuble (72) has for months now been involved in grueling negotiations on the euro with his European colleagues. And Mario Draghi (67) shoulders the responsibility of his role as President of the European Central Bank in an equally self-evident manner.

NEW CONTRACT AT 72

Two years ago, the election of Pope Francis (78) heralded a new era in the Catholic Church, and Daniel Barenboim (72) recently extended his contract as general music director of the Berlin State Opera Unter den Linden until 2022. No one would dream of questioning the abilities of these individuals, much less demand that they retire.

Moreover, numerous age limits have been eliminated in recent years. For example, health insurance companies in Germany will now extend doctors' licenses to practice medicine past their 68th birthday. And the courts are increasingly vindicating claims pursued by plaintiffs in this regard: pursuant to a judgment of the European Court of Justice, Lufthansa pilots can no longer be forced to retire at 60. The German Federal Administrative Court has also declared that maximum age limits for publicly appointed and sworn experts are inadmissible.

However, age limits still apply in other areas of public life: mayors and district administrators in most of Germany's federal states may not be over 60 to 65 when they run for election. As recently as 2013, the Federal Constitutional Court rejected a complaint against a corresponding regulation in Bavaria, stating that the age limit was appropriate "to guarantee the continuous and effective exercise of office, presumably until the end of its regular term." Jurors at district and regional courts must also conclude their voluntary activities at the age of 70, and the office of public notaries ends by law on the holder's 70th birthday.

So why have age limits at all? Wouldn't it be simpler to abolish all limits, as is the case in the US? If you ask Ulrich Becker this question, don't expect to get a quick and simple answer. "Age limits fulfill different functions, and it's essential that we realize this," he says. For example, the imposition of minimum age limits is intended to ensure that people meet certain requirements that are entirely in the public interest. Candidates for the office of Federal President must be at least 40 years of age. The same applies to judges at the Federal Constitutional Court.

Similarly, maximum age limits often serve the purpose of protecting third parties or the public: police officers and firefighters have to retire early, as not only does their work make severe physical demands on them, but the safety of citizens is dependent on their willingness and capacity to do this work. The age limit for the acceptance of new applicants in these professions is correspondingly lower. The reason for this is that the investment made in the training and induction of employees must be worthwhile for employers.

Age limits can also protect the people to whom they apply, if it can be assumed that the exercise of a given pro-

Graphic: German Council of Economic Experts/Statista 2015

fession poses too great a burden on people from a certain age. This is another reason why police officers and firefighters, soldiers and miners are allowed to retire earlier than people in other professions. Such exceptions are expressly provided for in the equality directives and laws.

AN AGING POPULATION IS TESTING THE LIMITS

"All of the regulations governing age limits have one thing in common: they reflect a staircase of life that is familiar to us from previous centuries," explains Ulrich Becker. "The beginning of life is the time for learning, and parents provide for children at this stage. By mid-life, adults are expected to provide for themselves and to assume responsibility in the family, professional and public arenas. And in old age, when elderly people are no longer able to work, the family takes over again, or – since the late 19th century – the state."

This division remains valid today in principle. However, life expectancy has increased by more than 60 percent over the past century. Demographers confirm that, today, the average 70-year-old has the physical and mental capacities a 65-year-old would have had 30 years ago. "With an aging population, age limits generally tend to be too low," concludes Becker. "We should evaluate and adapt the age limits regularly – something we unfortunately do far too seldom."

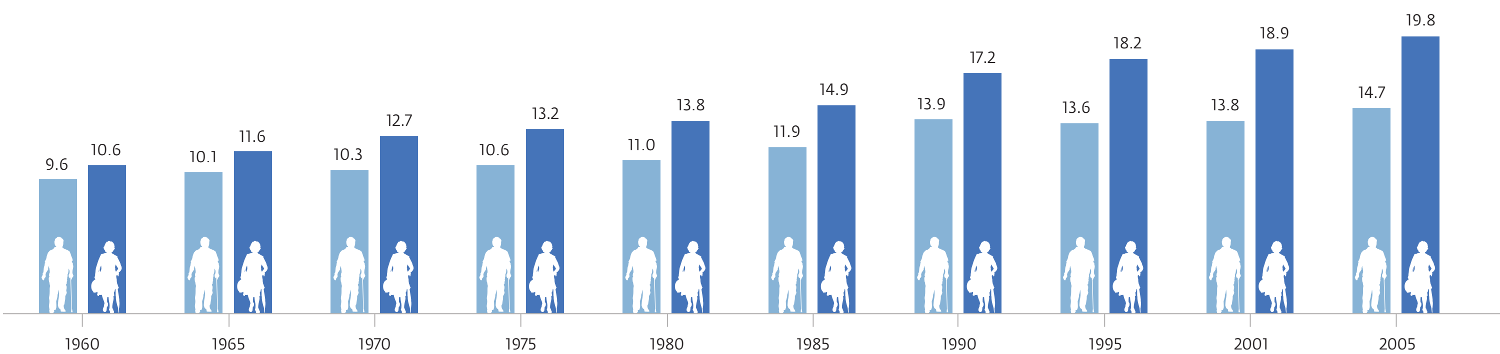
The situation in the area of statutory pension insurance is particularly critical. Pensioners in Germany currently draw their pensions for an average of more than 19 years; in 1960, they drew them for 10 years. Despite this, any reforms aimed at delaying the age at which pension payments begin are extremely unpopular. A survey carried out last year by Infratest Dimap revealed that over half of the German population would like to retire at the age of 63. Just under a third are willing to continue working until the normal retirement age, and only 14 percent can imagine continuing to work beyond the standard retirement age limit.

The degree to which pension rights shape our attitudes toward work is remarkable: while young people who don't work are accused of living at the expense of the community, once the effective date for retirement arrives, attitudes change radically. This also has a particular impact on our self-image: prior to retirement, many of us define ourselves through our profession, and draw a considerable share of our sense of self-worth from gainful employment. People don't change radically after retirement – whether physically, mentally or in terms of character – and yet both retirees and society consider it completely natural that it is no longer necessary to work.

STUDIES DEMONSTRATE THE PRODUCTIVITY OF THE ELDERLY

It's impossible to find any empirical evidence in support of the argument that older people are less productive than their younger counterparts and, accordingly, from an economic perspective alone, should retire sooner rather than later. Studies have been carried out on this topic at the Munich Center for the Economics of Aging (MEA), the second department of the Max Planck Institute for Social Law and Social Policy, headed by Axel Börsch-Supan. According to the findings of these studies, the performance of teams involving older em-

Photo: Axel Griesch



ployees is exactly the same as those composed of younger employees. Moreover, this was observed to be the case both in manufacturing industries and in the service sector.

The argument that older employees should withdraw from professional life so as to remain fit longer is equally untenable from a scientific perspective. On the contrary: early retirees tend to undergo more rapid mental decline than people of the same age who work longer. According to Axel Börsch-Supan, one reason for this could be that the workplace is also an important pillar of social life: even the company of colleagues of whom we're not particularly fond appears to be better than social isolation, as it provides cognitive challenges that keep our minds active and healthy.

So why are we so reluctant to abolish the clear dividing line between working life and retirement? Ulrich Becker attributes this phenomenon to the symbolic function of the retirement age limit. He sees its origin in historical developments: starting in 1891, Germany's first statutory pension insurance provided a disability pension in the case of incapacity to work, and an old-age pension from the age of 70 – for a 60-hour week and just a few days of vacation per year, which was the norm at the time.

"In reality, people were actually unable to work at 70 in those days," says Becker. In 1916, the age limit was reduced to 65, as was already the case in many other countries. In 1952, the International Labor Organization adopted 65 as a suitable age for retirement – despite the fact that life expectancy had already increased considerably by then.

"With this step, we distanced ourselves from the basic idea that the pension was intended to compensate for the loss of the capacity to work," says Ulrich Becker. "The retirement age was decoupled from the staircase of life." Instead, the age was defined up to which the individual had to provide for him or herself and after which society assumes responsibility. "That's the problem we now face if we raise the limit again in the 21st century," explains Becker. "The pension eligibility age has taken on a life of its own and has established a pattern of behavior in our minds – and we gradually need to let go of this now." It's a difficult parting – particularly because the age-65 limit was never carved in stone.

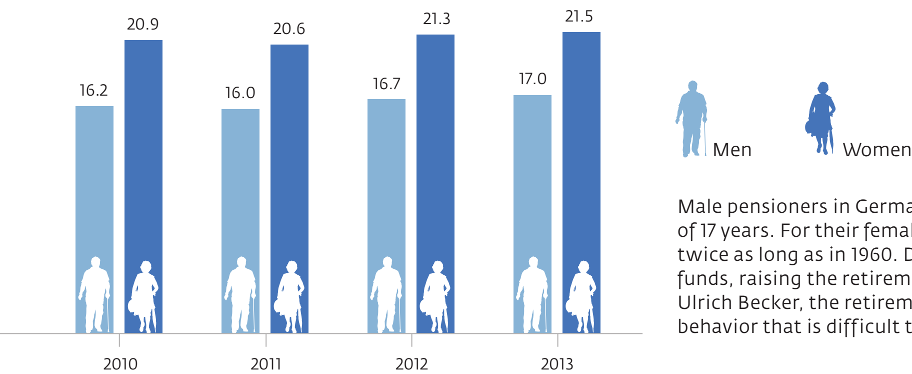
THE SHIFTING COURSE OF PENSION POLICY

In terms of retirement age, policy has followed a shifting course in recent decades. In the late 1980s, early retirement programs were introduced so that older workers could withdraw from the workforce and free up jobs for younger people. However, such programs proved largely ineffective in terms of their impact on the labor market, as companies used early retirement as a tool for cutting jobs during economically difficult times.

After the turn of the century, it became increasingly clear that pension insurance was unable to keep pace with demographic change. In 2008, the German government decided on the incremental introduction of a pensionable age of 67. Last year, however, a backwards step was taken with the introduction of pension eligibility for people with many years of insurance contributions, enabling people in at least some age groups to retire at 63.

The idea behind linking the start of retirement with the duration of social insurance contributions could offer an alternative to the traditional age limit. In Becker's view, however, this variant is – at least in its current form – not expedient: "Showing people that they don't have to work until 65, let alone 67, is sending the wrong signal."

Another possibility would be the introduction of individual tests starting at a certain age to ascertain whether specific people are healthy and capable enough to continue practicing their profession. In our individualized society, it would seem entirely fitting to judge people on the basis of, not their age, but their personal constitution. However, Ulrich Becker sees a serious disadvantage in this solution: "This



Male pensioners in Germany today enjoy an average retirement period of 17 years. For their female counterparts, retirement lasts over 21 years – twice as long as in 1960. Despite the corresponding burden on pension funds, raising the retirement age is extremely unpopular. According to Ulrich Becker, the retirement age limit has established a pattern of behavior that is difficult to change.

Graphic: designergold, based on original material from the Cologne Institute for Economic Research/2015 IW Medien

could be rather unpleasant for some individuals. Imagine you are told that your performance is declining and you're no longer able to do the job you have performed up to now."

Moreover, clear limits guarantee a certain level of predictability and allow for planning – not only in terms of pension insurance, but also for employers, for example. Ulrich Becker also considers this side of the coin: "The issue of retirement age also concerns how we regulate working conditions, namely: When does an employment relationship end? Up to now, the answer was: At the standard retirement age. This is stipulated in many collective wage agreements, for example."

If there were no age limit, employees could end their working lives at any time. However, employers wouldn't be able to make sensible plans and would possibly have to employ people for years who are no longer in full possession of their faculties.

"That's the reason why the age limit can't simply be abolished in Germany, as was done in the US: employers there can dismiss employees easily and quickly. Here in Germany, however, there's very strong protection against dismissal. And this is considered a great asset," says the Max Planck researcher. If we want to flexibly extend working life here in Germany – which would also make sense in Ulrich Becker's view – we would need special regulations so that those who would like to continue to work would have the option of doing so without complications.

BALANCE BETWEEN WORKING LIFE AND RETIREMENT

Becker wouldn't be in favor of any major changes to dismissal protection. Instead, he can imagine a system involving temporary contracts for older people. This, however, would involve the inclusion of the "age" criterion in the law as a reason for limiting the duration of employment. "Or you could model dismissal protection on the staircase of life," suggests Becker. "That is, make it more difficult to dismiss younger workers than older ones. But as you can see, here, too, it's simply impossible to get around the task of setting an age limit somewhere."

Ulrich Becker's ideas make one thing clear: especially in the area of social law, seemingly simple solutions, such as the abolition of age limits, are quickly doomed to fail when confronted with reality. Becker advises, in all of the debates, to not lose sight of the most essential aspect: "When someone retires, they should be protected against poverty in old age." The second factor is that, based on demographic change, we now have to provide for ourselves for a longer period. Becker seeks a balance here between the sometimes extreme positions in the pension debate.

"We are currently moving closer to the original intention that pensions secure people's means of subsistence when they are no longer able to work," says the scientist. "But we don't want to go back to a situation where people work until they collapse. We would like people to be able to enjoy their retirement – just not for too long." The trick here is to find a new balance between working life and retirement that meets the needs of the individual. ◂

TO THE POINT

- **Due to the rise in life expectancy and the increasing fitness of people between their mid-60s and mid-70s, many of the age limits defined up to now are too low.**
- **However, raising the retirement age is unpopular because, for many decades, the retirement age limit has marked the point at which it is socially acceptable to no longer work.**
- **Abolishing traditional age limits and introducing new alternatives is a legally complex process.**

Late Risers Are Cheated On More Frequently

Daily rhythm influences fatherhood in great tits

Sleeping in is more enjoyable, but it also lowers reproductive success – at least if you are a great tit. Researchers at the Max Planck Institute for Ornithology in Seewiesen and Radolfzell discovered that male great tits that rise later than their conspecifics are cheated on more frequently by their female mates. The researchers used mini-transmitters to monitor when the animals wake up in the morning. Also, under the skin of some of the males, they placed a small implant containing melatonin, a hormone that plays a major role in regulating the internal clock. As a result, birds that received a melatonin implant woke up later. Thus, instead of waking up early and defending their female against competitors, the males with the implant were still sleeping soundly while their mates amused themselves with other males. Many of the chicks in the nests were therefore the offspring of other males.

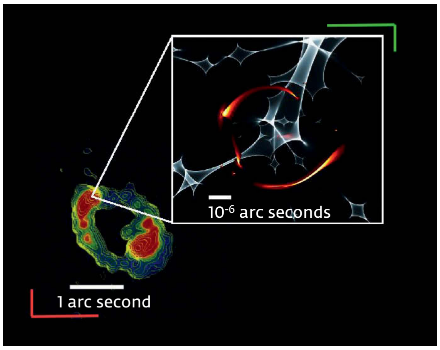
(FUNCTIONAL ECOLOGY, June 3, 2015)

A transmitter on the back of the great tit tells the researchers when the animal wakes up in the morning.

A Black Hole under the Gravitational Lens

Turbulent processes take place close to supermassive black holes, which lurk in the centers of nearly all galaxies. These massive monsters swallow up matter flowing in from the outside while at the same time producing gas jets that shoot out into space in two opposite directions. Researchers at the Max Planck Institute for Physics in Munich and the University of Geneva have now succeeded in localizing the origin of the high-energy gamma radiation in such a jet. To achieve this, the researchers observed an active galaxy known as PKS 1830-211, in which one of the two jets happens to be directed toward Earth. In addition, roughly half way between this blazar and Earth, there is a galaxy that acts as a gravitational lens, amplifying the light. The scientists conclude from the effects they observed that the registered gamma radiation originates from a compact region measuring just a few billion kilometers, and is generated very close to the black hole, or essentially at the foot of the jet.

(NATURE PHYSICS, published online, July 6, 2015)



Looking at a distant galaxy: The radio chart (bottom left) shows the image of the blazar PKS 1830-211 distorted by the gravitational lens effect. The detail on the right is a simulation of the micro-gravitational lens effect in the gamma ray region; direct observation of the orange ring – it also represents images of the blazar – isn't possible due to its small size.

Alzheimer's Spares Long-Term Musical Memory

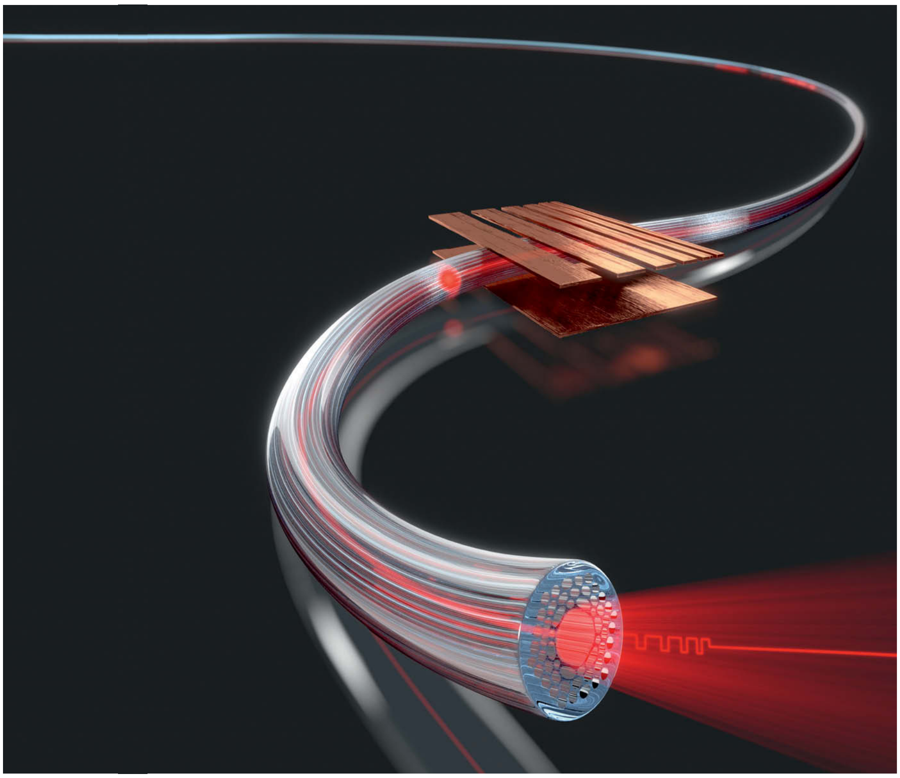
Alzheimer's erases a large part of patients' memory. The disease seems to spare only musical memory, as Alzheimer's patients can often recall musical pieces even when other memories have already faded. In some cases, they are able to sing lyrics of songs even when speaking has become almost impossible for them. Scientists at the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig wanted to know why musical memory is less affected by Alzheimer's. To this end, they first had to locate the seat of musical memory in the brain. The researchers played top-10 hits, children's songs, oldies and well known classical pieces to Alzheimer's patients while using magnetic resonance imaging to measure their brain activity. In this way, they identified the so-called supplementary motor cerebral cortex as the seat of long-term musical memory. Analyses of the brains of Alzheimer's patients show that this region is less affected by the disease: it loses fewer neurons than the other brain regions, and its metabolism doesn't decline as much.

