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Max Planck RESEARCH

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Big Data

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Cyber Attacks on Free Elections

IMAGING
Live View of the Focus of Disease

COLLECTIVE BEHAVIOR
Why Animals Swarm for Swarms

AESTHETICS
The Power of Art

Pictures of the Future

The Magazine for Research and Innovation

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Photo: Astrid Eckert/Munich

Operation Darkness

When, on a clear night, you gaze at twinkling stars, glimmering planets or the cloudy band of the Milky Way, you are actually seeing only half the story – or, to be more precise, a tiny fraction of it. With the telescopes available to us, using all of the possible ranges of the electromagnetic spectrum, we can observe only a mere one percent of the universe. The rest remains hidden, spread between dark energy and dark matter.

The latter makes up over 20 percent of the cosmos. And it is this mysterious substance that is the focus of scientists involved in the CRESST Experiment. Behind this simple sounding name is a complex experiment, the "Cryogenic Rare Event Search with Superconducting Thermometers."

The site of the unusual campaign is the deep underground laboratory under the Gran Sasso mountain range in Italy's Abruzzo region. Fully shielded by 1,400 meters of rock, the researchers here – from the Max Planck Institute for Physics, among others – have installed a special device whose job is to detect particles of dark matter. According to theory, these particles barely react with their environment. They can easily penetrate the various layers of lead, copper and polyethylene that shield CRESST from background radiation.

The detector can comprise up to 33 individual modules, each containing a 300-gram crystal made of calcium tungstate; the photo shows researchers who are in the process of fitting the measuring device with these. When a particle enters, it generates warmth. In addition, light results, which is then held in the enclosure and captured by a silicon wafer that also warms up in the process. To allow the thermometer to sense these inconceivably minimal temperature increases, CRESST works close to absolute zero at minus 273.15 degrees Celsius.

CRESST-III has been running since summer 2016 with 13 modules and heightened sensitivity. Yet dark matter is living up to its name: to date, there are no convincing findings that unequivocally prove its existence.

18 BIG DATA

ON THE COVER We live in the Information Age. The amount of data flowing through networks is increasing exponentially. Structuring and using this big data, as experts refer to it, in a meaningful way is becoming more and more challenging. New technologies are needed to manage the torrent.

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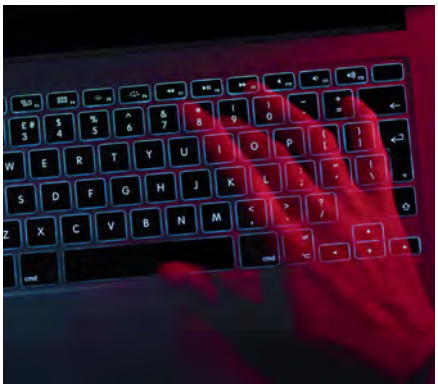

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Cover: Kai Weinsziehr, photos this page: akgimages/Imagno (large image), picture alliance/Cultura R

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Coping with the Past to Celebrate Its Anniversary

The Max Planck Institute of Psychiatry confronts its history

One hundred years is a reason to celebrate, but also to look back. During this time, much valuable knowledge was amassed at the German Research Institute for Psychiatric Research and at its successor institutions, the Max Planck Institute of Psychiatry and the Max Planck Institute of Neurobiology. However, during the National Socialist era, scientists at the German Research Institute also participated in planning the systematic extermination of individuals with physical, mental and emotional impairments. They also used human brain sections from their victims for their research – even after the war had come to an end. In March 2016, it came to light that additional preserved specimens from this time were still held in the archive of the Max Planck Institute of Psychiatry. Consequently, the Directors immediately initiated the creation of an inventory by external experts. In addition, a research program was established with the aim of reconstructing the identity of the Nazi victims.

In his speech at the celebration marking the centenary of the Institute, Max Planck President Martin Stratmann emphasized that transparency and openness for the past had top priority. With an eye to the present day, he admonished: "The thirst for knowledge has its limits. Gaining a scientific edge through human suffering is negligent and absolutely inexcusable."

Learning from history: At the celebration marking the centenary of the Max Planck Institute of Psychiatry, Max Planck President Martin Stratmann underscored the ethical responsibility of science.

Support for Open Access

Scientific organizations join forces to change the publication market

One year after its launch, the global initiative Open Access 2020 has received additional support. The 13th conference in Berlin in March 2017 brought together around 220 expert representatives from research and research-funding organizations from 34 countries. The focus was on their experiences with the fundamental transformation taking place in the publications market: for example, academic journals for which libraries must currently pay high subscription prices are to become freely accessible for all. "A year ago, we defined a common goal to make Open Access the norm in publishing. Today, the first groundbreaking contractual agreements with major publishing houses are a reality," says Max Planck President Martin Stratmann, who emphasized that the shift is intended to be accomplished in cooperation with the publishers. Publishing house managers therefore also took part in the conference at which a roadmap for the concrete implementation was further elaborated. In Europe, political support for Open Access has recently grown. The EU ministers responsible for this agreed that, by 2020, all research financed through EU funding must be published in a way that ensures unrestricted access to the publications.

Together for change: The Berlin conference in March was attended by participants from all over the world, such as Louise Page from the US Open Access project Public Library of Science (PLOS).

"Establishing the principle of excellence was a milestone"

Max Planck Nobel Prize laureate Erwin Neher on the consultations concerning the foundation of the European Research Council (ERC)

Nobel laureate Erwin Neher of the Max Planck Institute for Biophysical Chemistry is one of the pioneers of the European Research Council (ERC). Now in its tenth year, the institution is considered to be an international model for the effective sponsorship of outstanding research. Here, Neher speaks about some of the important decisions that marked the founding years, including a petition without which everything may have turned out differently.

Mr. Neher, you are a scientific researcher to the core – how did you end up in the very different world of research policy?
Erwin Neher: Indirectly, it was thanks to the then President of the EU Commission, Romano Prodi, who in 2000 declared that the European Union should become the world's greatest knowledge-based society. My assessment was quite clear: it takes basic research to create such a knowledge base. The Max Planck Society recommended me as a member of EURAB, the European Research Advisory Board. I was directly involved from 2001 to 2004, when discussions were being held with then EU Research Commissioner Philippe Busquin on how the associated funding should be structured. That's how I got drawn in to the whole business.

So it was a question of perseverance …
Yes, that's right. After two years of working with EURAB, my experience told me that the existing instruments were beyond repair. We needed something completely new. The classic model was oriented toward the competitiveness of European industry, not toward facilitating entirely new breakthroughs. Breakthroughs don't come when an official body determines what is important for European science and economics and then formulates projects that scientists can apply for. That would mean taking the same approach to research as a contractor building a bridge in Spain. The process must be reversed, as at the national level with the German Research Foundation: it must be the idea that is the decisive factor. The optimum idea, arrived at through competitive expert evaluation based on criteria of excellence, is the key to new knowledge. The fact that we were able to establish this kind of thinking at the EU level was indeed a milestone.

Was it difficult to communicate this change in perspective?
There were both supporters and critics. The core issue was, can we succeed in maintaining a focus purely on scientific excellence and avoid the dominance of proportionality? The scientific community agreed: the ERC should sponsor projects that originate in the world of science – projects that are high-risk and that are selected solely on the criterion of excellence. What is now universally recognized as a recipe for success was the subject of much dispute at the time.

Was there one specific moment that was decisive?
The discussion about the ERC was a recurrent issue at the EURAB, which directly advised the EU Research Commissioner in Brussels every few months. A situation once arose in which Philippe Busquin somewhat cryptically implied that the ERC was no longer on the list of projects that he wanted to carry through during his term of office. I took the initiative and gathered signatures from 45 Nobel Prize winners. We took the list to Brussels in October 2003, passed it on to Busquin and had a very good meeting. We did the same the following year, when Janez Potočnik of Slovenia had taken office. I believe that helped keep the idea alive. And Potočnik then put his weight behind the establishment of the ERC.

In his role as Max Planck President, Peter Gruss was a strong advocate of the ERC …
Peter Gruss was very committed. Above all he addressed the issue of how the ERC should be structured in order to be as independent as possible. There were two models embodying different EU regulations. The model chosen came under the aegis of the Commission but ultimately allowed the ERC to have the last word, at least in its scientific decision-making. The success of the project was certainly influenced by the efforts of Ernst-Ludwig Winnacker, the first Secretary General, and Fotis Kafatos, the first Chairperson of the Scientific Council. And the first 26 members of this body also played an important role. So the ERC had numerous founding fathers, as is usually the case with successful undertakings.

Erwin Neher

How would you rate the ERC today?
Given the previous EU funding for research, the ERC is a huge step forward, particularly for basic research. Thanks to the Scientific Council tying down the funding strands in the early years, beginning with the Starting Grants, then introducing the Advanced and Consolidator Grants, a broad spectrum within the span of an average scientific career is now covered. Of course, there is criticism of the bureaucracy, I hear it from colleagues who have ERC Grants. But overall it is a very good program that promotes truly top science. And of course I am happy to have had a part in it.

Interview: Jens Eschert

Photo: Amac Garbe

New Ties to the Netherlands and China

Two Max Planck Centers established in the fields of fluid dynamics and regenerative medicine

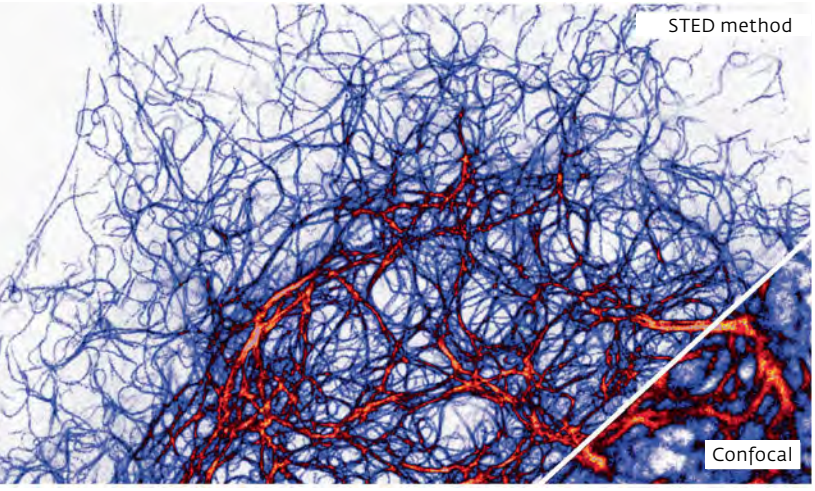
With partners in Guangzhou, China, and Enschede in the Netherlands, the Max Planck Society has founded two new Max Planck Centers. In the Center at the University of Twente, the Max Planck Institutes for Polymer Research and for Dynamics and Self-Organization will cooperate with two University groups. This will result in a pioneering center for the research of complex fluid dynamics – the movement in liquids and gases – which plays a central role in numerous natural and industrial processes. The Center is set to improve the teamwork of the partners and will enable the common usage of research infrastructures. The results are expected to facilitate, for example, advances in medical diagnostics and in the operation of wind turbines.

A further Center is being established in Guangzhou, China. There, the Max Planck Institutes for Molecular Biomedicine and for Heart and Lung Research will join forces with the Guangzhou Institute of Biomedicine and Health of the Chinese Academy of Sciences. Their common goal is to advance research into reprogrammed stem cells and provide new impetus for regenerative medicine. Both Centers will also serve to promote international exchange among talented young scientists.

Full of praise: At the opening of the Max Planck Center at the University of Twente, Max Planck President Stratmann acknowledged the high level of Dutch research and referred to the joint undertaking as a milestone for European science.

Technology Transfer across the Atlantic

Florida to become the American location for award-winning microscopy



Clear image: With the STED method, processes in living cells can be observed in far greater detail than with the confocal microscopes that are frequently used for research purposes (bottom right).

Abberior Instruments, the company owned by Max Planck Nobel Prize laureate Stefan Hell and headquartered in Göttingen, has founded a subsidiary in the US. Abberior produces microscopes based on the STED method Hell developed, which can be used to create high-resolution fluorescence images far below the diffraction limit. The campus of the Max Planck Florida Institute for Neuroscience was chosen as the location for the US center of operations. David Fitzpatrick, CEO and scientific Director of the Institute, is hopeful that this will also give the research a boost. "The latest improvements for this ultra-high resolution microscopy are the key to insightful discoveries in brain research and other areas," says Fitzpatrick. "The entire American life science industry will benefit from having better access to this technology." Stefan Hell stresses the strong scientific reputation of the campus in Jupiter. In addition to the Max Planck Institute, the campus is also home to Florida Atlantic University and a branch of The Scripps Research Institute.

Photos: Rikkert Harink/www.rikkertharink.nl (top), MPI for Biophysical Chemistry (below)

The Dilemma of Animal Research

Forum held at Max Planck Administrative Headquarters discusses animal ethics in science and society

In a declaration of principle on animal experimentation in basic research, the Max Planck Society has committed itself to strengthening transparency and communication regarding this controversial subject. To this end, a podium discussion was held in January at the Max Planck Society's Administrative Headquarters in Munich. Before an audience of 100 guests, two Max Planck Directors – brain researcher Wolf Singer and lawyer Anne Peters – and philosopher Dieter Birnbacher from Heinrich Heine University Düsseldorf discussed issues focusing on animal ethics. The starting point was the special nature of basic research: intrinsically a core value, constitutive for humanity, emphasized Singer. Birnbacher reinforced this, additionally stressing the application factor. Scientists must weigh up the knowledge gained and the possible benefit of their projects against the welfare of the animal. Peters pointed out the importance of defined criteria. For example, the EU guidelines on animal welfare stipulate the extent to which an animal may be stressed and that, in retrospect, these stress factors must be evaluated in proportion to the gain in scientific insight. Singer added that, owing to the extremely subject-specific reasons for animal research, it was necessary to have trust in the scientists. This is possible only through transparency.

Careful consideration: Moderated by science journalist Christina Berndt (center), Dieter Birnbacher, Wolf Singer and Anne Peters (from left) discussed animal research in light of ethical considerations.

Photo: Axel Griesch

On the Net

Smelly spectacle
The Max Planck Institute for Chemical Ecology in Jena was host to a very rare – and very stinky – event on the weekend of June 9-10, 2017. One of the world's smelliest flowers, *Amorphophallus titanium*, went into bloom for the first time in 14 years. The odoriferous plant, whose native habitat is Sumatra, Indonesia, is also known as the corpse flower because of its putrid aroma that proves irresistible to certain pollinators. About 1,000 flower lovers came to catch a glimpse – as well as a good whiff – of the plant after it was moved out into the open from the Institute's greenhouses.
www.ice.mpg.de/webcam/2017/05/amorphophallus/a_titanum_1080p.mp4

How Diseases Spread
Richard Neher from the Max Planck Institute for Developmental Biology, together with Trevor Bedford from the Fred Hutchinson Cancer Research Center in Seattle, was awarded the Open Science Prize. The two scientists are receiving the prize for their online tool nextstrain.org, with which the evolution and spread of pathogens such as Ebola and Zika can be monitored in real time. "The Ebola epidemic made clear to us just how useful a platform would be with which propagation pathways can be observed live," explains Richard Neher, who recently took a position at the Center for Molecular Life Science at the University of Basel.
www.nextstrain.org

Protection for Chimpanzees
To save western chimpanzees from extinction, Max Planck Director Christophe Boesch founded the Wild Chimpanzee Foundation 16 years ago. The non-profit organization campaigns to protect chimpanzees in the Ivory Coast, Guinea and Liberia. The research projects of the behavioral scientists at the Max Planck Institute for Evolutionary Anthropology also help to develop optimum protective measures. We talked to Boesch about the political situation in those countries, the role played by ecotourism, and cooperative projects with schools.
www.mpg.de/11074475/interview-boesch-chimpanzees

Cyber Attacks on Free Elections

Political elections are still conducted using paper ballots. In an age when we use the internet to find information and do our shopping, use apps to control home heating and even use online functions for ID cards, this is quite astounding. Wouldn't it be much easier and more convenient to vote for our politicians from our home computers or smartphones? Our author thinks not – and warns that, even without online elections, many electronic methods threaten to manipulate such processes.

TEXT **RAINER W. GERLING**

To make it clear from the start: there will be no online political elections for the foreseeable future – at least not in Germany. And that's a good thing. Of course, internet voting would be easy and convenient, and it's even possible that more people might vote online. Nevertheless, conducting an entire election process online is an idea that is better left alone. Voters' computers could be attacked from anywhere in the world, and the door would be wide open for various parties to manipulate proceedings. Ronald L. Rivest found an apt way to describe the matter: during a lecture in 2016 he answered a question regarding best practices for an internet election by asking what the best practices were for playing in the middle of a busy street.

Paper ballots are now used for voting in just 18 US states

Elections must be secret, free and secure. Secret means that nobody finds out how a voter voted. For an election to be truly free, voters must also not have any record of how they voted. Documenting your choice with a mobile phone photo from the voting booth isn't a good idea, either. It must be ensured that votes for a given candidate can't be bought or extorted. Secure means that the votes can be counted without manipulation. It's at this point that a certain degree of doubt surrounds voting machines such as those commonly seen in the US.

In the United States, only 18 of the 50 states still use exclusively paper ballots to cast votes. Ten states use at least some voting machines with no paper printouts (for potential manual recounts). With these devices, checking the digital vote count after the election is virtually impossible. Even when voters receive a paper slip to check their vote, which they then place in a ballot box, ordinary people still can't be certain that the machine recorded the same vote.

In principle, a mistrust of voting machines is advisable: there have been issues in the past with such devices' software. In 2008, it came to light that voting computers produced by Premier Election Solu-

Photo: picture alliance/Cultura R

It is presumably on behalf of foreign governments that hackers attempt to influence elections in democratic countries – also on the upcoming German parliamentary election. Identifying the perpetrators and their employers is exceptionally difficult.

tions "forgot" a portion of the votes when collating results from multiple voting machines. As a new approval process would take years, the company published a workaround in the form of amended operating instructions. This didn't technically prevent the operating error, but merely showed the operator how to avoid the error, so errors aren't precluded.

Voting machines' security systems are also extremely dubious. In a blog post for the Princeton Center for Information Technology Policy entitled *Decertifying the worst voting machine in the US*, expert Jeremy Epstein detailed the unbelievable security gaps in voting computers. For example, the encryption code for the Wi-Fi network's WEP security algorithm is "abcde." This code is "hard wired" and can't be changed. Some systems have gone without security patches since 2004. USB ports and other physical access points aren't always secured. If somebody can insert a USB device into an unsecured USB port, they can probably manipulate the machine. Bruce Schneier, an internationally recognized American IT security expert, reported that voting computers have the default passwords "abcde" or "admin". In addition, since voting computers also communicate via Wi-Fi, they are even susceptible to remote hacking.

Manipulated software teaches voting machines to play chess

In 2007, Dutch and German hackers demonstrated that a Nedap voting machine could be taught to play chess by adjusting its software, showing that the software could be amended as desired without authorization. Hacking voting machines certainly requires a lot of effort, but from the hacker's perspective, the serious implications resulting from a successful hack clearly justify the effort. Moreover, while companies have a strong interest in ensuring that their computer systems are secure and have security systems such as a firewall to protect against attacks from outside, in the case of voting machines, the operator is also a possible attacker. The operator can introduce extensive updates to the machine without arousing suspicion. Voters and election workers are also unable to carry out on-site inspections. Protecting the machine against manipulation by its operator is a much greater challenge.

Completely sealing off voting machines isn't an option, as the ballot papers, at least in their current form, must be programmed before each vote. This is generally done by inserting memory cards, which are often written using Windows computers. The same memory cards also serve to update the software: if a file with a specific name is present, the machine detects the file content as a software update and installs it. Anyone with access to the voting machine for even a short period can insert a memory card and introduce any arbitrary software.

The security of voting machines is rightly considered to be dubious; however, comprehensive manipulation is improbable. If voting computers are hacked, it can be assumed that not all models are affected, but rather only certain ones. Even with normal computers, we know that a hack of a Windows computer won't necessarily work with an Apple or Linux machine. And in the United States, 53 different voting machines produced by 17 different manufacturers are currently in use.

Furthermore, there is no evidence to date that voting computers have actually been manipulated. A group that includes the director of the University of Michigan Center for Computer Security and Society, J. Alex Halderman, alleged that Hillary Clinton received 7 percent fewer votes in Wisconsin constituencies that used voting machines compared with constituencies that used paper ballots. However, these differences could also be explained by systematic errors or random correlations between the type of voting machine and demographic factors. Therefore, we can only speculate as to whether US presidential elections were manipulated, but an unpleasant aftertaste and an uneasy feeling remain.

Voting machines have also been used in the past in Germany in various elections. Following two complaints against "the use of computerized voting machines," the German Federal Constitutional Court in 2009 declared the Federal Voting Machine Ordinance

to be unconstitutional "because it does not ensure the approval and use of only such voting machines as satisfy the constitutional prerequisites of the principle of publicity." One prerequisite is "that the main steps in the election process and the calculation of results can be inspected by citizens reliably and without the need for specialist knowledge." Current voting computers do not guarantee this. As a result, voting computers haven't been used in Germany since that time.

The question remains as to which factors speak in favor of the machines, if any at all. The only advantage is that they make counting simpler, faster and cheaper. They don't make the voting process easier for voters. Voting machines merely prevent invalid ballot papers from being submitted – but submitting an invalid vote can also be a conscious voting decision.

There are also many good reasons to retain classic paper ballots in political elections. Only when we are able to mark a ballot with a normal pen on normal paper can we ensure that counting takes place promptly and publicly – observing the principle of multiple-assessor verification. This verification principle is also ensured by having observers present when votes are cast.

Nevertheless, voting machines have probably not been banished from German polling stations for good. Manufacturers and local authorities with an eye on their funds will again attempt to introduce electronic systems to cast and tally votes. If voting machines are introduced, it mustn't be done by reasoning, "trust us, we'll do it right." And that "we" could be both the voting machine manufacturer and the state. The fundamental approach must be: "Glitches will occur, we have to identify and correct them." The possibility to conduct an audit must be included as part of an electronic voting process, and an audit of the election results absolutely must be carried out.

In the German federal elections in 2017, there will be no manipulated voting machines, but by no means does this preclude the risk of digital manipulation: voting results must be collected from polling stations, which is done over digital networks. Dieter Sarreither, the Federal Returning Officer, expects cyber attacks and has therefore had the administrative network well secured as a precaution. If necessary, telephone and fax communication can be used instead. In the election in the Netherlands on March 15, 2017, votes were counted by hand, as the software used to do so is considered to be susceptible to hacking. Couriers brought the results from the polling stations to regional election offices. Only then were computers used.

In Germany, the elections themselves can thus certainly be considered secure, but there is cause for concern that hackers may attempt to influence the

Digital criminals leave behind traces, but concrete evidence is rare

result during the run-up. This was clearly the case in the US: on January 6, 2017, the CIA, FBI and NSA published a joint report stating that Russian intelligence services had influenced the US presidential election. In addition, the computer network of the Democratic National Committee was hacked in July 2015. Large-scale document theft occurred through May 2016. These documents were later published by DC Leaks and WikiLeaks under the (potentially Russian) pseudonym Guccifer 2.0. As these documents were primarily intended to discredit the Democrats and their candidate, Hillary Clinton, this can be regarded as influencing the election – or at least attempting to do so. The Russian government has adamantly denied involvement.

There is no publicly available evidence that Russian intelligence services were behind these events. There are, however, fairly strong indications. Of course, such indications of digital wrongdoing are not as easy to identify as real-world evidence: at a classic crime scene, police find fingerprints, fibers and DNA traces that they can ultimately attribute to one or more individuals. With a digital crime scene, investigators find malicious software and IP or e-mail addresses when analyzing communications,

Photo: picture alliance/Cultura R

but attributing these bits and bytes to an individual is much more difficult than is the case with conventional evidence.

So digital forensic experts look, for example, for Russian or Chinese text fragments in the malware. This alone isn't proof, as it's entirely possible that a hacker from another country might have laid a false trail. If the forensic expert is lucky, the malware might be an optimized or advanced version of known malware that Russian or Chinese state services are known to have used in the past. There are then two clues. Data captured in a hack is transmitted to a server. This server is located with a provider somewhere in Europe or America. For this, the attackers simply rent computers from service providers and register domains. However, if the domain name was registered using an e-mail address that has previously been linked to Russian or Chinese state services, then this constitutes a further piece of evidence. The specific data transmission technique used might already be known to the investigators, and they can compare it with previous cases. The precise technical details of this analysis, however, are a closely guarded trade secret of the investigating secret services.

The interests involved may be a further clue: there is a high probability that an attack on the World Uyghur Congress would involve Chinese state agencies, as the World Uyghur Congress is one of the Five Poisons, the main threats to the Chinese state. If, however – as occurred on December 23, 2016 – a large power outage causes problems in Western Ukraine, and can be traced back to a cyber attack, then it is highly unlikely that Chinese state services are behind it. Several aspects here point toward Russian origins.

Extensive knowledge collected by security firms and authorities may be able to produce a plausible overall picture. The conclusive findings are published, though they aren't easily comprehensible from the outside. And of course a plausible picture is certainly not evidence that will stand up in court. In light of the events surrounding the US presidential election, the question is whether the German federal election is similarly vulnerable. At any rate, there have already been multiple cyber attacks on German political parties and governmental structures in the past 24 months.

In early 2015, hackers broke into the Parlakom network of the German Bundestag and copied 16 gigabytes of data. German security services believe that a hacker group close to the Russian state, known as APT28, among other names, was responsible for the attack. This group has been active since around 2004.

Attackers might attempt to manipulate public opinion before the German federal elections

The attack on French television broadcaster TV5 Monde in April 2015 was also attributed to APT28, as Hans-Georg Maaßen, President of Germany's domestic security agency, the BfV, described in a podium discussion at the Max Planck Society's IT Security Symposium in 2015. The attacks also served as a false flag operation, as the hack included a presumably faked claim of responsibility from a previously unknown Islamic group named Cyber Caliphate.

IT security company Trend Micro reported in May 2016 that the APT28 group had launched an attack against the CDU. It was done by operating a replicated CDU webmail server in Lithuania in order to tap user accounts and passwords through phishing e-mails.

In August 2016, one Heinrich Krammer sent an e-mail that seemingly came from NATO headquarters (the e-mail address ended in @hq.nato.int). The e-mail promised background information about, among other things, the military coup in Turkey. Anyone who clicked on the link installed malicious software on their computer. The e-mail's addressees were Sahra Wagenknecht and the head office of the political party *Die Linke*, as well as the CDU and its youth movement, *Junge Union*, in the Saarland. APT28 is suspected in security circles to have been behind this attack, too.

