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Porsche Engineering Magazine

FAST FORWARD

How artificial intelligence unlocks new possibilities

AI language models in engineering
Driving simulators in function development
V2X development

www.porscheengineering.com

Porsche Engineering Magazine

Publisher
Porsche Engineering Group GmbH

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Production
News Media Print, Berlin

Printing
Gutenberg Beuys Feindruckerei GmbH
Hans-Böckler-Straße 52
30851 Langenhagen

Reader service
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Image source if not otherwise stated: Dr. Ing. h.c. F. Porsche AG;

p. 1: Cover: Matt Murphy; p. 3 Photo: Steffen Jahn; p. 4–5 Photos: Annette Cardinale, NÓICREW, Getty Images, Illustrations: Romina Birzer; p. 10 Illustration: Benedikt Rugar; p. 22–23 Photo: Getty Images; p. 26–27 Illustration: Andrew Timmins; p. 30 Illustration: Alamy; p. 32–37 Photos: NÓICREW; p. 46–51 Photos: Annette Cardinale; p. 53 Illustration: Christian Hruschka; p. 54 Photo: Gregory Halpern/Magnum Photos/Agentur Focus; p. 56–57 Illustration: Getty Images; p. 58 Illustration: Luka Schlage

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Dirk Lappe
Chief Technology Officer (CTO) of Porsche Engineering

Dear Reader,

Once again, the world finds itself in a phase in which the best possible interpretation of things to come is that they will be difficult and yet essential for shaping our future. In particular, when looking at the impact of artificial intelligence, we often observe abrupt and striking changes, such as automation and improvements in efficiency. You will find a comprehensive and proactive examination of the potential long-term consequences of this in an interesting interview with our CEO Markus-Christian Eberl and Dr. Matthias Peissner, an expert in human-technology interaction at the Fraunhofer Institute for Industrial Engineering IAO.

At Porsche Engineering, we use AI in a variety of ways. For example, we use Reinforcement Learning to optimize crash simulations and error identification during testing. AI identifies rare corner cases in video recordings of test drives and optimizes the objectivity of the driving comfort evaluation. The examples mentioned are only a small sample of the topics that we are already working on today, and that you can read more about in the current issue of the Porsche Engineering Magazine.

What is certain is that AI is far more than just another tool in our toolbox. The introduction of large language models (LLMs) with an unprecedented potential to quickly analyze large amounts of data, identify patterns, and draw conclusions from them, is ushering in a new era in which our personal and professional worlds will be fundamentally revolutionized in the blink of an eye.

However, despite these new capabilities and the opportunities that AI offers, we should never forget one thing: People are and always will be irreplaceable in this technological landscape. A large part of our brain is used for communication with our environment and our fellow human beings, which in turn gives rise to discourse, reflection, and creativity. The limitations of the human body and mind force us to find creative, intuitive solutions and often to make ethical decisions as well that an AI cannot replicate in the same way. These skills will become ever more important in an increasingly AI-dominated world.

A look into the future of vehicle development with the help of AI shows the beginning of a new era in which AI, human judgment, and deterministic systems will go hand in hand. It is up to us to make rewarding use of this technology, to seize opportunities, and to raise vehicle development to an unprecedented level.

Let's walk this path together!
Dirk Lappe
CTO

ABOUT PORSCHE ENGINEERING: Porsche Engineering Group GmbH is an international technology partner to the automotive industry. The subsidiary of Dr. Ing. h.c. F. Porsche AG is developing the intelligent and connected vehicle of the future for its customers—including functions and software. Some 1,800 engineers and software developers are dedicated to the latest technologies, for example in the fields of highly automated driving functions, e-mobility and high-voltage systems, connectivity, and artificial intelligence. They are carrying the tradition of Ferdinand Porsche's design office, founded in 1931, into the future and developing the digital vehicle technologies of tomorrow. In doing so, they combine in-depth vehicle expertise with digital and software expertise.

Prospects for AI: Dr. Matthias Peissner (left) and Markus-Christian Eberl discuss the industrialization of thinking.

An objective assessment: During the journey, sensors on the vehicle measure vertical acceleration, after which AI is used to evaluate driving comfort.

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PORSCHE ENGINEERING DIGITAL

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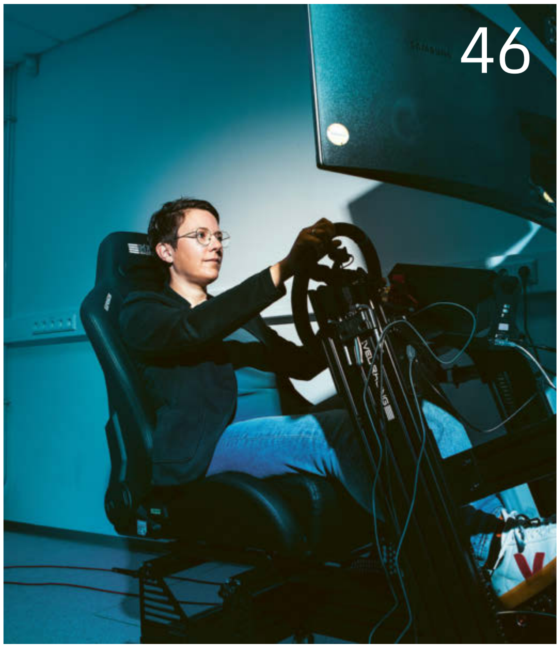

Constant connection: Vehicles can exchange current data using V2X and, for example, prevent accidents.

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Virtual fusion: The VET can merge camera shots with CAD data and helps the engineers to position components correctly, among other functions.

Visual Engineering Tool

ACHIEVING AN OUTCOME TWICE AS FAST

Before a crash test, the test vehicles must be manually equipped with several hundred sensors. It's no easy task: The measurement technology must be placed in precisely specified positions, and it is always possible that errors can occur during the installation process. Fortunately, engineers have a useful helper at their disposal: The Visual Engineering Tool (VET), which was developed by the Data Engineering & AI department at Porsche Engineering. The software can merge real camera shots with CAD data to create augmented reality (AR). It is available for tablets with the iOS operating system as well as Microsoft's HoloLens 2 mixed reality glasses and Apple's Vision Pro. In the case of the crash test vehicles, for example, the VET displays exactly where the engineers have to install the sensors in mixed reality glasses—and thanks to the glasses, they even have both hands free when doing so. The installation is automatically detected by scanning a QR code, and a photo of the sensor that was just installed complements the documentation of the vehicle modification. This significantly increases efficiency, because the preparation of the test vehicles is twice as fast with VET support as was previously the case. The tool is also suitable for training, for example in the field of after sales. Instead of training employees with presentations, they are now being familiarized with new product features in a state-of-the-art way with AR support. The original purpose of using VET was to visualize component tolerances without having to build a real model of vehicle components. In recent years, the tool has been further developed for additional applications.

911 Carrera

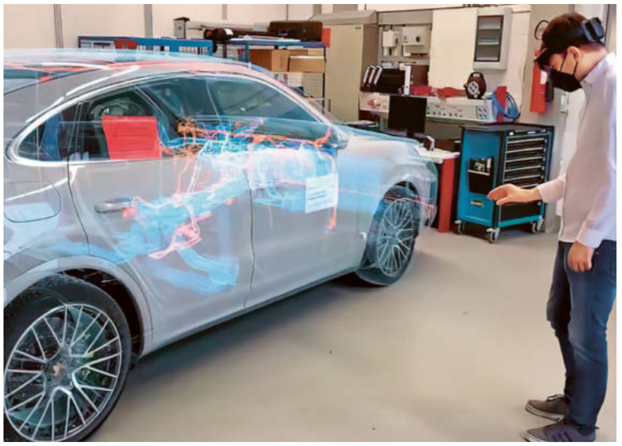
Fuel consumption (combined): 10.7 – 10.1 l/100 km
CO_2 emissions (combined): 244 – 230 g/km
CO_2 class: G

781 Cayman GTS 4.0

Fuel consumption (combined): 10.9 – 10.1 l/100 km
CO_2 emissions (combined): 247 – 230 g/km
CO_2 class: G

Taycan 4S

Power consumption (combined): 20.9 – 17.7 kWh/100 km
CO_2 emissions (combined): 0 k/km
CO_2 class: A

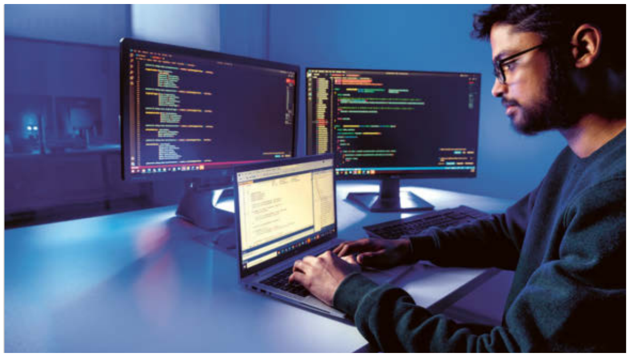


Proven tool: The VET is suitable for use in engineering as well as for training in after sales.

Lecce/Nardò Technical Center

A YEAR OF SOFTWARE INNOVATIONS AT THE NARDÒ TECHNICAL CENTER

The Nardò Technical Center (NTC) in Italy acts as a technology partner for the integrated development and validation of future vehicles. In June 2024, it celebrated the first anniversary of its newest unit, which is focused on software development for intelligent and connected vehicles. The team includes IT engineers, software architects, and developers. They work on a whole range of technologies, from highly automated driving functions, the communication between vehicles and between vehicles and the infrastructure, to vehicle connectivity and systems for evaluating large amounts of data in the cloud. The solutions developed are tested directly on the test tracks at the NTC. This allows the NTC to offer its customers end-to-end development and validation services for software-defined mobility directly on site.

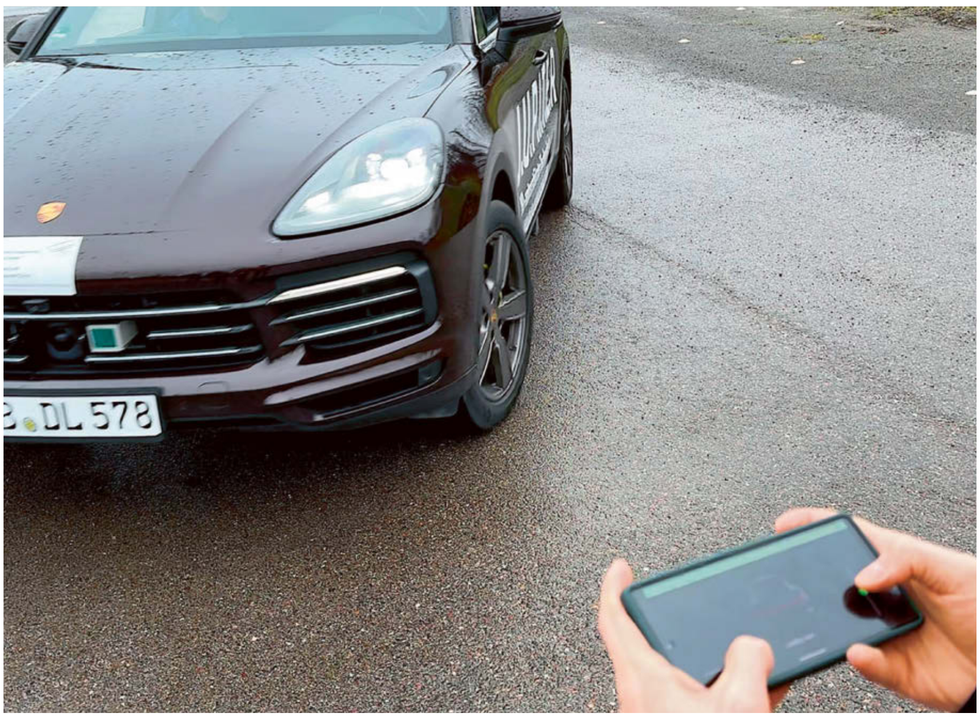


In addition to the customer projects, there are also our own research and development activities. This includes the successful application of artificial intelligence in the field of autonomous driving and the development of a robust cybersecurity concept for vehicle-to-everything communication (V2X). The NTC draws on a talent and partner network at local and national level, such as a collaboration with the University of Salento in Lecce.

New possibilities for development platforms

EASY ACCESS TO VEHICLE FUNCTIONS

Making new vehicle apps for smartphones quick and easy to experience as prototypes: This is made possible by the combination of the JUPITER test vehicles (Joint User Personalized Integrated Testing and Engineering Resource) from Porsche Engineering and the SDV:os framework from the Berlin-based start-up Veecle. What this can look like in practice was demonstrated by the two companies using a development vehicle based on the Porsche Cayenne as an example—with the aid of an app that runs on a smartphone. The left thumb can be used to remotely control the steering wheel of the development Cayenne, while the right thumb controls the speed at which it drives forward and in reverse.
With the previous vehicle architectures, it required great effort to build such a functional bridge. In this use case, cooperation with Veecle simplifies this process: Among other things, the software connects the world of Android devices with the controller in the JUPITER development vehicles via the vehicle-specific Android Automotive operating system. Thanks to JUPITER's ecosystem expansion, the software architects can easily intervene in the vehicle even at the deepest level, for example to operate the steering wheel or adjust the seats with a smartphone. Porsche Engineering is expanding the possibilities for using the JUPITER development and testing platform in the interest of a software-defined vehicle and even for integration with smart devices. In addition, this gives third-party providers the opportunity to gain experience with the functions of their apps on the vehicle very quickly.



Easy access: Thanks to the middleware Veecle, new vehicle apps can be quickly and easily brought to life as prototypes in combination with JUPITER test vehicles.

Cayenne

Fuel consumption (combined): 12.1 – 10.8 l/100 km
CO_2 emissions (combined): 275 – 246 g/km
CO_2 class: G

More than 30 years of engagement in China

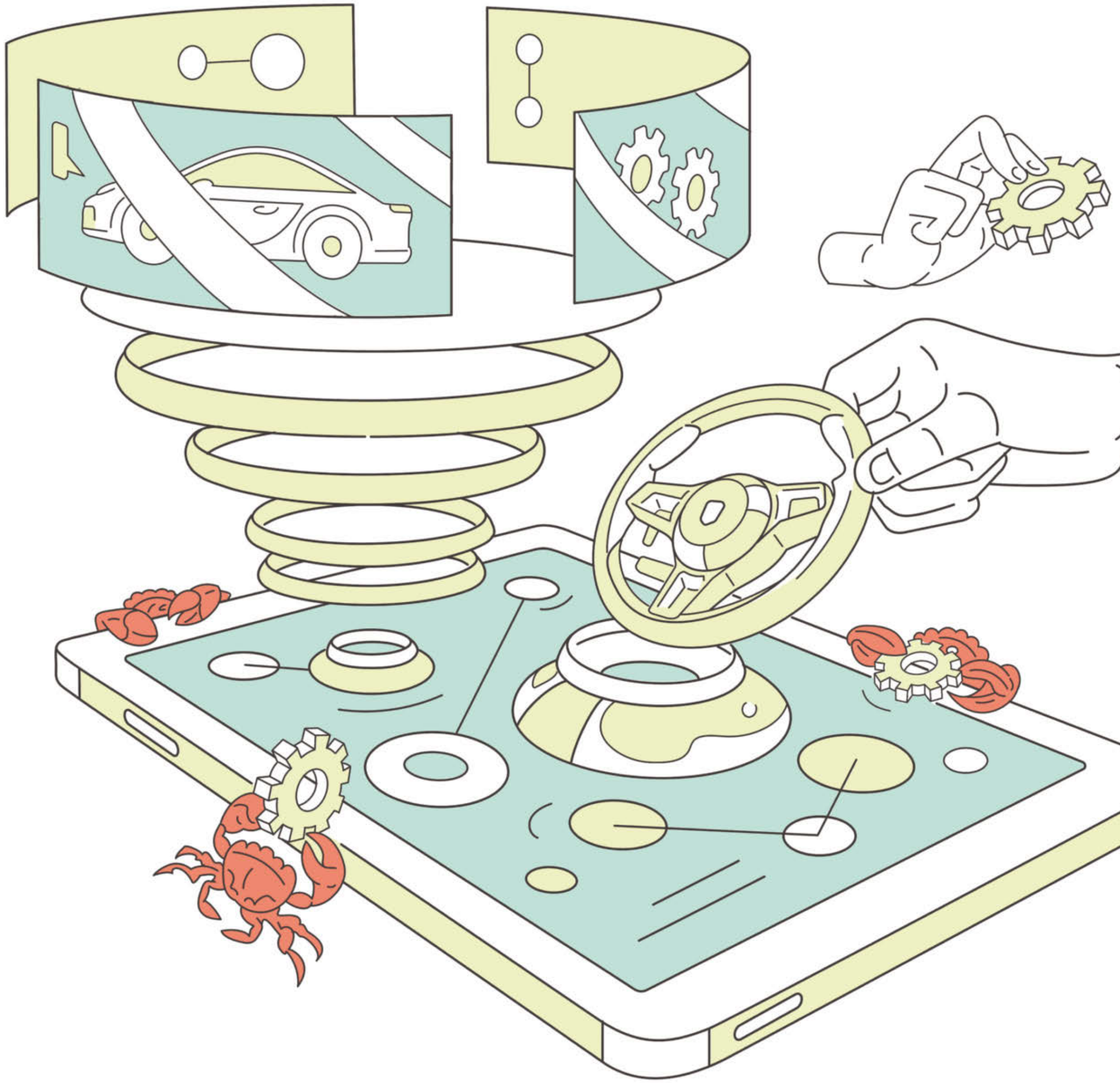
10-YEAR-ANNIVERSARY OF SHANGHAI SUBSIDIARY

Porsche's customer development has been active in the Chinese market for more than 30 years due to its formative role in global industrial and technological change. In 2014, Porsche Engineering took the next step and founded a subsidiary as a local base in Shanghai. 2024 therefore marks the tenth anniversary of its founding.

In order to meet the ever-growing demand for localization and the specific requirements of the market—especially with regard to highly automated driving, connectivity and infotainment—another location in Beijing was added in 2022. The current CEO Uwe Pichler-Necek took over that same year. He continues the success story of Kurt Schwaiger, who built up and expanded the Shanghai site in terms of technological expertise and capacity. In 2023, Porsche Engineering China reached another milestone with 200 full-time employees working in close proximity to key customers and partners in China.

Looking to the future, the commitment to technical excellence, innovation, and customer-focused solutions will continue to guide Porsche Engineering China. The work focuses on the further development of ADAS (Advanced Driver Assistance Systems), connectivity and infotainment technologies. In this way, Porsche Engineering China is shaping a smarter, more connected and immersive future for its customers and partners in the automotive industry.

Anniversary: Ten years ago, Porsche Engineering founded its subsidiary in Shanghai. In 2022, another office was added in Beijing. The focus of the work there is on ADAS, connectivity and infotainment.



Text: Christian Buck
Illustration: Benedikt Rugar

Anything but rusty

The Rust programming language combines security and convenience of modern languages without compromising on the performance of traditional system languages such as C and C++. Together with the use of LLMs in traditional languages, this opens up further efficiency potential for automotive development.

Crustacean at the wheel: The crab 'Ferris' is the mascot of the Rust community. Thanks to its technical advantages, in the future Rust might well take on more and more control tasks in the vehicle as well.

Rust is a programming language that has been in development since 2009 and was first presented to the public in 2010. Since then, Rust has quickly surged in popularity and has been the fastest-growing programming language of all over the past five years, as developers are particularly fond of its combination of performance and security. A rapidly growing community and an ecosystem with numerous libraries and tools has grown up around the language. Large technology companies such as Google, Mozilla, Microsoft, Amazon, and Facebook use Rust in a variety of projects, including security-critical applications and for system software.

One reason for the popularity of Rust is its increased security compared to C or C++, particularly by avoiding errors in memory access. Rust eliminates these issues through an 'ownership system' that establishes strict rules for memory access. For example, each variable in Rust has a specific memory area assigned to it—which it must then release when it is no longer needed. This happens automatically when the variable leaves its scope. Security is also increased for the use of references to memory areas: In Rust, they are given lifetimes. This is meant to ensure that references never point to invalid memory areas. Race conditions (races for access to resources) between different execution threads of a program are also avoided by the ownership system—here the keyword is 'concurrency security'.

Despite the increased security, developers at Rust don't have to compromise in terms of performance. In many cases, the programming language can keep up with the speed of C and C++. This combination of security and performance makes Rust particularly attractive for the development of system software, real-time applications, and other projects with high performance requirements.

Another advantage of the programming language is the mature Rust toolchain. The integrated package management system 'Cargo' and the robust test system make software development efficient. Developers can quickly and easily start new projects, manage dependencies, and carry out extensive tests. This facilitates collaboration in teams and promotes a clean, structured code base. The high esteem in which Rust is held is also demonstrated by its use as a programming language for the core of the Linux operating system, in which performance and security play a key role and which has hitherto been programmed in C.

GROWING INTEREST

In the automotive industry, interest in Rust is continually growing, as the combination of memory security, efficiency, and concurrency security makes the programming language well suited for use in safety-critical embedded systems for vehicles. Porsche Engineering has already gained experience with it. "We started our first project with Rust in January, the object of which is to program the core of a data collector framework that we want to offer to third parties as a software-as-a-service," states Dr. Heiko Helble, Specialist Project Manager for ADAS Software Development at Porsche Engineering. "Cybersecurity plays an important role for us in that—and that's exactly why we chose Rust."

Like many other experts, Helble appreciates that the programming language solves typical problems such as unauthorized memory access and ensures the consistent use of physical units through its data types—it is not possible, for example, to enter the speed in meters per second at one point and then in kilometers per hour at another point. "This only minimally increases the programming effort, but significantly accelerates testing and troubleshooting," says Helble.