(BRAIN, June 3, 2015)

Photos: Timothy Greives (top), Patnaik et al. 1994, Liege Conference on Gravitational Lenses and the Universe/Vovk (bottom)

A Multi-Purpose Sensor

A flying microbead in a hollow glass fiber measures temperature, vibrations and electric fields with high spatial resolution



Glass fibers can do more than transport data. A special type of glass fiber can also be used as a high-precision multi-purpose sensor, as researchers at the Max Planck Institute for the Science of Light in Erlangen have now demonstrated. The researchers sent a tiny glass bead through the interior of these photonic crystal fibers. The movement of the bead is influenced by different physical quantities, such as electric field, temperature and vibrations, and a laser is used to measure how the bead's path changes. The flying particle detects the quantities to be measured over long distances with high spatial precision, even under harsh conditions. The sensor fiber, which currently has a length of up to 400 meters, could help detect damage to high-voltage lines. (Nature Photonics, published online, June 8, 2015)

Measured in flight: A microbead that flies through the hollow channel in the interior of a photonic crystal fiber measures different physical quantities, such as the electric field of electrodes.

The Neanderthal in Us

A bone found in Romania reveals interbreeding among early modern humans in Europe

Neanderthals became extinct about 40,000 years ago, but they contributed on average 1 to 3 percent to the genomes of present-day humans from Europe and Asia. The two types of humans probably mixed with each other in the Middle East around 50,000 to 60,000 years ago, when modern humans left Africa and spread into the rest of the world. However, the intermingling could also have taken place in Europe, as modern humans and Neanderthals lived together there for up to 5,000 years. An international team of scientists that includes researchers from the Max Planck Institute for Evolutionary Anthropology have now found 6 to 9 percent Neanderthal DNA in a 37,000- to 42,000-year-old human mandible from Oase Cave in Romania. That's more than for any other human sequenced to date. Because large segments of the chromosomes are of Neanderthal origin, this individual must have had a Neanderthal in his family tree as recently as four to six generations back. However, the human from Oase Cave evidently has no direct descendants in present-day Europe. Consequently, some of the first modern humans mixed with the local Neanderthals in Europe, but then became extinct.
(Nature, June 22, 2015)

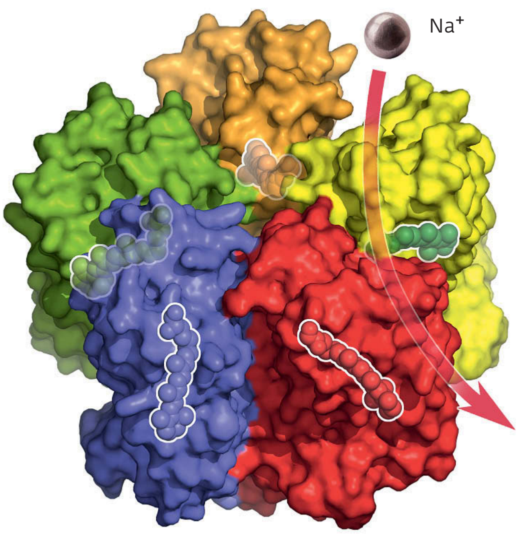
Part modern human, part Neanderthal: The 40,000-year-old mandible belonged to a modern human with Neanderthal ancestors.

Photos: Luca Fiorentini (top), MPI for Evolutionary Anthropology/Svante Pääbo (bottom)

A Switch for Neurons

The light-driven ion pump KR2 transports sodium ions out of neurons

Sometimes, the path from ocean floor to tool for brain research is a short one. A case in point: the ion pump KR2, which scientists discovered two years ago in the cell wall of the marine bacterium *Krokinobacter eikastus*. KR2 is a light-sensitive protein that transports positively charged sodium ions out of the cell. Scientists can integrate these ion transporters into the neuronal membrane, making it possible to control their activity using light impulses – a neuroscientific method that is known as optogenetics. A pump such as KR2 is a feature that was previously missing in the optogenetics toolkit. An international team of researchers has now uncovered the atomic structure of KR2. Together with researchers at the Max Planck Institute of Biophysics in Frankfurt, they also discovered that exchanging one amino acid turns KR2 from a sodium pump into a potassium pump. Neuroscientists could thus use the protein as a very effective off-switch for neurons, as outflowing potassium ions deactivate neurons. In combination with Channelrhodopsin-2, a light-activated channel through which sodium and calcium ions flow into the cell, the potassium pump would form a perfect pair of tools for precisely switching neurons on and off. (NATURE STRUCTURAL & MOLECULAR BIOLOGY, April 6, 2015)

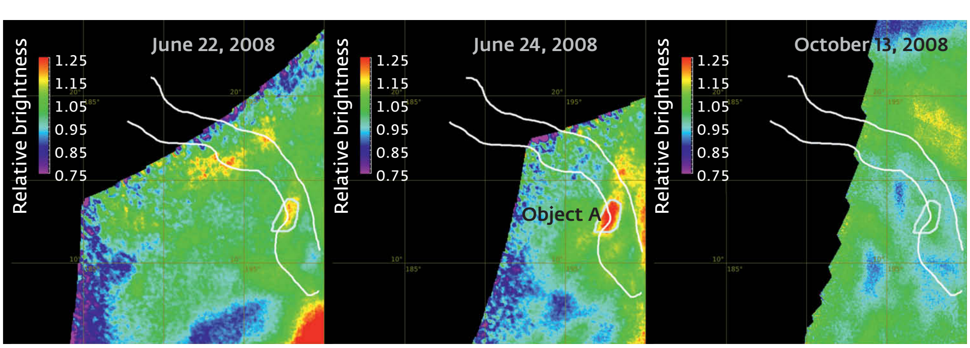


The KR2 complex, viewed from the side. Each of the five KR2 molecules binds and transports a sodium ion (purple). The pump activity is controlled by the small, light-activated retinal molecules (outlined in white).

Hot Lava Flows on Venus

Using a camera on board the *Venus Express* space probe, scientists discover strong evidence of active volcanism

Venus is considered to be Earth's sister: the two planets are nearly identical in size and have similar interior compositions. Scientists thus consider it likely that our neighbor has a hot core. This heat has to escape somehow, and one possibility is that it does so in the form of volcanic eruptions. For instance, a cataclysmic flood of lava may have completely changed the surface of Venus around 500 million years ago. But is the planet still volcanically active today? An international team headed by the Max Planck Institute for Solar System Research has now presented the best evidence to date that it is. The scientists analyzed measurement data from the ESA's *Venus Express* space probe and identified, on photos taken in 2008, four regions whose temperatures had increased drastically within just a few days. The team estimated that the smallest of these hotspots measures approximately one square kilometer and has a temperature of around 830 degrees Celsius. For comparison, the global average surface temperature is 480 degrees Celsius. (GEOPHYSICAL RESEARCH LETTERS, published online, May 2015)



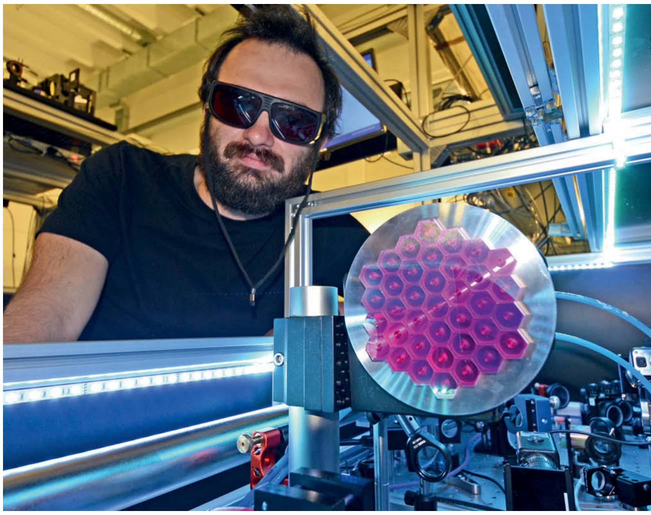
Tracks on the surface: The maps show changes in relative brightness in the Atla region, where the Ganiki Chasma rift zone is located. The images were captured on three different days. Red and orange indicate an increase, blue and green a decrease in brightness. One area, "Object A," shows a distinct increase on June 24, 2008.

Photos: Forschungszentrum Jülich/IBS Grenoble (top), E. Shalygin et al. (2015) (bottom)

A New X-Ray Source for Medicine

A light source for hard, brilliant X-rays makes even tiny structures in material visible

Bone fractures, tumors or arteriosclerosis – doctors today use X-ray examinations to detect numerous diseases. And X-ray images could soon provide even more information. Physicists at Ludwig-Maximilians-Universität (LMU) in Munich and the Max Planck Institute of Quantum Optics are now producing particularly brilliant X-ray light with sharply defined but variable wavelengths in a relatively compact device. They use extremely intense laser pulses to force electrons from gaseous hydrogen atoms onto a wave band, causing the particles to emit the desired light. This X-ray radiation makes it possible to resolve structures measuring little more than 10 micrometers and having various compositions – and this can be done not only in the field of medicine, but also in biology and materials science. Previously, radiation of the quality needed for this could only be produced in large and expensive synchrotron facilities. (Physical Review Letters, May 14, 2015)



Using laser light to produce X-ray flashes: Konstantin Khrennikov and his colleagues use the ATLAS laser system at Ludwig-Maximilians-Universität to produce brilliant X-ray light.

Shorter Lives for the Bold

Differences in personality influence survival in field crickets

A cricket in front of its burrow. For identification, the researchers marked it with a painted spot on its back.

Humans have a distinct personality: they are fearful, bold, cautious or adventurous. Animals have these traits, too. Researchers at the Max Planck Institute for Ornithology in Seewiesen have now found differences in risk behavior, and thus potentially different personalities, among individuals in a population of wild field crickets. They marked all crickets within a fenced-in meadow area and studied their behavior. One criterion for risk tolerance was the minimum distance at which the animals initiate escape when a potential threat approaches. The analyses showed that the crickets vary widely in their individual flight initiation distance and how far they are willing to venture from their burrows. It's not yet entirely clear whether boldness offers advantages with regard to searching for food or a partner, but it definitely also has disadvantages: bold field crickets die younger than less daring individuals, as predators such as shrews and birds prey on them more frequently. (Behavioral Ecology, April 22, 2015)

Photos: Thorsten Naeser (top), MPI for Ornithology/ P. Niemelä (bottom)

In Sync with the Leader

A person who says the right thing at the right time frequently becomes the leader of a group

Great leaders are often also great communicators. A special connection develops between leaders and their followers: according to scientists at the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig, the leader's so-called temporoparietal junction between the temporal and parietal lobes of the cerebral cortex begins to synchronize with the same brain region in their followers. In other words, the rhythms of the leader's and the group's brain activity begin to match.

The temporoparietal junction is important for empathy and for understanding others' mental states. Based on the brain activity, the Max Planck researchers even predicted who a group would elect as its leader, and when. According to their findings, the synchronization of the brain activity is based more on leaders' communication skills and less on how much they talk. The researchers therefore conclude that, among a group of peers, the individual who says the right thing at the right time usually emerges as the leader. (PNAS, March 23, 2015)

Diversity in Bloom

The forests of the Indo-Pacific region are as rich in tree species as the tropics in the Americas

There may be more species in the tropical forests of the world than previously thought, namely between 40,000 and 53,000. This was determined by an international team, of which Florian Wittmann, a researcher at the Max Planck Institute for Chemistry, was also a member, through counts at 207 locations in 43 countries, and subsequent extrapolations. Various estimates of the number of tropical tree species previously ranged between 37,000 and 50,000 species. The new result thus ranges in the upper end of these assumptions. What surprised the researchers most in the current study was that they found just as many tree species – 19,000 to 25,000 – in the tropical forests of the Indo-Pacific region as in the forests of Central and South America. They had previously assumed that the number of species there would be much lower. By comparison, there are just 124 different tree species in Central Europe. Florian Wittmann assumes that the current survey can serve as the basis for protection programs.

(Proceedings of the National Academy of Sciences, June 1, 2015)

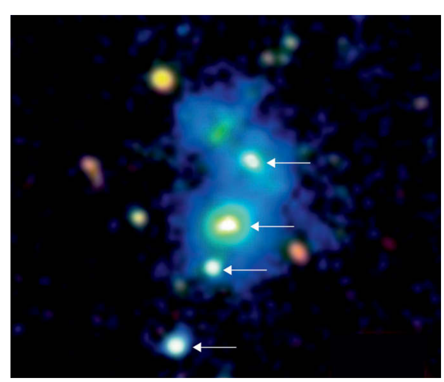
Riverbanks in the Brazilian rainforest are characterized by many different tree species. The forests of the Indo-Pacific region are just as rich in species as the American tropics.

Quasar Quartet Puzzles Scientists

Astronomers must rethink models of the development of large-scale cosmic structures

A quasar is like a cosmic power plant that is driven by the impact of matter on a massive black hole. The active stage lasts only about 10 million years. In this phase, such a galaxy nucleus is among the brightest objects in the universe. Now, using the 10-meter Keck telescope, astronomers working with Joseph Hennawi from the Max Planck Institute for Astronomy have discovered not just one, but four quasars in direct proximity to one another. The quartet resides in one of the most massive structures ever discovered in outer space, and is surrounded by a giant cloud of cool gas – the Jackpot Nebula. Its properties don't match at all with how scientists imagined the early universe. For instance, the models predict that massive structures from that time should be filled with extremely rarefied gas and have temperatures of around 10 million degrees. The gas in the Jackpot Nebula, by comparison, is a thousand times denser and a thousand times colder.

(Science, May 15, 2015)



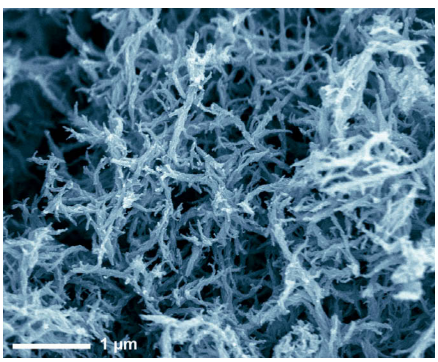
Rare find: This image shows the region in space with the quadruple quasars. The four quasars are indicated by arrows. The nebula in which the quasars are embedded is visible as a hazy, bluish structure. It has an expanse of around one million light-years. The quasars and nebula are so far away that their light takes about ten billion years to reach Earth.

Photos: Michael Welling/MPI for Chemistry (top), Arrigoni-Battaia & Hennawi/MPI for Astronomy (bottom)

Customized Carbon

Nanoparticles made from carbon could be used to store gases, or to produce hydrogen – scientists at the Max Planck Institute of Colloids and Interfaces in Golm, near Potsdam, can now give them the appropriate form and chemical composition for these uses. The researchers selectively produce nanoparticles having a spherical, sheet-like or fibrous structure by injecting various organic – that is, carbonaceous – liquids into a hot salt melt, such as zinc chloride. If necessary, they can incorporate metal or other foreign atoms into the particles by introducing appropriate substances. For technical applications, the versatile recipe is useful for synthesizing the nanoparticles, because their properties are highly dependent on their structure and composition. Until now, carbon nanostructures were produced by carbonizing solid substances, but this produces only spherical particles. Carbonizing liquids was deemed to be impossible. Initial tests showed that nickel-containing nanostructures created in this way are useful as catalysts for the electrolytic production of hydrogen from water. And they're more cost-effective than the noble-metal-based catalysts currently used for this. In some nanostructures, the researchers were also able to store large quantities of gas in relation to the mass of the nanoparticles.

(Angewandte Chemie International Edition, published online, March 4, 2015)

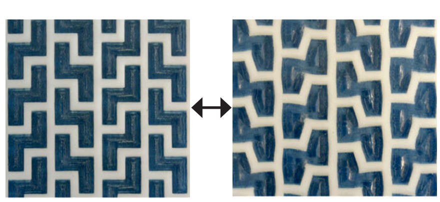


Fibrous and other nanostructures can be selectively produced by carbonizing various organic solvents in hot salt melts.

Actuators That Mimic Ice Plants

Engineers developing moveable robot components may soon take advantage of a trick that plants use. Researchers at the Max Planck Institute of Colloids and Interfaces in Potsdam and Harvard University in Cambridge (USA) have now presented a polymer material with a cellular structure that could be used as an actuator – that is, an actively movable component. The cells are designed in such a way that, when they are swelled by a liquid or compressed air, the structure expands in only one direction. In this way, the researchers mimic the purely physical mechanism by which the coverings of ice plant seed capsules open and close. The researchers at the Max Planck Institute of Colloids and Interfaces had clarified this movement mechanism in 2011. Movable components based on a similar design as the newly presented actuators could give robots particularly natural movement properties.

(Advanced Materials Interfaces, June 26, 2015)



The actuator developed by the Max Planck researchers consists of polymer cells made of non-swellable walls and a swellable interior. When the chambers absorb a liquid, the structure expands in one direction.

