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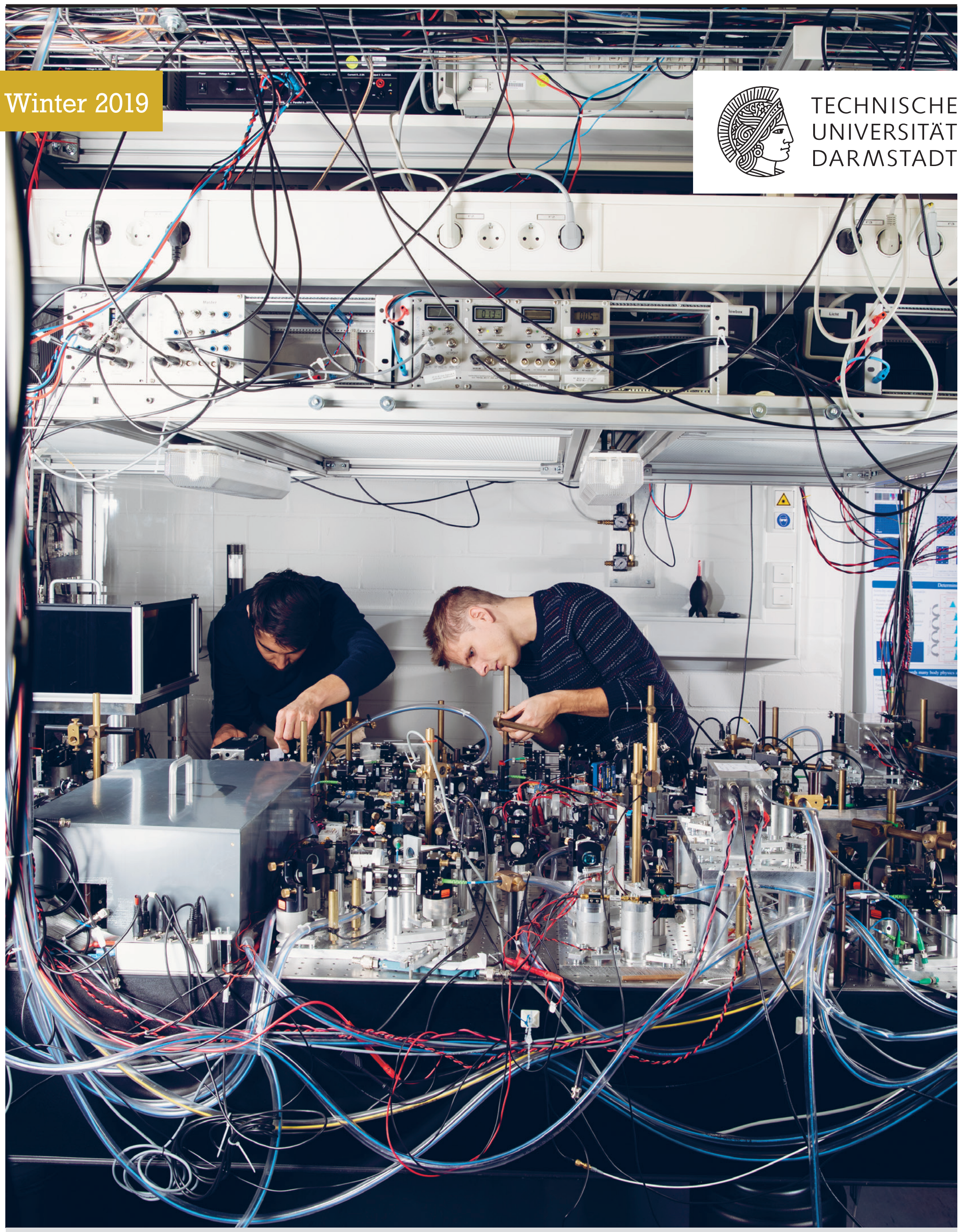

