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Max Planck RESEARCH
The Science Magazine of the Max Planck Society 3.2012

FOCUS
Biodiversity
The Valuable Diversity of Nature

RESEARCH POLICY
Freedom Creates Knowledge

ASTRONOMY
The Search for a Second Earth

TECHNOLOGY
The Power Grid's Got Rhythm

ART HISTORY
The Science of the Studio
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MaxPlanckResearch seeks to keep partners and friends of the Max Planck Society up to date on the latest research conducted at the Max Planck Institutes. Four editions of the magazine are published in German each year, all of which are translated into English. At present, the English version has a circulation of 10,000 copies (MaxPlanckForschung: 26,000 copies). It is free of charge. None of the views and opinions expressed in MaxPlanckResearch may be interpreted as representing the official views of the Max Planck Society and its associated bodies. Reproduction is permitted only with the prior approval of the publisher. Photographic rights may be granted by agreement.

The Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V. (Max Planck Society) comprises 80 institutes and research facilities where around 21,800 employees, including some 5,400 permanently employed scientists, work and conduct research. The annual budget for 2012 is 1.46 billion euros. Research activities of the Max Planck Society focus on basic research in natural sciences and the humanities. The Max Planck Society is a non-profit organization registered under private law as an incorporated association. Its central decision-making body is the Senate, with members from the world of politics, the scientific community, and the professional public, providing for a well-balanced partnership.
Open-Air Lab in the Amazon Rainforest

The setting in which researchers at the Max Planck Institute for Chemistry study which substances plants exchange with their environment is artificial, yet still as natural as possible. Nina Knothe, who works at the Mainz-based institute, is preparing such an experiment at the Max Planck Society’s sub-institute in Manaus, in the Brazilian Amazon rainforest, by checking the lighting conditions in a cuvette covered with an airtight film. Without artificial lighting, the plants that will later be placed in the vessel won’t get enough light. Tubes supply the plant with ambient air and discharge the gaseous metabolic products of the test subject. The second cuvette serves the researchers as a reference. This experiment helps the scientists learn more about the natural material cycle, as few other places in the world can match the low pollution level of the air in the Amazon rainforest. When they know more about the natural material cycle between the geosphere, the biosphere and the atmosphere, they will be better able to understand how humans interfere in this interplay.
Biodiversity

20 Census at the Zoo

Although everyone is talking about species protection, the lack of information about the species that need to be conserved can be quite shocking. Researchers are using special methods to gather important data about the lives of endangered animals. In this way, it is hoped that threatened animal species can be protected more effectively in the future.

26 Life on the Move

Whether birds that crisscross the globe, whales that navigate the vastness of the oceans or wildebeest on the African savannas – the major animal migrations in our world present an incomparable spectacle. Researchers are now using miniature transmitters on a wide variety of species to track their exact destinations and how they get there.

34 The Sea as a Gene Pool

The oceans are full of bacteria. Outwardly, they all look much the same, but there are many different species living a variety of ways of life. This bacterial diversity can be analyzed with the aid of metagenomics.

ON THE COVER: Whether in the water, in the air or on land – there is a wide variety of life. This biodiversity is considered to be the foundation of life, which is why scientists concern themselves both with diversity within and between species and with the diverse habitats.
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Astronomers have now discovered nearly 800 planets orbiting distant stars. So far, only three of them have been found to potentially offer life-sustaining conditions. However, there are probably many second Earths in the Milky Way. But how can traces of life be detected on exoplanets?

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Personal Portrait: Peter Hommelhoff

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New forms and sources of energy need new power lines as well. In the future, a larger number of small, distributed wind and solar installations in place of a smaller number of large power plants are projected to supply Germany with energy. Scientists are investigating how the high-voltage grid will respond to this and how it can be optimized.

ENVIRONMENT & CLIMATE

70 Powerhouse Earth
Our planet is at work: The sun drives the wind, the waves and the water cycle. Plants store the energy from light in sugar, supplying the fuel of life. Researchers are investigating how much energy flows in these processes and how much of this could be used on a sustainable basis.

CULTURE & SOCIETY

78 The Science of the Studio
Not only did they create impressive works of art, they also took an interest in alchemy, mathematics and the natural sciences. Now researchers are studying how artists in the early modern era discovered, depicted and circulated new knowledge.

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The Excellence Initiative and the Research Pact have created a momentum that is bringing change to the scientific system and those involved in it – a process that applies not just to universities, but also to research organizations, including the Helmholtz and Leibniz Associations, the Fraunhofer Gesellschaft and the Max Planck Society, as well as the German Research Foundation. With excellence as their target, these funding initiatives have led to a paradigm shift. In breaking with the dogma that all universities are equal and must remain so, they have revealed what has long existed beneath the rendered surface of Germany’s university landscape: the peaks of performance in individual disciplines and the beacons of research that shine in individual locations. Competition has triggered a process of combining existing strengths with those of partners at other scientific institutions and in industry. Not only has this created new opportunities, but there is now also an openness to competing and cooperating with the best, which in turn inspires success.

The non-university research organizations are making their own contributions. Indeed, it is no accident that their primary role here is in conjunction with excellent, high-profile universities. The Max Planck Society generally plays a part. In the first round of the Excellence Initiative, we were involved in more than two out of three of the successful clusters, and one in two of the graduate schools to receive support. These quotas have since been more than confirmed in the current second phase of the program.

This interconnection between the universities and other participants in the same locations shows that system diversity breeds research success – in matters relating to Germany’s future scientific system, this should be the goal. The continuing development of the research landscape is of central importance, for this will have a decisive effect on our country’s powers of innovation. There is a certain appeal in drafting a new scientific architecture that strips out the complexities that, over the decades, have become inherent in Germany’s research landscape. But let us exercise caution: the rule that “form follows function” has proven to be true particularly in the scientific system.

If we are not to risk missing the point, we must first be clear as to what science can do for society. Its function is to safeguard our nation’s prosperity and our quality of life, and not least also to help us overcome global challenges. To fulfill these functions, science must mean competing with the best of the best, as well as cooperating with world-leading partners – while having the freedom to develop and explore.

Let us first consider the universities, the beating heart of German research. Thanks to the Excellence Initiative, some universities are significantly improving their achievement levels, and thus also their international visibility. But it will still not be possible by 2017, when the Excellence Initiative expires for German universities, to rise to the very top of the international rankings. A fundamental obstacle lies in the structure of German universities: professors in Germany, in contrast to their colleagues at top universities such as Harvard or ETH Zurich, must perform a balancing act between leading-edge research and mass education.

But there is a simple way to raise the profile of the research potential that exists...
in Germany – and that is jointly funded by the federal government and all 16 regional states: were the Max Planck Society to have the status of a graduate university, like Rockefeller University in the US, for instance, it would be among the top five in the Shanghai ranking.

Irrespective of this, however, all those involved face the challenge of clearly defining and pursuing their own mission. The increase in networking must not lead to dilution. Developments in recent years have revealed that those with a clearly defined mission and an independent profile add greater scientific value to the system. Future models of cooperation must build on this premise. Working together facilitates the use of synergies and enables institutes and universities to continue their own development without compromising their respective missions. The goal is not to create new institutions, but to pursue science at its highest level.

Research spaces structured in this way are most likely to have the potential to heighten their international standing when multiple clusters of excellence supported by numerous partners are created in the same location. Prominent experts in the

Regions with high-performance clusters will set the pace

history of science anticipate that, in the future, there will no longer be any predominant individual scientific powers. On the contrary, the future belongs to mid-sized, flexible, autonomous entities. Those regions with high-performance clusters will set the pace. In the long term, I expect to see perhaps five such research campuses throughout Germany.

What is important is that, in these centers, the dividing walls will have been torn down, releasing new potential opportunities for cooperation. The research itself will determine the degree of networking, while each partner’s autonomy is preserved. The Max Planck institutes will be a source of excellence, international visibility and interdisciplinarity in these research spaces, to which they contribute fresh momentum.

The same applies to the anticipated 15 to 20 locations at which maybe only one outstanding cluster will establish itself in the long run. Here, too, Max Planck institutes can form the nucleus. Naturally, the other research institutions also contribute their own expertise. I am thinking here of the Fraunhofer institutes that work shoulder to shoulder with industry to translate fundamental new findings into practical applications, and of the Helmholtz Association, with its considerable infrastructures, and the regionally oriented Leibniz Association. These clusters should be linked throughout Germany, but also internationally.

In considering the research system of the future, we must be clear in our minds that science needs stable funding structures that are unambiguously oriented toward quality and mission. On the other hand, science is not suited to being used as a bargaining tool in the redistribution of income among the federal states, however great the temptation – and sometimes also the need. And it is accordingly counterproductive to erect alternative structures simply because the code for the redistribution of income between federal and regional governments or the ban on cooperation enshrined in Article 91b of the Basic Law stands in the way of a commensurate solution. It is currently unclear whether the move to change this Article will find broad support, enabling the federal government to begin permanently financing research facilities of excellence at universities.

Should the initiative not succeed, it will remain necessary for funding to be provided via defined programs. This would, in my opinion, be an option under the proviso that funds are limited to institutions that qualify on the basis of both mission and quality, irrespective of the logic behind the form of financing. Such a financing mechanism could be simplified with the aid of separate budgets held by the non-university institutions.

Of course I am familiar with the problems and concerns of the public sector – after all, I do not live in an ivory tower – whether it be rising costs or the brake on debt. Nevertheless, we are all profiting from the clear priority attached to innovation in past years. Finance ministers are currently harvesting the taxes yielded by this policy. Federal and regional budgets are measured in multi-billions. The Excellence Initiative II and the current Pact for Research and Innovation cost an average of 1.4 billion euros per year. Is that too much to pay for a potent scientific system that will safeguard our future prosperity?

According to Thomson Reuters, Germany today is one of the six most productive research nations, in second place behind the US – an outstanding result! Yet our current success is not a matter of course. It is essential, here and now, to do what it takes to power up German science to meet the challenges of the future.

Peter Gruss
President of the Max Planck Society
“As the home of 12 of its institutes, North Rhine-Westphalia is an extremely important location for the Max Planck Society,” said Peter Gruss at the Society’s Annual General Meeting, which was attended by around 650 guests from the fields of science, politics, business and society. The NRW institutes, in particular, set a good example when it comes to the transfer of findings from basic research to practical applications. Hannelore Kraft, Minister President of NRW, praised the contribution made by science to structural change in the region at her reception.

The federal state of North Rhine-Westphalia will contribute 45 million euros to the conversion of the Max Planck Institute for Bioanorganic Chemistry in Mülheim to an institute for chemical energy conversion – a solid investment, as noted by the newspaper Westdeutsche Allgemeine Zeitung: “The realization that the answer to a key question concerning Germany’s energy turnaround will be found in the Ruhr area can only be a matter for celebration.” Moreover: “We would wish that many more of the millions allocated to traditional subsidies would be re-dedicated to the promotion of this kind of research.” The high point of the Annual Meeting was the festive gathering at the Rheinterasse event venue in Düsseldorf, which was also addressed by Annette Schavan, Federal Minister of Education and Research, and Sylvia Löhrmann, Deputy Minister President of NRW.

What is Beautiful?

The new institute, for which co-financing of 45 million euros is being provided by the federal state of Hesse, aims to use scientific methods to explain the psychological, neuronal and socio-cultural basis of aesthetic perceptions and assessments in humans. Why, for example, do people perceive music and literature as varying in beauty depending on such factors as culture, society, historical era and individual taste? “In accordance with the mission of the Max Planck Society, the Max Planck Institute for Empirical Aesthetics will establish a completely new research field in Germany. Up to now, no institute in the world has focused on the topic of aesthetics in this form and used empirical methods to research it,” says Max Planck President Peter Gruss.

The new institute will be managed by a Board of Directors consisting of four scientists from the fields of literature, music, and empirical cognitive and social sciences. The institute’s research program will focus on music and literature and – in cooperation with the Max Planck art historical institutes in Florence and Rome – the visual arts.
Of Tapping Woodpeckers and Digital Rainbows

Max Planck Society donates prize money for the physics division of “Jugend forscht”

They are the researchers of tomorrow: Almost 11,000 young people took part in this year’s “Jugend forscht” science competition. After having supported the biology division of the competition for years, the Max Planck Society sponsored all of the prizes in this year’s physics division, totaling 50,000 euros. Wilhelm Boland, Director at the Max Planck Institute for Chemical Ecology in Jena, presented the prize certificate to Timm Piper, national winner and the competition’s youngest participant. “It was great fun. I’ve never been so happy to work on a Sunday. The professionalism with which young people approach research today is simply incredible,” says Boland, who was once a participant in a “Jugend forscht” competition himself. Piper (16) impressed the jury with his understanding of the principles of microscopy and the rigorous application of his ideas. The high school student has already filed a patent application for a new form of microscopic illumination that combines phase contrast with bright and dark field imaging.

Zooming in on the Sun

New solar telescope GREGOR to observe the Sun from Tenerife in unprecedented detail

Nighttime is the astronomer’s daytime. After all, if you want to see the stars, you must wait until it gets dark. However, there is one exception to this rule: the Sun. Close up, it can be used to study not only the characteristics of a typical star, but also its relationship to the planets. Observing eruptions of matter, sunspots, and even the solar magnetic field requires telescopes with large apertures. GREGOR, which was inaugurated on the island of Tenerife in May, is just such an instrument. With a mirror diameter of 1.5 meters, the telescope shows structures on the Sun on spatial scales as small as 70 kilometers, making it one of the world’s three most powerful instruments for observing the Sun.

At the site of GREGOR’s installation – the plateau at the foot of the 3,718-meter-high Teide volcano – conditions are ideal for observing the skies. A consortium of researchers from the Kiepenheuer-Institut für Sonnenphysik, the Leibniz Institute for Astrophysics Potsdam (AIP), the Institute for Astrophysics Göttingen, the Max Planck Institute for Solar System Research and other international partners commenced work on the construction of the solar telescope on Tenerife ten years ago. GREGOR has a completely open structure to prevent air turbulence in the optical path. Thanks to the main mirror, which is constructed from the heat-sensitive glass-ceramic Zerodur, and an adaptive lens, which uses a system of actuators and mirrors to compensate for the schlieren within the Earth’s atmosphere, GREGOR promises to deliver particularly clear images of the Sun.
“The most important discovery of recent decades”

Sandra Kortner from the Max Planck Institute of Physics on the discovery of what is thought to be the Higgs particle

The report made more headlines than almost any other discovery in the field of physics: On July 4, researchers from CERN near Geneva announced that they had found a new particle. Its mass lies just within the predicted range for the Higgs boson particle. The discovery is not only of interest for the media; its enormous significance for science is explained below by Sandra Kortner from the Max Planck Institute for Physics in Munich. Kortner is the head of a Minerva junior research group that carries out research on the ATLAS experiment at the Large Hadron Collider, and the coordinator of an international team.

Ms. Kortner, what is your reaction to the latest findings?

Sandra Kortner: I am very excited and enthusiastic. The measurement results from two detectors are very close. This is really phenomenal. It’s the most important discovery in particle physics of recent decades. This is a dream come true for me.

Do you believe that the long-sought Higgs particle has been found?

We have definitely discovered a new particle. At the moment, the data would suggest that it is the Higgs particle as predicted by the Standard Model. However, we will have to measure the properties of this particle in greater detail to clarify its identity.

Why are there still doubts about the identity of the particle?

We are unable to detect the Higgs particle directly. It arises in the course of a proton collision and decays into different components in mere fractions of a second. The theory predicts that a Higgs particle can decay in several different ways. The decay rates depend on the mass of the Higgs particle. This mass isn’t clearly predicted by the theory. We now have an approximate measured value of 125 to 126 gigaelectronvolts (GeV), but this will become more precise when we have more data. In ATLAS, we have thus far investigated only two of all of the possible decay channels with sufficient statistical significance. These results support the fact that this is a Higgs particle. However, we will have to investigate the other decay possibilities and rates to determine the properties more accurately.

Which other particles might also be possible?

Other particles could also exist that are, in a sense, messengers of a new physics beyond the Standard Model. These include, for example, the particles of the so-called theory of supersymmetry. Therefore, it could also be a supersymmetric Higgs boson. However, based on the currently available data, it isn’t yet possible to say whether this is the case.

Which properties of the particle will you and your colleagues measure in the future?

In addition to the mass, we want to measure, for example, the spin. In very simplified terms, this can be imagined as the rotation of the particle. The Standard Model predicts a zero value for the spin. These and other parameters are important because they will enter into the Standard Model. Their measurement will still take years.

Physicists today know an entire array of elementary particles. What’s so special about the Higgs boson?

The Standard Model has two types of particles: one type forms the building blocks of matter, while the other mediates the forces between them. These particles have very different masses. There are even massless particles, such as the photon. The Higgs mechanism, which also predicts the existence of the Higgs particle, explains how the particles attained their mass. In this respect, it is something special. It is the key Colliding knowledge: The new particle can’t be observed directly – it is created during the collision of protons and decays into different components within mere fractions of a second.
particle for understanding matter. However, the Higgs particle doesn’t explain the magnitude of the mass of particular particles. It doesn’t even predict the mass of the Higgs particle itself.

Assuming the identity of the particle is confirmed as Higgs, what’s the next step? We’re all convinced that, above a certain energy, a new physics that goes beyond the Standard Model must arise. The theory of supersymmetry is such an extension. It would explain why there are two different types of particles, namely the fermions, with half-integral spin, and the bosons, with integral spin. Supersymmetry predicts the existence of a large number of as yet undiscovered particles. The Large Hadron Collider (LHC) is ideal for finding these particles. In addition, the lightest predicted supersymmetry particle is a prime candidate for the mysterious dark matter. This search will also take us many more years to complete.

If it emerges that this discovery is, in fact, the Higgs particle, will it be awarded the Nobel Prize in Physics? I think so. However, I don’t think the prize will be awarded to CERN or the experiment collaborations, but to the scientists who proposed the Higgs mechanism. This could prove difficult, as several people made an important contribution to this process: In addition to Peter Higgs from the University of Edinburgh, Robert Brout and François Englert in Brussels, and Carl Hagen, Gerald Guralnik and Thomas Walker Kibble at Imperial College London also developed the theory almost simultaneously. Brout is dead, so there are five physicists who should still be honored. But the statutes of the Nobel Committee don’t allow this.

Could at least a few experimental physicists from the LHC or the detectors hope for a Nobel Prize? No, it isn’t possible to single out three people who played an outstanding role. This discovery was achieved through international collaboration, in which absolutely all of the participants contributed to the success. This is why none of us has any hope of being awarded the prize. Nevertheless, we are all very proud and overjoyed at the moment – today’s achievement alone is prize enough for us.

Interview: Thomas Bührke

Victory with the Sulfur Pearl

The audience-awarded prize for the “Science Summer” event in Lübeck went to a team from the Max Planck Institute for Marine Microbiology

And the winners are: Manfred Schlösser, Andreas Krupke, Wolfgang Hankeln, Lorenzo Franceschinis and Dennis Fink (left to right) photographed in front of the cross-section of a bacterium enlarged by a factor of one million.

Good research alone isn’t enough to win the “Wissenschaft interaktiv” competition; the content of the research must also be communicated very effectively. Which of the finalists selected by a jury of experts will go home with the 10,000 euros in prize money is decided by the audience of the “Science Summer” event, which was held in Lübeck this year. And this year’s audience opted for a contribution by the team from the Max Planck Institute for Marine Microbiology. Using an oversized model of a bacterial cell, videos and film clips about special species, such as the giant sulfur pearl, the winners presented a guided tour through the world of microorganisms (see also “On the Net,” page 12). Audience members with a particular interest in the topic were able to access more detailed material using their smartphones.

As is always the case with the Science Summer event, the main priority was facilitating direct dialogue between the researchers and the audience: “It’s very important that we also learn how to communicate about the science that inspires us. We had enormous fun doing this,” said Dennis Fink at the award ceremony. Upon completing their doctorates, Fink and his colleague Wolfgang Hankeln from the winning team expect their future at the Max Planck Institute in Bremen to involve science communication. Their idea for an agency that would support researchers in communicating their research topics to the public has already been approved for an EXIST Business Start-Up Grant by the Federal Ministry of Economics and Technology and the EU.

This is the second time in the five-year history of the “Wissenschaft interaktiv” competition that a team from the Max Planck Society has won: Carla Cederbaum and Elke Müller from the Max Planck Institute for Gravitational Physics claimed victory in 2001 with the project “From Newton to Einstein: A Journey through Space and Time.”
Location Luxemburg

The Max Planck Institute Luxemburg for International, European and Regulatory Procedural Law is under way

Two renowned legal experts have already been recruited for the new institute: Burkhard Hess from Ruprecht-Karls-Universität Heidelberg and Marco Ventoruzzo, professor at both Bocconi University School of Law in Milan and Pennsylvania State University. They plan to commence work there this year. The new Max Planck Institute will focus on the principles of court and administrative proceedings and cooperate with the Faculty of Law, Economics and Finance at the University of Luxemburg.

