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The life of an avatar is dependent on technology, including even the very act of its birth. For the virtual figure to look true to life and move realistically in its computer world, its creators need to have detailed information about the body of the real-life model, as well as about its movement. This is precisely the data that the first four-dimensional full-body scanner provides. This device was developed by Michael J. Black, Director at the Max Planck Institute for Intelligent Systems in Tübingen, together with American company 3dMD.

With 22 stereo cameras and 22 color cameras taking 60 images per second, the scanner captures a person in various positions and activities that Javier Romero, a scientist at the institute, demonstrates here. For the scan, red and blue squares are printed on Nick Schill, a professional model, and then illuminated with a quickly pulsating spot pattern. The two patterns help the researchers reconstruct the three-dimensional surface of the body and the skin naturally. Not only can this method be used to create true-to-life figures for computer games and films, but it also offers interesting perspectives for research in psychology and medicine. In this way, it will soon be possible to use the realistic avatars in conducting perception experiments on body awareness—for instance to prevent eating disorders.
Unfair: The view of women in the Bavarian legal education system is anything but balanced.

Light Switch in the Brain

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The discovery of a visual pigment in the cell membrane of an archaebacterium in the early 1970s is owed solely to a researcher's curiosity. Now, four decades after Dieter Oesterhelt's pioneering work at the Max Planck Institute of Biochemistry, bacteriorhodopsin and channel-rhodopsin are gaining ground as new tools in neurobiology.

26 Custom-Tailored Molecules
*Chlamydomonas reinhardtii*, a single-celled green alga, can't see much at all with its eye composed solely of photosensitive rhodopsin molecules. Yet there is more to algal rhodopsin than one would expect. In recent years, it has triggered a revolution in neurobiology. Ernst Bamberg from the Max Planck Institute of Biophysics helped make it famous.

32 Guided by Light
A zebrafish larva that is only a few days old isn't yet very mobile – at this age, it is capable of a few vigorous tail movements and not much else. For Herwig Baier at the Max Planck Institute of Neurobiology, however, that's enough. He wants to discover how the brain controls movement and behavior.

ON THE COVER. Beyond specialist circles, the discovery of light-sensitive channel proteins in the 1970s and 1980s hardly made a ripple. Initially, no one suspected that these ion channels would become a popular tool for neurobiologists. Today, neuroscientists can use light to switch individual neurons on and off and, in this way, investigate their role in the brain’s networks.
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Cyber-physical systems are in strong demand for their ability to optimize electricity consumption from renewable sources. They link sensors and actuators, such as power plants, with controls. Computer science specialists are developing mathematical methods for ensuring the reliability of these systems.

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The Sun is the Earth’s principal source of energy and climate driver. Yet sometimes it sends more light to the Earth than other times. Astronomers take these fluctuations in solar radiation into account in models to find out whether they contribute to global warming or counteract it.

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2014 Nobel Prize in Chemistry Goes to Stefan Hell

Highest scientific award for Director at the Max Planck Institute for Biophysical Chemistry

This year’s Nobel Prize in Chemistry honors pioneering work in the area of ultra-high-resolution fluorescence microscopy. Max Planck Director Stefan Hell shares the award with US scientists Eric Betzig and William E. Moerner. Hell revolutionized microscopy with his concept of Stimulated Emission Depletion (STED). It isn’t possible to perceive objects separately that are fewer than 200 nanometers (millionths of a millimeter) apart using traditional optical microscopes. Hell’s concept is thus based on a trick: As with the fluorescence microscope, fluorescing molecules are excited by a beam of light. However, a second beam of light then triggers the opposite effect: it immediately calms the molecules and keeps them dark. In addition, the STED beam has a hole in the middle so that the molecules on the edge of the stimulating light spot become dark, but the molecules in the center can continue to shine without being affected.

Thanks to this technology, cellular structures can be viewed at a level of detail up to ten times greater than that offered by traditional fluorescence microscopes. It is even possible to follow processes in the interior of living cells. STED can therefore make a valuable contribution to the search for the molecular causes of diseases and the mechanisms of drug action.

Strong Voices from Economic Research

Four Max Planck Directors among the top 20 in the FAZ Ranking of Economists

The entire country listens to these economic researchers – this was the headline under which the German newspaper Frankfurter Allgemeine Zeitung published its “2014 Ranking of Economists” in early September. Dietmar Harhoff, head of the Department of Innovation and Entrepreneurship Research at the Max Planck Institute for Innovation and Competition in Munich, placed fifth in the ranking. Three other Max Planck Directors were also among the top 20: Kai Konrad from the Max Planck Institute for Tax Law and Public Finance, Martin Hellwig from the Max Planck Institute for Research on Collective Goods in Bonn, and Axel Börsch-Supan, Director of the Munich Center for the Economics of Aging at the Max Planck Institute for Social Law and Social Policy.

A crucial role in the evaluation, according to the FAZ, is the influence of the economic researchers in the political arena and in the media, which accounts for 50 percent of their ranking. This was established on the basis of a survey carried out among parliamentarians and managers at the federal and state levels, as well as from media quotes published over the previous 12-month period. The other half of the evaluation focuses on the scientists’ research and is based on citations in trade journals from 2010 to 2014.

Among the top 20 German economists: Kai Konrad, Dietmar Harhoff, Martin Hellwig and Axel Börsch-Supan (clockwise from top left).
Cameras Roll for Science

MaxPlanckCinema goes online and is promoted via social media

A comprehensive series of films entitled “MaxPlanckCinema,” which provide original and ambitious presentations of research from the Max Planck institutes, has been produced over the past three years. With these films, the communications officers of the Max Planck Society aim to show that challenging scientific topics can be presented in formats that differ from those used in traditional adult education broadcasting. The educational suitability of the films was tested in cooperation with education experts from the University of Würzburg. Over 650 teachers throughout Germany participated in the online survey. The result: “The introduction stimulates the desire to learn, and the visualization makes many things clearer that would otherwise require lengthy verbal explanations.”

Various contributions from the series have received awards at numerous international festivals. Four films have been nominated for the Goethe Institute’s Science Film Festival 2014 alone, which takes place from October to December 2014 in Asia and attracts over 400,000 visitors. With the help of a social media campaign, the Max Planck Society is now gradually seeking to target particularly a younger audience with this gratis service.

Open Access to Historical Sources

The Max Planck Institute for the History of Science publishes Edition Open Sources

How many people have heard of Nicolò Tartaglia’s 1537 treatise Nova Scientia? The work, which forms the basis of modern ballistics, can be downloaded free of charge from Edition Open Sources. This was made possible by a cooperative effort between the Max Planck Institute for the History of Science with the History of Science Collections and the Department of the History of Science at the University of Oklahoma. Edition Open Sources set itself the goal of making primary sources from the history of science accessible to a wide audience. Each edition from the catalog, which currently includes six works, presents an original source with transcriptions and critical analyses. A PDF and e-book edition can also be obtained from the edition-open-sources.org Internet platform. And those who would like to hold a printed edition of one of the books in their hands can purchase print-on-demand editions. The Max Planck Institute for the History of Science is a pioneer of the Open Access movement, which promotes free access to scientific information throughout the world.
In principle, you’re "Life is longer without the wall"

Interview with sociologist Tobias Vogt from the Max Planck Institute for Demographic Research

Tobias Vogt

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Twenty-five years after the fall of the Berlin Wall, is it possible to say that the division of Germany has been overcome? Is life in the East and West now pretty much the same? Demographic indicators – above all mortality and fertility – are very helpful in providing answers to these questions. For this reason, politicians consult these metrics. Scientists at the Max Planck Institute for Demographic Research study both of these areas and quickly dispense with the idea that the East is already exactly the same as the West. A conversation with sociologist Tobias Vogt about this, as he puts it, “fruitful topic.”

These days, people everywhere are commemorating and celebrating the 25th anniversary of the fall of the Berlin Wall. But apparently the parallel existence of two German systems was not such a bad thing for you, right?

Tobias Vogt: (laughs) In principle, you’re right. I have to admit that, from a scientific perspective, the Wall was a gift. It gave us amazing experimental setups. A population is divided spatially, lives under completely different conditions for four decades and is then reunited. You could not have simulated these conditions in any experiment. Nevertheless, it was a good thing that the Wall came down again. This meant we could discover that the significant gap in the life expectancy of people in the West and East is closing again.

What is your own personal relationship with the GDR and the Wall?

I come from Jena and studied sociology and social policy in Halle and London. I was twelve years old when the wall came down. At that age you notice things changing. At school, in particular, a lot of things were different after 1990 – not just the curriculum. Many children stopped coming to school because their families had moved and jobs were lost. The streetscape changed, as did the coloration of the cities. And, something I can remember very clearly: as an exception, you were allowed to buy New Year’s firecrackers for October 3, 1990…

 Certain myths, which the Max Planck Institute is trying to dispel, persist in relation to East and West. Regarding the topic of the "East’s low birth rate," for example. What’s not right about this? The aim of the GDR in the 1970s was to increase its birth rate, so it launched a successful pro-natalist policy. I was born in 1977 and am more or less a child of this period myself. Then reunification came and the birth rate plummeted – probably due to the enormous insecurity faced by people. Fewer children were born at the time than during the two world wars. In the meantime, however, the East’s birth rate has overtaken that of the West again. In-depth analyses show that the number of children people ultimately had was higher than in the West; people merely delayed having children. This is not really surprising, as the attitude to children and external child care was always very different in the East than in the West.

Another myth concerns the influence of the GDR on current developments in East Germany. It wasn’t as significant as it seemed, was it?

The GDR was not an isolated phenomenon. Stable historical patterns can be observed in demographic sub-areas – what could be described as the staying power of history. Recent research shows that differences in relation to births outside marriage existed long before the GDR. This was not a result of the division of Germany. And life expectancy in Dresden was always higher than in some cities in the West.

Life expectancy and mortality are currently your own favorite topics. Why?

Even if they are not the main aspects of a research project – considerable attention is paid to these topics internationally and papers on them are always welcome at conferences. This is because an astonishing development has taken place in this area in the last 25 years: nowadays, women and men in the East live almost as long as they do in the West. They have really caught up and, as early as 2011, their life expectancy had increased by 6.6 and 7.9 years respectively since 1990. The corresponding increase in the West was only 3.9 for women and 5.7 for men. Even in Japan, the country with the world’s highest life expectancy, which has risen steeply in recent years, people gained fewer years of life than in the East.

And how do you explain this?

Older people, in particular, are benefiting from better medical care. Moreover, public spending for social insurance increased for Germans in the East. Their pensions are higher than before, which means that they have a better standard of living. The extra money may also be benefiting their children, who now take better care of their parents and enable them to have a carefree old age. There has also been a considerable decline in air pollution in eastern Germany.

How much longer will you be able to benefit scientifically from the “Wall experiment”? For quite a while, I think. The situation with regard to data is still unclear and many sources remain that have yet to be accessed. This phenomenon is familiar
On the Net

Shining New Light on the Nano World
The STED microscope developed by Stefan Hell breaks through, for the first time, the magical resolution limit of 200 nanometers that was formulated by Ernst Abbé over 100 years ago, and enables researchers to carry out optical microscope studies on living cells at the nanoscale. This film provides an illuminating and accessible presentation of the achievements of this year’s Nobel laureate in chemistry, who researches at the Max Planck Institute for Biophysical Chemistry in Göttingen.

www.youtube.com/watch?v=0NCNy6pVIZE

Postdoc Platform
How can you explain your own research topic in just two minutes? The Hyman Lab of the Max Planck Institute of Molecular Cell Biology and Genetics has announced a competition for postdocs. In addition to practical tips for young scientists, seminars and images, the resulting videos are included in a blog by the Dresden-based postdoc community presented on the Wordpress platform. The blog provides postdocs with an opportunity to exchange information and to network beyond the boundaries of their institutes and universities.
dresdenpostdocs.wordpress.com

Dossier on the Rosetta Mission
The Rosetta space probe has reached the destination of its decade-plus journey. The signal was received at the ESA control station in Darmstadt at 11:30 a.m. on August 6: the Rosetta has arrived at the comet 67P/Churyumov-Gerasimenko. The Philae lander touched down on the comet on November 12. Astronomy enthusiasts can find all of the important background information on the Rosetta mission – articles, images and videos – in a new Max Planck Dossier.
www.mpg.de/8310003/rosetta_mission

Max Planck Research Award for Quantum Physicists

Robert J. Schoelkopf and Jörg Wrachtrup recognized for their pioneering achievements

The future belongs to quantum computers. They can search through large volumes of data much faster than traditional computers – albeit mainly in theory up to now. The work carried out by Robert J. Schoelkopf and Jörg Wrachtrup represents a major advance in the development of quantum information technology. In honor of their achievements, the Alexander von Humboldt Foundation and the Max Planck Society have presented them with the Max Planck Research Award 2014. Jörg Wrachtrup, professor at the University of Stuttgart and Fellow of the Max Planck Institute for Solid State Research studies isolated spins in solid matter. Spin is a quantum mechanical property of electrons and atomic nuclei and turns them into tiny magnetic needles. Wrachtrup succeeded in reading out the orientation of a single spin in a diamond and controlling it for the first time. Such spins are suitable for use as, among other things, quantum bits, or qubits, the smallest computing units of a quantum computer. Robert J. Schoelkopf, professor at Yale University, is one of the inventors of superconducting qubits. Superconductors transport electricity with zero electrical resistance. The qubits that Schoelkopf developed with his colleagues consist of superconducting electronic circuits. Such circuits can assume defined energy states similar to those of an atom. The lowest two can also encode the “0” and “1” of a data bit.
Marginalized in the Name of the Law

The Bavarian legal education system likes to see itself as one of the best in the country. However, it has shortcomings in one particular area: practice cases, written exams and casual – and less casual – remarks in the study groups testify to an astonishing view of women. A story of Gucci handbags and childlessness.

TEXT DANIELA SCHWEIGLER

And then I would like to make you aware of the most important date in your legal traineeship calendar: the soccer tournament. I want to encourage all of the men today to start training.” These are the words I heard at the beginning of my professional legal training. For supposedly the most important event of the traineeship, there was clearly only a place on the sidelines reserved for women, which would turn out to be symptomatic of the following two years.

Over time, three constantly recurring basic patterns of discrimination emerged: First, women rarely even feature in the practice cases discussed in the study groups in preparation for the second state examination, or are heavily underrepresented compared to men. Second, where women do appear in the cases, they frequently occupy subordinate or evidently typical female roles. And finally, women are pretty much openly made to appear ridiculous not only within the context of these cases, but also by the study group leaders.

In the teaching materials, examination papers and practice cases, women are marginalized both through the language used and through their sometimes flagrant underrepresentation. Without exception, all of the scripts and overviews handed out by my study group leaders used only the masculine form in German, for example, for the terms judge, public prosecutor, witness or attorney-at-law. The following example illustrates that women are not also taken into consideration, as is often claimed. In the course on the code of criminal procedure, we were given fictitious proceedings of a trial containing numerous procedural errors that had to be identified as an exercise on the right of review. A total of 23 people, predominantly men, were mentioned in this 21-page document: the presiding district court judge Dr. Schnell; public prosecutor Bär as the representative of the district attorney’s office; senior court secretary Moll as the authenticating officer; the jurors Obermeier and Zoll; the accused Hans Müller; his defense attorney Zorn; the expert witnesses Dr. Heinrich Hiller and Dr. Konrad Zart; the witnesses Helmut Effner, a bricklayer, Hans Müller, Sr., a pensioner; Dr. Erwin Klug, a district court judge; Franz Effner, a specialist worker; Gerhard Menzel, a preci-
The accused was with his girlfriend, the attractive hairdresser Simone Mühlberger, at the swimming pool on Friedberger Strasse. While the accused and his girlfriend were chatting at the edge of the pool, the plaintiff and his companion let out an ear-piercing cry, chased one another around the pool and splashed each other with water. Miss Mühlberger was splashed twice in the face by the plaintiff with a large amount of water, badly affecting her new hairdo, which later had to be redone."
sion engineer; Siegfried Wagner, a bank employee; Dr. Heinrich Meyer, a physician; Ernst Pfleiderer, a managing director; Herbert Meister, a detective chief inspector; Ilja Mirkovic, an unskilled worker; Heinrich Ochs, a landlord; and Hugo Sauer, a waiter. The only women mentioned: the witnesses Maria Müller, a housewife, the spouse of the accused; and Senta Ludwig, a barmaid, fiancée of the accused.

Women are all too often taken into consideration only in relation to men, namely as their wives and – in this specific case – as a fiancée, which the accused additionally (!) had. This case study also reveals that this marginalization also concerns other groups of people, in particular those from immigrant backgrounds. It is noticeable here that only one person crops up who doesn’t have a typically German name, Ilja Mirkovic, who is an “unskilled worker.”

If women appear in practice cases and written exams, it is often as a mother, wife or housewife. Women primarily occupy the role of victim in criminal law. They are the victims of domestic violence or are helpless in some other way. The “43-year-old housewife Brigitte Mai [...] had no chance of defending herself,” for example, when the perpetrator snatched her car keys from behind, which was the scenario in one written exam. When women appear as the perpetrator, which rarely occurs, the crime it-

The primary concern is about outward appearances – damage to hairstyles, handbags or shoes

self is, of course, stereotypical. It might concern the theft of perfume, for example. In contrast to their male counterparts, who work as farmers, bank employees or carpenters, female jurors and witnesses are almost always “housewives.” The asymmetry is particularly evident in one written exam from 2013: Whereas the two young accused had “no qualifications” and lived “on welfare benefits,” the personal circumstances of the witness were: “Hanna Haas, aged 18, housewife.”

The roles are also clearly assigned in civil law. In a 2011 written exam, the “husband of the plaintiff purchased [...] the contested Rolls-Royce in June 2008 for 18,000 euros [...] and gifted, handed over and transferred ownership of it to his wife, the plaintiff, on New Year’s Eve in the same year, telling her that she should “have her own private vehicle.” One case discussed during the course concerned the consultation of two entrepreneurs when founding a company. It was of great importance to the two clients that “their wives should be provided for, as the respective family incomes had to date come primarily from equity interests.”

“Of course, my wife and sister-in-law would have no interest in keeping the company going themselves or only assuming personal liability,” was one of the reasons given. In a written exam on inheritance law, the client, an elderly woman, declared that her sons, Ulrich and Udo, had become “successful businessmen and both earned good salaries. However, neither of them had any children because their wives also worked.”

Family law naturally stands out, in particular, for cementing conventional gender roles. In the family law course, the female lecturer failed to deviate from the traditional allocation of roles in any case study: Without exception, the mother looked after the children, earned either no income or significantly less than her husband, and was therefore dependent on his alimony payments. Even beyond the specific cases, the lecturer didn’t miss the opportunity to emphasize at an opportune moment how damaging “third-party care” was for children and young people, referring to her previous position as a juvenile court judge.

The following case, covered when studying the equalization of matrimonial surplus, is also representative: The husband, a “hardworking businessman,” had debts of 20,000 euros at the time of marriage and today has assets of 20,000 euros. “However, he fell for his secretary, Dolores, and gave her 10,000 euros. [...] In contrast to Dolores, the husband kept a tight rein on his wife’s spending during the marriage. As she had entered the marriage with no assets and had been supportive of her husband and looked after the home, she had been unable to accrue any assets.”

A number of gender-specific stereotypes are reinforced here in concise form: First, there is the wom-
an’s financial dependence on the man. He clearly decides on the use of the family income and can keep his wife “on a tight rein.” Moreover, the wife is also personally forced into the role of victim. She has shown the proverbial “devotion and support” to her husband all these years, only to now be swiftly replaced by the secretary.

In addition to the consolidation of gender stereotypes, not one single case of a registered civil partnership came up during the family law course, which means another marginalized group must be mentioned here. In the course on income tax law, which took place prior to the Federal Constitutional Court’s decision on income splitting in 2013, the female lecturer also explained that registered civil partners could not be assigned to the income tax bracket III–V in Bavaria “because the computer will simply not process Mr. and Mr.”

In the already-discussed written exams and practice cases, women are even made to look blatantly ridiculous on a continual basis, as in this example where claims for damages have to be evaluated: “The accused was with his girlfriend, the attractive hairdresser Simone Mühlberger, at the swimming pool on Friedberger Strasse. While the accused and his girlfriend were chatting at the edge of the pool, the plaintiff and his companion let out an ear-piercing cry, chased one another around the pool and splashed each other with water. Miss Mühlberger was splashed twice in the face by the plaintiff with a large amount of water, badly affecting her new hairdo, which later had to be redone.”

The woman, or the “young lady,” as she is referred to, is reduced to her appearance. Her horizons clearly do not extend beyond the condition of her hairdo. “Photos of the witness shortly after the incident” are presented as evidence of the “damage.”

