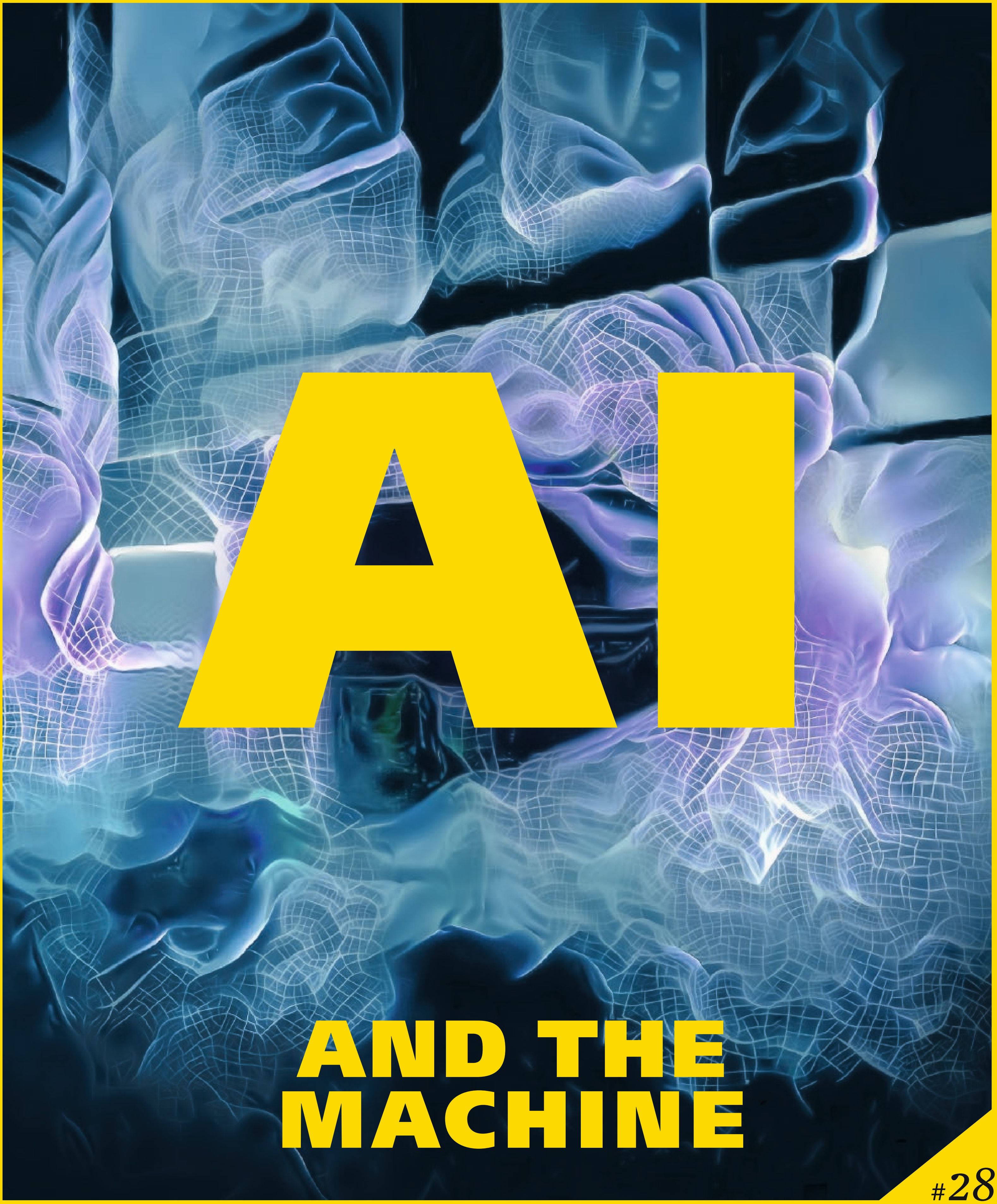
LASER COMMUNITY.

Of people and photons



AI AND THE MACHINE

#28

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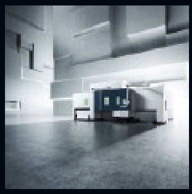

Our cover photo: how does AI get into the machine?

To create our cover page, a neural network identified the key shapes in the brain image and applied them to the picture of the machine.

Cover: PASIEKA www.fotosearch.de, TRUMPF (original image), M. Reinhardt via Deep-Dream-Generator (Motiv)

Better than its reputation

I like technology trends that prompt controversy and debate—and artificial intelligence (AI) definitely falls into that category. Let me make it clear right from the outset that I'm a huge fan of AI. I'm confident it will change and improve the world we live in. Admittedly, it won't always be easy, and not everything will work first time around, but isn't that always how things go? Particularly in our industry!

For decades, we have striven to understand and master laser light, learning from our discoveries and improving our manufacturing processes. And we have steadily increased our knowledge along the way.

This issue explores some of the stories that have emerged from this learning process. For example, how General Motors is gaining an increasingly sophisticated understanding of the keyhole in the welding process, and how Access Laser has learned to control light so accurately that it is revolutionizing dentistry. We also take a look at how psychiatrist Karl Deisseroth, a professor at Stanford University, is using a laser to investigate the question of free will. He is determined to understand how the human brain works. Thanks to AI, our machines and lasers are also starting to teach themselves how they can do things better. And that, surely, is a marvelous step forward!

We have already seen one of the first tangible results of this symbiosis between IT and machines in the manufacture of electric motors. AI offers the potential to massively improve both production and quality assurance processes in this area. One of the key steps in making an electric motor involves welding copper wires into a coil in what we call a hairpin winding. Conventional image processing algorithms determine the position of this hairpin to find exactly the right point for the laser to weld. If a weld seam does not meet the defined criteria, the motor must be removed from the line. Right now, our developers are training an AI to do that job on its own. It can detect whether a weld seam falls within the stipulated tolerances and notify the operator if it spots something is wrong. As well as maintaining consistently high weld seam quality, this AI solution eliminates time-consuming manual work because workers no longer have to check each weld individually.

Heated debate also tends to arise around topics that frighten or worry us. AI is likely to lead to such radical changes to our private and professional lives that I can completely understand why some people might feel uncomfortable. But I'm confident that the benefits outweigh the risks. Another way to look at AI is as a higher level of automation—and we all know that automation has made work easier for a lot of people, freeing up space for new, more interesting activities. AI is a huge opportunity. And it's better than its reputation might suggest.

DR.-ING. CHRISTIAN SCHMITZ

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Gernot Walter

Intriguing

Our interviewer obviously had lots of questions to ask when he went to talk to brain researcher Karl Deisseroth. But one thing fascinated all of us: in the famous experiment where the researcher controlled the mouse remotely by inserting a laser light cable into its brain, how did the mouse feel? Read the surprising answer on **page 16.**

Investigating

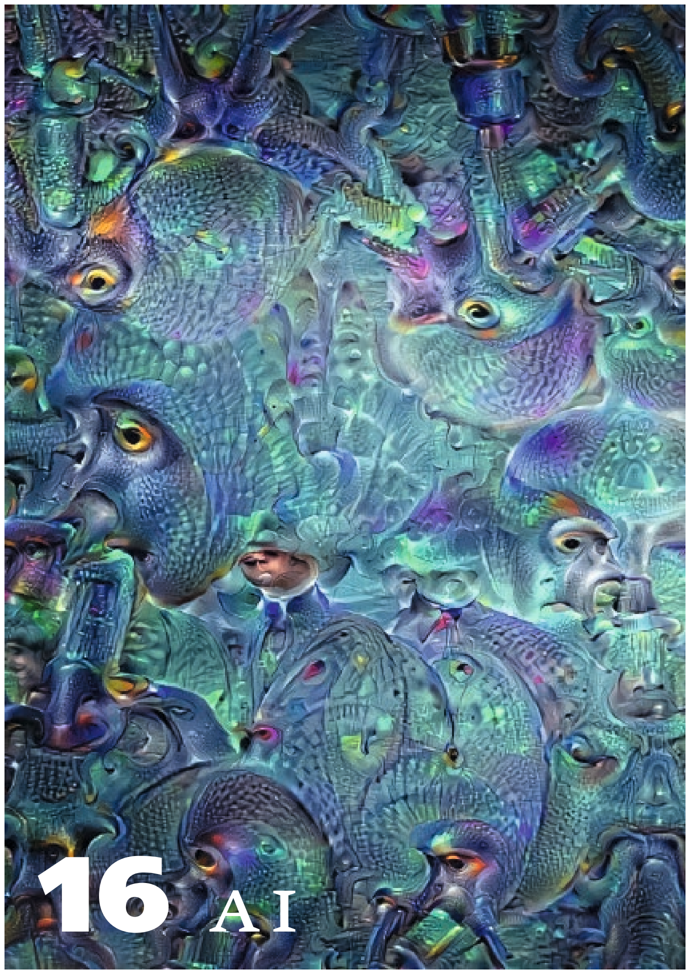
How did Berthold Leibinger look from behind in 1978? That was what illustrator Peter Bartels wanted to know. His job was to draw the entrepreneur as he headed off to investigate advances in laser technology. Frank Elstner came up with the solution in the form of a 1980 TV interview in which ZDF had filmed the presenter over Leibinger's shoulder. Check out his departure on **page 26.**

Inspiring

A marvel created by photon experts at TRUMPF subsidiary Ingeneric will be orbiting the Earth from 2022 onwards. We were eager to report on it, but then realized it doesn't use a laser. The Ocean Color Instrument is a passive telescope. Disappointed, we gazed into the sky and—lo and behold! We saw a whole bunch of lasers looking down on us. Find out what they do on **page 29.**

AdobeStock/Vasiliy Koval, Peter Bartels, NASA MODIS image courtesy Jeff Schmaltz

LASER



Frank Herfort, TRUMPF (original image), M. Reinhardt via Deep-Dream-Generator (Motiv)

CONTENTS

COMMUNITY.

Leon Zwiener, General Motors, Richard Morgenstein

POWER

Could a blue laser and copper make a good team? Experts are eagerly awaiting results from Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU).

BLUE HORIZONS

Physicist Stefanie Kohl conducts research into the optical properties of copper at FAU's Institute of Photonic Technologies (LPT).

The fact that copper reflects red light and high-power lasers operate at red or infrared wavelengths has always posed a dilemma. With e-mobility becoming more mainstream, however, the challenge of laser welding copper can no longer be avoided. At the University of Erlangen-Nürnberg, Stefanie Kohl has therefore decided to strike out on a new path—toward blue horizons.

Infrared lasers and copper are not exactly the best match. Put them together and you get a highly unstable process with lots of spatter and extremely low levels of repeatability. That's unfortunate, because the emergence of electromobility is rapidly making this combination more important than ever before.

The red metal is far better at absorbing light of shorter wavelengths, such as green or even blue. But with no sufficiently powerful beam sources outside the red portion of the spectrum, this knowledge has long been of little more than academic interest to researchers working on penetration welding processes for copper. Now things have changed, however, and users of the new green high-power lasers report clear benefits in applications such as welding batteries for electric vehicles. One example is a big improvement in the coupling behavior of high-energy laser light in the green region of the spectrum, leading to smoother, more stable processes.