Photos: MPI of Colloids and Interfaces (top), Advanced Materials Interfaces / MPIKG (bottom)

Gene Pattern Betrays the Culprit

After an infection with *Helicobacter pylori*, gene activity in the gastric cells resembles the activity of cancer cells

Around half of the global population is chronically infected with the stomach bacterium *Helicobacter pylori*. Around 1 percent go on to develop gastric adenocarcinoma – one of the deadliest forms of cancer. *Helicobacter pylori* can contribute to the development of stomach cancer. Scientists at the Max Planck Institute for Infection Biology in Berlin have now analyzed the genetic changes that occur in the genome of gastric cells soon after a Helicobacter infection.

Whereas cancer-causing radiation or chemicals cause random DNA damage, according to the scientists in Berlin, this pathogen damages the genome in a specific pattern. Over the course of the infection, *Helicobacter* turns off several genes that repair DNA segments. The researchers also determined that particularly active genes and genes located in regions near the edges of chromosomes are more likely than other genes to be damaged after infection. This mutation pattern resembles that of stomach cancer, underscoring the fact that *Helicobacter* plays a role in the development of this form of cancer.

The only other cancer that shows a similar genetic fingerprint is prostate cancer. The development of this type of cancer also involves a bacterium, *Propionibacterium acnes*. Genetic fingerprints of infections may thus even provide indications for bacterial pathogens as the cause of other cancers.

(Cell Reports, June 11, 2015)

The **Spin Doctor**

This physicist changed our world: It was **Stuart Parkin**'s developments in spintronics that first made Facebook and Google possible, as well as many other computer applications without which our everyday lives are now barely conceivable. Parkin has been Director at the **Max Planck Institute of Microstructure Physics** in Halle for one year now. For his colleagues there, his energy is impressive and challenging in equal measure.

TEXT **PETER HERGERSBERG**

The profession of physicist isn't generally regarded as physical labor. Still, Stuart Parkin doesn't need sports for recreation – he's almost constantly in motion. Like when, in May 2014, the Technology Academy Finland awarded him the Millennium Technology Prize – the world's highest-endowed technology prize, worth one million euros – and Parkin gave a speech for the occasion. He impressed the audience not only with his innovations for memory storage technology, but also with the route he took to get on stage: ceaselessly taking a couple steps forward, a couple steps back, then a slight detour to the table with the water glass, and onward again.

His hands, too, are always in motion. Sometimes one hand is making drawings in the air of the layer materials he developed, sometimes the other hand uses sweeping gestures to point to an image in his slides or to a particularly important statement, and sometimes both hands appear to be pulling down on a non-existent rope. As spry as he is, the gaunt figure is no surprise – he could also pass for a long-distance runner.

When Parkin spoke in Helsinki, he had been Director at the Max Planck Institute of Microstructure Physics and a professor at Martin Luther University of Halle-Wittenberg for a good month. Today, he can already look back on numerous scientific and technological successes. It is thanks to his discoveries that we can now store ever increasing amounts of information in an ever smaller space. "This makes it possible for us to use Facebook and Google," says the physicist. "Big data, too, is possible only because we can now store large amounts of data on relatively cheap devices."

Before Parkin explains in greater detail what he contributed to today's high-performance computers, he briefly outlines his background and shows some photos of the most important stages: "As a child, I always wanted to go to Cambridge, because of Isaac Newton – you've probably heard of him," says the Brit, who was born in Watford,

Dynamic – this is one characteristic Max Planck Director Claudia Felser uses to describe her husband Stuart Parkin. Even for a photo shoot, he hardly stands still.

Photos: Sven Döring (3)

Lively: The Construction Commission discusses the progress of the remodeling of the lab and workspaces in Stuart Parkin's Department.

not far from London. "Newton was both a student and a fellow at Trinity College – as was I."

After that, Parkin worked at the Paris-Sud University on organic superconductors. These are carbon-based materials that conduct electricity without resistance. Initially, he continued this research in 1982, after relocating to IBM's Almaden Research Center in San José, California. Since then, he has not only been appointed to various honorary and visiting professorships, but also as a consulting professor at Stanford University and as an IBM Fellow.

And now Halle an der Saale. Before presenting a photo of the Max Planck Institute of Microstructure Physics, he shows one of himself with his then fiancée – now wife – who is almost completely hidden behind a lavish bouquet of various orange-colored blossoms: Claudia Felser, Director at the Max Planck Institute for the Chemical Physics of Solids. "We're both very interested in materials," says Parkin. "She's the reason I'm going to Germany."

This is not something to be taken for granted – Claudia Felser characterizes him with these words: "Stuart is energetic and dynamic, and his first priority is science." She has no problem with this – on the contrary: it simplifies a lot of things, as she is quite similar. The liaison was thus initially also a professional one before it became a private one. Claudia Felser researches magnetic materials that could be used for Stuart Parkin's developments in electronics, or more accurately, in spintronics.

THE SPIN VALVE AS A SENSITIVE MAGNETIC SENSOR

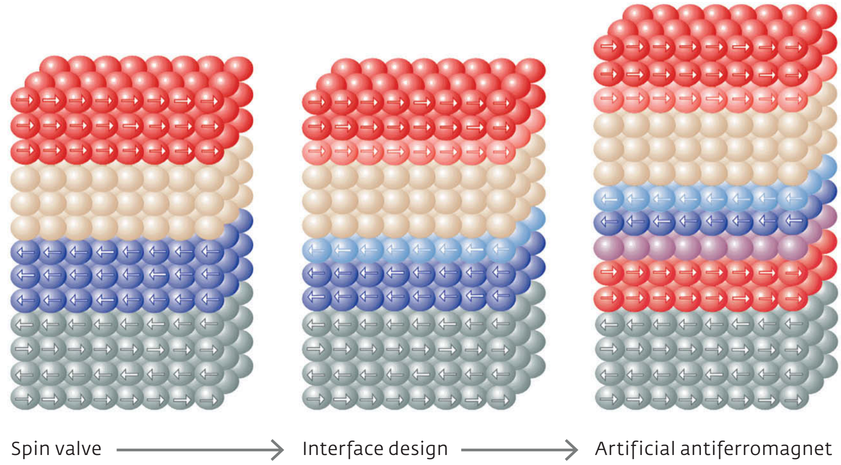
Spintronics takes advantage of not only the charge of electrons, but also their spin. The spin is a quantum mechanical property of electrons that turns each of these elementary particles into a tiny bar magnet. It can take on only two directions. In fact, it is due to the spins of countless electrons in a bar magnet – like those we know from physics lessons – that its ends can be only north or south poles. But the orientation of the spins also determines which data bit is stored in a magnetic islet that serves as the memory point on a hard drive.

Parkin is considered to be one of the pioneers of spintronics, not least due to what is perhaps his most relevant development to date: the spin valve, which is used in every hard drive today to read data.

In order to then also be able to decipher a data bit on a hard drive when the magnetic islands of individual memory points and thus their fields are extremely tiny, a particularly sensitive sensor is needed. This is precisely what the spin valve provides. The giant magnetoresistance that this magnetic sensor uses was discovered by Peter Grünberg and Albert Fert, who were awarded the Nobel Prize in Physics for it in 2007.

Grünberg and Fert noticed that the electrical resistance of sandwiches in which magnetic and non-magnetic materials are layered alternately drops dramatically when the sandwich is exposed to a strong magnetic field. "It wasn't immediately clear whether it

Photo: Sven Döring



Stacked: A spin valve consists of two magnetic cobalt layers (red and blue) and a non-magnetic copper layer (beige). An antiferromagnetic substrate (gray) serves to fix the polarity of the one cobalt layer. (The arrows symbolize the spin directions of the atoms.) But it is only through careful design of the interfaces (light red and light blue) and an artificial antiferromagnet that the spin valve becomes useful as the read head for hard drives. The artificial antiferromagnet is created by feeding one or two atomic layers of ruthenium (pink) into the bottom cobalt layer. The artificial antiferromagnet prevents antiferromagnetic coupling with the top cobalt layer.

would be possible to use the effect in technology," says Parkin.

Grünberg and Fert first observed giant magnetoresistance only in a layered material of iron and chrome that they produced using a rather exotic and elaborate technique. Moreover, the resistance changed most dramatically at low temperatures and very high magnetic fields. Thus, the phenomenon wasn't yet suitable for practical application. "The suggestions Peter Grünberg and Albert Fert made for a read head didn't work," says Parkin. He stepped up to change that.

In his lab at IBM's Almaden Research Center in San José, he discovered that the effect also occurs in other metal compositions, for instance in sandwiches composed of cobalt and copper. And that this was also true if the metals are produced using the more practical technique of sputter deposition. This discovery was spawned by necessity: "When I was there, IBM built an expensive molecular beam epitaxy facility like the one Grünberg and Fert used," says the physicist. "But the facility came with a new colleague, and then that was his equipment, so for me there was only enough money left for a small sputter system."

Of course sputter deposition doesn't create such beautiful crystalline structures, but that doesn't diminish the effect at all. And above all, this method is suitable for mass production of layer materials because it's much faster and it's very easy to layer different materials on top of one another.

But that was just one of the discoveries that helped put giant magnetoresistance in today's hard drives. Since the material sandwiches could now be produced so easily, Parkin tested all possible material combinations. And lo and behold, with a combination of cobalt and copper instead of iron and chrome, the effect also occurs at room temperature – a mandatory requirement for use in PCs.

95 PERCENT OF THE WORLD'S KNOWLEDGE IS STORED DIGITALLY

In addition, Parkin downsized the stack of numerous alternating magnetic and non-magnetic layers to a sandwich comprising just two magnetic cobalt layers and a non-magnetic copper layer. This is what led him to the spin valve. Although its resistance doesn't change as much in a magnetic field as a stack of many layers, this is compensated for by the fact that it changes even in magnetic fields 10,000 times weaker than those that Grünberg and Fert had to apply.

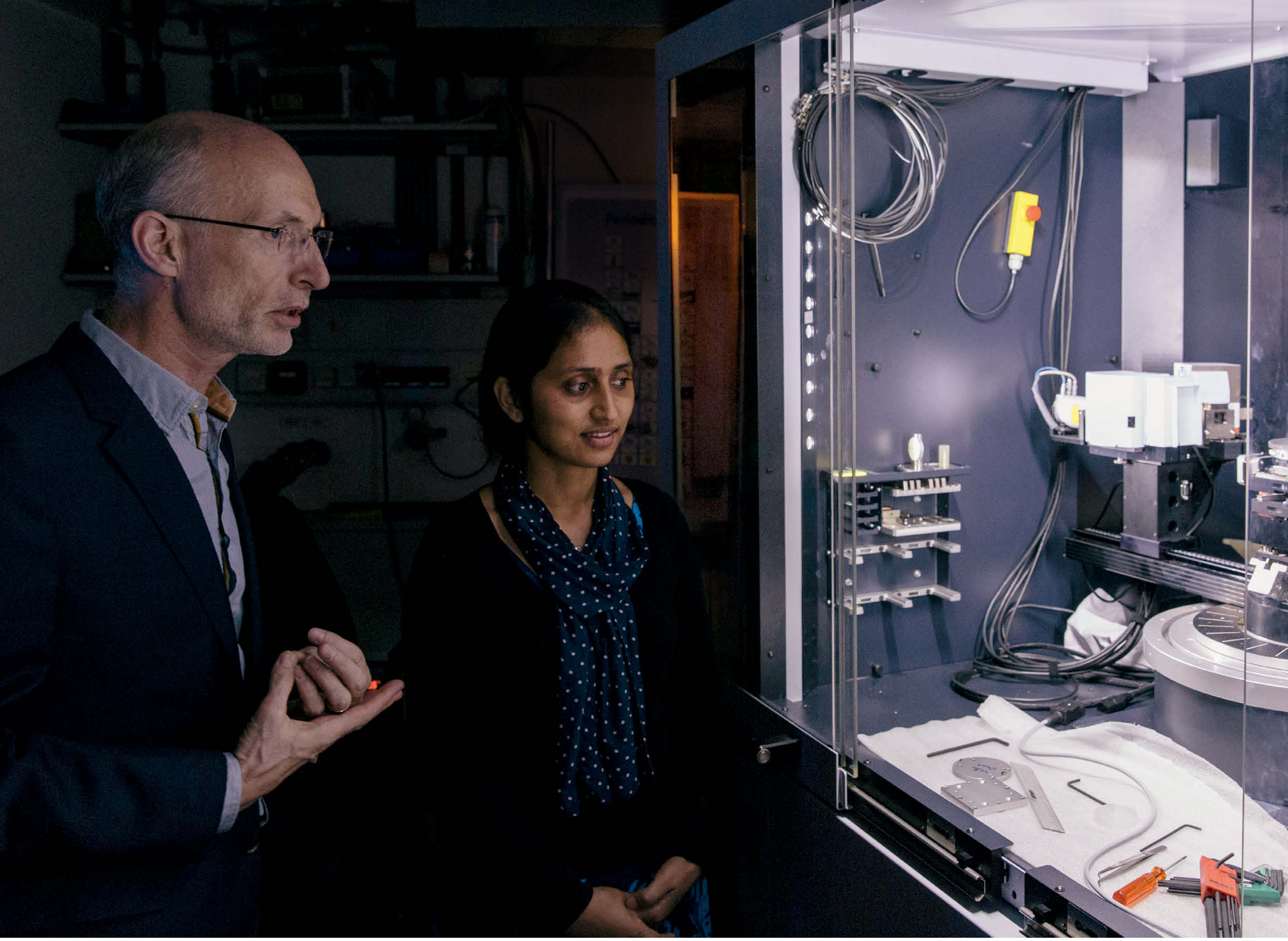
But even in this form, the spin valve still isn't suitable as the read head of a hard drive. In a spin valve that is small enough to scan the tiny memory points on a hard drive, the magnetic layers are so sensitive to each other that, again, they react only to very large external magnetic fields. The magnetic islands on a hard drive can't make a mark here. But Parkin discovered further idiosyncrasies in the interaction between magnetic and non-magnetic layers with a thickness of just a few atomic layers. Using these effects, it is possible to sensitize even an atomically thin spin valve to tiny magnetic fields. And it's far from trivial that giant magnetoresistance is effected at the interfaces between the magnetic and non-magnetic layers of the material and not in the interior of the layers.

"So I made the discoveries that make giant magnetoresistance useful," says Parkin confidently. "Our spin valve reacts to such weak magnetic fields that the magnetic regions on a hard drive could be made 1,000 times smaller." It is due in no small part to the fact that this increased storage density considerably that 95 percent of the world's knowledge today is stored digitally. Twenty years ago, it wasn't even 5 percent.

But that's still not enough for Stuart Parkin. During the past several years, he was already working at IBM on the next innovations, not only for increasing storage density, but also for making the information more quickly accessible than is the case with today's hard drives.

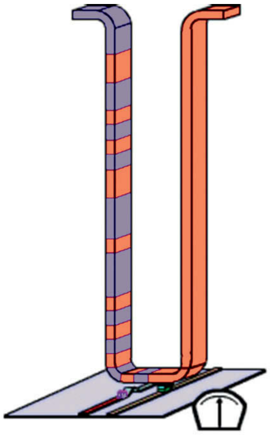
That is the aim of so-called racetrack memory. With this, a read head no longer speeds across the magnetic memory points. Instead, the magnetic regions

Graphic: Parkin et al., Phys. Rev. Lett. (1990), Phys. Rev. B (1991) Parkin, US Patent (1993)



Above: Stuart Parkin and Kumari Gaurav Rana discuss analyses obtained from an X-ray diffractometer. This instrument can be used to analyze the detailed structure of material layers such as those that Stuart Parkin will also be researching in Halle.

Below: In racetrack memory, short current surges push magnetic regions (red and blue zones) through a nanowire to a read head at a fixed location. Since this memory principle requires no moving mechanical parts, it permits faster data readout.



move at speeds of several hundred meters per second through nanowires to a fixed read head. Since there are no longer any moving mechanics, in terms of speed, racetrack memory would beat today's hard drives by a long shot. However, there are still too many defective components being produced today in the manufacture of these delicate magnetic structures. "But all the major computer companies are working on this type of memory," says Stuart Parkin. They could be ready for market in a few years.

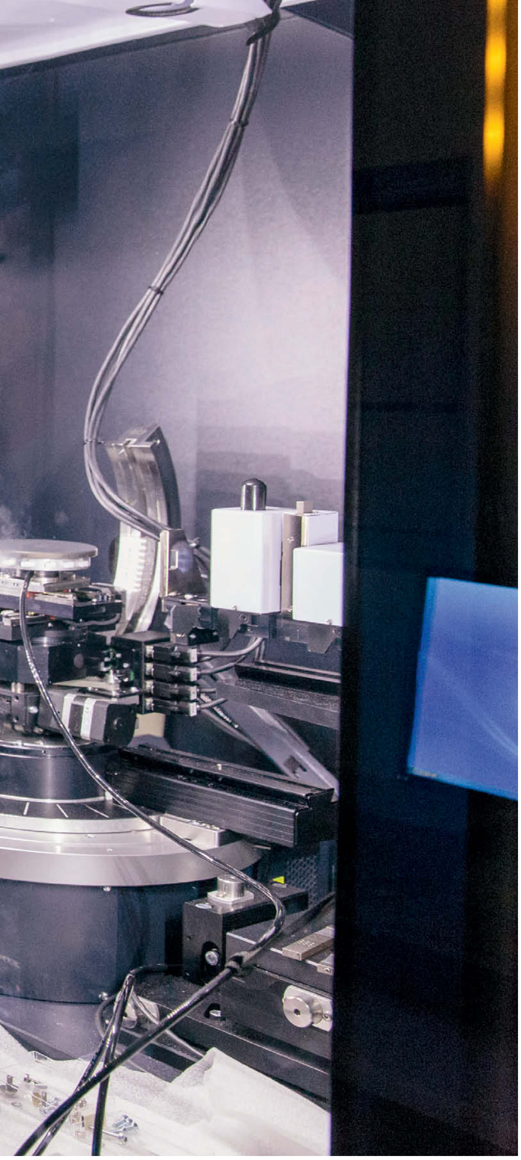
In Halle, Parkin will continue to pursue some of the latest concepts that he already developed while at IBM, but there will be room to develop new ideas, too. He brings the spirit of Silicon Valley to Saxony-Anhalt, says Claudia Felser. But nearly one year later, this inventive spirit is still commuting back and forth between San José and Halle approximately every two weeks. And you can tell that from looking at him this morning, after his return the previous day. "Nice to see you," he says by way of greeting, and adds, with a mixture of impatience and openness: "What are we doing now?"

