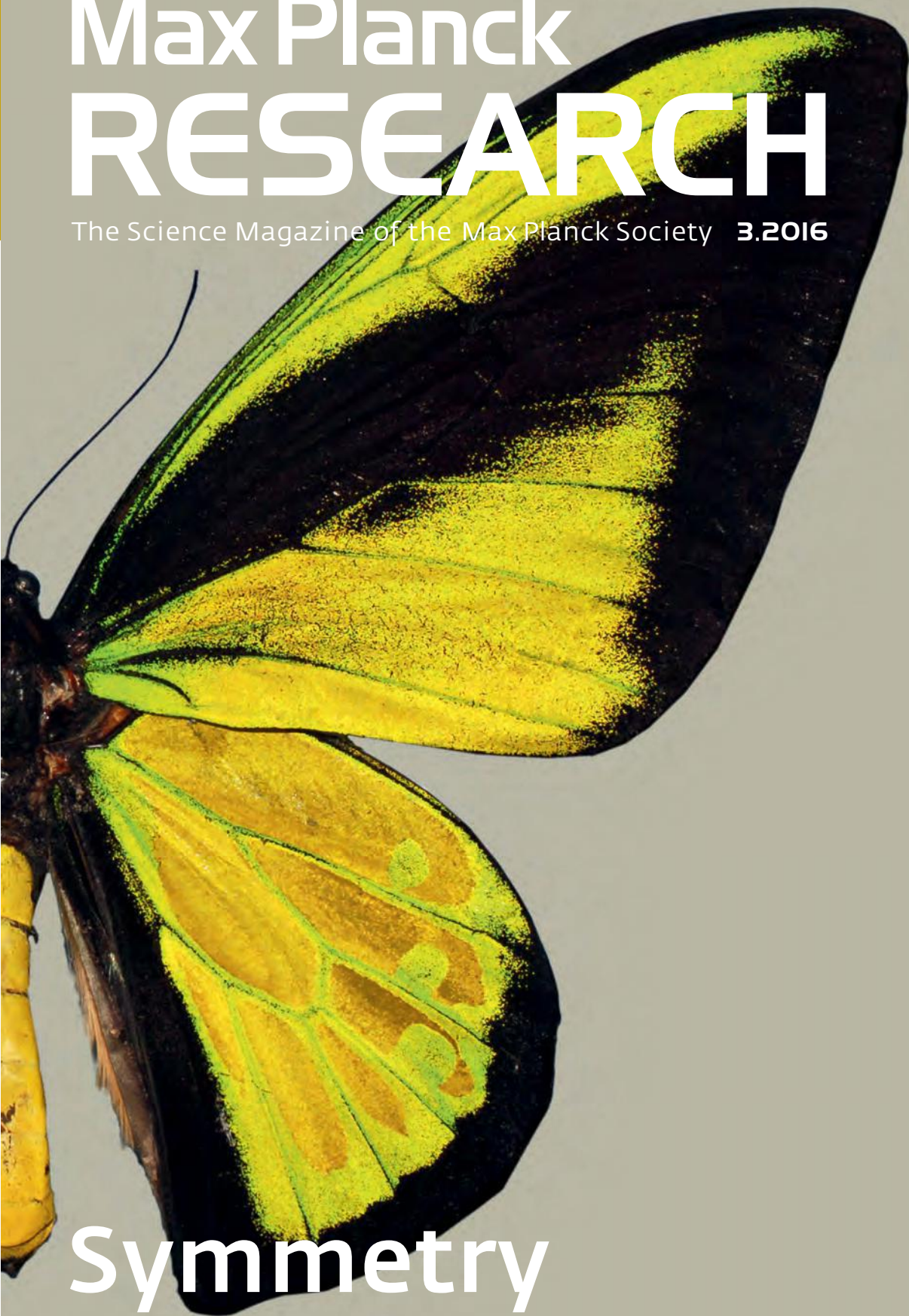


Max Planck RESEARCH

The Science Magazine of the Max Planck Society 3.2016



Symmetry

RESEARCH POLICY

Digital
Turning Point

ORNITHOLOGY

The
Master Singer

INFORMATICS

Computers
Make Faces

SOCIOLOGY

The Price of
Uncertainty



SIEMENS

Ingenuity for life

Pictures of the Future

The Magazine for Research and Innovation

Dossier – Autonomous Systems

About one of the most revolutionary developments in industrial history.

[siemens.com/pof-autonomous-systems](https://www.siemens.com/pof-autonomous-systems)



Photo: MPI for Empirical Aesthetics./Jörg Baumann

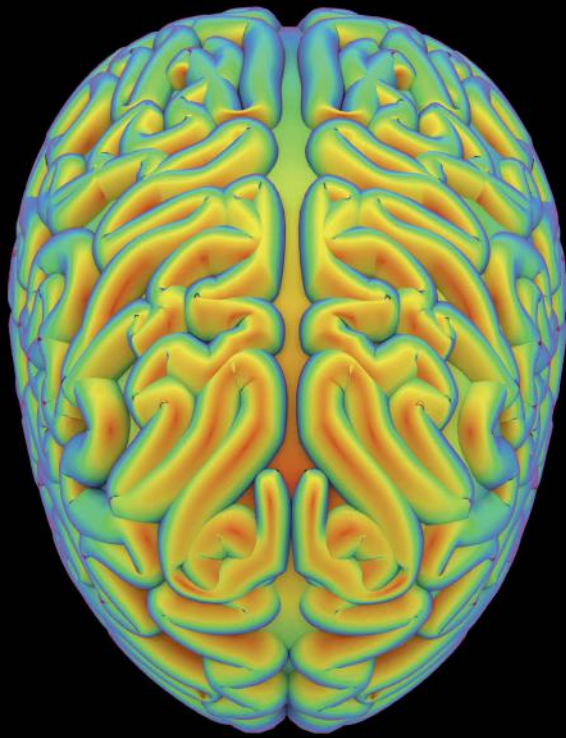
A Matter of Taste

When it comes to music, tastes obviously differ. But why do people actually play and listen to music? Why do they still go to concerts when they have long been able to listen to everything on sound storage or digital media? What does a music experience consist of? The right place to look for the answers to these questions is the ArtLab of the Max Planck Institute for Empirical Aesthetics in Frankfurt. Thanks to its special technical equipment, the Institute's multifunctional event room is a concert hall and a laboratory rolled into one. Sounds, facial expressions, gestures, interpretations and various physiological data from the artists and up to 46 listeners can be synchronously recorded and evaluated.

In May 2016, the vocal ensemble Cut Circle visited the Institute. The researchers in the ArtLab had access to the American octet and its conductor Jesse Rodin for three days. While the singers performed a wide range of pieces from their vast repertoire of early music, comprehensive data was tracked, such as EEG, ECG, respiratory rate and the artists' movement patterns.

At the final concert, however, the research focus was shifted to the audience. While the concertgoers listened to the performance, adhesive electrodes on their fingers measured their skin conductivity, and an armband took their pulse. At the same time, they used tablets to self-report information about their reception and assessment of the performance.

Incidentally, the evening program, entitled "My Fair Lady," referred to the strong veneration of the Virgin Mary in the 15th and 16th centuries, a phenomenon that is also reflected in the music of that period.



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Bilateral symmetry – mirror-image body halves – is a basic structural principle of higher organisms. Jochen Rink from the Max Planck Institute of Molecular Cell Biology and Genetics is studying flatworms to discover how symmetrical body structures arise.

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Everything in the universe owes its existence to a tiny imbalance between matter and antimatter. How it came about is a fundamental question of physics. Research groups at Max Planck Institutes in Heidelberg, Munich and Garching are using different approaches in their quest for an answer.

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At first glance, the body appears to be symmetrical, but in reality, it isn't. The asymmetry of the brain, for instance, seems to be an important factor in the functioning of our thought, speech and motor faculties. Researchers at the Max Planck Institute for Psycholinguistics are investigating the reasons behind this phenomenon.

ON THE COVER It's found in the basic building blocks of matter and in the vast expanses of the universe, in flowers, in butterflies and in our own bodies: symmetry is deeply embedded in nature. Perfect symmetry, however, is rare, and it is often precisely the little differences that offer the key advantage for our existence.

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It's becoming increasingly easy to store, transfer and analyze huge volumes of data. This can create a new dynamic in science.

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Focus on IT

Max Planck Society meets in Saarbrücken for its General Meeting




Turning point: Max Planck President Martin Stratmann opened the Plenary Assembly, which took place at the Alte Schmelz industrial heritage venue near Saarbrücken, with a talk on the significance of digitization.

fers to the increasing connectivity between everyday items and the internet, and between one another. The keynote speaker, Adi Shamir, cryptology expert and Turing Award winner from the Weizmann Institute in Israel, addressed the challenges presented by this development, especially in terms of data security.

Shamir subsequently discussed his theories at the podium with Dietmar Harhoff from the Max Planck Institute for Innovation and Competition, Ulrich Sieber from the Max Planck Institute for Foreign and International Criminal Law and Joachim Buhmann, Director of the Institute for Machine Learning at ETH Zurich. The Directors of

Saarbrücken as a location of excellence in IT set the tone for the Plenary Assembly that traditionally brings the Max Planck Society's General Meeting to a close. In his talk, President Martin Stratmann explored the turning point society has reached, brought about by digitization (see page 10 ff.). The focus then shifted to the "Internet of Things," which re-

the Max Planck Institutes and the research organization's main decision-making bodies had met beforehand at the two-day General Meeting.

 Videos from the Plenary Assembly: <https://www.mpg.de/10589352/max-planck-society-annual-meeting-2016>

Award-Worthy Aircraft

Max Planck Society sponsors winner of "Jugend forscht" competition

Germany's top entrants in the "Jugend forscht" science competition for young people received their awards in Paderborn in May. The Max Planck Society has endowed the prize in the physics category for many years now. This year, Karsten Danzmann, Director at the Max Planck Institute for Gravitational Physics, presented the award to Ivo Zell from Hesse. The 17-year-old built a model of a flying wing aircraft, which has optimized aerodynamics and significantly lower fuel consumption compared with conventional airplanes. Nevertheless, these special planes

also have disadvantages: they can easily go into a tailspin and are difficult to pilot.

Based on a concept from the 1930s, Ivo Zell designed a flying wing with stable flight characteristics. He tested its properties theoretically and experimentally using self-designed measuring instruments. While the young researcher was delighted with the award, it also brought back memories for the Max Planck Director: Karsten Danzmann was an award winner himself in the late 1960s in the "Schüler experimentieren" research competition for girls and boys under the age of 15.



Highflier: Award winner Ivo Zell receives his certificate from Max Planck Director Karsten Danzmann.

“They are turning their backs on the Enlightenment”

Ralph Hertwig, Director at the Max Planck Institute for Human Development, criticizes attempts to encourage citizens to behave in a certain way using psychological tricks.

Humans are imperfect. They often take the easy option instead of behaving rationally; they are pleasure-oriented rather than health-conscious. Some politicians would like to change that, particularly when such behavior has public spending implications or is detrimental to health or the environment. Psychologists and behavioral economists from the US have identified new ways to shift public behavior in desired directions. The method is known as “nudging,” and it is also being discussed in Germany. Ralph Hertwig from the Max Planck Institute for Human Development discusses the merits and shortcomings of nudging.

Mr. Hertwig, what methods are being used to encourage people to change their behavior?

Ralph Hertwig: The idea is to achieve the objective without creating financial incentives or imposing bans. Instead, typical human weaknesses, flaws or shortcomings are used that people are generally unaware of. This means most people don't even notice when they are being nudged.

Can you give any specific examples?

A big issue here is organ donation. In Germany, the Organ Transplant Act stipulates that people must be asked to actively consider and decide whether they wish to donate organs after their death – but they don't have to make a decision. The nudging approach would turn the choice around so that everyone becomes an organ donor unless they expressly opt out. And since refusing consent requires more effort than doing nothing, it is assumed that fewer people will object.

Wouldn't more donor organs be desirable?

Of course. Nevertheless, I take a critical view of the approach adopted by using such prompts. It assumes that most citizens would like to donate organs but don't fill out an organ donation form out of sheer laziness. Proponents argue that nudging leads people to make decisions from which they themselves benefit. However, this ap-

proach fails to recognize the diversity of human preferences. There are very understandable reasons for opting not to donate organs. In my view, the decision for or against is so personal and important that everyone should make it consciously.

So you take a critical view of the method?

What concerns me is the underlying view of human beings: it regards them as deficient and too lazy to think for themselves. The nudgers have given up on making people more knowledgeable and encouraging them to use their own reasoning. In a way, they are turning their backs on the Enlightenment.

Haven't we all been subtly influenced for many years, for example through advertising?

Nudging is actually nothing new. Cheap products have long been positioned lower on the shelf in supermarkets and the more expensive ones at eye level so that they sell better. What's new is the use of nudging for governmental purposes, and such tricks being used to influence the public. But this assumes that the government is generally well intentioned – most likely a very naive assumption. The nudgers also apparently deem themselves devoid of the shortcomings that they impute to others.

Are you categorically opposed to nudging?

It's not a black-and-white issue. There are situations where certain forms of nudging can be useful. For example, I believe that making fruit and vegetables easily accessible and candy less accessible in school cafeterias is perfectly legitimate so that children eat more healthily. But you have to carefully weigh up when such methods are appropriate and not simply patronizing, and consider what effect they achieve.

But it is an effective approach isn't it?

Yes, but often with limited scope. In the case of school cafeterias, the nudging effect ends when the kids leave the school grounds. Outside, the children are exposed



Ralph Hertwig

to precisely those temptations that were previously so carefully avoided, such as in the ice-cream parlor, at the bakery and in the supermarket. And eating obviously plays a key role in the family, but the influence definitely doesn't extend that far.

What is the alternative, then?

We have to support people in making good choices, a concept known as “boosting.” To promote healthy eating, we believe that children should be taught from an early age which foods are good for them and why. Parents could be provided with advice on practicing healthy eating habits with their children.

Like nudging, boosting uses scientific findings, but it applies them constructively. A prime example is children who are afraid of numbers and therefore struggle in math. A US study showed that when children are read stories containing numbers a few times a week instead of traditional bedtime stories, and playfully count along with the story and practice arithmetic, their performance in math at school improves significantly. That's exactly how boosting works. Nudging, on the other hand, would play on the fear of math. That's the crucial difference for me.

Interview: Mechthild Zimmermann

Teamwork for the Energy of the Future

MAXNET Energy draws on expertise of ten partners



Joint project: Teresa Sullivan, President of the University of Virginia, and Max Planck President Martin Stratmann signed the agreement on MAXNET Energy.

ity – is not a well developed technology. The catalysts used are either durable but expensive, or inexpensive but wear out easily.

The newly created MAXNET Energy project is looking for a solution to this dilemma. Scientists from a broad range of disciplines are involved, including from the Max Planck Institutes for Chemical Energy Conversion, Eisenforschung (iron research), Kohlenforschung (coal research), Polymer Research, of Colloids and Interfaces, Chemical Physics of Solids, and Dynamics of Complex Technical Systems, as well as the Fritz Haber Institute of the Max Planck Society. Partners from the Cardiff Catalysis Institute in the UK and the University of Virginia in the US are also participating in the venture. A cooperation agreement was signed in April.

A key requirement for achieving the energy transition is the storage of electricity generated by wind turbines and solar plants on a large scale. Power-to-gas plants, which use power from re-

newable sources to generate hydrogen, thus making it storable, offer great potential. However, the electrolysis of water – that is, the generation of hydrogen by splitting water with electric-

New Approach to Treating Schizophrenia

Lead Discovery Center in cooperation with Boehringer Ingelheim

A new active substance for treating schizophrenia is currently being developed at the Lead Discovery Center (LDC). The approach is based on research by Moritz Rossner and his team at the Max Planck Institute for Experimental Medicine in Göttingen. The scientists are examining the role that risk genes, combined with environment-related stress, play in the emergence of the illness and are conducting research into the underlying molecular biological mechanisms.

The goal of the collaboration with the LDC is to build on their research to find a new therapeutically effective substance to combat schizophrenia. The substance would

be developed into a potential active pharmaceutical ingredient that can then be transferred from industry to the pre-clinical and clinical development stages. The pharmaceutical company Boehringer Ingelheim is now also involved following the conclusion of an agreement in May. In return, Boehringer Ingelheim will have the option to exclusively license the new active substance.

The LDC was founded in 2008 as a subsidiary of Max Planck Innovation, the Max Planck Society's technology transfer company. The LDC aims to close the gap between basic research and application in the development of new drugs.



Potential: Moritz Rossner from the Max Planck Institute for Experimental Medicine has obtained highly promising results.

Open House on the Tübingen Campus

Max Planck Institutes invite the public to gain insight into animal testing

At a joint open house in June, the three Max Planck Institutes on the Tübingen campus presented their work to the public. Almost 1,000 visitors attended to learn about such topics as DNA sequencing, motion simulators and robot development, as well as animal testing – particularly at the Max Planck Institute for Biological Cybernetics. Since the release of film footage in September 2014, animal rights activists have been targeting the Institute.

It was of key importance to the scientists to explain the need for animal testing in basic research, and to provide

a first-hand look at the animal holding facilities. A special information room was set up where staff members were available to answer questions. Two in-depth presentations attracted an audience of more than 100 people. “Of course there were some visitors who are fundamentally opposed to animal research,” says Christina Bornschein, press officer at the Max Planck Institute for Biological Cybernetics. “But overall, a lively exchange took place and visitors greatly appreciated our decision to publicly present our research and answer critical questions in depth.”



Transparency: The Max Planck Society attaches great importance to openness in animal research. A brochure explains why animal testing is necessary.

On the Net



Ethnologists' Blog

Whether on refugee policy, the UK's Brexit decision or TTIP, the blog published by the Max Planck Institute for Social Anthropology in Halle is a rich source of information for anyone interested in politics or business. Personal contributions by Chris Hann, Matthijs Krul, Sylvia Terpe, Lale Yalçın-Heckmann and some of their younger colleagues provide food for thought and take readers off to China, Russia, Turkey and other, lesser-known parts of the world.

www.eth.mpg.de/3557160/blog

#ThatsMyScience

The Tübingen campus is introducing its young scientists on a new website: they answer questions about their research, what motivates them and what they like about Tübingen. Videos, photos and posts on Twitter and Facebook arouse curiosity and may well attract students to the city located between the Black Forest and the Swabian Mountains. Participants in the initiative include the Max Planck Institutes for Biological Cybernetics, for Developmental Biology and for Intelligent Systems, as well as the Friedrich Miescher Laboratory.

<http://tuebingenresearchcampus.com/research-in-tuebingen/thats-my-science>

Bringing Dinosaurs to Life

The Natural History Museum (NHM) in London, the Museum für Naturkunde in Berlin and the American Museum of Natural History in New York have launched an online exhibition comprising 300,000 specimens from its collection, as well as captivating 360-degree videos in which the exhibits come to life. The website is the result of a partnership with Google Arts & Culture and follows extensive work to digitize the museums' collections. Visitors can take a virtual walk through the museums' halls and galleries, and browse through nine virtual exhibitions.

Homepage: <https://www.google.com/cultural-institute/beta/project/natural-history>

Video: <https://www.youtube.com/watch?v=p86gh2HEsp0>

Digital Turning Point

There have been enormous developments in our ability to store, transfer and analyze huge data volumes, commonly referred to as big data. Not only are these developments having a dramatic effect on our daily lives, but they are also creating a new dynamic in science, as research fields are redefined and traditional boundaries between established disciplines lose their relevance.

TEXT **MARTIN STRATMANN**

Googling the German phrase “*Chancen und Risiken der Digitalisierung*” (“opportunities and risks of digitization”) together with the term “*Rede*” (“speech”) returns thousands of hits, while entering the same search in English yields a very modest number of results. Evidently the digital society as a discussion topic is in far greater demand in Germany than elsewhere. The question is: Are we talking at the expense of doing? Not just in research, not just among ourselves ... society as a whole in Germany must recog-

ing price decreases. The advent of printing in the 15th century and the Industrial Revolution in the 19th century are two examples of this. How much did it cost at the beginning of the 15th century for a monk to copy a book by hand? And what did it cost just a few decades later to disseminate Luther’s Bible?

How dramatically did the price of high-quality materials decline in the 19th century as machines made them faster and easier to manufacture? And what a technological revolution this decline unleashed! And today? Hardly a week goes by without a significant drop in the price of computing power, data storage and data transfer.

This goes hand in hand with a significant increase in performance: experts expect that, in ten years’ time, computers will be 60 times faster than they are today. The speed of processor chips is currently doubling every 18 months, while, thanks to developments in photonics, the transmission speed of fiber optic cable is doubling every nine months. As a result, we can now store, transfer and analyze vast quantities of data and build high-performance computer networks on a scale that until recently was unimaginable. >

In the heart of the virtual world: High-performance networks now exist on a scale that until recently was unimaginable. By the year 2025, the majority of the world population will have internet access.

In ten years’ time, computers
will be 60 times faster than
they are today

nize the signs of the times and take action. Therefore: Yes, we need to talk! Not just about digitization, but also about the associated transformation that extends to every area of society.

We have reached a turning point. Of course, the world has regularly experienced such turning points in the past, triggered by innovations and the result-



Consequently, our daily lives are changing with amazing speed. For instance, the number of people connected to the Internet rose from 350 million to more than two billion in the first decade of the new millennium. The number of cell phones rose from 750 million to more than 6 billion. By the year 2025, the majority of the world's population will have internet access via mobile devices. And in a single year, the number of people registering for a massive open

learning process, data-driven generation of hypotheses may soon help computers more quickly ask the right questions.

These are pioneering, even revolutionary processes. I do not believe that there has ever before been such a momentous change in so short a time in the history of mankind. Like every previous turning point, this one, too, is technological in origin, but its consequences for society go far beyond technology. The exchange of information, the interaction between individuals, has never before been so easy or so affordable. This in turn raises the quality of the potential results of these interactions to an entirely new level.

The individual is no longer just a consumer, but is now a participant – and that with partly unforeseeable consequences. Examples? We are all familiar with them: revolutions are powered by Facebook and Twitter, opinions are no longer formed by editors and journalists, but by like-minded people inside closed opinion bubbles that are barely penetrable from outside. And of course the internet is not immune to crime. Consider how private computers are hijacked by botnets and manipulated for criminal purposes.

Many – even elementary – life experiences today are shaped by our digital environment. Clearly, where so much innovation emerges in so short a time, the supporting industry flourishes. So how is Germany positioned at this turning point? After the speculative new economy bubble burst, we in Germany apparently lost our enthusiasm for new start-ups. Maybe we failed to fully understand that a turning point is always accompanied by exaggerations and that setbacks must be accepted, but that the underlying trend continues.

There is more to the rise of Google and Facebook, Amazon and Apple, than a simple structural change. The ascent of the software industry is not a bubble, but a fundamental economic paradigm shift. In Germany it seems that we are only slowly becoming aware of this insight. Maybe the considerable economic success of our industrial sector has rendered us a little too self-confident. But we also know from

Knowledge and findings will be available with an ease and on a scale never experienced before

online course (MOOC) at Harvard exceeded the total number of students enrolled in the entire 380 years since the university's founding.

The availability of information in the sciences has changed meteorically: libraries, the cathedrals of knowledge, have moved into cyberspace and are now accessible to almost everyone. This means that information is now nearly as easy to obtain in Chile or India as it is in Munich or Boston. If open access becomes reality as the gold standard for future publications, it will open the door to what I would call the "Google of Science." Knowledge and findings will be available with an ease and on a scale never experienced before. And this much is obvious: the limiting factor will not be the ability to store knowledge, but the capacity to analyze it.

Scientists read on average around 250 articles per year – a tiny sample of the knowledge available. Imagine, then, the spectacular potential hinted at by pilot studies in which IBM's Watson – a computer – is tasked with automatically selecting, extracting facts and even generating hypotheses – all on the basis of published literature. However spectacular this future promise may be, it will not be able to replace the actual scientists. Nevertheless, in the



our own postwar history that major branches of industry can disappear and leave wastelands that are slow to recover.

For us, the decisive questions are: What is the significance of the digital turning point for science? How should the Max Planck Society deal with it? And what needs to happen in order for Germany to maintain its industrial leadership?

I can offer a short answer to the question regarding the significance of digitization for science: it is all-embracing. Whether in physics, astrophysics, materials research, bioinformatics or the digital humanities – the collection, storage and analysis of enormous volumes of data play an increasingly decisive role. This makes another question increasingly important: How can we penetrate, summarize and present this incredibly diverse information in an easily comprehensible form?

Identifying regular patterns and relationships, highlighting structure in the tangled mass of data – this is a core element of artificial intelligence, which reached a major breakthrough in recent years. Not because we developed some kind of super-algorithm – the concepts of machine learning are, in fact, several decades old. But it is only now that we are able to exploit what has long existed on paper, the functional logic of multi-layered neural networks, thanks, on the one hand, to huge increases in computing power, and on the other hand, to the increasing availability of networked data. There can be no machine learning without big data.

Allow me to draw a comparison: artificial intelligence is our new night-vision goggles. By providing us with an intelligent, automated analysis of big data, it offers us a view of the world that we would never see using our conventional, traditional methods. Machine learning is becoming the basis and the interface technology for dealing with huge data volumes – in science and elsewhere.

How is the Max Planck Society responding to this turning point? I can say that we are investing heavily in computer science as the new basic science. Now and in the future, in and across all Sections. And be-

cause this investment cannot be undertaken through growth alone, we are stepping back from established science fields – reluctantly, if I'm honest. However, we have to bear in mind that science is about expanding our existing knowledge, so good science is at home wherever the steepest learning curves are to be

.....
**Good science is at home
wherever the steepest learning
curves are to be found**

found. For us, this means not just addressing new areas of research, but also redefining them, irrespective of disciplines and specialist fields.

In this process, basic principles and applications merge with one another and become indistinguishable; traditional boundaries lose their significance. Can the digital humanities really be separated from computer science or machine learning? And what about social computing: a domain of computer science with no knowledge of social sciences? Science is changing, and with it, the internal structures of the Max Planck Society – institutes that cross the lines between Sections are emerging, fields of work are converging.

Consider this example: At our new Institute for Intelligent Systems located at two sites – in Tübingen and Stuttgart – we cross the borders between engineering, computer science and neuroscience. The institute combines two elements with particularly steep learning curves: cognitive robotics and machine learning.

Previous pioneering achievements in artificial intelligence were developed for systems with a small number of variables and are not yet adequate to facilitate, for example, competent behavior in manipulation robots with high degrees of freedom. Genuinely autonomous behavior is still a long way from realization here. But in the future, the hardware – the



intelligent robotics – will be a fundamental part of the feedback loop consisting of perception, action and learning. This is why, at our institute, we aim to develop and combine hardware and software under the same roof.

This, by the way, is an approach that is extremely promising in Germany. We may not have developed any global internet platforms here, but when it comes to combining learning computer systems with hardware that possesses physical intelligence by design, we do have something to offer.

In locations where the Max Planck Society is restructuring, we also see ourselves as a driving force for supra-regional development. Here at the digital turning point, we are particularly aware of this responsibility. An exciting environment is developing around our Institute for Intelligent Systems in Stuttgart/Tübingen. We named it Cyber Valley. The hope is that it will one day link the Max Planck Institute with the neighboring universities, leading companies, a high density of junior scientist groups and a strong community of spin-offs. In other words, we aim to create a highly attractive cluster with international visibility – a home for scientists and nerds.

Many other projects are also under discussion within our Sections: from small-scale activities to potential new institutes. For example, we are deeply interested in the field of cryptography: How can we make communication today secure? The answer to this question could lie in a convergence of mathematics, quantum physics, optics and computer science.

Neuroprosthetics is quite clearly another field with the potential to be extremely fertile. The goal is to at least partially replace lost functions in the human nervous system with the aid of ultra-small technical systems. Is it possible to approach this goal without machine learning and intelligent robotics?

But also consider such topics as education, the right to be forgotten in the age of the internet, or privacy as a public commodity: all of these issues are of interest to our Human Sciences Section. And lastly, the digital humanities: What lies behind this label, and how do we put it into practice?

One task remains unchanged: the Max Planck Society will continue to build its institutes around outstanding scientists. We want to be a magnet for researchers from around the world in all of the research areas that are of interest to us. However, we must not concentrate solely on established fields in which this task is easily accomplished. We must also dare to venture into fields in which Germany and Europe have,

We need to appoint outstanding scientists in such fields as computer science

as yet, no prominent visibility. Of the 64 winners of the Turing Award to date – the Nobel Prize of the computer science field – 47 came from the US, 6 from England and 11 from six other countries. Not a single one from Germany!