The following case also follows a similar pattern – the woman’s only concern is of an external nature: “K is claiming damages against B, whose sharp-edged banisters caused damage to her Gucci handbag.” In a particularly tasteless example from a family law practice paper, the female client, a victim of domestic violence, in addition to filing for divorce, transfer of parental custody and alimony, was also making a claim for damages against her husband for the destruction of her high heels. The complainant first outlined how her spouse had beaten her, and then immediately afterwards, mentions “a pair of brown women’s low shoes and a pair of leather boots.” These had, in fact, “been cut up with a pair of scissors, and the heels had been sawn off in a fit of rage” by the husband.

In the 2011/I/2 written exam, the witness, Sabine Schopper from Starnberg, says: “I am the Christ’s neighbor and, since early 2009, often travel to Munich with Mrs. Christ to go shopping. We always drive with her car to Maximilianstrasse.” Mrs. Schopper is well informed of the goings-on in the neighborhood because: “I often look out of the window, as I’ve got lots of time on my hands.”

However, even beyond the cases highlighted here, women are continually – almost in passing – the subject of “snide comments” by the study group leaders: A judge once said, in relation to section 818, paragraph 3, of the German Civil Code, that women’s “preferred means of becoming impoverished was through the purchase of shoes and handbags.” Another judge poked fun at the “Alice Schwarzer mob,” which supported gender-neutral language in legislation, such as “investigating persons” instead of “investigating [male] officers” in section 152 of the German Judicature Act, calling them a “Punch and Judy show.”

Despite the fact that the presence of women is also increasing in legal training owing to the growing proportion of women working in the judicial system, the majority of study groups in Bavaria are led by men. This is especially true of study groups led by those in full-time positions. Older teaching material, mainly produced by men, is used all too often – by men and women – especially for past written exams, without them being revised to take account of the role models conveyed. The upshot is that the tra-
Daniela Schweigler, born in 1982, is an academic assistant at the Max Planck Institute for Social Law and Social Policy. She studied law, specializing in employment and social law, in Leipzig and Munich. From 2008 to 2011 she worked on her dissertation at the Max Planck Institute for Social Law and Social Policy, and was awarded her doctorate from the LMU in 2012. At the same time, she worked at a law firm. After her legal traineeship at the Higher Regional Court in Munich, she passed the second state law examination in 2013.

Learning is about working from the bottom up. However, it is women, in particular, who find themselves at the very bottom of the pile in Bavarian legal traineeships. Legal training in Bavaria has a sexism issue that manifests itself in both the cases used for training and in the teaching itself. In order to address the underlying structural causes – especially the lack of awareness of the issue – an institutionalized procedure at ministerial level is both desirable and necessary. The Upper Bavarian authority is exemplary in this respect.

Finally, the fact that there are also some very positive initial signs shouldn’t be overlooked. In the 2013/I written exam, the key persons from whose perspective the exam had to be completed were mainly women, including the presiding judge, the public prosecutor and the attorney-at-law. Whether this was coincidence or marks a change of trend remains to be seen. What is clear is that, as long as practice cases such as those outlined here are discussed in the study groups, the issue won’t be changed fundamentally – reflecting badly on Bavarian legal training, which is highly regarded in the profession.

This text was first published in Deutsche Richterzeitung, 2/2014. The publisher has kindly consented to its reproduction.
Research on the Go

The MaxPlanckApp for iOS and Android with news and videos

For iOS:

For Android:

Free Download
Dreaming of a Ship of Her Own

Max Planck scientists cooperate with partners in around 120 countries worldwide. Here they relate their personal experiences and impressions. Marine biologist Cecilia Alonso spent a number of years in Europe and returned to Uruguay in 2007. Since then, she sees her home country in a new light, and brings her knowledge and new experiences to research operations there.

When I visit Valizas, a fishing village on Uruguay’s Atlantic coast, I realize that it’s the ebb and flow of the tides that I find most fascinating. Today, only a couple of weathered wooden houses still form the old village core, unoccupied, standing on stilts in the middle of a lagoon, the waters flowing beneath them. It’s been awhile since village life took place in this barren environment, as the residents bowed to the constantly changing coastline a couple of decades ago and moved a few hundred meters northward. That’s just the way it is here – life is determined by the water. And there is little in the new Valizas that is reminiscent of the elemental force of the Atlantic Ocean that once threatened the village.

I returned to my native land on the east coast of South America about seven years ago – I wanted to take a new direction and have an impact. Even back then, I knew that it wouldn’t be all that easy. After all, after completing my doctorate at the Max Planck Institute for Marine Microbiology in Bremen, and a few years in the rich research landscape in Europe, I was a bit spoiled.

Marine research isn’t yet a top priority in South America; it involves a lot of persuasion, a lot of phone calls, a lot of politics. But this, too, is changing. More and more researchers are returning to Uruguay after their studies. And it’s not just knowledge they’re bringing with them.
We’re too demanding, people sometimes say. But actually, many researchers from here are also glad that, because of us, the standards from abroad are slowly starting to become standards here, also. That’s also why we came back, because we want to share the expensive equipment and sophisticated methods with the university, to help shape the change. And the resistance is slowly waning – we are very gradually finding our place. The only thing that remains a dream, for now, is having my own research ship. Then I could travel all by myself to the region where I do my research: the huge Río de la Plata estuary. The change taking place there is enormous.

The nutrient-rich freshwater currents of the Paraná and Uruguay rivers flow steadily into the sluggish, salty Atlantic. Ocean eddies, temperature gradients, sudden salt water – the ecosystem places heavy demands on its inhabitants. However, its tiniest ones, the microorganisms, adapt particularly quickly – and I want to gain an understanding of their lifestyle. Their survival ensures, if you will, that also the fishermen in Valizas can continue to put dinner on the table.

That’s why, here in Uruguay, outreach programs with the communities are very important. Together with those living on the coast, we then take water samples and talk about environmental protection. But to be honest, I’m the one who learns the most there – especially when the older folks wax nostalgic about how things used to be, telling stories about the old Valizas with its handsome wooden houses that are now found only in the lagoon, weathered and moldy. But if I think about it more, there are also some village inhabitants in Valizas who are adapting quite well to the change: the children. For them, the lagoon is simply a great summer playground.
Halobacteria belong to the archaebacteria. They have a particular preference for extremely saline environments.
Single-Celled Organisms Shed Light on Neurobiology

The discovery of a visual pigment in the cell membrane of an archaebacterium in the early 1970s is owed solely to a researcher’s curiosity: For three years, the scientific community wouldn’t believe Dieter Oesterhelt. Forty years after his pioneering work at the Max Planck Institute of Biochemistry in Martinsried, bacteriorhodopsin and channelrhodopsin, which stems from a single-celled green alga, are gaining ground as new tools in neurobiology.

It was more or less a coincidence that brought biochemist Dieter Oesterhelt into contact with Halobacterium salinarum. But this archaebacterium would eventually become the central research object of his scientific life for the next 40 years. Oesterhelt had done his doctorate in Feodor Lynen’s lab at the Max Planck Institute for Cell Chemistry (later the Max Planck Institute of Biochemistry) on a metabolic enzyme, fatty acid synthase. “A giant particle,” as he says, “whose structure could be decoded only through electron microscopy.”

This explains why the researcher went on a sabbatical in 1969, to San Francisco and Walther Stoeckenius, a renowned expert in the field of electron microscopy. Oesterhelt wanted to learn to use this technology in the lab with him.

Stoeckenius was interested in the membrane of the halobacterium because, at that time, the molecular struc-
tured of cell membranes was still a subject of controversy. “That was the so-called purple membrane, which is how it was known even then. But it was completely unclear what it was,” says Dieter Oesterhelt.

Allen Blaurock, who was likewise in Stoeckenius’ lab at the time, requested Oesterhelt’s assistance in preparing his samples. Oesterhelt experimented with different organic solvents to elute the lipids from the membrane: “So I extracted the purple membrane with chloroform/methanol – and suddenly I had a yellow extract,” he recalls.

Such a change in absorption across an area of nearly 200 nanometers seemed quite unusual to the young biochemist. But Allen Blaurock dismissed it – he had worked on frog retinas with Maurice Wilkins in London. Their X-ray experiments required them to irradiate the frog retina at a very specific angle. “But if we weren’t careful,” Blaurock told Oesterhelt, “the beam went into the frog’s lovely red eye, and suddenly it turned yellow.”

That was the decisive clue for Dieter Oesterhelt. He went to the library to retrieve the data on retinal, the light-absorbing pigment in the retina of vertebrates, and then analyzed the purple membrane using mass spectroscopy. No doubt about it: it was retinal. Walther Stoeckenius’ initial reaction, however, was less than euphoric – he said, quite simply: “That can’t be. That doesn’t exist in prokaryotes.”

The reviewer for the journal Nature likely had a similar view. The submitted publication was rejected with a note saying that the experiments were fine, but the analogy with rhodopsin was pretty far-fetched. “It was simply unacceptable to find retinal somewhere other than in an eye,” concludes Oesterhelt. So the first publication on bacteriorhodopsin, as the authors had christened their molecule, appeared in 1971 in the journal Nature New Biology.

PHOTOSYNTHESIS INVENTED NOT ONCE, BUT TWICE

Dieter Oesterhelt returned to Munich and – despite serious doubts on the part of his colleagues there – continued to work with the bacteriorhodopsin: “It seems to me to be quite an unusual thing, and it isn’t there without reason,” he explained to the skeptics. And then the shortage of collaborators was also accompanied by a shortage of equipment. The Max Planck Institute for Cell Chemistry moved out to Martinsried, while Oesterhelt remained in the originally shared labs at the Ludwig-Maximillans-Universität Institute of Biochemistry. “All I had left was a pH meter, a water bath and a projector,” he says. But this situation proved to be a blessing for the key experiment that followed, “because I simply couldn’t do much more.”

Oesterhelt was firmly convinced that the color change is associated with a function, so he worked on reversing it: “Quite simply, I tried every solvent in the world.” And then here, too, coincidence again played a role. Specifically, if I took ether, added salt, and then went to the window when the Sun was shining, the extract suddenly turned bright yellow; in the dark, the color changed back. That was the desired color change, but what was behind it?

“I simply placed a pH electrode in it,” says Oesterhelt. When the color changed from purple to yellow, protons were released, and when the color changed from yellow to purple, protons were taken up. Accordingly, the extract became acidic in the one case, and alkaline in the other. However, when such a release and uptake of protons...
It was simply unacceptable to find retinal somewhere other than in an eye."

takes place in a dense layer, such as a membrane, it would have to create a pumping effect.

The young biochemist imagined a proton pump – that is, a molecule that takes up protons from one direction and releases them in the other. Oesterhelt presented this idea to his dissertation supervisor Feodor Lynen. He said simply: “I don’t believe it, but I certainly hope that you’re right.” If the molecule pumps protons, then it should be possible to measure a pH change in a suspension of bacteria cells.

Dieter Oesterhelt set up his pH meter in the darkroom to see what would happen when he exposed intact cells. He set the pH meter to the highest sensitivity and then turned the light on: “The recorder gave a jerk and the needle shot straight to the upper limit.” In a few days, he had gathered the relevant readings and, with them, the proof that bacteriorhodopsin is, indeed, a light-driven proton pump.

By transporting protons out of the interior of the bacteria cell, a proton concentration gradient is created between inside and outside, and an electrical potential is built up across the membrane. “The process is just like charging a battery,” explains the Max Planck researcher. The energy of the protons flowing back in is used for enzymatic synthesis of ATP (adenosine triphosphate), the energy currency of the cell.

**EVEN MORE LIGHT-SWITCHED MEMBRANE PROTEINS**

This was in line with the chemiosmotic hypothesis proposed by Peter D. Mitchell back in 1961 – which earned him the Nobel Prize in Chemistry in 1978 – for which bacteriorhodopsin thus provided initial evidence. The purple membrane system is, next to the chlorophyll system of green plants, the second light-energy conversion principle of living nature. “In other words, evolution invented the fundamental process of photosynthesis not once, but twice,” says Dieter Oesterhelt.

In the years that followed, bacteriorhodopsin rose to become a model subject in bioenergetics, membrane biology and structural biology. Since the start of the second half of the 1970s, there have been more than a hundred publications on this topic each year. In 1977, Japanese researchers Matsuno-Yagi and Mukohata discovered a further pigment in the purple membrane of *Halobacterium salinarum*, but it differed from bacteriorhodopsin. It was long speculated that this was a light-activatable sodium pump.

Oesterhelt had since become Director at the Max Planck Institute of Biochemistry in Martinsried, and one of his first doctoral students there was chemist Peter Hegemann. He was originally supposed to isolate this sodium pump, which was called halorhodopsin. But then Janos Lanyi and Brigitte Schobert from the University of California showed that this membrane protein wasn’t pumping sodium ions out of the cell, but rather, it was pumping chloride ions into the cell. This
We hadn’t expected that the research on single-celled algae could one day interest the readers of a medical journal.«

would later take on an entirely new significance.

In 1986, Hegemann began leading a group of his own in Oesterhelt’s department of membrane biochemistry and, in the late 1980s, dedicated himself to a new object of study: the small, unicellular green alga *Chlamydomonas reinhardtii*. In *EMBO Molecular Medicine*, he and his co-author Georg Nagel later wrote: “When we conducted our experiments more than a decade earlier, we hadn’t expected that the research on the molecular mechanisms of the phototaxis of single-celled algae or the light-driven ion transport in archaeabacteria could one day be of interest to the readers of a medical journal.” But the road was rocky, and extremely long.

AN ALGA’S RED EYESPOT APPARATUS WAS PUZZLING

As a photosynthetic organism, *Chlamydomonas* seeks out areas where the light conditions are particularly favorable for photosynthesis. In doing so, it uses its long flagella to propel itself like a little breaststroker. This means that the photosynthesis apparatus of the small green alga doesn’t have to continually be adapted to changing light conditions. Scientists refer to such light-controlled orientation movements as phototaxis. They’ve been known since the 19th century. The light sensor responsible for phototaxis is located in the alga’s red eyespot apparatus.

Kenneth W. Foster, a former student of Max Delbrück, studied the phototactic movements of *Chlamydomonas* as a function of the light’s wavelength in order to obtain information about the light sensor’s properties. Using these so-called action spectra, he postulated – already back in 1980 – that the light sensor is a rhodopsin. Furthermore, a few years later, he succeeded in restoring the light-driven movements in “blind” algae by adding retinal. “But the photoreceptor researchers’ field didn’t recognize the significance of these findings at the time,” says Peter Hegemann.

However, the clue that a small, single-celled green alga uses a visual pigment that may be very similar to the one in the human eye aroused his interest. Together with his colleagues, Hegemann labored for ten years to obtain the alga’s photoreceptor in sufficient amounts and appropriate purity for protein chemical analyses, but the tests remained unsuccessful: “The radioactive labels yielded a completely undefined image,” he says. Today, the researchers know that there are ten different rhodopsins in the eyespot apparatus of *Chlamydomonas*.

Back then, only the electrophysiological measurements produced promising results: the photocurrents published in the journal *Nature* in 1991 not only showed that the photoreceptor did, in fact, have to be a rhodopsin, but they also revealed something else: unlike in the human eye, the current was quite obviously not transmitted via
a chemical signal cascade and thus amplified. Instead, the photoreceptor appeared to be coupled directly to an ion channel, as the photocurrents appeared extremely quickly, within just 30 microseconds (milliseconds of a second) after exposure.

Eight years later, Hegemann, who had since been appointed to a position at the University of Regensburg, made an even more pointed statement in a publication: “We assume that chlamy-rhodopsin is part of a rhodopsin-ion channel complex, or even forms the channel itself.” But the scientific community countered these explanations with similar skepticism as for Oesterhelt’s previous discovery of the first microbial rhodopsin.

It still wasn’t possible to list the key properties of this alleged rhodopsin channel. All electrophysiological derivations were carried out using a suction pipette. The researchers were thus always able to register only the total of the ion currents across a large membrane area, but not the current of a single channel.

A new approach was needed. In 2000, the Japanese Kazusa DNA Research Institute published thousands of newly decoded gene sequences from Chlamydomonas reinhardtii in freely accessible online databases. When looking through these sequences, the researchers in Regensburg discovered two longer sections that were similar to bacterial rhodopsin genes.

Hegemann asked Georg Nagel, then a research group leader at the Frankfurt-based Max Planck Institute for Biophysics in Ernst Bamberg’s department, to test the properties of the proteins encoded by these gene sequences.

Bamberg’s department had already accrued years of experience in the electrophysiological characterization of microbial rhodopsins. In order to document the transport characteristics of bacteriorhodopsin and halorhodopsin under electrically controlled conditions, the researchers had transferred them to the egg cells of claw frogs.

THE BIRTH OF OPTOGENETICS

Nagel and his colleagues now likewise tested the electrical properties of the proteins originating from Chlamydomonas in frog eggs. In June 2002, they presented the findings in the journal Science. It was the long-awaited proof that the algae rhodopsin was indeed the first example of a directly light-driven ion channel, and thus a completely novel membrane protein. After taking up light, channelrhodopsin-1 (ChR1), as the scientists had christened their “baby,” channels protons via the membrane into the cell interior; in contrast to the proton pump, bacteriorhodopsin, the ion transport requires no energy.

One year later, the researchers published their findings on the second light-activated ion channel, channelrhodopsin-2 (ChR2), which, in contrast to channelrhodopsin-1, also channels other positively charged particles, such as sodium ions. They had succeeded in incorporating channelrhodopsin-2 not only in frog eggs, but for the first time, also in human kidney cells.

This publication aroused the interest of Karl Deisseroth and Edward Boyden at Stanford University. The two researchers had already been discussing possibilities for controlling the electrical activity of nerve cells in the intact brain for some time. In March 2004, Deisseroth wrote an e-mail to Georg Nagel and asked whether he could, in the context of a collaboration, get a clone of channelrhodopsin-2. The package from Germany arrived a few weeks later.
Georg Nagel already managed to express bacteriorhodopsin in animal cells in 1995. In the egg cells of claw frogs (at the top right of the image, on the computer screen), and in this way, to study its electrophysiological characteristics under controlled conditions. But the neuroscientists showed little interest in this. This changed when Nagel succeeded in transferring channelrhodopsin-2 to frog eggs. Then several research groups dared to attempt, in 2005, to incorporate channelrhodopsin-2 in nerve cells – and succeeded – in order to use light to control their electrical activity. Only then did the researchers consider using also bacteriorhodopsin as an optogenetic tool. While nerve cells can be activated by light with channelrhodopsin-2, they can be switched off with bacteriorhodopsin.

1995 – 2005

Boyden, Deisseroth and Feng Zhang, who had subsequently joined them, considered how to proceed. In the months that followed, the researchers optimized their experimental setup. Using a harmless virus as a gene ferry, they managed to introduce the gene for channelrhodopsin-2 into cultivated hippocampus neurons. Via the promoter, a genetic switch, they were able to control which neuron type produces channelrhodopsin-2. The experiment worked, “incredibly well, actually,” as Deisseroth writes. “Using simple, harmless flashes of light, we were able to reliably control, with millisecond precision, when the opsin-producing nerve cells triggered action potentials.”

Together with the Max Planck researchers in Frankfurt, the three Americans published the findings in *Nature Neuroscience* in 2005. This breakthrough was virtually in the air – in parallel, Japanese researchers working with Hiromu Yawo succeeded in expressing channelrhodopsin-2 in PC12 cells. And Stefan Herlitze (then at Case Western Reserve University in Cleveland) was even successful in expressing channelrhodopsin-2 in the spinal cord of vertebrates. He was able to show – just like Alexander Gottschalk with the nematode *C. elegans*, incidentally – that light-activated opsins are indeed suitable for regulating neural networks in intact organisms. That was the actual start of the new research field of optogenetics.

So it was now possible to use light to activate nerve cells within neural circuits. The following year, Deisseroth attended a lecture at the Max Planck Institute in Frankfurt. He asked his German colleagues about an optogenetic tool that, conversely, permits nerve cells to be switched off using light. Bamberg and Nagel told him about their experiments with bacteriorhodopsin and halorhodopsin in frog eggs in the mid-1990s. And they recommended that he use halorhodopsin from *Natronomonas pharaonis*. Janos Lanyi had discovered it in 1999. In contrast to halorhodopsin from *Halobacterium salinarum*, it also works at low chloride concentrations, like those prevailing, for instance, in the mammalian brain.

At Stanford, Zhang now synthesized the corresponding gene and introduced it into nerve cells; at the same time, Alexander Gottschalk tested it successfully in *C. elegans*. In spring 2007, the researchers from Frankfurt and Stanford published their findings: while channelrhodopsin-2 works like an “on” switch, halorhodopsin can be used with light to suppress action potentials in the cell, so it works like an “off” switch. Three years later, Boyden and his team at MIT were then able to show that also the proton pump bacteriorhodopsin that Dieter Oesterhelt had already discovered in the early 1970s is capable of switching neurons off.

And so we come full circle after nearly half a century of basic research. What appeared to be a caprice of nature – a retinal-binding protein in the membrane of an obscure archaeabacterium – is becoming a paradigm for the interplay between light and life. Today, thousands of researchers are using optogenetic methods to analyze how activity patterns of specific neuron groups control complex physiological processes and behaviors. Pioneering work like that of Zhuo-Hua Pan at Wayne State University show that it isn’t just neurobiologists who can use optogenetics as a tool.