These developments present us with some highly practical research questions which we now intend to explore through models and test series at the Institute of Photonic Technologies (LPT) at FAU. For example, what are the relationships between wavelength, temperature, process stabilization and alloy composition? And how are these affected by the energy input, output and efficiency of the process? Judged by these criteria, how much better is green light than infrared? And if green is better than red, what happens when we take the next step into the blue region? Beam sources for these wavelengths are already available. So could this step yield further gains in process stability, reproducible quality and speed? Green beam sources are certainly where the future lies for copper. But it's exciting to think how much potential blue may eventually have, too!

Otti Zink, TRUMPF / Illustration Gernot Walter

GLORY

Reinhart Poprawe has made a huge contribution to the global development of laser technology. His plans for retirement are still up in the air, but there's certainly no chance of him getting bored.

A MAP OF THE UNIVERSE

Reinhart Poprawe, director of the Fraunhofer Institute for Laser Technology ILT, is one of the most notable figures in the field of industrial laser technology, both in Germany and worldwide. So what are his plans now that he is approaching retirement?

When Reinhart Poprawe discovered at the age of 12 that there was no map of the universe, he couldn't believe his ears. All at once, he realized just how many unexplained things there must still be in the world—and he vowed to make a difference.

In the 1970s, while studying physics in California, he was astonished to see what was then the world's biggest laser. From that point on, his career became increasingly entwined with the development of laser technology. In 1985, he joined the Fraunhofer Institute for Laser Technology in Aachen as a department head. He subsequently moved to Thyssen, but his enthusiasm for lasers never waned and he eventually returned to Fraunhofer ILT. In 1996, Poprawe took over as director of the ILT. That same year, he was appointed to the chair of laser technology at RWTH Aachen University. In this latter role, he encourages people to look beyond their familiar horizons, providing staff with an impressive 30,000 square meters of space on campus to work in interdisciplinary teams. Poprawe is always open to new ideas, arguing that this is the only way to fuel innovation. This receptiveness has now become an integral part of the institute's culture.

The research complex as a whole has grown from 250 to 800 staff over the past 20 years, giving rise to more than 30 new companies in the process. Aachen has become a major hub of laser technology in Germany and beyond, and Poprawe has become one of its most prominent figures, firmly enmeshed in the global laser community.

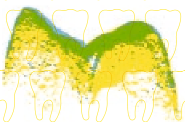
This year Poprawe is set to retire. His career was recently rounded off by an honorary professorship at Tsinghua University in Beijing as well as the distinguished Arthur L. Schawlow Award, which he received for his many years of service at the Laser Institute of America (LIA). Whoever takes his place will preside over a truly integrated interdisciplinary institute that is regarded as one of the most prestigious laser centers worldwide with excellent facilities for research and development.

Poprawe's next step is still undecided, but a map of the universe might well be in the cards! ■

Andreas Steindl / Fraunhofer ILT

"Say goodbye to toothache, kids!"

US company Access Laser is hoping to revolutionize dentistry with its DL-500 dental laser. Engineer Mike Adams explains why we won't have to be afraid of going to the dentist any more if this revolution takes hold.



Polarization sensitive optical coherence tomography utilizing a near-infrared laser maps a tooth surface. By overlaying images pre- and post-treatment, the volume of removed decaying enamel (green zones) is visualized. Due to the required pinpoint-accuracy this is a feat only possible utilizing dental lasers such as the DL-500.

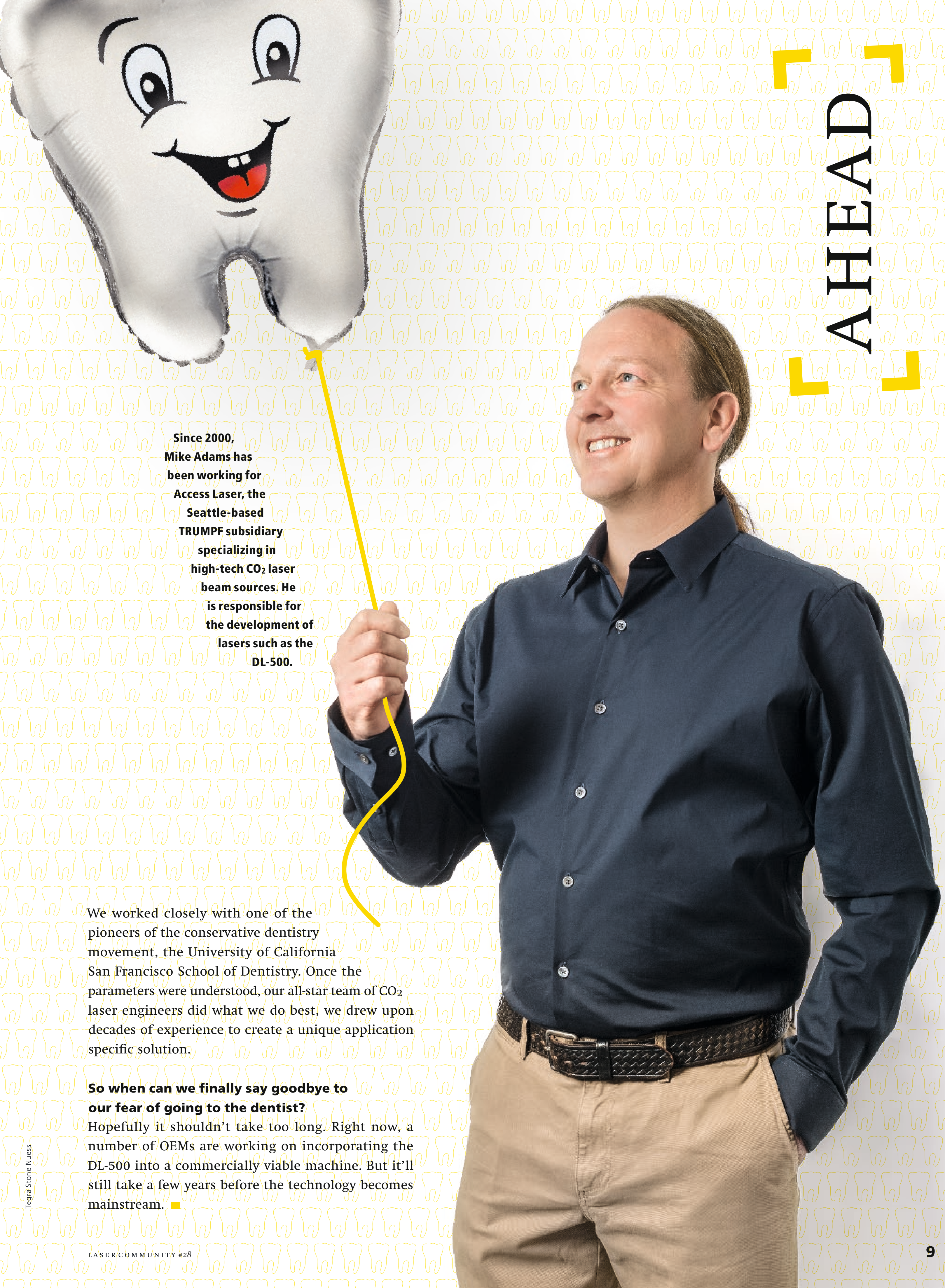
Mr. Adams, most of us associate the idea of a trip to the dentist with a sense of trepidation and, worst of all, a nasty drilling noise. Could that really be replaced by the gentle pulsing sound of a laser in the future?
Well, if the dentist was using our laser, the sound would be more pleasant for sure—and you certainly wouldn't have to be afraid of drilling. That's because our DL-500 is the first commercially available laser that is capable of replacing traditional drills and making treatment completely painless. Our aim is to trigger a new trend that could change the entire face of dentistry. Imagine a future in which kids could really say goodbye to toothache and never have to suffer from it again!

Before you tell us how you hope to achieve that, what's the current situation with lasers in dentistry?
Lasers have been used in dentistry since the 1990s. At first they were mostly Nd:YAG lasers, and they tended to be very large and expensive. Operating at a wavelength of 1.064 microns, they were totally unsuitable for dental hard tissue—in other words, for the tooth itself—and only provided limited soft tissue capabilities because there was simply too much heat build-up. The CO_2 laser with a wavelength of 10.6 microns was also introduced early on but had similar difficulties.

Since then several companies have introduced Er:YAGs at 2.94 microns which is primarily absorbed by water and thus ablates hard tissue via a secondary absorption where the water rapidly expands from liquid to gaseous steam. This micro-explosion of rapid expansion is what causes removal of enamel. However, this technique is slow, can still be painful for patients, and has limited efficacy for soft-tissue interaction as it does not provide hemostasis.

And now tell us your secret! What makes the DL-500 better?
Earlier dental lasers were originally designed for other purposes, the DL-500 is the first one developed specifically and exclusively for dentistry. It provides the ideal optical parameters for this application, and it's the first laser that works just as comfortably on both hard and soft tissue. That means it delivers pulse widths of less or equal to 25 microseconds at pulse energies greater than 10 millijoules, enabling the efficient and safe ablation of hard tissue while simultaneously providing exceptional soft tissue work. But as well as focusing on the specific beam characteristics, we also considered how the laser is used in practice. Any dentist can use the DL-500. It is very energy efficient and quiet, and it doesn't require any additional cooling. We have also made it so small that it will fit in any dental surgery setting.

How challenging was it to develop?
The idea of conservative dentistry that lasers enable has been thoroughly researched for over 30 years. So far it has not propelled a major shift in dental practices. The main challenge in developing this product was trying to understand the requirements that would enable this amazing research to be put into every dentists' hands.



AHEAD

Since 2000, Mike Adams has been working for Access Laser, the Seattle-based TRUMPF subsidiary specializing in high-tech CO_2 laser beam sources. He is responsible for the development of lasers such as the DL-500.

We worked closely with one of the pioneers of the conservative dentistry movement, the University of California San Francisco School of Dentistry. Once the parameters were understood, our all-star team of CO_2 laser engineers did what we do best, we drew upon decades of experience to create a unique application specific solution.

So when can we finally say goodbye to our fear of going to the dentist?

Hopefully it shouldn't take too long. Right now, a number of OEMs are working on incorporating the DL-500 into a commercially viable machine. But it'll still take a few years before the technology becomes mainstream. ■

Tegra Stone Nuess

Leon Zwiener

The Potsdam-based company Miethke produces high-tech medical devices that are implanted in people's brains and bodies

IDEAS KEEP COMING!

Medical device manufacturer Miethke acquired a marking laser to carry out precision cutting—but the story didn't end there.