This must not remain the case for the next 20 years. So what does Germany need to do? First of all, we must keep our eyes open: when a computer scientist in Germany scores an outstanding achievement, he or she is easily lured away – not just by Google, Apple and Facebook, but also by the small startups in Silicon Valley, who entice talent with their scope for creative development and flat hierarchies. The STEM gap in Germany is already far too wide.

We must increase our education and training capacities, create attractive research locations and, more than ever before, bring outstanding scientists to Germany – and at the same time stop the brain drain. In other words, we must invest significantly more, and we must do so quickly!

A glance at our history makes it clear that the Industrial Revolution was powered not just by coal and ore, but also by highly skilled labor. In the second half of the 19th century, Justus von Liebig fundamentally changed the study of chemistry. This change produced an entire generation of young

chemists who conducted research in the burgeoning dye factories. One of those was today's BASF, which remains a heavyweight in the chemical industry.

That was also a time of major investment. The universities were developed into international centers of excellence, while a new type of higher education emerged with the creation of technical universities. The Kaiser Wilhelm Society became the cradle of elite researchers in the sciences. Germany still profits from the dynamism of those days: our strong industry has survived catastrophic wars and continues to ensure our prosperity.

At present, the cards are being reshuffled, which is the hallmark of a turning point. Education and research are becoming more important than ever. We must make the same effort today that was made 100 years ago, and create the educational and research institutions that will ensure our prosperity in the decades to come. We must have the same courage.

Thanks to its reputation and its extremely flexible structure, the Max Planck Society can achieve a lot here. But it is also clear that there are limits to the restructuring of institutes. We are neither willing nor able to abandon established fields at the same speed at which computer science is developing, especially since these existing areas are also working very successfully at the forefront of scientific progress. We must therefore be willing to continue to increase our investment in science.

But maybe this also requires an initiative on the part of strong European countries. As the European Molecular Biology Laboratory (EMBL) has shown, a joint effort in the field of biomedicine has achieved a great deal in and for Europe. The EMBL is playing in the same league as Cold Spring Harbor, MIT and the Salk Institute in the US. We need the same commitment in the computer sciences! ◀



THE AUTHOR

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

This article formed the basis for the address given by Martin Stratmann at the General Meeting of the Max Planck Society in Saarbrücken in June 2016.



Tiptoeing through the Rainforest

Max Planck scientists cooperate with partners in around 120 countries worldwide. Here they relate their personal experiences and impressions. Behavioral biologist Amanda Monte is currently working on her doctorate at the Max Planck Institute for Ornithology in Seewiesen. She is researching how hummingbirds communicate in the Brazilian rainforest.

Rainy and not-quite-so-rainy – these are the two seasons in the rainforest. Nevertheless, all seasons in this complex ecosystem are incredibly fascinating for scientists. I work with hummingbirds of the genus *Colibri*. I record their voices and am trying to establish how they learn their sounds – songbirds and parrots, as well.

Unlike in other animals, the sounds these birds make are not instinctive, but a learned behavior – and a highly multifaceted one, at that. Different species of hummingbirds have different communication strategies: there are non-verbal species, which use wing or tail movements to communicate, and species whose males charm the females with the most sophisticated songs in what can only be described as a song competition.

In conducting my fieldwork, I spend many hours walking through the dense fog, my assistant at my side, and carrying, apart from my recording device, only the most essential piece of equipment: a knife. If we're lucky and spot a hummingbird, we observe this creature of rare beauty while recording its sounds and songs. This can be quite a dangerous undertaking! I once built a ladder for myself and almost fell off of it.

But this isn't the most dangerous aspect of my fieldwork in South America by a long shot. And I'm not afraid of snakes or jaguars. What I fear most are humans – the poachers and farmers. Poverty, more than anything else, drives them into the rainforest, where they chop down trees to make room for houses in which they can then live.



Amanda Monte, 29, studied biology and environmental behavioral research and obtained her master's degree in 2012 at the State University of Pará, where she specialized in biostatistics and behavioral theory and research. Since 2013 she has been working on her doctorate under the supervision of Director Manfred Gahr at the Max Planck Institute for Ornithology in Seewiesen. She is currently preparing her first scientific publication.

Although I'm not aware of any incidents involving violent attacks on field researchers, I don't even want to think about what would happen if they came across us. We move around in small groups of just two or three and are basically unarmed. All we have is a knife and an air gun to scare off wild animals. And people looking for a quick profit are far more dangerous than animals here in the northern Amazon, in Gunma Ecological Park, 40 kilometers from Belém, which I visited twice for my hummingbird research.

Fortunately, my second research area is much safer: Professor Mello Leitão's open-air museum in the south, near the Atlantic rainforest, where hummingbirds can fly around freely. All in all, I have recorded 12 different hummingbird species and hope that these recordings will help me gain a better understanding of how they produce their sounds and what strategies they use to do this.

I love my fieldwork. But I'm always glad to return to Seewiesen, too, mainly for the lovely surroundings and the cultural interaction on campus. It's a known fact that Brazilians tend to be isolated in South America because they speak Portuguese. Funnily enough, I learned a lot more about South America in Germany than I did when I still lived in Brazil.



A Worm Seeks Its Midpoint

Artists and architects of all eras have been inspired by symmetry in nature. This is hardly surprising, as symmetry is considered the epitome of beauty – and mirror symmetry is the absolute gold standard. **Jochen Rink** from the **Max Planck Institute of Molecular Cell Biology and Genetics** in Dresden is seeking to discover how organisms define the mirror plane and thereby fulfill the basic prerequisite for a symmetrical body structure. To do this he studies flatworms and their astonishing ability to regenerate missing body parts.

Planarians are almost impossible to kill – at least by chopping them into pieces. A complete worm can form from even the smallest parts; all that is required is the formation of a new body axis.



TEXT CATARINA PIETSCHMANN

While most of the worms sit motionless at the bottom of their culture dish, a few do leisurely rounds through their pool. With barely perceptible movements, they glide elegantly on thousands of microscopic cilia across the bottom of the plastic container they call home. This would be quite a majestic sight were it not for their large and rather comical eyes. Planarians squint and look, not ahead, but rigidly upward.

Over 60 species of these flatworms, which are all indeed very flat, inhabit a specially reserved breeding room here in Dresden. They were collected from all over the world and include some very rare eyeless specimens from caves, and others that have a string of eyes along the edge of their bodies. Flatworms are usually between 0.8 and 2.5 centimeters in length, but there are also some veritable giants that measure one meter in length. They usually come in different shades of brown or black, but some also have distinctive dots or stripes. They are easy to care for in the laboratory and pounce on the bits of calf liver or mealworms fed to them in their plastic boxes.

Given their bizarre appearance, one might almost think they made a deal with nature millions of years ago: Let others be beautiful, like the ladybirds

with their red wing cases with flashy black dots. We don't need all that. Give us something else instead: eternal youth!

For the price of eternal youth, some flatworm species even forego sex. The species that reproduce asexually are practically immortal, because every tenth cell in the worm body is actually a stem cell that can generate all of the different cell types indefinitely. For this reason, planarians self-renew constantly. For every dividing stem cell, a specialized cell dies, so the shape and size of the worms remains unchanged.

ONE BECOMES TWO

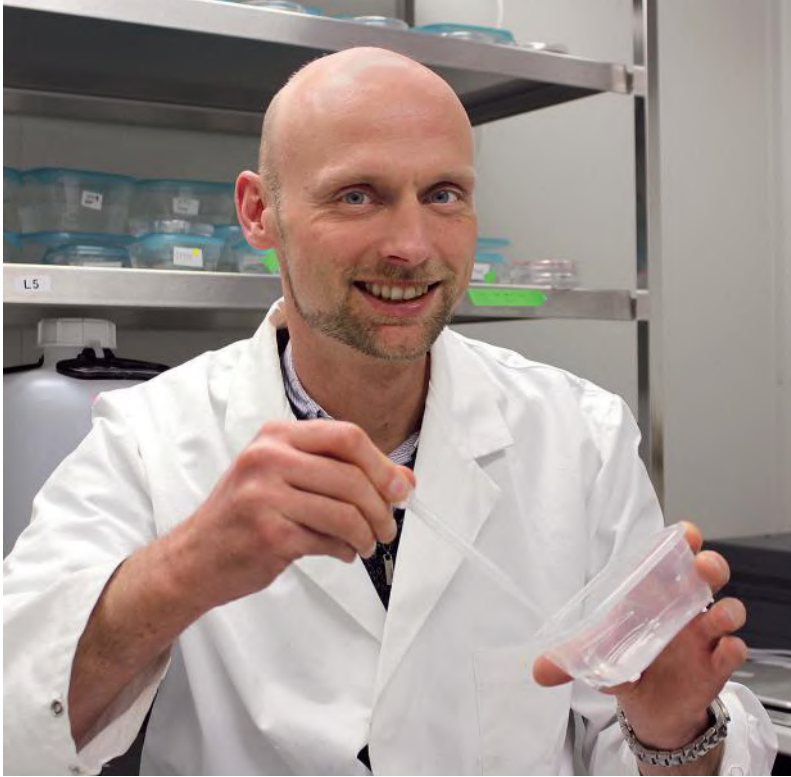
To reproduce, all they have to do is hold on tight with the tip of their tail while the head moves on. "After a few hours, the body tears apart and two complete worms regenerate from the two pieces in just two weeks," explains Jochen Rink from the Max Planck Institute in Dresden. This makes planarians one of the most sought-after test objects in stem cell research. Their extraordinary regeneration capacity may hold the key to eternal youth and to cures for many illnesses.

But there is something else about flatworms that fascinates Rink: not only can they build a complete organism from any random tissue piece, they even manage to restore perfect symme-

try during regeneration – regardless of whether the original animal was divided into two pieces or twenty. For example, strips of tissue that are cut from the side of a flatworm initially curl up into a tight corkscrew spiral and develop into completely independent organisms in a matter of days. This distinguishes flatworms from other regeneration specialists, such as the axolotl: although these salamanders can regenerate missing body parts, organs and even parts of the brain, the cut-off piece never develops into a new animal, but rather perishes.

Something the two animals do have in common, though, is the symmetry of their body plans. The foundations of symmetry are already laid in the early embryonic stages. Also the process of regeneration in planarians must ensure that the resulting body is symmetrical, or that the new parts re-complete the symmetry of the existing body. "This so-called bilateral symmetry – two mirror-image body halves – is a basic structural principle of higher organisms," says Rink.

Bilateral symmetry requires, first, an axis of symmetry, known as the midline. But how does an organism actually define a line? It is already known that evolution has come up with different ways of doing this. In vertebrates, for example, the dividing cells of the early

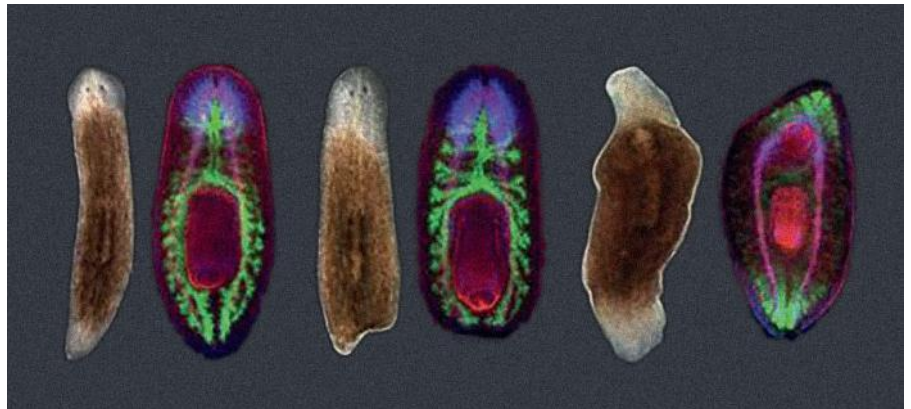


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GRATIS

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Left page Planarians are easy to care for: Apart from feeding and occasional water changes, Jochen Rink (top left) doesn't have to do much for them. They live in standard plastic household containers in the laboratory of the Max Planck Institute in Dresden (top right). They can reproduce very rapidly in these containers (bottom).

This page Planarians need the hedgehog signaling pathway to regenerate lost tissue. A middle piece (left) usually forms a head with a brain (blue) and the tail with two intestinal strands (green). If there is not enough hedgehog available (center), a normal head grows, but no tail. If there is too much hedgehog (right), a complete tail is formed instead of the head.



embryo migrate and gradually envelop the yolk mass like a tight-fitting hat. A subset of these cells reverses direction at a defined point, the so-called organizer, and marches back up against the flow on the inside of the hat. This produces a hemisphere composed of two cell layers.

STARTING POINT FOR THE MIDLINE

“The reversal point later turns into the midline of the body, and the head and tail form at its opposite ends.” Signaling networks in the cells control this process by switching certain genes on and off at the right time. In short, nature proceeds thus: a point is defined from which the cells migrate in opposite directions, and voilà – the line is created.

The fruit fly *Drosophila* takes a different approach to midline formation. Its embryos aren't spherical, but rather cigar-shaped. Signaling substances in the cells define “top” and “bottom,” which correspond to the back and belly halves of the future embryo. “Top”

and “bottom” signals suppress each other, but because the belly signals are stronger, all that remains of the top signals in the end is a clearly defined line along the back, which again becomes part of the midline of the emerging fly body.

And what about planarians? Rink and his colleagues started by looking for genes that are active only at the midline. The genes they encountered here included the BAMB1 and Slit genes, both of which are active only in cells located exactly along the midline: BAMB1 is active only in a narrow strip along the back, and Slit marks a broader V-shaped strip extending all the way from the head to the tip along the animals' belly side. Thus, the midline is defined, not by a single cell type, but by multiple types. Here, too, nature probably uses the same molecular mechanisms throughout the animal kingdom, as Slit is also active along the midline in flies and humans.

In the early 1960s, biologists accidentally discovered the dramatic consequences that arise when the formation

of symmetry in an organism malfunctions. Deformed lambs with only one eye were born on a few meadows in California. Like the Cyclops in Greek mythology, their eye sat in the middle of their head. It emerged that the ewes had eaten corn lilies. These plants contain a toxin that inhibits recognition of the hedgehog signaling protein in embryonic cells. Surprisingly, the defect was limited to the lambs' heads. The animals, which died soon after birth, had four normally formed legs.

“If we disrupt the hedgehog signaling pathway in planarians, something similar happens,” reports Rink. He and his colleagues varied the strength of the hedgehog signal in the worm body, cut off the head and tail, and observed the regenerating pieces. If the piece had far too little of the hedgehog signal, a perfect new head developed, but the tail was severely truncated; if too much of the hedgehog signal was present, the regeneration of the tail was perfectly fine, but the pieces regenerated a tail in place of the head. And if the hedgehog signal was only slightly raised, worms



with stunted and eyeless heads or, again, one-eyed Cyclops worms, regenerated. Except that in the case of the lambs, the one-eyed lambs had too little of the hedgehog signal.

NEURAL PATHWAYS FORM A LOOP

The researchers then eagerly turned their attention to the genes that mark the midline. In the animals with stunted heads, the midline gene BAMBI was active right through to the tip of the tail, but no longer in the head region. The stunted heads were also missing the nerve tracts, which reconnected into a loop below the head area. “So these animals don’t have a brain, just parts of the peripheral nervous system.” And because the new head tissue lacks any midline information, it is no longer bilaterally symmetric, but rather radially symmetric, similar to a sphere or a circle. In the one-eyed worms, in contrast, the BAMBI gene activity extends all the way from the tail tip to the head, but the nerve tracts are spaced much closer together than usual.

Rink concluded that “The midline targets the head and tail as end points. If these parts of the body are fully formed, then there is a complete mid-

line. If the head isn’t fully formed, problems with the midline arise, and result in one-eyed animals.” Clearly, the signaling systems that designate the midline are so finely tuned that they don’t tolerate any kind of disturbance. In order to track how a new midline forms, the researchers then cut narrow strips from the sides of some worms and used a green dye to visualize the activity of the Slit gene in these strips.

Immediately after cutting, the strip evidently contained no midline information. Just one day later, however, the first green cells appeared under the microscope. “Not in the middle, but along the edge of the wound,” Rink explains.

On the second day, two apparently distinct populations of green cells had formed – one centered approximately halfway along the length of the strip, and a second one right at its front end, likely the precursors of the midline in the head. Further, some green cells had already settled beyond the new midline, which eventually developed from the wound edge. “We still don’t know where these cells come from.” After six days, the pair of eyes had formed. The central population of green cells expanded and became the pharynx, which sits right in the middle of the an-

imal and serves as both the mouth and the anus. The midline doesn’t extend to the tip of the tail until the digestive tract is fully formed. The cells seem to operate like a construction team that completes the work at one location before moving on to the next.

SIGNALING SUBSTANCES DETERMINE POSITIONING

But how does the strip know that it was originally located on the right-hand side of the flatworm’s body and that it is now missing its left side? And what signals the completion of regeneration and the resulting growth arrest? “We still don’t know exactly how these processes work. They may be controlled by the concentration of signaling substances in the body,” says Rink. For example, if the concentration of a messenger substance were to decrease steadily from front to back, a cell could identify its position in the body based on the local concentration. If a cut were to be made at the location of the cell, this information could again be utilized to instruct regeneration of a head rather than a tail, or vice versa. The body and wound edges, too, likely assume important roles in the process of regeneration, as the cells from the



Above A narrow strip of lateral tissue doesn't usually contain any midline cells. After just one day, the first midline cells (green) form – not, however, in the middle of the tissue, but at the wound edge. Over the next few days, a line forms between the old (violet) and new (blue) tissue. Through the integration of new cells above this line (blue areas), it shifts more and more toward the middle until it finally becomes the midline.

Left page Regeneration of the midline: If a narrow strip is cut off from the side of a complete animal (gray in the graphic), the strip initially curls up in a corkscrew. Two days later, the tissue unfolds again and the cut has healed. After six days, a lot of new tissue has already formed on the former edge of the strip (light brown). On the tenth day, the strip has almost entirely reformed the missing parts. After 14 days, a mirror-symmetrical worm has formed from it again.

back and belly halves meet here. The tissue is able to recognize this. Moreover, some signals must be able to reach all cells of the body, since pricking the worm with a needle raises an alarm signal that compels all stem cells to divide more rapidly.

The system is so well controlled that it can estimate the severity of the injury. "This is important," says Jochen Rink. "The worm shouldn't grow a new head every time it suffers a small tear."

Rink's team also studied the genetic relationships among the flatworm species in the Institute's collection, as well as their capacity for regeneration. The scientists have evidence that the species that can no longer regenerate were once able to but lost the capacity over the course of evolution. "A single signaling pathway changed in them. Interestingly, this happened several times and in different locations," Rink says. He would now like to find out why this is the case.

The scientists also discovered another striking correlation: species that can no longer regenerate reproduce sexually. "So we suspect that the extraordinary regeneration capacity of planarians doesn't serve the purpose of wound healing at all, but that of reproduction." The ability to simply split in two

rather than having to go through the trouble of looking for a partner is an advantage if you happen to live in a puddle that will soon dry up.

ONE INDIVIDUAL, MANY STEM CELLS

Unlike in the fruit fly and zebrafish, it is not yet possible to make genetic modifications in flatworms. The ability to insert a gene for a fluorescent protein into the worm's genome and simply observe the growth of the midline would facilitate research considerably.

The fact that this has not been possible up to now is probably due to the organism's high number of stem cells. "When stem cells constantly divide in an animal that doesn't age, and each division carries an inherent risk of mutation, the animal should consist of many stem cell lines that mutate independently of one another. So maybe the worm is no longer a single individual, but many," says Rink, developing this idea further. A collective, as it were. Together with colleagues from the Max Planck Institute in Dresden, Rink's research group recently decoded the genome of planarians. This now provides a basis for testing the collective theory.

Flatworms are early descendants of the last common ancestor of all extant animal species, including humans. "This ancestor must have had a head and been bilaterally symmetrical." It would therefore appear that this form of mirror symmetry existed before the first animals developed a rigid spinal column and fins, legs or wings. The body structure of most living organisms today is mirror-symmetrical.

"Symmetry is very deeply rooted in biology. The underlying molecular programs were developed 500 million years ago in the Cambrian period," says Rink. Everything after that was merely a variation of the theme.

Bilateral symmetry, however, is more than a structural feature. It is the prerequisite for the definition of "front" and "back," and "left" or "right." Thus, the head-tail axis also dictates the direction of movement. "Maybe a bilaterally symmetric body plan became essential once organisms began to move using lateral appendages," says Rink. "If your right fin is bigger than your left one, you can only swim in circles." Unequal distributions of wings or legs are similarly inconvenient. On the other hand, most plant leaves also have a clear axis of mirror

SYMMETRY IN NATURE

Symmetry exists in both animate and inanimate nature. Sugar and amino acid molecules can have a mirror plane or behave like image and mirror image – a phenomenon known as chirality. A different spatial arrangement in an otherwise chemically identical molecule can alter its characteristics considerably: with mirror-image scent molecules, it can give rise to a grassy or citrus smell, and with drugs like thalidomide, it can result in the drug being either effective or harmful. Most minerals also arrange their atoms in symmetrically structured crystal lattices, like the double pyramids in diamonds and the cubes in table salt. Even snowflakes always have a six-fold axis of rotation.

Nature presents a special kind of symmetry in the structure of spirals. These arise in all orders of magnitude, from the DNA double helix to the arrangement of seeds in a sunflower head, animal horns, and galaxies. Because spirals don't have a mirror plane, they are per se asymmetri-



cal. However, they can behave like image and mirror image with each other – like the right and left hand. Organisms generally show a preference for one direction of rotation: in snail shells, the right-left ratio is 20,000 to 1. The field bindweed plant, in contrast, spirals exclusively to the left.

While the mirror plane is usually the only symmetrical element found in the animal kingdom, plants frequently have a combination of mirror planes or multiple axes of rotation or rotary mirror axes.

symmetry even though they never move. The deeper reason for symmetry in biology may therefore lie in transport or growth processes.

Overall, symmetry must have a purpose. Nevertheless, it is never perfect – just good enough for said purpose. “The right arm will never have the exact same number of cells as the left one,” says Rink.

So was symmetry a basis for complexity? The answer is probably yes, but there is an exception. We know of one single multicellular organism that is not symmetrical: *Trichoplax adhaerens*, which translates approximately as “hairy sticky plate.” It looks like a misshapen pancake. Thanks to muscle cells and a carpet of eyelash-like hairs on its belly side, this tiny, three-millimeter-long animal can move like an amoeba. “It’s a fascinating case, as it shows that symmetry isn’t absolutely essential for multicellular life.” Also, *Trichoplax* may have once been symmetrical and lost the trait due to a whim of nature. ◀

TO THE POINT

- **The BAMBI and Slit genes are involved in determining the middle of the body in flatworms – and possibly also in other organisms.**
- **Concentration gradients indicate to cells where they are located. This allows them to “remember” their position and orientation in the body if they become separated from the rest of the organism. Missing parts are then newly formed in the correct position.**
- **The capacity of planarians to regenerate entire body parts may not serve the purpose of wound healing, but instead represent an extreme form of asexual reproduction.**

GLOSSARY

Bilateral symmetry: This is the predominant form of symmetry in the animal kingdom. Over 95 percent of animal species are bilaterians, including humans. The middle of the body constitutes the axis of symmetry, at which every point on the right and the left can be reflected and brought into congruence with its opposite point. Some groups, such as the sea urchins and starfish, are bilateral as larvae but later become radially symmetrical.

Hedgehog: A signaling protein that controls embryonic development in most animals. The protein is part of a signaling pathway that consists of various enzymes and receptors within cells. The signaling pathway must have emerged at a very early stage in evolution, as it arises in almost all animal groups. In insects, it controls the formation of the body segments and wings. In vertebrates, the hedgehog signaling pathway is responsible for bilateral symmetry and the arrangement of limbs. Damage to this signaling pathway leads to significant malformations and can cause cancer.

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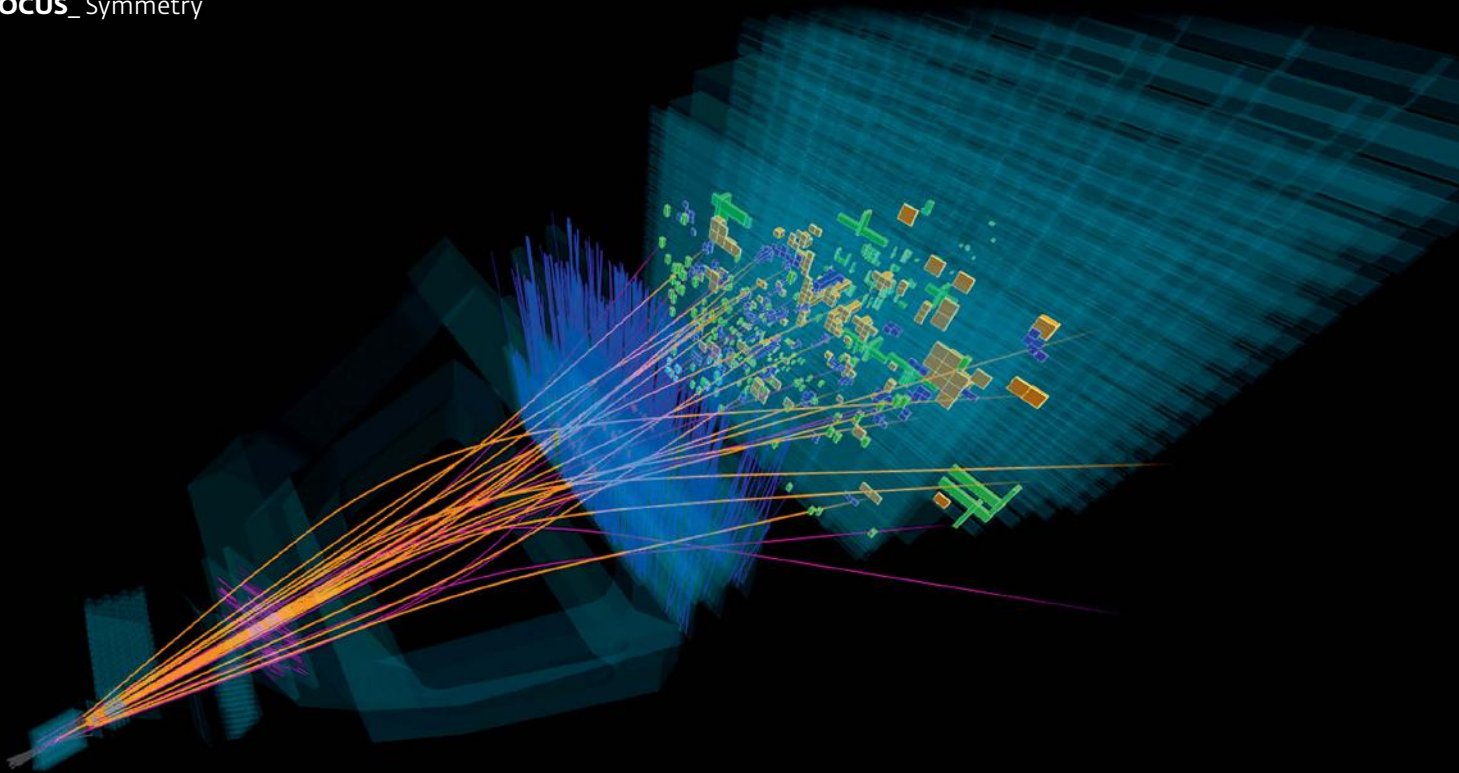
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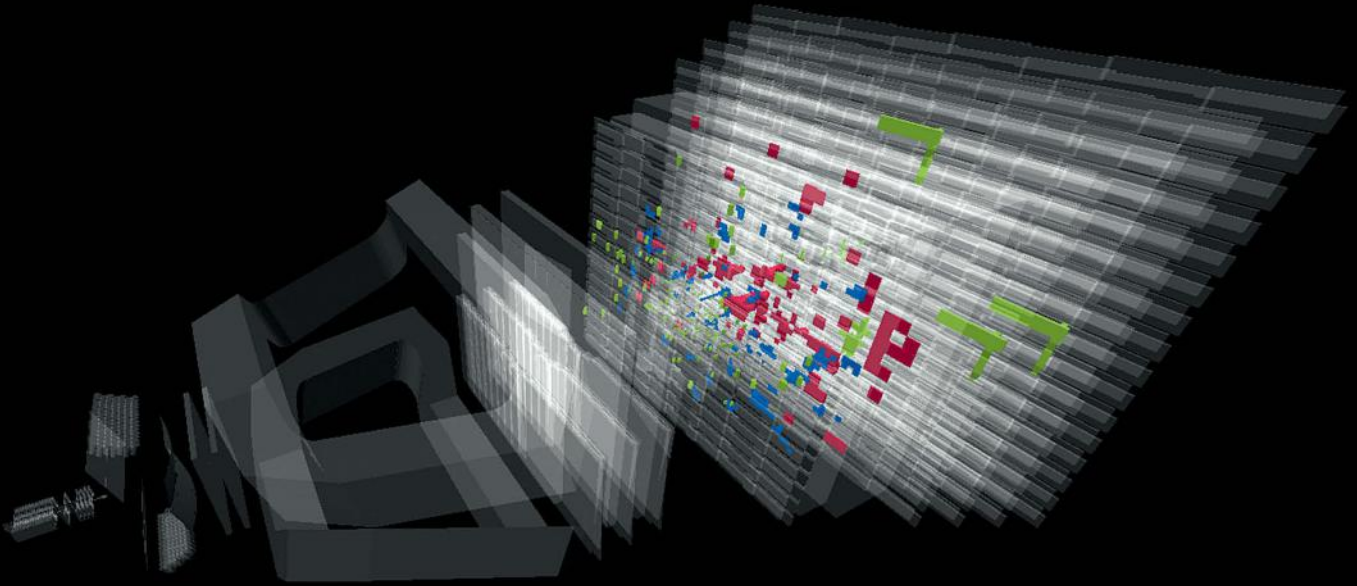
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Matter Undergoes the Vampire Test

It was nothing more than a tiny asymmetry between matter and its mirror image, antimatter, that led to an excess of matter in the universe. We owe our existence to this asymmetry. Research groups at **Max Planck Institutes** in **Heidelberg**, **Munich** and **Garching** are pursuing different routes to find out why matter, like vampires, has lost its mirror image.

