effzett

FORSCHUNGSZENTRUM JÜLICH'S MAGAZINE

2-23

Making AI fit

This needs the right training, computing power and a realistic assessment of capabilities

IMPROVEMENT
Preventive troubleshooting makes PV modules last longer

AMALGAMATION
Linking intelligent biochips with body cells

ENLARGEMENT
New devices and buildings for electron microscopy

↑

Fascinating fibres

Will it break or will it hold? While the edges look splintered, the central fibre bundle appears tough and unbreakable. This robustness fascinates Jülich fusion and materials researcher Alexander Lau. He analyzes and optimizes materials that could one day be used for the walls of nuclear fusion reactors. His scanning electron microscope image, which took second place in the "Participants Choice Award" at the Helmholtz Best Scientific Image Contest 2023, shows artfully interwoven tungsten fibres in a tungsten matrix. Finer than a human hair, these fibres are expected to significantly increase the resilience of the material.

Further images of the tungsten fibres (German):
go.fzj.de/effzett-wolframfasern

NEWS

COVER STORY

RESEARCH

SECTIONS

Man or machine?

In 1966, Joseph Weizenbaum developed a programme that is now considered as the mother of all chatbots: ELIZA. It imitates psychotherapy – and does this so well that many test subjects willingly poured their hearts out and attributed human feelings to the programme. The trick is: ELIZA asks questions and searches for terms in the answer that appear in its dictionary. If the programme finds a match, it displays a suitable phrase or question from its collection, or else it moves on to a new topic. The success of the algorithm consternated Weizenbaum – particularly the fact that some people seriously wanted to use the programme in therapy. For Weizenbaum, it was absolutely clear that ELIZA was only providing the illusion of a conversation. He remained an admonisher of computers and AI for life.

Today, many people – including Jülich researchers – see AI as an upcoming key technology that Germany should not miss out on. The clever programmes are already in use in some areas. Our cover story reveals how AI should be dealt with in science and what Jülich is doing with AI. We also tell about intelligent biochips, ways of detecting faulty solar modules and an amused scientist.

We hope you enjoy reading!
Your *effzett* editorial team

Publication details

effzett Forschungszentrum Jülich's magazine, ISSN 1433-7371

Published by: Forschungszentrum Jülich GmbH, 52425 Jülich, Germany

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Graphics and layout: SeitenPlan GmbH, Dortmund, Germany

Translation: Antje Becker, ROTPUNKT·Texte & Bild, Marburg, Germany

Images: Forschungszentrum Jülich/Markus Axer (34-35 (background)); Forschungszentrum Jülich/Sascha Kreklau (3 right, 10, 21, 28, 36-38); Forschungszentrum Jülich/Alexander Lau (2); Forschungszentrum Jülich/Ralf-Uwe Limbach (6 top, 7 top right (portrait), 9, 13, 17 right, 19, 26 (all portraits) and bottom, 33 bottom); Juri Barthel/Forschungszentrum Jülich (24-25 centre); Annalisa Bonafede (5 top); Mareen Fischinger (17 left, 34 (portrait)); Thomas Gulde/KIT (7 left); A. Husmann, M. McCartney, C. Boothroyd, R. Dunin-Borkowski (24-25 (front image)); Diana Köhne (27 (illustration)); C.J. Moeser, JetPhotos (23 (plane)); Georg Pöhlein (7 top left (portrait)); Markus Retzlaff @ Forschungszentrum Juelich (39); SeitenPlan (11 (illustration)); 29 (graphic design/illustration); SeitenPlan with Stable Diffusion and Adobe Firefly (cover, 3 left, 8, 12, 14-16, 18, 20 bottom); E. Simpson, Y. Hayashi, T. Kasama, R. Dunin-Borkowski (26 (background)); J. Thong, K. Harada, A. Tonomura, T. Akashi, T. Matsuda, Y. Togawa, C. Boothroyd, R. Dunin-Borkowski (24-25 (back image)); Michael Wodak/MFK (20 top, 22 left (portrait)); ZAE/Kurt Fuchs (30 bottom); all motifs mentioned below are from Shutterstock.com: hvostik (3 top centre, 22-23 (background illustration)); Lidiia (32-33 top); Loke Yek Mang (5 bottom); Sophon Nawit (3 bottom centre, 30-31 top); Andrey_Popov (40); spacezerocom (27 (background)); Bjoern Wylezich (6 bottom)

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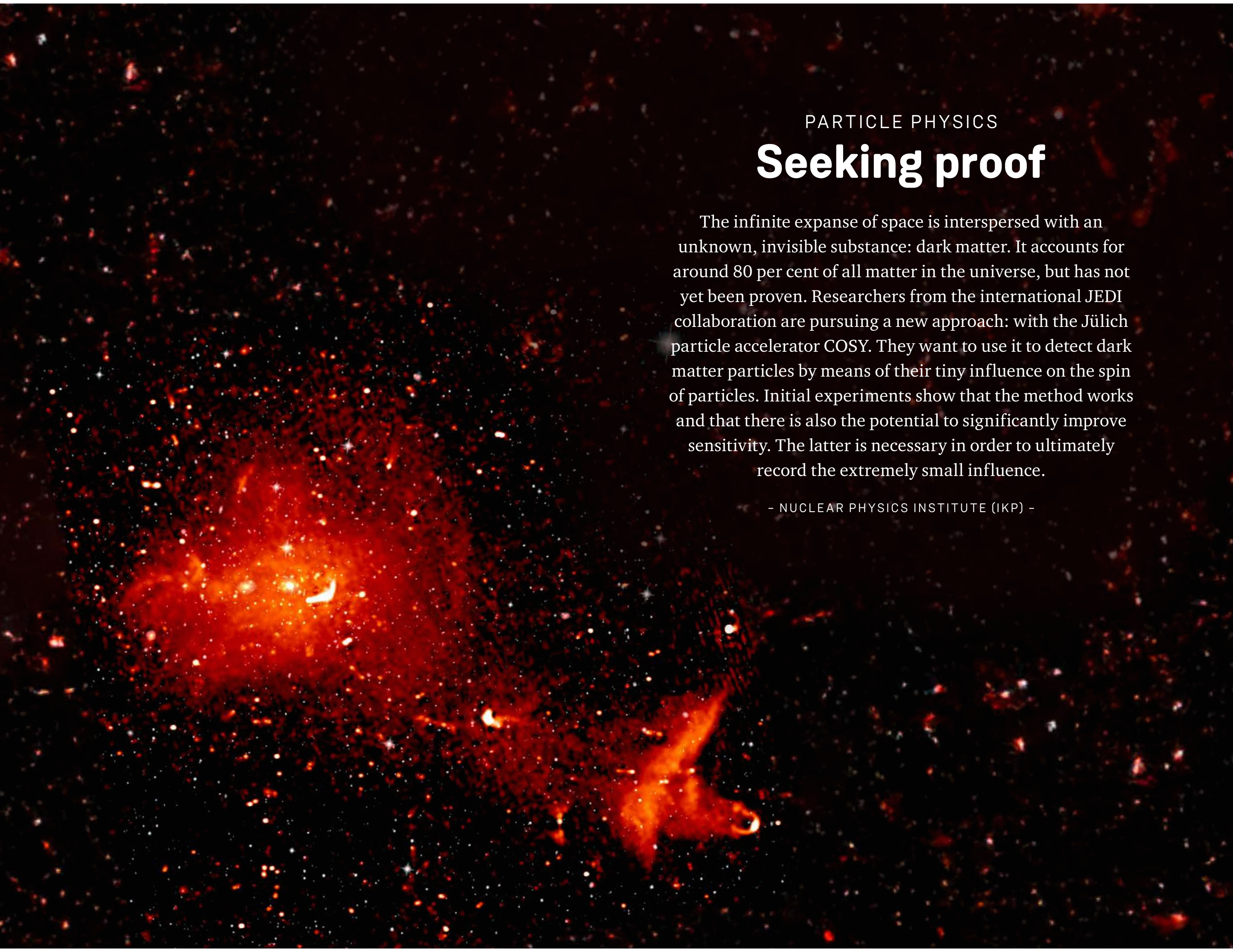


PARTICLE PHYSICS

Seeking proof

The infinite expanse of space is interspersed with an unknown, invisible substance: dark matter. It accounts for around 80 per cent of all matter in the universe, but has not yet been proven. Researchers from the international JEDI collaboration are pursuing a new approach: with the Jülich particle accelerator COSY. They want to use it to detect dark matter particles by means of their tiny influence on the spin of particles. Initial experiments show that the method works and that there is also the potential to significantly improve sensitivity. The latter is necessary in order to ultimately record the extremely small influence.

– NUCLEAR PHYSICS INSTITUTE (IKP) –

BIOTECHNOLOGY

Deep-sea enzyme breaks down plastic

Deep-sea organisms produce an enzyme that breaks down the plastic PET. This could help to combat the increasing pollution of oceans and coasts with, for example, plastic bottles made from PET. The enzyme is the first of its kind to be discovered in the deep sea. It has a different structure to previously known PET-degrading enzymes. It can decompose PET fully and is more efficient at 70 degrees Celsius than comparable enzymes at their optimum temperature. The new enzyme was discovered and decoded by researchers at Kiel University (CAU) with the participation of scientists from Jülich, Düsseldorf and Hamburg.

– INSTITUTE OF BIO- AND GEOSCIENCES (IBG) –

“In order to be successful, excellent research needs a lively exchange both internally and externally.”

Prof. Astrid Lambrecht – Chair of Forschungszentrum Jülich’s Board of Directors since 1 August 2023 – is convinced that the major challenges of our time can only be solved through interdisciplinary cooperation. In the future, Forschungszentrum Jülich will work even more closely with science, industry and politics to this end – in the region, nationally and internationally. The 56-year-old quantum physicist joined the Board of Directors in 2021. She was previously director at the Centre national de la recherche scientifique (CNRS) in Paris.

MATERIALS RESEARCH

“Metallic” relative

2D materials like graphene have unique properties and are seen as a future beacon of hope, such as for the semiconductor industry. Researchers from Jülich, India and Australia produced a metallic relative of graphene: molybdenum, a layer of the metal molybdenum with a thickness of just one atom. Molybdenum is suitable as a measuring tip for atomic force microscopes, for example, due to its stability and its exceptional electrical and thermal conductivity.

– PETER GRÜNBERG INSTITUTE (PGI) –

ENERGY RESEARCH

Save it, don’t spray it

Dimethyl ether, or DME for short, is used as a propellant in many deodorant spray bottles. Jülich scientists propose an additional future use of the gas: for storing hydrogen in order to transport it by ship over very long distances. Green hydrogen produced in Australia, for example, would be converted into DME on site with CO_2. The resulting gas could be stored in a similar way to butane in a camping gas cylinder – ideal for shipping in a storage tank. Once arrived at its destination, the hydrogen would be released again. The second decomposition product, CO_2, would be transported back and reused.

– INSTITUTE FOR SUSTAINABLE HYDROGEN ECONOMY (INW) –

ATMOSPHERIC RESEARCH

The influence of water vapour

Water vapour is the main natural greenhouse gas in the Earth's atmosphere. It roughly doubles the effects of anthropogenic greenhouse gases such as carbon dioxide (water vapour feedback). Models of the Intergovernmental Panel on Climate Change (IPCC) show quite well how the water vapour content in the lowest layer of the atmosphere, the troposphere, is changing. This is not the case for the transition to the next higher layer, however, the stratosphere. In collaboration with an international team, Jülich researchers have succeeded in greatly reducing the deviations between model calculations and satellite measurements. These improvements also help to better assess the influence of water vapour on wind systems and to thus improve weather simulations.