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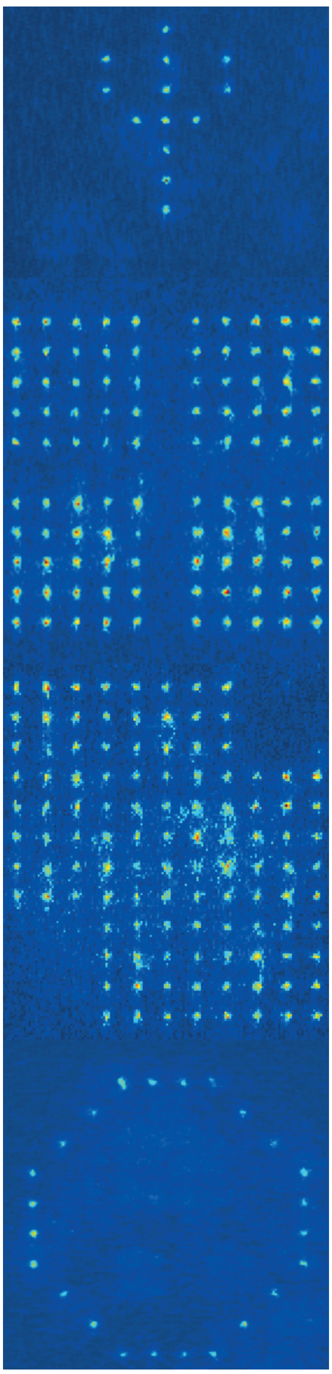
Sorted atoms for quantum computing

Scalable quantum systems of up to 111 individually addressible atoms can be assembled without defects and controlled reliably by laser light.



Photography: Gerhard Birkl

A physics research team at TU Darmstadt is developing an apparatus that arranges atoms in desired patterns. A quantum computer could work in the same way.

By Christian Meier

Professor Gerhard Birkl opens a metal door in the basement of the Physics Department of the Technische Universität Darmstadt. In a dimly lit room, a massive laboratory bench holds a collection of lenses, mirrors, lasers - and a vacuum chamber. The structure appears complex. However, considering its remarkable function, it is actually conceptually simple. The Darmstadt-based research team uses only light to move individual atoms and arrange them into regular lattices, pre-defined structures or even letters. „We can arrange the atoms in any two-dimensional pattern, error-free and with more atoms than all comparable experiments worldwide," says Birkl, whose team recently presented this new technology in a renowned journal.

"We can arrange the atoms in any two-dimensional pattern without defects."

As an example, the physicist shows photos on which blue spots form square patterns of atoms. The researchers are contributing to the field of quantum technology, which aims to exploit the effects of quantum physics for new applications. This includes more precise sensors or superfast quantum computers, which are expected to beat supercomputers in some tasks.

The first application targeted by Birkl's team is a so-called quantum simulator. For this purpose, the group wants to replicate whole molecules or crystals using individual atoms. Such models would enable researchers to better understand chemical reactions or smart materials such as superconductors in just a few years. Conventional computers quickly hit their limits in such simulations. The computational effort increases exponentially with the number of atoms that make up the models. Even supercomputers can at best model systems with around 50 particles. If, on the other hand, the materials to be investigated are reconstructed from real atoms, the effort increases considerably more slowly. Nevertheless, it is usually difficult to arrange an arbitrary number of particles. The „scalability", as physicists say, is limited. However, the new technology developed in Darmstadt makes it possible to construct larger models without much extra effort, says Birkl.

The researcher shows a glass pane with a fingernail-sized grey area in the centre. „This is a field of microlenses," Birkl explains. The grey comes from microscopically small lenses arranged at intervals of one tenth of a millimetre. When irradiated with a laser, each lens creates a tiny focal point and together they form a regular grid. „These spots with a high light intensity trap atoms," says Birkl. His group projects the focal spots at reduced separation of a few thousandths of a millimetre into a cloud of rubidium atoms in the vacuum chamber on the laboratory bench. Several atoms accumulate in each focal point. The target is exactly one atom per focal point. Confined in their trap, the particles collide. Pairs of atoms „kick" each other out, so that at the end either no atom remains in the focal point, or exactly one.