Pan successfully introduced channelrhodopsin-2 into the retinal cells of blind mice, giving them the ability to perceive light again. Other researchers have since expanded this approach – restoring eyesight in cases of degenerative retinal diseases could become one of the most promising clinical applications of optogenetics.
The colored light excites certain nerve cells in the brain of a rat. Researchers essentially activate or deactivate nerve cells with the touch of a button, allowing them to study for the first time what effects individual nerve cells have. This, in turn, makes it possible to study the network of billions of brain cells in intact organisms. Using gene technology methods, the opsins can be incorporated in very specific brain cells. It is thanks to this precision that optogenetics took hold so quickly; in 2010, the journal *Nature Methods* named it the »Method of the Year«.

**2010**

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What appeared to be a caprice of nature is becoming a paradigm for the interplay between light and life.

**TO THE POINT**

- In the early 1970s, Dieter Oesterhelt was the first to discover, in *Halobacterium salinarum*, a retinal, the pigment that, at the time, was known only from the retina of vertebrates. Retinal is a component in a membrane protein, bacteriorhodopsin. This is a light-driven proton pump that the bacterium uses to convert sunlight to chemical energy – a new form of photosynthesis.

- In 1980, the first indications were found that also the red eyespot apparatus of the green alga *Chlamydomonas reinhardtii* contains rhodopsin. In 2002, Peter Hegemann and Georg Nagel were able to prove beyond any doubt that this rhodopsin is the first example of a light-gated ion channel that is used to control the flagellar beat. The researchers called this novel protein channelrhodopsin.

- Various research groups succeeded in introducing the gene sequences of these membrane proteins into nerve cells and expressing it there. This made it possible for the first time to influence neural activity using light-switched channels or pumps in the membrane – and so optogenetics was born.

**GLOSSARY**

**Action potential:** This causes an electrical stimulus to be transmitted by changing the membrane potential – that is, the electrical potential across the membrane of a nerve cell.

**Archaebacteria, also known as archaea:** Single-celled organisms that emerged very early on in evolution and that have usually adapted to extreme habitats. In some properties, such as the lack of a nucleus, they are more like bacteria, and in others, more like eukaryotes.

**Ion channel:** The lipid bilayer of biological membranes is impermeable to charged molecules, so also to ions. Ion channels are proteins that extend through the membrane and allow electrically charged particles to cross through. The transport takes place along an existing electrochemical gradient, the concentration gradient.

**Ion pump:** Transmembrane proteins that regulate the transport of certain ions through a biological membrane are referred to as ion pumps. In contrast to ion channels, they facilitate the active transport of ions using energy. In this way, differences in the concentration of ions between the two sides of the membrane can be maintained.

**Optogenetics:** A relatively new field that deals with controlling genetically modified cells using light. It is based on light-activatable membrane proteins, such as bacteriorhodopsin and channelrhodopsin, built into, for instance, nerve cells.

**Prokaryotes:** Single-celled organisms whose DNA is not present in a cell nucleus; these include bacteria and archaebacteria. Prokaryotes are distinguished from eukaryotes, organisms having a nucleus.

**Rhodopsin:** A light-sensitive protein that contains retinal as a light-absorbing pigment.
**Custom-Tailored Molecules**

*Chlamydomonas reinhardtii*, a single-celled green alga, can’t see much at all with its eye composed solely of photosensitive rhodopsin molecules. Yet there is more to algal rhodopsin than one would expect. In recent years, it has triggered a revolution in neurobiology. Ernst Bamberg from the Max Planck Institute of Biophysics in Frankfurt helped make it famous. He is now researching these molecules and developing new variants for basic research and medical applications.

**TEXT** CATARINA PIETSCHMANN

All *Chlamydomonas* requires in order to see is an accumulation of proteins, known as an eyespot. Under a microscope, the eyespot appears as a yellow dot in an otherwise green algal cell. It allows *Chlamydomonas* to see what it needs to see – light, dark, and a few shades in between – so that the cell can swim closer to or further away from the water surface, depending on the light conditions.

The eyespot is composed of around 200 different proteins, including photosensitive rhodopsin molecules. Similar rhodopsins can also be found in the human eye, or more specifically, in the retinal photoreceptors, where they transduce the incident light into an electrical signal that is then transmitted to the brain for further processing.

Rhodopsins are made up of two components: the protein opsin and the carotenoid retinal, a photosensitive molecule. In the eye, the act of seeing starts when light straightens out the retinal, which takes on a bent shape in the dark. In humans and other mammals, this activates the rhodopsin and, via a multistage process, blocks positive ions from flooding into the cell.

**ALL-IN-ONE PHOTORECEPTOR AND ION CHANNEL**

In 2002, Bamberg and Georg Nagel, together with Peter Hegemann from Humboldt University in Berlin, discovered the mechanism of algal rhodopsins. The researchers transferred the rhodopsin gene to egg cells of a clawed frog and observed that the proteins combine the photoreceptor and the ion channel into one single protein. The rhodopsin in algae thus has a different function than the rhodopsins in mammals: the opsin itself forms an ion channel, which can be opened by light so that the ions can then pass through. As a result, the light stimuli are transduced faster into an electrical signal in an algal cell than they are in the human eye.

The researchers named this particular protein “channelrhodopsin.” They soon realized that this protein harbors great potential for science. In a comprehensive patent specification published following their discovery, they even included a detailed list of possible applications in the fields of neurobiology and biomedicine. “In retrospect, that was almost a rather presumptuous thing to do, but almost all of it has since come true. Today, there are hardly any applications for channelrhodopsins that aren’t included in our patent,” says Ernst Bamberg. To name just one example: a license extract for treating eye diseases has already been granted to a large pharmaceutical company.

It all sounds very simple, and with the methods of modern molecular biology, it is just that: When the gene for
A channelrhodopsin-2 molecule before and after exposure to light: The protein’s amino acid chain is rolled up into a spiral measuring seven times the diameter of the cell membrane. When exposed to incident light, helix 2 (turquoise) twists out (green), opening the ion channel for calcium (green spheres) and sodium ions (turquoise spheres). In the middle of the channel, the small, photosensitive retinal (green/turquoise) is bound to the protein.
one of the various channelrhodopsins – channelrhodopsin-2 – is implanted into a nerve cell, the cell then starts producing the ion channel and incorporating it into its cell membrane. The cell can now be switched on using blue light, and starts producing electrical stimuli. “Before, nerve cells could be activated only with microelectrodes. Thanks to channelrhodopsin-2, this relatively arduous procedure is no longer necessary in many neurobiological experimental set-ups, especially in live animals,” Bamberg explains. “Now, for example, it’s possible to alter the activity of nerve cells in a mouse’s brain with a laser beam and then analyze the resulting behavior on a cellular level.”

Basically, all that’s missing now is an off switch. As it so happens, nature already has a solution on hand for that, too: the bacterium *Natronomonas pharaonis*, which was discovered in an Egyptian salt lake in the 1980s, can brave the high salt concentration in its habitat only by accumulating even more salt inside the cell itself. Using the photosensitive ion pump halorhodopsin, it actively transports negatively charged chloride ions into the cell. As long as the halorhodopsin is active, it remains in this resting state and cannot be electrically activated. Bamberg had already studied this protein’s transport properties years earlier. The halorhodopsin is light-gated as well – albeit activated by yellow light, and not by blue light like channelrhodopsin-2.

Nerve cells containing the genes for channelrhodopsin-2 and halorhodopsin can therefore be switched on and off at will using light: blue light lets positive sodium and calcium ions flow in, thus making the cell more positive, while yellow light opens the gates for negatively charged chloride ions, shifting the cell potential into the negative range. “One of the major advantages here is that we can simply use different wavelengths of light to switch on or off individual, electrically excitable cells, such as nerve and muscle cells in cultures and in live animals, without the need for electrodes. What’s more, we can do it with much greater temporal and spatial resolution than ever before,” Bamberg concludes.

In 2005 – and also in 2007, together with Alexander Gottschalk from Frankfurt University – Bamberg and Nagel were able to use these molecular light switches to control the behavior of a living organism with light for the first time ever. They equipped nerve and muscle cells of the roundworm *C. elegans* with channelrhodopsin-2 and halorhodopsin. Blue light induced the worm to wriggle forward, while yellow light rendered it motionless. In a parallel study conducted in collaboration with Karl Deisseroth from Stanford University, the researchers showed that the two rhodopsins can also switch nerve cells in a cell culture on and off.

**GREATER PHOTOSensitivity, GREATER SPEED**

Bamberg is an expert on charge transports via cell membranes, namely via the barriers that serve both as a cell’s protective wall and as its interface with the surrounding environment. One of the current focal points of Bamberg’s research is developing new rhodopsin variants with optimized properties. However, this goal required an even deeper understanding of how the channel works. He therefore first investigated what factors determine the channel’s permeability to certain ions, and how the sensitivity to different wavelengths of light influences the channel’s activity. In so doing, Bamberg created the prerequisites needed to search for rhodopsins that are permeable only to specific ions, for example, or that are activated by other wavelengths.

Together with colleagues at the Max Planck Institute in Frankfurt and from Osnabrück University, he observed which segments of channelrhodopsin-2...
are needed to open the channel. “This gave us some clues about what channelrhodopsin needs to look like in order for it to acquire new properties,” Bamberg explains. The researchers achieve this by specifically altering the channelrhodopsin gene and creating new variants of the protein. At the same time, the scientists also inspect other channelrhodopsins (that have since been discovered in other algae species) in search of potentially suitable molecules for optogenetic applications.

First, they transfer the candidates onto eggs of the South African clawed frog (*Xenopus laevis*) or onto human kidney cells in a cell culture. It’s easier to study the channelrhodopsins in these particular cells. Only then do the nerve cells come into play. Each rhodopsin is tested to determine the wavelength of light that activates it, which ions it is permeable to, and how fast the channel opens and closes.

Using this method, Bamberg and his colleagues have developed the channelrhodopsin variant CatCh, among others, which can activate the nerve cells with just one-seventieth the amount of light. The channel can also be used to activate calcium-dependent ion channels.

Another innovation from Bamberg’s department is a coupled on/off switch for nerve cells. The researchers developed this switch by fusing together one channelrhodopsin and one halorhodopsin molecule. An interposed protein couples the switch proteins together and fixes them firmly in the cell membrane. “When one channelrhodopsin and one halorhodopsin gene are introduced into the cell’s genome separately, the cells produce different amounts of both proteins, so that one of the two is usually dominant. Thanks to our coupled protein, we can ensure that the on/off switch is always introduced in the desired location at a one-to-one ratio,” Ernst Bamberg explains. As a result, the activity of a cell can be switched on with blue light and switched off using yellow light under better-defined conditions and with greater precision than before.

Yet Bamberg and his team don’t just develop new molecules; they are also advancing the respective range of applications: Optogenetics could restore the sight of a person whose eyes no longer contain natural rhodopsin. This means, however, that the scientists would first need to conduct animal experiments to get other cells in the retina to produce the channelrhodopsin.

But how can genes for an algal protein be transferred to mammals? With viruses! More specifically, with a class of viruses that has already proven successful in other gene therapy approaches. These viruses are loaded with the channelrhodopsin gene, which they can then implant into a cell’s genome.

However, that doesn’t necessarily mean that the algal rhodopsin also works in the human eye. After all, no matter how similar the rhodopsins are to each other, their respective functions still differ significantly. While in-
incident light causes the channelrhodopsins to shift the electrical potential into the positive range via the cell membrane, light has the exact opposite effect in the human eye: it makes the photoreceptors on the inside more negative. This activates what are known as bipolar cells, which in turn become more positive on the inside. The signal is processed via the network of nerve cells in the eye and then transmitted to the brain via the optic nerve.

BLIND MICE FIND THEIR WAY TO LIGHT

The scientists from Basel and Paris thus resort to a trick: they implant channelrhodopsin-2 into the originally non-photosensitive bipolar or ganglion cells of mice, bypassing the dead photoreceptors. The results of the experiments were positive: After just a short while, mice that had gone blind due to a loss of photoreceptors and subsequently received a channelrhodopsin gene soon started heading straight for a light source. Furthermore, the animals retained their vision after the therapy ended, because the nerve cells containing the rhodopsin gene produce algal protein for life.

What makes this observation all the more astounding is the fact that the cells with the gene contain the construction manual for only the protein part of the channelrhodopsin. However, the photosensitive retinal isn’t a protein, and therefore isn’t decoded in the gene. Nevertheless, it is present in the bipolar cells, as every cell produces the raw material for the retinal – vitamin A. Thus, almost all mammals produce retinal. This means they practically produce a light antenna for free! “We were simply lucky that a rhodopsin from plants or bacteria works just as well in a mammal as it does in the original cell,” says Bamberg.

Together with the colleagues from Basel and Paris, Bamberg’s team has been conducting research into gene therapy treatments for retinal diseases for quite some time. For this purpose, Bamberg would like to create custom-tailored rhodopsins. The team’s primary focus lies on age-related macular degeneration, a disease that causes the photoreceptors at the point of highest visual acuity in the eye to deteriorate.

GENE THERAPY FOR THE EYE

Gene therapy could also be a suitable approach for other retinal diseases, since there are, in fact, several diseases that cause the eye’s photoreceptors to die off. “The fascinating thing about optogenetics is that treatments using algal rhodopsins don’t influence the development of the disease, but instead eliminate the end result. One single therapeutic approach could therefore be used to combat several different diseases.”

One particular problem that persists is the matter of adapting to different degrees of light intensity. The human eye has a dynamic range for light intensity of ten to twelve orders of magnitude. This allows us to see in different light conditions, be it in extremely bright reflections on a glacier or in a dark basement. The dynamic factor of the channelrhodopsins, however, spans only about one order of magnitude. This difficulty is being overcome through the development of glasses that use a camera that has a large dynamic range and that records the image and transmits it to photodiodes. The latter then project it onto the retina with a light intensity that is ideal for the channelrhodopsins.

Yet the optogenetic tools can be beneficial not just in the eye, but in other areas as well. “They basically work in all excitable cells, meaning first and foremost in muscle and nerve cells,” says Ernst Bamberg. And so the researcher presents a long list of possible applications in the medical field, ranging from brain stimulation in Parkinson patients, which can be achieved with greater precision using fiber optics and channelrhodopsins, to light-gated cardiac pacemakers and inner-ear implants. Researchers at Göttingen University Hospital, for example, have successfully implanted Bamberg’s CatCh
protein into the inner ear of mice. In some forms of epilepsy, an inhibiting ion pump could also suppress the uncontrolled electrical impulses emitted by neurons in the cerebral cortex.

There is thus a bright future ahead for the field of optogenetics. And even the alga has something to show for it: the German Botanical Society (DBG) awarded *Chlamydomonas reinhardtii* the title “Alga of the Year 2014.” Not just because its special eyespot is what made optogenetics possible in the first place. *Chlamydomonas* is also capable of other feats: thanks to its two thread-like flagella – and bearing in mind its relative body size – it can swim through water faster than most professional breaststroke swimmers over the 50-meter distance.

www.youtube.com/watch?v=dJ5MQluKcZY&feature=youtu.be

**FOCUS**

**Optogenetics**

**GLOSSARY**

**Macular degeneration:** An eye disease that causes the photoreceptors at the point of highest visual acuity (Macula lutea) in the retina to deteriorate. As the disease progresses, reading, driving or recognizing faces becomes increasingly difficult. Only the peripheral vision remains. Age-related macular degeneration is the leading cause of blindness in patients over the age of 50. In Germany, around two million people suffer from some form of macular degeneration.

**Rhodopsin:** The pigment molecule in the photoreceptors of vertebrates and invertebrates consists of a protein part (opsin) coupled with a small, photosensitive molecule (retinal). The rhodopsin of vertebrates activates a chain of enzymes that ultimately cause the ion channels to open or close. Furthermore, different microorganisms, such as bacteria, algae and fungi, also contain rhodopsins. However, these rhodopsins don’t activate other enzymes, but instead serve as ion channels or pumps themselves.

**TO THE POINT**

- New channelrhodopsin variants with enhanced properties are expected to make new applications possible in optogenetics. Researchers are therefore developing custom-tailored rhodopsin variants for basic research in neurobiology and potential biomedical applications in neuroprosthetics.
- Channelrhodopsins could one day restore sight to people suffering from retinal damage.

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Guided by Light

A zebrafish larva that is only a few days old isn’t yet very mobile: at this age, it is capable of a few vigorous tail movements and not much else. For Herwig Baier at the Max Planck Institute of Neurobiology in Martinsried, however, that’s enough. For him, a simple and, above all, transparent brain is much more important. His particular aim is to switch individual neurons on and off using light and thus discover how the brain controls movement and behavior.

TEXT HARALD RÖSCH

Herwig Baier only needs to switch on one laser for the little zebrafish to beat its tail. A glass fiber just a few thousandths of a millimeter thick directs the laser light to the larva’s head. To keep it from swimming away, its body is embedded in a gel-like agar, while its tail remains free to move. The tiny creature reacts to the push of a button: light on – movement; light off – pause.

Baier can use flashes of light to dictate to the animal what it should do. Optogenetics makes this possible: the gene for light-sensitive channel proteins, which comes from the single-celled alga *Chlamydomonas reinhardtii*, is inserted into the fish’s genetic material in such a way that it is active in certain neurons. These proteins, known as channelrhodopsins, were first described a little more than ten years ago by Ernst Bamberg, Georg Nagel and Peter Hegemann. They allow ions to flow into the interior of the cell, where they no longer control the algal cell, but instead control the neurons in the fish’s brain. Using this method, Herwig Baier wants to decode the networks that are important for the behavior of zebrafish.

Given that these little fish measure just a few millimeters in length, it may come as a surprise that the larvae even have a brain, let alone that we can learn something about the human brain from them. So, of all organisms, why are Baier and his research colleagues studying the nervous system of fish larvae?

First, because they are among the simplest vertebrates in existence: each zebrafish larva contains about a hundred thousand neurons; the human brain, in comparison, has around one hundred billion. Despite this, the basic architectures are comparable; the fish’s brain just consists of fewer components. Moreover, the larva and its brain are transparent – for the scientists who use light stimuli for their research, this is an unbeatable argument.

PIONEERS OF OPTOGENETICS

When Baier first experimented with channelrhodopsins, he was still working as a researcher at the University of California in San Francisco. Optogenetics was still in its infancy at that time. In 2005, Karl Deisseroth and Ed Boyden at Stanford University were the first to transfer the channelrhodopsin proteins from the alga into neurons in cell culture and thus control their activity. Baier immediately recognized the huge potential of this new method. He obtained the coveted rhodopsins from Deisseroth and began to investigate the fish brain with them.

Together with his colleagues at the time in Berkeley and San Francisco, he achieved his first success with optogenetics. He did so initially with a different light-sensitive molecule, a light-controlled glutamate receptor. Glutamate receptors are located on synapses and respond to the neurotransmitter glutamate. This is one way that nerve signals travel from one cell to the next. However, the ion channel developed by Ehud Isacoff, Dirk Trauner and others in 2006 is not activated by glutamate, but by light. It has a small, light-sensitive molecule that changes its spatial structure and, as a result, slips into the receptor’s binding pocket. Ions flow through the open channel pores and trigger an electrical signal in the neuron.

But that alone wasn’t enough. In order for the researchers to be able to systematically switch individual neurons on and off, the light-sensitive proteins should be present only in these cells.
Lights on for light-sensitive proteins in the fish brain: The photo montage shows how a genetically modified zebrafish larva responds to light by vigorously beating its tail.
Modern molecular biological methods that facilitate the genetic modification of fish helped Baier and his colleagues in this regard. It meant that they could place new genes in the genome in such a way that they become active only in a certain tissue or cell type – though which one wouldn’t be known beforehand.

Thus, from a plethora of different genetic lines, they needed to identify the fish in which the channels were formed in nerve cells that are important for the behavior they wanted to study. In this way, the researchers came across a cell type whose activity can trigger swimming movements: “Each time the laser beam activated these cells in the spinal cord, the larvae began to beat their tails as if they were swimming normally,” says Baier.

Further analysis revealed that he and his colleagues had stumbled across an old acquaintance: Kolmer-Agduhr cells. Instead of dendrites – the signal-receiving compartments of most neurons – these cells have a tuft of small finger-like appendages that extend into the central canal containing the spinal cord fluid. These “feelers” presumably measure chemical or mechanical changes there and forward these changes to the neural circuits in the spinal cord. Neurons that are in contact with the spinal cord fluid were observed for the first time almost 80 years ago and have since been discovered in all vertebrates studied, including humans. However, their function had remained a mystery over all those years.
Now it was clear: the Kolmer-Agduhr cells are involved in stimulating movement, at least in fish. With their inhibitory neurotransmitter gamma-aminobutyric acid, or GABA, they influence other neurons, which are in contact with muscles, and regulate tail beating.

Even in such a simple organism as the zebrafish larva, swimming isn’t just swimming. The animals can already master different behaviors such as orientation, approach and escape. The Kolmer-Agduhr cells seem to be involved in only forward swimming.