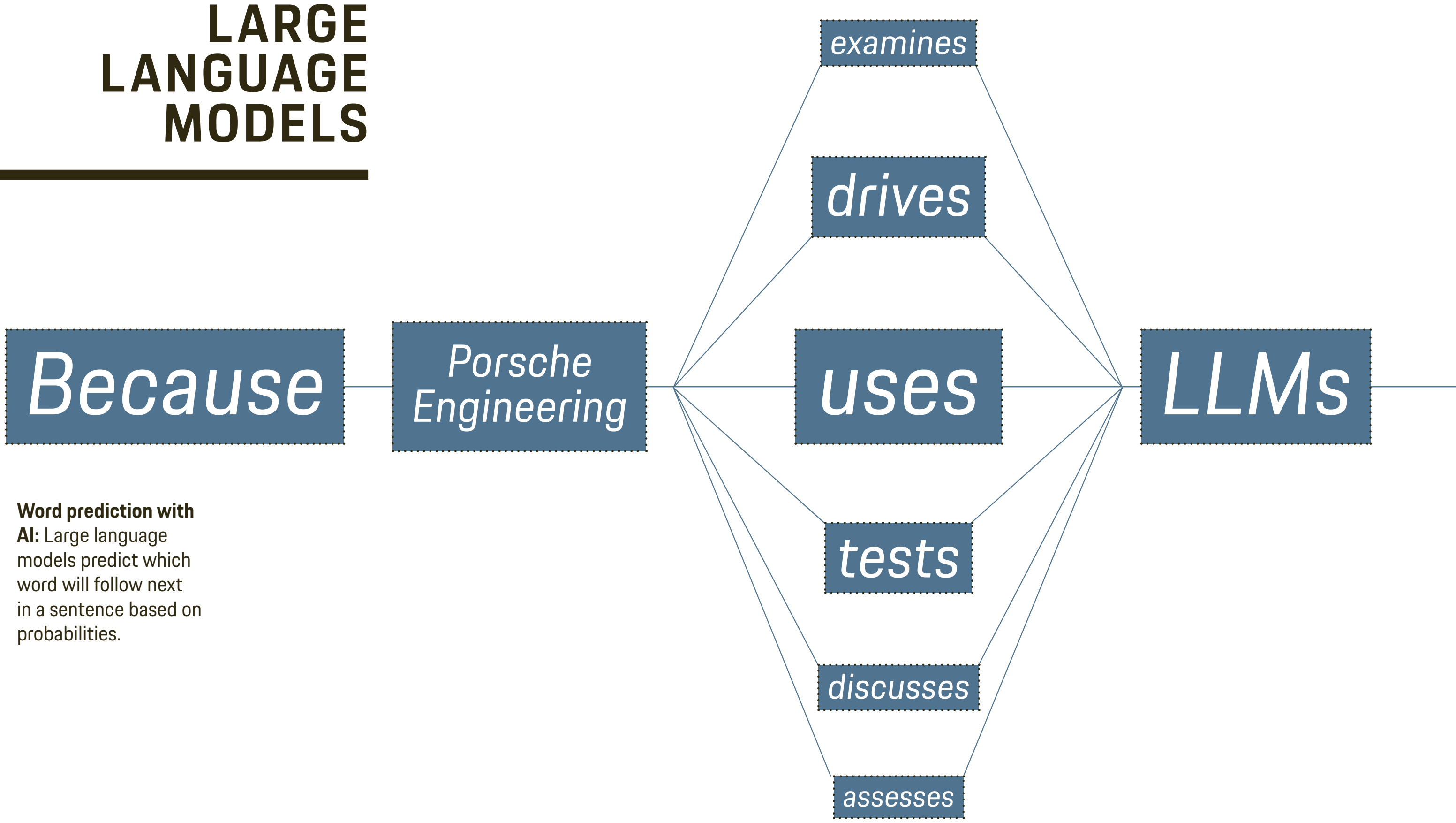
COMBINATION WITH AN LLM

A relatively new trend in software development is the combination of manual and AI-supported programming, for example using Large Language Models (LLMs). The programmer assigns a sub-task to an LLM and the AI then provides the source code. In principle, this is possible with any programming language, provided that the AI model has been trained with enough examples. "Although Rust is much younger than C and there is consequently much less training data, it already works very well," as Helble reports. "With an LLM, I solved a very complex task on the first go in 20 minutes for which I would have normally needed several hours. The software was immediately operable."

This type of AI-supported programming in languages such as C or C++ is already successfully being used at Porsche Engineering. "LLMs offer us valuable support in solving subtasks," reports Jonas Brandstetter, Development Engineer at Porsche Engineering. "This might be, for example, communication with peripheral hardware via particular interfaces. In the future, however, we could start with the customer's requirements, generate the tasks for the LLM from them, and ultimately get to the code that way." The key when using LLMs in software development is protecting confidential data. For this reason, Porsche Engineering uses internally accessible solutions that are based on LLMs but meet all data protection requirements.

TITLE

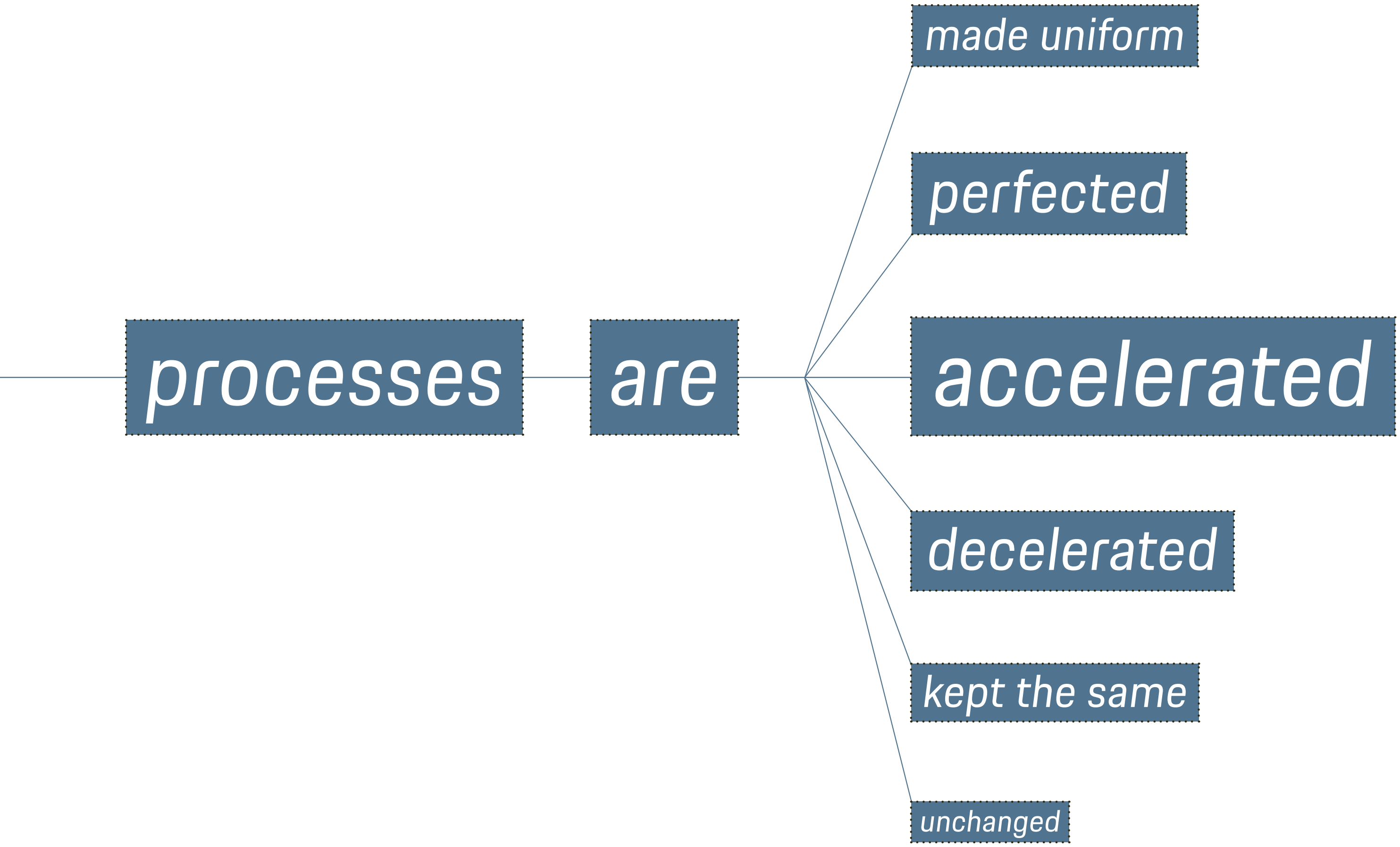
LARGE LANGUAGE MODELS



Word prediction with AI: Large language models predict which word will follow next in a sentence based on probabilities.

Thanks to artificial intelligence (AI), large language models (LLMs) can understand natural language and perform tasks such as text creation, answering questions or even translation. Porsche Engineering also uses LLMs in vehicle development, thereby increasing efficiency in the development process.

Text: Richard Backhaus

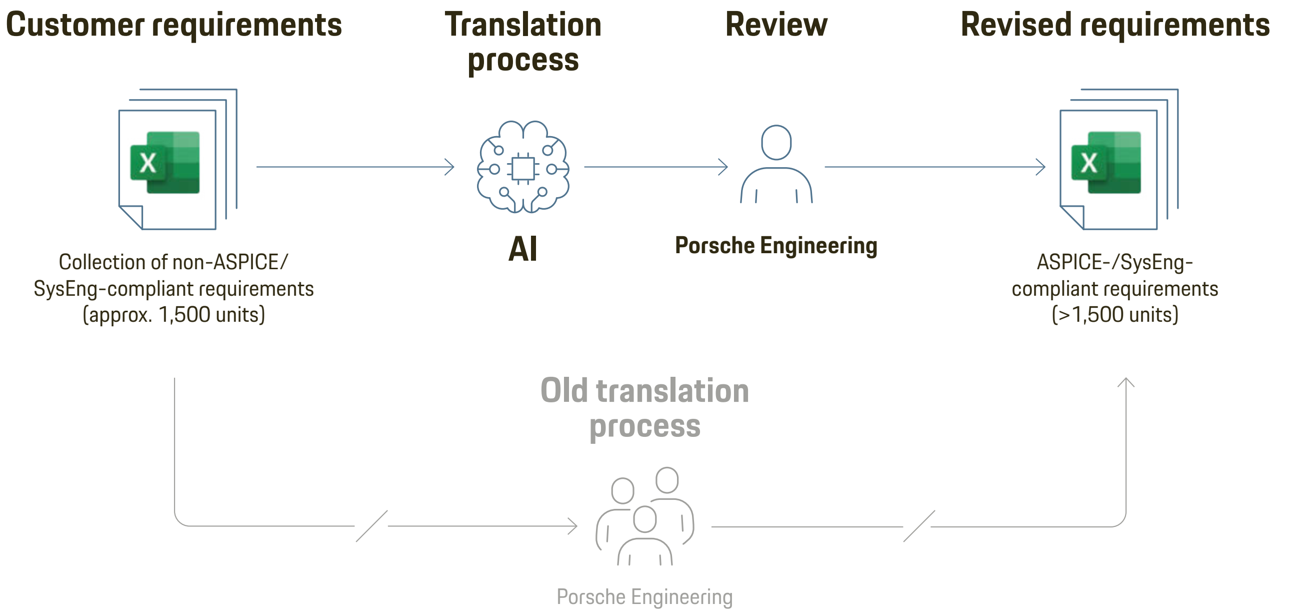


The Rosetta stone discovered in 1799 was a milestone in the deciphering of Egyptian writings. It contains a priestly decree from the ancient Greek-Macedonian-Ptolemaic dynasty, dated to 196 BC, in three different languages. By a comparison of the texts and characters, it offered a means of deciphering the Egyptian hieroglyphics, which were not decipherable until the 19th century. Since that time, the term 'Rosetta Stone' has been used to refer to an essential clue in decryption tasks.

Today, AI-based language models, known as large language models (LLMs), are regarded as the Rosetta Stone of the future. "A large language model is based on neural networks and is able to decode the meaning of natural language in context and machine-process it. LLMs can understand, process, and translate language, but also generate new texts," explains Dr. Joachim Schaper, Senior Manager AI and Big Data at Porsche Engineering.

Porsche Engineering uses LLMs to further increase efficiency in the development process. The company uses commercially available LLM tools such as ChatGPT from OpenAI or LLaMa from Meta. "These models are pre-trained by very large amounts of data from the internet and handle tasks such as writing texts on standard topics very well. For use in

MORE TIME FOR CREATIVE TASKS
DOCUMENT TRANSLATION WITH AI



Porsche Engineering uses Meta's **large language model LLaMa** (Large Language Model Meta AI) as its starting point for the automated translation of customer requirements into ASPICE-compliant documents. In order to adapt it to the specific requirements of automotive development in the field of high-voltage systems, it was trained with subject-specific content. Around **1,500 customer requirements** and the corresponding ASPICE-compliant documents were used as training data. As usual in this area, the LLM receives both the input and the required output in the form of Excel tables, in which lists of requirements can be displayed particularly effectively.

After training, the LLM is able to perform the translation into the ASPICE-compliant format independently with high-quality output. For **quality assurance**, experts from Porsche Engineering manually check each document to iron out any errors in this early development phase. However, using LLM saves time—because checking requires much less time than manual translation. Currently, the use of the LLM can reduce the effort involved by up to 50 percent. The goal is an 85 percent reduction. This allows human experts to contribute more to the creation of system specifications.

development, however, we need an LLM that also takes into account our engineering expertise," says Schaper. The technical knowledge of Porsche Engineering is taught to the AI using its own data sets from completed development projects.

One area of application for LLMs is the revision of customer specifications. Depending on the project, the client, and the development team, their content is written in very different forms. If an existing system is to be technically updated as part of a further development, Porsche Engineering often receives the requirements from existing customer specifications and the scope of the changes from its customers. Before the actual development task starts, the developers must completely work through the customer specifications and translate the information contained therein into concrete technical specifications in order to avoid development errors due to ambiguous specifications. Porsche Engineering has recently begun using predefined block templates in the revision of specifications: A basic principle of requirements engineering for the standardized and qualitative creation of requirements.

With the aid of this methodology, information is presented in a way that is clear, consistent, verifiable, accurate, and understandable. "Today, our engineers have to do the revision of the specifications as a manual activity. This ties up resources in development and is a monotonous activity for the employees," says Volker Reber, Senior Manager High-Voltage System Development at Porsche Engineering.

UNDERSTANDING THE CONTEXT

This task cannot be automated with conventional algorithms. As the formulations in the specifications are frequently not clear, the meaning has to be inferred from the context. Conventional software programs cannot do this intellectual step, but AI can. In the future, LLMs will therefore support the revision of specifications. "As a demonstration project, we revised the requirements catalog for a component of a vehicle," reports Reber.

To train the LLM, a dataset with a few hundred items of information was enough to prepare it for the new task. The model learned how to deal with different semantic forms in the original texts and also learned the text patterns for the output. "After this step, the specifications, consisting of a few thousand individual items of information, could be converted to the standard format much faster than through manual processing," says Reber.

As an extension of the project, the trained LLM is used for additional tasks in the field of specifications revision, such as checking for completeness and consistency with regard to the requirements of different systems of the vehicle described therein. The engineers 'only' have to check the result produced by the LLM, which means that the workload will decrease over time. "Since the AI is further trained by feedback of the results, the quality of the LLM continuously increases with each project. In the future, it will not only deliver faster, but also much better implementations than a human being could ever do," Schaper thinks.

"The specifications, consisting of a few thousand individual items of information, could be converted to the standard format much faster than through manual processing."

Volker Reber
Senior Manager High-Voltage System Development
at Porsche Engineering

A roughly

50

percent reduction in the effort required for the revision of specifications has been achieved with LLMs.

The LLM has already reduced the effort by around 50 percent during the first test. There are already ideas for further optimizations, which will enable this figure to be improved significantly. Nevertheless, human expertise will still be needed for these tasks in the future. For Porsche Engineering, the combination of specifically designed and trained AI systems and human expertise has a strategic importance. Many engineering tasks consist of sub-areas that require varying degrees of expertise, experience, and evaluation. Some companies already rely on regions with the best personnel cost

"Thanks to early adaptation in our projects, we are already significantly increasing efficiency in the development process by integrating LLM tools."

Dr. Joachim Schaper
Senior Manager AI and Big Data at Porsche Engineering

structure for certain areas of activity. Porsche Engineering relies on the use of tools such as AI for comparable activities and continues to pursue a strategy of high-level competence among its employees. The experts can then concentrate their valuable working time on the high-competence part of the task.

LLMs also offer potential for increasing efficiency in other areas of vehicle development. One example is data management during test drives with new vehicles or systems. If the test drivers detect a malfunction during the tests, they log it and feed it into a central database system. "Today, we have the challenge that unexpected system reactions are often not recognized as a previously recorded phenomenon and are entered into the system several times," explains Dr. Fabian Hinder, Lead Engineer at Porsche Engineering. This makes systematic troubleshooting more difficult, as the analysis of database information is associated with considerable manual effort.

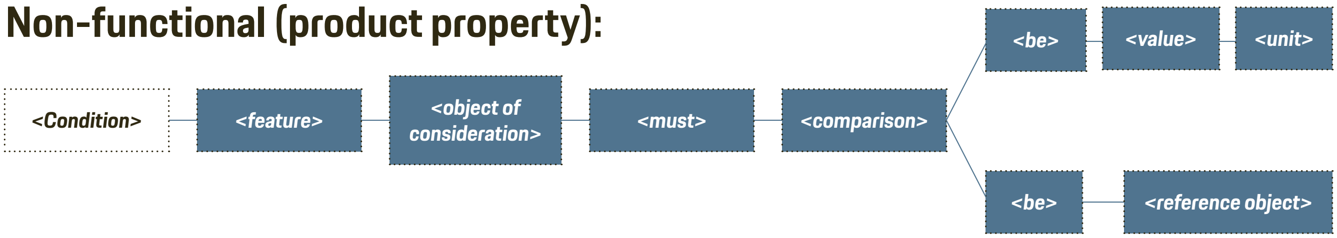
REAL-TIME FEEDBACK

Much like with the creation of specifications, LLM tools will also take over tasks such as the conversion of the input data into prefabricated semantic patterns and its comparison with existing database entries. The potential of the approach has been demonstrated by a Porsche Engineering team as part of a project in the field of vehicle connectivity. "The test engineer enters the information about their problem into the system during the ongoing tests, and the AI gives real-time feedback on which similar errors are known," says Hinder. The person then decides whether one of the saved patterns matches their entry or whether to create a new database entry. Errors can therefore be identified throughout the Group and assigned across several vehicle models and platforms.

Porsche Engineering is currently conducting another LLM project under the direction of Porsche's innovation management. Here, too, the goal is to simplify and accelerate everyday work. "Developers today have to manually query the aggregated data for a problem in the central database. In our lighthouse project, we are creating a concept with which the LLM will carry out this activity in the future," says Antoon Versteeg, Innovation Manager at Porsche and responsible for

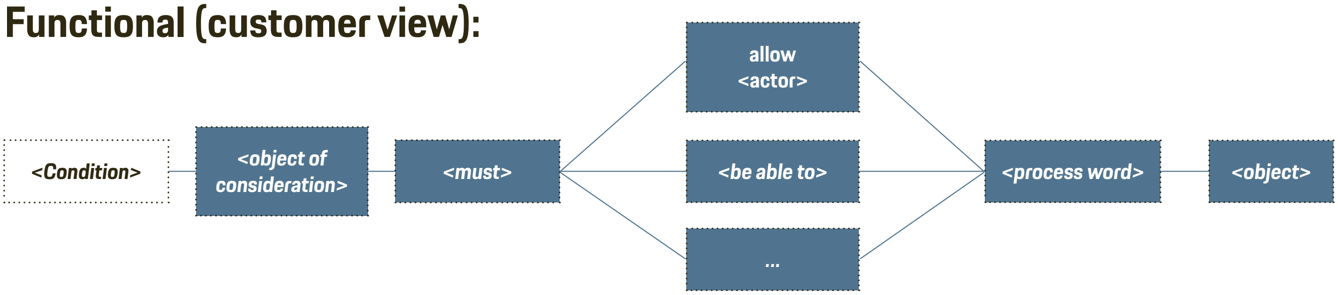
PRECISELY DEFINED OUTPUT FORMAT
CUSTOMER INPUT BECOMES CLEAR REQUIREMENTS

Non-functional (product property):



Example of a non-functional requirement:
Customer input: At an outside temperature of more than −10 °C , the range should be ≥ 400 km.
Translation: If the outside temperature is greater than −10 °C, the range of the vehicle must be greater than or equal to 400 km.

Functional (customer view):



Example of a functional requirement:
Customer input: The range must be displayed while driving.
Translation: As long as the journey continues, the vehicle must allow the driver to view the remaining range.

ASPICE defines exactly how **standard-compliant requirements** must be structured. Customers, on the other hand, usually formulate their wishes relatively freely in their specifications. The two examples show how the LLM translates potential customer requirements—one for a non-functional requirement that describes the **system**, and one for a functional requirement that describes the product from the **customer's perspective**. Through training with existing customer requirements and the associated ASPICE-compliant outputs, AI has learned to translate between ambiguously formulated specifications and the exact ASPICE format.

the Intelligent Enterprise innovation portfolio. "Unlike the other" LLM applications, however, we are dealing with a very large amount of complex numeric data that needs to be processed and synchronized."

The software developers therefore apply a variety of tricks that combine multiple classic numerical methods and AI. The experts receive results in just a few seconds. "The automotive industry is only just beginning to use LLMs, but thanks to their early adoption in our projects, we are already significantly increasing efficiency in the development process by integrating LLM tools," says Schaper.