TEXT **THOMAS BÜHRKE**



Down the centuries, philosophers have been haunted by the conundrum of why matter exists in the universe. Gottfried Wilhelm Leibniz put it in a nutshell: “Why is there something rather than nothing?” The problem is not only a philosophical one, but also a physical one, which is why physicists have spent decades searching for a solution to this mystery. As in many areas of physics, symmetries play a crucial role.

It’s been 100 years since mathematician Emmy Noether noticed the fundamental connections that exist between geometrical symmetries in space and time, and the laws of conservation in physics. The law of energy conservation, for example, follows from these symmetries: in a closed system, energy can neither be created nor destroyed. A perpetual motion machine is therefore impossible. The conservation of the total momentum, for example when two spheres collide, can be explained similarly on the basis of symmetry.

Over the last few decades, however, physicists have realized that it is not only symmetries that are important:

“We know these already – the big mystery is the asymmetries,” says Michael Schmelling, from the Max Planck Institute for Nuclear Physics, who is involved in one of the major experiments at the LHC particle accelerator at CERN in Geneva. In fact, if the construction kit of elementary particles had a completely symmetric structure, there would be no matter in the universe, and therefore neither Earth nor us humans.

ONE ANTIPARTICLE FOR EACH ELEMENTARY PARTICLE

The reason why perfect symmetry would have made the existence of matter impossible lies in the events during the Big Bang: according to our current thinking, the universe was filled with radiation and matter of inconceivably high temperature and density during the first billionth of a second. It was a seething mixture of particles that converted into radiation and back into matter.

Physicists know, however, that antiparticles are created in the same amount as particles in such an environment. This piece of knowledge, too, is already several decades old: for each

Searching for the asymmetry between matter and antimatter: Physicists at the LHC analyze the decay products of particles, which leave signals behind in the different detector layers; these signals are shown here as colored rectangular blocks.

type of elementary particle, there is a corresponding antiparticle that differs only in the sign of the electric charge, but has precisely identical properties otherwise. The antiproton, for example, looks like an ordinary proton, but has an opposite (negative) charge.

Although there is no doubt that antiparticles were created in the beginning, they are practically non-existent in the universe. This is because the two unequal partners have the fatal characteristic that they annihilate each other in a flash of radiation when they meet. For the Big Bang, this means that if perfect symmetry had existed at the time, there would have been just as many particles as antiparticles created in the sea of radiation – and they would all have mutually annihilated each other. The universe would then consist solely of radiation. So where does matter come from? >



Collisions under surveillance: Dmitry Popov (front), Michael Schmelling and Burkhard Schmidt (from left) watch the raw data being processed in the control room of the LHCb experiment.

In order for any matter to survive after the Big Bang, there must have been a tiny imbalance: only a very small number of particles remained each time when approximately one billion matter-antimatter pairs were annihilated. This difference appears to be very minute, but we owe our existence to it. The physicists have only a vague idea of how this asymmetry came about: “It can possibly be thought of as a phase transition, like water turning into ice upon freezing,” explains Schmelling. “The asymmetry was frozen in, so to speak, firmly cementing the dominance of matter in the universe.”

This theory goes back to Russian physicist and Nobel Peace Prize laureate Andrei Sakharov. When he published it in 1967, he based the theory on an experiment that had shaken physicists’ belief in nature’s symmetries to the very core three years earlier. James Cronin and Val Fitch had investigated the decay of so-called K mesons in an accelerator at Brookhaven National Laboratory. These particles con-

sist of two quarks, which are elementary particles, and they are unstable. Fractions of a second after being created they decay into other particles.

THE STANDARD MODEL IS FLEXIBLE TO A CERTAIN EXTENT

Cronin and Fitch investigated the decays of K mesons and compared them with those of anti-K mesons. When they found a tiny difference between the two decay modes on the order of one tenth of a percent, it was an absolute shock for the physics community. In this case, the perfect symmetry between matter and antimatter was violated, as physicists say.

But they were unable to explain the excess of matter in the Big Bang in this way; the asymmetry measured was much too small – it would have to be a billion times bigger. Theoreticians Toshihide Masukawa and Makoto Kobayashi incorporated this asymmetry into the Standard Model of particle physics and were awarded the Nobel Prize in Physics for their work in 2008.

Cronin and Fitch had already been honored with this distinction in 1980.

The Standard Model is like a construction kit that contains all known elementary particles and the forces acting between them. This model works wonderfully, but is flexible to a certain extent. Although it specifies the number and type of the particles, it can’t predict certain physical quantities, which must be taken from measurements. These include the masses, for example, which then have to be incorporated into the model.

An asymmetry like that observed in the neutral K-meson system can still be accommodated without the building collapsing. However, there are expected to be limits, and these have to be explored experimentally and theoretically. It only becomes really exciting when researchers discover asymmetries that break the bounds of the Standard Model: such discrepancies may explain the existence of matter, but they would force the physics community to abandon the old model and extend existing theory to encompass new physics, so to speak.

The researchers are therefore continuing their search for these deviations from perfect symmetry. More recently, this search has concentrated on a different species of meson: the B mesons, which exist in different variants. Today, the ideal instrument for studying these is the CERN Large Hadron Collider (LHC), in which protons circle in opposite directions and collide with extremely high energy. Many different particles form in the ensuing fireballs, including B mesons and their anti-partners, whose decay particles are analyzed with the LHCb detector.

Schmelling’s group made crucial contributions to the development and construction of the silicon detector for this device, which is the size of a three-story house. The silicon detector alone covers an area of around 11 square meters and can detect the pas-

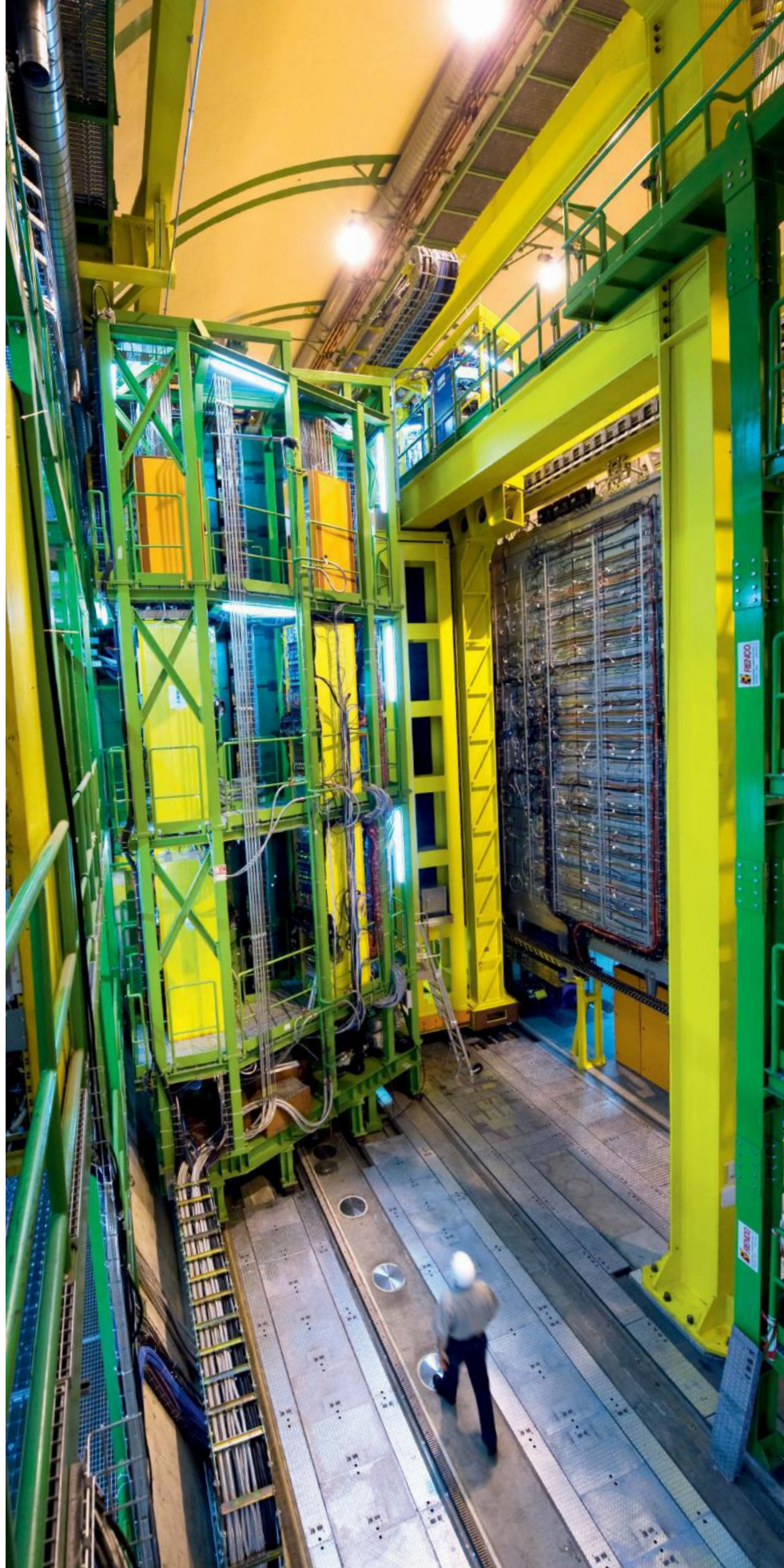
sage of a charged particle with an accuracy of 0.05 millimeters – approximately the thickness of a human hair.

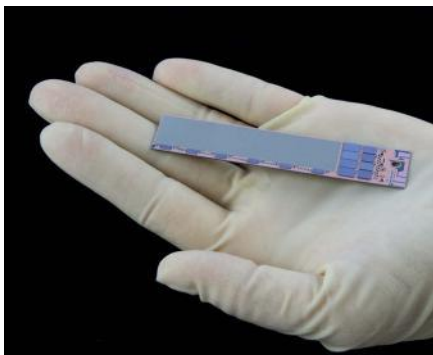
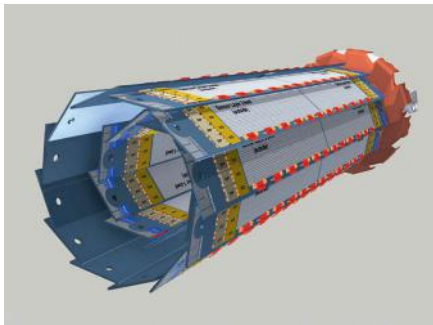
After physicists in the US and Japan had already discovered an asymmetry of 8 percent for B_0 mesons, the LHCb collaboration concentrated on the B_s , the brother meson, which can be produced in large numbers in the LHC. The surprise came three years ago: the researchers had found an asymmetry of unprecedented magnitude – 27 percent – when comparing the decays of B_s mesons and their anti-mesons. Were they finally hot on the trail of something that would lead them to the cause of the mysterious preference for matter during the Big Bang?

Unfortunately not – even this very strong asymmetry can probably still be explained as part of the Standard Model, as the theoreticians quickly announced. Only a value that does not fit in there could be an indication of a physics beyond the Standard Model, one that could make the excess of matter understandable. Scientists at the LHC are currently searching diligently for it, but so far without success.

The stream of data from the LHC is still a long way from being completely evaluated, however, and the search for a symmetry violation continues in the decays of other species of mesons. But Michael Schmelling wants to look for another effect that would shake the foundations of today's physics: the fact that the characteristics of a meson decay, such as the life of the particles, depend on spatial orientation – in other words, on the orientation of the experimental arrangement with respect to the fixed stars.

An abundance of experiments have confirmed to this day that space is isotropic – that is, it has no direction that





Christian Kiesling (right) and his colleagues assess the progress as the Belle-II detector at SuperKekB is being set up. Kiesling points to an opening that will house the vertex detector, whose task is to determine the exact position of the decay. The heart of this instrument is the dual-layer pixel detector (top left), inside which the decays take place. It is composed of modules whose image sensors each comprise 200,000 pixels (bottom left).

is somehow preferred. Physically, the direction in which a light beam is sent in free space is irrelevant; it will always propagate in the same way and with the same speed. The most precise experiments confirm this to an accuracy of 15 decimal places. But what about the decay properties of particles and antiparticles?

In order to approach this question, one has to consider the interparticle forces contained in the Standard Model construction kit. In the case of light, only the electromagnetic force is of any consequence. When particles decay, the so-called weak force, which acts only within the atomic nucleus, comes into play. It is theoretically conceivable that this weak force interacts with an unknown, hypothetical energy field that permeates space. This idea is not without reason. In 1998, cosmologists discovered that such an energy field does indeed exist in the universe: dark energy. It acts like pressure in a boiler, driving the universe apart and accelerating the expansion.

Analogously, one can therefore also imagine a direction-dependent background field that affects the weak force, but not the electromagnetic one. It would then be possible for the characteristics of a particle decay to depend

on the direction in which one was moving relative to this background field – just like the speed of a ship depends on whether it is moving with or against the current. This is all hypothetical, says Schmelling, “but we want to check it out.”

SEARCHING FOR VARIATIONS OVER ONE DAY

The task now is to compare the decays and other properties of particles and antiparticles relative to the hypothetical energy field, so depending on the orientation of the experimental setup with respect to the fixed stars. “If a dependence on orientation exists, we ought to see variations with a period of one day, because our orientation toward the fixed stars is different at night than during the day,” says Schmelling. The data has already been collected, and the LHC will provide more in the future.

The experiment at the LHC, which is tracking down the asymmetry between matter and antimatter, is to be additionally supplemented by a further accelerator experiment. If everything goes according to plan, it will start in two years: after an eight-year upgrade phase, the SuperKekB accelerator at the Tsukuba research center in Japan is to

run at full speed. In two separate rings each measuring three kilometers in circumference, electrons and antielectrons (positrons) circle in opposite directions and collide at a single location.

Although SuperKekB is smaller than the LHC and doesn’t accelerate the particles to anywhere near the energies achieved there, it is set up such that many more pairs of B mesons and their antiparticles are created during collisions than is the case at the LHC – and immediately decay again. Physicists therefore like to call it the B factory. In this installation, the background from other particles is significantly weaker, making data analysis easier than at the LHC. In addition, this installation allows researchers to study the B meson decay modes, which remain fundamentally hidden to the LHC.

Starting at the end of 2018, the super-factory is expected to produce up to 40 times as many B mesons per unit of time as its predecessor – which already held the world record until it was taken out of service in 2010. In order to be able to precisely analyze the decay products of the particles, the previous detector, called Belle, which detects the particles produced in the meson decay, had to undergo significant technical improvements.

The central element of Belle II is a vertex detector that can determine the direction of flight and the place of origin – the vertex – of a particle to within one-hundredth of a millimeter. The heart of this instrument is a pixel vertex detector that in turn consists of 40 image sensors. One of these sensors comprises 200,000 individual pixels.

If a particle impinges on such a pixel, a tiny signal is generated and amplified in the pixel itself. “Measuring a mere 50 by 60 micrometers, the pixels are small marvels in themselves,” says Christian Kiesling, the spokesperson of the international detector collaboration and a researcher at the Max Planck Institute for Physics in Munich. The pixel vertex detector was designed and built here and at the Munich-based semiconductor laboratory of the Max Planck Society. “Developing this detector, which is the only one of its kind in the world, cost us a lot of blood, sweat and tears,” says the scientist.

At the SuperKEKB, the researchers want to use Belle II primarily to study also those decay modes of B mesons that are extremely rare, because theoreticians provide very accurate predictions for these particles. In other words, the Standard Model is not as flexible here, and can best be checked experimentally. A further part of the program is to investigate other unstable particles as well – always in the hope of finding an asymmetry between particle and corresponding antiparticle somewhere that can explain the excess of matter in the world.

Whether at the LHC or SuperKEKB, the decay experiments take place at incredibly high energies. However, the search for the asymmetry between matter and antimatter can take other paths, too. The alternative consists simply in comparing the properties of elementary particles and their antiparticles as accurately as possible. They should be identical, apart from the sign. Any difference, however small, would contra-

dict today’s physics. Even the flexible Standard Model doesn’t leave any room for maneuver here.

A POSSIBLE ASYMMETRY IN THE MAGNETIC MOMENT

One group working with Klaus Blaum, Director at the Max Planck Institute for Nuclear Physics, is investigating the properties of protons, the nuclei of hydrogen atoms, and antiprotons. Thus far, the researchers have achieved the most accurate results for the comparison of the charge-to-mass ratio of the two particles. This combination is experimentally easier to measure than the individual quantities.

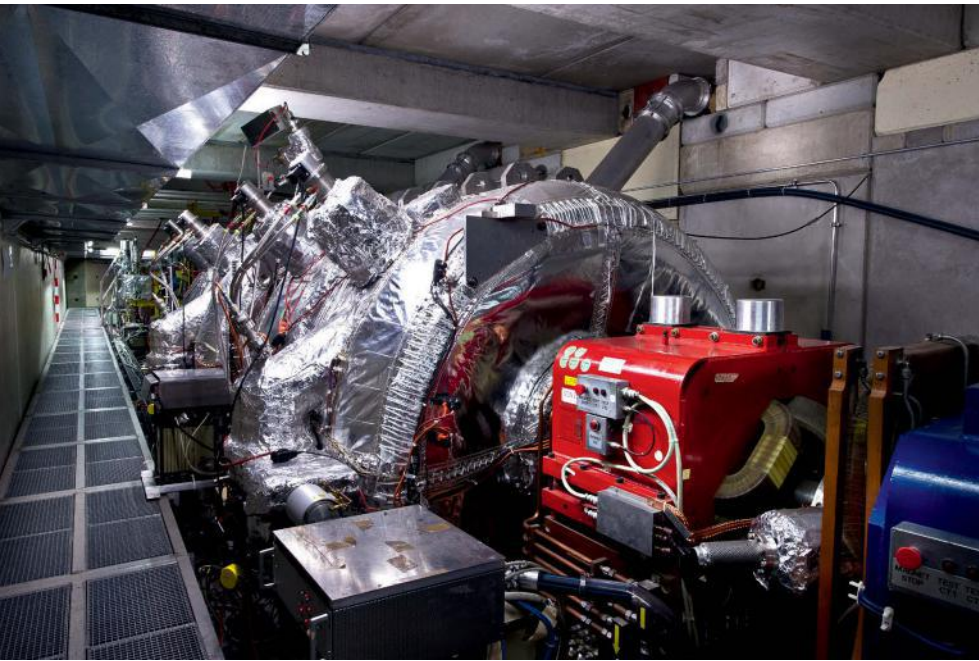
The procedure begins by transferring one proton or antiproton into a vacuum vessel where an electric field and a magnetic field trap and store it. The particle then executes a circular motion around the axis of the magnetic field; this orbiting can be measured very accurately and provides the sought-after quantity (MAXPLANCK-RESEARCH 4/2010, page 46 ff.). “This experiment is very delicate and requires a great deal of experience, because we are working with only a single proton or

antiproton,” says Klaus Blaum. In mid-2015, the BASE collaboration, headed by Blaum’s former colleague Stefan Ulmer, published the world’s most accurate result to date in the journal NATURE. The result shows that the charge-to-mass ratios of the two particles agree to within less than one part in a billion.

The researchers are now using this experimental experience to compare a further characteristic property of protons and antiprotons: the magnetic moment. This can be roughly thought of as the strength of the magnetic field generated by a single proton. The value is extremely small and more difficult to measure than the charge-to-mass ratio. According to theoretical predictions, however, it could be a prime contender for an asymmetry between matter and antimatter. The year before last, an international collaboration involving the group from Heidelberg, as well as the University of Mainz, GSI in Darmstadt and the RIKEN research institution in Japan, among others, successfully determined the magnetic moment of the proton to within three parts per billion – a world record! >

Researchers in Klaus Blaum’s group use a Penning trap to capture charged particles, such as protons and antiprotons. Ring-shaped electrodes generate the electric fields to trap the ions.





A storage device for antimatter: A decelerator at CERN slows down antiprotons, which are subsequently used in further experiments.

The researchers next plan to carry out the corresponding measurement on the antiproton. To do this, the physicists will have to take their apparatus to CERN, where a small accelerator, the Antiproton Decelerator, supplies the cold antiprotons. “We want to measure the magnetic moment of a single antiproton there and improve the accuracy ten- to a hundred-fold by the end of 2018,” explains Blaum. This is a race against time because, in September 2018, the LHC will be switched off for a protracted maintenance break, at which time antiproton production will come to a standstill as well.

Experimenting with antihydrogen – atoms that consist of one antiproton and one positron – is even more demanding. CERN is currently the only place in the world where these experiments are possible. The first tricky problem consists in bringing antiprotons and positrons together and cooling them to such an extent that they combine to form anti-atoms. The second problem occurs at precisely that moment: in contrast to their two components, the anti-atoms are electrically neutral and not so easy to trap and store.

But why go to all this trouble with atoms when investigations on elementary particles such as protons and their counterparts from the anti-world are

easier? One reason is, again, the accuracy that is possible with measurements on atoms. Hardly any quantum-physical value has been measured so accurately as one particular transition of the electron in the hydrogen atom. Physicists use the term transition to describe the lifting of an electron into a higher energy state or its falling back into a lower energy state.

DOES THE ANTI-APPLE FALL UP?

The fact that the energy exchanged during the transition can be measured so accurately owes to Theodor W. Hänsch, Director at the Max Planck Institute of Quantum Optics in Garching, who developed the so-called frequency comb, for which he was awarded the Nobel Prize in Physics in 2005. This technology enables the frequency of the hydrogen transition to be measured with a spectrometer to an accuracy of 14 decimal places, so if one aims to find minimal differences between matter and antimatter, this technique is the most accurate. Masaki Hori’s group at the Max Planck Institute in Garching has been working on this feat since 2008 as part of the international ATRAP collaboration.

But it is also possible to measure a second property on the antihydrogen,

one that could disclose a difference between matter and antimatter: free fall under the effect of gravity alone, which can be demonstrated only on electrically neutral particles. Alban Kellerbauer and his colleagues are working on such experiments at the Max Planck Institute for Nuclear Physics.

Their work is based on the somewhat exaggerated question: Does the anti-apple fall up? It doesn’t have to be quite that blatant – even the tiniest difference between matter and antimatter in free fall would be an assault on the very foundations of physics, especially on Einstein’s general theory of relativity. This assumes that all bodies fall with equal speed in the gravitational field regardless of their composition, shape or mass.

Since 2010, Kellerbauer’s team, together with colleagues from the international AEGIS collaboration, has been developing an apparatus at CERN to investigate the free fall of antihydrogen. Like their colleagues in the ATRAP collaboration, they must first produce its atoms from one antiproton and one positron, each of which is produced separately. The whole atoms now fly through a horizontal tube about one meter in length before they impinge on the detector.

If the anti-atoms behave like normal atoms, gravity will cause them to sink around ten micrometers (one millionth of a meter) over a distance of one meter. In order to check this, the physicists need a detector with very high spatial resolution. “It may sound antiquated, but our best experience has been with a photo emulsion,” says Alban Kellerbauer: “This enables us to determine the impact location to within 60 nanometers.”

Experimenting with antiparticles is very difficult because they prefer to unite with their matter partners in a flash of light, and these partners are found all around them in this world. The AEGIS group wants to prevent this self-destructive partner selection, of course. Although this is not easy experimentally, the researchers are doing all they can to complete their first mea-

surements before the LHC is switched off in fall 2018. “By then, we hope to have achieved an accuracy of 30 percent,” says Kellerbauer.

In principle, this will initially provide an answer only to the question of whether antimatter falls up or not. It would be incredible if it really were to take the opposite route of matter in the gravitational field. That would turn physics on its head and manifest a fundamental inequality between matter and antimatter in which only the most daring researchers would currently like to believe. It’s more likely that the difference between matter and antimatter is significantly more subtle. And it looks like the researchers will need to exercise patience for a while longer, regardless of which path they are pursuing in their search for this difference. ◀

TO THE POINT

- **Matter and antimatter formed in the Big Bang. An asymmetry between them meant that a small quantity of matter remained, but no antimatter. The excess cannot be explained as part of the Standard Model of particle physics.**
- **Physicists are searching for the asymmetry in different ways. At the LHC and SuperKekB particle accelerators, for example, they are analyzing the decays of short-lived B mesons, which consist of one quark and one antiquark. They are also comparing the physical properties of particles and antiparticles, such as their behavior in the gravitational field.**
- **The previously observed asymmetries during the decays of mesons can still be reconciled with the Standard Model and therefore can’t explain the excess of matter.**

GLOSSARY

Mesons themselves are not elementary particles, as they consist of one quark and one antiquark. More than 100 types of mesons are currently known; they differ in the quarks that are paired in them.

Standard Model of particle physics: This theory describes all elementary particles and the interaction between them with the exception of gravity. The excess of matter in the universe cannot be explained with the Standard Model, as this excess is based on an asymmetry between matter and antimatter that is incompatible with the Standard Model.



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A Cinch for the Brain

Our bodies, our behavior and even our brains are anything but symmetrical. And this seems to be an important factor in the seamless functioning of our thought, speech and motor faculties. Researchers at the **Max Planck Institute for Psycholinguistics** in Nijmegen are currently searching for genetic clues to this phenomenon. They want to decode the fundamental molecular biological mechanisms that contribute to asymmetry in the brain, and to identify possible causes for neurological disorders.

TEXT **STEFANIE REINBERGER**

At first glance, the human body appears to be completely symmetrical: two arms, two legs, two eyes, two ears. Even features like the nose and mouth appear to be evenly positioned in both halves of the face in most people. On closer inspection, though, we see that one leg is longer than the other, one hand is stronger, or maybe the left ear is positioned lower than the right one. This becomes even clearer when we take a look inside the body: the heart beats on the left-hand side; the liver and gallbladder, in contrast, are located in the right half of the body. The right kidney usually sits slightly lower than the left one, which is generally somewhat bigger and heavier.

The external appearance of the brain would also lead us to believe that it is a completely symmetrical struc-

ture. It's divided into two halves, both of which are equal in size and whose furrows and bulges follow a similar pattern. But the functional centers are extremely unevenly distributed. The right and left hemispheres specialize in different cognitive functions. They essentially divide up the work between them, possibly to expand the total range of tasks performed.

"Lateralization is a very distinct phenomenon in language," explains Clyde Francks, Research Group Leader in the Language and Genetics Department at the Max Planck Institute for Psycholinguistics in Nijmegen, in the Netherlands. "Speech is processed predominantly in the left half of the brain in most people." Only in less than 1 percent of the population are the main centers of speech processing in the right half – a phenomenon that occurs almost exclusively in left-handed people. >

A strong left: Rafael Nadal, for many years the world's number one men's tennis player, is right-handed but holds the racket in his left hand most of the time. Researchers are studying how the brains of left- and right-handed people differ.





Photo: Issei Kato/Reuters



» Lateralization is expressed differently from person to person – and not only in the few people whose brain is specialized mirror-inversely to the majority of people.

“Lateralization – both in the body structure and in the brain and behavior – is a basic biological principle,” says Francks. “In the brain, however, it seems to develop largely independently of the body,” he points out. The asymmetric structure of amino acids, which also determines how proteins are combined, is primarily responsible for the anatomy. Even in the earliest stages of embryonic development, the asymmetric structure of the molecules determines how the individual components are arranged in the newly developing organism.