In November 2016, WikiLeaks published 90 gigabytes of data (2,420 documents) from the German Bundestag's commission investigating the NSA affair. This data didn't appear to originate from the

Photo: picture alliance/Cultura R

Bundestag hack in early 2015. The parallels with the hackers' approach in the US are obvious. Consequently, it must be expected that, when the election campaign in Germany heats up, information from these hacks will surface on WikiLeaks or similar platforms.

The Federal Office for Information Security (BSI), Germany's national cyber security agency, is working intensively on the issue. In autumn 2016, BSI President Arne Schönbohm personally warned German political parties about reconnaissance conducted by hackers affiliated with other states. The suspicion is that attackers might attempt to manipulate public opinion prior to the German parliamentary elections. The focus is on opinions and ideas being posted on the internet or social networks by automated means. In March 2017, the BSI again expressly warned German political parties of expected cyber attacks during the election campaign.

In early February 2017, media reports stated that German secret services had found no evidence of targeted Russian disinformation. However, according to research by broadcasting companies NDR and WDR and the Süddeutsche Zeitung, the 50-page report described the reporting of Russian propaganda media such as the German-language versions of Russia Today and Sputnik News as downright "hostile." Where is the line between exaggerated reporting and disinformation?

States attempting to influence public opinion to suit their aims through disinformation, propaganda, fake news and alternative facts (once known as lies) is nothing new. However, as a result of the internet, social media and platforms such as WikiLeaks, the number of information providers has dramatically increased, and traditional journalistic ethics and truthfulness are often left by the wayside. It's difficult for traditional media and experts, or even state agencies, to make corrections and evaluations. Experience tells us, however, that if you throw enough mud, some is sure to stick. Ultimately, each citizen must decide for themselves what they believe and what they don't. Only one thing can help here: education. In that respect, Europeans should be less susceptible to alternative facts than citizens in the US, as the average level of education in Europe is higher. ◀

Photo: Axel Griesch

THE AUTHOR

Rainer W. Gerling, born in 1954, is the IT Security Officer of the Max Planck Society and honorary Professor of IT Security in the Department of Computer Science and Mathematics at the Munich University of Applied Sciences, where he is responsible for additional training on operational data protection. Gerling has published numerous essays in scholarly journals and books, and belongs to the editorial board of the magazines Datenschutz und Datensicherheit (Data Protection and Data Security) and IT-SICHERHEIT (IT Security). Since 2012, he has been Deputy Chairman of the German Association for Data Protection and Data Security (GDD).

I'm trying to find a good balance

Scientists from 94 countries around the globe work at the Max Planck Institutes. Here they relate their personal experiences and impressions. Gabriel Antonio Guerrero from California is doing his PhD at the Max Planck Institute for Biology of Ageing in Cologne. When he finishes, the 29-year-old plans to return the US, initially to attend medical school. After that he would like to obtain a position as an assistant professor of biomedicine.

I was born and raised in California and was just wrapping up my first year as a PhD student at the Sanford Burnham Prebys Medical Discovery Institute in La Jolla when I considered applying for another PhD position at the MPI for Biology of Ageing in Cologne. During my first visit to Europe I truly fell in love with the idea of living in Germany – a place where I don't even speak the native language. In the US, we believe that San Francisco is the most European of all American cities, so I figured that Cologne would be just like San Francisco. Of course that's not true at all, and it took some time to get used to life in Cologne. For example, on a typical morning in La Jolla I'd go to the beach around 7 a.m., surf for 1.5 hours and be in the lab by 9 a.m., whereas in Germany I'd have to travel 500 km to get to the nearest natural surfing spot: the popular Eisbach in Munich. So I took up climbing as a recreational sport instead – indoors for now, but if I find some other people who are interested, we can take a trip to some outdoor climbing spots.

When I first met my boss at the MPI, I was convinced that Max Planck is a place to do world-class research – simply because there are only two things that limit me here: my work ethic and my creativity. Molecular biologists spend a lot of time in the lab, but I have to say that I really like the German approach to work-life balance. People here really value their free

Graphic: iStockphoto

Gabriel Antonio Guerrero (29) studied biology and economics at San Diego State University while conducting research at the University of California San Diego. He initially began his PhD at the Sanford Burnham Prebys Medical Discovery Institute in La Jolla in the field of proteostasis. Since January 2015, Guerrero is doing his PhD at the Max Planck Institute for Biology of Ageing in Cologne. As a geneticist, he is investigating *C. elegans* and how neurons trigger protective mechanisms in the rest of the organism and what role these signals play in the aging process.

time and rarely take work home after an exhausting 12- to 14-hour day at the office. It's nice this way; the research might progress a little more slowly, but it's a lot more fun – so I'm trying to find a balance between the German science culture and the much more stressful one in the US.

Research is extremely competitive everywhere, but I would still like to stay in academia. My plan is to finish my doctorate at the MPI, then go back to the US and spend another four years in medical school before trying to find an assistant professorship in the biomedical sciences. I just love the idea of teaching other students – and I know that I have to conduct research myself before I can teach others how to do it.

It will take quite a while before I reach this goal, but it makes sense to invest time in education. My father is an assistant dean and professor of medicine. My parents had me just as my dad was starting his doctoral degree. They met at university, but both of them are children of first- and second-generation immigrants with Mexican and Native American backgrounds. My parents attained an unusually high level of education – even today, only around 5 percent of all PhD holders in the US are of Mexican descent.

In my previous PhD program I was one of only two Hispanic students, which is when I realized that I was part of a minority. Personally, though, I'm very Americanized. I've never experienced open racism in California, the state with the highest percentage of Hispanics, at roughly 40 percent. It was different for my parents though; it was only thanks to full scholarships that both of them could even afford to attend university, and they often felt discriminated against.

Equal access to education is still a problem for young people in the US today. That's why a school system that offers access to quality education for all students regardless of their social or ethnic background is more important than ever. There's still a long way to go before everyone in the US has the same educational opportunities that I had.

Photo: Private collection


Einstein@Home
World Year of Physics 2005
14:26:38
User: Amber L. Stuver
Total credit: 272724
Host credit: 77995
Team: Einstein@Penn State
Search information:
RA: 353.80
DE: -34.78
Percent done: 34.000%

Gravitational Waves
on Home Computers

The Einstein@Home project makes it possible for anyone to search for gravitational waves on their own PC, laptop or smartphone and thus become scientific explorer themselves. **Bruce Allen**, Director at the **Max Planck Institute for Gravitational Physics** in Hannover, is the founder of this citizen science project. The software is now also used to track down pulsars in big data. Researchers from the Max Planck Institute for Radio Astronomy in Bonn are also involved in this search.

TEXT **THOMAS BÜHRKE**

The discovery of a gravitational wave on September 14, 2015 with the LIGO detectors in the US is regarded as a scientific sensation and confirmed one of the final predictions of Albert Einstein's general theory of relativity. Scientists from the Max Planck Institute for Gravitational Physics in Golm and Hannover were significantly involved in the discovery (MaxPlanckResearch 1/2016, p. 78 ff.).

The first gravitational wave ever detected was unexpectedly strong. Its signal was even visible to the naked eye in the data stream that was continuously analyzed by the Hannover-based Atlas supercomputer. The first person to recognize the signal was a researcher from the Max Planck Institute. Yet matters could have turned out differently. Since the beginning of the LIGO measurements, scientists have been searching for weak periodic gravitational waves that are likely to be emitted by rapidly rotating neutron stars. Atlas is the world's largest cluster for data analysis, yet in undertaking this task, even it would be stretched to its limits.

The designers of gravitational wave detectors were aware of this problem right from the start, so two of them came up with an idea. Bruce Allen remembers distinctly: "It was August 19, 1999." He had met his colleague Stuart Anderson for a meal at the California Institute of Technology (Caltech). Allen had read an article in the Los Angeles Times about the SETI@home project. The search for signals from extraterrestrial intelligence in the data from large radio telescopes presented researchers with the same problems as those confronted by Allen and his colleagues: how can they find the periodic signals in the vast data chaos?

A NETWORK WITH ENORMOUS COMPUTING CAPACITY

SETI@home is based on a decentralized analysis of data that is distributed to thousands of private computers. It works like this: a person logs in with a home computer and then receives the software, which analyzes data whenever the screen saver starts. The results are automatically returned. In this way, the search for signals is distributed throughout a network with massive computing capacity. From the very beginning, SETI@home was extremely popular. However, the search for aliens has so far been in vain.

"I discussed with Stuart the possibility of searching the gravitational

Screen savers with a purpose: The Einstein@Home program automatically searches for rapidly rotating neutron stars in the data from gravitational wave detectors, gamma satellites and radio telescopes.

Photo: Composite based on images provided by the MPI for Gravitational Physics/B. Knispel and iStockphoto/Antonio Guillem

Left A satellite dish surrounded by nature: The Arecibo radio telescope in Puerto Rico has a diameter of 305 meters and listens for pulsar signals. Einstein@Home can detect them, thus transforming home PCs, smartphones and tablets into valuable tools for science.

Right page An idea that started in the cafeteria: In 1999, Bruce Allen, Director at the Max Planck Institute for Gravitational Physics in Hannover, discussed with a colleague the possibility of having the data from gravitational wave detectors scanned. The result of this discussion was Einstein@Home, a program in which hundreds of thousands of people worldwide have so far participated. Allen is standing next to the Atlas cluster, which plays a central role in the network.

wave data of the two LIGO instruments in the same way," says Bruce Allen. "But then the thought occurred to us that, while everyone is interested in aliens, who really cares about gravitational waves?" As a result, the idea died, at least temporarily. Yet, four years later, it was revived. Allen received a call from a SETI@home pioneer who was looking for a way to take part in the upcoming 2005 International Einstein Year.

Immediately thereafter, Allen remembered the conversation in the Caltech cafeteria and he suddenly saw a chance to realize the idea he had discussed at that time. He promptly applied to the National Science Foundation for a grant of two million dollars over three years that would involve the University of Berkeley and the Max Planck Institute. But this relatively small amount was not approved. It was now June 2004 and the Einstein Year was fast approaching.

Without further ado, Bruce Allen and his coworkers decided to develop the necessary software on their own. The project received its finishing touches through David Anderson, from the University of Berkeley, who had already written the software for SETI@home. "We transferred the software to our own project, which led to great advances in its realization," said Allen. Scientists were thus able to complete an initial version by February 2005, which they presented at a press conference held at the annual meeting of the American Association for the Advancement of Science.

The media was enthusiastic about the project. It was christened Einstein@Home and customized for the Einstein Year. The news spread quickly: according to Allen, within a few days, 20,000 participants had registered. This, in turn, attracted the attention of the National Science Foundation to the project, which now offered financial support with little administrative ado.

The Max Planck Institute for Gravitational Physics, where Allen was appointed Director in 2007, was a part of Einstein@Home from the very beginning. To date, several hundred thousand people throughout the world have participated in the project, with more constantly joining in, so that now 40,000 amateur researchers are actively involved – sometimes with several devices simultaneously.

SIGNALS ARE CHOPPED UP INTO SMALL PARCELS

There are around 100 other projects in which data is viewed by means of distributed computing. The spectrum extends from the development of drugs for combating malaria and molecular simulations of proteins all the way to the search for the greatest known prime number. Einstein@Home is one of the largest of these endeavors. It has now reached a total computing power of 1.7 petaflops per second, which is 1.7 billion calculation steps. This computer network is one of the 60 most powerful supercomputers worldwide.

"The Atlas cluster plays a central role in this network," says Bruce Allen. It prepares the signals received by the LIGO detectors and chops them into small packages. They are chosen so that each participating computer re-

Photo: NAIC-Arecibo Observatory

Photo: Frank Vinken

ceives no more than one megabyte of data per hour. Atlas requires only 1 percent of its output for this administrative activity. Data from the PCs and laptops are then sent back to Atlas and prepared for scientists, for example in the form of diagrams. If a promising point in the data stream is reported, Atlas examines it in detail.

Despite years of research, the search for gravitational waves remained unsuccessful. While this was somewhat frustrating, resourceful researchers were able to draw astrophysical conclusions from this very absence of a signal. The conclusions were reached concerning neutron stars – the remains of exploded suns with a size of around 20 kilometers.

These neutron stars have extreme properties. The matter in them is so strongly compressed that a teaspoon of it on Earth would weigh as much as a million long-distance trains. They also rotate very rapidly about their own axis. This creates excellent conditions for the emission of gravitational waves, where the frequency of such a wave would correspond to the rotational frequency of the body. But neutron stars emit these space-time waves only if they're not perfectly symmetrical.

Yet neutron stars are among the most spherical bodies in the universe, making them poor transmitters. The fact that no periodic signal has been received from them up to now says something about their symmetry. The intensity of a gravitational wave received on Earth decreases with the increasing distance of the neutron star. Moreover, LIGO detectors are most sensitive in the frequency range from several dozen to several hundred hertz. As a result, only statistical statements can be made about the shape of neutron stars.

Accordingly, there are no neutron stars with a rotational frequency of 100 hertz or more within a radius of about 1,000 light-years for which the surface differs by more than 10 centimeters from a perfect sphere. This is truly a very remarkable result. "In the electromagnetic wave range, we have already detected several thousand neutron stars – of a total of perhaps 100 million that exist in our Milky Way," says Maria Alessandra Papa from the Max Planck Institute in Hannover. "In the future, gravitational wave astronomy will offer a whole new way to gather more information about these unseen denizens of our universe."

BUNDLED RADIO WAVES SWEEP THE EARTH LIKE SEARCH LIGHTS

These findings are of great importance to astrophysicists. Nevertheless, the enthusiasm of even the biggest Einstein@Home enthusiast will begin to wane if no signal is caught over the years. This was a matter of deep concern to Bruce Allen, which is why he was seeking other areas of application. He found one in late 2007 after listening to a lecture by a radio astronomer on the search for pulsars.

Hidden behind these objects are neutron stars, which emit two bundles of radio waves in opposite directions along the magnetic field axis into space. If the axis of rotation and the magnetic field axis are inclined toward one another, then the two bundles of radio waves pass through space like the searchlights of a lighthouse. If they happen to traverse the Earth, telescopes

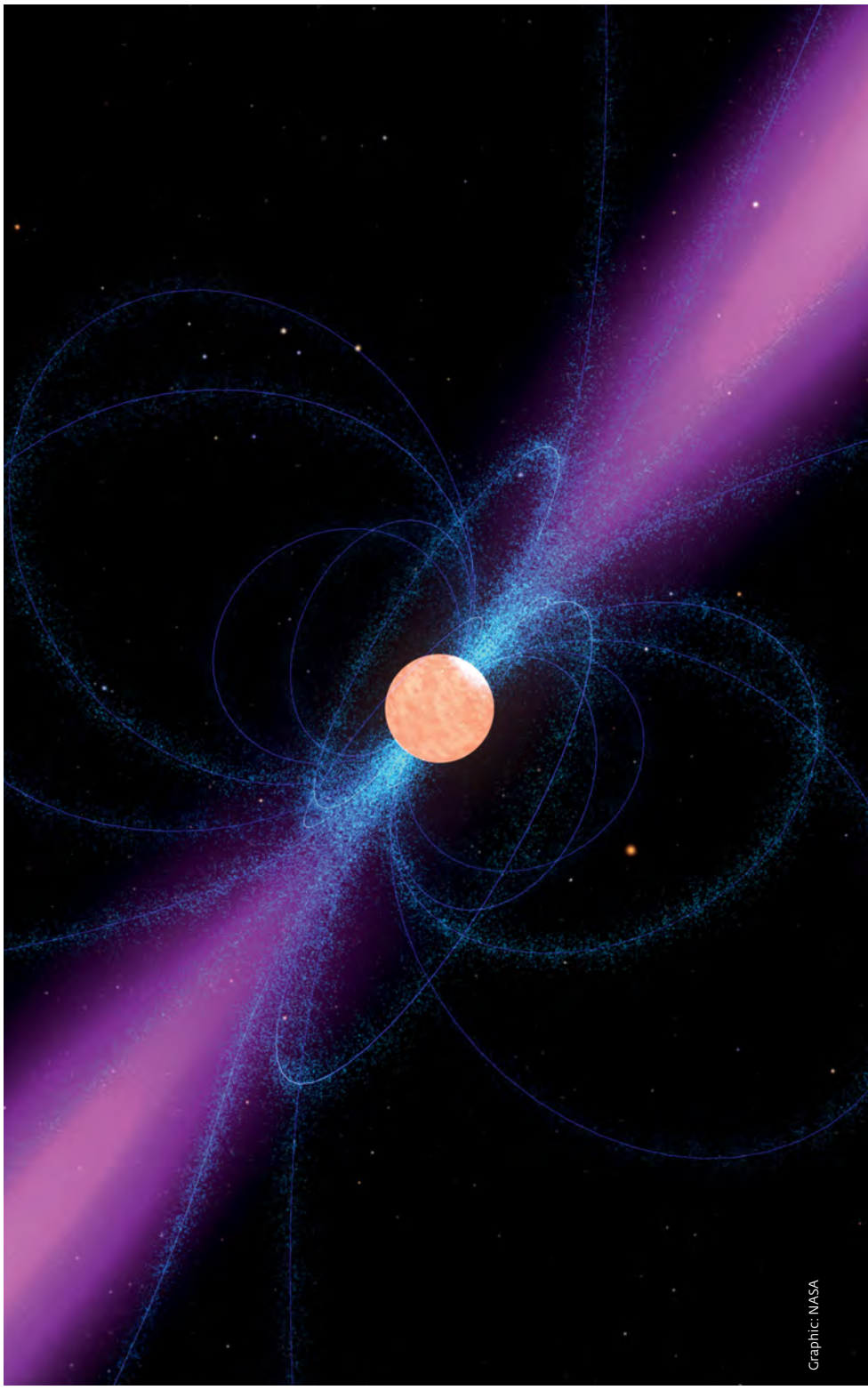
would receive a periodic signal with the rotation frequency of the pulsar.

Bruce Allen immediately realized that Einstein@Home could be applied to this area. Particularly for double systems in which a neutron star and a companion orbit one another, Einstein@Home could make a significant contribution to the discovery of such systems. "With their analytical methods, radio astronomers can find only pairs for which the orbital period is longer than an hour," says Allen. "We should also be able to track tighter pairs down to an orbital period of ten minutes."

Even though the analysis of the measurement data of radio telescopes is similar to that used in gravitational wave detectors, this expansion still required considerable effort. Doctoral student Benjamin Knispel found the endeavor to be especially fascinating and devoted himself to it. The subject matter even became his doctoral thesis. "The software had to be significantly modified," recalls Knispel. "The data from radio telescopes differs in many aspects from that detected by the LIGO detectors."

The biggest challenge is that physicists don't know whether a pulsar signal was actually hidden in the data record in question. And if it was, they don't know at what frequency. A further difficulty arises in the case of a pulsar in a double system. If it is moving toward us in its course, the pulses arrive in shorter intervals, while if it is moving away from us, the pulse sequence slows down. The pulse frequency therefore changes periodically with the orbital period of the pulsar.

"This blind search for signals of which the parameters are not known at all is very complex," explains Knispel. "We want to make the optimal use of our limited computing capacity, just as if a person wanted to win the biggest profit in a casino from a certain stake." Einstein@Home is ideal for these blind searches, because it is particularly efficient to analyze small data packages



Graphic: NASA

Left page A cosmic lighthouse: The strong magnetic field of a neutron star creates bundles of radiation at its poles in the form of two cones that, with a bit of luck, will traverse the Earth and reveal a pulsar – an object that blinks rhythmically.

Right A look at the data: Maria Alessandra Papa from the Max Planck Institute in Hannover coordinates the search for a continuous signal from gravitational waves, such as those that neutron stars should produce. In the future, the researcher hopes to learn more about a large, invisible population of these objects that has thus far been invisible.

Photo: T. Damm/Max Planck Institute for Gravitational Physics

with a high level of data processing power. Because of the many decentralized private computers, the computing power is obtained almost for free.

THE SUCCESSFUL SEARCH FOR UNKNOWN BEEPERS

Since March 2009, Einstein@Home is also searching for radio pulsars. The data is provided by the PALFA project (Pulsar Surveys with the Arecibo L-Feed Array) that is being carried out by the Arecibo Observatory through its 305-meter antenna. It took only about a year until the first discovery. The PCs of two participants had discovered a conspicuous signal in the same data set.

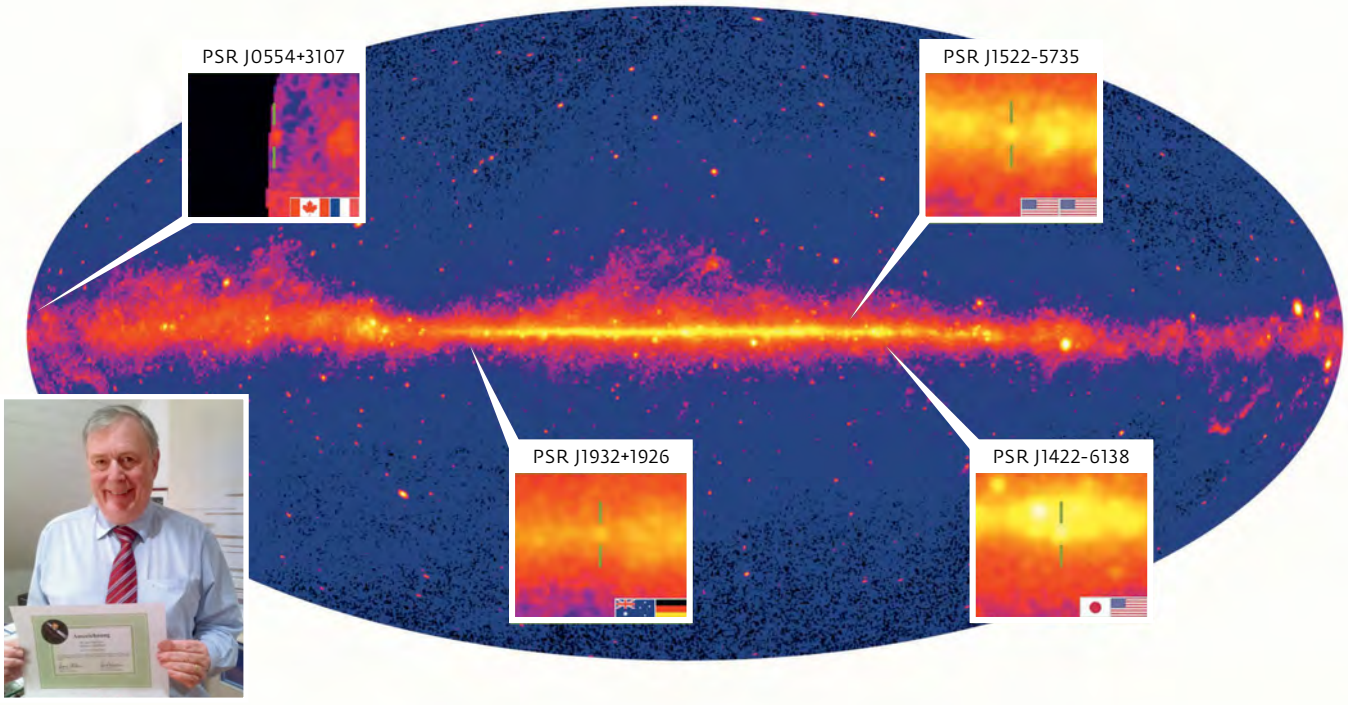
A subsequent analysis with Atlas confirmed the find. Then the professionals took over. In July 2010, astronomers searched for the previously unknown beeper with the radio telescope in Green Bank (USA). They were successful in their search: it was a pulsar that spins around its axis 41 times per second. Astronomers directed further radio telescopes at the newly discovered heavenly body, including the Effelsberg 100-meter antenna of the Max Planck Institute for Radio Astronomy. These observations have shown that the pulsar is a loner located about 17,000 light-years away from Earth, and that it has a magnetic field around 20 billion times stronger than that of Earth.

To date, Einstein@Home has led to the discovery of a total of 55 radio pulsars, including some rare specimens, such as an object 25,000 light-years away named PSR J1913 + 1102. This is a pair consisting of a pulsar and a neutron star; the two revolve around one another with a five-hour orbital period. However, the neutron star can't be detected as a pulsar – probably because its radio wave emissions don't traverse the Earth.

"With a total of 2.88 solar masses, we now have a new record for the total mass of a system composed of two neutron stars," says Paulo Freire from the Max Planck Institute for Radio Astronomy in Bonn, who is extensively involved in Einstein@Home. These rare double neutron stars are unique labs for testing relativity theory in strong gravitational fields – a special area of the group headed by Michael Kramer, Director at the Institute.

Most of the currently 2,500 known radio pulsars that have been identified in space are isolated and rotate as single stars. Only 255 of them are located in double systems, and only a handful orbit around another neutron star. This is where Einstein@Home hit the bull's eye.

However, the success story doesn't end here. Since August 2011, the Einstein@Home computers have also been rummaging through data from the Fermi space telescope. This telescope detects cosmic gamma radiation, which is of a significantly higher energy level than radio waves or visible light. The detection of pulsars in this manner is an enormous challenge because the



The joy of discovery: Hans-Peter Tobler of Rellingen is one of those lucky amateur astronomers whose computers identified the signals from the first four gamma pulsars. In the background is an image of the Milky Way showing the positions of the pulsars. The flags in the enlargements refer to the nationalities of Einstein@Home users who participated in the discovery.

gamma radiation received is extremely weak: on average, Fermi detects only about 10 gamma photons per day from a typical pulsar! It therefore takes years of data collection to detect a pulsating signal – in the absence of prior knowledge as to pulse frequency and phase, meaning the positions of the pulses in the data stream.

This intricate analysis problem is precisely where Einstein@Home demonstrates its strength. First the software had to once again be rewritten and made more efficient, but the effort was immediately rewarded: within a year, the participants had detected more than a dozen pulsars in the Fermi data, and since then, further discoveries have been achieved exclusively with Einstein@Home.

Astrophysicists recently published a catalog of 13 newly discovered gamma pulsars. Using only a single home PC, the search would have taken more than 1,000 years. Einstein@Home was able to accomplish this within a year, although only a part of the project's performance capacity was utilized. A total of one-third of all such discovered objects has been due to the use of the decentralized computers.

AMATEUR ASTRONOMERS DETECT FOUR GAMMA PULSARS

The new data is of great importance for research because it isn't yet clear just how pulsars generate radiation. Gamma radiation and radio waves are probably generated in different areas above the surface, which is why information about the various radiation types can give us an overall picture of these fascinating celestial bodies.

Successful amateur researchers who participate in Einstein@Home are informed by e-mail, receive a certificate and are specifically acknowledged in the scientific publication pertaining to their work. Hans-Peter Tobler from Rellingen, something of an old hand at these matters, is one of them. He was already participating in SETI@home and immediately signed up in the beginning stages of Einstein@Home. Just about four years ago, he received the news that he was one of the discoverers of the first four gamma pulsars.