– INSTITUTE OF ENERGY AND CLIMATE RESEARCH (IEK) –

RESEARCH FUNDING

ERC Grants for pioneering projects

Two Jülich researchers can look forward to funding of up to €10 million over the next six years: Prof. Carsten Sachse and Prof. Karl Mayrhofer each received a Synergy Grant from the European Research Council ERC. The grants support pioneering projects that, due to their complexity, cannot be realized by individual groups alone. The team led by Carsten Sachse, director at the Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons (ER-C), is working with partners from Germany and Switzerland to develop a cryo-electron microscopy method that can be used to examine the 3D structure of molecules in tissue samples and biological cells in even greater detail. The team led by Karl Mayrhofer, director at the Helmholtz Institute Erlangen-Nürnberg (HI ERN), will work together with researchers from Denmark, Germany and Switzerland to find long-lasting catalyst materials for the production of hydrogen.

– ERNST RUSKA-CENTRE FOR MICROSCOPY AND SPECTROSCOPY WITH ELECTRONS (ER-C)/HELMHOLTZ INSTITUTE ERLANGEN-NÜRNBERG (HI ERN) –

1,000,000,000,000,000,000

– in words: one quintillion or one million times one million times one million. The first European exascale supercomputer JUPITER can perform this many floating point operations per second. This is equivalent to the computing power of ten million modern notebooks. Designed for simulations and AI applications in science and industry, the computer is scheduled to go into operation at Forschungszentrum Jülich in 2024.

– JÜLICH SUPERCOMPUTING CENTRE (JSC) –

Further information at: fz-juelich.de/jupiter

The long summer of AI

The artificial intelligence boom has only just started. With its unique computer infrastructure and technical expertise, Jülich can make an important contribution.

← This and all other illustrations in the cover story were created with the help of artificial intelligence.

Artificial intelligence is no modern-day phenomenon. As early as 1966, the language program ELIZA was able to trick computer users into believing that they were having a dialogue with a real person. In the 1970s, the first expert systems were established to help make complex decisions on the basis of their knowledge base. The MYCIN programme, for example, suggested antibiotics to combat bacteria in blood infections. Some 15 years later, however, interest in AI was rapidly declining. The algorithms had been unable to fulfil the high expectations, so disappointment spread. This also reduced the financial support for ambitious projects.

This paralysing phase has gone down in the history of artificial intelligence as the "AI winter". It lasted for over a decade. But times have changed, says Dr. Jenia Jitsev from the Jülich Supercomputing Centre (JSC): "We are at the beginning of a long AI summer. The fruits are ripening. AI systems are currently delivering results that are revolutionary, for example in speech and image processing. And there's currently no indication of a fundamental blockade that could lead to another ice age."

↑ Artificial intelligence expert: Jenia Jitsev

QUALIFIED FOR UNIVERSITY

The computer scientist heads the Scalable Learning & Multi-Purpose AI Lab at JSC. He is firmly convinced that artificial intelligence will be the key technology of the 21st century. Language programmes such as ChatGPT have demonstrated the power of the technology to many people outside professional circles. With the programme, it is possible to conduct conversations in natural language. It writes speeches, poems and summaries, it programmes – and, passing the Bavarian "Abitur", has even earned the university entrance qualification.

At the same time, the algorithm does not have a deeper understanding of the relationships it is writing about. It has been fed with an unimaginably large amount of text data from electronic books and websites. Using this data, it has independently worked out how a language works – with what probability a certain word follows another.

"Of course, these chatbots still come with certain uncertainties. Not everything they say should be taken at face value. When it comes to scientific uses in particular, we need to take a close look at how plausible the AI's results are," Jenia Jitsev points out (see also p. 12). "As sophisticated tools, however, AI systems could take over a whole range of tasks for us in the future, much like a personal assistant."

A large language model is currently being co-developed at Jülich: As the European counterpart to the established systems, OpenGPT-X will be geared entirely to the needs of the continent. For example, it complies with European data protection regulations. It is being trained at Jülich in German using high-quality sources.

> **"Europe has both the necessary computing power and expertise in software development to be innovative in AI."**
>
> THOMAS LIPPERT

The "engine" behind this chatbot is categorized as a foundation model. These are powerful algorithms that have been pre-trained with a large amount of largely unstructured data. They can be adapted to specific tasks in a second training step, for example as an assistance system in medicine that helps doctors make diagnoses or choose a therapy. It is these foundation models that are largely responsible for the current AI boom.

Models of this size require powerful, customized hardware. That is exactly what Jülich can offer: "For years, we have been working with partners to develop ever more powerful computers and provide AI computing time for scientists at JSC," explains JSC director Prof. Thomas Lippert, adding, "In particular, the installation of the GPU-based JUWELS booster in 2020 – one of Europe's fastest supercomputers – proved to be groundbreaking for the use of AI models." (see box)

Around 60 projects that utilize AI and machine learning methods are now running on the JUWELS mainframe, such as – in addition to OpenGPT-X – the image model of the German LAION initiative, on which the Stable Diffusion image generator is based. It creates detailed, professional images based on short descriptive texts. "These AI models need not take a back seat to commercial models from the USA," says Thomas Lippert. "But they have the advantage that they are published as open source and are comparatively secure in terms of data protection."

ENABLING BREAKTHROUGHS

In addition, Europe's first exascale computer, JUPITER, will go online at Jülich in 2024 and break the mark of one trillion computing operations per second. JUPITER, too, has a GPU booster module, which enables unique breakthroughs in the field of artificial intelligence. As part of the European supercomputing initiative EuroHPC JU, the system will be available for AI applications in research and industry.

After all, Jülich is not only laying the foundations for using AI by developing and improving AI models. Artificial intelligence also delivers results for various Jülich research areas, for example in the life sciences, medicine and neurosciences, such as in the detection of brain tumours (see p. 20). Machine learning also helps with the exploration of new materials or weather forecasting (see p. 18).

However, experience to date shows that the transfer of AI knowledge from research to industry in particular can unlock further potential: whereas Germany is one of the leading countries in terms of the number of scientific publications on artificial intelligence, only one in eight companies in

What are GPUs?

Graphics processing units are perfect for training the deep neural networks that are behind most high-performance AI algorithms. While the GPU computing cores are not quite as powerful as those of universal processors (CPUs), there are significantly more of them on a single processor. This allows the GPUs to process data in parallel to a high degree, which gives them a considerable speed advantage in machine learning tasks in which a large number of rather simple calculations have to be performed.

the country uses such technologies. The German government's AI action plan aims at helping to close this gap: around €1.6 billion are to be channelled into the research, development and application of artificial intelligence. The Jülich supercomputers with their AI boosters will play a major role in this. This is because one of the fields of action identified in the action plan is the targeted expansion of the AI infrastructure.

In an international comparison, the USA still dominates the AI market. Large companies such as Google and Meta, the Facebook parent company, in particular are investing in machine learning, and the AI sector in the USA, India and China is currently growing much faster than in Europe. Germany, France and Italy recently announced their intention to cooperate more closely in the development of AI – for there is still a lot to do to ensure that the long summer of artificial intelligence will not pass us by.

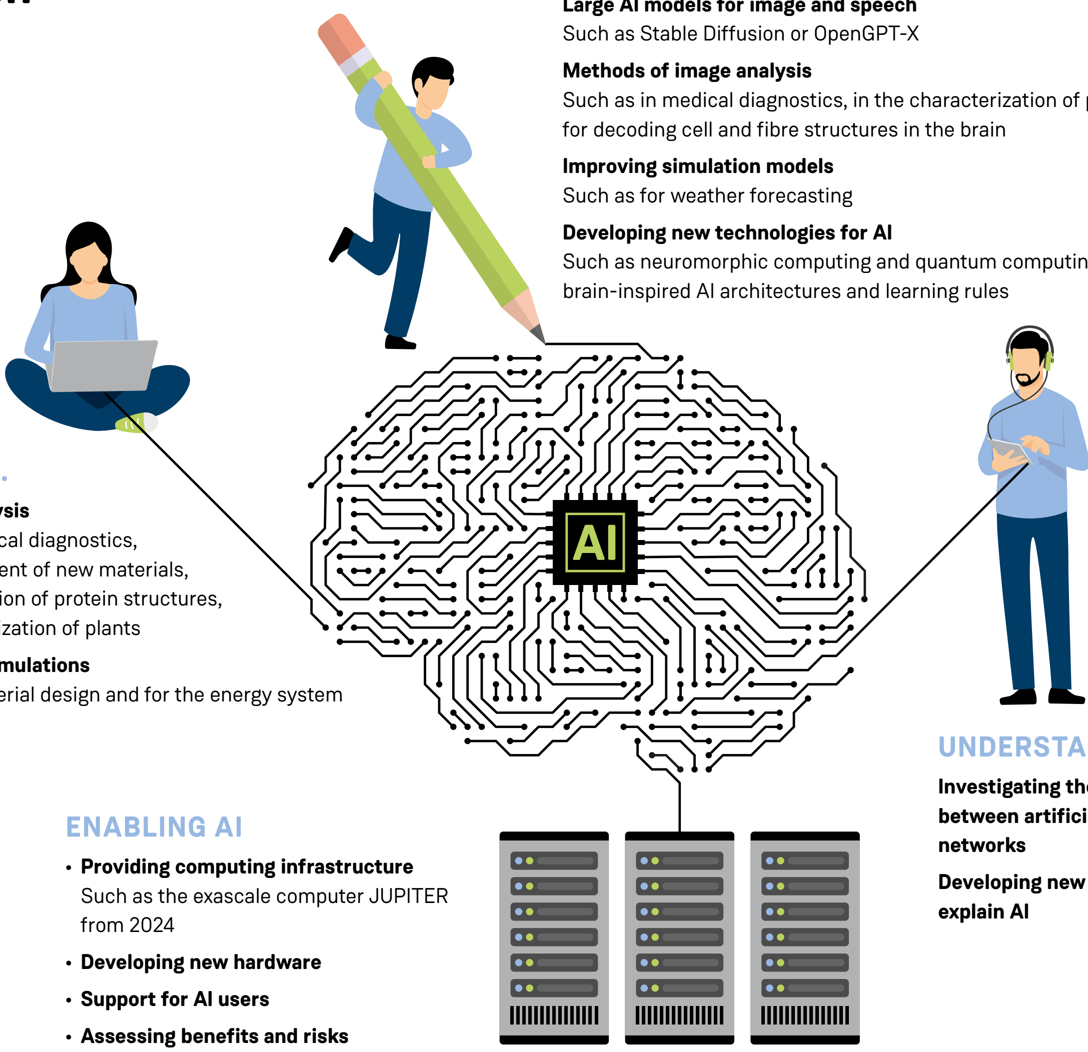
ARNDT REUNING

60

projects

that use AI and machine learning methods are now running on the Jülich mainframe computer JUWELS.

Artificial intelligence at Jülich



ADVANCING AI

Large AI models for image and speech
Such as Stable Diffusion or OpenGPT-X

Methods of image analysis
Such as in medical diagnostics, in the characterization of plants, for decoding cell and fibre structures in the brain

Improving simulation models
Such as for weather forecasting

Developing new technologies for AI
Such as neuromorphic computing and quantum computing, brain-inspired AI architectures and learning rules

USING AI ...