One in every thousand babies is born with hydrocephalus, or fluid on the brain, a condition in which too much cerebrospinal fluid (CSF) builds up within the brain ventricles. It causes a wide range of symptoms from early on in life, including headaches and frequent vomiting. Hydrocephalus is incurable but treatable, and an implant can significantly improve patients' quality of life. Miethke—a high-tech medical device company based in Potsdam, Germany—manufactures the hydrocephalus valves, or shunts, that drain excess cerebrospinal fluid from the brain to return CSF pressure to normal. But the idea of inserting a medical device in a child's body can still seem startling to some people. "Obviously you have to work at the very highest standards—and it takes a lot of laser technology to meet those standards while still keeping the process economically viable," says Christian Gleumes, a project manager in Miethke's research and development department. "We have our own lasers, but some of the bought-in parts we use are also produced using laser light."

Working with suppliers hasn't always been easy, however. "Our hydrocephalus valves are about ten millimeters long and four millimeters in diameter, and some of them contain a delicate, flat spring made of ultra-thin titanium foil that is just 0.05 millimeters thick. Obviously that has to be cold formed, in this case with ultrashort pulse (USP) lasers." But the supplier that Miethke chose to do this job had a tough time adapting to the new methods and took too long to deliver the part. "We got fed up waiting, so we decided to bring the technology in-house and do it ourselves," says Gleumes.

CUTTING TODAY, MARKING TOMORROW
A few weeks later, on a visit to TRUMPF's Laser Application Center, he took the TRUMPF engineers by surprise when he suggested cutting the foil with a marking laser instead of a beam source designed for cutting. The TruMicro Mark is the first TRUMPF laser to use ultrashort pulses for marking—but at that point it wasn't even commercially available. "Obviously there are more economical machines for precision cutting than a marking laser," says Gleumes. "But the idea was that it could boost redundancy by acting as a backup in case our main marking laser ever broke down." Right now, Miethke uses just one nanopulse laser to mark its medical devices. "That's a potential bottleneck. If it goes offline, everything grinds to a halt." Hence the advantage of having a second laser waiting in the wings.

Tests by the TRUMPF application lab on precision cutting with the USP marking laser were successful—and Miethke was promptly signed up as a test customer for the TruMicro Mark. "We only produce small batches in this specialist segment of our business, so we weren't using the ultrashort pulse laser to its full capacity. We wondered what else we could do with the machine since it was already there—and of course we realized the most logical step was to use the marking laser for marking!"

THE MOST AWKWARD PART It didn't take long to find the perfect candidate for marking: the small hydrocephalus valve itself. The valve marking is subject to strict UDI requirements: it must be corrosion resistant, readable by humans and machines alike throughout the lifetime of the device and biocompatible with zero contaminants in the material. "It's a small part made of grade 5 titanium," says Gleumes. "It has a polished, reflective surface that is also rounded, so it's pretty much the worst-case scenario for a marking process!" Back in the TRUMPF application lab, engineers from the two companies came up with a process to tackle this challenging component. The USP laser produces what is known as a black marking—a nanopatterned surface structure that absorbs and scatters rays of light, creating an extremely dark, matt appearance without ablating any material. "I was very impressed with the results," says Gleumes. "The marking is perfectly readable in any light, whatever angle you look at it from." This process leaves the metallic structure of the titanium surface virtually unchanged while maintaining full biocompatibility.

The outstanding quality of the marking gave Gleumes another idea. At that time, Miethke was using an engraving process to apply markings to the tools physicians use to adjust the company's hydrocephalus valves: "You could feel the engraving when you touched it, and it didn't look that great. Yet those are the parts that physicians, our customers, handle on a regular basis! A perfect design is a sign of quality, and that's something we believe in very strongly." The tools are made of anodized aluminum, and the tests with black marking proved to be equally successful in this case. "Deep black lettering that you can't even feel. The new marking is really something! It looks just as good in the muted lighting of the chief physician's office as it does in a brightly lit operating room."

AND HOW ABOUT …? With three successful innovations already under his belt, Gleumes was inspired to come up with yet another idea. Miethke also makes parts from sapphire. The company's existing laser machine couldn't mark that material, so they had resorted to using stickers. "We kept having problems with bubbles of air getting trapped under the sticker. We tried our luck with the USP marking laser and the results were outstanding," says Gleumes, explaining how they were able to eliminate the stickers for new products.

His next idea delved even deeper into the company's range of products. One of Miethke's products is equipped with electronics that are protected by a polymer screen cut from polyether ether ketone (PEEK). "The machining process was really tough because the material is so hard to cut," says Gleumes. "What's more, we would have preferred the screen to have been made from ceramic, an inert material that is better suited to this particular application. We also wanted to make the ceramic screens in-house so that we wouldn't have to depend on a supplier." So Gleumes began experimenting with ways of cutting thin aluminum oxide ceramic with the USP laser. "It worked perfectly. And the best thing is that we can apply three-dimensional structures to the surface that protect the implant electronics even more effectively," says Gleumes.

That sparked his interest in the whole issue of surfaces. "Right now we're experimenting with ways of using the laser to create hydrophobic and hydrophilic surfaces on our parts. It seems that once you get hold of an ultrashort pulse laser, you are constantly finding new things you can do with it!"

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Right: Black markings on tiny, curved surfaces.

Below: Christian Gleumes (right) is constantly coming up with new ideas for his USP marking laser.

„ONCE YOU GET HOLD OF AN ULTRASHORT PULSE LASER, YOU ARE CONSTANTLY FINDING NEW THINGS YOU CAN DO WITH IT."

Christian Gleumes, R&D project manager at Miethke

Leon Zwiener


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The key to the keyhole

BY JOSHUA SOLOMON

Laser welding offers many advantages in vehicle body manufacturing, but also some unexplained sources of defects. We decided to take a closer look at the process here at General Motors—and in doing so, we discovered both why defects occur and how we can avoid them.

Our industry has long been plagued by the question of how to better manage and control welding processes. We needed a crystal ball to answer that question—and now we have one in the form of a numerical simulation.

It is well known that laser welding with oscillation is a good option for joining aluminum alloys. However, since measuring and monitoring a high-speed process is quite challenging, the underlying reasons why it is effective remained unclear. Equally elusive were the mechanisms of porosity-related defects. To combat these previously unavoidable defects, we needed to incorporate additional weld seams for safety, significantly limiting the freedom our product engineers had in the design process.

Determined to eradicate the limitations caused by porosity, we went right to the heart of the matter—which in this case meant the keyhole. Our team at the GM Technical Center has developed an advanced software model to study the laser-to-material interaction during welding. This software has enabled us to perform precision analyses of welding, optimize the process in the virtual world, and then directly apply the results in real-world manufacturing.

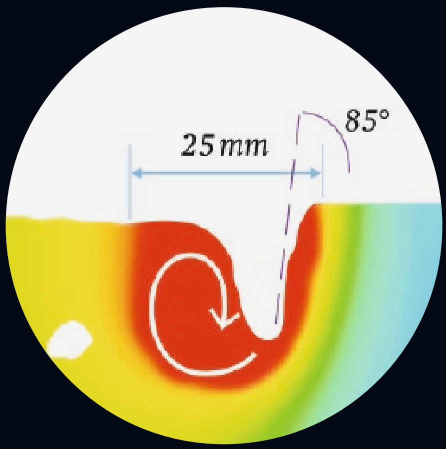
Based on two case studies involving laser lap welding and laser edge welding, our aim in this article is to show how we can use the model to better understand keyhole dynamics and pore formation and to find ways of reducing defects. These kinds of welds are typical in processes such as welding the door inner panel to the window frame reinforcement. Both cases involved welding AA5182-0 aluminum alloy—joining a 1.5 millimeter top sheet to 2 millimeter bottom sheet.

LAP WELDING When lap welding in a straight line—in other words, without oscillation—at a relatively low laser power of 2.5 kW and a welding speed of 3 m/min, our model reveals pronounced pore formation in the seam. Though we understood that pore formation was influenced by the flow in the melt pool, our model revealed the dynamics of these currents in more detail than could be obtained with any high-speed camera. These currents are the result of the interaction between multiple forces, many of which are temperature-dependent.

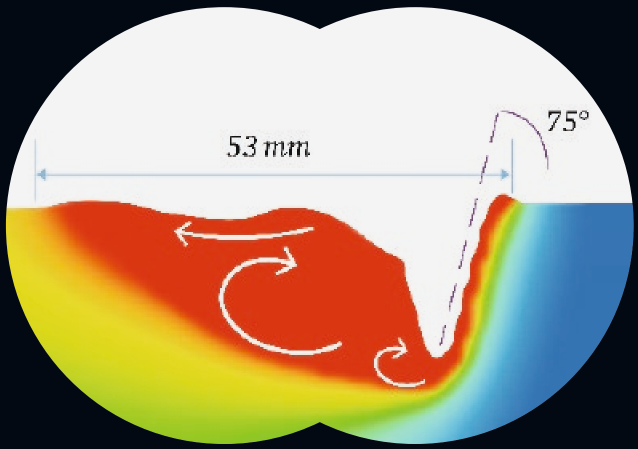
Thus, fluctuations in temperature lead to melt flow instabilities in the pool. When we heat the material with the laser, we generate what is referred to as recoil pressure. As molten material is pushed down, a vortex is created, the speed of which is dependent on the conditions in the keyhole and the state of the melt pool. At lower power and speed, the laser beam hits the rear of the keyhole wall and intensifies turbulence in the molten pool. In the worst case, this can cause the keyhole to collapse, trapping gas and leading to the formation of bubbles. Moreover, if the speed is too low, the weld pool is too short and the bubbles remain trapped beneath the solidifying surface, creating the undesirable phenomenon of pores in the seam.

Increasing the energy to 6 kW and the speed to 12 m/min elongates the weld pool, keeping the keyhole stable and leading to significantly fewer trapped bubbles. At high speed, the laser beam primarily hits the front wall of the keyhole, as opposed to the back wall, which limits force imbalance and consequently prevents collapse which would cause bubble formation.

Preventing defects is not solely a matter of increasing the speed, however, because high speeds create disadvantages of their own. In the context of lap welds, one disadvantage is narrower weld interface between the top and bottom sheets, which reduces the mechanical strength of the weld. This worsens further if there is any gap between the sheets. High welding speeds lead to large end craters, and with increasing speeds, ever higher laser power is required to achieve the necessary penetration depth. However, constantly increasing laser power comes with financial costs and other complications, and



a) It may look intriguing in the simulation, but the formation of porosity is a definite problem when it comes to real-life welding. Low speeds can cause the keyhole to collapse, leaving bubbles trapped in the solidifying material.



b) A digital model provides an opportunity to find robust solutions to this problem: higher speeds lead to elongation of the melt pool—and that keeps the keyhole stable.

at GM, where we use the 6 kW TruDisk for remote welding, there are advantages to keeping a common equipment set.

The virtual model shows us we can solve the problem of porosity by using oscillation. Scanner optics from TRUMPF enable us to achieve the high speeds, precise positioning, and control we need—with the focused spot travelling 450 mm/s and faster in some cases. Beam oscillation elongates the melt pool, making flow behavior more stable, thus preventing defects such as porosity. At the same time, oscillation is a controllable parameter for increasing seam width in a stable way. Mechanical testing of real-world welds have validated the simulation—transverse tensile and shear strength increased by almost 40 percent compared to straight-line welding or spot welding.