The resulting pattern is haphazardly thrown together. „To put it in order, we can selectively move individual atoms from an occupied to an unoccupied site," says Birkl. This is how the physicists write desired patterns into the grid. First they make the atoms visible. A laser shines on the particles, which respond by emitting light. A camera records the pattern of light points. Now it is known which places of the grid are occupied by atoms and which are not. In order to bring the particles into the desired structure, such as a square, the researchers use what are known as optical tweezers. This is a laser beam whose focus can be moved from one grid point to any other. By increasing the light intensity of the tweezers an atom

Information

Atoms – Photones – Quantum
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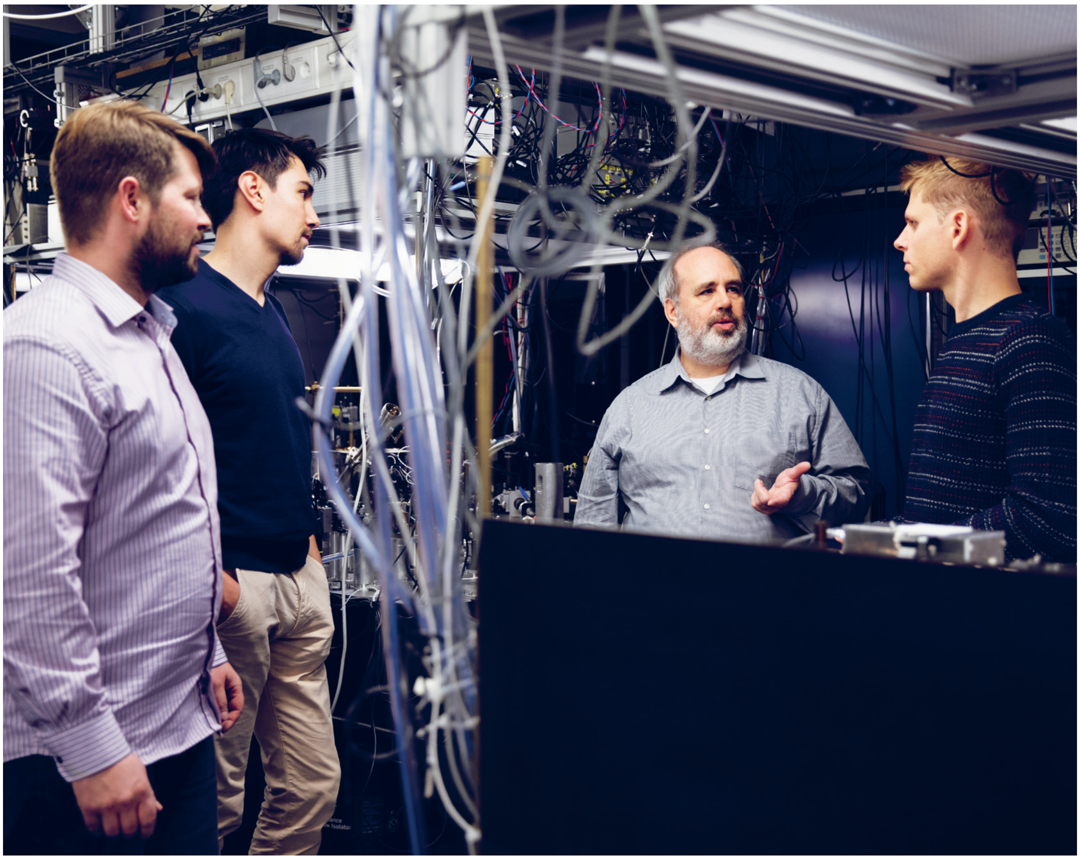

Photography: Katrin Binner

The next steps towards a functional quantum simulator: Malte Schlosser, Daniel Ohl de Mello, Gerhard Birkl, and Dominik Schäffner (from left) plan the upcoming experimental runs.

can be picked up, by decreasing the light intensity it can be set down again. In this way, the tool moves an atom from one place to another. An algorithm calculates the optimum sequence of such moves in order to achieve the target pattern as quickly as possible.

So far, the team from Darmstadt has succeeded in arranging 111 atoms without anydefects. "That's the current world record," says Birkl. He adds that scaling up to considerably more particles is merely a technical matter. "We already have microlens fields with more than 10,000 individual lenses; one million lenses are easy to produce." Holding so many atoms would also require more powerful lasers, but these do exist. First, however, the researchers are planning initial simulations of real materials. "We are particularly interested in simulating graphene," says Birkl. This is a very stable network composed of hexagons of carbon atoms, resembling honeycombs. The so-called "miracle material" is often used to produce high-strength materials or, due to its unique electronic properties, particularly precise sensors or fast computing chips.