... for data analysis
Such as in medical diagnostics, in the development of new materials, in the investigation of protein structures, in the characterization of plants

... to improve simulations
Such as for material design and for the energy system

UNDERSTANDING AI

Investigating the relationships between artificial and biological networks

Developing new methods to explain AI

ENABLING AI

- **Providing computing infrastructure**
  Such as the exascale computer JUPITER from 2024
- **Developing new hardware**
- **Support for AI users**
- **Assessing benefits and risks**

Is it safe?

AI is continuing to establish itself as a tool in science. If you want to use it, you should also be aware of the limitations of these methods: to what extent can the results of an algorithm be trusted? How much control is possible?

Omniscient algorithms that write essays on any topic, write poems or summarize books in an instant; competent chatbots that talk like a human conversation partner; graphics programmes that, based on brief descriptions, create images appearing both photorealistic and surreal – the tools of artificial intelligence (AI) seem to have arrived at the centre of society.

AI has already been playing an important role in science for years – for example, as a diagnostic aid in medicine. Pattern recognition is a prime example: on computer tomography images of the brain, for instance, intelligent algorithms can detect critical aneurysms, which are dangerous dilations of blood vessels, or they can classify skin cancer into benign and malignant tumours.

↑ Jülich experts Bert Heinrichs (left) and Stefan Kesselheim recommend to always view AI results with a certain degree of scepticism.

Still, algorithms can also deliver incorrect results. “They might be right in 99 out of 100 cases and wrong once. Which makes it difficult: we often don’t even understand why they are wrong in this one case,” says Prof. Bert Heinrichs, who heads the “Neuroethics and Ethics in AI” research group at the Institute of Neurosciences and Medicine (INM-7).

The experts’ lack of understanding is due to the fact that the algorithms usually play their cards close to the chest. They do not make their decisions according to predetermined rules, but learn on their own. In the case of skin cancer detection, the AI is fed countless photos of malignant melanomas (malignant tumours). Using this training data, it searches for specific characteristics that characterize this form of cancer. The AI receives feedback as to whether it was wrong or right after each round.

On the basis of this feedback, the AI adjusts its search patterns. In this way, the AI’s results keep getting better over the course of the training. However, the specific characteristics of an image on which the AI bases its decision cannot easily be determined. It resembles a black box. For users, therefore, the recurrent question is: how reliable are AI statements? Can I trust the algorithms?

THINK BEFORE CALCULATING

“It’s often not so easy to answer these questions, particularly in research. In the case of a medical diagnosis, for example, I can have a doctor check whether a result is correct. But if the AI suggests a new material, I can’t be sure whether it will really do what it’s supposed to without testing,” says Dr. Stefan Kesselheim. He heads the Simulation and Data Lab “Applied Machine Learning” at the Jülich Supercomputing Centre (JSC), which supports research groups in implementing new AI applications. “An AI is always a complicated arithmetic formula that receives an input and produces a result. Before I get started, I need to think carefully about what I can use the result for. We also help with this assessment,” says Kesselheim.

The reliability of the delivered result depends on many factors: “Because of the black box problem, I don’t know exactly how the result came about.” The selection and type of data used to train an AI plays an important role in this. In general, according to the physicist, “The more extensive and varied the training data, the better the predictions.” Users need to be aware of these limitations in order to judge the validity of AI results. “AI is a powerful tool, but it’s not omnipotent – and it’s not really intelligent either,” cautions Kesselheim. “The methods often fail when it comes to generalizing the things they have learned to data that they have not seen during training.”

Like Kesselheim, Bert Heinrichs also recommends that AI results always be viewed with a certain degree of scepticism and the algorithm not blindly be trusted. As a philosopher, however, he struggles with the concept of trust. “Trust is a concept that originates in the interpersonal sphere: we trust other people, such as a doctor or a colleague,” he explains.

In colloquial language, however, we also use the term to refer to objects, he admits. “A mountaineer would probably say that they can trust their rope. This means they assume that the rope will not break the next moment,” explains Heinrichs. He prefers the term reliability to trust. Referring to AI, this means: “We must learn to assess its reliability – that is, to learn to deal appropriately with the fact that we can’t look into the black box – and develop methods which allow us to judge whether a result is meaningful,” says the Jülich researcher.

“We must learn to assess the reliability of AI – that is, to learn to deal appropriately with the fact that we can’t look into the black box.”

BERT HEINRICHS

Various criteria can be used to check whether a climbing rope is reliable: when purchasing, for example, by means of the European standard EN 892 or, in the event of wear, through visual, tactile and load tests. Comparable control criteria are required – and in some cases possible – for the results of AI as well. One example of is the research of Prof. Alexander Schug, who heads the NIC research group “Computational Structural Biology”. The physicist is interested in complex protein molecules. Fulfilling a variety of tasks in the organism, they offer an interesting target for drug development. For this, it is important to understand the detailed function of a protein in the body. The key to this is hidden in their three-dimensional structure.

CLOSING IN ON THE HOLY GRAIL

It is complex to determine this structure experimentally. For this reason, efforts have long been made to derive the molecular structure from the sequence of the individual building blocks. “This is the Holy Grail of structural biology,” says Alexander Schug. AI programmes can now predict the three-dimensional structure of any protein with astonishingly high quality – and in just a few minutes. Experimental determination, on the other hand, takes weeks, if not months. Another advantage of these AI methods: many provide not only a prediction, but also an assessment of the extent to which the result should be trusted. All the same, scepticism is also essential for Schug: “You must take a critical look at every calculated structure and ask yourself whether this result is plausible. And if there really are doubts, you simply need to test the whole thing experimentally,” says the Jülich researcher.

The results of AI processes cannot always be controlled by experts, however, as is the case with Prof. Timo Dickscheid’s research. He uses AI at the Institute of Neurosciences and Medicine (INM-1) to analyze huge amounts of image data from the finest slices of the brain. Among other things, the AI helps to recognize neuronal cells or to reassemble two-dimensional images into three-dimensional tissue on the computer. “Such algorithms are a widespread and very helpful tool in neuroscience today. Due to the large amount of data involved, however, we have to proceed differently than purely experimentally,” says Dickscheid.

A second AI programme can be used instead, working independently of the first AI and automatically taking over quality control. It compares, for example, how many cells the first AI programme marked when evaluating the image data from tissue sections and focuses specifically on detecting “surprises” in the data stream. If, for example, unexpectedly few cells are marked

in an image, the control AI raises the alarm. “It then reports, ‘The result looks somewhat strange, you need to look at it again manually’,” explains Dickscheid.

AVOIDING BIAS

Another control option is to shed light into the black box – by designing the algorithm in such a way that the results it delivers can be explained. “This is called Explainable AI, which in simple terms gives us an insight into the way AI thinks,” says Dickscheid. In medicine, for example, an AI of this type could explain in a short text why it suggests a certain diagnosis based on an X-ray image. To do this, the analysis tool is coupled with a language model that formulates sentences in natural language and explains why an aneurysm has formed here, for example, based on the thickening of an artery. “This model must of course be adapted to the respective application, that is it should be trained using specialist literature so that it can draw on a suitable pool of facts for its answers,” says the computer scientist.

Comprehensive training is generally the basis for reliable statements. There are pitfalls in this too, however, warns Bert Heinrichs: for some applications, there is simply not enough data available, for example when it comes to rare diseases, or it is extremely time-consuming to produce any data at all. In materials science, for example, it can take half a day to produce an image of ceramic coatings. In cases like these, it may not be possible to produce enough data in a reasonable amount of time.

But distortions can occur even if sufficient data is available. This happens when training is biased, for example, that is, when the training data is not balanced. “Such a bias can be quite subtle,” says Heinrichs. If, for example, a certain skin colour is disproportionately often represented in the

> "This is called Explainable AI, which in simple terms gives us an insight into the way AI thinks."
>
> TIMO DICKSCHEID

training images for skin cancer detection, this could lead to the AI learning an incorrect pattern and, thus, overlooking some tumours.

Another example is voice modules for chatbots such as ChatGPT, for smartphones or household appliances, where voice assistants respond to verbal questions and commands. One important point to keep in mind here is that language can be racist. Training data should therefore exhibit a certain degree of heterogeneity so that they do not distort the result in a particular direction.

THE HUMAN FACTOR

However, Heinrichs believes that researchers should always bear in mind that even when selecting data carefully, there is a risk of bias: "On the one hand, everyone in the world has a special perspective. This means that our value assumptions are always to some extent involved in the selection of training data, for example," he points out. "And secondly: we don't always know exactly what a heterogeneous training data set looks like. It's therefore not easy to anticipate possible bias."

The extent to which scientific experts can rely on an AI algorithm therefore depends on several factors. How well tested is the method? What are the controls? What initial data was available? The consequences of an incorrect result also play a major role. If the structure of a protein is incorrectly proposed in the development of a drug, this would become apparent in preclinical study at the latest. That would also be a kind of quality control.

The same applies to weather forecasts: on the one hand, results can be checked promptly, while on the other hand, errors are considered less dramatic, as today's weather forecasts are not always perfectly reliable either. The situation is somewhat different with climate models, the predictions of which relate to much longer time periods. "It would be highly problematic, for example, if an AI were to come to the conclusion that the rise in temperature could be stopped with a certain measure, and after implementing this measure, it turned out 20 years later that it doesn't work at all," Stefan Kesselheim points out. AI results should not be seen as the one single truth, but only as an indication, says the physicist.

"We need to maintain a kind of holistic common sense and keep reminding ourselves that these algorithms only see a snippet. AI can undoubtedly do certain tasks for us very efficiently, but when it comes to reliability, we must remain very vigilant and always critically scrutinize individual results," summarizes Heinrichs. So we will probably not be in a position to do without the human understanding of contexts and relations in the future.

ARNDT REUNING

↑ Control of AI results is possible: structural biologist Alexander Schug (right) needs elaborate experiments for this. For Timo Dickscheid, who works with images of brain slices, a second AI method or Explainable AI would be a better possibility.

AI with responsibility

Whether discrimination in a job application process or disinformation on the Internet: artificial intelligence needs an ethical and legal framework. In Europe, the AI Act is intended to ensure that intelligent algorithms are regulated. As a consultant for several research projects on AI in neurosciences and medicine, Bert Heinrichs has closely followed the legislative process: "The AI Act provides for AI systems to be categorized according to certain risk classes. The higher the risk, the stricter the manufacturers' duties of documenting and testing become. Applications in medicine, for example, always belong in this high-risk category." The philosopher's expertise is also in demand for the funding programme of the renowned European Research Council (ERC) – as a reviewer for the ethical evaluation of project proposals: "Among other things, we are also talking about aspects of possible discrimination here," explains the researcher. "If we know, for example, that an algorithm in medicine is not working properly for a certain minority due to a bias in the training data, then it is open to question whether public money should be spent on it."

Intelligent weather forecast

Artificial intelligence has found its way into weather and climate research as well, says Priv.-Doz. Martin Schultz from the Institute for Advanced Simulation (IAS). Just five years ago, meteorologists were sceptical about AI models, but the algorithms have now proven their efficiency.

What is special about AI models for weather forecasting?
Classic forecasting models are based on systems of equations that reflect the physics of weather events. They are so complex that they can only be solved with great computational effort, as they consist of a large number of individual equations that have to be calculated as closely as possible in spatial terms.

AI models, on the other hand, learn from the past. They are trained using historical weather data that goes back four decades. The AI models "memorize" what happened during this period and can use this knowledge to make predictions for the current weather conditions.