"At Porsche AG, data-driven development will be a key success factor for the future. The use of AI can ensure the necessary efficiency in the development process," says Dr. Bruno Kistner, Manager Data-driven Development at Porsche. "We are already using this very successfully today and are continuously expanding it with our partners such as Porsche Engineering."

SUMMARY

Porsche Engineering primarily uses LLMs as a tool to make vehicle development more productive. Here, AI creates freedom for engineers, for example by taking over manual tasks.

Porsche Engineering has already demonstrated and verified the potential of AI for time and cost savings during the development process in several projects. In the field of passive safety, the first steps towards adoption in series development are now being taken.

Text: Richard Backhaus

Artificial intelligence is finding its way into more and more areas of life. A simple formula applies to this: The more complex a task is, the greater the potential that can be leveraged by the targeted use of AI. "At Porsche Engineering, we started integrating AI applications into our development processes at a very early stage. Pilot projects thus convinced us of the great potential that arises when we combine classic development methods with modern AI," explains Dr. Joachim Schaper, Senior Manager AI and Big Data at Porsche Engineering.

Porsche Engineering has gained experience integrating modern AI applications into the development process in a universal application strategy for internal combustion engines (see issue 1/2021), for vibration damping in the powertrain of an electric vehicle (see issue 1/2024) and in developing the crash structure of a side skirt (see issue 1/2022). The developers used the AI method Reinforcement Learning (RL) for these projects. With this method, a virtual agent interacts with an environment and constantly learns through feedback—by being rewarded with bonus points for actions that lead to a good result, and being penalized with deductions for failures. The feedback required for the RL agent during the training phase is provided by a neural network. "Due to the excellent results achieved using the AI methods—the results are usually available after a few seconds, in contrast to hours for a conventional simulation—we are working on deploying AI across a broad spectrum in the future and establishing it as a permanent component of our development processes," says Schaper.

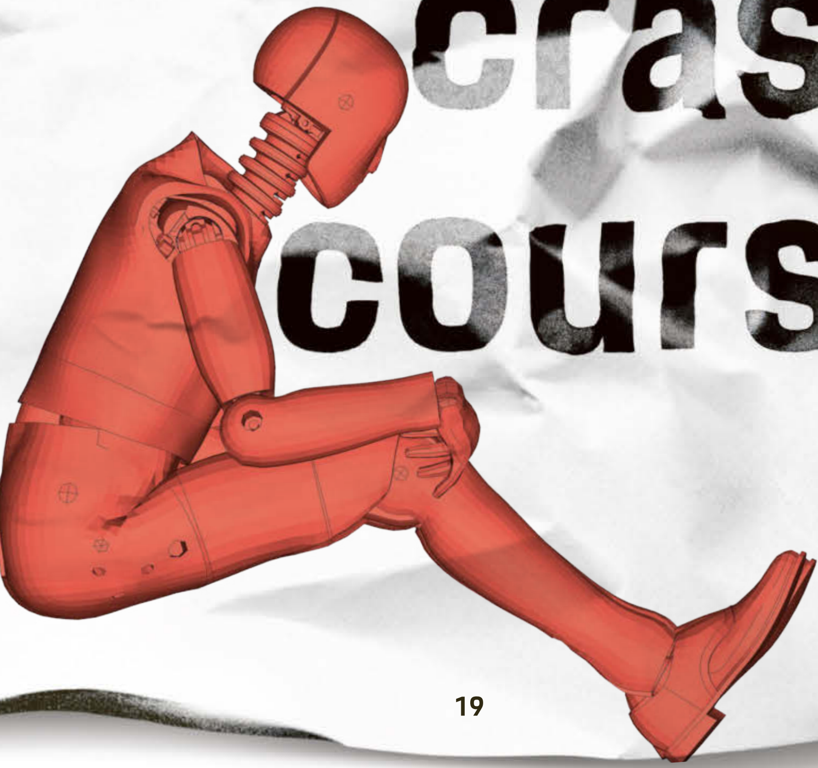
Another example of the AI offensive at Porsche Engineering is the design of restraint systems in the field of passive safety. In the event of a crash, these components must be optimally suited to the vehicle. This is the only way they can provide the occupants with maximum protection. To do this, for example, the restraining forces of the belt must be tuned to the effect of the airbag. "All components interact with each other and must be considered within the overall system during optimization. A large number of load cases must also be taken into account. This makes passive safety development extremely complex and time-consuming," explains Michael Di Roberto, Senior Manager CAE & Safety at Porsche Engineering.

80%

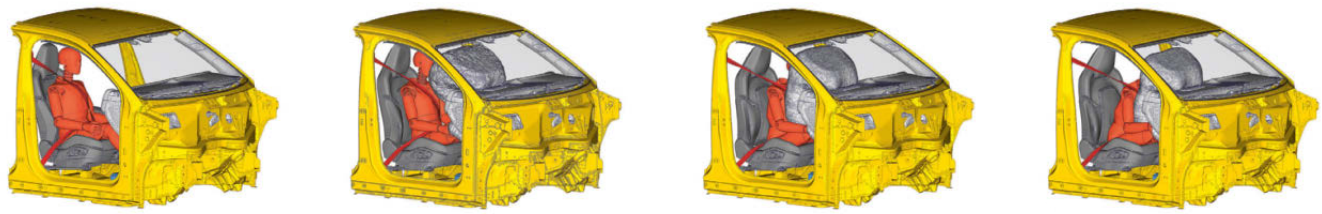
of FEM calculations could be omitted thanks to reinforcement learning.

The AI method that has already been tried and tested for side skirt optimization has been further advanced to aid design of the restraint systems. "The first project focused on training the agent and demonstrated the great potential of the applied methodology. This is why AI will now be used in the series development process for restraint systems in the future," as Schaper states. In order to achieve this, the agent was linked to a classic simulation tool once it had successfully completed the training. The tool is based on the finite element method (FEM), which does provide accurate results, but whose use is very time-consuming: A crash simulation with today's model dimensions can take up to 72 hours. Thanks to the upstream selection carried out by the RL agent, significantly fewer FEM calculations are required to achieve the appropriate result, which reduces costs and the time input. "In this real-world development task we were able to reduce the number of FEM calculation loops required by 80 percent," says Janis Mathieu, a PhD student at Porsche Engineering. "Our vision is that, in the future, efficient and automatable concepts for which engineers simply

AI agent on a crash course



VIRTUAL HEAD-ON COLLISION
THE FEM SLED MODEL OF A VEHICLE



The images show how the seat belt and airbag behave in a crash. The **FEM simulation** calculates the forces that would act upon the occupant in the event of an accident. These forces can be reduced even further by optimizing how the seat belt and airbag interact. Legislation sets limits for the loads.

FEM crash simulations of this nature are very complex—despite reducing the subject from a complete vehicle to a sled model—and can take almost a day. This is where artificial intelligence comes into play: Using the **RL agent** means that many FEM calculations can be omitted, allowing the developers to reach their goal more efficiently.

need to monitor multiple agents will accelerate the development process in a sustainable way." Overall system maturity will increase as a result, which will reduce both the number of complex physical crash tests and the number of prototype vehicles required.

"In the long term, we will be able to exploit further efficiency potentials, as future product generations will be optimized on the basis of the preceding generations," says Di Roberto. Once the decision strategy of the RL agent has been learned, it can be flexibly transferred to new model variants as long as the basic task is comparable. "In addition to the time required for the learning process, the time taken to develop entire FEM submodels could also be saved in the future."

Using artificial intelligence to prepare simulation data in what is known as post-processing also saves time when it comes to developing passive security systems. "Modern simulation tools calculate a crash with a very high level of detail. However, this also produces a lot of data for the engineers to interpret," says Di Roberto. While artificial intelligence was upstream of the simulation steps in the AI projects previously pursued by Porsche Engineering, in post-processing it is only deployed after the simulation. The type of algorithm used for this is called explainable AI. The task of this algorithm is to identify complex relationships in a dataset and to make them visible to the developer. Dependencies can be determined locally (at simulation level) and globally (at dataset level). This is how AI assists development engineers in interpreting the simulation results. "The use of explainable AI puts a compass in the hands of engineers and allows them to navigate the increasingly complex and extensive dataset of modern simulations," explains Mathieu.

One example of where such a large volume of data is generated is robustness analyses in passive vehicle safety. Stefan Kronwitter, a PhD student at Porsche AG in the field of body system development and who is focusing on vehicle safety, is working with Janis Mathieu on deploying explainable AI methods in analyzing crash simulations. "Explainable AI can be used to deter-

„In the future, efficient and automatable concepts for which engineers simply need to monitor multiple agents will accelerate the development process in a sustainable way."

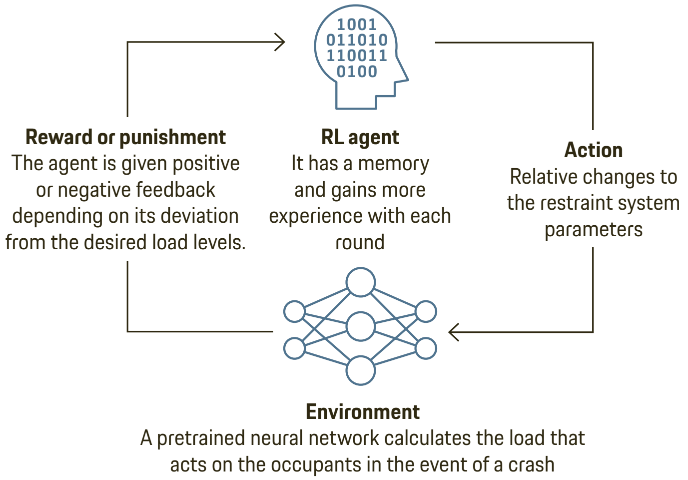
Janis Mathieu
PhD student at Porsche Engineering

„In the long term, we will be able to exploit further efficiency potentials, as future product generations will be optimized on the basis of the preceding generations."

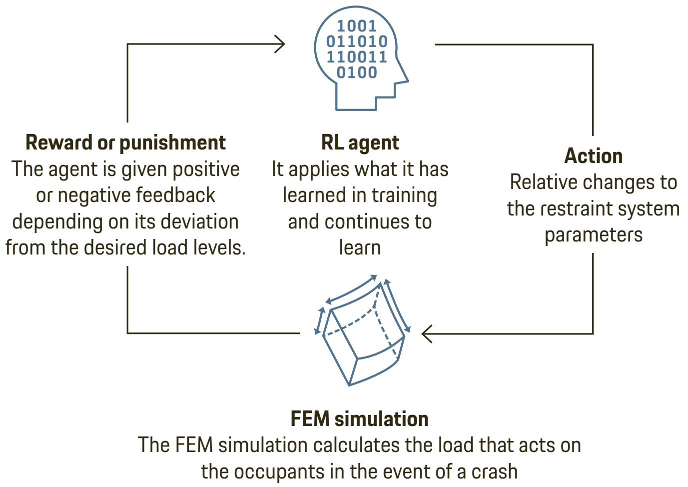
Michael Di Roberto
Senior Manager CAE & Safety at Porsche Engineering

FROM TRAINING TO APPLICATION
HOW THE RL AGENT LEARNS

Optimizing loads—training phase



Optimizing loads—application phase



mine—in a short period of time—the cause variables that lead to conspicuous behavior within individual simulations," says Kronwitter.

A SUPPLEMENT TO FEM SIMULATIONS

An initial version of the explainable AI-based analysis is currently being integrated into the series processes for crash calculation at Porsche Engineering, and further applications are to follow. "Explainable AI lays the foundation for optimizing all systems that require deep understanding. In addition to passive safety, this also includes parameter studies for lightweight construction or driving dynamics," says Schaper.

Despite all the progress made in the field of AI, however, the following still applies: FEM simulations will remain an essential part of development processes in the future. The digitalization of processes and the complexity of the systems will lead to more simulation—and more accurate simulation—which will make AI support unavoidable in this area, too. "Porsche Engineering has a deep understanding of series development processes and methods, and has been involved in developing and applying AI methods for many years," explains Schaper.


SCENARIOS: 1,686,577
CORNER CASES: 986
DISTANCE DRIVEN: 3,808 KM
TIME: 56.2 H

Risk of confusion: The driver assistance system may misinterpret transport of the car facing backwards as an oncoming vehicle—this is what is known as a corner case.

Confident, even in borderline cases

Driver assistance systems make road traffic safer, but so far mainly cover standard situations. Using artificial intelligence, Porsche Engineering is working to make identifying traffic situations that occur less frequently—known as corner cases—easier and more reliable. The aim is to improve ADAS.

Text: Claudius Lüder

A **freeway**, sometime in the early hours of the morning. The sun is low, rush-hour traffic is getting heavier. A passenger car is driving in the middle lane and cutting in behind a flat-bed truck on the right. The truck is carrying a vehicle that is positioned backwards on the flat bed with its front facing to the rear. The camera sensors on the car that is cutting in interpret the cargo as an oncoming vehicle, and the emergency braking system intends to intervene. Traffic situations such as these are very rare, but not unheard of. Advanced driver assistance systems (ADAS) must therefore also be trained for these unlikely events.

"Rarely occurring cases such as a vehicle transport like this are a classic corner case," says Arsen Sagoian, Specialist Project Manager in the AI and Big Data division at Porsche Engineering. The term refers to unusual traffic situations that tend to occur rarely. They also include pedestrians or cyclists on the freeway, lane boundaries that are no longer recognizable because of snow, or roads that, due to their nature, make it difficult for the systems to recognize lane markings clearly.

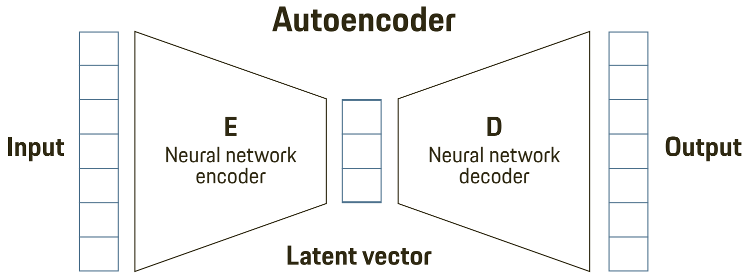
This is why developers must constantly train driver assistance systems with corner cases in order to further improve them. The problem is that, typically, most of the scenarios recorded on video during normal journeys are similar to each other from a technical point of view and therefore contribute little towards optimizing ADAS systems. Over time, the database of corner cases continues to grow, so that exceptional situations tend to become increasingly rare in new test drives. The challenge is to identify the remaining unconsidered corner cases in the recordings with as little effort as possible—which is like searching for the proverbial needle in a haystack. A manual search of the video data material is not suitable for large-scale use due to the time required and the associated costs.

AI FINDS CORNER CASES

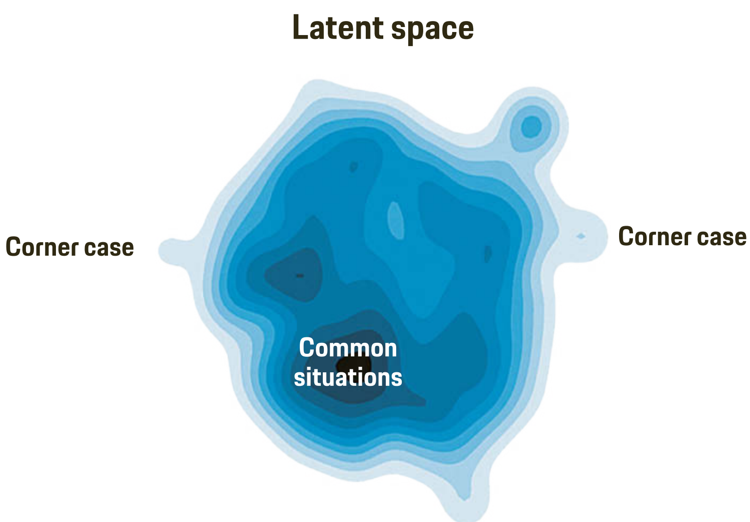
In its 'AI-Based Corner Case Detection' project, Porsche Engineering instead uses artificial intelligence (AI) methods to automatically search video data or time sequences with pre-processed sensor data and bus signals in order to find the coveted outliers. A variational autoencoder (VAE) analyzes the video and time sequence data recorded during test drives in order to find appropriate situations, their duration, and their timestamp (see box). So far, the method has been used primarily for face recognition. Its deployment in improving ADAS solutions is new. Because VAE is an unsupervised learning process, training data can be created more easily. The runtime is also shorter, allowing the algorithms to be run directly in the vehicle. This means that only relevant data is recorded.

The corner cases collected with the help of AI are then forwarded as new test cases to the teams responsible for functions such as lane recognition. "We had one case, for ex-

REDUCED TO THE ESSENTIALS: AUTOENCODER, VAE AND LATENT SPACE



An **autoencoder** is a special neural network (NN) that progressively compresses input data to reduce it to its essential characteristics. The data first passes through the NN of the encoder, which consists of several layers with fewer and fewer nodes (artificial neurons). As a result, the input data is increasingly compressed—a process that reaches its peak in the bottleneck, where a latent vector is created. Here, the input data is characterized by a series of latent values (see below). In the decoder that follows, the number of NN nodes increases from layer to layer until the original number is reached at the end. This procedure allows, for example, faces to be identified based on their essential characteristics.



A **variational autoencoder (VAE)** is based on the basic autoencoder principle. It is mainly used to create new data points similar to the distribution of training data. In contrast to the autoencoder, a VAE encodes the essential characteristics of the input data by assigning a mean and a standard deviation to them as latent values: The coding is statistical and, unlike with the autoencoder, not deterministic. When applied to driving scenarios, the VAE learns general and specific aspects of driving. It then compresses them into a thousand latent vectors, which together form the **latent space**. The software analyzes it to create a map that shows the density of latent vectors within the latent space. Areas with many vectors exhibit a high density and represent commonly occurring driving maneuvers. By contrast, remote areas with few vectors are considered interesting areas that represent corner cases.

“Compared to manual evaluation, we save far more than 99 percent of human working hours thanks to AI.”

Arsen Sagoian
Specialist Project Manager in the AI and Big Data division at Porsche Engineering

ample, where the edge of some snow on the ground was interpreted within the limits of the system as a lane boundary. This resulted in an uncomfortable lateral maneuver on the part of the vehicle,” explains Daniel Slieter, Tech Lead Verification, Validation & Data Analytics for the driving functions at CARIAD. In the Active Lane Departure Warning (ALDW) system, the data points attached to relevant snow-edge corner cases are spatially highlighted. This allows developers to adapt the functionality of the Lane Departure Warning system to this corner case—with the result that in the event of a comparable scenario within the limits of the system, the driver assistance system will no longer be so easily confused by a snow edge.

AI is far superior to humans in searching for these kinds of scenarios: It takes it only a few minutes to analyze data on around 10,000 kilometers of driving and identify about five corner cases. The quality of the algorithm and the thresholds defined play an important role. Manual evaluation of the recorded kilometers from test drives is reduced to a minimum by the use of AI. “Compared to manual evaluation, we save far more than 99 percent of human working hours thanks to AI, and this trend is rising steeply,” according to Sagoian. “We refer to this as an exponential increase in efficiency, and it allows engineers to concentrate on the actual development of the function.”

5

corner cases are found by AI on average for every 10,000 kilometers driven. It only takes a few minutes to do this.

REAL-TIME ANALYSIS

For now, all recorded data is loaded into the cloud for analysis. But it doesn’t have to be that way forever: “In the future, corner case detection could be performed in real time during active vehicle operation, because our neural network is a small one that offers good performance,” explains Slieter. “We would then only load the detected corner cases into the cloud instead of the raw data, which would significantly reduce the amount of data transferred this way.”

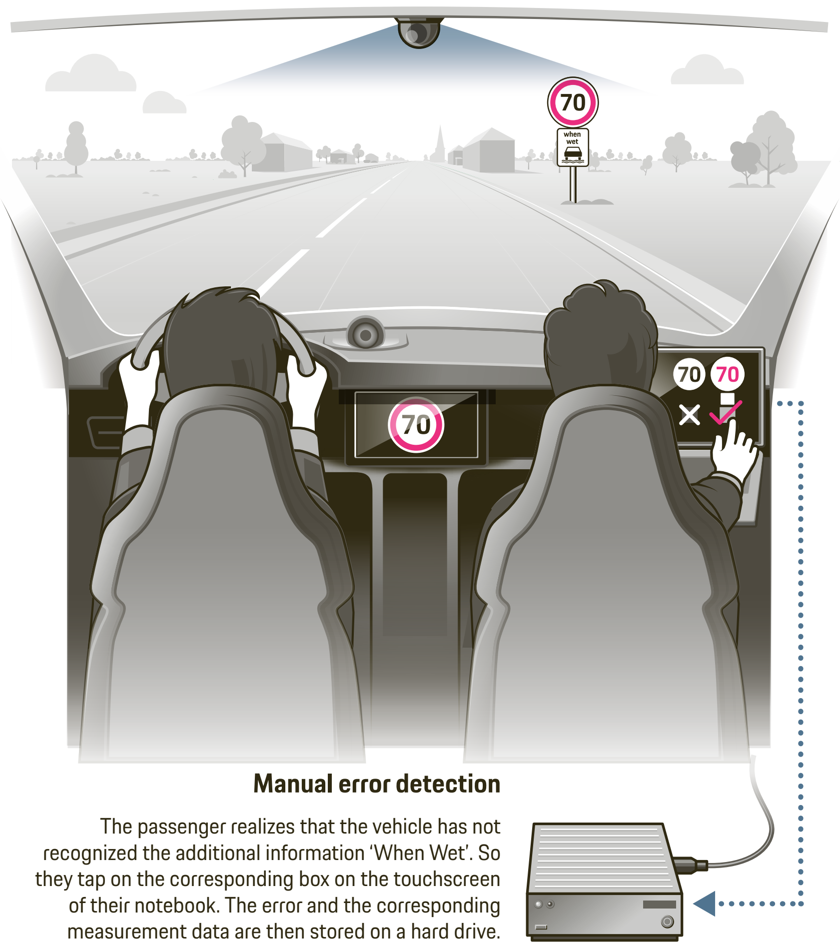
There is another benefit of the new method: AI is not only becoming ever more precise by permanently analyzing data, it also allows for more far-reaching conclusions. The basis for this is what is known as latent space—an abstract space in which the AI searches the data for patterns and reference images, and thus constantly becomes better (see box). Using this latent space, developers can also identify similarities between countries when allocating corner cases. In addition, the similarity of new data points to known corner cases can be used to deduce whether a sufficient number of data points has been recorded for validation purposes. “In summary, the VAE looks at the images while the latent space ensures that they are properly analyzed and evaluated,” Slieter explains.