The cause and the mechanisms that lead to the asymmetry in the brain and in its function, in contrast, are still largely unclear. It is very likely that genetics play an important role here. This is suggested by the fact that the differences between the two halves of the brain are already very apparent

early in development. A case in point is handedness – an effect that is also related to lateralization in the brain, and that simultaneously constitutes the most striking asymmetric behavioral principle. Even in ten-week-old human fetuses, an ultrasound scan shows that 85 percent of the growing babies move the right arm more frequently than the left. Once the fetuses are 15 weeks old, the thumb that they prefer to suck is a highly accurate indicator of which hand they will favor as an adult.

DISCOVERY OF AN INITIAL LEFT-HANDEDNESS GENE

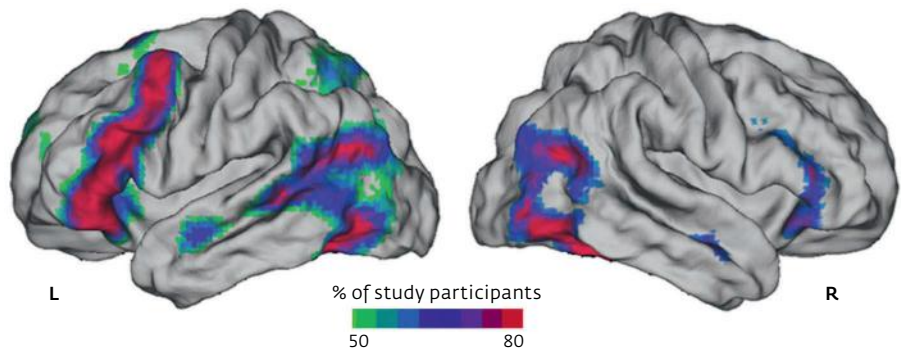
Clyde Francks has been fascinated by the lateralization of the brain for many years now. A zoologist, he has been searching for genes underlying handedness at the Wellcome Trust Centre

for Human Genetics in Oxford, UK, since 2002, initially as a doctoral student and later as an academic staff member. In 2007, he published details of the discovery of a gene called LR-RTM1 (leucine-rich repeat transmembrane neuronal 1), which may be linked to the tendency toward left-handedness and is passed down through the paternal line.

In Oxford, Francks worked for a while with Simon E. Fisher, who is currently a Director at the Max Planck Institute for Psycholinguistics. Fisher, however, was focused on other topics. He had discovered the widely known gene FOXP2, which plays a key role in speech and language, in 2001. When Fisher joined the Max Planck Institute for Psycholinguistics in 2010 to set up the new Language and Genetics Department, he recruited his former colleague. The subject of “asymmetry in the brain

Left Tulya Kavaklioglu is a member of Clyde Francks' research group. As part of her doctorate, she is looking for genes that influence left-handedness. Researchers are interested in the links between handedness and the various functionalities of the two cerebral hemispheres.

Right Studies using magnetic resonance imaging (MRI) show that more than 90 percent of right-handed people process language more in the left cerebral hemisphere than in the right one. The same applies to around 80 percent of left-handed people. The rare phenomenon of increased language processing in the right cerebral hemisphere manifests itself almost exclusively in left-handed people.



and behavior” thus arrived at the Max Planck Institute in Nijmegen together with Clyde Francks.

French physician Paul Broca had already discovered in the early 1860s that the important functional centers for language and speech are distributed asymmetrically across the brain. He had stumbled across a strange phenomenon: if a particular area in the left half of the brain was destroyed, those affected were still able to understand what was being said to them, but they were no longer capable of expressing themselves verbally. Patients whose injuries were located on the opposite side of the brain, however, thus affecting the right hemisphere, did not display these deficits.

The Frenchman had discovered one of the main centers of speech, named Broca's area after him, which is now considered to play an important role in speech production as well as in the processing of sentence structure and grammar. Another important center of language, Wernicke's area, was discovered by German neurologist Carl Wernicke (1848–1905) just a few years later, in

1874. This region of the brain plays an important role in language comprehension – and just like Broca's area, the Wernicke region is located on the left in most people.

DIFFERENCES BETWEEN MEN AND WOMEN

More recent scientific studies based on functional imaging, which can be used to depict the active regions of the brain based on blood circulation or sugar metabolism, have shown that the relevant areas for language and language processing are distributed across the brain, often even in regions that are far apart from one another. Researchers thus also report language and speech activity in the right hemisphere – albeit less than in the left hemisphere.

Moreover, lateralization is expressed differently from person to person – and not only in the few people whose brain is specialized mirror-inversely to the majority of people. The brains of people whose center of language processing is located principally on the left also differ in terms of how pro-

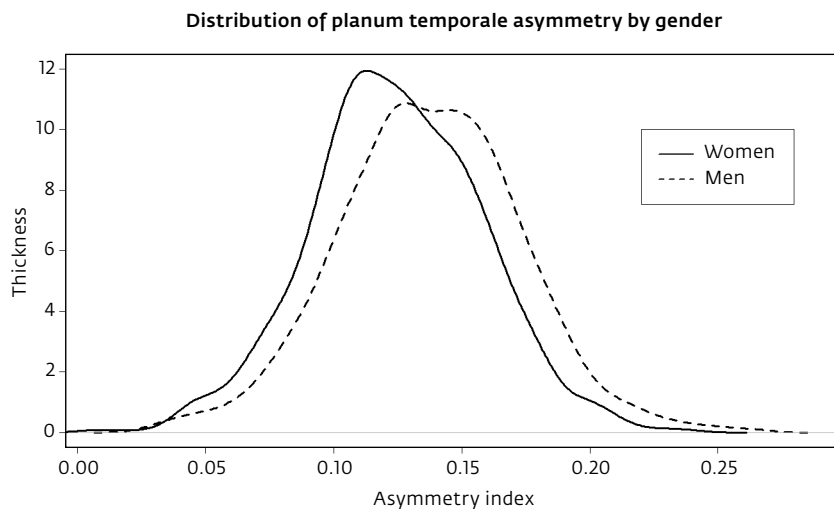
nounced the asymmetry is. This may even affect just individual areas of the brain. But how does this affect an individual's cognitive functions? And how does it affect the differences between men and women?

Previous research findings provided very different answers to the gender question. In 2008, for example, a team of researchers from the University Medical Center Utrecht in the Netherlands carried out a meta-analysis. The scientists analyzed data from 13 studies on handedness and the lateralization of certain regions and functions of the brain. They concluded that, although men are more frequently left-handed than women, they did not identify any differences whatsoever between the sexes in the regions and the functions of the brain that the Dutch researchers had included in their study.

Francks wasn't convinced. As in the past, he suspected that there were slight differences between the sexes. Together with doctoral student Tulio Guadalupe, he therefore decided to investigate it again himself. The two scientists analyzed images of brain scans of more

Below Gender-specific differences are found in the asymmetry of the planum temporale, an area that is located in both cerebral hemispheres: left-right asymmetry is generally less pronounced in women than in men. Men with less-pronounced left-right asymmetry often experience reading difficulties.

Right The molecular biology lab at the Max Planck Institute for Psycholinguistics offers researchers the opportunity to study at cellular level the effect of certain genes on the development of the brain.



than 2,300 healthy men and women. In this study, they were able to access data that research groups in various institutions in the Netherlands had been collecting since 2007 as part of the Brain Imaging Genetics Study, as well as data from a long-term German study on health. It is only through collaborative research endeavors like this that it is even possible to generate such a large group of subjects – and thus obtain a data quantity whose final analysis is truly statistically meaningful.

In their study, Francks and Guadalupe concentrated on the planum temporale, a region of the brain that their colleagues in Utrecht already had in their sights. The planum temporale sits on both sides of the brain in the temporal lobe and plays a role in the processing of language and music, but it also has an influence on absolute pitch. In around 90 percent of the population, it is more pronounced on the left side

of the brain and can be up to five times bigger there than its equivalent on the right-hand side. Researchers also see a connection between a lack of left-right asymmetry in the planum temporale and dyslexia. Those affected by this disorder have difficulty reading and understanding words even though their intelligence, eyesight and hearing have developed normally.

SURPRISING LINK TO SEX HORMONES

Francks and his colleague measured the planum temporale using very exact methods to determine the volume of areas of the brain. When the researchers had finally analyzed the available data, it was clear that there is indeed a difference between men and women – at least in the planum temporale. Francks' studies showed that this region in the female brain is less

lateralized than in men. Now, it can't be concluded from this result that women are therefore the weaker readers. "That is not the case," emphasizes Francks. "But men in whom the left-right asymmetry of the planum temporale is less pronounced have a greater tendency to be dyslexic."

Francks was not satisfied with a pure survey – ultimately, his work is concerned primarily with decoding the mechanisms of lateralization. Therefore, in the next step, he and Guadalupe analyzed the genetic data that he had on his subjects. The researchers concentrated on searching for so-called single nucleotide polymorphisms (SNPs). These are not mutations, but rather gene variations that occur with a certain frequency in the population and in which only a single base pair is modified in the DNA strand.

The results were interesting: in conjunction with the manifestation of left-



Graphic: Max Planck Institute for Psycholinguistics



» We can be very sure that there is no single gene variation that determines handedness or brain asymmetry.

right asymmetry in the planum temporale, the researchers found a particularly high number of SNPs in genes that are involved in the metabolism of steroid hormones, namely, among other things, in the synthesis of male and female sex hormones. And the functioning of the steroid hormones actually appears to have an effect on the lateralization of the planum temporale in both men and women. However, it is still unclear what role steroid hormones ultimately play in reading and linguistic ability. Francks wants to solve this puzzle in future research projects.

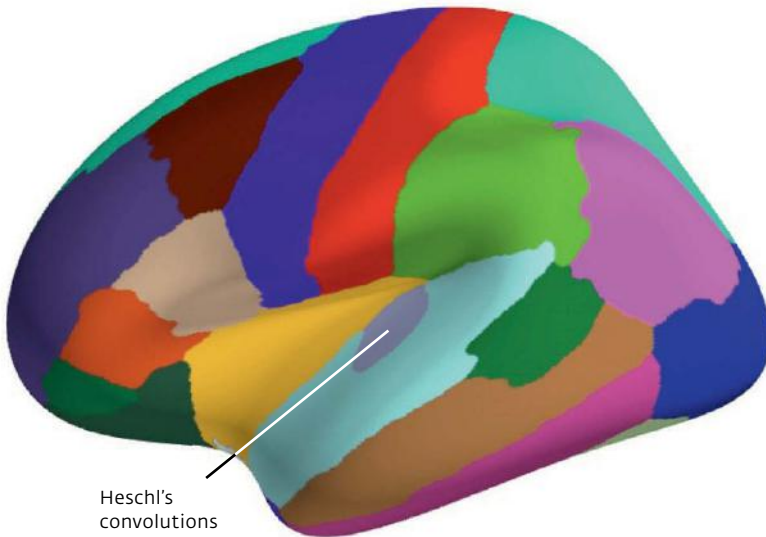
Much of the work done by Clyde Francks and his team in Nijmegen seems, at first glance, almost simple:

they choose a prominent, asymmetric region in the brain and check whether gene variations exist that can explain this asymmetry. But it's not quite that straightforward. The search for genetic causes of the lateralization is akin to the proverbial search for a needle in a haystack. This was revealed, for example, when the researchers examined Heschl's convolutions, as they are known. This region of the brain is located in the temporal lobe in both cerebral hemispheres; it houses the primary auditory cortex and is important for language comprehension. Not only are Heschl's convolutions more strongly pronounced in the left cerebral hemisphere in most people, but their shape

also varies considerably between individuals – anatomical peculiarities that, to a certain extent, must be inherited. Nevertheless, despite studying the data of more than 3,000 test subjects, the Max Planck researchers couldn't detect any gene variations that occur uniquely in conjunction with the manifestation of Heschl's convolutions.

GENETIC INFLUENCES ARE COMPLEX AND MULTIFACETED

Equally sobering is the current search for other genes for handedness. Just last year, the Nijmegen-based researchers analyzed the genetic material of 17 members of a Pakistani family that in-



Heschl's convolutions



Left For scientists, the brain is much more than simply gray matter. The folds and indentations in the cerebral cortex form a specific pattern. Individual functions can be allocated to specific sections: the primary auditory cortex, for instance, is located in the Heschl's convolutions.

Right Handedness manifests itself at a very early stage. Based on the preferred thumb, hand preference can be clearly determined, not only in babies, but even in 15-week-old embryos.

cluded a remarkably high number of left-handed individuals. “These are really the best conditions for detecting genetic material for the phenomenon,” says Tulya Kavaklioglu, the doctoral student entrusted with this topic in Francks’ team. “Still, we found absolutely nothing.”

Frustrating for the doctoral student, yet an important finding for this area of research. The apparent failure underscores how complex and multifaceted the genetic influences must be that ultimately lead to a certain region of the brain being more strongly lateralized in some people than in others, or to certain individuals preferring the left hand over the right hand.

“We can be very sure that there is no single gene variation that determines handedness or brain asymmetry,” emphasizes Francks. Instead, a number of variations in the genome seem to ultimately lead to the anatomical manifestation that researchers see in their brain scans or simply in their subjects’ preferred hand. This is similar to body size, eye color and individ-

ual weight: here, too, a myriad of SNPs and other forms of modifications in the genome influence the phenotype – the observable physical characteristics. In addition, at least height and weight are also shaped by environmental influences, a phenomenon that could also play a part in the lateralization of the brain.

DISRUPTED ASYMMETRY COULD CAUSE DISORDERS

Added to this are so-called epigenetic mechanisms, DNA modifications that affect whether and to what extent a certain gene or a certain variation even has any impact. In 2014, Francks’ team detected such an effect in the LRRTM1 gene. This is the gene that Francks associated with the propensity for left-handedness during his time in Oxford – at least when there is hypermethylation of LRRTM1, that is, when it contains too few methyl groups compared to a “healthy” variant. This involves small chemical appendages on the DNA that affect the activity of a

gene, in other words how frequently it is transcribed.

All of this clearly shows that anyone searching for genetic causes for asymmetry in the brain and behavior needs not only stamina but, most importantly, a large number of test subjects. This is the only way that slight effects can be detected. To this end, large research networks have been established in recent years. These include the international consortium ENIGMA (Enhancing Neuro Imaging Genetics through Meta-Analysis), whose objective is to pool data from imaging procedures and genetic studies in order to gain a better understanding of the brain and its functioning in very large groups of subjects. Clyde Francks heads up the Lateralization group in this network.

At this point, the question may well be asked: Why are the Nijmegen researchers even making such a major effort to detect a few fine genetic traces that make tiny contributions to the individual brain anatomy? Is it important to know why Heschl’s convolutions are manifested in a particular way in one

person and slightly differently in another? And what is the use of knowing about genes that help determine whether we prefer to use our right or left hand for certain activities?

“We are interested in understanding the fundamental genetic and molecular biological principles that lead to lateralization of the brain,” says Francks. Disorders such as schizophrenia also appear to be linked to insufficient cerebral lateralization. And deviations in the asymmetry of certain structures deep inside the cerebrum evidently play a role in hyperactivity in children. “If we understand the mechanisms of how the asymmetry occurs, we can then move on to investigating at what point something goes wrong if the lateralization is damaged,” says Francks. And that would be an important first step in one day helping people affected by the phenomenon. ◀

TO THE POINT

- **The two halves of the human brain perform different tasks, but the asymmetry varies in each individual.**
- **There is no clear link between right- and left-handedness and the distribution of other functions in the human brain. Thus, in terms of language processing, the brain structure of left-handed people is, in most cases, similar to that of right-handed people.**
- **Certain brain asymmetries manifest themselves differently in men and women.**
- **The search for the genetic causes of right- and left-handedness and of deviations in brain symmetry has proved to be difficult.**

GLOSSARY

Lateralization: A basic biological principle whereby the human body, despite its symmetrical appearance, exhibits anatomical and functional differences between the right and left halves. Lateralization of the brain is most apparent in language processing.

Single Nucleotide Polymorphism (SNP): A variation of an individual base pair in a DNA strand. SNPs are inherited and hereditary genetic variants – in contrast to mutations, which generally indicate a new modification.

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Formula for Preventing Power Outages

Search for weak points in grid to become easier

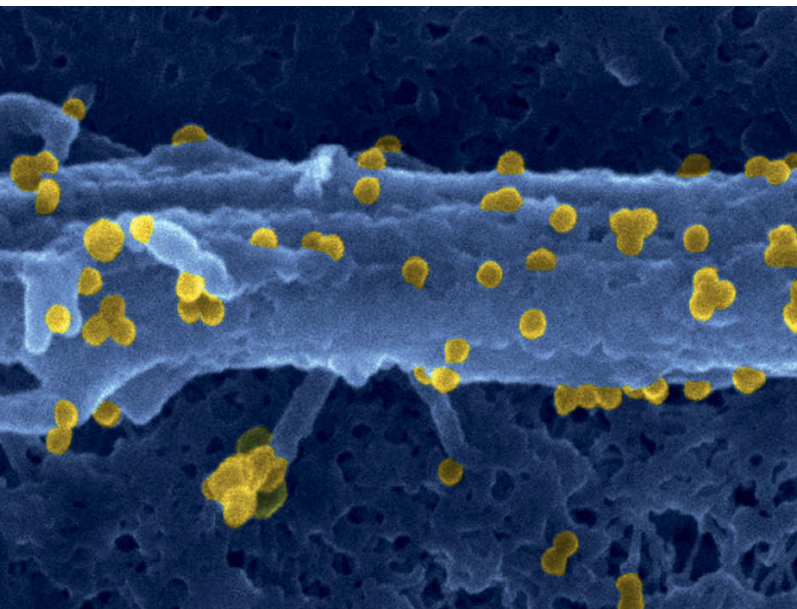
The risk of power outages will soon be easier to assess than before. A team of researchers headed by Marc Timme at the Max Planck Institute for Dynamics and Self-Organization have developed a simple formula for identifying power lines whose failure can cause the lights to go out in an entire region or city. Their formula takes into account not only how much electricity a line transports but also whether the surrounding electricity network can compensate for the malfunction of the heavily used line. Until now, several thousand complicated simulations were needed to determine this. (www.mpg.de/10447869)

A simple formula can predict whether the failure of a power line will cause a regional power outage.



Old New Weapons against Viruses

Existing drugs could soon be used to fight Chikungunya infections



Chikungunya viruses (yellow) are transmitted by mosquitoes. Once it has survived the infection, the body has lifelong immunity to the virus.

The mosquito-borne Chikungunya virus has been spreading in South America and the Caribbean since 2013 and is now threatening southern Europe and the southern states of the US. It causes flu-like symptoms with fever and joint pain that can last for months, with occasional fatalities. As the process for the development of new drugs is expensive and protracted, scientists at the Max Planck Institute for Infection Biology in Berlin have developed a new strategy that should make the development of a treatment more effective. Up to now, researchers targeted primarily the pathogen's proteins in the fight against infections. The scientists in Berlin, however, target the proteins the virus needs to be able to infect humans. They want to prevent the reproduction of the pathogen with the help of substances that specifically affect these proteins. The scientists have identified two substances – including, surprisingly, a widely used antipsychotic drug – that inhibit the Chikungunya virus in mice without triggering side effects. According to the scientists, human host cells have several proteins that are needed not only by the Chikungunya virus but also by other viruses. These could provide a starting point for the development of broad-spectrum antiviral drugs. (www.mpg.de/10500598)

Children of Older Mothers Do Better

A study by Mikko Myrskylä, Director at the Max Planck Institute for Demographic Research in Rostock, and Kieron Barclay from the London School of Economics proves that the biological risks associated with pregnancy in later life are more than compensated by the positive social developments in the corresponding period. The health and educational opportunities of people in industrialized nations are improving from year to year. In their study, the scientists analyzed data from more than 1.5 million Swedish women and men born between 1960 and 1991. The researchers discovered that children born in the later years of this period performed better at school and were more likely to attend university than those born in the earlier years. Clear differences were even observed among children in the same family: the children of older mothers attended school or college for one year longer on average than their 20-year-old

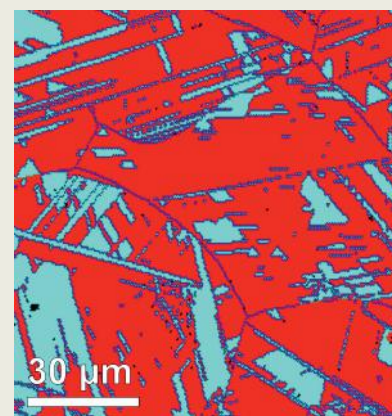
siblings. "So whether a woman had a child at 20 or 40 makes a huge difference for the child," says Myrskylä. (www.mpg.de/10411999)



The blessing of a late birth: Children born today have better opportunities.

Strength and Ductility for Alloys

For the steel industry, there may be a way out of a dilemma that has been around for as long as people have been processing metal. Scientists from the Max-Planck-Institut für Eisenforschung (iron research) in Düsseldorf have presented a new type of metallic material that is extremely strong but also ductile. Up to now, one of these material properties could be improved only at the expense of the other. The researchers in Düsseldorf changed this by combining the advantages of steel with those of high-entropy alloys. High-entropy alloys contain similar volumes of five or more metals. They can be particularly strong but, unlike steel, they are also brittle. Steels, in contrast, consist mainly of iron and are particularly ductile if the small crystals from which they are formed can change their structure. The researchers in Düsseldorf have now also made this kind of structural change possible in high-entropy alloys, despite it having previously been considered to be unfavorable in such alloys. In this way, they are helping to enable metal components to be designed with thinner sheets, thus conserving resources. (www.mpg.de/10536074)



An alloy made of iron, manganese, cobalt and chrome becomes ductile because it can have two co-existing crystal structures, and one structure can transform into the other. The two crystal structures can be identified by the two different colors in this cross-section of the material, which was produced using electron backscatter diffraction.

Suspense in the Movie Theater Air

Exhaled breath of moviegoers reveals the scene playing on screen

With some movies, the air is heavy with suspense – quite literally. Scientists at the Max Planck Institute for Chemistry and the Johannes Guten-

berg University Mainz analyzed the air in movie theaters during various movie screenings and determined that each movie leaves a characteristic pattern in the air. The concentrations of carbon dioxide and isoprene in the air increase during particularly tense moments in movies, probably because the audience tenses up during such scenes and breathes faster. With these tests, the researchers aim to establish whether human breath has a significant impact on the concentration of trace gases in the atmosphere. Despite the detectable traces of these gases in movie theater air, their findings to date indicate that this is not the case. (www.mpg.de/10508367)

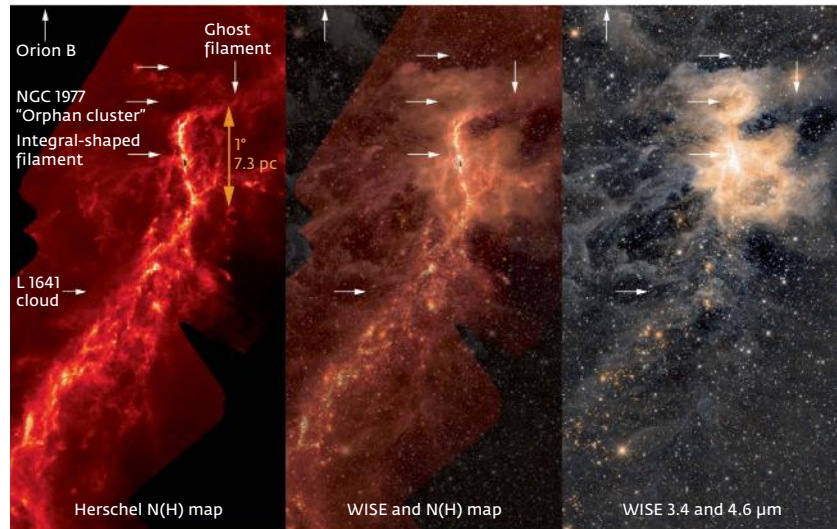


When the tension in the movie rises, breathing changes and the concentrations of carbon dioxide and isoprene increase. Researchers analyzed this phenomenon among moviegoers.

The Secret Life of the Orion Nebula

The interplay of magnetic fields and gravitation in the gas cloud leads to the birth of new stars

Stars and even entire star clusters are constantly being born in space. According to the standard models of star formation, this occurs inside gas clouds that collapse under their own gravity. Amelia Stutz and Andrew Gould from the Max Planck Institute for Astronomy in Heidelberg have now proposed another mechanism. The researchers came up with it when they investigated an integral-shaped filament of gas and dust, which also includes the Orion nebula. In their scenario, the filament is a flexible structure that undulates back and forth. The interplay of magnetic fields and gravitation should allow instabilities to arise, some of which are known from plasma physics and which could enable the formation of one star cluster after another. Protostars would be found only along the dense spine of the filament, and infant stars would arise primarily outside the filament – as is observed in reality. (www.mpg.de/10515222)



Birthplace of suns: The integral-shaped filament, the two star clusters above the filament, and cloud L1641 in the south can be seen on these images of the Orion A star formation region. The image on the left shows a density map compiled from data from the *Herschel Space Observatory*, the image on the right an infrared image taken by the *WISE* space telescope. The photo in the center is a combination of the two images.

Other People's Happiness

Inequality can reduce satisfaction in the better-off

$$\text{Happiness}(t) = w_0 + w_1 \sum_{j=1}^t \gamma^{t-j} \text{CR}_j + w_2 \sum_{j=1}^t \gamma^{t-j} \text{EV}_j + w_3 \sum_{j=1}^t \gamma^{t-j} \text{RPE}_j + w_4 \sum_{j=1}^t \gamma^{t-j} \max(\text{R}_j - \text{O}_j, 0) + w_5 \sum_{j=1}^t \gamma^{t-j} \max(\text{O}_j - \text{R}_j, 0)$$

The unequal distribution of happiness reduces well-being – even among those who are favored by fortune. Scientists from the Max Planck UCL Centre for Computational Psychiatry and Ageing Research in London carried out a study involving games of chance. Participants were informed whether the other players had won or lost in the same games. During the experiment they were asked at regular intervals how happy they felt. It emerged that the winners were happier on average when their co-players also won. This could be attributed to guilt. However, some losers were happier when other

players also lost, which in turn could be attributed to envy. In another test, the same participants were asked to share a small sum of money anonymously with another person. People whose happiness was particularly affected by receiving more than others handed over 30 percent of their money, while those who suffered more from the disadvantage they faced gave only 10 percent. As a result, a link was established for the first time between people's generosity and the extent to which inequality impacts their happiness. (www.mpg.de/10604496)

When Foes Become Friends

A few modifications in the genome transform a fungal plant pathogen into a potentially beneficial organism

Sometimes it doesn't take much to turn foes into friends. Researchers at the Max Planck Institute for Plant Breeding Research in Cologne discovered that modifications to 13 percent of the genes of a soil fungus that is harmful to *Arabidopsis thaliana* (thale cress) can transform the fungus into a beneficial organism. To do this, the scientists compared the genome of the beneficial fungus with that of a closely related harmful species. The analysis showed that the beneficial fungus had lost many genes that its

harmful cousin uses to circumvent the plant's immune system. Moreover, in some cases, the pathogenic genes it still possesses are no longer read. The plant relies on its immune system to decide whether or not to allow the fungus access to its roots: while *Arabidopsis* plants growing in low-phosphate soil reduce their immune response so that the beneficial fungus can supply them with vital phosphate, their immune system blocks the fungus in phosphate-rich soils. (www.mpg.de/10433805)

The Effect of Bacterial Ice Nuclei

Microbes induce the formation of ice crystals by changing the order and dynamics of surface water molecules



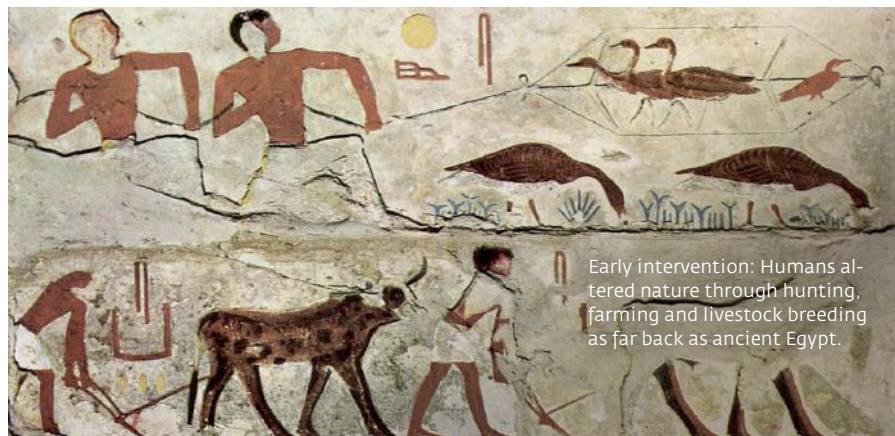
Ice crystals: Max Planck researchers have discovered that certain bacteria affect the ordering and dynamics of water molecules in water droplets.