What are the advantages of AI algorithms?
Firstly, they in effect provide better predictions in certain areas than the classic models. Secondly, they are particularly efficient. Once an AI model has been trained, the costs for computing power go down significantly – they are around a hundred to a thousand times lower. This would allow forecasts to be updated much more frequently, for example every hour.

What restrictions apply to the new models?
The training is very time-consuming. The models only really pay off if you can manage with just a few training runs and can use the models for a long time. There are also areas in which AI algorithms are inferior to traditional models. A typhoon may be forecast earlier using conventional methods, while a cold snap may be predicted better by artificial intelligence. We are currently still gaining experience as to which model is more suitable in which case.

Why did many meteorologists have reservations about AI models for a long time?
AI predictions were not convincing until five years ago, as the state of the art at that time was simply not sufficient to generate reliable forecasts. The models were much smaller. They were not able to depict the complexity of the atmosphere. But this has now changed and the AI models have become considerably larger. The latest generation of AI models delivers results that are close to or even better than conventional predictions.

↑ Localized heavy rainfall can often only be announced a few minutes in advance. Martin Schultz hopes to be able to prolong the warning time with AI methods.

How can the predictive power of a model be assessed?
There are extensive methods for the evaluation of weather models that can also be used to assess AI models. This makes it possible to quantify how well the prediction patterns correspond to reality. The robustness of the models is also important, however, that is, how well they can predict situations for which there is no training data. There are first indications that large AI models have actually developed something like an understanding of the physics behind the weather based on the training data – without explicitly knowing these laws of nature. That gives us hope.

Are such models also suitable for long-term climate forecasts?
We are still at the beginning of research in this area. This is because simulations in climate research depend heavily on the boundary conditions, such as on CO_2 concentrations and ice sheets, for example. In other words, on variables that change over very long time scales. However, there is not enough data available on these variables. Hybrid models are therefore a current approach: at their core, they are classic physical models that work on a rather coarse scale. Only the small-scale processes, such as cloud formation, are calculated by an AI.

INTERVIEW BY ARNDT REUNING.

Detecting brain tumours precisely and quickly

Amino acid PET is an important tool in diagnosing brain tumours. However, determining the exact size of a tumour takes time and is not routine. An AI is set to change that. It can analyze PET images as well as experienced doctors – only much faster.

For the diagnosis and treatment of a brain tumour, it is important to determine the exact size and volume in order to be able to check whether the tumour is responding to treatment or whether it is continuing to grow. Clinics often use magnetic resonance imaging (MRI) for this, which specifically records structural changes in the tissue. However, these do not necessarily reflect the actual extent of the tumour. Another imaging procedure records the altered metabolism of the cancer cells and often provides results that differ from MRI: amino acid positron emission tomography (PET).

On the downside, determining the tumour volume using PET scans is very time-consuming. This is why the method is rarely used routinely. In the future, this is set to change – thanks to artificial intelligence (AI).

Researchers from Jülich, Heidelberg and Cologne have developed a deep learning algorithm called JuST_BrainPET* that automatically recognizes brain tumours on PET scans and determines their volume. The team used 699 PET scans from 555 brain tumour patients for this purpose. The AI results agree very well with the values that experts determine from PET scans. Plus: the AI only needs a few minutes to do this.

The research team also had the algorithm assess the chances of success of treating patients with gliomas, which are the most common malignant brain tumours. "The clinical assessment of the AI as regards the response to therapy and prognosis was just as good as that of a specialist – and it took only a fraction of the time," says principal investigator Priv.-Doz. Philipp Lohmann from the Institute of Neurosciences and Medicine (INM-4). "Our no-cost, freely available AI tool can't replace doctors, but it can support them. We hope that it will encourage doctors to use amino acid PET more frequently with brain tumour patients – especially if they have little experience with the method."

JANOSCH DEEG

↑ Philipp Lohmann is a researcher in the Brain Tumours research group.

How PET works

PET uses radioactively labelled biomolecules to make metabolic processes visible. Amino acids have proven particularly useful for the imaging of brain tumours. The rapidly growing cancer cells take up the amino acids much faster than the healthy brain cells. Based on the enriched amino acids, the PET images can be used to determine the location and size of the metabolically active tumour.

Download JuST_BrainPET: go.fzj.de/effzett-just-brainpet

* JUST_BrainPET: Juelich Segmentation Tool for Brain Tumor PET

↑

What are you researching right now, Ms Genzel?

Dr. Franziska Genzel, scientist at the Institute of Bio- and Geosciences (IBG-4)

"In the ToxPot project, I want to utilize the above-ground parts of the potato plant, that is, the leaves, flowers and berries. These have mostly ended up in the compost so far. However, they contain valuable substances: alkaloids, which make for interesting starting materials for bio-based plant protection products and the pharmaceutical industry. My colleagues and I are investigating how the cultivar, plant organs and developmental stage of the plants influence the content of known alkaloids. We also want to identify other industrially usable ingredients."

Household air pollutants

It is not only car exhaust fumes that pollute the air in our cities. Chemical substances in cleaning agents and cosmetic products also contribute to this. Georgios Gkatzelis is tracking down such sources.

↑ Organic trace gases are at the centre of Georgios Gkatzelis' research at the Institute of Energy and Climate Research (IEK-8).

The sky is blue, the view is good – Georgios Gkatzelis takes a quick photo of the impressive New York skyline, then turns his attention back to his measuring devices. With the instruments on board a NASA aircraft that was converted into a laboratory (see box), he and his colleagues capture the breath of big cities – or, more precisely, its components: mixtures of gases and tiny suspended particles, so-called aerosols. "Aerosols produced in cities pose a major threat to human health. A well-known example is car exhaust fumes and the soot particles they contain," says the chemical engineer with a doctorate who heads the "Organic Trace Gases" research group at Jülich. The measurements in the flying lab are part of AEROMMA, a measurement campaign on air quality and climate over North America conducted in the summer of 2023.

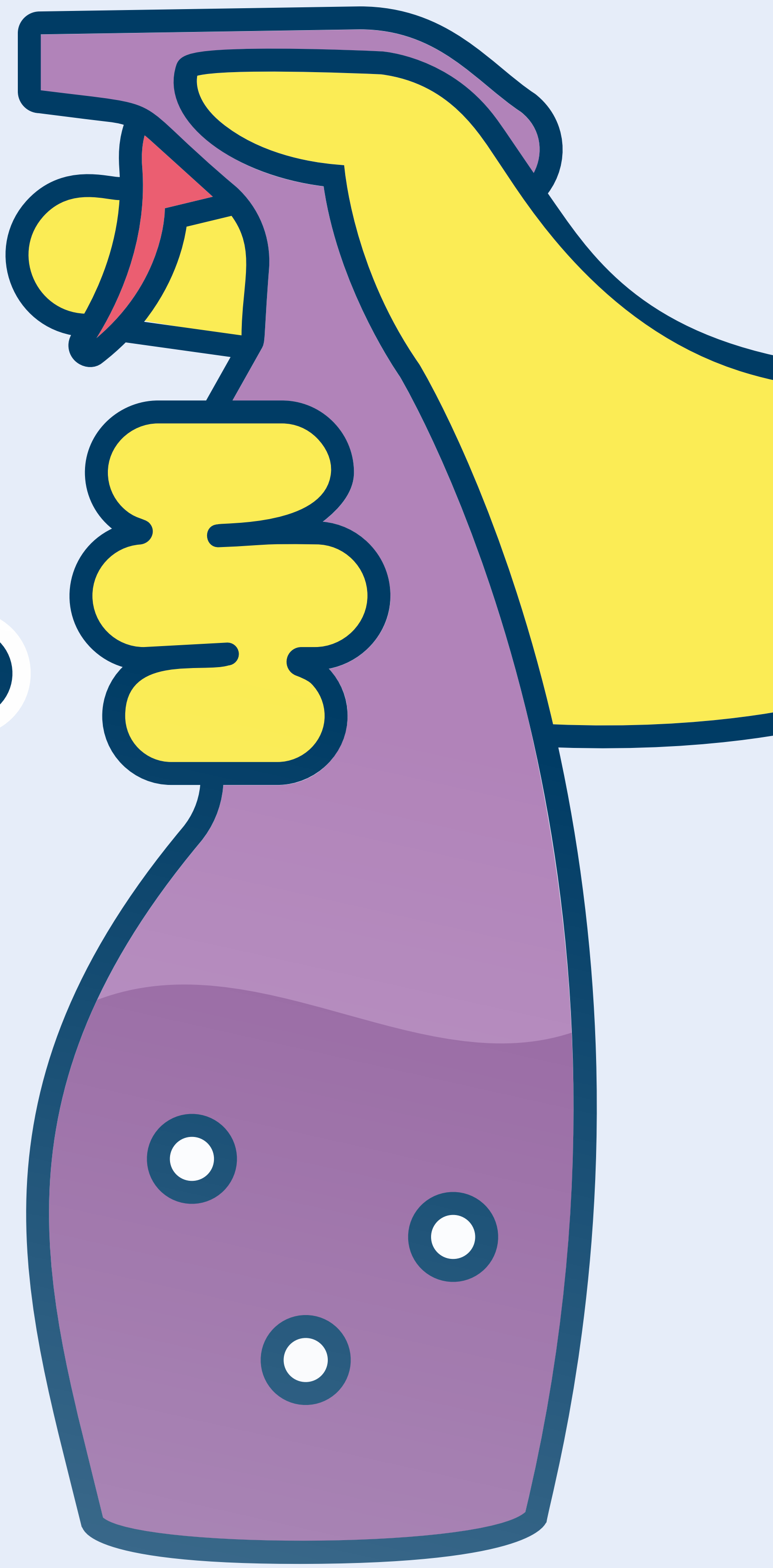
MORE AEROSOLS THAN EXPECTED

Aerosols in the air are not only a result of combustion processes in vehicles or industry, but they also originate from the oxidation of gas-phase emissions from cleaning agents, care and cosmetic products, or cooking. It is these emissions that Gkatzelis is particularly interested in: "With measurements on the ground, we have already been able to prove that, in US cities, household chemicals have replaced car exhaust fumes as the main source of organic vapors," the Greek scientist explains. Due to their chemical properties, these gas-phase molecules often react in the atmosphere to form the so-called secondary organic aerosol, or SOA for short. "However, household chemicals have hardly been considered in air pollution models so far," says Gkatzelis. "This could explain why the models always predict less SOA than we measure in reality."

Thus, more knowledge regarding the role of household chemicals in urban aerosol pollution is urgently needed. Gkatzelis and his team want to fill this gap. Initial analyses of their AEROMMA measurements over Chicago, for example, show that the concentration of compounds that originate from household chemicals is substantial and contribute to the formation of harmful ozone and SOA. "This example shows how our results could improve air quality prediction models," says Gkatzelis. He dedicates his research to his scientific mentor, Jülich climate researcher Prof. Astrid Kiendler-Scharr, who passed away in February 2023.

"In order to understand the exact correlations and be able to recommend countermeasures, however, we still need to find out more about SOA formation," says the researcher. The ERC Starting Grant he received in 2022 will help with this. In the CHANEL project, his team will use the €1.5 million in funding to determine the chemical composition of emissions from household chemicals in European cities. Additional experiments in a controlled atmospheric simulation chamber will help to reconstruct chemical reaction pathways and identify the potential of such sources to form SOA.