Escape movements, for example, can also be performed without these cells, even though the animal also flips its tail to make these movements. Another type of neuron in the spinal cord is involved in this: Rohon Beard cells. If these cells are equipped with light-sensitive ion channels, a light impulse triggers a C-shaped curvature of the body, as if the animal were trying to escape.

And the scientists noticed something else: the larvae don’t need a brain for swimming! Even when the connection between the brain and the spinal cord is severed, the Kolmer-Agduhr cells still allow the animal to beat its tail. The neurons in the spinal cord seem to be connected in such a way that they can control the muscles as required all on their own.

The spinal cord is thus not just a connecting cable to the muscles, it also acts as a type of control center with its own networks. Some of these networks form central pattern generators. These are groups of neurons that are connected to one another in such a way that they are active in certain rhythms. Once they have been stimulated – by neurons such as Kolmer-Agduhr cells – they generate a rhythmic pattern of activity with which they control sequences of movements.

CIRCUITS FOR AUTOMATED MOVEMENTS

Such pattern generators govern motor processes across the entire animal kingdom: insects use them to coordinate the movement of their six legs, fish to coordinate their tail beating, and humans, their legs. These circuits are the reason we don’t have to think about every step as we put one foot in front of the other. Instead, the brain has to intervene only occasionally, for example when it wants to start, modify or stop the movement. The advantage of this principle is that the complex signals for controlling movement are outsourced to the spinal cord, saving the brain space and energy.

Thanks to optogenetics, Baier and his colleagues were able to reveal the role of individual neuron types in the spinal cord. Since then, the technology has developed further. Instead of the light-sensitive glutamate receptor, Baier now relies almost exclusively on the channelrhodopsins obtained from Chlamydomonas. In the meantime, a light-controlled ion pump has also been added to the collection: halorhodopsin from the bacterium Natronomonas pharaonis. This can be used to switch neurons off rather than on. Several genetically modified zebrafish lines now exist that produce these proteins in almost all possible cell types.

Equipped with these tools, Baier set out to examine the motor circuits in the brain. Neurobiologists have long disagreed about whether complex behaviors are based on decentralized or modular networks in the brain. With a decentralized architecture, behavior arises from the activity of widely distributed circuits from many neurons in
different parts of the brain. The cells involved have no specific function. They often contribute in varying combinations to different movement patterns.

Circuits with a modular organization, on the other hand, are composed of smaller subunits. Different groups of neurons control different aspects of behavior. Cells have a specific task to perform within the modules. Complicated behaviors therefore arise out of the interaction of a small number of comparatively simple circuits.

The latter scenario actually appears to be the case for networks controlling movements in zebrafish larvae. Baier and his colleagues have proven that specific populations of neurons in the zebrafish brain control specific aspects of swimming. “It works similarly to how a boat works. A network produces the signals for swimming – that’s the engine. Another steers – the tiller. And there’s even a gearbox,” explains Baier.

ENGINE AND TILLER IN THE FISH BRAIN

Baier discovered the engine first: neurons in the reticular formation near the spinal cord give the order to swim. “When we activate these cells with channelrhodopsin, the larvae start to beat their tails. If we inhibit them with halorhodopsin, they stop. In the brain, these neurons are the only ones that need to be active for the larva to be able to swim,” says Baier.

Baier and his colleagues – at the Max Planck Institute in Martinsried since 2011 – recently also tracked down the rudder. They found it in the reticular formation in the brain of the fish,
or to be more precise, in a collection of neurons known as the nMLF. This discovery revealed the great potential of optogenetics: if just the activity of these cells is measured in the conventional way, it emerges that they are active in all possible swimming movements. At first glance, they therefore appear to be part of a non-specialized, decentralized network that forms the basis for all variants of tail movement.

Only the selective switching on of the nMLF cells reveals that this is not actually the case. If the cells are activated on the left side of the brain, the tail bends to the left. If the nMLF cells on the right are switched on, the tail points to the right. In the experiment, it looks as if the tail follows the beam of light as the laser wanders from the left to the right nMLF. “The fish controls the swimming direction by bending its tail. The nMLF cells are therefore less responsible for the swimming as such, and more responsible for the steering,” says Baier. This is also demonstrated when the scientists systematically switch off individual cells on one side of the brain. The larvae can still perform a wide variety of movements, such as beat their tails, but they can no longer swim straight ahead. The tail is deflected in one direction, causing the fish to turn in a circle.

Ruben Portugues, a Max Planck Research Group Leader at Baier’s institute, and his colleagues have also identified the gear mechanism for tail beating in the reticular formation. Individual nMLF cells regulate the swimming speed by controlling the duration of tail beating. Others control the tail beat frequency. In this way, the animal can switch to a higher or lower gear and swim faster or slower.

The neurons in the fish brain thus perform a variety of tasks when swimming. Depending on whether the larva is swimming around looking for food, for example, or bolting from a predator, the different networks work together to generate the optimum behavior for the respective situation.

Swimming is therefore an example of a behavior that is based on a modular network. The individual modules involved may be relatively small: “A few dozen neurons in the brain are probably sufficient to position the tail of the fish,” says Baier. When it comes to changing gears while swimming, less than a handful are needed: only four nMLF cells are required.

**LARGE NETWORKS FOR MEMORY**

In contrast, other brain functions may use decentralized networks. We know from the marine snail *Aplysia californica* that extensive networks are active when they withdraw their gills. In the human brain, as well, stored memory traces seem to be based on large networks. In these cases, the network’s state of activity is crucial; the individual cell is presumably insignificant.

It’s not yet completely clear which behaviors are based on decentralized networks and which are based on modular networks. In principle, both seem possible. The specific requirements of the respective brain function could play a role: memory traces, for example, must presumably be stored on a decentralized basis, as they comprise learned movements or specific recollections. Moreover, they are formed and retrieved before, during or after a behavior. Information that is learned can also influence very different patterns of behavior. Distributed networks, in which individual cells have no specific function and may be part of several circuits, are therefore probably better suited to this. Behaviors with a manageable number of variants, such as walking, running, jumping, turning, etc., differ fundamentally. In such cases, a modular organization presumably suffices.

Baier and his colleagues are interested in yet another aspect, namely how information from the sensory organs is incorporated into, and influences, behavior. For example, if a shadow falls across the eye of the zebrafish, its escape program is triggered. This process is known as sensorimotor transformation. One of the places this process takes
place is the tectum, a region in the midbrain of fish and other vertebrates. Information from the sensory organs is processed here and forwarded to the motor system.

Thomas Helmbrecht, a doctoral student in Baier’s department, discovered that escape movements can be induced by optogenetically activating cells at the back of the tectum. This can be explained by the architecture of this area: the tectum contains a map of the entire visual field. “Neurons in the eye that process, for example, stimuli from the back of the larva’s visual field are also linked to the back of the tectum. An object that approaches from behind represents a potential danger. This could explain why a flight response is triggered primarily there,” says Helmbrecht.

Baier is convinced that many of the findings from the brain and spinal cord of the fish can be applied generally: “In the development of the nervous system, evolution changes, first and foremost, what already exists. Whatever has proven its worth is retained or developed further. Since the gait of terrestrial vertebrates evolved from the fish’s trunk and fin movements, the underlying circuits are probably based on the same principles.”

From the light-sensitive proteins of an alga known only to botanists, to the nervous system of fish larvae, to the human brain, the paths along which science makes new discoveries are often tangled and unpredictable. The success story of optogenetics is a prime example of this.

**TO THE POINT**

- The swimming behavior of fish is based on neural networks in the brain and spinal cord that are comprised of small, local modules. Different modules can be combined with one another depending on the requirement at hand.
- Each neuron performs a specific task. Even switching a few cells on and off can change an entire behavior.

**GLOSSARY**

Sensorimotor transformation: Movements are rarely performed completely independently of external influences. They are often triggered by environmental stimuli, which are perceived via the sensory organs. At the same time, sensory organs need to determine deviations from a desired movement so that the motor system can correct them via the relevant signals. Sensory and motor networks are therefore closely connected and exchange information.

Central pattern generators: Networks of neurons that are independently rhythmically active. Even three neurons, of which two mutually activate each other and the third inhibits the other two from a specific activity threshold, can form such a rhythmically active network. Pattern generators are present in invertebrates and vertebrates, and control involuntary standardized movements such as the beating of an insect’s wings or the human gait. When walking, the pattern generators in the spinal cord are linked together for the two legs so that different gaits (walking, trotting or running) are generated.
Die auflagenstärkste hochschul- und wissenschaftspolitische Zeitschrift Deutschlands. Leseprobe unter: www.forschung-und-lehre.de oder per Fax 0228 902 66-90
Violence Is a Guy Thing

Killing conspecifics doesn’t fit the placid image many people have of chimpanzees. But are these acts of violence perhaps merely the consequence of humans increasingly changing the animals’ habitat and disturbing their social life? An international team of researchers that also includes scientists from the Max Planck Institute for Evolutionary Anthropology in Leipzig has now evaluated data from the past 50 years on this issue. According to their findings, humans don’t influence the frequency of deadly violence. The killing of conspecifics is much more a result of adaptation to their natural habitat conditions. For instance, killing occurs more frequently among chimpanzees when the population density is high and large numbers of males live together. The animals eliminate rivals in this way. Males usually kill other non-kin males in smaller groups – this keeps the risk to themselves low. Bonobos, in contrast, which are closely related to chimpanzees, are extremely peaceful: researchers have observed just one killing among them in 50 years. (Nature, September 18, 2014)

A Protective Umbrella for Fuel Cells

Fuel cells could soon be able to generate electricity more cost-efficiently than previously. Scientists at Ruhr-Universität Bochum and the Max Planck Institute for Chemical Energy Conversion in Mülheim an der Ruhr have found a way to convert hydrogen contained in them into water, with enzymes acting as valuable biocatalysts. Currently, scientists and engineers use metal-based catalysts for this process. While these are efficient and stable, they are only available in small quantities and are therefore expensive. The likewise highly efficient enzymes, or hydrogenases, to be precise, are more readily available and economical, but are quickly destroyed in the conditions that exist in a fuel cell. The research team from Bochum and Mülheim has now developed a redox hydrogel consisting of a polymer that catches the destructive oxygen before it destroys the hydrogenases. (Nature Chemistry, August 3, 2014)

The redox hydrogel developed by researchers in Bochum and Mülheim an der Ruhr acts as a protective shield for a hydrogenase.
The Way to the Top

Thanks to their asymmetrical form, some slipper-shaped microorganisms can swim to the surface of water on their own.

Up toward the sun and food supplies – how slipper-shaped microorganisms find their way safely to the water’s surface has been explained by an international team headed by Clemens Bechinger from the Max Planck Institute for Intelligent Systems and the University of Stuttgart using an extremely simple trick of physics. The shape of the unicellular organisms looks like an asymmetric pear. The researchers emulated this with tiny, L-shaped swimming bodies. They gave the microswimmers thrust by heating up their underside so that the surrounding fluid warms up, generating a thermic propulsive force. Two forces then impact on an L-shaped particle while swimming: gravity tips the “L” toward the long limb. The frictional force pushes it in the direction of the short limb. At a suitable speed, the effects of the two forces cancel one another out and propel the swimming body upward. This method could also soon be used to enable the self-organized steering of swimming microrobots. (Nature Communications, September 19, 2014)

Computer Diagnostics

PhenIX identifies genetic diseases

People with genetic diseases often have to embark upon an odyssey from one doctor to the next: fewer than half of all patients suspected of having a genetic disease actually receive a satisfactory diagnosis. Scientists from the Charité in Berlin and the Max Planck Institute for Molecular Genetics have now developed the PhenIX software, which reliably identifies genetic diseases. In contrast to previous tests, the program combines the analysis of genetic irregularities with the patient’s clinical presentation. In the first step, a specific search is conducted by the patient’s physician for around 3,000 genes known to cause diseases. In the second step, a database is searched for the patient’s symptoms. From the relevant symptoms, PhenIX determines an overlap with the most likely diseases responsible. In a pilot study on patients for whom no diagnosis could be made despite years of investigation, the procedure identified the exact cause of illness in over 25 percent of the cases. PhenIX is already available to hospitals that have the necessary technical equipment. (Science Translational Medicine, September 3, 2014)

Highly Sensitive Biosensors

Molecule detectors enable improvement in medical diagnostics

It may soon be possible to diagnose some illnesses more easily and at an earlier stage, thus enabling more effective treatment. Two research groups at the Max Planck Institute for the Science of Light in Erlangen recently unveiled two biosensors that can be deployed to detect individual, unlabeled biomolecules. A team headed by Vahid Sandoghdar has developed an optical detector that makes the scattered light, that is, the shadow, of individual proteins and other biomolecules visible. Using an optical microsphere and gold nanoparticles, researchers led by Frank Vollmer have amplified the interaction of light with DNA to the extent that they can now track interactions between individual DNA molecule segments. Detectors for single biomolecules are of interest in clinical diagnostics, research into disease mechanisms, and environmental analyses. (Nature Communications, July 29, 2014 & Nature Nanotechnology, August 31, 2014)

A glass microsphere and gold nanowire mounted on it amplify light so strongly that it is possible to detect individual DNA fragments.
Births Out of Wedlock in the East

Non-marital births are more common in eastern Germany than in the West

Even 25 years after the fall of the Berlin Wall, starting a family is still a fundamentally different process in eastern and western Germany. While 59 percent of births in the new federal states are non-marital, the proportion in the old western states is half as high. This disparity was, in fact, increased by the division of Germany, but it was not caused by it. As far back as the late 19th century, the proportion of non-marital births in large parts of western Germany stood at between 2 and 8 percent, while it is 12 percent in modern-day eastern Germany. Whereas agriculture in the East was characterized by dispersed farms and large numbers of seasonal workers during this period, western Germany was dominated by smaller, family-run farms. Curbing non-marital births was therefore seen as a matter of great concern in the West to prevent inheritance disputes, for example. As long ago as the 19th century, large proportions of the population in eastern Germany rejected religious rituals. Given the long history of these differences, it is unlikely that they will disappear over the coming decades. Rather than the East, it is the West in Germany that emerges as the exception here, as a low percentage of non-marital births – as found in the old federal states – is increasingly becoming the exception in the European context. (Population, Space and Place 2014)

As early as 1937, the proportion of non-marital births, at an average of 10.2 percent, was considerably higher east of the subsequent German-German border than west of it (6.3 percent). In 2012, it was more than twice as high in the East (58.8 percent) as in the West (28.4 percent).

Colorful Cuttlefish

Max Planck researchers study the dynamic “passing clouds” in Metasepia tullbergi

Cuttlefish are masters of color display – their pigment cells allow them to adapt their skin color to their immediate environment and produce propagating color waves along their bodies. What these “passing clouds” signify during mating and hunting hasn’t yet been determined. Using high-speed video, researchers at the Max Planck Institute for Brain Research in Frankfurt observed the dark bands that pass over the body surface of the cuttlefish Metasepia tullbergi. The researchers identified eight regions in which color waves pass over the body in different directions without crossing the boundaries into neighboring ones. Metasepia are able to combine these areas in different ways and thus create different displays of color. Active regions are also perfectly synchronized, which means the bands reach the boundary of their region at exactly the same time. The researchers want to combine these results with findings from neurobiological investigations, which are now being planned. Their objective is to decipher the connectivity of the nerve cells responsible for the color waves in cuttlefish. (Current Biology, August 4, 2014)

The Metasepia tullbergi fully deserves its name: Paintpot cuttlefish.
Radio Burst from the Charioteer

Astronomers observe mysterious flash from far beyond our galaxy

Fast radio bursts from outer space last just a few milliseconds. Researchers at the Parkes Observatory in Australia recorded such events for the first time several years ago, but no other telescope has confirmed the phenomenon. Had the Australians been picking up signals originating from Earth? Using the Arecibo radio antenna in Puerto Rico, however, astronomers have discovered another radio burst that lasted just a few seconds and came from the direction of the Charioteer constellation. This observation by a group led by Laura Spitler from the Max Planck Institute for Radio Astronomy in Bonn provides new evidence of the mysterious pulses that appear to come from deep in outer space. Astronomers are still speculating about their source: possibilities include evaporating black holes, merging neutron stars or flares from magnetars – neutron stars with extremely powerful magnetic fields. (Astrophysical Journal, July 10, 2014)

Encircled radio source: This optical sky image shows the area in the direction of the Charioteer constellation where the fast radio burst FRB121102 was detected. The position of the burst, between the old supernova remnant S147 and the star formation region IC 410, is marked with a green circle.

Algae Provide Gas

Algae could soon become a rich source of regenerative fuel. The microorganisms naturally produce hydrogen with sunlight as a source of energy. But they would have to become 10 to 100 times more efficient to feasibly generate energy for widespread application. Scientists from the Max Planck Institutes for Chemical Energy Conversion and Kohlenforschung (coal research) in Mülheim and from the Ruhr-Universität Bochum have contributed toward this goal with a recent project. Through genetic engineering, they increased the efficiency of the enzymes that aid the algae in producing hydrogen by a factor of five. In their experiments, the researchers isolated the biocatalysts in test tubes to obtain fuel. However, it is also possible to breed algae with the modified enzymes in water tanks and to extract the gas. (Energy & Environmental Science, July 29, 2014)

Birth of a Star in Quick Time

Scientists observe the nurseries of massive stars in our galaxy

Massive stars are born in the coldest parts of the Milky Way – deep inside clouds of dust that are so dense that they almost completely swallow up the radiation in the visible and infrared ranges. To follow the earliest stages of the birth, astronomers had to observe longer wavelengths. They thus remapped the plane of our galaxy at a wavelength of 0.87 millimeters. Using the 12-meter APEX telescope, they detected various clumps of gas and dust. Based on their distribution, a team headed by Timea Csengeri from the Max Planck Institute for Radio Astronomy in Bonn estimated the time scale for the formation of stars. The researchers discovered that the process seems to proceed very rapidly, taking only 75,000 years on average. Not only is the lifetime of massive stars around 1,000 times shorter than less massive ones, but their birth phase also proceeds much more quickly. (Astronomy & Astrophysics, May 12, 2014)
Looking into the Heart of a Catastrophe

Researchers observe gamma-ray lines from a type Ia supernova

In type Ia supernovas, a white dwarf star collects material from its companion until it explodes, releasing large amounts of radiation. However, astronomers hadn’t been able to provide evidence of gamma rays directly from such a catastrophe. This has now been achieved for the first time by researchers from the Max Planck Institutes for Astrophysics (Eugene Churazov) and for Extraterrestrial Physics (Roland Diehl) in Garching using SN 2014J, which flared up in the M 82 spiral galaxy this year. One of the studies also tested the conventional theories that the white dwarf must exceed a critical mass limit before the explosion. However, the observations of the group led by Diehl suggest that the flow of matter from a companion star ignited the white dwarf “from the outside” without reaching the critical mass limit. (Science Express, July 31, 2014 and Nature, August 28, 2014)

New Species without Sex

Grafted plants can transfer their entire genetic material to a partner

In horticulture and viticulture, growers have long made use of the fact that even plants that can’t be crossed can be grafted together at their contact zones. By grafting elite grape cultivars onto pest-resistant rootstocks, for example, they thwart pests living in the soil. Varieties can transfer their entire genetic material to a partner at the contact zones. Researchers from the Max Planck Institute of Molecular Plant Physiology in Golm grafted the tobacco plant Nicotiana glauca onto Nicotiana tabacum, which can’t be crossed with it, and then bred new plants from the contact tissue. The daughter plants not only received each of the two antibiotic-resistant genes that the researchers had previously introduced into the genetic material of the two parents, but they also possessed exactly the same number of chromosomes as the two parents. The new plants and their offspring can reproduce without any problem – the researchers succeeded in creating a new tobacco plant species. Breeders can use this method to create new plant varieties with higher yields or more robust growth.
Carbon, Stay Awhile!

Precipitation is an important climate factor in the carbon cycle

Plants play a crucial role in the global climate system, removing the greenhouse gas carbon dioxide from the air and converting it into carbohydrates. Carbon can be stored for several years or even decades before it is converted back into CO₂ and returned to the atmosphere. The average global carbon turnover time in land ecosystems is 23 years, as an international research team headed by Nuno Carvalhais and Markus Reichstein from the Max Planck Institute for Biogeochemistry in Jena has discovered. In the humid and warm tropics, it takes just 15 years before a carbon atom is released back into the atmosphere. However, at cold, higher latitudes, such as the Siberian tundra, it takes 255 years. The researchers also established that land ecosystems store approximately 2,800 billion tons of carbon, which is 400 billion tons more than previously assumed. A surprising discovery: precipitation plays just as important a role as temperature in determining the turnover time. (Nature, September 25, 2014)

The world map arches upward relief-like where carbon is retained for relatively long periods in land ecosystems. The areas where the turnover time depends heavily on temperature appear in red. The greater the influence of precipitation, the deeper an area's shade of blue.