The freezing point of water is anything but cut-and-dried. Small droplets of the purest water don't freeze until the temperature reaches minus 37 degrees Celsius. Crystallization nuclei, such as bacteria with ice-forming proteins on their surface, are needed for ice crystals to develop at just below 0 degrees Celsius. Researchers at the Max Planck Institutes for Chemistry and for Polymer Research have now explained the molecular mechanism by which proteins cause water molecules to solidify. According to their research, the proteins generate ordered structures in the water and dissipate heat. These findings aid in better understanding the conditions under which frost damage occurs in plants, but that's not all: as the bacteria also occur in the atmosphere, where they likewise promote the formation of ice crystals, they also play a role in the formation of clouds and precipitation – a major factor behind the uncertainty of weather and climate forecasts. (www.mpg.de/10470442)

Humans Have Influenced Ecosystems for Thousands of Years

Humans have been shaping the Earth's landscapes for many thousands of years. A review of archeological data collected over the last 30 years reveals the extent of this intervention. The study, which was headed by Nicole Boivin, Director at the Max Planck Institute for the Science of Human History and a scientist at the University of Oxford, identifies four major phases in which human activity caused far-reaching changes in the Earth's ecosystems. Fossil evidence from the period between 50,000 and 10,000 years ago shows that around two-thirds of the 150 megafauna species that existed at the

time became extinct with the spread of modern humans. The emergence of agriculture and cattle breeding then gave rise to new evolutionary pressure on plants and animals, and resulted in the number of wild vertebrates becoming "vanishingly small" compared with the number of domesticated animals. Moreover, the human colonization of islands involved such extensive species resettlement that the archaeologists refer to "transported landscapes." The emergence of early urban societies and extensive trade relations gave rise, in turn, to a period of intensive agriculture. (www.mpg.de/10558677)



Early intervention: Humans altered nature through hunting, farming and livestock breeding as far back as ancient Egypt.

Mommy's Darlings

Female rhesus monkeys form closer bonds with their daughters than with their sons

Many mammals develop close ties with certain members of their species. Whether males or females form closer bonds with each other most likely depends on which sex leaves the birth group on reaching sexual maturity and establishes new relationships in a different group. Observations by scientists from the Max Planck Institute for Evolutionary Anthropology in Leipzig also confirm this. In the case of rhesus monkeys, the males leave their birth group at the age of four. Females, on the other hand, remain with their birth group and rely on strong ties with other group members for their survival. The aggressive behavior of the mothers toward their male offspring in the first year of life appears to prevent the latter from forming close relationships with their group. Although the mothers provide the same care and attention to their offspring of both sexes, they are considerably less aggressive toward their female young and allow closer contact with them.

Rhesus monkey mothers are more aggressive toward their sons than toward their daughters in the first year of their lives.



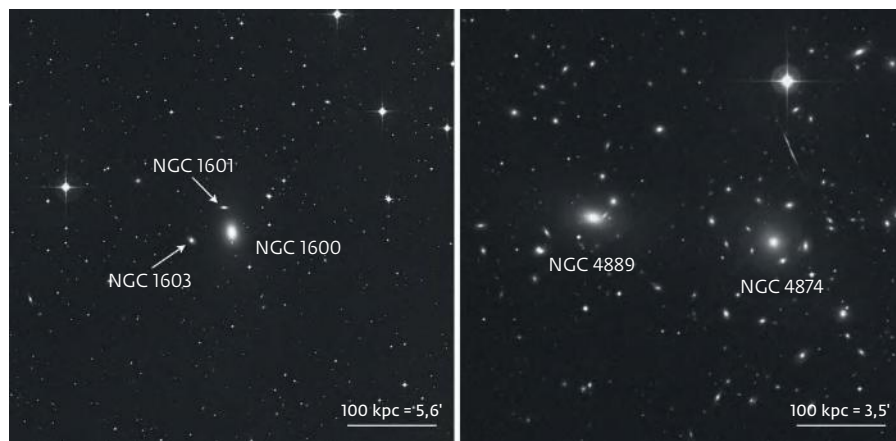
Black Hole in a Lonely Galaxy

Astronomers find a cosmic object with unusual characteristics

The growth of massive black holes isn't confined to large galaxy clusters. An international team of astronomers from the Max Planck Institute for Extrater-

restrial Physics and from the US and Canada have found a black hole with a mass of around 17 billion solar masses – one of the most massive black holes

found to date – at the center of NGC 1600, an elliptical galaxy that is relatively isolated in space. "Other galaxies that harbor extremely massive black holes are typically located in dense regions of the universe populated by many other galaxies and clusters," says Jens Thomas, an astronomer in Garching. Equally remarkable is the fact that the center of NGC 1600 appears to be unusually diffuse – as though it were missing billions of stars. They may have been ejected during an earlier collision with one or more other galaxies. (www.mpg.de/10431399)



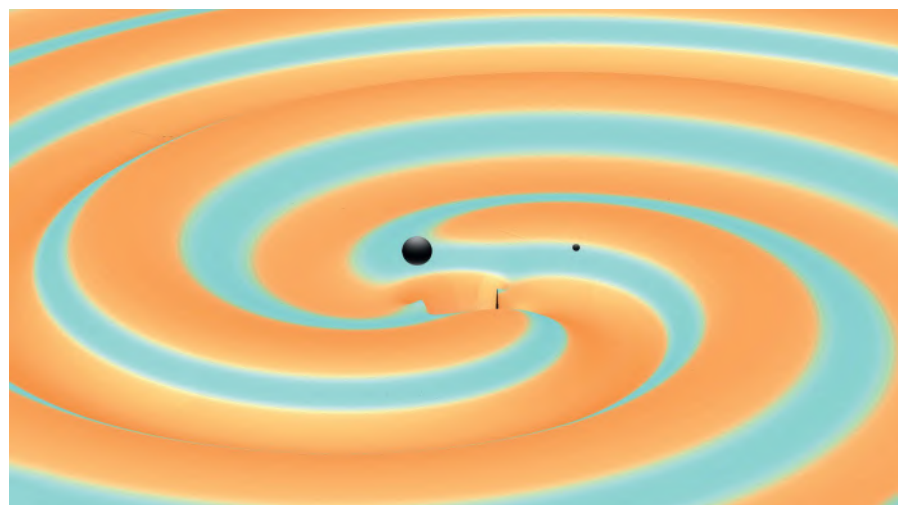
The elliptical galaxy NGC 1600 harbors an extremely massive black hole with a mass 17 billion times that of the Sun. The core is highly diffuse and lacks many stars – probably the result of a previous galaxy-galaxy merger.

Gravitational Waves 2.0

Researchers again observe signal originating from two merging black holes

Scientists working at the two American LIGO instruments detected a second gravitational wave. The signal was recorded on December 26, 2015 and named GW151226. It originates from a pair of black holes of around 14 and 8 solar masses. The two black holes merged at a distance of some 1.4 billion light years from Earth. The researchers also discovered that at least one of the black holes had previously rotated about its own axis. The merger then emitted the equivalent of around 1 solar mass in gravitational wave energy, leaving behind a rotating black

hole measuring 21 solar masses. The second event was much weaker than the first one detected in September 2015 and was buried in the detector noise. "With this second observation we are truly on the way to genuine gravitational wave astronomy," says Karsten Danzmann, Director at the Max Planck Institute for Gravitational Physics in Hannover. The researchers at the Institute contributed significantly to the discovery by providing highly accurate wave models and advanced detector technology, among other things. (www.mpg.de/10600416)



Cosmic dance of death: The simulation shows how two black holes with solar masses of 14 and 8 circle each other. The researchers measured 27 orbits before the black holes merged. The colors reflect different gravitational fields: cyan represents weak fields, and orange, strong ones.

Bearded Dragons Sleep Deeply

The brain's sleep phases developed early in vertebrate evolution

Sleep is ubiquitous in the animal kingdom: from insects and worms to mammals and humans – they all regularly take time out. Measurements carried out by researchers at the Max Planck Institute for Brain Research in Frankfurt have now shown that primeval vertebrates such as reptiles have sleep phases that resemble those of mammals in many respects. For example, the neuroscientists observed regular low-frequency and high-amplitude waves in the brains of bearded dragons during one phase of sleep. During two other phases, the neurons fire in strong pulses (delta phase), similar to the waking state, accompanied by rapid eye movements (REM sleep). The researchers also observed some differences: the lizards' sleep cycle is extremely fast, lasting only 80 seconds, while in humans it lasts between 60 and 90 minutes. The major similarities would suggest that the REM and delta phases of the brain are at least as old as the common ancestor of reptiles, birds and mammals, which lived around 320 million years ago. (www.mpg.de/10477322)

Kids Also Gossip

Five-year-olds judge the behavior of others, thus influencing their reputations

"It's better to play with Anna, Daisy always cheats!" The gossiping so typical of, and often criticized in, adults starts relatively early in childhood development: children as young as five judge the behavior of their peers and so help other children choose a suitable playmate. This is the finding of a behavioral study carried out by researchers at the Max Planck Institute for Evolutionary Anthropology in Leipzig. As part of the study, three- and five-year-old children were

asked to collect tokens and share an agreed number of them with a playmate. The researchers observed that the five-year-olds warned other children about tight-fisted participants. Although the three-year-olds also helped out with information, they didn't judge the behavior of their playmates. Thus, even preschool children can exchange information about others through gossip and so identify cooperative partners. (www.mpg.de/10484061)



The Master Singer

From the tropical rainforest to the urban jungle, birds have conquered many habitats on our planet – and they sing in nearly all of them. **Henrik Brumm** at the **Max Planck Institute for Ornithology** in Seewiesen studies how they use song to communicate with each other. He has taken a particular liking to one extraordinarily talented singer.

TEXT **CLAUDIA STEINERT**

Whenever his cat lays a dead bird in front of his door, Henrik Brumm vacillates between sympathy and scientific curiosity. His inquiring mind usually wins out, and Brumm studies the bird's vocal organ, called the syrinx. At least this way the animal still makes a contribution to science. After all, Henrik Brumm is a behavioral biologist. He wants to know how animals communicate with each other – how they court each other, for instance, or how they tell each other about the best feeding areas, and how they defend their territory. That's why, since completing his doctoral thesis, Brumm has been researching what is likely the most complex form of communication in the animal kingdom: birdsong.

Of the more than 10,000 known bird species, around 4,000 are songbirds. While every bird can produce sounds, not all of them can sing. The cuckoo, for example, can manage little more than his eponymous call. Parrots imitate sounds and even human speech, but that doesn't make them songbirds.

Only those whose vocal apparatus – the syrinx mentioned above – comprises particularly complex structures fall into this category.

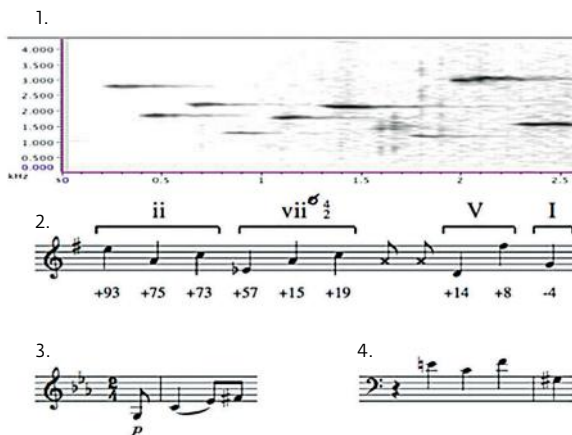
For his doctoral thesis, Henrik Brumm studied how the urban noise in Berlin affects the communication of nightingales – how the birds get their message across over the sounds of cars honking, sirens wailing and airplanes roaring around them. Germany's capital was ideal for his project: no other major German city has such a large nightingale population. They prefer to build their nests on the ground amid herbaceous hedges that sprawl over lawn edges and curbs, and that are not always trimmed as frequently as in other cities.

ON THE PROWL AT DAWN

Brumm's decision to carry out the nightingale project wasn't entirely without ulterior motive: it suited his biorhythm. Unlike most songbirds, the nightingale sings not only at sunrise, but also at night. Brumm envisioned himself taking off before or after hitting a few

Henrik Brumm records birdsong in a forest near Starnberg. The image on this page shows a common chaffinch.





Left King of the singers: Most of the 80 species in the wren family use loud and complex songs, but no other bird can match the musician wren – his melodic singing is unique in the animal kingdom.

Right The song of the musician wren has striking similarities to human compositions: song frequency over time (1), transcription of the notes of the song (2), opening melody of the second movement of Haydn's Symphony No. 103 (3), and the opening of Bach's Fugue No. 20 in A minor, BWV 889 (4).

pubs, equipped with a night vision device, laser rangefinder and sound level meter. But that didn't pan out. "I really got cheated on that one," he says with a wink.

The university had to cut costs. Rather than a night vision device and laser rangefinder, his supervisor gave him binoculars and a tape measure. Working in the dark was thus impossible. From then on, he dragged himself out of bed at 3:30 each morning and got on his bicycle. He pedaled to the city highway, roamed through parks and stood for hours at highly frequented intersections. As soon as he saw a nightingale, he held up his sound level meter and recording device.

After recording the song, he rolled out his tape measure and measured the distance between himself and the bird. From the distance and the sound level, he then calculated the absolute volume of the song. His conclusion: the more noise surrounding the nightingales, the louder they sing. They display what is known as the Lombard effect.

Lombard was a French physician who noticed, some 100 years ago, that we involuntarily adjust our volume according to the noise level of the environment, so that those we are talking to can better understand us. And it is precisely this trick that birds, too, use

to make themselves heard in the city. "Nightingales sing more loudly during the week than on the weekend, because the streets are louder on weekdays," explains Brumm.

Birdsong is so characteristic that ornithologists can recognize a species by it. But that takes practice – except in the case of one of their representatives: "Even amateurs can identify the musician wren," says Brumm. This bird, which lives in the Amazon and measures just 12 centimeters, is smaller than a sparrow and has similarly inconspicuous coloring. But while it's not much to look at, when it opens its beak and begins to sing, it sounds as if music were floating through the jungle.

A VIRTUOSO IN THE RAINFOREST

The musician wren has gained quite some renown in its native habitat. Due to its remarkable song, it is as significant in the culture of indigenous peoples as the nightingale is in ours. The locals revere the small bird, which they call "Uirapuru," and numerous legends have been woven around it. Anyone who hears it sing will enjoy good fortune in hunting, in love, or even in all aspects of life. Some restaurateurs or shop owners even bury a dead Uirapuru in front of their door in

the hope that it will improve business. When the Uirapuru sings, so the stories go, all other animals in the forest fall silent and gather around it to listen to its songs.

Yet the song of the Uirapuru serves a very practical purpose: like all songbirds, it uses its melodies to attract female birds during mating season. The female birds can tell from the song how viable a male bird is, and consider it a sign that the singer evidently managed to conquer a food-rich territory – how else would he have so much time for singing! In the Amazon, communication by song is also important for another reason. In the undergrowth of the tropical rainforest, with visibility often below three meters, it is very difficult for animals to see their potential partners. Calls and songs, however, penetrate the dense vegetation.

In 2003, Brumm himself stood in the jungle of the Amazon rainforest for the first time. Around him, everything was green, with trees and bushes blocking his view. Suddenly he heard this song and he immediately knew: it's him – the musical bird that he had previously known only from audio recordings. Henrik Brumm wanted to know why the musician wren sings like that. Why do its songs sound to humans like a concert musician's performance, while

other birds sound like children leaning to play the recorder? No one knew.

At the University of St Andrews in Scotland, he met musicologist Emily Doolittle. Doolittle was looking for biologists who research animal sounds. Brumm was looking for someone who understood more about music than he did. Together, the two began to develop an experiment to answer the questions that had long occupied Brumm: why does the song of the musician wren sound like music? The findings needed to be quantifiable. They wanted facts and figures, not subjective opinions.

Of course Brumm would have preferred to travel through the Amazon himself and collect bird sounds, but no one would have paid him to do that. So Brumm and Doolittle used the xeno-canto database, where anyone – scientists and amateurs alike – can upload recordings of bird songs. This put an incredible variety of bird sounds from around the world at researchers' fingertips.

First they reproduced the songs of many different musician wrens using a synthesizer, as listeners in the experiment were not to know that the melodies were birdsong. Next, they jumbled up the individual notes of each song. They didn't change the pitch or duration of the notes – only the order. They played both the original and the jumbled version for study participants: concert pianists, garage band founders, and people with no musical inclinations. They were asked to decide which of the two variants sounds more musical. The original melody was the clear winner. "Even those who knew nothing about music agreed," says Brumm.

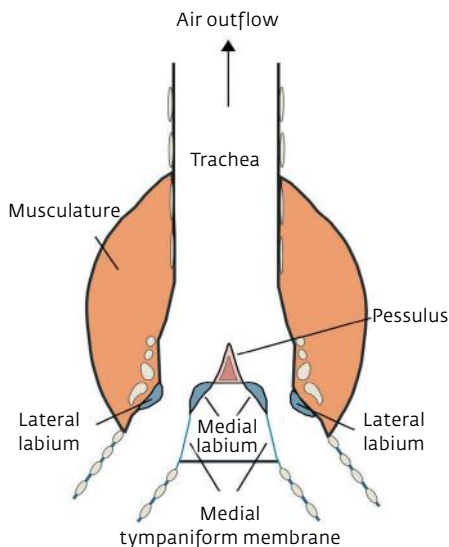
Since the researchers had not altered either the notes themselves or their duration, only one factor remained. It had to be the note intervals – the spans between successive notes. "Of course we don't know whether the bird has any perception of intervals or tonality," says Brumm. But that wasn't his concern. Brumm's aim wasn't to discover whether the musician wren is musical. He also didn't want to know whether the bird perhaps even carries within it what some invoke as the primeval music that



Henrik Brumm analyzes the songs of his feathered study subjects on the computer – using the latest software to fathom every last detail.



Below Unlike mammals, who produce sounds with their larynx, birds vocalize using a unique organ called the syrinx, which is located at the base of the trachea where it branches into the primary bronchi. Songbirds have a two-part syrinx that houses a separate sound source in each bronchus, each of which is controlled by a separate set of muscles. These muscles adjust the tension and position of the labia, known as the medial and lateral labia, and the medial tympaniform membrane and in this way, in conjunction with additional factors, regulate the pitch of the song. Since different neurons in the bird brain control the muscles, the two sides of the syrinx function independently of one another. Songbirds can therefore sing two different notes at the same time, or alternate between the right and left sides in rapid succession.



is supposed to have inspired all man-made music. He only wanted to know why the song of this little bird sounds so pleasing and beautiful.

Upon analyzing the melodies more closely, it turned out that the musician wren does, in fact, sing particularly often in what are known as perfect consonances. He warbles in fourths, fifths or octaves – that’s what music theorists call an interval of four, five or eight tonal steps. To our ears, these intervals sound particularly harmonic; they are also used in many folk and children’s songs. Imperfect consonances are much rarer in the song of the musician wren, and they avoid dissonances, which occur frequently in jazz music and create disharmony.

EVOLUTION AS A COMPOSER

Our perception of perfect consonances as harmonic and beautiful isn’t merely a construct of Western culture. It also has something to do with our order-loving brains and the physics of soundwaves. For every note, soundwaves vibrate at a certain frequency: the faster they vibrate, the higher the frequency. When the frequencies of two notes are in a simple mathematical ratio – for instance, one frequency is twice as high as the other – we perceive the interval

as calm and harmonic. An octave has the frequency ratio 2:1, a fifth, 2:3, and a fourth 3:4.

“The intriguing question is why this one bird species specialized in consonant intervals,” says Brumm. This type of song probably gives the birds an evolutionary advantage. The female birds could be the driving force behind this: if they prefer harmonic songs and mate more frequently with male birds who sing them, this trait would become dominant. Each generation would then be somewhat more musical than the one that preceded it. What remains unclear is why this preference for consonances developed specifically in musician wrens and not in any other birds. To date, no other species has been found to prefer perfect consonances. To our ears, many bird species sing downright unmusically.

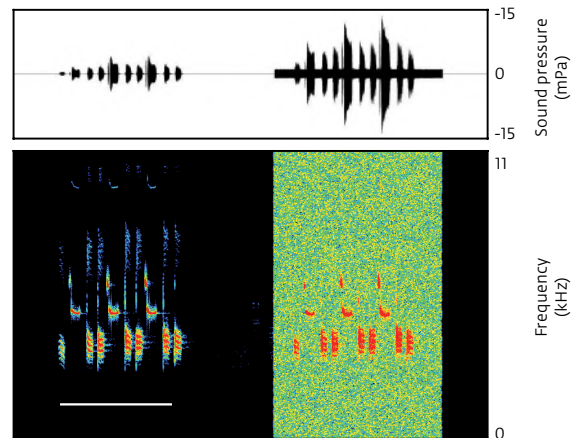
Songbirds learn singing the way humans learn speaking: the chicks imitate what the adults sing to them. To produce sound, however, birds don’t use the larynx, but rather the syrinx, which is located at the base of the trachea where it branches into the primary bronchi. This allows birds to produce two notes simultaneously and sing a duet with themselves.

Brumm and his colleagues discovered that birds and humans, despite

Left page In the soundproof lab, the researcher tests what female birds most enjoy listening to. The animals can play songs themselves by pressing a button. Female birds just can't get enough of the song of male birds of their own species: they listen to it several hundred times a day.

Top right Birds sing twice as loud (right) in a noisy environment as they do in a quiet one (left).

Bottom right Frequency spectrum of the song under the same conditions as above.



their different anatomies, use the same mechanism to produce sound. It is a system that is particularly forgiving of errors. When humans speak, the elastic vocal cords open and close. The combination of air pressure and muscle tension in the vocal cords produces a certain tone. Children who are just learning to speak must experiment for a very long time to learn which combination produces which sound.

If there were just one correct vocal cord position for each sound, it would be incredibly difficult to imitate sounds accurately. However, because the elastic vocal cords don't just open and close, but in the process also undulate like a wave, there are multiple correct positions that all produce the same tone. The syrinx of birds works on the same principle. It is thus much easier for children and chicks to learn how to speak and sing, respectively. Not only did Brumm and his colleagues discover this principle in birds, they also showed that all birds – from the sparrow to the ostrich – possess this mechanism. “The principle seems to have proven successful.”

In big cities, however, it is rapidly becoming more difficult for birds to communicate, due to the noise that engulfs every metropolis like a cheese dome. The World Health Organization estimates that 200,000 people in the European Union die each year from cardiovascular diseases caused by constant noise. Brumm is now investigating

whether noise leads to sleep disturbances in birds, too, or triggers chronic stress in them, causes their cells to age faster or disrupts their immune system functioning. “The birds could be a model for better understanding these processes in humans.”

For some time now, Brumm has been studying bird populations at Berlin's Tegel Airport. He originally wanted to test how they behave when

the terminals eventually close and peace and quiet descends on the nesting sites in the northern part of the capital city, but that hasn't happened yet: “The operators of Berlin's new airport thwarted that.” So the field studies there will have to wait another couple of years. In the meantime, Brumm plays Munich's traffic noise to the birds at the Max Planck Institute in Seewiesen. ◀

TO THE POINT

- Loud environments make it more difficult for birds to communicate, so they adapt their song and likewise sing louder – a phenomenon referred to as the Lombard effect.
- To human ears, the song of the musician wren sounds like music because the bird sings in perfect consonances. The melody is made up of fourths, fifths or octaves. It is not known how the birds themselves perceive their song or whether they have any concept of consonance, tonality or theme.
- Birds and humans produce sounds in the same way: the vocal cords of mammals and the labia of the syrinx in birds oscillate in the same patterns of overlapping waves.

GLOSSARY

Musician wren: A member of the wren family, this bird lives in the Amazon, where it has a large range. Due to its unusual song, the species plays a prominent role in South American mythology and folklore, and even the English name points to the bird's distinctive musicality. The nearest relatives of the musician wren (the chestnut-breasted wren and the song wren) have much simpler songs. Only the musician wren favors perfect consonances in its song.

Lombard effect: This phenomenon, named after French physician Étienne Lombard, causes people (and also some animals) to adjust their voice to the volume of their environment. If the surrounding noise level increases, people involuntarily speak more loudly. If, for example, several people are speaking in a small room, the volume in the room may gradually grow louder and louder.

Computers Make Faces

These days, animated figures in films and in computer games are often true to life. After all, they are created with sophisticated three-dimensional models of bodies and faces. **Christian Theobalt** and his colleagues at the **Max Planck Institute for Informatics** in Saarbrücken are making it much easier for graphic artists to generate such models – enabling applications that were previously inconceivable.

TEXT **TIM SCHRÖDER**

Actor Tom Cruise is a cool guy. In *Minority Report*, he shines as a hard-boiled fighter against evil. He is cast as a policeman in the year 2054 – and as you would expect from science fiction, he is surrounded by a huge amount of high tech. But looking at the movie today, only 14 years after its premiere, there are parts of the vision of the future that don't look very advanced. In a scene that seemed very futuristic back then, the actor moves his hand to open screen windows on a glass wall that serves as a monitor. He stretches and shrinks the images with finger motions, then conjures them away with a brisk swipe. That looks stylish, but when he does so he is wearing a black glove with luminous dots – a data glove. And today scientists simply grin at that.

This principle, where Tom Cruise controls a computer with a data glove, has been around in movies for about 20 years, and is still being used for new productions. A person is filmed wearing a whole bodysuit with markers that

a computer can use to follow – track – the position of the head, body, arms and legs. This enables the movement to be transferred into a scene in a movie of a computer world, for example, to animate a fictional figure in a human way. But this kind of tracking is complex. Actors have to struggle into gloves and a full bodysuit.

ANALYZING REALITY IN MOTION WITH THE LEAST EFFORT

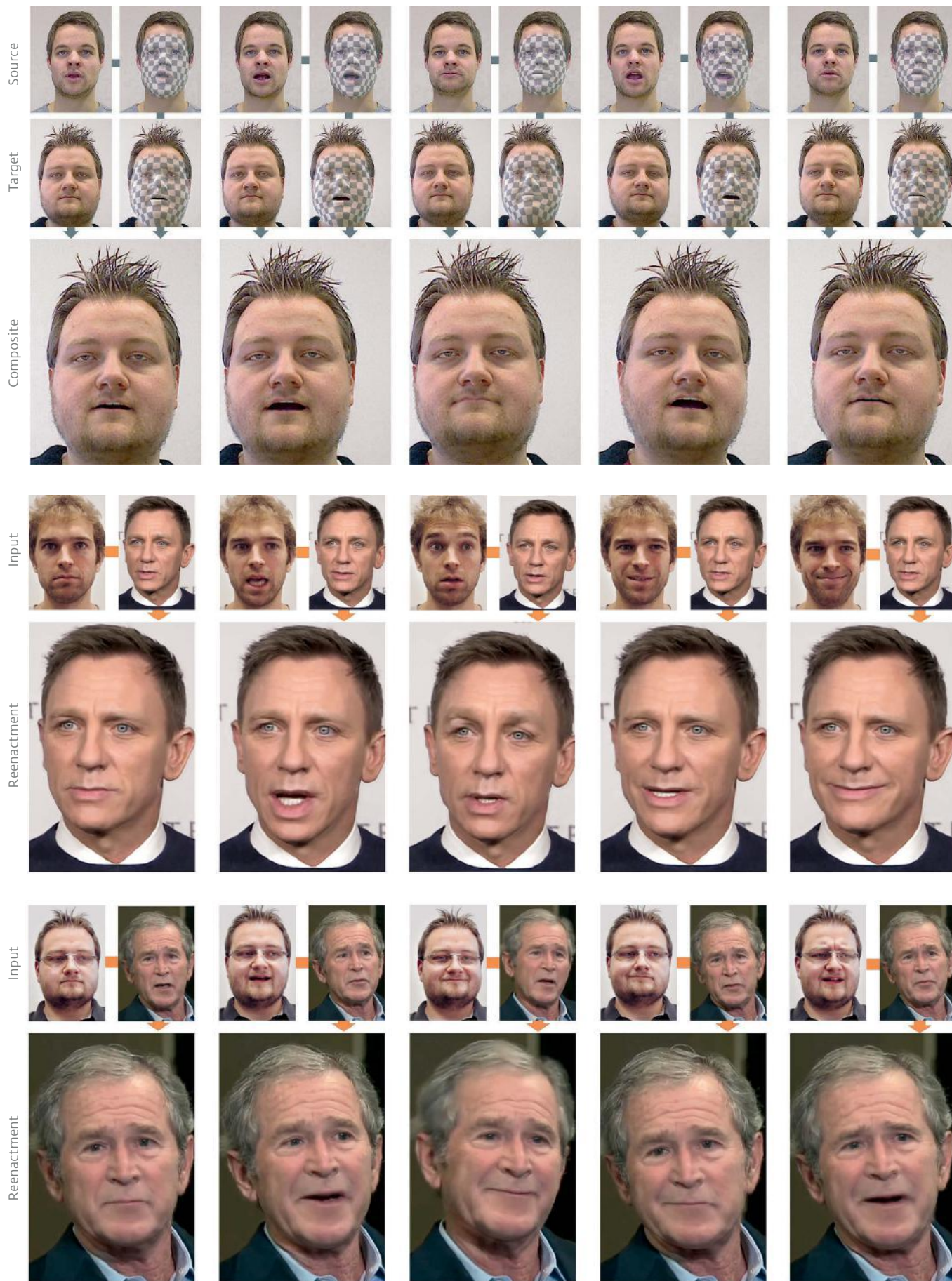
Christian Theobalt and his colleagues at the Max Planck Institute for Informatics can take some of the credit for the fact that tracking with markers is gradually going out of fashion. The computer scientist leads the Graphics, Vision and Video Research Group at the Institute. He is working at the interface between computer graphics and image recognition. Theobalt's main aim is to teach computers to analyze reality in motion with the least possible effort and, above all, at high speed, and then convert this into accurately detailed three dimensional

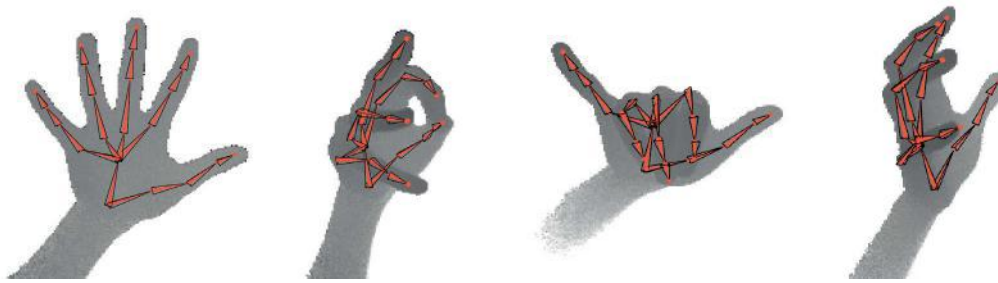
virtual models that precisely capture the shape and reflective properties of a figure, as well as the lighting of a scene.

