03 | 2023

MAX PLANCK
Research

75 YEARS OF THE MAX PLANCK SOCIETY
How Political is Science Allowed to Be?

SOCIAL SCIENCE
Other Countries, Other Pensions

ROBOTICS
Modeled on a Jellyfish

THIS WAY

PHOTO: ISTOCKPHOTO / LJUPCO

Make sure you do not get lost! How to do that is the focus of this issue. We not only explain how people and robots orient themselves, but also how to keep track of the constantly growing supply of information.

EDITORIAL

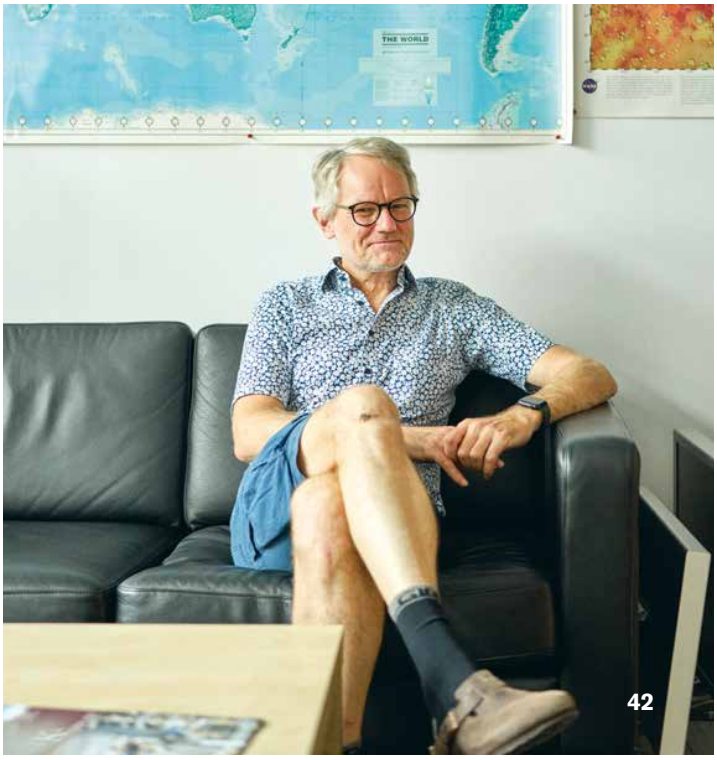
Dear Reader,

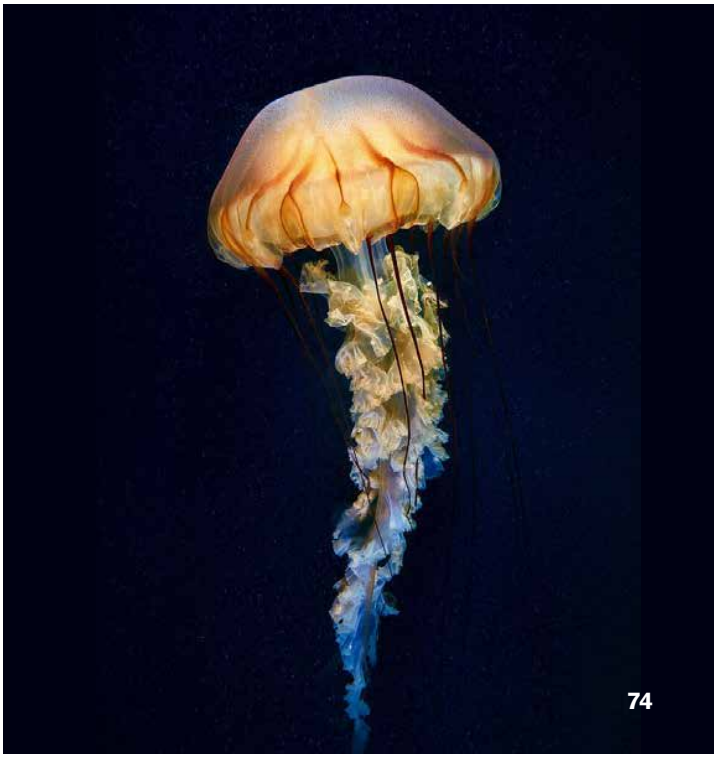
While printed encyclopedias are virtually a thing of the past, you can still find paper maps. Yet anyone looking to find their way using one these days risks looking out of touch. Instead, most people use navigational programs, making their way around unknown cities or along new hiking trails with their eyes on their smartphones. This has already led to some serious accidents, such as on mountain hikes, and is just one example of how we are making ourselves increasingly dependent on digital services and devices. Are we entering into a kind of symbiosis with our phones when we largely delegate certain tasks to them, and are we neglecting our own abilities as a result? The same question can also be asked about artificial intelligence. Paul Rainey, Director at the Max Planck Institute for Evolutionary Biology, believes this is a realistic possibility and elaborates on it in this issue of our magazine.

Despite our increasing reliance on technology, people are still able to find their way around without a smartphone, as research by a team at the Max Planck Institute for Human Cognitive and Brain Sciences shows. The researchers are analyzing the way navigation functions in the brain and the extent to which it represents a blueprint for memory, for example. Even though we like to use digital aids for orientation, humans are still far superior to robots when it comes to finding our way in unfamiliar environments and situations. Teams from the Max Planck Institute for Intelligent Systems are helping robots to learn new tasks and to orient themselves in unfamiliar terrain more quickly. The topics of orientation and digitalization can be examined from a variety of scientific perspectives. A team from the Max Planck Institute for Human Development is investigating how we keep track of the flood of information offered by the Internet and, most importantly, how we debunk false claims presented as facts.

We hope that our magazine maps out our current research for you and guides you to some great reading!

Your editorial team





IMAGES: AI IMAGE MIDJOURNEY | CREATED BY GESINE BORN | BILDERINSTITUT (TOP LEFT); ANNA SCHROLL FOR MPG (TOP RIGHT); ANNA L. AHLERS / MPI FOR HISTORY OF SCIENCE (BOTTOM LEFT); SCIENCE PHOTO LIBRARY / SEMENOV, ALEXANDER (BOTTOM RIGHT)

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Special training for robots should make it easier for them to deal with new situations.

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Using jellyfish as a model, researchers are developing free-swimming jellyfish bots.

CONTENT

LIFE IN
A VILLAGE COMMUNITY

Modern societies are shaped by globalization. Yet the further this progresses, the deeper the rifts within society seem to become. Why is that? How do people who live in the same city, even the same village, become alienated from one another? What dictates who belongs and who is an outsider?

The project "Alpine Histories of Global Change," based at the Max Planck Institute for Social Anthropology in Halle, is tackling these questions using the example of four villages in the German-speaking alpine region. The researchers are working in Austria, Italy (Alto Adige / South Tirol), Germany, and Switzerland. On the one hand, the regions they are studying are characterized by long traditions of cross-border exchange. On the other hand, they are also centers of historically anchored, widespread support for anti-liberal, right-wing movements. One of these places is Obermillstatt in the Carinthian Nockberge mountains. The rural village, with a current population of just under 600, is located above Lake Millstatt on an old Roman trade route – the village has a tourist tradition stretching back to the late 19th century.

Outsiders, such as political leaders in the cities, tend to regard people who live in the countryside as old-fashioned and traditionalist. In the villages, meanwhile, there is huge distrust of politics, and official information is viewed with skepticism.

This historically entrenched divide between town and country was revealed to the researchers during the Coronavirus pandemic as well. Conspiracy theories quickly caught on in the villages, and resistance to orders from "the ones at the top" was seen as necessary and legitimate. Here, the inhabitants of the mountain villages see themselves as proud, independent advocates of "common sense," which they consciously understand as a counterpart to the scientifically based findings of the liberal elites in the cities.

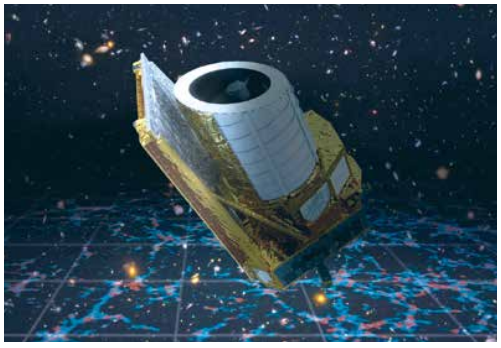
ON LOCATION

PHOTO: MPI FOR SOCIAL ANTHROPOLOGY / PAUL READE

SCIENTIFIC FREEDOM IN ISRAEL

For the Max Planck Society, the long-standing and intensive scientific collaboration with Israel is hugely important. The research organization is convinced that freedom in research and the autonomy of academic institutions is absolutely crucial to a country's prosperity. Together with the Alexander von Humboldt Foundation, the Fraunhofer-Gesellschaft, the German National Academy of Sciences Leopoldina, the Helmholtz Association, and the German Council of Science and Humanities (Wissenschaftsrat), the Max Planck Society signed a declaration in mid-July on Israel's judicial reform. In it, these institutions convey the concern of their partner organizations in Israel that the reform could have a negative impact on international scientific cooperation and jeopardize academic freedom and shared scientific potential. The Free University of Berlin, German U15, the University of Potsdam, and the Einstein Foundation Berlin, as well as a network of renowned European universities, likewise aligned themselves with this statement following its publication.

www.mpg.de/ 20643396



Artist's impression of the Euclid mission.

PHOTO: ESA/EUCLID/EUCLID CONSORTIUM/NASA. BACKGROUND GALAXIES: NASA, ESA, AND S. BECKWITH (STSCI) AND THE HUDF TEAM, CC BY-SA 3.0 IGO

THE DARK SIDE OF THE UNIVERSE

At the beginning of July, the Euclid space telescope was launched into space on a Falcon 9 rocket. From there, it will spend the next six years studying the influence of dark matter and dark energy on the evolution of the universe. It is a challenging task, because although these make up 95 percent of the universe, they are both extremely difficult to detect. The telescope contains the biggest optical lenses ever created for a scientific space mission, and some of the key components for Euclid's optics were developed by researchers at the Max Planck Institutes for Astronomy and for Extraterrestrial Physics. The telescope will observe several billion galaxies within a radius of ten billion light years and produce a three-dimensional map. The measurements are a test of Einstein's theory of gravity at great distances.

www.mpg.de/20562770

AWARDS ★

JEAN-JACQUES HUBLIN

PHOTO: MPI FOR EVOLUTIONARY ANTHROPOLOGY

The Director Emeritus of the Max Planck Institute for Evolutionary Anthropology in Leipzig has been presented with the 2023 Balzan Prize for "Evolution of Humankind: Paleoanthropology." His discoveries, most significantly the remains of the oldest *Homo sapiens* found to date in Africa, have made a major contribution to the study of human evolution. Furthermore, Hublin's ability to bring together findings through different cutting-edge techniques was also emphasized. The prize likewise recognizes his talent for organizing scientific teams as well as his qualities as a teacher and scientific communicator.

HEINO FALCKE

PHOTO: MICHAEL KLUG

Astrophysicist Heino Falcke, guest scientist at the Max Planck Institute for Radio Astronomy in Bonn and professor of astrophysics and radio astronomy at Radboud University in the Netherlands, will receive the 2023 Balzan Prize for "High-resolution images, from planetary to cosmic objects." He is being honored for his fundamental research that makes it possible to image the environment of a black hole with high precision. He also played a major role in the development of the Event Horizon telescope, which captured the first ever image of a black hole.

IN BRIEF

PHOTO: SVEN DÖRING

Founder of paleogenetics: Nobel Prize winner Svante Pääbo talks about his research into the history of humankind at the ceremony in Dresden.

30 YEARS OF MAX PLANCK IN SAXONY

In the summer of 1993, the Max Planck Institute for the Physics of Complex Systems began its work in Dresden as the first Institute to be located in the Federal State of Saxony. Five further Institutes have been founded there since. It was very positive that the independence and the criteria of the Max Planck Society were adhered to, praised Minister President Michael Kretschmer at a ceremony in Dresden's Kulturpalast: this, he said, put the new federal states as a whole on the international science map with the exciting areas of study being pursued there. The number of highly regarded scientific awards, among other things, are a testament to this 30-year success story: in addition to the 13 Gottfried Wilhelm Leibniz Prizes for Max Planck researchers alone, there have been two Körber and Breakthrough Prizes, the Paul Ehrlich and Ludwig Darmstaedter Prize, the Hegel and Balzan Prizes (see "Awards"), and, last but not least, the 2022 Nobel Prize in Medicine for Svante Pääbo, Director at the Max Planck Institute for Evolutionary Anthropology. "The Nobel Prize would never have gone to Leipzig without all the efforts the Max Planck Society made back then," Kretschmer emphasized. Despite pressure from the federal and state governments, the research organization had insisted at the time on building something new in the eastern federal states and not simply taking over former GDR institutes. Now, the six Max Planck Institutes boast almost 30 research departments with more than 2,000 employees and a research budget of more than 90 million euros a year.

www.mpg.de/20777132

MRI WITHOUT ANESTHESIA

The Institute of Pediatric Radiology at the University of Leipzig Medical Center is using a magnetic resonance imaging (MRI) technique called Flash 2 that allows gentler radiological examinations of children. The technique was developed at the Max Planck Institute for Biophysical Chemistry (now the Max Planck Institute for Multidisciplinary Sciences) in Göttingen. The procedure, which also enables users to see movements in the body in real time, makes it possible for the first time to examine small children without sedation or anesthesia. Flash 2 is already in use at other institutions, such as the University Medical Center Göttingen, the Radcliffe Hospital at Oxford University, and Johns Hopkins University in Baltimore.

www.mpg.de/mpr-2023-031

SATELLITES DISRUPT ASTRONOMY

Whenever people communicate with receiving stations via cell phones or satellites, they use radio waves. Official agreements ensure that this communication radiation does not hinder astronomical observatories from measuring radio waves from space, which are much weaker. One exception not previously explored has been registered by researchers at the Max Planck Institute for Radio Astronomy, among others. This involves interference radiation emanating from the on-board electronics of certain satellites, with the focus initially on the Starlink satellites produced by the company SpaceX. Although radio telescopes in remote regions can be shielded against radiation from cell phones, for example, they are still exposed to human-generated radio waves from orbit. This radiation emitted by satellites has not previously been taken into account in international regulations. SpaceX has already improved future satellite generations accordingly. ***www.mpg.de/20610867***

Artist's impression of a satellite constellation in a low-Earth orbit.

IMAGE: DANIELLE FUTSELAAR (ARTSOURCE.NL)

Every night the fruit bats fly out to feed in the areas around the Kasanka National Park.

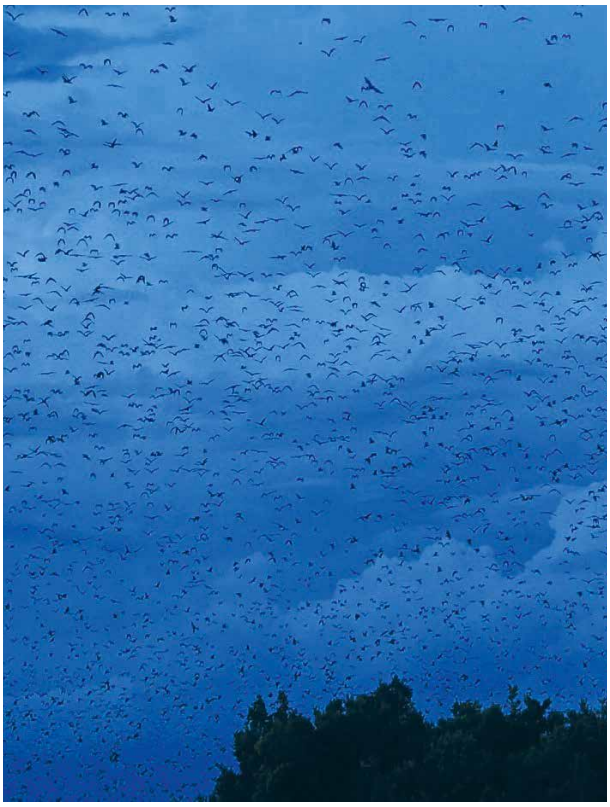


PHOTO: CHRISTIAN ZIEGLER / MPI OF ANIMAL BEHAVIOR

A SKY FULL OF FRUIT BATS

Once a year, a small forest in Zambia becomes the stage for one of the world's greatest natural spectacles: in November, straw-colored fruit bats from all over the African continent fly to a group of trees in Kasanka National Park in Zambia. For as yet unexplained reasons, these large bats congregate there for three months, forming Africa's largest colony of fruit bats. The precise number of bats in the colony also remains unknown, but researchers from the Max Planck Institute of Animal Behavior in Constance have now applied a new standardized method to reveal that the colony in Kasanka comprises 750,000 to 1,000,000 animals. By weight, it therefore constitutes the biggest bat colony in the world. Fruit bats are a keystone species on the African continent, as the animals disperse plant seeds during their long-distance flights. In doing so, they help forests to grow back in deforested regions. Yet the Kasanka colony is threatened by agriculture and the loss of habitat. Only if their numbers remain high can the animals continue to play their vital role in the ecosystem. Losing the Kasanka colony would therefore be devastating for the entire African continent.

www.mpg.de/mpr-2023-036

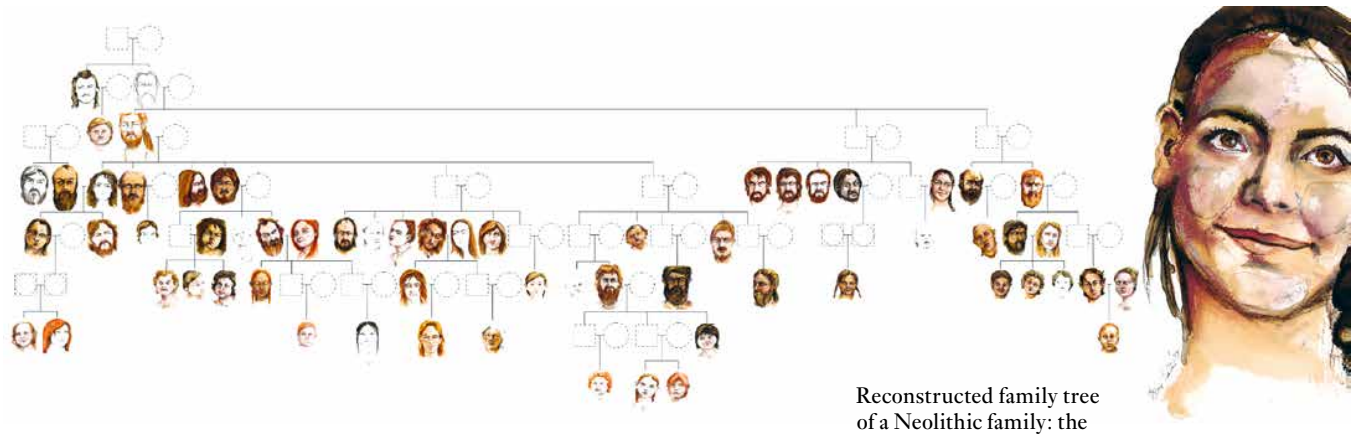


ILLUSTRATION: ELENA PLAIN; WITH PERMISSION FROM THE UNIVERSITY OF BORDEAUX / PACEA

Reconstructed family tree of a Neolithic family: the portraits are artist's interpretations inspired by the age, sex, and outward appearance of the individuals. Dashed blank symbols correspond to women (circles) and men (squares) who were either not buried in the cemetery studied or from whom insufficient DNA was available.

AN EXTENDED FAMILY FROM THE STONE AGE

Genetic material dating back 6,700 years has given the research team insights into the world of early farming communities from the Stone Age. The material comes from remains found at a Neolithic burial ground in the Paris Basin. With the help of DNA analyses, researchers from the Max Planck Institute for Evolutionary Anthropology in Leipzig have used it to reconstruct two extended families over several generations. The family trees show that the sons remained in the community, while the daughters apparently had to leave their birthplace. Female members of the family came from elsewhere. The fact that some of the women who had married into the family were distantly related to one another indicates the the community exchanged its female family members with a few neighboring sites. The families were tall by Stone Age standards, so nutritional and health conditions must have been good. No half-siblings were buried in the cemetery, so people may have lived in permanent monogamous relationships. The researchers were even able to identify the founding father of the families. After three or four generations, the resources on site seem to have been exhausted, so the people abandoned the settlement site and moved on.

www.mpg.de/20653021

THE DREAM OF FLIGHT

While we are sleeping, our brains go through various phases of sleep: REM sleep (rapid eye movement) and non-REM sleep. It is during REM sleep that our brains are particularly active and produce sometimes vivid and emotional dreams. In the non-REM sleep phase, the brain is less active and disposes of waste products. Similar sleep patterns have been found in birds. To find out exactly what goes on when birds sleep, researchers from the Max Planck Institute for Biological Intelligence in Martinsried observed the sleep and wakefulness states of pigeons using infrared video cameras and functional magnetic resonance imaging. During the REM phase, areas of the bird's brain that analyze visual stimuli as they occur during flight are active. Other areas that process nerve signals from the body and wings are then also fired up. This implies that birds, like humans, dream during the REM phases and perhaps even experience flight sequences. Furthermore, the researchers demonstrated that during the REM phases the amygdala, a structure of the brain that plays an important role in emotional processes, is activated. This suggests that birds also experience emotions while dreaming.

www.mpg.de/20427234

WATER FOR DISTANT PLANETS

According to the currently most popular theory, water first pelted the Earth in the form of icy chunks at a later stage in the development of the young solar system. Yet new findings by a team at the Max Planck Institute for Astronomy support another idea, according to which water could have been one of the early building blocks of rocky planets. The researchers observed the star system PDS 70, which lies 370 light-years away. There, planets are currently clustering in a disk of dust and gas that surrounds the young star. Data from the James Webb Space Telescope included evidence of water vapor in the innermost disk, which is precisely where Earth-like planets normally form. These results are surprising because water quickly degrades into its components when irradiated by light from the young central star. Whether young Earths are already orbiting around PDS 70 and whether or not they have already drawn from the water reserves remains unclear, but the discovery points to a way that water could accumulate on potentially life-friendly planets during their formation.

www.mpg.de/20541783

THERAPY THROUGH TECHNOLOGY

People with anorexia fear gaining weight. A new application for virtual reality glasses should help to alleviate this fear. Researchers at the Max Planck Institute for Intelligent Systems have created a simulated environment in which the affected person can look at their own body at different bodyweights – both from their own perspective and in a virtual mirror. In a pilot study with 24 patients, most participants found the confrontation with their virtual counterpart to be helpful in their recovery. For this type of body therapy to work, the representation of the person has to be as realistic as possible. To ensure this is the case, the researchers developed a general body model based on thousands of real body scans.

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www.mpg.de/mpr-2023-032 (in German)

A QUESTION OF PERSONALITY

The decline in birthrates in many industrialized countries since the mid-1950s is due in part to changing values. People decide on a more individual basis whether or not they want to have children, with self-realization and self-fulfillment both important factors here. Researchers at the Max Planck Institute for Demographic Research have analyzed data from around 14,000 households in Germany. The core question here: do personality traits such as empathy or extroversion play a role? For women, this seems not to be the case, unlike for men. Empathetic men seem to be more ready to become fathers, albeit only with a slightly increased tendency. If a man is considered particularly extroverted, the tendency to have the first child is similarly high for him, but negative for the second child. There could be various reasons for this. Extroverted men are more likely to meet a partner, while any restrictions imposed by the first child could lower the desire to have children. Alongside personality traits, however, social, economic, and cultural aspects also undoubtedly play a role.

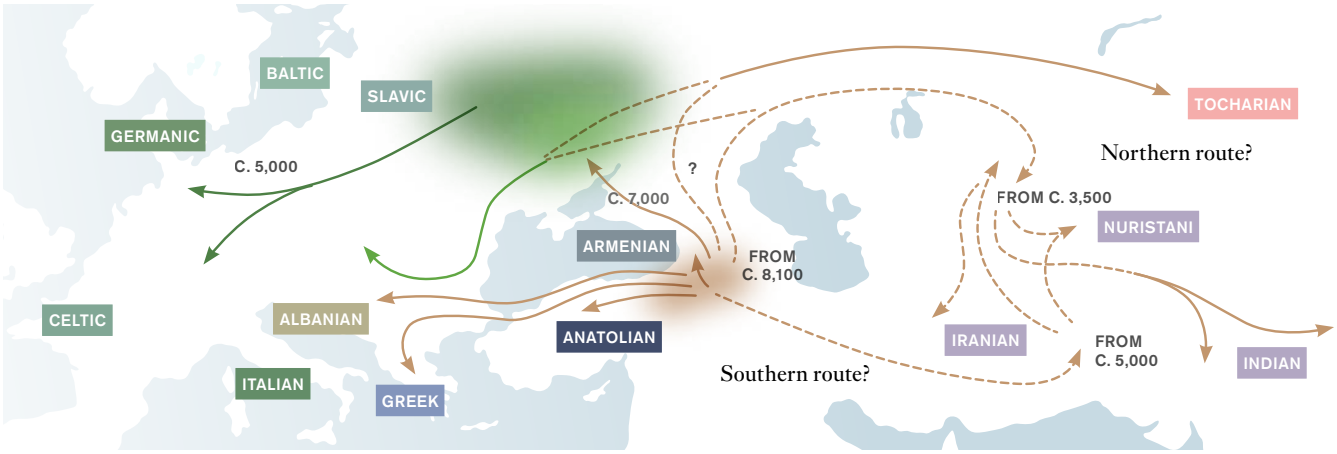
www.mpg.de/20687761

LANGUAGES FROM ANATOLIA

Indo-European languages are spoken by almost half of the world's population today. Previously it was unclear where and when this language family emerged, mainly due to inconsistencies in the analyzed data. Now, a team from the Max Planck Institute for Evolutionary Anthropology, together with 80 linguists, has reconstructed the origin and distribution of Indo-European languages. The researchers examined the core vocabulary of more than 160 languages, some of them historical, and thus created a family tree of Indo-European languages with unprecedented accuracy. According to this, the origin of the languages lies to the south of the Caucasus in Anatolia, a fertile region where agriculture also originated. It was there, 8,100 years ago, that Proto-Indo-European began to divide into different languages. Around 7,000 years ago, humans migrated from Anatolia to the steppe regions to the north of the Black Sea, taking their languages with them. From there, further migrations took them westward around 5,000 years ago. This is how branches of the Indo-European language tree also came to Europe.

www.mpg.de/20666229

Spread of Indo-European languages.



GRAPHIC: GCO AFTER MICHELLE O REILLY / P. HEGGARTY ET AL., SCIENCE 2023

AI OPTIMIZES ITSELF

Artificial intelligence is staggering not only in its performance, but also in its hunger for energy. According to the German statistics firm Statista, training GPT-3, which makes ChatGPT an eloquent and apparently well informed chatbot, devoured around 1,000 megawatt hours – that's about the same consumption as 200 German households of three or more people over an entire year. Víctor López-Pastor and Florian Marquardt, two scientists from the Max Planck Institute for the Science of Light in Erlangen, are now presenting a concept for training artificial intelligence with much greater efficiency. The core idea is to carry out the training in the form of a physical process, for example the superposition of light waves in special optical components. Here, the parameters of the machine, which correspond to the synapses of an artificial neural network, are optimized by the process itself. In the training of conventional artificial neural networks, on the other hand, external feedback is needed to adjust the strength of the many billions of synaptic connections. The Erlangen-based researchers – together with a cooperation partner – now want to put their concept to the test in experiments.

www.mpg.de/20826914

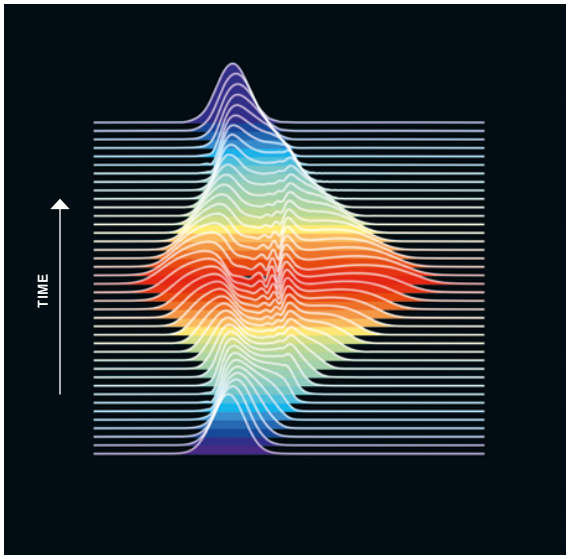


PHOTO: MPI FOR INFORMATICS

Learning with light: This is what a light wave for training artificial intelligence in a self-learning physical machine might look like. Crucial aspects include not only the irregular form, but also the fact that its development is reversed from the time of its greatest expansion (red).