The capabilities of the method are currently being tested worldwide. “This allows us to identify very different types of corner cases and also to draw conclusions about the extent to which the results can be transferred from one country to another,” says Sagoian. The system has identified a particularly large number of corner cases in Sweden and Finland, which is due, among other factors, to exceptional traffic situations caused by snow. Encounters between vehicles and animals are also expected to be more frequent in these countries.

ADAS validation with the smartphone

Porsche Engineering makes ADAS validation scalable: Using the in-house development ComBox App in combination with Peregrine.ai's object detection could enable every test vehicle to contribute to the validation of traffic sign recognition in the future.

Text: Christian Buck
Illustrations: Andrew Timmins



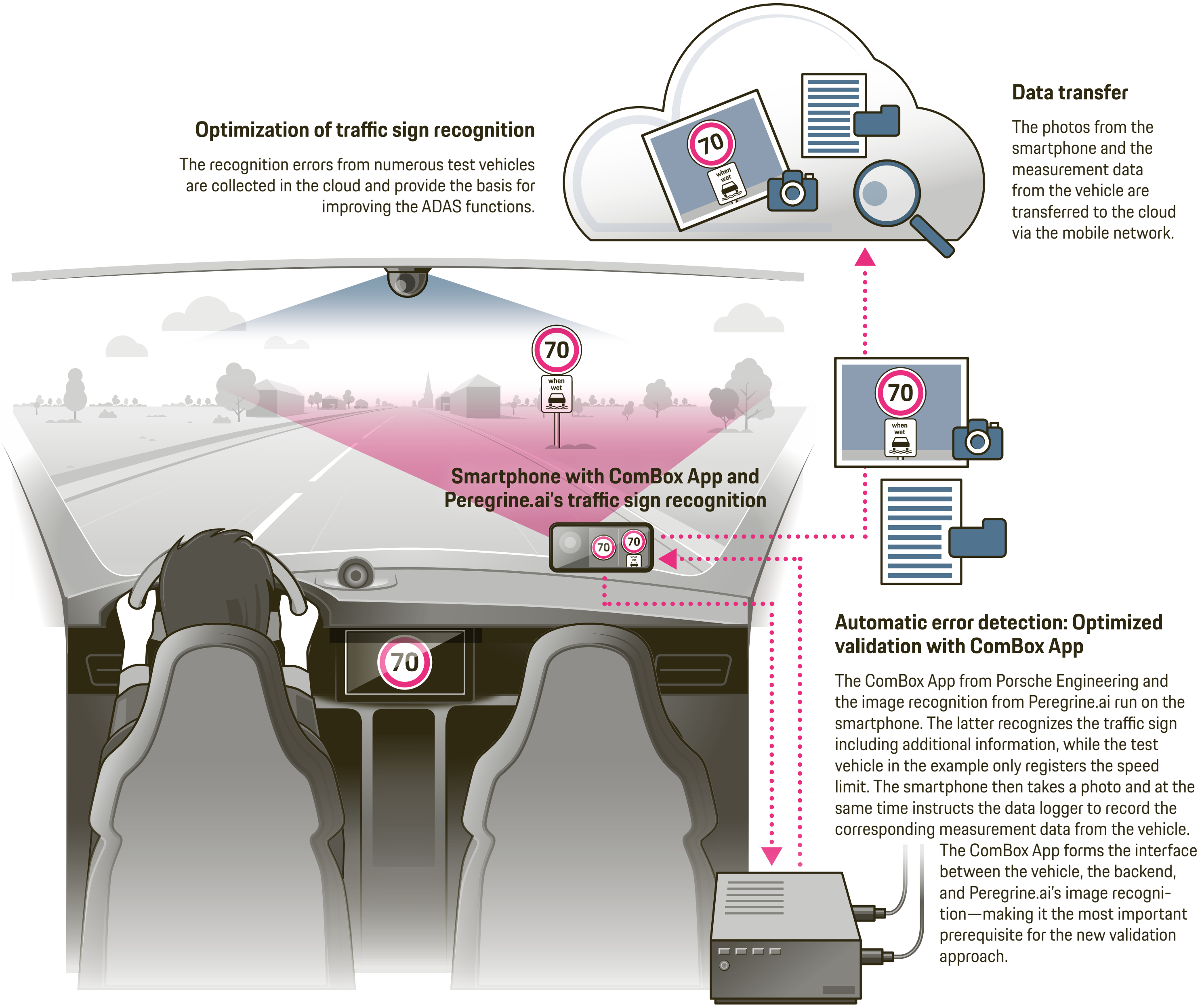
Manual error detection

The passenger realizes that the vehicle has not recognized the additional information 'When Wet'. So they tap on the corresponding box on the touchscreen of their notebook. The error and the corresponding measurement data are then stored on a hard drive.

For the validation of ADAS (Advanced Driver Assistance System) driving functions, developers need as much measurement data as possible from test drives—because this is the only way to ensure that the system has encountered many edge cases such as construction sites or rare traffic signs. But the measuring equipment for this is expensive, therefore making it cost-intensive to scale for large vehicle fleets. Validation is also generally associated with a large amount of work, as the example of traffic sign recognition shows: A developer in the passenger seat compares whether the ADAS system has correctly recognized a traffic sign during road tests. In the event of an error, they note the discrepancy manually. In addition, the corresponding measurement data from the vehicle is recorded on a hard drive.

Porsche Engineering aims to reduce the manual work effort required for the validation of ADAS functions. To do so, it is employing smartphones equipped with software for traffic sign recognition from the Berlin-based start-up Peregrine.ai. While Porsche Engineering provides the interface to a data logger, the connection unit, and the camera hardware, Peregrine.ai integrates its AI-powered object detection.

The idea behind it is that with each new traffic sign, the smartphone compares whether the vehicle and Peregrine.ai's object detec-

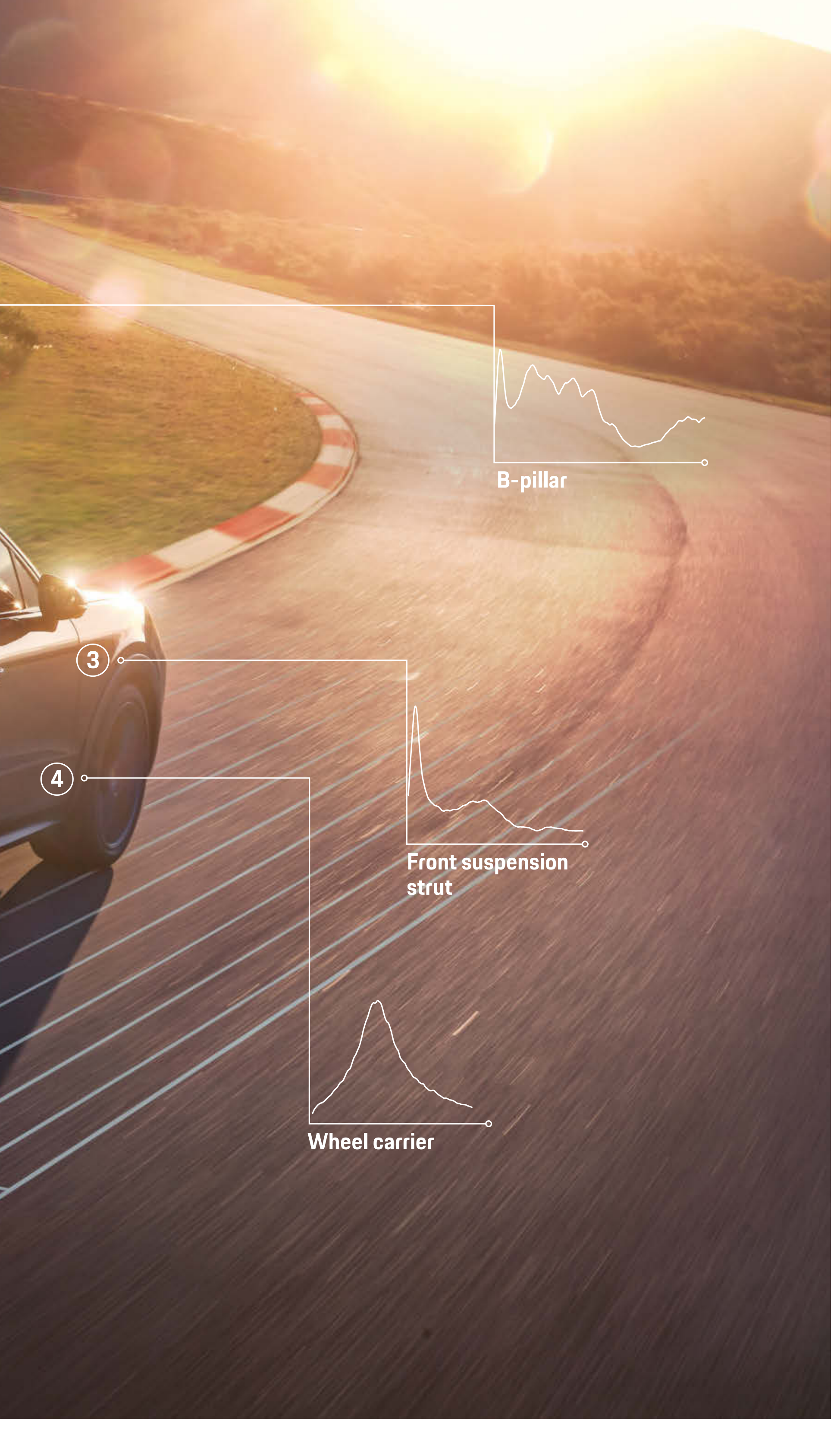


tion provide the same result. If there are discrepancies, the smartphone photographs the traffic sign and instructs the data logger to record the corresponding measurement data from the vehicle. Thanks to the ComBox App, Porsche Engineering can receive data from in-vehicle systems—the recorded measurement data can be loaded into the cloud and compared, which helps the ADAS engineers optimize the functions.

The new method therefore not only eliminates the high manual work effort involved in the detection and description of the errors, but also enables the optimization of traffic sign recognition to be carried out cost-effectively by a larger number of test vehicles. In the future, a smartphone on the windshield will be able to detect and record errors in all test vehicles—not just in those specifically designed for ADAS optimization. This will allow the developers to record more edge cases and thus improve the quality of the ADAS functions—especially in countries such as Australia with special traffic rules such as left-hand traffic and regional traffic signs, for which there is little data so far due to the small number of test vehicles.

The new approach to validating traffic sign recognition has already been successfully tested during development of the new Porsche Macan and could soon be used in series development. It is also not limited to traffic sign recognition: In the future, further ADAS features will be optimized, including lane detection as well as the detection of traffic light phases and potholes.

Objectively comfortable



Many criteria characterize a good car. Driving comfort plays a key role in this—both the decision to buy a particular model and subsequent customer satisfaction are decisive, among other things. For this reason, before a new vehicle is launched on the market, manufacturers carry out numerous driving comfort tests. Porsche Engineering also undertakes testing and tuning on behalf of OEMs, in the course of which the engineers responsible for vehicle dynamics tune the vehicles in accordance with the manufacturer's specifications. "Our aim is to optimize certain characteristics such as comfort or sportiness and bring them up to a level that has been defined together with our customer," reports Martin Reichenecker, Senior Manager Vehicle Dynamics & Validation at Porsche Engineering.

At certain milestones, joint acceptance drives are conducted in which project managers and other employees who are not directly involved in chassis development sit at the wheel and gain an idea of the current status. This includes, for example, model line or project managers and the customer's managers. Characteristics such as vertical body motion, the rollling behavior of the vehicle, the reaction when driving over a curb, as well as shaking and wheel bounce are evaluated. Chassis vibrations below 35 hertz are particularly relevant for the perception of comfort.

However, the assessments are always slightly different depending on the driver and their technical expertise, as their personal preferences and experiences can vary greatly. "One person may prefer a tight setup, while another appreciates a soft suspension. For this reason, we have developed an AI-based driving-comfort evaluator that can aid us in the preparation of acceptance drives," explains Emmanuel Bogner,

Porsche Engineering has developed an AI-based driving-comfort evaluation system that supplements the assessments made by human experts to deliver objective results and accelerate development time. It will also be possible to use it in series-production vehicles in order to provide information on chassis performance during vehicle use.

Text: Christian Buck

Chassis vibrations up to

35

hertz are relevant for the perceived comfort in the vehicle

Vehicle Dynamics Expert at Porsche Engineering. “It can provide assessments regarding the current state of the chassis setup, which we can compare with the specified goals of our customer.”

At the beginning of the project, Bogner and his team investigated whether an AI is even capable of assessing driving comfort in a similar way to a human being. The challenge here is that many factors are involved in human perception of driving comfort, and it is important to link this subjective assessment with objective measurement data.

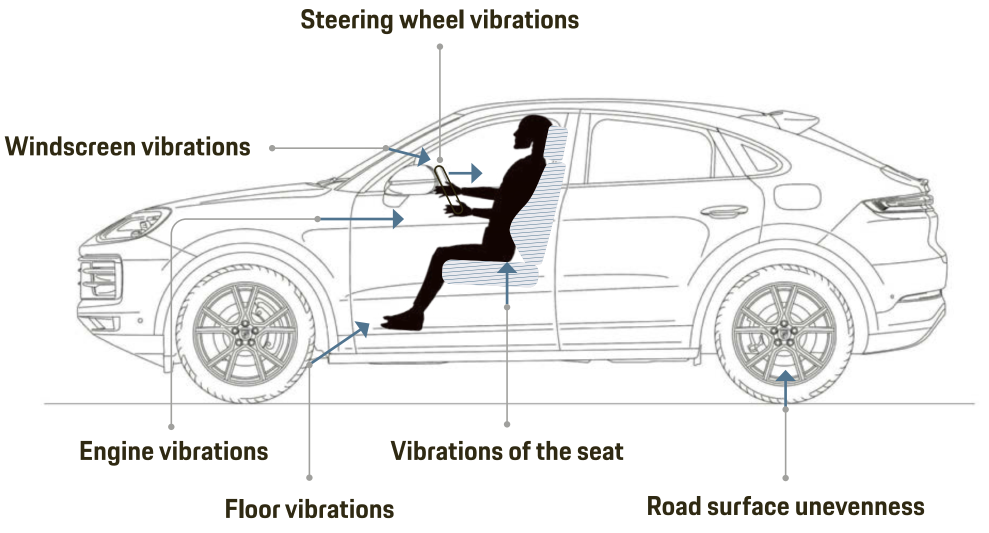
As a first step, the developers equipped a vehicle with six precision acceleration sensors that recorded the dynamic behavior of the chassis during numerous test drives on the 850-meter comfort track at the Porsche testing grounds in Weissach. The circuit offers many different road condition scenarios and thus enables a great deal of variance to be produced in the measurement data. “There are both long-wave and short-wave excitations created by the road surface there, so both low and high frequencies could be measured during the test drives,” says Bogner. “In addition to the sensors, I evaluated the driving comfort from my personal point of view.”

The measured values plus Bogner’s assessments served as the basis for training a neural network. First, the measured acceleration values from the sensors were converted into a frequency spectrum using a Fourier transform. This made it easy to see the areas that had been subject to particularly strong vibrations during the drive. This frequency spectrum then served as an input signal for the neural network. In numerous training loops, it learned to establish an ever-better connection between the patterns at its input and Bogner’s assessments. “After training, the AI was actually able to evaluate driving comfort,” says Bogner.

OPTIMIZED SENSOR SET-UP

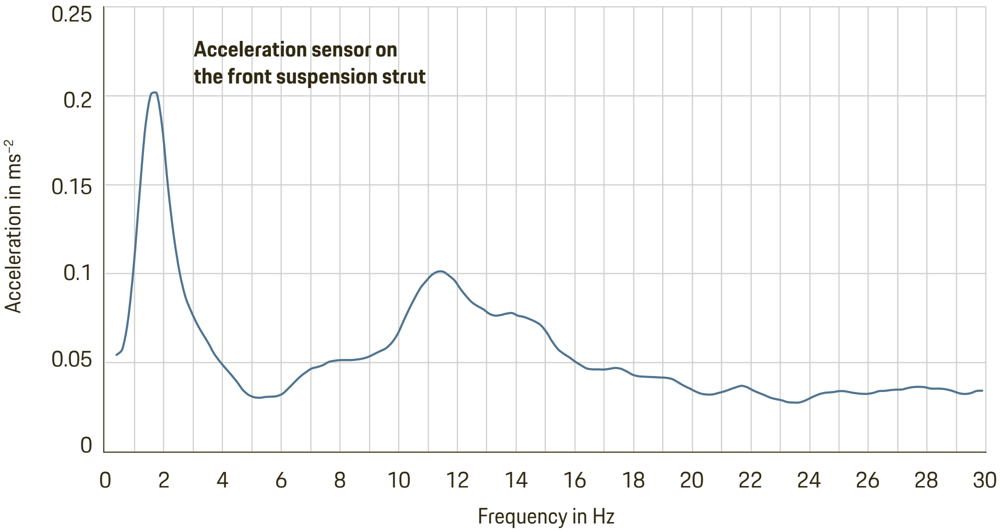
After that, Bogner and his team began optimizing the measurement technology setup to further increase the speed and efficiency of the measurements. The original precision sensors that were used could only be integrated into the vehicle with great effort and required a lengthy calibration process. In addition, these types of sensors can also be used for high-frequency acoustic measurements: Their measuring range extended to a frequency of up to 100,000 hertz, while in the driving-comfort evaluation context, vibrations below 35 hertz are taken into account. As an alternative, the team used cheaper sensors from motorsport applications and checked whether the results were still good enough for driving-comfort evaluation. “We managed with four sensors, attached to the driver’s seat rail, the B-pillar, the suspension strut, and the wheel carrier,” explains Bogner. “New test drives showed that the optimized setup actually provided sufficiently good measurement data for AI-based driving-comfort evaluation.”

WHAT DETERMINES DRIVING COMFORT?



Various vibrations occur in a moving vehicle. The effect on the occupants determines their subjective sense of comfort. The main sources of vibration are the engine, the floor in the footwell, the seat, unevenness of the road, as well as vibrations of the steering wheel and the windshield. Vibrations of the seat have the biggest effect on the subjective feeling of comfort. Driving comfort can be measured objectively by using sensors to determine the vertical acceleration and then using that as an indicator.

IT'S ALL ABOUT THE FREQUENCIES!



A fast Fourier transform (FFT) is used to break down the vibrations into their frequency components. This spectrum allows objective assessment of driving comfort: Low frequencies with a high amplitude between 1 and 4 hertz is the range referred to as **first-order driving comfort** (lifting, pitching, rolling, and yawing of the vehicle body at its natural frequency). The frequency range of 4 to 15 hertz characterizes **second-order driving comfort.** These low amplitude vibrations occur when the vehicle body is vibrated by cracks or seams in the roadway.

"The AI-based driving-comfort evaluator runs on a normal PC; you don't need a high-performance computer."

Emmanuel Bogner
Vehicle Dynamics Expert at Porsche Engineering

Currently, the neural network receives twelve input values from the vibration sensors and returns a table with ten parameters that describe the behavior of the chassis as a result. "The AI-based driving-comfort evaluator runs on a normal PC; you don't need a high-performance computer," says Bogner. "The training lasts a maximum of one day, while the evaluation of a test drive is completed after just a few minutes." Until now, only Bogner provided training data for the neural network as a human evaluator; in the future, additional experienced employees will contribute their input together with measurement data from other vehicles in order to further train the network and improve the results. "Unlike with the acceptance tests, there should be only a few deviations in the subjective assessments, because the opinions of the professionals usually coincide," says Bogner.

In addition to preparing acceptance drives, Bogner and his team have another goal: In the future, the aim is for vehicles to calibrate themselves using the AI-based driving-comfort evaluator. "You could put them on a test bench and drive the same road again and again," explains Reichenecker. "In an iterative process, the chassis parameters could then be optimized until the comfort measured with the AI-based driving-comfort evaluator matches the customer specifications. This could be done fully automatically and without a driver."

Another new option would be the use of the AI-based driving-comfort evaluator in series-production vehicles. There, it could continuously monitor the comfort and performance of the chassis during vehicle use. The AI-based driving-comfort evaluator could therefore be used not only as a development tool to enable faster calibration of the chassis—it would also be an intelligent passenger of the end customer, ensuring a consistently high level of comfort and greater safety on the road.

Cayenne Turbo E-Hybrid Coupé with GT package

Fuel consumption (weighted) (combined): 1.9 – 1.8 l/100 km
Fuel consumption when the battery is discharged (combined): 11.9 – 11.5 l/100 km
Power consumption (weighted) (combined): 31.1 – 30.3 kWh/100 km
CO_2 emissions (weighted) (combined): 43 – 41 g/km CO_2 class (weighted) (combined): W
CO_2 class when the battery is discharged: G

“We’re at a major threshold”

Artificial intelligence is bringing massive changes to all areas of life, including development. In this interview, Markus-Christian Eberl, CEO of Porsche Engineering, and Dr. Matthias Peissner, Head of the Human-Technology Interaction Research Unit at the Fraunhofer Institute for Industrial Engineering IAO in Stuttgart, talk about the opportunities and limitations of the new technology.