His working group has two main research focuses: the recognition of movements and the analysis of faces. It isn't only filmmakers who could use these methods, to adjust the expression of an actor or animate fantasy figures. Computer game developers could similarly provide avatars with natural movements and facial expressions. And robots could utilize the techniques of scene analysis so that they could get an exact picture of their environment. Above all, they must be able to distinguish people in the background from relevant objects in the foreground. Another major application area is augmented reality, the mixing of reality with a virtual world to allow virtual objects to be moved with gestures.

In the future, Theobalt's research should save the film and games industries alone thousands of person-years in work throughout the world, since it isn't only the tracking with markers

Right Changing faces: Computer scientists from Saarbrücken transfer the facial expression of an actor in a source video onto an actor in a target video. Gray and brown arrows indicate the workflow. In the top two rows, the morphable 3D face models of the source and the target are shown in a chessboard pattern laid over the tracked faces. In the fourth and sixth rows from the top, the original facial expressions of the source and the target can be seen.





Franziska Müller (right page) has developed a software that efficiently tracks even subtle movements of a hand with rather low calculating effort and reconstructs the gestures in a 3D model. To make sure that the captured positions are anatomically possible, the program utilizes a model of the hand skeleton, shown in red (left page).

that makes the animation of films and video sequences an arduous task. Graphic artists convert recordings of a real person into a mathematical model, generate figures from it and transfer these into a computer game or movie sequence.

Today, a lot of this work has to be done by hand. For example, to get the artificial face of an actor that is copied into a particularly spectacular move sequence to smile convincingly or to wrinkle its forehead requires computer graphic artists to invest many hours of precision work.

As far as the first part of his research goes – motion capturing – there are still some obstacles to overcome. For example, in order to allow the scary Gollum to appear in the *Hobbit* and *Lord of the Rings* movies, the filmmakers transferred the body and the movements of an actor onto a model. They adapted the pose and in particular the face to their idea of the fantasy creature, textured the figure with Gollum skin and copied it into a cave world generated on the computer.

In order for the actor's movements to be converted into a model by the computer, the actor, and particularly the face, must be perfectly illuminated in special studios and recorded in different poses by several cameras so that concealed parts of the body are captured. And of course the recording studios must be relatively empty apart from the actor, as any objects present would confuse the computer in the analysis of the scene.

"It would be much simpler if we could just record people in the open air, in a perfectly normal environment and with varying lighting conditions," says

Theobalt. "And preferably with only one camera to reduce the effort – that's precisely what we are aiming for." Until recently, that was inconceivable. Step by step, Theobalt and his ten colleagues are approaching their target.

RECOGNIZING THE MOST SUBTLE GRASPING MOVEMENTS

Doctoral student Franziska Müller and her colleague Srinath Sridhar want to help the computer recognize the movements of hands more reliably and transfer them to a three-dimensional model. That is particularly difficult, because the rapid movement of a hand and its fingers often leaves some parts out of the camera's field of view. But being able to follow the fingers exactly is important for operating devices with gestures in augmented reality. "For this, the computer must be able to interpret the hand gestures correctly," says Franziska Müller.

Müller is already much further than what Tom Cruise did in *Minority Report*. Cruise rearranged the images on a monitor with coarse hand movements. But Müller's computer can recognize the most subtle grasping movements. To do this, she switches on a small camera on her computer screen and measures the three-dimensional shape of an object with laser beams. On the otherwise white screen, an artificial hand appears and follows all of her finger movements. Müller presses her thumb and index finger together. She opens and closes her hand. And the artificial hand on the screen carries out every movement.

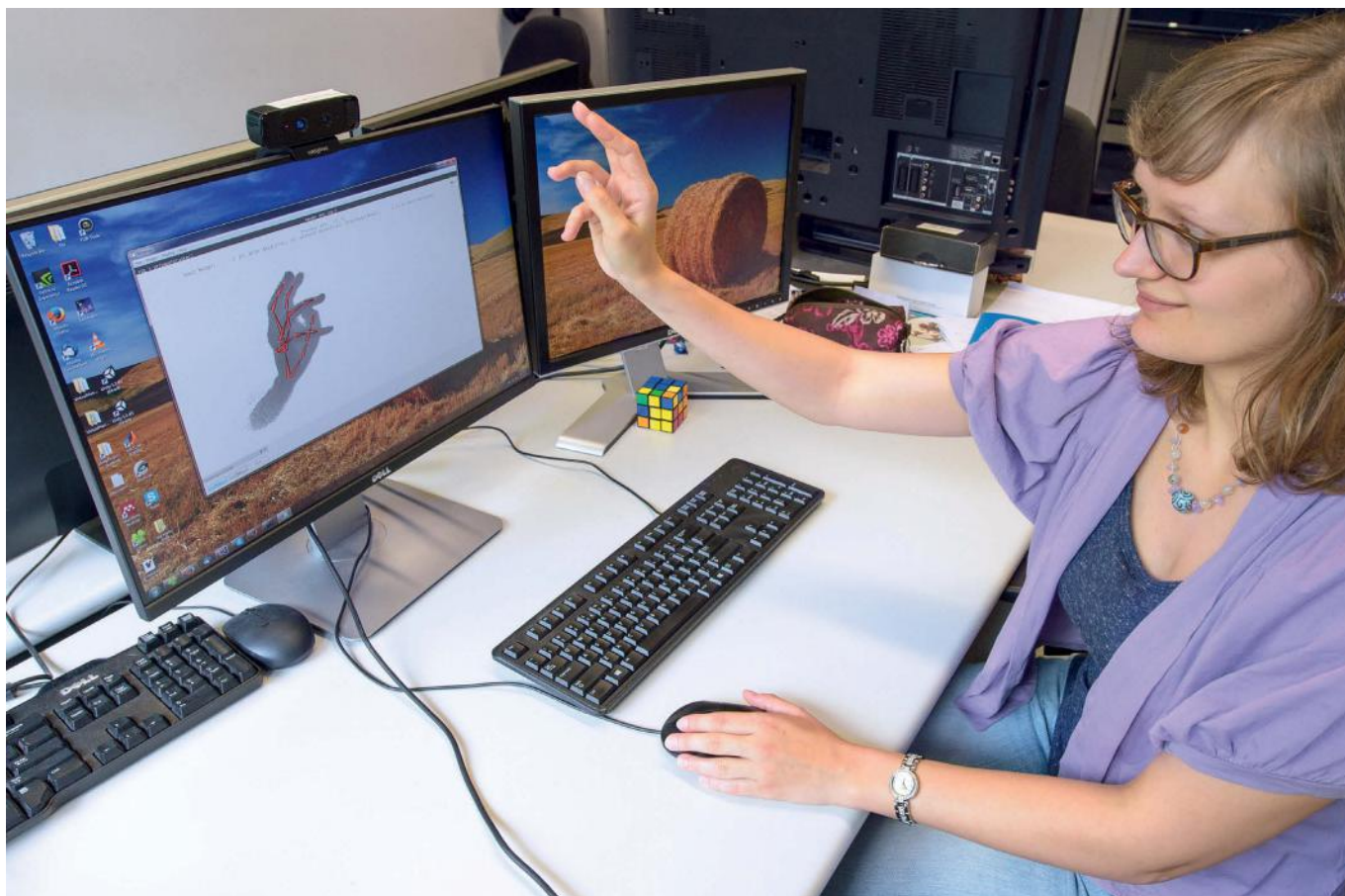
As so often, the devil is in the details: the computer must keep calculat-

ing the position of the fingers, and that in fractions of a second, or else the image on the screen would falter and jerk. And of course analyzing the gesture must take into account the parts of the hand that happen to be concealed from the camera. "That's only possible with mathematical procedures that reduce the quantity of image data and can still calculate the position correctly," explains Franziska Müller.

Concretely, it is a matter of the mathematical analysis of distance data. The small depth camera on Müller's monitor measures the run time of the light for every image point – for instance, to a fingertip or the ball of the thumb and back.

Franziska Müller switches on another program she bought from a software company that already offers a program for real-time hand measurement. The result is disappointing: When the researcher moves her hand quickly, the program can no longer follow. The model of the hand on the monitor suddenly loses fingers; for a moment, a finger appears in a wrong position. It gets really bad when one finger conceals another. The hand on the screen partially dissolves. The software she bought has problems importing the image data correctly into the model.

The reason: conventional programs can't handle the enormous computing load for calculating stable three-dimensional movements from images from one camera perspective. Müller therefore uses a different procedure. Her software arranges the measured values for individual pixels so that neighboring pixels at the same distance from the camera are represented as Gaussian



clouds. In this way, the number of points can be reduced considerably. This shortens the computing time, which allows Müller's program to keep up even when she moves her hand quickly.

Müller's software compares the calculations from the distance measurements with a model skeleton already stored in the program. This gives the computer an idea which hand and finger positions are possible.

Müller also uses a computer learning procedure that estimates which part of the hand a pixel belongs to in fractions of a second on the basis of probabilities. Franziska Müller has fed the computer with training data: it has learned how a hand can look when it is rotated or moved. In addition, she has built in another kind of error estimation in her program that excludes values that make no sense in terms of hand anatomy.

"Thanks to Franziska's work, we can now measure subtle finger movements too, such as when one rubs thumb and index finger together," says Theobalt. "Conventional programs can't resolve that at all."

The hand is, of course, not everything. In many cases, the movement of a whole body must be captured. The

Saarbrücken-based team uses a skeleton model that was developed in Theobalt's group and gives their software a degree of anatomical knowledge.

"We are slowly departing from classical motion analysis," says Theobalt. The computer normally orients itself toward characteristic structures in a sequence of images, not only marker points, but also image regions that have a similar appearance. "We call this procedure correspondence finding. The computer tries to follow an object that slowly moves in a sequence of images." The problem: with changes in lighting, these procedures produce significantly more errors, because the corresponding image points keep changing their luminosity.

Theobalt's team has not only made the movement analysis more independent of the environment and lighting, but reduced the number of cameras necessary from over eight to three. For this purpose, Theobalt applies machine learning. In this way, the researchers can compensate for the computer's briefly losing track of concealed body parts with only a few cameras and changing lighting. They train the machine learning tool with images of

different poses so that it learns to identify the body parts.

The combined approach makes the movement analysis of Theobalt's group especially efficient. This is the first procedure that can measure the movement of the complete skeleton in 3D quickly and very robustly – not just in a carefully lit studio, but outside in any kind of environment with continually changing lighting conditions.

Former doctoral students and post-docs of Theobalt's have founded the company TheCapture, which specializes in motion analysis with the help of the skeleton model. The company offers software that analyzes the position and motion of the limbs from video recordings from one or a few cameras, even in real time. "The software is used to analyze the fast motion sequences of athletes or to investigate the body positions of people at their workplace," says Theobalt.

The challenges with facial recognition, the second focus of the working group in Saarbrücken, are altogether similar. To produce realistic-looking high-resolution 3D facial models, the face of a person must be illuminated in a defined way and recorded by several

cameras. Only then can the computer calculate the three-dimensional shape of the face and cleanly reconstruct little wrinkles as well as reflections from the skin. To transfer the face of an actor into artificial worlds, they have to record many different facial expressions: laughing, looking mean or raising their eyebrows. It takes a lot of effort to model an expression that hasn't been previously recorded onto a face in a film scene.

CONSTRUCTION OF THE MODEL IN FOUR PARALLEL STEPS

The role of facial recognition is not limited to the movie and computer game industries. Novel fatigue alarms in cars rely on the interpretation of facial features, for example. Some companies are also working on procedures for interpreting lip movements. For instance, automatic speech recognition could be significantly improved, as not only the audio channel is used, but also the lip movements in the video image.

Theobalt wants to simplify facial recognition in a similar way to motion analysis and create three-dimensional models that can produce facial expressions that were not recorded in the creation of the model. His team is working on transferring video recordings made of faces with a single camera and uncontrolled lighting into 3D facial models. Unlike conventional calculation procedures, the technology is so fast that the model can follow the expressions of a filmed person.

In order to reconstruct a moving artificial face in acceptable time from the simple video image of a single camera, Theobalt must travel a different path from previous methods. He calls it inverse rendering. The term rendering, from computer graphics, stands for the precise calculation of correctly illuminated images from a model of the scene. In inverse rendering this is turned around, and the model of lighting, reflectivity and geometry that best elucidates the appearance and the shading in the image is calculated. The facial reconstruction becomes very robust to scene changes and functions independently of whether the sun is shining or the sky in front of the window is overcast.

The trick: Instead of analyzing a face with wrinkles, shadows and reflections under studio conditions pixel by pixel, Theobalt's team divides the construction of the model into four parallel steps: first, the recognition of the shape of the face; second, the reconstruction of how this changes with different facial expressions; third, the estimation of the reflective properties of the surface of the face, known as reflectivity; and fourth, the estimation of the lighting in the room.

The challenge associated with the recognition of the shape of the face and its changes is to extract spatial information from the two-dimensional video signal from the camera – the position of the prominent nose or sunken eyes, or the shape of the mouth. "We overlay the

image of the face with a 3D facial model that was developed here at the Institute a few years ago (see *MAXPLANCK-RESEARCH* 4/2011, p. 62)," says Theobalt. "Its strength is reconstructing a 3D face from sparse image information."

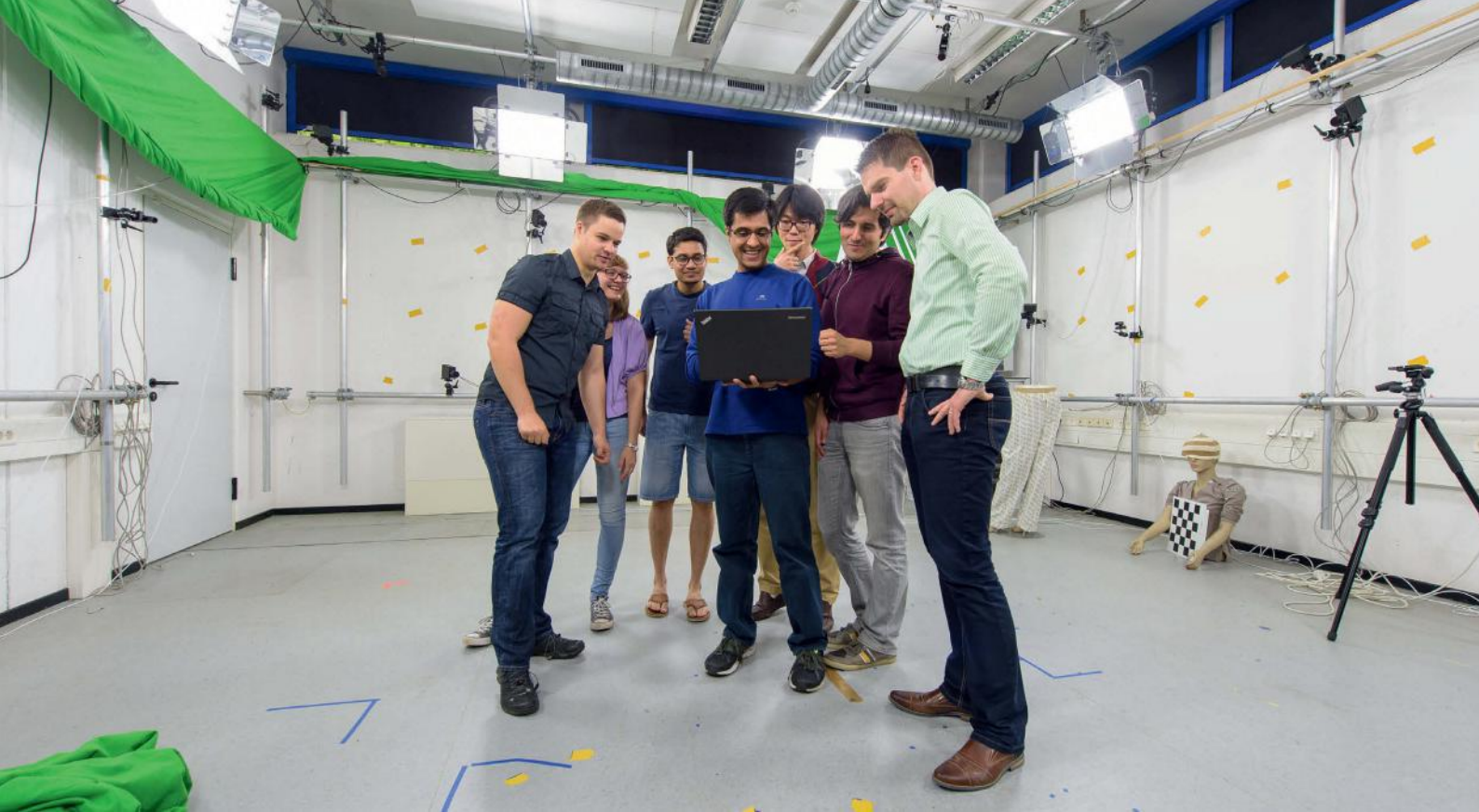
Separately from the recognition of the shape, inverse rendering analyzes the information about light and shadow in a scene, or the reflectivity. "First we calculate from that the lighting conditions prevailing in the space," explains Theobalt. Subsequently, the computer can let the light in the space react with the shape of the face. It can then draw conclusions about the 3D shape, including fine details, from the shading in the face in the video. In several iterations, the computer compares the facial model it produced in fractions of a second to resemble the actual video image, and adjusts it until it agrees with the original. This happens so fast that the model can smoothly reflect even rapid changes of the features of the face.

How well inverse rendering works was recently shown by Theobalt's post-doc Michael Zollhöfer together with colleagues from the universities in Stanford and Erlangen. The researcher made a splash in the media when he succeeded in transferring the expression of one face to another in real time – "reenactment" of an expression.

Zollhöfer shows how this works. He switches on a conventional camera the size of a bar of chocolate and photographs his face. It appears on the monitor, which the computer first covers with

The method of Christian Theobalt's team also captures the motion of whole bodies in 3D models, shown here for a boxer.





To analyze reality in motion and to capture not only the shapes of bodies and faces, but also their reflective properties and the lighting of a scene is the mission of Michael Zollhöfer, Franziska Müller, Abhimitra Meka, Dushyant Mehta, Hyeonwoo Kim, Pablo Garrido and Christian Theobalt.

a grid. “The computer is now calculating the model of my face, which takes a few seconds,” says Zollhöfer. But then it goes quickly. Like a Venetian carnival mask, the three-dimensional animated representation of Zollhöfer’s face appears on a second screen. If Zollhöfer moves his mouth, the mask follows his movement.

Then he switches on a video of Arnold Schwarzenegger being interviewed on a second monitor. The software generates a model from Schwarzenegger’s face in the computer. Then the sensation: When Zollhöfer opens his mouth, Arnold also opens his mouth. Zollhöfer wrinkles his nose, grins, wrinkles his forehead – and the image of Arnold obediently follows every motion. “As you can see, my facial expression is transferred in real time onto the facial model of Arnold Schwarzenegger,” says Zollhöfer.

For the movie industry, this means that a naturally appearing expression can be directly transferred from one person into the moving video sequence. This is a minor revolution. Not least because one can now simply transfer any kind of facial expression into a model of a face.

Some producers have since already knocked on his door. However, he

still has to disappoint them. “We still have to optimize our facial model, especially the lip movements, because people are extremely good at noticing small inaccuracies,” says the research-

er. If the lips don’t close one hundred percent correctly with a sound, that has a very disturbing effect. “But I think we’ll get there in a few years,” says Theobalt. ◀

TO THE POINT

- In order to achieve natural effects for the expressions and movements of animated figures in movies, computer games or other applications in virtual or augmented reality, graphic designers have been using three-dimensional models of faces or bodies generated with enormous effort.
- Christian Theobalt and his colleagues are developing methods to analyze and transfer the movements of faces and bodies to models using recordings from one or a few cameras with arbitrary lighting and in an arbitrary environment, and with relatively little computer power.
- The researchers can use anatomical models stored in their software, as well as methods of computer learning.
- Thanks to the minimum effort required to transfer movements into three-dimensional models, applications that used to be inconceivable will now become possible. For example, the researchers can transfer the expression of one person onto the face of another in real time.

GLOSSARY

Motion analysis: Various methods are used in this technology, also known as motion capturing, to record the movements of people in three dimensions. Older procedures here depend on markers and precisely defined recording conditions.

Computer learning: Computers are trained for various tasks using many data sets. This helps them learn to recognize objects such as a table, even if they have seen only similar objects in the past, or see the object from an unfamiliar perspective.

Getting to the Bottom of the Deep Sea

The ocean is her passion, the seabed her lab bench. **Antje Boetius** from the **Max Planck Institute for Marine Microbiology** in Bremen always has multiple objectives in her sights: from discovery and precautionary research to technological development and scientific communication. It's an act that involves a lot of juggling – sometimes in rubber boots, sometimes in high heels.

TEXT **TIM SCHRÖDER**

Lectures abroad, preparatory paperwork for expeditions, team meetings, committees: “If you want to meet up soon, it would be best if you come by immediately – otherwise, it won’t be possible for another two weeks,” says Antje Boetius on the phone. “How about five o’clock?” Friday, 5 p.m. – the weekend has already started for a lot of people, but she squeezes in the interview before calling it a day because she believes in the importance of scientific communication, and she has resolved to deal with inquiries about her work immediately.

“Yes, I work quite a lot,” she says later, “around 14 hours a day. And on the weekend I like to work on my manuscripts – really.” Boetius stresses the “really” as though she wants to leave no doubt about the fact that she enjoys her work. But that’s obvious anyway. It’s approaching evening and she comes across as energetic and fresh, as if the week had just begun. There’s no doubt about it, Antje Boetius is passionate about her research.

The marine biologist’s to-do list is endless. She is head of the Joint Research Group for Deep-Sea Ecology and Technology at the Max Planck Institute for Marine Microbiology in Bremen and the Alfred Wegener Institute (Helmholtz Centre for Polar and Ma-

rine Research) in Bremerhaven. She is also Professor of Geomicrobiology at the University of Bremen and Vice Director of The Oceans in the Earth System excellence cluster at the MARUM Center for Marine Environmental Sciences in Bremen. She has at least three balls in the air at all times – and juggles them all successfully.

SPECIES DIVERSITY ON THE SEABED

The main topic of her research is the role of the seabed and its inhabitants within the Earth system – a very broad topic, as the seabed accounts for two-thirds of the Earth’s surface, and its biodiversity exceeds that of the terrestrial habitats. The issues Boetius tackles are equally diverse. “Around every five years, I change the focus of my work – sometimes I work on a particular biogeochemical process, such as the consumption of the climate gas methane; sometimes on the biodiversity on the seabed; and sometimes on the reaction of marine ecosystems to the melting of the sea ice and human interventions.”

Irrespective of what she is working on, Boetius aims to spend as much time as possible at sea, observing nature directly. In total, she has spent several years of her life on research ships.

When she talks about this, she sounds like an old sea dog who longs to be back on the high seas again. “I make sure that I go on an expedition at least once a year,” she says.

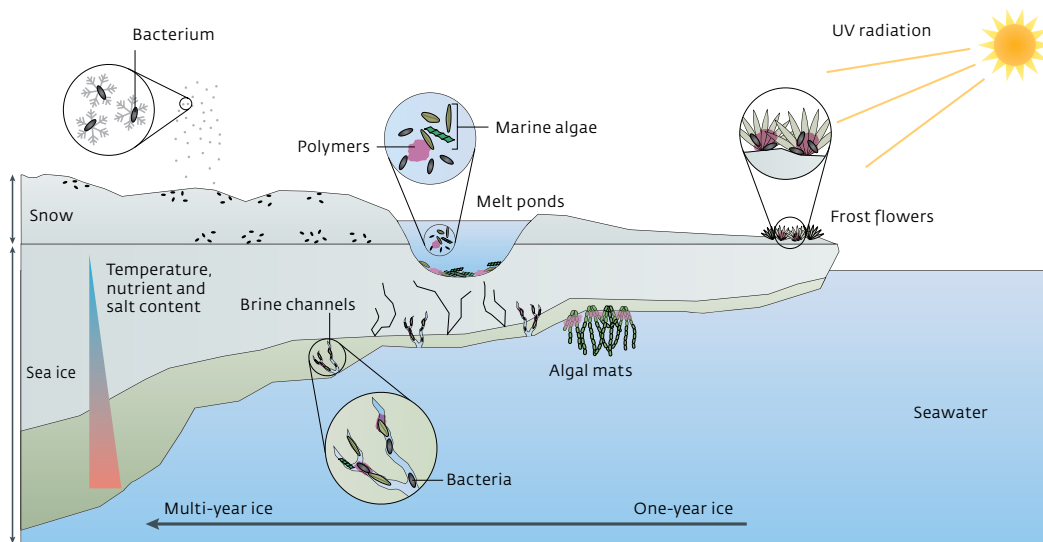
Boetius is a deep-sea researcher and has plunged to the remote ocean depths with diving boats many times – in the Atlantic, Indian and Pacific Oceans and in the Mediterranean and Polar Seas. Aided by spotlights, she has observed pale deep-sea fish, vividly colored sea cucumbers, bizarre giant worms and delicate brittle stars. What she is most interested in, however, are the smallest of life forms: bacteria. They may be microscopic, but they are extremely important, as they metabolize an enormous volume of substances and even influence the Earth’s climate in the process.

Boetius was born in Frankfurt am Main and grew up in Darmstadt, far from the sea, but she made up for this distance from the water with her imagination. She is the first-born child in her family. Her mother is a teacher who taught her to read at an early age – she started reading when she was three and her favorite activity as a child was to bury herself in a book. Pirate novels, *Treasure Island*, *Moby Dick* and everything by Jules Verne. She loved them all.

She watched little or no television, and when she did, it was the diving



Antje Boetius in her expedition gear: The equipment for the next trip is being packed in crates in the expedition hall of the Max Planck Institute in Bremen. On the left, a "deep sea lander," a freefall device that measures the respiration of bacteria in the deep sea and can also take samples. The researchers first used it under closed ice cover near the North Pole.