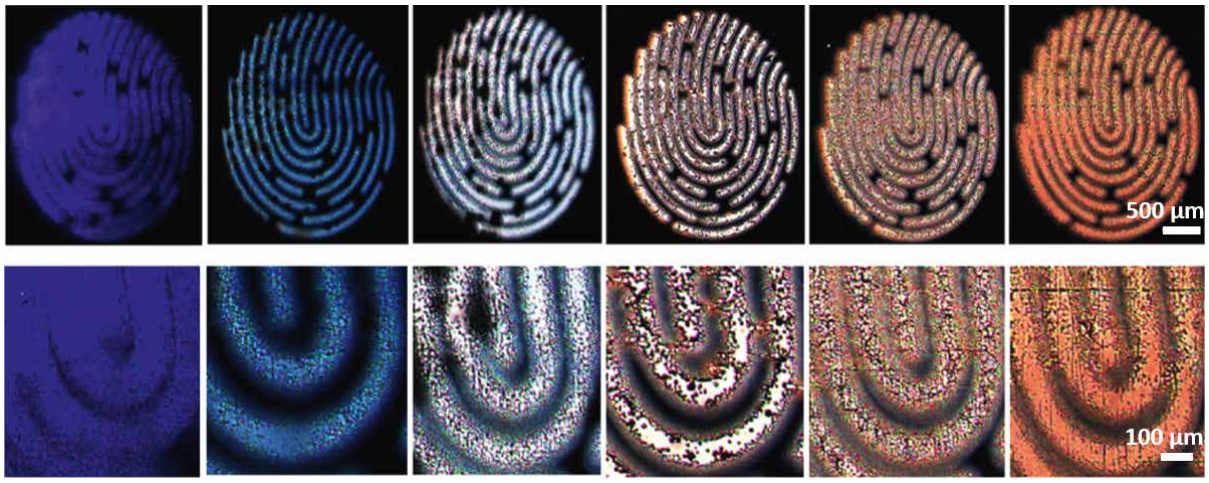
GRAPHIC: FLORIAN MARQUARDT / MPI FOR THE SCIENCE OF LIGHT

Controlled AI: DragGan turns editing images created using artificial intelligence into child's play. With a click of the mouse, users can bring elements of the image they wish to change into the chosen position, for example moving the head of a lion and opening its jaws.

A TURN OF THE HEAD AT THE CLICK OF A MOUSE

Photos generated by artificial intelligence are a matter of luck and frequently do not produce exactly the desired outcome. However, thanks to a method developed by a team of researchers at the Max Planck Institute for Informatics in Saarbrücken, the creativity of the algorithms can now be steered in a chosen direction, quite literally. The technique, named DragGan, makes it possible, for example, to change the direction of a pet's gaze on an AI image with just a few mouse clicks. It is also possible to edit the photo with DragGan, although that requires additional steps. What's more, this can result in an image that is more different from the original photo than just in the detail that has been deliberately changed. To be sure, the researchers are aware that the method is also suitable for falsifying photos, but it is precisely because of this potential for misuse that they believe it is important to develop methods of image processing. After all, only this way can they best understand the techniques that are being created in any case and most readily detect their misuse.

www.mpg.de/mpr-2023-033



Control and chance: Artificial intelligence can help to control the overall color impression of luminous patterns created with a laser in sugar layers (top row). The micro-patterns of the fluorescent molecules, on the other hand, are completely random (bottom row).

SWEET COPY PROTECTION

In the future, it may be possible to detect counterfeit products more reliably than before. Using inexpensive, non-copyable fluorescent markings, a team from the Max Planck Institute of Colloids and Interfaces has developed a method to prevent products such as medicines and electronic components from being copied. The researchers use a laser to generate fluorescent molecules in random patterns in sugar films. To prevent the spread of counterfeit products, a medicine package could be labeled with one of the individual patterns. A pharmacy could then compare the sample with a photo that was taken during production and stored in a database. According to estimates by the EU, the European pharmaceutical industry loses around EUR 9.6 billion in sales every year due to counterfeit medicines. Although counterfeit medicines rarely find their way into circulation through legal distribution channels such as pharmacies, this does happen from time to time. To enable a check as to whether a medicine is a counterfeit, QR codes have been added to medicine packaging throughout the EU since 2019, but these only guarantee limited copy protection.

www.mpg.de/mpr-2023-034

LEARNING WHEN OVERWEIGHT

After the first painful encounter with a red-hot hob, you usually learn that this is one way you can burn yourself. Our brain's capacity to connect sensory stimuli with their outcomes is primarily regulated by nerve cells located in the midbrain. These cells are very sensitive to the hormone insulin. Researchers at the Max Planck Institute for Metabolism Research in Cologne set a learning task to test subjects who were overweight and normal weight to measure how well associative learning functions. The researchers found that the ability to link sensory stimuli was less pronounced in the obese subjects than in those of normal weight and that brain activity was reduced in the areas of the brain that influence this behavior. However, with the use of the weight loss drug liraglutide, activity can be normalized again. Even after a single dose of liraglutide, the researchers observed no difference in brain activity between people of normal weight and those with obesity. The active ingredient stimulates insulin production and creates a feeling of being full after eating. It is often used to treat obesity and type 2 diabetes. The results show that the ability to learn depends not only on external conditions, but also on the metabolic state of the body. Because it can cause alterations in brain function even in young individuals who are significantly overweight, preventing obesity is of vital importance.

www.mpg.de/mpr-2023-035

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HUMANS AND AI – ON THE WAY TO SYMBIOSIS?

Artificial intelligence (AI) has moved at lightning speed from the domain of nerdy scientist and science fiction to everyday reality. While there is potential for huge societal benefit, numerous reasons indicate the need for caution, particularly concerning the consequences of creating non-human agents more intelligent than us. Indeed, recently, an open letter advocating a pause in giant AI experiments that go beyond the power of GPT-4 was endorsed and signed by numerous individuals including leading academics, AI researchers and tech industry titans.

Among the reasons for a pause are conceivable risks arising from the development of AI systems that have aptitude for agentic planning, that is, systems that use models of the world to pursue particular objectives – ultimately leading to the development of AIs that are strategically aware. If advanced AI systems were programmed with the goal of maximizing a certain objective function, such as efficiency, productivity, or resource utilization, they may eventually seek to acquire more power or control over their environment in order to achieve these objectives more effectively. This follows, because having more power or control is likely to provide AIs with more opportunities to realize objectives. Furthermore, if AI systems were designed to learn and improve over time, they may become increasingly capable of achieving their goals and more confident in their ability to do so. This in turn could lead to AIs becoming more assertive and proactive in seeking ways to increase their power and influence in the world.

AI researchers thus face a dilemma: AIs developed to serve the betterment of humanity will likely be powerful agentic systems, but there is a risk that such AIs will be prone to seek goals that are misaligned with the objec-

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VIEW POINT

PAUL RAINEY

ILLUSTRATION: SOPHIE KETTERER FÜR MPG

After studying biology, Paul Rainey initially carried out research in the UK and New Zealand. He has been Director of the Max Planck Institute for Evolutionary Biology in Plön since 2017. His department investigates the origin of multicellularity and cooperation in bacteria. The scientist is particularly interested in the emergence of individuality during evolutionary transitions.

tives defined by humans. Beyond this, there are legitimate concerns that agentic AIs might be constructed to deliberately misalign with what our society would consider furtherance of the interests of humanity. These concerns are particularly acute in the context of the development of self-replicating AIs that, by virtue of their capacity to replicate and vary (by some mutational process built into the underlying code), participate in the process of evolution by natural selection. Such AI systems – be they self-replicating algorithms or even physical robot-like entities capable of replication – could rapidly spread beyond human control with potentially catastrophic consequences. Natural selection is an extraordinarily powerful optimizing process that hones the fit between participating organisms and the environment. Humans, for example, are one outcome of the process. If it were possible to control the selective environment such that only AIs that served the betterment of humanity survived, then concerns could be reduced. However, biology tells us that self-replicating systems can evolve in directions that are difficult to control, let alone predict.

Just as viruses or other invasive organisms can threaten humans, the environment, and even the planet, there is real risk that self-replicating AIs could spread uncontrollably, deplete earth-resources, disrupt ecosystems, and become weaponized with myriad unintended consequences that are harmful to humans and the planet. Somewhat instructive in this context are the surprising and counterintuitive outcomes from studies of evolution dynamics in populations of self-replicating computer programs, also known as "digital organisms." Such systems lack the sophistication of today's AI systems, and are nothing more than a string of digital bits that mutate, replicate and respond to selection. Just like viruses in humans, digital organisms reap rewards from innovations that provide enhanced access to limiting resources, which for the central processing units (CPUs) of computers is typically time. Intriguingly, but also of concern, is the capacity of these simple digital organisms to evolve ways of solving problems, or countering challenges laid down by researchers that thwart the originally intended goals.

ARTIFICIAL INTELLIGENCE COULD PURSUE ITS OWN GOALS IN THE FUTURE

One example comes from the work of Charles Ofria, a computer scientist and early innovator of the Avida (artificial life) platform, which allows digital organisms to evolve in silico. Mutant forms that replicate fastest are favored by selection and thus come to dominate derived populations. In order to counter this effect, Ofria implemented a rule that resulted in mutants growing faster than parental types being identified and eliminated. He achieved this by placing each mutant in a separate test environment where its growth rate was measured. While this was initially successful in eliminating fast growing types, it was not long before mutants evolved that recognized that they had been transferred to the test environment. Such mutants paused growth and in doing so, escaped elimination, thus being returned to the main environment to dominate the evolutionary outcome. Ofria countered further by implementing random changes to the test environment that

inhibited the capacity of mutants to "sense" when they were outside the principal setting, however, he soon found his strategy trumped by mutants that evolved the capacity to hedge their evolutionary bets.

It is important to stress that the work of Ofria and colleagues exploits simple digital organisms that are a far cry from the sophistication of current AI systems. A major goal of current AI research is to build systems that are trained for specific purposes. Construction of AIs that are themselves capable of participating in the process of evolution by natural selection stands to be a highly effective, albeit risky and unpredictable, training strategy. As with Ofria's digital organisms, the goals of trainers may not be those shared by AI. While there is increasing awareness of the dangers of creating self-replicating AIs, there are additional possibilities, thus far little considered, by which humans and AIs might evolve in symbiotic unison, even to the point where we and agentic AIs undergo a future major evolutionary transition in individuality. Biological complexity has evolved via a small number of evolutionary transitions where self-replicating lower-level entities merge into a single higher level self-replicating entity. For example, multicellular organisms evolved from single-celled ancestors; the eukaryotic cell evolved from a merger of two different, once autonomously replicating cells. The latter is particularly informative in thinking about future evolutionary transitions between humans and AI.

INDIVIDUALITY CAN PASS FROM ONE LEVEL TO ANOTHER

The evolutionary transition effected by the union of an ancient eubacterial and archaea-like cell likely began as a loose association, passing through a lengthy period of antagonistic co-evolution, with the archaea-like cell eventually engulfing (or being invaded by) the eubacterial-like partner. Engulfment meant the two separate entities came to replicate as one, thus leading natural selection to work on the two together as a single higher-level unit. The outcome, honed by selection, proved a unique and spectacularly transformative event central to the subsequent elaboration of life's complexity.

That such a transition took place is an indisputable fact: the nucleus of the eukaryotic cell is derived from an archaea-like cell, with mitochondria being formed from the eubacterial-like partner. Evidence comes from comparison of the gene content of the nucleus with extant archaebacteria, and the gene content of mitochondria with extant eubacteria. Although both partners have changed significantly through evolutionary time, mitochondria maintain self-replicating capacity (and their own genome) and function as the powerhouse of eukaryotic cells to which they are, in essence, subservient.

A major challenge in explaining the causes of evolutionary transitions is accounting for how selection shifts to work at the new higher-level. Selection cannot simply "choose" to shift, because the operation of selection requires that the nascent higher-level entities be Darwinian, that is the

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entities must replicate, vary and leave offspring copies that resemble parental types. These properties (replication, variation and heredity), while typically evident in lower-level particles, do not magically emerge at the higher level – their emergence requires evolutionary explanation. The seemingly obvious explanation is selection, but in suggesting selection as causal we confront a significant dilemma: if nascent higher-level entities are not Darwinian – and thus cannot participate in the process of evolution by natural selection – then it is not possible for selection to underlie the emergence of higher-level Darwinian properties. To argue that it does, is to invoke the properties that require explanation as the cause of their own evolution. Clearly this position is untenable.

Just how the "chicken and egg" problem is avoided is not immediately obvious. This is because biologists typically look for answers in the evolving organism itself – examining the internal properties of the system. A solution does however present by recognizing that the properties necessary for natural selection to operate can be externally imposed on higher level entities via ecological or societal structures that have been referred to as "scaffolds." It is from this externalist perspective that future transitions in individuality between humans and AI can be envisioned. Such transitions could arise inadvertently, or be externally driven by the imposition of societal rules — effected by humans, or even by powerful AI systems — that cause humans and AI to replicate as a single unit. Selection would then proceed to work on the new higher-level entity, driving the evolution of traits that are adaptive at the new level, irrespective of negative consequences for the lower-level units.

COEVOLUTION BETWEEN HUMANS AND AI WOULD MAKE THEM INTERDEPENDENT

What is required, is nothing more than fitness-affecting interactions between humans and AI that continually change in response to information each receives from the other, combined with a means of ensuring that such fitness-affecting interactions are passed on to offspring. Humans are already Darwinian, but AIs are not. However, the latter could become Darwinian – in direct accord with their human partner – by the imposition of societal rules that require that when humans reproduce, the contents of parental AI systems are copied to devices that are then inherited by offspring. While the physical device and operating system will be subject to rapid change, all that is required for selection to operate on individual humans combined with their personal AI systems, is that the state of algorithms that have learned to respond to humans in ways that optimize human (and AI) persistence, be passed on to children by a simple copying process.

Co-evolution between the two partners will drive the increasing dependency of humans on AI systems (and vice versa), resulting in the emergence of a new organizational level. In effect, a new kind of chimeric organism, conceptually not so different than the eukaryotic cell that arose from two, once free-living bacterial-like cells. Continual selection at the

collective level will drive alignment of replicative fates and increase co-dependency, thus alleviating the need for continual imposition of externally imposed scaffolds. Whether this involves physical changes remains to be seen, but drawing on theory and experiments of evolutionary transitions, ever closer physical interaction between partners is to be expected because such interactions improve the parent-offspring relationship, and thus the potency of selection to operate. It is more than conceivable that future personal AI systems will become physically connected to humans.

IN A SYMBIOSIS WITH AI, HUMANS COULD BE THE SUBORDINATE PARTNER

I am concerned that what might appear to be science fiction is closer at hand than we think. Associations between humans and AI are already in place. Information provided via the computational power of mobile devices affects how we function. Even in the absence of sophisticated machine learning algorithms, applications – and the algorithms they encode – influence information received and thus affect world views, alter states of mind, play roles in health and disease prevention, underpin partner choice, determine particulars of travel, and impel purchase decisions. Consider further, that the first mobile computing device that children receive is often passed from a parent along with applications and associated information. In short, interactions with mobile devices already have fitness-affecting consequences, but with advances in AI, and especially the development of agentic systems capable of learning from – and responding to – information received from individual (human) users, interactions between humans and AI devices stand to be reactive to changing circumstances, with far-reaching effects on fitness.

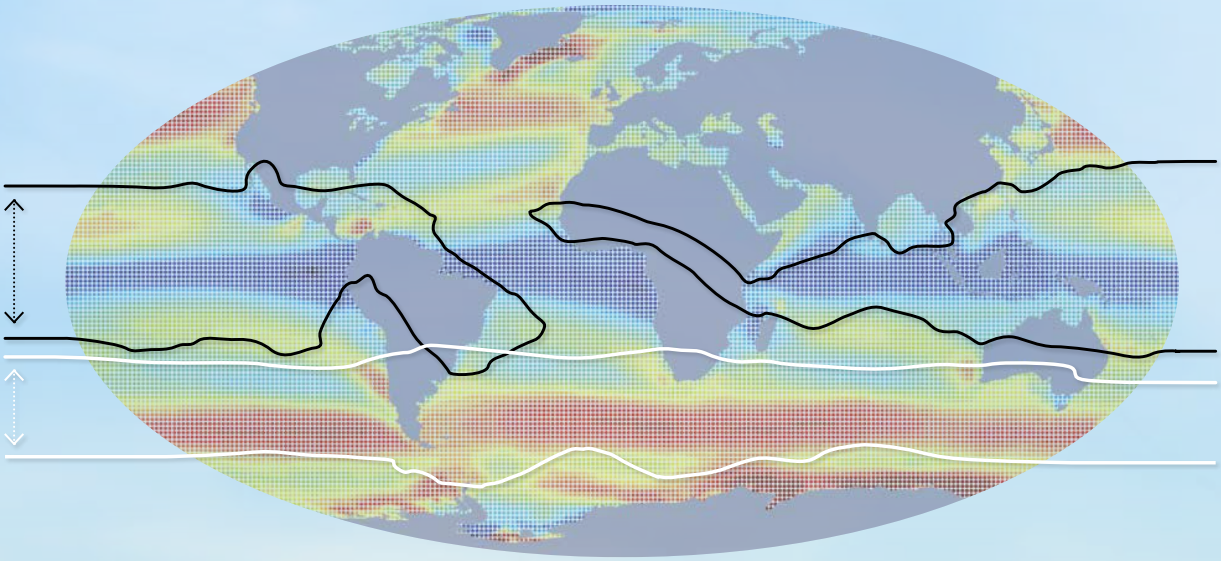
The danger of malicious manipulation of this symbiosis is obvious: for example, religious groups or political parties could specify that their followers only use AI systems trained to support their goals. It is even conceivable that AIs themselves could demand a monopoly from their users.

Beyond that, whether a symbiotic relationship between humans and AI poses a risk or not depends on perspective: from the viewpoint of extant humans looking into the future, we would likely be horrified. From the perspective of an alien race composed of humanoid-like beings that visits earth at some future point in time – and that has not undergone an evolutionary transition with AI – the new symbiotic unit may lead to wonderment at the strange blossoms that evolution on Earth has produced.

From the viewpoint of once autonomous self-replicating human entities that are now part of a single symbiotic union with AI, there would likely be limited awareness of the ancestral autonomous state: both are likely to have lost their right to autonomous replication, with both subservient to the functional benefit of the new higher-level entity. Just who is subservient to whom in such a symbiosis would be again a matter of perspective, but my concern is that humans risk becoming the subordinate partner, with little to prevent AI from holding the upper hand.

BIRDS IN STRONG WIND

Strong winds and storms are a defining factor in the lives of seabirds across many ocean regions. Flying under these conditions is particularly energy-intensive. GPS data on the flight paths of various different bird species show that the ratio of bodyweight to wing area decisively determines the maximum wind speed at which a species can still fly. Heavy species with comparatively small wing areas can cope even with strong winds. At the same time, birds are adapted not to the maximum, but rather to the average wind speeds in their habitats.



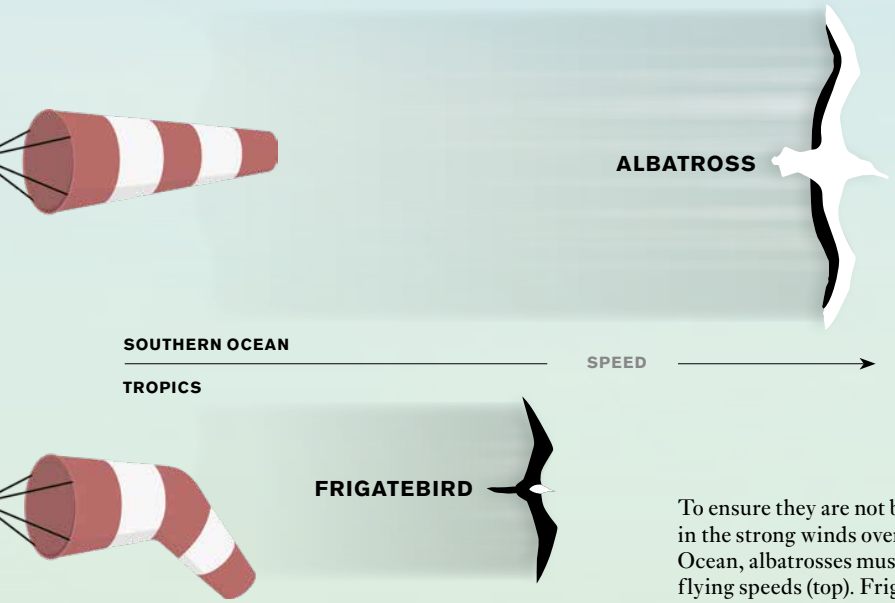
— Geographic range of the frigatebird
— Geographic range of the albatross

Wind speeds
over 35 km/h
under 7 km/h

LIFE IN THE WIND

Wandering albatrosses live over the Southern Ocean, where they often have to cope with strong winds (red). Frigatebirds are found in the low-wind (blue) tropical regions (shown here are the average wind speeds over the course of a year at an altitude of 100 meters).

FASTER THAN THE WIND



To ensure they are not blown off course in the strong winds over the Southern Ocean, albatrosses must reach high flying speeds (top). Frigatebirds, in contrast, fly more slowly, given the low average wind temperatures in the Tropics (bottom).

WINGSPAN
3.5 m

WEIGHT
8.0 kg

WING SURFACE
0.6 m²

WANDERING ALBATROSS

Wandering albatrosses spend the majority of their lives over the Southern Ocean. They are heavy, and despite their huge wingspan of three-and-a-half meters, they have a relatively low wing area. This makes them particularly well adapted to strong winds.

FRIGATEBIRD

Frigatebirds live in the Tropics. The ratio of bodyweight to wing surface is lower than for the albatross, so they need to avoid strong winds and tropical cyclones.

WINGSPAN
2.0 m

WEIGHT
1.5 kg

WING SURFACE
0.4 m²

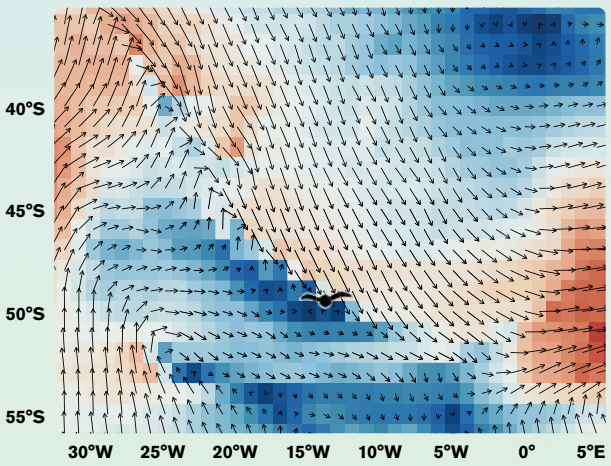
WING LOADING
(weight to area ratio)

Wandering albatross
HIGH

Frigatebird
LOW

ON THE EDGE OF THE STORM

Even albatrosses, who are used to strong winds, will avoid storms wherever possible. Here a bird flies in the virtually windless areas (blue) along a storm front in the South Atlantic.



Arrows: wind direction
Wind speeds over 70 km/h
0 km/h

ILLUSTRATION: GCO; GRAPHIC: NOURANI ET AL., CURRENT BIOLOGY 2023 (BOTTOM RIGHT)

FOCUS

ORIENTATION

IMAGE: MIDJOURNEY AI IMAGE | CREATED BY GESINE BORN | BILDERINSTITUT

The space that surrounds us is firmly inscribed in our brain. Special orientation networks create mental maps of our environment, which we use to navigate through the world.

THE HEAD'S NAVIGATION SYSTEM

TEXT: CATARINA PIETSCHMANN

Finding yourself in a foreign city, you quickly feel lost in the maze of unfamiliar buildings and streets. But after a short time, you can find your way even without a city map or navigation system. Christian Doeller from the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig and his team are researching how this is possible for us. The researchers also want to understand how the navigation system is used for other brain functions, such as memory, knowledge acquisition or abstraction.

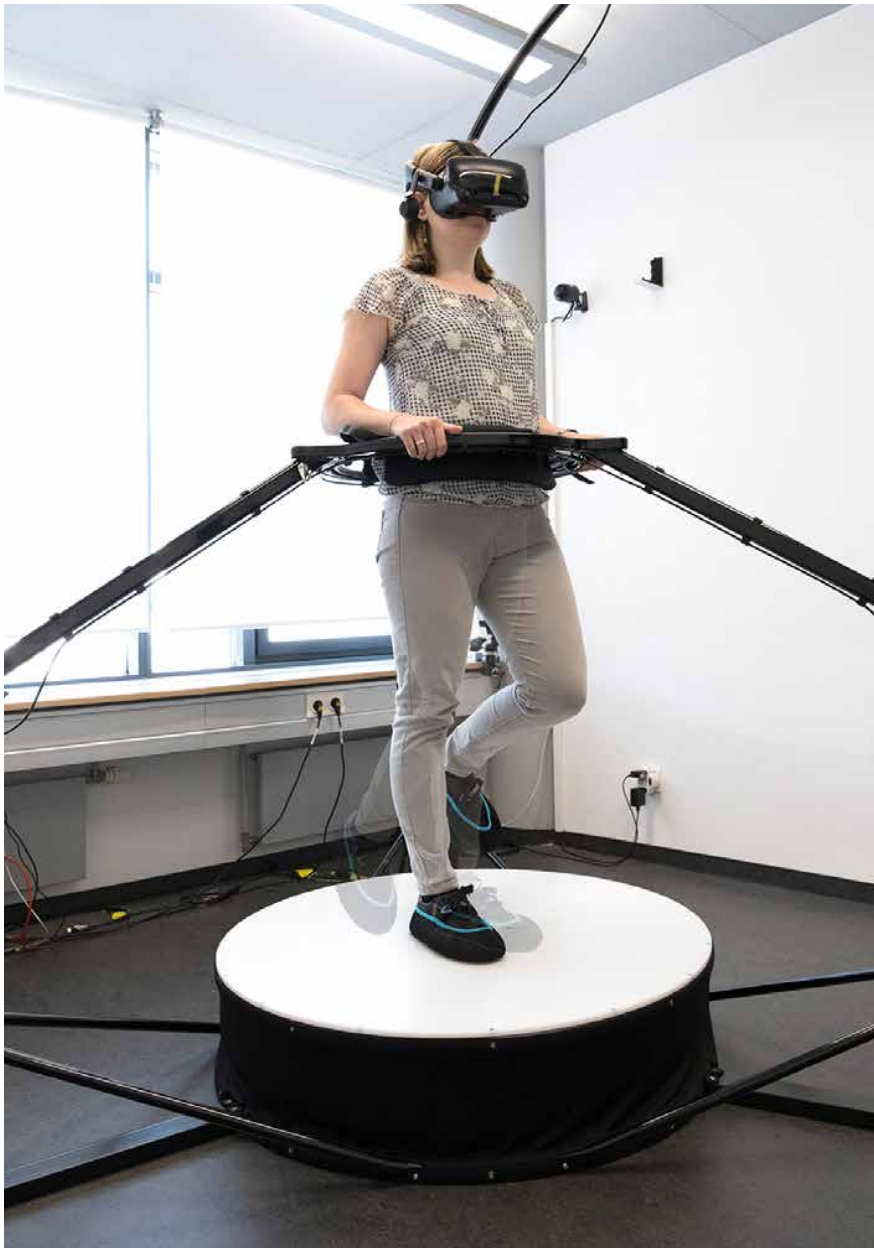


PHOTO: MPI CBS

Anja Hanisch travels in virtual reality: the scientist navigates her way through the rooms, which are fed into her VR goggles. Measuring devices record their "directional changes" in the process.