LASER EDGE WELDING As we moved on to our study of edge welding in the virtual world, we had already put into practice some of the lessons learned from lap welding, allowing us to prevent certain welding defects from occurring. We instead concentrated on optimizing the critical weld dimensions, specifically the throat thickness and leg length. We are able to maximize the mechanical performance by adjusting settings such as oscillation amplitude, frequency, and focus position. There was one particularly interesting result that came out of our model and was validated by results of real-world testing: when oscillation welding in a lap-fillet weld, the modes switch continuously between heat conduction and deep penetration. As the weld progresses over this joint, the spot changes from a shallow keyhole—or none at all—to a deep keyhole, and then back again. This finding is quite profound, because—setting aluminum aside for a moment—it also suggests that we could make significant improvements to welding of coated steels by influencing the outgassing of zinc vapor, for example.

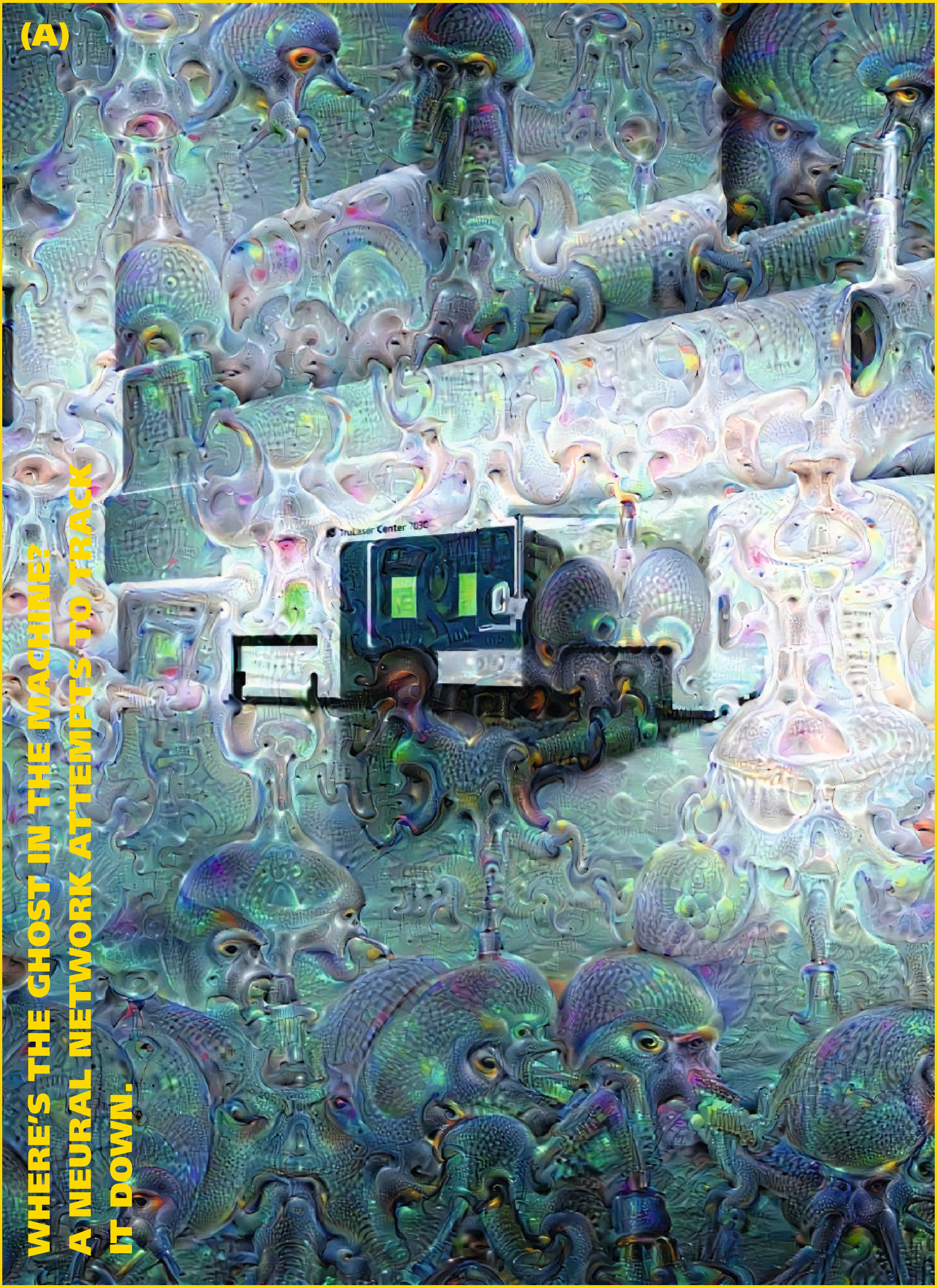
Our digital model has allowed us to not only understand the previously unmeasurable environment of the molten pool and keyhole, but also to predict and optimize it. One example is the fact that oscillation causes two different regions to form in the melt pool: a shallow, elongated region with a gentle flow, and a second one with a stronger flow around the keyhole. To increase penetration depth, we cannot simply increase power to deepen the keyhole, as this would result in keyhole collapse and porosity. Fortunately, we did not need to test all the combinations of laser parameters in real welds to solve this issue—through the simulation, we found that maintaining the same energy per unit length while increasing the oscillation frequency increased penetration depth.

In summary, both our case studies demonstrated that our simulation accurately predicts the result of process parameter changes. I must admit that the accuracy of the predictions was a pleasant surprise for us, and we have already incorporated findings from the numerical model into our manufacturing processes. We feel confident that modelling will become a standard tool in the industry within the next few years. It doesn't take a crystal ball to tell us that! ■

JOSHUA SOLOMON is a process engineer at General Motors. He is responsible for advanced technology and welding at the GM Technical Center in Warren, Michigan, US. His journey into the realm of lasers began in Germany, where he worked on laser welding for the first time as a development engineer at Daimler.

(A)

WHERE'S THE GHOST IN THE MACHINE? A NEURAL NETWORK ATTEMPTS TO TRACK IT DOWN.



TRUMPF (original image), M. Reinhardt via Deep-Dream-Generator (Motiv)

BRAIN POWER UNLEASHED

Artificial intelligence is transforming industry. So where are we right now? And what changes lie ahead? Join us on a journey into the future of laser material processing.

Chess players accepted defeat long ago. When an IBM supercomputer beat world chess champion Garry Kasparov at his own game in 1996, there was no longer any doubt that artificial intelligence, or AI, was far superior to humans—at least when it came to chess. But the story didn't end there. Fueled by remarkable quantities of data and driven by incredible computing power, the AI developed moves that were so novel, elegant and surprising—moves that no human player would ever have come up with—that they elevated chess to an entirely new level. Nowadays, anyone who is serious about playing chess knows how much they can learn from AI, so they deliberately pit their skills against it to pick up tricks and ideas. Ultimately, this has made human players better than ever before.

THE NEXT STEP IN INDUSTRY 4.0 IS AI.

Chess players have learned to accept and enjoy this process—but for mechanical engineers, production planners and design engineers, the journey is only just beginning. The whirlwind of Industry 4.0 is now reaching its peak as artificial intelligence sweeps into the world of manufacturing. AI long ago swallowed up critical tasks in other sectors that do not produce physical goods. In banks and the financial sector, for instance, algorithms already assess peoples' creditworthiness, buy and sell shares and detect credit card fraud. In the realm of medicine, they help doctors diagnose conditions such as skin cancer, and in the online retail world they support pricing and other marketing tools. But now the time has come for algorithms to make themselves useful on the shop floor, too.

STRENGTH IN NUMBERS It all starts with the areas where algorithms can play to their strengths, namely in organizational, non-material processes. That's where programs with AI components are already flexing their muscles, with self-learning algorithms checking production planning strategies and helping to ensure optimum capacity utilization. But that's not all: they are also helping to manage the invoicing process, correctly assigning each invoice and sending it on schedule. Handwritten orders can now be automatically incorporated in SAP using text and speech recognition. And every time these machine brains succeed—as well as every time they fail—they become a little bit smarter and increase their chances of doing things better next time.

AI neurons have only recently taken a step closer to the actual machines on the shop floor. Once again, the first and easiest point of entry is the 'soft' digital side of the machinery. Predictive maintenance is a good example. Fed with huge quantities of historical data and connected to sensors, an AI can detect when a machine needs maintenance and forward the data to production planners. This prevents unexpected downtime and enables companies to plan their maintenance work more efficiently, integrating it more smoothly in the production process. Occasionally, something might still go wrong—but, even then, an AI is on hand to help. At TRUMPF, for instance, self-learning software supports the quality assurance team on a production line for highly sophisticated flatbed laser machines. In the past, any problems encountered during test runs would require the team to inspect or even replace numerous parts of the machine—a laborious process that wasn't even guaranteed to succeed. Nowadays, sensors capture huge quantities of data in a short test run and send it to the cloud where it is compared with all previously known information and analyzed accordingly. It takes no more than a few seconds for the software to run through countless operating states. If it detects any irregularities, it can give its human colleagues a precise description of where the error most probably lies and how it should be corrected. Once again, the software gets better each time it's used.

Now, however, the time has come for AI to cross over to the other side. It is meeting metal head on, bridging the gap from a realm where data is the only currency to the real, solid core of industry where physical things are made. Unlike the software applications that are used for tasks such as production planning, however, AI struggles to carry out test runs on real parts in industrial applications. In this environment, one false move can result in car doors or electronic components ending up on the scrap heap. What's more, AI isn't even an option unless machines have been specifically designed to incorporate it—and arguably there's little point in adding a brain to an interlocking gripper that simply moves back and forth. For algorithms to actually learn something and make use of what they learn, the machines must have a high degree of freedom.

AI MAKES MACHINES BETTER AND BETTER OVER TIME.

HARD SIDE The fully automatic TruLaser Center 7030 laser system from TRUMPF is one of the first examples of how this can be applied to the 'hard' side of industry. In this case, the required degrees of freedom stem from the 180 movable pins that are supported by an AI. The machine cuts parts from a metal sheet and then removes them automatically. Currently, this repetitive job is often done by hand because the parts may tilt slightly as they come out of the sheet. A human can easily jiggle the part into the correct position—but this task can quickly overwhelm an automated solution. Not any more, however. In the TruLaser Center 7030 system, pins lift the part from the scrap skeleton from below while suction plates hold it in place from above. What makes things trickier is that these cut parts come in an almost endless assortment of shapes, sizes and thicknesses. But if a part gets stuck on the first try, the suction plates and pins simply repeat the process in a slightly different way until they succeed. The machine sends all the data on these failed attempts to the cloud where it is evaluated centrally. In the future, all TruLaser Center 7030 systems will receive regular updates, allowing each and every user to benefit from what the algorithms have learned worldwide. This huge pool of machines, all connected to the same central hub, offers real benefits to users by making their individual machines better and better over time.