“Thanks to the presence of the European institutions in Luxemburg, particularly the European Court of Justice, Luxemburg is an ideal location for the new institute,” says Peter Gruss, President of the Max Planck Society. For François Biltgen, Minister for Higher Education and Research in Luxemburg, the establishment of this Max Planck Institute represents the completion of a further milestone in the evolution of the research landscape in Luxemburg. It is planned to develop the Luxemburg-based institute into an international competence center for legal studies. The Grand Duchy has already approved sustainable long-term financing of the institute.

Guided Tour of the World of Microorganisms

A team from the Max Planck Institute for Marine Microbiology in Bremen won the 10,000-euro "Wissenschaft interaktiv 2012" prize that is awarded each year by the audience of the "Summer Science" event. The honored exhibit led visitors on a guided tour of the world of microorganisms and provided answers to many questions: How prevalent are microorganisms in the environment? Which chemical compounds can they use to live? What role do they play in climate change? The story of the creation of the exhibition work is presented in an entertaining YouTube video.

www.youtube.com/user/MediomixMedia

The Earth, Socially Networked

What would the Earth post about us humans in its social networking profile if it could? The Earthbook shows, in time lapse, how the planet builds a virtual relationship with humans – and quickly raises the question as to whether the Earth would like to be friends with a species that exploits its natural resources.

www.youtube.com/watch?v=YNSNu1qBqhE

Science Images from a New Perspective

The traveling exhibition "Images of Science," which can be seen in St. Petersburg starting September 3, 2012, is now also available on the Internet. Users can click from photograph to photograph and view detailed information about how the individual images were created. Scientists from the 80 Max Planck institutes submit the images each year as part of a competition. The resulting exhibition, which includes over 50 large-format images, provides fascinating insight into the world of science.

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Some forty years ago, bacteriologist George Packer Berry made a confession in a speech to his students at Harvard Medical School: “Our university has done its best to communicate to you the latest discoveries in medical science, but around half of what we have taught you is probably wrong. Unfortunately I am not able at this time to tell you which half.” While his fellow professors nodded in agreement, the parents in the audience, who had paid handsomely for their children’s education, were not amused. Like most of their fellow citizens, they expected science to produce guaranteed, grounded knowledge, to manage it carefully, and to pass it on to young people.

Politicians never tire of hailing knowledge as the raw material of new technologies and thus of progress and prosperity. Socially and politically, knowledge and science are synonyms – inseparable parts of a whole that share the same mission. Fulfilling this mission is expensive, so our society wants to steer the world of science and knowledge as precisely as it possibly can.

Yet this image of knowledge and science distorts reality and causes many of the problems European science is currently facing. We can resolve these problems only if we understand the difference between science and knowledge, and then foster each of them in distinct and appropriate ways. After all, science concerns itself less with knowledge than it does with ignorance. It tries to turn ignorance into knowledge – and considers this act of transformation more important than the result.

Most researchers regard the knowledge they generate almost as a byproduct of their work, and they are happy to leave its organization and management to others. From this perspective, a biochemistry textbook is not biochemistry but the history of biochemistry – a summary of what biochemists already know, or at least should know. Real biochemistry, in contrast, would be a surprising experimental result, an important suggestion from a colleague, or a lecture about a new discovery. Research scientists are

**TEXT GOTTFRIED SCHATZ**

**Freedom Creates Knowledge**

Knowledge changes constantly as research probes the validity of existing knowledge and converts ignorance into new knowledge. Research may also create new ignorance by discovering entirely novel territories whose very existence we had not imagined. Our author analyzes the conditions most conducive to drawing back the curtains.

Researchers regard the knowledge they create as a byproduct...
truly at home, not in the warm embrace of certainty, but on the fringes, where knowledge stares ignorance in the face.

Still, in the reality of everyday science, most scientists devote the bulk of their time to managing and disseminating knowledge. Only a small minority work on turning ignorance into knowledge. Within this minority of researchers, only a tiny elite is destined to achieve the loftiest goal of science: creating new ignorance. The onslaught of scientific research constantly changes the world of knowledge – and thus changes us. We may be able to temporarily manipulate knowledge, even falsify it, but in the long run, it is always stronger than we are. It obeys its own laws, which we can neither know precisely nor change. “Nothing is more powerful than an idea whose time has come”: Victor Hugo may not have actually said that, but it is nonetheless true.

Although we have only limited ability to control it, knowledge is still a vital part of our genetic inheritance. We humans have not one, but two hereditary systems – one chemical and one cultural. The chemical system consists of threadlike DNA molecules and a few cellular structures; it determines what we can be. The cultural system consists of the transmission of knowledge and values; it determines what we then actually become.

Our chemical system barely distinguishes us from other mammals, but our cultural system is unique in nature. It gives us language, art, science and ethical responsibility. Both of these inheritance systems transmit knowledge from one generation to the next with great reliability, but they do make occasional mistakes.

Transmission errors in the chemical system – mutations – change our bodies, while transmission errors in the cultural system change how we think and behave. In the long run, such errors protect us from biological and cultural stasis, but in the short term, they can be catastrophic. When the error rate in the chemical system is too high (for example because of exposure to powerful radiation), a population or even an entire species can disappear forever. And when the error rate in the cultural system exceeds a certain level (for instance in revolutions or in long-lasting dictatorships), a culture can die.

In our evolution from animals to modern humans, the amount of knowledge stored in our chemical inheritance system has increased only modestly. Apes and mice both have almost as many genes as we humans do. In contrast, the knowledge stored in our cultural system has increased by many orders of magnitude – and is now threatening to overwhelm the transmission capacity of the system. In technology and in the natural sciences, data, knowledge and understanding have grown exponentially since the
middle of the 18th century, and even hyperbolically since the second half of the 20th century. At first sight, the digital revolution may seem to be enabling us to manage this explosion of information without effort: we can store, organize and analyze enormous amounts of data at unbelievable speeds and then transmit it all over the world. And even though electronic brains and storage media are currently approaching their physical limits, new inventions will almost certainly overcome them.

Yet such advances will not keep our knowledge safe, as today’s digital storage media are not durable. Magnetic tapes, hard drives and optical devices can rarely store data safely for longer than a few decades. The Domesday Book, which was written for William the Conqueror in 1085 as a land register for his kingdom, can still be admired in its climate-controlled display case in Kew, but the digital version of 1986 has become largely unreadable. As we cannot yet store digital data for long periods, we must constantly “refresh” it by recopying – which is essentially transferring them from one sinking ship to another that will likewise sink soon.

Beyond its instability, digitally stored knowledge is also vulnerable to accidental or intentional corruption. It is child’s play to alter digital data without leaving any traces. Today, photographs no longer prove anything at all, as they can be digitally manipulated in so many ways. In his dark vision of the future, 1984, George Orwell described a totalitarian regime that doctors all reports about past and current events so thoroughly that the fabrications can no longer be detected later. I welcome the European Community’s efforts to digitize our cultural heritage as exhaustively as possible, but I am also concerned about the vulnerability of such data. Pilate’s cynical question, “What is truth?” is omnipresent in the digital world.

We scientists do not, however, find the facts that knowledge is never definitive and that it can’t yet be stored safely in digital form as threatening as it may sound. As already mentioned, we have an ambiguous relationship with knowledge: we do everything we can to create it, but as soon as we have done so, we mistrust it and never stop calling it into question. The possession of knowledge is less important to us than the conviction that we can always generate it anew through observation and critical thinking.

Knowledge is a child of the past and, in a constantly changing world, can never guarantee us the future. This power is reserved for the eternal youth of scientific inquisitiveness, which searches the present for the hypotheses of the future. This process calls for people with new ideas who challenge existing knowledge and dogmas, for only those who swim against the current can discover new wellsprings of knowledge. It takes people who see what everyone else sees, but then think what nobody has ever thought before. It takes people who intuitively recognize that the path from A to C does not lead through B, as everyone else thinks it will, but through X or Z. All this demands intellectual courage – a researcher’s most important gift.

Genuine researchers never hesitate to head into dangerous waters that promise new knowledge. American scholar John Augustus Shedd gave us researchers a good motto for our work: “A ship in harbor is safe, but that’s not what ships are made for.”

Knowledge is precious, but it shouldn’t be overrated. By putting too much emphasis on knowledge, our schools, universities and political institutions stifle independent, critical thinking – the heart blood of science. Like all too many politicians, the public at large sees research as a strictly logical process in which researchers patiently put pieces together until the carefully planned building is complete. But innovative research is almost the exact opposite: it is intuitive; it can’t be planned; it is full of surprises; it may even be chaotic – just like innovative art.

Innovative art and science are not strolls on carefully tended paths, but expeditions into uncharted wilderness, where artists and researchers often lose their way. In an orderly, peaceful world, the maps have already been drawn and the creative researchers are already elsewhere – somewhere their intuition has led them.

Our schools, universities and research ministries place too one-sided an emphasis on knowledge.
Science in Europe suffers from the mistaken belief that research will be more innovative if it is given narrow, concrete goals. A fatal consequence of this misunderstanding is the official research programs that force researchers to concentrate on “relevant” problems: deforestation, AIDS, gender studies, cancer and climate change. Such politically motivated basic research is also referred to as “focused” research. Often, researchers are required to work as networks with partners who are “balanced” in terms of gender, language or geographic location. But it is absurd to expect basic research to be “focused,” “relevant” or “interdisciplinary” and to be performed in mandatory networks.

Innovative research creates its own goals and methods; if they are ordered top-down from the outset, then the research can never be innovative. Innovation can be planned only to a very limited extent, and is driven by contrarian individuals. This has nothing to do with scientific arrogance; rather, it is a consequence of the special laws and the fragility of human creativity.

Most countries in Europe are busy expanding their scientific bureaucracies, many of which are now as complex as a Swiss watch, without, however, even remotely approaching the same precision. The purpose of an administration is to prevent exceptions, unexpected situations and mistakes, and to ensure that everything proceeds according to predetermined rules. For this reason, the management and dissemination of knowledge benefit greatly from an efficient scientific administration. But since exceptions, unexpected situations and mistakes are the very essence of innovative research, administration necessarily poses an obstacle to scientific discovery. An overblown administration therefore inevitably inhibits innovation. The same is true of the tendency to coordinate the work of individual researchers as seamlessly as possible. Organization is the enemy of innovation – and coordination the enemy of motivation.

If we wish to foster science in Europe, we must not forget that knowledge and science have different characters and inhabit different worlds. Science in Europe doesn’t need elaborate “programs,” but merely adherence to three simple rules. First, we must rigorously select the most talented researchers – even if such a selection contradicts a widespread but twisted understanding of democracy. Second, we must systematically give those talented people the necessary means to do their work – even if that means less money for run-of-the-mill research. And finally, we must allow them enough time and freedom to follow their own intuition and ideas.

THE AUTHOR

Gottfried Schatz, born in 1936, is professor emeritus at the Institute for Biochemistry at the University of Basel Center for Molecular Life Sciences. Born in Austria, he studied chemistry and biochemistry at the University of Vienna, the Public Health Research Institute of the city of New York, and Cornell University in Ithaca, New York, before joining the University of Basel. Professor Schatz was involved in the discovery of mitochondrial DNA. This article is the text of a speech he delivered on the occasion of the 50th anniversary of the foundation of the Max Planck Institute of Immunobiology and Epigenetics. It also appears in slightly modified form as an essay in the collected volume Wa(h)re Wissenschaft (Austrian Academy of Sciences, 2011).
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Although everyone is talking about species protection, the lack of information about the species that need to be conserved can be quite shocking. To ensure that threatened animal species can be protected more effectively, the research team working with Dalia Amor Conde in the Conservation Demography Research Area of the Evolutionary Biodemography department headed by James W. Vaupel at the Max Planck Institute for Demographic Research in Rostock is using special methods to gather important data about the lives of endangered animals.

TEXT KLAUS WILHELM

The jaguar has taken the bait. Now the dogs make their grand entrance – at dawn, in the service of science and for the protection of the big cats. Tony Rivera, an experienced former jaguar hunter, lets his pack of hounds off the leash. They have picked up the scent of the jaguar across the dense Mayan rainforest of the southern Mexican state of Yucatán. Fernando Colchero and his assistant hurry behind the panting dogs. For years, he and his colleague Dalia Conde, together with researchers from the National Autonomous University of Mexico (UNAM) and the conservation NGO Jaguar Conservancy, have been studying the habitat and movement behavior of the charismatic predators in the Yucatán peninsula, Guatemala and Belize.

Normally, when jaguars are pursued, they simply make themselves scarce. But not this time! Instead of fleeing up the next tree, the animal decides to attack. The jaguar leaps onto one of the dogs in a single bound. He fights for his life until his barking fades away. To everyone’s surprise, the jaguar then releases its victim and disappears into the undergrowth.

“We thought the dog was dead,” recalls Colchero today. The young man and his companion run after the big cat, which suddenly darts out from the green mass of vegetation again, confronting its pursuers. “It was about to go for us,” says Colchero, “the adrenaline rush in my body was incredible.”

His companion lashes out with a machete. Meanwhile, Colchero steps toward the jaguar, which then actually hesitates. At that moment, the rest of the research team arrive and sedate the indignant animal with a dart.

“The dog that was attacked wasn’t dead at all, he just played dead,” says Colchero, a native of Mexico. “It was a female jaguar. Females don’t bite dogs to death, but male jaguars do.” The jaguar is fitted with a collar equipped with a GPS device that will track it as it moves about in its habitat. Such data from the cooperative project conducted by the Max Planck Institute and the Mexican non-governmental organization Jaguar Conservancy is crucial for future research in Rostock and for protecting the animals.

“That was a stressful project,” confirms Dalia Amor Conde, Colchero’s partner in both his professional and private life. “One time, members of the team were kidnapped by drug dealers in the forest in Guatemala,” says the young biologist. Luckily, no one was hurt, but we had to change our field site and we lost one year of data.

The two scientists look out from the meeting room in the Rostock-based Max Planck Institute directly across an arm of the Baltic Sea, onto a scene that is completely different from what they would experience in the jungle heat. Cool, calm, picturesque. With them are Owen Jones and Alexander Scheuerlein. Together they form a key part of the Evolutionary Biodemography department (EvoDemo). The biologists, mathematicians and statisticians have something completely new in mind: they want to transfer human demographic methods to animal populations.

As a discipline originally tailored to humans, demography uses statistical methods to figure out how populations evolve. It deals with age structures, births and mortality, as well as the environmental and social factors that change the population. These are all things that can also apply to animal populations. Dalia Conde, head of the Conservation Demography Area, thus views the extinction of a species as a demographic process.

The flexible fertility and mortality rates lead to a situation where the populations of a species become smaller and smaller. If many populations shrink,
eventually the entire species will disappear. “In order to be able to use management programs to protect species more effectively, we need to understand the demographic processes of these species,” says Conde.

As an example, biologists have for a number of years now been using population viability analysis, as it is known, to calculate the probability of a population becoming extinct after a certain period of time. Demographic factors are incorporated into the assessment: What is the mortality rate of a species over the course of its life? How many young does it have, or in other words, how fertile is it?

Critics, however, constantly challenge the method, as it delivers reliable results only if it is based on realistic data. “But due to a lack of data, many of the analyses are based on vague expert opinions on a species,” says Dalia Conde.

The biologist therefore initiated a project called DatLife – a digital platform that systematically collects all the globally available demographic infor-
Photos: Jaguar Conservancy; graphics: Animal Conservation

mation that has ever been published about all known animals. It illustrates just how flimsy the scientific basis is that underlies much of the data. Many of the assessments made about how long a species can live are based on just one individual.

Researchers at the MPIDR know the maximum lifespan of only 1 percent of amphibians, 7 percent of reptiles, 14 percent of birds and 23 percent of mammals. “Not nearly enough,” remarks Alexander Scheuerlein, “and the maximum lifespan doesn’t yet say much in terms of a viability analysis.”

The situation is even worse when it comes to other demographic data. Even in the case of mammals, basic information is known for just 2 percent of species. The reason for this dire state of affairs is simple: the Max Planck researchers’ experience in capturing jaguars clearly shows how difficult it is to collect demographic data in the wild. They have thus been working on an alternative for the last two years: zoological gardens.

INCOMPLETE SPECIES INVENTORY IN ZOOS

A total of 850 zoos around the world are linked via the International Species Information System (ISIS) and supply this treasure trove with new demographic data about their inhabitants on an ongoing basis. Reliable data on more than 2.5 million individuals has been collected to date, some of it covering accurate descriptions recorded over more than 40 years: time of birth and death, onset of sexual maturity, number of offspring and rate of reproduction – everything is there.

For the first time ever, the Rostock scientists, together with their ISIS colleague Nate Flesness, determined the composition of the cohort of inhabitants in the world’s zoos. This means that 25 percent of all bird species and 20 percent of all mammals are represented in zoos, but only 12 percent of reptiles and 4 percent of amphibians. Some 66 percent of all mammal species classified as vulnerable, endangered or critically endangered are kept in zoos.

The figures for endangered birds, reptiles and amphibians, on the other hand, are significantly lower. “Overall, one in seven endangered animal species is in captivity,” says Dalia Conde. “There is room for improvement, but it’s better than nothing.”

The question remains as to what the demographic data relating to zoo inhabitants really means and whether it reveals anything about their wild relatives. “Let’s take the mortality of species,” says Alexander Scheuerlein, drawing a few curves on a sheet of paper.
They illustrate the likelihood of animals dying at certain stages of life. This is linked to the principles of evolution.

An animal’s fitness, in evolutionary terms, is measured solely by the number of its progeny, which in turn is determined by fertility and mortality. “So we can understand evolution only against the background of demography,” says Owen Jones, describing the EvoDemo group’s philosophy. “Evolutionary processes affect species demography – and vice versa.”

The popularly held theory purports that mortality increases as life progresses, while fertility decreases. However, Alexander Scheuerlein cannot detect this rule universally in the demographic data sets that he has collected. Some species show a constant mortality rate, such as the freshwater polyp, Hydra. For many others, it is very high shortly after birth, but then decreases progressively – even into old age in the case of tortoises. “Probably because they are getting bigger all the time and can stand up to natural predators more effectively.”

The mortality curves of baboons and chimpanzees are fundamentally similar to those of humans. The Max Planck researchers have now constructed mortality curves for around 100 animal species, all of them based on data collected in field and laboratory studies.

**LIFE’S MORE COMFORTABLE IN THE ZOO**

The Rostock-based researchers are currently analyzing the demographic data submitted by the zoos. They are using it to construct mortality curves and compare them with reliable curves of populations living in the wild. They want to find out the extent to which the curves differ. It is clear that life is very different and much tougher in the wild than it is in zoological gardens. After all, wild animals aren’t routinely cared for by a vet in the way that zoo inhabitants are.

While no findings are yet available on the differences in important demographic data, the MPIDR team certainly has some initial presumptions. Paired birds whose social systems aren’t complex probably have similar mortality rates in the zoo and in the wild. The mortality curves run in parallel even though the zoo inhabitants naturally live longer.

The situation is somewhat different for social animals like baboons. For animals like these, natural social systems are often different in the zoo, where there are no longer any alpha or beta males. This has a sustained influence on mortality rates.

Through such comparisons, the scientists want to obtain enough information to enable them to draw conclusions about the demography of wild animal species for which they have no data. This data could then be fed into new population viability analyses – with ultimately much more meaningful information for the management of endangered species. “I trust this data much more than vague expert opinions,” emphasizes Dalia Conde.

The data from the zoos could also be used as control populations for future field studies on endangered spe-
cies. In the zoo, animals aren’t subject to the same environmental influences as they are in the wild. Comparison with the zoo controls should also provide the researchers with valuable information about which environmental factors, such as climate change, affect the demography of wild species.

LACK OF DATA MAKES SPECIES PROTECTION MORE DIFFICULT

All of this requires sophisticated methods, processes and programs. The Max Planck researchers, Colchero, Jones and Maren Rebke, also a member of EvoDemo, have just developed a software program to analyze field study data. It is called BaSTA (for Bayesian Survival Trajectory Analysis) and its purpose is to close the gaps and resolve the shortcomings that constantly arise in field studies. Ordinarily, scientists acquire their demographic data by capturing animals, putting tracking collars with an ID number on them or ringing them. In this way, they can follow the animal’s fate. Ideally, the animal’s age is known. It should also be noted in any later measurements, and the time of death should be recorded.

In reality, however, the researchers often don’t know the animals’ ages. Or they can reconstruct only part of the lifespan. Nevertheless, in order to get results, they simply estimate the mortality and use only individuals whose age is known. “Both of these things reduce the information value of a study,” says Colchero. This can result in incorrect mortality data even in the last stage of life. And the biologists rarely find all of the animals previously included in their study. Are they already dead, or is there some other reason for their disappearance?

In short, much of the demographic data remains vague, and consequently, so do the recommendations for species protection. Out of necessity, biologists and statisticians recently developed statistical processes that complete the sketchy data collections by adding sound assumptions. Many of these methods are good, but complicated for the average user. “BaSTA, on the other hand, is child’s play to use,” says Owen Jones enthusiastically.