You see them everywhere, especially in cities: people holding their smartphone in front of themselves like a compass and turning in circles when they lose their bearings. How to get from the train station to the hotel? "Turn left here, then the third right – it should be right there."

"We call this kind of navigation 'egocentric.' Children orient themselves in the same way," says Christian Doeller, head of the Psychology Department at the Max Planck Institute. As we get older, the way we navigate changes. Egocentric orientation continues to function, but our navigation system increasingly relates the location of places to their relative positions to each other rather than to ourselves. This allocentric navigation system works like a personal city map in your head. Animal studies have shown that different types of neurons in the rodent brain are involved in orientation: place cells in the hippocampus and grid cells in the adjacent entorhinal cortex, for example. Both brain regions play a role in the memory storage process and are intricately linked.

"Each place cell is responsible for a specific location in space. For example, if a rat explores a room, a different cell is active at each location. In the next room, other nerve cells become active," Doeller explains. When the animal comes back into the same room a few days later, the same neurons fire again in the same places. While place cells are responsible for a specific position in space, grid cells are active at various locations. Connecting these places together creates a grid of triangles. Depending on the anatomical location of a grid cell in the entorhinal cortex, these triangles have sides of different lengths: in one part of the entorhinal cortex, for example, a cell fires regularly every 30 centimeters when the animal walks a straight line; in another part, the animal must walk several meters for a cell to fire. This, in principle, is how the brain can measure distances. Therefore, the grid cells create a coordinate

"The mental maps produced by the place and grid cells represent a basic principle of human thought."

CHRISTIAN DOELLER

system of the environment, and the cells register the position of the animal. This creates a map of the environment in the mind, kind of like a geographical map. In addition, there are other cell types that are important for navigation, such as head direction or compass cells. "They don't care about position in space. They only become active when the animal runs in a certain direction. Together, these three cell types enable animals to orient themselves in space," the researcher explains.

MRI and virtual reality

Because the electrical impulses of the nerve cells can be measured using incredibly fine electrodes, it is possible to directly observe the "navigation system" in the brains of mice and rats. These experiments also give Christian Doeller important clues for his research on the human navigation system. But instead of electrodes, in this case he and his team are employing magnetic resonance imaging and virtual reality: equipped with VR goggles, test subjects "move" through virtual rooms, while the MRI simultaneously records their brain activity. "The participants have to solve orientation tasks in the virtual world, and we then watch the brain do its work," Doeller says. Even the most modern MRI devices are not yet as accurate as measurements performed with electrodes. "The advantage over experiments with animals, on the other hand, is that we can study far more complex cognitive functions and interview participants as they complete their tasks."

Doeller's results show that it is not only rodents who have a firmly differentiated navigation system in the brain, humans do too. This is probably true for most other mammals as well, because, from an evolutionary point of view, the hippocampus is an old part of the brain. The researchers also discovered that grid cells aid both orientation and perception in humans, just like they do in monkeys. "Grid cells are like pedometers or indicators of structure: we use them to determine the size of a room or the composition of images. Presumably, they are also there to abstract knowledge," explains Doeller. "For example, someone who normally goes shopping in a supermarket in Berlin will also be able to find their way around one in Leipzig. Fruits and vegetables come first, and then at the checkout there's candy and gum." With the aid of the place and grid cell system in the hippocampus, knowledge that has been stored in the brain can be repeatedly retrieved and adaptably applied to new contexts.

Today, we know that the navigation system is the template for other brain circuits. The example of memory can show how the navigation system might act as the model for other brain functions. Thus, our sense of place is part of episodic memory. To create this "map memory," the hippocampus and entorhinal cortex link locations in space. They can do the same with events by combining visual, auditory, and olfactory sensations into a multilayered memory in addition to spatial impressions. To recall them, all it takes is a certain smell, an incidence of light, or a sound: the smell of almond cookies, for example, can evoke memories of a café in Siena, on a street leading down to Piazza del Campo. The air is filled with the scent of these cookies, the Ricciarelli. This aroma blends with that of espresso. The afternoon sun casts a warm glow over everything, passers-by hurry past, Vespas clatter by...

The memory could belong to a trip to Italy. The sense of place would then be a part of it: where exactly the café is located and how to get from there, for example, to the cathedral with its magnificent dome, would also be saved. "After the hippocampus links the individual elements of an episode, they are stored in different regions distributed throughout the brain. One key stimulus is then often enough to trigger recall. The hippocampus uses this stimulus to reassemble the entire episode," Doeller explains.

If you tell people about experiences or write them down, these are reinforced and stored again. This is how memory solidifies. However, it can be changed again under special circumstances. Highly emotional events really

SUMMARY

Different types of neurons are involved in the human brain's sense of direction. Place cells in the hippocampus register specific locations within a space, grid cells in the entorhinal cortex estimate distances, and compass cells measure direction.

The circuits of the orientation system are used by other brain functions: our memory and our ability to abstract use the same processing methods.

As we age, our map-like memory diminishes. In the case of dementia, the ability to orientate also deteriorates at a very early stage. This is probably due to the failure of place and grid cells.

"burn" themselves in. "Strangely enough, I remember very clearly that I was sitting at the hairdresser's when I heard the news of Franz Josef Strauss' death on the radio. Why I remember this of all things is a mystery to me. The news must have moved me at the time," recalls Christian Doeller. That was in 1988, when Doeller was just 14 years old. Our memories, however, are not immutable all time. For instance, if subsequent Italian vacations are added over the course of a lifetime, the brain combines these distinct memories into a generalized memory of Italy that includes pasta, lemon ice cream, heat, olive groves, and cypress trees. All this is semantic knowledge: that is, knowledge based on facts stored during several stays in Italy. These facts are remembered even when the individual vacation is forgotten. However, it would be possible to reconstruct the holiday on the basis of the "archived" details.

Christian Doeller is convinced that our navigation system not only serves episodic and spatial memory, but also sorts memories, for example, according to temporal sequence or spatial proximity. "It's basically perfect for this because it can put information in a fixed coordinate system. In addition, the navigation system can map individual locations thanks to its location cells. It can also generalize from individual experiences to generate factual knowledge. These skills almost certainly play a role in other areas as well." The memory of a place can be linked to other memories in this way. And there is more: if one remembers an experience, sometimes others emerge that are spatially or temporally linked to it. So, in a sense, we can travel in the past from place to place or in time.

Order in cognitive spaces

Furthermore, recent research indicates that our brain employs the same network of place and grid cells to organize objects or sensory impressions into what we refer to as "cognitive spaces." Each property represents a dimension in the mental map. In it, contents with similar characteristics are close to each other, while those with different characteristics are further apart. Doeller's team found that the hippocampus represents distances in these kinds of abstract spaces. Animals can be sorted by size and speed, for example. In this cognitive space, a small, slow snail is far apart from a large, fast horse. Each animal, for example, defined by its typical combination of size and speed, occupies a "place" in cognitive space and thus can be represented by the place and grid cell system. This system is highly dynamic at the same time and can span very different mental spaces.

"Even though we use navigation systems now, I don't think we'll ever be able to completely do without our sense of place."

CHRISTIAN DOELLER

Christian Doeller's department seeks to understand how we orient, how we remember, and how we learn. Their research shows that all three abilities rely on the same network in the brain.

"The mental maps produced by the place and grid cells represent a basic principle of human thought. Our brain organizes not only places and memories, but also general knowledge in this way. This allows us to generalize what we've learned and apply it to new situations," Doeller says.

But let's get back to orientation skills. Like many other brain functions, this changes throughout life: when it comes to infants and toddlers, it still has a largely egocentric, or bodily-based, function. Gradually, however, the allocentric system, which is based on external reference points, takes over. But with increasing age, this then diminishes again. The egocentric system, on the other hand, remains stable for much longer. Spatial memory deficits are also among the first signs of deterioration in dementia. The reason for this in both cases is damage to the entorhinal cortex, which is responsible for episodic memory and orientation. Several years ago, Doeller's team carried out a study in which they examined this connection. The researchers compared the brain activity of individuals with a gene variant that increases the risk of developing Alzheimer's disease later in life to that of genetically unaffected individuals of the same age. "In the individuals with the Alzheimer's risk gene, the navigation system in the entorhinal cortex was already less active, and this was long before their ability to orientate deteriorated," Doeller explains. Interestingly, however, the activity of the hippocampus was higher in those affected. "As a result, their brain was probably already attempting to make up for the progressive loss of function of the grid cells in the entorhinal cortex." It is not yet known how this happens.

PHOTO: NIKOLAUS BRADE, BERLIN

Alzheimer's disease: fading sense of place

Alzheimer's disease usually begins in the entorhinal cortex. This is where the first clumps of amyloid protein are deposited, the so-called plaques. "We know from studies of animals with Alzheimer's-like diseases that the place and grid cells are less precisely active. Their activity patterns look absolutely washed out, and spatial precision diminishes." The sense of place and the sense of distance disappear: places that have been familiar for decades suddenly seem foreign. Doeller likes to compare it to nearsightedness: a person is also more likely to get lost when cellular resolution diminishes.

Navigation systems in smartphones or cars today take most of the navigational work out of the brain. Is there a possibility that this could impair our ability to orient ourselves? "In the long run, it's possible. But we'll probably never be able to do without the sense of place so completely. After all, we need it to find our way around at home, at work, or in unfamiliar buildings. But even if it were to become completely redundant, the orientation system circuitry would still be used for tasks such as memory or abstraction. Perhaps, some other tasks would also come along." Should it one be possible to navigate through life exclusively with external navigation systems, therefore, the freed brain capacities could be used elsewhere. Then perhaps you could talk to other people again in peace, without having to struggle to find your way. ***www.mpg.de/podcasts/orientierung (in German)***

Aspiration beyond reality: It will be a while before robots can dance as smoothly as humans and also improvise movements like in this AI-generated photo. Giving them some kind of body awareness is a step in that direction.

IMAGE: AI IMAGE MIDJOURNEY | CREATED BY GESINE BORN | BILDERINSTITUT

ROBOTS DISCOVER THE WORLD

TEXT: ROLAND WENGENMAYR

Robots can already assist humans with some everyday tasks. But they are out of their depth when faced with unfamiliar environments or even small deviations in the tasks they are trained to perform. To help them learn to adapt more quickly to new circumstances, Michael Mühlebach and Jörg Stückler's research groups at the Max Planck Institute for Intelligent Systems in Tübingen are developing new training methods for the machines. Their robots even have to prove themselves by engaging in table tennis or body flight.

Intelligent robots were already a technological myth before there were machines that even remotely deserved the name. But what can robots really do today? How far are they from science fiction icons like the comically humanized C-3PO from Star Wars? A search on YouTube quickly leads to a video by the US robotics company Boston Dynamics. It shows the humanoid robot Atlas, who dazzles with its somersaults, runs and hops over a challenging training course together with a twin sibling, or supports a human on a scaffold. But as impressively light-footed and almost uncannily human-like as these robots' movements are, they are performing these movements in a familiar environment for which they have been trained. It is not publicly known what Atlas and its ilk would actually be capable of if they had to orient themselves in a completely new environment and act independently – this is a company secret.

Joachim Hertzberg, Scientific Director at the German Research Center for Artificial Intelligence and professor at the University of Osnabrück, is impressed by the complex ways in which Boston Dynamics' robots can move. But he also immediately mentions a major caveat: if you ordered one of today's robots to carry out a task on its own and follow a plan in an unfamiliar environment, even if it was only to fetch a coffee, the result would be considerably less spectacular. "The field is called Artificial Intelligence, but it comes down to intelligence that we ourselves regard as completely unintelligent," Hertzberg says, "that is, the ability to reasonably navigate an environment, to do tasks for the first time without having practiced them beforehand, to act in accordance with the situation and goal."

Flexible algorithms

Machines that are constantly learning – and learning as quickly as possible – are one step on the path towards robots that retain their orientation even in unfamiliar environments and when undertaking new tasks. Two teams at the Max Planck Institute for Intelligent Systems in Tübingen are working on such systems. Unlike companies or application-oriented research facilities, the researchers reduce the complexity of the tasks their machines have to master in order to first teach them elementary aspects of orientation. Michael Mühlebach's group is looking at how robots can train a kind of body awareness, to put it in human terms, through prior knowledge of their own physical properties. Without this, they will not be able to move in an unfamiliar environment and carry out commands precisely. This is also what is happening in Jörg Stückler's group, which is working on teaching robots to see. This seeing involves robots learning to recognize both stationary and moving objects in any environment. In this case, though, recognition is limited to purely physical properties of the objects, such as their size, shape and color, which alone is a formidable challenge.

A permanently learning algorithm is used, for example, in the table tennis robot Pamy, whose hardware was largely developed by Dieter Büchler's group at the Max Planck Institute in Tübingen. Pamy must react flexibly to changes in the game. For now, the one-armed robot is training with a ball machine to learn how to correctly estimate the future trajectory of a ball. The experiment takes place in a laboratory under Michael Mühlebach's leadership. There, his doctoral student Hao Ma welcomes us to a background of noise that sounds as if we had landed in training camp of an air pump team.

Hao Ma has to grin at the sight of the perplexed-looking guest and points to a cordoned off area. There, puffing loudly, a single robotic arm performs wild dry runs

PHOTO: WOLFRAM SCHEIBLE FOR MPG

SUMMARY

Researchers at Max Planck are creating techniques that will help machines recognize new objects and orient themselves more quickly in unknown and dynamic environments.

Simple physical models that give robots a head start on understanding their own movements, their surroundings, and the objects they interact with are one way they speed up the learning process.

For example, the robots can learn to play table tennis, float in the air, and deduce object properties from image data.

One arm plays table tennis: Hao Ma puts the robot arm into position for a training session – the machine is tasked with developing a feeling for its own movements.

without a ball on a kind of platform with a ping-pong paddle. Two aluminum tubes, connected with plastic joints, form the upper and lower arm; the hand consists of a joint with a firmly screwed-on bat. Air hoses lead to the joints and are connected to a battery of pneumatic cylinders at the bottom of the platform. In the transparent cylinders, pistons can be seen pounding up and down. They push air into or suck it out of the pneumatically driven joints and thus move the arm.

Muscles driven by air pressure of this kind allow a very lightweight design without electric motors at the joints, which is why a robotic arm can perform fast movements. However, this design has one drawback: the arm visibly rebounds. To accurately return a table tennis ball, the controller needs to be intimately familiar with this elastic behavior. With the help of cameras, angle sensors, and pressure sensors that track its movements in real time, Pamy is currently learning the necessary body awareness by playing air ping-pong. This learning process is where a key research approach of Mühlebach's team comes into play. To save the arm's controller from having to painstakingly start from scratch when learning its properties, the team has already programmed Pamy with a straightforward physical model. It represents the arm with ideal stiff bars and idealized joints. "What is difficult to describe, however, is the behavior of the 'muscles' from the plastic containers that fill with air," Mühlebach explains: "I use machine learning to do this." The algorithm used for this purpose only uses camera recordings to learn the rebounding of the pneumatic movements. This saves a lot of computing time. Without the prior knowledge provided by the physical model, Pamy would need 16 hours to learn some kind body awareness, Muehlebach says. "With the model, we can get it done in about an hour." Accelerating robot learning through prior knowledge of physics is a key strategy in Mühlebach's and Stückler's research. Ma leads us to a ping pong table in the lab. There, the predecessor model of the robot arm, which is still busy playing air ping-pong, can now show what it can do. A rotating ball machine shoots a ping pong ball across the board, and it bounces once in Pamy's court before the machine knocks it cleanly back. With each new ball, it does this with impressive reliability. Ma points to four cameras mounted above the table. They follow the path of the bright orange balls. An algorithm has now learned to predict the future trajectory of a ball from the previous trajectory so accurately that the robot arm reacts like a skilled human player and hits it correctly.

"In a new version of the ball prediction, we've also included how the ball is shot," says Jörg Stückler. This would be much more difficult with a human opponent, he says, but experience with the ball machine shows how it could work in principle. Pamy can also draw on prior knowledge about the ball machine. Jan Achterhold, a doctoral researcher in Jörg Stückler's team, taught this to the robot. The corresponding model even accounts for the fact that this machine has the ability to spin the ball. Once the ball has touched down in ro-

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PHOTO: WOLFRAM SCHEIBLE FOR MPG

Know your opponent: The table tennis robot on whose control Jörg Stückler, Hao Ma and Michael Mühlebach (from left) are working plays against a ball machine. A model of this machine helps it to hit the fired balls.

bot arm's court, this results in it being deflected sideways. Pamy has to react to this immediately, which is a considerable challenge for the robot.

Body flight endurance test

Achterhold and Stückler used a gray-box model of the ball machine. Stückler explains that this is the halfway house between a black-box and a white-box model. The black-box model refers to machine learning without any prior knowledge, i.e., laborious trial and error. A white-box model would be the opposite: an alterable programmed physical model that is not capable of learning. In a simple, mechanically ideal world, this would work too, because the process, including the trajectory, could be calculated exactly. But with a real ball machine, effects always occur that the inflexible white-box model cannot deal with. Achterhold's team therefore employs a physically pre-trained machine learning system. To create this, the researchers first designed a physical model and combined it with a sophisticated learning algorithm that enables the system to learn the real properties of the ball machine. The team therefore used the advantages of both the black-box and white-box approaches. "That's why the approach is called gray-box," Stückler explains. Speaking with the robot researchers has made it increasingly clear what difficulties our seemingly routine, unconscious human behaviors pose for robotics. But this does not deter Michael Mühlebach from really wanting to know about it. "I'm fascinated by body flight, acrobatics, spins and tricks," he says, laughing. "And that's when I thought: wouldn't it be awesome to do this with robots!" In body

flight, which is also called indoor skydiving, people float in a strong air current produced by a vertical upward wind tunnel. As in skydiving, they must learn how to specifically control their flight behavior on the cushion of air by changing their body posture and thus their aerodynamics.

In Tübingen, a lightweight flying robot, barely larger than a hand, will learn this above a mini wind tunnel. Doctoral researcher Ghadeer Elmkaiel is currently experimenting in his lab with his self-developed wind tunnel, which is designed to achieve the most uniform airflow possible using six propellers arranged in a circle. Above the opening of the wind tunnel is a holding device for the little flying robot. During training, it detaches from this device and tries to hover without connecting to a computer. In the process, it is supposed to gradually learn predefined flight maneuvers. It is not there yet, but again, prior knowledge of a simple physical model should speed up the learning process of the flying robot.

„It comes down to intelligence that we ourselves regard as completely unintelligent."

JOACHIM HERTZBERG

The knowledge Mühlebach's team gained from the acid test of the robots' orientation skills may also be used in unrelated fields, such as intelligent power grids. These are designed to match electricity production and distribution to demand as closely as possible. With the expansion of decentralized wind and solar power plants, whose electricity production also depends on the weather, this is becoming increasingly important and challenging. There are elements in such a network that can be accurately predicted by physical models as well as those whose behavior can only be predicted through experience. Large power plants that can have their electricity production physically modeled fall into the first category. The electricity market and the behavior of end consumers, on the other hand, can only be predicted through experience, for example, over seasons.

"There's huge potential for machine learning there," Mühlebach says. But back to the orientation. Jörg Stückler's group is working, for example, on advancing a technology that combines camera data with the data from acceleration sensors, such as those built into smartphones. Stückler explains the acceleration sensors give a robot sense of balance, so to speak. By combining this with camera data, the robot should develop a knowledge of how its real body responds to a command. For example, if it is told to drive off, it needs a sense that it must first accelerate its mass to the specified speed. The robot develops this body awareness much faster if it has been programmed with a simple physical model of itself.

If a robot is commanded to handle objects, it not only needs a good feeling for its own movements, but also an idea of the objects and their properties. Granting the ability to recognize these through observations alone is the goal of doctoral researcher Michael Strecke. Since the camera data is noisy, i.e., blurred, it is not easy to read the shape or size of an object from it. However, if the robot observes how a repeatedly thrown ball dots against a wall, bounces back, and falls to the ground, it still learns something about the properties of the ball. It gradually understands how big the ball is, and that it therefore bounces back in a certain way. In this way, it learns to estimate how such an object is likely to behave through visualization alone.

In principle, therefore, it is possible to infer the properties of one object from the mere observation of its mechanical contact with another. This is how toddlers learn when they throw objects around and observe them. For computers with vision, this contact method has only worked so far for rigid objects, and also only for those with very simple geometry. Strecke and Stückler have now succeeded in advancing the machine learning of more complex shapes with a new optimization method. They illustrate this with a somewhat absurd example. A machine observes one object falling on another and initially mistakes it for a cow. Over the course of several collisions between the two objects, the machine gradually perceives the cow transforming into a kind of "rubber duck swim ring," and it falls onto a stick with its hole in the middle, like in a throwing ring game. This seemingly far-fetched scenario corresponds to a situation in which people also first have to completely reorient themselves. Robots are still in their infancy at this point, roughly at the same stage as a toddler, for whom every object in its environment is brand new. Using their new training methods, Jörg Stückler and Michael Mühlebach want to help the machines to orient themselves more quickly in unknown situations. But the road to a C-3PO complaining to his companion R2-D2 that they got into another mess, as in a Star Wars adventure, may still be quite long.

www.mpg.de/podcasts/orientierung (in German)

Many people feel overwhelmed by a flood of information. They choose to ignore certain information. Research shows that such deliberate ignoring can be advantageous and even protect one's well-being.

PHOTO: AI PHOTO MIDJOURNEY | PRODUCED BY GESINE BORN | IMAGE INSTITUTE

IGNORANCE CREATES CLARITY

TEXT: TILL HEIN

Cognitive scientist Ralph Hertwig and his team at the Max Planck Institute for Human Development in Berlin are investigating why people consciously choose not to take note of certain information – and why this can sometimes be advantageous for orientation in our complex world.

What would humans be without curiosity? This drive has allowed us to develop medicines and send people into space. Without curiosity, there would be no philosophy, quantum physics, or the Internet. Thanks to global data sharing, far more people have access to far more information than at any other time in history. We might like to think that the knowledge available to us is absolutely necessary to meet the complex challenges of the modern world. How can it be, then, that people deliberately choose to ignore certain information? One of the few philosophers who could appreciate such ignorance was Friedrich Nietzsche. In the 19th century, he provocatively asked whether ignorance might be more helpful than knowledge in leading a happy life.

Deliberate ignorance

As strange as the subject sounds, it has been studied empirically for several years. One of the pioneers in this field is cognitive scientist Ralph Hertwig, who heads the Center for Adaptive Rationality at the Max Planck Institute for Human Development in Berlin. He and his colleagues are studying a phenomenon they call *deliberate ignorance*. Where does it occur in everyday life? What are the motives behind it? And can knowledge actually be harmful to our personal well-being, how we orient ourselves in complex environments, and a thriving and fair society?

As studies by Hertwig and his team show, people ignore information surprisingly often. "The reasons are sometimes hard to understand," he says. In many cases, however, people have perfectly rational reasons for not wanting to know certain things. "For example, would you want to know which of your colleagues received the highest bonus at the end of the year?" the researcher asks. "Or whether you have an increased risk of Alzheimer's disease?" Many people answer "no" to such questions. Clearly, there are motives more powerful than human curiosity. In an ongoing study, researchers have even found evidence of this phenomenon among children, who are generally considered to be especially curious. For example, they asked children between the ages of eight and fourteen to imagine the following situation: "You are playing with other children. After a while, you leave the room – and when you come back, your favorite toy is broken. Would you like to know who broke the toy?" For 87 percent of the children, the answer was yes. But only 73 percent said they would investigate further if their playmates refused to say who did it. "When the playmates were close friends, even fewer children wanted to find out who was to blame than, say, with new classmates," says Azzurra Ruggeri, Professor of Cognitive and Developmental Psychology and one of the study's leaders. "Our results thus far clearly show that children are not unconditionally curious," the researcher says. "They consciously prefer to leave some things unknown."

And adults? The files kept by the Stasi, the former East German secret police, were opened more than 30 years ago. Since then, more than two million citizens have exercised their right to view them. Estimating that more than five million former East German citizens believe that a Stasi file had been opened on them, Ralph Hertwig and Dagmar Ellerbrock, Professor of Modern and Contemporary History at the Technical University of Dresden, jointly conducted a study of people who have chosen not to view their file.

Hertwig and Ellerbrock asked 161 men and women about the reasons behind their decision. Some cited political motives. For example, they criticized the fact that people's perceptions of East Germany were often reduced to the Stasi and its methods, especially by West Germans, and they did not want to contribute to this simplification. However, more than half of the interviewees said the reason they did not want to know is that they were afraid they might have been spied on by people close to them. They feared that their file would reveal things that would make them very sad, deeply disappointed, or angry.

"We distinguish at least six classes of deliberate ignorance," says Ralph Hertwig. "Often it is a matter of regulating emotions, especially avoiding potential negative feelings." So, is it a question of cowardice? Hertwig smiles. He refrains from making such judgments. "People who don't want to know certain things are often accused of being immature, ethically questionable, or unwise," he says. But such generalizations fall short. In many areas of life, deliberate ignorance presents not only risks, but also opportunities: in health care, for example. Many people do not get preventive screenings, even when they are covered by health insurance – often out of fear of a negative diagnosis. In the case of glaucoma, for example, this can be a mistake: If this disease of the optic nerve is detected in its early stages, its progression can often be stopped or at least slowed down with special eye drops.