The same applies to monitoring weld seams and cut edges. TRUMPF is currently training a self-learning software program that uses optical sensors to assess the quality of weld seams and edges and notifies users whenever these deviate from the stipulated tolerance range. Researchers are putting the AI's performance to the test in the complex task of welding hairpin windings for electric motors. Once again, the software becomes increasingly confident in its judgment the more times it performs the task. Soon it will be capable of assessing laser processing results not only much faster than a human expert, but also much more accurately.

SMART LASERS The changes sweeping industry in general are particularly relevant to laser applications, which already inhabit a realm beyond the hard border that AI is currently seeking to cross. Unlike milling cutters, drills and all other mechanical tools, the laser is fully in its element in the digital world.

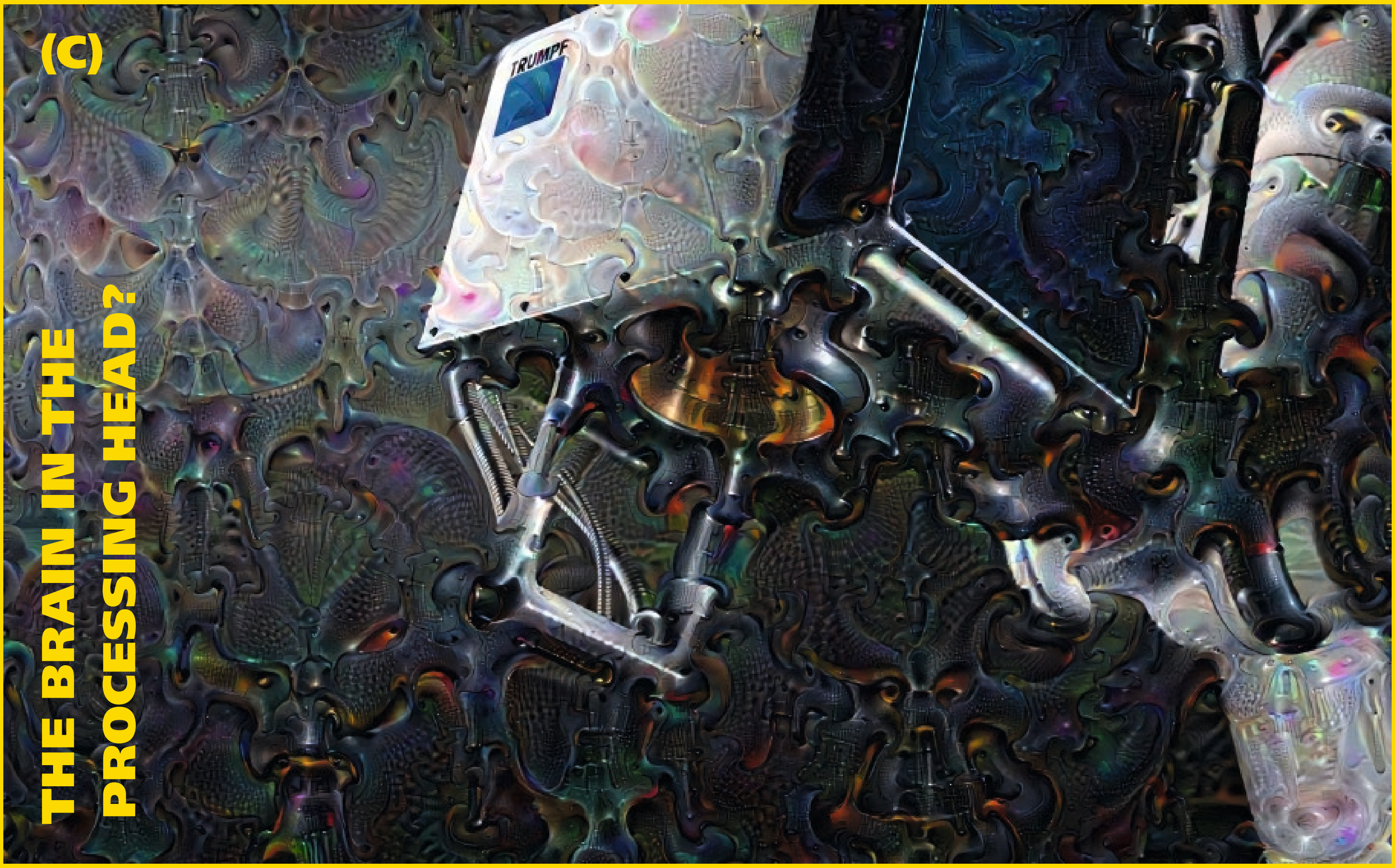
Ever since their first use in industry, lasers have been numerically controlled and primed to create real objects out of data. And that's not the only advantage lasers have over their mechanical counterparts: with laser systems, the only thing standing between the data and the product is a physically unconstrained beam of light. From Industry 4.0 to AI's introduction in industrial domains, it is hard to imagine a tool that is more flexible, adaptable and direct than the laser. Whenever an AI generates a new processing strategy—whether through a series of nuanced adjustments or, as in AI chess, through a sudden blinding flash of paradigm-shifting inspiration—the laser can tap straight into that pure information and immediately put it into practice. It's impossible to imagine any greater degree of freedom.

Lasers also score highly on their ability to capture vast quantities of data using a whole host of sensors—data that is steadily becoming more and more valuable. Algorithms trained on the basis of human experience can constantly detect new patterns in this jumble of information, invisible to the human eye, and then use these patterns to draw conclusions. Researchers worldwide are developing these kinds of AI systems right this second. And the results will gradually improve not just laser material processing, but also lasers themselves.

Much like today's chess players, laser users a decade into the future will be the best laser users of all time—and they will have learned to love their AI. ■

Contact: Jens Ottnad, head of pre-development networked systems, TRUMPF, phone: +49 7156 303-31902, Jens.Ottnad@trumpf.com

TRUMPF (original image), M. Reinhardt via Deep-Dream-Generator (Motiv)



(C) THE BRAIN IN THE PROCESSING HEAD?

BY WORKING TOGETHER TO EVALUATE DATA, COMPANIES CAN BENEFIT FROM THE RESULTS OF AI.

Christin Schäfer A statistician who developed AI solutions for Deutsche Bank before founding her own company—acs plus—in 2016. The services she offers include the development of machine learning applications, a field in which she collaborates with TRUMPF. Schäfer has been a member of the German federal government's Data Ethics Commission since 2018.

Torsten Kröger Kröger is professor of computer science and director of the Intelligent Process Control and Robotics Laboratory (IPR) at Karlsruhe Institute of Technology (KIT) and a visiting scientist at Stanford University. He founded a robotics start-up that was acquired by Google in 2014. He was subsequently appointed Head of the Robotics Software Division at Google's parent company Alphabet. Kröger has been working with TRUMPF on AI solutions since 2018.

Private, KIT, TRUMPF (original image), M. Reinhardt via Deep-Dream-Generator (Motiv)

"The machines will program themselves."

How will AI transform industry? We got the developers' perspective from AI expert Christin Schäfer and KIT robotics professor Torsten Kröger.

What's the current status of AI in industry?

Schäfer: All these machine learning technologies are unbelievably powerful, especially if you can process sensor data such as image files, for example. Some companies can already point to flagship achievements in certain areas, while others are still in the starting blocks. I think the biggest potential lies in streamlining production processes and administration and in developing new services and products. We're also gradually starting to see people using data-driven algorithms directly in the manufacturing process.

Kröger: In terms of motor skills—for example a robot acting autonomously in a real environment and learning as it goes along—things are still in their infancy. But in recent years we have seen a huge leap forward in the realm of perception, such as identifying conditions and patterns.

What potential do you see?

Kröger: To be frank, many of the automated systems in factories are poorly programmed. There is definitely potential for supervised machine learning to significantly accelerate all the production processes in sectors such as the automotive industry. That could really boost efficiency. The same point actually applies to smaller companies, too. Programming has always been one of the big hurdles that stops smaller businesses from purchasing machines and robots. But now it's getting easier all the time, especially with support from AI. Anyone in the small batch, low-volume business can slash their operating costs if they can make reprogramming quicker and easier, or even automate it entirely.

So where are the stumbling blocks at the moment?

Schäfer: I always tell people to take a really close look at the problem they want to solve. Right now, many companies are focusing on deep neural networks and are determined to put them to use. The problem is that these methods require huge quantities of data. For learning to take place, you typically have to feed the neural network with millions of pieces of data, and sometimes that is simply not available. Unfortunately, when they do snap out of the neural network pipedream, many people end up dismissing it as a load of nonsense, which is definitely not the case. We still have traditional statistical methods that can be used to achieve major efficiency gains with comparatively little effort. Neural networks are definitely the way forward, but only in cases where they actually make sense!

Kröger: I agree. The problem is the quantity and quality of the available data, plus the effort it takes to make it usable.

So how do you go about solving that data problem?

Kröger: Using simulations. In industrial settings you can't simply come along and produce a few million faulty parts before the algorithm finally learns what works. But there are plenty of processes in industry that are easy to simulate, and that provides synthetic data that we can use to train algorithms.

Schäfer: Cooperation is another option, in other words companies sharing their data. You can't get enough data for a neural network from one company alone, but you can get a lot more by combining data from all the companies within a certain sector. That means companies taking a long, hard look at their USP. In most cases, I doubt that their USP lies in their production data. Once companies are ready to join forces in evaluating and labelling data, they will gain immense benefits from the results that AI can offer.

Where do you think we will be in ten years' time?

Kröger: We will gradually reach a point where machines can program themselves. Humans will simply tell the machines what part they need and what features it should have. The software will create a full-fledged design and the machines will be able to get straight down to work. So the level of automation on the shop floor will be much higher than it is today, and manufacturing will be tremendously efficient.

Schäfer: I expect to see huge changes in the supply chain, and equally big changes in capacity utilization. There will be online platforms where individual machines and entire companies will automatically post their available capacity in real time and accept orders. A self-learning AI will manage production planning, submit the corresponding orders to suppliers and handle the logistics. The infrastructure for all that is already in place. ■

BRIEF GLOSSARY OF INDUSTRIAL AI

[ARTIFICIAL INTELLIGENCE]
(AI) Everybody's talking about it (including us), but there is no exhaustive definition of the term either in business or in the scientific community. Essentially, it means getting machines to behave in an autonomous, intelligent way. But opinions differ as to what 'intelligent' really means in this context.

[ARTIFICIAL NEURAL NETWORK]
An attempt to build an abstract model of how the human brain works. Used in contexts such as deep learning.

[MACHINE LEARNING]
(ML) A subset of AI that is particularly relevant to industry. Based on examples (i.e. data), software algorithms learn to recognize a pattern and apply this learning to solve a task—for example visually distinguishing between a good weld seam and a bad one. Various learning strategies are available.

[DEEP LEARNING]
A subset of ML. An artificial neural network is fed with vast quantities of data. It then draws its own inferences autonomously, without human support.