Ready for Mating at the Right Time

Fish aren't generally considered particularly communicative – unjustly so, as they possess several communications channels. One of them is chemical signals emitted into the water. Scientists from the Max Planck Institute for Chemical Ecology in Jena have discovered a steroid in the urine of male tilapia fish. The males send the signal to attract mating partners. The steroid also boosts the hormone production of the females and accelerates oocyte maturation. The males can then fertilize the released eggs. The discovery may help make the aquaculture of the tilapias, a popular food fish, more efficient: breeders can use pheromones to increase female fertility. (Current Biology, published online ahead of print on August 21, 2014)

Even nanotubes start out small: An end cap (bottom left) is produced from planar carbon, and forms the seed for the growth of a carbon nanotube (right). The structural models and the images taken with a scanning tunneling microscope are shown.

Custom-Made Nanotubes

It will soon be possible to specifically equip carbon nanotubes with the properties they require for electronic applications. Researchers at Empa in Dübendorf, Switzerland, and from the Max Planck Institute for Solid State Research in Stuttgart have succeeded for the first time in growing single-walled carbon nanotubes (CNTs) with a single, pre-specified structure. All of the nanotubes therefore have identical electronic properties. Other production methods result in a mixture of single-walled and double-walled tubes of different lengths and structures. To prevent this from occurring, the team produced the nanotubes from custom-made organic precursor molecules based on an idea that originated from the Stuttgart-based Max Planck researchers. The tubes grow on a platinum surface in a self-organized process. In the future, such CNTs could, for instance, be used in ultra-sensitive light detectors and miniscule transistors. (Nature, August 7, 2014)
Rendezvous with a Primordial Rock

Although the comparison with the manned moon landing may appear somewhat exaggerated, Rosetta is undoubtedly one of space travel’s most daring enterprises: For the first time in history, a probe is accompanying a comet on its orbit around the Sun – and in mid-November, it set down the Philae lander on its surface. Scientists from the Max Planck Institute for Solar System Research in Göttingen have front row seats for the evaluation of the images and data from the comet named 67P/Churyumov-Gerasimenko.

TEXT HELMUT HORNUNG
This is the very heart of the comet 67P/Churyumov-Gerasimenko as seen by the onboard camera of the Rosetta probe on August 3, 2014.

**MARCH 2, 2004, 8:17 A.M. CET**

Darkness still shrouds the Kourou spaceport in French Guiana as an Ariane 5G+ rocket shoots up into the cloudy sky, leaving a fiery trail in its wake. On board is a freight that is intended to shed more light on the origins of the solar system: Rosetta. The probe itself is slightly larger than a Smart car. Its two long wings with solar panels for the energy supply give it the appearance of a strange insect. Aboard Rosetta, in addition to the SREM detector for detecting high-energy particle radiation, are eleven instruments and a box as large as a refrigerator: Philae. It is to perform the trick of landing on the nucleus of a comet and conduct measurements there over several months with the aid of ten scientific devices.

Rosetta’s history goes back to 1984. At that time, the European Space Agency ESA decided to undertake a mission to the nucleus of a comet, initially in partnership with NASA. After budget cuts forced the Americans to withdraw, the Europeans continued the plan alone. In Germany, the German Aerospace Center and the Max Planck Institute for Aeronomics (since 2004: Solar System Research) were initially the major players in the project, with the latter making a significant contribution to the development and construction of the lander, among other things.

On January 13, 2003, Rosetta and Philae were due to lift off to the Wirtanen comet. But a rocket from the Ariane 5 series, like the one that was to transport the ambitious mission, had performed a spectacularly unsuccessful lift-off a few weeks prior. The European space program was halted temporarily, and the start of the comet scout postponed by more than a year. Moreover, a new destination had to be found. The choice was ultimately 67P/Churyumov-Gerasimenko. Two scientists, Churyumov and Gerasimenko, at the Institute for Astrophysics in Alma-Ata/Kazakhstan had discovered the celestial body as a tiny star on a photographic plate in the fall of 1969.

In the past, the gravitational field of the planet Jupiter had influenced the trajectory of “Chury.” Before 1840, it orbited the Sun at a considerable distance, and the lack of heat meant it had not been able to develop any cometary activity up to this point. In other words, the nucleus should still be relatively fresh and pristine – which researchers see as a benefit. In its present orbit, the comet approaches the Sun to within a distance of around 193 million kilometers (Earth’s distance to the Sun: 150 million kilometers) every 6 years and 203 days.

**SEPTEMBER 7, 2008, 10:14 P.M. CEST**

Signals from the depths of space appear on the screens at ESA’s European Space Operations Center (ESOC) in Darmstadt. The flight engineers immediately forward them to the Max Planck Institute for Solar System Research. Although it is the middle of the night, 14 scientists here filter the first images from the raw data. These show a rock with an elongated shape that tapers to a point at one end; countless craters cover its surface, with a particularly large crater measuring two kilometers in diameter located at the North Pole. The subject is around 360 million kilometers from Earth – and shows the Šteins asteroid. Rosetta passed by it on September 5, 2008 at a distance of 800 kilometers.

Although the OSIRIS telecamera switches into safety mode nine minutes before the rendezvous and only the wide-angle camera is working, the researchers are satisfied with their instruments. OSIRIS is the abbreviation for Optical, Spectroscopic and Infrared Remote Imaging System. Two cameras constructed as mirror systems take images in the ultraviolet, visible and infrared spectral ranges. The light-sensitive CCD detectors comprise 2048 by 2048 pixels, with each of these pixels measuring 13.5 micrometers (one-thousandth of a millimeter).

Before its rendezvous with Šteins, Rosetta had flown past Earth on March 4, 2005 at a distance of just 1,955 kilometers. At that time, it was even possible to see the probe with binoculars. On February 25, 2007, Rosetta passed Mars; on November 13 of the same year, it again gained momentum with the aid of our planet. After the rendezvous with Šteins, it executed another Earth fly-by on November 13, 2009.

Why is this extremely complicated trajectory necessary? A direct flight from Earth to Churyumov-Gerasimenko would have required enormous quantities of fuel. During the so-called swing-by maneuvers on tortuous paths, Rosetta gained the energy it needed from the gravitational fields of the planets free of charge, as it were. During each of the three Earth swing-bys, the speed of the vehicle increased by around 20,000 kilometers per hour.

**JULY 10, 2010, 6:00 P.M. CEST**

The pace is infernal: Rosetta is travelling at no less than 54,000 kilometers per hour as it points its camera eyes at the asteroid Lutetia. This cosmic potato – its longitudinal dimension of around 126 kilometers making it significantly larger than Šteins – has a varied landscape with mountains, large numbers of large and small craters, scattered boulders and parallel grooves. The surface of the celestial object seems to be covered by a thick layer of fine-grained, loose material (regolith).
In October 2012, the probe reaches the point of its trajectory furthest from the Sun; around 795 million kilometers separate it from the warming rays. At this enormous distance, even the 64 square meters of the solar sail generate only small amounts of power. Nevertheless, it is sufficient to keep the vehicle reasonably warm and a clock on board ticking.

**JANUARY 20, 2014, 10:59 a.m. CET**

An alarm clock rings in space. Its job is to bring Rosetta out of hibernation after 957 days. The probe is whizzing around in the depths of space, nearly 815 million kilometers from Earth. It’s the beginning of anxious hours of waiting for the technicians, engineers and scientists in the European Space Operations Centre (ESOC) in Darmstadt.

Will Rosetta really wake up? If yes, the plan is as follows: The star sensors will slowly heat up to operating temperature, open their eyes and determine Rosetta’s position from the sky. The steady rotation of the probe about its axis will gradually come to a halt, and the parabolic dish measuring 2.2 meters in diameter will align itself toward Earth and send the first sign of life.

**JANUARY 20, 2014, 7:18 p.m. CET**

Owing to the huge distance, it takes a bit more than 45 minutes until the signal from Rosetta reaches Earth, is received by a dish in Goldstone, California.

**THE ROSETTA STONE AND THE ISLAND IN THE NILE**

In 1822, Egyptologist Jean-François Champollion (1790 to 1832) succeeded in deciphering hieroglyphics. He did this by analyzing the Rosetta Stone, which bears the same text in three languages: hieroglyphics, demotic and Ancient Greek. Taking its inspiration from this stone, the Rosetta mission aims to help solve the mystery of comets and the early evolution of the solar system.

Before the start, ESA announced a competition to find a name for the lander. Philae came out on top – named after an island in the Nile on which a temple complex once stood. One of the remaining obelisks bears an inscription in Greek and Egyptian, and was used to help decipher hieroglyphics.

With 3.5 grams per cubic centimeter, Lutetia has an unusually high density. From the spectra, specialists conclude that it has a composition comparable to those of meteorites belonging to the carbonaceous chondrites, which have a high carbon content. However, there are also similarities with the so-called enstatite chondrites, which contain the mineral enstatite.

Rosetta can’t solve the mystery of which family Lutetia belongs to, but the scientists are certain of one thing: “This is a completely new world that no one has ever seen before,” says Holger Sierks from the Max Planck Institute for Solar System Research, head of the OSIRIS team. The instrument provides images with a resolution of 60 meters per pixel. Some images even provide indications of a landslide within a crater. All in all, it’s a successful dress rehearsal for the meeting with Churyumov-Gerasimenko.

**JUNE 8, 2011**

After the engineers and technicians had installed upgraded software for the central computer in December 2010, they switched it off. Some months later, and slightly earlier than planned, on June 8, 2011, they then put the complete spacecraft into hibernation. Rosetta now slowly rotates about its own axis for stabilization.

Photos: ESA/Rosetta/MPG for OSIRIS Team MPG/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA

Ragged space potato: Rosetta photographed the two asteroids Šteins (left) and Lutetia during the fly-bys in September 2008 and July 2010. Despite the fleeting encounters, it succeeded in obtaining extremely detailed views, particularly of Lutetia. Craters, mountains and scattered rocks can be seen on its surface.
nia, and appears as a small line in an irregularly jagged green curve on the monitor in Darmstadt. Still, some scientists had expected that this would take place around 6:30 p.m. on January 20, 2014. It is now already after 7:00 p.m. and Rosetta has been overdue for three-quarters of an hour.

The nervousness is increasing at ESOC. Everyone present is looking up toward a monitor, as if spellbound. The clock in the control room shows 7:18 p.m. when a line finally appears on the screen – first short, then slowly becoming longer. Two technicians at the consoles are the first to throw up their arms. The cheering starts. People hug each other. A glass breaks somewhere. Rosetta is awake! It’s now setting off on the final stage of a more than ten-year journey.

MARCH 21, 2014

The picture looks as if it was taken by a well-equipped amateur astronomer. The magnificent globular cluster known as Messier 107 in the Serpent Bearer constellation shimmers slightly left of center. Diagonally above M 107 there appears a weak spot of light, which a layperson could easily overlook. But for Holger Sierks, it’s something very special: “To finally have our destination in sight after a ten-year trip through space is an indescribable feeling,” says the Max Planck researcher. The unassuming little star is none other than 67P/Churyumov-Gerasimenko, as seen through OSIRIS’ eyes.

The camera system on board Rosetta must operate to its performance limits. After all, more than five million kilometers separate the space probe and the comet from one another. This explains why the comet on the photos covers only a fraction of a pixel. What’s more, the celestial body glimmers like a very dim light; a series of exposures from 60 to 300 seconds and additional image processing are required to make it visible at all.

While Rosetta and its instruments are slowly awakening, Churyumov-Gerasimenko is still in a kind of slumber. This is typical behavior for a comet. As with all members of the Jupiter family, it spends most of its life in the icy depths of the planetary system at a similar distance from the Sun as the gas giant Jupiter. This is where countless bodies measuring several kilometers in size whiz about as dead lumps of rock and frozen gases, such as carbon dioxide and ice.

In all probability, “Chury” and its peers have their origins in the Kuiper Belt. This ring-like region at the very edge of our planetary system beyond Neptune’s orbit is more than 30 times as far from the Sun as the Earth is, and is populated with thousands of cosmic rocks. Under the influence of Neptune, the orbits of individual bodies gradually shift toward the other gas giants in the planetary system – right down to Jupiter.

“Despite this migration – and the collisions that may have preceded it – comets in the Jupiter family are some of the purest material that has been preserved from the birth of the solar system more than 4.6 billion years ago,” says Ulrich Christensen, Director at the Max Planck Institute for Solar System Research. While particularly the inner planets, such as Mercury and Venus, have undergone great changes as a result of the heat and the particle bombardment from the Sun and have lost volatile components, this material has been stored in an unaltered state in the ice of the comets for billions of years.

When the cosmic vagabond moves nearer to the Sun on its orbit, its surface begins to warm up, and water and frozen gases evaporate and entrain tiny dust particles. The comet becomes active: an atmosphere (coma) forms around its nucleus, and it finally develops the characteristic tail.
This material is what Rosetta will investigate in greater detail than ever before. “The space probe is a kind of laboratory that is operated on-site at the comet,” says Max Planck researcher Martin Hilchenbach, head of the COSIMA team. COSIMA is one of the instruments that are intended to specifically coax some of the secrets out of the cometary dust. In the microscopic, cauliflower-shaped pores of carriers measuring just a few millimeters in size, the dust catcher collects individual particles that are first localized under a microscope before being bombarded with indium ions. Ions are then released from the surface of the dust particles in this process and can be analyzed further. “We can identify not only individual elements, but also, above all, organic molecules,” says Hilchenbach.

APRIL 30, 2014

“Chury” really is a comet! At least the images taken by OSIRIS show a real coma. It stretches around 1,300 kilometers into space and envelops the nucleus with gas and dust. The researchers are astonished by this cloud, because the comet is still more than 600 million kilometers from the Sun. However, the splendor doesn’t last very long: photos from the beginning of June show 67P as a tiny star again with no activity whatsoever. The comet apparently woke up too early and immediately nodded off again.

OSIRIS further reveals that the nucleus, which measures five by three kilometers, rotates about its axis once every 12.4 hours – 20 minutes shorter than determined previously from Earth. If this isn’t due to a measurement error, something must have reduced the rotational time. This proves once again that comets are always good for a surprise.

JUNE 6, 2014

The comet is sweating. It’s releasing a large glass of water every second, or more precisely, around 300 grams of water vapor. This was determined by an instrument called MIRO. The small radio telescope receives signals from a respectable 350,000 kilometers; this is now the separation between Rosetta and 67P.

MIRO analyzes the microwave radiation that originates from the gas molecules. Water and other substances leave characteristic fingerprints on the light in this wavelength range. “The signals that water molecules leave in our measurement data can be detected particularly well,” says Paul Hartogh from the Max Planck Institute for Solar System Research, who supervised the development and construction of a subsystem of MIRO. The researcher is pleased with its sensitivity: it’s as if one were to discover the evaporation of a cup of hot tea on the moon from Earth.

JULY 14, 2014

A rubber duck is orbiting in space! At least this is what the images that show Churyumov-Gerasimenko from a distance of less than 12,000 kilometers suggest; on Earth, this would correspond roughly to the distance between Germany and Hawaii. The images from the middle of July prove that the nucleus of the comet consists of two clearly separated parts: a larger “body” on which a smaller “head” sits.

JULY 21, 2014

The rubber duck has a collar. Rosetta is now just 5,500 kilometers away and providing images with a resolution of 100 meters per pixel. The images clearly show that the “neck region” located between the “head” and the “body” appears much brighter. This is where an abyss some 1,000 meters deep opens up, and where the camera discovers so-called jets – fountains of dust. The brightness of the band could be caused by differences in material, different grain sizes or topographic effects. It is still unclear how 67P got its duck-like shape. A few researchers speculate as to whether the “head” and “body” were originally two separate objects.
JULY 25, 2014

The coma has appeared again. The images show an extensive cloud of dust around the nucleus. The diffuse cloud completely fills the camera’s field of view, an area measuring 150 by 150 kilometers. It appears to be only the inner region of the coma, in which the particle density is highest. The total structure should be significantly larger, but it can’t be imaged by Rosetta from a distance of a mere 2,500 kilometers. And so it seems that Churyumov-Gerasimenko – after a brief phase of activity in April – is finally fully awake.

AUGUST 6, 2014, 11:30 A.M. CEST

Arrived at last! Rosetta has travelled 6.4 billion kilometers. “After flying on the approach for nearly a decade, it seems almost unreal to have actually arrived,” says Max Planck researcher Holger Siers. Just before he made this statement, the European Control Centre in Darmstadt had received the redemptive signal. Rosetta had swiveled into pyramidal orbits around 67P, following a “triangular” orbit about the nucleus. The space probe initially approached the comet to within 100 kilometers; since the beginning of September, it has been 50 kilometers and less.

Even shortly before the thrust maneuver on August 6, the spatial resolution of the images was 5.5 meters per pixel, surpassing all previous images of cometary nuclei. In addition to stark differences in brightness on the surface, sharp-angled cliffs, mountains and deep escarpments now appear. Expanses of smooth surfaces and round hills can also be seen.

It is a landscape of strange beauty, partially formed by the comet’s activity. During earlier approaches to the Sun, volatile substances from its surface vaporized and entrained jets of dust. If these dust particles are too heavy or too slow to leave the gravitational field of the comet, they fall back to the surface, where they accumulate in places and create different geological formations.

AUGUST 25, 2014

As level as possible, not too much shade, not too much sunlight – and scientifically interesting: these are the conditions that the region on the nucleus of 67P/Churyumov-Gerasimenko where Philae will land must fulfill. Today, researchers and engineers announce five possible candidates: three of the potential landing sites are on the “head,” and the other two on the larger “body” of the comet. They are designated A, B, C, I and J.

“The most important criterion, of course, was that Philae is able to reach the areas in the first place,” says Hermann Bönhardt from the Max Planck Institute for Solar System Research, Lead Scientist of the lander mission. This does not apply to all regions. Even if one takes into account all conceivable velocities, trajectories and orientations of the space probe at the moment Philae undocks, as well as the different possible detaching speeds of the lander itself, the map of the comet still has no-go areas.

Equally important is that, from the landing site, there must be regular radio contact with the space probe in order to exchange operational commands and data. A surface that is as level as possible should ensure a safe landing. Moreover, six hours of sunlight are necessary every day for at least six months to charge Philae’s solar batteries. However, the Sun must
not shine for too long, either, otherwise the lander could overheat.

SEPTEMBER 10, 2014

Mapping a comet. The images transmitted by OSIRIS achieve a resolution of 75 centimeters per pixel. With areas characterized by steep cliffs, depressions, craters, scattered boulders and parallel grooves, 67P exhibits many different landscapes. Some of these regions appear quiet; others were apparently formed by the activity of the comet.

The scientists combine the various expansive landscapes into a map – and puzzle over it: “So far, nobody really understands how the morphological differences that we see have formed,” says Max Planck researcher Holger Sierks.

SEPTEMBER 16, 2014

J wins. Although the images show a very rugged terrain there, almost in the center of the “head” of the comet, computations show that the chances for a landing are good. The researchers and technicians take into account the topography of the area and the mechanical characteristics of Philae’s landing gear. The spot on which Philae touches down can be determined to within only 500 meters or so.

“This means we need, not one perfect spot, but a complete region where as many landing scenarios as possible have a happy end,” says Hermann Bönhardt. This area is dotted with relatively few large rocks that could present a danger to Philae, for example.
addition, measurements indicate that organic material is present here. Finally, CONSERT should find very acceptable conditions for its radio observations at the landing site selected.

CONSERT is the only experiment of the Rosetta mission that is part of both the orbiter and the lander. It is to use radio waves to investigate the inner structure of the comet's nucleus. A radio signal will be transmitted from the space probe through the nucleus to the lander and back. The shape of the nucleus and the flight path of the orbiter mean that not every spot on the surface of 67P is equally suited to penetrate the whole of the comet's nucleus. Landing site J is one of the best sites for this task. On October 14, 2014, J is confirmed. It is named “Agilkia.” One of the greatest adventures of space travel can begin.

NOVEMBER 12, 2014, 9:35 a.m. CET

Already on November 8, the ground crew had sent Philae the computer sequence that controls the landing via its orbiter. On the morning of November 12, the Rosetta mother ship is still hovering more than 22 kilometers above the surface of the comet. After the control center gives the final “Go!” three preloaded springs maneuver Philae away and push it off into space at 9:35 a.m. The refrigerator-sized box drifts away from Rosetta. Around two hours after separation, data transmission starts. The lander sends signals to the orbiter, which transmits them to Earth at the speed of light. Since the comet is flying through space at a distance of more than 500 million kilometers from our planet, these signals take 28 minutes and 20 seconds to arrive.

Around two hours after separation, the OSIRIS camera aboard Rosetta turns its gaze toward the landing probe as it retreats. “Philae is making good progress,” says Hermann Bönhardt. The current image proves that the landing gear has unfolded as it was intended to.

NOVEMBER 12, 2014, 4:34 p.m. CET

Touchdown, Philae has landed! The probe touches down at a speed of approximately one kilometer per hour. A cold gas thruster should now push the lander gently onto the comet’s surface, harpoons should be launched, and the screw-like tips of the three landing legs should also bore into the surface. But the cold gas thruster and the harpoons fail to work! Philae bounces off and floats for approximately 110 minutes around one kilometer further away. The probe then touches down again, lifts off slightly and, after a second little “hop,” finally lands for a third time.