The program can even be used to extrapolate times of birth and death. “We take as much data as possible from a study and use it to model parameters to close the gaps,” says Jones, the British biologist. No information is lost. This means that BaSTA will also be valuable for future jaguar studies. “In order to use our demographic models for protecting these and other animals, we need to understand their habitats,” says Dalia Conde. By this she means how big their habitat is and how they use it. The populations of big cats still seem to be reasonably robust, even though they have already lost 40 percent of their former habitat in Central and South America – especially in the Amazon region but also in the Mayan rainforest.

A major problem is the fragmentation of their habitat. For this reason, Dalia Conde and Fernando Colchero, supported by the Mexican government and several non-government organizations, have studied the role played by the construction of roads in the fragmentation of the jaguar’s habitat.

The scientists and their colleagues trekked through the Mayan rainforest for months, experiencing the misery of how difficult it is to apprehend the timid animals. They eventually caught seven females and four males. Since then, five of them have been wearing collars with radio telemetry sensors, and the others have been fitted with GPS collars. This enabled the two researchers to determine the animals’ positions four times a day for a number of years, and consequently to analyze the movement pattern of the big cats.

DIFFERENCES BETWEEN THE SEXES

At the end, the biologists loaded their data into a computer model. Their results showed that, while males are happy to live in densely populated areas and cross roads more frequently, the females purposely avoid these regions and only rarely cross the road. “They see the road and they turn around,” says Conde. “As if they were allergic to it.” The males,
daredevils that they often are, are also much more at risk of getting run over.

The researchers were able to use their model to identify locations at which the animals crossed the road most frequently. They advised the authorities to build bridges or tunnels for the jaguars precisely at those locations. Several jaguars (and other animals) have actually died already at one of the crossing hotspots predicted by the researchers. “Protective measures for the jaguars can also help other species,” confirms Colchero.

In a second study, Conde and Colchero have shown how the big cats use their habitat. The biologists have also verified that males and females have a different mentality. Male jaguars much more frequently live in areas of the forest where there are very tall trees and scarcely any undergrowth, as they know from experience that this is where they will find the best prey.

The females also wander through such regions, but they prefer areas with smaller trees and dense vegetation cover, which makes each movement difficult. “It is extremely hot and sticky here because it is much easier for the sun to penetrate through to the ground,” says Conde, who knows this from her own experience. Furthermore, the females, unlike the males, avoid large agricultural spaces, where they are largely unprotected.

The selection of locations appears to be carefully thought out. That’s because poachers also prefer forested areas with tall trees, where it is easy for them to get around. And they advance a maximum of four kilometers into the forest, meaning that they stay close to paths and roads wherever possible. “In this way, the females avoid male jaguars and poachers who could harm them and their young,” says Dalia Conde. Based on these findings, the biologists can give the conservationists specific information about the areas of the forest where conflicts between jaguars and humans are most likely to occur. And then they could work more with the local population in precisely these spots.

In a subsequent step, the Rostock biologists want to link the demographic data with their findings about the animals’ habitats in order to provide specific recommendations for species conservation programs. Some species, such as the black rhino, the European wolf, the West African goliath frog and the East African Agapornis parrots, live in a stable habitat, but their populations consist of only a few animals.

With the new knowledge about fertility and mortality rates, researchers could predict how many males and females would have to be released into the wild to ensure the evolution of a stable group. Conservation programs could also be optimized for declining habitats and semi-stable populations, as in the case of the jaguar.

In the worst case scenario – a shrinking habitat and declining population density, as is the case for many Australian amphibians – just one option remains: live in the zoo. And wait for better times.

TO THE POINT

- Reliable demographic data exists for only a fraction of all animal species. The DatLife database, which is expected to be online at the end of this year, therefore collects globally available information on all known animal species.
- Observations of zoo animals could help close any gaps in knowledge. But consideration must be given to the fact that life in captivity can have an effect on the demographics, with the result that species with complex social systems may possibly have a different mortality than their counterparts in the wild.
- Male jaguars in the Central American rainforest frequently live in densely populated areas and cross roads. Females, in contrast, live a more reserved existence and prefer forest areas with dense understory. The researchers can use this knowledge to refine their demographic models for the conservation of these predators and the improvement of protective measures.
Life on the Move

Whether birds that crisscross the globe, whales that navigate the vastness of the oceans or wildebeest on the African savannas – the major animal migrations in our world present an incomparable spectacle. Yet in many cases, surprisingly little is known about either their exact destinations or how they get there. At the Radolfzell observatory of the Max Planck Institute for Ornithology, Martin Wikelski and his team use miniature transmitters to track a wide variety of species on their travels.

Each year in October, millions of fruit bats land in Zambia’s Kasanka National Park before moving on in December. Their exact routes and behavior patterns can be tracked only with the aid of miniature flight recorders.
It is distinctly cool for an evening in May. The sun has just gone down and now the chilliness starts creeping up the spine. Beneath the eaves of the primary school in Konstanz, something is moving: a gentle rustling sound can be heard, overlaid by faint, high-pitched squeaks. Suddenly, it all happens very quickly: first one, then another, then five at once – they launch themselves in half-second intervals, dropping down in free fall almost to the ground before soaring back up, then shearing off to make room for the next one. These noctule bats are headed for the best feeding sites around Lake Constance. Tonight there are 89 of them. A few days ago there were 200. Some are already on their way to the far north, where midges and mosquitoes are far more numerous during the summer.

As part of their research at the Max Planck Institute for Ornithology, students from the University of Konstanz are out in the field in teams of two, armed with compasses and receivers. Days before, they helped bat expert Dina Dechmann fit several of the creatures with tracking tags. Now their task is to locate them and keep plotting their exact position. The rhythmic beeping of the transmitters is reminiscent of a heart monitor. Each bat sounds slightly different. The closer they are, the louder the tone. It’s going to be another long night. One team member takes the measurements, the other writes them down. Some will be on their feet until midnight, others until sunrise. No one knows what the night will bring – this is research with a touch of spookiness. Still, in teams of two, they aren’t alone.

“Bats, quite literally, live under the same roof as we do, but we know little about their migration routes,” says Dechmann. In addition to a transmitter, the creatures – which can live to be 10 to 12 years old – are also implanted with a microchip for recognition purposes. “Many of them migrate on a regular basis, while others stay here. The young ones don’t fly with their mothers. But how do they know where to go? And what the males do is completely unknown.”
Martin Wikelski is the Director of the Radolfzell observatory, one of two locations operated by the Max Planck Institute for Ornithology. Wikelski switched from Princeton University to Radolfzell in 2008. He, too, is fascinated by animal migrations – whether by land, by water or by air. Besides various bird species, he has tagged giant tortoises in the Galapagos Islands, Monarch butterflies in the US, and agoutis, a rodent species that measures up to 65 centimeters in length, in Panama. He uses the latest telemetry to realize Alexander von Humboldt’s vision of “understanding the appearance of physical things in their own context, [of understanding] nature as a whole whose inner forces give it life and movement.”

For Wikelski, the planet is really just a single pulsating organism. “Animals are constantly on the move. Some over only short stretches, others over huge distances.” Back in Princeton, he developed the Movebank platform, a global animal migration database that is now used by researchers the world over to store data on the movements of animals in the wild. One click is enough to track the migration of gulls tagged in Finland and Russia all the way to Istanbul and Lake Victoria in East Africa. Or the comparatively short distances covered by agoutis in the rainforest.

**RODENTS SPREAD TREE SEEDS**

These rodents eat the seeds of tropical trees, such as Brazil nuts, but they also bury some of them for hard times. The researchers therefore fitted nuts with transmitters and magnetic contacts. If a nut was moved, the magnet triggered an alarm. In this way, the biologists were able to track the nuts as they were carried from their native tree through the forest. In the course of a year, agoutis dug up and reburied one nut 36 times, wandering 600 meters through the rainforest as they did so. This also increases the chance that the nut will germinate and one day become a tree.

“We are familiar with perhaps one percent of the lives of animals in the wild, because up to now, it has been possible to observe them only sporadically,” Martin Wikelski explains. “But the animals carry our transmitters around their entire lives.” The tags not only measure time and place, they can also pick up temperature, acceleration, speed and even the animal’s heart rate. Given that each type of behavior entails typical patterns of acceleration, it is possible to conclude from the data what the animal is doing at any time. For example, the transmitters reveal how many pine needles a Capercaillie eats. For each species being tracked, the scientists discover new behavior patterns. “Basically, with this technology, we are also revolutionizing behavioral biology.”

Many species carry plant seeds with them on their travels, thus making a significant contribution to biodiversity.
Some seeds travel around the world in the digestive tract of migrating birds. Insects pollinate flowers as they move from one to another.

Around-the-clock observation gives researchers a completely new picture of a species. Species such as the Venezuelan oilbird, once suspected of destroying seeds, have proven to actually be spreading them. This bird, which has such a high oil content that it can be rendered or dried and burned as a torch, was formerly regarded as a rainforest parasite. Oilbirds spend their days in caves, flying out at night to feed on fruits. Back at their roosts, they excrete the seeds, which had no chance of germinating — or so it was thought.

“We caught and tagged two birds with transmitters. The next morning, we entered the cave — but there were no birds!” Martin Wikelski recalls. “We caught a few more, and they didn’t come back, either.” They tried a third time, and to their surprise, on the following day, the birds tagged first were back again. “It’s a completely different story: They fly to a tree, eat some fruit, then settle down 100 meters away and spit out the seeds. That’s the first propagation. Then they move on to the next tree.” After their last meal, they head for a roosting tree that can be up to 80 kilometers away, where they scatter more seeds. Only then do they return to their cave.

According to past estimates, there were some 10,000 oilbirds living in the Humboldt cave in Venezuela. Now scientists believe there could be three times as many, given that birds spending the night in trees had not previously been...
Bats, like migrating songbirds, cover long distances predominantly at night. As a result, researchers are compelled to make nightly excursions in vehicles converted into mobile receiving stations.

A mini-transmitter on the back of an orchid bee in the rainforest of Central America. The minimal 0.2-gram weight of the transmitter doesn’t impede the animal’s movements.

The scientists’ antennas pick up the signals from the transmitter, enabling them to create a movement profile.

WANDERING PHEASANTS IN THE HIMALAYAS

Wherever the researchers put their transmitters to work, they come upon something unexpected. Take, for example, the high-altitude wanderings of the Himalayan blood pheasants. These birds were tracked simply in order to discover whether all animal migrations follow similar natural laws. “We thought that when snow falls high up, or it gets too cold, they would move to lower altitudes. But some just walk three valleys further on and remain at the same height. And I really mean “walk”. They don’t fly; they literally walk up and down the mountains.”

This applies in the case of the African fruit bats whose behavior Wikelski’s colleague Dina Dechmann has been studying in Ghana. *Eidolon helvum*, the straw-colored fruit bat, is a long-distance flyer capable of travelling 1,500 kilometers across the continent. They are also suspected of spreading disease. Some tribes consider them to be a delicacy with aphrodisiac properties, and try to bring them down with shotguns. This is one reason why the population has drastically declined.

“Earlier studies indicated that this was a key species for the African rainforest, because they are efficient distributors of seeds,” explains the Swiss biologist. Accordingly, 96 percent of the trees are thought to be the product of fruit bat excretions. This is an unusual fact, given that most fruit eaters either remain permanently below the canopy of the tropical trees that provide their food supply, or excrete directly in situ.

The straw-colored fruit bat, in contrast, has a somewhat sluggish digestion. And as in the case of the oilbird, a 100-kilometer flight for a feed is a mere bagatelle. In fact, after eating, the bats may even fly the same distance back home. Dina Dechmann and her team are currently studying a colony of around 300,000 of the creatures in Accra. “During migration, this species can easily cover up to 400 kilometers in one night. We are interested in whether and how the group members of this highly social species communicate with one another.”

Locating them is still an arduous process and is possible only when they stop to roost during the day. Solar-powered transmitters don’t work well with nocturnal animals, even though they spend their days suspended in trees. For this reason, the scientists are developing powerful new GPS transmitters that can send a permanent stream of data.

OBSERVATION POSTS IN SPACE

Transmitters of this type are of central importance for another of Martin Wikelski’s major projects: International Cooperation of Animal Research Using Space, or Icarus, for short. Year after year, billions of songbirds, bats, and even insects migrate over huge distances. The ecological effects of their migration patterns and how they affect climate change are still largely unknown.

Modern sensors are so minuscule that even dragonflies can carry them in flight. “So we can even track insect migrations,” Wikelski explains. “In the future, we will be able to predict, for example, where locust swarms will oc-
“Some people laugh at the name,” Wikelski grins. “You know what happened to Icarus!” That particular hero of Greek mythology met a tragic end: when he flew too close to the sun with his homemade wings, the wax melted and he fell into the sea – a hazard that certainly doesn’t apply to this project. Initially, the transmitters will send their data to the International Space Station, then later to satellites. The European Space Agency and the German Aerospace Center didn’t just give Icarus the green light, they also promised substantial funding. Also on board are the German Research Foundation and the National Science Foundation in the US, which will take care of the data analysis via the Movebank database.

A study of goats in Sicily has shown what huge benefits such data might have. The animals also act as biosensors with the ability to detect impending natural disasters. “Over six months, we tracked the movements of the animals up and down the slopes of Mount Etna.” Wikelski zooms in on a computerized map of the area surrounding the volcano. Clicking on the lines of movement reveals details of times and dates. The lines form a wild pattern in which steady traces are interspersed with brief zigzag intermezzos and violent peaks, representing overnight sleep intervals, wild leaps up- and downhill, feeding pauses and brief naps. Wikelski picks out a particular point. “Here! At 1:00 a.m. the goats suddenly and quite unexpectedly became very active. At around 7:00 a.m., the volcano erupted.” Even in ancient times, there are descriptions of animals behaving oddly before an earthquake.
TO THE POINT

- Migrating animals have a strong influence on the earth’s ecosystems. They carry plant seeds and other species with them, and help them to spread.
- Pathogens and parasites, too, can be carried over great distances in this way.
- The Icarus initiative aims to develop a satellite-supported system that will allow for the permanent observation of even the tiniest creatures, such as insects, around the globe.

A “goat detector” for geological events – why not? After all, elephants detected the seakean beneath the Indian Ocean long before the first tsunami wave reached the coast. Those locals who followed the fleeing pachyderms into the interior owe their lives to the animals’ instincts. An application has since been made to patent the idea of just such a biological early-warning system.

“How I would like to sit upon the back of the gander Martin on such a fine morning,” thought the boy. “How fine it would be to ride through the warm, still air up above where I could look down on the earth, spread with green grass and beautiful flowers!” Of course Martin Wikelski, as a child, also read Selma Lagerlöf’s stories about Nils Holgersson: fantastic tales of a boy who flew with the wild geese, mounted on the back of a tame gander. He grins. “Basically, that’s just what we are doing now! We mount an animal with a spyglass and fly along. Soon, tiny little cameras will even let us see what the animal sees.”

For agoutis in Central and South America, Brazil nuts are a delicacy. The rodents collect the nuts and repeatedly bury and dig them up again as a food source for the rainy season. Since they don’t find them all again, they make a major contribution toward propagating the plants.

An African straw-colored fruit bat with a transmitter, sleeping in a tree. These bats commute daily between roosting and feeding sites that can often be several hundred kilometers apart.

Mini-transmitters have also been used to track North American Monarch butterflies on their annual migrations. Each fall, a large proportion of the butterflies travel up to 3,600 kilometers from North America to overwinter in southern Mexico.

Dina Dechmann and Jan Taylor from the University of Bialystok, Poland, on an observation tour through the Biebrza National Park in Eastern Poland.
The oceans are full of bacteria. Outwardly, they all look much the same, but there are many different species living a variety of ways of life. This has led Hanno Teeling, Bernhard Fuchs and Frank Oliver Glöckner from the Max Planck Institute for Marine Microbiology in Bremen to analyze bacterial diversity in the oceans with the aid of metagenomics. To do this, they first throw the whole bacterial genome into one pot, then decode the DNA molecules and sort the genetic mix back into individual bacterial groups.
FOCUS_Biodiversity

A beaker of seawater looks pretty dull at first glance. It is only under a microscope that a distinct universe of shapes and colors is revealed – the world of the tiniest micro-, nano- and picoplankton. Diatoms and radiolarians, in particular, really stand out under the microscope, with an endless variety of geometric shapes: from circles, ovals, triangles and squares to intricate filigree stars.

“Although the larger single-celled organisms are often spectacular, the vast majority of plankton consist of smaller bacteria,” says Frank Oliver Glöckner, head of the Microbial Genomics and Bioinformatics Research Group at the Max Planck Institute for Marine Microbiology in Bremen. “While these bacteria are virtually indistinguishable under the microscope, they actually show even greater differences in their ways of life.”

The species diversity of plankton has long been a puzzle to scientists, standing as it did in direct contradiction to the accepted ecological theories. In contrast to tropical rain forests with their many ecological niches, each offering different conditions for life, the oceans offer only huge, seemingly unvarying bodies of water with no clear

Millions of bacteria live in a single liter of seawater off of nutrient-rich coasts, such as the popular beaches of the North and Baltic seas. While hardly any differences can be seen under the microscope, the DNA rings of their genomes reveal their various ways of life.
exist permanently: sooner or later, the stronger species will win out and displace all of its weaker competitors. So how can a uniform habitat like the ocean harbor such great species diversity? Why isn’t the plankton dominated by a few species?

“We want to resolve this plankton paradox through our research,” says Frank Oliver Glöckner. “But before doing this, we need to get a proper idea of the full biodiversity of bacterial plankton. We want to know what species there are, how common they are and what function they have in the ecosystem.”

To do this, the scientist at the Bremen-based Max Planck Institute is relying on the newest genomic and computer-based techniques. As the bacteria look so similar under the microscope, differences in their genomes are the only reliable identification markers for individual species.

EXPERIMENTS, MODELS, GENETIC ANALYSES

At the institute in Bremen, Glöckner is working with researchers from various disciplines, including bioinformaticians, geneticists, microbiologists and ecologists. Ecologist Bernhard Fuchs is conducting experiments to investigate what the bacteria eat, as well as how they stick onto each other or to algae. His colleague Hanno Teeling has a very different job: “Computer analysis of a bacterial genome tells me what a cell might be capable of and what enzymatic tools it may be equipped with.”

Precisely because of their contrasting viewpoints, the two scientists attach great importance to a mutual exchange of views. “I’m working on the computer with organisms I’ve never seen,” explains Teeling, “and the single cell can become an abstract concept. Thanks to Bernhard Fuchs, I know whether the cells are really doing what I predicted with my data.”

Working together with scientists at the Alfred Wegener Institute for Polar and Marine Research, Jacobs University Bremen and the University of Greifswald.
wald, Teeling, Fuchs and Glöckner studied an algal bloom in the North Sea and recently published their results in the journal SCIENCE. “As soon as the level of solar irradiation exceeds a certain level in the spring, single-celled algae such as diatoms can proliferate massively within a few days,” explains Frank Oliver Glöckner. This sort of algal bloom often ends as quickly as it began: the nutrients dissolved in the water are depleted, and growth is inhibited.

In the end, the algae are either eaten up by zooplankton – crustaceans about a millimeter in size – or are killed by viral infection. And this is the moment of glory for the bacteria, which fall upon this feast of algal remains.

“The bacterioplankton changes dramatically after an algal bloom,” says Bernhard Fuchs. “We believe that this phenomenon is one aspect of the solution of the plankton paradox.”

WEAKLY MEEASUREMENTS IN THE NORTH SEA

The marine scientists collected the samples for their study at the permanent Kabeltonne research station run by the Biological Institute Helgoland, located in the narrow channel between the main island and the smaller Düne Island, a favorite of beachgoers. Since 1962, researchers have carried out weekly measurements of various environmental parameters off the island, such as salt content and water temperature – data that, given its regularity, is unique in the world and is important not only to the Bremen team. In summer 2009, even Craig Venter, one of the pioneers of genome research, paid a brief visit to Germany’s only off-shore island to take samples for genome analyses, just like the Bremen team.

Throughout 2009, the scientists traveled to the research station twice a week, each time taking up to 500 liters of North Sea water from a depth of one meter. At the laboratories of the Biological Institute Helgoland, they then measured the salt content, the concentrations of such nutrients as phosphate, silicate and nitrate, as well as levels of the green plant pigment chlorophyll A,
a measure of the number of algae in the water. Finally, they separated the bacteria, algae and viruses.

Back at the Max Planck institute in Bremen, it was then up to Bernhard Fuchs to determine the exact composition of this bacterial population. Using fluorescence in situ hybridization (FISH), the ecologist sent DNA probes into the cells to bind to the bacterial ribosome and cause it to light up with the aid of a fluorescing pigment. Since every probe recognizes only the ribosome of a specific group of bacteria, Fuchs can make this group visible in the water sample and count the individual cells using an automatic microscope. A species-specific marker gene can also be used to identify individual species in the sample.