Microorganisms in the atmosphere form condensation nuclei for snow crystals, which is how they end up in the Arctic ice (top left). Bacteria and single-celled algae populate snow, ice, melt ponds and frost flowers despite being exposed to stronger UV radiation from the sun there. The microorganisms in the ice secrete complex molecules (polymers) with which they can also influence the ice formation. When sea ice freezes, the salt and other dissolved substances are captured in tiny channels within the ice as highly concentrated brine. The brine channels, melt ponds, and especially also the underside of the sea ice, are special habitats for microorganisms. The *Melosira arctica* diatom can form thick biofilms under the ice.

films of Hans Hass and his wife Lotte and the adventures of Jacques-Yves Cousteau that attracted her attention. "It was amazing. To go on expeditions as a career, live on yachts, do research in a bikini, have all kinds of underwater adventures – all of that inspired me." During this period of her life, her parents separated, but the family reunited for holidays. Antje, her siblings, her mother, her father and his new partner travelled to the sea together, usually to the Atlantic coast in Ireland, France or Norway. They camped in the open country, paddled along the shore in rubber dinghies and trawled the crystal-clear water for animals.

When she was 12, her father gave her a small set of equipment for nature exploration: a weather station, binoculars, stereo magnifying glasses and a small centrifuge. She knew what she wanted to do from an early age: to study in Hamburg, where there are a lot of ships and the sea on the doorstep. She wanted to experience the sea as a researcher.

Boetius has certainly fulfilled that early career wish. Today, she is often out and about on the high seas, particularly in the Arctic, with the German research icebreaker *Polarstern*, which enables her to explore the ice-covered waters of the North Atlantic. She wants

to understand how climate change is altering life: the composition of the microorganisms in the ice, the production of algae in the water and thus also the food for deep-sea communities, and the deposits in the seafloor sediments.

ICE MELT IN THE ARCTIC

During the time she was travelling in the Arctic in 2012, the sea ice was melting at a faster rate than ever before. It was thin and littered with melt ponds, making it particularly bright below the ice. The marine alga *Melosira arctica* was able to grow particularly well under these conditions and form dense, seaweed-like forests under the ice. Due to the intense warming, however, the ice melted and the algae sank into the depths of the ocean in fist-sized clumps.

Boetius and her colleagues sent cameras down to the seabed, which provided them with astonishing images: the otherwise desert-like floor of the central Arctic was covered with a green algal carpet. Only a few sea cucumbers and brittle stars could make anything of the *Melosira* clumps. The deep-sea measurements carried out by the Max Planck researchers showed that the new food supply is being exploited mainly by bacteria that consume the oxygen in the seafloor on site. The researchers

were able to report and describe this unexpected reaction of the Arctic ecosystem to the ice melt in a report they produced on board the research vessel.

The next Arctic expedition took place in 2014 and tackled a completely different topic. This time, Boetius and her team were at sea to explore the Gakkel Ridge north of Greenland. It was suspected that there were hot springs and special biocoenoses at a sea mount on the seafloor here, four kilometers below the ice. Such springs are known to exist at mid-ocean ridges, where new Earth crust is formed and the ocean plates drift apart. The seawater penetrates deep into the mantle there, is heated by magma chambers, reacts with the rock and spews back up into the ocean full of energy and minerals. This is how hot springs provide a nutritional basis for bacteria, which, in turn, provide sustenance for higher life forms. Life flourishes there in a way that is found almost nowhere else in the deep sea.

No one had previously observed life at the hot springs in the Arctic, though, because the sea ice was blocking the way. Since 2001, there had been indications of surprisingly strong heat emissions and smoke plumes in the sea, but no images had yet been obtained of these extreme habitats in the ice-cold

Polar Sea. Boetius and her team had a plan – and a great deal of luck: even with full ice cover, they were able to deploy underwater vehicles from the *Polarstern* and search the sea floor. On the last day of the expedition, they struck gold: small vents, known as black smokers, surrounded by unfamiliar gardens of white glass sponges appeared on the images they recorded. The international team is currently working through these findings. They want to prove that the spreading of the Arctic Ocean functions differently than predicted. This is the kind of discovery that fills Antje Boetius with enthusiasm.

Antje Boetius took her first steps into the world of science at an early age. Despite being bored by biology lessons at school, with their focus on the description of plants and animals, upon completing her German school-leaving examination in 1986, she moved to Hamburg to study marine biology. A relative suggested that she enroll to study with deep-sea researcher Hjalmar Thiel at the Institute for Hydrobiology and Fisheries Science there.

At that time, Thiel was among the scientists who were studying life on the manganese nodule fields at the bottom of the Pacific Ocean. Back then, the large-scale mining of the nodules was being considered for the first time. As part of the international DISCOL project, the team of scientists headed by Hjalmar Thiel and Gerd Schriever plowed a few square kilometers of the seabed in order to investigate how life in the deep sea would react to such an intervention. It appeared that the mining of the manganese nodules was about to become a reality, but no ecological studies had been carried out on the consequences.

Thiel invited the young student to meet with him. He began by advising her to study all aspects of biology and not to specialize too early. But Antje Boetius already knew that she only wanted to focus on the sea. “He told me to get back to him when I had complet-



Boetius studied deep-sea mud volcanoes on an expedition to the Mediterranean with the *L'Atalante* research vessel in 2003.

ed my intermediate undergraduate diploma.” Antje Boetius was born in 1967, so she’s a baby boomer. The university lecture halls and labs were overflowing with students, and the waiting lists for the most interesting courses were long. She had to earn money to finance her studies, so she worked part-

time as a waitress in a pizzeria and as a secretary in an insurance company – “a very strange world,” she says, “where everything is about money.” The highlight of her undergraduate studies was her first short ship expedition, which finally convinced her that she belonged on a research vessel. >

When she started her main undergraduate studies in 1989, she was finally able to concentrate on marine research. She attended every lecture that had anything to do with water, including Thiel's deep-sea lectures. At one point, he was looking for assistants for a large-scale expedition on the *Meteor* research vessel in the northeast Atlantic, and to her delight, she was selected to participate. Before the trip started, however, Thiel put forward a surprise offer. He asked whether she would like to participate in an exchange program – there was a spot available at the Scripps Institution of Oceanography in the US. Scripps in La Jolla, one of the best-known marine research institutes in the world, directly on the surf beach! Give up her part-time jobs and interrupt her studies immediately after her first big expedition with the *Meteor*? What to do. But she didn't spend a lot of time deliberating, and started packing her bags for the trip to the US.

Antje Boetius has never regretted the decision. She is very enthusiastic about the direct contact between the researchers and students there, and the considerable attention paid to the students. She completed so many internships and courses at Scripps that the time she spent there was fully counted

toward her degree coursework; all that remained for her to do on her return was to write her degree thesis. To that end, she immediately participated in several research expeditions. And it was on one of these that she met her future partner, a crew member from Bremerhaven. Boetius packed the insights she gained from over four months of expedition into her thesis. "It was all very tightly calculated, but I learned so much in the process."

BREMERHAVEN – NOT USA

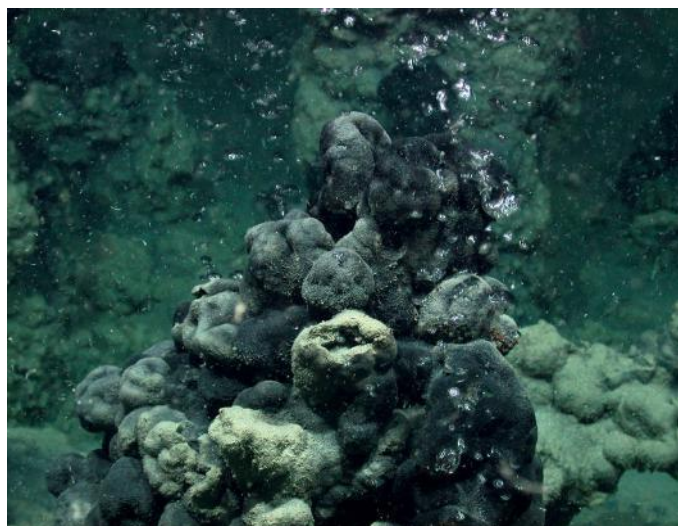
It had long been clear to Boetius that she wanted to continue in research and that the next step would involve doing a PhD. She had already familiarized herself with the microbiology of the sea floor on the research expeditions, but she didn't yet know where she should do her dissertation. She was longing to return to the US and the atmosphere at the institutes in California. On the other hand, her boyfriend was in Bremerhaven. The decision was made when her mentor from Scripps gave her a crucial piece of advice: if she wanted to make progress in the area of deep-sea microbiology, there was no better place to study than at the Alfred Wegener Institute with Karin Lochte, who is now

Director of the Helmholtz Centre. So Boetius remained in Bremerhaven.

For her doctoral studies, Boetius travelled to the Siberian continental shelf with the *Polarstern* for the first time in 1993. She took samples from the ice-covered deep sea and analyzed how the lack of nutrients influences the activity of the bacteria on the seafloor. "My dissertation was no sensation at the time," she says. "But the samples I took are a valuable source of information for new studies today. Nobody would have imagined back then that just 20 years later we would be working in completely ice-free areas." Thus, her data provides an important reference point when it comes to establishing how the Arctic bacterial communities are adapting to climate change.

"During this period, I was at sea for almost half the year and completely engrossed in expeditions. I simply wanted to be outside and gave little or no thought to my career," she says self-critically. It is important for researchers to stay informed about the general situation in science, to get to know new methods and carve out a research field for themselves. "I tell that to my doctoral students today, as it has become even more difficult to become independent at an early stage in your career."

In the Black Sea, bacteria populate gas sources at a depth of 260 meters and form towers standing several meters tall. These are supported internally by lime (left). The researchers use a glass bell jar to measure the gas emissions at a cold spring 850 meters below sea level in the Black Sea (right).





Boetius and her colleague Torben Klagge before a dive: The researchers studied the oxygen-free zones in the Black Sea in 2010 from the research submarine *Jago*. The German *Maria S. Merian* research vessel is in the background.

On completing her doctorate, she went to the Leibniz Institute for Baltic Sea Research in Warnemünde as a postdoc with Karin Lochte and worked for a time in the Indian Ocean. At the time, in the mid-1990s, new molecular biology techniques were emerging with which researchers could identify genetic relationships from the genomes of bacteria, particularly by comparing the ribosomal nucleic acids (16S rRNA sequencing). Marine microbiologists were using these methods to determine the diversity of unknown microorganisms and their distribution and activity.

For that reason, in 1999, Boetius moved to the Max Planck Institute for Marine Microbiology in Bremen, where she familiarized herself with the new methods in marine microbiology. Back then, methane deposits in the sea were becoming a major focus of scientific interest. Methane hydrate – also known as gas hydrate – is a solid, ice-like compound between seawater and methane that forms in the depths of the ocean at low temperatures. Such hydrates are found in different locations in the

oceans. Scientists all over the world are fascinated by them, as they could offer an interesting source of energy – but they could also cause landslides and tsunamis. Moreover, they are teeming with life: bizarre worms, mussels and unfamiliar microorganisms.

METHANE AS A FOOD SOURCE

But no one knew what the communities of animals in gas hydrates live on, as there was no known organism that could make direct use of methane. It was suspected that organisms from the Archaea kingdom decompose the methane and possibly obtain energy in this way. Boetius was able to participate in a GEOMAR expedition to Hydrate Ridge, in the Pacific, and studied the sediment samples taken there. She combined the 16S rRNA sequencing with another detection method known as fluorescent in situ hybridization (FISH). The FISH technique enables the microscopic differentiation of the bacterial species in a sample based on their genetic fingerprints. Specific nucleic

acid molecules marked with fluorescent dyes attach to the ribosomes of certain bacteria and cause them to light up.

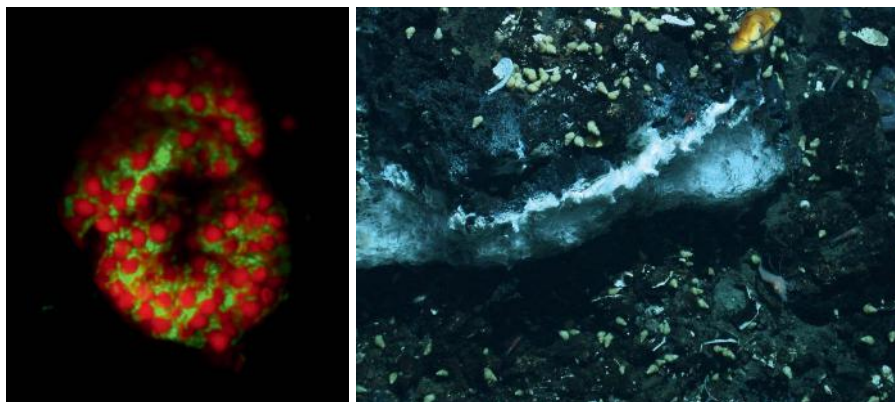
Strangely, two cell types that appeared to have grown onto each other always lit up under Boetius's microscope. They were bacteria that process sulfur compounds and microbes from the Archaea kingdom. She eventually realized what was going on here: the methane in the sea floor is processed jointly by the two. The solution to the mystery about life on the hydrates is cooperation! The bacteria create the right energy conditions for the archaea to be able to breathe the methane and, in return, benefit from the latter's decomposition products.

The renowned scientific journal *NATURE* published the story about the archaea-bacteria symbiosis, which provided the first indications of “anaerobic methane oxidation” on gas hydrates. The article met with great interest in the life and earth sciences, given that methane is a major greenhouse gas.

The scientific world had been asking itself for decades why the gas-rich

Left Shining duo: An accumulation of methane-oxidating archaea (red) and their symbiosis partners (green). The colors are generated by nucleic acids labeled with fluorescent dyes.

Right Methane hydrate in the Gulf of Mexico at a depth of almost 3,000 meters. Microorganisms feed on the methane it contains and, in turn, provide food for worms, snails and crabs.



ocean releases so little methane into the atmosphere, and how the climate would change if the methane hydrates dissolve due to the warming of the oceans.

MOVING UP THE CAREER LADDER

Boetius had achieved a major coup. While still a postdoc she was able to launch a major project at the Max Planck Institute to investigate the micro-world on the hydrates. The project was funded by the German Federal Ministry of Education and Research, and involved all of the departments at the Bremen-based Institute. Her career really took off then and a series of other projects followed. In 2003 she took over the leadership of the Microbial Habitats Research Group at the Max Planck Institute in Bremen. That same year, she was appointed to a professorship at the International University Bremen, the predecessor of Jacobs University.

She commenced numerous new projects on deep-sea research, many of them in cooperation with researchers from different countries. In 2008 she established the Joint Research Group between the Max Planck Institute and the Alfred Wegener Institute, and was appointed to a professorship for geomicrobiology at the University of Bremen. In addition to the projects on the dis-

covery of extreme habitats and the function of methane decomposition, she added other important research questions in the area of precautionary research to her repertoire: What happens when the ocean acidifies? How do microbial communities react to a lack of oxygen and over-fertilization? When does the sea floor recover after the removal of manganese nodules?

“I’m always interested in new tasks and challenges,” says Antje Boetius. “You just have to allow fate the chance to come up with one.” Like when she approached Thiel as a young school-leaver, or during her undergraduate studies when she applied for a place on the research voyage despite having very little chance of being chosen.

She requires a certain amount of individual initiative from her 60-plus staff members. “We work on projects in alternating teams so that each doctoral student and technician has several contacts – and I can always be reached by e-mail.” And something else is important to her: “When we go on an expedition together, we get to know each other in all kinds of situations. That creates trust.”

Boetius has led regular expeditions since 2006. She organizes the scientific tasks on board and coordinates the research work with the captain and crew. On big research vessels, researchers

from a large number of disciplines working on a diverse array of experiments and topics are usually tossed in together. As an expedition leader, she follows the example of her mentor Hjalmar Thiel and his colleagues. “I learned back then that, while you have to work hard on board to ensure that all of the tasks and sample collections are completed in a short time, it is also important to take breaks to celebrate and dance, because when the mood is good, everything works better.” That’s why she always has, not just rubber boots, but also her pumps on board with her.

As the expedition leader, she’s on her feet from early morning till late at night. The hours aren’t regular as the ship works around the clock. Good contact with the crew is important. “As researchers, we are merely guests on board the ship. I rely on the crew, as these people have many years of experience with the ship, the weather and our research equipment.” She ensures, for example, that the images that are transmitted from the depths of the ocean to the ship can be viewed on the bridge, and that the crew understands the research task. “So everyone can be part of what’s going on.”

Beyond the expeditions, however, Boetius has also taken on a range of management functions, for example as Chairperson of the Scientific Commission of the German Council of Science and Humanities, which is appointed by the German federal government, and Chairperson of the Research Buildings Committee. Every year, this committee evaluates applications involving total costs of 450 million euros for the construction of research buildings at universities. She is still delighted about the trust placed in her and the other members of the Council of Science and Humanities to develop the best possible strategies. “We get to decide on applications from a wide range of scientific dis-



In summer 2012, Boetius appeared on the German television program *Tietjen und Hirschhausen* with hosts Willi Weitzel (left) and Guido Cantz (second from the right). Through such media appearances, she hopes to inspire interest in science and the ocean.

ciplines.” She is very pleased with the positive response she has received on all of the committees, and with the diversity of experiences and contacts they provide. “Sometimes I even amaze myself – one minute I’m in oilskins on board the ship and the next I’m in a cocktail dress at an event attended by the German President. But I’m certain about one thing: my experience with strong winds, heavy seas and never-ending horizons always stands me in good stead.”

Scientific communication is also important to Boetius. She is currently the Chairperson of the “Science in Dialogue” steering committee, an initiative of the German research organizations. Whether for television, radio, podcasts or newspaper articles, she is happy to respond to all requests – especially from children who ask her how they can become marine researchers and how much money they could earn at the job. She collects the letters from children in a folder. She loves the conversation she has with young people, not only because they remind her of her own roots as a scientist, but “because this basic curiosity about everything in the world is so crucial and is still a driving force for me as a researcher.”

“Discovery research” is how she describes what she does today. She wants to understand the variety of ecosystems and the spatial distribution of organisms in unknown regions in the deep sea, not least with a view to identifying effective protective strategies for the sea. Discovery research as carried out by Humboldt? She laughs: “No, more as carried out by

Maria Sibylla Merian, the 17th-century nature researcher from Frankfurt. There have also been influential female discoverers.” The spirit of Maria Merian probably isn’t the only one that motivates her; the way she beams when she talks about her work suggests that she might just also have something of diver and filmmaker Lotte Hass about her. ◀

GLOSSARY

16S rRNA sequencing: The 16S ribosomal RNA is one of three RNA molecules that control the formation of proteins in bacterial ribosomes. The 16S rRNA gene changes very slowly through mutation, making it particularly well suited for identifying family relationships between bacteria. Based on the analysis of 16S rRNA genes, researchers can not only identify the species diversity in a sample, they can also determine how often the individual species arise.

Archaea: Single-celled organisms that have no cell nucleus. In the past they were referred to as archaeobacteria. However, their cells are clearly different in structure from bacterial cells, which is why they are now classified as a third domain of life along with bacteria and eukarya – organisms that have a nucleus. Based on some of their characteristics, archaea are even closer to the eukarya than the bacteria. Many archaea species are adapted to extreme environmental conditions. They are found, for example, in deep-sea hot springs and in salt lakes.

Methane hydrate: Also known as gas hydrate, it consists of methane that is trapped in ice. In the sea, it forms in the methane-saturated pore water of the seabed where the pressure is high and the temperature low enough: at a depth of around 300 meters in the Arctic. The surroundings of methane hydrates are particularly species-rich, as some microorganisms can use the methane to generate energy. Their waste products, such as hydrogen sulfide, are used by other microbes, as well as mussels, worms and crabs, which live in symbiosis with bacteria. It appears that there is far more methane hydrate on Earth than oil and gas. However, its mining and exploitation for energy generation are technologically challenging and not economically viable.



The Price of Uncertainty

Recently, Europe seems to be stumbling from one crisis to the next. In addition to the debt crisis that has been plaguing the continent for years, a lack of solidarity and trust has now emerged. Some social scientists have identified the origins of this unstable situation in the market-stimulating focus of politics since the 1970s. At the **Max Planck Sciences Po Center** in Paris, the team headed by **Jenny Andersson** and **Olivier Godechot** is investigating the question of how societies deal with instability.

TEXT **MECHTHILD ZIMMERMANN**

Germany in 2016 – rosy times for the country: Unemployment is at its lowest level in decades. Generous wage agreements are fostering wage growth, and pensions are rising noticeably, too. More money is available in public budgets than ever before. Crime is also at a low. Compared with the mid-1990s, the number of robberies and thefts has fallen by almost a third, and murders by almost half.

Germany in 2016 – the prevailing sentiment is pessimistic: Fear of economic decline, and jealousy and mistrust of those in control in politics, business and the media, are widespread across large sections of society. Conspiracy theories are circulated online, politicians are threatened. Sales of pepper spray and blank guns are skyrocketing. The *Alternative für Deutschland* right-wing populist party raked in more than 12 percent of the vote in three federal states.

Germany is not an exceptional case. Uncertainty and frustration are growing in many parts of Europe, and with them, the desire for simple political an-

swers like those provided by populist politicians of various allegiances. This is just as true for the economically fragile nations in eastern and southern Europe as it is for Austria, Switzerland and prosperous northern European nations. But where is this disappointment and uncertainty coming from?

Let's be clear from the outset – there is no simple answer to this question. Even the social sciences are unable to provide a comprehensive picture of all the various phenomena we are currently seeing. However, they are developing approaches that reveal the underlying causes and that go beyond the political thinking applied to date.

Historian and political scientist Jenny Andersson and economic sociologist Olivier Godechot focus primarily on the economic causes of social uncertainty. Both are directors at the Max Planck Sciences Po Center on Coping with Instability in Market Societies based in the heart of Paris. The Center, known as MaxPo for short, is a joint project between the Max Planck Institute for the Study of Societies in Co-



A deep divide: The gap between top earners, particularly those at banks, and people with precarious incomes has grown substantially.



Game over: After the financial crisis, there were major demonstrations in Frankfurt and around the globe against the wheeling and dealing of banks. Politicians responded, too – by increasing restrictions, raising controls and limiting bonus payments.

logne and the elite French university Sciences Po Paris, which has a strong social sciences orientation. The central question addressed by MaxPo is: How do societies influenced by the market react to instability? And how is the growing social inequality connected with this?

The researchers use the term “instability” to refer to several interconnected phenomena. The starting point for research in this area is economic instability, which manifests itself not only in economic cycles, but also in changes in the job market. After all, companies relocate jobs abroad or cut jobs even during upbeat periods. Employees

come to feel these changes in the form of increasing workloads, deadline pressure and rising expectations when it comes to their flexibility.

This pressure and the fear of job loss leads, in turn, to social instability – one’s hard-earned position in society is no longer secure. Even a good education doesn’t guarantee a job, as we are currently seeing in southern Europe. But the number of insecure employment relationships is growing in Germany, too, with a rise in fixed-term contracts, temporary work and so-called mini-jobs. Within society, instability goes hand in hand with uncertainty and fear of decline.

The new economic conditions have also resulted in an unstable situation for politicians in the period since the 1980s. Globalization is making parts of the economy more mobile, and the process of taxing them more difficult, as companies can threaten to relocate abroad. Many international groups now siphon their profits to countries with low tax rates. As a result, nations are going into debt to fulfill their obligations. Another source of political instability is the increasingly complex and rapidly changing party-political structure in almost all European countries.

“The starting point of instability was the oil crisis in the 1970s,” says Jenny Andersson. This was the first time “stagflation” was recorded in Western industrialized nations: stagnation of economic growth coupled with high inflation and high unemployment – a phenomenon that shouldn’t have been possible according to the then prevailing Keynesian economic theory.

In the 1930s, British economist John Maynard Keynes developed his “General Theory,” a groundbreaking approach that was able to explain for the first time why the economy didn’t recover after the Great Depression and unemployment remained dramatically high despite the fall in wages. Keynes viewed overall economic demand as the decisive factor in production and employment. In the decades that followed, Keynesians continued to develop the approach. This gave birth to theories that saw a connection between inflation and high demand, rising wages and low unemployment.

During the oil crisis, these explanations no longer applied. Unemployment figures rose dramatically, tax income collapsed, and states had to rein in their spending to get budget deficits under control. As a result, Keynes’ model lost its influence. Instead, liberal eco-

»» The problem is that market logic has come to dominate how we can even think about the future.

economic ideas prevailed that were implemented in the public sector with such concepts as “new public management.” “These were economic theories that viewed, for example, nationally organized public services as an obstacle to dynamic market development,” says Jenny Andersson. “Economists became convinced that public institutions work inefficiently and that their costs could be reduced through competition and market price mechanisms.”

One example of this is the social housing sector. Over the past few decades, the German government first gradually withdrew from housing construction, and then also from financial support for residential construction. Recently, however, it has become clear that the market doesn’t cover the demand for affordable housing. According to the latest figures, the rent in 95 percent of privately built new residential buildings is too expensive for average earners. Deficits are also showing in health care and the pension system.

Overall, the stable social and economic situation of the post-war decade has revealed itself to be a historical exception. However, the standards of this period have remained the benchmark in the collective memory – one reason

why, since then, many people feel like the government has let them down.

In parallel with this, society entered a period of fundamental change that continues to this day. The traditional ties to family, as well as to such institutions as the church, political parties and unions, are disappearing. The options available for shaping one’s career path are more wide-ranging than ever before. Migration has led to a multitude of cultures and religions, particularly in cities. Overall, society has become more diverse, but also more complex.

POLITICS IS DEPENDENT ON THE FINANCIAL MARKETS

In addition, digitalization and the immeasurable opportunities the internet offers are fundamentally changing the world around us. The freedom of each individual has increased, which also means that everyone carries greater responsibility. This opens up countless new possibilities, yet at the same time, many people feel uncertain, overwhelmed or overtaxed.

The financial crisis of 2007/2008 destabilized the economic and political situation further. Triggered by the bursting of the real estate bubble in the

US, the crisis led to many nations bailing out banks and taking on additional debt. The problems ultimately spilled over into the real economy and still burden many countries today with struggling economies, high unemployment and a mountain of debt.

“The financial crisis showed how dependent politics is – how dependent we all are – on the financial markets,” says Andersson. We see this, for instance, when rating agencies assess nations’ credit ratings, thus helping to determine how much scope for action a government has. This dependence is part of a phenomenon that researchers call “financialization.” The main characteristics of this phenomenon are the growing importance of the financial industry and the influence of its interests on politics and the real economy. Stock corporations, for instance, are under pressure to maximize profits in order to distribute them to shareholders – leading, in turn, to headcount reductions and production relocations to low-wage countries.

Olivier Godechot, the second Director at the Center in Paris, is dedicated to investigating the effects of financialization on social inequality in society. In a broad comparison of 18 OECD countries – including Germany, France, the US, the UK and Denmark – he analyzed the role financial markets and their activities played in the rise in inequality across these nations over the period from 1970 to 2011. “The first thing you notice is that the financial sector has grown considerably,” says Godechot. “Its share of the gross domestic product has increased from an average of 4 percent to nearly 7 percent.”

According to the researcher’s analyses, the rise in financial market activity resulted in an increase in social inequality. “In particular, the extraordinarily high wages and bonus payments

MAX PLANCK CENTER

Max Planck Centers connect Max Planck Institutes with the world’s best research facilities. They create a platform on which scientists and their international partners can bring knowledge, experience and expertise together and conduct research on a common basis. The aim is to foster exchange between young scientists, hold joint workshops and allow mutual access to technical facilities, equipment and libraries. The centers also ensure that this cooperation is more visible and that the Max Planck Society can raise its profile at the respective locations. There are currently 16 centers in Europe, Israel, the US, Canada, India, Japan and South Korea.

in the financial sector led to a widening of the gap between rich and poor,” explains the economic sociologist.

Olivier Godechot has also proven the influence of financialization on a regional level. In particular, the large financial centers are drivers of social inequality within a country. A nation’s highest incomes are usually concentrated here, and the gap between top earners and people with precarious income is particularly wide in these centers.

In another area of research, Olivier Godechot is focusing on how employers and employees at different ends of the wage scale deal with the growing inequality. To this end, one of the questions Godechot investigated was how bonus payments at banks have developed since the financial crisis. In response to the crisis, the EU limited bonus payments for bankers to a maximum of double the annual base salary from 2014 onward.

Olivier Godechot explains that the first reaction of the banks was to increase salaries. “British banks found an additional way of getting around this rule: they give their top employees a monthly allowance in addition to their salary and the permitted bonus payments. And this is structured in such a way that, like the bonuses, it has to be renegotiated every year.”

On the other hand, he says that bonus payments are falling in the sector overall. “We’re still unable to judge whether this is due primarily to profits declining, or whether it is also a response to the social pressure that bonus payments at the previous levels are no longer socially acceptable,” says the scientist.