NOVEMBER 15, 1:36 a.m. CET

The exact landing site is initially unknown. It’s possible that Philae touches the ground with only two of its three legs. The first images show rocky material and a cliff. Sunlight reaches the landing site for only one and a half hours a day, so the solar-powered batteries aren’t taking in enough energy. Thanks to the primary battery, however, the board instruments start to record data and conduct measurements as planned.

This “critical phase” of the scientific work ends after just under 60 hours. On November 15, 1:36 a.m., Philae falls into an automatic sleep mode; contact with it is interrupted. Whether the lander will make contact again remains uncertain. One thing, however, is certain: the mission has been successful. Rosetta will revolutionize our knowledge of comets!
Machines in Dialog

Cyber-physical systems are in strong demand for their ability to increase road traffic safety and optimize electricity consumption from renewable sources. They link vehicles to sensors that monitor traffic and order the car to brake if a dangerous situation arises, for example. Or they distribute electricity from multiple power plants to consumers as efficiently as possible. Rupak Majumdar, Director at the Max Planck Institute for Software Systems in Kaiserslautern, develops mathematical methods for ensuring the reliability of these networked systems.

Rupak Majumdar comes from India, is 38 years old and Director at the Max Planck Institute for Software Systems in Kaiserslautern in the German federal state of Rhineland-Palatinate. The press conference was called because he and three computer science professors from Saarland University were awarded the European Research Council’s largest research grant, valued at 9.3 million euros. Over the next six years, this money will serve to help them find a way to reconcile the conflict between safety and freedom on the World Wide Web. The Internet is one of the peripheral fields associated with Majumdar’s research.

His primary focus is on the foundations of what are known as cyber-physical systems (CPS). These systems are promising not only in terms of fostering economic growth, but also for finding solutions to major societal challenges. Their advantage is that they are rooted both in the real and in the digital world. They link physical sensors
and controls in devices, buildings, vehicles and medical equipment with communication networks such as the Internet. In this way, physical data can be gathered in a real environment and analyzed anywhere on the globe. The results can trigger further arithmetic instructions as needed, which in turn alter the real world via special actuators. Majumdar develops algorithms, or arithmetic instructions, that make it possible to increase the reliability of these kinds of complicated systems as early as in the design phase.

The press conference is over. Majumdar quickly swipes away the e-mails that appeared on his smartphone before rushing to his car. It's roughly a 70 kilometer drive from Saarbrücken to Kaiserslautern, where he has headed the Max Planck Institute since 2010. He also lives there, with his wife and two sons. Majumdar is in a rush. He promised to pick up his eldest son from school and take him to a friend's birthday party. That means he needs to be in Kaiserslautern in about an hour. In the future, cyber-physical systems could assist users with endeavors like this, as well. According to the agendaCPS study conducted by the National Academy of Science and Engineering (acatech), the resulting scenario could look something like this:

Majumdar enters his destination into his smartphone, in addition to the desired time of arrival, stopovers and costs. The smartphone, which is connected to various service providers via the Internet, contacts these providers and then lists the options. Majumdar decides to take the regional train. The ticket is inexpensive, and he can work during the commute. His smartphone then suggests renting a vehicle from a car-sharing provider located close to the train station in Kaiserslautern. He could use the car to pick up his son from school and drop him off at the birthday party.

Majumdar agrees. On the way to the central train station in Saarbrücken, his cell phone beeps. It displays a text message notifying him of the fact that his train will be running 20 minutes late because another train on the same track is experiencing technical difficulties, thus jeopardizing his time schedule. As an alternative, the system suggests renting a car here in Saarbrücken. Once again, Majumdar agrees, and the system now initiates two further operations in the background: it cancels the train ticket and rents a car from a service provider located directly in Saarbrücken. In order to be able to work during the trip, Majumdar selects the “self-driving vehicle” option. By the time he opens the car door just minutes later, the system has already sent his entire travel itinerary to the vehicle’s on-board computer.

This is made possible by the fact that his smartphone is connected to a kind of virtual butler on the Internet. Online, this calculates Majumdar’s agenda for today based on his selected settings. The assistant also constantly requests up-to-date information from service providers such as public transportation and car rental agencies. We could use our smartphones to determine the best route of travel, and even change our plans on the spur of the moment if our train is running late, for example.

Personal travel planning: Rupak Majumdar demonstrates how a cyber-physical system could, in the future, help link different modes of transport, such as public transportation and car rental agencies. We could use our smartphones to determine the best route of travel, and even change our plans on the spur of the moment if our train is running late, for example.
as traffic management systems and public transport operators. It uses this data to calculate alternatives, which it then lists as options that can be selected. Once Majumdar picks an alternative, the virtual assistant regularly verifies the real conditions. In the event of disruptions, it displays the relevant notifications on the smartphone’s display and also informs everyone else involved in the travel itinerary of the changes that are being made.

“In Los Angeles, something like that would have made my life a whole lot easier,” Majumdar explains, as he sits behind the steering wheel of his car. He spent six years there, teaching and researching as a professor at the University of California.

And the scenarios painted by the CPS prophet don’t end there. Cyber-physical systems are expected to make road traffic not only more comfortable and stress-free, but also safer. This would require equipping street lights, house façades, sidewalks and vehicles with sensors designed for early detection of the presence of dangerous objects or persons at risk.

If Majumdar were to approach his son’s school with the car and pass a bus waiting at a stop, for instance, it’s possible that the car would suddenly brake very hard. One reason may be that the sensors embedded in the asphalt might have detected a child standing behind the bus, out of view. The moment the child’s position is transmitted in real time to the virtual assistant in Majumdar’s car, the assistant immediately decides to play it safe. It initiates the braking process while at the same time using what is known as vehicle-to-vehicle communication to inform the cars driving behind Majumdar of the situation. These cars then brake as well in order to prevent a pile-up. Scientists hope that this kind of technology could help significantly reduce the number of traffic-related injuries and mortalities.

HELPING THE ELDERLY IN AN EMERGENCY AND WITH SHOPPING

Cyber-physical systems could also help to more easily deal with two other common societal challenges. In order to ensure that elderly persons can stay in their familiar surroundings for as long as possible, their apartments or houses would need to be equipped with sensors and voice-activated electronic devices. These would link together to form a cyber-physical system that learns to recognize the inhabitant’s behavior pattern when he or she is in a good state of health, and alert a doctor if any deviations from this pattern occur. If the inhabitant suffers from dementia, the system could also write shopping lists based on the food items stocked in their pantry, and monitor whether the person is taking their medication as required. The system could even detect if an elderly person falls, and initiate emergency measures.

Cyber-physical systems also play an important role in the transition from fossil fuels to renewable energy sources, with wind and solar power increasingly covering energy demand. However, the amount of electricity contributed by these energy sources naturally fluctuates. Thus, in order to ensure that the supply still satisfies the demand, the electricity must be transmitted using a clever mechanism. This approach is based on a vast energy information network that combines the regulation of the power grid with consumers, electricity producers and energy storage devices. The important components of this gigantic system include sensors in the form of smart meters located in households, along with information and communication technology, as well as adaptive arithmetic techniques.
Unlike conventional electricity meters, these sensors take into account the current energy prices and grid loads to make consumers aware of any power-guzzling appliances and give them tips on saving energy.

“In recent years there have been two key developments without which such scenarios would be absolutely unthinkable,” explains Manfred Broy, professor of computer science at Technische Universität München (TUM). “This is the triumph of the Internet, spurred on by increasingly powerful and more-affordable computers,” says the professor. Not to mention the increased use of embedded systems. While these small computers have limited capability, they feature sensors and actuators that help them understand and control the physical world.

Researchers and engineers are already faced with a series of challenges when it comes to designing and developing embedded systems. Cyber-physical systems significantly compound these difficulties. “The complexity of the systems that we want to build is always greater than the complexity that we can still reasonably monitor,” Majumdar explains. The development of brakes for cars is a prime example of this.

**GREATER COMPLEXITY: A MULTI-VEHICLE NETWORK**

In 1978, the anti-lock braking system (ABS) was considered a technological milestone because it ensured improved steering and directional stability when a car’s brakes were engaged. Seventeen years later, the automotive supplier Bosch launched the “electronic stability program” (ESP) for the Mercedes S-Class. As a combination of ABS, traction control and electronic brake-force distribution, it was designed to specifically decelerate individual wheels in order to prevent the vehicle from breaking away. Then, in 2003, Japanese car manufacturer Honda introduced the “Collision Mitigation Brake System” on the market. This type of emergency brake assist automatically initiates the braking process via the on-board computer as soon as it deems a situation critical. Using radio waves and laser beams, the system determines the distance between the vehicle and the obstacle. If the distance is too small, the system even triggers full braking.

Greater functionality requires a greater number of sensors and actuators, whose correct interaction in turn
increases the system’s complexity. An ABS affects only the wheel speed and brake force, while the ESP monitors the steering angle and various acceleration forces, specifically controls individual wheels and throttles the engine. The emergency brake assistant detects the car’s surroundings as well as potential obstacles. Current technology such as computer vision can even detect pedestrians in the vicinity. “All of this is taking place inside a vehicle, and now we want to access a network that is established between multiple driving vehicles. This takes us to a whole new level of complexity,” explains Majumdar.

**A CYBER-PHYSICAL SYSTEM WITH RESPONSIBILITIES**

Constantly mastering this growing complexity is just one of the numerous challenges faced by scientists in this field. But the public, too, must become involved. Not only must society ask itself whether it wants to relinquish the responsibility of full braking to sensors and program codes, it must also define rules and guidelines for other applications involving cyber-physical systems, such as those that care for the elderly and regulate power supply.

Yet before any of this can happen, the public must first learn to accept cyber-physical systems. This means that the systems must always work in a reliable manner. Not only must they meet the expectations of the consumers and the engineers alike, but they must also never malfunction and be available at all times. Even if individual components were to fail due an accident or as a result of damage, the ramifications must be kept to a minimum. And all of this must already be ensured while the systems are still being designed. This is where Rupak Majumdar comes into play.

The stairs, a combination of light-colored wooden flooring, metal and concrete, creak as he heads up to his office on the third floor of the Max Planck Institute for Software Systems in Kaiserslautern. The building still smells new – after all, the researchers just moved in last July. Six floors composed of offices, conference rooms and lounges surround a square-shaped atrium. With its second site in Saarbrücken and in addition to the Max Planck Institute for Informatics, this institute is one of two within the Max Planck Society devoted exclusively to computer science. This is where scientists research all kinds of structures and linkages of software systems. Here, Majumdar and his group develop methods that can be used to automatically check the operational safety of CPS.

**HIGH DEMANDS REGARDING RELIABILITY**

“Obviously, the system should never fail,” he explains, as he walks from his office to a meeting with his group. Before, it was possible to reboot the software if need be. “But the requirements are much greater, of course, when you design a control system for an entire electrical grid,” Majumdar says, and adds: “When certain functions don’t deliver the correct result within a clearly defined period of time, this can result in high costs or even, at worst, in a catastrophe.” It is already complicated to ensure the reliability of embedded systems. Yet in the case of cyber-physical systems, there is an added difficulty: their components operate in both the analog-real world and the digital one. This fact must be taken into account when developing the models for these systems.

In the digital world, reliability is defined as “robustness,” a term computer scientists use to express that the system continues working in a satisfactory
manner despite malfunctions. In the real world, which is described by control systems and differential equations, on the other hand, reliability is defined as “input-output stability.” Take a coil spring with a weight attached to one end as an example: No matter how far the weight is pulled down, once let go, the range of the spring pendulum won’t exceed the distance by which it was initially extended. Friction causes the swinging motion to gradually die off. The fact that in a spring pendulum system, the limited input signal, namely pulling the spring downward, also induces a limited output signal, namely the swinging motion of the spring pendulum, is described as input-output stability.

HUMAN FACTORS: A TOUGH NUT TO CRACK

Robustness and input-output stability can be applied only in their respective fields, so it isn’t possible to express and calculate them for “hybrid” systems such as cyber-physical systems. However, checking the reliability of precisely these systems is extremely important, for example with regard to ensuring a steady supply of electricity generated from solar and wind power. Majumdar has made a major contribution to this.

He expanded the definition of input-output stability from the world of real controls in such a way that it can now also be applied in the realm of bits and bytes. This is an important piece of the puzzle to also help assess the reliability of cyber-physical systems.

Yet for Majumdar, it isn’t just these different approaches to developing models based on control systems and software technology that prove to be a challenge; the human factors are also a tough nut to crack. He calls it the “semantic gap”: various experts are involved in developing a control system. However, each of them focuses only on their individual level of abstraction, which in turn can lead to errors in the overall system. That is why Majumdar’s goal is to be able to check all of the properties of such a system using an integrated program analysis.

The members of Majumdar’s group have gathered in the room, which offers a sweeping view of the campus of the TU Kaiserslautern. They are sitting on blue chairs pulled up to white tables, attentively watching a researcher who has already gone up to the whiteboard. Rayna Dimitrova completed her doctorate in Saarbrücken and now conducts research in Kaiserslautern. She is wearing blue jeans and a white fleece sweater. She quickly fills the two boards with arrows, Latin and Greek letters, round and wavy brackets. Whenever she explains something, her right hand repeatedly opens and closes the cap of the big marker she is holding.

ARRIVING AT THE BEST ABSTRACTION STEP BY STEP

Dimitrova’s research focuses on refining abstractions. “That’s what this game is all about,” explains Majumdar: “We throw away certain pieces of information, but we make sure that we have enough information left over to conduct the analysis.” This approach is also suitable for testing the system models. Previous methods have one major drawback: if you want to model everything with great precision, the sheer number of possible states that such a system could adopt becomes so large that many computers need too much time to complete the computations for the model – if they can complete them at all.

Majumdar and other researchers have further developed this approach and established what is known as “counterexample-guided abstraction refinement.” When applying this method, you start out with a very rough abstraction. Instead of modeling everything, the modeling is kept as cursory as possible. If the computation finds a possible
error, this error is then used as a point of origin to describe this particular segment of the model. This step is repeated until the analysis no longer detects any possible errors. The researchers use this method to arrive at the best abstraction step by step. This abstraction helps the researchers prove, in mathematical terms, that the system as a whole works exactly as it should.

After the presentation, Majumdar is back at his desk, reading his e-mails as his feet bob up and down to the tune of his keystrokes. A picture of a dinosaur, colored in using all sorts of colored pencils, is taped to the cabinet, where it forms a stark contrast to the whiteboard. The latter is covered in so many equations written in red, blue and black ink that the board itself has seemingly become a gray surface. The to-do list is visible in the top left-hand corner. The first ten tasks are written in large black letters, while the remaining items have been jotted down in small red letters. “We’re making progress, but many questions remain unanswered,” Majumdar explains. How can you check and certify that the systems will work even in the case of malicious attacks? How can it be guaranteed that they will protect the users’ data? And how can you make sure that the systems are easy to use, even for non-experts?

Night has fallen long before he gets into his ten-year-old Mercedes-Benz and drives home. One thing is certain: if cyber-physical systems develop the way he hopes they will, he will no longer have to worry as much about road safety on the way home.

To the point

- Cyber-physical systems can increase road traffic safety, make logistics more efficient or ensure a continuous power supply in a fluctuating power grid.
- In computer science, reliability is studied using models that aren’t compatible with the models of the physical world. Ensuring that a hybrid system – one that is rooted in both worlds – works reliably thus requires a comprehensive model.
- Max Planck researchers develop methods that ensure the reliability of cyber-physical systems. The scientists master the high level of complexity by searching for suitable abstractions. These abstractions help them ultimately ensure the reliability of the entire system.

Glossary

Cyber-physical systems: Systems in which sensors for processes in the physical, or real, world are linked to digital control units and actuators in the physical world. These systems use corresponding software to turn physical information into digital control commands for devices, which in turn carry out an action in the physical world.
The Sun –
A Mercurial Star

The Sun is the Earth’s principal source of energy and climate driver. Yet sometimes it sends more light to the Earth than other times. Astronomers working with Natalie Krivova at the Max Planck Institute for Solar System Research in Göttingen take these fluctuations in solar radiation into account in their models to find out whether they contribute to global warming or counteract it.

I actually need just two things for my work,” says Natalie Krivova, with a laugh, “a computer and time.” That’s surprising, as Natalie Krivova is an astronomer and focuses on the celestial body that is most crucial for life on Earth: the Sun. “Nevertheless, I’ve rarely ever looked through a telescope.” The researcher works in a small office at the Max Planck Institute for Solar System Research in Göttingen. On the wall hangs a whiteboard. Krivova has drawn a smiling sun on it with a green felt-tip marker. The Sun is her passion.

Natural scientists have been observing this star for more than 400 years, since Galileo Galilei developed the first powerful telescope. Since that time, mankind has learned a lot about the gigantic, hot, gaseous balloon. Some details, however, are still unclear. It was previously believed that the intensity of solar emitted radiation did not vary with time, and this was dubbed the solar constant. But now we know better: the radiant intensity of the Sun fluctuates – and this is significant for planet Earth, for life here is dependent on solar radiation.

And with the discussion surrounding climate change, the topic of solar radiation has gained additional significance in recent years. The question is whether the Sun, too, plays a role in the slow process of global warming – and if so, to what extent – or whether diminishing solar activity may even counteract anthropogenic climate change.

CLIMATE MODELS MUST ACCOUNT FOR SOLAR ACTIVITY

Natalie Krivova and her colleagues want to help answer this question. On their computers, they have developed physical computational models that simulate changes in solar activity over many centuries. This is crucial for climate researchers: “If I want to find out how severely the climate will change as a result of the emission of greenhouse gases, then of course I have to be able to assess all of the influences correctly,” says Krivova. “And as the Earth’s main source of energy, the Sun just happens to be the most important natural influencing factor.” No climate model can deliver reliable data if the solar activity isn’t computed correctly, she says.

Of course scientists today know the most important solar activity characteristics. Where solar light is vertically incident, around 1,360 watts of power strike one square meter of the Earth’s atmosphere. This value, which is calculated across all wavelengths of light, from ultraviolet to infrared, is called total solar irradiance (TSI). However, just how much energy reaches the Earth’s surface – on the continents and the ocean surface – depends on the wavelength of the solar light. Ultraviolet light, for example, is almost entirely absorbed in the upper layers of the atmosphere. It is therefore important to consider wavelengths individually.

The intensity of the solar radiation fluctuates over an approximately 11-year cycle. This up and down coincides with the increased occurrence and dis-
Climate engine with cyclic operation: The solar irradiance varies over an 11-year cycle, but also over longer periods. When the Sun is particularly active, many dark sunspots and bright faculae appear on its surface.
appearance of sunspots – dark spots on the Sun. The largest ones are visible from Earth with the naked eye. Chinese scientists even described sunspots many centuries ago. German pharmacist and amateur astronomer Samuel Heinrich Schwabe was the first to study them systematically, starting in 1843. However, it wasn’t until the 1970s, when satellites were sent into space with measuring instruments on board, that astronomers noticed that the Sun’s radiant flux also changes with the sunspot cycle.

The Sun at the peak (left) and at a minimum of its activity: The Kodaikanal Observatory in India photographed our star in 1928 (left) and 1933. The images show the intensity in the calcium II line of the optical spectrum.

Solar radiative flux is highest at the peak of the 11-year cycle, when particularly many sunspots are visible. Today, we know that the TSI increases by about one watt at this time. During a sunspot minimum, in contrast, hardly any spots can be seen. Radiant flux decreases during this period.

LONG-TERM TRENDS BESIDES THE 11-YEAR CYCLE

One watt – that sounds negligible, but the impact on the Earth is apparently considerable. In the 17th century, there was a particularly cold period in Europe that is now known as the Little Ice Age. Dutch artist Hendrick Avercamp captured winter impressions in his well-known paintings – ice skaters, villages enveloped in snow. At that time, rivers froze over until well into spring. In the mountains, the snow didn’t melt, even in summer. In historical astronomical records, hardly any sunspots are mentioned for this period. Accordingly, the solar activity at that time is likely to have been very low for several decades.
Compared with the models of other research groups, Krivova’s irradiance model has proven to be very reliable.

So there isn’t just the 11-year cycle, but also a long-term trend that may change the climate on Earth over longer periods. For instance, astronomers have found indications that, over the course of the past 300 to 400 years, radiative flux may have increased by roughly another one watt. The exact figure isn’t yet known.

Interestingly, during the solar cycle, radiative flux doesn’t fluctuate with the same amplitude across the entire solar spectrum. More than 50 percent of the variation in the radiative flux comes from the ultraviolet range. And for a long time, this wasn’t taken into account in solar and climate models.

In the atmosphere, the ultraviolet radiation reacts with ozone molecules, thus governing the ozone balance. In addition, it reacts with nitrogen and many other molecules. “We don’t know exactly how these reactions change over the course of the solar cycle,” says Natalie Krivova. “But there are indications that reactions take place in the atmosphere that further increase the effect of the solar irradiance,” says Krivova.

