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Porsche Engineering
Magazine

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System integration in the chassis Battery Digital Twin Megatrends in automotive development

THE GREAT FUSION

How the vehicle and software are merging


PORSCHE
Room for five.
And thousands of adventures.
THE NEW CAYENNE TURBO E-HYBRID COUPÉ.
FURTHER TOGETHER.
Fuel consumption combined in l/100 km: 2.0–1.7 (WLTP, weighted); CO_2 emissions combined in g/km: 46–40 (WLTP, weighted);
electricity consumption combined in kWh/100 km: 31.8–30.1 (WLTP, weighted);
electric range according to WLTP in km: 70–72 (EAER) · 76–81 (EAER city); Status: 11/2023

Dirk Philipp
Managing Director of Commerce / Chief Operating Officer (CFO/COO), Porsche Engineering

Dear Reader,

In modern vehicles, hardware and software are increasingly merging to become one and the same. Many customers expect their digital world to be fully integrated into their vehicle. At the same time, digital technologies are enhancing our previous vehicle experience considerably. It is the use of software that is making new functions a reality—functions such as automation, connectivity, and personalization. A 'software-defined vehicle' will result in new customer experiences, however will also require more advanced hardware, new forms of collaboration, and innovative development processes.

Porsche Engineering adapted to this development at an early stage and has consistently advanced and built up new expertise in digital fields and methods in the years since. We know how to develop software and functions—and we also know how to test them and integrate them in a vehicle successfully. In doing so, we apply virtual and real methods as well as generative artificial intelligence.

Speed is increasingly becoming a significant competitive factor in our industry, and digital tools will help us to stay ahead. Digital twins of components and test tracks, for example, allow us to carry out more and more tests virtually and thereby save valuable time—despite the growing complexity of vehicle development. The use of AI methods, meanwhile, means that we can increase the maturity level and the speed of development. Large language models can also be used in development, and this with a high degree of efficiency.

Global access to development data can further accelerate these processes. That is why we are making more intense use of the cloud as a central data hub for employees at our locations in Europe, China, and the US. Because the cloud and specific car IT expertise are of great strategic importance, a new team at Porsche Engineering concentrates exclusively on advancing both fields to make them the backbone of the entire company.

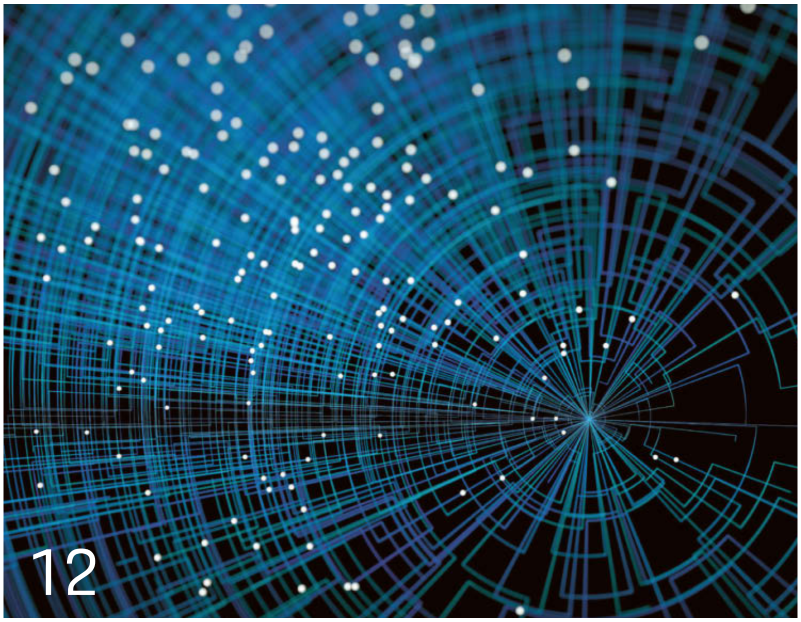
As you can see, software forms a key component of our solutions. That is why we have dedicated this issue of Porsche Engineering Magazine to the 'great fusion' of software and vehicle, and all the exciting facets it entails. In my role as Managing Director of Commerce and Chief Operating Officer (CFO/COO) of Porsche Engineering with responsibility for IT and digitalization, I am really looking forward to showing you our world of software-based vehicle development, without, of course, losing sight of the hardware.

I hope you enjoy reading this issue of the magazine.

Dirk Philipp

→ **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.

Intelligent strategy: Through reinforcement learning, PERL finds a strategy that leads to the optimal calibration result for an entire function.



Visionaries: Federico Magno (left) and Dirk Lappe discuss major future trends in an interview.

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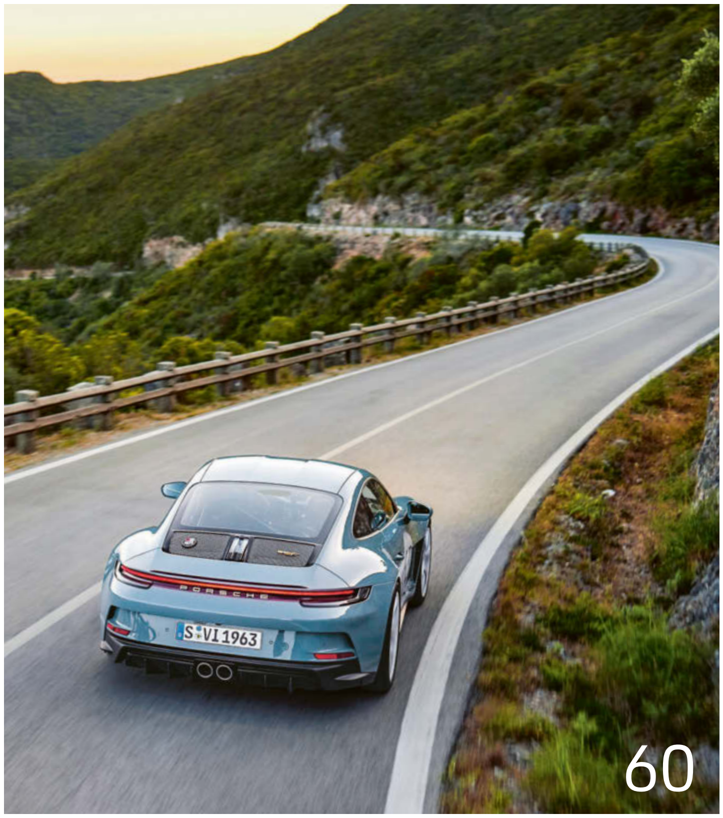
PORSCHE ENGINEERING DIGITAL

Pure pleasure: The 911 S/T offers a unique combination of agility and driving dynamics.



Tailor-made solution: The infotainment system has been tailored to the needs of Chinese customers.

CONTRIBUTORS

As a journalist for more than 25 years, **Richard Backhaus** deals with all topics that relate to fascinating and innovative automotive technology.

Emily Piwowar is co-founder of the photographer collective "NÓI CREW". She photographed one of the two major interviews in this issue.

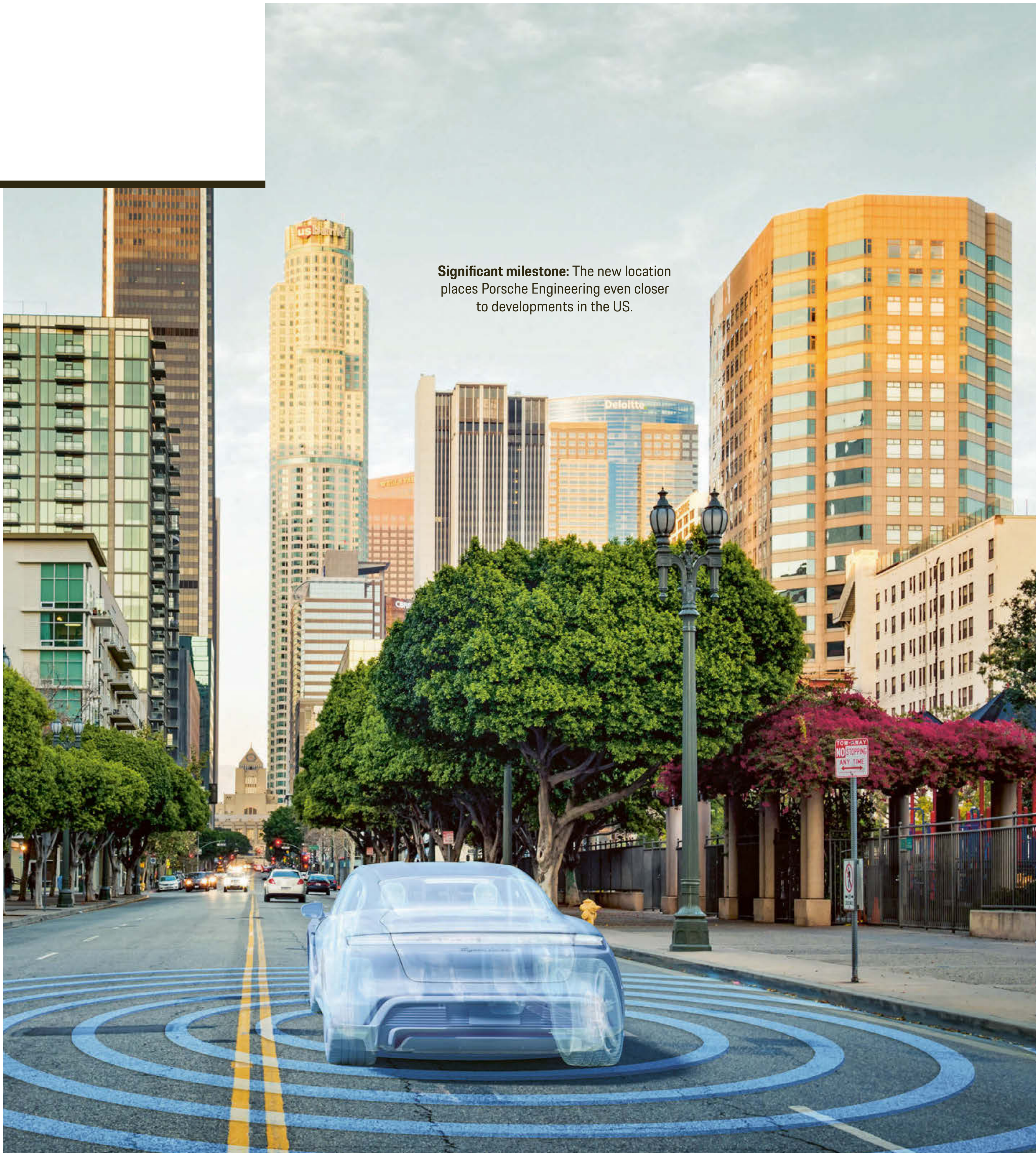
Constantin Gillies is a freelance business journalist and book author. Important topics for him, along with business, are technology and internet.

NEWS 01/2024

Taycan

Power consumption (combined): 24.1–22 kWh/100 km
CO_2 emissions (combined): 0 g/km
Electric range (combined): 370–510 km
Electric range (urban): 440–627 km

All consumption figures according to WLTP; as of 11/2023



Significant milestone: The new location places Porsche Engineering even closer to developments in the US.

← US

NEW US SUBSIDIARY

Porsche Engineering is expanding its global network with a new presence in the United States. Porsche Engineering Services North America, Inc. will have its operative headquarters near Los Angeles. As in the other markets where Porsche Engineering is represented, the task of the newly formed team will be to evaluate market-specific vehicle functions and digital services, including connectivity and infotainment, and to factor them into development. “From a strategic point of view, establishing a presence in the US is an important milestone in expanding our capabilities to meet future demand," says Markus-Christian Eberl, Chairman of the Executive Board of Porsche Engineering. “Our presence in the market will allow our engineers and our colleagues in testing and quality to gather detailed knowledge about the market and combine this with their comprehensive vehicle, function, and software know-how to offer first-class technology services.”