[SUPERVISED LEARNING]
A machine learning strategy. A human helps the algorithm learn, for example by structuring and classifying the data beforehand. That enables the program to subsequently assess new, unclassified data. In a variant known as reinforcement learning, the learning process is reinforced by pre-programmed rewards or penalties.

[ALGORITHM]
In simple terms, an algorithm is a formal description of a set of step-by-step procedures for making a decision. If A, then B. Software algorithms often contain many complex sets of instructions.

[BIG DATA]
A much hyped buzzword. Essentially, big data is about deriving meaningful insights from huge unstructured datasets, for example using deep learning.

[PERCEPTION]
In the context of machine learning, perception is the ability to identify and evaluate relationships. Input data typically include images, sounds and other sensor data. Researchers have been making huge progress in this area for years, for instance with automatic speech and facial recognition.

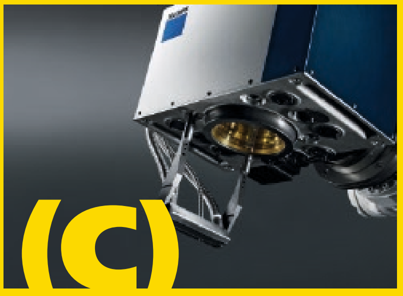
[MOTOR SKILLS]
In machine learning, motor skills refer to a robot's ability to move freely within a space and interact with physical objects without programming. The intelligence lies in the motor itself which can observe itself through sensors as it operates in real time. Research in this area is still in its early stages.

[NEURAL ARTWORKS

THE IMAGES IN THIS ARTICLE STEM FROM AN EXPERIMENT CARRIED OUT AT GOOGLE IN 2015. A TEAM THERE DECIDED TO FIND OUT WHAT NEURAL NETWORKS SEE WHEN THEY ENGAGE WITH IMAGES. ONE OF THEIR RESULTS WAS THE ONLINE APP HTTP://DEEPDREAMGENERATOR.COM

A neural network trained on faces attempted to make sense of this image of the TruLaser 7030 AI machine.

If a neural network learns patterns from the Valyrian culture dreamed up by the author of Game of Thrones, what dreams will it come up with?



The neural network that tackled this photo of an I-PFO had the image of a brain as its search task.

TRUMPF

ULTRAFAST VARIFOCAL LENSES IN LASER MATERIAL PROCESSING

High-throughput laser materials processing requires precise control of the laser beam position. As part of her doctoral dissertation at Princeton University, Ting-Hsuan Chen (27) developed a new technique based on rapidly scanning the laser focal point along the optical axis using an ultrafast variable focal length lens. As well as improving the efficiency of material processing, this also opens the door to enhancing the laser processing of parts with uneven topographies. Read the full dissertation:

https://dataspace.princeton.edu/jspui/handle/88435/dsp01dn39x4241

LASER STRUCTURING FOR MICRO AND NANO PHOTONICS

In recent years, numerous researchers have used femtosecond laser pulses to modify and fabricate metals, semiconductors and dielectrics for micro and nano photonic applications. In his PhD thesis submitted to Swinburne University of Technology in Melbourne, Xuewen Wang (27) summarizes the results of this work and highlights the advantages and strategies of the various methods used. The full paper is available online:

http://hdl.handle.net/1959.3/440411

So what does the future hold for light as a tool? Work by four young researchers gives some idea of what possibilities lie ahead.

LATEST → RESEARCH

LASER DEPOSITION OF NANOPARTICLES ON SILICON WAFERS

For his doctoral dissertation at the Technical University of Berlin, Mohammad Hossein Azhdast (38) transferred thin layers of aluminum and copper nanoparticles from coated glass or donor film to a silicon wafer substrate using laser radiation. He investigated how the pulse durations and wavelengths of different Nd:YAG lasers affect the deposition process. Laser radiation is an important technique for generating patterns with high resolution. It offers significant potential for micro and nano device fabrication, wire bonding and 3D interconnect processes. Read more here:

https://d-nb.info/1165650436/34

ULTRASOUND-AIDED LASER JOINING OF METALS TO PLASTICS

In recent years, much interest has been shown in joining dissimilar materials such as light metals and plastics, especially in the automobile and biomedical industries. This is primarily achieved by means of a technique known as laser-assisted metal and plastic joining. In some cases, however, this results in the formation of gas bubbles that reduce joint strength. As part of her doctoral thesis at The Hong Kong Polytechnic University, Yujiao Chen (30) developed an ultrasound-aided laser joining process that eliminates laser-induced bubbles and strengthens the bond between plastics and metals. Read the full paper:

http://hdl.handle.net/10397/73136

A lot can go wrong with the human skeleton (left). Production manager Nadeschda Morozova (top) dedicates her time to fabricating custom-made replacement parts. And her work at CONMET now encompasses far more than just screws and plates.

Frank Herfort

Working to the bone

Spinal disorders are on the rise in industrialized countries. 3D-printed titanium implants offer hope in some of the most severe cases.

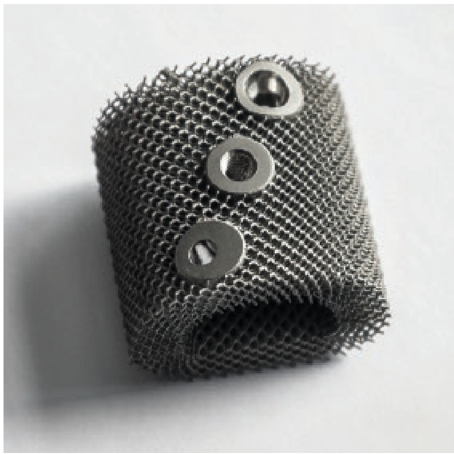
At first glance, these little grey blocks may seem unremarkable—but they have the power to change people's lives. Known as interbody cages, they are a type of spinal implant that can be inserted as a space holder between two vertebrae to restore the natural height of the vertebral segment. For this to succeed, the cages need to meet stringent design requirements. As well as withstanding mechanical stress, they need to be lightweight and also biocompatible so that the body doesn't reject them. The Moscow-based company CONMET currently produces cages on a TRUMPF TruPrint 1000 using 3D printing technology. In the medium term, general manager Dmitry Tetyukhin plans to deploy a TruPrint 3000 to ramp up to full-scale production.

PERFECT CANDIDATE FOR 3D PRINTING

Back pain is a widespread condition in industrialized countries and the most common health complaint overall. Those affected suffer pain and reduced mobility on a daily basis. In the most severe cases, problems such as a herniated disc can only be treated surgically by stiffening the affected segment using an implant. As far back

A healthy dose of powder: CONMET taps into the potential of 3D printing in two different ways. Firstly, to print custom-made implants and, secondly, to develop innovative mass-produced implants.

What the eye can't see: the surfaces 3D printing can produce are the key to promoting a connection between the bone and the implant.



Prototype for 3D printed cages: for a long time, spinal fusion was the option of last resort for a herniated disc, but now 3D printed cages can restore vertebral segments to their natural height, allowing patients to return to pain-free mobility. This requires cages that are not only biocompatible, but also resilient enough to ensure that none of the mesh tears or crumbles. Fortunately, 3D printing is more than up to the task.

as 1993, Moscow-based company CONMET recognized the transformative potential of 3D prototyping technologies as a means of fabricating custom-made medical implants. Since then, CONMET has worked closely with research centers and industry partners to research and test oral and maxillofacial implants. As the leading implant manufacturer in the Commonwealth of Independent States (CIS), the company is now keen to consolidate its position by tapping into the promising market of spinal implants, says CONMET production manager Nadeschda Morozova: "Surgeons treating degenerative spinal disorders and spinal injuries implant a cage in around 60 percent of cases—so demand is high."

The cages themselves are made of a biocompatible titanium alloy. One of the key challenges cage manufacturers face is how to create a surface that has exactly the right level of porosity, Morozova explains: "Porous structures promote osseointegration, in other words direct structural and functional connection between the living bone and the surface of the implant. These structures are almost impossible to fabricate using conventional methods such as turning, milling and casting, so 3D printing has a clear competitive edge."

CONMET uses a Tru Print 1000 from TRUMPF to develop parameters and test different geometries and materials. "Our aim is to better understand all the processes involved," says Morozova. "That will enable us to produce custom-made, patient-specific implants and give us the groundwork we need to embark on full-scale production at the earliest possible stage."

This is the second 3D printer from TRUMPF to be commissioned at CONMET. In early 2018, the company began using a TruPrint 1000 to make dental and craniomaxillofacial implants for cancer and traumatology patients. As well as the machine itself, TRUMPF also supplied the appropriate titanium powder, substrate plate, recoater tool and software. TRUMPF's high level of expertise and the overall success of the collaborative process were the deciding factors behind Dmitry Tetyukhin's decision to acquire the second printer. Morozova explains: "The TRUMPF experts in Ditzingen and their colleagues at the Moscow subsidiary offered us extensive support and advice to help us introduce the new technology and proved to be truly reliable partners. Their expertise played an invaluable role in the second project, too—for example when it came to determining the right parameters." CONMET plans to purchase a TruPrint 3000 to kick off full-scale production of its spinal implants. ■

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Frank Herfort

A TRIP ACROSS THE POND

An episode from the life of Berthold Leibinger. Retraced by Athnassios Kaliudis and illustrated by Peter Bartels.

This story is based on real events, including Leibinger's journey to the US in the winter of 1978, his visits to laser manufacturers and the world premiere at the EMO trade fair. The rest is fiction, including our description of Leibinger's thoughts and feelings.

USA, 1964: Chandra Kumar Naranbhai Patel, an electrical engineer and physicist, develops the first CO_2 laser with continuous output power in his laboratory. Three years later, the US-based company Coherent Radiation Inc. launches the first laser that can cut metal. Trade journals worldwide praise this new 'miracle tool' to the skies.

Ten thousand meters above the Atlantic, Berthold Leibinger checks through his travel documents one last time. It's February 1978, and he has arranged to visit various laser manufacturers in the US. But this long-haul flight is doing little to recharge his batteries for the days ahead. Far from relaxing, his mind is racing with thoughts about lasers. Ten years earlier, the laser had been little more than a nifty gadget. Its grotesquely huge resonators made it far too awkward and impractical, so it was mostly confined to test laboratories. But now lasers had become smaller, more manageable and sturdy enough to put to good use. Some people in the US were already cutting metal sheets with lasers and talking excitedly about installing lasers in machine tools. Leibinger was determined to see all this with his own eyes. After all, cutting free-form contours in metal sheets was the domain of nibbling machines—and the press had branded him the Nibbler King for good reason! Leibinger fidgeted around in his airplane seat. What if the laser was just as good as a nibbler at cutting metal—or even better? And what if the laser was faster? His mind whirred with all the possible implications.

Peter Bartels

Berthold Leibinger was a senior figure and partner at TRUMPF who spent his whole life working as an entrepreneur and philanthropist. After studying engineering in Stuttgart and spending two years in the US, he joined TRUMPF in 1961 when the company was still a fledgling machine maker. He fueled the company's growth with numerous inventions, for which he received remuneration in the form of shares. He thus became a partner in the company in 1966 in addition to his role as CEO. Under his stewardship, TRUMPF evolved into one of the world's leading machine toolmakers. Leibinger is now regarded as one of the pioneers in the industrial application of lasers. He died on October 16, 2018, aged 87.