That is why Krivova’s model SATIRE (Spectral And Total Irradiance Reconstruction) also takes the fluctuations in the UV light into account. “Although the UV light makes up just 8 percent of the total solar irradiance,” she says, “the fluctuations are considerable, and if the effect of the UV changes amplifies solar influence on the atmosphere, we have to account for this in our models.”

In order for models describing natural phenomena such as climate change and solar radiation to reflect reality accurately and make reliable forecasts for the future, they have to be fed with measurement data from the past. Simulating the sea level requires level measurements, simulating solar activity, radiation measurements and many other solar observations from satellites.

**ISOTOPE MEASUREMENTS SERVE AS SUBSTITUTE DATA**

However, the researchers have a fundamental problem with the data situation. The physical reconstructions have to cover long periods: if you want to know how the climate and Sun will change in the coming decades and centuries, then you also need data that covers long periods of time – centuries, or better yet, millennia. But we have reliable measurements for only a few decades to feed into the models.

The data that Natalie Krivova feeds into her models goes back to 1974, and the sunspot counts, back to Galileo Galilei. But then? If there are no actual measurements, researchers rely on substitute data, known as proxies. That’s what Natalie Krivova does, as well.

The Sun’s total radiative flux fluctuates over an 11-year cycle. The SATIRE-S model (red dots) reproduces over 92 percent of measured irradiance variations (black dots). When the short, deep drops in TSI occur, dark spots wander across the Sun’s visible surface.
The astronomer uses measurements of the heavy carbon isotope $^{14}\text{C}$, or of the beryllium isotope $^{10}\text{Be}$, as proxies. These two radioactive isotopes are produced in the atmosphere by bombardment with high-energy cosmic particles, $^{14}\text{C}$, for example, when a nitrogen isotope decays. $^{14}\text{C}$ is incorporated into the global carbon cycle after a few years by plants absorbing it as carbon. Plants always absorb $^{14}\text{C}$ in a proportion corresponding to that in the air. The $^{14}\text{C}$ uptake ends when the plant dies. Then its proportion decreases, for instance in the wood of a dead tree, due to the radioactive decay of the isotope – in the case of $^{14}\text{C}$, with a half-life of 5,730 years.

From the $^{14}\text{C}$ content of wood samples today, it is possible to calculate the $^{14}\text{C}$ concentration in the atmosphere at the time the carbon was incorporated into the wood. To do this, researchers must know the age of the sample. This can be determined based on the characteristic growth rings found in tree trunks, for which there are now complete profiles that go far back.

**THE SOLAR IRRADIANCE OVER THE PAST 11,000 YEARS**

The atmospheric $^{14}\text{C}$ concentration at a given time, as ascertained from tree ring samples, stands in direct relation to how severely the Earth is bombarded with energetic charged particles.

The driver of the fluctuations in particle bombardment is the Sun’s magnetic field. It acts as a protective shield for the Earth, weakening the flux of high-energy cosmic particles. When the Sun’s magnetic field is weaker, the Earth is less well protected. The solar magnetic field is also responsible for the formation of sunspots and the solar irradiance changes. Thus, $^{14}\text{C}$ measurements from tree ring samples can also be used to reconstruct, indirectly, via the strength of the magnetic field, the solar irradiance.

In a similar way, the $^{10}\text{Be}$ data can serve as proxy data for the solar irradiance. However, beryllium precipitates out of the atmosphere and eventually falls to the ground. Historical traces of beryllium can be found today, for example, deep in the icy armor of glaciers on Greenland and in the Antarctic.

Together with other researchers, Krivova succeeded, with the aid of these proxies, in computing, in detail, the variability of the solar irradiance.
for the past 11,000 years since the last ice age. Compared with the models of other research groups, Krivova’s simulation tool proved to be very reliable. Climate modelers therefore use it also for those simulations that are included in the Intergovernmental Panel on Climate Change (IPCC) climate report.

But it can still be better, Krivova believes. Sunspots and $^{14}\text{C}$ proxies aren’t everything – the variability of the solar radiation depends on many factors. Sunspots emerge primarily in regions in which the Sun’s magnetic field is particularly strong. Here, the strong magnetic field hinders the heat transfer from the Sun’s interior to its outer boundary. Sunspots are thus areas on the Sun’s surface where less radiation is emitted, which is why they appear darker.

One would expect the radiative flux of the Sun to decrease when particularly many sunspots occur at the cycle’s peak, but the opposite is the case. This is because, simultaneously, during the active phase, many smaller, bright regions appear that are best visible in UV light. The number of these faculae, as they are called – torches – increases much more than that of spots, which compensates for the radiation attenuation in the sunspots.

Unlike sunspots, faculae are not well seen in visible light. Researchers use magnetographs for this, special instruments on satellites that make the changes in the magnetic field clearly visible – and in this way discern not only sunspots, but also faculae, because they also harbor magnetic fields.

**UNEXPLOITED TREASURE: PHOTOS IN THE CALCIUM II LINE**

Krivova feeds her model with the images from the magnetograph, the so-called magnetograms, and the information they contain on the size of the faculae. In this way, together with her doctoral student Kok Leng Yeo, she succeeded in refining the model in such a way that it is currently considered to be the most precise irradiance model available.

But there is one problem: unlike with the sunspots, there is, as yet, no usable faculae data from the time before the satellite era. Magnetograms of sufficient quality have been researched only since the early 1970s, so not yet long enough. Therefore, together with her doctoral student Theodosios Chatzistergos, Krivova wants to take advan-
tage of an as-yet-unexploited treasure: around 100 years ago, astronomers began using a special method to photograph the Sun. They used photo plates that are sensitive only in a certain region of the solar spectrum, in the so-called calcium II line. At this wavelength, faculae are particularly bright.

THE NETWORK COULD EXPLAIN LONG-TERM TRENDS

The calcium II photographs haven’t yet been thoroughly analyzed. Theodosios Chatzistergos intends to do this – an enormous task. He aims to systematically study 60,000 individual images from three observatories for faculae structures. To do this, he wrote software that automatically detects the faculae areas in the images. By comparing images from three different observatories, he hopes to detect artifacts and image errors. “We hope that this unique faculae data will help us gain an even better understanding of the variability of the solar irradiance,” says Krivova.

And then Natalie Krivova has yet another faint hope: in addition to the sunspots and the faculae, there is a third structure on the Sun’s surface that influences solar brightness. A fine network of even smaller bright spots that astronomers refer to simply as the network. “We know little about the network,” says Krivova. “We suspect that it likewise has a cycle, which is, however, weaker and extended in time compared with the sunspot cycle.”

Krivova and also other researchers believe that this network contributes to the gradual long-term changes in solar irradiance characterized by extended periods during which there are especially many or few sunspots, such as the Little Ice Age. “Secular change” is the term experts use for this long-term trend – “slow, systematic change.” “The role the network plays in this is still poorly understood – so we hope that, in the calcium II images, we will also be able to recognize and analyze the network.”

As far as the long-term change in the solar activity is concerned, the Sun is evidently currently in what, from the perspective of Earth’s inhabitants, is a very interesting phase. Sunspot counts in the past years indicate that solar activity is on the decline again after 60 very active years. For the coming decades, the researchers expect a decrease in solar activity. Climate change skeptics now claim that this cooling could counterbalance the global warming caused by human emissions of greenhouse gases. But Krivova dismisses this: “Current scientific work and the reports of the IPCC clearly show that greenhouse gases have contributed many times more than the Sun to the change in the Earth’s heat balance in the past decades.”

UV IRRADIANCE TO BE STUDIED IN GREATER DETAIL

Krivova plans to continue her endeavors to understand the Sun’s capricious nature. For her, this also, and especially, includes a more precise investigation of ultraviolet radiation – which, after all, contributes significantly to the variability of solar irradiance. UV irradiance is modulated primarily by the magnetic field in the Sun’s upper atmosphere, the chromosphere.
The chromosphere floats above the photosphere, which we humans see from Earth as the apparent surface of the gaseous balloon that is the Sun. However, the processes that take place in the chromosphere are so complicated that it is very difficult to incorporate them in models. Now, though, Natalie Krivova aims to embed in her models a sort of calculation module for the chromosphere.

Her working group at the Max Planck Institute for Solar System Research isn’t alone with its studies on solar irradiance. She and her colleagues cooperate closely with other groups in the Sun and Heliosphere Department headed by Sami Solanki. This work, in turn, is part of the ROMIC (Role of the Middle atmosphere in Climate) research program, which is sponsored by the Federal Ministry of Education and Research, and in which the middle Earth atmosphere is being studied in greater detail.

Although the weather and the climate on Earth take place in the atmospheric layers near the ground – the troposphere – the processes that take place in the layers above that have a major impact on the troposphere. Even today, researchers don’t really understand the processes taking place in the middle atmosphere. Knowledge about the Sun’s impact is also fragmentary.

Natalie Krivova and her colleagues at the Max Planck Institute for Solar System Research will therefore continue, again and again, to explore uncharted solar territory.

**GLOSSARY**

**Faculae:** Bright structures on the Sun’s surface. They frequently occur when the Sun is particularly active.

**Total solar irradiance (TSI):** The amount of solar radiative energy incident per square meter at the top of the Earth’s atmosphere, at 1 A.U., which is the mean distance between the Sun and the Earth.

**Network:** A web of small, bright elements that may contribute to the long-term changes in solar brightness, but that has, as yet, been little investigated.
Time travel with the Molecular Clock

Migration isn’t a new phenomenon, but new insights suggest that modern-day Europeans actually have at least three ancestral populations. This finding was published by Johannes Krause and his colleagues in September and was prominently featured on the cover of Nature. As it happens, the paleogeneticist himself is currently thinking about migrating, and will henceforth travel through time as a Founding Director of the Max Planck Institute for the Science of Human History in Jena. For him, looking back millennia into the past seems to be no problem.

TEXT CATARINA PIETSCHMANN

The air is abuzz with chatter and clinking glasses. It’s a hot July afternoon in Tübingen and it seems like half the town is out and about today – in search of a table in the shade in front of the historic, newly restored city hall. Today, Johannes Krause decided to leave his institute, which is within walking distance, earlier than usual. If you were to see him sitting here in the café – rebellious curls, gray T-shirt, boyish appearance, with a tangible enthusiasm in his voice – you might easily mistake him for a college student in his senior year, or at most a doctoral candidate. A biologist, perhaps, or a philosopher.

The indolence of college life? That’s something the 34-year-old professor of archaeo- and paleogenetics at the Institute for Archaeological Sciences doesn’t have much time for. Especially now that he is about to leave for Jena to take on his position as one of the two Founding Directors of the new Max Planck Institute for the Science of Human History. At the moment, Krause is the youngest Max Planck Director – incredible! How is this possible?

Almost two years have passed since Johannes Krause applied for a professorship in Kiel in connection with the MPI in Plön. “I wasn’t really suited for the position, to be honest.” And the twelve Max Planck Directors who interviewed him thought so, too. But then some of them asked him a question that took him by surprise: Since you’re already here – could you see yourself setting up a new institute for us?

A FUTURE-ORIENTED LOOK INTO THE PAST

What Krause didn’t know was that, at that time, the Max Planck Society was already planning to realign the MPI for Economics in Jena and was looking for a new Director. The members of the interview panel were aware of his excellent scientific career profile, which he had built up under the guidance of his mentor, Svante Pääbo, at the MPI for Evolutionary Anthropology. And so it was soon decided that he and Russell Gray – a molecular biologist from Tübingen who focuses on the analysis of ancient DNA, and an evolutionary biologist from New Zealand who conducts, among other things, linguistics research – would jointly set up the new institute.

It’s a future-oriented concept for looking back into the past. It’s about the history of mankind. About the evolution of language and of Homo sapiens, the anatomical modern human. They will apply their respective methods to reconstruct – or disprove – the annals of human history. After all, linguistics and genetics aren’t as different as they may seem at first glance.

“Migration and merging are reflected not just in genetics, but also in language,” says Krause. “Russell Gray develops evolutionary trees of language families that show signs of merging as well as splitting. This allowed him to identify the time frame in which the Indo-Germanic languages diversified.”

While not a single word has been passed down to us from the prehistoric age, archaeologically proven migration patterns could serve as calibration points. And since language (similar to a genome) undergoes certain “mutations” over time, models based on historical, archaeological and linguistic
The spiral shape suits the expert on ancient DNA: Johannes Krause on the way to the top – inside the institute’s old building in Jena.
facts can help compute the time periods in which languages are likely to have split. “Over the course of the past 1,000 to 2,000 years, there are several examples of populations that merged but adopted the language of the new location. By contrast, the colonization of America resulted in the language of the indigenous people becoming completely displaced,” Krause explains. They have met only a few times so far, yet the scientist from Tübingen is already enthusiastically incorporating the research findings of his soon-to-be colleague from the other side of the globe into joint project ideas for the new institute. He and Gray plan to tackle many endeavors together.

For example, the Migration Period that began around 375 A.D., when the Huns invaded Eastern Central Europe, and lasted until the 6th century: What really happened? Archaeological finds from that era are typically rare and have often been subject to vague interpretations. Who fled where and merged with whom? Genes don’t lie. They can provide precise data even when all that historians and archaeologists can sometimes do is hypothesize. Another example is the Austronesian expansion. Gray studies (linguistically) the settlement of Polynesia via Southeast Asia that occurred 3,000 to 4,000 years ago. “As a result of the colonization that took place over the past 500 years, many genetic patterns have been overwritten. That’s why we’re currently trying to reconstruct the early settlement process using very old human DNA samples taken from that region,” Krause explains, outlining their first plans.

He himself is particularly interested in how modern humans spread out across Europe. “Did they come in waves because of the recurring ice ages? We don’t know.”

A third department is also planned for the institute. “Since Gray and I have a very empirical approach to historical research, we need someone to conduct that research directly – a historian or an archaeologist.” In fact, the underlying idea of the institute’s guiding concept marks the renaissance of a scientific field: “More than 100 years ago, the natural sciences and the humanities drifted apart. Here in Jena, we want to try to bring them back together.” That’s precisely what Krause is already doing in Tübingen. He teaches classical archaeologists the foundations of genetics. To him, it comes as no surprise that this approach would work out well; after all, he spent many years of his scientific career at the Leipzig-based Max Planck Institute for Evolutionary Anthropology, which follows a similar interdisciplinary approach.

Paleogenetics is a young scientific field that didn’t come about until the 1980s. Only a small number of laboratories worldwide have the equipment and experience to analyze DNA samples taken from mummies or ancient skeletons. Even the process of merely isolating DNA from ancient remains is highly complicated, as not every shard of bone that is thousands of years old still contains usable genetic material. And if it does, the DNA is usually highly degraded and contaminated with the genetic traces of bacteria, fungi and plants that were flushed into the porous material by rainwater. Later, archaeologists and museum employees left traces of their own genetic material behind on the bone. “Five percent of authentic human DNA – that would be considered quite a substantial amount...
in an ancient bone sample,” Krause emphasizes. The result is usually just a tiny amount of DNA weighing no more than a few nanograms – billionths of a gram. Today, in order to prevent the researchers from leaving further traces behind on the material samples, the DNA isolation and sequencing preparations are conducted exclusively in cleanrooms by staff members wearing sterile protective clothing.

“Ancient DNA is highly degraded. The individual fragments are only about 50 base pairs long, and at the ends of these fragments, cytosine has often been chemically altered into uracil,” Krause explains. “That’s a shame, but it’s also a sure sign that the DNA fragments being examined are, in fact, ancient genetic material.” After the sample is pulverized, the protein remnants are enzymatically degraded and the remaining genetic material is isolated. The resulting DNA extract is a complex mixture containing genetic material from various organisms. The ancient human DNA is subsequently fished from that DNA soup – a process that requires a “fishing rod.” “And that often takes the form of genetic material of modern-day humans,” reveals Krause, as he talks about a trick that seems simple enough. “One million single-stranded DNA fragments fixed on a small glass slide recognize their counterpart in the DNA extract from early Homo sapiens and bind to it.” Now all the researchers have to do is pull the DNA that is bound to the glass slide out of the mix, decode their sequence, and analyze them using bioinformatics methods.

The Neanderthal genome, which Johannes Krause helped reconstruct, differs from that of 21st century humans by only 0.1 percent. Modern populations from around the globe have even fewer genetic differences in their DNA. A person’s phenotype – the color of their skin, eyes, hair, and so on – is determined by a few dozen of our 20,000 genes. However, most of our genetic variation is shared between modern human populations. Genetically speaking, every form of racism is an absolute joke. Human populations are mostly the same.

**HITCHING A RIDE ACROSS THE ATLANTIC**

Teeth, incidentally, are the best source of ancient DNA. As a kind of “time capsule within a time capsule,” they often still contain dried blood and nerve cells – and with a little bit of luck, even the genetic fingerprint of a nasty little germ. The pathogens that cause leprosy, tuberculosis and bubonic plague, for example, like to cling to nerve ends. Apart from ancient DNA and human evolution, Krause also focuses on historical pathogens and their co-evolution with humans. Several years ago, he used a small number of teeth that were recovered from a London cemetery to reconstruct the genome of *Yersinia pestis*: the pathogen of the Black Death that wiped out nearly half of Europe’s population back in the Middle Ages.

What traces were left behind in human genes when our ancestors came into contact with pathogens? Along which routes and with which host did the plague or the tuberculosis bacillus travel around the globe? “Tuberculosis already existed on the American continent before Columbus set foot on it,” Krause reports. “Using 1,000-year-old skeletal samples from Peru, we were able
to show that the local pathogen is closely related to the tuberculosis pathogen that affects modern-day sea lions. It likely originated in Africa around just 5,000 years ago, and finally made its way to the indigenous peoples in South America.” How was this possible? “You could say the germ ‘hitchhiked’ across the Atlantic on the sea lions. We assume the Native Americans in Peru contracted the disease by ingesting contaminated seal meat.”

Just like humans, germs, too, undergo evolutionary changes. By comparing the genomes of ancient and modern-day pathogens, scientists can determine the rate at which these germs undergo mutations. “The leprosy pathogen, for example, changes very slowly, whereas the tuberculosis pathogen changes much more rapidly. This knowledge helps us keep a better lookout for certain pathogens, because germs that change rapidly also become resistant to antibiotics more quickly.” Medical experts and microbiologists hardly ever concern themselves with historical pathogens. Why is that? “They don’t make use of the concept of time,” Krause smiles, “which means they can hardly read the ‘molecular clock’.” Furthermore, ancient mutations also hold clues about the functions or structures that the pathogens used to adapt to the human host and that new drugs could potentially target. The fact that paleogeneticists like Krause know more about the historical pathogens of the plague, syphilis, leprosy and tuberculosis than microbiologists and doctors do about their modern “descendants” is a bitter truth. All the more reason for Krause to delve deeper into this research field in Jena.

REVISITING HIS PERSONAL PAST

For Johannes Krause, making a new start in Thuringia also means returning home. He grew up in Leinefelde in the Eichsfeld region in western Thuringia, which is nestled in a hilly countryside, surrounded by people with close ties to their homeland. “I like comparing it to the village that Asterix and Obelix come from,” he chuckles. This Catholic enclave in the otherwise Protestant state of Thuringia was too religious for the government of the former German Democratic Republic (GDR), which tried to counteract these sentiments in the 1960s by building his home town a socialist planned city that offered 4,000 jobs. With moderate success – “some 50 percent of the inhabitants have since moved away, because a cotton mill in central Europe doesn’t make much sense.”

Some of his family lived directly in the border region between the two Germanies. Visiting them meant having to file an application for a visitation permit and walking past fences and guard dogs. Johannes Krause was ten years old when the Berlin Wall came down, and the socialist state into which he had been born suddenly became little more than a controversial chapter in the country’s history books. “A good example of a social experiment that failed miserably,” says Krause, who no longer has any illusions. “If it wasn’t possible even in central Europe, then how is it supposed to work in other regions of the world?”

He vividly remembers his first trip to the nearby town of Göttingen, in the West. The different smells wafting through the supermarket, the yoghurt shelves stocked with a seemingly endless range of flavors. He had stood in front of the toy shelves in the Karstadt department store with his mouth agape. “Sometimes I think back to the GDR and it somehow reminds me of North Korea.” Not just because of the monotonous range of available goods, but also because of the drills children had to perform in kindergarten and in school.

His parents weren’t able to pursue their desired careers for having made remarks criticizing the state system. It was therefore also unlikely that Johannes Krause would have been allowed to attend university. However,
he doesn’t regret having grown up in a socialist state. “My political views are rather left-wing and liberal. Had I grown up in the West, I’m sure my left-wing views would be much more extreme. What I learned is that real socialism and the human factor simply aren’t compatible.”