↓ Hackathon

A HACKATHON FOR OPTIMUM PROBLEM SOLVING

On June 13 and 14, 2023, Porsche Engineering held a hackathon in Ostrava, Czech Republic. “The aim was to find a faster and more efficient solution for handling vehicle data in Python,” reports Jan Wörner in the field of Complete Vehicle Development, Data Driven Testing & Vehicle Functions. “The task at hand is relevant to the whole company, but commercial tools are not really suitable as it’s often difficult to integrate them into an automated data processing pipeline.” Six teams with a total of 22 members—from the Cluj, Timișoara, Prague, Ostrava, and Bietigheim locations—accepted the challenge. The "Data Vampires" team emerged victorious: Their solution was the most compelling in terms of performance, resource consumption, and accuracy of information. “We’d like to hold more hackathons in the future,” says Wörner, “as they represent a great opportunity to solve complex problems that we find tough to crack over the course of our projects. Creating an international platform allows experts from across the company in Europe to participate, and provide each other with support through teamwork.”

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Employees from five locations took part in the hackathon in Ostrava.

→ Corporate Social Responsibility

COMMITMENT TO THE LOCAL COMMUNITY

For over seven years now, Porsche Engineering Romania has been involved in diverse activities to help shape the future of local communities. Employees on site find it important to make a contribution to advancing both technological and social issues. A community of more than 50 employees from Cluj and Timișoara volunteer in projects that are close to their hearts. The projects concentrate on the areas of environment, social development, and education. For example, the Cluj-based initiative 'Ladies in Tech' now has 32 active members who focus on empowering women and providing educational activities for children from poorer families. The company also provides financial support to several projects, such as renovating schools, offering summer camps for children who have battled cancer, and supporting the robotics group at a high school in Cluj.

Close to their hearts: Employees at Porsche Engineering Romania are actively involved in social issues.

Growth: Our locations in Beijing and Shanghai make on-site developments possible, and are currently expanding their capacities.

↓ Shanghai and Beijing

MORE THAN 200 EMPLOYEES IN CHINA

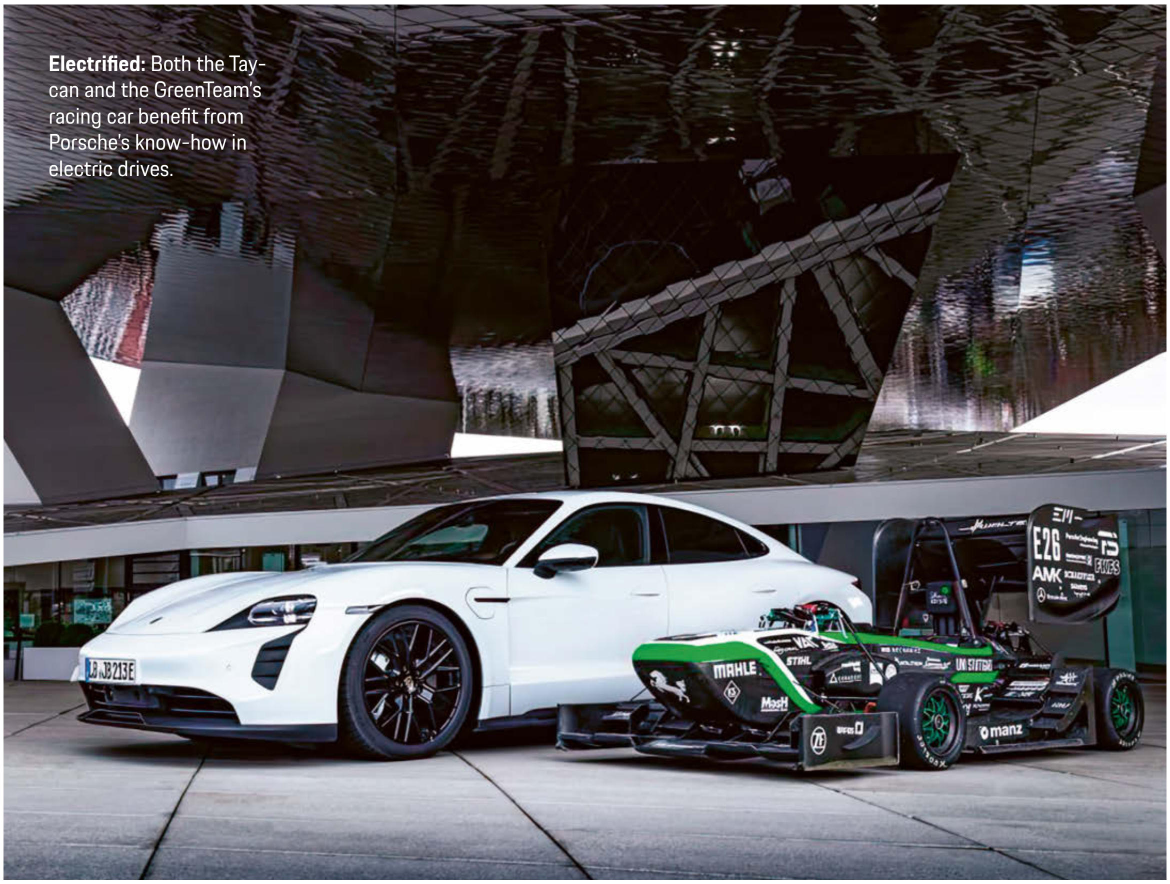
Porsche Engineering China is growing. The two locations —Shanghai and Beijing—reached a significant milestone in September: They now have more than 200 full-time employees. Porsche Engineering has been active in China for over 30 years. In order to better understand the local market dynamics and develop China-specific solutions, it opened its first location in Shanghai in 2014. Since 2022, a team in Beijing has also been working on topics such as highly automated driving, connectivity, infotainment, and driver assistance systems.

FORMULA STUDENT GERMANY: GREENTEAM

Since 2011, Porsche Engineering has been supporting the GreenTeam from the University of Stuttgart in the Formula Student engineering competition. This year, the up-and-coming young engineers claimed overall eighth place at Formula Student Electric Germany. The team took tenth place at the Driverless Cup as part of Formula Student Germany. The team benefits from the know-how and infrastructure of Porsche Engineering. “Thanks to the expertise in the field of high-voltage cells and the provision of state-of-the-art high-voltage test benches, we were able to push our battery to the limit,” says the team. “Another crucial factor was our ability to use the exclusive testing grounds in Weissach. This is where everything we had learned came together and not only helped us to test the race car, but also to take our drivers to a new level.” Formula Student teams also receive support at some of Porsche Engineering’s locations outside Germany—Prague, Cluj, Nardò, and Shanghai.

“One crucial factor was our ability to use the exclusive testing grounds in Weissach.”

Formula Student’s GreenTeam
University of Stuttgart



Electrified: Both the Taycan and the GreenTeam’s racing car benefit from Porsche’s know-how in electric drives.

Taycan

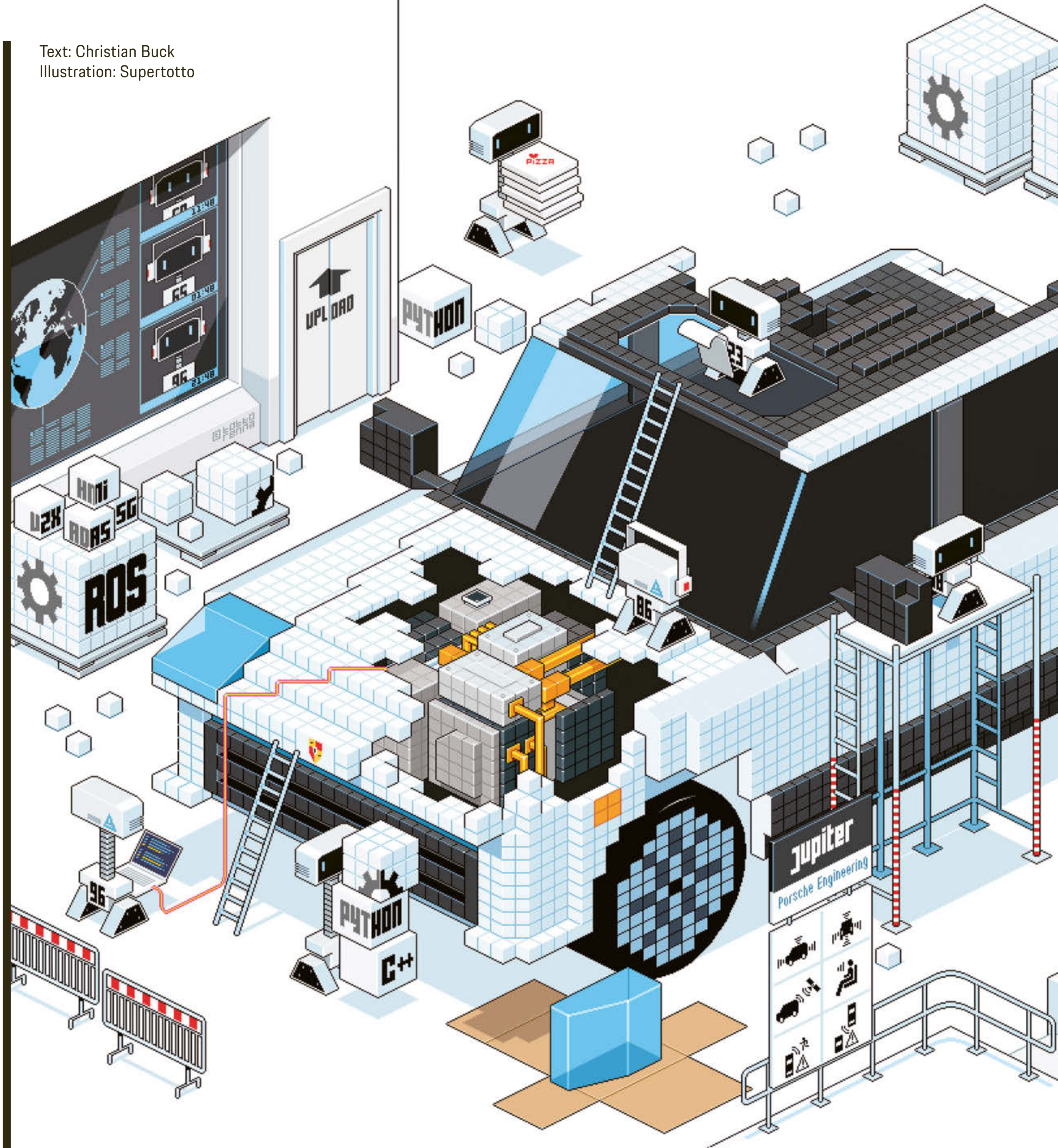
Power consumption (combined): 24.1–22 kWh/100 km
CO_2 emissions (combined): 0 g/km
Electric range (combined): 370–510 km
Electric range (urban): 440–627 km

All consumption figures according to WLTP; as of 11/2023

TO THE POINT.

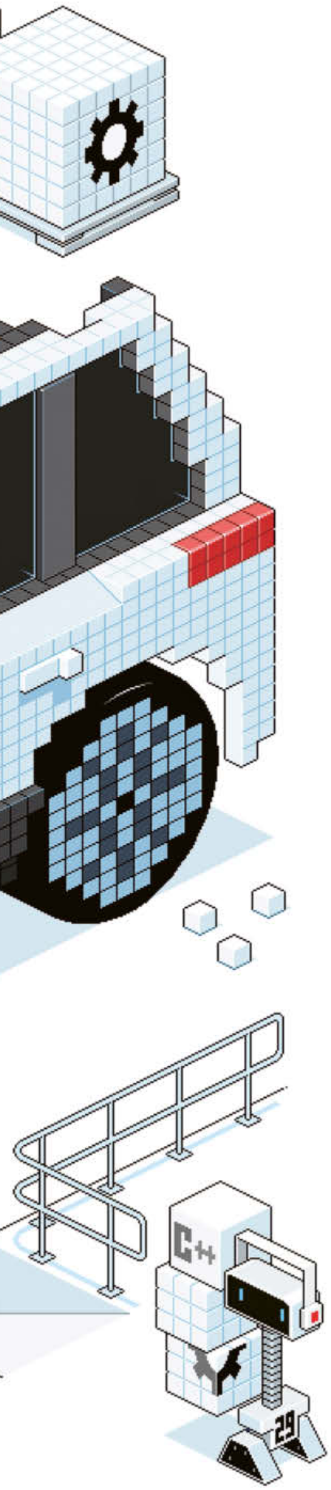
New technologies are driving development in the automotive industry. In this section, we get straight 'to the point' on the hot issues of the moment.