"IF A PAINTING APPEALS TO ME, I BUY IT"

At this point, he has no time to chat. He hurries to his office; he has various meetings scheduled for this morning, some of which were arranged spontaneously, disrupting his original schedule.

Parkin's office is dominated by a conference table that seats ten. In the background stands a desk, next to which hangs a poster-sized painting of a Buddha's face. He likes art, but has no preference for a specific artist or epoch. "When I see a painting that appeals to me, I buy it," he says. That's why he sometimes takes advantage of his conference trips throughout the world to visit galleries.

Photo: Sven Döring; graphic: Stuart Parkin



Even if he already has a painting to adorn his office in Halle, he can't conduct his research here yet. Various modifications and new construction, as well as some renovations, must be completed first in order to equip the lab in Parkin's Department to meet his expectations. The Construction Commission is meeting to discuss the current planning status. It quickly becomes clear that they're pretty far behind schedule. Parkin is sorry to hear this and says: "I want to start now!" But many building measures can't be carried out as originally planned. In addition, new requirements have been added. With their combined English skills, the construction experts try to explain the problems to Parkin.

Parkin sits up very straight, elbows resting on the table, his ankles crossed under his chair. One foot bounces with a frequency approaching a CPU clock speed. A long time is spent discussing a new water supply, as the cooling water for experiments with magnetic materials can't be contaminated with iron.

Stuart Parkin is becoming familiar with German fire safety regulations and local construction law. When the discussion turns to getting a construction permit from the City of Halle, he interjects jokingly: That won't be a problem, he met the mayor yesterday, he'll take care of that. But of course he knows it's not that simple. For someone who really wants nothing more than to pursue his research ideas, that must be annoying. "But if that's how the rules are, you just have to accept it," he says after the meeting. As high as his standards are for his lab facilities, and as much as he would like to have his department completely set up already, he is also pragmatic.

And when the initial difficulties have been overcome, it should be possible to conduct research with even greater freedom at a Max Planck Institute than in the company lab. "At IBM, you get promoted from one day to the next, and in order to hire additional doctoral students or postdocs, you need funding from other sources that are becoming increasingly difficult to access," he says. "At the Max Planck Institute, I can employ more scientists and engage in more projects." Moreover, the Max Planck Society offers funding and freedom for long-term projects.

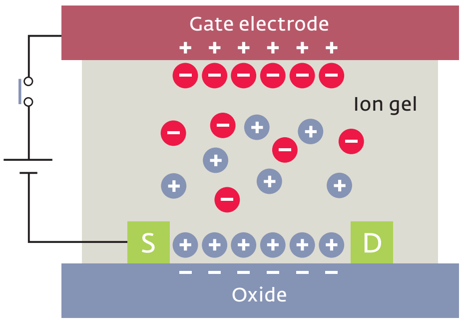
After the Construction Commission has headed home again, taking many unresolved questions with it, it's time for a photo shoot. When Parkin steps out of his office into the institute foyer, he points to the plain gray interior with hanging steel lamps of the same color: "Isn't it ugly?" When no answer is immediately forthcoming, he provides it himself and proclaims, laughing, that he will change a few things here, too. As one who appreciates art, he has high standards for his working environment, not only in terms of practicality, but also with regard to his personal sense of aesthetics.

After a few more meetings in late afternoon, it's time for the conversation for this article. Parkin is supposed to talk about the motivation for his tireless research activities, explain a few more details about his previous work, and outline what his plans are for his new research facility. And because the photographer still doesn't have enough photos, the interview takes place while we take a walk to the river Saale, which runs near the institute.

"THE DETERIORATION IS WHAT GIVES HALLE ITS CHARM"

"Wow, isn't it beautiful here!" Parkin exclaims repeatedly on the walk across Peißnitz Island. And he becomes even more enthusiastic when he realizes that he will cross this park when he makes his way from his future home to the institute on foot or by bicycle. The house he and Claudia Felser are building will be just three kilometers away, on the bank of the Saale. "We agreed that Claudia would move from Dresden to Halle if I come all the way here from California," he says in response to the question of whether Dresden wouldn't also have been an attractive place for the scientist couple to live. But as this walk showed, if it wasn't clear before, Halle, too, has some highly appealing aspects.

During the walk along the Saale, Parkin is particularly taken with the café in Peißnitzhaus, which also lures visitors on this mild April day with a beer garden. Like many of the older buildings in Halle, this small castle, built in the late 19th century, has acquired a patina. That's what Parkin likes: "The certain degree of deterioration one sees here is what gives Halle its charm, I think." >



Information processing like in the human brain: In a transistor that, like neurons, is switched using ions, a small voltage applied to the gate electrode causes ions from an ion gel to be deposited on the gate electrode and on an oxide layer lying opposite. Oxide ions are then released from the oxide, making this layer conductive and allowing a current to flow between the source (S) and drain (D) electrodes.

But as appealing as Halle is, that is, of course, not the reason why he's coming here. Here, he finds the conditions he needs to pursue his many ideas, and not only in spintronics. He wants to develop computers that compute in a similar way to how we think. And that means, above all, as energy efficiently. "The brain of a rat works about as quickly and with the same memory capacity as the supercomputer Blue Gene/L, but needs only one ten-millionth of the energy."

This efficiency can't be achieved with either conventional electronics or spintronics. The former always operates with losses that drive up the power demand. The latter is even more inefficient, since the spin currents used here first have to be produced from charge currents. Furthermore, there is, as yet, no functioning concept for not only storing, but also processing information in the form of electronic spins.

So Parkin wants to do it in a manner similar to human neurons, which exchange information by taking up and releasing ions. And he already has a concept for doing this, which he developed with some preliminary work at IBM. He found a way to charge an electrical insulator with ions from an ionic liquid, thus switching it, or in other words, bringing it from an electrically insulating state to a conductive one. "We noticed that we need only tiny amounts of ions for this," he explains. So such a transistor would work much more efficiently than those currently in use. Today, the smallest computing elements of a processor operate in that electrons are pumped into or suctioned out of a semiconductor. That costs more energy than directing a relatively small amount of ions on a surface.

ON VACATION, WORK WILL BE DONE ONLY DURING THE DAY

"We're still at the very beginning with these liquid electronics," says the scientist. Particularly for these kinds of projects, which still have a long way to go before they can be used in applications, IBM lacks the patience. To come up with such a fundamentally new approach to new computer technology, Parkin and his staff must, of course, constantly search for radically new physical effects. However, Parkin isn't interested in these effects for their own sake. "The principles are interesting, but for me, it's important that they offer a potential application in the long run."

Thus, in Halle, he wants to prepare the way for computers to one day be capable of computing as energy efficiently as the brain of a human or a rat. The fact that the 60-year-old will soon reach the retirement age of an ordinary employee should present no obstacle. His contract in Halle already runs until he turns 70, and there is an option for him to renew until the age of 75. In any case, it's difficult to imagine him retiring – he already has a hard enough time taking a vacation. Therefore, for their honeymoon, which he and his wife plan to spend in Scotland, the couple agreed on a compromise: they will work during the day and take the evenings off.

Part-time vacation – Claudia Felser calls it a nano-honeymoon – seems to be the best solution, following their initial experiences with short getaways. As she explains, they stopped in the Fiji Islands for two days on their way from a conference in the US to a conference in Australia. "When we weren't able to depart after the second day, he got so jittery that he could hardly manage the third day." ◂

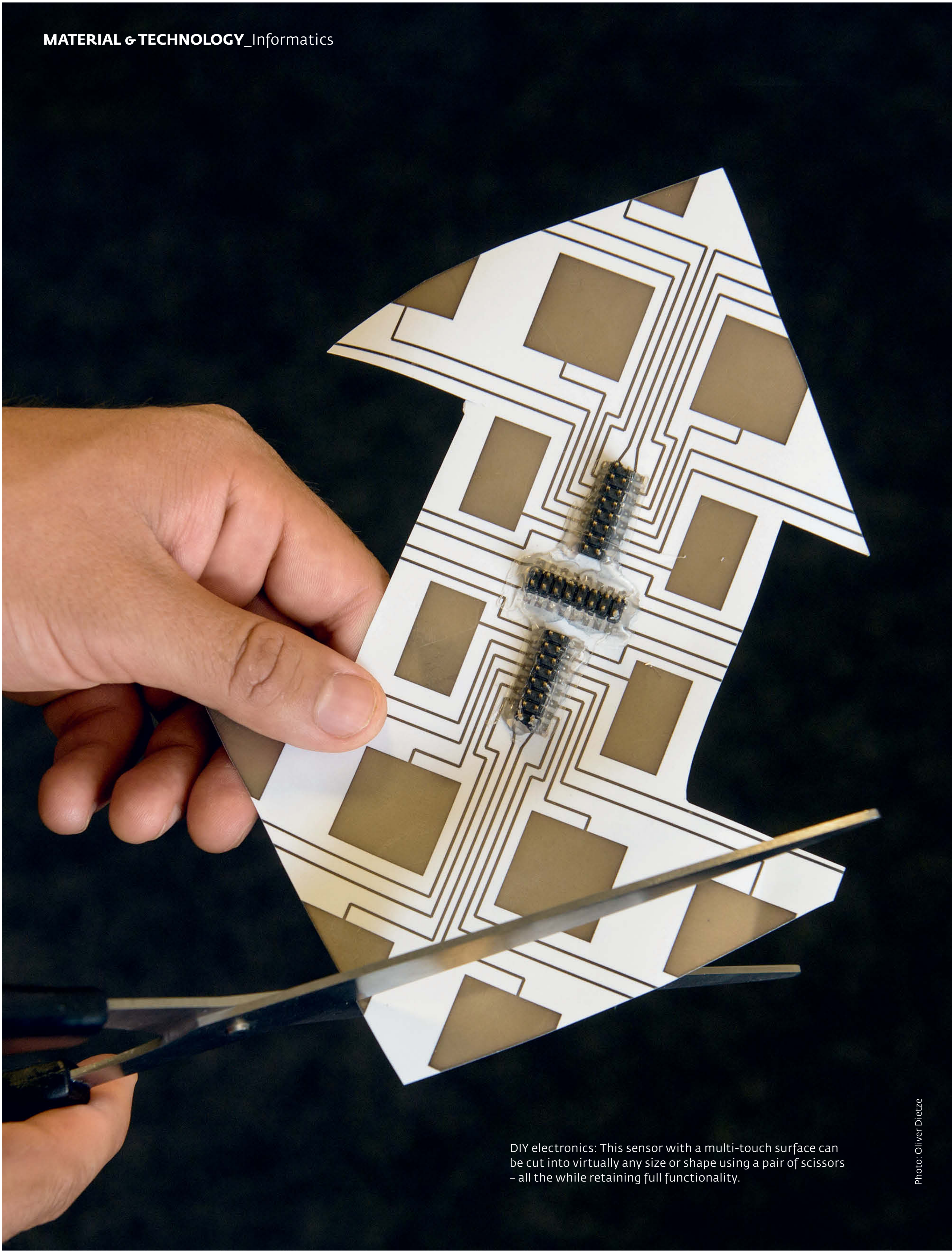
GLOSSARY

Big data: Thanks to digital technologies, today it is possible to record and process far larger amounts of data than just 20 years ago. This facilitates new approaches in science, but it is also exploited in business and by secret services.

Molecular beam epitaxy: This method also makes it possible to produce very thin layers, albeit in the form of a single crystal. For this, a substance is evaporated and applied to a substrate in the form of a directed beam. This method is slow and requires a very high vacuum.

Sputter deposition: A method for producing thin material layers. For this, a beam of charged noble gas atoms is used to knock atoms out of a material. These atoms are then deposited in individual layers on a substrate. This method produces thin layers faster than molecular beam epitaxy and doesn't require as high a vacuum, making it more versatile and suitable for mass production.

Graphic: Stuart Parkin



DIY electronics: This sensor with a multi-touch surface can be cut into virtually any size or shape using a pair of scissors – all the while retaining full functionality.

Photo: Oliver Dietze

Displays
Straight from the Printer

His research looks hip and colorful. The prototypes are made from wood, paper and plastic. Cut, printed or pressed. But there's more to them than meets the eye: **Jürgen Steimle** and his team at the **Max Planck Institute for Informatics** and at **Saarland University** in Saarbrücken are concentrating their efforts on a fully interconnected world in which, for example, computing devices are activated via skin-worn sensors.

TEXT **GORDON BOLDUAN**

Taped to the office wall is a science poster informing readers about miniature screens on fingernails. Mounted next to it is a pegboard with screwdrivers, pliers and even hammers. Suspended from the ceiling is a camera system composed of aluminum insertion rails and six infrared cameras, and across the rough gray carpet, numerous electric cables snake their way around stacks of transparent plastic boxes.

One of the tables is covered with myriad notepads surrounding a black keyboard and a flat-screen monitor. At the very center stands the balsa wood prototype of an apparatus, back to back with a structure consisting of acrylic glass, micro-controllers, circuit boards and colorful plastic wires.

These are the kinds of contrasts that Jürgen Steimle brings together, not only in his laboratory, but also in his research. The sign on the door reads "Lab Space." Steimle set up this area for his students and doctoral candidates at Saarland University's Cluster of Excellence on Multimodal Computing and Interaction, where he heads the independent research group on Embodied Interaction. He also conducts research at the Max Planck Institute for Informatics, which is within walking distance of the university building.

COMMUNICATION IN AN INTERACTIVE WORLD

Jürgen Steimle and his students are convinced that, a few years from now, every object will contain a computer. That's why their focus lies on the principles that make it possible to work and communicate with the hidden electronic components in such a completely interactive world.

Mobile terminals with impractical designs not only irritate users in day-to-day life – they also become the object of ridicule. Social media platforms such as Facebook are full of popular posts predicting how clunky smartphones or the Apple Watch would look if engineers had designed them a decade ago with the technology available to them at that time.

What the scoffers fail to account for, however, is that even the most modern technological possibilities are often far from ideal for users. "Today, if I want to activate my smartwatch via touch input, I have only a small display available, and most of it will be obscured by my fingers," explains Jürgen Steimle, referring to what his colleagues call the "big thumb problem."

The 35-year-old computer scientist studies what happens when product development focuses solely on what is technologically feasible, and seeks to tackle the problems that arise as a result by nipping them in the bud: "The shape of devices must not be restricted to the limits of today's technology! Only then can we develop customized forms of interaction that can be integrated into items and objects that we use in our real world in so many different ways," explains Steimle. One of the tools he uses for this purpose is user studies. His goal is to develop the modes of interaction of the future.

BASIC RESEARCH ON TWO LEVELS

"Printed electronics is the key technology for us right now. It allows us to develop electronic components that have entirely new properties and are ultrathin, shapeable and even stretchable. They no longer bear any resemblance to conventional computers," says Steimle. By adopting this approach, he conducts basic research on two levels at the same time: based on systematic surveys, he designs completely new modes of interaction; and he implements the latter using technologies that themselves are still in the development phase.

A huge shelf divides the "Lab Space" into two parts, with the right half being reserved for the workbenches and electronic equipment. The members of Steimle's group – three doctoral students and two master's candidates – have gathered in the left half of the room. They're sitting at two tables that were pushed together in front of a wall, and stuck to that wall are a number of round, yellow cue cards with handwritten notes; on one of the tables, Steimle placed a workshop kit filled with colored markers and pieces of construction paper cut to size.

Steimle sits at the table with his back facing the window, which offers a view of Saarbrücken's informatics campus, including the Max Planck Institute for Software Systems, the Intel Visual Computing Institute and the Center for Bioinformatics.

Using creative techniques and the right tools to find answers to questions in a group setting is a method that the researcher became well acquainted with during his time at the Massachusetts Institute of Technology's Media Lab,

Working on the future: The research conducted by Jürgen Steimle (left) and his team focuses on developing electronic components with entirely new properties. This includes the iSkin sensor, which detects touch input on the user's skin. The sticker pictured on the right was designed for the forearm and is used to activate a digital music player. The researchers integrated a number of touch keys – for "Play/ Pause," "Fast Forward," "Rewind" and "Volume."

where he worked as a visiting assistant professor in 2012 and 2013. Steimle's career began in 2009 when he published his doctoral dissertation, which the German Informatics Society (GI) distinguished as being the best in the German-speaking countries.

Since 2013, Steimle has been working as an independent head of a junior research group at the Cluster of Excellence in Saarbrücken. The Cluster of Excellence introduced this position to grant its currently 15 researchers the freedom to set up or expand their own groups and define their own agenda. In order to ensure that they have the scientific liberties they require for their work, each team receives a budget. Furthermore, all heads of junior research groups are allowed to supervise their own doctoral students.

Daniel Gröger is the newest member of Steimle's team. Since October of last year, the doctoral student has been working on a completely new three-dimensional printing method. So new, in fact, that Steimle swears his students to secrecy and urges them to refrain from broadcasting the news to the international tech-blogger community via Facebook or Twitter.