Birkl's team can adjust the interactions between the atoms to explore the properties of a simulated material. For this purpose, they excite the particles in such a way that they enlarge and interact with each other more strongly. Graphene is also a particularly suitable test model because it consists of only one layer of atoms, i.e. a 2-dimensional pattern like the atomic pattern in Birkl's apparatus. Most molecules, however, have a three-dimensional structure, and crystals do anyway. "It is nonetheless possible to arrange several focal planes consecutively in several layers," says Birkl. His team is already working on this. 3D grids can then also be used to write 3D patterns.

The method developed in Darmstadt could also be useful for future quantum computers. These should eventually solve computing problems whose complexity goes far beyond the capacities of conventional supercomputers. This includes detecting hidden patterns in vast amounts of data. Such computers will require thousands, if not millions, of "quantum bits" for this. Atoms which can store the two data values 0 and 1 simultaneously are predestined to realise this type of storage unit. "We can already perform basic operations between quantum bits in our apparatus", Birkl explains. One of the most advanced computers might therefore one day be found in the Darmstadt basement laboratory.

The author is a science writer and holds a doctorate in Physics.

Publications:
„Defect-Free Assembly of 2D Clusters of More Than 100 Single-Atom Quantum Systems", Physical Review Letters 122, 203601 (2019).

Generally comprehensible presentation: „The defect-free assembly of 2-D clusters with over 100 single-atom quantum systems", https://phys.org/news/2019-05-defect-free-d-clusters-single-atom-quantum.html

Helicopter money

For years the European Central Bank (ECB) has been trying to stimulate the economy. Experts are also considering "helicopter money". Economists of TU Darmstadt have studied what people would do with it.

Photography: Katrin Binner

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By Jutta Witte

"Let us suppose now that one day a helicopter flies over this community and drops an additional $1,000 in bills from the sky, which is, of course, hastily collected by the members of this community. Let us suppose further that everyone is convinced that this is a unique event which will never be repeated." This thought experiment developed by the US economist Milton Friedman in 1969 appears to be experiencing a renaissance in these days. Behind this is the assumption that there is a close relationship between inflation and deflation and the amount of money people have in their account, as well as the question of whether a one-time financial injection has a positive effect on the economy.

It is clear that, for the European economy to avoid falling from a nominal interest rate of zero and very low inflation into a deflationary spiral, new strategies are needed. "At the moment the ECB's monetary policy options for investment incentives are shrinking," states Professor Michael Neugart, Head of the Institute for Public Economics and Economic Policy at TU Darmstadt. The expert, who has analysed the effects of helicopter money in his latest study together with Dr. Uros Djuric, believes the instruments at the disposal of the central bankers in Frankfurt have been exhausted. Until the economic crisis of 2007, lowering the nominal interest rate was considered to be a standard tool for reviving the economy. For the lower the interest rate, the greater the willingness of business banks to borrow money from the ECB and to pass on the favourable terms directly to their customers. Companies subsequently invest, saving becomes unattractive because of low interest rates and people buy consumer goods.

However, this base rate cannot fall below zero. Currently it is zero, which means this option is no longer available to the ECB to pump money into the economy. Instead it has resorted to buying up government bonds in the bond market, a strategy which is controversial, because it could be a form of hidden state financing. The Federal Constitutional Court has already set limits for this reason: The ECB may only hold less than one third of all of the government bonds issued by the country concerned. Here too the limit is therefore in sight.

"It is no surprise that people are thinking again more or less out loud about unconventional instruments such as helicopter money," explains Neugart.

However, the fascinating question being asked not only by the economists of TU Darmstadt is: Would it actually be good, beyond its metaphorical meaning, for providing a boost to the stagnating economy in the eurozone? And would it have a positive impact on people's buying behaviour and therefore on prices and inflation?

Currently experts are discussing two ways of distributing the helicopter money among the people. In the first method, the governments of the EU member states receive money from the ECB and pass it on to their citizens, for example by way of a tax refund. However, as this is government financing not covered by the mandate of the ECB, the second method appears to be better: The ECB sends the money directly to the households by cheque or transfer.