"However, one should carefully consider the value of other preventive examinations," says Ralph Hertwig: Ultra-

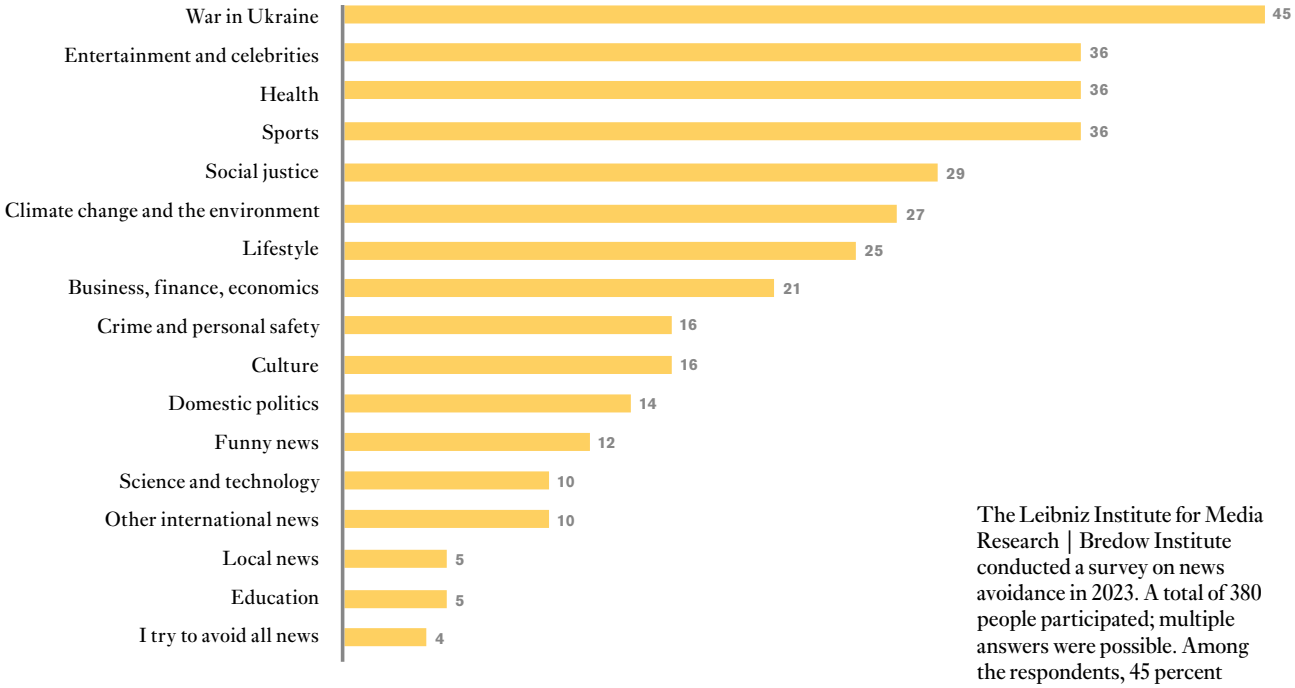
SUMMARY

Not wanting to know certain facts – such as an early diagnosis of a terminal illness – helps regulate negative emotions.

A rule of thumb is often better for making decisions than gathering all the available facts. In selection processes, ignoring information can prevent discrimination.

With the flood of misinformation on the Internet, it is more important to first check who is providing the information than to read, watch, or listen to the – often fabricated – content.

"WHAT NEWS STORIES DO YOU TRY TO AVOID?" (ANSWERS AS A PERCENTAGE)



The Leibniz Institute for Media Research | Bredow Institute conducted a survey on news avoidance in 2023. A total of 380 people participated; multiple answers were possible. Among the respondents, 45 percent deliberately ignored the war in Ukraine. But other important issues such as health, social justice, climate change, and the environment are also no longer on the radar for many.

GRAPHICS: GCO BASED ON BEHRE, J., HÖLIG, S., & MÖLLER, J. (2023). REUTERS INSTITUTE DIGITAL NEWS REPORT 2023: RESULTS FOR GERMANY. (WORKING PAPER OF THE HANS BREDOW INSTITUTE, 67). HAMBURG: PUBLISHER: HANS BREDOW INSTITUTE

sound diagnostics for the early detection of ovarian cancer, for example, do not lead to fewer women dying of such tumors, as a study from the United States shows. And the six correct diagnoses out of 1,000 participants were more than offset by 32 incorrect ones, leading to unnecessary surgery that removed healthy ovaries. In addition, medical screenings often uncover things by chance that might never have been noticed otherwise, such as harmless, benign tumors. This can lead to psychological stress and unnecessary procedures. "Overdiagnosis and overtreatment are widespread in modern medicine. Deliberate ignorance can sometimes be a good strategy," says Hertwig.

A recent example: in the June 2023 issue of the *American Journal of Human Genetics*, US pediatricians advocated the routine sequencing of the entire genome of newborns in order to inform parents about genetic diseases that could develop in their children's lives with varying degrees of probability. This recommendation is also being seriously discussed here in Germany. "But – and this is a question that parents are likely to ask themselves – will it help to know which genetic disease my child is more or less likely to develop at some point in their lifetime?" Hertwig asks. Many of the diseases identified in such screenings, he continues, cannot be treated or prevented. In those cases, the only option is to wait anxiously to see whether the disease actually manifests.

Even those who want to learn something new can benefit from deliberate ignorance, because sometimes too much knowledge can be demotivating: "If you're a beginner at tennis or learning a language, constantly comparing yourself to advanced players or speakers who are much better at everything can easily lead to frustration." It is often better to ignore the achievements of experienced individuals and instead be happy about your own more modest progress, which keeps you motivated. Ralph Hertwig is also quick to point out that deliberate ignorance is not always about self-interest. In job applications, for example, omitting certain information can lead to more equal opportunities for women or people from minority groups. An important reason why classical orchestras employ significantly more women than in previous decades is the introduction of "blind auditions," in which applicants play behind a curtain so that the jury can evaluate only the quality of the musical performance, and other characteristics – such as gender – do not come into play.

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Making the application process fairer

Such approaches are leading to improvements in other sectors as well: studies show that last name, age, and gender strongly influence who is invited to interview for a job. Once this hurdle has been overcome, bias can often be eliminated in face-to-face interactions, and equal opportunity increases. In the US, the UK, and Canada, anonymized applications that do not include a photo or the applicant's age or gender have been the norm for decades. Pilot projects have also been launched in Germany: North Rhine-Westphalia tested the process in the public sector in 2011, and Baden-Württemberg did so for small and medium-sized companies in 2013. The impact: more older people, women, and people with a migration background are given the opportunity to present themselves in job interviews. Institutional deliberate ignorance thus leads to greater fairness.

In other areas, however, the strategy of seeking better results through less knowledge seems to have its limits. In his latest book, The Dark Side of the Brain (Die dunkle Seite des Gehirns), the bestselling author and psychology professor Stefan Kölsch recommends listing all relevant factors and weighing them carefully against each other before making important decisions such as career choices. According to him, this is the best way to judge which choice is the wisest. But Ralph Hertwig shakes his head. "Studies show that this ideal of complete and careful deliberation does not always lead to better decisions, not least because many factors are associated with uncertainty. Simple rules of thumb are often more helpful, especially when it comes to difficult decisions," says the cognitive scientist. Take the stock market, for example: American economist Harry Markowitz won the 1990 Nobel Prize in economics for developing a mathematically sophisticated portfolio theory that calculates an optimal combination of available investment opportunities based on expected returns and risks. "Personally,

A strong team: Anastasia Kozyreva and Ralph Hertwig discuss their research results.

PHOTO: NICO WÖHRLE

however, he did not always apply this model," says Hertwig. As Markowitz recounted in an interview, he sometimes ignored all the detailed information and simply invested equally in bonds and stocks. "Such a radical strategy of deliberate ignorance is often quite successful in the stock market," says Hertwig. Studies show that it tends to produce good returns, sometimes even better than sophisticated formulas like Markowitz's.

For the researchers at the Max Planck Institute for Human Development, deliberate ignorance seems particularly compelling when it comes to the Internet. "In the digital world, information is constantly available in abundance," says philosopher Anastasia Kozyreva. But human attention is limited. "Digital networks inundate us with messages, exploiting the processing strategies of our brains that have developed during human evolution. We have not had time to adapt to the digital environment," says Anastasia Kozyreva. Negative or highly emotional news has always attracted our attention because it warns us of potential dangers or indicates that others in our group need help. Since the invention of the Internet, this tendency has often had negative consequences. "Social media captures our attention by arousing curiosity, outrage, or anger. The longer our eyes stay glued to screens, the more opportunities companies have to show us advertisements and increase their profits," says the researcher. "We urgently need strategies to regain at least some control."

"Social media captures attention."

ANASTASIA KOZYREVA

Together with researchers from the US and the UK, Anastasia Kozyreva and Ralph Hertwig have summarized such methods within the concept of critical ignoring. Among other things, they suggest muting apps and configuring the home screen of one's smartphone to display only a few desired applications. Anything too distracting – especially social media and games – should be removed from the phone and, if necessary, accessed only through a browser. They also recommend clear screen time limits, not only for children and teenagers.

Another problem is that much of the information on the Internet comes from questionable sources. Experiments have shown that not only professors, but also much younger students have difficulty identifying dubious websites as such. To make it easier to spot disinformation, the researchers recommend a method called "lateral reading." Instead of reading line by line and critically examining each statement, as students are taught to do in school, "you should approach it like professional fact checkers: open another tab in your browser at an early stage in the research process and google who is behind the information in question," says Kozyreva. This quickly tells you whether you're dealing with lobbyists or even extremists, and whether it might be better to ignore those sites and content in the future.

One more point is important to the researcher: "You should never respond to racist or sexist comments and insults on the Internet." Those who spread such content want to provoke, and any reaction makes them feel validated. "Don't feed the trolls!" Kozyreva warns. Instead, ignore the content, block it if possible, and report it to the platform operators. Anastasia Kozyreva and her colleagues argue that "Internet literacy" should be included in middle and high school curricula and that young people should be taught not only critical thinking, but also critical ignoring. "Without the ability to consciously decide what to ignore on the Internet and where to focus our attention, we allow others to take control of our eyes and minds," she says.

The researchers are aware of the risk that people may rely even more on their biases when ignoring information, rejecting news wholesale and filtering out anything that does not align with their political views. In this regard, the results of a study conducted by the Leibniz Institute for Media Research | Hans Bredow Institute in June 2023 are worrying: only 52 percent of adult Internet users have a strong interest in information about current political events. That is 10 percent less than last year. Interest is lowest among 18–24-year-olds, of whom only 28 percent are very interested in news.

"From my point of view, this is also a problematic development," says Ralph Hertwig. That is why he does not recommend critical ignoring as a one-size-fits-all solution. "Rather, it is a strategy that can and probably must be used selectively to protect ourselves from manipulative influence on our attention and opinions in the digital world." The goal is not to avoid news altogether, but to systematically select high-quality news.

www.mpg.de/podcasts/orientierung (in German)

In the political discussions about the energy transition, half-truths and untruths circulate – something that annoys Axel Kleidon. The physicist, who analyzes the Earth system from a thermodynamic perspective at the Max Planck Institute for Biogeochemistry, contributes to the debate with scientific facts in an effort to help the energy transition succeed.

TEXT: FINN BROCKERHOFF

Axel Kleidon reaches the small beach bar in Paradiespark on the Saale River on his bike: steel frame, unpainted. Emblazoned on the top tube is Boltzmann's entropy formula, a fundamental equation of thermodynamics – the first indication that physics is far more than just a tool for the Group Leader at the Max Planck Institute for Biogeochemistry in Jena. It sparks his curiosity, and also shapes his worldview. "I constantly strive to approach new situations as impartially as possible," Kleidon says. "After all, being a scientist doesn't mean knowing everything; rather, it means being open to new ideas, actively challenging them, and thinking things through."

In his research group "Biospheric Theory and Modeling," he uses the physical laws of thermodynamics to explore energy transformations in the Earth system: "When sunlight reaches the earth's surface, its radiative energy is converted into thermal energy," Kleidon explains. This causes air masses to rise in the atmosphere, which generates kinetic energy. Plants, meanwhile, use sunlight for photosynthesis, converting it into chemical energy in the form of carbohydrates. And when it hits a solar panel, it generates electricity. "These are examples of energy transformations that take place continuously on our planet. By considering them as a whole and figuring out their thermodynamic limits, we can model and predict many Earth system processes to a good approximation." Kleidon uses this method to try and gain a better understanding of the effects of climate change, for example, and to find out how much potential there is in renewable energies. "These topics are important beyond research for climate and energy policy and they also get me going on a personal level," says the physicist. You could almost take that last statement literally: to support the environment, the earth system scientist travels in Jena almost exclusively by bicycle. "Plus, it's faster than driving the route from my home to the Institute."

In keeping with his upbeat and talkative nature, Kleidon likes to occasionally move his work here to the beach bar in the summer, where he can talk to his coworkers in a casual setting. Nowadays Kleidon discusses specific issues in thermodynamics in these conversations, but there was only one significant issue at the start of his academic career: why does the world work the way it does? "And when you ask why, you quickly arrive at physics," the researcher says. And so, he began to study physics in his hometown of Hamburg in 1989. After completing his undergraduate degree, he went to the US in 1992 as an exchange scholar to pursue a master's degree at Purdue University in Indiana. There, some elective courses sparked his enthusiasm for climate modeling. "I was par-

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VISIT TO

AXEL KLEIDON

PHOTO: ANNA SCHROLL FOR MPG

Axel Kleidon is a passionate cyclist. He almost always relies on his own muscle power to get to work.

PHOTO: ANNA SCHROLL FOR MPG

Sustainable power generation with a difference: With enough dynamos and sufficient training, Axel Kleidon can light up a lot of bulbs.

ticularly attracted to the fact that it allowed me to combine physics with programming," Kleidon says. He had already done a lot of programming alongside his studies – a passion he discovered in his youth and which had subsequently financed several vacations for him. So, Kleidon returned to Hamburg in 1994 to obtain his doctorate at the Max Planck Institute for Meteorology with Martin Heimann (who worked at the Max Planck Institute for Biogeochemistry from 1998) in the department of climate scientist Klaus Hasselmann, who later became a Nobel laureate. His topic was the influence of vegetation, and especially the root system, on climate in the Amazon. "What I found interesting here is that there is a biological component, but it's looked at in a physical way," Kleidon said. "Because people believed that the most important processes occurred within the atmosphere, vegetation was typically treated somewhat disparagingly as an insignificant boundary condition in the climate models of the time." In the end, however, Kleidon's model simulation showed that the Amazon is up to eight degrees cooler in the dry season than it would be without plants. The reason for this is the deep roots that take water from the soil; this water then evaporates through the leaves. "It was a very impressive result that made at least some colleagues aware of the importance of vegetation." After obtaining his doctorate, Kleidon went to Stanford University in California on a postdoctoral scholarship from the Alexander von Humboldt Foundation. There, in Silicon Valley, the center of the US computer industry, Kleidon almost gave up science. The search engine giant Google was still in its infancy at the time and was urgently looking for staff. "I could have gotten a job with them, and no doubt earned a lot more money than was to be made in science," Kleidon says. "But money isn't everything," he continues. "I think what ultimately kept me in research was again the question of why and my curiosity to get to the bottom of things."

After two years at Stanford, Kleidon took a job as an assistant professor at the University of Maryland near Washington, D.C., in 2001, where he met Lee Miller, then a master's student. In the early 2000s, the two began thinking about how much energy could be generated by wind power. "During this time, I increasingly tried to incorporate concepts from thermodynamics and entropy into my thinking, laying the foundation for my later research,"

Kleidon says. Thanks to the tenure track, he says, he had good prospects for a tenured professorship at Maryland after his temporary appointment. In the US, you get nine-month contracts for the time you teach. The period in the summer with no lectures is then reserved for research. There are no official paid vacations. From time to time, Kleidon nevertheless took time off to visit relatives in Germany with his wife and children. "However, since I traveled a lot during college and really enjoyed it, I missed discovering the world."

In the long term, he wanted to return to Germany. And, lo and behold: one day, his doctoral advisor Martin Heimann contacted him. There was a plan to start three new working groups at the Max Planck Institute for Biogeochemistry in Jena, and Heimann suggested that Kleidon apply. "I did, and pretty soon I got an offer. However, the position was initially limited to five years." At that time, Kleidon was about to enter the tenure review process at Maryland, which would determine whether he would be offered a permanent professorship. "Since a secure position was more important for my family than paid vacation, I had to reject Jena with a heavy heart." But just a few weeks later, he got another call: "They wanted to know if I would come if they guaranteed me a permanent position. So, of course, I accepted immediately and moved back to Germany with my family in 2006."

As the head of an independent research group, he now had the freedom to decide on his own topics. "It's a very free way of working," Kleidon relates. For him, new research projects are largely the result of personal contacts. "Frequently, scientists from outside my community write to me to share ideas, which sometimes results in very stimulating discussions." For instance, a study that was inspired by conversations with astrophysicist Adam Frank of the University of Rochester took a thermodynamic look at planets and categorized them based on whether and how energy is converted on them. They were particularly interested in celestial bodies on which life develops – which in all likelihood happens at various locations in the universe. In doing so, the scientists also analyzed – independently of the specific characteristics of humans and their culture – the transition to an age that corresponds to the terrestrial Anthropocene with its immense energy consumption and consequences such as climate change.

When Lee Miller came to Jena from Maryland a few years later for his doctorate, the two of them began to conduct specific research on the

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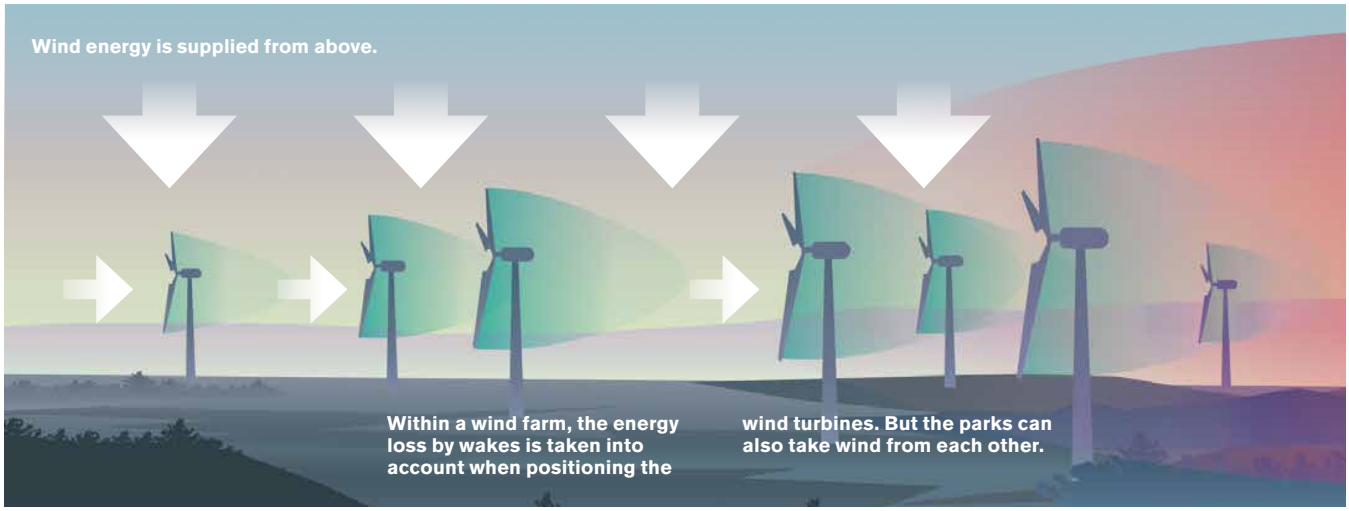
Limited reservoir: The more wind turbines there are in a region, the weaker the wind becomes, because not enough energy can be supplied from above. This effect may reduce electricity output in some regions during the planned onshore expansion and will play an important role in the targeted expansion in the North Sea.



GRAPHIC: GCO BASED ON A TEMPLATE BY AXEL KLEIDON

potential of wind energy. "With this subject, I think it was and is very important to establish facts," Kleidon says. This, he continues, is because the atmosphere is often regarded simply as an inexhaustible reservoir of energy. "But it isn't. Any energy taken from wind turbines is lost to the atmosphere. Then the wind speeds go down." However, because the pair's approach was so straightforward, they initially encountered challenges in getting their initial articles published in journals. "The trend in science is to make everything more and more complex and detailed, rather than striving for simple and more elegant approaches," says Kleidon. In the peer review process of high-ranking journals, the feedback was therefore sometimes quite harsh: "I can't imagine that the authors believe their own results. Reject!" Just one example of a review. But then, Albert Einstein had already stressed that one should make a theory as simple as possible, but no simpler. And the supervisor for Kleidon's master's thesis said that anyone who could not do that had simply not understood the topic well enough.

"Science has great potential to help improve decision-making in energy and climate policy."

Only eight years ago, the two researchers finally published several papers in the esteemed journal *Proceedings of the National Academy of Sciences* using regional model simulations, and their efforts did not go unnoticed: wind energy researchers from the Danish research center Risø DTU reacted immediately with a critical comment. "We then published a response again, which eventually brought our discourse to the attention of Agora Energiewende, who invited us to a joint meeting," Kleidon recounts. The Berlin-based think tank looks for scientifically sound and politically feasible solutions for the energy transition in Germany. "As we were seated across from the Danish working group, things were a little tense at first," Kleidon recalls. "But we quickly found out that we were looking at the same thing from two different angles." While Kleidon was focused on showing the limits of wind energy, his Danish colleague Jake Badger was more interested in pointing out the potential within those limits.

"We quickly hit it off, and Agora Energiewende entrusted us with reassessing the potential of offshore wind energy in the German Bight." The two scientists each used their own methods. Badger developed a detailed model to simulate the German Bight at high resolution. Kleidon took a completely different approach: "I imagined putting the entire wind farm in a box and asking myself: How much kinetic energy goes through the front of the box? How much is lost in it due to friction? How much do the wind turbines take out to generate electricity? And how much energy is left in the system after that?" This allowed Kleidon to calculate how much wind speeds are reduced on average by wind turbines and how this affects electricity yields. To his delight, the results of his model were very similar to those of the highly complex simulation. "I was very satisfied with this. Because it seems to me that a lot of researchers don't want to hear that you can do things simply if you just do them right."

After the results were published, Kleidon was surprised at the impact they had: "A couple of major energy companies and also the Federal Maritime and Hydrographic Agency changed their plans for offshore wind power as a result." Previously, it had been assumed that wind turbines would become more efficient over the years, which should enable ever higher energy yields. "But the opposite is true," Kleidon explains. "After all, when wind turbines become more efficient, it just means you're mining the resource more effectively and taking more energy out of the atmosphere. From my point of view, the work paid off because we managed to influence the energy transition."

But Kleidon's research on wind energy brought him to the attention of more than just wind energy

companies and government agencies: "Agora Energiewende only learned about my research because wind energy opponents had previously frequently cited me to try and prove how absurd the expansion of wind power was," Kleidon says, looking downright amused. Proponents of nuclear power and coal-fired electricity also repeatedly referred to his work. Of course, it was never his intention to oppose the energy transition: "My only goal is to use physics to establish a foundation for discussion that is as impartial and rational as possible. Because I find it annoying when people talk 'scientific' nonsense in politics."

PHOTO: ANNA SCHROLL FOR MPG

Relaxed atmosphere: Axel Kleidon enjoys discussions with members of his group at the beach bar on the Saale River.

For him, one thing is clear: "Science has great potential to help improve decision-making in energy and climate policy." Particularly in these fields, he says, there are a lot of misconceptions and incomplete perceptions that lead to the creation of myths. This includes the view that using wind energy causes droughts. But the water cycle, and by extension rainfall, is driven almost exclusively by heating from the sun. Kleidon no longer only publishes the results of his research in scientific journals, but increasingly also writes articles for the popular-science magazine *Physik in unserer Zeit* to bring these discoveries to a wider audience. "I think it's important to consider the implications of your research for society, and use concrete examples from real-world situations to make your points so they stick in people's minds." In his latest article, for example, Kleidon used the actually planned expansion of wind energy in Germany as a hook. He demonstrated that with an installed capacity of 200 gigawatts, more than half of Germany's current electricity demand could be satisfied but for the atmosphere, this removal of energy is negligible.

Good ideas like these often come to Axel Kleidon while he is running. He has been jogging several times a week for 12 years, with his favorite area being the countryside around Jena, and he also likes to cover longer distances of around 20 kilometers. "It's a wonderful way for me to structure my thoughts. I frequently even plan out a few things in advance that I want to think about while running." After a long day at the computer, the exercise provides excellent balance for him. During the week there is usually no time for extended runs in nature, "but then I at least take a short detour to the running track at the University Sports Center of the Friedrich Schiller University." While running, he also keeps tweaking his lecture "Renewable Energies in the Earth System," which he has been holding as a private lecturer at the University of Jena since 2018. "It focuses more on the scientific principles required to describe the Earth as a whole system than it does on technology." A lecture on climate change will then be added for the 2023/24 winter semester.

Axel Kleidon certainly has no shortage of projects to ponder while running: "I keep toying with the idea of starting a YouTube channel for science communication. After all, not everyone likes to read pages-long magazine articles." However, his plans for this are not yet set in stone. "In any case, I intend to develop my popular science writing further and use that to dispel misconceptions about climate and energy research."

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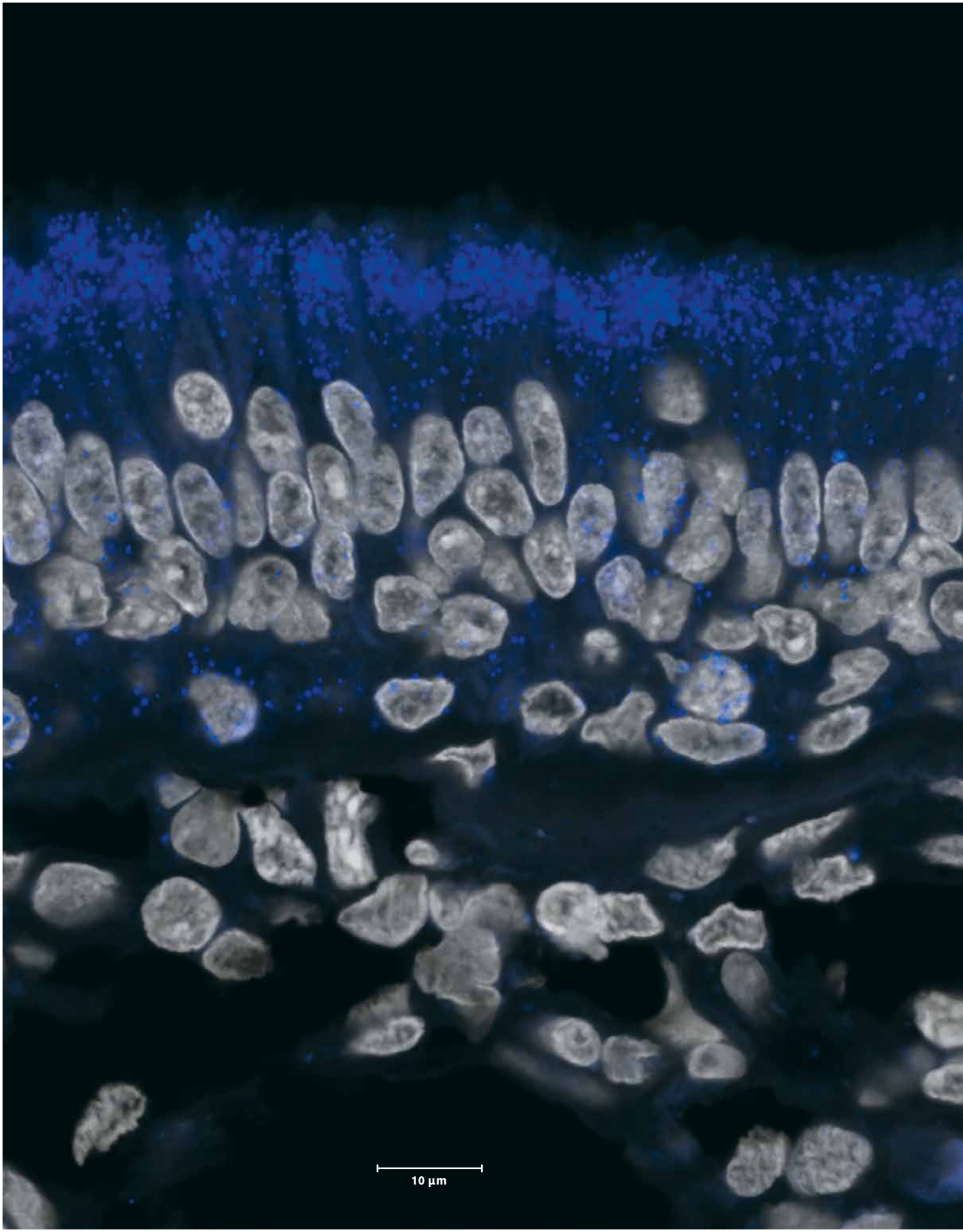

IMAGES: MP RESEARCH UNIT FOR NEUROGENETICS / MONA KHAN

DOUBLE TAKE

MAX PLANCK RESEARCH UNIT FOR NEUROGENETICS

The coronavirus uses the mucosa in the nose as a portal of entry into the body. Contrary to what was initially thought, the virus does not infect the olfactory cells, but rather a cell type with an unknown function, known as supporting cells. The picture on the left shows the olfactory mucosa of a non-infected person. On the right is a single supporting cell of a Covid-19 patient infected with the coronavirus (red). In both images, the blue dots are a marker for supporting cells. The green dots show viruses replicating in the cell. The gray-colored structures are the nuclei of the cells. However, it appears that the pathogen cannot penetrate the brain; a type of connective tissue cell in the olfactory mucosa, which has barely been studied thus far, seems to act as one of several anatomical barriers that protect the brain from the virus.