EXPLOSIVE PROLIFERATION

"By doing this, we were able to determine exactly how the composition of the bacterial population in the water changes during an algal bloom," says the ecologist. According to their data, alphaproteobacteria dominate in the water during the time before the algal bloom. But as soon as the massive algal proliferation takes place over the course of a few days, there is a dramatic change in this community. Flavobacteria by the name of Ulvibacter begin to divide rapidly, quadrupling their cell count within a week.

Just a few days later – with the algae already decimated by hungry zooplankton and viral infection – the Ulvibacter population collapses suddenly, with Formosa flavobacteria taking their place. They, too, initially proliferate on a grand scale, but their numbers drop drastically just a week later.

“And so it goes, with one group proliferating explosively, perishing again after a few days, and then being replaced by another group,” explains Bernhard Fuchs. “It’s only a few weeks after the algal bloom that the situation settles down and returns to the alphaproteobacteria-dominated status.” During this phase, there is little or no detectable evidence of most of these short-term upstarts in the water.

DNA: LIKE GOES WITH LIKE

But the true artistry consists in assigning the individual DNA molecules from this varied and motley genomic mixture to the various bacterial species. “As you might expect, the DNA snippets don’t carry nameplates, so we don’t know which bacteria they belong to. Because of this, one of our programs carries out an extensive similarity analysis with the identified genes on the DNA molecules,” says Hanno Teeling.

For instance, the computer looks for the most similar known gene of a known bacterial species, or identifies in the DNA code sequence characteristic patterns that occur only in a certain group. Finally, it sorts the individual snippets together with the genes they contain into virtual piles. “In this way, we get a fairly accurate idea of which genes belong to a certain group of bacteria,” says Teeling.

The task of the scientists from Greifswald who were involved in the study was now to fish out the metaproteome
– in other words, all the proteins – from the samples and to identify them. Since proteins can be matched up with their genes using special algorithms, and the genes of the various bacterial groups had been identified thanks to the metagenome analysis in Bremen, the scientists were able to say exactly which protein belongs to which bacterial group.

The team headed by Teeling, Fuchs and Glöckner now had all the information it needed: the exact composition of the bacterial community in various phases before, during and after the algal bloom; the genetic makeup of the individual groups; the proteins and the temporal development of the environmental conditions. The scientists now collated all this data and established connections. “If, for example, a certain sugar is released from the algal remains after the bloom, and if a certain gene is simultaneously activated in a bacterial group, this is a strong indicator of the presence of a key protein that helps the group in question with the uptake of that sugar,” says Hanno Teeling.

**PROTEINS THAT BREAK DOWN SUGAR**

The team from Bremen managed to identify an entire array of these key proteins, thus finally finding a solution to the puzzling dynamics of the bacterial population. The first big winner of the algal bloom, the flavobacterium

> So far, climate change hasn’t altered the community of bacterial species in the seas.
Ulhibacter, produced large quantities of substances known as TonB-dependent transport proteins, which carry large molecules directly into the interior of the cell. At the same time, the scientists found an increase in enzymes used to break down complex algal carbohydrates such as laminarin. In contrast, the latecomers among the winners show a predominance of transport proteins for short protein fragments, as well as transporters for the nutrient phosphate and for simple sugars.

**NICHES SEPARATED BY TIME**

“It seems that the bacteria adopt completely different feeding strategies,” explains Bernhard Fuchs. Some alphaproteobacteria can use smaller nutrients very efficiently, as they specialize in low nutrient concentrations. For this reason, they predominate in the phases between algal blooms. Ulhibacter, on the other hand, with the help of its enzymatic tool kit, can utilize the rich supply of algal remains directly after the bloom, and is the first to break down the long-chain carbohydrates. In contrast, the groups that follow concentrate on smaller and smaller molecules and utilize the leftovers. “It’s a bit like in the Serengeti – the lions come first, then the hyenas, the jackals, and finally, the vultures,” says Teeling.

Thus, the bacteria occupy ecological niches in the sea that are separated from one another, not by space, like in the rainforest, but by time. By specializing in various phases after the bloom, they avoid the competition. Suddenly, even the plankton paradox doesn’t seem so paradoxical, since the time separation maintains a high species diversity in the bacterioplankton. “Our study is the first high time resolution analysis of a microbial community at the genus level,” says Frank Oliver Glöckner. “This was possible only through the extraordinary leap forward made by sequencing technology in recent years.” Indeed, today’s high-performance sequencers work in completely different spheres even than at the time of the Human Genome Project. “At that time, it took 10 years to sequence the entire human genome. Today, it could be done in 14 minutes,” says the biologist.

Glöckner is already working at full tilt to develop this technology further and to make his bioinformatics tools usable for other scientists as well. January 2012 saw the start of the international Micro B3 (Biodiversity, Bioinformatics, Biotechnology) project. Frank Oliver Glöckner is coordinating the consortium of 32 academic and industrial partners and has big plans. “In 2012, we want to organize an Ocean Sampling Day – on that day, water samples will be taken using standardized methods all around the world, and analyzed as they were in our own study. Our aim is to determine the size and the differences in bacterial biodiversity in the world’s oceans.”

Studies of this type could possibly explain the influence of climate change on marine bacterial communities. The consequences of the North Sea warming of 1.2 degrees Celsius since 1962 are already apparent on a large scale: cold-loving indigenous fish such as the cod are moving into the Norwegian Sea, whereas southern species such as striped red mullet and sardines appear to feel more comfortable in the German Bight.
TO THE POINT

- The water of the oceans offers organisms few spatially separated habitats. Despite this, the seas are home to countless microorganisms (the plankton paradox).
- Marine bacteria adopt a variety of feeding strategies. They can occupy niches separated by time, thus avoiding competition with other species.
- After an algal bloom, the bacterial community is dominated by one species after another for short periods, each of them able to make optimum use of the available food supply.

ENZYMES FOR INDUSTRY

However, the aim of the Bremen-based scientists isn’t just to use metagenomics to study the composition of the ocean’s species communities. The genes and proteins that they encountered during their analyses could also help in the development of new active substances or materials. In his research, Glöckner is cooperating closely with partners from the biotechnology sector: “Enzymes have many potential uses, because they speed up chemical reactions and lower energy consumption.”

The Max Planck researchers are therefore working with various companies that are testing the new enzymes the researchers found in the bacterial genomes for possible use in the manufacture of drugs or detergents.

After all, many of the bacterial genomes, most of them consisting of 3,000 to 8,000 genes, have hardly been studied yet. For 30 to 40 percent of them, the experts know very accurately which proteins they code for and what exactly these proteins do. “These are primarily the enzymes involved in basic metabolism, which every group of bacteria needs for survival. In another third of them, we have a rough idea of the group to which a gene belongs, for example whether it codes for a lipase that can break down fats,” says Glöckner. But the last third are completely unknown and consist of genes whose existence is only suspected by the researchers. They are now seeking to unearth this genetic treasure.
Atoms in Quantum Dialog

Quantum bits can now be transmitted between two atoms in a controlled manner and reversibly stored in the atoms.

The door to a completely new way of transmitting information is now open. Physicists working with Stephan Ritter and Gerhard Rempe at the Max Planck Institute of Quantum Optics in Garching created an elementary quantum network in which they transmitted quantum information between two atoms trapped in resonators. Quantum information is stored in particular energy states of atoms, for example, and transmitted using special states of photons. Quantum information possesses fundamentally different characteristics than the conventional information with which, for instance, most computers today operate, and is transmitted over telephone cables or fiber optics. This raises hope that information will be able to be processed more efficiently in some applications. However, the information must be handled with extreme care so that it doesn’t lose its quantum character. The physicists in Garching have now, for the first time, transmitted quantum bits in the form of individual photons from one atom to another over a 60-meter-long fiber optic cable and reliably stored them in the receptor atom. This configuration is suitable for more than just exchanging information between computers, when they one day calculate using quantum bits. (Nature, April 12, 2012)

Step by Step to the Right Diagnosis

Various combinations of biomarkers are required to clearly distinguish between tuberculosis and sarcoidosis.

Biomarkers or combinations of several biomarkers – known as biosignatures – are markers with which physicians are able to identify a disease. Such biosignatures are apparently not always unambiguous. Researchers at the Max Planck Institute for Infection Biology discovered that the biosignatures of tuberculosis and sarcoidosis closely resemble one another. To this end, the Berlin-based researchers created complete profiles of genes and micro-RNAs, as well as important blood-borne inflammatory mediators for tuberculosis and sarcoidosis. Although unhealthy and healthy individuals can, of course, be distinguished through a series of changes, the differentiation of tuberculosis from sarcoidosis is almost impossible with the same combination of biomarkers. Thus, a single signature is insufficient to unambiguously identify some illnesses. Multiple biosignatures are better suited for this: one for differentiating between diseased and healthy individuals, and additional ones for differentiating between the individual diseases. In African countries, for example, tuberculosis, AIDS and malaria could be quickly and unambiguously diagnosed in this way. (PNAS, May 2, 2012)

Thanks to a particularly resilient envelope, tuberculosis bacteria can survive for years in the cytophages, or white blood cells, of the immune system and be released again when the immune system weakens. Here, the bacteria (yellow) are surrounded by the cell membrane of a cytophage, or white blood cell (red).
Fuel for the Black Hole

New observations show the dust torus surrounding the supermassive black hole in the center of a galaxy.

Black holes devour everything that comes too close to them. Gas and dust from the vicinity serve as fuel. An international team headed by Gerd Weigelt from the Max Planck Institute for Radio Astronomy in Bonn has now taken a closer look at this storeroom. Using near-infrared interferometry, the researchers observed the inner region of Galaxy NGC 3783, where a black hole is located, surrounded by a torus of dust. This forms a reservoir of material from which the hot gaseous disk and the supermassive black hole feed. The torus measures half a light-year across. To measure it within the galaxy that is located approximately 150 million light years away, the astronomers required very high resolution. They achieved this by superposing the infrared light from several individual telescopes of the Very Large Telescope Interferometer of the European Southern Observatory.

Optics with Gamma Vision

In optics, not much happens without kinks – that is, without bending. Light rays allow detailed analysis of a material or a biological process only because they can be deflected and focused with lenses. Scientists at Ludwig Maximilian University in Munich and the Max Planck Institute of Quantum Optics in Garching have now focused gamma rays for the first time. In doing so, they toppled the decades-old fundamental assumption in physics that this extremely energetic radiation can’t be deflected. Using gamma-ray optics and isotopes that respond to gamma rays quite sensitively, tumors could be simultaneously combated and the success of the treatment monitored, for instance. In addition, gamma rays could help to more precisely investigate the aging process inside lithium batteries in order to ultimately suppress it. Current analytical methods can only reveal these processes on the batteries’ surface.

Organization is Half the Battle

The cell membrane consists of a double layer of fat molecules that contain proteins. However, according to the latest findings of scientists at the Max Planck Institute of Biochemistry in Martinsried, these membrane proteins are not distributed randomly over the surface of a cell. Instead, they are organized in bounded areas of the membrane. Accordingly, the cell membrane of yeast cells consists completely of these domains, which contain one or more types of proteins. These zones are essential for membrane proteins because the proteins function efficiently only in their own domains. The patchwork quilt of protein domains presumably arises because fat molecules also form these areas in the cell membrane. As fats within one domain having identical or similar anchor molecules fix proteins, they direct the proteins into bounded areas.
**Wallflowers of the Earth System**

Algae, lichens and mosses have been unfairly ignored in the global carbon dioxide and nitrogen balance up to now.

Algae, lichens and mosses on walls and roofs are usually considered to be ugly or annoying, and the scientific community had long disregarded them as well – completely unjustly. The cryptogamic cover, as the flat growths are referred to scientifically, plays a more important role in the global nitrogen budget, and thus also for climate, than previously assumed. They cover an estimated 30 percent of the land mass surface worldwide, which also includes surfaces of plants. And, as scientists led by Ulrich Pöschl at the Max Planck Institute for Chemistry in Mainz discovered, they fix about half of the nitrogen that becomes bound naturally on land, and absorb as much carbon dioxide annually as is formed by forest fires and biomass combustion. These findings help improve models of global material cycles and the climate that have thus far neglected the carbon and nitrogen equilibrium of the cryptogamic cover. (*Nature Geoscience*, June 3, 2012)

Underestimated players in the global mass balance: The yellow-scale lichen (*Xanthoria parietina*) populates a limb here with other lichens. Lichens belong to the cryptogams and are a biocenosis of one fungus and one blue or green alga each. Cryptogamic cover can bind carbon and nitrogen from the air, depending on the species.

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**At the Edge of Space and Time**

*Galaxy HDF850.1 appears just as it did 12.5 billion years ago*

HDF850.1 is invisible in the sky survey of the Hubble space telescope. However, astronomers knew from other observations that the object concealed one of the most productive galaxies in the universe – a Milky Way system with an extremely high birth rate of 1,000 suns per year. Now, a team headed by Fabian Walter from the Max Planck Institute for Astronomy in Heidelberg has established the distance to HDF850.1 for the first time: the light that reaches us from there today left on its trip when the cosmos was just 10 percent as old as it is now, or in other words about 12.5 billion years ago. The researchers used six radio antennas of the IRAM Observatory for their millimeter-wavelength observations. They derived the vast distance from the spectral lines they measured. In addition, they found that HDF850.1 is not alone, but rather belongs to a cluster of proto-galaxies – systems that formed a few hundred million years after the birth of the universe. (*Nature*, June 14, 2012)

Gazing into the depths of the universe: The light that we receive from Galaxy HDF850.1 (concentric yellow lines on the right part of the image) traveled for 12.5 billion years to reach us.
Two Molecules in Space

Spectrometers on an airborne observatory detect OD and HS\(^*\)

The airborne observatory SOFIA has delivered a wealth of results. Shortly after the first series of scientific flights with the GREAT instrument, researchers detected two molecules in outer space and investigated various stages of stellar birth in detail. A German consortium headed by Rolf Güsten from the Max Planck Institute for Radio Astronomy in Bonn developed the spectrometer. Among other things, GREAT obtained direct proof of protostellar envelope collapse from three infant stars that allows conclusions to be drawn about the dynamic processes of stellar birth. Another important discovery was the first evidence of two new molecules in the universe: OD, an isotopic variant of hydroxyl (OH) in which the hydrogen atom has been replaced by its heavier isotope deuterium, as well as sulfanyl (HS\(^*\)), or hydrosulfide. (Astronomy & Astrophysics, May 10, 2012)

Colorful birth: The photo shows the area of stellar birth around Rho Ophiuchi, at a distance of about 400 light-years. GREAT first detected the molecule OD in the universe there. The instrument also found sulfanyl (HS\(^*\)), or hydrosulfide. Developed by a German consortium, the spectrometer (above) is one of the instruments on board the airborne observatory SOFIA (top).

Chimpanzees Cultivate Food Culture

Neighboring groups use different tools despite similar ecological conditions in their habitats

Chimpanzee cracking nuts with a stone hammer. An essential precondition for the formation of cultures is the transfer of information or capabilities to the next generation, independent of genes. A research team from the Max Planck Institute for Evolutionary Anthropology in Leipzig observed that adjacent groups of chimpanzees living under similar ecological conditions and hardly distinguishable from one another genetically are able to develop distinct cultures. Chimpanzee groups in the West African country of Ivory Coast crack nuts with help of stone and wooden hammers, using tree roots as anvils. According to the findings, the hammers used differed significantly in material and size from group to group. The animals in two groups, for example, replaced stone hammers with wooden ones over the course of a season, while the members of another group consistently preferred stone hammers – and that even though there was always sufficient wood and stones available throughout all regions. The selection of a specific tool is therefore not only an adaptation to changing environmental conditions themselves, but rather a cultural behavior that is learned and handed down within the group. (Current Biology, May 10, 2012)
Still No Life on Mars

Intense UV radiation on the red planet releases methane from organic material transported to the surface by meteorites

Some astronomers eagerly pursue every clue about life on Mars – but one of them might just have gotten away from them. The methane that was discovered in the Martian atmosphere nine years ago and that was considered as a possible sign of living organisms very probably originates from a geochemical process. An international research team led by Frank Keppler of the Max Planck Institute for Chemistry in Mainz has established that a meteorite found on Earth releases methane when the scientists irradiate it with intense ultraviolet light under Martian conditions. The constituents of the heavenly body resemble those of meteorites and stellar dust particles from space that bring carbon-containing molecules with them and continually collide with the Martian surface. Some researchers considered the methane on Mars to be evidence of extraterrestrial life because, on Earth, it originates primarily in biological processes. (Nature, May 31, 2012)

The Incisive Design of the Spider Claw

The animals owe their predatory success to, among other things, the ingenious composition and structure of the material that makes up their venomous fangs

Flies and other insect prey can do little to counter the bite of a spider – even though their armor consists mainly of chitin and proteins, just like the venomous fangs of the predator. However, the exact chemical make-up and microstructure of the venomous fangs have been optimized to be able to penetrate the armor of the prey. A research team headed by Yael Politi and Peter Fratzl from the Max Planck Institute of Colloids and Interfaces in Potsdam discovered this while researching the wandering spider Cupiennius salei. Accordingly, the chitin fiber in the venomous fangs runs parallel to the trajectory of the spider bite; they are more rigid in this direction than perpendicular to it. Moreover, the proteins that form the tip and shell of the fang are strongly cross-linked with metal ions, so that they transfer pressure especially well to the cuticular armor. These findings can provide inspiration as to how similar materials can be optimized for various applications. (Advanced Functional Materials, March 22, 2012)
Soil erosion due to advanced industrialization, deforestation and intensive agriculture in coastal areas flushes nutrient-rich soil into the sea and leads to the dying off of coral reefs. Researchers from the Bremen-based Max Planck Institute for Marine Microbiology have now explained the causes of the death of the corals. According to their findings, the digestion of nutrients in the sedimentary deposits by naturally occurring bacteria causes oxygen depletion and, together with an acidification of the environment, triggers a chain reaction. At the end of this phase, the microorganisms release hydrogen sulfide from the damaged coral tissue. This cellular toxin kills the surrounding polyps within a very short time. Even the smallest amount of organic material is sufficient to produce the fatal effect for the coral. Sediments with little organic content that are stirred up by wind and wave action, in contrast, have almost no effect on the reefs. (PNAS, May 21, 2012)

Reef-building corals along the Great Barrier Reef off the east coast of Australia. They are covered by a two-millimeter layer of sediment that is carried into the sea by rivers.

Lactic Acid for Nerve Cells

Glial cells transfer metabolic products to nerve cells

A group of highly specialized cells known as oligodendrocytes surround the nerve filaments of the brain and spinal cord. This insulating layer, also known as the myelitic sheath, not only increases the transmission speed of the nerve filaments and reduces their energy consumption, it additionally provides the nerve cells with energy-rich metabolic products. A study by researchers at the Max Planck Institute for Experimental Medicine in Göttingen has shown that the oligodendrocytes obtain energy primarily from the cleavage of sugar into lactic acid in their mitochondria. The oligodendrocytes can use metabolic products themselves that result from the cleavage of the glucose as components for the construction of the myelins in their cellular walls. In addition, they transfer the lactic acid to the axons of the nerve cells, which create energy out of it in their own mitochondria. Among other things, a lack of energy could thus be the reason why nerve cells are often irreversibly damaged in multiple sclerosis when the myelin sheath is destroyed. (NATURE, April 29, 2012)

Electron micrographic cross-section of optic nerve axons. The axons are surrounded by oligodendrocytes that wind around them in several layers. Between them are the astrocytes, another type of glial cell.
The Search for a Second Earth

To date, astronomers have discovered nearly 800 planets orbiting distant stars. So far, only three of them have been found to potentially offer life-sustaining conditions. However, there are probably many second Earths in the Milky Way. But how can traces of life be detected on exoplanets? At the Max Planck Institute for Astronomy in Heidelberg, Lisa Kaltenegger is trying to answer this question.

TEXT THOMAS BÜHRKE
Max Planck once said of himself that, on leaving school, he could just as well have studied music as the classics. The fact that he opted for physics was thanks to his math teacher and the “desire to study the laws of nature in greater detail.” Lisa Kaltenegger is certainly modest enough not to compare herself with the pioneer of quantum physics, but what they have in common are their wide-ranging interests and the impetus provided by a committed teacher.

Unlike Max Planck, Lisa actually did start with a broad range of disciplines, studying Japanese, film and media studies, business studies, engineering physics and astronomy in order to find out what fascinated her most. This meant she was constantly commuting to and fro between the University of Technology and the Karl-Franzens University in Graz. “It was a ten-minute bike ride,” she says, to explain how she coped with this pentathlon of courses.

**SPECTRAL FINGERPRINT OF OUR PLANET**

She couldn’t keep this up long term, obviously, and finally she settled on engineering physics and astronomy – though a career advisor had urged against a career in the natural sciences. It would be difficult for a woman to hold her own in the field, he said.