"I am very sceptical whether an instrument which will more likely make the people uncertain and which possibly will have no effect on the inflation rate should be used."

Neugart and Djuric have considered both channels in their behavioural economic study. They wanted to know what the people would do with such a financial injection, what expectations they attached to the helicopter money and their opinion of it as an instrument of monetary policy. The experts compared four scenarios. In the first, the participants had to imagine that they and all other citizens in the eurozone receive a one-time payment in the amount of EUR 1,200 from the Ministry of Finance, financed by money from the ECB. In the second, that they obtain this amount in the form of a cheque directly from the ECB and in the third, that the EUR 1,200 is paid out in twelve monthly instalments. Scenario four – a lottery win of EUR 1,200 – served as the control group.

All scenarios produced a central result: The interviewees would spend around 40 per cent of a windfall such as the helicopter money, put around a further 40 per cent in their piggy bank and use the remainder of around 20 per cent to repay their debts. What is interesting from the viewpoint of the researchers is that a phenomenon known as the "Ricardian equivalence" clearly does not apply here. According to this theory, people will act cautiously when they receive a monetary gift from the government, if the government has only borrowed the money itself. The fear that they will have to repay it sometime under these conditions results in such a payment not having any effect on consumption. "We did not observe this in our study," explains Neugart.

The around 40 per cent which would be spent on consumption is considered by the researchers to be a very positive sign. "The helicopter money could perhaps help us to come out of recession initially. However, we cannot predict whether it will have a lasting effect." Overall, the study proves that the spending behaviour in all helicopter scenarios would be no different than in the case of a lottery win. In addition, the majority of interviewees do not expect prices to rise as a result of such an instrument, nor do they expect it to have an effect on the overall economic situation. Instead, Neugart believes that the wide scatter of answers shows that many participants are uncertain, because they do not know what they are really dealing with with the helicopter money.

"Overall I am very sceptical whether an instrument which will more likely make the people uncertain, whose medial effect is not predictable and which possibly will have no effect on the inflation rate should be used," stated the expert. He recommends a different strategy for solving the problems in the eurozone and backs fiscal policy measures which encourage investment in industries of the future such as road construction, mobility, the energy sector or digital infrastructure instead of an "ultra relaxed" monetary policy: "These are good opportunities to invest in and I would suspect that these projects have a return that is greater than zero."

The author is a science writer and holds a doctorate in History.

Data base and framework

The data used in the study "Helicopter money: survey evidence on expectation formation and consumption behaviour" of Uros Djuric and Michael Neugart originates from the representative panel of German Social Sciences Infrastructure Services (GESIS) e.V. In this mixed mode panel, around 4,900 participants aged between 18 and 70 were interviewed. The study questions were answered in the spring of 2016. At this time, GDP had risen compared to the previous year by 1.5 per cent, the unemployment rate had fallen further to 4.1 % and the inflation rate was 1.67 %.

Publication:
https://doi.org/10.1093/oep/

AI that knows what it doesn't know

Julia Vinogradska's algorithms make machine learning more reliable.

By Boris Hänßler

Julia Vinogradska, research scientist at the Bosch Center for Artificial Intelligence, stands together with her doctoral supervisor Jan Peters, professor of Intelligent Autonomous Systems at TU Darmstadt, in front of a robot arm suspended on a frame. The robot has a table tennis racket tightly attached to its endeffector as though it were ready for a game. Jan Peters taught the robot how to play tetherball some time back using so-called reinforcement learning. Such machine learning algorithms always perform well in simulation on the professor's computer. But when Peters transferred it to the robot arm, it played as expected initially but then suddenly drew back powerfully to make a shot with the result that the robot arm smashed into its joint limits with major damages.

"What is special about Julia's policy search approaches is that they allow accurately estimating the system uncertainty about its knowledge with regard to the physical world."

Vinogradska looks both at the robot and at her dissertation advisor. She has a lot of experience with learning algorithms that do not always acquire the behaviours which they should – despite many advances in artificial intelligence (AI). One characteristic she has in common with her doctoral supervisor: "If something does not work, I get stubborn," she said. "I simply have to make it work." Peters, whose graduates are today pushing ahead with AI projects worldwide, has high hopes in the Ukrainian-born student. Justifiably so: In her highly regarded dissertation that Peters supervised, Vinogradska developed novel reinforcement learning methods with strong guarantees on performance as well as an improved efficiency. Their joint research resulted in three patents.