Measurements have already been taken at Jülich – in front of the Seecasino canteen. "This is a controlled environment," explains Gkatzelis.



“We knew what was cooked, how many people came to eat, and how often cleaning was done.” This means that emissions could be clearly attributed to sources. In cities, this is more difficult because such information, obviously, does not exist. Only more data can help here, and this is why Gkatzelis will also take to lofty heights in Germany: in addition to measurement campaigns on the ground, he is planning flights over several cities with a zeppelin.

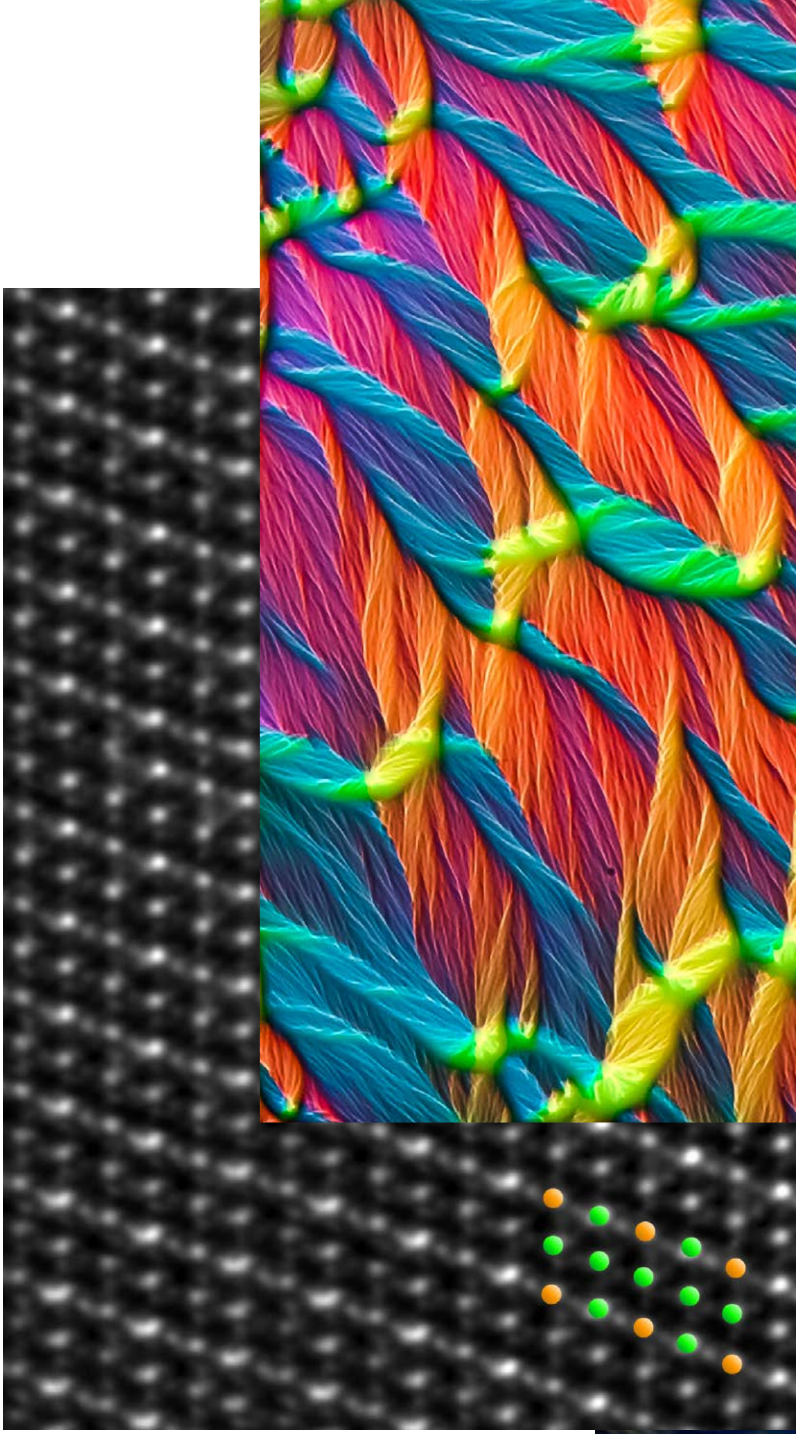
JANOSCH DEEG

The flying laboratory

The US space agency NASA converted the aircraft, a Douglas DC-8 built in 1969, from passenger aircraft to research aircraft in 1984. Instead of 175 passengers, it now carries between 30 and 40 researchers and about 30 measuring instruments to measure the quality of the air. In some places, holes were cut in the wall to mount sensors on the outside and connect them to the scientific instruments inside.

Atoms under the lens

The Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons (ER-C) has, for almost 20 years, dedicated itself to the task of imaging and analyzing materials down to the atomic and molecular level. It is now entering a new era.



↑ Electron microscopes make tiny details visible. The colours in the top image show the different directions of the magnetic field in a 20-nanometre-thin layer of polycrystalline cobalt.

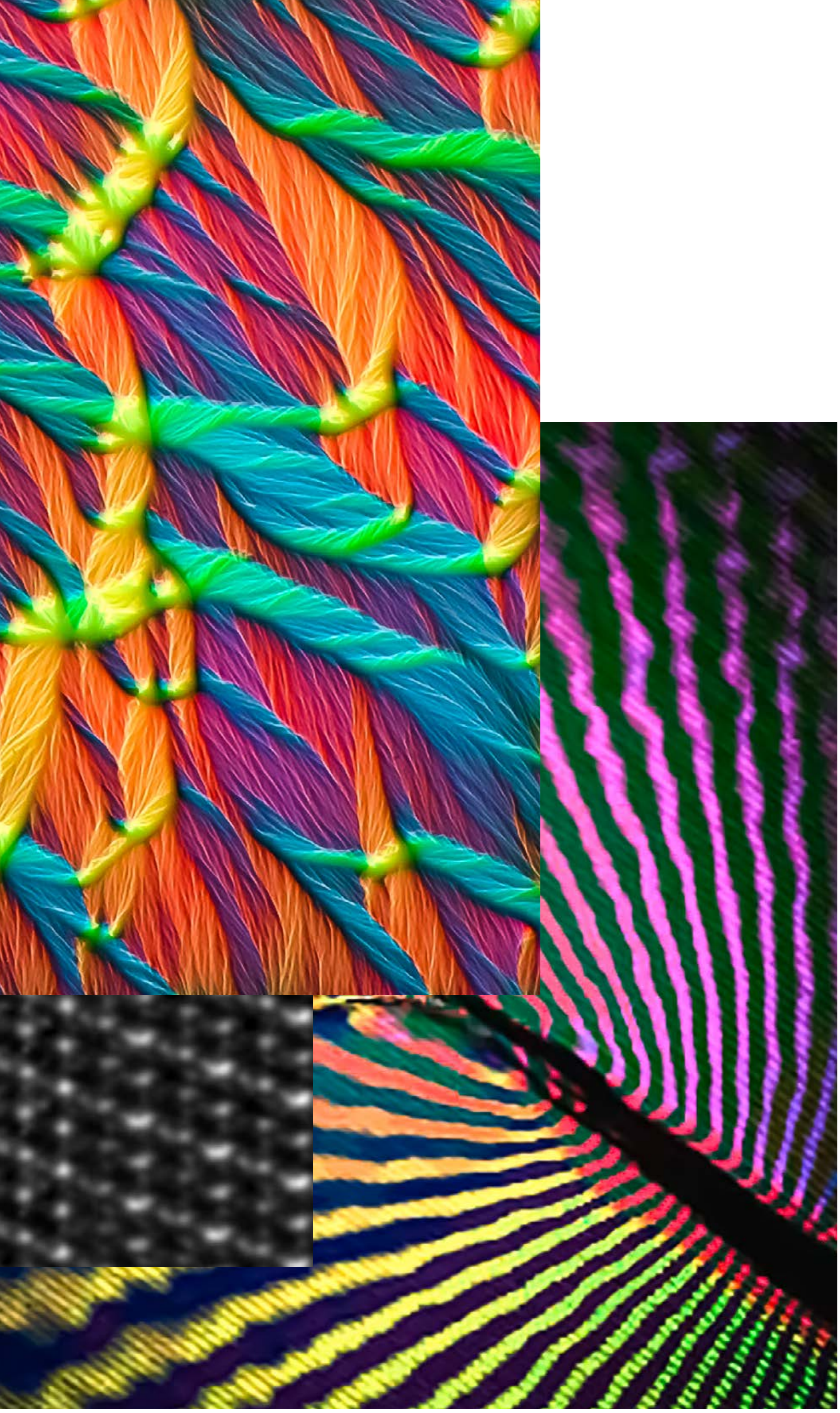
The project name ER-C 2.0 suggests an update as would be usual with software. "But to describe our project as a simple improvement would be an understatement," says Prof Carsten Sachse, one of the three ER-C directors. "It's about more than that. As a national research infrastructure (see "Of major importance" at the end of the article), we are entering a new dimension – with new devices, new applications and new opportunities for science and industry."

Five globally unique electron microscopes (see "Microscope profiles") are designed to elicit information from materials and biological samples that is more detailed than any previously available. For example, they look for the position and chemical state of individual atoms or changes in the structure of substances that take place within a few femtoseconds – that is, one quadrillionth of a second. Detailed insights like these enable scientists to develop innovative materials – such as for energy transition – or new medicines more quickly.

The sensitive electron microscopes need a perfect environment for maximum performance: free from vibration, shielded from electromagnetic radiation and with a constant temperature. Due to be fully operational in autumn 2024, a €23 million research building offers exactly that. Among other things, its foundation is a huge concrete block up to 1.5 metres thick, which ensures that vibrations from passing lorries, for example, do not distort the measurement results.

EVERYTHING UNDER ONE ROOF

However, the new building is not only designed for the microscopes. "Until now, the scientists at ER-C have been spread across several buildings. The fact that we will be under one roof in the



Microscope profiles

TOMO
Atom probe tomography and high-resolution electron microscopy are combined in one device for the first time. With this, it should become possible to precisely determine the type and position of millions of atoms in a volume of several thousand cubic nanometres with a single measurement.

BIO
The first microscope cooled with a helium cryostat, which is equipped with lens correctors to make atoms in biological samples visible at -250°C.

SPECTRO
The first ultra-low temperature in-situ microscope with ultra-high energy resolution. It will be used to analyze the electronic structure and vibrations of radiation-sensitive samples and polymers and to investigate atomic or molecular processes.

OPERANDO
Ultra-high vacuum microscope to study materials while they are in use – for example during the operation of a battery.