"Of course I was delighted and at first could hardly believe it when Bruce Allen got in touch with me," he recalls. "The certificate, which came later, has been framed and given a place on my desk," says the former economist, who has had a deep love for astronomy since youth.

Einstein@Home can look back on an impressive history of discovery, even if its actual intention – the detection of gravitational waves – hasn't yet been realized. And Allen isn't all that optimistic about the future. "Over the past few years, more and more people have switched from laptops and PCs to tablets and smartphones, which are

Photo: Knispel/Pletsch/AEI/NASA/DOE/Fermi LAT Collaboration/Hans-Peter Tobler

devices that have been designed to maximize battery time." In other words, idle times with screen savers are a thing of the past. But the Max Planck researchers have come up with a new idea.

Since July 2013, they have been offering the software for Android smartphones and tablets. In order to preserve battery life, minimize load times and avoid using up download quotas, the software calculates only when the device is connected to a WLAN network and the battery charge is above 90 percent. Currently about 4,000 active participants are registered – which is encouraging. "I hope that we will finally find the first gravitational wave signal in the data of the improved LIGO detectors," says Allen. This would mean that, for the first time, amateurs would have been involved in a discovery worthy of a Nobel Prize. ◂

TO THE POINT

- **The project for distributed computing called Einstein@Home has been underway since 2005. The project has enabled tens of thousands of participants throughout the world to search the data provided by the LIGO detectors for signals from gravitational waves.**
- **Since 2009, an extension of the software has made it possible to search data from radio telescopes, and since 2011 it has also been possible to search for pulsars in gamma ray satellite data. This has facilitated the discovery of 55 radio pulsars and 19 gamma pulsars.**
- **Since 2013 it has also been possible to search with Android smartphones and tablets.**

GLOSSARY

Gravitational waves: Curves in space-time produced by the accelerated motion of celestial bodies. Gravitational waves move through space at the speed of light and were first detected on September 14, 2015.

LIGO: This observatory consists of two detectors, each of which has laser arms with a length of four kilometers. The detectors are located in Hanford (Washington, USA) and Livingston (Louisiana, USA). After an upgrade, the sensitivity of the detectors was significantly increased. As a result, the observatory has been operating under the name Advanced LIGO since 2015.

Distributed computing: A combination of independent computers that work as a single system and analyze large amounts of data. The Atlas supercomputer coordinates the independent computers that participate in Einstein@Home.

Analog information overload: Censuses conducted in the 19th and early 20th centuries generated huge amounts of paper that required manual sorting.

Stacking **Data**

Big data isn't an entirely new phenomenon, as far as historians of science are concerned. Even in the 18th and 19th centuries, scholars, scientists and state authorities collected huge quantities of data, and analyzing all this raw material posed a challenge back then just as it does today. A group led by **Elena Aronova**, **Christine von Oertzen** and **David Sepkoski** at the **Max Planck Institute for the History of Science** in Berlin looks at the methods used in the past – many of them unexpected – and examines how changes in data handling has ultimately brought about changes in science and society.

TEXT **TINA HEIDBORN**

Prussia, mid-19th century: At the census bureau in Berlin, a tabulator reads out the enumeration lists of the current census. The counting staff, seated around a large table, listen attentively; each of them is responsible for a separate category. When the operation is complete, the marks they made in their section of a big interim table form are counted and the resulting numbers noted in a statistical table for publication. This marking process was not only very time consuming, it was also costly and error prone.

Some twenty years later: The scene is a private apartment in the Prenzlauer Berg district of Berlin, where the wife of a statistics employee is tallying up the counting cards of the current census. The cards were delivered in large wooden crates of 5,000 or 10,000 units by the Prussian Statistical Bureau. In this middle-class parlor, they are now being carefully sorted into stacks according to a precisely defined scheme. The housewife has hired a domestic maid to free herself up for this home-based piecework. Along with her two sisters, a brother-in-law, an unemployed trader, two widows and two unmarried young ladies from the neighborhood, she is earning good money helping to evaluate the results of the census. They work more than ten hours a day, seven days a week. For historian

Photo: akg-images / Imagno

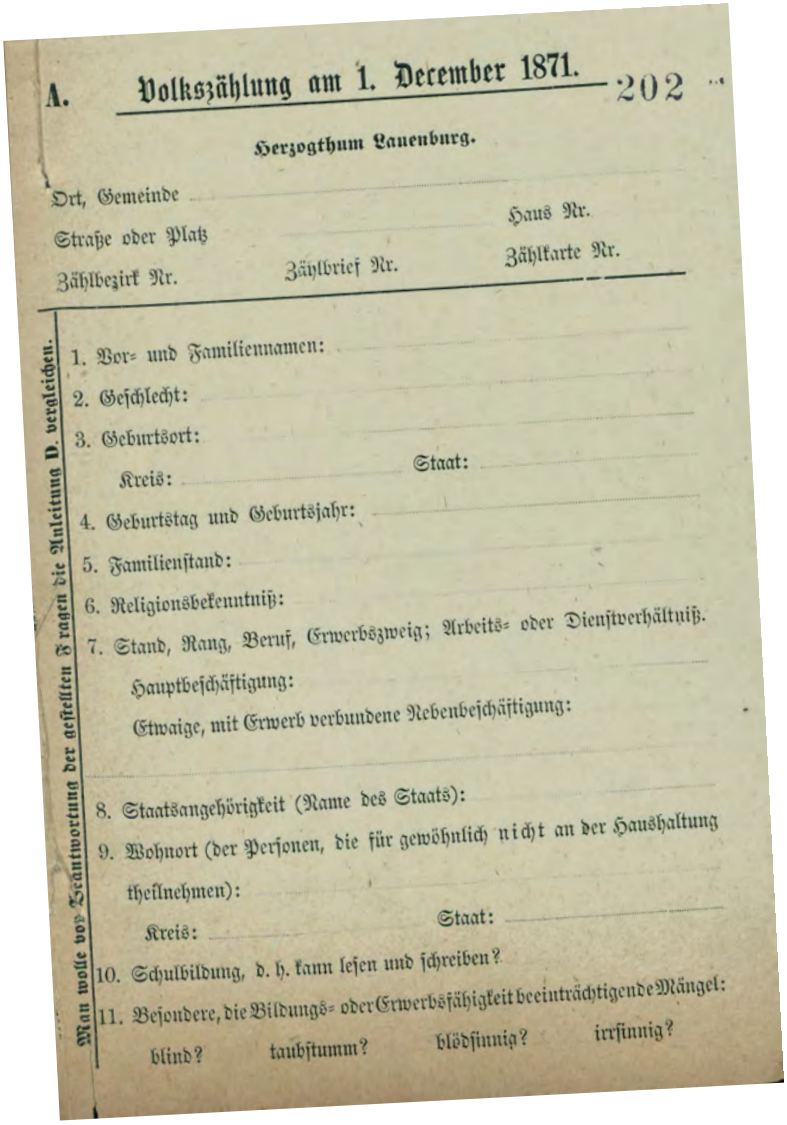
» 19th-century statisticians freed the data from rigid lists – they made data move. This was the beginning of modern data processing.

of science Christine von Oertzen, these two scenes reflect a crucial leap in the history of mass data processing.

"Then as now, the term data was used in very different ways. What is particularly interesting is that the Prussian authorities changed their method of conducting censuses in the 1860s. For the first time, they used a specific concept of data – it appears here in the sources," von Oertzen explains. "The authorities developed a definition of what they understood data to mean." It was Ernst Engel, appointed Director of the Royal Prussian Statistical Bureau in 1860, who established a vital conceptual distinction: he differentiated between the primary data collected in so-called enumeration lists and the processing of this data in tables. As the Director wrote, a table "contains a concentrated result, a summary and groupings of the information drawn from the lists." Engel was one of the leading figures behind the development of population statistics in Europe and, following Italy's example, introduced "counting slips" in Prussia in 1867. These slips made further processing of the gathered data in tables much simpler: the information collected from the enumeration lists was now transferred to the handy little cards, which were vaguely reminiscent of playing cards.

The counting slips provided a new way of accessing the information from the enumeration lists: it was now possible to handle the material in a literal sense. The slips could easily be counted, recounted or stacked and regrouped according to different criteria, so connections could be created between the various items of information from the survey lists. This had been precisely the problem with the marking process: another huge list had to be compiled for every new combination of criteria to be analyzed from the enumeration lists. The counting slips made it possible to correlate data. As Engel wrote in 1868: "The advantage of the counting slip method was that it allowed innumerable combinations of the individual data contained in the slips."

And Engel continued to optimize the method. A short while later he replaced the counting slips with individual counting cards that each respon-


A. Volkszählung am 1. December 1871. 202

Herzogthum Lauenburg.

Ort, Gemeinde

Straße oder Platz Haus Nr.

Zählbezirk Nr. Zählbrief Nr. Zählkarte Nr.

Man wolle vor Beantwortung der gestellten Fragen die Anleitung D. vergleichen.

1. Vor- und Familiennamen:
2. Geschlecht:
3. Geburtsort:
   Kreis: Staat:
4. Geburtstag und Geburtsjahr:
5. Familienstand:
6. Religionsbekenntniß:
7. Stand, Rang, Beruf, Erwerbszweig; Arbeits- oder Dienstverhältniß.
   Hauptbeschäftigung:
   Etwaige, mit Erwerb verbundene Nebenbeschäftigung:
8. Staatsangehörigkeit (Name des Staats):
9. Wohnort (der Personen, die für gewöhnlich nicht an der Haushaltung theilnehmen):
   Kreis: Staat:
10. Schulbildung, d. h. kann lesen und schreiben?
11. Besondere, die Bildungs- oder Erwerbsfähigkeit beeinträchtigende Mängel:
    blind? taubstumm? blödsinnig? irrsinnig?

Inconspicuous revolution: The Prussian counting card introduced in 1871 brought about a fundamental shift in processing census data.

Photo: Secret State Archives Prussian Cultural Heritage Foundation (GStA PK)

Desperately overcrowded: Population growth and mobility led to miserable living conditions, especially in big cities like Berlin. Improved census data analysis revealed such conditions in detail.

dent had to fill out themselves: they were approximately DIN A5 format in size, about four times larger than the counting slips, but equally manageable. On these, the residents of Prussia were required to provide numerous personal details, including age, place of birth, family and professional status, and reading ability. This saved Engel the trouble of having to use enumeration lists, and it did away with the interim stage of manually transferring data to counting slips.

SOCIAL INJUSTICES BECAME VISIBLE FOR THE FIRST TIME

"The Prussian statisticians were delighted at their new-found ability to combine different criteria," says historian Christine von Oertzen. They began analyzing the cards in three count runs, each focusing on several criteria. It was now possible to focus specifically on Catholic women in rural areas, for example, or unmarried Protestant workers in small towns. Being an ambitious statistician, this was precisely Engel's aim: he was in search of methods that not only improved the counting as such, but that also allowed more far-reaching insights to be gleaned from the material. "It's difficult for us today to grasp just what a major improvement this was," says von Oertzen. It was a breakthrough that allowed a previously unknown degree of differentiation in data analysis. "The Prussians wanted the census to provide a snapshot that captured the current situation." For the first time, the census material could be used to scrutinize social problems quantitatively, such as the high child mortality rate. Or else the information was broken down to see where large numbers of people who were not related to each other lived under one roof – another indicator of poverty.

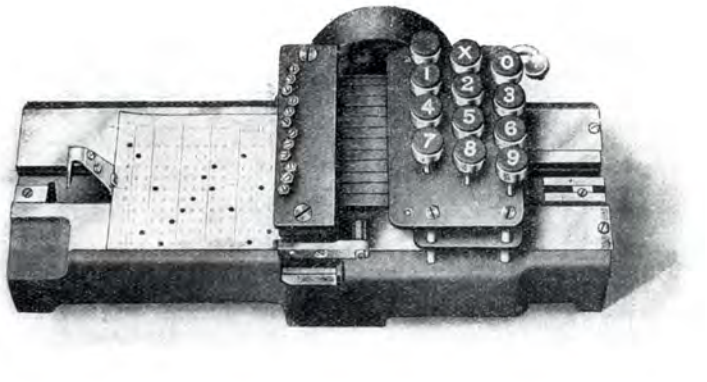
As a historian of science, Christine von Oertzen is particularly interested in the development of technologies and their concrete application. She regards the changeover from lists to maneuverable paper media such as counting slips and cards from 1860 onward as a data processing revolution that has thus far received little attention: "Statisticians freed the data from rigid lists – they made data move. This is what marks the beginning of modern data processing, not the introduction of Hollerith machines and mechanization." In von Oertzen's opinion, the significance of Hollerith's supposedly groundbreaking method is exaggerated.

Herman Hollerith, an engineer, presented his invention at the Paris Exposition in 1889: a method using punch

Photo: akg-images

THE NEW CENSUS OF THE UNITED STATES—THE ELECTRICAL ENUMERATING MECHANISM.—[See page 132.]

Photo: akg-images



Left Hollerith machines – tabulating machines based on punch cards – were first used in the US census of 1890. At the time, this required laborious preparatory work, as all data had to be punched into the cards by hand.

Right It wasn't until later that punch keyboards were sophisticated enough to be operated quickly – as in the case of this model from the 1920s.

Photo: akg-images

cards with machines for sorting and tabulating. It was first used for the American census in 1890. The idea occurred to Hollerith when he saw ticket inspectors in America punching railway tickets as a way of storing information: the ticket was punched in a different place depending on who presented the ticket (to denote the place of boarding, destination, travel class or fare, for example). The advantage of the Hollerith cards was that they could be read by machines, so the counting and sorting process was considerably faster. For the 1890 census, though, the information still had to be punched into the 63 million cards by hand.

DATA ANALYSIS WAS LIKE BRINGING IN THE HARVEST

Some European states, such as Austria-Hungary and the Russian Empire, introduced Hollerith's system right away, and it is generally regarded as a crucial step forward in the history of modern data processing.

At the turn of the century, however, the Prussians believed their own manual method was at least equally effective. As moveable data carriers, the Prussian counting cards were based on the same principle as the Hollerith cards. According to Christine von Oertzen, European statisticians such as Engel established a key cornerstone of the information technology era 20 years prior by introducing the principle of card counting.

The use of slips and cards also allowed the Prussian authorities to outsource the job of data analysis quite literally: it became a task that was typically carried out by women in their homes. The state delegated this work to the wives of its census workers and officials, and held the latter responsible. Hefty wage deductions were put in place to punish slipshod work and thus keep revisions to a minimum. It was during her archival research that von Oertzen came across the unusually large Prenzlauer Berg tabulating team described above. "The data had to be analyzed quickly – it was seasonal labor, like bringing in the harvest," she explains. "We often tend to regard data as not being physical." But when von Oertzen started to dig deeper into the history of Prussian data processing before 1900, the data started to grow "hands and feet," as she puts it – it took on the concrete, tangible form of millions of cards sent back and forth between the census bureau and many private dwellings in Berlin.

Incidentally, the Prussian statisticians were quick to draw attention to the fact that Hollerith machines threatened to take people's jobs away. Ernst Engel's successor Emil Blenck insisted that his agency had a mandate to provide work first and foremost for war veterans – though he conveniently failed to mention that it was no longer impoverished veterans doing most of the work but in fact middle-class housewives.

IMPOSING ORDER ON AN AMBIGUOUS REALITY

While they were busy sorting, stacking and counting census data in their parlors, the women were faced with the fundamental dilemma underlying all data processing: forcing a complex and often ambiguous reality into the supposedly distinct statistical categories provided. In the Prussian census of December 1, 1890, for example, respondents were required to indicate "Kinship or other relationship with the head of the household." The answers not only came in millions of different scripts – some barely legible – but they also covered an enormously diverse range of terms, since people were expected to enter the information in their own words. The women had to

Women often performed the work of transferring data onto punch cards, as here in the US census office in 1908. Piano players were given preference because of their ability to operate the punch keyboard quickly and without errors.

classify the responses into seven categories. The census bureau wanted foster children and pensioners counted in one category, for example, but soldiers, subtenants, and day lodgers – night workers who rented a bed that was unused during the daytime – to be subsumed under different rubrics. "The women were required to sort the cards before counting them. This was an essential operation – anything but mechanical or mindless," says Christine von Oertzen. "It required considerable interpretation and analysis. Diligence and reliability weren't sufficient: the women had to be relatively well educated to be able to classify the information correctly.

BIG DATA DEPENDS ON HUMAN WORK, AS WELL

The census bureau included a sample sheet with model answers, and this shows just how difficult it was to fit the data into the given categories. When it came to the respondent's relationship with the head of household, for example, the statistics were supposed to reflect two separate categories: "Category 2: Servants to the head of household" and "Category 3: Helpmates to the head of household." The examples provided in the instruction sheet stipulated that Category 2 should include rural maidservants, governesses, lady's companions, "household helpers," housekeepers, household support staff and maids, as well as menials and coach drivers, while Category 3 was to include "Workers, house tutors, apprentices and head housekeepers" as well as those fitting such a general description as "in work." Why did those who described themselves as a "housekeeper" fall into Category 2 while others who stated their position as "head housekeeper" fell into Category 3?

"There's this idea that handling data is straightforward because the data itself is self-explanatory – that counting is all that's required, which is a simple task. I believe that's an illusion," says Christine von Oertzen. Her study shows vividly just how much the data collected had to be analyzed and evaluated more than 100 years ago. And today, in the much-vaunted age of big data? "Of course we're interested in continuity and ruptures," says the historian. Despite digitization, there is still a lot of human work involved, she says – even for big data today, at the beginning of the 21st century: the mass of data must be made compatible, and it must be updated and maintained for ongoing use. "These are things we are only too inclined to overlook," says von Oertzen.

IN THE PAST, TOO, QUANTITY WAS DEEMED TO MATTER MOST

And what about the assumption that digital data is a new kind of scientific object, and that computerized data processing represents a new scientific method? "Some people believe that scientific research will be exclusively data-driven in the future," says the researcher. The claim is that science will become a simple matter of using automated algorithms to process huge datasets rather than putting forward hypotheses and testing them. Von Oertzen's study of mass data gathering in the past has tended to make her skeptical of this idea.

The dream of achieving completeness in scientific data gathering – an increasingly widespread vision in the age of big data – is something Christine von Oertzen has also seen before. "In the 19th century there was an enormously enthusiastic belief that data could be used to create a comprehensive record of reality," she says. Scientists in a broad range of disciplines attempted to amass particular data in search of an

Photo: Library of Congress, Prints and Photographs Collection, Washington, D.C.

» There's this idea that handling data is straightforward because the data itself is self-explanatory. That's an illusion.

overall picture – whether in astronomy, linguistics, evolutionary biology or taxonomy. The motto for many research projects back then was: quantity matters most.

Yet this was precisely what caused problems, too. Libraries and scholars used card indexes in their attempt to get a handle on the vastly increasing flood of information. David Sepkoski, co-organizer of the working group, traces the origins of data-driven research in taxonomy and paleontology. He examines how the study of paleontology, which originated in the 19th century, involved the development of classification systems for fossils over a long period of time, and how scientists classified and archived information on extinct species of a bygone era using paper tools to create databases – long before the advent of computers. Paleontologist Heinrich Georg Bronn (1800–1862) drew on existing catalogs and compendia, for example, but reorganized the mass of data they contained. He subjected the data to quantitative analysis by restructuring it according to his own scientific hypotheses, compiling charts and diagrams to illustrate at a glance the emergence, proliferation, diversification and extinction of species. The system he used to reorganize the material on paper was later used as a model for electronic and digital paleontological databases.

In observational disciplines such as astronomy, which had always been oriented toward data collection, the quantity of data exploded in the wake of new technological capabilities such as photographing the night sky or using electronic and ultimately digital super telescopes. As a result, astronomers' work shifted more and more from observing the sky toward merging different data formats to analyze and correlate the collected data in a meaningful way. Sharing and circulating data thus became the core activity of astronomy, transforming the culture of the entire discipline.

DATA TODAY CAN BE DETACHED FROM ITS CONTEXT

Large-scale geophysical data became a veritable exchange currency during the Cold War, as Elena Aronova, co-organizer of the Berlin-based working group, discovered. American and Soviet data centers collected and archived vast masses of data in analog form, but the vision of making this material freely available to scientists in both the East and the West was only partly put into practice, hampered not only by political constraints but also by technological limitations of analog storage media.

What is new in the digital age, according to the group of historians of science in Berlin, is the ability to detach data entirely from its original context. Once collected and digitized, information is no longer limited to a specific location as it was with the data centers in the Cold War: it can be freed entirely from its original context and used in other ways. This is what happened, for example, with medical data collected in the 1990s from the Pima indigenous people of the Gila River Indian Community Reservation in Arizona: the medical data of the members of this tribe of American Indians was originally collected with the consent of the individuals involved, the aim being to study excess weight and diabetic tendencies within the group. This particular collection of data has since become freely available online and is now used mainly to optimize computer-based machine learning. The movement of this data – without the consent of the original subjects – highlights the complicated politics of data mobility in the digital age.

Mapping the world through data raises new issues and has now reached new dimensions as a result of modern-day digitization. However, if we look back at the data practices of the past, we quickly realize just how old the foundations are that shape datification as we know it today. ◂

TO THE POINT

- **Scientists were already collecting large quantities of data in the 18th and 19th centuries in the hope of being able to create a snapshot of reality. Scientific work shifted increasingly toward data analysis.**
- **The Prussian Statistical Bureau revolutionized data processing in the mid-19th century by using counting cards. This enabled data to be combined according to different criteria, thereby revealing unfamiliar interconnections.**

Treasure Hunt **in the Data Jungle**

Researchers normally formulate a hypothesis before beginning an experiment and collecting data. **Pauli Miettinen** from the **Max Planck Institute for Informatics** in Saarbrücken is turning this scientific principle on its head with a new procedure for analyzing data – redescription mining. The software can analyze existing datasets and retrospectively extract hypotheses and unexpected correlations. These, in turn, give scientists important clues for asking new questions – for example, when the task is to capture the political mood among the population.

TEXT **TIM SCHRÖDER**

Over the decades, computers have learned to complete specified tasks. They can solve complex equations, predict the weather, and now even reply in a human voice to such questions as "Where can I find a good, inexpensive Chinese restaurant near here?" However, Pauli Miettinen from the Max Planck Institute for Informatics in Saarbrücken has taken things one step further. He has taught computers to answer questions that nobody has asked them yet – and in this way to discern connections that humans wouldn't have noticed on their own.

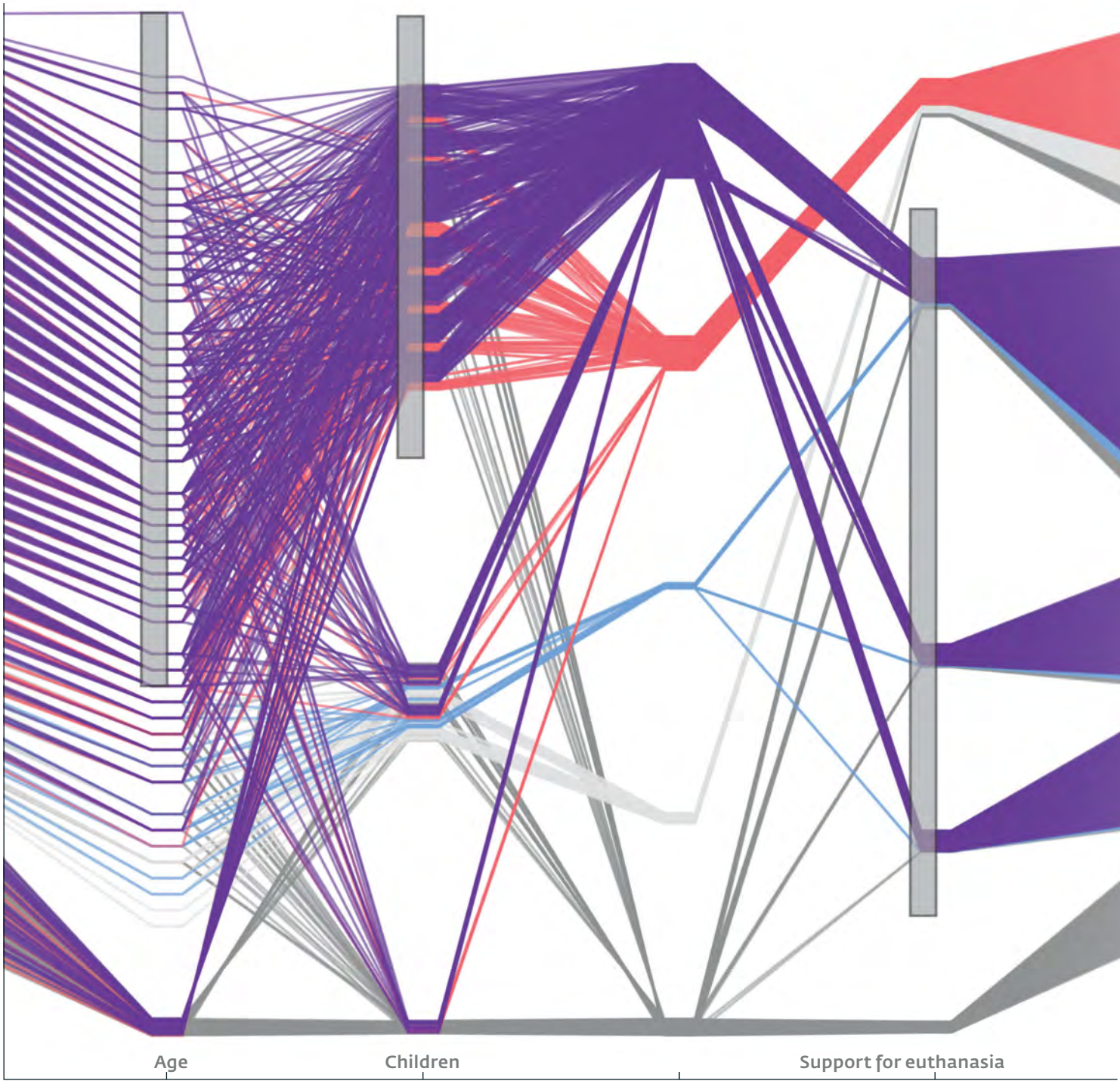
With that, Pauli Miettinen is pretty close to looking into a crystal ball. He himself describes his work a little more soberly: "Basically, all we're doing is generating a new hypothesis from existing data." That sounds modest, but it's nothing less than a minor revolution in the ways of scientific work. For centuries, researchers have always proceeded in accordance with the same template, regardless of the discipline. First they posit a hypothesis such as: "Man is descended from the apes." Then they test this hypothesis through observation and by collecting data.