AN ELASTIC SENSOR WORN ON THE SKIN

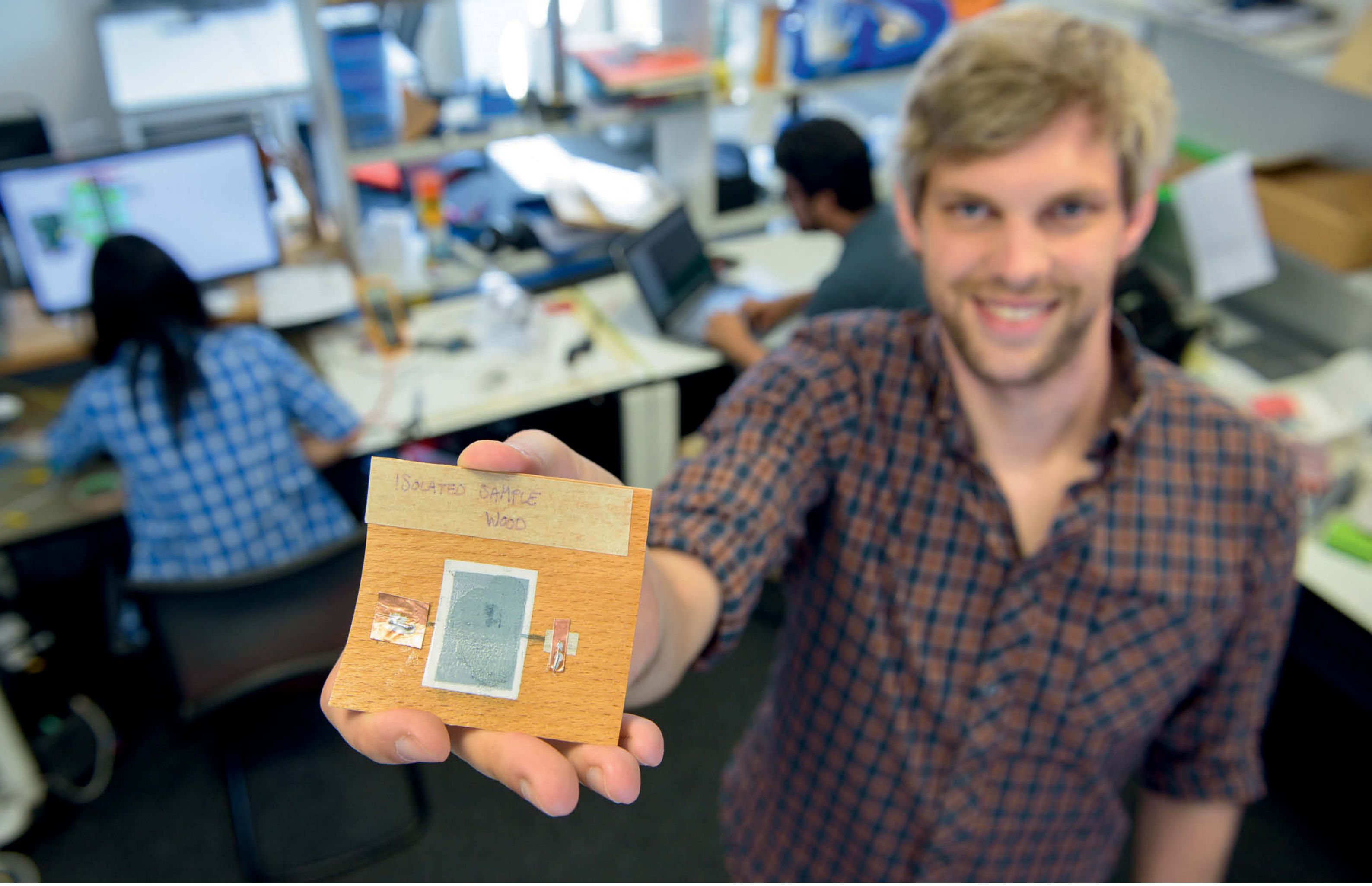
Speaking in English and using short, precise sentences, Jürgen Steimle outlines his expectations regarding the upcoming brainstorming session. He's looking for applications for the components that can already be printed in three dimensions. The group's task is now to jointly come up with ideas. Everyone grabs one of the colored, rectangular cue cards. For the next few minutes, the only sound heard in the room is that of markers scribbling away.

However, in the case of the most recent project, iSkin, with which Steimle's doctoral student Martin Weigel is currently causing a stir around the globe, the researchers opted for a different approach. "We made a conscious decision not to start out with the technology, but to use the skin as a natural medium instead," says Steimle. Skin has a larger surface area than any smartwatch. They conducted a survey among 22 participants – 25 years old on average – and asked them what kinds of actions they would perform on their skin if it could serve as an input sensor for mobile terminals.

"Interestingly enough, an additional dimension came to light: expressive interaction. When physically interacting with their skin, the users didn't just touch it – they also pressed it firmly, pulled it or even twisted it," says Steimle. Based on these insights, the researchers developed a prototype of a sensor.

"It is the first elastic, skin-worn sensor that can be used to interact with computing devices," says Steimle. The elasticity posed a considerable challenge, he recalls, because it requires conductors that don't break when stretched. To solve this problem, the computer scientists from Saarbrücken collaborated with materials scientists from Carnegie Mellon University in the US. The latter had devised a method of combining different types of silicone that would be suitable for this kind of sensor. >

Photo: Saarland University, Embodied Interaction Group



Prototypes: Doctoral student Simon Olberding holds up a thin, light-emitting display that the scientists printed onto wood using the PrintScreen technique. The display detects the user's touch input through the veneer. This method was also used to enhance a conventional Swatch wristwatch by printing the display onto the band with symbols that alert the user – for example when a new e-mail has been received.

Photos: Oliver Dietze (top), Saarland University, Embodied Interaction Group (bottom)

Furthermore, silicone is a skin-friendly material that can easily be affixed to the skin using a medical adhesive. Pressing a particular part of the sticker would allow you to take an incoming phone call or adjust the volume of your headphones, for example.

AESTHETICS MATTER, TOO

Yet the scientists from Saarbrücken didn't content themselves with merely solving the device's functionality issues – not by a long shot. "Our goal was to create a sensor that truly takes a person's individual sense of aesthetics into account. This means it needed to look good and make a visual statement that the respective wearer can identify with," says Steimle.

For that reason, the researchers also developed procedures that allow designers to turn lines, shapes and silhouettes into iSkin sensors according to their own personal taste. The result: when placed on the skin, the semi-transparent control interfaces look like artistic tattoos and no longer bear any resemblance to conventional control elements.

Back in the brainstorming session, the members of Steimle's team are now taking turns presenting their ideas by holding up their cue cards to show the drawing and explaining it in a nutshell. Next, the cards are stacked at the center of the table and everyone takes a few to add their own notes and then hand them to the person on their right. The cards are passed around the table for the next 15 minutes. Many of them make Steimle smile, and some of them even prompt him to grab a new card so he can add additional thoughts in small letters using a broad marker.

This method of continuous reflection is also evident in his projects. Another major goal that Steimle's group has set itself is devising a simple method that would allow average users to adapt technology to their own personal needs. Steimle and his doctoral student Simon Olberding have already come up with a solution to this problem by building a prototype of their project called PrintScreen. The prototype is set up on a separate table for demonstration purposes.

A postcard depicting a vintage automobile serves as an example. When a button is pressed, the rear axle and steering column light up in the same color. This is made possible by two segments of a flexible display that have the same shape as the car parts. Steimle's group printed the display using a conventional inkjet printer. The printable screen is electroluminescent: it emits light when an electric voltage is applied.

Until now, it was possible to produce displays only in large series, but not for individual users. The researchers in Saarbrücken have changed that. The process they developed works as follows: Using a software program such as Microsoft Word or PowerPoint, the user designs a digital template of his or her customized display. They can now print the template using one of two methods devised by the researchers. This is done using the inkjet or silkscreen printing technique. In both cases, the ink contains conductive materials.

Although these techniques may have different strengths and weaknesses, they can be carried out by a single person in anywhere from a few minutes to four hours. The result: displays that have a relatively high resolution and are only 0.1 millimeters thick. Printing an A4-sized sheet of paper costs around 20 euros; the most expensive element here is the special ink.

And it gets even better: due to the fact that these techniques can also be used to print on such materials as paper, plastics, leather, ceramics, stone, metal and wood, users can create all sorts of two- and even three-dimensional shapes. According to the researchers, even touch-sensitive displays can be printed in this manner, thus opening up this technology to a broad range of possible applications.

Thanks to these techniques, displays can be integrated into pretty much any everyday item – not just paper objects, but also furniture and home furnishings, for example, or bags and wearable accessories. One possible application would be to use this technology to enhance the band of a wristwatch so that it lights up when the user receives a text message. “And if we now combine our method with three-dimensional printing, we would be able to print three-dimensional objects that display information and react to touch input,” says Jürgen Steimle.

RELAXING WITH A CELLO SUITE BY BACH

In the meantime, the cards being passed around in the brainstorming session are now orange – the group already used up the green stack. Yet even the luxury of working with a professional workshop kit can’t compensate for bad handwriting. Instead of “wearables” – computing devices worn by the user – Steimle reads out “werewolves” and gives everyone at the table an incredulous stare. The team bursts into laughter.

Twenty minutes later, the last person in the group snaps the cap back onto the tip of their marker. The students push the cards toward the center of the table, and every single card is now discussed. The brainstorming session brings forth keywords such as “personalized smartphone cases,” “interactive rings” and “devices worn on the body.” At the end of the session, Daniel Gröger holds a big batch of cards in his hands and uses his thumb to flick through them like banknotes.

A few hours later, Jürgen Steimle is sitting in his office, albeit in front of his desk rather than behind it. He has placed another chair in front of him, and propped up against the backrest is a yellow book of sheet music. Steimle keeps his eyes glued to the notes while his left hand holds the neck of a cello and his right hand lets the bow glide across the strings. As he plays Bach’s Cello Suite No. 1, he is completely immersed in the music. Back in his days as a student in Freiburg, Steimle made a living as a cellist, and he performed in Russia and France as a member of the Academic Orchestra. Nowadays, the music helps him relax after a busy day of work.

Steimle scratches, hammers, plucks, strokes. He coaxes both the lowest and the highest notes out of his instrument before putting down his bow for a minute: “It’s a relatively simple tool, yet you can use it to create a highly complex world. It’s this contrast that I find so fascinating – also in my research.” ◂

TO THE POINT

- **Our world is becoming increasingly interconnected. Researchers predict that virtually every object will contain a computer in the near future.**
- **Printed electronics are currently regarded as being a key technology. Thanks to these components, scientists can develop computing devices that boast entirely new properties and are ultra-thin, shapeable and even stretchable.**
- **Jürgen Steimle and his team study the principles of working and communicating with these embedded computers.**
- **The scientists are researching a new method for printing personalized computing devices, for example. In another project, they focus on human skin as an input sensor for mobile terminals.**

Balance in the Biotope

Biodiversity provides many ecological advantages. Using large-scale field tests, **Gerd Gleixner** and **Ernst-Detlef Schulze**, scientists at the **Max Planck Institute for Biogeochemistry** in Jena, carry out research on biodiversity in meadows and forests, and explore its impacts on ecosystems and the Earth's carbon balance. Their studies also yield surprising insights into the factors that really serve the purpose of species protection.

TEXT **CATARINA PIETSCHMANN**

Fieldwork in the meadow: The Jena Experiment extends across a 16-hectare site on the edge of the city north of the Saale River. Scientists study how species diversity affects the functioning of ecosystems and the carbon balance of the soil there.

Photo: Catarina Pietschmann

Grasses and flowers as far as the eye can see. The view is dotted with colored wooden pegs that demarcate the individual large and small plots. Thermal imaging cameras monitor a number of the plots from a bird's-eye perspective.

The Jena Experiment extends across an area of 16 hectares on the edge of the city and is bounded to the northeast by the Saale River. Behind it stand hills, some of them wooded and others speckled with meadow orchards. In the heat of the midday sun, there's not a single cloud in the sky – a perfect day for experiments with carbon dioxide labeled with the heavy carbon isotope ^{13}C. "Photosynthesis operates at full throttle only when it's really sunny, and the plants metabolize the labeled gas very quickly," explains Gerd Gleixner. He leads the Molecular Biogeochemistry Working Group at the Max Planck Institute for Biogeochemistry in Jena, and he wants to determine how the interaction between different species of flora and fauna affects the functioning of ecosystems, and whether greater diversity could buffer the effects of changing and extreme environmental conditions.

Along the back boundary of the meadow, around 20 students and scientists wearing straw hats as protection against the blazing sun crouch close to the ground on plastic stools. Metal frames stand on small squares of the meadow. On top of the frames are cubiform Plexiglas domes through which the labeled carbon dioxide flows onto the green test areas for 30 minutes. Following a specific timetable, the researchers cut grasses and plants, blade by blade, from the test squares and lay them on colored trays divided by species. These will be analyzed later in the lab to determine how quickly the special CO_2 was used to form sugars and to which specific parts of the plant they were transported.

Other students focus on the root area and puncture their plots like piec-

Markus Lange (left) and Gerd Gleixner analyze the organic substances that are contained in the soil water and that reveal much about the processes at work in an ecosystem. The water collects in bottles in which a vacuum prevails. The containers stand in a tub that has been sunk into the ground.

es of Swiss cheese by removing soil and root samples. They sift the soil under canopies at the other end of the meadow. Like the cleaned and washed root systems, the soil is placed in sample bags for analysis.

The Jena Experiment has been running for 13 years now. When the 20-square-meter experimental area was established in 2002, it was just a field leased by Friedrich Schiller University Jena. The Max Planck Society purchased the seeds for planting using the organization's central funding, and the work began. Sixty species from four major plant groups that are typical of the Saaleaue meadows were planted: grasses, small herbs, tall herbs and legumes. They included plants as common as the dandelion, campanula, daisy, buttercup, red clover, alfalfa, scabiosa and ribwort. Each species was planted both as a monoculture and in combinations of 2, 4, 8, 16 and, finally, all 60 species. And the entire process was repeated four times in block strips parallel to the Saale River so that the distance from the river and the resulting differences in the soil could be compared statistically.

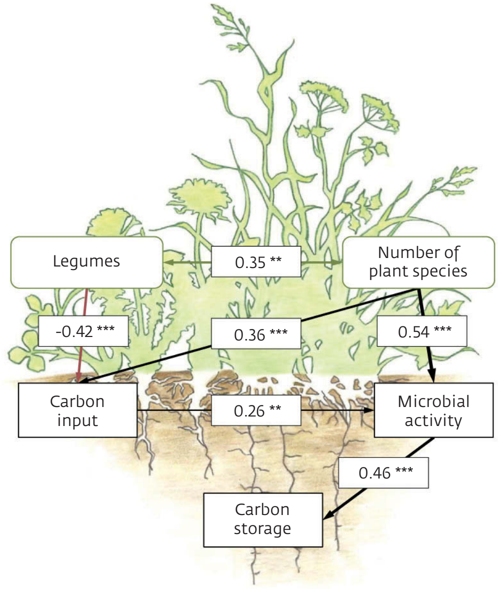
THE "WHO WITH WHOM" OF THE ECOSYSTEM

Only in some areas of the meadow, in the bare ground, was nothing at all allowed to grow, and this remains the case today. At the outset, even the earthworms were driven away from here with electric shocks. "If we want to study the carbon storage in the soil, we also need to know how it behaves when it has no vegetation at all," says Gleixner. The opposite extreme is represented by areas that were left to the forces of nature, on which whatever vegetation blows in or thrives is allowed to grow. These comparison plots are overgrown and are already starting to turn into forests.

To maintain the experiment, the parcels that were sown are cut and weeded twice a year by an army of students. The helpers remove every single plant that doesn't belong to the exclusive 60 species. The 480 test squares are otherwise left to their own devices (and those of the researchers). In addition to research groups from Friedrich Schiller University Jena and the Max Planck Society, scientists from numerous other German institutes, as well as Swiss and Dutch scientists from a DFG team of researchers, pursue their interests relating to the "meadow system" here. Botanists, entomologists, microbiologists, hydrologists and other experts use the area jointly to unravel the "who's who" and "who with whom" of the ecosystem – both above and below ground.

Gerd Gleixner is a biogeochemist and is primarily interested in the latter. His team's activities include taking soil water and soil gas samples, which trickle from the soil into bottles via narrow tubes. In the laboratory, the researchers extract the organic fraction, which comprises a conglomeration of numerous small molecules. "It's the finger-

Photo: Anna Schroll



How do the different characteristics of an ecosystem influence each other? What impact does this have on the volume of carbon stored in the soil? The black arrows indicate a positive influence, the red ones a negative influence. The closer the number on an arrow is to 1, the greater the influence. The more asterisks a number has, the more significant it is. A high number of plant species therefore increases the microbial activity in the soil and the carbon storage. The researchers therefore suspect that microorganisms in the soil result in carbon storage.

print of the ecosystem, so to speak," says Gleixner. Plants, microorganisms, worms and whatever else crawls through the soil leave living and posthumous traces in it, and Gleixner's team attempts to read these traces.

There's an entire hall at the institute filled with instruments for various kinds of chromatography, mass spectrometers and other high-tech equipment. The molecule cocktails are separated here in increasing detail and analyzed. Long-chain hydrocarbons, for example, usually come from foliage, and short-chain ones from microorganisms. "We're a long way from being able to identify every signal. However, we take all the information together, compare ecosystems and examine whether the same markers are found in the same systems," explains Gleixner. Members of his team have already travelled as far as Siberia, Tibet and Patagonia to compare ecosystems.