Safe on the ground in Hartford, Connecticut, Leibinger pulls his coat tighter around him. It's the middle of a bitterly cold winter on the East Coast. Leibinger's first port of call is United Technologies. There he meets a Mr. Carstens, who waxes lyrical about the wonders of lasers. Leibinger is impatient to see the laser in action. Eventually, Carstens takes a cigar box out of the drawer and empties some samples onto the table. He can't help smiling, and is barely able to conceal his pride in his new tool. Leibinger can't take his eyes off the laser-cut samples in front of him. He picks one up and runs his fingers over the contours. The cut edges are rough and have a noticeable burr, and there are bits of weld stuck to the bottom. Carstens talks enthusiastically about how effortlessly and silently the laser works, but Leibinger isn't really listening; he's still too busy inspecting the samples. They are nowhere near ready for industrial application and would clearly need significant rework before they could be put to use. Nevertheless, a vision starts to form in Leibinger's head: what if the cut edges could be made smooth enough? What then?

The scene shifts to Carstens' factory floor. They are standing in front of the laser. A flick of a switch, and an invisible light dances across the metal sheet. A few sparks fly, and the part is cut from the sheet—job done! Leibinger is thinking about his copy nibbler, picturing the mechanical sensor moving along a template and the machine nibbling its way through the metal. He glances at the laser; it is clearly an elegant and innovative solution, even if it needs some perfecting. Leibinger can't shake off the sudden feeling that his punching press is clunky and antiquated. Meanwhile, the vision in his head continues to take shape.

His visit to United Technologies over, Leibinger flies to California and meets other laser manufacturers. The weather improves as he moves from east to west—and so do the lasers. On the airplane back to Germany, he stares at the samples on the folding tray table in front of him, lost in thought. Gradually his mouth curls into a smile. Leibinger has an intuition—a crystal clear vision—and right there and then he makes a decision: as soon as he gets home, he will be sending an order to the US. It's time to buy a laser.

Germany, 1979: at the EMO exhibition, rumors have been flying of a new machine tool with a combined processing head, and everyone is eagerly awaiting the live demonstration. The machine operator launches the program and the punching tool kicks off by punching a start hole. Then the laser fires up, dancing across the metal and cutting complex contours in the sheet. The Nibbler King has successfully showcased his first combination punch laser machine! The production of copy nibblers ceased just a few years later, with the laser taking over their role entirely. □

i4.0

Breaking down boundaries

DIGITALIZATION IS SHIFTING OUR FOCUS. NOT ONLY TOWARD TECHNOLOGY, BUT ALSO TOWARD COLLABORATION. AND THAT'S GOOD NEWS FOR EVERYONE.

In today's Internet of Things, everything communicates with everything. This offers clear benefits that also extend to the sheet metal fabrication sector, because connecting individual components can save companies a lot of time. Sheet metal fabricators currently spend up to 80 percent of their production time on indirect processes and, on average, 50 percent of their jobs involve batch sizes of four or fewer parts. Viewed as a proportion of overall throughput time, the actual processing time is extremely low in the sheet fabrication business.

TRUMPF sees potential for improvement in this area—and that's exactly what our TruConnect digitalization solutions are designed to exploit. This also requires us to boost our connectivity in-house, linking not just our internal departments such as development and sales, but also extending this network of connections to the customers and partners outside our company's walls.

The TruConnect development process has the capacity to dissolve the borders between hardware, software, sales and service, eliminating the divisions between departments and business areas that still exist today. That's because software-based digitalization solutions do not come about through rigid plans or in isolated departments. Instead, they often involve many different departments working together with partners both inside and outside the company—just like our Track & Trace indoor positioning system. We also believe in getting our customers on board right from the very start, because we rely on timely feedback from them to perfect our products and tailor them to our customers' requirements. We also work closely with universities and research institutes. Experience has shown that highly complex Industry 4.0 products are most likely to thrive in open innovation ecosystems and not behind the closed doors of a single department.

All this has an effect on our organization. Each agile team of experts takes responsibility for making far-reaching decisions, with managers primarily taking the role of facilitators and networkers. As organizational structures become more flexible and adaptable, management teams are increasingly focusing on augmenting people's know-how and enabling teams to manage themselves in a way that benefits the organization. Their task lies in organizing collaboration between many different individuals and bringing different disciplines together. This interdisciplinary, boundary-breaking way of thinking and acting helps ensure that we always bring out the best for our customers in connected sheet metal fabrication. ■

Julia Duwe is chief agile manager at TRUMPF.

TRUMPF

EYE IN THE SKY

Satellites and laser technology are a match made in heaven: together, they are measuring the world with previously unimaginable accuracy.

ADM-AEOLUS

Atmospheric Dynamics Mission

Agency: ESA **Mission:** to observe and measure wind profiles **Active:** since 2018 **Laser:** ultraviolet laser lidar measures moisture distribution, air flow and wind conditions in the atmosphere at various altitudes.

ICE SAT-2

Ice, Cloud and Land Elevation Satellite 2

Agency: NASA **Mission:** to track changes in the thickness of ice caps **Active:** since 2018 **Laser:** lidar system operating in the green band measures the Earth's surface and determines changes from one satellite pass to the next based on differences in propagation time.

GRACE-FO

Gravity Recovery And Climate Experiment Follow-On

Agency: NASA **Mission:** to measure the Earth's gravity field **Active:** since 2018 **Laser:** two satellites use a microwave instrument and a laser ranging interferometer to detect changes in the Earth's gravity field by measuring the changing distance between them.

LISA

Laser Interferometer Space Antenna

Agency: ESA **Mission:** to measure gravitational waves **Active:** from 2034 **Laser:** three satellites will form a laser interferometer with 2.5 million-kilometer-long arms, opening up new regions of the gravitational wave spectrum.

SLR

Satellite Laser Ranging

Agency: NASA, ESA **Mission:** to determine satellite positions with a high degree of accuracy **Active:** since 1970 **Laser:** satellites can only provide precise measurements of the Earth if we can determine their position in relation to the Earth with a high degree of accuracy. This is achieved through laser measurements by Earth-based observatories.

CATS

Cloud Aerosol Transport System

Agency: NASA **Mission:** to measure the distribution of dust and pollution in the atmosphere **Active:** from 2015 to 2017 **Laser:** operating at infrared, green and ultraviolet wavelengths, a lidar onboard the ISS was used to determine cloud layer height, thickness, and depth.

Gernot Walter

"The question of free will …

Professor Karl Deisseroth has set himself the task of understanding the brain. To help him achieve this goal, he developed a method called optogenetics, which uses a laser to influence thoughts and decisions.

How would you describe the brain, Professor Deisseroth?
The human brain is a soft yet very dense organ somewhere between pink and brown in color. It weighs approximately one and a half kilograms and has a wrinkled appearance. It is these wrinkles that give us our capacity for highly complex reasoning.

That was a quick jump from the brain's appearance to our capacity for thought.
Right, and that's because the two things are so interlinked. Obviously it's important to start by acknowledging that the brain consists of matter, that it is an organ made up of cells. But it can sometimes feel strange to view it in those terms because, at the same time, the brain is the source of all our thoughts, feelings, desires, memories, and impressions—in other words our entire personality. Everything that makes up who we are as a person comes from this mass of cells we call neurons. How is that even possible?

My question exactly! How is that possible?
Essentially it boils down to a philosophical question of what the brain actually is. Ultimately, I think two perspectives are correct: the brain is a dynamic object, and it consists both of cells as well as what those cells create. Optogenetics can help us understand how those cells give rise to things such as perception, cognition and action. It is a method that puts us in the role of a composer or conductor in an orchestra of information, telling different cells in different areas of the brain what they should do when, and dictating when and if they should synchronize with each other. We can then observe the perception, cognition and action that occurs as a result.

The field of optogenetics you refer to is your area of specialization. Could you sum up what it involves?
Optogenetics employs laser light in exactly the opposite way to how it is normally used in biology. We don't use it to observe things, but to make things happen. In simple terms, we employ laser light to make certain neurons fire—in other words, we stimulate them to emit electrical impulses and thus to generate information in the brain. Let me briefly explain how that works. Normally neurons do not react to light. That makes sense, because it's always dark in the brain. So that means we have to trick them. Using an artificial virus, we inject a photosensitive gene into the brain that converts light pulses into electrical impulses. We employ various other genetic tricks to define exactly which neurons are "infected" with the gene. The advantage of this laser method is the level of precision it gives us in choosing which neurons to activate. It is much more precise than any other method. So far we have applied it to rodents and other mammals, as well as fish and invertebrates. For example, we stimulate very precise and specific neurons in the mouse's brain, observe what happens as a result and use those findings to learn more about their brains.

Typing your name into a search engine brings up a video of a mouse almost immediately. The mouse has a fiber optic cable threaded directly into its brain. Flashing a light through the cable causes the mouse to run in a circle. But when no light passes through the cable, the mouse behaves completely normally.
Yes, that was an experiment we did in 2007. We used our optogenetics method to stimulate the part of the mouse's motor cortex that controls movement toward the left. When the cable lights up, the mouse always runs to the left, in a circle.

What does the mouse feel about that? Does it sense it is being controlled by someone else? Or does it actually think it wants to run in a circle?
Obviously we can't know that for sure, but we can see very clearly if a mouse is disturbed or frightened, because it would freeze. We don't observe any of that kind of behavior when we pass laser light through the

Richard Morgenstein

...remains unanswered—at least for now"

cable or when we switch it off—everything just seems normal. Based on our assumption that the mouse would be frightened if it felt it was being controlled by an external force, we conclude that the mouse is fine with the situation—though obviously it probably hadn't planned to run to the left in a circle. I tried something similar on myself to find out how it felt. Using transcranial magnetic stimulation, I stimulated the motor cortex that controls my right hand. When I activated the magnetic pulse, my hand twitched. I watched and sensed that I was moving it. But I experienced neither the feeling that I wanted to move, nor the feeling that I was being externally controlled. The movement was simply happening. My right thumb was moving and I was fine with that.

What does that tell us about free will?
Nothing new, really. We are constantly using medicine and psychiatry to influence people's feelings and actions, whether through drugs, brain stimulation or simply talk therapy. Take advertising, for example. Isn't that essentially a way of manipulating your desires? And is optogenetics, fundamentally, any different? It merely shows that our actions and decisions are carried out through electrical signals. But I don't think these findings actually answer the question as to whether or not we have free will. What optogenetics can do, however, is help us phrase this question in more precise terms. For example, is there an organizing force, a principle in the brain, that controls the electrical signals? And if so, how deep within the brain is it located? Some people think there isn't one, or at least not one of any particular interest. Others think this organizing force really does exist. But of course that prompts the question of where this force might come from. Whatever the case, the question of free will remains unanswered, at least for now.

"A vast panoply of mysteries still awaits us."