Text: Christian Buck
Illustration: Supertotto



Rapid prototyping

Developing automated or connected driving functions is a major challenge. In JUPITER test vehicles from Porsche Engineering, the Robot Operating System (ROS) speeds up development of new and innovative functions so that they can be experienced sooner.



Since 2007, researchers around the world have been working on advancing the Robot Operating System (ROS)—initially at the Stanford Artificial Intelligence Laboratory, and now as part of the Open Source Robotics Foundation (OSRF). Even if the name suggests otherwise, ROS is, strictly speaking, not a standalone operating system, and instead builds on systems such as Linux or Windows to act as a mediation layer between hardware and software. Among other components, ROS provides a wide range of device drivers, which means that new sensors and actuators can be easily integrated into existing systems. In addition, ROS sees itself as a "software toolbox" for research and for application-driven automation.

Porsche Engineering has been using ROS since 2019. The company's engineers, working together with ADAS engineers at Porsche, have developed their own complex software interfaces to link the ROS layer with the bus systems of series production vehicles. This means that new features can be seamlessly integrated into existing vehicles, which can in turn be used as a new form of "assembly carrier for software functions". This is the approach taken by Porsche Engineering in its JUPITER test vehicles (Joint User Personalized Integrated Testing and Engineering Resource). These vehicles can be equipped with numerous sensors for automated driving functions, including, at the moment, stereo cameras and lidar. "Thanks to ROS, the lidar sensors were installed and integrated within just one week, and after a day of commissioning, we were able to start recording test data straight away," reports Marcel Pelzer, a development engineer for driver assistance systems and the head of the JUPITER project at Porsche Engineering. "Integration and commissioning times that take between several days and several weeks are quite common."

ROS applications are made up of individual nodes that communicate with each other. To support this, ROS also supplies many software libraries for the purposes of standardized data exchange, data visualization, debugging, and more. "This allows new nodes to start using the data from other nodes immediately," explains Pelzer. "You don't need to know from the start who should talk to whom, and the standardized messages also help to adapt algorithms to a wide range of sensors."

This makes ROS attractive not only for robot construction but also for developing new automated or connected driving functions, because these applications demand that new software and sensors are available to experience in prototype vehicles quickly. In addition to simple integration of new hardware, the node concept in particular offers a decisive advantage: Advanced Driver Assistance Systems (ADAS) functions can be flexibly implemented as new nodes, and how they interact with one another can be tested on a unified platform.

As another example, Pelzer cites the implementation of an advanced parking assistance function as a prototype. "In series development, it usually takes several months before supplier solutions for a driver assistance function are available in the vehicle. In the JUPITER vehicle, we were able to implement a reversing assist function for automatic pedestrian recognition with only one developer and within half the usual time."

As well as rapid implementation of new sensors and functions, the JUPITER vehicles offer the developers further benefits: Sensors are installed at potential positions for future series production in order to evaluate how the positioning affects the algorithm. In addition, access to sensors' raw data is possible—as is access to the vehicle bus and, in turn, to all actuators.

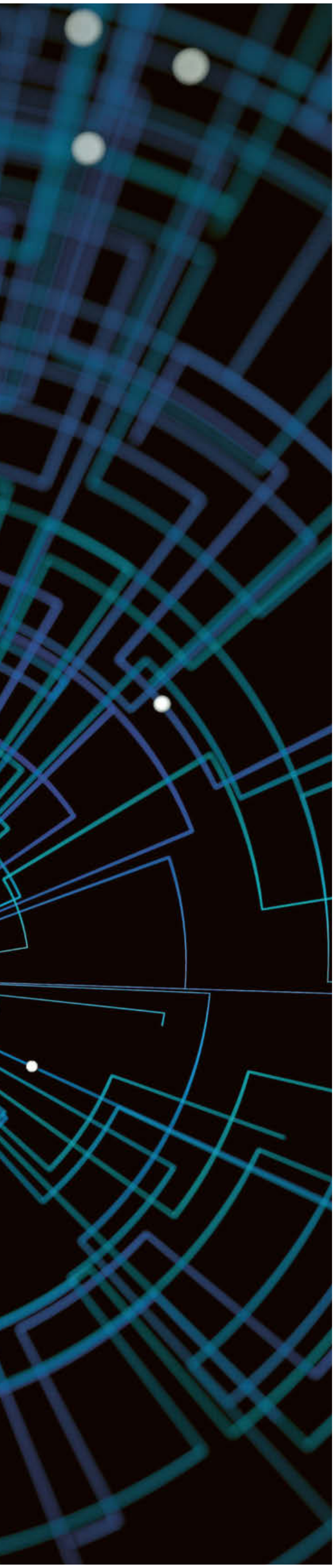
By using ROS, developers can implement new driving functions as nodes in ROS at any time without much additional work. A total of 50 to 60 nodes are active for various functions and sub-functions in a JUPITER vehicle—always with the option of dynamically expanding the system with additional nodes during runtime. What's more, the ROS source code is open source, ROS supports various programming languages such as C++ and Python, and there is a large community on hand to offer inspiration and help with problems. This allows engineers at Porsche Engineering to concentrate on the essentials: Function development.

The new version, ROS 2, builds on the experience gained with ROS. Its communication infrastructure is also certified for automotive applications thanks to the DDS standard (Data Distribution Services), meaning that ROS 2 could theoretically be used in series production vehicles. Depending on the data source, DDS offers the major advantage of being able to configure properties (quality of service), transport mechanisms, and access rights, thereby making the best possible use of hardware resources. "ROS has proven to be an excellent platform for testing new technologies and offering cutting edge technologies to our customers," Pelzer concludes. "This allows us to quickly demonstrate use cases and significantly reduce the time-to-delivery to our customers. We are proud of this, because the intelligent acceleration of delivery and provision times of solutions to complex tasks is an essential part of our activities to optimize processes and methods. In addition, ROS makes it possible to use a standardized basis to investigate how several technology domains such as ADAS, V2X, artificial intelligence, and simulation interact with one another. This allows us to take advantage of many synergies in the development of tomorrow's connected and intelligent vehicles."

COVER STORY

PERL

Smart decision-making process: PERL uses reinforcement learning to find an optimal calibration strategy.



DATA INPUT BY THE AI AGENT

PERL, the virtual calibration software from Porsche Engineering, shifts the majority of ECU data entry to AI. This reduces the need for bench tests and test drives in the calibration phase of the vehicle. The results of initial customer projects demonstrate the huge potential offered by the new methodology.

Text: Richard Backhaus

When applying new vehicle functions, the engineers have to put in an ever-greater amount of work, because with the increasing range of functions and the growing system connectivity of modern vehicles, the number of tests and the number of relevant parameters required for the calibration also increases significantly. In order to be able to cope with the higher complexity in the future while also increasing development efficiency, Porsche Engineering uses artificial intelligence (AI) to calibrate the control units and input data. "With Porsche Engineering Reinforcement Learning—PERL for short—we are turning the calibration of driving functions into a smart decision-making process," says Matteo Skull, Lead Engineer at Porsche Engineering.

PERL is based on deep reinforcement learning, a self-learning AI process. The basic idea is that instead of optimizing individual parameters, the AI develops a strategy that leads to the best possible calibration result for an entire function. The advantages are the high degree of process efficiency of the methodology, as it is self-learning, and the universal applicability to many areas of vehicle development (see also Porsche Engineering Magazine 1/2021 on the principle of PERL). "Porsche Engineering recognized at an early stage the potential of deep reinforcement learning for the automated calibration of control units. Since 2017, we have been working on PERL together with AI experts from the Porsche Engineering sites in Cluj and in Timisoara, Romania, and have been continuously developing the methodology ever since," says Dr. Matthias Bach, Senior Manager HV Battery Calibration and Diagnostics and Diagnostics at Porsche Engineering. More than 50 patents have been registered for PERL in the time since.

Thanks to this expertise, Porsche Engineering is one of the first companies worldwide to have validated a methodology for AI-supported calibration and to have integrated it into the development process for new vehicle systems. In the meantime, PERL has already been used for the calibration process in two customer projects. In the first, Porsche Engineering has been cooperating with the FZI Research Center for Information Technology in Karlsruhe and with Porsche for about three years. In this project, PERL is used to coordinate the fuel mixture formation for a new gasoline engine for hybrid vehicles. In the second project, PERL is used for the calibration of vibration damping in the powertrain of a Porsche electric vehicle.

CALIBRATION OF CONTROLLERS

In both cases, AI is used to calibrate controllers, which poses a particular challenge. Thomas Rudolf, PhD student at Porsche Engineering and the FZI, explains: "The calibration of control functions is a complex task, because we need to control highly dynamic processes precisely. In the mixture formation for an engine, for example, the injection quantity must be correctly adjusted for each speed and torque combination using parameter maps so that the lambda value—the control variable for optimum operation of exhaust gas aftertreatment—matches the target."

The main challenge this involves is the dead time resulting from the spatial distance between the engine and the sensor system at the end of the exhaust tract, coupled with the high speed at which the control system must work, say, during a load change. If the control system reacts too slowly, the function of the emission control system will be impaired and emissions will increase. If regulation is too aggressive, the system may see-saw.

It is therefore crucial to find a balance between the two extremes. "Customized parameterization of complex and varied control systems in the automotive industry continues to be a major challenge. Modern learning methods can significantly accelerate the extensive, cost-intensive, and sometimes manual calibration and make it more efficient," says Prof. Sören Hohmann, Head of the Institute of Control Systems at Karlsruhe Institute of Technology (KIT) and Director at the FZI, summarizing the advantages of AI use.

PERL is able to align the wide range of control parameters for highly dynamic engine operation in a way that sets the optimum mixture. "This makes PERL an indispensable development tool—especially for future, stricter emission standards that will require even more precise lambda control in all operating areas," adds Bach. Dr. Galabina Aleksieva-Rausch, who is responsible for processes, quality, and method development at Porsche, shares his assessment: "As part of a study of the potential offered by PERL, we used it in parallel with conventional calibration to ensure comparability of the results. The result was much better than expected: Calibration using the AI approach was already almost as good as that of the series calibration, even without any fine adjustment."

The maturity of the calibration data generated in the computer using AI depends heavily on the task in question, but is usually between 80 and 90 percent. Fine tuning and validation of the raw calibration are then carried out by means of bench tests and test drives, which must remain an integral part of the calibration in the future due to the requirements for quality control and assurance. PERL also supports the applicator with these tasks, because the program can run in the background during tests and uses the data obtained to make suggestions for further optimization of the calibration.

At present, the efficiency gained by using PERL for series development cannot yet be quantified. However, it is already clear that AI-supported calibration methods such as PERL can significantly accelerate the overall development process: "Thanks to PERL, we can run the calibration at a much earlier stage and get valid results more quickly. We then take those results and approach the subsequent development steps in a much more focused and therefore more efficient way," says Stefano Chini from Aleksieva-Rausch's team. The second application case using PERL is vibration damping in the powertrain of an electric vehicle. In this instance, the engineers are trying to attenuate a disruptive vibration in the powertrain with the input

Depending on the task, a maturity level of up to

90%

for calibration data can be achieved using PERL. Fine tuning and validation of the raw calibration are carried out by means of bench tests and test drives.

Over

50

patents have now been registered for PERL by Porsche Engineering.