MEANINGFUL INFORMATION FROM LARGE VOLUMES OF DATA

The data analysis tool that Miettinen and his team developed turns this principle on its head. It uses existing data, analyzes it and makes entirely new connections – some of which are astonishing. The method used is pretty much the cutting edge in the world of data analysis. It's called redescription mining, which, freely interpreted, means something like "alternative description." In other words, Miettinen and his colleagues search for new correlations in existing data, for new statements contained in the data – for new ways of describing the data. In this way, they are helping to track down treasure in the data jungle.

Any kind of data can be analyzed with the method, and that, too, is one of the strengths of redescription mining – and the volume of data that can be processed is just about unlimited. For example, the procedure can help extract meaningful information from the large volumes of data that are collected everywhere today.

Pauli Miettinen and his colleagues showed what the method can do using data from his home country of Finland: information on Finnish politicians who stood as candidates for a seat in parliament in 2011 and 2015. For his analysis, the researcher combined two datasets: the first contained publicly available data on the politicians' social background, their age, origin, education and marital status. The second dataset contained replies to questions the politicians had answered for a web service. >



Graphic: Pauli Miettinen/MPI for Informatics

One line for every politician: This chart was produced by the Siren software in analyzing the sociodemographic data and political attitudes, in this case specifically on euthanasia, of candidates in the Finnish parliamentary elections. One finding: candidates over 34 and those with children are more likely to reject euthanasia.

Illuminating the data jungle: Pauli Miettinen and his staff developed software by the name of Siren (right-hand page) in order to identify associations in datasets that had not yet been formulated as a hypothesis at the time the data was collected.

Photo: Tom Pingel

Such web services have been extraordinarily popular for some years – the German Wahl-O-Mat website is fashionable, to name but one. The idea is that politicians and voters answer the same questions independently of each other, and the website reveals to the voter which party or candidate they have the greatest degree of agreement with. Miettinen fed the information on the social background of 675 politicians into Siren, the redescription mining software his team developed, as well as their answers to 31 questions, such as: "Are you in favor of legalizing euthanasia?"

POLITICIANS' DATA AS A TEST OF REDESCRIPTION MINING

For Pauli Miettinen, it wasn't about discovering the details of what each politician thinks. And the fact that he used data from politicians was more a matter of chance and owed to the fact that he was simply looking for freely available data about people with which he could test Siren. Politicians' data is freely available. He wouldn't have been able to access other personal data for reasons of data protection. Ultimately, he wanted to prove that it's possible to determine the opinions and moods in a society based on where people come from and the statements they make.

"Our datasets are neither huge nor representative, but they reveal the principle clearly," says Miettinen. "Our analysis also showed that researchers without a software tool would be out of their depth even with a manageable volume of data such as this." Because the association that the software establishes between the two datasets – in this case, the sociodemographic background and the politicians' lists of answers – are sometimes hard to track down. At least if the study hasn't been correspondingly designed from the outset. For instance, the software found out, among other things, that people between 34 and 74 and people with children tend to reject euthanasia.

Such results are remarkable above all because Siren extracted them from two datasets that were originally collected for different purposes and actually have nothing to do with each other. In the 2015 list of questions, it was asked merely whether the respondent is in favor of euthanasia or not. The

software, however, establishes a much more complex connection by discovering further things in common, on the one hand between people who are in favor of euthanasia, and on the other, between those who reject it. "It delivers wholly new statements retrospectively and generates valuable answers to questions that no one had thought of at the time," says Miettinen.

The correlations identified by Siren can be very interesting for scientific work. Above all because the software presents many "AND"/"OR" links that many other data analysis programs can't identify with this degree of complexity. Scientists can use Siren to formulate completely new hypotheses – for example: "Middle-aged people reject euthanasia." Such aspects can, in turn, stimulate future scientific studies or surveys. Siren is available to researchers of all disciplines and can be downloaded free of charge from siren.mpi-inf.mpg.de.

Scientists can feed their data into the software as easily as with a statistics program. Siren then uncovers numerous correlations in a matter of minutes. "Of course, some correlations are trivial or meaningless," says Pauli Miettinen. A statement such as "People over 60 are less interested in available spots in daycare centers," for example, would hardly be surprising.

Time and again, however, Siren comes up with surprises, as another experiment of Miettinen's shows. In this case, he worked with biologists to feed the software with information on the distribution of Europe's mammals. One dataset contained 54,000 individual records of mammals with location details, and the second, the climate data of different locations and regions – for instance, the maximum and minimum temperatures and rainfall figures. These datasets, too, had originally been collected independently of each other, came from different sources and actually had nothing to do with each other. "This example underscores the sheer volume of data you often have to deal with when you link two datasets," says Miettinen.

SIREN DEFINES RULES AND EXCEPTIONS

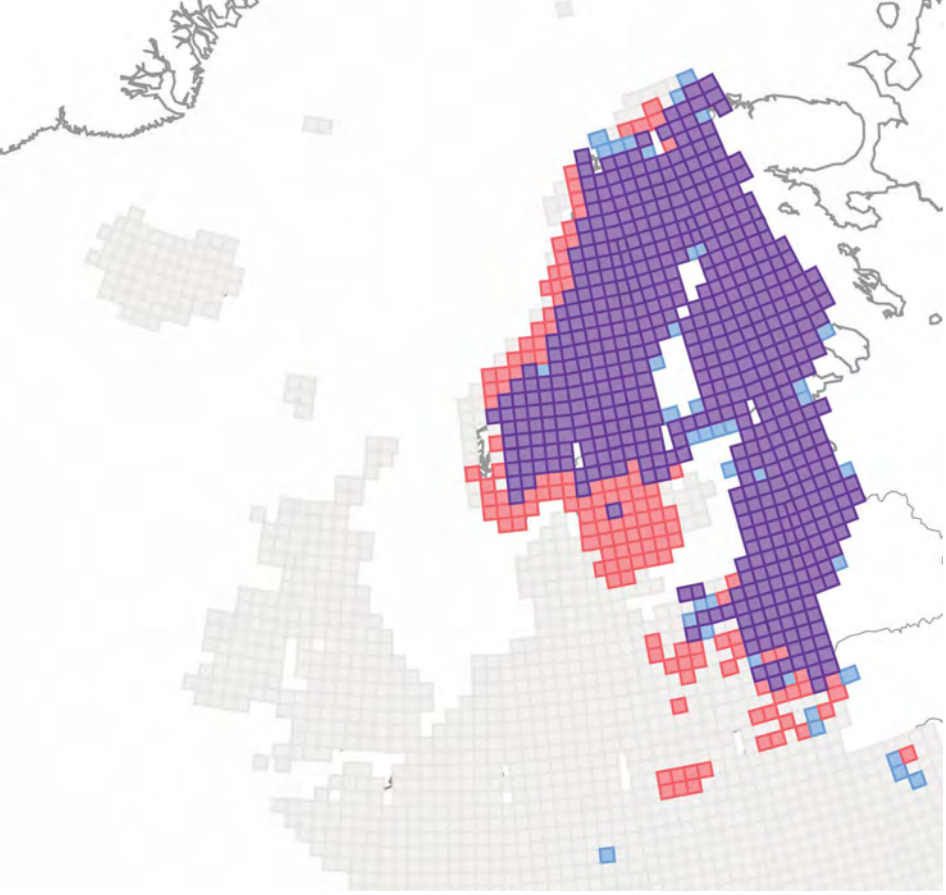
The study was actually supposed to clarify to what extent mammal populations in Europe might move in response to global warming. But Siren identified some unconnected correlations that were revealing for biologists – on the habitats of moose, for example. As the software discovered, moose are found primarily in regions in which the maximum temperature in February lies between -10 and 0 degrees Celsius, and in July between 12 and 25 degrees Celsius. In addition, the rainfall in August in these regions is between 57 and 136 millimeters. However, there are some exceptions to this rule, which Siren also identified: for example, moose also live on the coast of Norway, where there is more rainfall in August. And there is a small population of moose in Austria in a region with significantly higher temperatures in February.

Thanks to Siren, biologists can gain a better understanding of the climatic conditions that apply to the distribution of moose and other mammals – although this wasn't the original purpose of the study. However, they still have to define the rules and decide how to treat the Austrian moose population, for example. "Biologists can define the conditions in such a way that those habitats are also included, or they can view situations such as the one in Austria as an anomaly," says Miettinen.

Software tools such as Siren are rare to date, as the discipline of redescription mining is still relatively young – computer scientists have only been using this method for around 10 years. There are also only a few groups in the world working on this subject, even though Siren is decidedly versatile. Not only can the program establish correlations between two different datasets, but it can also find associations in a single data pool. Programming software to enable it to process large volumes of "AND"/"OR" links or negations such as "If x is true, y is impossible," is a challenge, says Miettinen. "It's fairly difficult to translate that into algorithms."

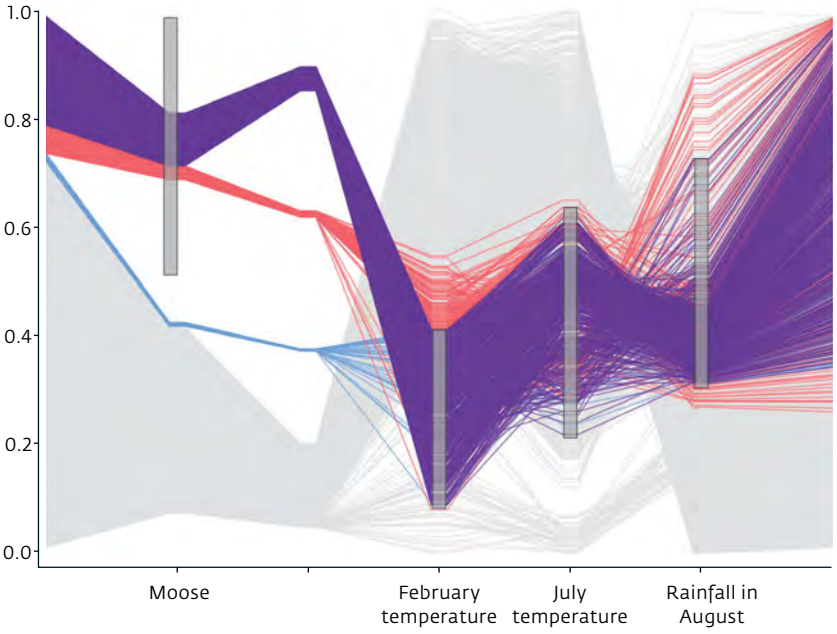
However, it is relatively easy to explain how redescription mining programs work. They search for similarities between the objects in a dataset – such similarities can be the same answers given by politicians to certain questions, the same level of education or marital status, or the same age. The

Photo: MPI for Informatics



Above Siren analyzed whether the habitats of European mammals can be explained by the climatic conditions in the respective region. The purple and red fields show where moose live. The climatic conditions in the purple areas match the expectations of the biologists: maximum temperatures in February between -10 and 0 degrees Celsius, in July between 12 and 25 degrees Celsius and rainfall in August between 57 and 136 millimeters. Moose also live in the red areas even though these don't meet the criteria. The biggest surprise to the biologists was their presence in a region of Austria with significantly higher temperatures. There are no moose in the blue regions even though the climate fits.

Below This chart shows the same associations for the individual habitats, each represented by a line. A value of over 0.5 for moose signifies that the species occurs there, and a value below 0.5, that it doesn't. The average temperatures and volumes of rainfall in February, July and August have also been assigned relative values. The gray bars define the models Siren built in each case. The lines for the individual sites are grouped depending on whether moose are present and on what values are encountered for temperature and precipitation, and are colored accordingly. It doesn't matter where the lines intersect with the left and right edge of the chart.



software establishes correlations between all these aspects. First it selects simple, so-called weak correlations – for example, it classifies people according to whether they are in favor of euthanasia or reject it.

These simple associations are then complemented by more precise associations in the second step – for example, by the question of whether people who reject euthanasia have children. In the next step, the software takes age into account. Step by step, the software adds any number of additional links, and in this way identifies the objects that have the greatest similarity. These results are then used to generate the universal hypothesis or correlation.

SEVERAL EXPLANATIONS FOR ONE DATASET

With redescription mining, the program simultaneously tests how probable or accurate any discovered correlation is likely to be. As a computer scientist would put it: the software maximizes the "Jaccard coefficient" – a value by which the similarity between two so-called support sets can be measured, such as Finnish politicians with certain characteristics.

Gerhard Weikum, Director at the Max Planck Institute for Informatics

Graphics: Pauli Miettinen/MPI for Informatics (2)

Pauli Miettinen, Sanjar Karaev and Saskia Metzler (from left) discuss how they will be able to refine data mining in the future.

and Head of the Databases and Information Systems Department, regards redescription mining as an extremely useful tool when it comes to analyzing large volumes of data. The purpose of data mining is generally to find interesting patterns in large, multidimensional databases. "An analyst wanting to draw conclusions from it often also needs an explanation or compact characterization of a pattern," says Weikum. "Redescription mining is extremely useful in such cases because it supplies not just one explanation for a database but several."

Weikum gives an example: A computer program could recognize a pattern in a database comprising people who work for a high-tech company, have a long commute every day and earn a high annual salary of between 100,000 and 300,000 dollars. Redescription mining would be able to generate an alternative description of this group from the data that might look as follows: IT experts who have a university degree in a technical field, come from Asia and work in a US metropolitan area.

Even if the term redescription mining sounds unfamiliar and abstract to non-computer scientists, Pauli Miettinen encourages researchers from other disciplines to use the software. It's easy to operate, he says, and can be used for very different questions. In addition, it's suitable for both so-called confirmatory and exploratory analyses, he says. These differ in that an analysis starts either with or without a working hypothesis.

An example of a confirmatory analysis was the study of mammal populations where it was expected that climate change will change their distribution. In an exploratory analysis, on the other hand, the software tackles a dataset with no preconceptions. In that regard, an exploratory analysis with redescription mining is essentially a surprise package that can overturn old hypotheses or conjure up new ones.

Users generally work with Siren on their own. In difficult cases, however, Pauli Miettinen adds support – for instance if it is unclear whether the data is fundamentally suitable for reviewing a hypothesis. In this way, Siren can show many scientific questions in a new light – and it's a little reminiscent of the machine from the book *The Hitchhiker's Guide to the Galaxy*, which calculates for several million years only to spit out the number 42 in response to the question of the meaning of life. That is, of course, relatively meaningless. The machine advises the baffled person to embark on a search for the right question for which the answer "42" makes sense. If they had had Siren, they might have found the right question. ◂

TO THE POINT

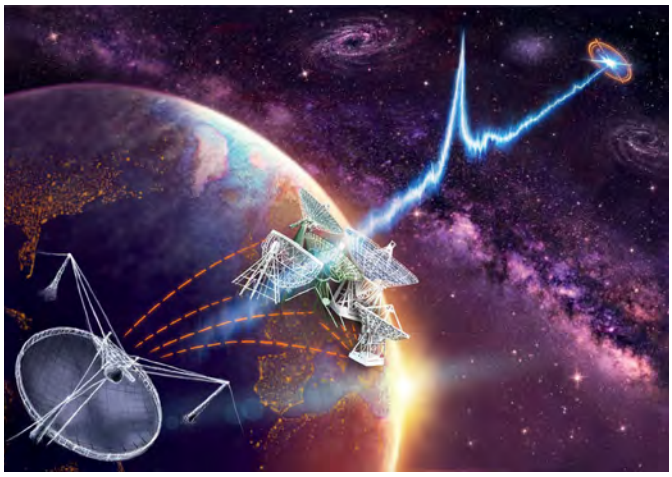
- **Researchers at the Max Planck Institute for Informatics use a software known as Siren to generate new hypotheses from existing data. This method of data analysis is called redescription mining.**
- **Using Siren, the researchers analyzed, among other things, the connections between the sociodemographic background and the political attitudes of candidates in the Finnish parliamentary elections, as well as the climatic conditions prevailing in the habitats of European land mammals, specifically of moose.**
- **The software is available to researchers of all disciplines and can be downloaded free of charge from siren.mpi-inf.mpg.de.**

Photo: Tom Pingel

Radio Burst from a Dwarf Galaxy

Astronomers discover the origin of one of these mysterious radio flashes

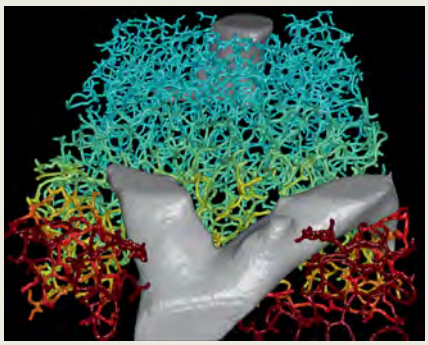
Astronomers successfully pinpointed the exact location of a "fast radio burst" for the first time. These short-duration radio flashes have been observed for several years now, but it wasn't previously known where they come from. An international team working with Laura Spitler from the Max Planck Institute for Radio Astronomy has now solved this mystery. To do so, the researchers used a network of radio telescopes to observe not just one, but multiple bursts from a source called FRB 121102. The high angular resolution made it possible to precisely localize the position to within a fraction of an arc second. Using the 8-meter Gemini North telescope in Hawaii, they were then able to identify the radio bursts' galaxy of origin and, based on its measured spectrum, determine its distance from us – more than three billion light-years. Despite this success, the cause of the radio bursts remains a mystery. However, the fact that FRB 121102 comes from a dwarf galaxy in which much more massive stars are able to form than is the case in our Milky Way may provide a clue. Perhaps this burst originated in the collapsed remnant of such a star. (www.mpg.de/10886843)



Artistic representation of the radio telescopes in the European VLBI network (EVN) used to observe the FRB 121102 radio burst.

Virtual Liver Could Reduce Need for Animal Research

Researchers simulate biliary fluid dynamics in the liver to predict drug-induced liver damage



Three-dimensional model of the bile duct network that transports bile from the liver to the intestine. The colors indicate the bile's flow rate (blue: slow; red: fast).

The liver is the central metabolic organ in the body and plays a crucial role in detoxification, making it particularly prone to drug-induced damage. This is why animal research is a legal requirement for testing the liver toxicity of new drugs. The liver produces bile in order to break down lipids and excrete waste products, and the bile is transported to the intestine through a finely branched network of channels. A research team at the Max Planck Institute for Molecular Cell Biology and Genetics in Dresden used high-resolution microscopes to examine this network in mice and analyze the layout and structure of the channels. Then the researchers developed a 3D model of the bile ducts that can simulate the flow properties of bile. The model enables researchers to investigate liver diseases and the effects of drugs on the liver, such as cholestasis – the impairment of bile flow – which frequently occurs with new active substances. Next, the researchers aim to adapt the model to reflect the conditions in the human liver. Although animal research will continue to be necessary for the foreseeable future, the model could contribute to reducing the number of experiments involving animals. (www.mpg.de/11186866)

Graphics: Danielle Futselaar (www.artsource.nl) (top); MPI f. Molecular Cell Biology and Genetics (bottom)

Speed Dating among Birds

During mating season, male pectoral sandpipers fly across a huge breeding range

Highly elaborate courtship rituals, exhausting fights with rivals, hardly any sleep and also, if they're lucky, a copulation – a visit to their breeding grounds in the Arctic appears to be hardly less strenuous for pectoral sandpipers than the journey there. This is the conclusion scientists from the Max Planck Institute for Ornithology in Seewiesen reached after they equipped 120 male pectoral sandpipers with small mobile satellite transmitters that come off again by themselves after a time. According to the data they obtained in this way, after flying up to 14,000 kilometers from their wintering grounds, these birds often fly thousands of kilometers more through their breeding grounds in the Arctic. Within four weeks, they visit up to 24 potential breeding sites so as not to miss any mating opportunities, and possibly even to mate multiple times. They can do this because they don't defend any territory and don't support the females in caring for the offspring. During mating season, the males hardly sleep at all so that they can court the females and fend off their rivals nearly around the clock during the long summer days in the Arctic. In the end, though, only a few males actually succeed in siring offspring. (www.mpg.de/10888750)

The mating flight of male pectoral sandpipers – which weigh in at about 100 grams – is characterized by throat inflation and deep hooting calls.

Early Forestry in the Amazon

Indigenous inhabitants left their mark on the rainforest by domesticating tree species in the pre-Columbian era

Humans have been shaping the Amazon rainforest much longer than previously assumed. As an international team including Florian Wittmann from the Max Planck Institute for Chemistry in Mainz discovered, the indigenous peoples of Amazonia began growing and propagating such plants as the Brazil nut, the cacao tree and the acai palm as far back as 8,000 years ago. These domesticated trees are therefore still found in the Amazon rainforest more frequently today than would be expected if humans had not intervened. In addition, they exhibit fewer genetic variations than occur when species propagate naturally. The notion that the vast rainforests were untouched by human influence before the Spanish arrived in South America is therefore incorrect. (www.mpg.de/11147178)

Cultivated primeval forest: Humans shaped the flora in the Amazon Basin to a greater extent than was previously thought – for instance with acai palms, as in the Humaitá National Forest in the state of Amazonas, Brazil.

Photos: MPI for Ornithology (top), Carolina Levis (bottom)

A 50,000-Year Connection to Country

DNA analyses show unique attachment of Australian aborigines to their homeland

Aborigines preserve their traditions through such events as the DanceSite Festival in Alice Springs, Australia. Research can help them answer the question of just where they come from.

Australian Aborigines have exceptionally deep roots in their respective regions: the approximately 400 linguistic and regional groups have continuously inhabited the same territory for as many as 50,000 years. A team of researchers, including Wolfgang Haak from the Max Planck Institute for the Science of Human History, used 111 historical hair samples to analyze mitochondrial DNA, which allows tracing of maternal ancestry. The results show that modern Aborigines are the descendants of a single founding population that settled in Australia 50,000 years ago. At that time, the land was still part of the ancient continent of Sahul, which was connected to New Guinea by a land bridge. The rise in sea level later separated Australia and New Guinea, after which the populations spread along the continent's east and west coasts within 1,500 to 2,000 years. Thereafter, the settlers remained loyal to their regions – even when there were no natural barriers to further migration. The study was conducted as part of the Aboriginal Heritage Project, which is aimed at helping people with Aboriginal heritage to trace their regional ancestry. (www.mpg.de/11153645 – available only in German)

Green Chemistry from the Mussel Foot

The byssal threads are produced by a combination of self-organized and biologically regulated processes

The chemical industry can learn a lot from the common mussel. Not only is the mollusk's mother of pearl remarkably tough, but the byssal threads with which it clings to the seafloor are also particularly tear-resistant, and their ends adhere under water better than any other material. Furthermore, the way in which the mussel spins the complex threads in its foot could serve as a blueprint for an environmentally friendly production process for synthetic composite materials. Scientists working with Matt Harrington at the Max Planck Institute of Colloids and Interfaces in Potsdam discovered that key bioproduction steps proceed autonomously, that is, without any active intervention by the mussel. The only reason the core, the cuticle and the adhesive plaque at the end of a byssal thread are produced at the correct sites is because the mussels secrete the respective starting substances in a precisely coordinated fashion into the right locations in a fine groove in their foot. This finding could point to a way to use simple technologies to get polymers to arrange themselves into larger structures, largely without using heavy-metal catalysts. (www.mpg.de/11091566)

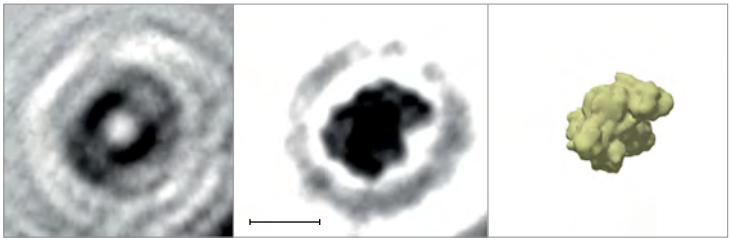
The byssal threads of mussels adhere under water better than any glue from a tube. They are strong, elastic, hard and self-healing.

Photos: Rusty Stewart/Flickr (CC BY-NC-ND 2.0) (top); Science Photo Library/King-Holmes, James (bottom)

Holograms for Biomedicine

Low-energy electron beams can be used to study the three-dimensional structure of individual proteins

Biologists will soon have a brand new instrument for surveying the toolbox of life: electron holography. Scientists at the University of Zurich and the Max Planck Institute for Solid State Research in Stuttgart used very low-energy electrons to record holograms of single proteins for the first time, making their three-dimensional structure visible. This particularly gentle method enables – unlike standard structural biology methods – these biomolecules to be studied in the form in which they perform their various tasks in living organisms. Electron holograms of proteins could thus not only improve our understanding of biochemical processes, but also facilitate the search for new active substances. (www.mpg.de/10996153)



The image of the protein albumin (center) is calculated (the bar corresponds to 5 nanometers) from the hologram (left). The holographic image corresponds very well with a simulation (right).

New Biomarkers for Bowel Cancer Treatment

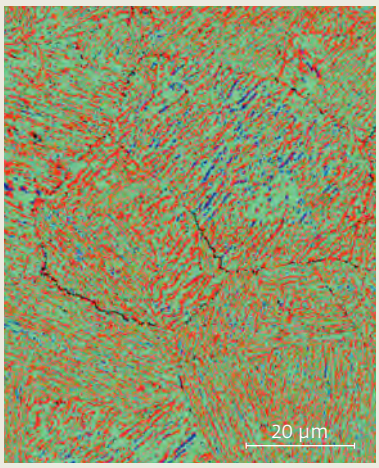
Scientists can predict in the lab how an anti-tumor drug will affect cancer cells

Bowel cancer is the third most common form of cancer in the world, with most cases affecting the colon and rectum. There are many different subgroups of these so-called colorectal carcinomas, and the effectiveness of the available drugs varies – there is no one drug that works for every patient. A public-private consortium that also includes researchers from the Max Planck Institute for Molecular Genetics in Berlin identified biomarkers that may soon make it possible to treat colorectal cancer patients individually based on tumor type. First, the researchers essentially compiled a molecular fingerprint of all the tumor groups. Then they tested how the tumors respond to various treatments, and in this way, linked a tumor's fingerprint to its response to various active substances. Among other things, the research team discovered molecules that can predict the effectiveness of the chemotherapy drug 5FU and Cetuximab – two drugs commonly used to treat this disease. (www.mpg.de/11044397)

Steel with a Bone Structure

Microlamellae prevent rapid material fatigue

Material fatigue can have similarly fatal consequences in traffic as when a driver becomes tired. In 1998, for instance, more than 100 people died when an ICE train derailed in Eschede, Germany, because the steel in one of the wheel tires had worn out and cracked. A type of steel that Dirk Ponge and Dierk Raabe developed at the Max-Planck-Institut für Eisenforschung in Düsseldorf could help prevent accidents like this. As the researchers have now discovered through an international cooperation, this material, like bones, is made up of microlamellae, so tiny cracks that occur when this steel is exposed to stress don't propagate very rapidly. As a result, the material doesn't fail as quickly.



Tiny lamellae reduce the rate at which a new type of steel fails. Red and green indicate different crystal structures.