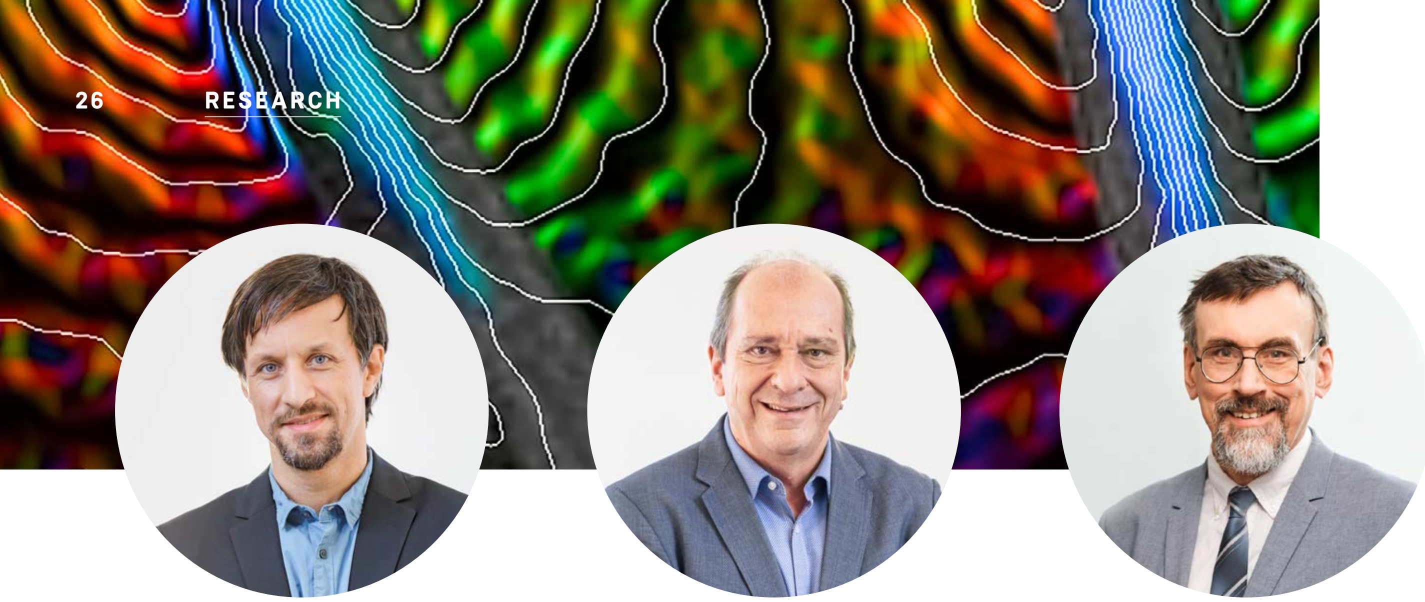
FEMTO
Microscope with femtosecond resolution to analyze dynamic and ultrafast processes in the nanometre range.

future and have more space for interdisciplinary exchange, for example, is of great value," says the director, Prof. Joachim Mayer. The head of Materials Science and Technology is convinced that innovations often result from building bridges between disciplines.

There are three that benefit from one another in ER-C: the two traditional disciplines of materials science and solid state physics, plus the life sciences, which were added around five years ago. "With highly sensitive methods, electron microscopy can also be used for biological and medical questions," says Sachse, head of Structural Biology. Electron microscopes can today be used to determine the structure of the body's own proteins and see, for example, how drugs bind to them.

ACCESS TO THE LATEST DEVICES

In the course of its almost 20-year history, ER-C has repeatedly worked with companies and academic partners to advance microscopes and



↑ The three directors of the ER-C: Carsten Sachse heads Structural Biology.

↑ Joachim Mayer is responsible for Materials Science and Technology.

↑ Rafal Dunin-Borkowski is head of Physics of Nanoscale Systems.

methods. “The companies supply us with their latest devices. Our scientists test them, develop new software and then give feedback on what they noticed,” explains the director, Prof. Rafal Dunin-Borkowski, head of Physics of Nanoscale Systems. “Based on this feedback, the companies provided us with improved versions of the devices, so we had access to new technologies before anyone else did – a perfect example of knowledge and technology transfer that benefits research and application.”

The ER-C directors can now expand their collaboration with the companies even further – by developing new cooling technologies, for example, to investigate quantum materials: “The funding associated with the inclusion of ER-C 2.0 in the national roadmap for research infrastructures opens up much better opportunities for us on this,” says Dunin-Borkowski. “The new era can begin.”

FRANK FRICK

Contributions to structural change

ER-C 2.0 provides a valuable incentive for companies to locate in the Rhineland region. With its high-performance microscopes in one place, ER-C 2.0 offers, for example, the IT and energy technology industries unique opportunities to analyze and advance materials for energy storage or quantum processors. Pharmaceutical and medical companies settling down in the region can also receive support. This is not just a matter of equipment and expertise, but also of a highly qualified workforce. The Centre also specifically promotes the willingness of its scientists to spin off companies. Microscope manufacturers and their suppliers also benefit from it, for example through contact with the numerous users of the devices. Jülich, RWTH Aachen University and Heinrich Heine University Düsseldorf are involved in setting up the national competence centre for high-resolution electron microscopy and are cooperating with various partners.

Of major importance

Large-scale equipment and instruments, but also data collections, computer networks and meeting centres, for example, are classified as research infrastructures. Large-scale devices such as electron microscopes in particular enable promising basic research and technological advances, but are generally expensive, complex and time-consuming to maintain. The Federal Ministry of Education and Research is funding selected infrastructures that are of major importance for Germany as a centre of science with a national roadmap – a kind of schedule for the long-term orientation of cutting-edge research. The infrastructures funded in this programme each receive over €50 million.

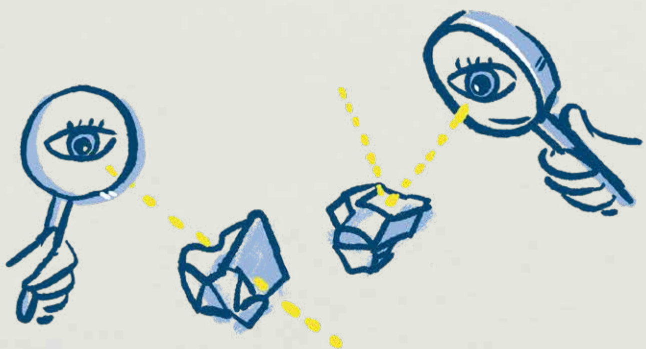
KNOWING-IT-ALL

ELECTRON MICROSCOPE

Electron microscopes (EM) allow tiny structures to be made visible like a gigantic magnifying glass – right down to individual atoms! They are now standard in biology and materials research, for example.

1931

Ernst Ruska and Max Knoll present the first electron microscope. Ruska will be awarded the Nobel Prize for this in 1986.



SHINING THROUGH AND SCANNING

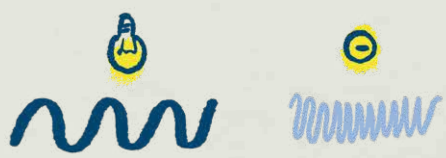
There are two main types: transmission electron microscopes transmit an electron beam that "shines trough" the object. In a scanning electron microscope, the beam scans the surface.

WHAT IS JÜLICH DOING?

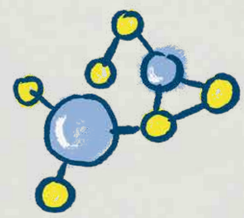
The Ernst Ruska-Centre (ER-C) operates state-of-the-art electron microscopy. Jülich researchers use them for biology, energy research and materials research. They also improve equipment and methods.

HIGH RESOLUTION – HUH?

Electron microscopes do not use a beam of light like conventional microscopes, but a beam of electrons.



Electrons have a wavelength up to a million times smaller than light – and the smaller the wavelength, the higher the resolution.

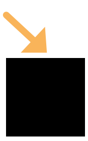


This makes it possible to recognize the atomic structure of a substance – that is, to decode structures that are only a few nanometres in size.

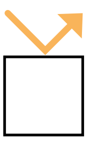
Cool compromise

How can global warming be mitigated? One way is to plant trees, as they remove CO_2 from the atmosphere. However, trees reduce another cooling effect: the reflection of sunlight on the land surface. Model calculations show what will most likely benefit the climate.

Albedo
is the reflectivity of a surface. The extent of reflection is shown as a percentage. Two extreme cases:



Dark body
Almost complete absorption, strong warming, albedo: almost 0%



Light body
Almost complete reflection, hardly any warming, albedo: almost 100%

Do something for the climate, plant a tree! What sounds like a good idea at first is not always the best solution. "Forests reflect significantly less sunlight than most other terrestrial ecosystems, for example. Instead, they absorb more light, which contributes to global warming," says Dr. Alexander Graf from the Institute of Bio- and Geosciences (IBG-3). Researchers call this effect – the reflection of sunlight – albedo.

Trees also have another, long-term positive influence on the climate: "They absorb CO_2, which has a cooling effect on the climate," says Graf. Before trees can absorb CO_2, however, they have to grow first. "Therefore, if trees are planted, the warming effect due to the reduced albedo makes itself felt much faster than the cooling effect from the increasing CO_2 storage," explains the Jülich researcher.

Together with scientists from 14 countries, Graf investigated the extent of the influence of the two effects and the role that different types of vegetation play. They used data from the global FLUXNET network, which provided information from 176 regional environmental monitoring networks on greenhouse gas, water and energy balances, including the reflection of sunlight. This also includes locations managed by IBG-3. The international team used the data to calculate various scenarios – including what would happen if each site was reorganized to absorb the maximum possible amount of CO_2. "This would mean afforestation for some locations, while for others it would only mean a change in agricultural or forestry methods and the selection of plant species," says Graf. In the long term, this would lead to the maximum possible cooling effect on global warming. Still, no matter how many trees were theoretically planted, the researchers

arrived at the same result for all locations: in the first 20 years, there will be moderate global net warming before the strong cooling effect sets in worldwide.

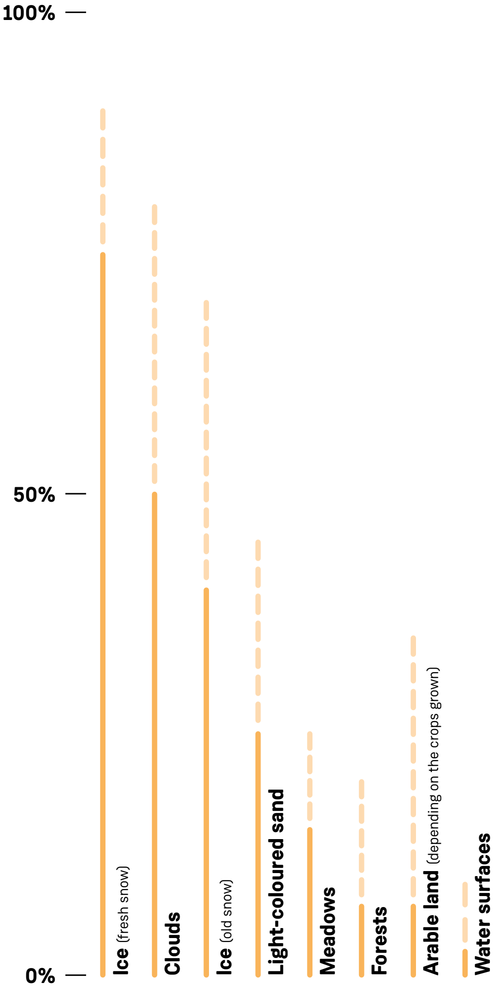
"The question is whether we can afford additional slight warming over the next two decades. We may have already passed climate tipping points during this period," says Graf. An alternative could be to moderately increase both CO_2 absorption and albedo – at least at locations where this is possible. This could mean planting dark arable land with catch crops during the fallow period, which increases the albedo and binds more CO_2, or, in other places, to plant an initially loose stand of trees on a light-coloured meadow instead of dense forests on dark, bare ground.