Taycan (Illustration)

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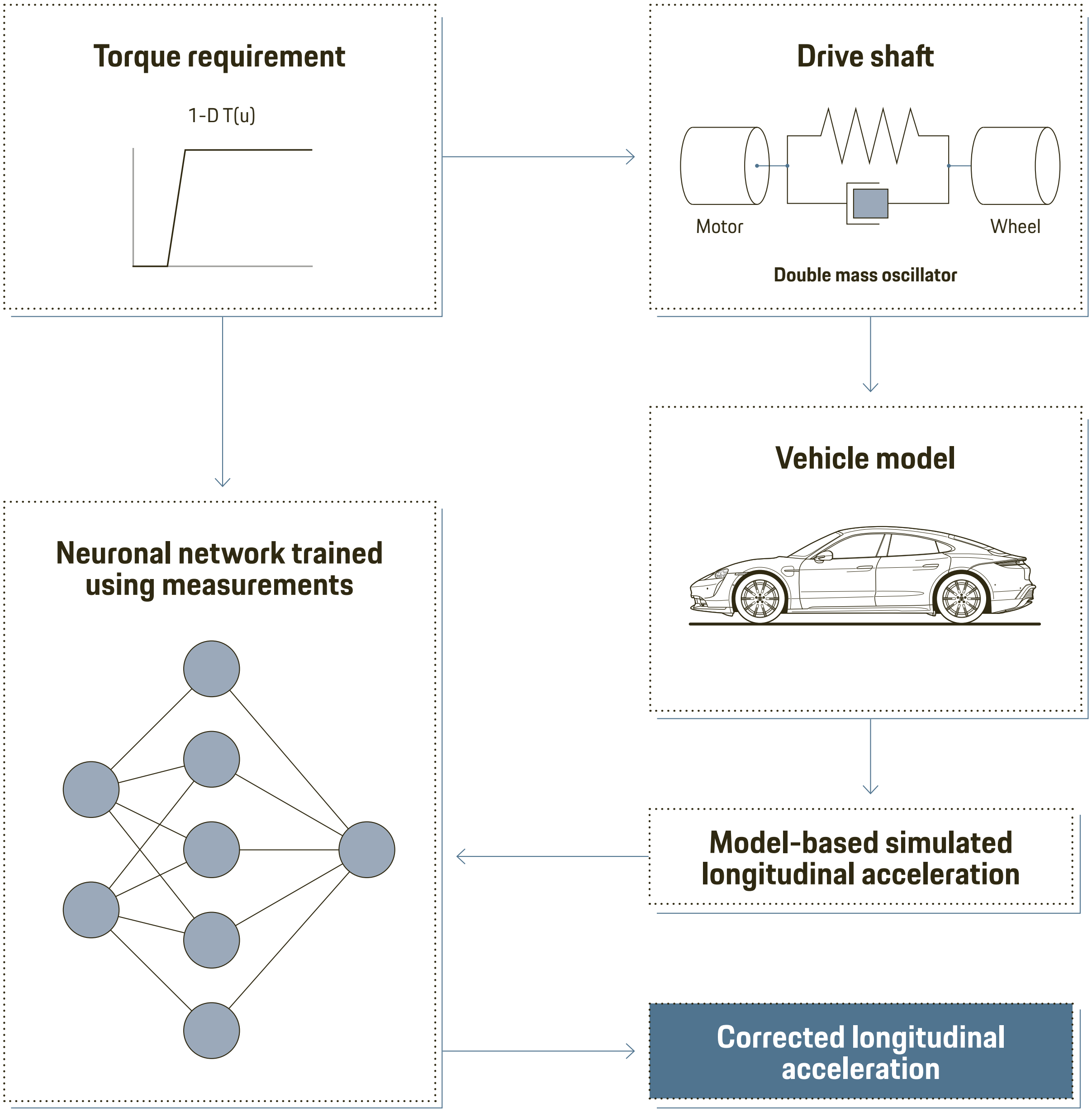
"Modern learning methods can significantly accelerate the extensive, cost-intensive, and sometimes manual calibration and make it more efficient."

Prof. Sören Hohmann
Head of the Institute of Control Systems at KIT and Director at the FZI

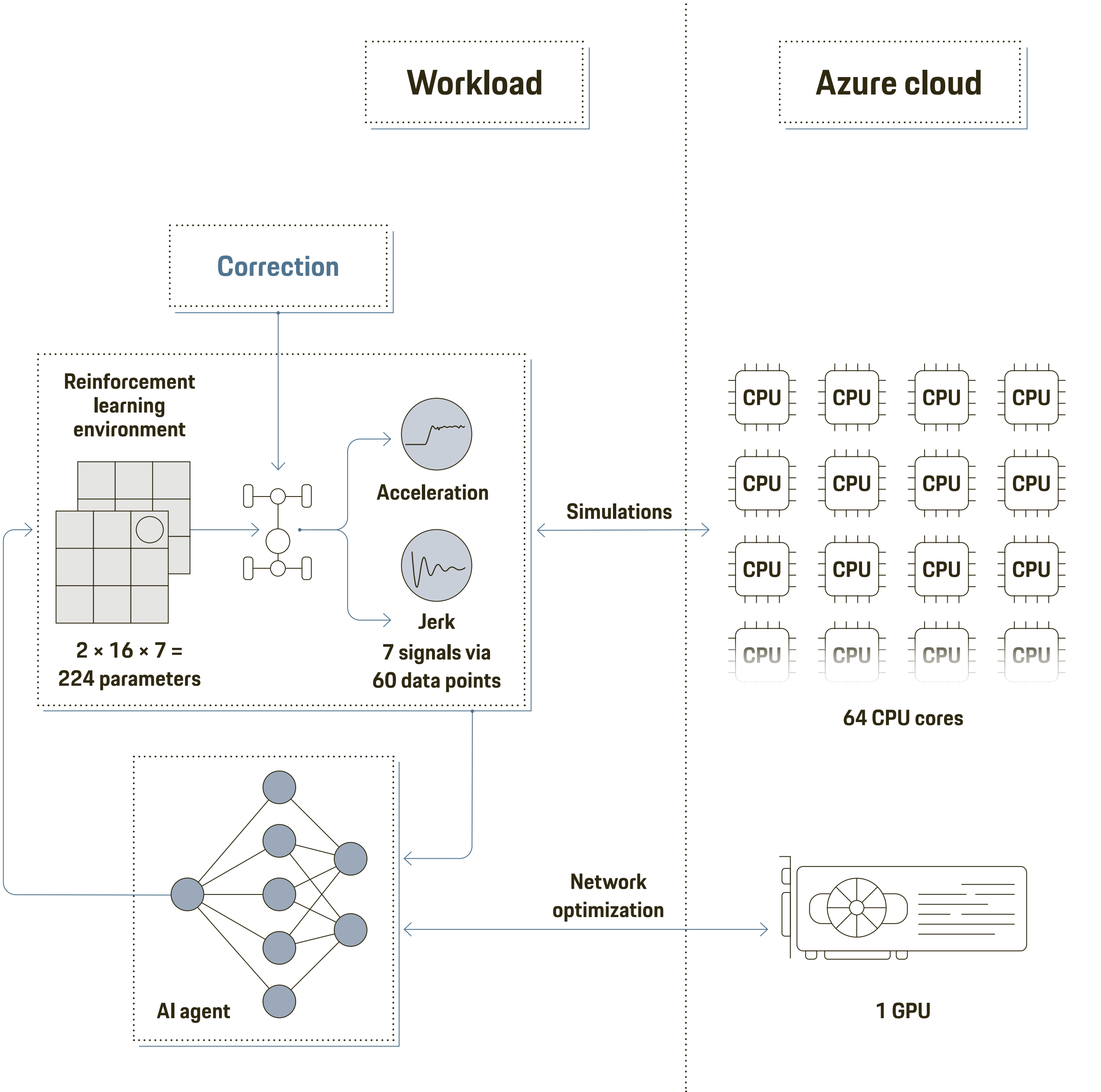
VIBRATION DAMPING CALIBRATION
NEURONAL NETWORK IMPROVES SIMULATION ACCURACY

For effective vibration damping, the motor in an electric vehicle must be actuated at the right time and correctly synchronized. In addition, the counter-vibration must not be too strong, because the motor torque required to generate the counter-pulses is not available for propulsion. In order to be able to use PERL, the developers first used test bench data to compile a model of the chassis physics of actual vibration profiles. The model was then expanded using neuronal networks. The hardware model simulates the physics while the artificial neuronal network bridges the accuracy gap between the real world and the simulation.



PERL POLICY TRAINING
CLOUD COMPUTING ACCELERATES CALCULATIONS

The agent was trained using a large dataset and randomly initialized maps to ensure a good generalization of the strategy. 64 CPU cores in the cloud processed the simulations in parallel, which resulted in a significant acceleration of calculations compared to the use of a local machine. The strategy has been optimized with a graphics processor in the cloud.



of a specific countermeasure—the same principle is used in headphones, say, and known as noise canceling. This calibration mainly concerns excitations in the range of 1 to 15 hertz, which are often perceived by the occupants in the vehicle as vibrations and, in the worst case, can even damage the powertrain. As with the mixture formation in the engine, optimal control is crucial to the functioning of the system, because for effective damping, the vehicle's electric motor must be actuated at the right time and correctly synchronized. In addition, the counter-vibration must not be too strong, because the motor torque required to generate the counter-pulses is not available for propulsion. This means that, when this concept is applied, comfort and driving dynamics interact directly with one another.

FINDING THE OPTIMUM BALANCE

Applicators must therefore find an optimum balance between comfort and sportiness when designing the vibration damping. In order to achieve the best possible result—the result typical for Porsche—three maps per electrically driven axle are simultaneously supplied with data to achieve vibration damping. Due to the high level of complexity, a robust initial input of data to the control units requires a great deal of effort if done manually. Only when the control units have received the data can the applicators start the fine calibration work. "One of PERL's main objectives was to shorten this period. From the very beginning, the focus was on a universal application for AI for very different vehicle platforms and derivatives," says Maurice Hauß, software engineer at Porsche.

In order to be able to use PERL, the development teams at Porsche Engineering and Porsche first used individual test bench data to compile a model of the chassis physics of real-life vibration profiles; this model was expanded using neuronal networks. "The hardware model simulates the physics while the artificial neuronal network bridges the accuracy gap between the real world and the simulation," explains Skull. The PERL core methodology was then applied. The AI agent was trained on the hybrid model using a large dataset and randomly initialized maps; this ensures a good generalization of the strategy.

After the end of the extensive training, it took only a few seconds in target deployment for the agent to complete the vehicle-specific calibration adaptation. In addition, it was possible to transfer the AI strategy from the original vehicle to other derivatives—including ones with different powertrains—without modification and in some cases without the need for vehicle-specific measurements The expectations associated with the use of PERL were thereby far exceeded. "With new variants, thanks to PERL, we can start the calibration with precalculated data; other test car users can work on the vehicle calibration in parallel during this time and do not have to wait for us," explains Tobias Roulet, Manager E-Vehicle Calibration at Porsche. "In total, we can save one to two weeks of calibration time. What's more, PERL enters valid data in advance, so there is no risk of damage due to incorrect calibration data when the powertrain is first commissioned."

After the successful completion of both customer projects, the customer assessment has been entirely positive. "PERL has proven that the approach is universally applicable for all types of data entry and that AI can significantly reduce the work and time required in the calibration. This means that the newly developed PERL methodology makes a major contribution to a strategic goal of Porsche Engineering: To ensure a short delivery time of high-quality solutions for complex tasks—for the benefit of our customers," according to Bach. An expansion of PERL usage at Porsche is already in the planning stage. The program is to be used, for example, to optimize the camshaft bearing control calibration.

"PERL has proven that the approach is universally applicable for all types of data entry and that AI can significantly reduce the work and time required in the calibration."

Dr. Matthias Bach
Senior Manager Battery Calibration and Diagnostics at Porsche Engineering

SUMMARY

Porsche Engineering uses reinforcement learning (RL) for the calibration of driving functions. The new approach means that a large part of the data input is performed by AI; only at the end is manual fine-tuning carried out on the test track. In addition, a single trained RL agent can handle the calibration of several vehicle derivatives. As a method, RL significantly reduces the time and costs involved in the calibration.

Concentrated expertise: Albrecht Böttiger (left) and Jürgen Bortolazzi next to a JUPITER test vehicle.