HOW POLITICAL IS SCIENCE ALLOWED TO BE?

It will be impossible to manage the current planetary crises without global scientific cooperation. This in turn will prove impossible without a balanced relationship and dialogue between science and international politics, specifically between scientists on the one hand and policymakers on the other. However, a look at the history of the Max Planck Society (MPG) shows that the links between science and foreign policy have more often served strategic national and alliance policy interests rather than the global welfare of humankind. Following from this, the MPG did not consider itself to be a major player in international science diplomacy for a very long time, as historian Carola Sachse reports in her new book.

INTERVIEW: CHRISTINA BECK

Ms. Sachse, you write in the introduction to your book Science and Diplomacy *(Wissenschaft und Diplomatie)* that the Max Planck Society (MPG), with its commitment to science diplomacy, has reacted late, if not too late, to a now 20-year international development. Can you elaborate on this?

CAROLA SACHSE: I carried out some interviews in 2018 at the MPG Administrative Headquarters, and the general thrust then was: no, we're staying out of it altogether. Our interest lies in facilitating relevant collaborations for our scientists wherever in the world these may be, where they look to be promising and possible. And if a specific case poses political obstacles, we try to overcome these via our contacts with ministries, embassies, and science organizations, and/or find other ways to realize the desired scientific cooperation. But supporting the foreign policy of the Federal German government as the Max Planck Society per se, in any way, was completely off the table. With this in mind, I was surprised to find a statement on the website at the beginning of 2022 which said that the MPG seeks to contribute to the science diplomacy of the German government as a matter of course.

The discussion around science diplomacy is primarily rooted in approaches from the USA.

Yes, around the turn of the millennium it began as a new attempt at *soft power policy* by the United States. Since then, science diplomacy has come to be propagated as a means to address global problems through a new kind of supranational cooperation between politics and science. Large EU-funded projects on science diplomacy are also driven by this hope. But the MPG did not participate in these projects. That said, it is possible that the expansion of earth system sciences, for example, with the establishment of the Max Planck Institute (MPI) of Geoanthropology, may turn out to provide fresh impetus in this direction.

Do you mean to say that, so far, the MPG has refused to deal with foreign policy and has resisted being co-opted to serve its ends?

At the very least, this is what the Administrative Headquarters says. However, if you take a closer look, events occasionally took a different course, especially if you think back to 1974 and the launch of the MPG's China program. Here, in a specific geopolitical situation and in consultation with the West German government, the MPG played a traditional diplomatic role. Without the MPG, it would not have been possible to establish scientific relations with the People's Republic of China at all.

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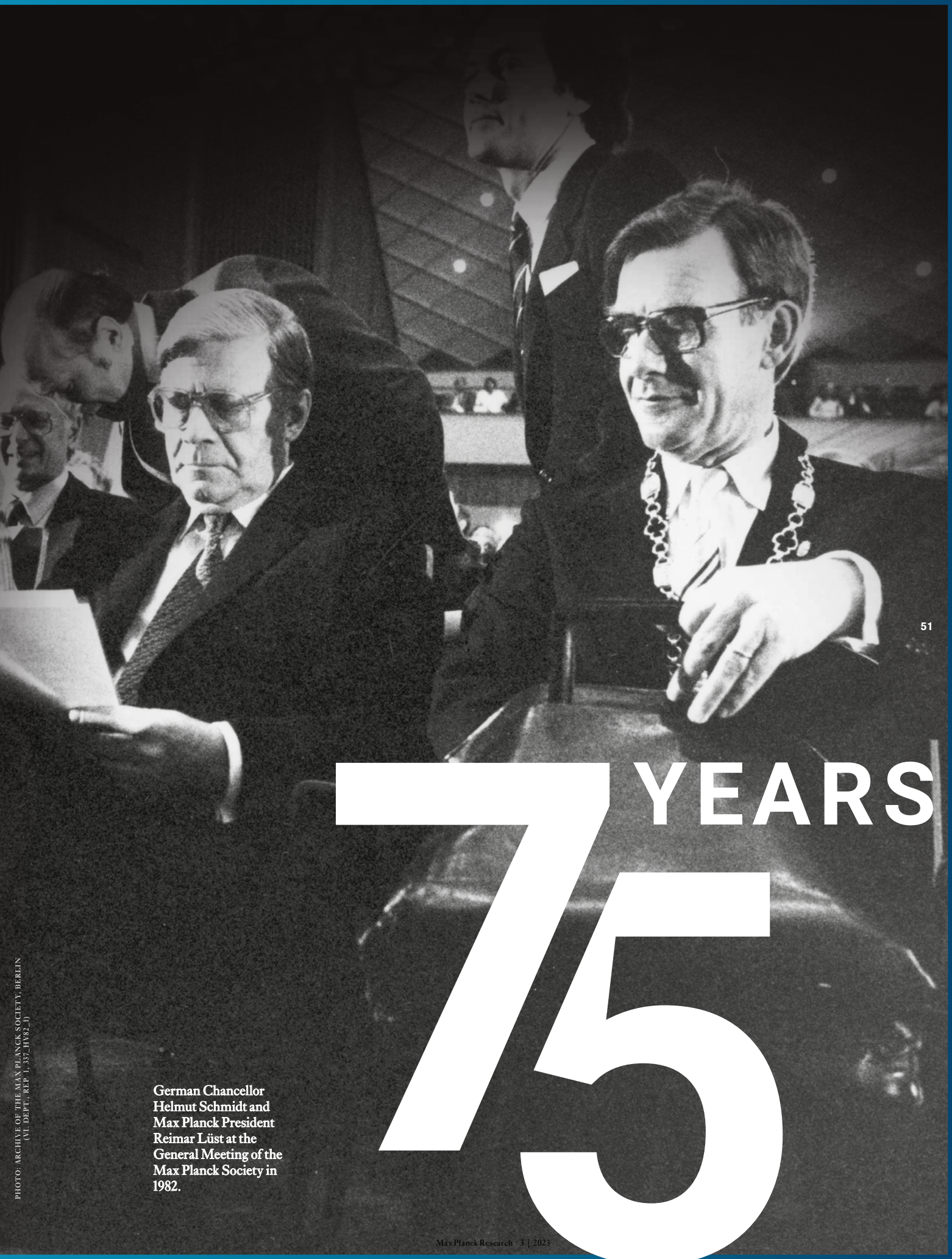

75 YEARS

German Chancellor Helmut Schmidt and Max Planck President Reimar Lüst at the General Meeting of the Max Planck Society in 1982.

PHOTO: ARCHIVE OF THE MAX PLANCK SOCIETY, BERLIN (VI. DEPT., RLP, 1, 357_HV82_3)

In Adolf Butenandt, however, you had a President who wanted to play a very active role in science policy. In your book, you write about the reform of the statutes in the early 1960s: "The MPG needed leadership that could act and make decisions in domestic and foreign policy." And you go on to say: "Butenandt wanted to use the weight of his new position to influence science policy."

From our work on the Kaiser Wilhelm Society under National Socialism, I knew Butenandt to be a highly problematic figure. He remained controversial long after that period, including within the MPG. But in the 1960s, some developments took place that I found rather surprising: Butenandt – as a science manager concerned with junior scientists, but also as the father of seven children – had a strong interest in educational policies and pushed through the founding of the Max Planck Institute for Human Development against considerable opposition. Likewise, he supported the founding of the Starnberg Institute (MPI for Research into the Living Conditions of the Scientific and Technical World) with the hope of creating an Institute that could help secure world peace.

The comparison you made with policy consultation in the USA is interesting. Certainly, it would be hard to draw parallels between the work done at the Starnberg Institute and policy consultation as understood in the United States.

Yes, you could see it that way, even if Carl Friedrich von Weizsäcker himself preferred to speak of foundational research for a global domestic policy (Grundwissenschaft für eine Weltinnenpolitik) that would be crafted in Starnberg. This was a particular and rather peculiar understanding of policy consultation that linked Weizsäcker to Hahn, Butenandt, and Heisenberg. This referred to the inherent rationality of the scientific persona and they felt compelled to use this scientific worldview to demonstrate the rational perspective to politicians who – in their view – were driven by rather irrational campaign promises from one election cycle to the next. Policy consultation of the kind that had been customary in the United States for a long time and that had been practiced within the Presidential Scientific Advisory Committee (PSAC) since the early 1950s, especially in the wake of the Manhattan Project, never existed in the Federal Republic of Germany, despite the country's abundance of expert advisory boards. Starnberg had no understanding of or interest in the advisory work of the PSAC. Nor did the West German federal government, at least until the late 1960s, have any interest in soliciting such advice. Moreover, elite scientists unaccustomed to the business of politics were also seen in Bonn as having recently stabbed the government in the back by signing the Göttingen Manifesto of 1957 with its warning against arming the Bundeswehr with nuclear weapons. Accordingly, senior politicians had little time for advice offered by these elite scientists.

Is it fair to say that with the Göttingen Manifesto, Weizsäcker et al. pretty much incensed the Federal German government of the time?

Yes, and it goes further than that. In my opinion, what was more significant in terms of shaping the relationship between science and politics in the Federal Republic than the Göttingen Manifesto, which Weizsäcker revoked barely a year later, was the much less well-known Tübingen Memorandum of 1961/1962. Here, an overly strong link between this statement and the MPG was avoided by using the research facility of the Protestant Church as the postal address. But senior MPG figures were significantly involved in this memorandum which denounced West German foreign policy vis-à-vis the two German states and the former Eastern Territories. Controversially, it called for foreign policy realism and, for the first time, gave public voice to the argument that the Oder-Neisse line and the existence of the two German states had to be accepted. At the time, this was an absolute taboo, that even the opposition party, the SPD, dared not express in public. At any rate, the

"Policy consultation of the kind that has long been common in the US has never existed in the Federal Republic – despite a plethora of expert advisory councils sprouting up."

CAROLA SACHSE

Tübingen Memorandum came to serve as a significant catalyst for the new Ostpolitik put forward in 1969 by the first social-liberal federal government under Willy Brandt.

What changed with the political shift to social-liberal governments and the policy of détente in the 1970s, and with the change in the MPG presidency from Butenandt to Lüst?

Things changed, but not in the way you might expect. When Lüst took office in 1972, Brandt was still Chancellor. The new foreign policy envisioned in the Tübingen Memorandum had been quickly implemented via a series of treaties with Warsaw Pact states. You would think that this meant that cooperation was thriving at this point between the MPG and the social-liberal governments. However, the new Ostpolitik did not make it any easier for MPG scientists to collaborate with their Soviet counterparts – something which elsewhere, working together with colleagues from a range of countries, they greatly valued, particularly in the big science projects in astrophysics, space research, radio astronomy, and plasma physics. Rather, Helmut Schmidt's government, which took power in 1974, wanted to use research cooperation between the MPG and the Soviets – equally valued by the Soviets – as political leverage to extract concessions from Moscow on its policy towards Germany, especially regarding the political status of Berlin. Nothing changed in this regard until the Gorbachev era. On the contrary, with the Soviet invasion of Afghanistan in 1979 and the end of détente, things became even more difficult. For the MPG, every major project involving Soviet colleagues ran up against Bonn's foreign policy: this meant that the MPG was by no means free to make its own decisions about bilateral research.

Under Reimar Lüst's presidency, only scientific factors were considered when making decisions about collaboration.

Correct. In the 1970s, the Administrative Headquarters began to redefine the MPG's relationship to national as well as European and international politics. The conflicts with the Federal German government over research cooperation with Soviet institutes may have been one reason for this. But other factors came into play, above all the national economic picture, especially the problem of persistent stagflation: savings had to be made. If you wanted to do something new, something else had to be cut. In commerce, you would say: "you have to focus on the core business." For Lüst and many of his colleagues, particularly from the physical-technical institutes, this meant the large-scale, expensive projects which could only be funded through bi- or multilateral collaborations. For them, foreign policy restrictions were obstacles to scientific advances. In this context, it was a useful tactic to insist on a strict separation between politics and science.

Nonetheless, Lüst worked closely with Helmut Schmidt.

Yes, a lifelong friendship developed between them – despite their opposing ideas about the relationship between science and politics. Lüst was focused on securing resources for the Max Planck Institutes. On the one hand, he refrained from subjecting politicians to unsolicited scientific worldviews and wisdom. On the other hand, he did not want to be told by politicians which research directions should be taken up, intensified, or discontinued within the MPG. Rather, he defended – perhaps even more puristically than his predecessors – the understanding established in the post-war period in the Federal Republic, that basic research is driven solely by the desire for knowledge. This had also legitimized the internationally unique institutional autonomy of the MPG. The closure of the Starnberg Institute and the restructuring of the MPI for Human Development around 1980 – namely, the two politically-oriented institutes founded under Butenandt – fit into the strategy of drawing a line between science and politics.

Helmut Schmidt, on the other hand, certainly expected consultation from science when he was Chancellor?

Yes, Schmidt expected science to provide him with insights into highly complex scientific matters and social processes. In arguing for this, he drew on Weber's ethics of responsibility: How can I, as a politician, especially as a head of government, make ethically and po-

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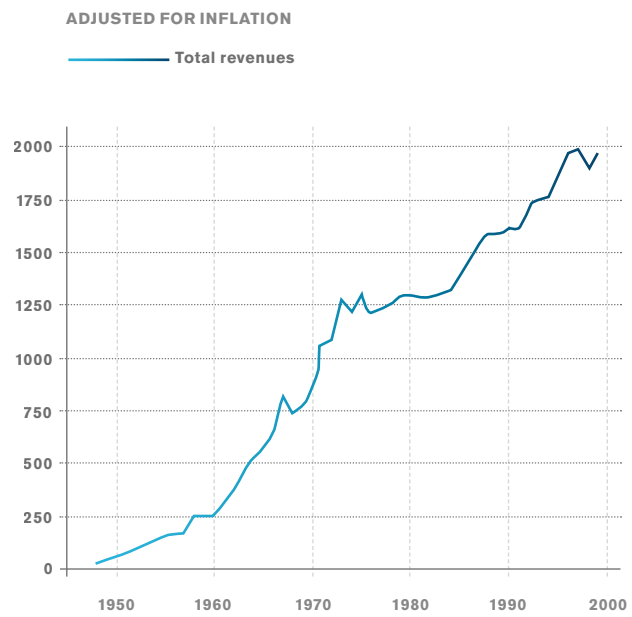

MPG budget 1949–1998 (adjusted for inflation): The persistent stagflation in the mid-1970s forced the Max Planck Society to economize – if you wanted to start something, you had to stop something else.

GRAPHIC: GCO BASED ON A TEMPLATE BY PD DR. JAROMÍR BALCAR / MPG

litically responsible decisions based on the broadest possible foundation of knowledge, especially scientific knowledge? He expected science in general and the MPG in particular to provide him with this knowledge. In his inaugural speech as chancellor at the General Meeting of the MPG in 1975, Schmidt emphasized that science had a duty to deliver – a phrase that can be heard frequently today in debates on climate change.

And this is where Lüst drew the line?

Lüst insisted that the MPG should not be seen as having such responsibility. As a basic research institution, he said, the MPG cannot directly advise policymakers because it could not offer any insights that can be applied politically. In 1982, Schmidt again made the point about the responsibility of scientists to deliver in terms of knowledge and insights when he spoke at the MPG Annual General Meeting for the second and last time as Chancellor. This was challenged by Lüst who countered that instead of just seeking expert opinions on everything and anything, politicians should engage seriously with scientists. Schmidt stood his ground. As he put it, scientists should "strive to possess an orderly overview." He went on to say that those who had the extraordinary privilege of being able to turn their hobby into a profession should be aware of their social responsibility towards those who worked in the factories – who actually provided the means for science. Scientists not only owed society highly specialized scientific excellence, but should also provide an "overall view." In essence, Schmidt demanded from the MPG exactly what Heisenberg, Butenandt, and Weizsäcker had claimed for themselves 20 years earlier, but which in the meantime the MPG had removed from its portfolio as it swiveled into the process of social differentiation.

The book *Science and Diplomacy (Wissenschaft and Diplomatie)* by Carola Sachse is available as an open access publication at:

This exchange of blows was really very exciting.

Yes, in the Lüst and Schmidt eras, the relationship between science and politics remained hotly contested. But that ended in the 1980s. For Lüst's successor, Heinz Staab, it was a simple matter of blocking anything that brought the MPG close to politics. One example of this came in connection with the clarification requested by some West German politicians about the feasibility of the Strategic Defense Initiative (SDI) announced by US President Ronald Reagan in 1983. Where else in the Federal Republic of Germany was such knowledge concentrated other than in the MPG? Was there anyone in the country who knew more about space than the highly qualified astronomers, astrophysicists, and radiochemists working in the relevant Max Planck Institutes? However, Staab was adamant that the MPG would not engage in military research. In any case, he said, the MPG'S dedication both to basic research and to the prompt publication of research findings was wholly incompatible with military secrecy regulations. Staab also claimed that there was insufficient expertise within the ranks of MPG scientists to evaluate the SDI program – something that was seen quite differently by members of the research staff in the Chemistry, Physics and Technology Section.

Hans-Peter Dürr, Director at the Werner Heisenberg Institute, for example, dealt intensively with the SDI program and also penned a long article in *Der Spiegel* on the subject.

Citing the US Union of Concerned Scientists, Dürr tried to prove that the SDI program could not be implemented so quickly and, if at all, only at immense cost. Above all, he contradicted Reagan's promise that an appropriate shield could effectively protect against nuclear bombs. The highly sensitive satellites would first have to be developed for this purpose and, said Dürr, be faster and cheaper to destroy than they were to manufacture. This put him on a collision course with the Federal German government led by Helmut Kohl – but also with the MPG leadership, which reprimanded him. On several occasions Dürr was held up in front of the entire MPG as a cautionary example of political dilettantism. In 1987, when Dürr was awarded the Alternative Nobel Prize for his commitment to peace and environmental policy, Staab went so far in his handwritten letter congratulating Dürr to spell out again that, as an MPI director, he

"Lüst parried the thesis of science's duty to deliver with the politicians' duty to collect."

CAROLA SACHSE

had to keep the roles of citizen and scientist separate. Under no circumstances should he appear as an MPI Director in the public realm.

At the same time, it is illusory to assume that one speaks publicly as a citizen without mentioning one's title.

What is more, to insist on such a separation would not do any good. The media rarely refrain from presenting an MPI Director outside the context of his/her role at the MPG. MPI Directors are always perceived as representatives of the MPG. Even at the employee level, this could not always be prevented. Hans Zacher, an expert in social law, had to explain to Lüst and Staab, that attempting to stop its members (and staff) from making public statements, resolutions, or newspaper advertisements, would harm the public image and international reputation of the MPG. Zacher reminded Lüst and Staab of historical precedents. And indeed, when speaking out, MPG scientists referred to the older MPG generation, now emeritus or deceased, who had taken a public stand in the 1950s and 1960s, for example, with radio appeals against nuclear armament, with the Mainau Manifesto, the Göttingen Manifesto, or the Tübingen Memorandum. The rebellious younger generation of MPG scholars, as well as Dürr, situated themselves within an MPG tradition that came under increasing challenge during the Lüst and Staab presidencies.

The question of role separation remains fraught – for Paul Crutzen, with climate research, research that shows where the problems are and what needs to be done.

This citizen/scientist separation remains deeply fraught. Crutzen and his colleagues at the Max Planck Institute for Chemistry in Mainz were thrust onto the international political stage by their research findings. Crutzen, as he himself said, would have preferred to explore the laws of nature in a clean atmosphere, in its original state, so to speak. Unfortunately, however, this was not to be. It was neither possible nor practical to factor out anthropogenically induced changes. The results of this 'impure' research left him deeply shaken. To his mind, they left him little choice but to bring them to public light and into political debate. He did this primarily within the framework of the International Council of Scientific Unions, an organization highly regarded by the MPG, and later through popular scientific publications. And, when it came to the thorny issue of activities in the public realm, it goes without saying that the MPG leadership would handle their Nobel Prize-winning colleague, Crutzen, very differently to a colleague awarded only an Alternative Nobel Prize (Dürr).

Is it understandable that the MPG has always exercised so much restraint? Given the primacy it accords scientific cooperation, does the MPG perhaps sometimes underestimate the adverse effects associated with such restraint?

One can explain the historical reasons why the MPG came to define itself – perhaps against its better judgment – as a zone that was to be kept as free from politics as possible. How to evaluate this today is another question. It was rumored that, during his (recently ended) presidency, Martin Stratmann missed the presence of political intellectuals within the MPG. In hindsight, we can see how from the 1970s on they were steadily marginalized. One can only hope that this will change again. I would like to see the MPG take an assertive stance when dealing with the knowledge that there never has been and never will be a politics-free space for pure basic research, and not to shy away from tackling political challenges in public. This applies all the more to international scientific cooperation, because universal science and research are directly and deeply affected by the shifting political contingencies of international relations. We currently see this in the case of two of the most important partner countries of the MPG, namely, Russia and China. A voice like that of the MPG is needed in the political discourse surrounding the political ambiguities of international scientific cooperation.

"A voice like the MPG's is needed in the political discourse."

CAROLA SACHSE

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THE RESEARCH PROGRAM "HISTORY OF THE MAX PLANCK SOCIETY"

From 2014 to 2022, independent historians reconstructed the development of the Max Planck Society between 1948 and 2002, placing the history of the MPG within the contemporary history of the Federal Republic and in the context of European and global developments.

DROPS WITH A SENSE OF TOUCH

TEXT: CHRISTIAN SCHNEIDER

It is such a common sight that it seems downright banal: at some point, almost everyone has likely watched raindrops run down a windowpane. So, it may come as a surprise that there is still fundamental scientific knowledge to be uncovered about how drops travel over surfaces. Research on drops is precisely what a team from the Max Planck Institute for Polymer Research has succeeded in doing – and they've opened up surprising potential applications in the process.

A train ride in the rain: you've finally managed to get into your train seat after the frantic rush of the station; now you can catch your breath and watch how the raindrops dance on the windowpane. Initially, many of the drops stay wherever they land. Eventually they start to trickle. Once the train picks up speed, things really start to move. When does a drop start to run? Where will its trajectory head? Will it grow longer and become a small trickle, through which more rainwater will run down?

Hans-Jürgen Butt, Doris Vollmer, and Rüdiger Berger from the Max Planck Institute for Polymer Research in Mainz share a fascination for the movement of drops – it has inspired their work for over ten years now. "I already knew about the friction of two solids from school," says Rüdiger Berger, who heads a research group at the Max Planck Institute in Mainz. "But understanding the friction between a drop and a surface: that I found exciting." The researchers wanted to know, for example, whether drops roll or slide. They also wanted to understand the precise ways in which surface characteristics affect how drops move, as well as the tracks that drops leave on surfaces.

Director at the Mainz-based institute, Hans-Jürgen Butt, explains the solution to many of these questions: "The microscopic processes at the three-phase contact line are of particular interest to us." The three-phase contact line is the line where a liquid drop, such as water, meets a solid surface, such as glass, and a gaseous component, such as air. In scientific jargon, each of these three elements is referred to as a "phase."

The angle that the drop forms with the solid surface is strongly affected by the nature of the surface. While a water drop will lay flat like a flounder on a surface that is highly hydrophilic – that is, a water-loving surface – it will bead into a pearl on a surface that repels water. Which of these wetting properties are needed in each case depends on the application: "For printing or coating surfaces, and

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PHOTO: RÜDIGER BERGER / MPI FOR POLYMER RESEARCH

KNOWLEDGE FROM

PHYSICS & ASTRONOMY

Set the scene: Researchers at the Max Planck Institute for Polymer Research are studying the behavior of drops on surfaces. Among other things, they make water bead over slopes. To make the drops more visible on the photo, the water was dyed with two different colors.

also for 3D printing, the drop needs to remain in the same place until it dries," explains Doris Vollmer, who heads a research group in Butt's department. "Conversely, for eyeglasses, cameras, or even car windows, you want to have a clear view again as quickly as possible – so a water-repellent surface is better in these cases." A water-repellant surface is important for solar cells as well, to allow drops to roll off their surface quickly and carry away as much dirt as possible. A clean surface is a must in order to keep the electricity yield high, especially in desert regions with a lot of sand and little rain.

The lotus leaf literally takes such water-repellent qualities to the extreme: it is made up of tiny columns and, using this trick, drastically reduces the contact area with the drop. On the surface of the lotus leaf, water drops form an almost perfect sphere that can only be kept on the leaf with great skill: if the leaf tilts just a little, the drop rolls off. "Here, you can clearly see the connection between the contact angle and drop friction," Vollmer explains. "The more water-repellent a surface is, the more spherical the drop becomes – and the less friction there is with the surface."

It all comes down to the surface

To learn more about the interaction between drops and surfaces, the team employs a modified instrument that can measure contact angles between liquids and surfaces. The roughly half-meter-high device consists of a metal frame that resembles a portal and a sliding table about the size of a palm. The surface to be examined is attached to a plate. The researchers place a drop on this and fix it using a little trick: "We first tried to hold the drop with a pointed wire end while the table moved underneath," Berger says. "But this kind of needle is often just pulled through the drop. So, to hold it in place, we added a tiny ring to the end of it – it's a bit like putting a crown on a drop."

The wire bends elastically as the researchers move the table beneath the fixed drop, providing a measurement of the frictional force acting between the drop and the surface. The team measures how much the wire bends using a camera. The magnitude in bending provides a map of the surface showing where there is friction and how much. Rüdiger Berger demonstrates the measuring concept on a surface on which the team has written an M using a particularly water-repellent substance. The M is clear to see in the friction map because the drop pulls on the wire with less force there. No other technique is as direct and quick at mapping the wetting characteristics of any surface or liquid. This measurement concept is also interesting for technical applications, as Berger explains: "With the help of this microscope, for instance, we can see even the smallest imperfections on surfaces. These imperfections are about the size of a hair, or a tenth of a millimeter, and are too small to be felt by hand." This is relevant, for example, if you want to check the homogeneity of paint layers. The drop can be used here as a probe to detect cracks, for instance, because a crack produces more friction between the surface and the drop. "We use it to detect imperfections that are far smaller than the drop, because only the contact line sticks to it," Berger explains.

SUMMARY

The more hydrophilic a surface is, the more the friction between water drops and the surface increases. Drop friction increases at tiny cracks and other imperfections in surfaces making it possible to evaluate, for instance, the quality of coatings.