Reinforcement learning do their name justice: They reinforce good behaviour. Most artificial intelligence systems employ just supervised learning, which only reproduces the examples shown by a teacher. In contrast, a reinforcement learning system learns from its own mistakes – based on punishment and reward. Not unlike human practice in sports. For example, if a human tries to learn to hit a target using a bow and arrow, they are frustrated if the arrow misses the target and happy if it gets closer. Such feelings are deeply rooted in the brain's chemistry where neurotransmitters such as dopamine reinforce behaviour.

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Robots use reinforcement learning in this way, for example, to learn to walk. If the robot falls over, the algorithm receives negative points as punishment. If the robot manages to move without falling over, it wins positive points. The quest for receiving a high score pushes the robot gradually towards an optimal solution – provided it is given sufficient time. The famous artificial intelligence program AlphaGo taught the board game Go so well with such an approach at world class level -- forcing world's best human Go player into early retirement.

Reinforcement learning can also used for industrial applications. Here, however, a problem with such machine learning method has become apparent: if the learning is unsuccessful, and the machine reacts similarly extremely as in the case of table tennis, people working in the vicinity risk serious injury. To prevent this behaviour from happening, such systems cannot learn only with data from simulations but requires practical experience. This further disadvantage can make reinforcement learning application expensive.

At Bosch, applications are currently being conducted on a control plant for a so-called throttle valve. The policy regulates the input of the petrol/air mixture into a combustion engine. Optimisation can save a lot of energy – but if something goes wrong, the engine may be damaged. That is why the throttle valve is fitted with a sensor unit. The sensor data feeds into the learning process, and the AI system gradually figures out how to operate the valve more efficiently. During this process, however, millions of data points need to be generated during the interaction between the system and the sensor unit. "In contrast to a Go game that can be simulated, the learning process is conducted on a real test bed, and is, therefore, very expensive" according to Vinogradska.

Her doctoral work and patents focus on data efficiency and the reliability of such AI methods. Her reinforcement learning algorithms are based on numerical quadrature, an approximation of integrals. Her approach ensures that the system learns with as few interactions as possible – while, nevertheless, remaining as reliable as possible.

Assessing the stability and reliability of any technical system working is difficult. Particularly if the solution has been obtained by machine learning. "Such complex systems have an infinite number of states, and it is impossible for us to test them all," Vinogradska said. Uncertainties remain. Engineers take these manually into account – but typically only based on one specific state. This was too little for Vinogradska.

Photography: Katrin Binner

Tossing ball to each other just like they did with their ideas: Dr Julia Vinogradska and Professor Jan Peters. The machine learning algorithms developed as a result are considered pioneering for both playful robots as well as for industrial production and new products.

"What is special about Julia's policy search approaches is that they allow accurately estimating the system uncertainty about its knowledge with regard to the physical world" according to Peters. With this knowledge the system no longer reacts extremely to changes in the input data. "All methods of machine learning have so far been unable to cope well with major jumps in the input data," Julia Vinogradska pointed out. And Peters added: "It is very difficult to develop good algorithms for this problem, and Julia's are outstanding – there is currently no method that is anywhere near as good."

The author is a science writer and holds a doctorate in History.

Resolute in a men's domain

Julia Vinogradska has made AI methods more safe – and more efficient. Her doctoral work resulted in three patents and numerous publications in distinguished journals such as IEEE Transactions on Pattern Analysis and Machine Intelligence. Moreover, she was awarded the Young Scientists Medal by the Werner von Siemens-Ring foundation. She is currently a research scientist at the Bosch Center for Artificial Intelligence (BAIC) in Renningen near Stuttgart, one of the few centres for basic research worldwide run by a company. BAIC was founded in early 2017 and meanwhile encompasses seven international centres with more than 180 AI experts, all working on making artificial intelligence more useful, more robust and more explainable.