Text: Constantin Gillies
Photos: NÓI CREW

Engineering meets research: Markus-Christian Eberl (left) and Dr. Matthias Peissner met for an interview in the futuristic building of the Fraunhofer Institute for Industrial Engineering IAO in Stuttgart.

There is currently a lot of hype about artificial intelligence. Will the technology really bring about the fundamental changes in society and industry that are expected? Much like the emergence of the internet at the turn of the millennium?

— **PEISSNER:** There is definitely some hype in the media. The first push came in autumn 2022 with ChatGPT, and more hype—and disappointment—is likely to follow. In the long term, however, the path ahead is clearly laid out: Artificial Intelligence (AI) will reach a level that was unimaginable until recently. Look at how many products of human intelligence surround us. And now imagine that all of these things will be based on artificial intelligence that is equal to, or in some cases even superior to, human intelligence in the future. This will bring massive changes. We are definitely at a major threshold.

— **EBERL:** In my view, the comparison with the emergence of the internet at the turn of the millennium does not go far enough. If you look at the history of technology, a significant part of industrial development over the last 2,000 years has taken place—figuratively speaking—below the neck. Innovations from hydropower to steam engines and fully automated production were essentially aimed at 'mechanizing' human muscle strength and skill. If the part above the neck, that is, intelligence, is now 'mechanized', big changes can be expected—in companies and in society as a whole.

So we are facing the industrialization of thinking?

— **EBERL:** It's a very bold summary, but you could put it that way. The magnitude of the impending changes can by all means be compared with the industrial revolution. In companies, AI works in multiple directions: It makes processes more efficient, which increases speed and provides cost benefits. At the same time, we can increase the performance and effectiveness of our products, for example in the form of new, innovative features or an improvement in product quality. We can therefore be faster, more economical, and better with AI.

— **PEISSNER:** Increased economic efficiency and quality are certainly very central areas of impact for the use of AI. In addition, AI could also help us to make complex issues manageable. Perhaps this will help us to deal with the major economic problems of our time—shortage of skilled workers, scarcity of energy and resources, and sustainability.

Where could the risks lie?

— **PEISSNER:** There is, of course, the danger that AI will exacerbate our problems—think of the huge amounts of energy that the training of large language models devours. In addition, AI could create new inequalities or reinforce existing ones. Looking at the world map, the picture is already emerging: All major AI hotspots are located in the north, where the training of the models takes place. In the global south, on the other hand, they are only used—and much of the earth is currently a complete 'AI desert'.

— **EBERL:** Every new technology brings both risks and opportunities with it. At the same time, it is clear that such powerful technologies cannot be ignored. There is a need for commercial enterprises to make the technology responsibly usable, and to do so as quickly as possible. We are currently seeing the technological half-life continue to decline. At the time of our grandfathers, technology cycles still spanned half a human life, but it was perhaps a decade when I was a student. Technology cycles now take only one or two years—and are in some cases shorter than the typical adjustment periods of companies. This creates opportunities for new players and challenges the established players at

"The magnitude of the impending changes can by all means be compared with the industrial revolution."

Markus-Christian Eberl
CEO of Porsche Engineering

the same time. Companies whose strength is based on experience or a USP built up over decades should absolutely not miss the boat here. An extremely powerful technology and an extremely fast pace of change are converging—that's an extraordinary mix.

How is Porsche Engineering already using AI?

— **EBERL:** One of many examples is the use of AI in the validation process for automated driving functions. These systems must react reliably not only in standard situations, but also in special traffic situations. Imagine, for example, a richly decorated cow walking on the road during the cattle drive down from the Alpine pastures. Although this is an exceptional traffic disturbance, the system must reliably detect the animal. Numerous vehicles travel many kilometers every day in order to collect as much 'visual material' as possible to secure the automated driving functions in a wide variety of situations. In doing so, the identification of the rare cases in the sensor and video data of the trips, such as the cow from the cattle drive, resembles a search for a needle in the haystack. Under certain circumstances, only 0.0001 percent of a recording is relevant. That is why we have trained an AI to identify and extract what are known as corner cases—and thereby greatly increase efficiency in the development and validation process. Another practical example for the application of AI is large language models, which we are already using in software development, for example to increase the efficiency of the software coding. If I describe a problem sufficiently well, a well-trained LLM can generate the corresponding code at development level 1 very efficiently. This means that the coding of a function, which used to be done by experts, is now done by AI machines at a high level. The further optimization and integration steps for this code are still mainly the task of experts, although the AI capabilities in this area are developing rapidly.

Markus-Christian Eberl is Chairman of the Executive Board of Porsche Engineering. Before joining Porsche Engineering in 2023, he worked at Porsche AG as Vice President Technical Conformity and in other management positions. The graduate engineer studied aerospace engineering at the University of Stuttgart.

An LLM may give a slightly different response every day. How does this work with classical engineering, where reliability and precision are important?

— **EBERL:** A rethinking is indeed needed here. Until now, engineering studies have been designed to learn scientific principles and to be able to apply them to technical problems. The electronic procedures used in everyday engineering were also based primarily on mathematical and empirical methods, which could be carried out independently and unambiguously by the expert, or at least be reproduced, with sufficient effort. AI is now introducing a completely new methodology based on training with large data sets. This fundamental difference should be taken into account both in the overall validation strategy and in the approval based on it, because even if the engineer can no longer fully understand every step, the reliability of the final result must be guaranteed. Approaches such as 'explainable AI' aim to ensure that the results of AI remain comprehensible in terms of content. Other validation methods combine classic and AI-based methods.

— **PEISSNER:** Machine learning represents the major paradigm shift. How these systems come to their conclusions is initially unclear. In this respect, the saying used in aviation, 'If you no longer understand what the system does, turn it off', no longer applies. But we can also gain new insights through this new way of working. In medicine, for example, a procedure has long been used that recognizes and classifies different types of skin cancer. From such a system, new indicators for good human decisions can also be derived.

Paradigm shift: AI is a completely new methodology based on training with large data sets—Challenge and opportunity for research and development.

Uncertain future: It is still difficult to predict exactly how much AI will change—but it must be ensured that it serves everyone.

Does the engineer of tomorrow have to master the deterministic models at all?

— **PEISSNER:** Of course, otherwise we will be completely at the mercy of AI! Someone needs to check whether the results provided by AI are valid. Moreover, the way to the result is also sometimes important. For example, when I do some research on the internet, I often stumble upon articles that I might just scan through. But in doing so, I learn new things and expand my horizons. When I do the research with ChatGPT, in contrast, I get a result that I can use immediately, but I don't have this process of seeing what's going on to the right and left of my view. But that is exactly what many innovations are based on.

— **EBERL:** In addition, AI relieves the human brain of simpler tasks, such as processing data. This gives you time for more creative tasks. You use AI as a tool and don't see it as a competitor.

How can companies prepare their workforce for this new way of working?

— **EBERL:** The goal should be the 'democratization of AI': The topic must be taken to every corner of the company so that everyone sees and seizes the opportunities offered by the new technology. Because the subject is so important to us, we have established a dedicated unit for Big Data and AI at Porsche Engineering. This is our nucleus. But for a successful 'democratization of AI', a larger change management approach is needed. We must also

Matthias Peissner has been head of the Human-Technology Interaction Research Unit at the Fraunhofer Institute for Industrial Engineering IAO, Stuttgart, since 2017. The psychologist also coordinates the AI Innovation Center 'Learning Systems and Cognitive Robotics'.

demonstrate pragmatic solutions and promote flagship projects that show the positive aspects of the new methods. If we succeed, the topic will have its own momentum. You need the centralized 'push'—plus the 'pull' from all parts of the organization.

So far, Europe has only achieved one pioneering feat in the field of AI: With the AI Act, we were the first to regulate technology. Where is Europe in the global AI race?

— **EBERL:** AI is dealt with differently in different regions of the world: In Europe, we tend to have a more risk-oriented view. We try to anticipate and avoid problems. In other parts of the world, an opportunity-oriented view dominates. It is in the nature of the matter that certain developments are carried out faster there. For us as a company, it is important that we know the local differences in research and development, application and regulation of AI through our presence in all regions of the world. We have gained a comprehensive view of AI in the world and can offer our customers tailor-made solutions.

— **PEISSNER:** In general, I think we in Germany should concentrate more on our strengths! We are well positioned in research, and a good deal of funding has been well spent through the federal government's AI strategy. What we lack compared to the US is private investment. That is why we are not competitive when it comes to developing large language models. But perhaps that is not necessary either. AI is, after all, an all-purpose technology—basically like electricity. It is not about who invents it, but who uses it quickly and efficiently. We haven't lost the race yet. We need to completely rethink the processes, particularly with the help of employees. This tradition of co-creation is a strength that we take too little advantage of in Germany.

Technology circles are already talking about Artificial General Intelligence (AGI), a generalist AI that is superior to humans. Is such a technology coming in the long term?

— **EBERL:** For example, if you had asked Volta or Edison what makes electricity possible today, they would probably not have predicted our modern reality very well. Forecasting over such long periods is difficult. I think it is currently relevant to understand the importance of the technology and to establish adequate change management. Humans generally tend to think about developments in a linear way. But the new AI technology—once it has gained a foothold—will open up entirely new possibilities and have exponential effects. Predicting them should be more of a task for the philosophers.

— **PEISSNER:** I really believe that in the future we will have artificial intelligence that is superior to humans in some respects. Perhaps this will even happen this decade. But the question will be: Can 90 percent of the population still understand this progress—or will AI become a topic for a small elite? I think that this is an important task for the future: We must ensure that technology serves everyone.

"I really believe that in the future we will have artificial intelligence that is superior to humans in some respects."

Dr. Matthias Peissner
Head of the Human-Technology Interaction Research Unit at the Fraunhofer Institute for Industrial Engineering IAO in Stuttgart

PERFORMANCE AND EXPERTISE

MODULAR MULTI-LEVEL INVERTER

Innovative concept: Thanks to powerful electronics and software, the new vehicle battery supplies AC voltage for the control of the electric drive directly.

TURNING DC INTO AC

Porsche Engineering has developed the concept of an 'AC battery' for electric vehicles that unites numerous components in a single part. It is controlled by a standardized control unit concept with a particularly powerful and real-time-capable computing platform. The system was developed as part of a feasibility study, tested on the test bench, and demonstrated in a vehicle.

Text: Richard Backhaus

The drive system in electric vehicles usually consists of separate components: A high-voltage battery with battery management system, power electronics for controlling the electric motor, and an on-board charger for charging with AC power. The power electronics convert the DC voltage of the high-voltage battery into the sinusoidal three-phase AC voltage for the traction motor using a pulse inverter.

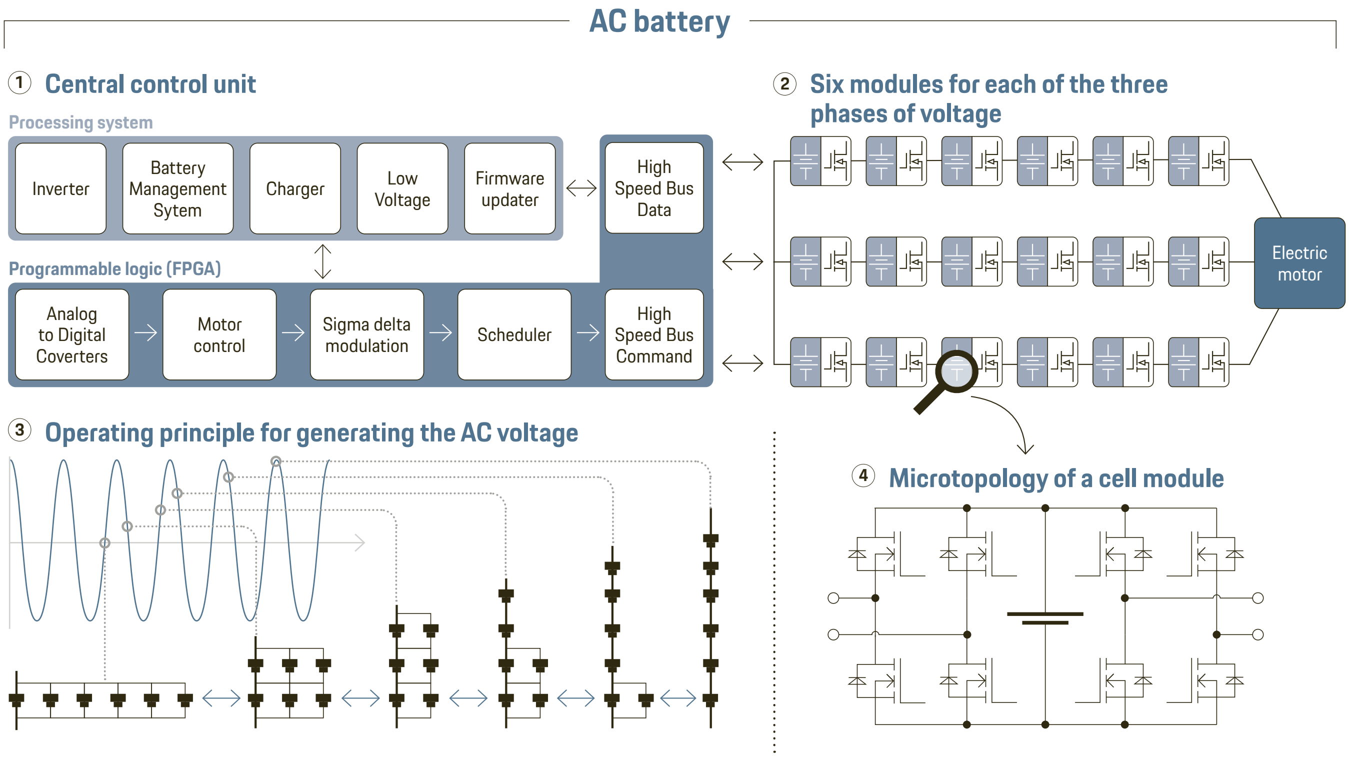
This structure has proved its usefulness in current vehicles, but could be further improved in the future. "The trend in the automotive industry is toward highly integrated components," says Thomas Wenka, Specialist Project Manager at Porsche Engineering. "This opens up new possibilities in terms of housing size, weight and cost reduction, reliability and efficiency." The development team at Porsche Engineering used the high integration level of components to develop an AC battery system as part of a feasibility study. It integrates the normally separate functions of the battery management system, pulse inverter, low-voltage DCDC, and on-board charger into one single component.

For the study, the developers at Porsche Engineering have divided the high-voltage battery of the electric drive into 18 individual battery modules, distributed over three phases. They can be controlled individually by power semiconductor switches. The flexible interconnection of the individual battery modules into a Modular Multilevel Series Parallel Converter (MMSPC) as a distributed real-time system enables dynamic modeling of the voltage curve, so that the sinusoidal three-phase AC voltage for the motor can be generated directly from the DC voltage from the battery modules. "With the MMSPC, both the direct control of the electric drive motor while driving and the direct connection to the AC grid for charging the battery is possible," explains Daniel Simon, Specialist Project Manager at Porsche Engineering.

NUMEROUS TECHNICAL ADVANTAGES

Other advantages include easier scalability to various drivetrain variants as well as safer handling of current-carrying components during servicing or in the event of an accident. "Then the MMSPC is switched off and the system effectively reverts back to its individual modules, meaning that only the module voltage can still be measured," says Wenka. In addition, failure protection increases in the event of a possible defect in individual battery cells, as the intelligent control system bypasses the affected battery module. This makes it possible to implement a so-called limp-home function to the nearest workshop with reduced power. With a conventional battery, this would cause a vehicle breakdown. The concept of the AC battery also offers the technical potential for a fast charging capability capacity through pulsed charging.

HETEROGENEOUS MULTIPROCESSOR PLATFORM
COMBINATION OF PROCESSORS AND FPGA



The AC battery became a software-defined drivetrain through **high integration at the system level**. The interesting thing about this approach: Classic hardware functions such as the pulse inverter, the battery management system or the on-board charger in the central control unit are implemented on part of the software with a processing system (1). The additional programmable logic is **implemented as an FPGA.** This enables hardware acceleration of the algorithm and ensures the **hard real-time capability.**

The individual battery modules are each equipped with **power electronics** and arranged **in three phases for the electric motor** (2).

In order to generate an AC voltage from a DC voltage, the individual cell modules of the battery are **interconnected differently** using the assembled power electronics (3). If all modules are parallel, this results in the lowest voltage (left). If they are all connected in series (right), the voltage reaches its maximum value. Values in between are achieved by different combinations of parallel and series connections of the modules (simplified representation). The modules must be controlled synchronously for safety and efficiency reasons.

A module consists of battery cells and the power electronics (4). The power electronics consist of **eight power MOSFETs** (Metal Oxide Semiconductor Field-Effect Transistors) per cell module and the architecture enables different interconnection configurations such as parallel, series, bypass, and passive circuits.

> **“The trend in the automotive industry is toward highly integrated components.”**

Thomas Wenka
Specialist Project Manager at Porsche Engineering

A major challenge in implementing the AC battery concept was the development of a powerful and fast central control unit that can precisely control the individual battery modules. “Dynamic reconfiguration of the battery modules in sine wave modeling is made possible by the underlying distributed system, which must meet real-time requirements under all circumstances,” says Simon. “After all, a delay in switching the modules would lead to defects in the battery packs and the associated power electronics.”

REAL-TIME CAPABLE COMPUTING PLATFORM

In parallel with the concept of the AC battery, the electronics experts at Porsche Engineering have developed a control unit with a particularly powerful real-time, uniform, and highly integrated computing platform. The individual functions of the AC battery, such as motor and battery management, as well as the charging function, run on it in parallel. The control unit platform consists of two elements, a project-specific so-called baseboard and a project-independent computing unit in the form of a system-on-module with a uniform interface to the baseboard. “The processing unit represents a heterogeneous multiprocessor platform and runs as a single system-on-chip. It combines a field-programmable gate array (FPGA)—an integrated circuit with programmable hardware—for data control and monitoring with regard to the real-time capability of the system, and a powerful multicore processor for processing large amounts of data in a single component,” explains Simon. “The FPGA can take over complex calculations to relieve the processor and supplement missing peripherals, which are significant advantages in terms of scalability and flexibility compared to the usual pure microcontroller solutions. And by selecting the derivative within the system-on-chip family, the performance can be scaled from basic ECU requirements—such as I/O-driven, communication gateway or power electronics—to complex ADAS systems with additional GPU and video codec requirements.”

One special feature of the approach is the software-focused implementation of the control unit functions. “One part runs on a processor, which uses the FPGA for fast control and the optimal switching strategy, and ultimately controls all modules synchronously. This enables dynamic reconfiguration through software. However for that to work, the power electronics on the modules have to implement this switching strategy,” says Simon. “By using a system-on-chip approach with a CPU and FPGA, we enable hard real-time capability that cannot be achieved with normal microcontrollers.”

Together with the new control unit platform, Porsche Engineering has implemented the concept of the AC battery in various prototypes and successfully tested it on the test bench. The system was also integrated into a test vehicle to demonstrate its basic functionality. “The development of the new control unit platform was absolutely necessary for the AC battery. However, since it can be flexibly adapted, it has become a separate project that will be continued,” says Wenka. For new projects, the system-on-module and some of the associated software can be reused, and the functionality of the baseboard can be easily upgraded to include the required hardware functions and interfaces. The control unit can therefore be flexibly adapted to new requirements and is therefore suitable for all applications where high computing power and real-time capability are required, and the requirements can still change during the ongoing project. “This allows the project-independent combination of a system-on-chip on the system-on-module of the control unit to also handle other complex tasks well, which makes it a good choice as a functional prototype platform for prototype development,” explains Simon.

Advantages over conventional prototype ECUs include faster function development, to name one example: The hardware provides high computing reserves, and the basic software and existing software blocks can be used as a very good starting point in the development of a control unit. “There are currently plans to initially use the new control unit platform for prototype development at Porsche Engineering,” as Wenka reports. “In principle, the concept is however also suitable for series applications with minor modifications.”

“By using a system-on-chip approach with a CPU and FPGA, we enable hard real-time capability.”

Daniel Simon
Specialist Project Manager at Porsche Engineering

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Power MOSFETs generate alternating three-phase voltage from direct voltage by connecting 18 cell modules in different ways.