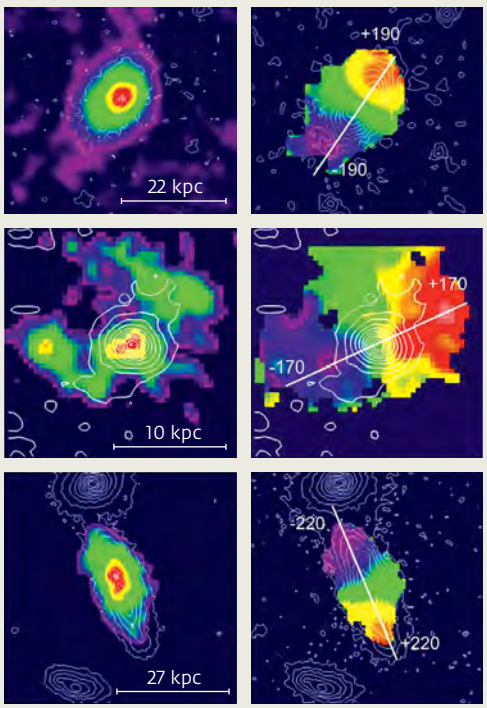
Photos: Jean-Nicolas Longchamp/University of Zurich (top), M. Wang, Max-Planck-Institut für Eisenforschung GmbH (bottom)

Most People Don't Want to Know Their Future

Learning what the future holds, good or bad, is not appealing to most

Want to know what the future holds? Most people would rather not. They prefer to remain uncertain about what life has in store for them, even if the news is positive. That's what scientists at the Max Planck Institute for Human Development and the University of Granada determined after surveying more than 2,000 adults in Germany and Spain. Only 1 percent of participants consistently wanted to know what the future held. In contrast, 86 to 90 percent would not want to be informed about upcoming negative events, such as the failure of their marriage or the death of their partner. In addition, 40 to 77 percent preferred to remain ignorant of upcoming positive events, such as their soccer team's victory or Christmas presents. Researchers call this phenomenon deliberate ignorance. It stands in contradiction to the established knowledge that humans basically strive for certainty and accrual of information. Gerd Gigerenzer, the study's lead author, explains deliberate ignorance with the widespread fear of bad news and with the desire to maintain the enjoyment of suspense that pleasurable events provide. (www.mpg.de/11070648)

In Greek mythology, seeress Cassandra's knowledge of the future becomes a curse. Today, that is precisely why most people prefer not to know what the future holds in store for them.



Dark Matter Not Found

Milky Way systems in the early universe consist mainly of gas and stars

A new set of observations of galaxies in the early universe shows that these galaxies are completely dominated by "normal" matter. A team of researchers working with Reinhard Genzel from the Max Planck Institute for Extraterrestrial Physics found that dark matter evidently plays a much smaller role there than in star systems in today's galaxies. The astronomers used spectral imaging to observe several hundred massive, star-forming galaxies in the early universe. This technique enabled the researchers to determine the rotation curves of the galaxies, which in turn provide valuable information about the distribution of both baryonic (normal) and dark mass at the peak of cosmic galaxy formation, 10 billion years ago. They found that the rotation velocities of the stars in the outer regions of the galaxies decrease, which speaks against the existence of an invisible mass. Furthermore, the star disks appear to be thicker and more turbulent than those in today's galaxies. (www.mpg.de/11170451)

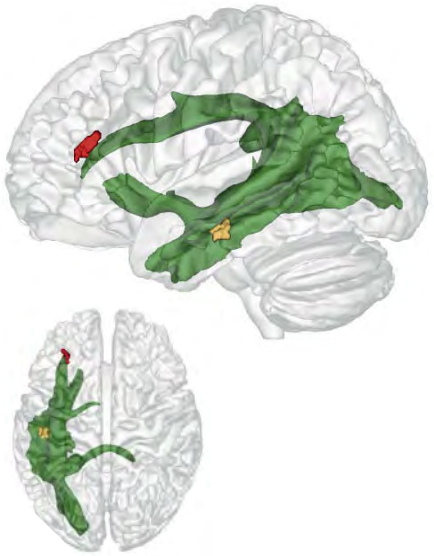
Galaxies in focus: For each of the three galaxies, the right column shows a velocity map. All galaxies show a clear rotation pattern, with blue areas moving toward the observer and red areas moving away from the observer.

Photos: Flickr/Internet Archive Book Images/public domain (top), MPI for Extraterrestrial Physics (bottom)

A Connection to Others' Thoughts

Researchers discover brain structure that helps us understand others

At about the age of four, a child's brain undergoes an important change: it begins to understand that others have different thoughts than its own. It can now do what a three-year-old can't: put itself in someone else's shoes. According to scientists at the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig, this milestone in brain development is tied to the formation of a neural connection, the arcuate fasciculus. This bundle of nerve cell processes forms a link between two brain regions: one is located at the back of the temporal lobe of the cerebrum and helps the adult brain think about other people and their thoughts. The second region is an area in the frontal lobe of the cerebrum that is involved in keeping things at different levels of abstraction, thus helping us distinguish between reality and someone else's thoughts. Only when these two brain regions are connected by the arcuate fasciculus can children start to understand what others think. (www.mpg.de/11182982)



Beginning at age four, the arcuate fasciculus (green) forms a link between a region at the back of the temporal lobe (yellow) and a region in the frontal lobe of the cerebrum (red).

Growth despite Fasting

A new diet developed for fruit flies improves development and fecundity without decreasing lifespan

There are many recommendations for living a long and healthy life, one of which is to eat less. But that can have unpleasant consequences: flies and mice that were put on a diet, for example, displayed slower development and lower fecundity. So a nutrition plan was sought that would provide the positive effects of a diet but without its negative side effects. A research group at the Max Planck Institute for Biology of Ageing has now developed a diet for fruit flies and mice based on the organisms' own amino acid profiles. Flies fed this diet had a lower calorie intake than flies fed a standard diet, and they lived just as long. Despite being on a diet, they develop faster, grow bigger in size and lay more eggs. The researchers therefore suspect that a diet precisely tailored to our amino acid profile would have a positive effect on human health. (www.mpg.de/11160115)

In nature, the fruit fly *Drosophila melanogaster* feeds on ripe fruit. When fed a diet that precisely reflects the composition of amino acids in their bodies, the flies became sated more quickly, but still grew faster.

Older but Bolder

A study conducted at the Max Planck Institute for Human Development has shown that, contrary to popular belief, older people take greater risks in certain situations than younger people. In the study, participants had to choose between two options, each of which offered a different probability of winning or losing a larger or smaller sum of money. In each case, they knew their chances of success. Ultimately, the older participants were more likely than the younger ones to choose the riskier option – because they were more optimistic in their assessments of the possibility of winning and were thus more daring in their choices. The findings suggest that age differences in risk-taking behavior are strongly influenced by situation. Previous studies generally investigated the choice between a safe and a risky option and thus reached a different conclusion. The current study also showed that older participants made worse decisions than younger ones: they were less likely to choose the option with the higher expected monetary return, presumably because of their decreasing ability to process information and solve problems as quickly as younger people. (www.mpg.de/11155381)

Photos: MPI for Human Cognitive and Brain Sciences (top), MPI for Biology of Ageing/Grönke (bottom)

From England to Germany via France and the US: Microbiologist Ruth Ley has not only worked on a diverse array of bacteria over the course of her career, she has also encountered a cultural difference or two between various countries.

Exploring the **Microbial Cosmos**

The human body is home to countless microbes. The intestinal tract, in particular, is colonized by innumerable bacteria. As a young environmental microbiologist, **Ruth Ley** never imagined that she would one day find herself interested in the human gut and the microbiota that reside in it. Today she conducts research at the **Max Planck Institute for Developmental Biology** in Tübingen, investigating the role the countless intestinal bacteria play in our health.

TEXT **CORNELIA STOLZE**

The different stages of her career read like a travel agency's top exclusive nature and adventure destinations: A semester on Mo'orea, a small tropical island in the South Pacific near Tahiti; several weeks on Guadeloupe in the Caribbean; three years out and about in Hawaii's national parks. Next, a longer stay in Boulder, Colorado with regular high-alpine skiing and trekking in the Rocky Mountains. Then on to an excursion to Mexico's salt flats thanks to a NASA Fellowship and – as the icing on the cake – a several-week Antarctic expedition.

Ruth Ley, who has been a Director at the Max Planck Institute for Developmental Biology since mid-2016, has seen a good bit of the world. Her passion for travel, however, has nothing to do with a jet-set lifestyle or a fondness for extreme sports. "To be honest, I should have been the last person to go, for instance, on these tours of the Rocky Mountains. I'm an awful skier," says Ley, and laughs. It was her scientific interest in ecology that led her to remote corners of the globe.

She has studied the biology of the reef at Mo'orea, where the University of California, Berkeley maintains a research station, caught lizards for a project on Guadeloupe, investigated Hawaii's ecosystem ecology and analyzed the microbial diversity of Mexico's salt flats. "At that time I would have gone anywhere for an interesting project – what I cared about most was working with people I could learn from," says Ley. Little things like heat or cold have never put her off doing her research. English by birth, she learned to adapt to new challenges at an early age and not to be easily deterred by obstacles.

She became a backcountry skier, for instance, when her job as a biologist required such skills. While working on her PhD at the University of Colorado, she often had to don leather mountain boots and Telemark skis and trudge across snowy, windswept slopes at subzero temperatures to reach altitudes of up to 3,700 meters before heading off back home across country. "And all that effort just to collect samples of sand and gravel up there for our research," adds Ley with a grin.

An unusual project indeed. Especially for a biologist whose focus, after studying at the University of California, Berkeley, had turned to the interactions of living organisms with their environment and to the investigation of microbes and their complex communities. According to many scientists at the time, the ground in which Ley took measurements and samples in summer and winter alike was lifeless at extreme altitudes like those above the tree line in the Rocky Mountains. It was widely believed that neither bacteria nor oth-

Photo: Jörg Abendroth/derphotograph.de

Bacteria have colonized nearly every habitat on Earth. Ruth Ley visited some of them on her research expeditions.

Above The scientist in one of Antarctica's Dry Valleys.

Right A piece of a bacterial mat from Mexico.

er microbes could survive the inhospitable conditions of frosty winters in sand or gravel under as much as 10 meters of snow.

Ley's research soon showed that this was incorrect. She discovered that such regions did indeed present signs of life. Measurements showed that, somewhere between the ground and the snow, ammonia was being oxidized to form nitrate. Her previous scientific investigations of Hawaiian soils had taught her that such a thing was possible only if certain microbes were present. That's why Ley went to the trouble of setting up her measuring equipment between the sand and snow high up in the mountains. Back in the laboratory, she searched her soil samples for traces of bacteria and other kinds of life.

Success wasn't long in coming. Thanks to her treks through snow and ice, Ley was able to prove that high-alpine soils aren't lifeless at all; rather, they are the permanent habitat of numerous species of bacteria. For her doctoral thesis, she identified microbes

Photos: Private collection (2)

» The decision to conduct research at a medical faculty was one of the best I ever made in my career.

that, protected from cold by the thick snow cover, are also active in winter – thus contradicting some of the theories held by geologists.

RAISED WITH CULTURAL DIFFERENCES

Ley's courage in challenging old certainties and exploring new territory isn't surprising. At the age of six. she moved with her parents and two sisters from Surrey in the UK to Paris. Her father was an engineer and had been offered an attractive post there. That left the daughters little choice but to rapidly adapt to the new environment and learn the unfamiliar language as quickly as possible.

Seven years later came the next change. Ley, now 13 years old, had grown to feel very much at home in her new country, and spoke only French with her friends and sisters. Once again, the move was due to her father's job. This time it was to another continent – from Europe to Palo Alto in California's Silicon Valley. Again she discovered that both school and everyday life followed completely different rules than before.

"It was difficult adjusting," Ley recalls. "France and the US are culturally very different." Once more, she and her sisters had to learn new daily "codes" of behavior. Things that were normal and common in one country, Ley discovered, were considered snobby and elitist in another – and vice versa. Ley's British accent, which to the ears of her American schoolmates initially made her sound pretentious, was the first thing that made her stand out (she had continued to speak English with her parents through the years). She was also confronted with differing status symbols and eating habits. A small example? Ruth Ley thinks for a moment. "Baguette and Camembert would be one. In Paris that's a simple lunch for normal working people. In California it has the aura – who knows why – of a high-society lunch."

She made similar observations at school. In France you addressed your teachers quite naturally using the polite *vous* form, or as *monsieur* or *madame*. In the US, students and teachers, so it appeared at first glance, were suddenly on the same level. Everyone used the egalitarian English "you," and teachers were simply "Bob" or "Jane." But Ley quickly realized that appearances could be deceptive. Despite the seemingly more relaxed rules, American kids had, to her amazement, much more respect for authority in school. "In Paris, kids made off with anything that wasn't nailed down. I never experienced that in California."

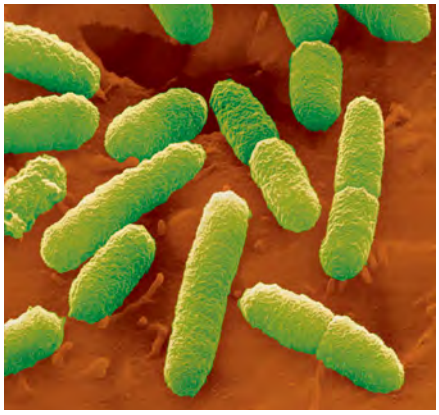
Without doubt, such radical and opposing cultural habits take some getting used to. But experiencing early on in life that it's worth being open to new ideas and examining things carefully stands you in good stead for a life pioneering a completely new scientific discipline. Ruth Ley is now in the vanguard of a field of research that has been expanding at a breathtaking pace over the last few years. Her aim is to decode the microbiome: the collection of microbes that, numbering in the millions, colonize the human body as permanent inhabitants of the skin and digestive tract. One thing we can already say for sure is that microbiome research is shedding new light on unexpected relationships that control our bodies.

UNKNOWN LODGERS

Together with other researchers, Ley was able to show for the first time that the human microbiome is much more than just a collection of stowaways that help break down food into usable components. In fact, the myriad microorganisms in the intestines play a crucial role in our health and contribute, for instance, to obesity, diabetes and chronic autoimmune disorders. Medications, in turn, can have deleterious effects on the microbiome.

The individual intestinal microbiota each of us possesses depends on where we have been in life, as we don't pick up microbes until we are born. Before then, our intestines are thought to be sterile. The first bacterial species to populate the intestines come from a newborn's immediate environment and are composed of maternal vaginal, gut and skin bacteria. Little by little, other species of bacteria from the environment are added. The microbiome's community composition at any given time depends primarily on our diet, but also on many other factors. This means the microbiome of each individual, each family and each human population can have a distinct composition.

In Tübingen, Ruth Ley aims to investigate how genes, the immune system and environmental factors affect the human microbiome. The intestinal bacterium *Escherichia coli* (right) is an infrequent member of this bacterial community. Most strains are harmless, but some can also trigger infectious diseases.



Medical care also plays an important role in our intestinal microbiota. After only one week of antibiotics, for example, the composition and activity of the microorganisms alters dramatically. Dozens of species may disappear and others take their place. Measurements show that many of the approximately 2,000 chemical metabolic products commonly found in feces – a sort of fingerprint for bacterial activity – change temporarily in concentration following antibiotic ingestion.

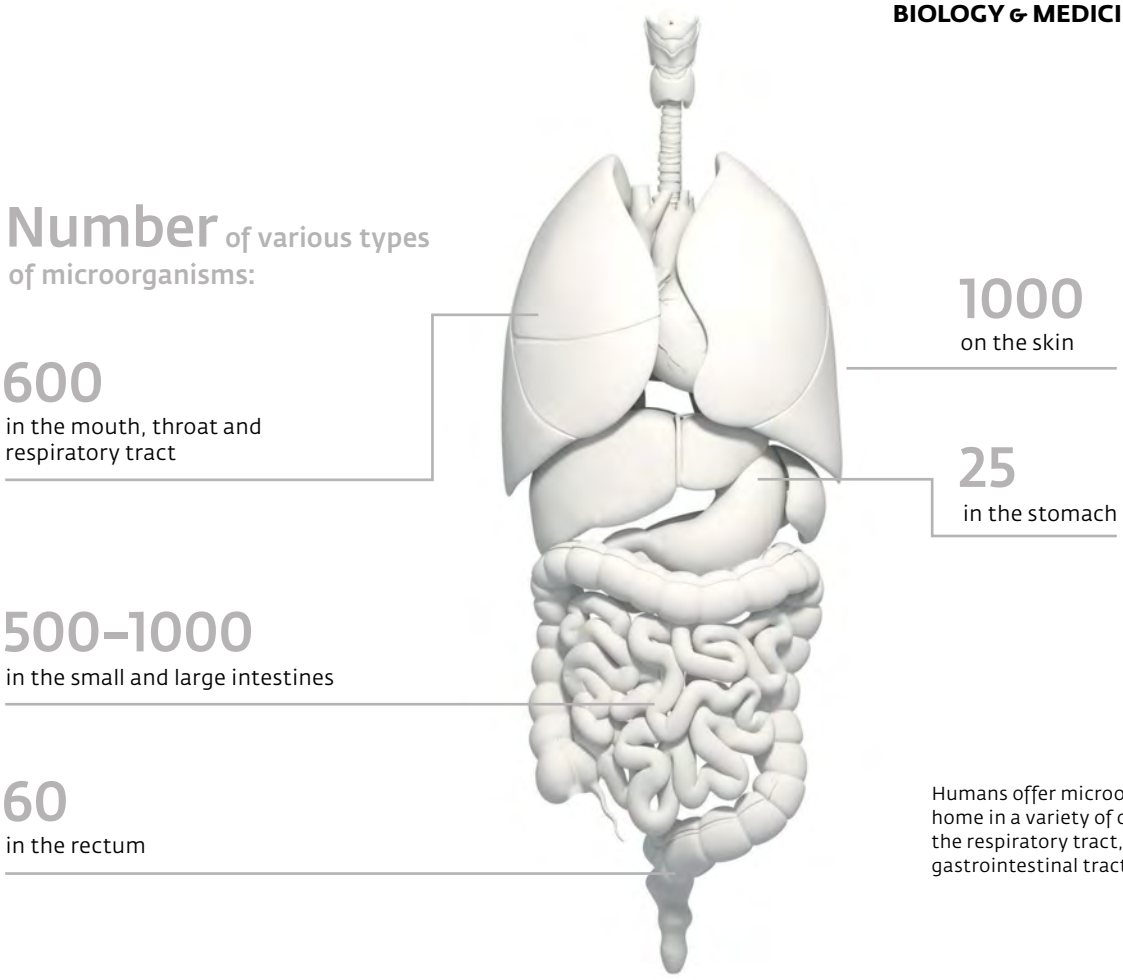
"Essentially, we've known for a long time that certain bacteria in the human intestinal tract are very important for the body," explains Ley. "Despite this, we knew very little about most of them until the early 2000s." The reason was that most of these microscopically small organisms couldn't be investigated in the lab, as we weren't yet able to grow them in culture dishes using artificial nutrient media.

"But microbiome research has exploded since 2004," says Ley. Several advances have been critical. First, the composition of the intestinal microbiome can now be determined using molecular biology methods, eliminating the need to culture the bacteria in the laboratory. In addition, modern sequencing techniques now enable us to rapidly decode the genetic composition of microbes, and computer analysis of data has accelerated tremendously.

USING MICE WITH NO INTESTINAL FLORA AS A MODEL

In the early 2000s, researchers from Washington University in St. Louis (USA) working with clinician Jeffrey Gordon investigated the link between obesity and gut bacteria using germ-free mice. Raised from birth in a bacteria-free environment, these animals have no intestinal microbiota of their own. This makes them an ideal model for elucidating the influence of specific members of the microbiome on health. With microbiota-free mice, scientists are able not only to precisely control the type of food they are given, but also to administer selected intesti-

Photo: Jörg Abendroth/derphotograph.de (top), Jürgen Berger/MPI for Developmental Biology



Humans offer microorganisms a home in a variety of organs, including the respiratory tract, the skin and the gastrointestinal tract.

nal bacteria to test the effects of the microbes and of differing diets on individual functions of the body.

Just when Gordon's team started to sequence the genome of gut bacteria, Ley joined the team. It was a decision that proved fortuitous for a number of people. Ley had already met a research colleague who would go on to become her life partner. Lars Angenent, a successful Dutch bioprocess engineer, had been working at the same university as Ley in Boulder. Soon afterwards, however, he was offered a position as an assistant professor at Washington University in St. Louis, while Ley stayed on at the University of Colorado. The couple traveled back and forth between the two cities for several years – and for much of that time with no prospects of ever being able to live in the same place.

Then they had a sudden stroke of fortune. Ley discovered that Gordon's team in the medical faculty of Washington University offered the perfect working environment for somebody with precisely her expertise. Not only was Gordon's laboratory large and successful; he and his colleagues were in the process of applying techniques from Ley's specialty field – environmental microbiology – to research into the microbes of the human digestive tract. Ley therefore left him a message one day asking if he needed a microbial ecologist. After visiting and interviewing with Gordon and his group, she joined as a postdoc in fall 2004.

MICROBIOME MIXTURE AFFECTS BODY WEIGHT

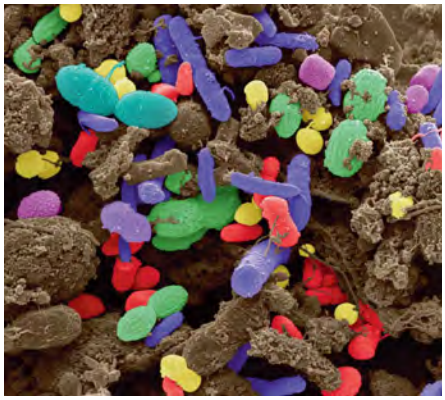
A short time later, Gordon's team published a groundbreaking paper. For the first time in medical history, the scientists were able to show that – contrary to long-held belief – our body weight is by no means solely dependent on how much we eat and how much energy we expend through exercise. A third factor, the microbial composition of our intestines, is involved.

The researchers employed an elegant trick to prove this. They transferred the intestinal microbiome of conventionally raised laboratory mice to germ-free mice. Despite having unlimited access to food, the animals that are kept in sterile conditions and that possess no intestinal bacteria of their own normally have extremely little body fat. That changed abruptly when they were colonized by gut microbiota. Even though the mice ate no more food than before, their fat stores grew.

Shortly afterwards, Ley was able to demonstrate another connection between microbes and body weight in a clinical weight-loss study involving 12 obese individuals. The results showed that, similar to mice, obese and normal-weight people can have different mixtures of bacteria in their intestinal tract. The most marked difference was in the proportion of the two most common representatives of intestinal bacteria, the *Firmicutes* and *Bacteroidetes* phyla. Obese individuals enrolled in this study, Ley found, had significantly more *Firmicutes* and fewer *Bacteroidetes* than normal-weight people, and their microbiomes came to resemble those of the lean controls more as they lost weight.

Gordon's team then went one step further. This time they transferred intestinal microbiomes from normal-weight and from genetically obese laboratory mice into germ-free mice. The

Graphic: Science Photo Library



Left Bacteria are essential for effective digestion: More than half of human feces consists of excreted intestinal bacteria.

Above The composition of the bacterial community also affects body weight: Obese mice have more *Firmicutes* bacteria than *Bacteroidetes*; this relationship is reversed in animals with a normal body weight.

results were clear: mice that had been germ-free and had been given a microbiome from obese rodents became fatter than those that received microbiomes from lean donors.

The result electrified the whole team. For the first time, researchers had been able to demonstrate that a propensity for obesity could be transferred from one animal to another – simply by manipulating the mixture of the microbiome in their gut. "It was one of those 'Oh my God!' moments. We were absolutely elated," Gordon told a reporter. Ley, too, found her time in Gordon's team to be a particularly inspiring experience: "I never thought I would be applying for a job at a medical faculty, but that decision was one of the best I ever made in my career."

FAMILY AND CAREER

Among other things, the large number of groundbreaking papers she has published in the last few years testifies to this. She discovered, for instance, that the intestinal microbiota changes drastically during pregnancy, which impacts the mother's metabolism and thus ensures the optimal provision of nutrients to the fetus. Just as significantly, Ley worked on identifying human genetic determinants of the microbiome – in other words, how much of the variation in the microbiome is due to our genes.

Last but not least, Ley's crossover to biomedical research had another fruitful outcome for her and Angenent, who is now her husband. Since their time in St. Louis, the two researchers have not only started a family – their son is now 10 years old – Ley and Angenent have since also succeeded in planning their career moves from post to post together. In 2008, Ley moved with her husband and son to Ithaca, New York, where they continued their work at Cornell University. In 2013 she became an associate professor in the Department of Molecular Biology and Genetics.

At the Max Planck Institute in Tübingen, Ley plans to establish a new microbiome research program over the next few years. She is currently also expanding her laboratories as well as forming new joint research teams involving the Institute and the Faculty of Medicine at the University of Tübingen.

One special focus of her future research will be performing large-scale studies to sample microbes from the intestines of individuals from different backgrounds. Using these samples, she aims to investigate what effects genes, the immune system and environmental factors have on human intestinal microbiota. As Angenent has taken up a position as a Humboldt Professor in the Department of Geoscience at the University of Tübingen, their shared life as researchers can now continue. ◀

GLOSSARY

Microbiome: The totality of all microorganisms that inhabit a living organism. Humans, for instance, are home to 10 times more microbes than their bodies possess cells. It is estimated that each of us is inhabited by approximately 100 trillion bacteria. Most of these live in the intestines, but we also have lodgers on our skin, in the oral and nasal cavities, and on our sex organs. There is frequently a symbiosis between humans and microbes, benefiting both. Some bacteria, however, are only "table companions", neither harming nor helping.

Firmicutes/Bacteroidetes: Two phyla of bacteria, usually with differing cell wall structures. Firmicute bacteria convert fiber into short-chain fatty acids that the body can absorb. The *Bacteroidetes* phylum, in contrast, breaks down complex polysaccharides. Together they account for the majority of the intestinal microbiota.