"Cutting-edge technology solutions for automated driving"

Advanced driver assistance systems and automated driving functions increase convenience and safety. In this interview, Jürgen Bortolazzi (Director Driver Assistance and Automated Driving at Porsche) and Albrecht Böttiger (Director Advanced Driver Assistance Systems at Porsche Engineering) talk about the current state of technology and the future of driving.

Text: Christian Buck
Photos: Nói Crew

What role will driver assistance systems and highly automated driving play in the future—particularly for Porsche customers?

— **BORTOLAZZI:** When it comes to driver assistance systems, Porsche customers expect the highest level of support, convenience, and safety. We can and must offer state-of-the-art technological solutions—including ones in the field of automated driving. But the underlying premise will continue to apply: A Porsche will always first and foremost be a car for people who want to drive themselves.

— **BÖTTIGER:** We are, however, increasingly finding that Porsche customers want to have support in special situations—for example in traffic jams and when searching for a parking space. Take the situation in big cities like Shanghai, Beijing or Los Angeles, for example. You can't drive a Porsche in a dynamic manner there like you can on a picturesque country road in the Black Forest. Rather than concentrating on stop-and-go traffic, anyone would presumably like to use that time profitably, for example doing other activities that are not allowed and are not possible when actively driving.

You just referred to legal requirements. Are they harmonized globally or are there major differences?

— **BORTOLAZZI:** We see very large differences in this area. There are worldwide regulations such as the UN's ECE regulations for the technical requirements for vehicles that many countries use for orientation. But we also have to deal with a lot of country-specific circumstances. China in particular is increasingly emancipating itself and introducing its own approval and legal regulations to the market.

At what level of automated driving are we right now?

— **BORTOLAZZI:** We're at level 2, so still assisted driving. At this point, drivers continue to assume full responsibility. We're currently working hard on an enhancement of level 2, which is being widely referred to as level 2+. In the future, drivers will be able to take their hands off the steering wheel. At the same, the vehicle has to monitor that drivers remain ready to take control at all times. In other words, we have to monitor that they have their eyes on the road, that they are still observing the traffic situation, and that they can resume control at any time.

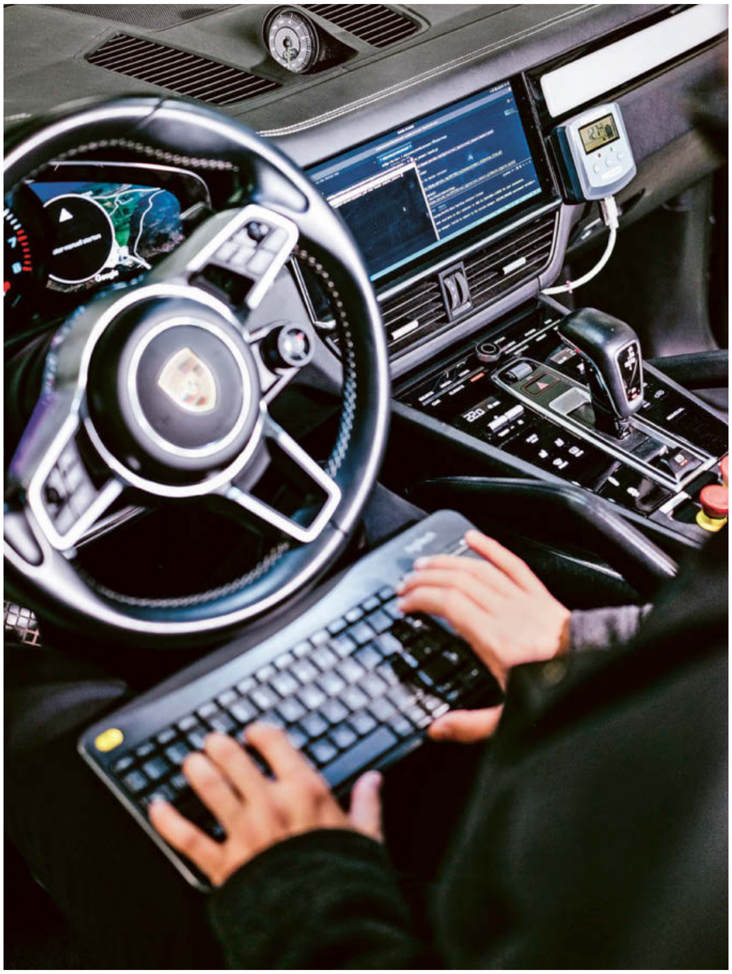
Some OEMs are currently at the threshold of advancing from level 2 to level 3 of automated driving. How big is the leap from level 2 to level 3?

— **BORTOLAZZI:** It's more of a major leap, because a redundancy path has to be implemented in the vehicle. It assumes control—at least for a certain time—of the driving function when the main system reaches its limits or a problem occurs. There's a significant effort involved in that, including in adjacent systems such as the brakes, steering, and power supply.

— **BÖTTIGER:** We moved from level 1 to level 2 rather quickly, for example from simple longitudinal control to combined longitudinal and lateral control. The leap to level 3, however, is taking more time—despite the massive acceleration of the development processes through data-driven development. That is primarily due to the requisite fallback level, which in addition to the material costs in the vehicles also involves a major effort in terms of implementation in development.

— **BORTOLAZZI:** At level 4, this fallback level will be even more pronounced, so that the vehicle can be operated in redundancy mode over a longer period of time. This is accompanied by additional redundancy—for example in the powertrain system, enabling the vehicle to exit the freeway of its own accord, if needed.

Putting future technologies to the test: With JUPITER, Porsche Engineering has built a scalable ADAS architecture platform to prepare new technologies more efficiently for series development. The platform is continuously being developed further in the international software environment.



In the US, there are already robotaxis without drivers. Are the manufacturers there ahead of the European OEMs with regard to autonomous driving?

— **BÖTTIGER:** In this case, we have to differentiate between the use cases. Robotaxis have a limited scope of action or operational design domain within cities and the vehicles belong to service providers or fleet operators—much like driverless buses today. For vehicles that belong to individual customers and are operated by them personally, the focus is placed on the development of supported driving on the freeway or in traffic jams, and not on driverless driving. It's primarily a question of greater distances. This is why there are differences in orientation here. So we can't draw the conclusion that the US manufacturers are further advanced because they no longer require a driver.

How do things look for the Chinese manufacturers?

— **BORTOLAZZI:** Our observations suggest that the Chinese manufacturers are approaching the topic of automation very ambitiously. That is certainly facilitated by the fact that it is funded and incentivized by the state. This year, for example, we expect legislation approving level 3. The way this is manifested is also somewhat different there: Chinese manufacturers have a lot of technology on board, with control units with very high processing power in addition to the sensor technology. But it still remains to be seen if that will lead to vehicle functions that are actually practical.

What technologies are you focusing on in the development of highly automated driving functions?

— **BORTOLAZZI:** For safety reasons, our current level-3 and level-4 concepts include three self-contained physical sensing principles: radar, lidar and cameras. These are proven technologies, but still have potential for further improvement, for example through imaging radars. These are high-resolution radars that, like lidar, create a three-dimensional image of the environment.

— **BÖTTIGER:** Porsche Engineering has in-depth expertise in all three sensor types, including the expertise gained through its international locations. But we also have the capabilities necessary for development up to level 4 in the area of control unit platforms, including, for example, graphics resources and accelerators for neural networks. The use of AI is increasingly indispensable, particularly in the field of environment perception and data-driven development—we have made this our consistent focus with our own in-house international AI competence center. And when it comes to the requisite processes, methods and tools, we are currently working on being able to map them from software development through to validation and approval. This is a topic that we are really delving into and which we view as essential for approval for customers.

"We are increasingly finding that Porsche customers want to have support in special situations—for example in traffic jams and when searching for a parking space."

Albrecht Böttiger
Director Advanced Driver Assistance Systems at Porsche Engineering

Dynamic development: With the aid of the JUPITER test vehicles, it is possible to allow new functions to be experienced, and have them verified, rapidly.

What is the unique selling point of Porsche Engineering with regard to the development process?

— **BÖTTIGER:** Along with hardware and real vehicles, we are able to, in particular, utilize the virtual tools along the entire V model for the end-to-end development of ADAS functions. They allow us, for example, to simulate and test the emerging functions, even before ECUs exist as hardware. Another of our strengths is our worldwide locations, which allow us to operate hardware-in-the-loop test benches and thus continue the test operation, as well as development, around the clock. Errors that were discovered in Shanghai, for example, are immediately factored into an update that is then tested in Europe. Thanks to this international presence, we are also in a position to support real test drives in the markets. This means we can carry out the application and validation required locally on the market with physical test systems in the respective location.

How will vehicles change generally if driving is increasingly performed by technology?

— **BORTOLAZZI:** Automated driving requires higher IT performance in the vehicle. We need high-performance computers on board that process sensor data and then take on the planning and implementation of the route. There will also be broadband communication between the vehicle and the digital infrastructure, in which, for example, electronic maps and swarm data are stored, i.e. movement profiles and traffic information, as well as warnings about accidents. There will also be vehicle-to-X communication as soon as the relevant standards have been established.

— **BÖTTIGER:** The numerous components that have to be integrated are particularly important in this regard. The installation space must be created; as a rule, integration must occur without affecting the visible exterior of the vehicle. However, certain components may also be deliberately highlighted as a feature—this is an approach that we often see in other markets such as China: There, lidars are sometimes not concealed, and instead deliberately highlighted.

Speaking of which: How can the new vehicle functions be combined with the styling?

— **BORTOLAZZI:** We want to make technology visible—but in a way that makes it look really intentional. Porsche's design philosophy is very clean with clear lines and uninterrupted geometries. On the other hand, the optical sensors must always have a certain angle of view. Integrating that cleanly is definitely a major challenge. Therefore, we work intensively with our design and technology specialists in body development.

What does highly automated driving mean for the interior?

— **BORTOLAZZI:** Our vision is to provide our customers with an adequate experience in the interior in automated driving mode. Depending on whether the driver wants to concentrate on office work, communication or entertainment, the surfaces of the vehicle are made usable through displays or projections, for example. However, the safety aspect is always important: We have to ensure occupant protection in any event, because accidents, for example due to errors made by other road users, cannot be entirely ruled out in automated driving scenarios. Passengers also have to be protected in relaxed positions. We need intelligent airbag and new restraint systems that are integrated into the seats. In addition, there is high-precision interior and occupant monitoring so that the vehicle can recognize exactly what position the driver or passengers are in and what the optimal deployment strategy for these restraint systems would be.

The development of driver assistance systems and automated driving functions is highly complex. Does Porsche cooperate with other companies in this area?

— **BORTOLAZZI:** Porsche Engineering is an important partner, as the company has built up a number of fundamental capabilities over many years. This applies, for instance, to data-driven development, but also to the topic of simulation. That said, I would also like to mention the software development skills that we continue to build and expand together. There are also the nearshore and international locations of Porsche Engineering, which are very important to us

Jürgen Bortolazzi
has been Director Driver Assistance and Automated Driving at Porsche AG since 2022. He has a doctorate in electrical engineering and also teaches as an honorary professor at the Karlsruhe Institute of Technology (KIT).

"Automated driving requires higher IT performance in the vehicle. This is why we need high-performance computers on board."

Jürgen Bortolazzi

"We are able to map the entire end-to-end development along the V model – by utilizing real vehicles and virtual tools."

Albrecht Böttiger

Albrecht Böttiger has been Director Advanced Driver Assistance Systems at Porsche Engineering since 2023. Previously, the graduate physicist worked on advanced driver assistance systems and highly automated driving functions at Porsche from 2010 on.

because we have to test and validate new systems in many different regions due to the different approval conditions. Porsche Engineering offers us excellent support in all these areas.

Another partner is Mobileye. Why did you choose to work with this company in particular?

— **BORTOLAZZI:** Mobileye is currently one of the technology leaders. The company has done more than ten years of intensive development work in the field of driver assistance systems and automated driving. In addition to a function stack, Mobileye also offers a system-on-chip solution—already in its sixth generation—that incorporates a great deal of experience. There is also a complete digital ecosystem with a cloud-based map and efficient coupling of the vehicle with the map.

What milestones have been achieved as part of this cooperation?