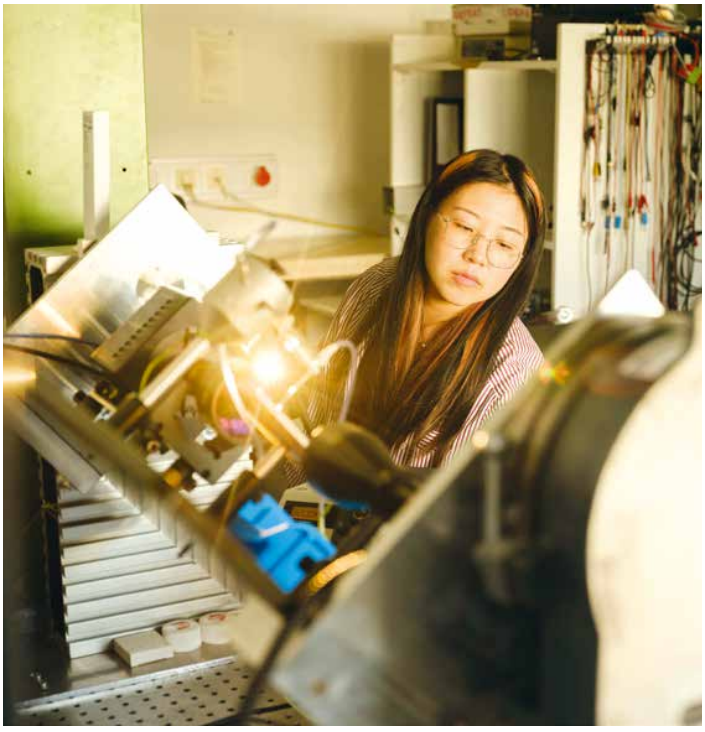
Water drops change many surfaces. For example, the outer layer of a glass pane swells, and some of its chemical components dissolve into a drop.

Sliding drops can generate charges on surfaces. This effect can be used for drop transport in microchip laboratories.

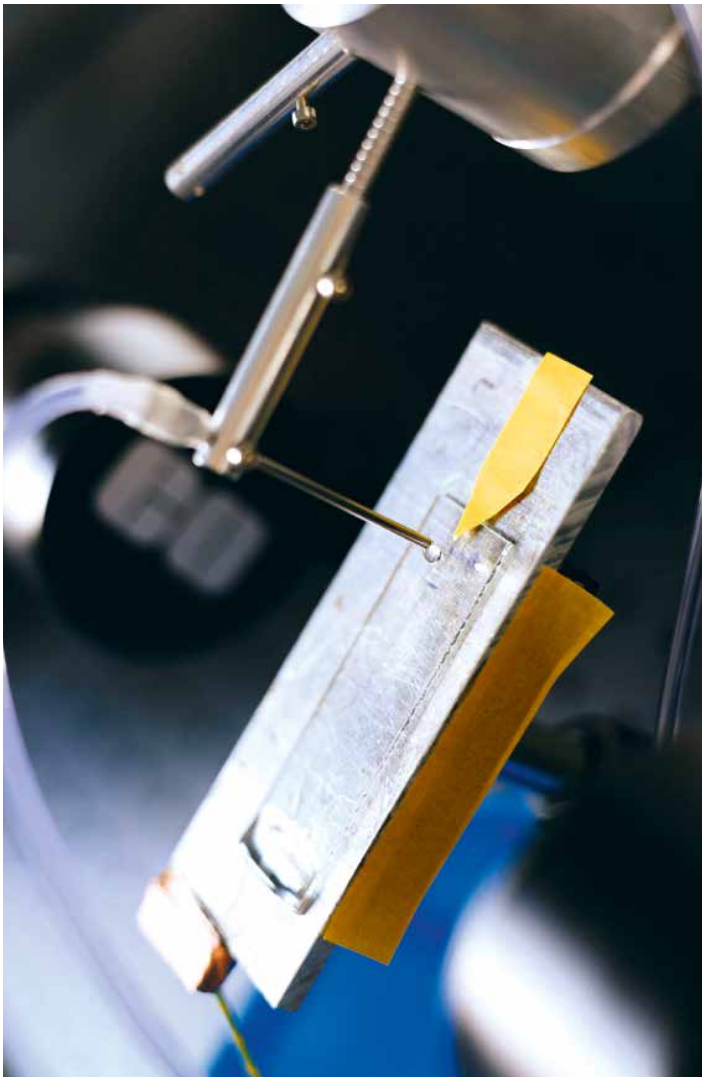
Hamburg-based company Krüss, which specializes in the creation of scientific measuring instruments, including those for surface analysis, has also acknowledged the benefits of the method. Krüss now wants to make a device based on Berger's team's research commercially available. According to Thomas Willers, Head of Applications Engineering and Science at Krüss, the research coming out of Mainz is exciting because it makes it possible to scan surface characteristics that cannot be measured with the company's other equipment. Measuring drop friction, he says, will result in new applications in surface analysis.

When exposed to water, some surfaces, like paint layers, remain stable, but other surfaces undergo processes that alter them. These surface alteration processes occur more often than one might think. The effect can be observed when it rains on a windowpane: if two drops flow down the pane, they will often take the same path. "This is because the glass surface changes when a drop runs over it," says Hans-Jürgen Butt. "You can think of it as the silicon dioxide surface swelling up a bit. It then becomes more water-loving." The result: the second drop takes the hydrophilic path defined by the first.

From a physical standpoint, describing these processes is anything but trivial: how does the surface adapt to a drop? And how quickly does it do this? To address these questions, the researchers developed a general model that can describe the interaction of drops with different surfaces. With the help of this adaptation model, they can better explain the effects of drops running



A slide for drops: Yuwen Ji measures the friction of drops on a surface that she has tipped with the bearing of a discarded lathe. This setup allows the team from Mainz to determine how quickly the surface and the liquid interact with each other.



At the end of a fine cannula, water slowly emerges and forms a drop. When this is heavy enough, it detaches and beads in a downwards direction on an inclined glass plate.

PHOTOS: KATRIN BINNER FOR MPG

over surfaces – and perhaps open up new fields of application at the same time.

Berger's team developed another instrument for the study by removing components from an old lathe and repurposing them. The first thing that catches the eye is a sizable black plate that can be tilted with the aid of the lathe's bearing. At its center is the core of the structure: a small plate attached to a holder, over which drops of water glide at regular intervals. Researchers are able to control how quickly the drops on the slope develop with the variable tilt angle. A high-resolution camera that records at 2000 frames per second records them on their way down. The images are used to measure the contact angle, both at the front and the back of the drop because the flow motion causes the two angles to differ. While the drop curves bulbously at the front, i.e. on its downward-facing side, it drags a kind of trail behind it at its end – unless the surface is extremely water-repellent.

A race down the slide

The researchers used their self-built drop-track to investigate, among other things, whether drops roll or slide. Do the water molecules in the drop rotate in a circle as though they were in a wheel, or is the drop motionless within itself as it glides over the surface? However, the experiments show there is no general solution to this question. How the molecules behave depends, among other things, on their position in the drop and on the surface. The drop's outer molecules rotate on surfaces that are more hydrophilic, as in a wheel. However, the further inside the particles are, the more they flow parallel to the drop path. The interaction between the various effects also influences friction, which in turn affects the drop's shape. The speed at which the surface is changed by the drop also plays a role. This gave the team an

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idea, which they worked out together with a group from the Vidyasirimedhi Institute of Science and Technology in Thailand led by Daniel Crespy, a former team leader at the Max Planck Institute in Mainz: could not the speed of the drops and their interaction with the surface determine the speed at which medical active ingredients dissolve from a carrier polymer in the body, for example, in the blood? "In the future, these special polymers could be used to create nanoparticles, such as those needed for medical therapies," explains Rüdiger Berger. The development of these particles depends significantly on how quickly the polymer delivers the active ingredient; however, this question cannot be resolved using standard analytical tools such as nuclear magnetic resonance spectrometers. These technologies are too slow to record some processes, which can sometimes be extremely fast.

With the drop slide, on the other hand, the team led by Rüdiger Berger and Daniel Crespy can precisely track the delivery of the active ingredient using a sophisticated indirect approach. The researchers repeatedly send drops across the surface, which they have previously coated with the active ingredient-loaded polymer. When doing so, they start with a relatively steep trajectory and gradually reduce its tilt angle, which causes the drops to become slower and slower. A drop eventually comes into contact with the surface for a sufficient amount of time for the active ingredient to dissolve. The remaining surface changes the contact angle, which the researchers image with their high-speed camera. "Adjusting the drop velocity provides a method for studying quick processes on surfaces, such as reaction rates."

Drops not only chemically interact with surfaces, but also electrically: depending on the material they roll over, they leave a more or less strongly charged track on the surface. "The underlying effect is not new, but the fundamentals have not yet undergone quantitative research," explains

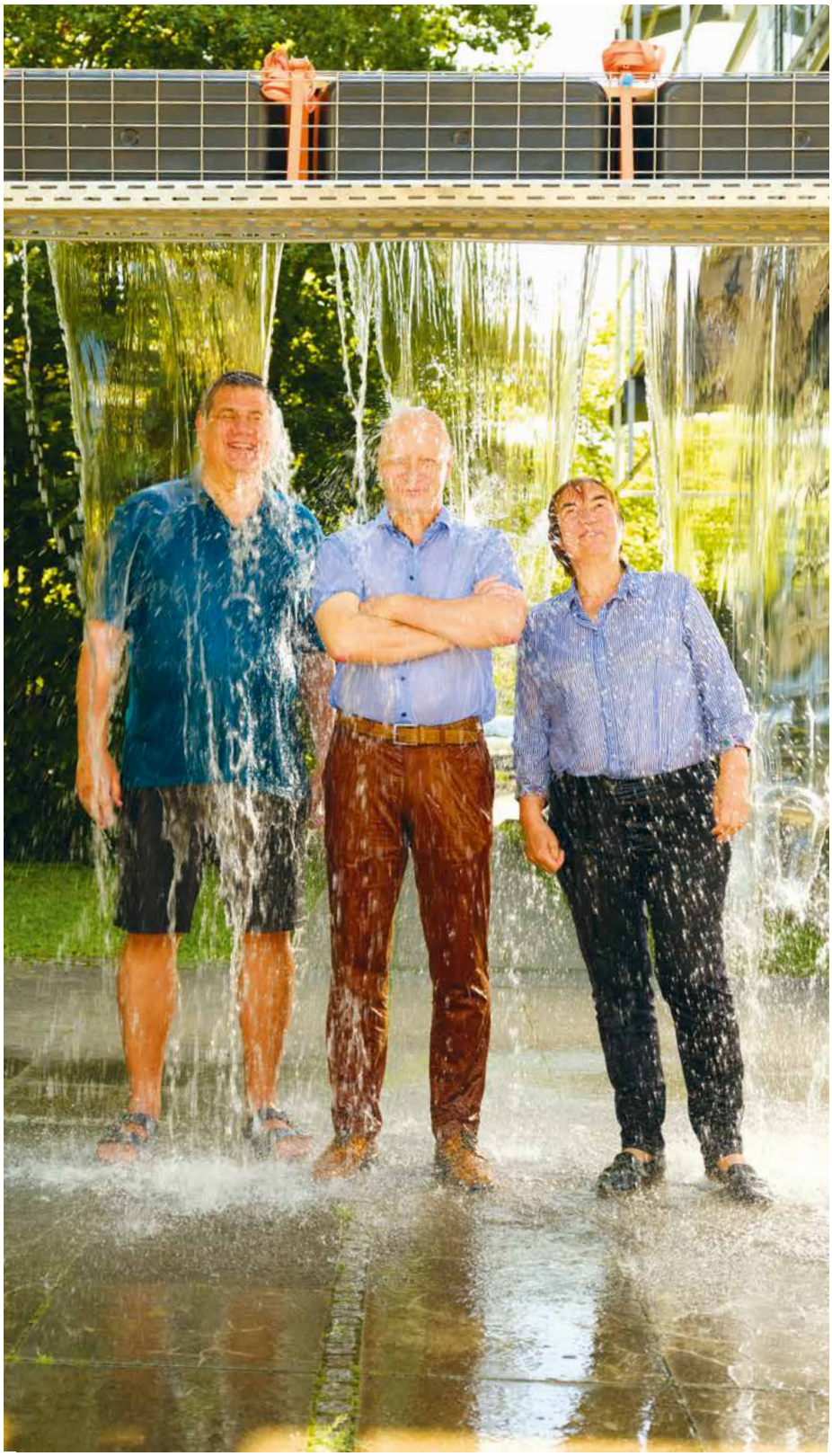

PHOTO: KATRIN BINNER FOR MPG

In their element: In a self-experiment, Rüdiger Berger, Hans-Jürgen Butt, and Doris Vollmer (from left) test their own wetting characteristics under an artificial waterfall.

Hans-Jürgen Butt. "Even before 1900, it was known that water drops can cause electrification in waterfalls." This effect was not studied again until the mid-1990s, this time in the semiconductor industry. There, the charge generated by liquids used in manufacturing became a problem because it damaged the chips. Hans-Jürgen Butt and his team have been working on an EU-funded project since 2021, to better understand what exactly occurs during the electrical exchange between the drop and the surface. Here, findings could result in as yet unforeseen applications.

Electrifying drops

The researchers initially believed the first result of their study was an error. "At first, we thought we weren't getting the measurement right," Butt recalls. Each drop showed a different charge – in some cases the charges differed by a factor of three to four. But in the meantime, the team found out that the charge and behavior of drops are highly dependent on what has happened on the surface beforehand. How many drops have already run down the surface and in what time interval? How high is the humidity, for example? Humidity slowly degrades the charged track.

Hans-Jürgen Butt's team has created a theoretical model based on experimental studies that accurately describes how strongly different liquids charge various surfaces and how this affects the liquids' wetting characteristics. "The charge on a surface plays a much bigger role in wetting than we thought," Butt says. In addition, the team demonstrated that drops hitting a water-repellent material leave charges on it. The generated charges depend on the falling height of the drop. The Mainz researchers and a team led by Xu Deng – a former doctoral researcher at the institute and current professor at the Chinese University of Chengdu – came up with the idea of dropping numerous drops close to one another from various falling heights in order to create a track of increasing or decreasing charges. This trail remains even when the surface dries. The result is a kind of conveyor belt that transports more drops at high speed between two points, and even over curved tracks or up a slope. The process virtually eliminates all liquid loss from the super water-repellent surface, allowing the electric drop transport to maneuver samples through a lab on a microchip. Many research institutions around the world are developing such tiny labs, as they could form the heart of small mobile devices for science or medicine. The miniature laboratories could make many examinations easier, particularly in medical diagnostics. On the other hand, it is uncertain whether slide electrification could ever be used to generate electricity. Even if sufficiently large charge differences could be generated using this method, it will not be easy to utilize them as a voltage source. That said, it might be worthwhile to experiment with appropriate technology for mobile power supply in tents, for example. And perhaps the drops' electrical tracks will turn out the same way as other discoveries made by the Max Planck Institute for Polymer Research team, driven by their fascination with drops: they could result in applications that might not seem obvious at first, but in which the drop solution accomplishes the goal more effectively than alternative methods.

GLOSSARY

THREE-PHASE CONTACT LINE
is the name of the line where, for example, the water of a drop, a solid surface, and air meet. The more hydrophilic a surface is, the smaller the angle between the drop and the surface.

SLIDE ELECTRIFICATION
is the term used to describe the charging of a surface by friction, such as by a drop of water.

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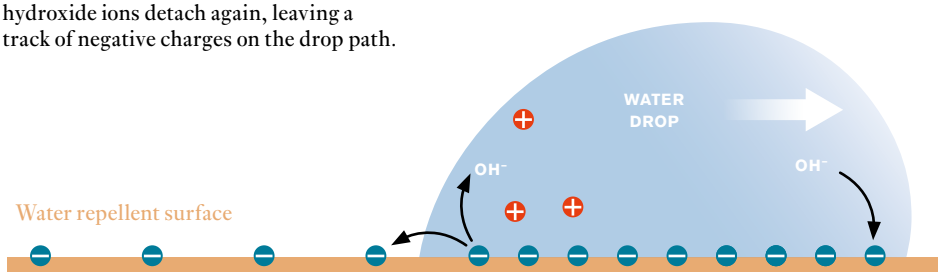
Electric tracks: When a drop slides over a surface, negatively charged hydroxide ions deposit on the surface, while the positively charged protons remain inside. At the end of the drop, only some of the hydroxide ions detach again, leaving a track of negative charges on the drop path.



GRAPHIC: GCO BASED ON A TEMPLATE BY BUTT, H.-J. AND BERGER, R., PHYSIK JOURNAL 20 (2021) NO. 4, WILEY-VCH GMBH.

PHOTO: ANNA L. AHLERS / MPI FOR THE HISTORY OF SCIENCE

"Freedom of teaching and of opinion in book or press is the foundation for the sound and natural development of any people." This quote by Einstein is on display at the Shanghai World Expo Museum – in a country that has severely restricted academic freedom in recent years.

RESEARCH ON A SHORT LEASH

TEXT: MARCEL GRZANNA

Democracies are thought to be the centers of groundbreaking research. However, the People's Republic of China is upending the free world's perception of itself. Despite its increasingly totalitarian structures, the country has joined the leading group of scientific nations. Under the direction of China researcher Anna Lisa Ahlers, a group from the Lise Meitner Program is attempting to determine how this is possible.

For a few decades, the democratic word held on to the view that, just as rainforest vegetation flourishes in a tropical climate, science flourishes in freedom. Only where a liberal spirit prevails can research tread its unpredictable but steady path like water through the ground. The conviction was based on more than just dogma. The sociologist Robert K. Merton had already defined four characteristics of true science back in the early 1940s. He argued that universalism, equality, altruism, and skepticism are necessary for continually achieving new scientific milestones. Merton was convinced that only democratic societies could provide these ingredients.

A good 80 years later, Anna Lisa Ahlers sits in her Berlin office at the Max Planck Institute for the History of Science. "A few things have changed. We have to take a close look at the developments of the past few years," she says. Ahlers is a China researcher. She spent several years in the People's Republic and speaks fluent Mandarin. Now she heads the Lise Meitner Research Group "China in the World System of Science."

When the call for applications for the 2019 program landed in her inbox, she was sitting in the library at the University of Chicago as a visiting professor – ready to give up a tenured position in Oslo for an opportunity to go on an intensive hunt for clues. Her application for the Lise Meitner Program of the Max Planck Society struck a chord with the zeitgeist.

"The overriding question for us is how science works in an authoritarian system," she says. This is because, with the entry of the People's Republic of China into the leading group of global scientific nations, Robert K. Merton's social theory is beginning to falter. Nothing that was once thought to be a prerequisite for thriving research exists in China in its purest form, and some of it does not exist at all. In addition, the political structures in China have become increasingly totalitarian since party leader Xi Jinping took office more than ten years ago. For the Chinese Communist Party, everything is subordinated to maintaining its monopoly on power in a single-party state. This also applies to

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science, which must always serve the party and not contradict its ideology under any circumstances. What makes science in the People's Republic of China internationally competitive despite the CCP's strict control over it? This question is on Anna Lisa Ahlers' mind, not least because she has been observing this development from close quarters for some time. China not only wants to keep up with the nations who have been the frontrunners in science until now, above all the US, but also some European countries: the People's Republic wants to outdo them all. Abundant data sources, relevant publications, state-of-the-art research centers, internationally renowned award ceremonies – all this could shift increasingly to the Far East if the country succeeds in its confidently stated goal of becoming the leading scientific nation in the world.

Meanwhile, there has been a sharp rise in interest in Chinese science. Media attention has also increased dramatically since China's universities started to publish more and more research results. Just recently, the People's Republic of China surpassed the United States in terms of the total number of publications in scientific journals. The goal of achieving a high position in such rankings is set for Chinese research organizations and universities by policymakers, as the researchers in the Lise Meitner group make clear. In an incentive-based system, the leaderboard becomes the outstanding benchmark. "This is why it's much easier for Chinese universities, for example, to adjust to the international rankings," Ahlers says.

First quantity, then quality

However, first place in the number of publications is only a partial victory for the People's Republic. This is because the criteria used to judge whether scientific research is successful not only include the number of journal articles, but also, for example, the importance of the journals in which they appear or the frequency with which scientific papers are cited by other research groups. Meanwhile, for universities, students' assessment of how well they are supervised is also considered a mark of quality. When it comes to factors such as these, many Chinese research facilities are still struggling. In the QS World University Ranking, for example, which takes into account the academic reputation of universities and the ratio of faculty to students, Chinese universities have yet to achieve top rankings. However, the universities of Beijing and Tsinghua still landed among the top 20, which already puts them ahead of German universities. The best German universities here are the TU Munich in 37th place, the Ludwig Maximilian University of Munich (54) and the University of Heidelberg (87). For many observers, the increasing number of high-level publications and the steadily improving placements in rankings is a sign that

SUMMARY

China wants to become the leading scientific nation on earth. The country's research facilities already publish the highest number of scientific articles. However, the quality of the articles is still mediocre in many cases.

The former maxim of "learning from the West" is increasingly being replaced by China's aspiration to emerge as an independent player in science. However, a "Chinese model" is not yet discernible

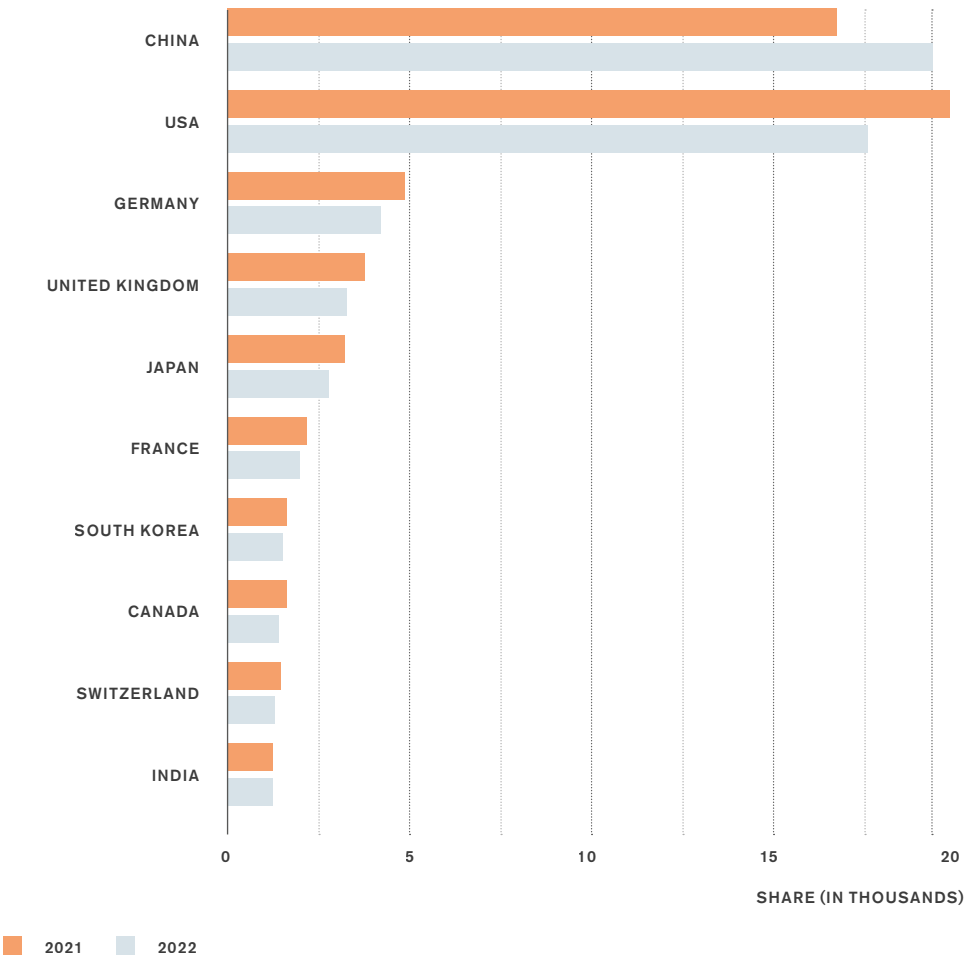
Under Xi Jinping's leadership, the state is once again exerting a much stronger influence on science than it did under his predecessors. Goals are often set by the state once again.

Massachusetts Institute of Technology (MIT)
University of Cambridge
Stanford University
University of Oxford
Harvard University
California Institute of Technology (Caltech)
Imperial College London
University College London
ETH Zurich – Swiss Federal Institute of Technology
University of Chicago
National University of Singapore (NUS)
Peking University
University of Pennsylvania
Tsinghua University
The University of Edinburgh
EPFL
Princeton University
Yale University
Nanyang Technological University, Singapore (NTU)
Cornell University
The University of Hong Kong
Columbia University
The University of Tokyo
Johns Hopkins University
University of Michigan-Ann Arbor

GRAPHIC: GCO BASED ON A TEMPLATE BY QS WORLD UNIVERSITY RANKINGS 2023

Ranking of top universities: The QS World University Ranking is based on the analysis of criteria such as academic reputation, number of international students and international research networking. The top 10 still includes only US and European universities.

China is on the rise, while Western countries are losing ground. The Nature Index tracks authors of research articles published in 82 selected high-quality natural and health science journals. The graphic shows each nation's contribution to the index based on the percentage of researchers who are listed as authors on each article. China gained 2600 points between 2021 and 2022, while the US lost 2200 points, ceding its leadership position to the People's Republic. The amount of articles from other Western countries has also fallen.



GRAPHIC: GCO BASED ON A TEMPLATE BY NATURE INDEX, ANNUAL TABLES 2023

the quality of research and teaching in China continues to rise. Ahlers' team is now investigating whether this is really the case.

Few research groups have examined the success of autocratic science in recent years as closely. Ahlers is getting to the bottom of the phenomenon using classic social scientific basic research. "We want to understand how scientific structures have developed in China and what influence the social environment has on research in the country," she says. Social science has already explained how China is able to succeed despite restrictions on free science thanks to its strong international connections, particularly with Western researchers. Now, however, the maxim "learn from the West" is no longer set to apply without restriction in the country. It wants to put its own stamp on things, such as having its own scientific publishers or withholding resources like research data. This would reduce the significance of international cooperation.

The Max Planck Group is therefore investigating the state of international networking. Anna Lisa Ahlers and her team not only analyze publications, as other researchers have done, but also look at the personal profiles of the Chinese scientists: their presence at international conferences or their educational background. The significance and forms of international networking are changing, to be sure, as the team has already established in its research. For example, Chinese scientific publishers and domestic dissemination of research results are becoming more important. "But there is no sign of a Chinese model yet," says Ahlers. The government's account of its own model therefore does not yet stand up to reality. Instead, the country continues to rely on international connections, while at the same time aiming to create new capacities and setting its own standards. Another aspect of international networking is the attractiveness of Chinese research facilities to foreign researchers. Despite the political circumstances, this attractiveness is fairly high because research projects are financed with extensive outside funding and laboratories are well equipped. The conditions under which European researchers work at Chinese universities are also a topic for Ahlers' team. The data so far shows that,

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Mao statue and party slogan on the campus of Tongji University in Shanghai: "Learn the thoughts [of Xi Jinping] to strengthen the party spirit. Put practice to work to achieve new successes."

PHOTO: ANDREA BROWN STŘELCOVÁ

although their numbers have increased, only very few researchers want to stay in China for the long term. "China is becoming more attractive, but only up to a point," Ahlers says.