THE BEST BACKDROP

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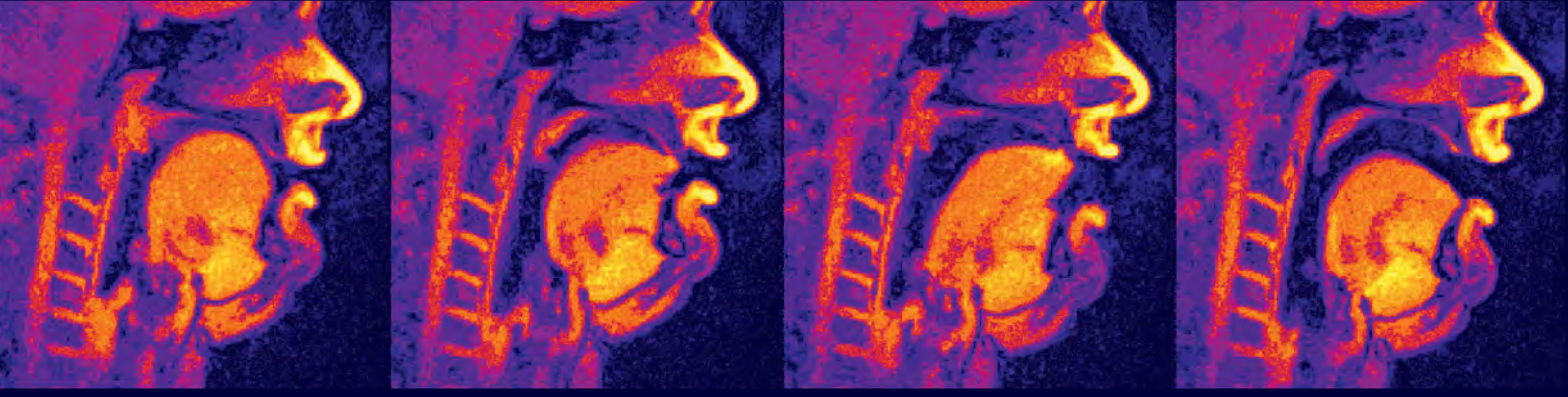
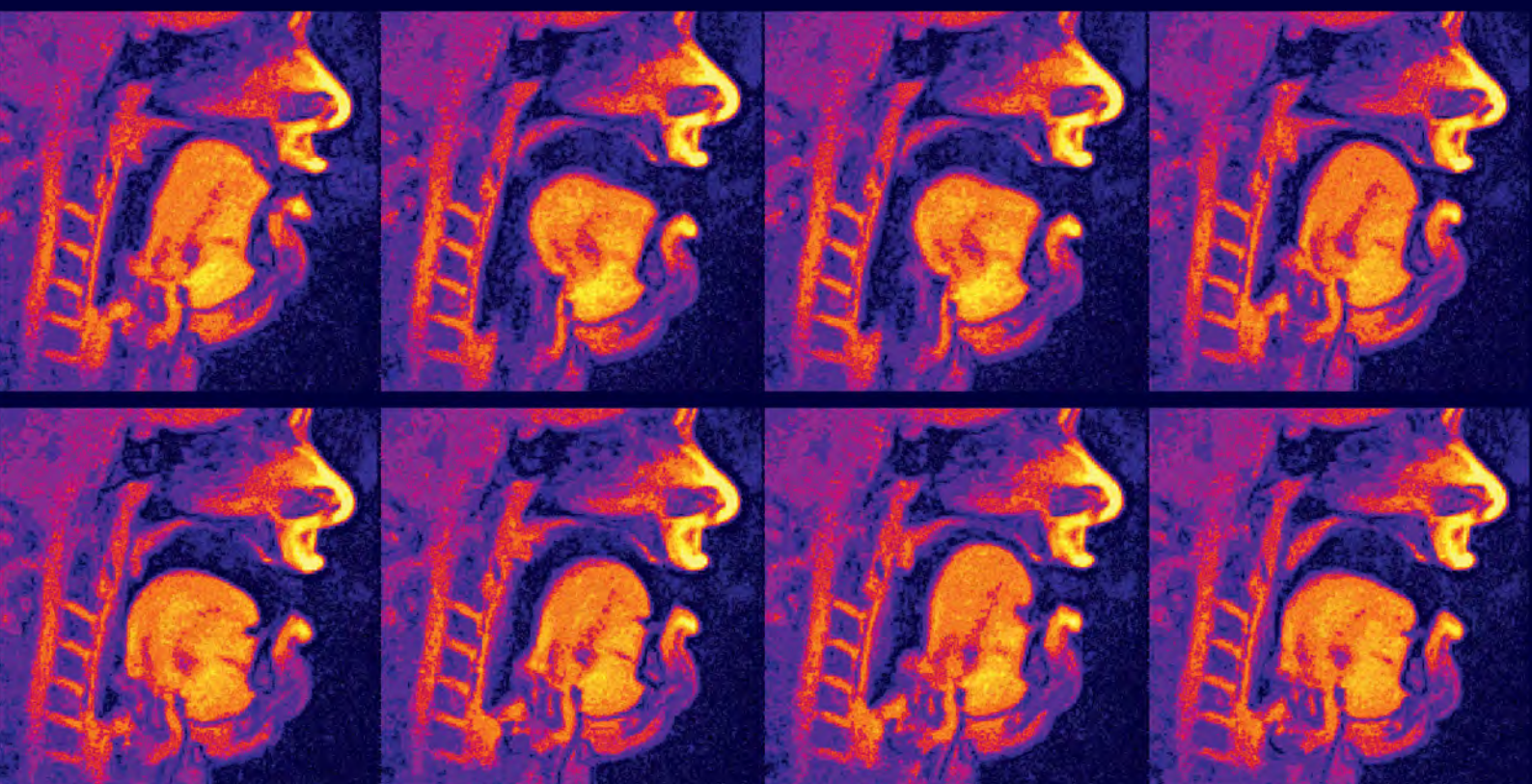


Live View
of the Focus of Disease

Doctors and patients can thank magnetic resonance imaging – and not least **Jens Frahm** – for the fact that many diseases can now be diagnosed far more effectively than they could 30 years ago. The research carried out by the director of the Biomedizinische NMR Forschungs GmbH (non-profit) at the **Max Planck Institute for Biophysical Chemistry** in Göttingen has greatly simplified the process of capturing images of the body's interior. Now the team from Göttingen wants to bring those images to life.



Singing lessons: The FLASH II technique can follow the tongue movements of a singer. It also facilitates the diagnosis of speech disorders.

TEXT **ROLAND WENGENMAYR**

When you're lying in the tunnel of a magnetic resonance imaging (MRI) scanner, you can be thankful that the examination will take only a few minutes rather than hours (despite the images being taken from a multitude of angles and with different contrasts). This improvement was achieved in the 1980s by scientists at the Max Planck Institute for Biophysical Chemistry. The first generation of these devices, which peered inside the human body without the use of harmful radiation, took several minutes to produce a single image. Worse still, to get sharp images, the patient had to lie motionless throughout the procedure.

This period generally calls to mind the early years of photography, when people had to hold very still for a long time to get a sharp image. However, photographic technology advanced rapidly, and eventually gave birth to motion picture films. Today, MRI is following a similar path toward moving images. And Jens Frahm, along with his staff, have been vigorously advancing that development for more than three decades now.

A key discovery by the Göttingen-based researchers was the FLASH technique in 1985, which drastically shortened the time needed to acquire a single image. Only then did MRI really take off, and today there are more than 30,000 scanners in the world that perform 100 million examinations a year. This breakthrough allows today's clinicians to study all body organs within a relatively short time and in three dimensions. Technical variants even use chemical information from the MRI signal to gain insights into metabolic processes in tissues and thus further improve our understanding of brain diseases and other disorders.

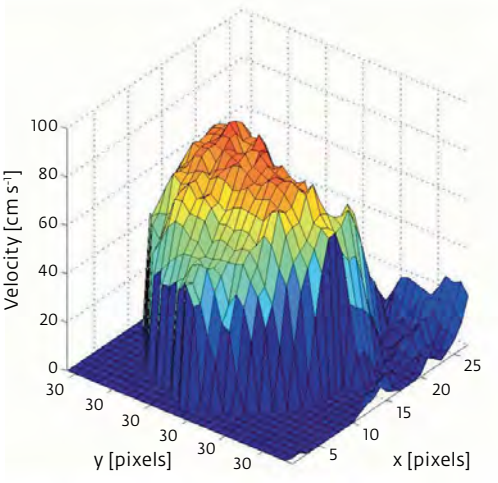
KEEN INTEREST IN THE FATES OF FELLOW HUMANS

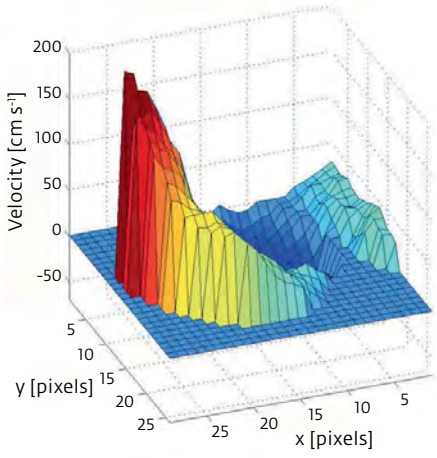
For some years now, the team has been teaching MRI how to move: their real-time image series deliver live videos of the body and its organs as they move. These series can follow the beating heart and swallowing and speaking processes, and even tongue movements while a subject is playing a brass instrument. These are just some aspects of Frahm's research. The physicist combines a warm-hearted interest in the fates of fellow humans with a fascination for medical technology, and he has devoted his entire scientific career to its advancement.

Magnetic resonance imaging in its present clinical form still isn't a really fast imaging method. However, it has the key advantage that it doesn't expose the body to harmful radiation. Because tissues have a high water content, the MRI method works with signals from water, or more precisely, from the nuclei of hydrogen atoms – the protons. This makes it possible to distinguish between various tissues, such as bones, muscles and organs, based on differences in their water content and internal structure. By contrast, it took a protracted period of development before X-rays, the first imaging process in the history of medicine, could show not only bones but also soft tissues – albeit often only with the help of contrast agents. Nevertheless, the first imaging technique was such a major advance that Wilhelm Conrad Röntgen was awarded the Nobel Prize for Physics for his discovery of X-radiation in 1901. Even back then it opened up new avenues of research, and that is precisely what Jens Frahm also hopes to achieve today through his research into magnetic resonance imaging.

Actually, the director of Biomedizinische NMR Forschungs GmbH at the Max Planck Institute for Biophysical Chemistry has already reached the retirement age for professors. "I'm now in the extension phase," he jokes, referring to the fact that the Max Planck Society has enabled him to continue his work for the next three years. >

Photo: Jens Frahm/MPI for Biophysical Chemistry





Above We have Jens Frahm and his colleagues to thank for the fact that MRI scans can now be performed relatively quickly.

Left Real-time MRI can be used to measure how fast blood is flowing through the aorta. The velocity profile for a cross-section of the aorta (x and y axes) just above the heart shows how well the aortic valve is functioning. With a healthy valve (left), blood flows fastest in the center of the vessel (red). If the valve doesn't open correctly (right), blood flows more slowly or even backwards in the center of the vessel (blue), but at higher speeds along the vessel wall, putting great strain on it.

In doing so, they are lending support to a scientist who was admitted to the "Hall of Fame of German Research" in 2016 and who has garnered numerous awards. Frahm was also instrumental in giving the Max Planck Society the most lucrative patent in its history. But before the licensing fees for the patent began to flow in, there was a bitter patent battle surrounding the FLASH technique, which Frahm fought with steely resolve – something you wouldn't immediately attribute to him from his pleasant and friendly manner.

The discovery of the FLASH technique in the mid-1980s by Jens Frahm's team in Göttingen accelerated examinations with MRI scanners by a factor of one hundred. It was only to be expected that every medical manufacturer wanted to use the method: General Electric, Philips, Siemens and others immediately jumped on the bandwagon. Then the plot thickened: some companies used the technology developed by Frahm's team happily enough, but then refused to recognize the team's patent and pay licensing fees to the Max Planck Society.

Fortunately, Frahm had the support of the patent experts at today's Max Planck Innovation GmbH. The man responsible for the case, Bernhard Hertel, waged a seven-year suit against pirate equipment manufacturers. Frahm had to explain the technical details of the FLASH technique to his own lawyers. "For me as a scientist it was fascinating to watch the whole spectacle," Frahm says with a grin. The opposing parties marshalled dozens of lawyers. "They even worked with forged documents," the physicist says, "and retained a Nobel laureate in chemistry as a scientific expert." But he wasn't familiar with the various types of magnetic resonance technology, and that was central to the matter. In the end,

Photo: Frank Vinken; graphic: Jens Frahm/MPI for Biophysical Chemistry

the Max Planck Society was victorious. By the time the final verdict was issued in 1993, the process had cost three million deutschmarks – but licensing fees from the FLASH patent, on the other hand, have brought the Max Planck Society a total of 155 million euros. To top things off, Frahm's research has produced other patents that have also generated millions of euros.

To understand why FLASH was such a breakthrough, it's important to understand the basic principle of magnetic resonance imaging. The signals are emitted directly from water protons, which are present in tissues in various concentrations. When exposed to a strong magnetic field, protons behave like tiny magnets that are aligned like compass needles. An MRI scanner produces such a field with the help of a wide-bore magnet, which is the tunnel in which the patient is examined. The aligned protons may be excited by a short radiofrequency pulse that causes them to send a radiofrequency signal themselves when gradually returning to their original state of equilibrium. A radiofrequency antenna, which can be placed, for instance, on the upper body to examine the chest, is then responsible for detecting the signals. To put it simply, the key information lies in the signal frequency and the signal duration, known as the relaxation time. Both are influenced by the protons' immediate environment, namely the local properties of the tissue. An MRI scanner uses the frequency to compute an image, and the relaxation time to differentiate tissues of various kinds.

ONE IMAGE FROM MANY INDIVIDUAL MEASUREMENTS

The MRI signal gets strongest when all protons are excited at once – at least that was the credo in the early years of MRI. It is also necessary to build up a single image by taking a large number of measurements. The problem is that protons that are used during a measurement take a relatively long time to return to their home position. This means long waiting periods between the many measurements.

The scientists in Göttingen bypassed this problem with the help of two tricks. The generally established method at the time used two radiofrequency pulses followed by an echo signal. In a first step, FLASH reduced the measurement to just one pulse and thus allowed for a second trick that really speeded things up. The new technique excites only a small portion of the protons and leaves most of them untouched, so that the next measurement can be taken immediately. "According to the state of the art in 1985, we were doing two things wrong," Frahm says wryly. But it is for precisely that reason that FLASH produced images in just a hundredth of the time originally needed.

Since then, the team in Göttingen has even refined its technique to the point that MRI is now on the threshold of being able to make the leap from stills to motion pictures. Although dynamic MRI sequences have been used in clinical practice for some time, they can capture only periodic processes, such as the beating heart. Currently, such films have to be assembled from measurements that can take several minutes to produce. For examinations of the heart, the MRI data is synchronized with a simultaneously recorded electrocardiogram (EKG). This trick enables a computer to correctly assign each image to a corresponding phase of the heartbeat in the finished video. Because MRI and EKG can interfere with each other, the technique is prone

» The bottleneck on the path to real-time MRI was the need for many different measurements to compute a single image.

to errors. Moreover, patients must usually hold their breath to ensure that the image isn't corrupted by respiratory motions.

The real-time MRI technique now developed by Frahm's team dispenses with such time-consuming procedures and discomforts. It delivers live video images of the body's interior – without the need for EKG and with patients breathing freely during the examination. Thanks to the refined form of the FLASH technique, the Göttingen team can acquire live body films at 30, 55 and, in extreme cases, as many as 100 frames per second.

The bottleneck on the path to real-time MRI was the need for many different measurements to compute a single high-quality image. Now there is a simple solution: the new FLASH-based technique creates images from only very few measurements, which moreover can be recorded much faster. The price to be paid is the staggering amount of number crunching needed to compute an image from little data. A computer must convert MRI measurements into a high-resolution video in real-time, meaning without any appreciable delay.

RESEARCHERS USE A TRICK TO SHORTEN THE COMPUTING TIME

The method used for dealing with scant data is distantly related to a technique used for fast video transmissions. Algorithms analyze only those sections of the image in a sequence that have changed from the previous image, and only those changes are transmitted, dramatically reducing the volume of data needed. The scientists in Göttingen are pursuing a similar strategy. The computer keeps any information from the previous images that hasn't changed, and for each frame, computes only those parts of the image that have changed. Using this trick, Frahm's team reduced the amount of data required for each image to just a few percent of what it was. Nevertheless, the MRI video images are sharp and clear. Two doctoral students at the time, Martin Uecker, now a professor at the University Medical Center Göttingen, and Shuo Zhang, who now works at Philips in Singapore, played a key role in the development.

Frahm and two colleagues demonstrated just how well the FLASH II technique works in the basement of the Institute, where an MRI scanner of the type used in hospitals is installed. Dirk Voit, who is also a physicist at the Göttingen-based Institute, guides a doctoral student into the tunnel. We then withdraw to the control room. Voit launches the program with a few mouse clicks. In the shielded room behind the window, the MRI machine springs audibly to life – and then the first images of our subject's torso form on the display.

Photos: sarah-willis.com

Photos: Frank Vinken (top); sarah-willis.com (bottom)

Above Jens Frahm's team is pursuing a number of ideas to further refine MRI, including real-time videos of the body's interior. Here, the researchers are discussing a suggestion by Zhengguo Tan.

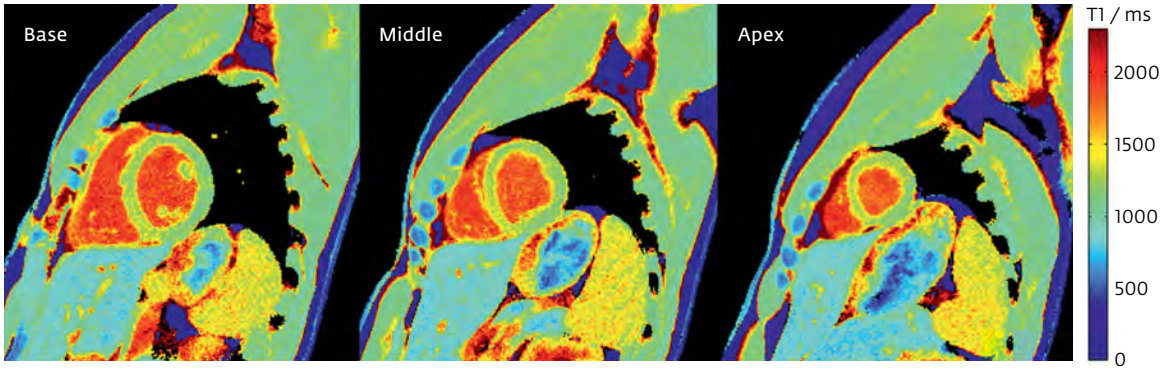
Below Sarah Willis, horn player in the Berlin Philharmonic, is one of the musicians whose tongue movements Peter Iltis (far left image), professor at Gordon College in Massachusetts, is analyzing with real-time MRI. For this purpose, Willis is lying in the MRI scanner while blowing through a tube into a horn made of a nonmagnetic alloy (link to a video of the project: http://sarah-willis.com/episodes/15-music-and-science/).

"First, we'll do cross-sectional images and examine the heart," Frahm explains, pointing to the display. After making a few adjustments, Frahm is satisfied: "We now have a four-chamber view that cuts right across the long axis of the heart, as it were. Even a layperson can immediately make out the four pumping heart chambers and also the flowing, eddying blood."

As the live transmission of the beating heart runs, Jens Frahm explains exactly how FLASH II technology represents a huge advance over conventional EKG-synchronized MRI. "Did you know that the heart actually must not beat with a perfectly regular rhythm?" he asks. "If it did, it would lead to mechanical problems, and the heart would never be able to continue working for a lifetime. Each heartbeat is a little shorter or a little longer than the previous one, and that is already at odds with what is required for conventional EKG-synchronized MRI of the heart," he explains. The heart would have to operate like a machine to march in time with the technical synchronization. "Of course, that's not the case in patients with cardiac arrhythmias," Frahm says, "and it is precisely those patients who doctors want to examine."

A LITTLE PINEAPPLE JUICE AS A CONTRAST MEDIUM

That's why hospitals are showing increasing interest in the real-time MRI from Göttingen. Manufacturers of MRI scanners, however, are still wary. After all, every new technology requires costly clinical testing and certifications. Nevertheless, Jens Frahm and his colleagues have joined forces with the University Medical Center Göttingen to apply the FLASH II technique to help the first patients, such as patients with swallowing disorders. With a little pineapple juice as a contrast medium, the live videos show what goes wrong when those patients try to swallow or when they suffer from reflux. >



Tissue maps of the chest: How quickly the water protons return to their equilibrium after being excited with a radiofrequency pulse depends on the T1 relaxation time, which is characteristic for the tissue type. These T1 maps of the chest show the base, the middle and the apex of the heart in its relaxed state. The almost perfectly round wall of the left cardiac chamber is shown in light green, and the blood in the chamber, in red. Skeletal muscle appears green, the liver blue-green and fatty tissue blue.

Professional players of brass instruments who find they can no longer play properly due to tongue cramps have a similar problem. The scientists discovered somewhat serendipitously that FLASH II can also help them. During a research project, Frahm's team recorded the playing technique of professional brass players to use the MRI videos for training purposes. The team in Göttingen performed MRI scans on several world-class musicians who were asked to play about 30 exercises on a valve-less, nonmagnetic natural horn. They then recorded the sound together with the rapid tongue movements at 55 frames per second.

"We found that not even elite musicians always do the same thing," Frahm says. "That's because we humans get very little if any sensory information about the back part of our tongue to control its precise position." But if musicians don't know exactly what their tongue is doing, it affects their teaching. Studying the video recordings made in Göttingen should now help to identify the ideal playing technique.

During the course of the project, the team also studied a musician from California who had speech problems and who also could no longer play correctly. "Together with the University Medical Center Göttingen, we also investigate cramps that occur during speech or stuttering," Frahm says. The MRI video showed that the placement of the musician's tongue was completely different from that of other horn players. He was, however, unable to simply change it. Frahm's team therefore came up with the idea of showing him his live MRI video stream in real-time as he was playing. "The visual control was so effective," Frahm says, "that it immediately enabled the musician to practice the correct tongue position." This experience led the researchers to an ongoing project. They are studying how suitable visual feedback is for coaching patients with speech disorders, as well as for brass players with tongue cramps.

For decades, Jens Frahm has been driven by the possibility of helping people in a direct and practical manner through basic research. Now he is intent on bringing MRI to life. "I still want to realize that dream!" he says. In the future, this could enable doctors to watch live what has gone wrong in the body. ◀

TO THE POINT

- **The FLASH technique has reduced the time required for MRI scans by a factor of one hundred, which is why this imaging technique is used so widely today.**
- **The FLASH technique excites only a portion of the total MRI signal for each measurement, thus allowing measurements to be taken in rapid succession without any waiting period.**
- **The Göttingen-based researchers came a step closer to real-time MRI by reducing the amount of data required for a single image. Live videos from the body's interior now help, for example, in the diagnosis of cardiovascular diseases, but they can also be used for swallowing or speech disorders and for musicians with tongue cramps.**

GLOSSARY

Magnet resonance imaging: This technique relies on the nuclei of hydrogen atoms (protons), which behave like little magnets in an external magnetic field. MRI detects radiofrequency signals from tissue water protons that are excited by a radiofrequency pulse from the scanner. These signals depend on the location in the MRI scanner and are used to compute an image. The technique can distinguish between various tissue types because they contain differing amounts of water with differing properties.

Photo: Jens Frahm/MPI for Biophysical Chemistry

Why Animals
Swarm for Swarms

Until recently, following the crowd was not seen as a desirable goal in life. These days, however, everyone is talking about swarm intelligence. But are swarms really smarter than individuals? And what rules, if any, do they follow? With the help of new computational techniques, **Iain Couzin** from the **Max Planck Institute for Ornithology** in Radolfzell imposes order on the seeming chaos of swarms.

TEXT **KLAUS WILHELM**

Baboon troops are strictly hierarchical with an alpha male ruling the roost. However, signs of democracy have recently been observed – for example, when the animals are hunting for food. "Even the uninformed animals in the troop participate in decisions about possible food locations and the route the troop will take to find them. This may be advantageous to the dominant male, as it means that he can benefit from the decisions of others when locating good food sources," explains Couzin, whose department conducts research at the University of Konstanz.

However, upon reaching the food source, the alpha male is the untested ruler again, and the other troop members must make do with his leftovers. "Even though individuals are self-interested, it appears that democratic principles still apply," says Couzin.

FROM CHILDHOOD CURIOSITY TO CUTTING-EDGE RESEARCHER

As a researcher, Couzin's heart beats faster when he tells stories like this. He comes across like a young boy in the process of discovering the world, but the biologist has been carrying out cutting-edge research for two decades and regularly makes astonishing discoveries. His research passion: the swarm, that most beguiling form of collective.

Photo: Axel Griesch

In nature, migrating locusts form swarms comprising over a billion individuals when too many animals live in one area. Iain Couzin wants to discover what determines the behavior of such swarms. His analyses have shown that the animals are driven by the fear of being eaten.

» A school of fish is a self-organizing system. Decisions are based on the movements of the individual animals

"The beauty of swarms fascinated me even as a child," says the 42-year-old Scot. "I always wanted to know why and how animals gather in large groups."

Today, swarm has become a byword for wisdom. Just 50 years ago, serious scientists fancied that telepathic forces were at work when, for example, thousands of fish move and turn together as if by magic. Even when a swarm spontaneously changes direction, order is maintained and there are seldom collisions. The animals coordinate their movements considerably better than humans driving in traffic.

Birds and insects have similar skills. Consider locusts, for instance. "We finally have some in the laboratory again!" Couzin's delight at this is evident. He has had to get by without the insects for a long time – too long for his taste.

HUNTING FOR LOCUSTS IN THE SAHARA

Couzin has many scientific passions, but he is particularly drawn to the behavior of insects – perhaps because locusts have helped him reach some very exciting research findings.

However, he almost paid a very high price for this: when he spent weeks looking for the legendary swarming animals in the Sahara some time ago, he almost died of starvation. "I hallucinated," he recalls, "and I thought I would die." In the end, all of the insects were blown away by a sand storm, and Couzin left Africa with no data.

Because of this experience, he focused on researching the insects in the laboratory. With his team, he built a circuit on which the locusts could move as they pleased. Every morning the scientists released up to 120 animals into the perfectly secured circuit. By evening, however, it was found that some locusts had disappeared. "This went on for days and I started to doubt my own sanity, or at least my ability to count." That was until he was able to examine video recordings of the goings-on in the arena in detail and made a startling discovery: the animals eat one another. After all, locusts are cannibals. Experts had considered them to be vegetarians and cooperative, for example when they suddenly form giant swarms and, as one of the great Biblical plagues, strip entire swaths of land bare.

"But their behavior has nothing to do with cooperation. Rather, they are driven by the fear of being cannibalized by others within the swarm," explains Couzin. When many insects come together, they can run out of essential nutrients, and that's when they begin to turn on one another. It was

Couzin (right) and his PhD student Jake Graving observe the swarm behavior of locusts in the laboratory. To this end, they built a circular track from which the animals can't escape.