Yet even a child growing up in the GDR was, first and foremost, just that – a child. Like all young boys, Johannes went through a “dinosaur phase,” treasuring one of the precious few books that dealt with this topic and had been published in Prague at the time. “That was my Bible,” he says, the passion still audible in his voice. “I was able to talk my father into collecting fossils with me. We went to all sorts of stone quarries in Thuringia and cracked open rocks.” While he didn’t come across any dinosaurs, he did find hundreds of ammonites that
soon found a new habitat in the family’s garden. Shortly after the fall of the Berlin Wall, castles and ruins in the border region became his next hunting grounds. “Overgrown, enchanted fairytale castles that had remained undisturbed for decades – it was just like in an Indiana Jones movie!”

What would have become of him if the Berlin Wall hadn’t come down? “I often asked myself that question. Maybe a craftsman like my father? Or a forest ranger?” He completed his community service imposed in lieu of military service at the Eichsfeld Hainich Werratal nature reserve, and really enjoyed working deep in the woods. But was that reason enough to spend the rest of his life there? No. He had been toying with the idea of becoming an archaeologist or an anthropologist for quite some time, but his career prospects were bleak. Things were to take a rather unexpected turn.

Around the year 2000 – Johannes Krause was 20 at the time – the Human Genome Project made everything and everyone believe they could soon relieve mankind from all evil. The biotech industry was booming, and technology was being developed at breakneck speed. “I’ve always been interested in the natural sciences, so why not biochemistry? I wasn’t even sure what that was about, exactly, to be honest,” he says today. The sheer amount of chemistry soon started to worry him, and he was all but ready to voluntarily drop out of his university in Leipzig. But then he spent a year abroad in Cork, Ireland. He was riveted by the lectures delivered by his enthusiastic genetics professor, and that was when Krause decided “to give biochemistry one more chance.”

STARTING OUT HIS CAREER AS AN ASSISTANT IN LEIPZIG

When he returned to Leipzig in 2003, he contacted a number of laboratories in search of a job as a student assistant. That’s how he met Svante Pääbo at the MPI for Evolutionary Anthropology. The timing couldn’t have been better: Pääbo had only just moved into the new institute building – there were new job openings, numerous project ideas, and lots of space to put them into practice. Krause’s employment contract for his position as a student assistant stipulated a 19-hour work week, but he ended up spending almost all of his spare time at the laboratory. First he worked on genetic studies involving chimpanzees, then cave bears. The link between genetics and archaeology – eureka! Johannes Krause had found his research field.

In his thesis, he elucidated the familial relationships between mammoths and African and Asian elephants. His thesis was published in the renowned journal *Nature* – pretty cool for a junior scientist. Krause established a new method for reconstructing the entire genome sequence of ancient mitochondrial DNA. And then Svante Pääbo offered him the opportunity to help sequence the genome of the Neanderthal …

Up until a few years before this, it had seemed downright impossible to isolate prehistoric DNA, let alone use it to reconstruct a complete genome. And the endeavor did, in fact, turn out to be extremely challenging. “In the end, we succeeded because we always bet on the right horse.”

The Neanderthal project was completed in 2010 with a surprising result,
Teeth are the best source of ancient DNA because they still contain traces of dried blood, nerve cells or the genetic fingerprints of ancient germs, such as the pathogen that causes bubonic plague (right).

Reconstructing the entire genome turned out to be extremely challenging. In the end, we succeeded because we always bet on the right horse.

namely that a little bit of Neanderthal – between 2 and 3 percent – can still be found today in all people outside Africa. This sparked a range of new projects. Krause was able to reconstruct the mitochondrial DNA extracted from a tiny knuckle bone discovered in the Denisova Cave in the Siberian Altai Mountains. He was able to show that the Denisova hominins were an independent population of the genus *Homo*, and that their mitochondrial DNA split away from that of the Neanderthals and modern-day humans more than one million years ago.

Instead of exploring castle ruins and stone quarries near his hometown, Johannes Krause now visits excavation sites in the Middle East, Indonesia and Africa, and travels all across Europe. He also frequently finds what he’s looking for in museums around the world. Talking the curators into giving you a few hundred milligrams of mummy or skeleton bone isn’t always easy.

The anthropological collections in Europe in particular are a real Eldorado for the researcher – albeit an ethically questionable one, as many of the items on exhibit were looted at random from their countries of origin during the colonial era. Important artifacts were scattered across the globe or disappeared in archives, unlabeled. As a result, historical traces of entire peoples were inadvertently eradicated. “But sometimes paleogenetics can also help tell the long-lost story of certain finds.” The indigenous population of Australia was uprooted so severely over the past 200 years, for example, that the idea of genetically reconstructing their population structure is currently under discussion.

**REVIVING A VISIONARY IDEA**

Johannes Krause is passionate about his research. He could talk for hours about further history-related questions that could be answered using genetics. And that comes as no surprise, as this young field of research is only just beginning to unfold. In Jena, he can now put his ideas into practice and stake a large “claim” for himself. The real work will begin there in early 2015. In the meantime, faster data cables are being installed in the buildings and a new laboratory will be constructed.

Johannes Krause will initially be commuting back and forth between the two cities, because he will retain his professorship in Tübingen for the time being. He has very little spare time. “Do such moments even exist?” he laughs. But that doesn’t really matter. “By choosing this career, I am practically living my hobby.” And this “hobby” can be combined with numerous other activities: he enjoys traveling, hiking and fishing, and tries to go jogging on a regular basis. Oh yes, and not to forget Argentine tango!

If history has taught us anything, then it is the fact that it repeats itself. Sometimes even for the better. It was 17 years ago that the Max Planck Society implemented a similarly visionary idea, which included commissioning Krause’s mentor-to-be, Svante Pääbo, with setting up the MPI for Evolutionary Anthropology in Leipzig. Against the backdrop of the disastrous actions of anthropologists in the Third Reich, this decision – which came 50 years after the end of the Nazi dictatorship – was still a risky step to take. But the concept proved to be successful. Had it not been, Johannes Krause wouldn’t be where he is today.
Eighty-five years ago, Harnack House opened its doors to academic guests from all over the world – a unique institution at the time. The Kaiser Wilhelm Society, the Max Planck Society’s predecessor organization, thus played a pioneering role in international networking. The House reopened in fall 2014 as a conference venue for the Max Planck Society, following extensive renovation work.

SUSANNE KIEWITZ

A Home for the World

Although the wine cellar had not yet been completed, Harnack House was handed over for use in May 1929. Around 400 prominent guests from business and industry, science and politics filled the ceremonial hall of the Kaiser Wilhelm Society’s (KWG) new clubhouse and guest accommodation. The paint on the walls barely had time to dry, as the building had only just been completed due to a long winter and dwindling funds. Nevertheless, everybody who was anybody turned up. Industrial magnate Gustav Krupp von Bohlen und Halbach acted as host, Foreign Minister Gustav Stresemann extended a warm welcome from the government of the German Reich, and US ambassador Jacob Schurman conveyed the best wishes of the diplomatic corps, whose members were well represented in the audience.

Even after the VIPs had left and the doors had opened to normal guests, there was still a tremendous onslaught. By midday, the new venue on the Dahlem research campus was practically overrun. The kitchen had anticipated 60 hungry lunch guests from the surrounding laboratories; instead, three times that many turned up to fill their stomachs.

Harnack House filled many gaps in Berlin’s science community of the 1920s and was unique in Germany. It immediately became a focal point for the employees of the Berlin-Dahlem research campus, which was built literally on a green field in 1911 and had neither shops nor cafés. It offered reasonably priced lunches every day, as well as sports activities, a tennis court, functional rooms, a library and a newspaper room with comfortable lounge chairs. Starting in 1938, there was also a swimming pool.

However, behind these practical amenities lay a vision of great political and social magnitude. In 1926, Adolf von Harnack, President of the KWG, proposed the construction of an international clubhouse and guest rooms. An expert committee would nominate suitable academic fellows as guests. The Dahlem-based research campus offered strong incentives, as its seven institutes conducted pioneering work in virus research, biochemistry, molecular biology and, starting in 1937, also in particle physics.

The idea wasn’t just scientifically beneficial – it also received political backing, as German foreign policy under Gustav Stresemann had, since 1923, increasingly focused on peace and international understanding. Germany, having lost the war, had been excluded from the international community starting in 1918, and was struggling to reestablish its reputation. With Stresemann’s help, Harnack persuaded the German parliament to support the building of the academic guesthouse. German industry, which had recently survived inflation, was also dependent on good foreign relations and had a vested interest in results from basic research. It thus made a generous contribution totaling 1.3 million Reichsmarks.

The driving force in the fundraising effort was Friedrich Glum. The young Secretary General of the Kaiser Wilhelm Society came up with the novel idea of dedicating rooms to individual major donors. The Vereinigte Stahlwerke, a leading player in the European coal and steel industry, financed the building of the lobby, which was called the Bismarck Hall at its request. IG Farben made a donation for the Duisberg Hall. Designed by Munich-based architect Carl Sattler, this room was modeled on a student pub where the institute assistants could enjoy jovial evenings.

Harnack House thus supported its founder’s goal of making science a vital component of the state in several ways. Echoing his sentiments, the German and international press acclaimed the newly opened venue as a place where “international understanding could be applied in practice.” Even in its first year of opening, the German Foreign Office liked the new building so much that it also accommo-

Intellectually stimulating dialogue: Rabindranath Tagore, the Indian Nobel Prize laureate in literature who corresponded with Albert Einstein, stayed at Harnack House on two occasions in 1930.
dated its diplomatic guests there. With Harnack House, the Kaiser Wilhelm Society had also created a new venue for its own communication. This was modeled on the numerous clubs found in Berlin at that time, where politicians, industrialists and business tycoons, as well as artists and journalists, fostered their network of contacts at official and informal events. Scientists also participated in this scene, but didn’t have their own spot.

That changed with the construction of Harnack House. The face-to-face exchange was very much in keeping with the spirit of its founder, as Adolf von Harnack emphasized in his opening address, saying that he had "enjoyed the wonderful experience of establishing close relationships, not just with business and industry, but also with industrialists, not just with banks, but also with bankers, and not just with the trade unions, but also with workers (...)."

The venue’s rapid success proved Harnack right. After just one year, Harnack House had recorded 200 overnight stays, including 98 foreign guests. There were actually only 13 rooms, including some family apartments, which had been personally suggested by Harnack, but these were increasingly frequently booked out. When a radio journalist reported on Harnack House in 1931, he mentioned a host of prominent figures who had stayed there. Rabindranath Tagore, the Indian Nobel Prize laureate in literature who corresponded with Albert Einstein, visited Harnack House twice in 1930, staying in the room adjacent to Heinrich Wölfflin, the art historian from Zurich. In his radio report, Berkeley professor Thomas Goodspeed lauded Harnack House as "unique as a home away from home."

By 1931, Harnack House had established its place in public life in Germany’s capital city. The well-respected newspaper Vossische Zeitung came up with a new column providing readers with the latest details on the "guests at Harnack House." In 1930, these also included Munich-based chemist Hans Fischer, who received news of his Nobel Prize while at Harnack House. With his presentation in the lecture hall, Fischer joined the list of eminent speakers who informed experts and laypersons alike about the latest scientific developments. Topics included astrophysics and ornithology, biochemistry and heredity studies; art history, history and jurisprudence were also permanent fixtures in the lecture program.

Harnack House’s guests included at least 35 current or future Nobel Prize laureates, among them many from the US. However, visitors also came from South America, China, Japan and even Australia. The timetable of Hapag-Lloyd’s Atlantic ships, which sailed weekly between Cuxhaven and New York, was close at hand in the reception office. The hotel-like routine also didn’t change after the National Socialists came to power in 1933. Harnack House remained an international meeting place. It was, however, increasingly under the influence of Nazi foreign policy and race ideology; in the first year after Hitler seized power, the number of guests from the US had already fallen by half.

After the enactment of the Nazi law "to reestablish the civil service" in April 1933, the KWG dismissed most of its Jewish scientists or those of Jewish background at the Kaiser Wilhelm Institutes in Dahlem, leaving them to face an uncertain future. With them disappeared a significant share of the regular visitors. Only those who held a foreign passport, like Lise Meitner, were allowed to stay and were welcome at Harnack House. The KWG’s official invitation policy at Harnack House nevertheless remained loyal to the regime. Secretary General Glum and later Ernst Telschow endeavored to establish good political contacts with the new leadership, and invited key figures of the Third Reich to the clubhouse.

Adolf Hitler visited Harnack House on two occasions, and Joseph Goebbels, Heinrich Himmler and Albert Speer were also guests. The public lecture series increasingly contained topics that appealed to the government, above all on race research and eugenics. The experts in these fields at the neighboring Kaiser Wilhelm Institute for Anthropology conducted research into human heredity studies and eugenics, and trained doctors and lawyers at Harnack House.

Harnack House remained an academic clubhouse until 1945, and starting in 1943, accommodated the bombed-out staff of the KWG. After the war, the US army finally confiscated the intact building in July 1945, turned it into an officers’ club and renovated it extensively. Situated close to the headquarters of the Berlin Brigade, which controlled the southwest of Berlin, Harnack House became a piece of America in Berlin and played a significant role in German-US relations until the fall of the Wall.

Harnack House’s academic tradition was increasingly forgotten, while the events program was dominated by balls and parties after Eckart Muthesius converted the Helmholtz lecture hall into a dance bar in 1953. The Americans mounted a memorial plaque on its door paying tribute to Adolf von Harnack for fostering German-American friendship. After the withdrawal of the Allies, the building was turned over to the Max Planck Society in 1996, which today uses it as a conference venue.
Building Bridges in Berlin

How six PhDnet doctoral students organized the “Visions in Science” conference

The biggest interdisciplinary conference for Max Planck junior scientists lasts three days, but the preparations take months. Any number of obstacles need to be overcome on the way – and still not everything ends up being perfect.

Breaking down barriers between scientific disciplines, promoting new intellectual approaches and understanding how others see things – this is the aspiration behind the meeting of some 100 doctoral students from all institutes who get together every year for the annual “Visions in Science” conference. Based loosely on mathematician Leonhard Euler and his Seven Bridges of Königsberg problem, the organizing team chose the motto “Bridge the Gap” as a sign of this exchange across all Sections of the MPG.

With such a large conference to stage, in Berlin, while also doing their doctoral work and facing many stumbling blocks along the way – the team that took on the task realized in hindsight that the conference motto could equally apply to the tricky feat of organization that went on behind the scenes.

The team consisting of Filippo Guarneri (MPI for Gravitational Physics, Golm), Gianna Triller (MPI for Infection Biology, Berlin), Jan Niklas Grieb (MPI for Extraterrestrial Physics, Garching), Stas Wüst (MPI for Heart and Lung Research, Bad Nauheim), Leonhard Horstmeyer (MPI for Mathematics in the Sciences, Leipzig) and Christoph Sträter (MPI for the Physics of Complex Systems, Dresden) did eventually manage to make the impossible possible – a fact that, despite careful planning, was ultimately attributable to compromises, improvisation and a bit of luck.

For example, the MPI for Infection Biology made its historic lecture hall on the Charité Campus available, the catering team made every effort to address everybody’s culinary needs, and the podium discussion was even arranged to take place in the spectacular...
lecture hall ruins at the Museum of Medical History. “We were thrilled to be able to get top scientists like Julia Fischer, Jürgen Renn and Alexander Borst to come and hold the scientific talks.”

But did they really manage to build actual, passable bridges between Julia Fischer’s field research with the friendly bonobos (behavioral biology) and areas such as Alexander Borst’s neurobiological work on the visual cortex of the fruit fly, which he presented with the catchy title “In the fly’s cockpit”? “Everyone presented their cutting-edge projects here, there’s no doubt about that. But evidence of thinking outside the box and even boldly presenting their visions for the next ten years – that’s something I would like to see even more of,” remarked Norman Gerster, team leader of Visions 2013.

Nevertheless, the event has been gathering speed since 2012 owing to the generous support of the MPG and sponsors like BASF, McKinsey, Lanxess and Corporate Quality, and the events in Bremen and Dresden generated a certain pressure to deliver. “That’s why, when I look back, I’m not entirely satisfied with the outcome of the conference,” said this year’s team leader, Filippo Guarneri.

What the critical junior scientist doesn’t mention is that he also wrote and defended his dissertation during the twelve months he was preparing the conference – preferring to dwell rather than to dwell on the positive experiences: “Our team gave its best and, for my part, I can say that I learned a great deal about team communication. And the conference was certainly better organized than any other I’ve ever attended,” he summed up, laughing.

All of the speeches are available to view on maxNet.tv:

maxload.rzg.mpg.de/wp

(maxNet.tv is accessible from within the internal IP realm and, of course, for maxNet users)

With disturbing footage of monkeys used in experimentation, animal rights activists are not seeking to present a full picture. When it comes to scandal-mongering, however, the truth is discarded, as the example of the Max Planck Institute for Biological Cybernetics shows.

In the programs broadcast by stern TV on September 10 and 17, illegally obtained footage from the animal holding facility of the Max Planck Institute for Biological Cybernetics was shown under the title “Suffering for Science.” A British (BUAV) and a German animal rights organization (SOKO Tierschutz) succeeded in infiltrating the MPI in Tübingen with an activist who was employed as an animal care worker for six months. SOKO Tierschutz praised this action as the largest “undercover investigation into animal welfare in Germany” to date.

A few minutes of film material were edited together from the 100 hours of footage. The selection of images was by no means an objective portrayal of the way animals are held and treated at the institute – the images chosen were those most suitable for making an emotional impact on people and discrediting animal experimentation research.

The images show animals directly after surgery. These images are hard to watch, but are hardly different than those after surgical intervention on humans. They show a seriously ill animal whose case the Max Planck Society explained in detail in the supplement to the position statement published on its website. SOKO Tierschutz misused this case to suggest misleading conclusions. Moreover, the images also showed behavioral patterns in animals that animal attendants and animal welfare officers at the institute had never observed.

There are now various pieces of evidence indicating that certain footage was actually provoked by manipulating the animals or their environment. Many images were produced when the infiltrated animal attendant was alone with the animals. This gave him the opportunity to influence the situation. The MPG has also outlined one such case in detail. These experiences are congruent with those of colleagues in the United Kingdom. There, Imperial College London fell victim to an undercover investigation in April 2013 carried out by the British animal rights organization BUAV.

In a compilation of shortcomings, the BUAV set out 180 alleged infringements of animal welfare regulations. The Animals in Science Regulation Unit (ASRU), the body responsible for monitoring animal experimentation in the UK, published the findings of its investigation several weeks ago. The accusations were substantiated in only five cases, but – according to the ASRU – “they did not involve significant avoidable or unnecessary pain, suffering, distress or lasting harm” at any time.

An initial investigation of the situation in Tübingen by Prof. Stefan Treue, the expert appointed by the President of the MPG, is also pointing in the same direction. The head of the German Primate Center confirmed that employees at the institute treated the animals with great care: “No neglect of the animals has been observed, and the documents provide evidence of close medical care of the animals at the institute,” said Treue. An investigation is, of course, being carried out independently of this by the authorities in Stuttgart, who have sent the institute a comprehensive list of questions.

National TV coverage was limited to stern TV and Bild, but there was clearly greater interest regionally, where the reporting was generally well balanced. However, the intensity and intolerant aggressiveness of the well-organized and interconnected animal rights activists on social media and via e-mail was very damning. Numerous Max Planck Society employees – not just those at the institute in Tübingen – were exposed to abuse and offensive remarks.

To ensure that their supporters continue to make donations, the animal rights organizations upped the ante: a demonstration was organized in Stuttgart at the end of October and the BUAV announced the publication of a comprehensive report. The question remains: Are the objectives of the organizations always as genuine as they claim?
A New Chapter for Harnack House

Nobel Prize laureate Eric Kandel gives the first Harnack Lecture before 250 invited guests

Bridge-building between the times – this is an apt motto for the re-inauguration of Harnack House in Dahlem. Eighty-five years after Adolf von Harnack inaugurated the building as an international meeting venue for the Kaiser Wilhelm Society (KWG), the villa designed by Carl Sattler is now a contemporary conference facility for the Max Planck Society following a two-year renovation period. “Respect for tradition inspired our architects to embrace the historic spirit of this venue using modern materials for the present era,” remarked Max Planck President Martin Stratmann at the opening ceremony in the Goethe Hall. He also thanked the patrons of the MPG whose financial support enabled the project to be carried out.

The new Harnack Lecture played a prominent part in the celebratory evening at the end of October. In the future, this honorary lecture will be held annually by an internationally renowned scientist at the invitation of the President. In this way, the MPG aims to commemorate the Founding President of the Kaiser Wilhelm Society and his commitment to an international focus, excellence and openness.

The series was launched by Eric Kandel, who also sought to build a bridge between the times in his lecture “Art and science in Vienna circa 1900.” With great humor and wit, he explored how the new contemporary psychoanalysis was reflected in the portrait art of Klimt, Kokoschka and Schiele, and also looked at the discoveries of modern neuroscience. Kandel, who was born in Vienna in 1929, had to flee from the Nazis to the US. With his Nobel Prize-winning neurological research, he made significant discoveries about the molecular bases of memory formation.

The Harnack Lecture on maxNet.tv:
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