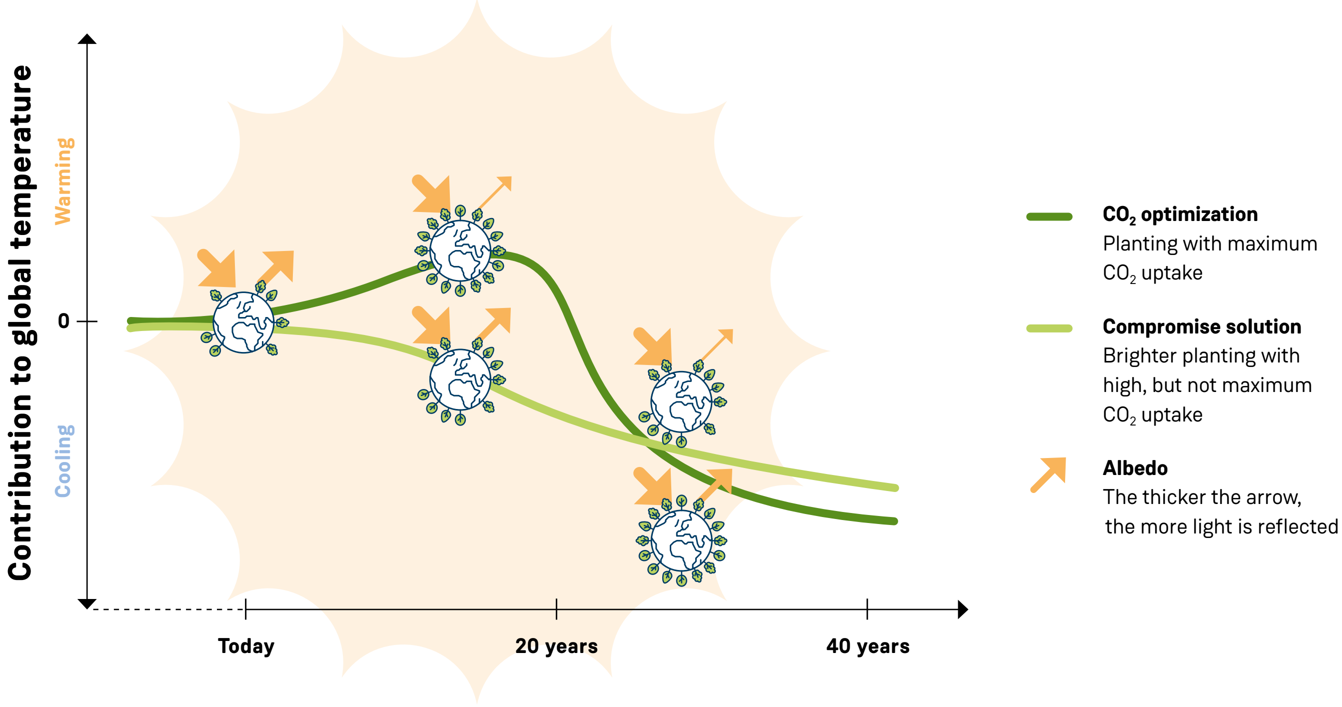
"This balanced scenario immediately results in a cooling effect on global warming, although, in the long term, this is less pronounced than the effect in the case of 'CO_2 optimization', which sets in later. Nevertheless, it could be a good compromise," summarizes Alexander Graf

CHRISTIAN HOHLFELD/BARBARA SCHUNK

↑ More dark forests or more light-coloured meadows? Alexander Graf analyzes approaches to limiting global warming.

Reflection from surfaces





Long live the PV system!

The yield and service life of solar systems is reduced by defects and material that ages too fast. This can be changed by detecting defects at an early stage – with the help of drones and AI, for example.

It is a sticky, hot summer's day. Rain has been dripping onto the shiny blue-black panels of the solar system for days. This should actually not be a problem – unless the protective layer of plastic film on the back of a module is damaged: thin hairline cracks are sufficient for moisture to soak in. This can lead to electronic components no longer being sufficiently insulated – and the solar system automatically switching off for safety reasons. The failure of just a single module is enough for such a scenario.

Tiny defects such as a hairline crack in the film are almost impossible to detect, and the fact that it can paralyze an entire solar park at short notice is not the only problem: "Damage caused by defective backs contributes to limiting the service life of a solar park to around 20 years at present, while it could reliably supply electricity for 50 years," says physicist Dr. Ian Marius Peters from the Helmholtz Institute Erlangen-Nürnberg for Renewable Energy (HI ERN), a Jülich branch office. He and his team are researching how to extend the service life of solar systems and minimize performance losses.

"Around 10 per cent of the modules don't last as long as they could," says Peters' colleague Dr. Claudia Buerhop-Lutz from HI ERN. "Some of the materials in the modules show the first signs of age-related degradation after just five years." This quickly ruins the efficiency gain of a new system with its initially higher efficiency levels. The researchers at HI ERN are therefore developing methods to recognize defects as early as possible, relying on three strategies: non-destructive measurements in the field, the use of high-resolution drone cameras, and the use of artificial intelligence (AI).

DESTRUCTION IS NOT NECESSARY

Claudia Buerhop-Lutz is focussed on the back of solar modules, which is made up of several layers of plastic film and protects the solar cell from water. "Films are playing an increasingly important role in the reliability of solar modules," says Buerhop-Lutz. "Corrosion, surface abrasion or peeling layers compromise the protection the films provide." Such damage has increasingly occurred in PV modules built between 2010 and 2012. According to the expert, less suitable materials may have been used during this time, but she has also found damage in newer systems.

Buerhop-Lutz and her team have developed a new method to examine the condition of the films directly in the field without damaging them. To

← Claudia Buerhop-Lutz uses drones, among other things, to check the condition of photovoltaic systems. This way, defects can be detected before a solar module fails.

AI finds errors in standard data

The HI ERN scientists can also filter out errors from the operators' usual monitoring data and analyze them using machine learning in the dig4MorE project. AI recognizes both performance deficits and error patterns that indicate specific malfunctions. "Modules are sometimes wired incorrectly, malfunctions only occur in individual parts or in certain climatic conditions," reports Buerhop-Lutz, who would like to get more data from the solar parks. "Operators often don't even realize the value of the information contained in their data," she observes. "We could unearth these treasures." The work of HI ERN researchers is already helping to make green power generation with PV systems more reliable. This is important because renewable sources are expected to supply at least 80 per cent of gross electricity consumption by 2030. Uncontrolled outages are undesirable.

this end, the researchers first analyzed numerous variants of the module backs made from different combinations of plastic films in the laboratory – a total of more than 30,000 modules from 30 solar parks – and also any visible damage. This has yielded a "backside" library with around 250 variants, which now serves as a comparison for infrared measurements of the modules in the field and helps to detect possible defects before they lead to module failure.

DRONES IN PAIRS

Aerial monitoring of the solar installations using drones is focussed on the front of the modules. In the COSIMA project, Buerhop-Lutz and her team combine two different methods: thermographic drones that can be used to detect hotspots – solar modules with localized overheating – and drones that measure electroluminescence. For the latter, the researchers reverse the process in the solar cell: when current is applied, the solar cell emits light – at the undamaged points.

"This allows us to recognize defects that are hidden deeper in the material," says the researcher. AI then sorts all the information. "The analysis not only provides the operators with the usual jumble of images, but also indicates where a loss of performance is imminent. This is true predictive maintenance," says Ian Marius Peters.

KATJA ENGEL

10

per cent

of the modules do not last as long as they could, says Dr. Claudia Buerhop-Lutz from the Helmholtz Institute Erlangen-Nürnberg for Renewable Energy (HI ERN).

Bioelectronics for humans

An international team led by Francesca Santoro developed an intelligent biochip that imitates the retina of the eye. With such bioelectronics and others like it, the group wants to correct malfunctions in the body and brain.

The fusion of man and machine is the epitome of a science fiction narrative. In real life, the first steps towards such cyborgs have long been taken: people have pacemakers for arrhythmias or cochlear implants to improve hearing, retinal implants help people who are almost blind to see at least a little. A new chip could help retinal implants fuse even better with the human body in the future: It is based on conductive polymers and light-sensitive molecules that can be used to imitate the retina, complete with visual pathways. It was developed by Prof. Francesca Santoro's research group at Jülich's Institute for Bioelectronics (IBI-3) in collaboration with RWTH Aachen University, the Istituto Italiano di Tecnologia in Genoa and the University of Naples.

"Our organic semiconductor recognizes how much light falls on it. Something similar happens in our eye. The amount of light that hits the individual photoreceptors ultimately creates the image in the brain," explains San-

Understanding neurons

In addition to the artificial retina, Santoro's team is developing other approaches for bio-electronic chips that can interact in a similar way with the human body, especially with the cells of the nervous system. "On the one hand, we are trying to reproduce the three-dimensional structure of the nerve cells and, on the other hand, their functions, such as the processing and storage of information,."

The biopolymers they used in the artificial retina proved to be a suitable starting material for this. "We can use them to reproduce the branched structure of human nerve cells with their many dendrites. You can think of it a bit like a tree," the scientist explains. This is important because real cells prefer such branched three-dimensional structures to smooth surfaces and, in this way, establish close contacts with the artificial ones.

Firstly, the different biochips can be used to study real neurons – for example, the cellular exchange of information. Secondly, Santoro and her team hope that they will someday be able to actively engage in the communication pathways of the cells with their components in order to trigger certain effects. For example, Santoro is thinking of remedying errors in the processing and transmission of information that occur in neurodegenerative diseases such as Parkinson's or Alzheimer's disease, or of supporting organs that no longer function properly. In addition, such components could also serve as an interface between artificial limbs or joints.

Computer technology could benefit as well. Due to their properties, the chips are predestined to serve as hardware for artificial neural networks. So far, AI programs are still working with classical processors that cannot adapt their structure. They merely imitate the self-learning principle of changing neural networks by means of sophisticated software. This is very inefficient. Artificial neurons could remedy this previous deficiency: "They would enable computer technology that imitates the way the brain works at all levels," says Santoro.

toro, who is Professor of Neuroelectronic Interfaces at RWTH Aachen University and also a visiting researcher at the Istituto Italiano di Tecnologia in Genoa.

EASY TO INTEGRATE

What is exceptional about the new semiconductor: it consists entirely of non-toxic organic components, is maleable and works with ions, that is, with charged atoms or molecules. It can thus be integrated into biological systems much better than conventional semiconductor components made of silicon, which are rigid and only work with electrons. "Our body cells specifically use ions to control certain processes and exchange information," explains the researcher. However, the development is, so far, only a proof of concept, she emphasizes. The material was synthesized and then characterized: "We were able to show that the typical properties of the retina can be imitated with it," she says.

The researchers are already thinking about another possible application: as light irradiation changes, in the short and long term, the conductivity of the polymer used, the chip could also function as an artificial synapse . Real synapses work in a similar way: by transmitting electrical signals, they change their size and efficiency, for example, which is the basis for our brain's learning and memory capacity. Santoro is looking ahead: "In future experiments, we want to couple the components with biological cells and connect many individual ones together."

JANOSCH DEEG

↑ Francesca Santoro has already received numerous awards for her research, including the Leopoldina Early Career Award 2022.

Pioneering work with a lasting effect

After ten years, the Human Brain Project (HBP) came to an end in September 2023. At the final symposium in Jülich, the scientific director, Jülich brain researcher Prof. Katrin Amunts, delivered a positive summary of the European joint project.

The HBP was one of the first projects funded by the EU through its Future and Emerging Technologies (FET) programme. "We can say today that the HBP has provided pioneering work in digital brain research," says the director of the Jülich Institute of Neurosciences and Medicine (INM-1), looking back. The linking of supercomputing and neuroscience enabled innovation and new insights, according to Amunts, and through the EBRAINS research infrastructure and a new type of collaboration, the HBP will have an impact on neuroscience for many years to come.