Less than twenty years later, Lisa Kaltenegger leads an Emmy Noether Group at the Max Planck Institute for Astronomy in Heidelberg, and is simultaneously a Research Associate at the renowned Harvard-Smithsonian Center for Astrophysics, where she spends three months of the year. She is one of the most creative and competent specialists in extrasolar planets. This year she was awarded the prestigious Heinz Maier-Leibnitz Prize for physics by the German Research Foundation and the German Ministry of Research.

In 1993, American astrophysicist Carl Sagan published the spectral fingerprint of the Earth, which had been recorded with the *Galileo* space probe. Inhabitants of distant planets could also make such a spectrum of our planet and use it to deduce our existence. Conversely, it should be possible for us to search for such traces of life on one of the exoplanets.

The discovery of the first exoplanet, a celestial body orbiting a distant star, created not only a new, fast-expanding branch of astronomy in 1995, but also electrified Lisa Kaltenegger in her final year at school. This enthusiasm was encouraged by a good physics teacher who also offered courses in astronomy. >
edge of both engineering and astronomy was clearly an asset in this position. Though *Darwin* was put on ice, as was a similar NASA mission, this didn’t mean that the search for a second Earth was abandoned – especially not by Lisa Kaltenegger. NASA’s *Kepler* mission in particular excited her, because its fascinating discoveries greatly increased the number of potential terrestrial planets, which made missions such as *Darwin* seem more realistic again. “Discovering traces of life on another planet would be one of the truly great steps in the exploration of the universe,” says Lisa. “This great discovery would have social, religious and philosophical consequences, of course. From the scientific point of view, it would also provide the opportunity to learn something about the evolution of our own planet and to take a purely statistical look into the future of terrestrial planets,” explains the Max Planck scientist.

Her work also focuses on Earth’s evolution in order to learn about habitable planets. The idea is simple in principle: “When we are able to investigate a distant rocky planet spectroscopically, what could be the indicators of life? We can’t assume that any possible life there is at the same stage of evolution as we are now.” So the first thing she did was to investigate how Earth’s atmosphere had evolved since the formation of our planet, which involved close collaboration with biologists and paleontologists.

In the beginning, carbon dioxide (CO$_2$), nitrogen and water dominated the primeval atmosphere. When the first organisms appeared about 3.5 billion years ago, they produced methane (CH$_4$), and later, oxygen. Its quantity grew and the increase in molecular oxygen (O$_2$) was accompanied by the proliferation of ozone (O$_3$) in the atmosphere. The concentration of oxygen, at 21 percent, has remained almost unchanged for around 300 million years.

PALEONTOLOGISTS AND BIOLOGISTS ALSO ON BOARD

“At the end of the 1990s, nobody in Austria was working on characterizing exoplanets,” says Lisa. She would have to leave the country. Research visits to the Instituto de Astrofísica de Canarias on Tenerife, Johns Hopkins University in Baltimore and the European Space Agency in the Netherlands followed. Here, she was part of a three-person design team working on the *Darwin* project, an ambitious plan to use several telescopes in space to find Earth-like planets around other stars and to characterize them. Her knowledge of both engineering and astronomy was clearly an asset in this position.

Those who want to roam far from home must first be familiar with their local surroundings. This explains why Lisa Kaltenegger is studying the evolution of the terrestrial atmosphere before she transfers these findings to other, as-yet unknown planets. She is particularly interested in which fingerprints would be observable in the spectra from different eras. For example, 3.9 billion years ago, in the early history of our planet, water (H$_2$O) and carbon dioxide (CO$_2$) predominated. Then the first organisms produced methane (CH$_4$), and later, oxygen. Its quantity grew, and the increase in molecular oxygen (O$_2$) was accompanied by the proliferation of ozone (O$_3$) in the atmosphere. The concentration of oxygen, at 21 percent, has remained almost unchanged for around 300 million years.
the atmosphere increased slowly at first, with fluctuations, until around 300 million years ago, when it reached about 21 percent, which has remained almost unchanged since. The increase in molecular oxygen, $O_2$, was accompanied by the increase of ozone ($O_3$). At the same time, the proportions of carbon dioxide and methane changed.

For a long time, astronomers had assumed that high concentrations of oxygen and ozone were, in themselves, certain indicators of life. But as Lisa Kaltenegger explains: “The crucial things are combinations – of molecular oxygen or ozone with a reducing gas such as methane, for example.” If present in larger quantities, these gases in combination are the better biosignature. Either substance alone can also be produced inorganically – oxygen through photoysis, when light from a sun splits carbon dioxide or water, for example. But oxygen and methane react rapidly with each other and produce water and carbon dioxide or monoxide. Therefore, in combination, these gases indicate strong sources of both chemicals, which can only be explained by a biological source of oxygen on a temperate planet. If all biota on our Earth were to suddenly stop producing oxygen, the oxygen would be as good as gone within around a million years. So if oxygen is produced inorganically, its proportion, and consequently that of ozone in the atmosphere, is likely to be very low.

As a postdoc at Harvard, Lisa Kaltenegger adapted an Earth atmospheric computer model to exoplanet atmospheres and, using fossil finds, explored how the chemical composition of Earth’s atmosphere varied during geological evolution. The resulting spectral fingerprint of our planet through geological time can indicate life. The surprisingly positive result was that, “For about half of Earth’s history to date, extraterrestrials could have detected traces of life in our atmosphere as a combination of oxygen or ozone with water.”

**NO GAS RECYCLING WITHOUT TECTONICS**

Something similar could then also hold true for other terrestrial exoplanets. Of course, all of these considerations require that life there function according to roughly the same chemical principles as it does here: it needs liquid water and is based on carbon chemistry. “We can’t simulate the effects that different forms of life not known to us would have on the atmosphere,” says Lisa. Nor can the scientist expect a second Earth to have the same physical characteristics as our planet, of course. It may, for example, be smaller or larger, hotter or cooler, drier or have more water. What is certain is that it must be a rocky planet, just like the Earth and Mercury, Venus and Mars in our solar system.

If a planet is more than twice as large and thus around ten times as heavy as Earth at the same density, it is more likely to be a gas planet, a kind of miniature Neptune. If it is very small, on the other hand, like Mars, it may not have tectonics. Yet tectonics plays a significant role in the evolution of a planet and its atmosphere. It is what allows a feedback mechanism that recycles gases like $CO_2$.

The lava descending into Earth’s interior can bind carbon dioxide and move it from the atmosphere. Volcanoes, in contrast, introduce $CO_2$ into the atmosphere again. Tectonics thus acts like a carbon dioxide buffer. If a planet doesn’t have this compensation mechanism, it can become too hot even with small increases in external influences, such as an increase in the luminosity of its sun over time. On the other hand, Earth, for its part, would have been completely frozen when it was young and the Sun less luminous.

Conditions for life as we know it can be detected in the atmosphere of an exoplanet many light-years away only if it is within the so-called habitable zone. This is the zone around a star where the temperatures prevailing on the surface of a planet are such that water can exist in liquid form – a prerequisite for life – and life can produce detectable atmospheric features. The stress here is on can, because whether this is really the case depends on the conditions on the planet.

So the discovery of an exoplanet in the habitable zone of its sun is exciting, but by no means proof that it has an environment that is potentially habitable. Mars, which orbits our Sun on the edge of its habitable zone, is a good example of a celestial body within this region that is, as far as we know, uninhabited.

On the computer, Lisa Kaltenegger simulates possible atmospheres and their detectable spectral fingerprints for the next generation of telescopes for al-

stellar eclipse: There are several ways to detect exoplanets. One of them uses the transit: Seen from Earth, the planet transits in front of its parent sun – as Venus transited in front of the Sun on June 5/6, 2012. Astronomers deduce the characteristics of the exoplanet from the decreasing brightness and the light curve during the passage; under the most favorable conditions, the method also allows spectral observations of the planet’s atmosphere.
ready detected extrasolar planets, as well as a wide grid of rocky planets, where she varies the different parameters, such as mass and radius of the planet, and luminosity and temperature of the star. The latter is also a very critical parameter because it increases with the age of the star. The luminosity of our Sun has increased by around 20 percent during the past two billion years.

The planet and its atmosphere will adapt to this gradual change. And in many cases, this will cause an exoplanet to migrate out of the habitable zone after a certain period of time as it becomes too hot on its surface. Earth won’t escape this fate, either. But we still have a few hundred million years before this happens.

Astronomers have discovered around 800 exoplanets since 1995, with new ones being added nearly every day. But most of them are gas planets, which can be detected more easily due to their large mass and size. Only a few of them are what is known as a super-Earth. These are planets that can be up to ten times more massive and up to twice as big as Earth, and rocky.

**ATMOSPHERIC MODELS FOR TWO HOT FAVORITES**

Two such super-Earths can be found at the edges of their respective habitable zones: Gliese 581d, which is 20 light-years away and seven times as massive as Earth, and HD 85512b, which is 36 light-years away and 3.6 times as massive as Earth. For these hot favorites, Lisa Kaltenegger used her computer model to calculate the atmospheric conditions that would enable liquid water on the surface.

The results she obtained differed greatly: On Gliese 581d, which orbits on the outer edge of the habitable zone, the CO$_2$ in the atmosphere alone would have to be at a pressure of seven bar in order for the greenhouse effect to heat it sufficiently. In contrast, HD 85512b, which is on the inner edge of the habitable zone, would have to be surrounded by a dense layer of clouds that block out the light of its sun to a large extent: “The clouds would have to cool the planet,” explains Kaltenegger.

Both conditions change the observable spectral fingerprint significantly and give us a first small glimpse into the exciting variety of the potentially terrestrial exoplanets. Purely philosophically, it is also attractive to imagine beings that live permanently under dense cloud cover and thus never see the sky and the stars. What kind of world view would they have?

Regardless, there will ultimately be only one way to answer the question of life in the universe: through observation. Lisa Kaltenegger’s dream is to soon get the first spectral fingerprint of an extrasolar rocky planet, and to then use her atmospheric models to scan for biomarkers. But even with the next generation of telescopes, this project will come up against the limits of technology and test the creativity of researchers and engineers.

Transits offer what is probably the best opportunity to study the atmosphere of an exoplanet with existing telescopes over the next ten years. They always occur when we just happen to be looking onto the edge of an exoplanetary system. Its planets then pass in front of the star once every orbit, and the stellar light gets filtered through the exoplanet’s atmosphere before it reaches us.

This is how the molecules leave their spectral fingerprint in the star’s light. But it is incredibly difficult to identify the biosignatures it contains, because the planetary atmosphere of rocky planets is so thin. This is easy to understand when you look at satellite pictures of Earth. Lisa Kaltenegger compares the planet and its atmosphere with an apple and its peel. *Hubble’s successor, the James Webb space telescope, is set to offer completely new possibilities from 2018. But despite its large main mirror, measuring 6.5 meters in diameter, it approaches the limit for terrestrial planets. For a system similar to that of the Earth and the Sun, Kaltenegger and other international colleagues have estimated that a spectrum has to be recorded for about one hundred hours on average in order to detect the weak biosignatures. Yet the transit period for Earth lasts only around 12 hours – and the planet needs about a year to orbit a Sun-
like star. It would thus take 10 years to add up to a spectrum of sufficient quality. A sobering calculation, especially since it exceeds the expected life of James Webb.

ONLY BRIGHT STARS PROVIDE CERTAIN MEASUREMENT RESULTS

Parent stars that are smaller, cooler and more common than the Sun offer greater hope. Their habitable zone is closer to the star than is the case for the Earth. Planets therefore need only a couple of months to complete one orbit. As a result, transits occur much more frequently, which would allow more spectral acquisitions per terrestrial year despite the shorter individual period of transit in front of the star.

“So it is extremely important to find one or more optimum candidates before James Webb is launched,” says Lisa Kaltenegger. That is why she is working on the American Transiting Exoplanet Survey Satellite (TESS) project, which is expected to search for terrestrial planets of near bright stars by 2016. This is important for the subsequent observations with James Webb, because only bright stars afford the opportunity to obtain a good spectrum within a reasonable period of time.

This is also the aim of the mission known as PLANetary Transits and Oscillation of stars (PLATO), which is in the European Space Agency’s selection phase together with four other satellite projects. However, its launch wouldn’t happen before 2022, which would place the first PLATO results in the time after the nominal service life of James Webb had ended.

The next generation of large telescopes will offer a second possibility to discover traces of life on exoplanets. This includes primarily the European Extremely Large Telescope, and the European Southern Observatory recently gave the go-ahead for its construction in the Chilean Andes. Its main mirror will be about 39 meters in diameter and should be operational by the end of this decade.

But there is one fundamental problem here: “The spectral lines we want to detect for the terrestrial exoplanets are, of course, also produced when the star’s light passes through the Earth’s atmosphere,” Lisa explains. Here, it will crucially depend on whether they succeed in separating the terrestrial from the extraterrestrial spectral lines. So there is still a lot to do and it is a difficult task. “But this is precisely what makes research interesting,” says Kaltenegger.

For the time being, the researcher has found her scientific home at the Max Planck Institute in Heidelberg, with her Emmy Noether Group until 2015. When asked what her dream destination would be, Kaltenegger has no particular answer. Her goal isn’t a specific university, nor a certain renowned institute. Not even the continent is that important to her. The decisive factor for her is the opportunity to pursue her research with as much freedom as possible, to have contact with students and be able to head an international team.

Who knows – maybe she will one day be part of the team that discovers the first traces of life on a distant celestial body. What will we then do with these findings? And what new, exciting questions will they pose at the same time?

TO THE POINT

- Of the 800 or so exoplanets discovered so far, only three, at most, offer life-sustaining conditions.
- Astronomers want to use spectral analysis to one day to detect traces of life on exoplanets. But the observation of such biosignatures is approaching the limits of their instruments. And what might the signature in the spectrum look like?
- To this end, Lisa Kaltenegger simulates possible atmospheres of extrasolar planets on the computer, varying the different parameters such as mass and radius of the planet, and luminosity and temperature of the star.
Electrons don’t have much in common with basketballs, apart from the fact that they are often portrayed as having the shape of a ball. Nevertheless, Peter Hommelhoff is as adept a player with one as he is with the other. In his experiments at the Max Planck Institute of Quantum Optics in Garching, where he heads a Max Planck research group, he has achieved a new level of control over these elementary particles.

**A Ball Artist in the Quantum Arena**

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**B locks, rebounds, jump shots – Peter Hommelhoff is a man who knows how to handle a ball. For years, the physicist spent weekend after weekend on the basketball court, defending his team’s basket, stealing rebounds and pushing his way through the defense. These days, this over-two-meter-tall man heads a research group at the Max Planck Institute of Quantum Optics in Garching. That doesn’t mean he no longer enjoys the game – quite the contrary. Now, however, instead of basketballs, Hommelhoff’s equipment is, in classical terms, 50 trillion times smaller: the 37-year-old is determined to manipulate the movement of electrons using laser light and microwaves.**

Hommelhoff’s court now is an optical table, packed full with lenses, mirrors and beam splitters. Water cools the systems, and nitrogen dispels the last of the dust particles. His shooting arm is a laser. His backboard and hoop are located in a vacuum chamber. Only his tricks are still the same: Peter Hommelhoff tries to knock electrons free, accelerate them and force them into a curved trajectory, systematically rebounding them and sinking the particles right where he wants them.

**PHYSICS SCORES WITH ITS LOGICAL LANGUAGE**

More than 20 years have passed since the foundation was laid for Hommelhoff’s career in sports and science. It was the summer of 1991. The student and his family had just moved from Bielefeld to Heidelberg. One of the first paths there led the 16-year-old to the basketball practice of the then German record holder USC Heidelberg. Before that, the lanky youth had only ever played with the large orange balls for fun – or to warm up for one of his many other sports, especially fencing. Now, however, in the city of the professionals, he wanted his training, too, to become more professional. “Still, I didn’t become a super-player – I guess I simply started too late for that,” says Hommelhoff today, and grins.

Heidelberg brought changes in terms of school, too. At home in Bielefeld, Hommelhoff would have taken advanced Latin and Greek without a second thought – two clear, well structured languages with logical grammar. In Baden, however, the Greek course was no longer quite so enjoyable, so he chose another subject with a language that is just as clearly structured and logical: physics.

He found the science interesting, even fascinating, but found other subjects to be intriguing, as well. Peter Hommelhoff had no idea what he ought to study. Luckily he had to do his military service after finishing his college entrance exams. Hommelhoff went into the navy, serving on the frigate “Emden” – despite being 2.03 meters tall. He worked as a navigator there, due to his aptitude for math and physics.

Near the end of his service, the private was forced to use his remaining vacation days. He flew to Mallorca for a
Peter Hommelhoff positions a camera over a window in the vacuum chamber to observe the electrons that a laser catapults from a nanotip. A shiny metallic heating cable is wrapped around the chamber. The cables serve to control the experiment and supply electricity to, among other things, an electron spectrometer.

week, where he spent his time cycling and thinking. Afterwards, Peter Hommelhoff was none the wiser. Nevertheless, he somehow decided to study physics. “Ultimately, I guess it was a conscious decision, but in any case, it was most certainly the right decision,” he says in retrospect.

THERE WERE NO DISTRACTIONS FROM STUDYING BEFORE GAMES

Peter Hommelhoff wanted to get out of small, lovely Heidelberg to study. He moved to Berlin. He was also moving up in terms of sports. OBC Wolmirstedt, a basketball club near Magdeburg, approached the physics student and offered him a spot in the regional league – the fourth highest German division at the time. Due to his height, Hommelhoff played center. He was something like a sweeper under the basket; he had to be assertive and demonstrate his physical strength. “Of course I would much rather have been dribbling and driving the ball forward,” says Hommelhoff. “But if you want to play, you do what the coach says.”

Every Friday, the student drove to Magdeburg, where he spent the night in an empty apartment that the club’s president had arranged for his son – just in case junior should one day study in Magdeburg. Saturday mornings, Hommelhoff studied for his courses, and afternoons, he played in the regional league in front of as many as 500 spectators. “I was always able to...
do my best studying before games, because there were no distractions there,” he recalls.

But the idyll came to an end after his intermediate exams. Students at Berlin’s universities went on strike, and Peter Hommelhoff wanted to leave – preferably to the US, basketball’s promised land, as he says. However, a year abroad in a completely different academic system would conflict with the goal of finishing his studies as quickly as possible. Instead, Hommelhoff went to Zurich, to the Swiss Federal Institute of Technology (ETH).

There, the young German focused on particle physics. The collision of electrons and protons at high energies became the topic of his thesis. He played basketball on the ETH team and won the bronze medal in the Swiss university basketball championships in 1999. The gold medal went to – of all people – friends from the University of Zurich who always practiced with the ETH players.

What made a much stronger impression, though, was a lecture that a fellow student told Hommelhoff about shortly before his final exams: a German quantum optics researcher had announced his participation in the central physics colloquium of the two faculties in Zurich, where he would report on his work. His name: Theodor Hänsch. He was no stranger to Peter Hommelhoff, who had already previously noticed the professor’s articles in physics journals.

Surprisingly few students found their way into the auditorium – among them Hommelhoff and his two friends: “At the very end, Hänsch looked over toward us three dolts and said something like: By the way, my group is looking for doctoral students.”

The two spoke briefly, Hänsch scribbled his e-mail address in Hommelhoff’s little notebook, and a couple of weeks later, the newly graduated physicist began working in Munich – although he had never taken a single optics course during his studies, with the exception of one required lecture in quantum electronics. “I simply found Theodor Hänsch’s lecture extremely interesting, and he really got me excited about the topic,” Peter Hommelhoff recalls. The physicist turned down other Ph.D. offers, including one from Hamburg and one from Zurich. “It was the right decision,” he says today. Quantum optics had Peter Hommelhoff firmly in its clutches.

As a scientist, he was moving onward and upward, but as a basketball player, he had to step back. He played – mostly for fun – in the second team of München Baskets, a small club in Upper Bavaria. But Peter Hommelhoff was still dreaming of the US. In 2003, after completing his doctorate summa cum laude under Theodor Hänsch, he realized his dream. “It had to happen sooner or later,” he says with a laugh.

THE GOAL: A WAVEGUIDE FOR SLOW ELECTRONS

Next stop: Stanford, California. Hommelhoff wasn’t up to snuff for the university team there – where professional NBA stars are born – if only because, as a postgraduate student, he was now much too old. But even without a regular team, there was always a group ready to play a pick-up game. “For four years there, I played everything I enjoyed playing, and most certainly not just center,” he says.

Over lunch, the physicists speculated about what would happen if they were to fire a laser at Hommelhoff’s extremely sharp electron sources. No sooner was the idea discussed than they had put it into action.
In his research, on the other hand, Hommelhoff stayed true to the tiny particles. He wanted to design a waveguide for slow electrons, but to do this, he first had to build a punctiform source for his elementary particles. Peter Hommelhoff experimented with extremely resistant tungsten wires, electrochemically etching them to make them sharp. This resulted in tips comprising just a couple dozen tungsten atoms. By coating them with palladium, they can even end in a single atom – an ideal electron dispenser.