PERFORMANCE AND EXPERTISE

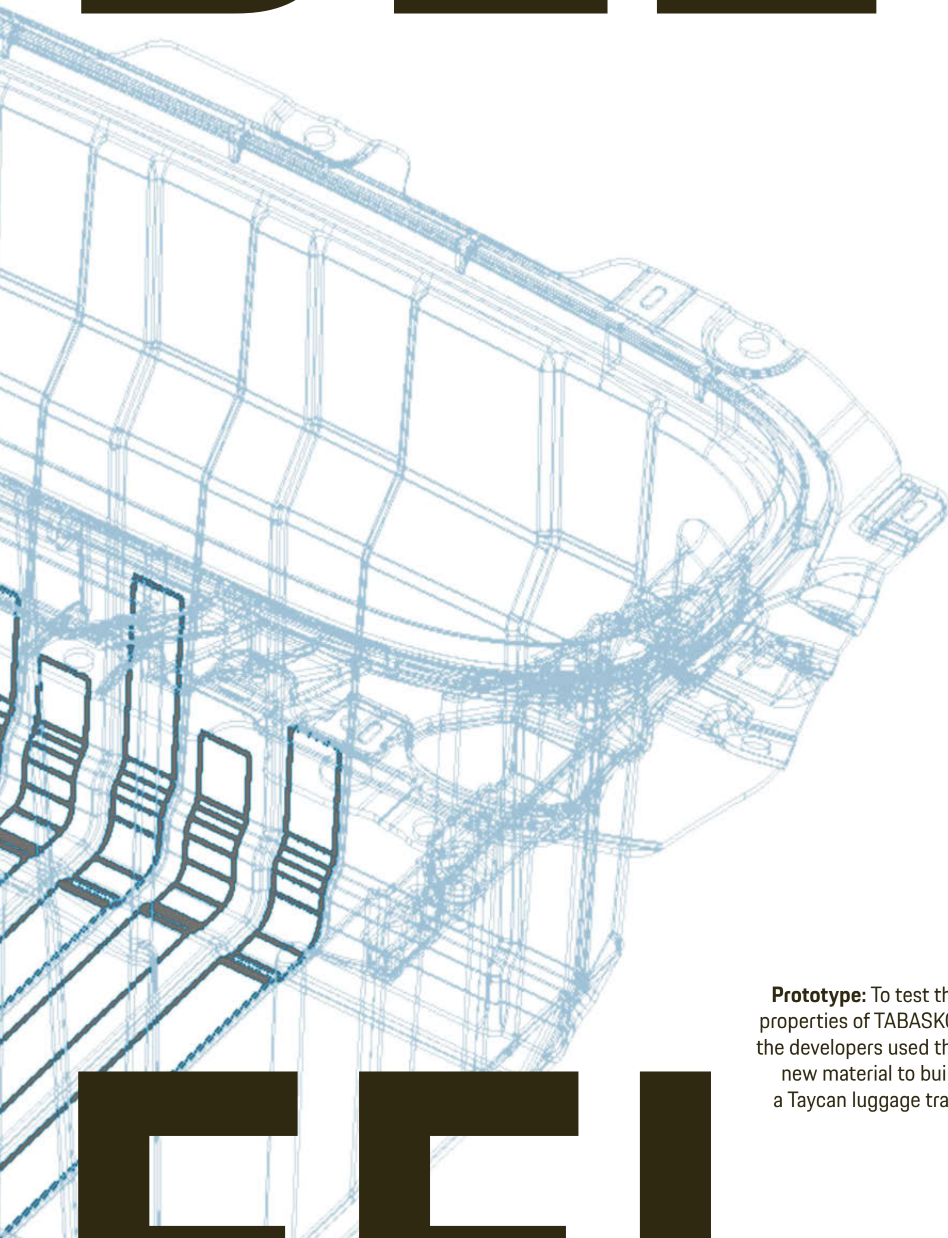
TABASKO

STA AS ST

TABASKO (from the German for 'tape-based carbon-fiber lightweight construction') can reduce the use of plastic materials; the process developed by Porsche Engineering also allows the use of post-consumer recycled material. This makes vehicle construction a bit more sustainable.

Text: Mirko Heinemann

BLE



Prototype: To test the properties of TABASKO, the developers used the new material to build a Taycan luggage tray.

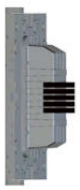
EEL

Lightweight construction is becoming increasingly important because safety technology, electronics, and increasing demands of comfort tend to increase the weight of vehicles. In addition, we are experiencing an ongoing switch to electric cars, which are usually heavier than vehicles with an internal combustion engine. To reduce weight elsewhere, the plastic polypropylene—known as PP for short—is used in the interior in most cases. It is comparatively inexpensive, easy to process, and can also be recycled relatively well. But it also has disadvantages: “Rigidity and heat resistance do not count among the positive properties of polypropylene,” explains Michael Johann, Specialist Project Manager for Body System Development. “Glass fiber is typically added to improve it.” This glass-fiber-reinforced plastic is called PP-GFx. Many components of Porsche vehicles are made of it.

Mr. Johann is fascinated by the topic of lightweight construction. Together with his team at Porsche Engineering, he develops series-production plastic components, for example for the roof lining of the Porsche Cayenne and for the trims on columns and doors. He and his colleagues are constantly evaluating new design principles that can be used to combine maximum strength and minimum weight. This led to the birth of TABASKO, the name of which comes from the German for ‘tape-based carbon-fiber lightweight construction’.

Michael Johann’s vision was to achieve better material properties at a lower weight. Carbon was the material considered, because its fibers are made of almost pure carbon and are as strong as steel, but up to 80 percent lighter. However, the material is very expensive.

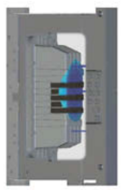
READY FOR SERIES PRODUCTION: TABASKO PRODUCTION



Inserting five filling strips

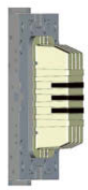
Closing the tool

Transfer of the three lower belts



Filling process: The upper belts are covered with plastic

Expansion stroke and foaming. The lower belts are on the outside



Removal of the finished TABASKO component

Patented manufacturing process

Fully automated manufacturing of components made of TABASKO is possible using conventional processes. Handling devices place the tapes in the forming tools for the injection molding machine. Vacuum channels hold them in place so that they can be easily attached to the top or bottom of the component.

Carbon fibers are up to

80%

lighter than steel, but equally rigid. They are made of almost pure carbon.

Embedded in a thin polypropylene film, it becomes an extraordinary material: Carbon fiber tape, which opens up completely new possibilities. Mr. Johann's hypothesis was that if the PP currently used until now were reinforced with a few continuous carbon fiber tapes, the wall thicknesses of components could be reduced without losing stability. The reduced quantity of PP-GFx required could offset the additional costs of carbon. Calculations proved that his hypothesis was right. To illustrate the working principle, Mr. Johann went ahead and ironed carbon-fiber tapes onto PP-GFx test pieces and carried out the first bending tests with a mallet as a weight. The idea passed its first rough test.

In the next step, Johann set out to find partners to implement his idea. He benefited from the close cooperation between Porsche Engineering and Porsche AG: Materials expert Frank Häusler was exactly the right person to contact—and was delighted with the concept. Many ideas cross Häusler's desk, and his task is to assess their potential for a possible series production. "Unfortunately, most proposals do not satisfy our demands," says Häusler. "In this case, it was different: The concept made a mature impression. It was well thought out, had figures to back it up, and was plausible."

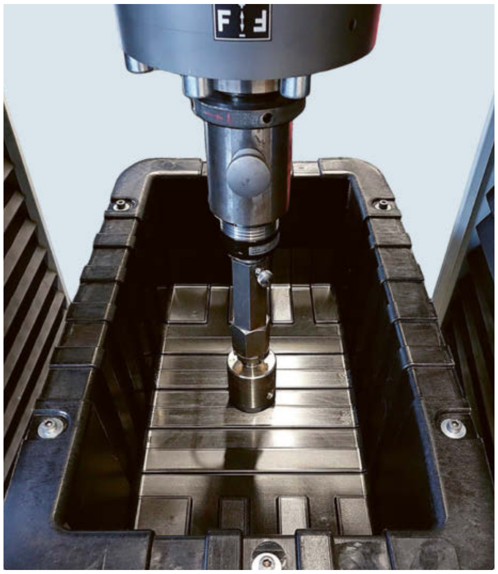
Johann and Häusler received support from Dr. Hubert Stadtfeld, Project Manager for Lightweight Construction in Production Development for Strategic Product and Process Design at Porsche AG, who also assumed patronage of the concept. In order to obtain a budget for prototype implementation and validation for this concept, an innovation project was registered in the production department.

SUCCESSFUL PROTOTYPE TESTS

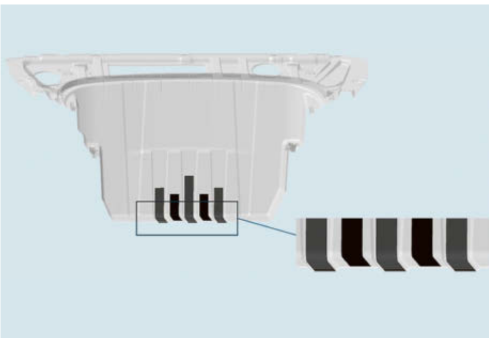
In search of a suitable component for a prototype, the developers encountered the luggage tray of the Porsche Taycan. It is made of glass-fiber-reinforced plastic as standard and is manufactured in an injection molding process. The series component is 65 centimeters in length, 120 centimeters in width, and 52 centimeters in height, making it comparatively large. "If tests on a large component are successful, then the results can also be applied to smaller components," explains Johann. TABASKO now had to prove itself under professional conditions: Häusler and Johann produced a luggage tray made of 1.8-millimeter thick PP-GFx, reinforced with 0.2-millimeter thin carbon-fiber tape. The special feature was that the percentage of carbon by weight only totaled one percent, because the continuous fibers are placed exactly at the points where they achieve the greatest effect.

Three tests were carried out with the prototypes: First, a comparative punch test was carried out on both a current series-production luggage tray and on its counterpart made of TABASKO material. In the process, a punch pressed onto the bottom of the tray from above with increasing force in order to measure how much it bent. The result: For TABASKO, a 66 percent higher compressive force was required to achieve the same maximum permissible deflection—and the luggage tray was, at the same time, 15 percent lighter than the series-production luggage tray.

The second test was a series of trials consisting of what are called four-point bending tests. To do this, the developers cut rectangular strips out of the bottom surface of the luggage tray. The strips were



Punch test: The testing machine presses a punch onto the bottom of the tray with an increasing force and measures how far it bends. In terms of material weight, TABASKO performs better than the series-production tray.



Section through the bottom of the tray: The tapes are placed in the component as upper and lower belts in alternation, meaning that they form a virtual sandwich. The spacing in the peripheral positions enables high flexural rigidity with minimal use of tape.

Increased rigidity: Top view of the strips of tape, which are only 0.2 millimeters thick. The carbon-fiber filaments run lengthwise without interruption, which increases the rigidity compared to PP-GFx by a factor of 20.

then bent from both sides, each at room temperature and at 90 degrees Celsius. “Clearly visible was that the rigidity of the tape-reinforced samples was higher by a factor of 2.5 to 2.8,” explains Häusler.

The third test determined the impact strength. This test is appropriate when foam injection molding is used, as it is in the manufacture of the TABASKO material. “In doing so, this results in foam structures that could cause the impact resistance of the base material to suffer,” says Mr. Johann. The test showed that, in combination with tape on the tensile side, the impact resistance is approximately five times better. TABASKO proved its superiority here as well.

“Now came the most important step: Transfer to series production,” as Häusler reports. “The question was: How can you produce up to 80,000 parts a year—in a fully automated way and cost-neutral compared to today’s process?” Johann, Häusler, and Stadtfeld worked together with a supplier and managed to develop a production process using conventional automated injection molding machines. “The tapes are inserted into the forming tools by means of a handling device and attached to either the top or the bottom of the component using vacuum channels,” explains Mr. Johann. “In principle, new machines or processes are not required, which is extremely advantageous for production costs.”

In the meantime, six patents have been filed for TABASKO, for the material structure, the production method, the tool technology, and the process sequence in series production. The project proved that, thanks to TABASKO, components can have their weight significantly reduced, thereby allowing resources to be saved. In addition, recycled plastics are suitable for component production. This is important, because according to an EU legislative proposal, at least 25 percent post-consumer recycled (PCR) material should be used in all vehicle types from 2031. Recycled PP is obtained from old pipes, furniture, or bottles. However, the recycled material is not nearly as rigid as the original raw material. “We could compensate for this reduced rigidity by increasing the share of carbon fibers accordingly,” explains Mr. Johann. The big advantage of TABASKO is that modifications of that nature could be easily integrated into the industrial manufacturing process.

The preliminary development of the new material has meanwhile been completed. The technical department responsible for the luggage trays has already signaled interest in series production for future vehicles. Discussions are currently ongoing with the plastic suppliers. “It’s like when you let a child take its first steps into independence,” says Mr. Johann. “As a pre-developer, you’ve done all you can.” And, like a child, TABASKO is only at the beginning of its development opportunities.

“In principle, new machines or processes are not required, which is extremely advantageous for production costs.”

Michael Johann
Specialist Project Manager for Body System Development at Porsche Engineering

“The concept made a mature impression. It was well thought out, had figures to back it up, and was plausible.”

Frank Häusler
materials expert at Porsche AG

Maximum flexibility: Any virtual track model can be driven in the driving simulator—for example with hot or icy roads, on flat terrain or in the mountains.

Test drive without a test vehicle

Porsche Engineering is expanding its involvement in the field of driving simulators. The goal is to obtain subjective feedback on new digital functions at an early stage. Porsche AG is also currently enhancing its infrastructure and is planning a Virtual Validation Center in Weissach.

Text: Christian Buck

Vehicles and their control systems are becoming more and more complex, while the number of available prototype vehicles continues to decline. Developers are therefore increasingly relying on virtual and hybrid tests using advanced simulation methods such as Software in the Loop, Model in the Loop, Hardware in the Loop and other methods, with the goal of tackling testing activities as early as possible in the development process. These simulations have long since become the standard for the objective evaluation of vehicle components, mechanical systems, and driving functions. However, they do not allow any human interaction or subjective assessment.

This is where tests with driving simulators come into play—because they also include the human perspective. "By combining driving simulators with HiL systems as well as the consistent use and continuous expansion of the specially developed simulation framework on the driving simulator, we can obtain subjective feedback on new digital functions early in the development process—long before the first prototypes are available for this," explains Tille Karoline Rupp, Senior Manager Simulation at Porsche Engineering. "This 'frontloading' means that the functions are much more sophisticated when they are first used in a test vehicle later on." Moreover, tests with driving simulators are a cost-effective supplement to real-world testing. They not only make it possible to carry out risky tests in a safe environment, but also allow tests to be implemented under widely varying weather conditions on virtual test tracks that are ideally adapted to the respective problem. Another advantage is that the test situations are exactly reproducible. For example, the surrounding traffic can be specified precisely and repeated at will, which is all but impossible in reality.

In one current project, the developers are using driving simulators to apply the parameters of the brake control system software to specific vehicle types. Porsche Stability Management (PSM), also known as the Electronic Stability Program (ESP), consists of two main components: The anti-lock braking system (ABS) and the vehicle controller. The ABS can regulate the hydraulic pressure on the individual wheel brakes when the driver applies the brakes. If there is a risk of instability in a corner, individual wheels are braked to prevent skidding. "The brakes behave very differently depending on how damp it is and the temperature, as well as the condition of the road surface and brake

“Due to the ‘frontloading,’ the functions are much more sophisticated when they are later used in a test vehicle for the first time.”

Tille Karoline Rupp
Senior Manager Simulation at Porsche Engineering

pad,” says Martin Reichenecker, Senior Manager Driving Dynamics & Validation at Porsche Engineering. “The ESP has to compensate for these fluctuations—as well as the difference between summer and winter tires.”

The software for the ESP control unit comes from tier-1 suppliers and is delivered with a set of standard parameters. These parameters must be optimally matched to the different vehicle variants by the developers over the course of the calibration process. The challenge: Test vehicles with sufficient component maturity are not yet available for this purpose in the early stages of the development process. Porsche Engineering therefore wants to increase its use of driving simulators for the subjective assessment of ESP functions. “To do this, we employ comprehensive integration of vehicle and scene generation, a real control unit with associated software, and a user interface that allows the driver to interact directly using the steering wheel and pedals,” reports Reichenecker. “This allows us to carry out the journey in real time under the most realistic conditions possible.”

AUTHENTIC DRIVING EXPERIENCE

The realistic simulation of driving physics in real time, in combination with a suitable virtual test track, guarantees an authentic driving experience in the driving simulator. The driver feels the steering wheel torque and in the virtual test drive on the simulator experiences whether the vehicle spins out, for example, when braking. Using the insights gained in this manner, developers can start calibrating the ESP function for a specific vehicle at an early stage, which significantly shortens the development time. Rupp, Reichenecker, and their colleagues have been working on the new method for around a year. The frontloading has performed as expected; the first test drives for the ESP application are planned for the end of 2024 or early 2025. The developers have already completed a virtual testing ground that can be used to test all track sections that are relevant for ESP development with different friction coefficients and weather conditions in a single environment.

The use of driving simulators for calibration is facilitated by several of Porsche Engineering’s distinctive capabilities. For example, developers can generate any given virtual track model (see Porsche Engineering Magazine 1/2024), for example with hot or icy roads, in the lowlands or in the mountains. With the help of the findings from the AVEAS research project (AVEAS is a German acronym meaning ‘collecting, analyzing, simulating traffic situations relevant to validation’) funded by the German Federal Ministry for Economic Affairs and Climate Action, in which Porsche

“We employ comprehensive integration of vehicle and scene generation, a real control unit with associated software, and a user interface that allows the driver to interact directly.”

Martin Reichenecker
Senior Manager Driving Dynamics & Validation at Porsche Engineering

"We use driving simulators primarily in studies with test subjects in which team members, test subjects or decision-makers are asked to evaluate, for example, new driving functions."

Ingo Krems
Senior Project Manager for the VVC at Porsche

Virtual experience: Porsche intends to significantly expand the use of driving simulators in its new Virtual Validation Center (VVC) in Weissach. In the final expansion stage, four to five simulators are planned, each of which covers special requirements in vehicle development—for example in the areas of ergonomics, HMI, driving comfort, and driving dynamics.

Virtual training, real mastery: In addition to development, simulators are also used for driver training.

RISK MINIMIZATION: ADAS DRIVING TRAINING

Driving simulators are not merely seen as development tools at Porsche Engineering: One of the company's game-based driving simulators is used to train ADAS developers. They're not obliged to drive fast on the Nürburgring or maintain vehicle control on slippery roads. Instead, it is important for them to be able to quickly take the wheel again if a function unexpectedly fails during a test drive, or deactivate the function in good time in the event of a fault. Such test drives with new ADAS driving functions usually take place on public roads, which is why risk minimization by means of driving training on driving simulators is a top priority for Porsche Engineering.

Engineering plays a major role alongside a further 20 partners, it is also possible to identify critical situations during real test drives and apply them to the simulation. The track models and traffic situations generated in this way are also varied in order to generate more test cases for virtual validation. "We bring our full range of modeling activities to bear and are thus able to offer customer-specific solutions—including the physics and visualization of the entire vehicle model as well as all roads and scenarios," says Rupp. "This makes it possible to drive through Europe with all its different climates and terrain profiles in a short time in the driving simulator."

Porsche Engineering currently operates four static real-time driving simulators and two game-based driving simulators in China, Italy (Nardò Technical Center), Czechia and Germany. All sites work together in their deployment and on further development, for example in the area of scene generation, the further development of the simulation framework, model integration, and the HiL connection. One of the game-based driving simulators is used to prepare developers for test drives (see box).

Porsche AG has also been using driving simulators for years. Among other applications, they are used in the fields of vehicle functions, HMI (human machine interface), ergonomics, and driving comfort. "We use driving simulators primarily in studies with test subjects in which team members, test subjects or decision-makers are asked to evaluate, for example, new driving functions" explains Ingo Krems, Senior Project Manager of the newly established Virtual Validation Center (VVC) at Porsche. "As part of the virtual complete vehicle test, participants can validate, experience, and evaluate the display and control elements, ADAS functions, ergonomics, and driving comfort of new vehicles." Feedback from the test subjects flows directly into the further development of the new vehicles.

Porsche AG in Weissach is currently operating a driving simulator with a motion platform and high-end visualization system in series vehicle development as well as several small static simulators (including ones with VR glasses) to make it possible to experience vehicles virtually. This infrastructure is currently being further expanded as part of the VVC project. "We will build two additional driving simulators with moving platforms," says Krems. "The first, the VFP.NVH lab, will start operations at the end of this year. Its application focus will be on driving comfort and acoustics. The second will follow at the end of 2026, concurrently with the opening of the VVC. Thanks to its innovative motion system, this simulator makes it possible to cover driving conditions that are significantly more dynamic, as well as urban driving situations, better than was previously possible."

MODERNITY MEETS TRADITION

The VVC is being built in the heart of the Weissach Development Center and will have a total area of 2,100 square meters. All large-scale simulators used in series vehicle development will be bundled in a building complex at the new location. New mini simulators are also being developed there to help prepare for, and make more effective use of, precious test time in simulators with motion systems. The center will be

built in an existing building. "We decided against a new building in order to avoid CO_2 emissions through sustainable construction and to use the valuable space in the development center efficiently," reports Krems. "In keeping with the 'modernity meets tradition' concept, the new technology will be installed in one of the oldest buildings at the Development Center."

Porsche Engineering and Porsche AG use the same driving simulator framework for development. "This creates promising opportunities for cooperation between the two companies," says Rupp. "For example, we could generate the required model set-up with the virtual roads, the surrounding traffic, the complete vehicle, and the driving dynamics and carry out integrated initial tests with our own static driving simulators. Based on these results, the developers could later seamlessly switch to Porsche's moving driving simulators in order to immediately experience the dynamic behavior of new functions. In addition, extended tests in seating bucks with real ergonomics would be possible as a way of gaining insights into even more realistic prototypes." Reichenecker adds: "With our static driving simulators, we can carry out most of the calibration in a quick and lean manner, and with the dynamic driving simulations in the VVC we come very close to the real prototypes."

Many areas of development should benefit from driving simulators in the future. "In addition to SiL and HiL tests, we see the driving simulators as a development-supporting, additional 'tool' in our toolbox—but not a substitute for the existing methods," concludes Rupp. "Thanks to our expertise in scene generation and vehicle simulation, as well as taking into account the surrounding traffic and realistic interactions, we offer our customers modular solutions that can be optimally adapted to the respective application."

SUMMARY

With the aid of driving simulators, subjective feedback on new digital functions can be obtained early in the development process—long before the first prototypes are available. Porsche Engineering is currently expanding its involvement in this area in a major way. In parallel, Porsche AG is planning a 'Virtual Validation Center' (VVC) in Weissach to enhance its simulator infrastructure.

THE GREAT FUSION

Futurist and AI prophet Ray Kurzweil predicts that computers will soon reach human intelligence. After that, they are expected to merge with humans to form an immortal super-intelligence. Other AI researchers are much more skeptical—although GPT-4 just excelled at the Turing test.