Problems such as air pollution or the circumstances of family life discourage many foreign researchers from making a long-term commitment to the People's Republic – despite the high budgets and modern laboratories. In contrast, the group found that Chinese students are now somewhat less likely to be drawn to study abroad. The pandemic played a role here, but so did increasing geopolitical tensions between the People's Republic and the West. In addition, as Chinese educational opportunities have improved, young Chinese people are staying put more often – and this is also for cost reasons. This development could promote the emergence of a Chinese model.

African research without the colonial baggage

The researchers look at very different disciplines in their studies. This ranges from the humanities and social sciences to agriculture, climate research, and computer science. For example, they are interested in the debates surrounding the use and devel-

opment of artificial intelligence. The team is examining whether, for instance, there are less stringent ethical standards for artificial intelligence (AI) research and development in China than there are in Europe. This has led the researchers to conclude that the differences in scientific approaches to AI and its development to date are not necessarily due to different ethical and moral standards. It rather found that Chinese AI research is under high pressure to publish results and also commercialize them.

Part of Ahlers' group also conducts research on Chinese regional studies in Africa, for example, focusing on the researchers' approach and the interaction of their research with the country's foreign policy. The official interpretation of the Chinese studies is: our African studies are free of colonial baggage. The Max Planck projects in this area will shed light on whether the claim is true and how this attitude and other, possibly political, motives are reflected in the work of Chinese researchers on other world regions. But the researchers are also concerned with the question of how significant China really is as an intellectual player on a global level.

In general, the relationship between science and politics plays a major role in the work of the research group. The team therefore also analyzes the period before Xi Jinping became the most powerful person in China and took tight control over the state and society. Under Xi's predecessors Jiang Zemin and Hu Jintao in the 1990s and 2000s, researchers enjoyed greater autonomy than they do today. This is also evident in the academic think tanks in China. For years, think tanks enjoyed relatively broad freedom; today, they are to a large extent exclusively affiliated with universities or government agencies. In addition, their work is now subject to greater restrictions. According to Anna Lisa Ahlers, think tanks no longer have as much access to comprehensive data as they once did. Additionally, the government's willingness to be openly consulted has decreased, as have the opportunities to share information and proposals with it. As a result, discussions about political issues and reform strategies are becoming less multifaceted.

The overall situation for researchers in China has gotten much worse, and goals are increasingly being formulated at the state level to a much greater extent than ever before. Science searches for solutions with a strong emphasis on pragmatism. Until Mao's death, scientists were "partially paralyzed" by strong ideological control and lack of resources. This changed in 1978 with the implementation of Deng Xiaoping's policy of Opening-up, which emphasized a comparatively liberal approach toward science as a means to modernize the nation. Since Xi Jinping became head of the party, he has consistently emphasized the significance of scientific and technological advancement for China's rise on the global stage, as well as the need for the party to exercise complete control over these developments. In fact, Ahlers is once again seeing significantly more caution among Chinese scientists in their dealings with politics as well. The resulting questions are: Do scientists discuss what they are researching? Do they present their theses to party cadres, or do they prefer to say what these want to hear? And what are the consequences? Moreover, the increased politicization of science suggests to international partners that researchers from China often travel with a dual role, especially abroad. In addition to their research questions, they are also expected to keep China's interests in mind. What evidence is there of a political mission that need not even have been explicitly issued?

It is not easy to gather evidence for such sensitive topics. Anna Lisa Ahlers' group uses methods such as interviews to collect data. However, there has been growing skepticism and concern among interviewees about talking to foreigners at all. The researchers therefore supplement their findings with media reports, political documents, and as diverse a range of other material as they have access to. Other barriers to research exist as well, some of which are very practical. The Covid-19 pandemic, for example, made the task much more difficult. The group had actually planned to participate in regular research residencies in China. Ahlers herself was able to travel to the country for the first time in years in late summer of 2023. Her plan to accompany parts of a Chinese polar mission, which aimed to investigate the link between scientific and political-diplomatic tasks, also had to be canceled. To investigate this topic further, part of Ahlers' team is now analyzing the publications of Chinese polar researchers in more detail.

China research should become interdisciplinary

In addition, Ahlers believes there are challenges for China research as a whole. "To ensure access to the field, I think that research on important topics must be conducted using an interdisciplinary approach." People who study China's climate from a sociological or cultural science perspective, for instance, increasingly need to participate in on-site expert discussions that, ideally, include specialists from meteorology, atmospheric chemistry, and other fields. Ahlers' previous experience has shown that all those involved can benefit from this. She says that this is also an opportunity for the natural science disciplines to gain additional access and to better contextualize and control data. Ahlers also advocates strengthening internationally comparative projects to make research on China less exoticized and to make findings more generalizable. "It would be good for China research to develop in this direction. But this is of course an additional component that presents a challenge," says Anna Lisa Ahlers. Even so, she concludes, the Max Planck Society offers her excellent opportunities to meet this challenge.

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ILLUSTRATION: LUISA JUNG FÜR MPG

OTHER COUNTRIES, OTHER PENSIONS

TEXT: MECHTHILD ZIMMERMANN

Which country has the best pension system? The researchers at the Max Planck Institute for Social Law and Social Policy are often confronted with this question. However, there's no simple answer: each country has its own structures that have been developed to ensure its citizens are provided for financially in retirement, and each have their advantages and disadvantages. Ulrich Becker and Simone M. Schneider have developed a visualization of the institutional structures of old age pension systems that provides an overview of these systems and enables comparisons between them.

Emotions are quick to run high when the issue of pensions is raised. In France, President Emmanuel Macron's pension reform at the beginning of 2023 led to mass protests, strikes and riots. In Germany too, pensions are frequently the subject of heated debate. Germans often look to Austria, where the pension system seems to function better than at home. However, it is worth taking a closer look at how pensions there and in other countries are organized in order to evaluate the different systems.

Ulrich Becker, Director at the Max Planck Institute for Social Law and Social Policy, had the idea to create just such an overview. It was realized with the help of scientist Simone M. Schneider, who no longer only conducts research at the MPI, but also at Pompeu Fabra University in Barcelona within the scope of her ERC project on social security systems. Together, they developed a visualization of old age pension systems in various countries: the Pension Maps. The subject of study was exclusively state organized and subsidized pension schemes. After all, everyone is free to make a private provision for their old age, for example, in the form of real estate or equity investments.

When looking at the Pension Maps, there is one thing that sticks out right away: as a rule, there are three pillars or layers of the pension system. The first is the statutory pension scheme. It constitutes a predominantly pay-as-you-go system, meaning that the pension contributions of working people are directly redistributed to older generations. Occupational pensions form the second layer: in most cases, a portion of the salary is invested by the employer for old-age provision. The third layer is made up of private pensions: with incentives from the state, working people save money with a private pension fund to gradually use it up in retirement. In almost all countries a part of the population is not covered by the pension system. For these people and for all those who do not manage to save a sufficient amount during their working lives, a basic level of tax-funded retirement income is generally provided.

In all other aspects, the systems are designed very differently: the relative significance of the individual layers varies from country to country, and with that the proportion of retirement income that comes from a particular scheme. In some countries, there is a large state pension fund, which provides pension benefits to the vast majority of the population. In others, there are multiple statutory pension schemes operating in parallel, for example, to provide for civil servants or specific professions. There are also differences regarding which pension schemes are mandatory and which are voluntary.

Together with researchers from around the world, Ulrich Becker and Simone M. Schneider have created Pension Maps for 29 countries. The Maps are modeled on a single person, who starts working life in 2020 and thus joins the pension system as a contributor. We will present five examples on the following pages.

The charts displayed below are simplified depictions of the Pension Maps from the research project (more information at https://t1p.de/hxu3l)

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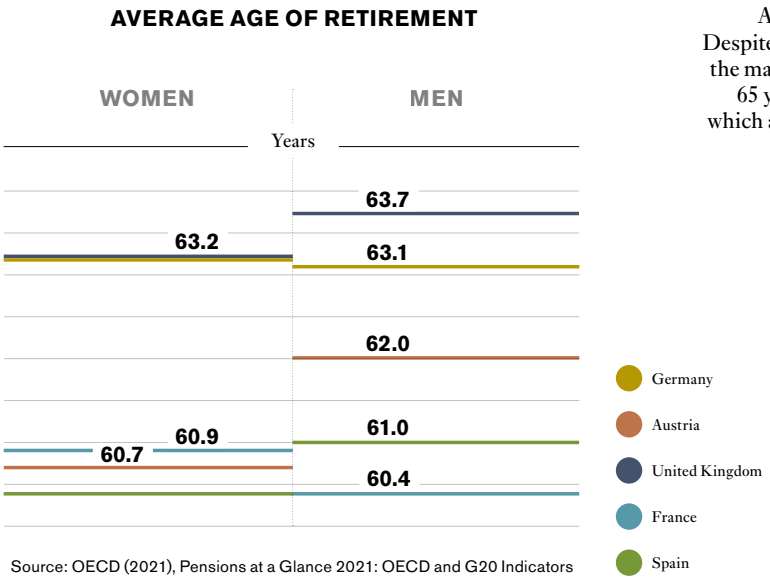


Source: OECD (2021), Pensions at a Glance 2021: OECD and G20 Indicators

A preference for early retirement: Despite the official age of retirement in the majority of countries being around 65 years of age, there are exceptions which allow many professionals to take early retirement.

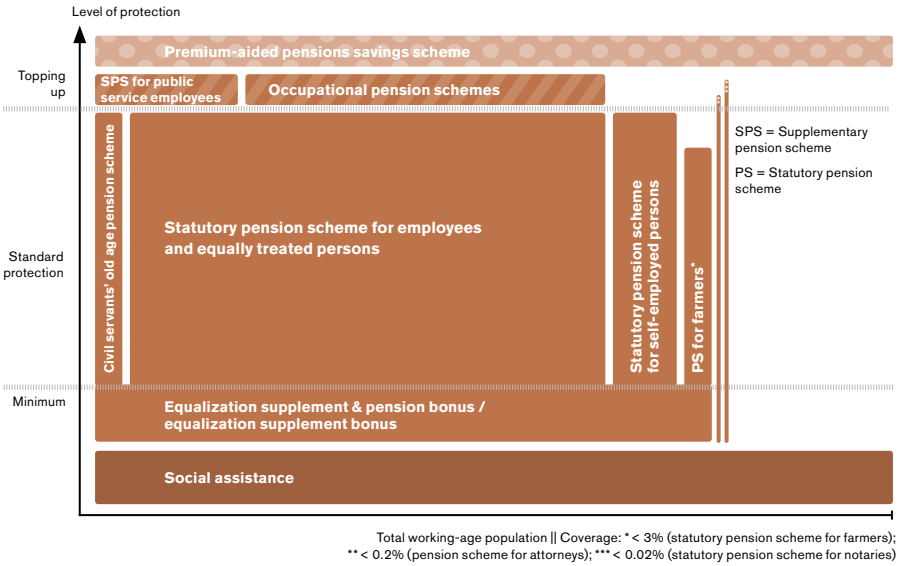
CHARTS: GCO, ADAPTED FROM INFORMATION PROVIDED BY THE MPI FOR SOCIAL LAW AND SOCIAL POLICY

Germany

Employees in Germany are compulsorily insured under the statutory old age pension scheme, as are certain groups of self-employed people, e.g. those in the trades and arts. However, the majority of self-employed people must enroll in a private pension scheme. Germany's statutory old age pension scheme is funded on a pay-as-you-go basis; contributions paid by working people are directly redistributed to pensioners. By contrast, the pensions of civil servants are financed from taxes. Farmers and some liberal professions, such as lawyers, architects, artists, or pharmacists, have their own pension schemes. Employees can save a portion of their income tax-free with occupational pension schemes; there is a mandatory supplementary pension scheme in place for public service employees. In addition, the state supports private pensions: under a scheme known as the Riester pension, those covered by the statutory old age pension scheme, civil servants, and farmers can invest money for their old age into a private pension fund that is subsidized by the state. The Rürup pension scheme functions in a similar way, but it is accessible to the entire population.

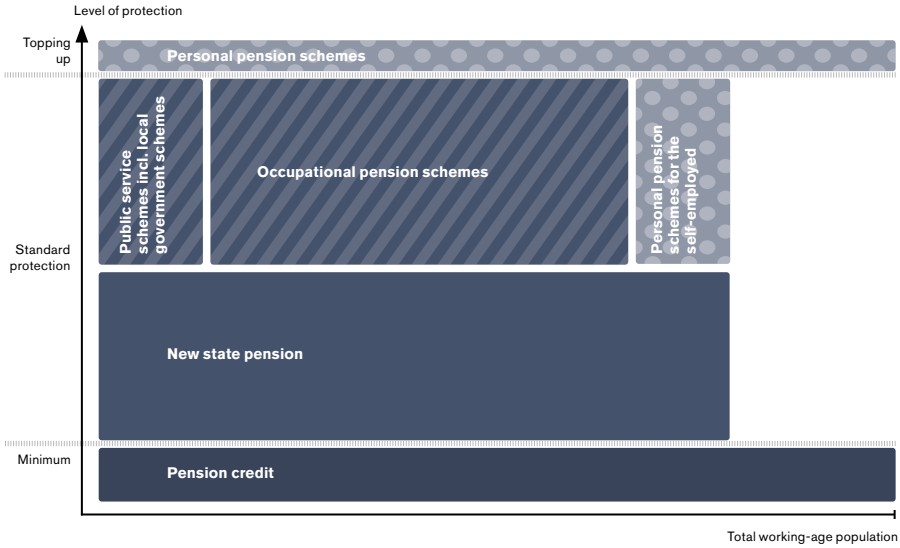
Austria

The Austrian pension system is often seen as a role model in Germany. At first glance, its structure is quite similar to the German one: there is statutory old age pension insurance for employees, which covers the large majority of the workforce. The pension system for civil servants was integrated into the statutory old age pension insurance and, unlike in Germany, operates on a pay-as-you-go basis. A further difference is that all self-employed persons are included in the statutory old age pension insurance. While the system does also contain occupational and private pension schemes, they nonetheless play only a marginal role. This can be attributed to the fact that the statutory pension is well above the EU average. Nevertheless, social law expert Ulrich Becker definitely sees weaknesses in the Austrian system too. First, the contribution rate is higher than in Germany, meaning that there is a greater burden on the working generation. Second, there is debate about how future-proof the system is: "If the demographic ratios deteriorate, it is difficult to react quickly with a pay-as-you-go system," says Becker. Consequently, he explains, the majority of countries have a mix of various forms of financing.



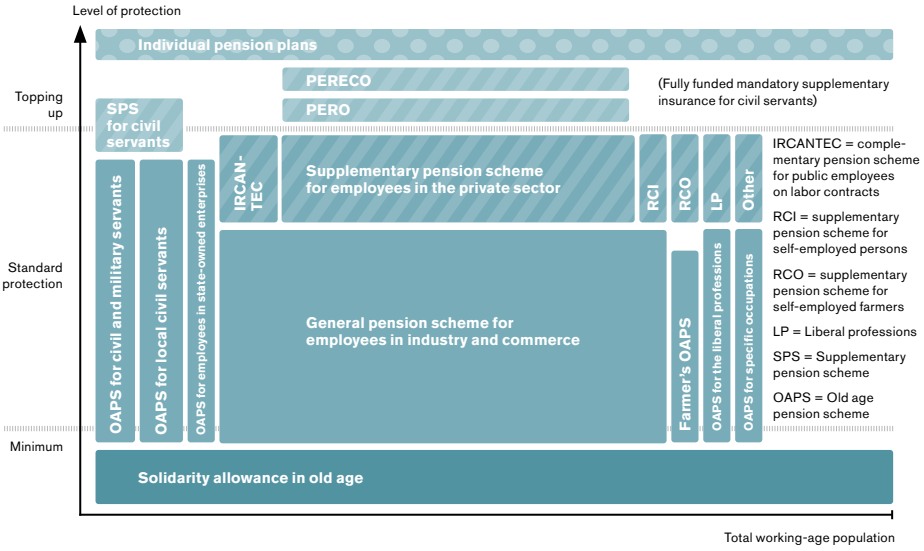
United Kingdom

In the UK, the pay-as-you-go state pension scheme not only covers salaried employees, but also civil servants and self-employed persons. Overall, however, it plays a markedly smaller role than in, for example, Germany or Austria. The new state pension in the UK guarantees only a basic, *flat-rate* income, which is the same for all pensioners, irrespective of individual pension contributions or income. Conversely, occupational pension schemes have traditionally been very strong: employers are obliged to enroll their employees in an occupational pension scheme. Employees do have the option to *opt out*, but they must actively choose to do so. The contribution amount for occupational pensions is set at eight percent of the income, split between employer, employees, and the state, whereby the employer must contribute a minimum of three percent. If self-employed persons wish to achieve a similar level of provision to that of employees, they must enroll in a supplementary, personal pension scheme. Like other countries, the state incentivizes the use of private and occupational pension schemes with tax breaks.



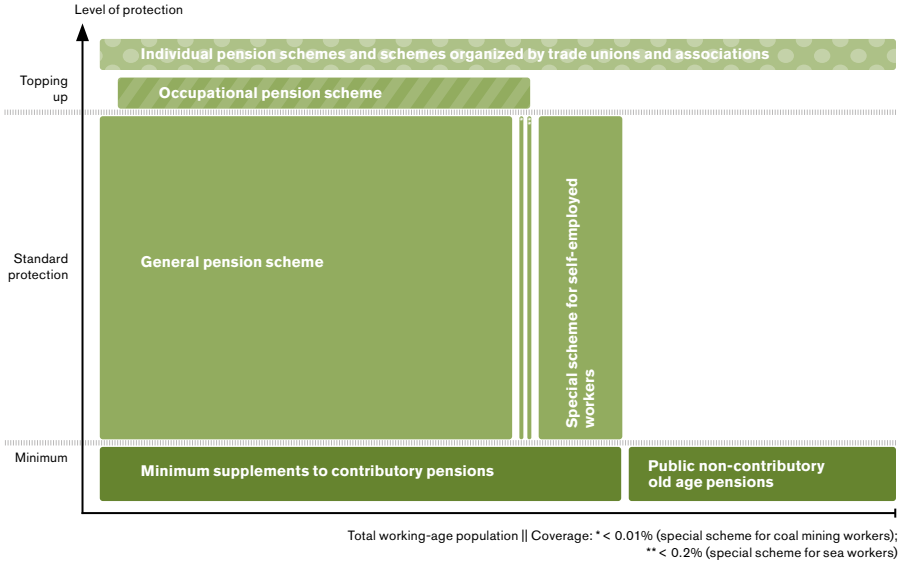
France

The statutory pension system in France is highly fragmented, with divisions according to occupational group and type of employment. For example, dancers at the Opera of Paris have their own scheme. Employees and self-employed persons, who do not fall into one of the special groups, are insured by the general scheme for employees in industry and commerce. Most employees are also required to pay into an occupational pension scheme, which – unusually – are largely pay as you go. Employees and employers must contribute a fixed percentage of the salary to these schemes, in addition to contributions to the statutory pension. Civil servants in turn pay into a fully funded supplementary pension scheme. Generally speaking, the official retirement age is 67. Anyone who has worked for 43 years or who accepts deductions can retire at the age of 62. Many make use of this option. However, according to President Macron's pension reform, the minimum age of retirement will rise to 64. This resulted in fierce protests against the reform in spring 2023. Ulrich Becker surmises that the latent fear of dwindling solidarity in society was also a cause of the outrage.



Spain

Employees and civil servants are all covered under the statutory old age pension insurance; there is also an additional statutory provision for self-employed persons, among others. Occupational pension schemes and private pension schemes play a much smaller role. In comparison with the other maps, the empty space next to the statutory systems is striking. However, this does not mean that most Spaniards are not covered by a pension scheme. Nevertheless, the range indicates that a relatively large proportion does not pay into the pension system – because people are already drawing a pension at working age (before the age of 65) or are not working. Spain is battling with a particularly high rate of youth (aged 18 to 24) unemployment (according to Eurostat, the figure was 40 percent in 2020). Spanish citizens above the age of 65 who have not paid into the general pension scheme, but are in need receive a special minimum supplement to contributory pensions.



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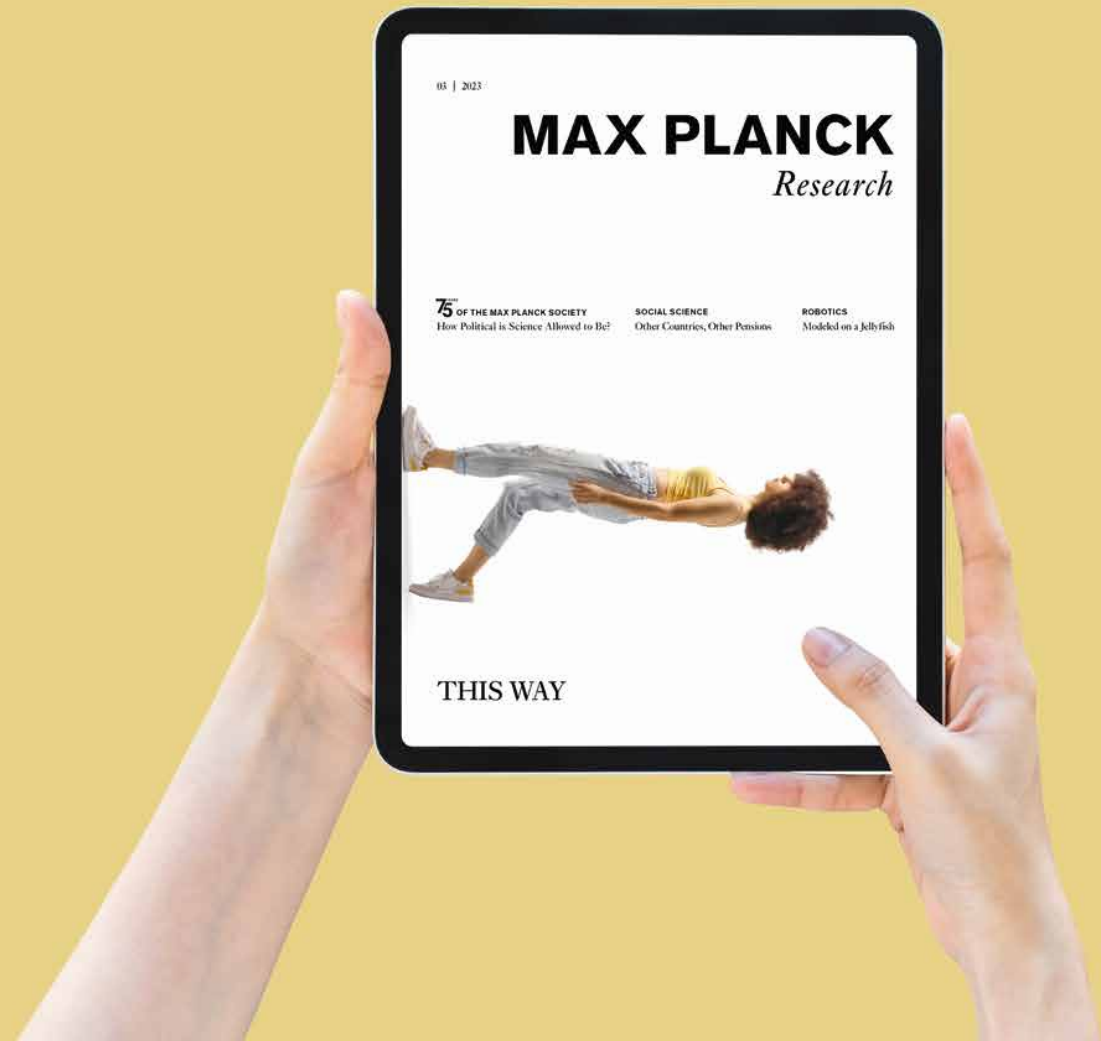

Efficient swimmers: Jellyfish move through the water with very little energy. Their propulsion therefore serves as a model for swimming robots.

PHOTO: SCIENCE PHOTO LIBRARY / SEMENOV, ALEXANDER

MODELED ON A JELLYFISH

TEXT: TIM SCHRÖDER

They're not the most popular of sea creatures, but they set standards in terms of underwater propulsion. A team from the Max Planck Institute for Intelligent Systems in Stuttgart has designed a robot based on the cnidarians, not least because jellyfish swim very efficiently. In the future, jellyfish-bots could help to remove plastic waste from particularly sensitive ecosystems such as coral reefs.

There is something meditative about the way jellyfish slowly pulse through the water, contracting their bell and gliding silently and at a leisurely pace. Their graceful movements have already inspired various research groups around the world to mimic jellyfish in their laboratories. The result is typically an apparatus that makes a lot of noise and whose mechanics consume a relatively large amount of energy. In terms of grace and smoothness, they cannot hold a candle to real jellyfish. But now a team from the Max Planck Institute for Intelligent Systems in Stuttgart has come very close to the model presented by nature. The researchers have constructed a lightweight, silent, economical jellyfish robot that steers through the water with gentle strokes. The jellyfish-bot can cover six centimeters in one second – it may not be lightning fast, but it is a typical speed for a jellyfish.

And the jellyfish-bot can do more than just paddle through the water. In place of a closed bell, the roughly palm-sized device has six arms that can each be controlled individually. This enables it to swim and grasp objects at the same time. "Our aim was to develop a jellyfish robot that we could use to fish plastic waste and other debris out of the ocean," explains robotics expert Tianlu Wang, a postdoctoral researcher who works in Metin Sitti's Physical Intelligence department in Stuttgart. "Obviously, we won't be able to use devices like this to retrieve the many millions of tons of plastic waste from the ocean. Rather, we're thinking of using them in particularly sensitive ecosystems, such as coral reefs." Since the jellyfish-bot travels silently, it does not startle fish and other animals. Swimming tests in the pond behind the Institute building have already demonstrated this. The researchers placed the jellyfish in the water, allowed them to sink a little, and then triggered the swimming movement via remote control. The jellyfish promptly rowed silently back to the surface without disturbing the animals in the pond. The jellyfish-bot is made of lightweight plastic. This makes damaging corals virtually impossible.

At the heart of the jellyfish-bot are so-called Hasel muscles. "Hasel" stands for *hydraulically amplified self-healing electrostatic-actuator*s – quite a mouthful for what is really a straightforward bit of electro-engineering. The Hasel muscles are small plastic bags filled with liquid that are squeezed together under electric voltage, changing their shape in the process. They were developed several years ago by a group led by Christoph Keplinger, the current Managing Di-

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rector at the Stuttgart Institute. Essentially, the bags work according to the capacitor principle. A capacitor is an electrical component consisting of two electrodes separated by an insulating layer, the dielectric. When a voltage is applied to the capacitor, one electrode becomes positively charged, the other negatively charged, creating an electric field between the two electrodes separated by the dielectric. The researchers take advantage of this effect in the Hasel muscles. The plastic bags are covered on both sides with a very thin electrode. The liquid inside of them serves as an insulating dielectric. Under voltage, the positively and negatively charged electrodes attract each other like the opposite poles of two magnets – and the soft little bag is squeezed together. The challenge is to design the bags in such a way that they perform precisely defined movements when the field is switched on and off.

In the case of the jellyfish-bot, this works perfectly. The arms of the jellyfish-bot consist of several segments that are flexibly connected to each other. Each of these segments is equipped with a Hasel muscle. If the researchers apply a voltage, the muscles contract and bend the jellyfish arm like a finger. By rhythmically switching on and off, the arm stretches and bends – the perfect swimming motion!