FIRING A LASER AT AN EXTREMELY SHARP ELECTRON SOURCE

Four months later, Hommelhoff and his wires got company. An additional postdoctoral student moved into the lab and built his experiment at the other end of the four-meter-long optical table. He was experimenting with femtosecond lasers, as they are called – light sources whose individual pulses are a few trillionths of a second long. Over lunch, the two physicists speculated what would likely happen if they were to fire such a laser at Hommelhoff’s extremely sharp electron sources.

No sooner was the idea discussed than they had put it into action. “It immediately became interesting and, ultimately, opened up an entirely new field of research,” recalls Peter Hommelhoff.

In laser light, the tips act much like a lightning rod, whose sharp, skyward-pointing piece of metal focuses the electric field lines, ensuring that the lightning hits precisely at that location. The tungsten tips likewise bundle a field: that of the laser light. They do
Peter Hommelhoff and his team guide the red laser so precisely that they can determine when wave peaks and valleys of the pulses strike their sharp tip. In this way, they control the movement of the electrons.

This so effectively that the laser can drive electrons out of the metal.

Since light is a wave that oscillates up and down with a high frequency, the particles that are released are treated much like a leaf at sea: first they are lifted up and expedited away from the tip, but the next half-wave drives the electrons back again. They sink and plonk down on the metal. “It’s almost as if one were throwing a ball against the wall,” says Peter Hommelhoff.

Like a rubber ball, the particles bounce off the tungsten tip and are hit by the laser light again. Its wave has since turned down once more, so the particles are accelerated again and now fly off for good. “This allows us to use the laser to control the emission of electrons – and to do so on an extremely fast time scale,” says the Max Planck researcher.

In Hommelhoff’s lab, the light required for this is produced by a titanium-sapphire laser. Its waves, which are emitted in the near infrared, oscillate up and down around 350 trillion times per second. That means every wave is about three femtoseconds long, or just three quadrillionths of a second. In addition, the laser is pulsed – that is, it is always turned on for only almost seven quadrillionths of a second and then stops again for a short time. Thus, about two light waves fit in each pulse.

This has consequences for the game with the electrons: depending when the laser is turned on, the maximum of the light wave may lie exactly in the middle of the pulse. Then there is hardly any room for additional waves. However, it can also happen that two wave peaks are distributed at the beginning and the end of the pulse. In the first case, all electrons are knocked out at the same time, while in the second case, the physicist can observe electron pairs that are released in quick succession.

Actually, “observe” is an exaggeration: the processes are so quick and take place in such a small space that there isn’t a microscope in the world with which they can be observed directly. Instead, Hommelhoff registers the energy distribution of the released electrons that land on a detector.

**ON THE WAY TO THE WORLD’S FASTEST SWITCH**

This reveals interesting phenomena. In their very own quantum world, elementary particles don’t just behave like tiny basketballs, they also have the characteristics of a wave. As soon as two
electrons are knocked free, their waves can overlap and partially cancel each other out. The detector displays a stripe pattern that physicists call interference. In his experiments, Hommelhoff even managed to systematically change the appearance of this interference pattern – by specifying exactly where the individual light waves occur within the larger laser pulse.

This fine-tuning became possible due to a device known as a frequency comb. Theodor Hänsch, Hommelhoff’s doctoral adviser, developed it and received the Physics Nobel Prize for it in 2005. “The frequency comb is very powerful technology, and we expect to see additional revolutionary applications,” says Peter Hommelhoff. After all, it shouldn’t be restricted to interference patterns on detectors. Among other things, the physicist is currently working on making electrons fly from a tungsten tip to another electrode using systematically manipulated laser pulses. If he succeeds, it would be possible to switch an electrical current on and off with light alone. It would be the world’s fastest switch.

**HOW CAN ELECTRON MOVEMENT BE MANIPULATED?**

Hommelhoff’s away game in California took four years, and then his home town called. The physicist applied to lead a Max Planck research group, got the job, and once again had to choose – this time between Berlin and Munich: the Fritz Haber Institute or the Max Planck Institute of Quantum Optics? “The folks in Berlin had a lot to offer,” recalls Peter Hommelhoff. They got points for a lab in a villa in Dahlem, for a new air conditioning system, which is crucial for his experiments, for parquet floors – and for the prospect of becoming quite a star in a few years as the only quantum optics researcher at the institute. In Garching, in contrast, he risked being outshone by a newly minted Nobel laureate in the field of quantum optics, and by renowned research groups who were also doing research in this field.

Nevertheless, Peter Hommelhoff chose the Max Planck Institute of Quantum Optics. “I wanted the certainty of an institute where there were already many lasers and a lot of know-how available,” he says today.

But the certainty is illusory. Hommelhoff had to start from scratch in Garching, too. The time needed to set up his new lab dragged on. It took one and a half years just to get the air conditioning up and running. A high-precision laser can’t be operated without clean air with a constant temperature. But the AC company that was specially hired for the project failed to get the job done. “It was an absolute nightmare,” says Peter Hommelhoff.

Today, four years later, everything is working. The research group now has ten members, and the conditions, according to Hommelhoff, are “brilliant.” Additional experiments have been added to those to knock the electrons free, including the waveguide, the idea for which originally set the whole ball in motion back in Stanford.

The experiments are always about systematically manipulating the movement of electrons. Nevertheless, Hommelhoff still doesn’t want to see that as the dominating question behind his work. “In basic research, it is unrealistic to set a goal and then try to achieve it at all costs,” he says. Rather, the physicist advocates research driven by curiosity – without, however, allowing it to become arbitrary: “Instead of one big question, let us rather be guided by success and failure, follow paths that look interesting, turn off to go down others, and...
then sometimes follow a detour and come back to the original problem.”

The latest experiment of the group in Garching, for example, involves using lasers to accelerate electrons. To date, electrical fields are used for this, for instance in a synchrotron ring or a free-electron laser, which produce a very intense, brilliant light with accelerated electrons. Using light to cause acceleration isn’t actually possible: like the leaf on the billowing sea, the charged particles, too, are merely tossed about by the alternating field of a light wave.

Hommelhoff and his team hope to change this using a clever trick: The physicists procured a discarded electron microscope and sent its beam across a glass plate at a short distance above it. In the glass, they had previously etched tiny grooves running vertical to the direction of the electrons’ flight, and measuring just a few hundred nanometers – one nanometer is one millionth of a millimeter – wide and deep.

**TECHNOLOGY FOR IMPROVED ELECTRON ACCELERATORS**

While the electrons dart across the plate, the researchers send laser light through their glass construct from below. Since the speed of light in glass is somewhat less than in a vacuum, the wave is disrupted above the grooved plate: an electron making its way across the plate is initially accelerated over the gap in the grating. Over the next groove, however, it isn’t slowed down again, but rather likewise accelerated by the delayed wave front. In this way, it continuously gains energy. “We essentially adjust the spacing and the width of the grooves to the speed of the electrons and the laser wavelength so that the electron always sees only the accelerating component of the field,” says Peter Hommelhoff.

It should, theoretically, be possible to achieve, already in the first configuration, the same performance as in a conventional particle accelerator. Later, so they hope, this technology should make much smaller and more efficient accelerators possible. The experiment is already set to go in the institute in Garching, but the first targeted shots have yet to be fired.

“To achieve an effect, the electrons have to pass over the glass at a distance of one hundred nanometers. That is very demanding,” says Peter Hommelhoff. Demanding, but doable. The 37-year-old has hardly managed to play any basketball recently – but to play in the quantum arena, he still has to have a good aim and a very special knack for handling a ball.

**GLOSSARY**

**Frequency comb:** An optical instrument whose core consists of a femtosecond laser that emits light in extremely short, regular pulses. According to a relationship discovered by French mathematician and physicist Joseph Fourier, the regular sequence of the pulses is reflected in the frequency spectrum of the light. It is, namely, no longer continuous, but rather, like the teeth of a comb, exhibits very sharp lines with fixed spacing. Theodor W. Hänsch found a way to precisely determine the position of a frequency line of the comb and thus the position of all lines, creating an extremely precise measuring instrument for optical frequencies.

**Quantum optics:** Deals with the interaction of light and matter, focusing on their quantum properties. Among these is wave-particle duality, according to which light is considered to be not only a wave but also a particle (photon). The particle properties are noticeable, for instance, when electrons are knocked out of a fine metal tip. However, when they are subsequently accelerated back to the tip and then away again, they take on the wave characteristics of light.

**Waveguide:** A medium in which waves, especially electromagnetic waves, systematically propagate in one direction. A waveguide (for electrons differs from an electrical conductor such as a metal wire in that the electrons in it are guided through a vacuum using electrical fields, and display their wave properties. Physicists have not yet succeeded in observing the latter.
New forms and sources of energy need new power lines as well. In the future, a larger number of small, distributed wind and solar installations in place of a smaller number of large power plants are projected to supply Germany with energy. At the Max Planck Institute for Dynamics and Self-Organization, the Network Dynamics Group headed by Marc Timme is investigating how the high-voltage grid will respond to this and how it can be optimized.
Any people abruptly became aware of just how delicate a large power grid can be when the lights went out around 10 p.m. on November 4, 2006. The outage didn’t affect just televisions and light bulbs – it also took streetcars offline, even in distant Austria. All of this happened even though just one single power transmission line in northern Germany had been shut down – the 380-kV Conneforde high-voltage line over the Ems River.

A huge new transoceanic liner was on its way from the shipyard in Papenburg to the North Sea; a ship so tall that it came dangerously close to the overhead transmission line. The power was turned off as a precaution – with fatal consequences: pressing the off switch turned half of Europe upside down because the grid operators hadn’t properly coordinated how to compensate for the loss. In the end, distant regions in Germany, France, Belgium, Italy, Austria and Spain were without power for several hours.

Power grids are incredibly complex and aren’t completely understood, even today. Of course, there are a lot of safety features that normally prevent power outages. Still, the example of the Conneforde line shows that it sometimes takes just one misunderstanding for the world to come to a standstill. The power grid will become even more complex in the future, with the expansion of renewable energy. New wind parks and solar parks are developing and need their own lines connected to the European integrated network. For the North Sea alone, there are hundreds of wind power installations planned, which are set to deliver 20 gigawatts of power – as much as 12 nuclear power plants. Critics are afraid that the massive expansion could weaken the power grid.

To understand these concerns, it helps to take a look at the physical foundations of our power system. The European integrated network operates with alternating current. This current pulsates in phase with the rhythm of power station generators. Electromagnets as tall as houses, yet just like those in a bicycle generator, rotate inside a copper winding. The current changes its sign 100 times per second; 50 times plus and 50 times minus, which makes a frequency of 50 hertz. All power station generators and large electric motors in Central and Western Europe rotate in close coordination with this frequency so that they operate synchronously.

MANY SMALL POWER PLANTS TO REPLACE A FEW LARGE ONES

Before power plants go online, their operators carefully adjust the generator frequency to match the 50-hertz grid frequency. If one power plant goes down, other power plants have to do its job and are ramped up. However, since that takes some time, their generators initially slow down in order to keep the power level up. As a result, the grid frequency falls slightly. If one line goes down, other lines must take over its load – and must themselves not be permitted to collapse, causing a blackout. In addition, the frequency in various regions of the network can drift apart due to a line breakdown. If the frequency varies too strongly, the network gets out of synchronization. Uncontrolled fluctuations and short circuits are the result. To prevent this, the system executes an emergency shutdown when it detects a frequency disparity; a power outage occurs.

Controlling the supply of power is thus a difficult process, but it has been worked out pretty well in the current German transmission grid – with the exception of the case of the Conn-
enforcing line. But will it work just as well in the power grid of the future?

The power grid today is oriented toward large, centralized coal- or gas-fired plants and nuclear power plants that supply primarily the surrounding regions with power. If more and more solar and wind installations are connected to this network, critics worry that it could become less stable. Their skepticism is not unfounded. After all, the power provided by wind turbines and photovoltaic installations fluctuates with the weather. But what the skeptics hardly noticed until now is that the network architecture will also change completely. The large power plants that serve primarily their immediate vicinity will be gone, replaced by many smaller, distributed power producers.

It could be more difficult to synchronize the frequency of their power outputs than to bring a few large players into a common cadence – the same way a cellist and pianist achieve a common rhythm more easily than a large orchestra. Large power plants will continue to come online, of course, but some of these will be powerful wind parks in northern Germany, whose power is also intended for use in the south of the country.

A DISTRIBUTED NETWORK IS MORE STABLE

A distributed network like this might not deliver power as reliably as we are accustomed to. That was at least a possibility that mathematicians and physicists from the Network Dynamics Group at the Max Planck Institute for Dynamics and Self-Organization in Göttingen began to consider. They are investigating how the new network structure and the fluctuating available power will affect the stability of the electricity supply. Recommendations follow from this about how to make the network more robust for the transition to new energy sources.

The scientists working with Marc Timme began with the question of whether a power grid made up of decentralized power plants is more frequently threatened with power outages. This study of distributed networks also lays the groundwork for the working group to subsequently investigate how fluctuating power output affects the network. They established from their calculations that network instability wouldn’t be as bad as one might imagine. Quite the contrary: the researchers compared various power grids with one another, from classic grids in which large nuclear or coal-fired power plants predominate, to those with many small-scale power plants. Their
EMERGING SMALL-SCALE POWER PLANTS \textcolor{red}{\textbf{MINI POWER STATIONS LOAD DOWN INDIVIDUAL LINES LESS}}

To answer these questions, the team first did the calculations for the simplest conceivable network: the connection between one power station and one consumer. “Both stable and unstable states can actually be created, even here. Situations can arise in which the capacity of a power line is suddenly no longer sufficient, even if the power rating is the same,” says Dirk Witthaut, a scientist in Timme’s working group. Sometimes oscillations in the supply and demand for voltage that don’t run completely parallel to each other are enough to cause a collapse of the connection. As it was shown, it is possible to use sample networks like this to establish under what conditions even large networks can become unstable.

These investigations still haven’t answered the question of how stable a branched network with distributed mini power plants would actually be. “Strictly speaking, mathematicians differentiate between two terms – robustness and stability,” says Timme. To test stability, researchers begin with a network having fixed connections and defined characteristics, for example a fixed number of power plants and constant power consumption.

Mathematicians test the extent to which this system remains stable when external disruptions occur – if, say, an aluminum factory that eats up power is suddenly shut down. Robustness, in contrast, provides information about how the system copes with spontaneous internal changes such as a power line outage – or the shutting down of a transmission line. Timme’s working group investigated both attributes.

Here, too, the scientists first had to simplify. The team designed power grids in which power plants steadily produce power and consumers constantly absorb power. What is new is that Timme takes into account the frequency within highly branched networks, the oscillation of alternating current, and the dreaded frequency drift in various areas of the network. As an example, the researchers chose a power grid of the size of Great Britain and dominated by large power plants. One by one, they replaced individual major power plants with several small-
scale installations. Then they sent power through the lines – sometimes more, sometimes less.

In the process, the scientists observed that a network with many small, distributed power plants remains synchronized just as well as the network that is still distributing power throughout Germany at present. And it even remains more stable. “In the distributed branched network, individual lines are loaded less,” says Witthaut. That makes sense, since the power in a network like this can search out alternative routes to the consumer when the output of the power plants is increased. If there is only one main line, it quickly becomes overloaded. As a consequence, a distributed network is fundamentally more capable.

Of course the researchers didn’t do the calculations for just one power grid. They repeatedly varied the number of power plants using a random number generator, along with their positions and the interweaving of the power line routes. In this way, they showed that their assertions are valid not for just one power grid, but for all possible networks.

The calculations for robustness worked out just as clearly. The Göttingen-based researchers tested this by capping the individual power lines mathematically. As it turned out, there are considerably more critical power lines in a power grid where major power stations predominate – irreplaceable power cables that the stability of the entire network depends on. If these fail, a black out à la Ems can hardly be prevented. Their model showed that
How robust is the grid? Researchers in Göttingen used the British power grid as an example to calculate what happens when individual lines go down. If one of the blue connections is interrupted, a power outage over the entire grid is improbable. For the dark red routes, the probability of a total collapse is almost 50 percent.

**Probability of a power outage if a connection is disrupted (in %)**

0 10 20 30 40 50

The main lines between England and Scotland are especially critical. As the number of distributed mini power stations rises, the number of these critical lines falls significantly. “The distributed power grid of the future will be both more stable and more robust in the event of damage,” says Timme.

**NEW ROUTES CAN IMPAIR THE FLOW OF POWER**

Up to now, no research group had been able to make such strong assertions. Danish scientists had investigated relatively simple networks – rings in which power stations and consumers were strung like pearls in a necklace. “However, these investigations didn’t take into account the network effects that result if you join many of these rings with one another,” says Timme. The England model does this thoroughly. In addition, the Max Planck researchers take into account the “non-linear dynamics” – the oscillation of the current.

Marc Timme and his colleagues carried the analysis of the power grid even further and found evidence of an effect that was previously unknown in the world of power generation: Braess’ paradox. At the end of the 1960s, mathematician Dietrich Braess discovered that new traffic routes didn’t necessarily improve traffic flow, but rather, to the contrary, can cause more congestion. This occurred when drivers were able to follow alternative routes between A and B prior to the construction of the supposed shortcut. Bottlenecks along these stretches aren’t so heavily loaded that they slow the traffic flow.

The new road now shortens the travel distance, so that all drivers suddenly take the same route. However, if the supposed shortcut connects the bottlenecks with one another in a disadvantageous way, and all drivers must now pass through these narrow spots, the traffic becomes congested there. The bottom line is that the drivers then have longer travel times than before the construction of the new road. For this reason, road planners, too, would do well to take Braess’ paradox into account for new projects.

Dirk Witthaut and Marc Timme have now discovered that this paradoxical situation can also arise in power grids. “The paradox wasn’t an issue with the old power grid because the power lines from major power stations primarily branched out radially in many directions,” explains Witthaut. “In a modern, highly branched, distributed network with hundreds of circuits and connections, it becomes highly relevant.”

In the power grid, in contrast, the oscillations are the main reason the paradox can arise. Alternating current can be imagined as a smoothly fluctuating sine wave. The phase of this wave can be different at various points in the network – the voltages at these points may all oscillate with the same frequency, but rather than being in phase, they are shifted in relation to each other instead. In the present-day grid, this isn’t necessarily noticeable, as the individual regions within it are largely centrally supplied. If the voltage of a power station in northern Germany oscillates slightly shifted in relation to the voltage of one in the south, it makes no difference because both supply primarily their respective regions and they hardly sense one another.

But the following situation can be a problem: In the power grid, numerous rings can be identified in which several nodes are connected with one another. If the phase of the alternating current from one station to the next is only slightly shifted in such a ring, that isn’t a problem. All that matters is that this phase shift meets certain mathematical conditions in each circuit.

If a new direct line is now laid between two non-adjacent nodes in a ring, this supplementary connection should actually facilitate the current flow. However, it results in the creation of two additional rings in which the conditions for the phase shift must also be satisfied. But that doesn’t always happen.

**HOW DOES THE NETWORK DEAL WITH FLUCTUATING POWER?**

“In physics, this phenomenon is known as frustration,” explains Marc Timme. “The system is frustrated because it can’t satisfy all of the conditions simultaneously.” This leads to Braess’ paradox: since the current now prefers to flow over the new shortcut, it essentially obstructs the rest of the network. Current flow is thus worse throughout the network than it was in the original power line system without the new route that is actually intended to improve the flow.
Dirk Witthaut illustrates Braess’ paradox in the power grid with an image: “Instead of phase shift, imagine three people at a table, where each person has one domino piece inscribed with a one and a six. They won’t succeed in placing the three dominoes in a circle so that every ‘one’ touches another ‘one.’ It just doesn’t work.”

The team carried out calculations for power grids according to Braess and demonstrated for the first time that the paradox also applies to these oscillating systems – and that even though it was originally formulated for traffic flow, a simple linear system. The conclusions of the working group are striking: approximately 5 percent of all newly connected links in the power grids that were investigated proved to be disadvantageous. They make the entire network less stable. “Braess’ paradox really has to be kept in mind for future expansion of power grids to include a fluctuating power supply,” says Marc Timme. It could also be important when high-capacity routes connect the wind parks in the North and Baltic Seas to consumers in the south.

Thus far, Timme and his colleagues still haven’t taken short-term fluctuations of wind and solar power production into account in their calculations. They want to do this now in cooperation with researchers at Siemens in Munich and the Institute for Information Technology (OFFIS) at the University of Oldenburg. Yet the insights obtained so far already have a practical application – Marc Timme is certain of that: “Our results already provide an important principle for guiding the operation of future networks, because the basic research we’ve already completed forms the foundation for operating a real network with fluctuations.”

TO THE POINT
- If power is soon increasingly obtained from regenerative energy sources, the architecture of the high-voltage grid will change: small-scale distributed power plants will replace large nuclear power plants that supply primarily their immediate vicinity. In addition, large wind parks in northern Germany will come online and must supply the south as well.
- Distributed expansion of the network will make the energy supply more stable because individual lines won’t be as heavily loaded.
- New lines can destabilize the electricity supply if they connect points in the network where the relative phase of their voltage swings is shifted too much and the voltage swings are too far out of cadence. This disrupts the connection, which also affects other parts of the network.