— **BORTOLAZZI:** We have had cameras in Porsche vehicles based on Mobileye technology for several years. Now the new ECU platform is being added. It offers a high-performance interface to the electronic map and a highly advanced sensor system—in particular the camera belt, which provides 360-degree monitoring.

One last question: Do you prefer to drive yourself or to be driven? And what are you most looking forward to when the car takes over for you?

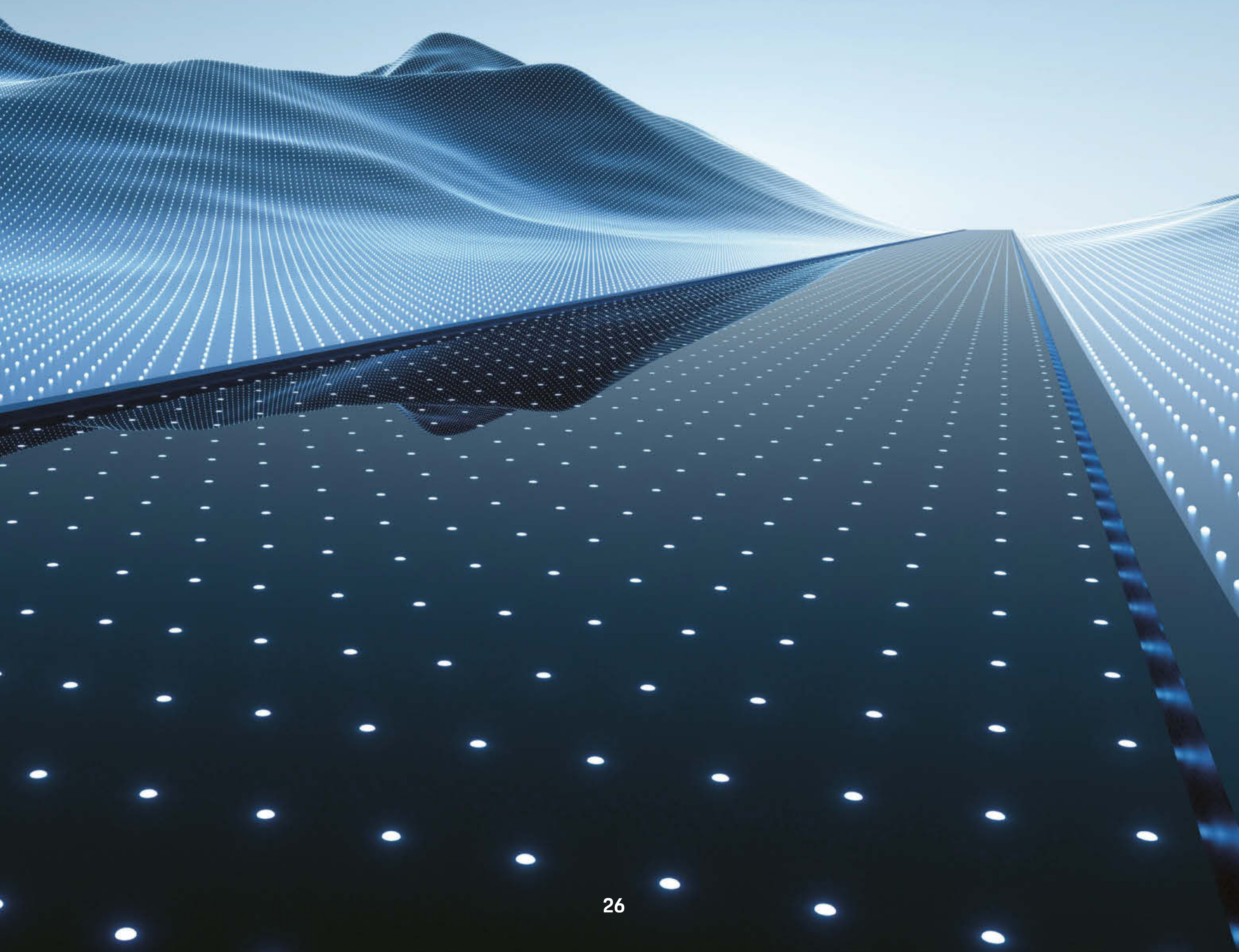
— **BÖTTIGER:** When I'm on the Stelvio Pass road in a 911 convertible, I don't have any need for level 3. Then I want to drive myself. Likewise in the Black Forest. But whenever I'm in the city, I already switch on the combined longitudinal-transverse assistant, which offers me a lot of relaxation and convenience. If I didn't have to drive myself at all, I would surf the internet or do business things. Or watch sports and other videos.

— **BORTOLAZZI:** I would prefer to use automated driving for the journey to the office—for example, to make use of my 50 kilometer commute in the morning while in traffic jams or in stop-and-go traffic on the freeway.

"Our vision is to provide our customers with an adequate experience in the interior in automated driving mode."

Jürgen Bortolazzi
Director Driver Assistance and Automated Driving at Porsche

Virtual worlds: for real.



Virtual validation is becoming increasingly important, for example for testing during development and validating driver assistance systems or connected driving functions. The prerequisite for this are so-called scenes or track models that Porsche Engineering generates for customers using its own end-to-end tool chain. This involves a complex process for which conventional map data is in no way sufficient.

Text: Constantin Gillies

Before the new Porsche Cayenne was presented in April last year, the prototype had already driven four million test kilometers. But that was just the trips on real roads and off-road terrain—not including the virtual test drives in simulation. Nowadays, more than 1,000 kilometers are driven on the computer for every real-life test kilometer. The engineers generate a digital twin of the vehicle and then put it through its paces in virtual test drives in a simulation environment on a synthetic or hybrid test bench (SiL, HiL, ViL)—primarily in situations that rarely occur in real life or are too dangerous to test in real conditions. How does the cruise control react, for example, when there's a wild boar waiting at the end of a curve?

For the validation of driver assistance systems and highly automated driving functions, it becomes indispensable to test such so-called 'corner cases' in countless variants and different levels of criticality. This, in turn, makes another resource increasingly important: virtual roads and environments. "Every function that needs to be validated by a simulation requires a route model—a digital twin of the road and environment," explains Tille Karoline Rupp, Senior Manager Simulation at Porsche Engineering. In the past, such scenes or track models were often generated manually, but that method is insufficient to meet the rising demand—after all, many billions of test kilometers will have to be driven on the way to the autonomous car. "A high degree of automation is crucial," says Rupp. Porsche Engineering has developed its own end-to-end tool chain to generate virtual test tracks from a range of raw data—almost entirely without manual intervention.

One example of source material for scene generation is high-resolution maps from suppliers or real test drives that Porsche Engineering itself carries out with its JUPITER (Joint User Personalized Integrated Testing and Engineering Resource) test vehicles. Map data from public services such as Google Maps are not suitable

"Every function that needs to be validated using simulation requires a track model—a digital twin of the road and its environment."

Tille Karoline Rupp
Senior Manager Simulation at Porsche Engineering.

for scene generation or track modeling. "We sometimes go down to the millimeter level and need information about lane and road width as well as three-dimensional cross-slopes," says Tobias Watzl, Development Engineer and responsible for track modeling. Because the data basis differs from country to country, a local presence is sometimes critical. In China, for example, special legal requirements apply to the collection of geo-referenced road data. Thanks to its teams in Shanghai and Beijing, Porsche Engineering can assume responsibility for individual project scopes on site—always in cooperation with the experts from other locations.

STEP-BY-STEP CONSTRUCTION OF THE TRACK MODEL

In the first step, a logical model of the road is derived from the map data. It describes its course according to road construction guidelines using mathematical functions—mostly polynomial equations. The logical road model is stored as an ASAM OpenDRIVE® file—a format that is managed and updated by the standardization organization ASAM e.V. (Association for Standardization of Automation and Measuring Systems).

In the second step, a three-dimensional model of the road is generated—this being a visual representation that can not only be viewed on the screen, but can also interact with sensor models. This virtual test track can be changed in any way required, adding slip roads or infinite circuits. Generic scenes with no real-life counterpart are also adapted to the driving function to be tested. If the objective is an algorithm for traffic sign recognition, for example, numerous different signs are placed along the road. Alternatively, the engineers can also model real roads—such as the A8 freeway from Stuttgart to Munich. Such georeferenced scenes are required, for example, if the function to be tested uses an internal map.

Initially, the 3D model represents the road only. However, in order to be able to optimize camera-based functions such as lane detection, the virtual track model must look like it does in reality. To do this, it is given a virtual environment. For this purpose, Porsche Engineering has integrated the 3D graphics software Houdini into its pipeline, which is also used in the film industry. This allows for generate realistic-looking trees or buildings along the road. The information about where which objects are located along the road is extracted from sources such as the open map service OpenStreetMap (OSM).

However, modeling a photorealistic digital road and its environment is very time-consuming. "If all the input data is correct, an hour of computing time is required for about ten kilometers," Watzl says. This requires a balancing act by engineers: The track model

"We sometimes go down to the millimeter level and need information about lane and road width as well as three-dimensional cross-slopes."

Tobias Watzl
Development Engineer at Porsche Engineering

"We need jointly defined quality requirements in order to be able to combine the best available tools in a reliable tool chain."

Marcel Langer
Product Owner for Simulation and Testing at CARIAD

needs enough details to be able to reliably validate the respective driving function, however can't be too large or it is likely to require too much computing power. To ensure that the simulation ultimately runs smoothly, distant or irrelevant objects are removed or modeled in a highly simplified form.

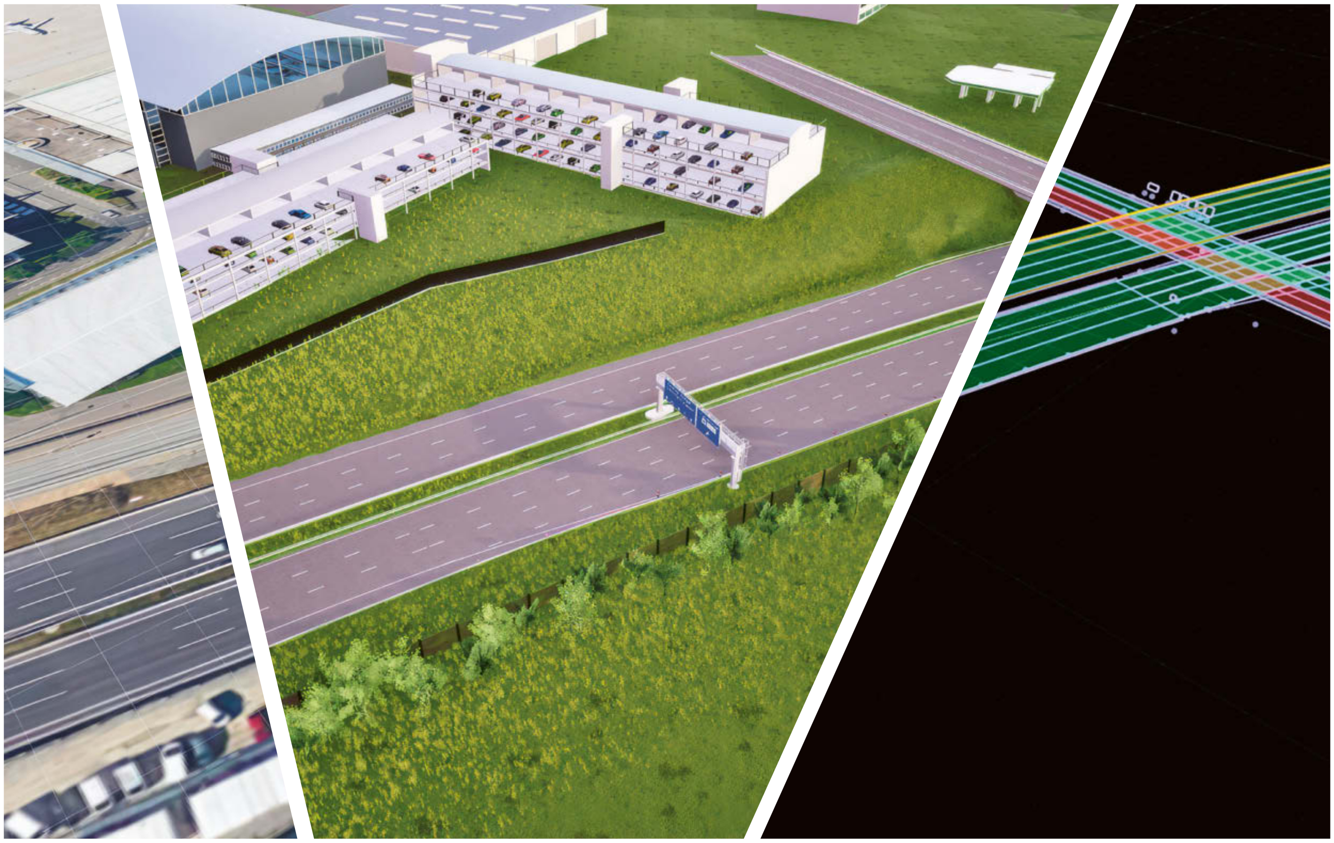
AUTOMATED TOOL CHAIN

The highest possible degree of automation is crucial for efficient track modeling. The international team from Porsche Engineering has therefore developed its own end-to-end tool chain: All steps from the logical road descriptions to the finished 3D model with environment run automatically. This requires a wealth of digital intelligence: Assuming that the logical road model does not exhibit any inclination, but 70 meters are documented in the ground elevation data, the algorithm has to recognize that there is a tunnel at this point and add the matching tunnel to the 3D model.