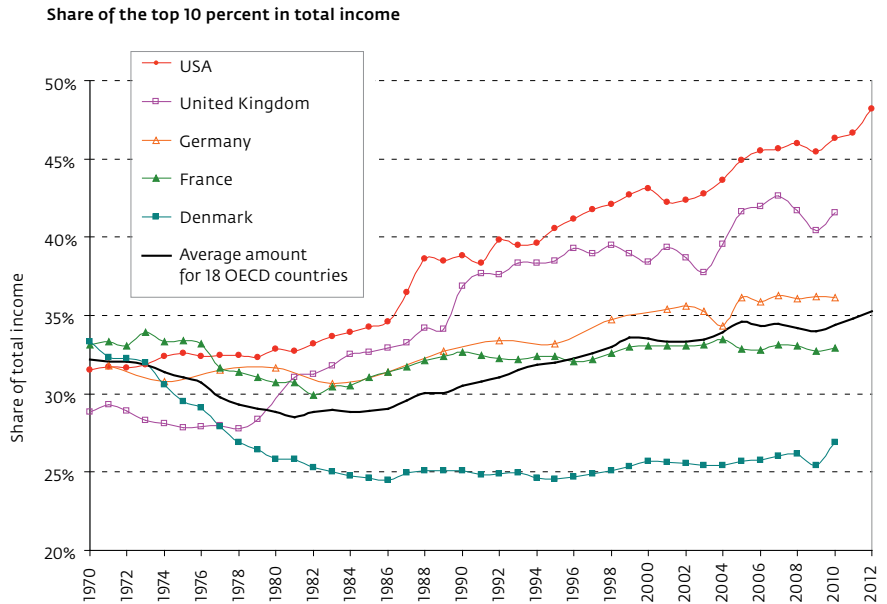
One hallmark of MaxPo is the wide range of approaches pooled here. These range from the micro-level – the question of how specific groups and individuals deal with the growing uncertainties – to the macro-level, analyzing the major social trends involved.

Jenny Andersson took up her post at the Center in November 2015. Her



Above Economic historian Jenny Andersson and economic sociologist Olivier Godechot head the Max Planck Sciences Po Center in Paris.

Below Inequality is growing. The top 10 percent of earners now receive an average of 35 percent of the total income from work – sometimes even more. Olivier Godechot analyzed data on this topic from 18 OECD countries.



main focus is forecasts in the political and business spheres. Forecasts, predictions and scenarios of this kind significantly influence political decision-making in areas ranging from budget planning, which is based on tax estimates, to law-making and regulatory issues.

“Forecasts are a paradoxical phenomenon,” says Jenny Andersson. “On the one hand, you never know whether predictions will really come true, so in a way, they also contribute to uncertainty. On the other hand, politicians – and particularly the financial industry – need predictions to channel expecta-

tions. In this way, they can also have a stabilizing effect – sometimes even becoming a self-fulfilling prophecy.”

This became particularly evident when the financial crisis became acute: “For financial market institutions, it had to be ensured that their solvency wouldn’t be put at risk,” explains Andersson. “That was why the first reaction to the financial crisis was to calm fears on the markets and prevent players from responding irrationally and thus further intensifying the crisis.” This included the announcement by ECB President Mario Draghi that the European Central Bank was willing to do “whatever it takes” to preserve the euro – including purchasing government bonds. The consequence has since become known as the “Draghi effect” – the financial markets settled down.

Jenny Andersson criticizes the fact that the actual causes of the crisis were left untouched. The power of financial market players, the dominance of the markets and the expectation of perpetual growth – all of these things remained intact. “The problem is that market logic has come to dominate how we can even think about the future,” she explains, and cites the example of austerity politics – the strict approach that national budgets have to be protected against further debt even in economically difficult times by cutting expenditure and increasing taxes.

“Citizens are told that the state has to save and make cuts to ensure stability for the future. In reality, this austerity policy delivers primarily on the expectations of the financial markets – they are stabilized. But this process makes it difficult to discuss socio-economic alternatives, and the future is disregarded,” says Andersson.

And that’s where we come full circle to the current political developments, particularly the resurgence of populist parties. “Especially in social and economic policy, the traditional mainstream parties don’t offer any alternative to austerity,” says Jenny An-

dersson. As a historian, she has extensively examined the history of social democracy in Europe.

CRISES CAN CHANGE POLITICS FOR THE BETTER

The social democratic parties are said to have lost the trust of their electing classes in the 1990s by giving up principles like the redistribution of wealth and social security in favor of market-conforming goals – with tangible impacts for vast swaths of the population: “In the 1970s and 1980s, economic uncertainty was a phenomenon that affected particularly the working class. Now the middle class, too, has begun to feel threatened and is looking for answers in the form of populist parties,” says Andersson.

Many are now seeing parallels to the 1930s and the consequences that followed from that crisis and the growing inequality. As a historian, Jenny Andersson pleads for a more nuanced view

of history, and for us to learn from positive examples: “The Great Depression of the 1930s also led politicians in the US to develop strategies to curb negative impacts of market mechanisms – through active labor market policies and national social institutions that promoted solidarity between the different social classes.”

Olivier Godechot notes that the Center’s work is helping to uncover both the causes and the effects of increasing instability. The aim is to gain a clearer picture of economic, social and political correlations – a key prerequisite for developing new approaches and thus countering populist movements across all countries.

With regard to the last financial crisis, the Directors of the MaxPo agree that it remains to be seen which political responses will ultimately endure. “And we have to carefully analyze which political solutions and which social approaches were or are successful, and which are not.” ◀

TO THE POINT

- For people in Europe, the situation in the past few decades has become more unstable in many respects.
- Society has changed: institutions like the church, political parties and unions have lost authority, and the diversity of cultures and lifestyles has grown, as has financial inequality.
- Changes in business, such as globalization and the introduction of new technologies, and the growing pay gap between low and top earners are key contributors to instability.
- Politicians have granted business greater freedom since the 1970s. At the same time, politics has become more dependent on business – for example in that companies can threaten nations with relocation.
- Academics at the Max Planck Sciences Po Center in Paris are working to uncover the causes and effects of the increasing instability and develop approaches that go above and beyond the existing framework of political thinking.

GLOSSARY

Austerity: The concept that nations should also save during economically difficult periods and raise taxes in order to avoid increasing debt.

Financialization: The growing influence of the financial industry on politics and the real economy. This includes the rules of the financial sector – above all the short-term maximization of profits – gaining influence in other sectors.

Liaison in a Test Tube

In the mid-1970s, Georges Köhler, later Director at the **Max Planck Institute of Immunobiology** in Freiburg, succeeded in fusing together a short-lived immune cell and a rapidly dividing cancer cell. The result was an immortal cell chimera with the ability to produce identical (“monoclonal”) antibodies, ushering in a revolution in biology and medical science. In 1984, Köhler was awarded the Nobel Prize along with César Milstein and Niels Kaj Jerne. The researcher, who died young, would have celebrated his 70th birthday this year.

TEXT **ELKE MAIER**

Pregnant or not? The frog can tell: if urine from a woman is injected into a female African clawed frog and the hormones in the urine cause the frog to lay eggs within a day, the answer is yes. Of course, it's easier and faster to test for pregnancy using a test strip: the result appears in the form of a colored line within minutes. The basis of the test is monoclonal antibodies that bind to the pregnancy hormone human chorionic gonadotropin, triggering the color reaction.

Since it became possible to produce them in the laboratory, monoclonal antibodies have revolutionized far more than just pregnancy testing. As universal molecular biology tools, they are now an indispensable part of biological and medical science: They help identify individual molecules in mixtures, detect cancer cells in the body, and diagnose diseases. They also play a role in organ transplantations and cancer therapy.

The method of creating monoclonal antibodies wasn't the result of biomedical research with a view to achieving marketable results. Its discoverers were passionate basic researchers whose aim was to improve our understanding of how the immune system works. The younger of the two, Georges Köhler, was just 28 years old at the time of the breakthrough.

Georges Jean Franz Köhler was born in Munich on April 17, 1946. After studying biology in Freiburg, he took up doctoral studies at the Institute of Immunology in Basel, a think tank funded by the pharmaceutical company Hoffmann-La-Roche. His supervisor, Fritz Melchers, didn't realize at the time that he was dealing with a future Nobel Prize laureate and wondered about his doctoral student's lax work ethic: “Georges liked to be out in nature. He never worked on weekends. But he often had a lot of crazy ideas,” says Melchers today.

What interested Köhler most was the kaleidoscopic variety of antibodies. These Y-shaped molecules form our immune system's first line of defense. They have the task of binding to invaders, such as viruses, bacteria, toxins or even cancer cells, and eliminating them from the body. Every antibody has its very own “foe”: recesses at the ends of its two arms fit precisely into a specific foreign structure, known as an antigen, like a key in a lock. When an antibody encounters its counterpart – whether a soluble protein, the surface of a bacterium or a cancer cell – it binds firmly to it.

Antibodies are produced by B lymphocytes, white blood cells that are able to recognize foreign structures and proliferate. In order for the body to be armed against a wide range of antigens, an armada of several million different antibodies patrols the bloodstream. Each B lymphocyte produces just one very explicit type of antibody.

How this immense number of different antibodies comes about has long been a mystery: Are the various plans encoded in the DNA, or are they produced in B lymphocytes as a result of random mutations? Researchers had been stumped by this question. To answer it, they needed immune cells that could be grown in the laboratory and that also produced antibodies with known specificity against a particular target molecule. The problem was that normal lymphocytes quickly perish outside the body.

Despite this obstacle, Georges Köhler was determined to tackle the antibody problem. He hoped to obtain the tools for doing so from immunologist César Milstein, who was conducting

Casting a critical eye: Georges Köhler examining his latest experiments in the laboratory. As a basic researcher, his aim was to unravel the secrets of the immune system. Conveniently, he discovered monoclonal antibodies as a byproduct of his research efforts.



Photo: Wolfgang Filser/MPC

research at the MRC Laboratory of Molecular Biology in Cambridge. Milstein was regarded as a brilliant experimenter and specialist in the field of cell fusion. In the spring of 1974, Georges Köhler set off for England together with his wife Claudia and their three children.

Milstein's laboratory had succeeded in cultivating myeloma cells obtained from mice. These degenerate immune cells behaved exactly like cancer cells in that they were able to propagate indefinitely. At the same time, they produced antibodies, albeit of unknown specificity. B lymphocytes, however, produced a specific type of antibody, but died in cultures. A cell was sought that could do both: proliferate in the laboratory and also produce specific antibodies.

The solution occurred to him in bed one night, Georges Köhler later recounted: What if a lymphocyte could be fused with a myeloma cell? Would it then be possible to transfer the frenzied reproductive behavior of the tumor cell to the immune cell? Köhler imagined cobbling together an immortal, antibody-producing chimeric cell. "I was suddenly wide awake and couldn't get back to sleep. I thought about it all night long. The

DIE ZEIT from May 11, 1984



Monoclonal antibodies did not originate from targeted medical research but from the dreams of a young biologist. Georges Köhler [...] was searching for a simple experimental method for his immunological research.

next morning at breakfast, I told Claudia about my nocturnal thoughts," he reported. At the institute, he immediately sought out Milstein in the basement among the cell cultures to discuss his idea with him.

In the fall of 1974, Georges Köhler set to work. As a test antigen he used red blood cells from sheep, which he injected into mice. Once the immune response had run its course in the mice, he removed their spleens. He homogenized the spleen tissue to access the B lymphocytes that are particularly prevalent there, and then mixed these with myeloma cells. To help the liaison along, Köhler reached into the immunologist bag of tricks and added a special virus to act as a molecular matchmaker. Now it was a matter of waiting to see if the two cell types would accept the forced marriage and produce the desired type of antibody.

For seven weeks, Köhler kept the cells in a nutrient solution, where they multiplied without restraint. Only then did he dare to conduct the ultimate test: would the hybridomas – as the hybrid cells were called – produce antibodies against the test antigen? To find out, he transferred the cells to Petri dishes with medium containing red blood cells from sheep. If the desired antibodies were present, they would bind to the blood cells and break them down. Bright halos, called plaques, would then appear around the cell colonies.

Köhler started his experiment at around 5 p.m. It would take four or five hours to obtain a result – enough time to enjoy a re-



A toast: Georges Köhler (middle) and his colleagues at the Institute drink to the Nobel Prize.

laxing dinner at home. Then he returned to the institute. He took his wife along for moral support in case the experiment failed. Together, the two entered the windowless lab in the institute's basement. Köhler picked up the first two Petri dishes. The plaques stood out clearly against the dark background.

"I cheered, I kissed my wife, I was ecstatic. It was the best result I could imagine," he later recalled. Georges Köhler had created cellular factories that produce identical antibodies as if on an assembly line. Because they are all derived from the same cell line, they are called monoclonal.

On August 7, 1975, Köhler and Milstein published their method in the prestigious journal *NATURE*. "Such cultures could be valuable for medical and industrial use," they wrote at the end of their article. That, as it turned out, was a monumental understatement.

A short time later, the hybridoma technique triumphantly entered laboratories. It soon became very clear that it was much more than a useful research tool for immunologists. It enabled scientists to fashion tailor-made antibodies against any antigen – in virtually unlimited quantities.

Monoclonal antibodies can be added, for example, to a complex mixture to target individual molecules. They can be tagged with bright dyes and then released to track down bacteria, viruses or cancer cells. They can be used as transport vehicles for delivering drugs directly to specific tumors. They help prevent post-transplantation tissue rejection. The possibilities are endless.

For the pharmaceutical industry, monoclonal antibodies have become a billion-dollar business. Before their publication appeared, Milstein had offered the method to the British government for patenting. He received no reply. Evidently, the government officials somehow missed the landmark moment of molecular biology.

After his discovery of the century, Georges Köhler was inundated with offers. He rejected them all. Instead of succumbing to the temptation to become "the highest-paid custom tailor of monoclonal antibodies," he remained loyal to basic research. In 1984, he became Director at the Max Planck Institute of Immunobiology in Freiburg. A short time later, a call came from Stockholm: Georges Köhler and César Milstein had been awarded the Nobel Prize in Medicine, together with Danish immunologist Niels Kaj Jerne. In the following years, Köhler worked to unravel the mysteries of the immune system. On March 1, 1995, he died of heart failure. He was only 48 years old.

Meeting up at Summer School

More than 25 courses reach around 1,300 junior scientists



Exchanging ideas at the Summer School in Jena: Susann Fiedler (2nd from left), Leader of the Gielen-Leyendecker Research Group at the MPI for Research on Collective Goods, in conversation with course participants. A total of 11 lecturers and five speakers took part in the four-week School, which brings together both young and established legal experts, psychologists and economists.

Using the time between terms in summer to teach science: Max Planck Institutes from Hamburg to Munich offer courses explicitly for external participants.

With its origins at universities in the US, the principle of offering Summer Schools between terms has also established itself at Max Planck Institutes.

Although they aren't universities, these Schools offer a range of courses for young academics and provide insight into scientific research. This past summer, over 25 courses were offered, often organized by the International Max Planck Research Schools (IMPRS) dedicated to training doctoral students.

A survey at the institutes shows that these courses are attended by a total of nearly 1,300 young scientists. These include master's and doctoral students as well as postdocs, with a clear majority coming from external institutions. "We hold workshops and conferences throughout the year, but our International School is oriented mainly toward students and young visiting scientists," says Hans-Georg Libuda, IMPRS coordinator at the MPI for Solid State Research in Stuttgart. Their School has been taking place in summer or fall for the past 15 years now, with this year's three-day event focused on energy conversion. "As the participants range from master's students to postdocs, we offer both introductory lectures and in-depth workshops." For the Institute's own IMPRS doctoral students, the Summer School is part of the curriculum; a bit less than

Successful Kick-Off Symposium for Alumni and Active Members

While US universities maintain close links between former and active members of their institutions over the course of decades, this type of alumni culture is not that common in Germany. The MPG wants to do more in this area, which is why the Max Planck Alumni Association e.V. (MPAA) was founded with the support of Administrative Headquarters and under the guidance of six former Max Planck researchers. This summer, the inaugural Max Planck Symposium for Alumni and Early Career Researchers was held, with 200 participants from 30 countries in attendance. In his opening speech, Max Planck Vice President Ferdi Schüth emphasized how pleased the MPG is that the alumni network is actively run by former members.

Numerous alumni from science and industry gave speeches and provided insights into their career paths: Anke Post, alumna of the MPI of Psychiatry, traveled from the UK, where she now conducts

research for US pharmaceuticals group Eli Lilly. She defused prejudices regarding the pharmaceuticals industry and explained how similar it is to daily research work, particularly at companies with an academic approach. Sascha Brozek, alumnus of the MPI for Gravitational Physics, traveled to Berlin from Helsinki. As vice president of Kone, an elevator manufacturer, he not only succeeded in sharing his fascination for elevators, but also provided useful tips for entering professional life via the consulting business.

The three-day symposium also focused on the further development of the MPAA, and workshops were held on founding new companies and writing effective scholarship applications. The "Cultural Running Dinner" featuring cuisine from a wide range of countries rounded out the event, with all guests requested to come in their traditional national dress. Many guests duly obliged, and attire ranged from glittery saris to fine silk garments.

half of the expected 125 participants come from other institutions, adds Libuda. He is pleased that he has once again been able to attract high-caliber lecturers from such institutions as EPFL Lausanne and TU Vienna. Ten Max Planck scientists also took part in the tightly organized program, among them two Directors from the Stuttgart-based MPI.

The summer courses vary from institute to institute in terms of both duration and content. Each year since 2009, the MPI of Biochemistry in Martinsried, for example, has offered the MaxQuant Summer School, a special

course focusing on the use of its MaxQuant software in the field of proteomics research. This year around 160 external participants attended a five-day course in Oxford, headed by software developer Jürgen Cox. As at most Schools, a selection procedure is applied to determine in advance whether participants have the necessary background knowledge.

The Summer Schools held in 2016 by the MPI for Chemical Energy Conversion in the Gelsenkirchen Science Park – in cooperation with the Fritz Haber Institute of the MPG and the University of Mainz – have a broader

focus. Other Schools offer specialist programs for small groups. One example is the Earth System and Climate Modeling School, organized by the MPI for Meteorology in Hamburg with various European partner institutes. Comprising three weeks of lectures and workshops, the third such school for around 30 doctoral students focusing on climate and Earth system research took place at the University of Helsinki. Also on the agenda was a joint excursion: after all, the Schools are aimed not only at broadening participants' knowledge, but also at facilitating new contacts.

Ambassadors for Open Access Provide Practical Tips

The MPI in Magdeburg recently devoted an afternoon entirely to the subject of free access to scientific knowledge

The invited speakers offered facts and opinions from a variety of perspectives. By way of introduction, Kristina Reinhold, Head Librarian at the MPI, explained the basic concepts and forms of Open Access (OA). Jon Tennant, a doctoral student at Imperial College, London, then gave a report from the junior researcher perspective. His strong views, such as "Open Access wins all arguments, all the time," led to a lively discussion that continued into the coffee break.

Next, Kai Geschuhn of the Max Planck Digital Library spoke about the new international "OA2020" initiative, which the Max Planck Society is pursuing together with other research organizations. The goal is to achieve a large-scale reorientation of those scientific journals that are currently published by subscription. Supported by current studies, Geschuhn showed that, with the funds expended on subscriptions today, it would be possible to effect a complete transformation to OA. Rather than subscribing to traditional journals as in the past, it would then be a case of paying the one-time publication costs per article.

In conclusion, local Open Access ambassadors Jan Heiland and Robert Flassig reported on the effects of closed and open access in the day-to-day lives of researchers. The afternoon proved a source of great satisfaction to the audience, which comprised around 30 members of the MPI, covering the entire spectrum from master's students to Directors. The workshop was one of a series of similar

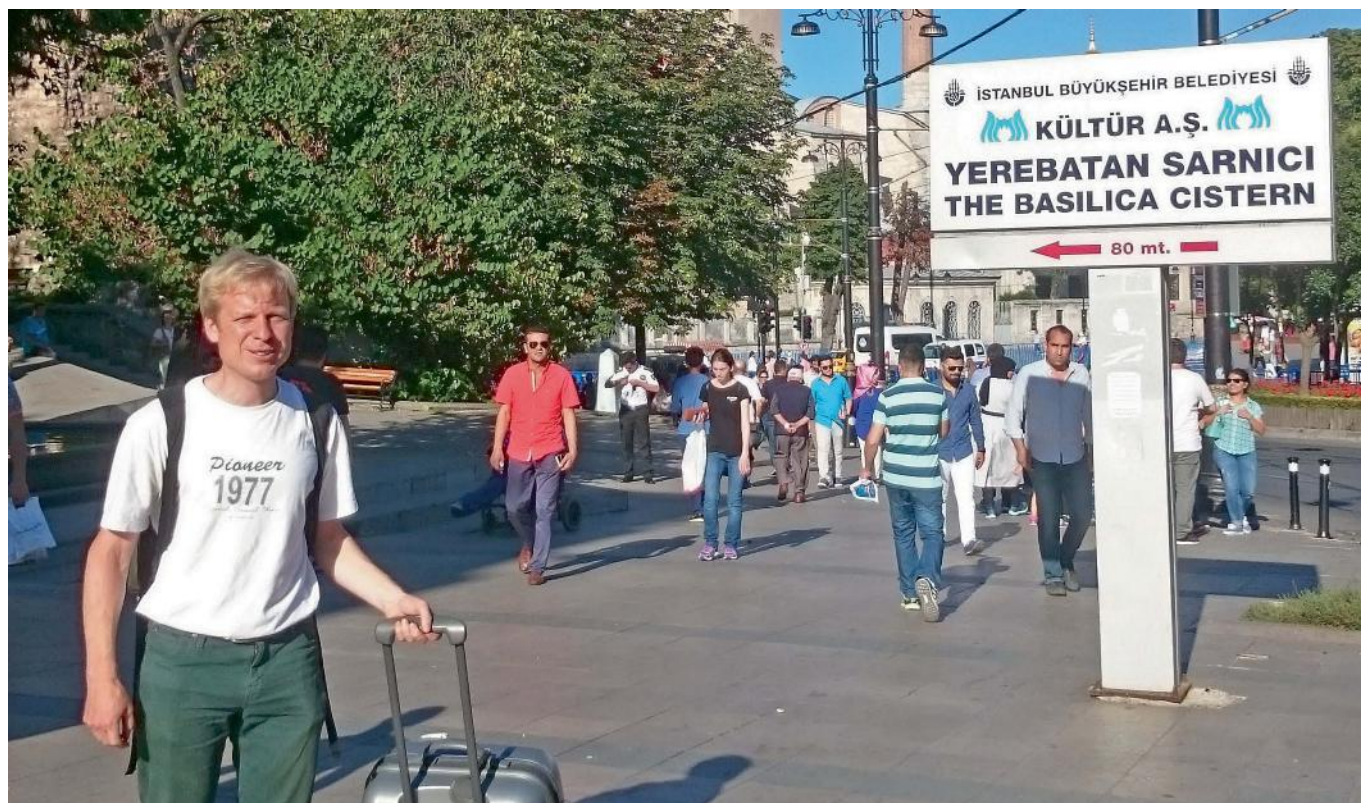


Workshop organizers: Head Librarian Kristina Reinhold and postdocs Jan Heiland and Robert J. Flassig (from left)

events at various institutes, another of which will take place shortly before the end of the year at the MPI for Human Cognitive and Brain Sciences in Leipzig.

Much Uncertainty Still Remains

A scientist from Jena reports on how he experienced the attempted coup in Turkey while on a business trip to Istanbul



An uneasy feeling: Ingo Schöning in Sultanahmet Square in the old city of Istanbul. The day after this photo was taken, an attempted coup was launched.

Ingo Schöning doesn't come across as one who is easily perturbed. However, when, after receiving a call on his mobile from a worried neighbor, the post-doc from the MPI for Biogeochemistry in Jena read the Internet reports on the attempted military coup against President Recep Tayyip Erdoğan, he "suddenly felt very uneasy." Unaware of the events, he had spent the evening of July 15 strolling through the old city with a doctoral student who was also intending to take part in the EUROSOIL conference in Istanbul. Now he found himself reading about the blockade of the Bosphorus Bridge and tanks at the airport. He was unable to sleep for the noise of aircraft.

When he and his colleague ventured out onto the street the next morning, the city was initially as if deserted, until more and more cars appeared on the

streets with horns blaring and national flags flying, proclaiming Erdoğan's victory over the rebels. In view of the dramatic situation, the organizers abruptly postponed the conference. The next step was to take the first possible flight home, which "fortunately passed without incident."

A PLEA FOR RESEARCH FREEDOM

After the first few days, in which the newspapers were filled with reports of fatalities and mass arrests, the wave of restrictions imposed by the government in the wake of the coup began to reach the international science community.

The call by Turkey's Council of Higher Education ordering members of academic staff to return home and banning academics from travelling abroad

presented a conundrum for administrators at several MPIs. They contacted their Turkish research colleagues to ask how they could help. President Stratmann publicly criticized this restriction of research freedom, and made it clear that the MPG "supports Turkish researchers at its institutes in this difficult situation." The Turkish demands for scientists to return have since been relativized.

The international EUROSOIL conference for which Ingo Schöning had traveled to Istanbul is now set to take place in October. The scientist is not sure whether he will be attending. Absent colleagues could excessively reduce the value of the meeting; on the other hand, the exchange with Turkish scientists is now all the more important. And once again, uncertainty prevails.

Research Establishments

- Institute / research center
- Sub-institute / external branch
- Other research establishments
- Associated research organizations

The Netherlands

- Nijmegen

Italy

- Rome
- Florence

USA

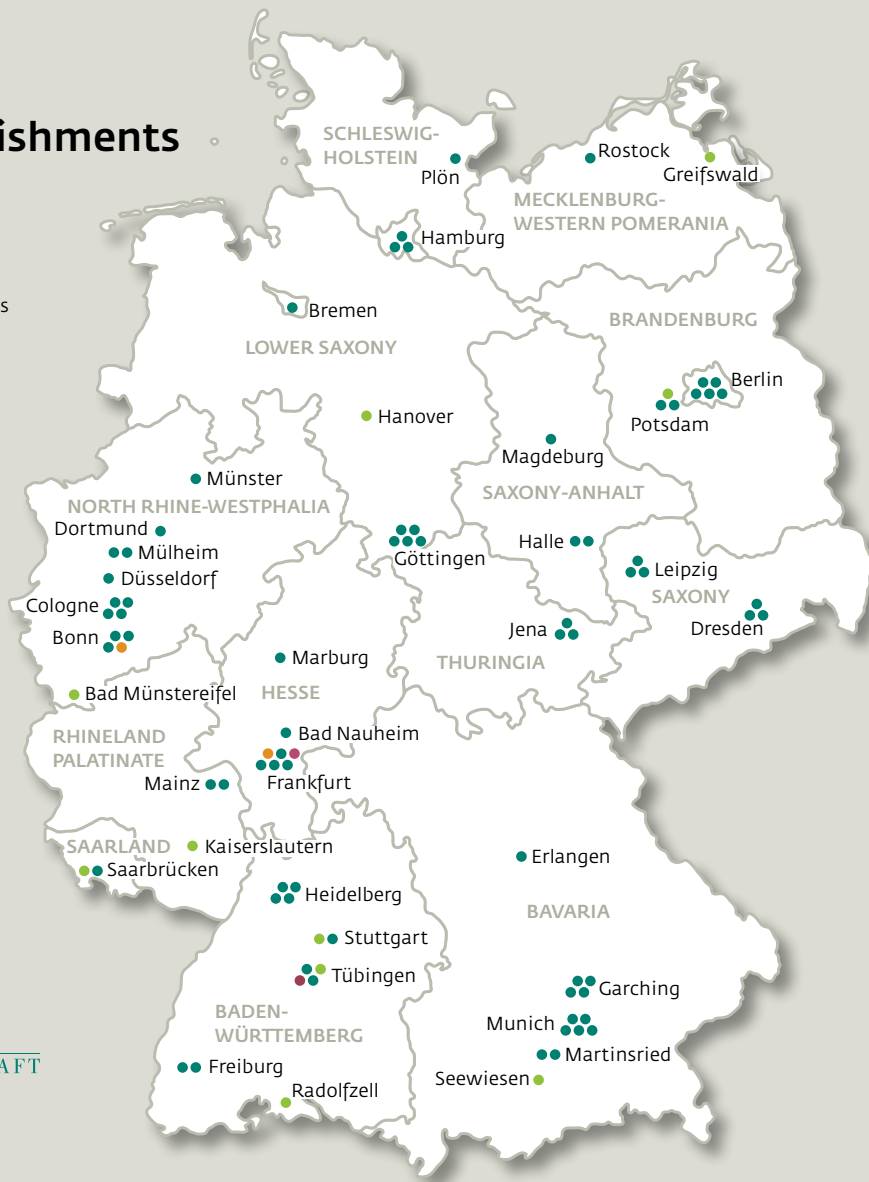
- Jupiter, Florida

Brazil

- Manaus

Luxembourg

- Luxembourg



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