GLOSSARY
Braess’ paradox: If new connections are made in a traffic network or power grid, these can reduce the flow of traffic or the transport of power if parts of the network are joined with one another whose characteristics when connected directly lead to mutual obstruction.
Phase shift: This describes the relative state of two fluctuations to each other and whether the oscillations reach their maximum or minimum values at the same moment or slightly shifted in relation to one another.
Robustness: Indicates how the network responds to internal perturbations, for example the collapse of an important high-voltage line.
Stability: Indicates how well the power grid can cope with external perturbations, say when a large consumer taps into the voltage.
Vast amounts of energy circulate in the earth system: Winds such as this typhoon over Japan reflect a total of 1,000 terawatts of power that drives the world's atmospheric motion.
Our planet is at work: The sun drives the wind, the waves and the water cycle. Plants store the energy from light in sugar, supplying the fuel of life. Geothermal forces knead the earth, while the moon and the sun primarily keep the oceans in motion. Axel Kleidon and his team at the Max Planck Institute for Biogeochemistry in Jena are investigating how much energy flows in these processes and how much of this could be used on a sustainable basis in order to satisfy mankind’s energy needs.

TEXT ROLAND WENGENMAYR

When you talk to Axel Kleidon in his office in the round glass tower of the Max Planck Institute for Biogeochemistry, you end up talking about aliens at some point. And one question quickly surfaces: What would extraterrestrial astronomers be able to observe through their instruments if they pointed them at Earth? Would they recognize that there is life pulsating on this small blue planet? Kleidon has no doubts: “They would need only to discover that both oxygen and methane are present simultaneously in the earth’s atmosphere.”

Back in the 1960s, British scientist James Lovelock already came up with the idea that free oxygen in a planet’s atmosphere was an unequivocal fingerprint of life, as the aggressive oxygen reacts chemically with many substances in the environment. These include methane, which is known to even burn in air. If life on Earth were to go on strike, the oxygen would disappear from our air; however, the carbon dioxide content would be considerably higher. The atmosphere would then have slid into a chemical equilibrium in which not much happens.

LIFE BRINGS THE ATMOSPHERE OUT OF EQUILIBRIUM

Such an Earth would be a barren, lifeless wasteland, like that on our inhospitable neighboring planets. The thin, cold atmosphere surrounding Mars and the oppressive greenhouse hell on Venus consist almost solely of carbon dioxide. This gas is chemically so inert that the composition of such an atmosphere hardly changes at all. Not without life, in any case.
“So it’s characteristic for life that the chemical composition of the atmosphere isn’t in equilibrium,” says Kleidon. Plant photosynthesis continuously drives a global material cycle. It keeps the oxygen content of our air stable at 21 percent and removes excess carbon dioxide from it.

**BIOLOGY IMPACTS**

**GEOCHEMISTRY AND GEOLOGY**

Living organisms also massively reshape the surface of the earth. Kleidon points through the window to the hilly countryside beyond. “This is the famous Jena muschelkalk, which was produced biologically and stores a large amount of carbon dioxide.” Here, in an ancient ocean, the fossil organisms created a huge layer of limestone over millions of years. This occurred in a food chain that started with algae – so, once again, plant life. This gigantic reorganization of entire landscapes by living organisms continues today.

Biology determines the chemistry and the geology of our planet in an extremely active and highly visible way. The name of Kleidon’s field of expertise, biogeochemistry, also reflects the fact that living matter and dead matter are closely interlinked on planet earth. However, his team digs around, not in the prehistoric sea bed surrounding them, but rather in computer-based data mines. Axel Kleidon is a theoretician, and he and his Max Planck junior research group investigate the entire “earth system.”

For the researchers, this is the totality of all important climatic, geological and biological processes, including all important cycles in the atmosphere, on the earth’s surface and below ground. These cycles, which also include photosynthetic biomass production, are closely interconnected. Kleidon is particularly interested in learning what kind of energy drives these processes, and from which key sources this driving energy originates.

The earth system from an energetic perspective: The sun radiates 175,000 terawatts (TW) onto the earth, geothermal energy provides 50 terawatts, the gravitation of the moon and the sun, 5. The diagram illustrates which processes are driven by the energy and how the energy flows can be used.
The Jena-based scientists also use the complex models of climate research. But, as Axel Kleidon says, he loves to condense the core processes that are taken into account in the complex simulations into simple models. For these, he requires only pencil and paper – or the blackboard.

Perhaps his propensity for simple, yet surprising and profound thoughts comes from the fact that he has in-depth insight into numerous scientific disciplines. He studied physics in Hamburg and later at Purdue University in Indiana – plus mathematics and meteorology. After several years as a scientist at Stanford University and the University of Maryland, he arrived in Jena in 2006.

**EARTH RESEMBLES A HEAT ENGINE**

When the Max Planck scientist explains how he sees the earth system on the whole, a famous scene from a movie comes to mind: the physics teacher, Bömmel, introducing his students to the workings of the steam engine in the German film classic *Die Feuerzangenbowle* (The Punch Bowl). The question as to whether Kleidon also considers earth to be a steam engine makes him laugh. He says yes, but adds, more precisely, that he treats the earth system as a so-called heat engine – the general case of steam engine and combustion engine.

This isn’t the only way he views earth, but it provides surprising results. In explaining why this is a scientifically sound procedure, we go on a long imaginary journey that takes us from the sun’s radiation to the playroom of Kleidon’s son. Eventually we arrive at the question of how much renewable energy the earth system can sustainably provide.

We start at the sun. Its radiation is the earth’s main energy source, with a power capacity totaling an enormous 175,000 terawatts. One terawatt is 1,000 billion watts. The heat that rises from earth’s interior and manages to move entire continental plates, shaking the earth with earthquakes and causing volcanoes to erupt, is the second largest engine in the earth system, but supplies only around one 3,500th of the energy: it feeds from the decay of natural radioactive elements and the slow cooling and solidifying of the earth’s liquid core and supplies around 50 terawatts.

It is useful to compare this with the constant flow of primary energy that mankind as a whole consumes. “This is currently around 16 terawatts,” says Axel Kleidon. Thus, for this continuous kneading process, the earth requires only around three times the power that the human race today consumes – albeit in different forms – as primary energy. Talking to Kleidon gives one a completely new sense of just how energy-hungry our species is.

The tides are a further source of energy. When the moon and sun pull at the earth, their gravitational forces pump energy into our planet, albeit relatively little, corresponding to sustained power of five terawatts.

If the earth is seen as a “steam engine” – or more precisely a heat engine – geothermal heat and tides can safely be ignored. This leaves a pure radiation balance as the earth system’s main driver. On the one side of the balance is the radiation from the sun; on the other, the energy re-radiated by earth into space. This ultimately gets rid of the solar energy.

These two rates of energy must be in balance, otherwise our planet would become hotter and hotter, or colder and colder. But wait a minute, the layperson might think: Surely the earth system consumes energy? The wind, waves, hydrologic cycle, plants – all are ultimately driven by sunlight and take a piece of the solar energy cake. The earth must thus absorb more energy than it emits? Wrong! All players in the earth system continuously convert the energy flowing through it from one form into another. The total energy remains constant. At the end of the complex chain, only pure heat energy remains. And the earth radiates this back into space again, just like the radiator of a car engine.

The driving force behind the earth system is thus the conversion of the radiant solar energy into other energy forms. This energy reaches the earth as radiation with relatively short wave-lengths corresponding to a temperature at the sun’s surface of around 5,500 degrees Celsius. The re-radiation from the earth into space has much longer wavelengths and is much colder: minus 18 degrees. In between, the solar energy has driven life on earth by photosynthesis – like a complex transmission unit that shifts thermal processes down a gear, as it were.

And this is exactly why the image of the heat engine is so apt. A steam engine also has a hot energy source, namely the fire in the boiler that produces steam. This performs mechanical work, but ultimately has to be cooled and condensed back to water again. The cooling process corresponds to the re-radiation from earth into space. In order to be able to work, all heat engines require a hot reservoir for the energy input and a cold reservoir to dispose of the heat. This applies to combustion engines and power plant turbines alike.
Even the work that these engines perform eventually converts into heat. When we drive by car from home to our vacation destination and back again, the chemical energy of the fuel consumed in the process has been converted into pure waste heat with the aid of the ever-present friction. This heat can’t be used for technical purposes, and has drained away into the environment anyway.

**THE EARTH SYSTEM CAN’T RUN BACKWARDS**

In the 19th century, this realization from the world of nascent steam engines led to the theory of thermodynamics. What started with engineering became a field of physics that has fundamental significance for the earth system, as well. It is the laws of thermodynamics that give physical processes a direction.

“This is why the earth system can’t simply run backwards like a film,” explains Axel Kleidon, “that is, absorb cold, long-wave radiation from all directions in space and radiate hot, short-wave radiation to the sun as rays.” This is something the visitor must first digest – especially since the scientist now steers toward a term with which even many physics students initially grapple: entropy.

Fortunately, we can all understand the nature of entropy with an illustrative example, as we battle it continuously in our everyday lives. Axel Kleidon’s son is no exception. He likes to play with Legos, and every day he experiences something fundamental with which we are all familiar: The building

It is particularly sensible to collect solar energy in deserts. The Ivanpah power plant (above) which is shown here as a model and is being built in California’s Mojave Desert, is set to supply almost 400 megawatts of power starting in 2013. In many places, however – for instance in the Erlasee solar park in northern Bavaria (right) – photovoltaics competes with photosynthesis, which uses sunlight to produce biomass.

Regions of the world where the Desertec Initiative believes photovoltaic power generation is feasible.
blocks, which are nicely arranged in boxes to start with, appear to spread themselves across the entire room. “This isn’t just a spatial effect, resulting in you eventually stepping on the bricks wherever you walk,” says Kleidon. “The orderly arrangement of the bricks according to their color also transforms into a colorful mix.”

In the child’s room, a mysterious force comes into play that – from the human point of view – strives to change nice order into not-so-nice disorder. This is nothing other than entropy, which increases as the apparent disorder increases. And it wants to carry on indefinitely.

Why is this so? This can be understood if one approaches the ever-present phenomenon from the viewpoint of statistical physics – the modern child of thermodynamics. In statistical terms, the tidy room where the Lego bricks are sorted into boxes according to color is only one state among an incredibly large number of equal states. Each of these states represents a different distribution of the Lego bricks across the room.

This image makes clear that the tidy state is quite unlikely. If Kleidon’s son had tens of billions of years to play with Legos, this state would also occur at some time purely by chance – at least this is what the statistical consideration says. Since his son won’t live that long, he must actively tidy up. “And this spatial concentration and sorting requires work,” says Kleidon. This applies not only to Legos, but very generally.

**SOLAR RADIATION IS ORDERLY, THE EARTH’S, DISORDERLY**

Legos are therefore wonderfully suited to helping one understand the nature of entropy. The laws of thermodynamics state that entropy drives all natural systems toward maximum disorder. As always, it is also quite possible to resist the law. Life does so by utilizing energy to produce ordered structures: the photosynthetic reaction center in plant cells, for example, is a highly ordered molecular Lego set that collects sunlight in order to produce usable energy in the form of sugar.

But breaking the law, which ultimately doesn’t happen, has its price: somewhere else, entropy inevitably has to increase in order to compensate. Earth simply deposits this excess of entropy in space.

Axel Kleidon explains the export mechanism thus: “The radiation from the sun is highly ordered compared to the radiation from earth.” In fact, solar radiation is nicely ordered in two respects. On the one hand, all solar light quanta arrive with a clean spatial order from one direction – from the sun. The earth, however, re-radiates diffusely in all directions, so the spatial disorder is much greater. On the other hand, solar radiation consists of relatively few light quanta that harbor relatively large amounts of energy.

The cool re-radiation from earth into space, in contrast, contains many more light quanta that are relatively low in energy. In the Lego analogy, it might help to think of it like this: while the light quanta from the sun correspond to assembled Lego cars, the debris of individual bricks that results as play progresses corresponds to the radi-
Solar radiation drives a hierarchy of many cycles on earth. It heats the earth’s surface on land, for example, which in turn heats the layer of air above it like a hotplate. The warm air near the ground then rises like a hot-air balloon, taking moisture up to cloud level. Cold air then sinks to the ground, where it heats up. If this convection cycle runs during the day, it boosts the global wind and water cycle in the weather system.

The researchers in Jena can model these essential, major cycles in the earth system and realistically estimate how much of the solar power flows into each cycle. They can draw very concrete, astonishing conclusions from the results. This also applies to the question of how much power we can draw from the earth system in the form of renewable energy without changing it in the long term.

One example is the use of wind power over land. It is at the end of a chain that begins with 1,000 terawatts. This is how much power flows into the global production of wind as a result of solar heating. Around half of this is inherent to the wind near the earth’s surface, meaning it can be reached by wind turbines. Since the land areas are smaller than the oceanic areas, 125 terawatts remain. However, turbulence in the atmosphere, or, simply, friction in the air, uses up another 77 terawatts of this. This leaves around 50 terawatts of wind power that can, in principle, be used for technical purposes over land.

If this power were used to the full, the global weather machine would begin to falter. A maximum of 10 percent could be sustainably used, estimates Axel Kleidon. These 5 terawatts thus correspond to just under a third of mankind’s overall energy requirements.

On land, only around 5 terawatts of wind energy can be used sustainably. Wind parks in the ocean could increase this potential, not least because the low-level wind over the oceans carries around 375 terawatts, and over land only 125 terawatts, of which a mere fraction is available for energy generation.
The good news, according to Kleidon, is that we can expand the use of wind power on land – and offshore – quite a lot in comparison to today. It is, however, subject to surprisingly narrow natural limits. The Jena-based researchers recently calculated that the fast jet streams of wind in the upper atmosphere could supply 200 times less energy – if it were already possible to use them – than was previously thought. This destroys many high-flying visions of floating wind parks in the stratosphere.

Solar energy, in contrast, is present in abundance. This affects the production of solar electricity, as well as food, which of course is converted solar energy. “There would therefore be no change in the overall balance if we were to simply convert existing farmland into solar parks,” explains the scientist. Instead, we must turn unproductive desert areas, which currently convert solar radiation unused into waste heat, into productive areas. So the Desertec Initiative, which is planning large-scale solar power stations in the Sahara, is basically heading in the right direction.

**PHOTOSYNTHESIS PRODUCES 200 TW OF POWER WORLDWIDE**

According to Kleidon’s findings, mankind can sustainably increase the overall power of the earth system if it uses solar energy intelligently. By doing so, it could actually manage the earth and herald a revolution similar to that ignited by the invention of farming.

Life itself has already been doing this for many millions of years – and that on a massive scale. The numbers in Kleidon’s power balance show this. In the global earth system, photosynthesis provides a gigantic capacity of more than 200 terawatts. That’s roughly four times as much as the contribution from geothermal power, and more than twice times as much as our global consumption of primary energy.

Seen from space, this biotic productivity shows up not only in the green color of earth’s landscapes; as Kleidon points out, the relatively small-scale cloud formations, too, are ultimately a clear fingerprint of plant activity on earth. Rainforests, such as the Amazon, have a massive impact on the local weather and thus the cloud structures in a very localized area – which, on a global scale, is what even the Amazon represents.

**WITH DEEP ROOTS, PLANTS COOL THE CLIMATE MORE STRONGLY**

In fact, it was the vegetation of the Amazon that brought Kleidon to his research field. “In the southern hemisphere, there is a marked dry season in the tropics,” he explains. However, in the Amazon basin, it never gets as hot as the climate models from Kleidon’s time as a doctoral student erroneously calculated. A report in the journal *Nature* on the deep roots of the rain-forest trees in the Amazon gave Kleidon an idea about where the error might lie. He designed a “grounded” climate model that took the root systems of the trees into account.

During the dry season, deep roots allow plants to draw more of the excess water that is stored in the soil from the rainy season. The trees can thus vaporize a lot of water even in the dry season. And in fact, the new model then simulated a much cooler climate that comes close to reality in the Amazon. “The effect was enormous,” says Kleidon, whose delight is still evident today.

The result of this plant activity is that real mushroom clouds – for example thunderstorm cells – are produced above such rainforests. Such sharply defined cloud structures are lacking on Venus and Mars. So for extraterrestrial astronomers, there are countless signs that would indicate that there is vibrant life on planet earth.

**GLOSSARY**

**Entropy:** This is derived from the number of states a system can take on and still have the same energy content. Since there are always many more equally energetic disordered states than ordered ones, the entropy of disordered systems is greater than that of ordered ones. Entropy is thus often illustrated as the measure of disorder. Processes occur spontaneously only if the entropy of the entire system increases in the process. Finally, entropy is also deemed to be a measure of the quality of energy. If energy has a high quality, it means that work can be done with it.

**Earth system:** In this concept, the earth is seen as a system in which the atmosphere, rivers and lakes, ice, soil and rock, and life interact with each other in a multitude of ways.

**Photosynthesis:** This process converts light energy into chemical energy. Plants, bacteria and algae use it to produce, among other things, sugar from carbon dioxide and water, releasing oxygen in the process.

**Thermodynamics:** Describes the rules for possible energy conversions. It can be used to determine, for example, how much work a system can perform when energy is converted from one form into another.
Not only did they create impressive works of art, they also took an interest in alchemy, mathematics and the natural sciences. At the Max Planck Institute for the History of Science in Berlin, researchers headed by Sven Dupré are studying how artists in the early modern era discovered, depicted and circulated new knowledge through their works.

TEXT: BIRGIT FENZEL

There is no way that Karin Leonhard would be willing to taste some of the things her colleagues have cooked up on the kitchen stove. They stick strictly to the recipes of the old masters, albeit not those of the culinary arts, but of painting. As an art historian herself, Karin Leonhard knows the background to these peculiar kitchen experiments: “We are attempting to recreate, on the basis of old texts, the way paints were manufactured. Industrially produced paints in tubes were not available until the middle of the 19th century. Prior to that, anyone who needed paint had to make their own.” Some of the raw materials were sourced from plants, while other ingredients came from the apothecary’s poison cabinet. It was no accident that recipe book author Valentin Boltz of Rufach, writing in the year 1549 in his Illuminierbuch, a treatise on the manufacture and use of paints, urged the reader to exercise caution in using auripigment – arsenic trisulfide – to make the color yellow. “This is a woeful, yet beautiful paint. When you rub it, take care to bind your mouth and nostrils, lest you breathe in the vapor and the dust. And beware not to lick a brush of this color, for it is harmful.”

THE RESEARCHERS USE A VARIETY OF APPROACHES IN THEIR WORK

Karin Leonhard, a native of Munich, is one of the team headed by Sven Dupré. Since October of last year, they have...
Playing with colors: This page from the Cologne Pattern Book depicts the manifold mixtures and combinations used to illuminate books.
The 16th century saw the emergence of a new literary genre, the books of secrets or books of wonders.

been studying “Artistic Knowledge in Pre-Modern Europe” from a variety of perspectives. This interdisciplinary research group at the Max Planck Institute for the History of Science in Berlin draws on various methodological approaches, as well as the wealth of experience of its members – after all, the group is made up of historians of science and technology and experts in art and restoration.

HUNDREDS OF THE OLD MASTERS’ RECIPES

In a sub-section of the project devoted to the written communication of knowledge, Karin Leonhard and her colleague Sylvie Neven, among others, are collecting the recipes of the old masters. “That’s everything that relates to the manufacture and preparation of paints, such as how to make a naturalistic red to depict lips, or pigments for gilding, lacquering, and how to make ink, bronze casting and sculpture. There are even instructions on which paint to use for which elements of an artwork,” adds Sylvie Neven. The recipes come not just from genres such as painting and illumination, but from the goldsmith’s art, from glass and porcelain decoration, and from other areas of the applied arts.

Six months into the project, art historian Karin and Sylvie, an expert in the technology of art, have already assembled and digitized several hundred such recipes. Among them are transcriptions of the 15th-century Strasbourg Manuscript (destroyed by fire). For a long time, this recipe book was believed to be the oldest German-language source for the study of Northern European painting techniques. While Sylvie Neven concentrates on documents from the period between 1350 and 1500, Karin Leonard collects examples from the 16th and 17th centuries.

“Part of what we are interested in is tracing the path that leads to the modern system of colors. After all, many of these documents are an attempt to develop an understanding of the order and structure of colors,” says Karin, describing an aspect of her work that goes beyond a simple inventory of knowledge. The two researchers also want to discover the role these recipes played in training young artists in the workshop, and find out which of them were in circulation outside of the workshop setting.

In fact, contemporary interest in these treatises from the atelier wasn’t restricted to members of the same craft. Alchemists and doctors of medicine also held the artists’ expertise in high regard. “Word had gotten around that artists had a great deal of experimental knowledge at their fingertips,” Karin explains. Scholars, art lovers and patrons were instrumental in transferring such knowledge from the workshops to the world. The rise of typographical reproduction techniques took it one step further.