Moreover, quality assurance and using the data in various simulation environments without major modifications are also key elements. "We verify the data semantically with regard to drivability, importability and compliance with the standard," emphasizes Rupp. For example, jumps in the road geometry that may occur due to measurement errors must be identified automatically. In addition to drivability testing in the respective simulation environments, a quality checker tool from CARIAD is used. It checks whether an ASAM OpenDRIVE® file is standard-compliant and can be used without limitations in the desired simulation environment.

Together with CARIAD and ASAM, Porsche Engineering has launched an initiative that aims to enable the interchangeability of standards and the ability to assess their quality. In the resulting *ASAM Quality Checker project*, a review framework will be developed in 2024 together with other project partners as an important basis for improving the interchangeability of standards. "Scalable simulation solutions can only exist with standards that are interpreted and implemented uniformly," emphasize Marius Dupuis, CEO of ASAM, and CTO Ben Engel. "Without standards, the world is indescribable." This assessment is confirmed by users: "In addition to the standards, we need jointly defined quality requirements in order to be able to combine the best available tools to develop or set-up a reliable tool chain," says Marcel Langer, Product Owner Simulation and Testing at CARIAD. When it comes to adapting the model to the simulation environment, Porsche Engineering can play to its strengths. "We know the requirements for the simulations inside and out because we develop them ourselves and use them successfully in customer projects," as Rupp underscores. One

FROM REAL TO REALISTIC: TWO COMPONENTS OF SCENE GENERATION



Scene generation is a depiction of a scenario that usually exists in reality (aerial view at left). It consists of two components that match each other in terms of geometry and content: firstly, a logical-mathematical description of the road network and objects (right) and a 3D model of the drivable area and surroundings (centre). Scene generation is an essential component for virtual validation and development-supporting testing on synthetic and hybrid test benches (SiL, HiL, ViL).

example is hardware-in-the-loop systems, which make it possible to test the function of a real control unit in a virtual vehicle with the corresponding environment and surrounding traffic. This reduces the need for real tests. Porsche Engineering employs a high number of such HiL systems.

ADVANCING WITH WEATHER AND AI

As we proceed towards highly automated driving, virtual test tracks will need to become more extensive and detailed in the future. "There is still a lot of potential," says Watzl. Here's an example: At the moment, it's always summer in the virtual world—the roads are clean and dry. "In the future, a winter variant could be introduced, with piles of snow on the side of the road that cover lane markings," says Watzl. What's important is that not only piles of snow, but also, for example, piles of leaves or puddles are displayed visually. In addition, their physical properties must also be reproduced correctly. After all, there is a crucial difference between optical and physical detection of of the sensors—and thus also a difference in how the driver assistance systems will react.

To further increase the level of detail, Porsche Engineering is planning to apply its internal expertise in artificial intelligence. "AI can automatically analyze satellite images and provide information about the landscape or buildings," says Rupp by way of example. In addition, the technology can be used to automatically extract elements such as traffic signs from video recordings. This could significantly accelerate the adaptation of a route model to another country.

Approximately

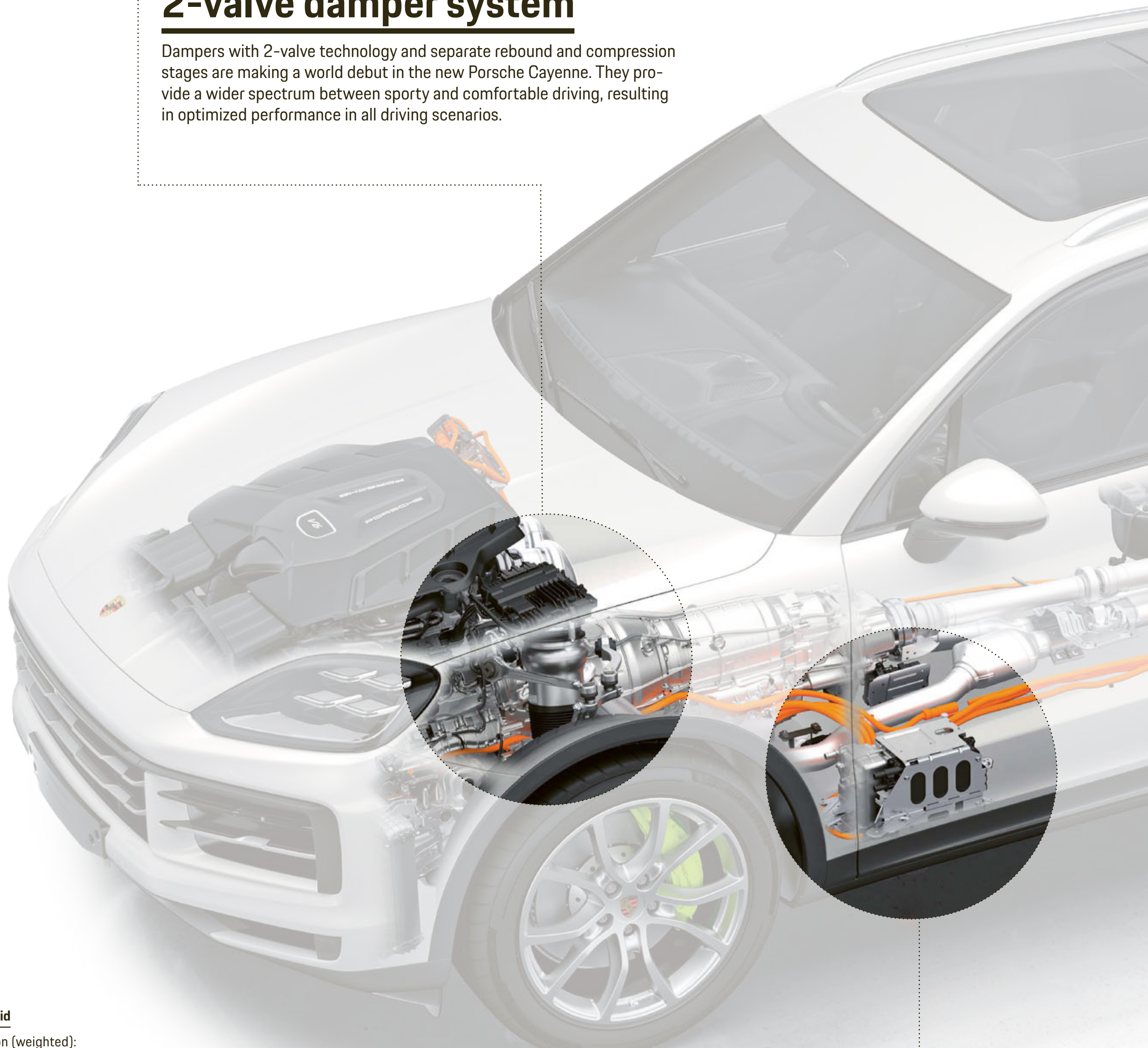
1 h

of computing time is required for 10 km of virtual roads.

1.

2-valve damper system

Dampers with 2-valve technology and separate rebound and compression stages are making a world debut in the new Porsche Cayenne. They provide a wider spectrum between sporty and comfortable driving, resulting in optimized performance in all driving scenarios.



Cayenne E-Hybrid

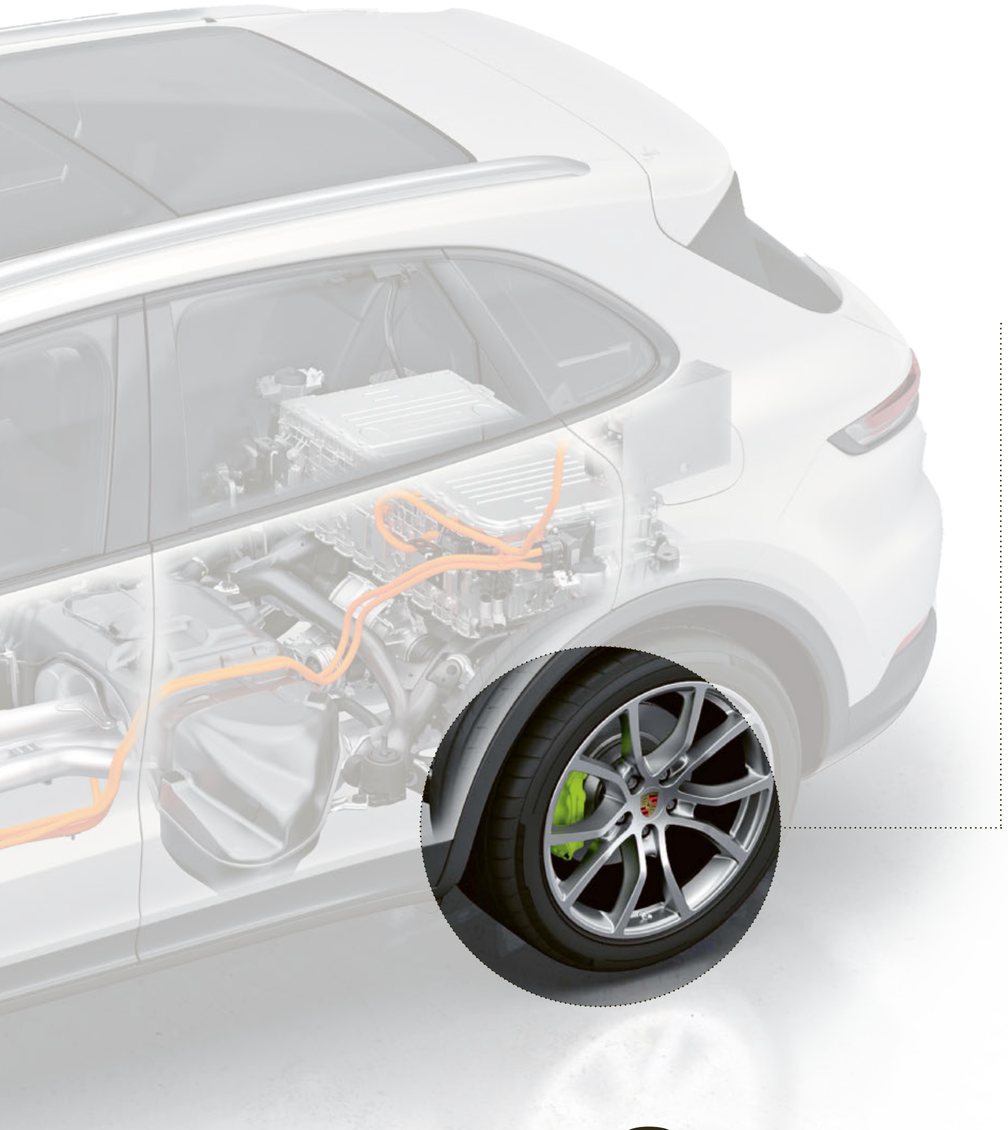
Fuel consumption (weighted):
2.0–1.4 l/100 km
CO_2 emissions (combined): 46–31 g/km
Combined power consumption (weighted):
31.8–28.6 kWh/100 km
Electric range WLTP (EAER): 66–78 km
Electric range WLTP urban (EAER city): 76–90 km

All consumption figures according to WLTP; as of 11/2023

3.