Obviously we constantly influence other people's feelings, even through something as simple as talking to them. But this form of remote control is surely on a completely different level. How does it actually feel to control a mouse remotely?
It's a powerful and meaningful experience. It forges a connection to the animal and somehow seems miraculous every time it happens. I think what makes the experience so powerful is the immediacy of it, the swift response.

But doesn't it also feel somewhat unsettling?
Yes, absolutely. The precision, immediacy and predictability with which we can trigger actions can certainly feel unsettling at times, and I understand why that might disturb some people.

a) What does the mouse feel when we control its decisions?

b) Karl Deisseroth opts to experiment on himself using transcranial magnetic stimulation—his thumb twitches.

c) This form of remote control actually feels surprisingly fine.

Could optogenetics eventually be used in a negative way to manipulate human beings?
I don't think so. This technology doesn't really lend itself to that kind of abuse. You have to develop a gene and inject it using a virus. It's all very awkward, time-consuming, expensive and complicated. But obviously we need to contemplate those kinds of possibilities, however unlikely they may seem.

We've been talking about the brain as a generic concept, but is every human brain really the same?
In some ways yes, and in other ways no. We're confident that all human brains have a number of broad principles in common. For example, dopamine neurons do much the same thing in every brain, which include triggering feelings of happiness and contentment. Our experiments on rats and mice support that supposition. But when you take a closer look, things get more complicated. The structure of the brain is not predefined in any real detail. It's a jumble of cells that are arranged differently in each case. So the whole issue is actually rather complex.

Your work extends across many boundaries, from virology and psychiatry

to animal behavior, optics, microbiology and chemistry. How would you define your profession?
That's very true! I suppose I primarily see myself as a neuroscientist and psychiatrist.

What prompted your fascination with the brain?
Even as a child I was introspective and interested in how my own brain worked and why I acted in the way I did. Eventually I began to take an interest in the same question for other people, too. Everyone was so different and responded so differently, even to similar things, and I wondered why. Then came my experience of working with psychiatric patients at medical school. Their responses were even less predictable, and sometimes the patients had their own individual conception of reality. I found it fascinating, and I felt a huge affinity for that area of specialization. But I also saw the suffering and distress those people were feeling, and I wanted to alleviate that. There were two illnesses that I found particularly interesting: autism and severe, treatment-resistant depression. Both those diseases are very debilitating for patients and are almost impossible to treat with drugs or any other methods. One of the goals I have set myself in my career is to gain a better understanding of those two diseases.

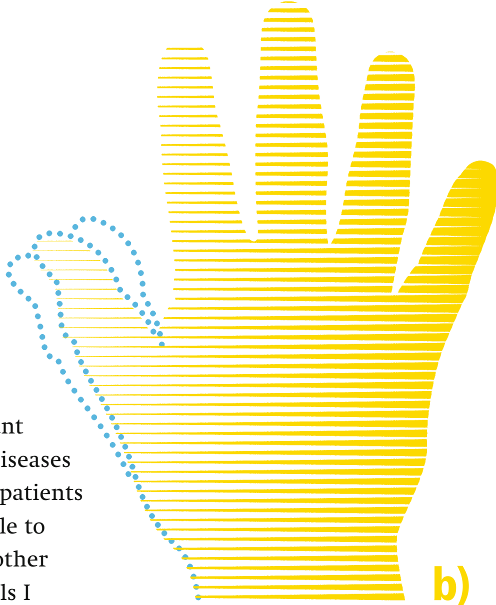
Are you working on a new form of treatment?
As a psychiatrist, I continue to treat patients every week at the hospital, but as a scientist I focus more on the fundamentals. Right now my aim is not to find any one specific therapy, but rather to understand how a brain normally functions. And optogenetics offers us the long-term prospect of finally being able to test our hypotheses more precisely.

How far have we actually progressed along the path toward understanding the brain?
It's hard to say, but we certainly understand less than 50 percent, that much is sure, despite all the progress we have made in recent years. A vast panoply of mysteries still awaits us!

Can a brain ever really understand how the brain works?
Someday, yes. I would stake money on humanity being able to achieve that. Put simply, we humans are very good at understanding things that we have no real business understanding! We think symbolically, create maps, construct analogies and break down complexity. And with higher dimensional mathematics, for example, we are able to understand fields that should really be out of our reach. One day we'll crack the brain, too! ■

"We humans are simply very good at understanding things that we have no real business understanding."

KARL DEISSEROTH, born in Boston in 1971, is a psychiatrist, neurobiologist and bioengineer at Stanford University in California. He is regarded as the founder of optogenetics, a discipline that investigates the brain by stimulating neurons with laser light. He also developed a method of turning post-mortem brains optically transparent and preserving them in this state, enabling the intricacies of the brain's structure to be understood in three dimensions. Deisseroth has received 23 prestigious science prizes for his research work, including the 2018 Berthold Leibinger Zukunftspreis.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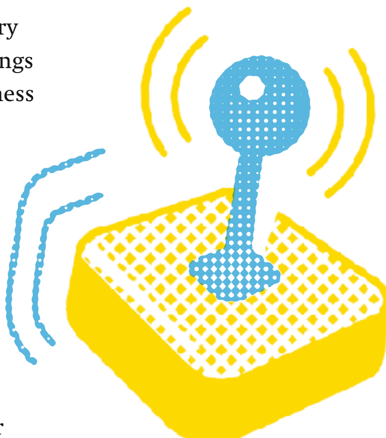
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Gernot Walter

I love you, Bender!

MACHINES WITH DISTINCT PERSONALITIES CAN MAKE OUR WORLD A RICHER PLACE. BUT WHAT EFFECT MIGHT THEY HAVE ON OUR CHILDREN'S COFFEE HABITS?

I don't know about you, but I've been thinking a lot about the future recently. It might be because everyone is arguing about climate change, or perhaps because I recently became a father again. But it could also be a subconscious fear that I will soon be replaced by a machine that can write better columns than me. Because the time has come for artificial intelligence to make its way out of science fiction and into reality!

Just think: we already have fully automated laser machines that can load and cut metal sheets and eject the parts all by themselves, or check the quality of weld seams and remove bad parts from the line. As they work, they learn how to be more and more efficient, and soon they will be transferring that knowledge to other machines. OK, I admit it's not quite Hollywood material. In the major blockbusters, AI isn't generally engaged in removing sheet metal parts, but rather doing things like sending terminators into the past to, well, terminate the leader of the resistance in a war between humans and machines. The logical conclusion of all this is intelligent machines with distinct personalities, machines that can get bored and afraid, depressed and annoyed, and even crack jokes. Take Wall-E, for example, a robot garbage collector left alone on Earth who appeared in the computer-animated film of the same name. Or Bender, the lazy, egotistical cigar-smoking metal robot from the animated TV show Futurama. Hollywood has even given us machines that are capable of love. Like Samantha, for example, an operating system in the science fiction film Her, who falls in love with the human protagonist Theodore (it's reciprocated!)—with dramatic consequences.

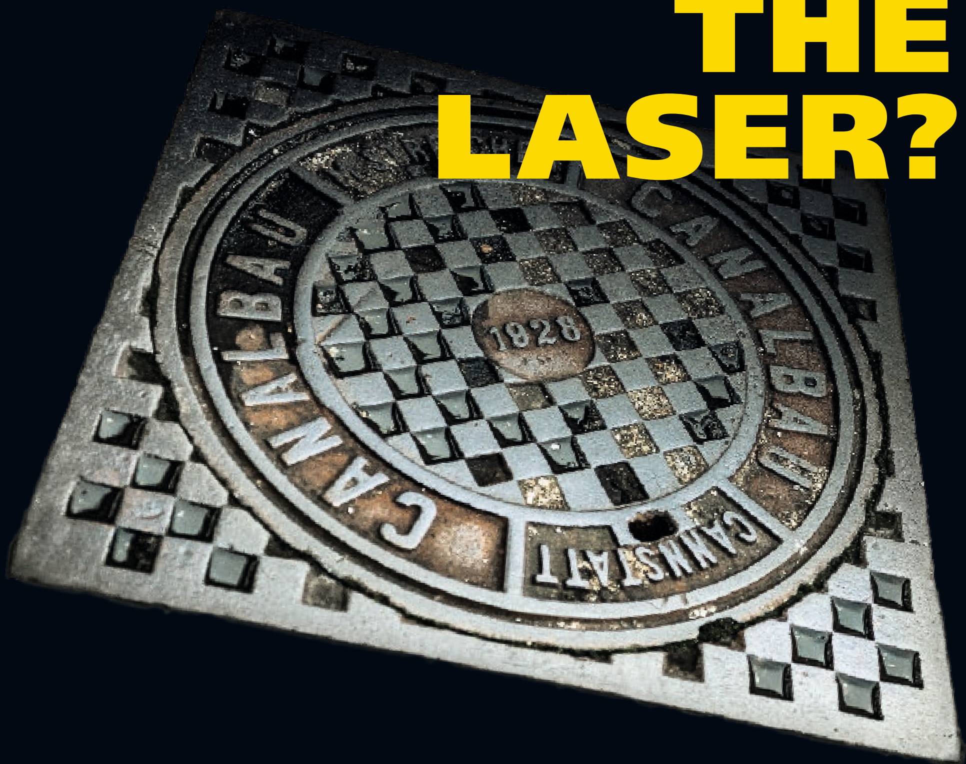
That got me thinking about some perfectly realistic scenarios that might lie ahead. In one of them, I picture my granddaughter heading to work sometime in the future and cursing the bending machine (shout out to Bender!) because the coffee machine is lovesick again and only able to pump out some undrinkable gloop instead of a proper espresso. When that happens, I hope she'll remember that it all started right here and now with the automated removal of cut metal parts from a machine … ■

Laser Community's editor-in-chief Athanassios Kaliudis writes a regular column on the laser as an object of popular culture.

→ *Have you ever fallen in love with an AI?*
Let me know by email: athanassios.kaliudis@trumpf.com

Gernot Walter

WHERE'S THE LASER?



In the sewers! Obviously it's pretty dirty down there, so before things get out of control, sewer cleaning companies drop a 'bomb' down the drain. The bomb is a device that blasts dirt off the walls by spraying water through up to 15 nozzles. It takes quite a few steps to manufacture these complex nozzles—so it turns out it's the perfect job for a 3D printer. Heilbronn University of Applied Sciences worked together with TRUMPF to redesign and print the nozzles. As well as reducing the number of production steps, the 3D printing method also saves water, because the flow characteristics of the new nozzles means they can blast dirt off the walls even more effectively. ■

Gernot Walter

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MAYAN BUILDINGS

We've all seen pictures of the Mayan pyramids and palaces. But what else lies beneath the jungles of Guatemala? What was life like for the average Mayan citizen? Researchers used lidar to scan 2,100 square kilometers of rainforest and then digitally removed the forest canopy. The resulting images show small ruined structures, irrigation channels and paths, revealing much about the demographic structure and lifestyles of this mysterious civilization.

PACUMA/Estrada-Belli

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