Photo: Axel Griesch

The fish cellar at the University of Konstanz is lined with aquariums like in a pet shop. The researchers keep predominantly sunbleaks and golden shiners to study what guides the behavior of fish swarms.

found that each individual attempts to eat the one in front of it, and to avoid being eaten by those behind. The result is a mobile cannibalistic horde on a "forced march".

This discovery was considered nothing short of groundbreaking in expert circles. Couzin and his colleagues found further experimental evidence supporting his theory by severing the nerves in the insects' abdomens so that they no longer felt the bites from behind. The locusts immediately lost their ability to form a swarm.

With the aid of a computer simulation, Couzin's team later discovered that the locusts follow the laws of particle physics. The animals are akin to a "flowing magnetic field." Their bodies align with each other much like small magnets. Changes in the position and orientation of one "particle" can cause neighboring particles to change their position, too. The individual animals in a swarm synchronize their movements in this way, even over distances of several kilometers.

ANALYSES IN THE WILD, IN THE LAB AND ON THE COMPUTER

This example illustrates Couzin's unconventional approach to his research – holistic, if you will. He analyzes the animals' behavior in the wild, in the laboratory and in virtual realities, thus obtaining more comprehensive insights. To do this, he needs biologists, computer scientists, physicists and mathematicians on his team. "We have to teach the computer experts and biologists to speak the same language." Only by working together can they reconstruct animal swarms on the computer. These computer models trace each individual in a swarm and reconstruct the animals' fields of vision. In this way, the scientists aim to decode the rules that govern the swarm.

In addition to locusts, Couzin is also fascinated by another swarm-forming group of organisms: fish. For instance, he studies the golden shiner fish – a native of North America –as juveniles, with a length of around seven centimeters. In daylight, they swim in schools, but they remain motionless when it is dark. The fish follow clear rules when schooling: they seek out the proximity of conspecifics but without colliding with them; a fish on the edge of the school is often the first to react to a stimulus and thus disproportionately influences the movement of the entire group. Furthermore, individual fish tend to adopt the direction selected by a majority. If six fish swim to the left and five to the right, the swarm frequently opts for the left. >

Photo: Axel Griesch

Sunbleaks glide through huge basins. Cameras record their every movement.

With the help of his computer models, Couzin identified three factors that control the behavior of a fish school: attraction, repulsion and alignment of the individuals. For example, if the researchers steer virtual individuals in their simulation slightly in one direction, the group will very likely follow. "So, a school of fish is a self-organizing system. Decisions are based on the movements of the individual animals," explains Couzin. If individual animals change direction, or suddenly swim more slowly, their neighbors usually react. The sum of the position and direction changes ultimately determines where the school will swim. Furthermore, the process unfolds very quickly and allows individuals to share their "knowledge" with others. The school is therefore more effective as a collective than each of its individual members.

The swarm forms something akin to a collective brain. This enables rapid decision-making and allows many thousands of organisms to literally meld into a single entity. "Even complex swarm behavior can arise from simple interactions between the individuals. The animals don't even have to explicitly signal to one another. By responding to the movements of their neighbors, individuals can make highly effective collective decisions," explains Couzin.

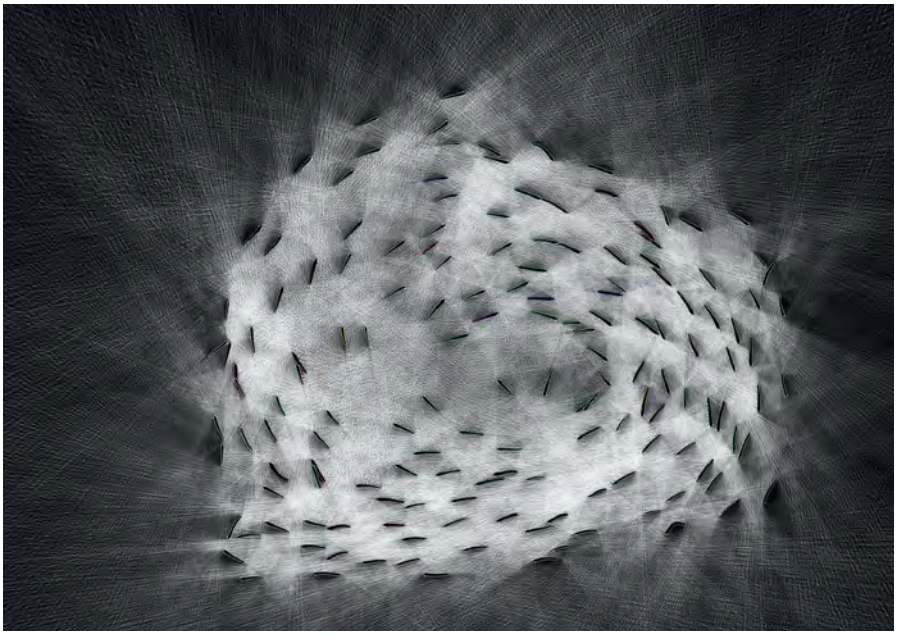
SMALLER GROUPS MAY MAKE BETTER DECISIONS

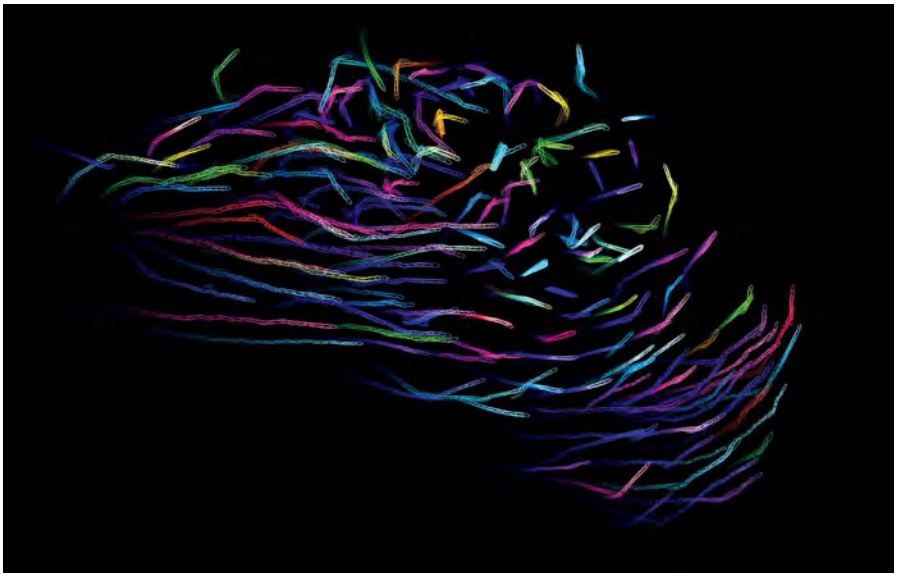
However, as one of Couzin's most recent studies suggests, the wisdom of a swarm can diminish if it becomes too big. Sometimes small groups make more prudent decisions. This contradicts the conventional teaching, which takes the view that bigger groups make better decisions. "According to this view, each member of the group makes independent decisions based on the same environmental cues," says Couzin.

But such conditions are almost impossible to fulfill in reality. Individuals in close proximity within a group tend to have access to similar sensory information, so the cues they experience will not be independent, but correlated. Furthermore, individuals may use multiple cues, or sensory modalities, when making decisions. Using computer simulations of decision-making, Couzin and his colleague Albert Kao were able to demonstrate that the conventional view of the wisdom of crowds does not hold up when this realism is added. In most cases, they found that small to medium-sized groups with between five and 25 members work best. "So the bigger a group gets, the poorer the decisions it seems to make," says Couzin, summarizing their findings.

But do these laws apply only to egalitarian fish and bird swarms, or do they also apply to animal groups that, like the above-described baboons, exhibit a strong dominance hierarchy? How do

Photo: Axel Griesch





Top Camera image of a swarm of golden shiners in the lab. The fields of vision of the individual fish are highlighted. The greater the overlap between the fields of vision, the brighter they are. The image shows that the fish prefer to stay in positions with the greatest overlap between the fields of vision.

Bottom Swimming movements of golden shiners in a swarm. The colors indicate different individuals.

the animals agree on a direction as they wander through their territory? This is a question that has interested Couzin for years. However, keeping track of the animals when they are on the move is a daunting task. Their movement over rough terrain is simply too swift for researchers to keep up.

When Couzin visited the Max Planck Institute in Radolfzell in 2012, his future colleague Martin Wikelski was able to offer him a solution to this problem. Wikelski develops transmitters with which he can track the movements of a wide variety of species from a distance. For example, the biologist had previously fitted 33 baboons in Kenya with GPS collars. The devices recorded information about the whereabouts of the primates on a second-by-second basis, which Wikelski was then able to evaluate on the computer. Immediately after moving with his research group from Princeton University to Lake Constance, Couzin began to test his models using the data from the wild baboons.

To be able to evaluate the copious GPS data they had accumulated, the scientists created a new software program that accounted for the baboons' movements in real life. In addition, the team observed the animals on site in Kenya. Using the results of their field studies, the researchers were then able to optimize the software, allowing them to determine how the baboons decide on a particular route when they are on the move. "When individual animals move away from the group, the others have to decide whether to follow them or not. In this way, these animals express their opinion about which route they prefer. If they head off in different directions, undecided members of the group tend to follow the majority," explains Couzin.

Moreover, the route chosen by the dominant animals was found not to influence the collective decision-making process. Even the alpha male accepts the decision of his entourage and complies with it. The ignorant and undecided group members may have a particularly important role here: "In our computational models, we find that uninformed individuals facilitate and accelerate the process of finding a col-

Photos: Iain Couzin

PEOPLE AS SENSORS

Of all the species Couzin has studied to date, the movements of groups of people have turned out to be the most predictable. His team developed computer vision software for tracking the movements of individual people in large crowds. They record information about where the individuals look and how they behave with each other.

The software is intended to help avoid disasters like the Duisburg Love Parade in 2010. The scientists can use it, for instance, to understand and simulate how crowds of people move in a street. In this way, potential sources of danger during the construction of new buildings and neighborhoods can be avoided from the outset.

In one study, Couzin hired actors and set them the task of behaving in a conspicuous manner on a shopping street and in a large train station. He wanted to find out how passers-by would react to unusual behavior exhibited by individuals. His analyses show that important information can be gleaned from the way people look. People do detect suspicious behavior, perhaps because they consider it to be a potential source of danger. However, they don't usually do anything about it.

Couzin found that observing the gaze of pedestrians allows individuals to be employed as sensors. Furthermore, he found that individuals in crowds follow the gaze of nearby pedestrians. Using a computer program, he and his team were able to analyze these gaze responses, allowing them to detect suspicious behaviors. Such technology could provide useful early-stage indicators of potential hazards even before the people themselves raise the alarm.

The lines of sight of individuals in a crowd of people can be recorded and evaluated using image analysis software. This enables the early identification of conspicuous behavior that may be indicative of potential danger.

lective solution. If, in contrast, many animals have their own ideas about the right route to take, it takes longer for the group to be able to agree on the direction they will all take."

CHOOSING THE RIGHT ROUTE

But what happens when a stalemate occurs and the different views can't be reconciled? When the same number of animals want to go left and right? Then it depends on the angle between the two preferred options: "If it is smaller than about 90 degrees, the animals following behind opt for the middle path, and in the case of larger angles, they exhibit a strong tendency to select the direction preferred by the bigger subgroup. "That is exactly what we predicted with the model we created for fish," says Couzin. Hence, like the fish, the baboons also follow a majority-rules principle in their collective decision-making, providing evidence that this is a fundamental principle of swarm behavior across species.

More-recent studies by Couzin and his team have now shown that the baboons also consider their physical environment when deciding which route to take. Using a drone, the researchers took a large number of aerial images of the animals' habitat and, from these, created a high-resolution three-dimensional reconstruction of their habitat. This allowed them to relate baboon movement decisions not only to social factors, but also to the environmental structure. They found that the animals employ roads built by humans, and sometimes also paths beaten by other animals. "This enables them to move faster and more easily between the locations where they feed and sleep," says Ariana Strandburg-Peshkin, a former doctoral student in Couzin's department. Vegetation, for example, is a considerable obstacle to the animals' movements. Groups slow down in densely vegetated areas, and it is more difficult

Photo and graphic: Iain Couzin

Baboons live in hierarchical groups. However, important decisions are not dictated by the group leaders, but are made democratically. If the group members can't agree on the route to be taken, the undecided apes follow the majority – irrespective of the direction chosen by the dominant animals.

for the baboons to adapt to each other in the directions they take.

A third discovery was that, instead of reacting to the positions of others, baboon motion is more strongly influenced by the routes taken by other baboons within the previous five-minute period – baboons are effectively following in the footsteps of others. "And the greater the number of baboons that cross a certain point in this period, the more attractive it becomes," explains Strandburg-Peshkin. In this, the baboons somewhat resemble ants, which recognize olfactory traces left by members of their species along their routes. It isn't yet entirely clear whether the baboons also perceive such scents or whether they simply observe and remember the paths taken by their "predecessors."

Locusts, fish, baboons, ants – Couzin has examined a huge range of organisms in detail and has repeatedly encountered similar laws and rules governing collective life. He is hopeful that the Center for Visual Computing of Collectives, a major new project he initiated in Konstanz, will uncover far-reaching new insights.

The Center is due to commence operation in three years' time, and will be one of the most modern facilities available for research on collective behavior. The scientists working there will be able to observe animal swarms in virtual holographic 3-D environments and measure their movements precisely. Specially developed transmitters, sensors and image processing will enable the simultaneous tracking of thousands of individuals in real time.

Five smaller virtual environments where the researchers present real fish schools with a virtual world are already in operation today. Although the fish swim in empty pools, they see virtual rocks, water plants and predators. It will soon be clear whether the fish behave naturally in this environment or not. "It will be unique. Only in Germany would it be possible to build such a research center," says Couzin. But he still wants to work with locusts again – this time in a more relaxed setting, in the tranquility of Konstanz. ◀

TO THE POINT

- **The individual animals in a swarm often follow relatively simple rules when responding to others, such as a tendency to be attracted toward, and align direction of travel with, others while maintaining personal space and avoiding collisions.**
- **The principle of majority rule applies in many animal groups: members normally follow the direction in which the majority of their neighbors are moving.**
- **Uninformed or unbiased individuals play a profound role in collective decision-making. They allow groups to make faster, and in some cases smarter, decisions.**

GLOSSARY

Swarm intelligence: When individuals contribute their skills to a collective, the group can develop characteristics that none of the individuals themselves have. This improves the performance of the group as a whole and can enable it to develop into a kind of superorganism. Examples of swarm intelligence include ant colonies and the internet.

Photo: mhgallery/123RF

The Power of Art

Winfried Menninghaus, a researcher at the **Max Planck Institute for Empirical Aesthetics** in Frankfurt am Main, is studying how people react, not just mentally, but also physically to poetry and prose. For many classical philologists and Germanists, his work is a betrayal of their disciplines. But the scientist and his team have actually succeeded in rendering the effect of poetic and rhetorical language measurable for the first time – even in such intangible categories as elegance or such curious phenomena as the trash film cult.

TEXT **MARTIN ROOS**

Among the greenery in the interior courtyard of the Max Planck Institute for Empirical Aesthetics stands a row of pink-colored letters of nearly human height. Their reference to beauty ("*schön*") seems to point rather insistently to precisely what the researchers here are concerned with. "No, no," Winfried Menninghaus protests, half laughing, half resigned. It was the real estate company that erected the illuminated sculpture to advertise the building. "Pure coincidence," says Menninghaus about the "kitsch in pink," clapping his hands together. A tall, lean man with untamed hair that sticks out like that of Doc Brown, the inventor in the fantasy film *Back to the Future*, he is head of the Language and Literature Department and Founding Director of the Institute, which was established in 2012.

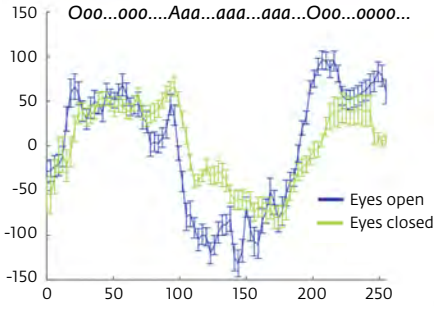
It is more than mere beauty that matters here. The researchers investigate how people react physiologically to aesthetic stimuli – to film, dance, music or, yes, language and poetry. "Who likes what and why?" is their alliterative slogan. "We develop aesthetic theories that integrate approaches drawn from philosophy, psychology and neuroscience," says Menninghaus, "and we subject them to a variety of tests."

A MINIATURE CAMERA FILMS THE GOOSE BUMPS

Here, watching films and listening to music and poetry is an act undertaken in the service of science. But it would be a mistake to imagine the test participants lying around on soft cushions and plied with exquisite beverages while Scheherazade whispers poems to them and Josephine Baker performs an interpretive dance of the alphabet. The Institute procedures call to mind a medical research laboratory. The test persons are seated in soundproof booths, where sensors attached to their fingertips measure skin resistance, monitors on their wrists record their heart rate and, depending on their emotional state, a miniature camera films the goose bumps on their arms. Some of them wear an electrode cap on their head to record the activity of nerve cells in the brain. "Almost everything can be measured nowadays," explains Menninghaus, "such as how long a participant spends looking at which word.

Photo: plainpicture/Lohfink

Individual impact: Art need not be beautiful – it can appeal, move and exhilarate, but also shock or disturb.



Top Kurt Schwitters reciting his *Ursonate*, a poem consisting solely of sounds.

Bottom At a performance at the Institute, the researchers discovered that the middle part of the second movement appealed less to the audience than other parts. Surprisingly, the effect was more marked among those who watched than among those who closed their eyes.

That gives us an indication of the dynamics of attention processes."

Since the beginning of his academic career, Menninghaus has been concerned with researching the effects of beauty and basic features of aesthetic sensibility. Today he is regarded as one of the most versatile and simultaneously most controversial literary scholars – he is no stranger to criticism. Menninghaus is aware of the silent arrogance with which natural scientists look at such a "soft" discipline as aesthetics. He also senses the deep skepticism that most literary scholars feel for the methodologies of natural science, and thus also for him. Critics ask: How is one supposed to measure the quality of a poem by such criteria as twitching eyes and sweating armpits? Are Menninghaus and others like him like the alchemists of old in search of the formula for gold – or in this case, the recipe for the perfect poem?

"Of course not," says Menninghaus, "we don't do recipes here. It is primarily a question of perception." He shrugs off the accusation that his research is just "nitpicking." But the tendency on the part of many colleagues to use "poetics of effect" as a term of abuse is something he cannot accept. Menninghaus cites the great linguist and semiotician Roman Jakobson, who once taught that our "poetic language function" is always "on." Accordingly, we perceive an aesthetic quality in even quite banal sentences. The Max Planck researcher looked about for proofs of this thesis – and found them: "We can now say that Jakobson was right. Because we see proof of the omnipresence of the poetic language function daily at our Institute."

Together with ten colleagues, including Germanists, literary and film scholars and neuroscientists, Menninghaus is constantly developing new categories and methods to meaningfully describe features that have an aesthetic impact – from verbal descriptions such as "beautiful", "boring", "exciting" or "humorous" to comparative studies of language structures in terms of rhythm, meter or linguistic melody.

POETRY IS AS STIRRING AS MUSIC

In the Institute's own ArtLab, a kind of multifunctional concert and event space filled with high-tech audio-video equipment and wiring harnesses for test persons, two Institute staff members have been testing the effect of Kurt Schwitters' by no means easily digestible Dadaist *Ursonate*: neuroscientists and linguistic psychologists Mathias Scharinger and Valentin Wagner invited 44 volunteers – individuals who were not entirely averse to Schwitters' idiosyncratic sense of humor – to the ArtLab. But why choose such a hybrid

Photos: London 1944, photographer: Ernst Schwitters; photo: Kurt Schwitters archive at the Sprengel Museum Hanover; photographer: Aline Gwose/Michael Herling, Sprengel Museum Hanover © VG Bild-Kunst, Bonn 2013; graphic: MPI for Empirical Aesthetics

Measured audience: In the ArtLab, a performance space equipped for research, the scientists can measure the physical effects of artistic presentations. For example, skin resistance measured at the fingers can give clues to the emotional excitement of the spectators.

piece of music, such a disturbing mix of primitive and monkey calls, of throaty and mating song?

"We deliberately wanted to exclude the semantic level, to focus purely on the sound level," says Scharinger. The researchers used monitors and electrodes to measure heart rate and skin conductance. Both during and after the concert, the test persons were also required to answer questions about the effect of the live performance and their emotional state via an electronic tablet. A large number of adjectives were available to define their aesthetic verdict – from "intense" and "melodic" to "demanding" and "chaotic" to "irritating" or "absurd." The researchers' goal was to discover the connection between the acoustic parameters, the purely subjective reports by the audience and their physiological reactions.

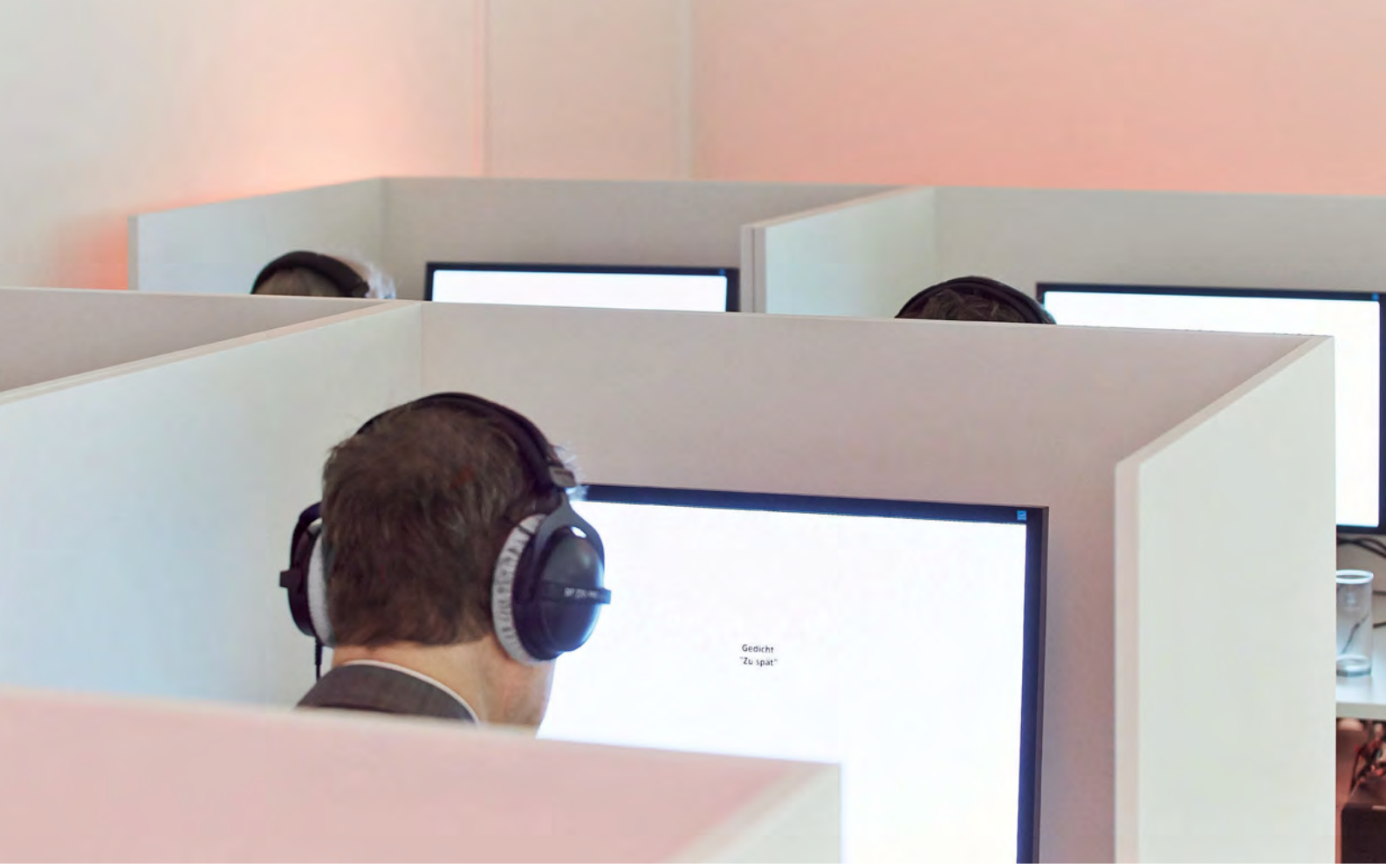
No final results are available as yet. However, the scientists expect a treasure trove of findings: "Once we have precisely analyzed which acoustic and linguistic properties correspond with which physical reactions," Wagner explains, "we will be able to provide information on the linguistic properties down to the exact syllable" – in other words, which highs and lows, which combinations of consonants and vowels trigger accelerated heart rate, boredom or even rejection. One thing is certain: "Regardless of which texts we hear or read, our physical selves always respond," Menninghaus adds.

Poetry moves us emotionally almost as much as our favorite music, he explains. The powerful effect of lyric verse is attributable to the fact that not only have we for many generations – at least since ancient times – been familiar with metrical speech, with Christian hymns and later with folk songs, but each of us has since birth, through preverbal communication with our parents, become accustomed to verse and rhythm. To oversimplify the point: "It is through verse that we come to language," says Menninghaus. This is why our attention is particularly drawn to rhythm and rhyme. The researchers demonstrate this using structured sentences from which certain stylistic features are specifically removed in order to see which ones stimulate the aesthetic desires of readers or listeners and in what way.

THE MORE TEARS, THE GREATER THE ENJOYMENT

When the phrase "planets are ill prophets" is presented to test subjects without the alliterative rhyme ("the stars are ill prophets"), the statement has a measurably lower "presence," or expressive power. If not the rhyme, but the rhythm is removed from the original sentence, as in: "planets are highly unreliable prophets," the statement is also reduced in effect. Devoid of both rhyme and rhythm, the sentence regains some of its presence, not least because it is now clearly understandable: "stars are not trustworthy prophets." However, of all the sentence variants, despite the somewhat crude content, the original statement "planets are ill prophets" unambiguously achieves the greatest impact. The rea-

Photo: Jörg Baumann



Listening for science: Test persons listen to a poem before answering questions on how moving and how beautiful they found the verses to be. In this way, the researchers can compile aesthetic judgments on works dating from different eras.

son is that our aesthetic and affective perception responds more strongly to metrical language.

"We also respond attentively to sentences or verses when they violate certain rules," explains Menninghaus. For instance, Ikea's German slogan "*Wohnst du noch oder lebst du schon?*" (Are you still living, or are you already alive?) violates several rules. The question "Are you still living?" is abbreviated and should normally read something like: "Are you still living in your old apartment?" And "Are you already alive?" is paradoxical, given that one may be "still" alive, but hardly "already" alive. Taken together, the two questions would be entirely meaningless were it not clear that this is a message from a furniture store. "Our brains have to work hard and fill in gaps to decode the sentence. And that is what makes it so pithy," explains Menninghaus.