The EBRAINS platform contains digital tools and data sets developed in the project and is a unique, public digital library of the brain. It will continue to be available to the neuroscientific community after the end of the HBP. This also applies to the Julich Brain Atlas, a three-dimensional digital atlas of the human brain. "The atlas depicts 200 areas of the brain with unprecedented detail – a kind of Google Maps for the brain," explains the Jülich researcher.

Scientists have also developed implants that stimulate neurons in order to overcome blindness and paralysis. Another example is personalized brain models of epilepsy patients who do not respond to medication. These virtual models can be used to identify the brain regions in which seizures occur, which allows surgical procedures to be planned more precisely. Researchers were also inspired by the human brain to improve the energy efficiency of artificial intelligence.

The future has also already been considered: around 100 international authors recently published a position paper initiated by the HBP – a roadmap for the next ten years of digital neuroscience. "Even though the HBP has been completed, we still have a lot of research to do," emphasizes Katrin Amunts.

CHRISTIAN HOHLFELD

Interview with Katrin Amunts on the end of the HBP: helmholtz.de/en/newsroom/article/a-key-for-further-brain-research

Jülich HBP page: fz-juelich.de/en/research/information-and-the-brain/hbp

500+
participating researchers

19
involved countries

10
years of project duration

"The legacy of the HBP are not only important findings and, with EBRAINS, a publicly accessible infrastructure, but also a community that would otherwise not have come together in this way."

KATRIN AMUNTS

155
cooperating institutions

607
million budget total

160
freely accessible digital tools

3,000+
publications

Research(er) with pleasure

He loves electrobeats as much as electrochemistry: Rainer Waser does not fit into any pigeonhole. The 68-year-old scientist is both a visionary and a tinkerer – someone who looks beyond the boundaries of individual disciplines, who is inspiring and infectious, and who never misses out on fun and enjoyment.

↑ Rainer Waser is Director of Electronic Materials at the Peter Grünberg Institute (PGI-7) and professor at RWTH Aachen University. He is considered one of the most cited representatives of his fields of research.

His first chemistry laboratory in Heusenstamm was closed against his will. At that time, the spark not only literally ignited in his parents' basement, but also in his mind: 15-year-old Rainer Waser wanted to become a chemist. After the unintended real-life "spark", however, he had to promise his parents that he would not open his "basement lab" again until he actually studied chemistry. "That's what I started doing in 1974," the 68-year-old recalls. He reopened the lab one room further – in the slightly larger basement toilet. "I had direct access to water and electrical connections there."

NO FEAR OF LIMITS

For many years, he experimented within these four walls. He tinkered, drilled and built test stands as well as electronic systems such as amplifiers and loudspeakers. "I poured all my pocket money into this," says Waser and smiles –

> **“Interesting research often takes place at the interfaces of disciplines.”**
>
> RAINER WASER

something the director of the Peter Grünberg Institute likes to do a lot: his motto is “research with pleasure”.

The anecdote from Waser’s youth reveals a lot about the successful natural scientist and engineer, who received the Gottfried Wilhelm Leibniz Prize in 2014 for his research on resistive switches as memory in information technology. Waser is someone who likes to consider disciplines anew, who is not afraid to cross boundaries, always looking for new challenges and solutions: “Interesting research often takes place at the interfaces of disciplines,” Waser sums up.

The best example of this is his research on memristive devices. These have properties similar to nerve cells in the human brain and are therefore considered a promising basis for neuromorphic circuits. They could be used to build energy-efficient computers modelled on the brain, such as those needed for AI applications. Waser had discovered how the components function at the atomic level and thus laid the foundation for their technical use.

Sounds futuristic, but the father of two and patchwork father of four has always been a bit ahead of his time: for his doctorate at the Technical University of Darmstadt in the early 1980s, he built a fully automatic, computer-controlled test bench. “It’s standard today, but there was nothing like that back then,” says Waser. He had a Z 80 sent to him from England, where he spent two semesters abroad as a scholarship holder of the German Academic Scholarship Foundation in Southampton: “The computer consisted of one huge circuit board and a thousand individual parts – and had no screen or memory,” he recalls. The doctoral researcher even had to write the software himself, in computer code.

NO THOUGHT OF FAILURE

He did not waste a single thought on failure. In the end, all that was missing was an electrochemical measuring system, a so-called potentiostat, said to cost DM5,000 – money that the institute could not afford. Waser bet his doctoral supervisor Konrad Georg Weil a meal that he would succeed in building the device himself within a week. The doctoral supervisor lost. “I hardly slept and kept drilling, soldering and measuring around the clock in my basement lab. I exposed the boards with my mother’s sunlamp. Sounds a bit crazy, I guess,” says Waser. In Waser’s life, nothing is impossible. When talking about his research, his enthusiasm is irresistible – always with a quiet smile or grin, polite, never pushy, but full of energy and drive.

However, his love of electrochemistry and physics is not the end point of his enthusiasm. For example, he used the time between leaving school and starting at university to attend lectures in Frankfurt and Darmstadt: quantum mechanics, philosophy and music theory – the inquisitive young Waser took it all in, “even if a lot of it was way beyond my level of knowledge at the time”. En passant he wrote a paper on the sociology of music, which later won an award at the European level. For music in and of itself: here, too, Waser cannot be pigeonholed. The man, almost 1.90 metres tall, listens to medieval sounds as well as metal, classical music, electronic beats or world

music. When he sits at his computer in his office at home in Aachen, he always listens to music.

One of his most memorable musical experiences: a visit to Belgium's Tomorrowland festival in 2015, a mecca for techno and rave fans – at the age of 59. "Fantastic!", he still raves today. When he celebrated his 60th birthday a few months later, the festival with its fairytale ambiance served as a template for him. "First there were many great scientific lectures, and later there was dancing, dressed up to the motto '60 Years of Craziness' – research with pleasure," says the professor of electronic materials.

EASY-GOING AND AIMING AT 100

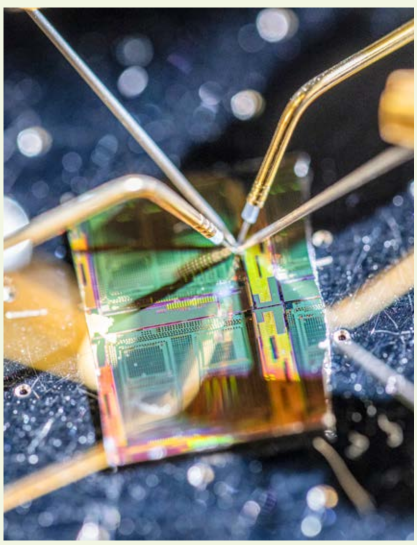
2024 will mark the official the end. He is placid about his "after work" time: "After all, no one is stopping me from continuing. But I don't know what I'm going to do yet." In any case, he wants to devote more time to philosophy. "There are also more fitness activities on the agenda," says Waser, who has a hang-gliding licence, goes skiing and roller-skating. At the moment, he limits himself to a few minutes of trampolining in his own house – to music, of course: "In a minimum of time, I deliberately bring my pulse up to 130 once a day. That's healthy and goes easy on the joints." He also has his long-term goal in mind: when he turns 100, he wants to throw a big birthday party where he chooses the music and dances. "With the help of an exoskeleton, if necessary," says Rainer Waser and smiles. One can bet he will, too.

KATJA LÜERS

Neuromorphic computing: becoming as efficient as the brain

More power, less energy use – this is how researchers imagine the computer of the future. A new type is to make this possible: the neuromorphic computer. At its core are so-called memristive components, which are modelled on the human brain.

For certain tasks, such as recognizing patterns and language, our brain only needs around one ten-thousandth of the energy that a conventional computer consumes. One of the reasons for this: the memory and processor in computers are separated from each other, and large amounts of data have to be constantly transported back and forth. This costs energy and slows down the calculations. The brain is different: there, calculations are performed directly in the data memory, the biological synapses. Memristive components – to whose development Rainer Waser and his teams at Jülich and RWTH Aachen University have made a significant contribution – utilize this principle. They can store information through an adjustable resistance value and process it at the same time. The components are also compatible with conventional microelectronics and can be miniaturized very well down to the nanometre range. Artificial intelligence (AI) and machine learning in particular could benefit from respective neuromorphic systems.



↑ Memristive memory components, also known as memristors, are considered to be extremely fast, energy-saving and can be miniaturized very well down to the nanometre range.

In the NEUROTEC project, which Rainer Waser is coordinating, the partners are working on practice-orientated demonstrators for AI applications. They want to show how much more efficient neuro-inspired AI will be. The project entered its second phase at the end of 2021 and is funded by the Federal Ministry of Education and Research with €36.5 million until 2026.

THUMBS UP

ONLINE GAME BAC-MAN

Where does the smell of sweat come from?

When we sweat, we sometimes develop an unpleasant body odour. This is not caused by sweat itself, but by bacteria. They nestle in the armpits, where they break down molecules from sweat into smaller components. Some people find the odour of these building blocks unpleasant. Researchers from the University of Oxford and the University of York are investigating these processes and have modelled the molecular mechanisms on the well-known arcade game Pac Man: as "Bac-Man", the aim is to eat sweat molecules and compete against other bacteria.

– BOANDBEYOND.WEB.OX.AC.UK –

SCIENCE COMICS

Art meets science

Illustrations can help to present complex ideas and research results in an understandable way. The Young Academy Fellows of the Academy of Sciences and Humanities in Hamburg are focussing on a special kind of illustration: science comics! The Fellows worked hand in hand with artists to translate their science into drawn images and put them together into stories. The result? An unusual and inspiring experience for all comic and science enthusiasts!

– AWHAMBURG.DE/EN/SUPPORTING-JUNIOR-RESEARCHERS/YOUNG-ACADEMY-FELLOWS/SCIENCE-COMICS.HTML –

EXPEDITION BLOG

Flying high with PHILEAS

Everyday life in research often means spending days in the lab or at the desk. Sometimes, however, the spirit of discovery drives scientists outside – on expeditions into the wilderness or up in the air to collect new data. This time had come for Jan Kaumanns in the summer of 2023: in Alaska, the Jülich climate researcher used the HALO research aircraft to send measuring instruments to altitudes of up to 15 kilometres in order to detect greenhouse gases and aerosols on behalf of the PHILEAS campaign. In his blog, Kaumanns covers the flights, measurement results that were not intended to be found, breathtaking landscapes and one or two anecdotes along the way.

– BLOGS.FZ-JUELICH.DE/CLIMATERESEARCH/CATEGORY/PHILEAS –

RESEARCH IN A TOOT

What are the benefits of the Buildings Energy Act? A web tool from Jülich shows how legal requirements for heating systems affect Germany's climate targets.

Germany wants to be greenhouse gas neutral by 2045. The Buildings Energy Act (GEG) is intended to contribute to this. Details such as the replacement deadlines for oil and gas heating systems had been the subject of controversial debate for months. In the view of the researchers from the Institute of Energy and Climate Research (IEK-3), however, the GEG is not enough for Germany to achieve its climate targets. With their web tool, citizens can test for themselves the impact of measures and their changes.

heatingsystems.fz-juelich.de

From now we'll toot! We have changed the network: this page will from now on offer Jülich research as a Mastodon "toot".
social.fz-juelich.de

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Shaping Change