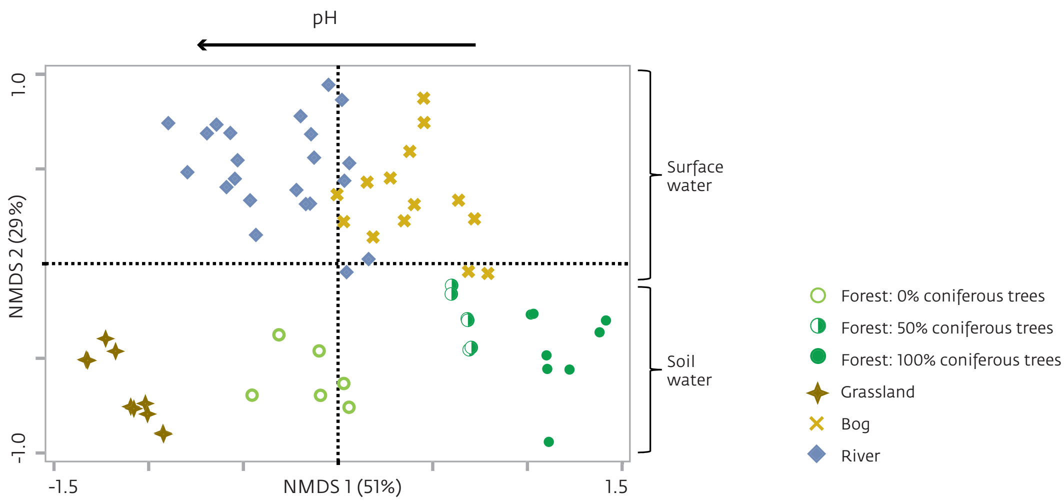
GREATER DIVERSITY MEANS MORE CARBON STORAGE

The researchers have long known that the biomass in a location increases with the diversity of the plants that grow in it – entirely without the help of fertilizers! The importance of this artificial supplement is clearly overestimated. "In agriculture, most fertilizer is spread in spring, gets washed away by the rain, and is of no benefit to the small plants," says Gleixner.

What's more astonishing, however, is that, with greater diversity, the volume of carbon and nitrogen stored by the soil also increases. Gleixner asks himself: Where does it all come from? What role do microorganisms play here and which ones are involved in this process? Do they work as separate groups, or is there a community effect? To find answers to these questions, he not only tests the chemical structure of the soil, he also analyzes the DNA and RNA of its minute inhabitants. Thus, species-rich meadows provide more nutrients to the soil organisms, increasing the productivity and genetic diversity of the microbial community. "Soil organisms are unselfish communists. They share everything – from food to their own genetic material. As a result, the population is constantly changing, and breaks down all carbon in the soil, in most cases to form carbon dioxide, or methane when there is little oxygen." >

Graphic: Nature Communications; photos: Anna Schroll (bottom left and right), Catarina Pietschmann (bottom center)

Gerd Gleixner (left) and his colleagues study, among other things, the volume of carbon stored in the soil. To do this, they take soil and plant samples to see exactly where and how much labeled CO_2 the plants have processed. The metal frame (center) was previously covered by a Plexiglas dome through which the marked carbon dioxide flowed onto the small plants.



Above: The molecular fingerprints of different ecosystems in the water: In a global project, thousands of organic substances in surface and soil water were tested using ultrahigh resolution mass spectrometry. This gives NMDS (non-metric multidimensional scaling) values, which act as ecosystem fingerprints.
The horizontal axis (NMDS 1) explains 51 percent of the differences in the data set and the vertical axis (NMDS 2) 29 percent. The substances extracted from water originating from coniferous, deciduous and mixed forests, as well as from grasslands, bogs and rivers, can be differentiated in this way. The pH value of the soil is an important factor here.

Below: Martin Göbel uses a ^{14}C accelerator mass spectrometer to analyze the content of the radioactive carbon isotope ^{14}C in soil samples. As the concentration of the isotope declines with the increasing age of the material, the tests provide information about the conversion and origin of the carbon in the soil.

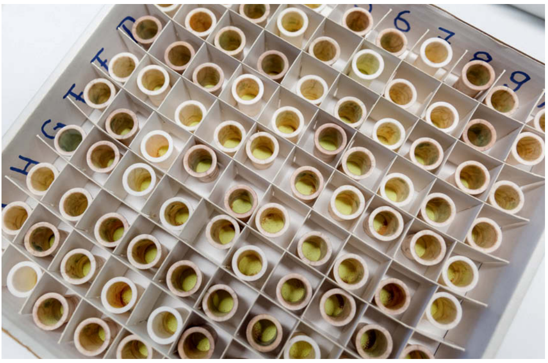
The microbes even process pollutants in this way, rendering them harmless. This is essential for clean drinking water. However, as demonstrated by the ^{13}C analyses of the green waste, part of the meadow community also benefits from this. “Ground-level plants like plantains, whose wide fleshy leaves practically lie on the ground, process primarily the CO_2 that diffuses from the soil and bind it again.” For this reason, the researchers detected very little of the heavy carbon ^{13}C in them. “Tall grasses, in contrast, breathe in almost exclusively whatever is available in the air.”

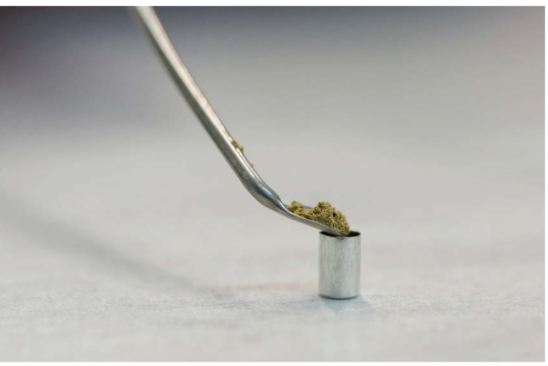
Whereas the researchers initially assumed that the material flows in a meadow are ideal if individual representatives of the four major plant groups are combined on it, they now realize that the presence of plants with different characteristics in an ecosystem is far more important – and the likelihood of attaining a thriving mix increases with the number of species. This correlation is tested in so-called trait-based experiments, in which plants are deliberately mixed based on two primary characteristics.

The first of these is the timing of their growth and flowering, and the second is the form of shoots and roots they develop. “Grasses grow fastest in the spring, while legumes still present strong growth in the fall,” explains Gleixner. Over the course of the year, a good mixture of early and late species yields the best result. Multispectral cameras, which record individual test areas daily at different wavelengths, document the growth of individual plants and their levels of chlorophyll and other pigments. In terms of root formation, a good mix of shallow- and deep-rooting plants can make optimum use of the nutrients in the soil. What applies to the roots also applies to the leaves and flowers: high and low, wide and narrow – the more diverse the mix, the better the use made of the available resources, namely the sun, nutrients and moisture.

And multiculturalism makes ecosystems strong! “The resistance of the meadow to external stresses such as drought and infestations of pests and mice increases with greater diversity,” says Ernst-Detlef Schulze, the initiator

Graphic: Roth, V.-N., Dittmar, T., Gaupp, R., Gleixner, G., 2014. Ecosystem-specific composition of dissolved organic matter. Vadose Zone Journal; photo: Sven Döring





Searching for traces in the soil: To measure the inorganic carbon and nitrogen content of the soil samples, the samples are weighed into and burned in small ceramic pots (top left) so that only inorganic substances remain. To trace the carbon and nitrogen metabolic pathways and rates in plants, the Jena-based scientists carry out experiments with heavy carbon and nitrogen isotopes. Franziska Günther analyzes the isotope pattern of biomarkers using a combination of gas chromatography and mass spectrometry (right). To carry out other analyses of the isotope ratios, the researchers weigh samples into tin capsules (bottom left) and then burn them.

Photos: Sven Döring (3)

of the Jena Experiment and guardian angel of the test meadow to the present day. "Our monocultures proved to be most sensitive. Most of them succumbed to harmful organisms." Even the otherwise indestructible daisy: Without spacers that prevent the direct transmission of infections from one plant to another, it contracts a fungal infection and dies. "It's the 'cold in a kindergarten' phenomenon," says Schulze, smiling.

Plant diversity also has a positive impact on the diversity of the other organisms – the animals. This was confirmed by a consortium of zoologists that focuses on aphids, grasshoppers, soil fungi, worms and plant pathogens. This was a new concept for nature conservation, which had previously been focused on the question of whether the butterflies should be protected or plant diversity. "The latter, obviously, because by doing so, we also protect the butterflies," says Schulze. Insects detect the smell of flowers from miles away and follow the scent like a red thread. Pathogens also find it easy to spread as their spores are carried over long distances by the wind. The soil organisms are slowest. Some of them haven't even managed to reach the middle of the test meadow yet.

"EVERY SPECIES HAS ITS MERIT"

The longer the Jena Experiment runs, the more interesting it becomes, says Schulze. Particularly where the plots weren't managed: one small meadow with each level of diversity hasn't been weeded since 2003. "We wanted to know how many species would assemble there." The answer is almost exactly 30. Not only do the ecosystems that started with fewer species level off at this number, but also those that started with significantly more species. "We constantly lose species in the plots where we originally sowed 60 species," says Schulze. "Assuming that 30 is the magic number for floodplains, it would be possible to calculate how many grasshoppers, butterflies, dragonflies, plant suckers and mice gather there."

So what is the most important insight gained from the Jena Experiment for Gerd Gleixner? "Basically, that every species has its merit. A large species pool ensures the survival of the plant community. And thus ours, too." Gleixner thinks in terms of very long periods of time, as demonstrated by his second research focus, the reconstruction of the paleoclimate. "If you look at the ice ages and how plant communities changed over major long-term climate developments, species that may be completely insignificant now could suddenly become important." For this reason alone, not a single one of them is extraneous.

"Basically, we have nothing to worry about," Gleixner adds, grinning. "We know that three million years after a major catastrophe, the plants are back. Whether the human race will still be around is a different question entirely."

But back to the present: For Ernst-Detlef Schulze, a research dream was re-

With the Biotree Experiment, Ernst-Detlef Schulze (right) and his team are seeking to establish how species diversity develops in different types of forests. The researchers also take climate data into account, which is recorded with, among other things, a weather station (left) in Kaltenborn, near Bad Salzungen in Thuringia.

alized with the Jena Experiment: repeating on the fertile loam soil of the Saaleaue alluvial plain the long-term experiment on the karstic sandy soil of Cedar Creek in Minnesota that yielded the very first insights into biodiversity. And because the situation around the turn of the millennium was propitious – the former GDR's old military and border areas were available for reforestation and amazing subsidies were available for such projects – Schulze went one better with the Biotree project. For Schulze, who is now 74 and still heads an Emeritus Group at the Max Planck Institute in Jena, this project was essential: "Herbs and grasses grow fast and easily, but one-third of our landscape is forest. The question as to whether the diversity laws we observe on the meadows also apply in forests was still completely open."

No sooner said than done: together with the Thuringia federal state forest authority, the researchers converted a military training area with sand and sandstone soil near Bad Salzungen, a tank training area with calcareous dry soil in the Thuringian Basin, and a fen with black soil on limestone into test areas. The bomb disposal units had barely packed and left when the researchers and their helpers got started with the planting of 5,000 trees on the 90 hectares of land. The test plots, on which monocultures, two, four or eight tree species grow in chessboard formations, are one hectare in size and divided into three parts. "One part was left to its own devices, the second was regularly thinned out, and the third was enhanced with rare tree species," says Schulze. For example, individual cherry trees were added to a mixed spruce-beech plantation.

MANAGED FOREST HAS GREATEST DIVERSITY

The early years were far from easy for the two-year tree nursery novices. "They had real difficulties asserting themselves against the grass and often had to be cut free and, in some cases, even replanted," explains Schulze. But in recompense for all their hard work, the researchers were rewarded with surprising findings on all plots. The tree species that prevailed were the most unexpected ones. For example, larches dominated on the extremely dry superficial and stony soils of the Thuringia Basin, while the beech trees failed miserably. "Previously, anyone wanting to grow deciduous forests had to plant at least one-third beech, or else they wouldn't be granted a subsidy. This was completely incorrect," says Schulze. Thanks to Biotree, the regulations have now been changed, and Thuringia forestry interns are now trained here on the test site.

Biotree met with great interest in Europe and was converted into an EU project for which comparable test areas were established in Belgium, Italy, Finland, Sweden and the Czech Republic. The experiment is now also part of the global TreeDivNet, which encompasses 18 similar projects comprising a total of almost one million trees in test locations ranging from Australia and China to Central America and Canada.

And what insights have emerged from Biotree, which is conceived as a 100-year-long endeavor? The greatest diversity is found in managed forests – and not in protected areas. "The most species-rich constellation is the even-aged stand in the deciduous forest," says Schulze. In even-aged forests, all of the trees are planted in the same year. The fact that the trees here were all planted in the same decade has no influence on the species diversity, but the fact that such forests are managed does.

Photo: MPI for Biogeochemistry (left), Thomas Stephan (right)

For this reason they have more herbs, more light indicators – namely species that don't tolerate a closed crown canopy – more deadwood, mosses, fungi and soil bacteria than any nature conservation area.

"As absurd as it may sound, the creation of a national park can reduce biodiversity considerably," says Schulze with a grin. "If a forest is placed under a nature conservation order, for example the Hainich forested hill chain in the Thuringia Basin, huge numbers of species are lost, particularly through game browsing." In contrast, not a single species has become extinct in a managed forest since records began over 250 years ago. Sustainable forest management thus offers the best species protection.

Ernst-Detlef Schulze has very clear views on the topic of nature conservation, and he can back them up with scientific evidence. "In Germany, 560 plant species are classified as endangered, and 42 have already become extinct. But 960 new species have emerged!" These are so-called apomictic species that don't reproduce sexually – that is, through pollination. In these plants, diploid cells – cells with two sets of chromosomes – assume the function of the fertilized ovum, so they reproduce asexually. These species are completely ignored by the Red Lists. "Whether we like it or not, we must finally acknowledge that a powerful evolutionary process is unfolding in our agricultural deserts!" Almost one-third of new species in Germany arose through malfunctions. "And this happened, not in spite of management, but because of it." Over 250 dandelion species formed vegetatively.

According to Schulze, nature conservation in Germany is based on three pillars that face in different directions. He places a Venn diagram on the table: there are 825 rare and potentially threatened species on the Red Lists for Germany. The number of legally protected species is 370. And then there are the 303 species that arise exclusively or almost exclusively in Germany and for which people are responsible. "But only 55 species are common to all three categories." This makes it practically impossible for forest and meadow owners to identify the plants they should tend with particular care. "There are endangered species that aren't protected and protected species that aren't endangered! Something's gone very wrong here!"

STUDIES ON THE BEST FENCING AGAINST GAME

Schulze really feels strongly about this topic. It's a good thing the forest itself is so peaceful. He himself has been managing a deciduous and coniferous forest in Thuringia for some time, and a small plot of "almost virgin forest" in Romania. His own deciduous forest, a delectable slice of diversity, as he describes it, contains 18 tree species, including old wild pear and apple trees. "Quite sour and inedible," he says.

In healthy ecosystems, the flora and fauna form a single entity, in meadows and in forests where wild animals hungry for leaves roam. Schulze carries out studies in his own forest on browsing damage and the best fencing systems for keeping game out. "In Romania I have bears, wolves and lynx, and here in Thuringia there are deer, stags and mouflon. And I have to regulate the stocks!" he adds. In full compliance with the shooting quotas, of course. This is also a controversial topic. But hunting and forestry share a particular task: to conserve the biological balance and species diversity in forests. Schulze has a hunting license of course and, like most hunters, he builds his own perches. This explains the plastic splint on his leg. He recently fell while building a perch and tore his Achilles tendon. Ouch! Ernst-Detlef Schulze waves dismissively, "Bah! It's not that serious." As far as he's concerned, species diversity and conservation are matters of far greater importance. ◂

TO THE POINT

- **In the Jena Experiment, scientists study how species diversity affects ecosystem functions on 480 meadow plots with varying levels of biodiversity.**
- **Test areas with higher levels of species diversity are more resistant to malfunctions, and their soil stores greater volumes of carbon.**
- **The number of species in floodplains that are left to their own devices levels off at around 30.**
- **The Biotree field experiment involving different forest ecosystems showed that the greatest species diversity is found in managed forests.**
- **The conservation of species requires a solution that unites the different approaches that currently exist and also takes the different locations of ecosystems into account.**

GLOSSARY

^{13}C-labeling: This is used, among others things, to trace the route taken by carbon in a metabolic process or chemical reaction. To this end, the heavy carbon isotope ^{13}C is added to a starting compound, for example CO_2, as a replacement for the usual ^{12}C carbon isotope. In various phases and following conversion, it is detected in the conversion products, for example in new biomass.

Diploid cells: These cells have a double set of chromosomes, while haploid cells have only one set. When an organism reproduces sexually, its gametes – eggs, sperm or pollen – are haploid.