For a long time the Menninghaus team also pondered the question of whether positive and negative feelings, joy and sadness, cancel each other out when appreciating art. They found that it is just the opposite. "The measurement curves for physical reactions to negative and positive effects both peaked at almost exactly the same time," says Menninghaus. To put it another way, the more the tears flow, the greater the enjoyment is. It's a matter of "being moved."

ELEGANCE CAN ENDURE INTO OLD AGE

And that, for Menninghaus, brings things full circle, back to an ancient discipline that had long been forgotten, not least due its misuse during the Third Reich: rhetoric. "Among its wealth of figures of speech and poetic features, there were always some important factors that determined aesthetic appreciation," Menninghaus explains. But rhetoric was scarcely perceived in this way any longer. It is precisely the *movere* of ancient rhetoric, the power to move, to stir and to shake up, that fascinates Menninghaus.

It was not without reason that he and his team conducted several studies on "being moved." These impressively show that "being moved" almost always involves a mix of joy and sadness. Thus, ancient rhetoric remains highly modern. Which is another reason why Winfried Menninghaus is very keen to amalgamate the language production elements of rhetoric with aesthetic theory, literary and musicological analysis techniques, linguistic modeling and the latest methods and theories in the fields of psychology and neuroscience.

One of Menninghaus' latest projects addresses the subject of elegance. "Judgments on elegance generally overlap broadly with judgments on beauty," he says. An elegant car is also judged to be a beautiful car. On the other hand, not everything that is beautiful is also elegant. To establish the fine distinctions, the researchers have introduced two further categories: grace – which borders closely on elegance – and sexiness, or sexual appeal – which also falls within the broad field of beauty but has little overlap with elegance.

Photo: Jörg Baumann

To be able to make psychometrically well founded statements about the beauty, elegance, grace or sexiness of an object, it isn't sufficient to simply ask how beautiful, elegant, graceful or sexy the object is. It requires numerous features that correlate positively or negatively with elegance. Menninghaus and his team have therefore studied elegance as a highly multidimensional construct with associations such as "fine," "tasteful," "fluid," "harmonious," "valuable," "unpretentious," "light," "slender" and many more.

The researchers evaluated such attributions and combined the results to be able to make reliable, nuanced statements about the elegance of a wide variety of objects – from cutlery to lingerie and nightwear to yachts, luxury hotels and bridges. The "near-perfect dissociation between sexiness and elegance" is particularly striking in relation to age: while much sexiness may be expected of young men and women, elegance is not. And for older men and women, the precise opposite applies. Beauty, says Menninghaus, is right in the middle of that: it outlasts the high degree of sexiness expected of young women and men by around two decades before declining steeply, leaving elegance as the sole manifestation of good looks that is achievable up to an advanced age. Elegance scores peak only among the over-50-year-olds and can in some cases endure far beyond the age of 80. "Compared with the age profiles for sexiness and beauty, the profile for elegance exhibits the smallest differences between men and women," explains Menninghaus – a result with huge potential, not least for the clothing sector. "The fashion industry still lacks an understanding of this connection."

WE OFTEN LIKE WHAT WE ARE FAMILIAR WITH

For all the rigors of science, the exuberant researcher is always ready for some serious fun. For example, when one of his staff, film scholar Keyvan Sarkhosh, asked trash movie audiences, "Why are you watching this?", the results proved to be quite a surprise. "The very first answer cited boredom with the mainstream and frustration with the propensity of Hollywood to constantly replicate itself," says Sarkhosh. The researcher chose shark horror films as his examples – among them *Sharknado*, an American disaster movie dating from 2013 with several sequels.

Critics panned Sharknado with its flying, man-eating sharks, blood, gore and screams as "absolute garbage" and "the worst film of the year" – but "quite amusing" for all that. And that is just the point: some consider the story of the monster sharks to be devoid of style or taste, while others see it as an artistic treat of a decidedly different kind.

The genuinely surprising and, for the public at large, most important finding of the study is that the trash film audience – with an average age of

Popular man-eaters: Sharks often play a central role in trash movies such as *Sharknado*, a disaster movie with several sequels and an astonishing number of fans. A study revealed the trash movie audience to be educated to an above-average standard and interested in culture.

Photo: SYFY

Creative team: To render the effect of literature measurable, Winfried Menninghaus (right) works with a team of researchers drawn from various disciplines. Among them are neurolinguist Mathias Scharinger (left) and philosopher and psychologist Valentin Wagner (center).

35 – is by no means comprised of individuals of low intelligence or educational achievement. On the contrary: "Our subjects proved to have an above-average standard of education. They have numerous cultural interests, visit theaters and museums, and watch niche TV channels such as Arte," explains Sarkhosh.

WELCOME TO POP CULTURE

For one thing, trash fans take pleasure in watching anti-films with a certain ironic detachment. Their enjoyment is primarily a product of their aesthetic interest in the realization of clichés and allusions to B movies they have seen before. "An important factor in determining what people like or don't like is what they have already seen or perceived in the past – for example in their teens or mid-twenties," Sarkhosh adds. Menninghaus describes this phenomenon, the familiarity principle, as one of the "strongest determinants of aesthetic enjoyment."

The idea of art devoid of beauty, the phenomenon that objects that by common standards are perceived as ugly can also possess an aesthetic appeal of their own, is not new. It was familiar even in ancient times, the depictions of the satyrs being one example. The guilty pleasure derived by connoisseurs of trash movies is a kind of cinematic celebration of tastelessness. According to Sarkhosh, it can be attributed to carnivalesque culture – a "counterculture that allows unorthodox freedoms."

For Winfried Menninghaus, there were two other reasons why the trash study proved surprising: "The data was clearer and more meaningful than we had expected." And: "What we couldn't even remotely have anticipated was the huge media response to the publication of our study. Welcome to pop culture!" Within six weeks, more than 1,000 reviews appeared in newspapers the world over, with interview requests from as far away as Africa. Menninghaus is still amazed: "I'll never manage that with all our other studies put together."

Who knows. Keyvan Sarkhosh is already working on a new study. This time, the focus is on fans of kitsch movies and their passion for sugar-sweet, rose-tinted feel-good movies with a guaranteed happy ending, like *Pretty Woman* or *Dirty Dancing*. Of course, the question will be the same here as well: "Why do you even watch this?" We wait with bated breath. ◂

TO THE POINT

- **Scientists are measuring the strong emotional effect that literature has on individuals: rhymes and sentences or verses that violate certain rules particularly attract our attention.**
- **The researchers also use surveys to determine what distinguishes aesthetic judgments such as "elegance." It is striking that people are increasingly described as elegant from their fourth decade onward.**
- **The trash film research project is gathering data on the viewers of this genre and their love for ugliness.**

Photos: MPI for Empirical Aesthetics/F. Bernoully

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A Quantum of Energy

Electrons that circle around a positively charged nucleus on stable orbits? When Niels Bohr presents his new model of the atom in 1913, many colleagues shake their heads. Shortly afterward, a successful proof is put forward: **James Franck**, who will later become a department head at the **Kaiser Wilhelm Institute for Physical Chemistry and Electrochemistry** in Berlin-Dahlem, and his colleague Gustav Hertz receive the 1925 Nobel Prize in Physics for this work. Initially, though, the two have no idea just what they have discovered here.

TEXT **ELKE MAIER**

April 1940. In Niels Bohr's laboratory in Copenhagen stands 54-year-old chemist George de Hevesy, holding a Nobel Prize medal in his hand. It belongs to Jewish physicist James Franck. To keep it safe from the Nazis, Franck had entrusted it to his friend and colleague Bohr, and he, in turn, had given it to de Hevesy.

The Germans had now occupied Denmark and were already marching through the streets of the capital. There was no time to lose. De Hevesy pours aqua regia over the prestigious medal and waits until the corrosive mixture of concentrated hydrochloric and nitric acid has dissolved the metal. When the occupying powers turn the laboratory upside down, the beaker with its precious contents stands unnoticed among numerous others.

Particles on a collision course: James Franck (left) and Gustav Hertz studied collisions between electrons and atoms.

The gold is later handed over to the Royal Swedish Academy of Sciences, which has a new medal minted from it. On January 31, 1952, James Franck is able to receive the coveted honor for a second time – for an experiment whose significance he and his colleague Gustav Hertz were initially unable to fully appreciate. But first things first.

James Franck is born in Hamburg on August 26, 1882. He is the second child of banker Jacob Franck and his wife Rebecca. James is to receive a classical education at the high school he attends, the Wilhelm Gymnasium. However, he has no appreciation for ancient languages and is thus deemed to "show little promise" as a student. He is much more interested in connections: even at an advanced age, James Franck remembers a eureka moment during his Greek class when he suddenly realized why a grease spot in his exercise book "makes the opaque paper translucent."

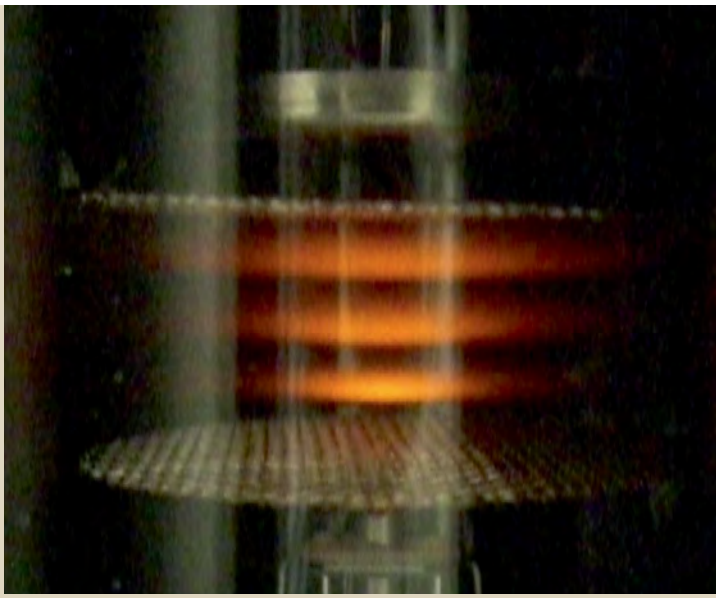
Following high school – where he had to repeat a year – he enrolls at Heidelberg University to study economics and law for his father's sake. Only later does he assert himself and switch to chemistry and then finally to physics. His new place of study, Berlin, is the top choice for this and the center of attraction for the most influential physicists of the time, among them Heinrich Rubens, Emil Warburg and Max Planck, and later also Paul Drude and Albert Einstein. Franck completes his doctorate in 1906 at the Physics Institute of Berlin University on the mobility of ions in gas discharges and becomes a research assistant there.

Also working at the same Institute is Gustav Hertz, who is five years his junior and whose uncle Heinrich Hertz – after whom the unit of frequency is named – had discovered electromagnetic waves, a major key to communications technology. James Franck and Gustav Hertz become friends and launch a joint project to study the interaction between atoms and electrons.

The apparatus consists – in simplified terms – of a glass flask filled with mercury gas. Inside are a negatively charged thermionic cathode and a positive anode, with a voltage applied between them. This causes electrons to be continuously emitted at the cathode and accelerated toward the anode. En route, they collide with the mercury atoms. As soon as the electrons reach the anode, the researchers measure their speed. In this way, they aim to determine how much kinetic energy the electrons have lost through the collisions with the gas atoms.

The scientists observe the following: If a low voltage is applied, the electrons hurtle toward the finish with their speed unchanged. If the electron energy reaches 4.9 electronvolts (eV), the speed of the arriving electrons approaches zero, and in a darkened room, a thin luminescent band appears just in front of the anode. If the voltage is increased further, the electrons speed up again, and the luminescent band moves toward the cathode. At twice the critical value, the speed is suddenly zero, and a second luminescent band is formed, a third one at triple the value – and so on and so forth.

Photos: Wikimedia Commons



Band by band: The gas atoms emit the energy they have received from the electrons in the form of light. In the experiment shown here, mercury gas was replaced with neon, which produces an orange glow.

What was happening here? In their 1914 publication, James Franck and Gustav Hertz write that an energy of 4.9 eV ionizes the mercury atom, or in other words, ejects an electron from its shell – a mistake, as it would turn out. What the two had overlooked in their zeal was that, just a few months prior, Niels Bohr had presented a theoretical model of the structure of the atom that fit their observation perfectly.

In his publication, Bohr describes a kind of miniature planetary system in which electrons circle around a positively charged nucleus on stable orbits. These orbits – so-called shells – have fixed separations from each other. If one now wants to move an electron from one shell to the next (further out), a very specific amount of energy is required that depends on the species of the atom. Niels Bohr, who knew all about "the wonderful experiment of Franck and Hertz," guessed that this amount was precisely 4.9 eV in the case of mercury. He would be proved right about this.

Without knowing it, Franck and Hertz had proved that electrons can be excited only by the right quantum of energy – one of the key statements of Bohr's theory. If the amount of energy is too low, electron and atom collide without an energy transfer taking place. The electron transfers its energy to the atom only when the critical threshold of 4.9 electronvolts is reached. After such a collision, the electron is initially at rest before being accelerated again by the voltage – and it again passes on the energy it collects in the process upon reaching 4.9 eV. The luminescence is caused by the atom re-emitting the absorbed energy in the form of light.

Der Spiegel 19/1957

» The Nazis didn't yet dare to attack Nobel laureate James Franck, one of the most noble minds among the not always noble nuclear physicists, because he was too well known. The upstanding man resigned in April 1933 to make a point and out of solidarity […]

Only later do the two scientists realize how crucial their experiment was: "It was as if a researcher wanted to explore unknown territory and realized that he already had a complete map of this territory in his hands without knowing it," Franck writes in retrospect. James Franck and Gustav Hertz receive the 1925 Nobel Prize in Physics for their experiment.

In April 1914, Gustav Hertz presents the results at a meeting of the German Physical Society in Berlin. Just over three months later, World War I starts. James Franck enlists. Like Gustav Hertz, he is sent to the front to work under Fritz Haber in gas warfare. Both are later also assigned to the Kaiser Wilhelm Institute for Physical Chemistry and Electrochemistry in Berlin-Dahlem. One of their tasks is to test whether gas masks are fit for purpose using themselves as guinea pigs.

Between 1917 and 1921, James Franck works as a department head at the Kaiser Wilhelm Institute for Physical Chemistry and Electrochemistry in Berlin under Director Fritz Haber. He then switches to the University of Göttingen as a professor of experimental physics. In 1933, he is supposed to become Director of the Physics Institute at Berlin University, but this never happened.

On January 30, 1933, Adolf Hitler becomes Reich Chancellor, and a few weeks later, the "Law for the Restoration of the Professional Civil Service" comes into force. It states that civil servants of non-Aryan descent are to be retired. Although James Franck, as a former front-line soldier, is exempt, he can't accept the affront. He resigns voluntarily out of protest, but hardly any of his colleagues demonstrate solidarity with him.

In the same year, he and his family leave Germany. Franck spends more than a year as a visiting scientist with Niels Bohr in Copenhagen, takes on a professorship at Johns Hopkins University in Baltimore, then moves to the University of Chicago in 1938. During World War II, he is part of the team there working on the Manhattan Project to develop the atomic bomb. When he learns that the bomb is to be used against Japan even after Nazi Germany has capitulated, he takes a stand. Together with six other scientists, he draws up a memorandum that will go down in history as the Franck Report and speaks out against the use of the atomic bomb in Japan.

In the report, the researchers draw attention to the danger of a nuclear arms race and advocate demonstrating the destructive force of the new weapon in an uninhabited area instead of attacking Japan. Their appeal goes unheeded. On August 6, 1945, the bomb explodes over Hiroshima, and three days later, Nagasaki is hit. Japan capitulates.

After the war, James Franck focuses his research activities on the field of photosynthesis, a process in which solar energy is absorbed and conserved in the form of a chemical bond. The scientist thus remains true to his favorite topic: the energy transfer between atoms and molecules. After the war, Gustav Hertz is obliged to work as a specialist for the Soviet atomic bomb project; on his return in 1955 he takes over the management of the Institute of Physics at Leipzig University. He is the only Nobel laureate to live and work in East Germany. Franck dies at the age of 81 during a visit to Göttingen, and Hertz at the age of 88 in East Berlin.

The Franck-Hertz experiment is now one of the classical experiments in physics. Teachers like to demonstrate it in physics lessons as important support for Bohr's model of the atom and proof of quantum theory.

Making It Easier to Plan a Career

"Career Steps Opportunities" aims for feedback / new network starts work

A series of events in Berlin, Göttingen and Tübingen entitled "Career Steps Opportunities" shed light on various aspects of career planning and development. The goal is to increase awareness of gender equity at all levels of hierarchy within the internal scientific community.

At the beginning of March, the Max Planck Society invited Cornelia Quennet-Thielen, State Secretary at the Federal Ministry of Education and Research, and other guests, including the improvisational theater group "Freiwild," to the Harnack House in Berlin for the opening event, which ended with a three-voice chorus of thanks and left a smile on the participants' faces. The four performers earned thunderous applause for their conference summary in the form of a highly idiosyncratic version of "Little Red Riding Hood."

The event began with a retrospective look at the path taken by the Max Planck Society to promote equality. And a successful path it's been, too, as Cornelia Quennet-Thielen confirmed, pointing out that, in ten years, the MPG had tripled its number of female Directors. She described the improvement in equal opportunity symbolized by this increase as an expression of structural and cultural change. Still, she appealed to the management of the Max Planck Society, represented by patron and Vice President Angela Friederici and acting Secretary General Rüdiger Willems, not to waver in their efforts.

The contribution by Stefanie Lohaus, publisher of Missy Magazine, was met with thoughtful nodding as she explained that, in terms of female involvement, science differed little from the music and arts scene: "We have the same problems. Gender equity isn't just a question of access and equal rights, it is also dependent on where the encouragement and support comes from, who believes that building a career is a natural choice and who takes care of children and family."

At workshops on work-life balance, gender awareness and science careers, the predominantly young male and female scientists were asked to share their personal experiences and desires so as to hear how the Max Planck Institutes could better respond to their needs. It soon became clear that gender equity won't be achieved without effort, and that an awareness of the situation is an essential skill for modern managers.

This is by no means a matter of course, as the often-repeated requests for individual help and flexible working hours demonstrated. "But there are now research group leaders who allow their team members exactly this latitude," as event organizer and MPG Gender Equality Officer Ulla Weber discovered. One female group leader with six children told her: "The main thing is that they are present on the one day a week on which the group meeting takes place."

The Department of Personnel and Personnel Law at Administrative Headquarters took advantage of the opening event to cement the first links in a career support network. On the pattern of the links between the Welcome Officers at the Max Planck Institutes, the aim is to establish a "Career Steps Network" in concert with the Institute employees tasked with career support. One hundred individuals have already linked up on maxNet to exchange ideas.

Impressions from "Career Steps Opportunities" with Cornelia Quennet-Thielen (below right), State Secretary at the Federal Ministry of Education and Research, and the improvisational theater group Freiwild (below left).

Photos: Arne Sattler/MPG

OpenCon 2017 in Berlin

Three-day program at the Harnack House from November 11 to 13

The Max Planck Society will be hosting the OpenCon 2017 organized by SPARC and the Right to Research Coalition. About 200 international participants around the globe will come together from November 11 to 13 at the Harnack House, the Society's conference center in Berlin, Germany, to promote openness in scholarly communication.

OpenCon, the platform for the next generation to learn about Open Access, Open Education and Open Data, brings together the most engaged students and early career academic professionals from all over the world. Attendance at OpenCon is by application only, and the majority of past participants receive travel scholarships.

OpenCon 2017's three-day program will begin with two days of keynotes, panels and interactive workshops. OpenCon places an emphasis on highlighting diverse early career voices, while complementing them with such leading experts as Wikipedia founder Jimmy Wales and European Parliament Member Julia Reda, who attended prior OpenCons.

The third day will feature an all-day session where participants have the opportunity to craft new campaigns, lay the foundations for new resources and form collaborations that will continue long after the November conference is over. The speakers for 2017 will be released later.

In 2013, the Max Planck Society and SPARC organized the first Open Access conference dedicated to early career researchers in the run-up to the "Berlin 11" Open Access conference. That conference turned out to be the initial spark for OpenCon. Organized by the Right to Research Coalition and SPARC, OpenCon 2017 builds on the success of the first three OpenCon conferences, which collectively convened approximately 500 participants from 80 countries.

In addition, OpenCon's unique structure has supported 70 satellite events, enabling more than 4,100 attendees across 32 countries to participate in an in-person OpenCon event. Throughout the year, hundreds of these individuals remain engaged through monthly community calls, regular webcasts and a very active community discussion list.

Since initiating the "Berlin Declaration on Open Access to Knowledge in the Sciences and Humanities" in 2003, the Max Planck Society is pursuing a broad and comprehensive Open Access agenda. The Max Planck Society is committed to consistently supporting Open Access on all levels. In particular, it is crucial to foster the engagement of the next generation of scholars because students and early career researchers face challenges from a scholarly publishing in transition.

For more information about the conference and to sign up for updates, please visit www.opencon2017.org/updates.

Award-Winning Research Video

One of the films from the Max Planck Cinema series, "Biomaterials – Patent solutions by nature," has won the Technology Prize for 2016 at the Goethe Institute Science Film Festival. The film depicts the research carried out by Peter Fratzl at the Max Planck Institute of Colloids and Interfaces and optimally meets the required criteria: according to the international jury, "It exemplifies those decisive technologies that will change our lives in the 21st century."

The Goethe Institute presented awards in six categories. The Technology Prize is endowed with 1,000 euros. The Festival brings science to life on screen in an entertaining, creative and exciting way. It toured 16 countries last fall.

Established in 2006 the Ernst Haage Prize honors young scientists for outstanding achievements in the field of chemical energy conversion and fosters young academics in particular.
The prize is awarded by the Ernst Haage-Foundation and is endowed with € 7,500.

Research Award in „Chemical Energy Conversion"

Nominees must be scientists who hold a doctorate from a German research institution/university. They should have their primary residence in Germany, be no more than 40 years old and not have a permanent employment contract.

Nominations may be submitted to the Foundation's Board of Trustees by ***September 15th 2017*** and should include the following documents:

- Two pages of laudation
- Curriculum vitae in table form
- Complete publication list
- Up to three reprints of works by the nominee

Personal applications cannot be considered.

The prize recognizes outstanding scientific achievements in the field of chemical energy conversion, for example in the following divisions:

- Hydrogen as a medium for transferring and storing energy
- Photovoltaic storage solutions
- Electrochemical storage
- Biomass and bioenergy
- CO_2 transformation
- Hydrogen oxidation and electrolysis
- Reduction of nitrogen
- Artificial and natural photosynthesis
- Development of new experimental and theoretical methods to find new application areas in the energy research.

Ernst Haage Prize
call for proposals 2017

Directorate of the
Max Planck Institute
for Chemical Energy Conversion
Attn. Ms. Christin Ernst
Stiftstr. 34-36
D-45470 Mülheim an der Ruhr
Catchword: Ernst Haage

For further information on the Ernst Haage Prize, the Foundation and award ceremony, please visit http://www.cec.mpg.de

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Prof. Dr. Serena DeBeer
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Prof. Dr. Frank Neese

MAX-PLANCK-INSTITUT FÜR
CHEMISCHE ENERGIEKONVERSION

Shaw Prize for Simon D.M. White

Max Planck Director receives award for numerical simulations of structure formation in the early universe

This year's Shaw Prize for Astronomy goes to Simon D.M. White, Director at the Max Planck Institute for Astrophysics, for his contributions to understanding structure formation in the universe. The Shaw Prize is awarded annually in the life sciences, mathematics and astronomy by the Shaw Prize Foundation in Hong Kong. A gold medal and prize money of 1.2 million US dollars will be awarded in each area at a ceremony in Hong Kong on September 26, 2017.

This year's Shaw Prize for Astronomy goes to Simon D.M. White, Director at the Max Planck Institute for Astrophysics.

The universe was born 13.8 billion years ago in the Big Bang. But how did the cosmos we observe today, with its billions of galaxies of different shapes and sizes, develop from this enormous explosion? Apparently, as Simon White and his collaborator Martin Rees first hypothesized in 1978, gigantic clouds of material separated from expansion and fell back on themselves under the influence of gravity when the universe was just a few hundred million years old, and galaxies then formed as gas cooled and condensed at the centers of immense halos of the mysterious dark matter that is still detected only through its gravitational effects.

Over four decades, Simon White and his students and collaborators have simulated this scenario with ever-increasing realism on the largest available computers. A well known recent example was the Millennium Simulation, carried out in 2005 on the Max Planck Society's Garching supercomputer in collaboration with Volker Springel and others. This simulation tracked the development of structure and the formation of 20 million galaxies throughout a region of space measuring more than two billion light-years across.

In fact, such simulations produce a kind of cosmic net in which matter accumulates in and flows along filaments on the edges of gigantic bubbles. This is precisely the structure that astronomers observe in the real universe on very large scales. The work of White and his colleagues demonstrates how such complex structures develop from the simple, near-uniform conditions initially hypothesized, but now directly observed, to be present in the early universe.

Simon White was born in 1951 in Ashford, England. He earned a first degree in mathematics from Jesus College, Cambridge in 1972, an MSc in astronomy from the University of Toronto in 1974 and a PhD from Cambridge University in 1977. In the 1980s, White teamed up with Marc Davis, George Efstathiou and Carlos Frenk to show that the "Cold Dark Matter" theory (CDM) was consistent with the formation of galaxies and other cosmological structures.

In the 1990s he, together with Julio Navarro and Carlos Frenk, showed that all dark matter halos have a simple "universal" structure that can be predicted from the material content and geometry of the universe and current ideas about its very early evolution. White was a Lindemann Fellow at the Astronomy Department of the University of California at Berkeley in 1977 and 1978, and a research fellow at Churchill College, Cambridge from 1978 to 1980.

He was then a senior fellow at the Space Sciences Laboratory of UC Berkeley (1980–1984) before joining the Faculty of Astronomy at the University of Arizona (1984–1991). In 1991, White returned to the Institute of Astronomy in Cambridge and was director of the European Association for Research in Astronomy from 1992 to 1994. Since 1994, White has been Director at the Max Planck Institute for Astrophysics in Garching.

In addition to numerous other prizes and awards, Simon D.M. White has won the Helen B. Warner Prize from the American Astronomy Society, the Dannie Heineman Prize for Astrophysics, a gold medal from the Royal Astronomical Society and the Gruber Cosmology Prize.

Photo: Max Planck Institute for Astrophysics

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- Florence

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- Jupiter, Florida

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- Manaus

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- Luxembourg

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