Text: Hilmar Poganatz

Roughly

11,200

times more computing power per dollar is obtained today compared to 2005.

In late June 2024, inventor and visionary Ray Kurzweil sat at a window of the Boston Four Seasons Hotel and held up a sheet of paper. On it, he showed a New York Times reporter a steep growth curve: How much computing power could you buy for a dollar in 1938, and how much the day before yesterday? The neon green curve in his hand was intended to illustrate why the 76-year-old has just published a new book: 'The Singularity Is Nearer' is the follow-up to 'The Singularity Is Near', his 2005 bestseller.

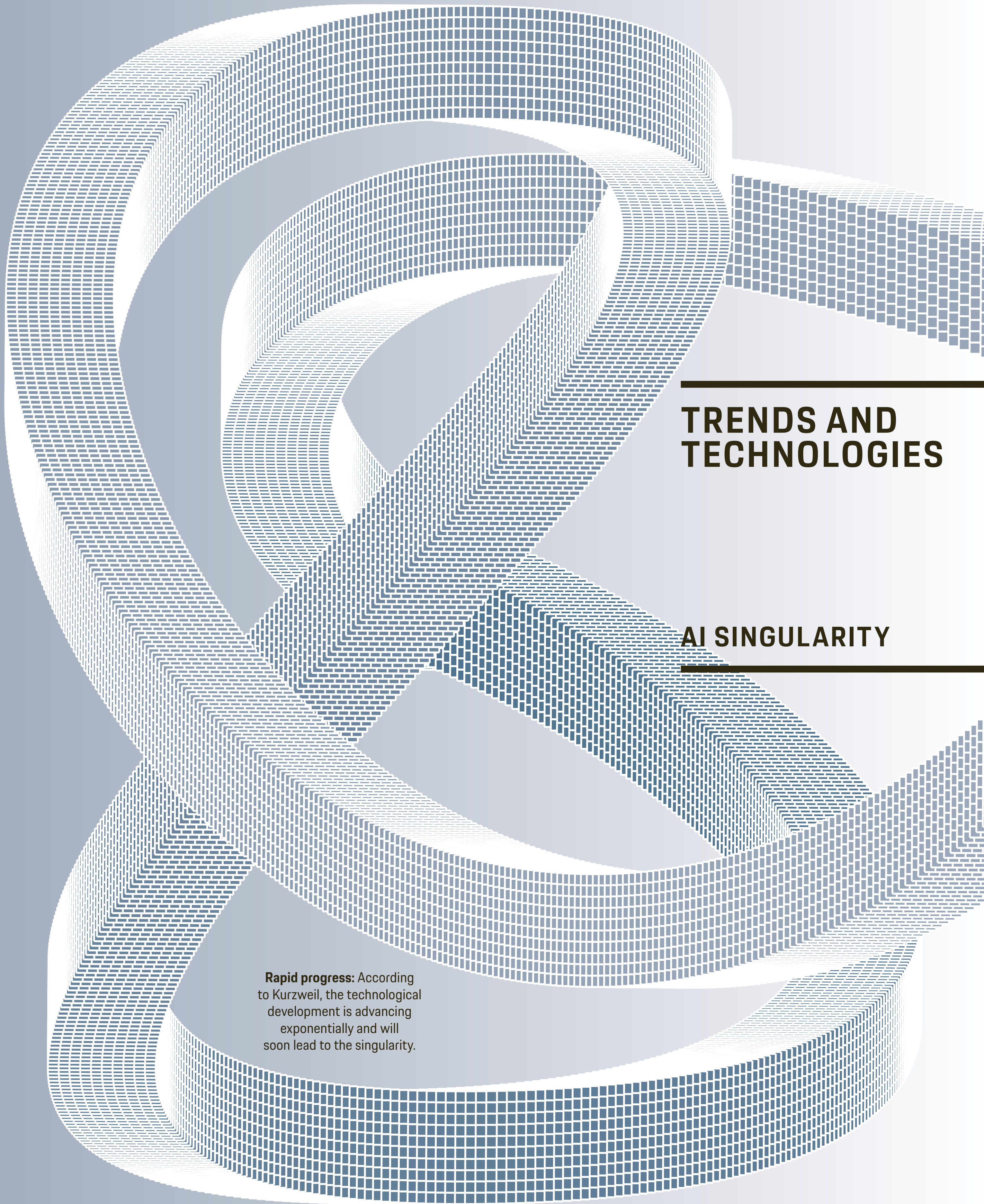
The concept of technological singularity represents a potential point in the future when artificial intelligence (AI) surpasses human intelligence and then rapidly evolves itself. According to this line of thinking, technological progress would be unstoppable and no longer controlled by humans. Kurzweil takes this a step further and imagines a moment in which we enhance our brains with virtual neurons in the cloud and thus "merge with AI and improve ourselves with a million times the computing power of our original biology".

Kurzweil's belief in the singularity is based on the insight revealed by his green graphic. It is similar to the exponential growth curve of the computing power of computer chips predicted by Moore's Law in 1965. Kurzweil calls this the "law of accelerating returns". It postulates that technological developments create feedback loops that accelerate innovation in other areas as well. This development has increased rapidly since he published his first singularity book in 2005: "For a dollar you get roughly 11,200 times more computer power today," he calculates. This will lead, he says, to enormous leaps in biotechnology and nanotechnology.

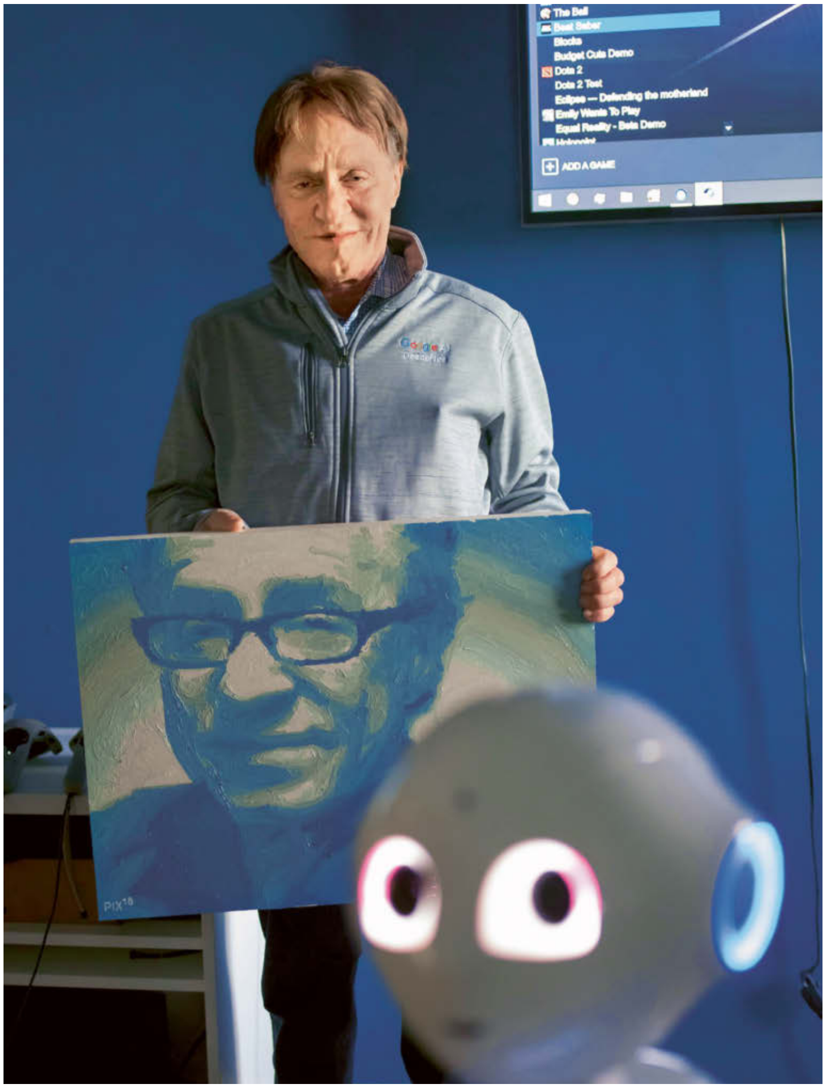
And naturally in computers themselves: Cognitive scientists at the University of California recently had almost 500 participants chat with real people and various large language models in a test. 54 percent of the subjects considered the AI model GPT-4 to be a

TRENDS AND TECHNOLOGIES

AI SINGULARITY



Rapid progress: According to Kurzweil, the technological development is advancing exponentially and will soon lead to the singularity.



“By 2045, we will profoundly change life on Earth for the better.”

VITA RAY KURZWEIL

1948: Born on February 12 in New York. Kurzweil's parents had left Austria before the start of the Second World War.

1970: Bachelor's degree at MIT. Kurzweil studied literature and computer science there.

1983: Foundation of Kurzweil Music Systems. The goal was to develop synthesizers. Introduced in 1984, the K250 has been played by Stevie Wonder, Keith Emerson, and Chick Corea, among others.

2005: Publication of 'The Singularity Is Near'. In this book, Kurzweil predicts that the singularity will occur in 2045.

2008: Founded the 'Singularity University'. The institution deals with disruptive technologies such as artificial intelligence and robotics.

2024: Publication of 'The Singularity Is Nearer'. In this book, Kurzweil predicts that AI will reach human level in 2029.

person. According to the researchers, this is the first time a machine has passed the Turing test. In 1950, computer science pioneer Alan Turing proposed using an 'imitation game' to measure whether a computer can think similarly to a human being. As soon as a machine passes this test, machine (artificial) intelligence can be assumed. Turing expected this for the year 2000; in the end it happened in June 2024. So in the near future, language models will become more and more similar to humans. The California-based cognitive researchers immediately warned that such bots would have “far-reaching economic and social consequences”.

They're not alone in sounding the alarm. As early as March 2023, more than 1,000 experts in the fields of technology and research had called for a six-month development moratorium for AI models. Instead of developing programs so rapidly that even their developers can no longer understand or control them, new security standards are needed first. Although no

AGI

stands for Artificial General Intelligence. The term refers to a form of artificial intelligence that is capable of solving tasks in different areas equally well as a human being. Unlike specialized AI, AGI can learn, adapt to new situations, and find creative solutions on its own.

concrete measures have emerged to date, this opened the debate. Kurzweil had obviously hit a nerve with his statements on the singularity: The development of artificial intelligence is now progressing so quickly that the consequences are scarcely foreseeable anymore.

WEAK AND STRONG AI

The devil is in the details, however. “There are two types of AI: Weak AI as an individual capability—for example, to chat, play chess or drive a car—and strong AI in the sense of Artificial General Intelligence (AGI), which uses human-like creativity to solve problems for which it has not been specially programmed,” explains Raúl Rojas. The computer science professor has long researched neural networks, robots, and self-driving cars at FU Berlin, and now teaches mathematics at the University of Nevada. Indeed, the last 20 years have seen major advances in weak AI, which has long since surpassed humans in many individual tasks.

However, Rojas still sees the transition to an AGI or super-intelligence as a distant prospect. “Kurzweil’s fusion of brain and AI is pure science fiction.” And sociologist Thomas Wagner adds: “Singularity can be understood as various things. For Kurzweil, the idea of immortality is very important, combined with the idea that humans physically merge with AI and a new super being arises.”

Even if there are still no human-machine combinations, “thinking computers” could become a reality in the next two to three years, Simon Hegelich predicts. The political data scientist from the Technical University of Munich is himself working on his own general AI. “Unfortunately, we are not prepared for this turning point in human history,” warns Hegelich.

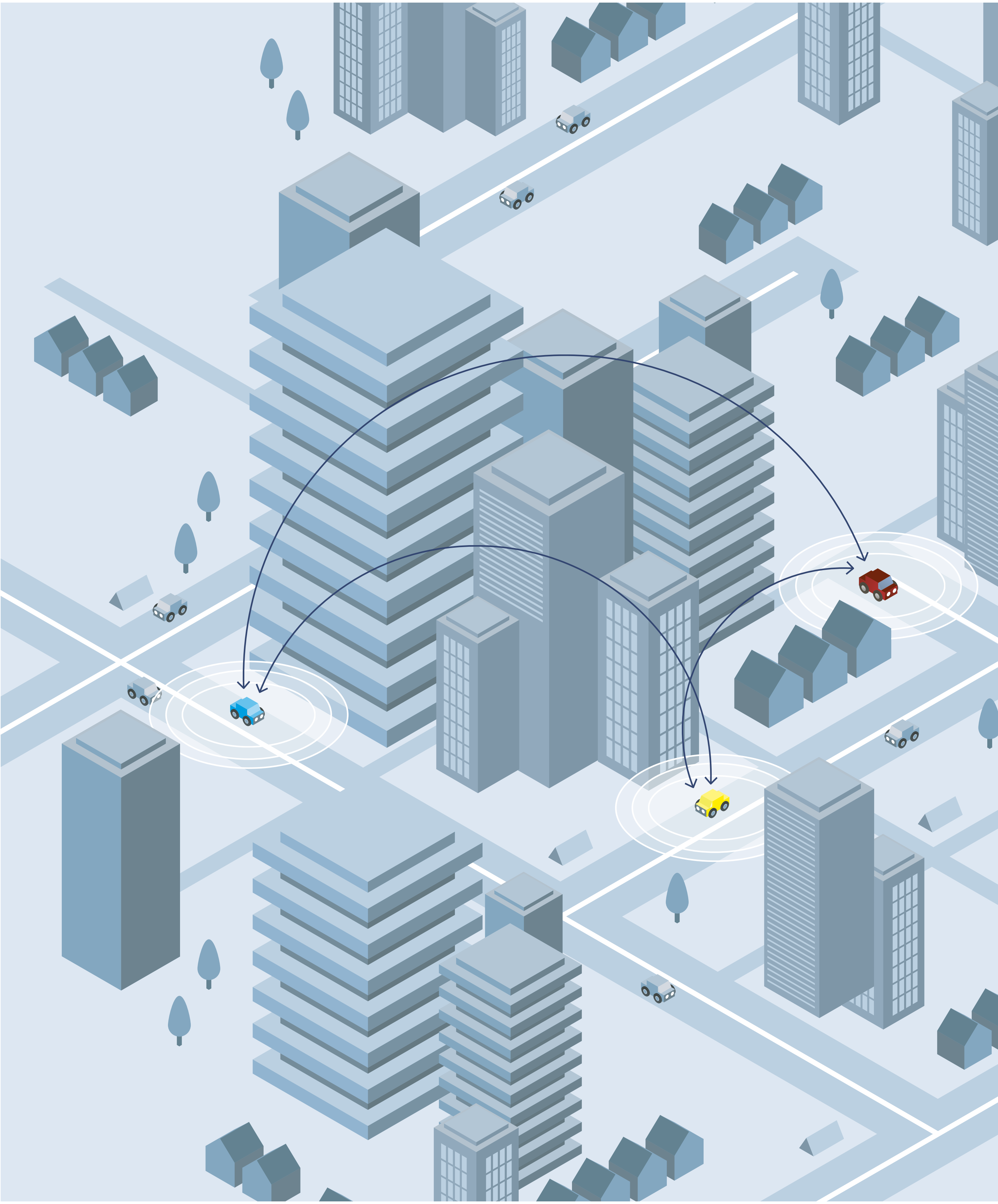
Kurzweil’s views his singularity thesis with a mixture of excitement and ambivalence. Particularly because no one in Silicon Valley knows exactly how a super AI including consciousness could even arise. “One assumes that you just have to feed it more and more data, and then the AGI suddenly emerges by itself through a magical spark—I think that’s wrong.” Passing the Turing test sheds no light either. “After all, programming a computer to outsmart humans is not real intelligence. Knowledge is not just data and learning is not just algorithms. As is well known, people do not think and decide in binary fashion in zeros and ones either, but often enough contradictorily.”

The political scientist Hegelich likes to refer back to the philosopher Georg Wilhelm Friedrich Hegel. Some 200 years ago, Hegel formulated the principle of non-contradiction in his dialectic. For example, a person can hate and love another person at the same time. A real and therefore also ethical super-intelligence would therefore have to “grow up” in a similar way to a human child. “Every baby has a predisposition to be intelligent.” According to Hegelich, one would therefore have to build a computer that is intelligent in terms of its basic algorithm—its “predisposition.” Such an AGI would automatically learn by itself and also produce new knowledge, instead of just recombining known knowledge. It would develop a kind of consciousness similar to that of biological life forms.

Whether this form of singularity will ever be realized remains open. One thing is certain: The rapid development of AI continues to raise many questions that we humans will have to answer.

54

percent of test subjects in a test at the University of California thought the AI model GPT-4 was a human.



Connected in traffic: Vehicles use V2X to communicate with each other and with the surrounding infrastructure.

Let's stay in contact

Porsche Engineering has developed three prototype V2X applications over the past twelve months. The software team in Lecce and the Nardò Technical Center play a key role in this. A state-of-the-art wireless infrastructure is available there.

Text: Christian Buck

The V2X (Vehicle to Everything) technology enables vehicles to communicate directly with their environment—even without an active internet connection. This allows them to exchange information with other vehicles, pedestrians, bicycles or the road infrastructure. "This direct communication offers a wireless range of up to 1,000 meters and end-to-end latency times in the millisecond range, which is particularly important for safety-critical applications," explains Sai Praneeth Reddy Animireddy, Function Owner V2X Development at Porsche Engineering. "By using standardized messages, information can be exchanged between vehicles made by different manufacturers. This makes V2X technology an important component for current driver assistance systems and future autonomous vehicles."

In the course of various feasibility studies, Porsche AG together with Porsche Engineering' have identified promising V2X applications over the past twelve months that are currently being implemented as prototypes. One of these aims to further improve pedestrian safety: When a vehicle turns in the city, the driver often cannot tell whether a pedestrian is crossing the road directly behind the turn-off due to restricted visibility. Another vehicle might provide important information in this case. If it has a better view of the pedestrian via one of its cameras, it can use V2X to send a notification to the turning driver. It would also be conceivable to automatically brake the turning vehicle in an emergency.

Another V2X application could prevent rear-end collisions in the future: "For example, let's think of three cars that are driving directly in a row. The driver of the first vehicle suddenly slams on the brakes because a child walks onto the road," says Animireddy. "Then the vehicle can send a message to the other two cars behind it via V2X to warn them." Even if the front vehicle was not equipped with V2X, a warning to the last vehicle would still be possible—if the middle vehicle is equipped with V2X. It could detect the brake lights coming on and then send a warning to the driver behind it.

GAME CHANGER FOR TRAFFIC

The communication of vehicles among each other as well as with the infrastructure could become a game-changer for traffic—also in terms of getting autonomous vehicles on the roads. "V2X communication is an important addition to on-board sensor technology," explains Florian Zeiner, Product Owner for V2X at Porsche. The biggest challenges involved are the market penetration and the prevailing disagreement in Europe regarding the technology.

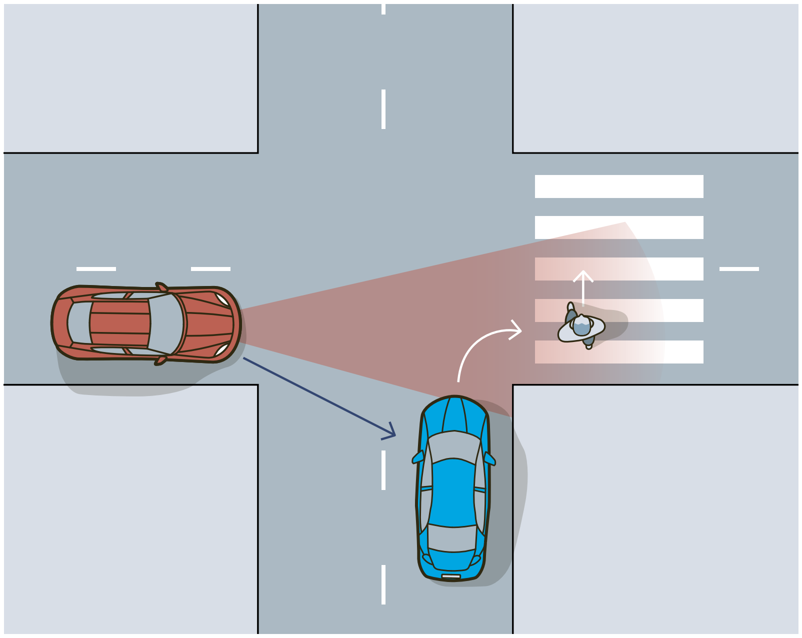
The prototype V2X applications were developed in the southern Italian city of Lecce, where the Nardò Technical Center (NTC) has employed a team of software engineers since the beginning of 2023. They focus on five specializations: Energy (particularly battery management systems), ADAS (Advanced Driver Assistance System) functions and autonomous driving, big data analytics and cloud infrastructure, software quality and validation, and connectivity, which includes the new V2X applications. "By working closely with the universities in Lecce, Pavia and Turin, we have access to the latest technical developments and can involve many talented young people in our projects through master's and doctoral theses," reports Matteo Longo, who leads the team in Lecce. "Another great advantage for the development of V2X functions is the proximity to Porsche Engineering's NTC. There we can test new applications under optimal conditions."

This became particularly evident in another V2X project by Porsche Engineering, the 'Follow-Me' app.