Julia Vinogradska was born in Ukraine. She came to Germany with her parents at the age of nine and later studied mathematics with a minor in computer science at Stuttgart University. "My choice of minor subject was not exactly easy for me." She explained: "I stood outside a lecture room full of exclusively male students, that put me off – but my father was a software developer and encouraged me." She actually ended up being the only woman in all computer science lectures that she subsequently attended. "But I still enjoyed my studies tremendously," she says smilingly.

During undergraduate studies, she focused on algebra and theoretical computer science. She wanted her doctoral work to be more application-oriented. Thus, she applied for an industrial doctorate offered by the company Bosch in cooperation with the TU Darmstadt. She started in a small research group that subsequently became the large research unit of the Bosch Center for Artificial Intelligence. Vinogradska's research in reinforcement learning is meanwhile one of ten separate areas of research at the Bosch Center for Artificial Intelligence.

Her current aim is to encourage young women not to be deterred by the low share of women in the field. "My experience was thoroughly positive at all times. I have never had the feeling of somehow incurring disadvantages. I am pleased to say I also was never unfairly promoted over others either. I would not have liked that." Computer science is a multi-faceted subject with an immense range of possibilities – particularly at TU Darmstadt. Julia Vinogradska can recommend both wholeheartedly.

Better Monitoring for climate protection

The success of the Paris Agreement depends on the effective monitoring of climate policy measures. Political scientists at TU Darmstadt explain in a new study how this can be improved.

By Jutta Witte

The signatories of the 2015 Paris Agreement not only agreed to limit global warming to well below two degrees, but each country also put forward concrete measures to reduce greenhouse gases and secure financial support. In order to assess the effectiveness of for example subsidies for renewable energies or regulations designed to improve the energy efficiency of buildings, policy monitored is essential. However, standardised policy monitoring, which permits comparative conclusions across the European Union, has so far remained elusive.

"At European level we simply do not know enough about the impact of many climate policies and therefore struggle to identify the best measures," explains Kai Schulze, Assistant Professor at the Institute for Housing and Environment (Institut Wohnen und Umwelt, IWU) and the Institute of Political Science at (IfP) of TU Darmstadt. The EU member states must report annually to the European Environment Agency EEA on current levels of greenhouse gas emissions and every two years on implemented and planned climate policies and measures.

The climate policy-based data submitted to the EEA is not only very heterogeneous, but also primarily represents estimates of future impacts. "The share of ex post data to understand past policy impact is very low," reports Dr. Jonas Schönefeld, a Research Associate at the IfP. In their new study, Schönefeld, Schulze and two colleagues from Finland and the United Kingdom looked into the factors driving good monitoring and how the quality of the monitoring processes can be improved.

The political scientists specifically focused on the role of political institutions, on legislation and the operational implementation of monitoring mechanisms and thirdly on the quality of the monitoring data. Their findings demonstrate that EU members with higher overall public spending report in a timelier fashion than countries with a smaller public budgets. By contrast, countries which were at the forefront of monitoring and evaluating their climate policies ten years ago still remain ahead today. At the same time, there are significant learning effects in policy monitoring across the countries, evidenced by greater levels of quantification.

"In other words, climate policy monitoring systems are improving over time," stresses Schönefeld. However, this will not happen on its own. In order to permanently improve the monitoring systems and in particular the collection of ex post data, the study suggests that the European Commission and the EEA need to provide technical support and raise greater awareness among the member states that monitoring needs to be a high political priority. Summing up the findings, Schönefeld explains: "Monitoring systems require resources, reliable institutional frameworks and committed political stakeholders."

The author is a science writer and holds a doctorate in History.

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Experts on climate policy: Dr. Jonas Schönefeld (left) and Professor Kai Schulze

Photography: Katrin Binner

Cooperation

The study "Policy Monitoring in the EU: The Impact of Institutions, Implementation and Quality" relies on quantitative regression models and qualitative interviews. It was co-funded by the Federal Ministry of Science and Research as part of the Kopernikus project ENavi (funding code: 03SFK4P0) and appears in a special issue of *German Political Science Quarterly.*
http://dx.doi.org/10.1007/s11615-019-00209-2

Aside from TU Darmstadt, the research team also involved colleagues from the Tyndall Centre for Climate Change Research at the School of Environmental Sciences of the University of East Anglia UEA and the Finnish Environment Institute SYKE.