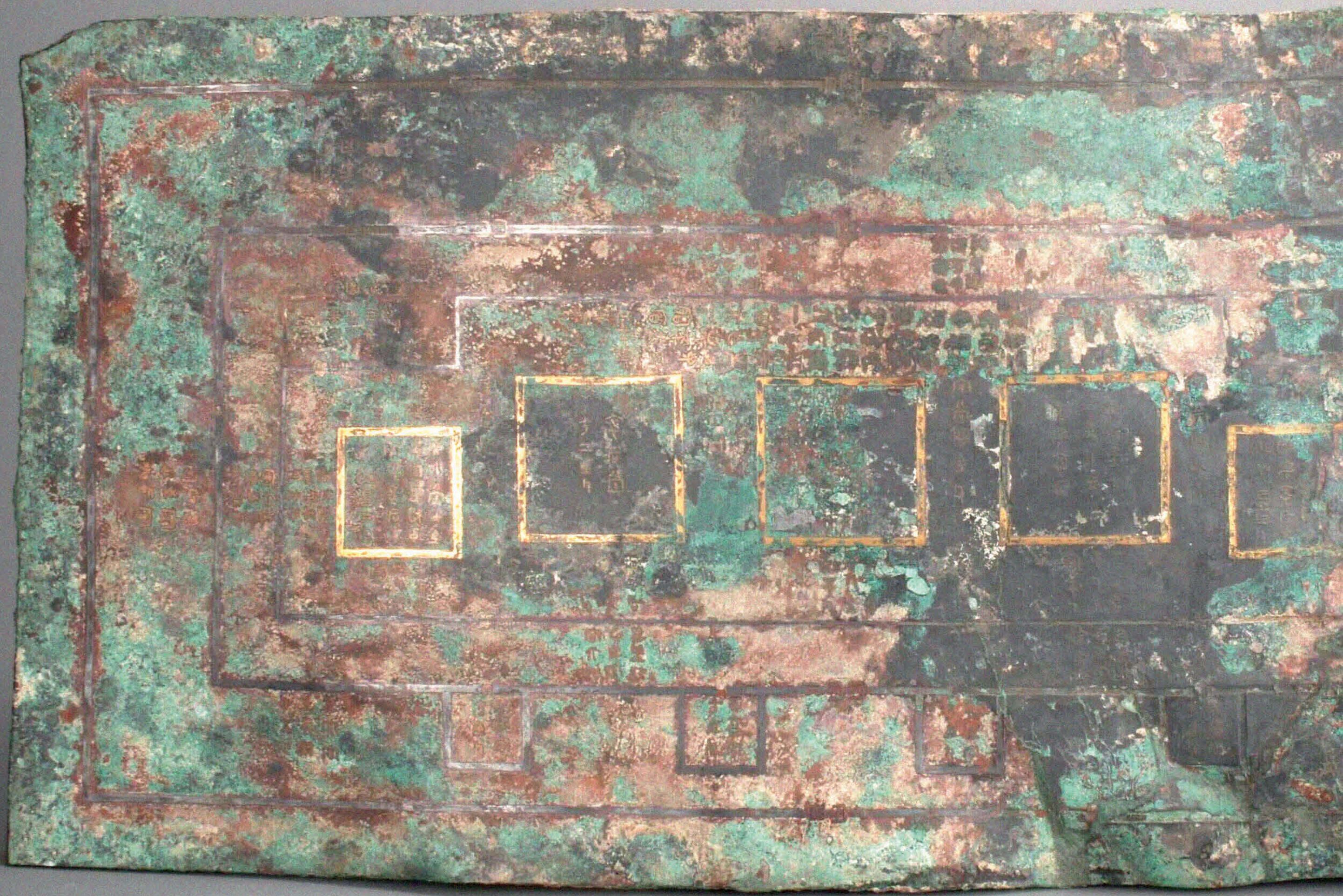


Photo: Hebei Provincial Museum at Shijiazhuang, Hebei Province, China

The Master Plans of the Mandarins

The ancient Chinese invented not only fireworks, porcelain and the wheelbarrow, but the precursor of post-its as well – those self-sticking, yellow pieces of paper used for writing down all sorts of notes. These are the kinds of sources that **Dagmar Schäfer** and her team at the **Max Planck Institute for the History of Science** in Berlin examine to learn more about planning histories and their impact on society, thereby also challenging the paradigms of their own discipline.

TEXT **BIRGIT FENZEL**

Writing things down on countless scraps of paper is not necessarily a sign of a chaotic state. In fact, it can, now and again, mean the exact opposite. This is the case with the yellow notes affixed to sketches, artifacts and memoranda on display at the Palace Museum in Beijing. They have become the object of study of one of the projects headed by science historian Dagmar Schäfer from the Max Planck Institute for the History of Science in Berlin, and their importance goes beyond bearing testimony to the administrative zeal of imperial court officials in bygone times. Together with her department "Artefacts, Action and Knowledge" at the Max Planck Institute for the History of Science, Schäfer uses these kinds of sources to reconstruct and analyze planning histories pertaining to a wide range of projects, eras and cultures. "Our goal is to find out how knowledge is generated by actions and preserved in artifacts," she explains.

Planning is defined as the process of thinking about future actions in order to prepare the decisions that must be made for advancing these actions. "The goal is always to make things work," is Schäfer's "translation" of the intention that lies behind any plan. In this regard, the Chinese precursors of modern post-it notes not only provide thorough insight into the project management methods practiced in a particular time period and culture, but also shed light on the role of management processes and organizational structures in the development of technology and knowledge in general. "For us, each individual project establishes a precedent that we study to reveal how popular certain strategies were, and how people handled them," says Schäfer in explanation of her approach, which always starts from the premise that science is also an ongoing and collective process.

"Most knowledge was not created single-handedly by some lone heroes, but is instead the result of a complex process and collective effort," says Schäfer, who discovered that the collection of artifacts and notes exhibited in the Palace Museum not only constitutes an unusually continuous documentation of the countless ways in which humans planned their actions, but also reveals alternative approaches to creating knowledge in all areas of life. "Planning was part of virtually every type of activity: from baking cakes to studying the night sky to performing experimental lab work." The remarkably broad spectrum of instructions and directions issued in ancient China also grant her insight into what people at that time perceived to be their ideal universal order and methodology. "The concept of planning consisted in understanding the importance of small details for the overall big picture," Schäfer says, describing the recurring approach to many planning histories. >

Weighty artifact: This approximately 2,300-year-old bronze plate, roughly 100 by 50 centimeters in size, reveals the significance of planning processes in ancient China – the representational value of the floor plan portraying the tomb of the king of Zhongshan is essentially equivalent to that of the mausoleum itself. The symmetrical contours of the building are depicted with gold and silver inlays, while engraved text fragments label the objects, state measurements and distances and refer to an official directive. As a result, this document shows that a highly developed administrative apparatus was already in place.

Due to its use as a decorative flower, food source and medicinal ingredient, lotus was cultivated extensively. The lotus money generated with this product is listed as a separate currency in the financial records archived in the administrative files.

One of the sources she mentions is the renowned philosopher Zhu Xi (1130–1200), who preached to his contemporaries that the key to successfully executing big plans was to bring order into the small, everyday things. “The way he saw it, the correct placement of the ancestral shrine in each individual household was the first step in the process of organizing society and state,” Schäfer says, as she explains the beliefs of the famous teacher who served as adviser to the emperor during the Song dynasty, which lasted from 960 to 1279.

A COMPLEX WEB

According to the science historian, the planning histories also highlight the significant impact that the historical process of negotiating between the ideals and realities of political, social and material order had on the development of cultures of knowledge. “That’s because the clash with reality also meant that the question of whether knowledge and methodologies could be generalized beyond the scope of specialist areas was put to the test time and again,” Dagmar Schäfer determined. The popularity trend of the yellow notes ran parallel to the – at times futile – attempts of court officials to gather technical and artisanal expertise and production at the imperial court. She regards these notes as being elements of an increasingly complex web of codifications and models introduced by the Qing dynasty in response to problems that arose in the management of certain areas of production when putting the grand master plans of the Mandarins into practice.

After all, just like the Song emperors, the Qing emperors, who reigned from 1644 to 1912, also regarded the skilled crafts and trades to be the key to economic success, giving them top priority by declaring them a matter of the court. The emperors even held their officials personally accountable for the growth and prosperity of silk production, porcelain manufacturing and other money-making trades. “One of the notable elements that set the Manchurian Qing dynasty apart was the fact that it institutionalized a body of experts at the imperial court,” Schäfer explains. The task of these technocrats, many of whom had little or no formal education, she says, was to oversee and assist in the technology-, material- and organization-related steps that led from an idea to actual production and application. This systematic integration of workshops into the state’s bureaucracy apparatus was fueled by the desire to be a part of it all: The Manchurian rulers fought for access to and control over areas of knowledge characterized by Chinese tradition and expertise.

Yet the craftsmen were not necessarily willing to make themselves or their trade secrets – many of which had been in their families for generations – fully available to the emperor. One example that Schäfer came across in her research consists of countless written records by imperial court officials who countered the state’s official account by documenting how difficult it was for the court to entice the best craftsmen from cities such as Hangzhou, Nanjing and Suzhou to leave the rich South and settle in the northern capital of Beijing. “Attempts at persuading jade carvers to relocate to the court failed on a regular basis,” she reports. The same applied to silk spinners and weavers: Due to the arid climate and lacking proximity to their traditional markets and production areas, the court robes and tribute silks they produced in Beijing would have been of an inferior quality, which is why they steadfastly refused to move to the imperial court. “Experts who were resettled against their will tried every trick in the book to be granted early release from service.” The imperial workshops at court gradually turned into “design studios,” while the actual production activities remained in Jiangnan, Schäfer explains. Consequently,

Photo: Harvard University

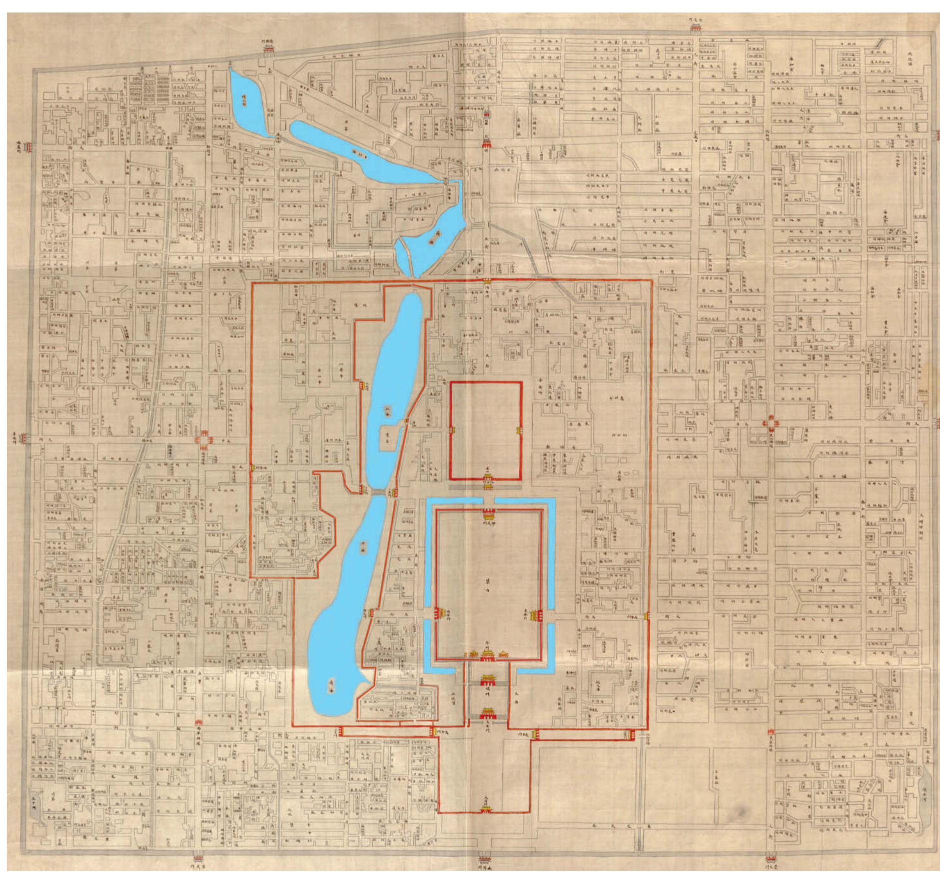
» Most knowledge was not created single-handedly by some lone heroes.

the researcher learned by comparing order specifications and surviving artifacts, even the meticulously elaborated production plans could not prevent a certain amount of frictional loss – a problem that is all too prevalent in our modern day and age as well, especially in the top-down approach that is commonly applied in project structure planning. Even back in ancient China, the devil – as is so often the case – was in the details.

LUCRATIVE LOTUS MANAGEMENT

Another example illustrating the utmost precision with which the Qing dynasty organized its administrative structure was the cultivation of lotus, which is the object of study of Schäfer's colleague Martina Siebert, who summarizes her project in a charming manner: "This plant was part of the imperial household, which was essentially a kind of palace machine that 'produced' money, matter and identity for the Manchurian imperial court." Between the 17th and 19th centuries, the cultivation of this aquatic plant, which is highly prevalent across China, was developed into a complex system. "The regulations sometimes also stipulated the minutest steps," says Siebert. The court even issued instructions regarding the yellow hue and textile quality of the pieces of cloth in which the roots were to be wrapped and handed over to the palace kitchen. (The roots came from a shallow, 47-hectare body of water in the West Park, where lotus plants were cultivated on a grand scale right next to the Forbidden City in Beijing.) Or rules that dictated how to turn worn-out boat punt poles into the scythes that were used to cut off withered lotus leaves or trim the vegetation growing on the rooftops of the buildings.

And then there were other tasks that the court let the gardening department organize and carry out on its own. The only requirement was for the department to disclose all financial expenditures to the central office of the imperial household in the form of monthly or annual reports. This autonomy was partly based on the income generated by leasing a total of 212 hectares of water gardens suitable for growing lotus in the "Inner City" and northwest and south of Beijing, as well as by selling excess lotus cultivated in the West Park. By examining the meticu-



The meticulous documentation of even the smallest steps of lotus management also comprised a precise definition of the cultivation areas (shown here in blue) in the Imperial City (red outline) and beyond the palace grounds.

Photo: Library of Congress, Geography and Map Division

» The key to successfully executing big plans is to bring order into the small, everyday things.

lously archived financial records, Siebert found out how lucrative lotus management really was. In 1814 the gardening department generated a revenue of around 57 kilograms of silver, which was listed in the administrative files and regulations as “lotus money” and virtually treated as a currency in its own right.

PROJECT PLANNERS THOUGHT OUTSIDE THE BOX

Yet lotus had more than just a monetary value, Martina Siebert recounts. The plant was an ingredient used in cooking and medicine, a decorative garden flower and an agricultural product – and required a whole lot of work. “Due to the fact that the flowering lotus was an important visual element of the West Park’s landscape and surely served as the inspiration for the occasional poem, vast amounts of withered leaves had to be cut off and carted away in the fall. In order to harvest the lotus roots, helpers had to wade through the muddy, shallow lakes, loosening the soil through treading and pulling out the horizontally growing root chains.” Martina Siebert summarizes this organizational effort by pointing out that all of these activities needed to be coordinated with the schedule of court receptions of foreign delegates, ritual ceremonies and imperial festivities.

Planning histories such as these provide the Berlin-based science historians insight into how and when knowledge was systematized, what was put down in writing, what was considered expertise, and which areas and processes were taken for granted or deliberately ignored. The researchers also discovered that new knowledge was continuously gained that was in fact not restricted to the respective project or product, but instead developed only after variations had been introduced into the ongoing process.

“Historically speaking, knowledge was often created as the result of people trying to solve specific problems,” says Schäfer. Yet a large number of her examples indicate that, despite their strong focus on practical application, many Chinese project planners also thought outside the box. While researching an episode from the history of livestock farming, Schäfer came across a prime example of lateral planning. When the Song state lost political control of the north in the 10th century, this development entailed the loss of oxen and horses, which were traditionally bred in that very region and were vital for transport and military efforts. As a countermeasure, the imperial officials not only set up their own stud farms and breeding establishments, but also founded a separate area of expertise called “Methods for Compensating for Diseases and Disorders.” In addition to rules regulating the care and treatment of humans and animals, this field encompassed ideas on water engineering, seed selection and moral education, as well as on the teaching of knowledge related to language, literature and philosophy.

“In China, the sciences were promoted very differently than in Europe,” says Schäfer. For an extensive period of time, the Western world believed that the key to enlightenment was theoretical knowledge. “Yet if we look at Chinese planning histories, we see that practical implementation was highly influential in the development of scientific thinking and activity.” This provides her with more than one piece of evidence showing that the boundaries between the history of science and the history of technology can’t be as clearly drawn as some like to believe. “Our findings certainly add another dimension to the extensive debate about the role played by the history of technology,” she says with conviction. But perhaps even more important for her is the realization that continuing to scrutinize the traditional paradigms of the history of science is the right thing to do. “I believe that my work in China shows where it’s worth taking a closer look in all regions of the world.” ◂

TO THE POINT

- **The plans forged by officials of the imperial court in China can still be retraced centuries later. Sketches, invoices, plans, notes – in short: all kinds of artifacts – help science historians reconstruct planning histories.**
- **Planning histories can shed light on the defining elements of individual cultures of knowledge: Which processes and structures shaped actions, and how did the ideals and realities of political, social and material order flow into these actions?**
- **The cultivation of lotus at the imperial court during the Qing dynasty provides two key insights: first, that this plant played a comprehensively regulated double role as a decorative flower during the blooming season and as a food source during the root harvest; and second, that – symbolically speaking – the cultivation of lotus was a small cog in the wheel of the palace machine, which was supervised by the imperial household and generated money, matter and identity.**

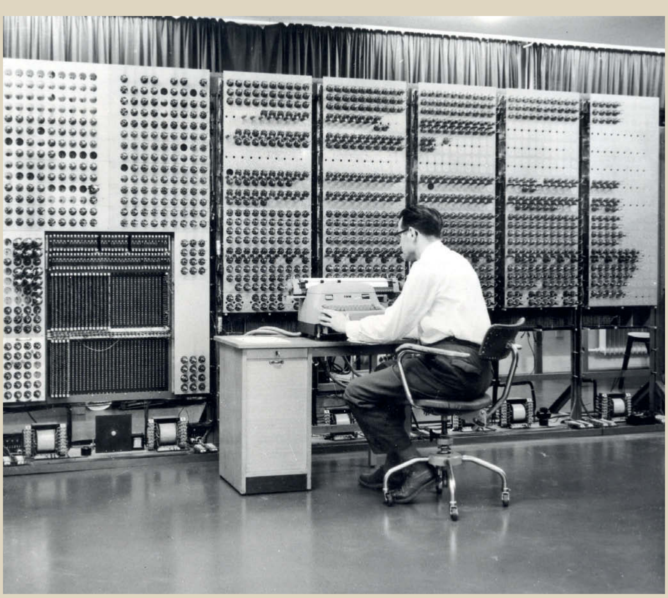
When Computers Learned To Compute

Science without computers? Unthinkable, nowadays! Yet over half a century ago, that was commonplace. Then, in the early 1950s, mathematician and physicist **Heinz Billing** entered the scene – and introduced the Max Planck Society to electronic computing. It all started with the “Göttingen 1.”

TEXT **TIM SCHRÖDER**

Many students at the Max Planck Institute for Physics were surprised when they entered the auditorium for the first time. Coming from the last room on the right was a loud chugging noise. Peering through the door’s frosted window pane revealed nothing. Yet through the ventilation holes that someone had drilled in the bottom door panel they heard a powerful ticking noise, as if from 100 clocks. Initially, none of the young students really knew what was hiding behind the frosted glass pane. And the sign reading “G1” next to the door only made matters even more mysterious. When Heinz Billing finally unveiled the secret during a lecture, they were all the more fascinated.