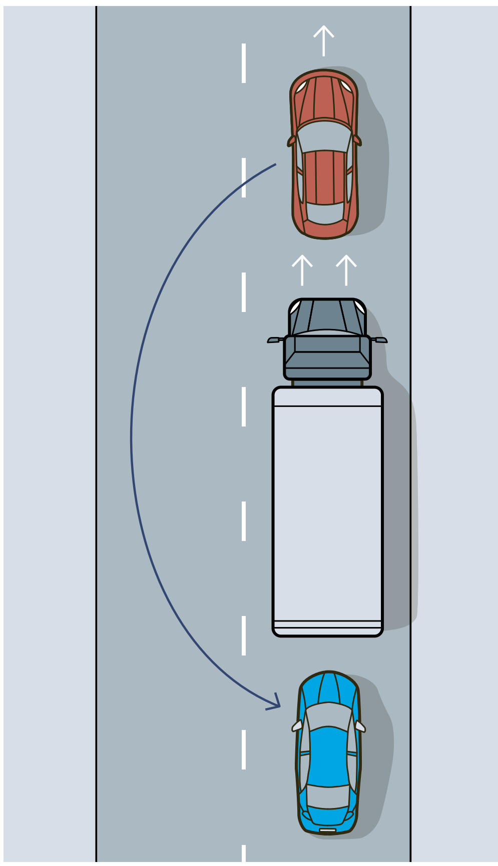
VEHICLES IN CONVERSATION

GREATER ROAD SAFETY THANKS TO V2X

Scenario 1: Pedestrian protection



Scenario 2: Prevention of rear-end collisions



In the first scenario, a vehicle is turning right just as **a person is crossing the road**—but the driver cannot see them. The other vehicle is in a better position and can detect the person on the road with its camera. It sends a warning to the first vehicle to prevent an accident.

In the second scenario, **two cars and one truck are driving in a row.** The front passenger car brakes, which the driver right at the back can't see. The front passenger car sends a message to all vehicles behind it and informs them of the braking. This also enables the driver in back to brake in good time despite poor visibility.

"We used a mix of simulations and prototype development to develop the Follow-Me app."

Sai Praneeth Reddy Animireddy
Function Owner V2X Development at Porsche Engineering

The idea behind it: Several Porsche vehicles drive in a convoy, for example as part of a joint excursion or on the way to an event. Or a group of developers are on the road with test vehicles. By using V2X data exchange, all participants see the position of the other vehicles on their displays as well as other information such as the respective distances between the vehicles or the best speed to be able to stay together as a group. "Any person can also send messages to the group, for example to suggest a coffee break or a stop for recharging the battery," says Animireddy.

MULTIPLE COMMUNICATION CHANNELS

The technical basis for this is what is known as 'sidelink communication', which wirelessly connects the vehicles directly to each other at a frequency of 5.9 gigahertz. It avoids the detour via the cellular network, which would incur costs and in which the data packets would take much longer to arrive. The underlying standards are ETSI Sidelink Messages (Europe), CN-SAE (China), and SAE (USA). In some cases, however, direct data exchange between the vehicles is not possible—for example, because the maximum range of roughly 1,000 meters has been exceeded or an obstacle interrupts the wireless link. In this case, the app automatically switches over and uses the cellular network to send and receive messages. The data exchange is then based on the Cellular-V2X standard.

"Automatic switchover between sidelink communication and data exchange using the cellular network was one of the challenges in this project," as Longo reports. "In smart cities, vehicles can also communicate with the intelligent infrastructure, for example to find a parking space. There, the V2X applications must master up to three different data connections: The sidelink with other vehicles, V2X via the cellular network, and communication with the Smart City." The team benefited from its close proximity to the Nardò Technical Center, particularly when testing the automatic switchover between the different communication channels. In addition to the private 5G network there, the developers also have roadside units at their disposal that simulate the infrastructure of a Smart City. "On the NTC test tracks, we tested the Follow-Me app extensively, later adding test drives on public roads in Germany and Italy," says Longo.

The engineers also employed a variety of different development methods. "We used a mix of simulations and prototype development to develop the Follow-Me app while simultaneously ensuring compliance with V2X message standards," says Animireddy. "It was also important to us for the app to access a backend as little as possible. This is the only way to guarantee its functionality even if there is no connection to the internet." Unauthorized access to the data is prevented by a public key infrastructure (PKI) and ETSI ITS security architecture. "We ensure data protection through anonymization and pseudonymization technologies. As a result, personal data cannot be directly associated with individuals," says Animireddy.

Porsche expert Zeiner is satisfied with the result: "The Follow-Me app is a great fit with the Porsche community. It also shows the possibilities that V2X will offer in the future. The new software team in Lecce was able to implement the prototypes in a very short time—from the development to the testing of the new functions." The basis for their success was the international cooperation of several sites across national borders. "V2X is the basis for many future applications, which is why almost all OEMs are investing in the topic," Longo concludes. "Our connectivity developers in Lecce have greatly expanded their expertise on V2X, and our strong results are mainly due to them. The feasibility studies show that we have the expertise and tools necessary for it. In short: We're ready for V2X."

Up to

1,000

meters can be bridged via sidelink between two vehicles for the exchange of messages.

PKI

stands for 'Public Key Infrastructure'. PKI uses a system of public and private keys to securely encrypt data and confirm the identity of people and websites. Digital certificates ensure that the keys are genuine and that communication stays secure.

DOUBLE PLEASURE

Porsche has fundamentally upgraded the 911. The new 911 Carrera GTS is the first road-approved 911 equipped with a super-lightweight performance hybrid. The 911 Carrera will also be available immediately upon the launch of the new model.

Text: Dr. Ing. h.c. F. Porsche AG

PORSCHE AND PRODUCT

911 CARRERA GTS
911 CARRERA

Built for performance: Porsche engineers drew on insights gained from motorsport for the conceptual design of the hybrid system.

911 Carrera

Fuel consumption* (combined)
(WLTP) 10.7–10.1 l/100 km
CO_2 emissions* (combined)
(WLTP) 244–230 g/km
CO_2 class G

911 Carrera GTS

Fuel consumption* (combined)
(WLTP) 11.0–10.5 l/100 km
CO_2 emissions* (combined)
(WLTP) 251–239 g/km
CO_2 class G

911 Carrera GTS (2023)

Fuel consumption* (combined)
(WLTP) 11.4–10.4 l/100 km
CO_2 emissions* (combined)
(WLTP) 258–236 g/km
CO_2 class G

911 Targa 4 GTS

Fuel consumption* (combined)
(WLTP) 11.0–10.8 l/100 km
CO_2 emissions* (combined)
(WLTP) 250–244 g/km
CO_2 class G

The new 911 offers not only a revamped design, but also improved aerodynamics, a fresh interior, upgraded standard equipment, and expanded connectivity. The innovative performance hybrid drive system in the new 911 Carrera GTS is a premiere: At its heart is a newly developed 3.6-liter boxer engine, which delivers 357 kW (485 PS) of power and 570 Nm of torque even without electrical assistance—a power increase of 45 kW (61 PS). An enlarged bore of 97 mm and an increased stroke of 81 mm increase the displacement by 0.6 liters compared to its predecessor. The engine has VarioCam camshaft control and a valve control with rocker arms. It maintains the ideal mixture ratio of fuel and air over the entire map (lambda equal to 1).

The powertrain also includes a permanent magnet synchronous motor integrated into the new eight-speed dual-clutch transmission (PDK). Even at idle speed, it supports the boxer engine with a drive torque of up to 150 Nm and provides a maximum output of 40 kW, increasing the system output to 398 kW (541 PS) and 610 Nm. Porsche couples both electric motors to a lightweight and compact high-voltage battery. It corresponds in size and weight to a conventional 12-volt starter battery, but stores up to 1.9 kWh of energy (gross) and operates at a voltage of 400 V. It is charged by an integrated electric motor in the newly developed exhaust gas turbocharger, positioned between the compressor and turbine wheel. It brings the charger up to speed in the shortest possible time, but can also function as a generator and generate up to 11 kW (15 PS) of electrical power.

Porsche engineers drew on insights gained from motorsport for the conceptual design of the hybrid system. “The result is a unique drive that fits into the overall concept of the 911 and significantly enhances its performance,” says Frank Moser, Vice President Model Lines 911 and 718. This means the new 911 Carrera GTS also undercuts its predecessor in the start phase in particular. It accelerates from 0 to 100 km/h in just three seconds and reaches a top speed of 312 km/h. At the same time, the efficient performance hybrid reduces CO_2 emissions with significantly less

“A unique drive system that fits into the overall concept of the 911 and significantly enhances its performance.”

Frank Moser
Vice President Model Line 911/718
at Porsche AG

extra weight compared to plug-in hybrid vehicles. The weight increase over its predecessor is a mere 50 kilograms.

STANDARD REAR-AXLE STEERING

The suspension of the 911 Carrera GTS has also been comprehensively revised. For the first time, rear-axle steering now comes as standard. It increases stability at high speeds and reduces the turning circle. Porsche has integrated the Porsche Dynamic Chassis Control (PDCC) anti-roll stabilization system into the high-voltage system of the performance hybrid. This enables the use of an electro-hydraulic control, which makes the system even more flexible and precise. The sports suspension with a variable damper system (PASM) and a ride height lowered by 10 mm provide characteristic GTS handling.

The 911 Carrera still features a 3.0-liter boxer engine with twin turbocharging, which has also been comprehensively revamped. Among other things, it has now adopted the intercooler from the Turbo models, which now sits directly under the rear lid grille above the engine. The turbochargers in the new 911 Carrera were still reserved for the GTS models in its predecessor. With these modifications, Porsche achieves a reduction in emissions along with a power boost to 290 kW (394 PS) and a maximum torque of 450 Nm. This allows the new 911 Carrera Coupé to sprint to 100 km/h in 4.1 seconds (3.9 seconds with the Sport Chrono package) and reach a top speed of 294 km/h.

Performance figures for the hybrid drive system in the new 911 Carrera GTS

357 kW (485 PS)
Power output

570
Nm torque

312 km/h
Top speed

3 seconds
0 to 100 km/h

State-of-the-art technology: For the first time, the 911 has a fully digital instrument cluster with up to seven views.

IMPROVED AERODYNAMICS

Porsche has streamlined the exterior design of the 911 with a variety of measures. Most of them, such as new, model-specific front bumpers, improve the aerodynamics and performance of the sports car. For the first time, Porsche has also integrated all light functions into the now-standard matrix LED headlights, with their characteristic four-point light graphics. This makes it possible to omit the front lights and creates space for larger cooling vents. On the 911 Carrera GTS models, the front end has five vertically arranged active cooling air flaps visible from the outside and another hidden flap on each side. They are complemented by adaptive front diffusers in the underbody which were

Powerful drive: The 911 Carrera still features a 3.0-liter boxer engine with twin turbocharging.

Performance figures for the boxer engine in the 911 Carrera

290 kW (394 PS)
Power output

↓

450
Nm torque

↓

294 km/h
Top speed

↓

4.1 seconds
0 to 100 km/h

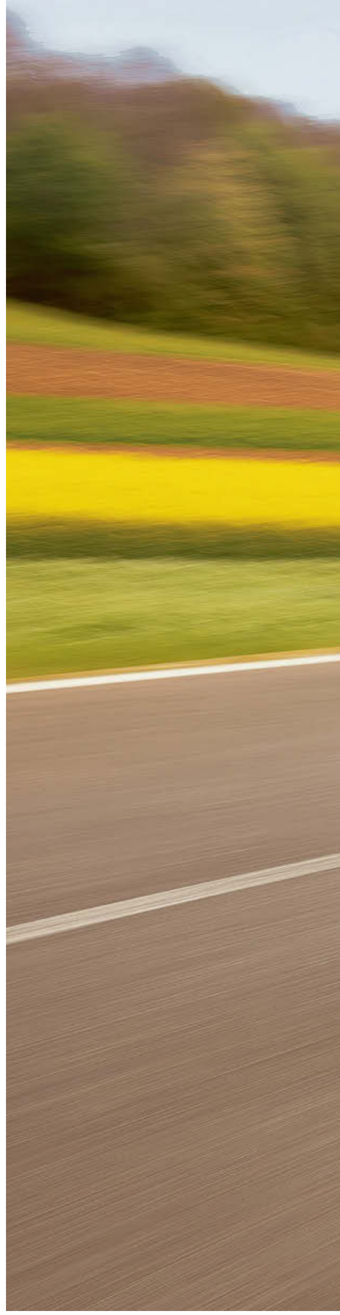
installed for the first time in the 911 and are controlled together with the cooling air flaps. These elements direct the air flow as required: When power requirements are minimal, closed flaps optimize the aerodynamics. When power demand is high—for example in on-track situations—the flaps direct large amounts of air to the car's radiators.

INTELLIGENT HEADLIGHTS

The sensors for the assistance systems are now located behind a high-gloss surface below the number plate. Optionally, Porsche offers the new headlights with an HD matrix LED function with more than 32,000 light points. This high-performance high beam illuminates the road to a distance of over 600 meters. It also offers innovative additional functions such as a driving-mode-dependent dynamic cornering light, lane brightening, construction site and bottleneck light and a non-dazzling high beam that is precise to the pixel.

The rear of the 911 also has a new look: The redesigned light strip with an integrated arc and 'PORSCHE' logo makes the rear appear deeper and wider. A redesigned rear grille with five fins per side connects to the rear window to form a graphic unit that fades into the retractable spoiler below. The number plate is positioned higher, with a clearly structured rear bumper. Model-specific exhaust systems are seamlessly integrated into the striking diffuser fins. A sports exhaust system is optionally available for the 911 Carrera models. The 911 Carrera GTS models come standard with a GTS-specific sports exhaust system.

An optional aero kit further enhances the performance of the 911 Coupé. It includes a distinctive SportDesign front bumper with a unique front spoiler,



New look for the rear: The redesigned light strip with an integrated arc and 'PORSCHE' logo makes the rear appear deeper and wider.

matching side sill panels and a lighter, fixed rear wing. These components reduce lift and improve the grip of the sports car.

In the cockpit, Porsche combines the familiar 911 design language with state-of-the-art technology: The Porsche Driver Experience control concept focuses on the driver's axis and intuitive, faster operation. Essential control elements have been arranged directly on or around the steering wheel. These include the standard mode switch, the revised driver assistance lever and, for the first time in the 911, a start button—to the left of the steering wheel, naturally.

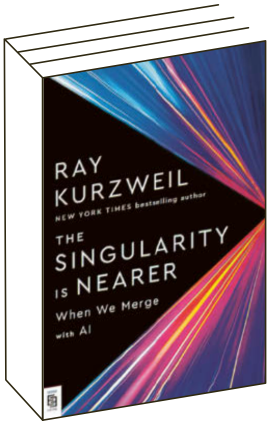
ALL-DIGITAL INSTRUMENT CLUSTER

For the first time, the 911 has a fully digital instrument cluster. The 12.6-inch curved display can be extensively customized. It offers up to seven views, including an exclusive Classic display inspired by the traditional 5-tube design with a central tachometer. The Porsche Communication Management (PCM) system is still operated via the high-resolution central display with a 10.9-inch screen. The customizability of the driving modes and the operation of the driver assistance systems have, in turn, been significantly improved.

The upgraded 911 also has new connectivity features. A QR code significantly simplifies the logging-on process to the PCM with the Porsche ID. Apple CarPlay® is more deeply integrated into the car. If desired, it displays information in the instrument cluster and enables the operation of vehicle functions directly in the Apple® ecosystem, for example via the Siri® voice assistant. For the first time, video streaming is also optionally available while parked. Apps such as Spotify® and Apple Music® can be used as native apps in the PCM without a connected smartphone.

Deeper knowledge

↓



BOOK

Exponential future

If Ray Kurzweil is correct, we will soon merge with AI and thereby increase our intelligence millions of times over.

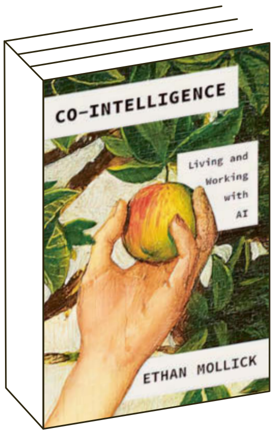
The Singularity is Nearer
Ray Kurzweil
Viking

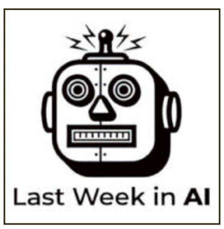
BOOK

Our colleague AI

Workmate, co-teacher, and coach: In the opinion of the author, this could be the role of artificial intelligence in the future.

Co-Intelligence
Ethan Mollick
WH Allen





PODCAST

Keeping up to date

This popular podcast provides weekly summaries and discussions about the most interesting developments in AI, deep learning, robotics, and more.

Last Week in AI
lastweekin.ai

The big picture

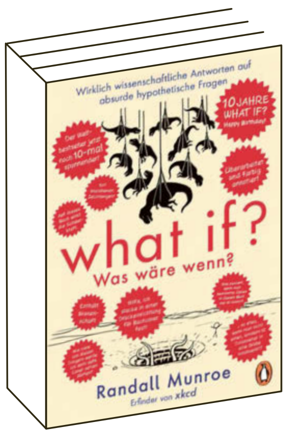
↓

PODCAST

Fight for survival

Every week, *Real Survival Stories* presents tales of ordinary people who have found themselves in exceptional situations—and suddenly have to fight for their lives.

Real Survival Stories
www.noiser.com/real-survival-stories



BOOK

What if?

The special edition on the occasion of the 10th anniversary of Randall Munroe's bestseller once again answers absurdly hypothetical scientific questions.

What if?
Randall Munroe
Penguin

For the child in all of us

↓

GAME

Smile, it's almost over

In this party game, dinosaurs must survive in a dangerous world. They face risks such as sinking into lava or being attacked by saber-toothed rodents. The goal is to survive and earn as many points as possible.

Happy Little Dinosaurs
Unstable Games

GAME

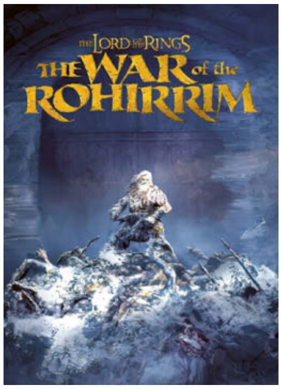
Let's build a subway!

This game is all about creating a completely new London Underground network. However, the lines must never cross. The key here is to stay calm and not let yourself become flustered.

Next Station London
Blue Orange

Intelligent entertainment

↓



FILM

Legendary battle in Helm's Deep

In this anime by Kenji Kamiyama, the King of Rohan builds Hornburg fortress in the gorge known as Helm's Deep. A bloody battle is imminent, one that will go down in the history books of Middle-earth.

The Lord of the Rings: The War of the Rohirrim
Warner Bros.

PODCAST

"Houston, we've had a problem."

Season 1 of this podcast tells the story of the people who made Apollo 11's moon landing possible. Season 2 deals with the Apollo 13 mission, which almost ended in a disaster.

13 Minutes to the Moon
BBC News World Service

FILM

Kinds of Kindness

Three stories exploring the dynamics of human relationships. A star-studded episodic film by Yorgos Lanthimos.

Kinds of Kindness
Available from selected streaming service providers

Base vehicle | **Supplementary unit (setup)** | **Coupled vehicles**

Aerial rescue device | **Supplementary unit (extinguishing)** | **Coupled vehicles**

1978

The German Federal Ministry of Research and Technology wanted to have improved firefighting vehicles developed and turned to Porsche for this. Two years later, the engineers presented the modular O.R.B.I.T. concept.

In 1976, the Federal Ministry of Research and Technology commissioned Dr. Ing. h.c. Porsche AG to conduct a study entitled 'Fundamental research for the development of improved fire engines to optimize performance in firefighting and other operations'. The aim was to provide the volunteer and professional fire brigades of what was then West Germany with a family of vehicles with which they could transport the right technology and sufficient personnel to the deployment site in the shortest possible time.

At the beginning of the project, the engineers obtained an overview of the current state of the art and the practical experiences of the firefighters. To this end, they sent a questionnaire to all West German fire departments and ten voluntary fire departments about their deployments in 1976. One of the results from more than 100,000 deployments that were appraised: Roughly 90 percent of the burn victims had died from carbon monoxide poisoning. Many of them could have been saved if they had received medical help earlier.

Modular concept: The O.R.B.I.T. base vehicle was designed to be combined with various supplementary units—including a telescopic aerial rescue system with a lift function.

In order to optimize fire department operations, in July 1978 Porsche engineers presented O.R.B.I.T. (German acronym for optimized rescue, fire fighting with technical assistance system). It was based on a modular system consisting of a basic vehicle with chassis, cab and body as well as various supplementary units—including a telescopic aerial rescue system with lift function, a jump rescue device, and a radio-controlled extinguishing pump system. To facilitate firefighting, a protective helmet with an integrated breathing apparatus and communication system was also part of O.R.B.I.T.

The engineers summarized the advantages of O.R.B.I.T. as follows: "Together with the technical equipment of the vehicles and the separation into supplementary and base vehicles, any sensible combination of personnel and technology can therefore be deployed or withdrawn."Unfortunately, no prototypes were, however, built—also because the 50 percent industry contribution to funding that was being aimed for failed to materialize. Perhaps the advanced approach by the Porsche developers was simply too far ahead of its time.

Porsche Engineering Magazine

Publisher
Porsche Engineering Group GmbH

Editor-in-Chief
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Production
News Media Print, Berlin

Printing
optimal media GmbH
Glienholzweg 7
17207 Röbel/Müritz

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Image source if not otherwise stated: Dr. Ing. h.c. F. Porsche AG;

p. 1: Cover: Matt Murphy; p. 3 Photo: Steffen Jahn; p. 4–5 Photos: Annette Cardinale, NÓICREW, Getty Images, Illustrations: Romina Birzer; p. 10 Illustration: Benedikt Rugar; p. 22–23 Photo: Getty Images; p. 26–27 Illustration: Andrew Timmins; p. 30 Illustration: Alamy; p. 32–37 Photos: NÓICREW; p. 46–51 Photos: Annette Cardinale; p. 53 Illustration: Christian Hruschka; p. 54 Photo: Gregory Halpern/Magnum Photos/Agentur Focus; p. 56–57 Illustration: Getty Images; p. 58 Illustration: Luka Schlage

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