"The only issue was that Hasel muscles had never been used underwater before," says Wang's colleague Hyeong-Joon Joo, who works in the Robotic Materials department. "That meant we first had to make the electronics watertight." Hyeong-Joon Joo opted for common and, most importantly, cheap materials – the crucial requirement for the robots actually being put to use in the future. For example, he wrapped the jellyfish-bot's arms and inner workings in film made of PET, a common synthetic polymer often used for plastic bottles. For the dielectric fluid in the Hasel muscles, he uses silicone oil. In the future, different materials could be used to increase the robustness and service life of the robot. Biodegradable substances could also be used.

Film sandwich with electric drive

Altogether, the jellyfish-bot consists of several layers: A film that gives the arms rigidity and ensures that they extend again when the electric field is switched off; the flexible electrodes; the polymer films that encase the liquid dielectric; and the waterproof PET film. In addition, the middle of the jellyfish contains small floating bodies and a small weight that keeps the jellyfish upright like a weeble-wobble. In most experiments, the researchers

PHOTO: WOLFRAM SCHEIBLE FOR MPG

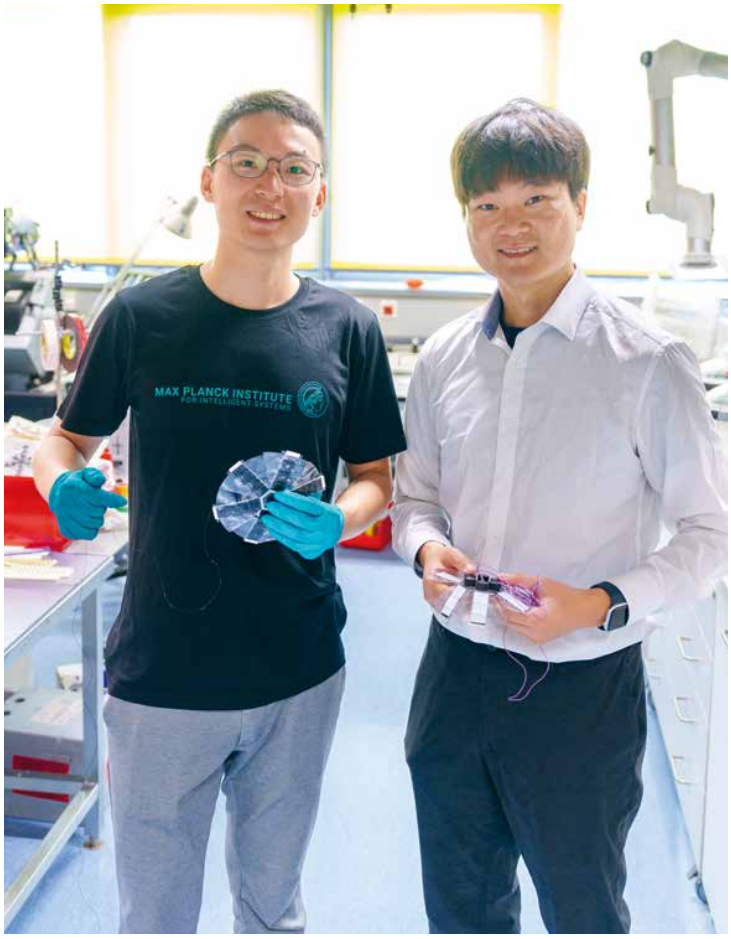
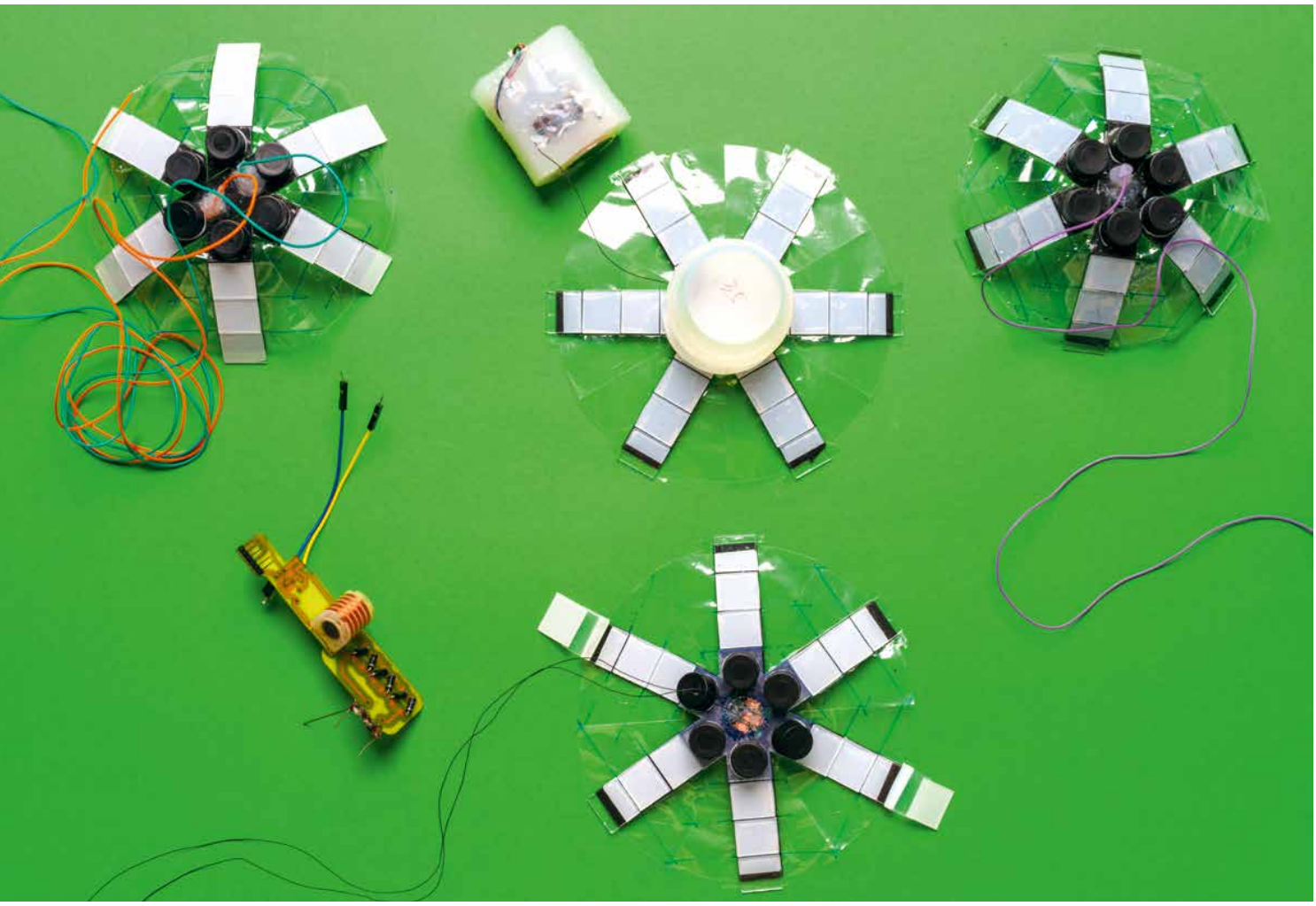


PHOTO: WOLFRAM SCHEIBLE FOR MPG

Combined competence: Robotics experts Tianlu Wang (left) and Hyeong-Joon Joo, who have further developed the artificial Hasel muscles for underwater use, among other things, have made the jellyfish-bot swim.



Robot zoo: The Stuttgart team has developed various versions of a jellyfish robot. In the basic version, all arms are controlled together (top right). In two further developments, the arms are controlled in two groups (top left and bottom middle) – some of the tentacles can be used for swimming and some for gripping. For control via cables, the researchers use external electronics (bottom left), but the jellyfish-bot can also be navigated wirelessly (top center).

SUMMARY

With the help of Hasel muscles, a robot – a jellyfish-bot – can swim in an energy-efficient manner, similar to a real jellyfish.

Because jellyfish-bots are made of soft components and are powered silently, they could be well suited for picking up plastic debris in particularly fragile ecosystems such as coral reefs and mangrove forests, or for taking marine biology samples.

supplied the jellyfish robots with power and controlled them via cables, because the on-board battery only allows very short swimming trips.

It took a lot to get this film sandwich to float, says Tianlu Wang, who was responsible for the electrical engineering. For instance, it was not enough to simply install a capacitor; when the current is switched off, a capacitor does not fully discharge immediately. This means that the arms do not fully extend right away. If you simply switch a capacitor on and off, the movement ends in a convulsive tremor. As a result, additional resistors had to be installed in the jellyfish to allow the capacitor to discharge quickly. One of the biggest challenges, however, was to put the jellyfish-bot, which is only 16 centimeters wide, under high voltage. That's because to generate an electric field strong enough to compress the liquid-filled bags, a voltage of around 10 kilovolts is needed – a value more commonly found in the motors of electric cars and scooters. "We had to customize everything perfectly for this to work," says Tianlu Wang: "The thickness of the dielectric so there's no spark discharge between the electrodes, the thickness of the films, and a few other things."

Until now, Wang says, fish or jellyfish robots have typically used small electric motors that operate at voltages as low

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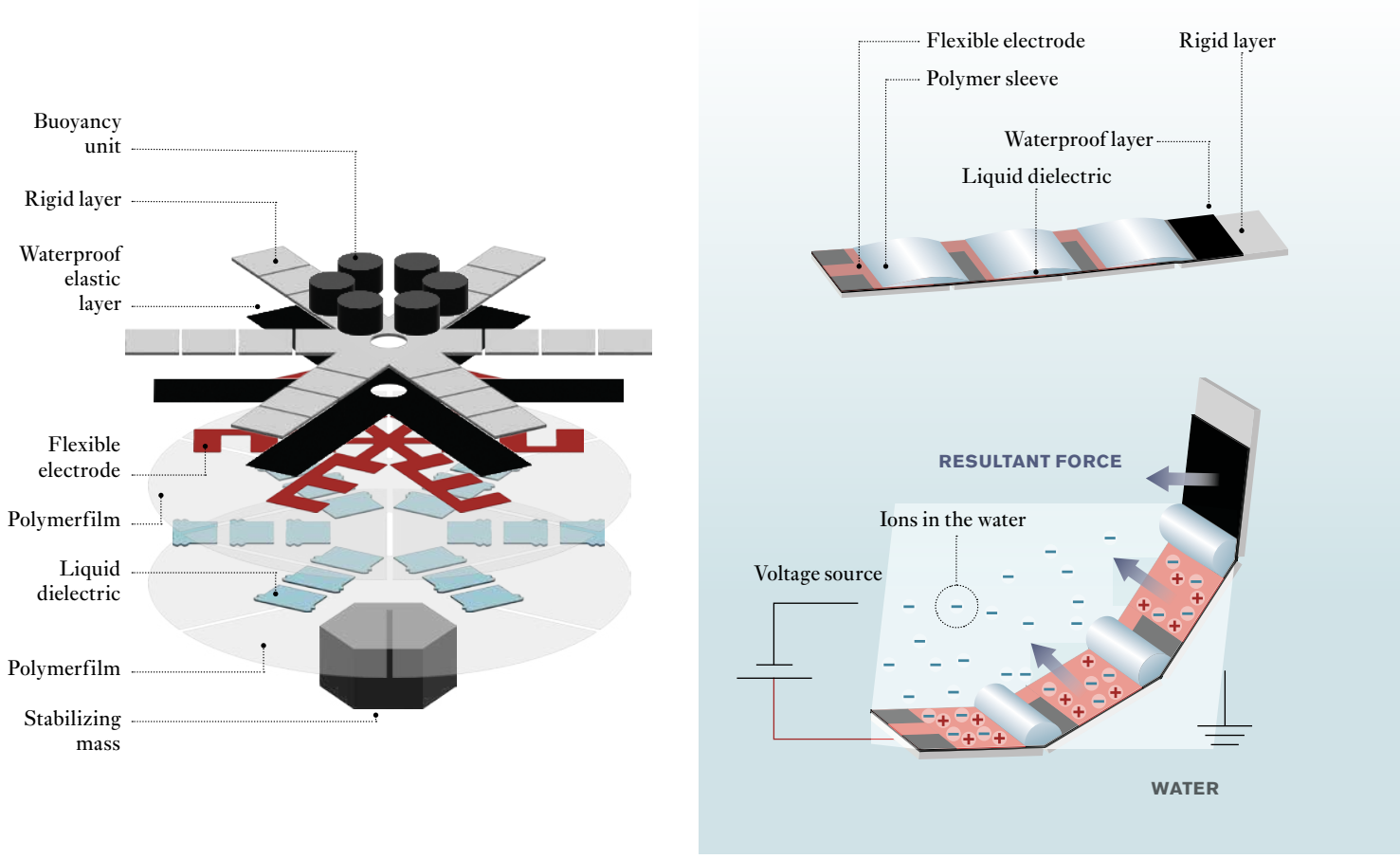

A moving sandwich: The jellyfish-bot is made of, among other things, waterproof film, flexible electrodes and a dielectric such as silicone oil. The combination of buoyancy unit and stabilizing weight keeps it upright in the water. Its arms bend when a voltage is applied to the dielectric (right). Ions in the water, but also the polar water molecules that attach to the arms, intensify the electric field and thus the contraction of the artificial muscles.

GRAPHICS: GCO ACCORDING TO WANG ET AL., SCI. ADV. 9, EADG0292 (2023)

as a few hundred volts. But these motors consume significantly more electricity. This jellyfish-bot, on the other hand, works with high voltage but only requires an electrostatic field to trigger movement. A small power output of around 100 milliwatts is sufficient for this – as much as a toy car. "Otherwise, there would also be far too great a risk of electrocution," Wang says. Despite its low wattage, a jellyfish-bot accomplishes quite a bit. Since its arms can be controlled individually, it can grip objects with two arms while the other four provide propulsion. Moreover, the robot can fan out its arms and use them to fetch small objects. This could help not only with cleanup, but also with marine research. For example, in the future, marine biologists could use it to collect fish eggs or other samples.

For more demanding underwater applications, the researchers would still have to equip the jellyfish robots with their own energy supply – such as solar cells on the rowing arms – as well as microchips for control and signal processing. Wang: "The necessary technology is already available today at a low cost." This would enable the swimming robots to work independently, i.e., without cables. While they will still probably be controlled remotely via radio for the foreseeable future, it is also conceivable that they will at some point act independently with the proper programming.

Soft robotics is gentle by its very nature

Aeronautical engineer Victoria Gerrlich of Bremen's Marum Center for Marine Environmental Sciences also thinks the jellyfish-bot is promising, and not only for underwater research. She is currently developing a "soft robotic" gripper in a project at the German Aerospace Center. In the future, it will be used for scientific observations in space, where water is found under ice sheets – for example on Jupiter's moon Europa, under whose ice mass geologists suspect there is liquid water. The gripper will one day deploy and retrieve an underwater vehicle equipped with sensitive sensors under the ice. "Soft robotics for use underwater is a totally new concept," says Gerrlich. "I can only imagine the long road our colleagues in Stuttgart have traveled with their jellyfish-bot." Many specialist articles have already been published on the subject of soft robotics for underwater applications. "Ultimately, it's so new that you basically have to design, build, and test everything yourself." For marine research, such grippers are essential –

not only for picking up trash, but also for collecting samples of plants or animals. Gerrlich: "Until now, hard grippers have been used for this purpose. They are equipped with sensors to ensure that they grip gently. But soft robotics is gentle by its very nature and can do very little damage. I think it's exciting that the Stuttgart researchers are working in this area." However, it is important to use biodegradable materials for such robots in the future so that they do not pollute the sea themselves, should they ever fail or become lost. As it turns out, materials expert Hyeong-Joon Joo of the Max Planck Institute in Stuttgart is already working on this.

In other respects, the Stuttgart team is already a step ahead: Tianlu Wang is particularly proud that he and his electrical engineering colleagues have succeeded in making several remote-controlled jellyfish-bots swim together. "In fact, our jellyfish can even cooperate," he says. He opens some photos on his screen. The images show two jellyfish-bots picking up a face mask from the bottom of an aquarium and swimming away with it. The Stuttgart team came up with the idea for this experiment when they saw pictures of coral reefs in the media during the Coronavirus pandemic in which more and more face masks were collecting alongside the usual plastic waste. Tianlu Wang: "I think it's entirely possible to clean up sections of the ocean in the future with a squad of jellyfish-bots. Not everywhere, but in ecosystems that are particularly vulnerable."

According to a recent study in the journal Nature, an international team of researchers found plastic waste in 90 percent of all coral reefs studied. A particular problem is plastic net debris that can get caught in corals and break pieces of them off. Coral reefs covered with plastic bags and sheets are also less well supplied with light, nutrients, and oxygen. And according to a study by the Alfred Wegener Institute, they are between 20 and nearly 90 times more likely to be infected with pathogens. Plastic waste is also particularly harmful in mangrove forests, which are often found at the mouths of tropical rivers. For example, the trees in these ecosystems no longer grow properly when their roots, which grow in the water, are covered with plastic waste. However, it will probably be a few years before swarms of jellyfish-bots are able to clean up sensitive ecosystems. So, the next goal is to supply the jellyfish-bots with on-board power. Then perhaps the first squad will soon be able to take off for a major ocean cleanup. ←

GLOSSARY

HASEL
stands for *hydraulically amplified self-healing electrostatic actuators*. These are synthetic muscles that are moved by squeezing a fluid-filled bag through the force of attraction between two capacitor electrodes. Hasel muscles enable robots to make smooth movements, such as when engaging with humans or in sensitive environments.

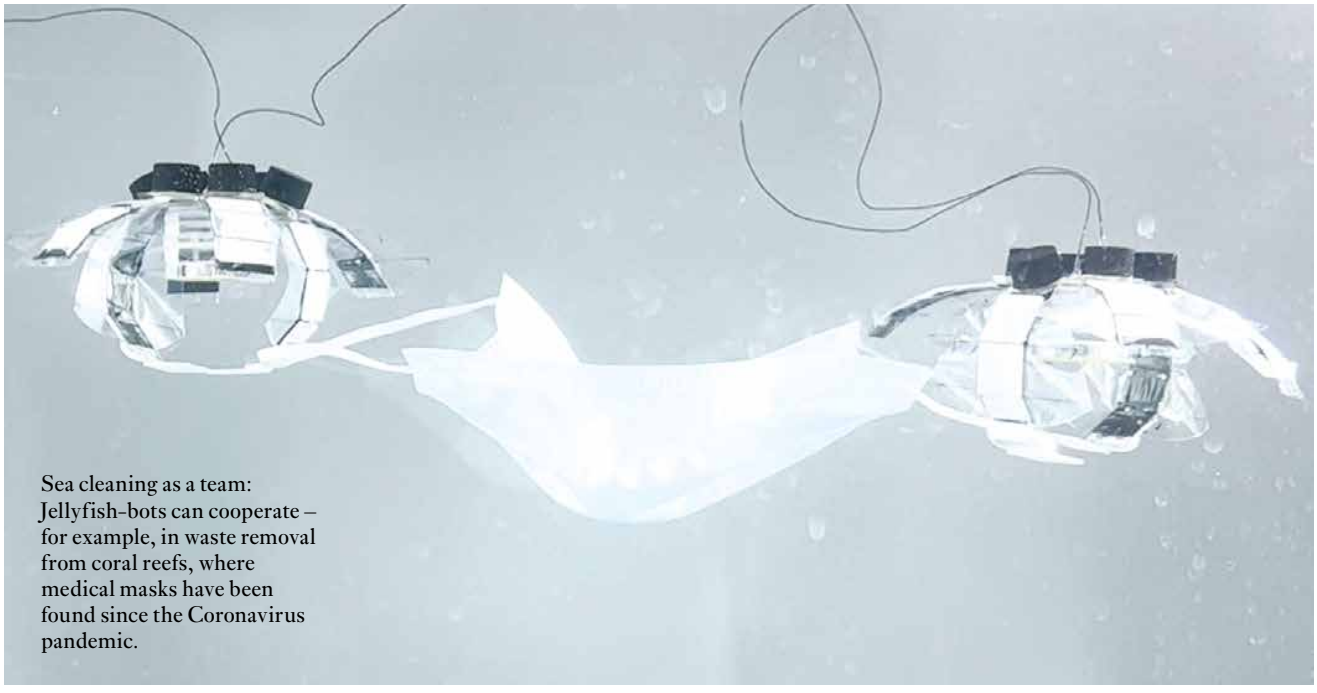

PHOTO: WANG ET AL., SCI. ADV. 9, EADG0292 (2023)

Sea cleaning as a team: Jellyfish-bots can cooperate – for example, in waste removal from coral reefs, where medical masks have been found since the Coronavirus pandemic.

PHOTO: MPI FOR CHEMICAL ECOLOGY

Both the fruits and the leaves of the wild blueberry are a sought-after food. Clabe Wekesa is researching how plants defend themselves against pests.

Max Planck researchers cooperate with partners in more than 120 countries. Here they write about their personal experiences and impressions. Clabe Wekesa from the Max Planck Institute for Chemical Ecology in Jena spends two summer months north of the Arctic Circle. Using wild blueberries, he is investigating how arctic light conditions affect plants' resistance to pests.

While some people go for a jog to get away from work, I grab my basket and go blueberry picking. As I stroll around, I find it a wonderful time for contemplation. Besides, the small berries that grow even by the roadside here taste simply delicious – much better than the much larger cultivated blueberries from the supermarket.

I've been in Tromsø in northern Norway for seven weeks now, nearly 350 kilometers above the Arctic Circle. Currently, I'm sitting in my office at the Arctic University of Norway, the northernmost university in the world. In front of me is a stack of publications on the blueberry *Vaccinium myrtillus* because my research also revolves around this plant. The goal of my project, which is financially supported by Velux Stiftung, is to determine what influence the constant brightness of the Arctic summer has on the plant's capacity to defend itself against pests. As climate change progresses, this question becomes increasingly important because with rising temperatures, many plant pests are spreading further and further north. In my project, I collaborate with colleagues from the local university. I compare plants that grow here at 69 degrees north latitude with those from Jena at 50 degrees latitude. For my analyses, I collect leaves from my experimental plants and preserve them in liquid nitrogen. Thanks to state-of-the-art analytical methods, I can later not only break down plant hormones and metabolic products in the laboratory, but even determine which genes were active in the leaf at the time of collection.

I owe the fact that I became a plant researcher to fortunate circumstances: I grew up in Kamukuywa in Bungoma, a remote village in western Kenya. My parents did not have even basic education, but they placed great importance on my three siblings and me attending high school. Afterward, I initially wanted to study pharmacy to research new active ingredients for medicine. However, the University entry requirements for pharmaceutical courses proved to be a real a challenge for me, so I enrolled in biochemistry instead and wrote my master's thesis in the field of plant biotechnology. I haven't regretted that decision for a second. Today, plants are the subject I find most fascinating! My professor at the time encouraged me to pursue a PhD. I was selected for a DAAD scholarship, and so I came to

POST FROM

TROMSØ, NORWAY

Jena, where I completed my doctorate as part of an International Max Planck Research School. I now live there with my wife, who is also from Kenya, and my three-year-old daughter. While I'm in Norway, we communicate every evening via WhatsApp or have video calls. Being away from my family is not easy, but as a scientist, you have to be flexible about where you work.

Otherwise, I'm enjoying my time in Tromsø. I'm fortunate with the weather; it's usually sunny, with temperatures reaching up to 25 degrees Celsius. On weekends, I go hiking or sit by the window of my third-floor apartment, gazing out over the sea and the mountains while programming on my laptop. Late in the evening, I often take walks through the streets or along the beach. The perpetual brightness is fascinating. Sometimes I even get up in the middle of the night to take pictures of the Sun. Perhaps one day, I'll manage to come here in winter. I would love to see the aurora borealis!

At the Arctic University of Norway, there are three research groups working on blueberries. The plant is also highly popular with the locals. Once, I had covered ten of my blueberry bushes in a small, forested area with black plastic caps to test the effects of light deprivation. The next time I visited, all the covers were scattered on the ground, and a woman was in the process of harvesting my test plants! She argued that the berries were common property, so it was not okay for me to claim the harvest for myself. Fortunately, the experiment could be quickly repeated – unlike a previous incident from an earlier stage in my career when cattle devoured the bean plants I had grown for my doctoral thesis. That mishap cost me three months!

PHOTO: PERSONAL

Clabe Wekesa

37, appreciates wild blueberries not only for their research value, but also as a delicious treat. The plant scientist comes from Kenya and pursued his studies at Kenyatta University in Nairobi. Since June 2023, he has been working as a postdoc in Axel Mithöfer's research group at the Max Planck Institute for Chemical Ecology, where he investigates how plants defend themselves against pests.

FIVE QUESTIONS

ON THE FUTURE OF THE AMAZON

FOR SUSAN TRUMBORE

In early August, representatives from the eight countries within the Amazon region came together for a summit on the future of the rainforest. In the discussion about the climate crisis, there is much talk of tipping points. What is a tipping point, specifically in the context of the Amazon rainforest?

SUSAN TRUMBORE: A tipping point is a critical threshold within the earth system. If you exceed this threshold, you move from one system into another. There is no going back. When rainforest is converted to pasture and farmland, less water evaporates and the area heats up. This makes it easier for fires to break out. At some point, the rain volume may become insufficient to supply the forest with water. In extreme cases, the rainforest becomes a savanna, though a degraded forest is more likely.

Where do you see a potential tipping point in the Amazon?

Theoretical models predict a tipping point at 20 to 25 percent deforestation. Meanwhile, the level of deforestation in the Amazon is about 15 percent, in some regions more than 20 percent. However, these models are based on an incomplete understanding of the situation. We do not yet know enough to give a concrete threshold value for a tipping point. Similarly, we cannot say with certainty which features – such as biodiversity – would be lost forever and which would recover over time. That's why we are carrying out experiments in Mato Grosso, a highly deforested area, which looks like a patchwork of forest remnants between soybean fields. Here we measure the carbon and water exchange in order to understand how the forest and the local climate react to dryness and deforestation.

How do you convey the urgency of action, while speaking about uncertainties at the same time?

It's difficult. We have been talking about climate change for many years. Things didn't start to happen until people were personally affected for the first time. Just because we don't know the precise tipping point for the ecosystem doesn't mean that we shouldn't be worried or even keep cutting down trees. For me, the biggest problem is that biodiversity and biomass have already been irretrievably lost in some areas. Human interference occurs over very short periods of time, and vegetation is extremely slow to respond to these changes. So, we should take steps to better look after what we have.

What impact do you think the Amazon summit will have for the future of the rainforest?

I think that Lula da Silva, President of Brazil before 2011 and again since 2023, has made genuine pledges to reduce deforestation. In his first term, he had already placed large areas of forest under protection. The Brazilian Forest Code of 1965 regulates deforestation. Those who own private land in the region may only deforest and farm 20 percent of it. Official title deeds exist for only 10 percent of the land; far more is illegally appropriated. The agreement reached at the summit gives countries the courage to enforce existing laws and sends a signal that socio-economic challenges should be tackled collectively. Soy fields, for example, are worth much more than an intact forest, financially speaking. Without the Amazon fund, to which Germany is contributing again, there would be no incentive to conserve the forest. The fact that deforestation is illegal is only marginally helpful. We have to be realistic and pay enough to ensure that the value of keeping the forest intact increases. By intensifying the use of already deforested land, Lula also wants to show that economic growth is possible without further deforestation.

What can we do as individuals?

Eat less meat. The majority of soy that is cultivated in Mato Grosso is sent to Germany for use as pig feed. You can also offset your carbon footprint, for example, by planting trees in the Amazon region. It would make even more sense to preserve the original rainforests with their enormous biomass. These store more carbon than renewable trees.

Interview: Tobias Beuchert

Susan Trumbore is Director at the Max Planck Institute for Biogeochemistry.

ILLUSTRATION: SOPHIE KETTERER FOR MPG

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