The G1 could be considered Germany’s first supercomputer. And its creator, Heinz Billing, the pioneer who taught the Max Planck Society how to perform electronic computations on a major scale. Back then, in 1952, most Germans had other things on their minds. The war had left behind a ravaged country. People tried to slowly settle back into a normal day-to-day life. And the same applied to the country’s colleges, universities and research institutes, where scientific activity was only gradually beginning to pick up pace again. In the Max Planck Society, hardly anyone thought that mainframe computers would one day be solving questions posed in astro- and plasma physics. Heinz Billing did.



Heinz Billing had studied mathematics and physics during the 1930s. After obtaining his doctorate, he applied to the Institute for Aerodynamic Testing (AVA) in Göttingen in 1938 to avoid military service. He was drafted anyway. Luckily for him, he didn’t have to fight at the frontlines: the former director of the AVA was able to convince the authorities that Billing was “indispensable” for the institute. Since radar technology wasn’t yet very sophisticated back then, he wanted Billing to develop microphones for fighter planes that could detect enemy aircraft by their propeller sounds. However, this meant suppressing the noises made by the plane’s own propeller.

Billing came up with the idea of damping the plane’s own propeller sounds in the microphone signal. To do this, he produced a recording of the propeller noise and glued it onto a small rotary drum, thus creating an infinitely looped audio tape that he could use for his experiments. He wasn’t able to suppress the noises, because the rhythm of the humming propellers was just too irregular. But what Heinz Billing had in fact created – albeit unwittingly – was the key to Germany’s first research computer.

After the war ended, work was temporarily suspended for several months and wasn’t resumed until the fall of 1945. Institutes belonging to the precursor of the Max Planck Society, the Kaiser Wilhelm Society, moved into the old AVA building, including the Institute for Physics with Werner Heisenberg, Max von Laue and Carl Friedrich von Weizsäcker, as well as Max Planck and Otto Hahn. Surrounded by outstanding physicists, Heinz Billing was now in excellent company. He began searching for a new field of activity and set up the laboratory for high-frequency technology.

In the late summer of 1947, British computer experts visited the institute, among them the British computer science pioneer Alan M. Turing, who had managed to crack Germany’s Enigma machine during the Second World War. In conversation with the British visitors, Heinz Billing learned that they were working on something called the “automatic calculation engine.” He was enthralled and began designing a calculation engine of his own: the “Göttingen 1” – G1.

In June 1950, the engine was complete. Just like today’s computers, it operated using binary code, where letters and numbers are represented by zeros and ones – the number 1, for example,

Masterpiece of engineering: The Göttingen computer G3, here being put into operation in 1960. Sitting at the console is Billing’s colleague, Arno Carlsberg.

Photo: Archive of the Max Planck Society would read "0001." In Billing's calculation machine, the states 0 and 1 were mostly set using a mechanical relay that switched back and forth between "power on" for the 1 and "power off" for the 0. Approximately 100 relays ticked and clicked ceaselessly and produced a constant noise that the students would hear on their way to the auditorium.

Apart from the relay, Billing also equipped the machine with 476 small electron tubes of the kind that were used in tube radios at that time. These tubes were able to switch back and forth much faster than the mechanical relay. The beating heart of the G1 was a magnetic drum memory, which Heinz Billing had developed several years prior. Even though it rotated at 3,000 rpm, its capacity – compared to today's computers – was extremely small. The memory could store only up to 26 numbers. An arithmetic operation such as multiplication took approximately one second.

Yet back then that was roughly ten times faster than the performance of conventional mechanical calculation machines. For his physicist colleagues, the G1 was extremely important. Especially Ludwig Biermann, head of the astrophysics department in Göttingen, used the machine frequently. Along with Billing, Biermann was the one who recognized the potential that electronic calculation machines held for scientific research.

Ludwig Biermann encouraged Heinz Billing to build new machines. Thus, in 1955, Billing unveiled the G2, which was comprised solely of electron tubes and was able to compute ten times faster

Süddeutsche Zeitung, April 29, 1982

» Heinz Billing, who pioneered the development of electronic computers in Germany, is now being honored with a commemorative colloquium held at the Max Planck Society in Munich in celebration of his newly conferred emeritus status. In 1948 Billing (…) invented the magnetic drum memory for computers.«

than its predecessor. Friedrich Hertweck, who was a student in Göttingen at that time and later went on to head the computer science division at the Max Planck Institute for Plasma Physics in Garching, remembers that time well. "The G1 behind the frosted glass pane and the G2 fascinated me – and I earned a little bit of money watching over the machines at night," Hertweck says today.

As the memories of the G1 and G2 were still so small, calculation programs were fed into the machines in the form of punched tape. Intermediate data was also punched into tape and then fed right back into the machine so the latter could perform new calculations. Sometimes a tape would jump out of the guideway, or a relay would snag. "That meant someone had to be there at night to remedy the malfunction," says Hertweck.

Hertweck also remembers Heinz Billing very well: "Billing was full of energy – and yet he was a quiet guy who you'd often see leaning against a doorway with a cigarette dangling from his lips." In Friedrich Hertweck's opinion, Billing's great achievement was that he provided science with calculation engines in the 1950s and 1960s, even before mainframe computers were commercially available.

Final switch: Computer pioneer Heinz Billing at his computing machine, the G3, as it is being powered down for the very last time – after 12 years of service – during a small ceremony on November 9, 1972.

Back then, many scientists wavered between being excited about these novel calculation machines and rejecting them. A working group of astrophysicists in Heidelberg asked the computer scientists from Göttingen to calculate the trajectory of a newly discovered asteroid using the G2. At the same time, the Heidelberg team had around 20 secretaries perform the same calculations with the help of small tabletop calculation devices.

Ultimately, the results produced in Göttingen diverged significantly from those in Heidelberg, leading the astrophysicists in Heidelberg to believe that the calculation engine in Göttingen had failed. It later turned out that it was, in fact, not the machine that had been too inaccurate, but the calculations from Heidelberg. "It wasn't until the 1960s that people started realizing how important mainframe computers are for conducting research," says Hertweck.

In 1958 the Max Planck Institute for Physics moved from Göttingen to Munich and was renamed the Max Planck Institute for Physics and Astrophysics. In 1960 the G2 was superseded by the G3, which was already capable of performing between 5,000 and 10,000 operations per second. That was also the time when the world's first commercially available mainframe computer, the IBM 7090, was launched on the market. Heinz Billing was the one who always advised the Max Planck Society in all matters regarding the purchase of these machines, which cost several million Deutschmarks at the time. He was thus elected chairman of the Advisory Committee for Computers founded in 1968.

Even though computer pioneer Heinz Billing was ahead of his time, he never went on to become a major manufacturer of commercial computers. But that wasn't necessary. "I believe he was absolutely content that his machines paved the way for countless scientific projects," says Friedrich Hertweck. By the time more and more industrial mainframe computers became available on the market, Billing returned to his original area of expertise: physics. He now worked as an astrophysicist, seeking to prove the existence of gravitational waves – the cosmic echo of the Big Bang – postulated by Albert Einstein.

Today, Heinz Billing lives in Garching. Around the time of his 100th birthday in April 2014, American scientists researching in Antarctica claimed to have detected gravitational waves for the first time ever – though that was an error, as it later turned out. But perhaps Heinz Billing's great passion is mainframe computers after all. "Sometimes I hear my father talk in his sleep," says his son Heiner Billing. "Just a few days ago he said: 'Now we have to recalculate which algorithms we can use to multiply two large numbers.'"

Photo: Archive of the Max Planck Society

Nobel Knowledge at First Hand

Young scientists exchange ideas with 65 Nobel laureates on Lake Constance

"One thing is certain: when the Nobel Meeting is taking place, the average age around here drops by a good 20 years," says a bookseller jokingly, as yet another group of young participants hurries past his shop clutching their trademark gray canvas bags. They have to be quick, their program timetable is tight.

For 65 years now, the Lindau Nobel Laureate Meetings have been crammed with lectures, master classes, dinners and receptions – it's often not until the events wind down in the evening that the opportunity arises to dangle tired feet in the water and catch a breath down by the harbor. Explaining the relaxed atmosphere, a Japanese doctoral student relates that "the only ones here who really feel the stress are the organizers and the journalists – everything is already organized for us junior researchers, and each of us has a personal timetable." Then, with a smile, he bites into one of the famous local apples in his lunch packet. He was one of around 650 junior scientists from almost 90 countries who came to meet with 65 of the world's finest scientists. Also among those attending were 19 Max Planck doctoral students and postdocs who, as a whole, reflected the theme of the Meeting: the interaction between the research fields of biology, medicine, chemistry and physics.

The fact that interdisciplinary thinking often comes to the fore only when scientists find themselves in difficult situations is likely to have been one of the central topics of discussion at this 65th Nobel Meeting. More than ever before, the laureates showed themselves willing to talk about the obstacles and setbacks that proved to be a decisive a decisive spur to their research. Among those invited to Lindau for the first time this year was Max Planck Director Stefan Hell, 2014 winner of the Nobel Prize in Chemistry. In his quest to develop high-resolution STED microscopy, which supports the analysis of objects even smaller than the wavelength of light, he too had to bridge the boundaries between physics, chemistry and biology.

Does the recipe for success lie in a willingness to take risks? "Of course," said Hell during a panel debate in Lindau's municipal theater: "It worries me that people today prefer to polish their résumés, rather than having the courage to devote themselves to a problem regardless." He believes that financial and structural safeguards should be put in place to allow junior scientists to pursue such risky projects and ideas.

The MPG provided 2,500 euros in funding for each of its junior scientists who attended the Lindau Nobel Laureate Meeting. And not only that: all of the Max Planck scientists, both junior and renowned, enjoyed an opportunity to exchange ideas in a relaxed atmosphere at the Max Planck dinner on June 30.

What did you gain from the Meeting in Lindau?

Ashok Keerthi, 28, doctoral student at the MPI for Polymer Research
The energy among all of the participants in Lindau is impressive, and was really infectious! I found myself thinking of what Harold Kroto once said, that one should "approach a problem with the curiosity of a child – they don't know where they are going, but go they will." And that's just how most Nobel laureates seem to achieve success; they just keep on going, out of sheer curiosity. At the Max Planck dinner Theodor Hänsch told us that even at the age of 73 he still has his own laboratory with apparatus that he alone uses. "Don't you ever rest?" we asked him. And he replied: "Of course I do! I rest in my office when I'm experimenting!"

Johanna Lampinen, 27, doctoral student at the MPI for Biology of Ageing
The interdisciplinary focus was, in my opinion, a huge gain: The participants didn't know one another in advance, and they were all quite open and communicative. That was precisely how I got to talking to Richard Roberts. He gave me the courage to choose a topic that has defeated many who came before me and that I had always been advised against. Who knows? Maybe I'll follow it through. As I discovered time and again in Lindau, this stubbornness seems to me to be an important success factor. So far, I haven't found the right question to ask. But if I were to do so, I would certainly take the risk and get to work.

Fotos: Adrian Schröder / Lindau Nobel Laureates Meeting (4)

Hang Su, 34, doctoral student at the MPI for Chemistry
My career in science has, fortunately, progressed smoothly so far, the tips I gained in Lindau were nevertheless very inspiring. For example, the Nobel laureates were very honest about the times when they really felt unmotivated and no longer knew where to turn. In fact, I learned something very important: However exciting risky projects may be, it is essential to maintain a balance between risk and security. If there's a question to be asked that presents a lower risk, and can be answered using standardized procedures, it makes sense to address it. With this approach in mind, after visiting Lindau I was able to rethink and newly plan one of my current experiments.

Aoife Fogarty, 27, doctoral student at the MPI for Polymer Research
The most important message that I learned in Lindau was that it doesn't matter whether your career fits any standard pattern. Even the careers of the Nobel laureates are littered with detours, obstacles and odd decisions that often put them on the right track. The most important things along this tortuous path are to ask valid scientific questions, to believe in oneself, to be determined, and to have an eye for detail. If I can manage all that, I could well imagine working as a scientist until well into old age. After all, in Lindau we met scientists who, at well over 80, are still busy in the laboratory on a daily basis. That really impressed me.

Prince's Programme Provides Career Springboard

The MPG has used the prize money that accompanied its Prince of Asturias Award to fund a grant programme to support Spanish junior scientists – that's how Belen Masia came to the MPI for Informatics as a postdoc

Belén Masiá at an MIT Technology Review Innovation Conference

After just a short time at the institute in Saarbrücken, Belen Masia is now set to spend two years at the University of Stanford, with which the MPI for Informatics has been successfully operating a virtual institute since 2003. When that time is up, she will then set up a Max Planck Research Group in Saarbrücken. "This is a unique opportunity for me," says the 29-year-old. It was while studying for her doctorate at the University of Zaragoza in Spain that she acquired the expertise that now underpins her career in Germany. While still in Spain, she made her first contacts with scientists at the institute, and is now able to build on those.

Belen Masia is one of 19 grant recipients who have taken part in the Max Planck Prince of Asturias Mobility Programme. The funding derives from the Prince of Asturias Award for International Cooperation presented to MPG in the fall of 2013 by the then Crown Prince, now the King of Spain. The then MPG President, Peter Gruss, made the decision that the MPG should use the award to finance research residencies for Spanish junior scientists at MPIs. The 50,000 euros in prize money was matched with an equal amount of MPG's own resources, providing a fund of 100,000 euros for grants. As a result, 17 doctoral students and postdocs were able to benefit. One of the postdocs was Belen Masia.

Highly-qualified women like Belen Masia are rising to the very top in the field of informatics. "We are still a minority in a male domain," she says, "but we are catching up." She has had no difficulties so far in making her way in a competitive environment, but finds it rather an incentive to repeatedly reinvent herself.

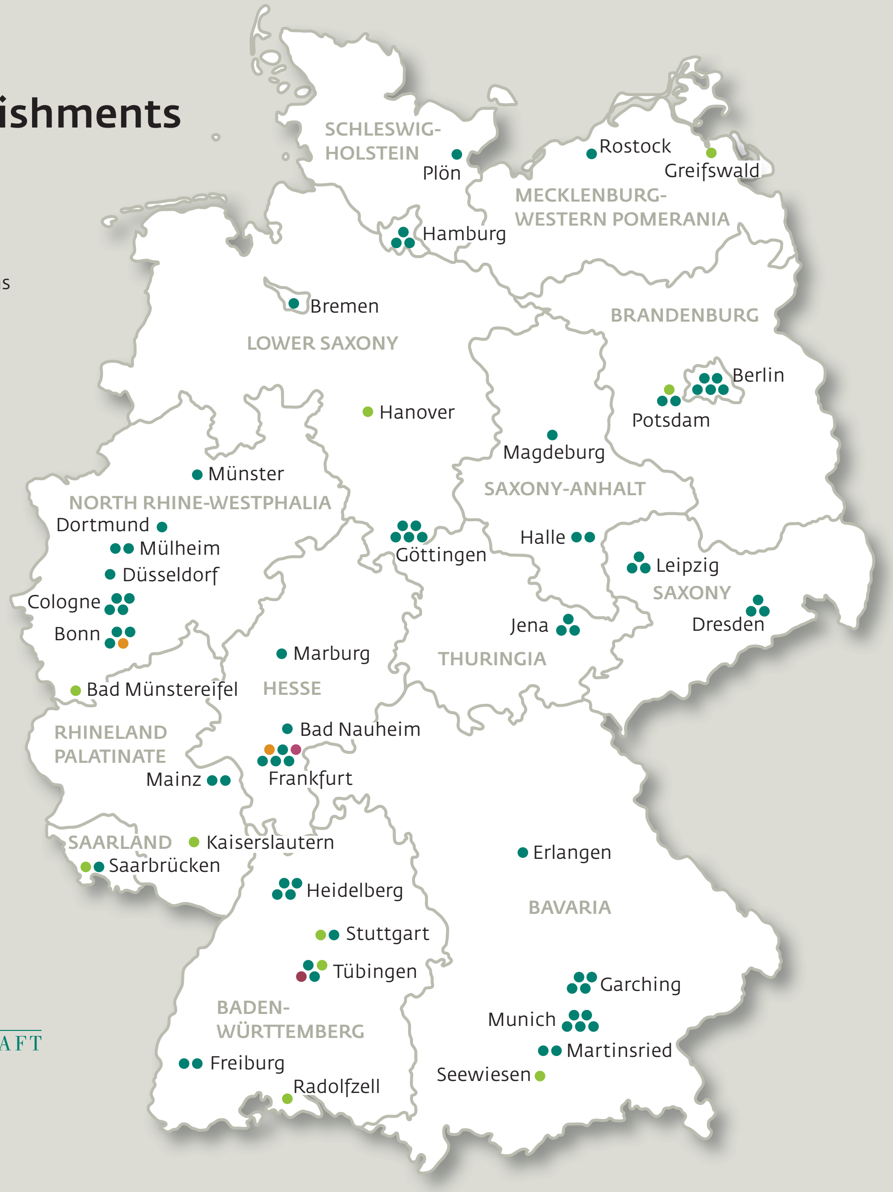
This also includes traveling a great deal. After spending time at the MIT Media Lab in Boston, as a visiting scientist at Microsoft in Lisbon and with China's Broadband Network and Digital Media Lab in Beijing, she earned her doctorate in Computer Science and Systems Engineering in Zaragoza.

"Sadly, research funding in Spain is constantly being cut back and many grants have been frozen entirely," she relates. Even if things improve in the coming years, she believes that research in Spain will take some time to recover. Nevertheless, she would sincerely like to return home one day. Until then, her nomadic existence will continue. "What's next? Who knows?"

In 2013, the MPG received the Prince of Asturias Award for International Cooperation.

Foto: MIT Technology Review (Screenshot); Prinz-von-Asturien- Stiftung (unten)

Research Establishments



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