“The handwritten records, notes and pattern books began to be published,” Karin Leonhard continues. The 16th century saw the emergence of a new literary genre, the so-called books of secrets or books of wonders that were based on these artists’ recipes. One famous example of a book of secrets was Giambattista della Porta’s Magia naturalis of 1558. As is already becoming clear, the emphasis of many of these treatises lay on the manufacture of pigments and other raw materials and how to use them. In Sven Dupré’s opinion, portraying the painter as an alchemist isn’t as wide of the mark as many might suppose. “Contemporary art historians portrayed them in just this way,” the head of the research group concludes from his reading of historical sources. “As far back as the 16th century, Giorgio Vasari and Karel van Mander described the painter Jan van Eyck as an alchemist, ascribing to him the discovery of oil paint.”

HOW TO TURN GUM RESIN INTO A BEAUTIFUL GOLDEN YELLOW

The latter claim doesn’t quite accord with the facts – oil paint had already been described in an earlier text. Still, in the days of van Eyck, the art of making paints was without doubt a science in itself, in which artists used not just the same apparatus as the masters of alchemy and transmutation, but also the same raw materials, some of which were hazardous. The only difference was that they were less concerned with making gold than using water and alcohol to turn gum resin into a beautiful golden yellow. Or staining window glass shades
1 Life in the undergrowth: Otto Marseus van Schrieck painted this sottobosco with snake, thistles and butterflies.

2 A dragon that isn’t a dragon: This 18th-century fake was made from the stretched skin of a stingray. Similar preserved specimens can be found even in the 16th-century collections of curiosities.

3 Nature and art: Two of the dragonflies have real wings, the third set is painted. The picture originates from Joris Hoefnagel’s Animalia Rationalia et Insecta, 1575–1580.
Alchemy wasn’t the only science that artists of the Renaissance studied in theory and in practice.

of yellow—a process described in a 16th-century manuscript in terms that applied to the making of gold.

Nor was alchemy the only science the artists of the Renaissance studied in theory and in practice. Sven Dupré outlines the change of mood that took place in the workshops of artists who no longer regarded themselves as mere artisans: “By the early 17th century at the very latest, the interest taken by artists in alchemy went far beyond the methods of practical chemistry necessary to manufacture pigments.”

ARTISTS REGARDED AS EXPERTS IN THE WORKINGS OF NATURE

“The intellectual life of the artist increasingly leaned toward the worlds of scholarship and science,” says the Max Planck researcher, describing the new spirit of the times. But artists had studied nature long before the 17th century. The new development began in the course of the late 15th and early 16th centuries, as artists came to be seen by others—both patrons and natural philosophers—as experts on matters of nature and the natural sciences. During this time, both painters and scholars became more and more concerned with the study of nature and the intellectual topics of contemporary interest.

Sven Dupré cites Lorenzo Ghiberti, a Florentine sculptor, jeweler and glass painter, as a prime example of what was going on in the early 15th century. He left behind extensive records that provide evidence of his familiarity with learned texts on the subject of lenses. The aspiration to be perceived as an intellectual is even more clearly expressed in the writings of the painter Peter Paul Rubens on alchemy. “The weight attached in these works to the spiritual and cabbalistic elements demonstrates the aspiration of the artist to be regarded as a pictor doctus,” says Sven Dupré.

However, more interesting to the researcher than even the changes in how artists saw themselves is the role of the artist as a communicator of scholarly content. “We would like to find out not just how knowledge circulated among artists themselves, but also how it was used in the production of new works of
A sub-project is thus investigating the role of the artist as a producer and recipient of scientific texts. In search of answers, researcher Barbara Tramelli is examining the artistic scene in 16th-century Milan.

Her attention is focused on the painter Giovanni Paolo Lomazzo, whose writings provide valuable information about the knowledge that circulated among the likes of Bernardino Baldini, Guido Mazzenta, Girolamo Cardano and other protagonists of intellectual life, as well as about how they acquired and shared this knowledge. “Lomazzo is a prime example of the intellectualization of the artistic profession, a process in which the reading of and references to texts became important elements,” says art historian Barbara Tramelli.

The artist as reader and recipient is also the subject of another sub-project in which Sven Dupré is studying the circulation of the works of Arab mathematician Alhazen among artists from the 15th century onward. In his treatise De aspectibus written in the year 1021, Alhazen addressed aspects of optics and the refraction and reflection of light. “Some of the definitive artists of the Western world were familiar with the work of Alhazen,” says Dupré. In absorbing his findings, artists acquired a valuable treasure trove of knowledge about light and color, enabling them to achieve their desire of creating the perfect illusion of three-dimensional space – and to demonstrate a mastery of optics in the process.

Painters – above all the Dutch artists – were interested in both the colors and the effects of light when reflected or refracted by different textures, surfaces and substances. In the opinion of the researchers in Berlin, the way in which artists applied these optical discoveries is closely related with an understanding of materials, including their optical qualities.

"This knowledge was given visual form with the aid of various material objects in the artist’s workshop,” Dupré explains. Great artists were often also great collectors, hoarding not just pigments of every kind, but also feathers, plants, dried animals, sea shells and precious stones. The extent to which these curious collections may have contributed to their knowledge is another of the questions the Berlin-based project seeks to answer.

Artists also produced numerous exhibits for the collections of art and curiosities that enjoyed increasing popular-
1 Jan van Eyck optimized the mimetic potential of oil painting and developed a system of painting that was particularly well suited to reproducing light and color, especially the way light is reflected and refracted by different materials. The effect is seen here in the miter of St. Donatian.

2 The processes used in glass making were similar to those employed by alchemists. "Distillation", Jan van der Straet (Stradanus): Nova reperta, 1584.

In their efforts to achieve representations that were as true to nature as could be, some artists of the late Renaissance set aside their brushes, preferring to apply certain materials as a direct part of the picture. For example, when depicting butterflies, some artists pressed the wings directly into the wet paint on their canvas, says Karin Leonhard, describing a procedure that, in the opinion of some of his contemporaries, Dutchman Elias van den Broeck took to extremes.

TOADS AND BEETLES SCURRY OVER MOSSY GROUND

Such was his predilection for butterfly impressions that van den Broeck was expelled from the guild of painters in Antwerp and compelled to move to Amsterdam. A contemporary of his reported that “the velvet-trousered seigneurs of the first city accused him of having glued the butterflies rather than painting them, indeed so in a huff were they that they did not consider that the glued butterflies are more beautiful and more natural than their painted counterparts, since they not only retain their entire markings, but also last longer than the painted ones.”
Our work also contributes to the current debate about the introduction of a doctorate in the arts.

Of still greater interest to Karin Leohnard are the works of his putative role model Otto Marseus van Schrieck, which contain the earliest examples of impressed butterflies. In the course of a journey through Italy on which he set out in 1648, van Schrieck progressed from still-life images of flowers to depictions of the forest floor. In his naturist compositions, toads, beetles and snakes writhe and scurry over mossy grounds, thistles, poppies and fungi thrive and butterflies and other insects swarm.

For the scientists in Berlin, van Schrieck is a prime example of the artist as a researcher. It was, after all, no accident that the Dutchman’s contemporaries knew him by a nickname that tells all. Thanks to his fascination for the study of nature, he was known as “de Snuffelaer” – the sleuth. “Because everywhere he went, he sought out strangely colored and mottled snakes, lizards, caterpillars, spiders, butterflies and rare plants and herbs,” noted Samuel van Hoogstraten, painter of portraits and historical scenes, in his treatise *Introduction to the High Art of Painting* dating from 1678. Following his return from Italy, van Schrieck is said to have created his own research habitat east of his home in Amsterdam, where he bred and observed amphibians and reptiles.

Thanks to their position between art and science, artists such as Otto Marseus van Schrieck are ideal subjects for the project undertaken by the researchers in Berlin. Sven Dupré explains that his intentions extend beyond pure scientific interest: “Ultimately, our work also contributes to the current debate about the introduction of a doctorate in the arts.” The discussions now taking place about the importance of research in the arts as well as the differing opinions held by universities and academies of art regarding a doctorate in the arts show that this issue is as topical now as it was in the early modern era.

**CAN A WORK OF ART CONTAIN KNOWLEDGE?**

“The questions that tie us as historians into the current debate are, what is artistic knowledge? How is it passed on? Apart from written dissertations, are there other forms in which research work can be presented for evaluation as part of a doctorate?” explains Sven Dupré. In other words, “Can we say that a work of art contains knowledge?”

Whereas antagonists categorically deny that art can have such qualities, for the advocates, it is beyond question. The “Artistic Knowledge” project undertaken by the scientists in Berlin is presently still in its early stages. However, the researchers are already quite certain of one thing: by the beginning of the modern era, if not before, many artists were the equal of the scholars of their day in both research effort and scientific achievement.

**GLOSSARY**

Renaissance: The term used to describe the period between 1400 and 1600 that encompassed the transition from the Middle Ages to the Modern Era. In cultural terms, this period saw a revival of ancient ideals in art and science.

Transmutation: The name given by alchemists to the conversion of base metals such as lead and mercury into noble metals, specifically gold and silver.
For Valentin Braitenberg, the brain was the most interesting research subject in the world, apart from the world itself. A former Director at the Max Planck Institute for Biological Cybernetics in Tübingen, he spent thousands of hours poring over a microscope to get to the bottom of this most complex of organs. His purpose was to examine the fiber pathways in various areas of the brain and to search for their functions.

TEXT ELKE MAIER

Rome, 1948. In the anatomical laboratory of a psychiatric clinic, where neurologists work at the dissecting table to find the causes of language impairment, locomotor disorders and mental derangement, an ambitious medical student is looking through a microscope at a piece of brain tissue. What he sees stays with him forever: “A structure made up of fine threads, so many and so fine that even the strongest magnification of the microscope was hardly sufficient to allow all of them to be seen clearly. Some of the threads ran together in bundles and in layers in specific directions; others lay seemingly randomly distributed every which way through the tissue. Embedded in this felted mass of fibers, it was possible to discern spherical structures, the nuclei of the nerve cells [...].”

The name of the student was Valentin Braitenberg, and this experience in the laboratory was to define his career. At the time of his death last September, at the age of 85, he was one of the foremost neuroscientists in the world. It was during his time in the laboratory in Rome that he set his heart on studying the network in the brain. He was convinced that this tangle held the key to understanding how “the mental functions originate in our heads.”

Braitenberg’s professors were less optimistic. In their view, it was impossible to understand these processes simply because their complexity went beyond the analytical abilities of humans. They thought the interwoven fibers were an impenetrable jumble, and advised their student not to waste too much time thinking about the brain functions hidden within it.

But it was not so easy to dissuade Valentin Braitenberg from pursuing his ideas, particularly when a goatee-sporting, cigar-smoking mathematics professor from Massachusetts added fuel to the fire: Norbert Wiener, a former child prodigy and one of the first researchers in the new area of cybernetics, had published a book that same year entitled Cybernetics or Control and Communication in the Animal and the Machine. It conveyed some of the euphoria generated by the new electronic computing machines that heralded a new era for some scientists. Braitenberg was deeply impressed by the book. Were these computers not also so complex that it was impossible to understand them from the outside? And were they not nevertheless constructed by someone who must have thought them through completely?

After studying in Innsbruck and Rome, Valentin Braitenberg, who was born in Bolzano on June 18, 1926, became a specialist in neurology and psychiatry and obtained a German postdoctoral lecturing qualification in information theory and cybernetics, the science concerned with the control processes in living organisms and machines. As a professor of cybernetics at the University of Naples and, from 1968, a Director at the Max Planck Institute for Biological Cybernetics in Tübingen, he concentrated on the body’s crucial control centers.

His approach was that of a neuroanatomist: his goal was to describe the typical structure of a certain part of the brain in order to deduce its function. He liked to describe this work as “spying on God,” for which, he said, he spent at least 10,000 hours sitting at his microscope, “looking at thin sections of brain from top to bottom and every which way under 100x to 100,000x magnification.” He had, he said, enjoyed this as much as other people enjoy spending the same amount of time traveling the world.

In 1968, he was appointed a Director at the Max Planck Institute for Biological Cybernetics in Tübingen.
The spatial resolution that the fly achieves with this arrangement is not as good as that of a human, but the temporal resolution is much better. Were *Musca domestica* to watch a movie at the cinema, it would not see continuous action on the screen, but a series of separate, rod-shaped eyes which abut each other on the surface to appear like honeycomb. Each of these “ommatidia” is equipped with its own lens and registers a small section of the environment. The brain then composes a meaningful mosaic of the many individual images. But how must the individual eyes be wired to avoid gaps and overlaps of the mosaic tiles?

The researchers investigated this question with wafer-thin sections of tissue, which they dyed and studied under the microscope in order to reconstruct the fiber pathways. This meticulous exercise resulted in the first detailed circuit diagrams of the eye of a fly. Above all, the scientists were astonished by how accurately the 3,000 ommatidia in each eye are wired up. Six neighboring single eyes conduct their signals through the same cable to a shared nerve cell, which bundles the information and passes it on. The brain can thus filter out interference before it computes an overall picture from the individual images.

**Frankfurter Allgemeine Zeitung, September 14, 2011**

No one could present knowledge about the intelligence hidden in nature more convincingly than Valentino Braitenberg: long after his retirement, his 14 machines, which he simply called ‘vehicles,’ achieved quasi-cult status in robotics.

The first of these imaginary beings is a simple little motorized cart with a temperature sensor. Its responses are easy to comprehend: it travels faster in a warm environment than in a cold one. On the other hand, vehicle number 14, the most sophisticated, gives the impression of having free will and being able to make independent decisions. Nevertheless, it is a comprehensible construction of wires, switches, threshold devices and detectors – and bears no comparison with the human brain with its hundred billion nerve cells and a million kilometer-long fibers that, if laid end to end, would reach from the earth to the far side of the moon and back again.

“Imagine the inside of St. Peter’s in Rome filled with a huge quantity of fibers around a millimeter in diameter that crisscross the building in every direction creating a firm mat – then you have an idea of what the brain looks like when magnified a thousand times,” writes Braitenberg.

It is hardly surprising, then, that where many questions about the brain are concerned, we are still clueless about what is going on in our own heads. However, a glance at the past reveals how much more we do know, thanks to scientists like Valentino Braitenberg: for many hundreds of years, scholars thought that the soft mass inside the skull was merely “slime for cooling the heart.”
Researchers Measure Atmosphere in Soccer Stadium

Field experiment in Mainz shows that concentration is crucial not only on the pitch

Scientists at the MPI for Chemistry analyze the air in sold-out Mainz stadium – and draw some interesting conclusions.

Dense crowds of soccer fans stream into Coface Arena in anticipation of an exciting game – the home match between Mainz 05 and VfL Wolfsburg. Two teams of researchers from the MPI for Chemistry are just as excited as they wait for the game to begin. Their goal is to analyze the air in the stadium using state-of-the-art trace-gas and aerosol measuring technology.

Thanks to the management of the Mainz Bundesliga clubs, Frank Drewnick and Jonathan Williams were able to deploy their measuring equipment in the stadium at the end of last season and collect data that they will use to find out whether and how the composition of trace gases and particles in the stadium air changes during a game.

THE EFFECT OF SNACK STANDS

While the arena offered Drewnick and his doctoral student Peter Faber the perfect starting point for a research study on aerosols, it was the ideal opportunity for Williams and postdoc Patrick Veres to carry out a test: “We will soon be taking a new proton transfer mass spectrometer, known as PTR-MS-TOF for short, on a field campaign to Peru. We wanted to iron out any final growing pains in advance and test its capacity,” says Williams.

The concentration of small organic particles in the air in the stadium was surprisingly high during the match. Initially, several sources came into question: secondary aerosols, which could stem from organic vapors caused by the UV light of the floodlights, cigarette smoke, or particles from the snack stalls in the stadium, also known as cooking aerosols. “Our analyses show only a very slight contribution from the first two sources. It seems cooking accounts for the dominant proportion,” explains Drewnick. Snacks sizzle at no fewer than 17 stands during the game. In addition to producing the hearty snacks, the stands also generate tiny droplets of fat. These spread throughout the air, leading to a high concentration of organic particles in the stadium. “Our measurements speak...
Top-Notch Employer

According to a recent survey, the Max Planck Society is the most popular employer among biologists, chemists and physicists.

Where would you like to work after you graduate? This question was answered by 23,000 German students across all semesters and disciplines at a total of 107 universities. According to the Universum Student Survey 2012, the Max Planck Society is a favorite among young scientists. A total of 32.9 percent of students would like to work for Germany’s most successful research organization, 20.4 percent for the Fraunhofer-Gesellschaft and 19.5 percent for Bayer.

Since 2008, the Max Planck Society has been the undisputed number one. And the MPS is in good company: among economists, Audi leads the way at 17.6 percent, just ahead of BMW (15.8 percent) and Porsche (13.3 percent). Among engineers, Audi again leads the field, with 24.5 percent – ahead of BMW (22.2 percent) and Siemens (23 percent). Computer scientists would prefer to work for search engine provider Google, which 32.5 percent of respondents named as their favorite employer, followed by Microsoft (21.3 percent) and Apple (17.8 percent).

Jonathan Williams hopes to use the data in the near future to be able to create a sort of “world emissions map” of the substances people exhale. It should show the concentrations of trace gases that are emitted in human exhaled air. Further measurements would certainly be necessary – always at locations where the emission effects of humans dominate. “The stadium was an ideal location for that,” says Williams.

The field experiment in the stadium showed one more thing: after the game, which ended in a 0:0 draw, all concentrations rapidly declined again within less than half an hour. The stadium is thus equipped with an exemplary self-cleaning process – at least in terms of the air.

Jonathan Williams’ new instrument also proved its own quality. “We were able to record very clear profiles for all the substances we measured in the air in the stadium. The PTR-MS-TOF thus performed very well in identifying different substances with a variety of rapidly changing sources,” explains Williams.
Award-Winning Family-Friendly Personnel Policy

The Max Planck Society has successfully passed an audit conducted by non-profit organization berufundfamilie GmbH for the third time and once again received a certificate for its family-friendly personnel policy. Now the next step is to implement the new voluntary undertaking, which is tailored specifically to the research organization, and to firmly embed the measures designed to promote a better work-life balance in the corporate culture.

The Max Planck Society is still the only research organization to be certified in its entirety. And it doesn’t shy away from the steep costs involved: the evaluation carried out by specially trained and authorized auditors before the certificate is awarded is a comprehensive process that the company itself must pay for and support with a great deal of its own effort. “By doing this, we hope that we can sensitize all institutes to the importance of achieving a good work-life balance,” says Secretary General Dr. Ludwig Kronthaler, explaining the Max Planck Society’s commitment to this undertaking. The Society also hopes to enhance the appeal of the research organization at the international level, attract highly qualified employees, and increase employee motivation through better operating conditions.

The 2012 re-auditing process was based on the theme “consolidation” and included interviews with employees from different employee groups. The framework and culture of the family-friendly personnel policy were examined and the results were reflected back to top management. After all, it’s not enough to offer family-friendly measures; it is essential to also create an environment that enables employees to avail themselves of these measures without reservation. Otherwise, family-friendly policies are nothing more than lip service.

One of the objectives of the voluntary undertaking is thus to firmly instill an awareness of family issues in the management framework. This includes incorporating the issue of family and career in mandatory seminars on personnel management of managers, and specifically inquiring about the issue during staff appraisals and performance reviews. Communication between Administrative Headquarters and the institutes on the specific issues, for example during meetings of heads of administration, must be intensified and the relevant internal communication level in the Max Planck institutes expanded. Moreover, the positions of equal opportunities commissioners must be strengthened in the institutes. Other teleworking options must also be explored, and existing father role models presented as examples.

The Max Planck Society was one of 371 employers to be awarded a certificate for a family-friendly personnel policy. Throughout Germany, 998 companies, institutions and universities now carry the special logo. A total of roughly 1.9 million employees and 1.2 million students will benefit from the audit.

Scholarship Amounts Standardized

Since July 1, doctoral grant holders at the Max Planck Society have been receiving a standard funding amount of 1,365 euros per month. This was approved by the Executive Committee at the Annual Meeting in Düsseldorf. “Aligning the guidelines governing support for junior scientists ensures that the maximum amount granted is binding and applies as the standard rate at all institutes,” emphasizes Peter Gruss, President of the Max Planck Society. The arrangement applies both to new funding and to the more than 2,200 junior scientists who are already receiving a doctoral grant. An additional allowance of up to 100 euros per month will also be paid for health insurance. PhDnet welcomes the decision, as it means that scholarship holders and doctoral students with a funding agreement are “more or less financially equal at all institutes.”

For MPS President Peter Gruss, grants are a proven tool for funding graduates in Germany and abroad: “They enable us to attract more junior talent for doctoral studies in Germany. It was important for us to safeguard the value of the Max Planck grant so that it is also recognized as a model internationally.”
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