Pulse inverter

Reducing the pulse frequency of the pulse inverter increases its efficiency, enabling a ten percent boost in the power output of the motor. Potentially irritating sounds are avoided through artificial noise around the carrier frequency.



2.

Brake system

The new Porsche Cayenne aims to maximize recuperation when braking in order to increase its electric range. The hydraulic friction brake comes into play, for example, when the deceleration of the electric motor is insufficient. The software for the electromechanical brake booster ensures that the transition is imperceptible.

System integration

The optimal integration of software into the vehicle is decisive in determining the performance and the customer experience. This is also the case with the new Porsche Cayenne, for which Porsche Engineering has developed large parts of the propulsion system and chassis in collaboration with Porsche and suppliers. Thanks to innovative hardware and customized software, the luxury SUV delivers a characteristic Porsche driving experience.

Text: Christian Buck

"One of our central tasks is system integration. This includes the implementation of code in ECUs as well as the calibration and verification of new functions."

Eva-Verena Ziegahn
Director Drive System at Porsche Engineering

Software is increasingly becoming the decisive factor in the vehicle, because it enables new functions and plays an increasingly big role in value creation. However, the customer experience does not depend exclusively on the skills of the programmers—it is also crucial to combine and harmonize software and vehicle hardware in a way that results in optimal performance. This in a way applies in particular to the propulsion system and chassis, which significantly influence the driving experience. Porsche Engineering has therefore founded the new 'Drive System' division, in which experts for hardware and software work closely together in the areas of chassis and propulsion system. The team has the ability to develop and integrate complete systems—from requirement definition and function development, calibrating software and actuators, testing and validation.

FOCUS ON SYSTEM INTEGRATION

"One of our central tasks is system integration," says Eva-Verena Ziegahn, Director Drive System at Porsche Engineering. "This includes the implementation of code in ECUs as well as the calibration and validation of new functions." Porsche Engineering took charge of numerous development scopes while work was progressing on the Porsche Cayenne. From the beginning, the seamless integration of hardware and software was the focus for the propulsion system and chassis. "The Cayenne is characterized by the wide spectrum of driving comfort and sportiness," explains Ziegahn. "This is achieved, for example in the case of active anti-roll stabilization, through innovative software and parameterization as well as integration into the overall chassis. In the process, we have to factor in the complex interactions in the chassis, where all-wheel drive, front and rear-axle steering, the brake system and the electric drive influence the driving experience."

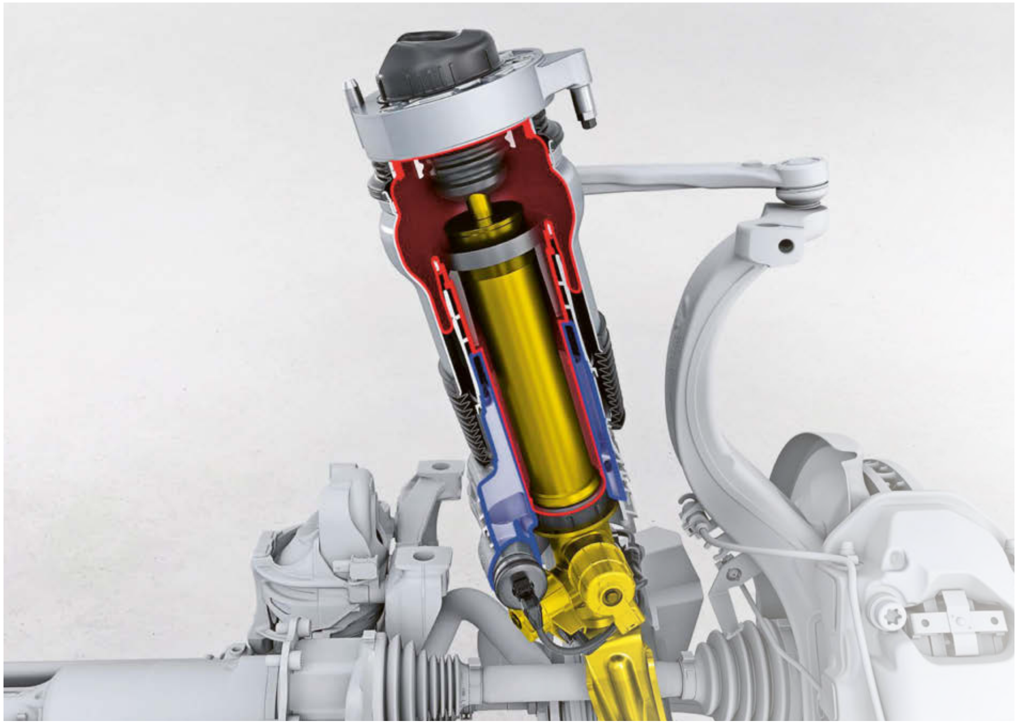
Ziegahn calls the development and calibration of an innovative system in the chassis as an example of a successful interaction between hardware and software: Dampers with 2-valve technology and separate rebound and compression stages are being used for the first time in the luxury SUV. Developed by Porsche Engineering together with a supplier, they allow a broader spectrum between sporty and comfortable driving, resulting in optimized performance in all driving situations. The innovative hardware also made a notable difference when it came to the requirements for software development: "Due to the new 2-valve dampers, the controller components had to be changed and new interfaces to the basic software had to be defined," as Fabian Heitkamp reports, development engineer at Porsche and responsible for the electric chassis platform (EFP). "Moreover, there was only a little we were able to adopt from the previous version for the control unit and the basic software. In short: No stone has been left unturned."

COOPERATION WITH CARIAD

Porsche Engineering had component responsibility for the new control unit and also jointly coordinated the development of the new basic software with Porsche at the supplier. "We also assumed responsibility for the complete functional software," explains Marcus Schmid, Development Engineer at Porsche Engineering and responsible for integration man-

The EFP is the central control unit for the chassis. It records the speed, the height values, the vertical, rolling and pitching movements of the car, the friction coefficient of the road surface, the current driving status such as understeer or oversteer and the data of the chassis systems involved. From this, it calculates the optimal operation of these components and coordinates them quickly and precisely. Thanks to the central control, the customer experiences more pronounced driving characteristics—precise cornering, increased driving dynamics and high driving comfort.

2-VALVE DAMPER SYSTEM
INNOVATIVE PERFORMANCE AT ALL TIMES



The innovative **2-valve damper** system was jointly developed by Porsche Engineering and a supplier. The innovative hardware also required extensive changes to the software for the control unit: Due to the higher complexity of the component as well as the joint development for other model lines, 17 functions are now required instead of 10 previously. To keep pace with the tight schedule and master the high complexity of the task, the developers tested the new software long before the new control unit and the new basic software were available.

"Due to the higher complexity as well as the joint development for other model lines, we needed 17 functions instead of 10 previously."

Marcus Schmid
Development Engineer at Porsche Engineering

agement. "Due to the higher complexity of the new 2-chamber air spring/2-valve damper system as well as the joint development for further model lines, we needed 17 instead of the previous 10 functions, some of which came from us and some from CARIAD."

To keep pace with the tight schedule and master the high complexity of the task, the developers tested the new software long before the new control unit and the new basic software were available. "We try to test the communication and interaction of the various functions as early as possible via hardware-in-the-loop (HiL) or on the test bench," says Ziegahn. "At Porsche Engineering, we have built up an international team at our various locations that supports us at an early stage—both in function development and in HiL testing." The importance of such methods is also emphasized by Michael Becker, Cayenne Chassis Project Manager at Porsche AG: "Without these methods, we would have no chance at all, because it's impossible to install a software version in the car and simply drive off with it right away. With HiL tests, for example, we can check whether the individual software components work together at all. And we can't forget that there are many points in the chassis that are relevant from a legal standpoint."

“Without methods like HiL, we would have no chance at all, because it’s impossible to install a software version in the car and simply drive off with it right away.”

Michael Becker
Cayenne Chassis Project Manager at Porsche

Even in the early stages of development, the developers were able to implement numerous optimizations thanks to virtual methods, making it possible to focus primarily on the fine-tuning in later stages of the development. This will continue to be crucial in the future, as the complexity of the systems and components continues to rise. At the start of the process, model-in-the-loop tests (MiL) examining the behavior of the MATLAB/Simulink models from which the code was later to be generated were carried out. The code then had to demonstrate that it fulfilled requirements in software-in-the-loop tests (SiL). This was followed by processor-in-the-loop (PiL) tests, in which the code ran on a microprocessor that was very similar to the model used later in the ECU. As soon as the new ECU and the new basic software were available, tests were carried out on hardware-in-the-loop test benches.

“Porsche Engineering was able to cover the entire chain—from function development and implementation of the functions in the basic software to the tests and integration in the vehicle,” as Heitkamp underscores. This was made possible by an international team encompassing the whole range of required skills. Experts from Germany, the Czech Republic and Romania were responsible for code generation and the development

BRAKE SYSTEM
IMPERCEPTIBLE TRANSITION

The **brake system** consists of two components: The hydraulic friction brake and the electric motor. The software of the the recuperation function is responsible for the transition (blending) between the two. It also compensates for changing properties of the friction brake, for example due to temperature fluctuations or wear. One particular challenge was that the calculations run on different control units. The software for the brake system could therefore only be applied in the ECU group.

of functions as well as their testing and validation in networked teams, including SiL and HiL tests and test automation. "Porsche Engineering always provided the required resources right when we needed them," says Heitkamp. "In this way, we were able to complete the project on time despite all the challenges."

IMPERCEPTIBLE BLENDING OF FRICTION AND RECUPERATIVE BRAKE

The developers also focused on the interaction between hardware and software for the brake system for the new Cayenne. Their task: The driver should have the best possible pedal feel and should not be able to perceive the respective share of the hydraulic friction brake and the share of the electric motor in vehicle deceleration. The recuperation function is responsible for this 'blending' between the hydraulic friction brake and recuperative braking. The exact composition of this mix depends on numerous factors. "Basically, our goal is to use recuperative braking as much as possible, thereby reducing the average energy requirements of the vehicle as much as possible and thus, among other things, increasing the electric range of the vehicle," explains Lisa Helbig, Development Engineer for Brake and Steering Systems at Porsche Engineering. "The hydraulic friction brake comes into play, for example, when the deceleration of the electric motor is insufficient or when the vehicle could become unstable due to recuperation on the rear axle."

The interconnected software components of the brake system also helps to compensate for changing characteristics of the friction brake in the best possible way. Both the temperature and the wear on the brake over time are taken into account. One particular challenge is that the algorithms run on different control units, which is why the software for the braking system could only be applied to the overall system of control units. While the software for the eBKV originated from a supplier, Porsche Engineering handled the calibration of the functions and their testing. The final step was the approval of the vehicles together with Porsche.

SIGNIFICANTLY BETTER PEDAL FEEL

"We have achieved our goal: The driver does not perceive any interaction during the transition between recuperative and hydraulic braking," as Alexandros Athanasiadis sums up, who was responsible for the approval at Porsche. "Compared to its predecessor, we were able to further optimize the blending. In the end, we are measured by the pedal feel, which we were able to design optimally with the help of the software." As an example, he mentions the new "cold characteristic" for the friction brake. It provides greater brake boosting when the car drives off while the brakes are still cold—and thereby ensures the desired constant pedal feel. In addition to comfort, the efficiency of the Cayenne is also improved by the new design of the recuperation function: The deceleration capacity of the recuperation of the new Cayenne has been increased to up to 88 kilowatts, a roughly 30 percent increase. Moreover, recuperation can now be deployed almost until the vehicle comes to a standstill; before now, the limit was 14 km/h.

Up to

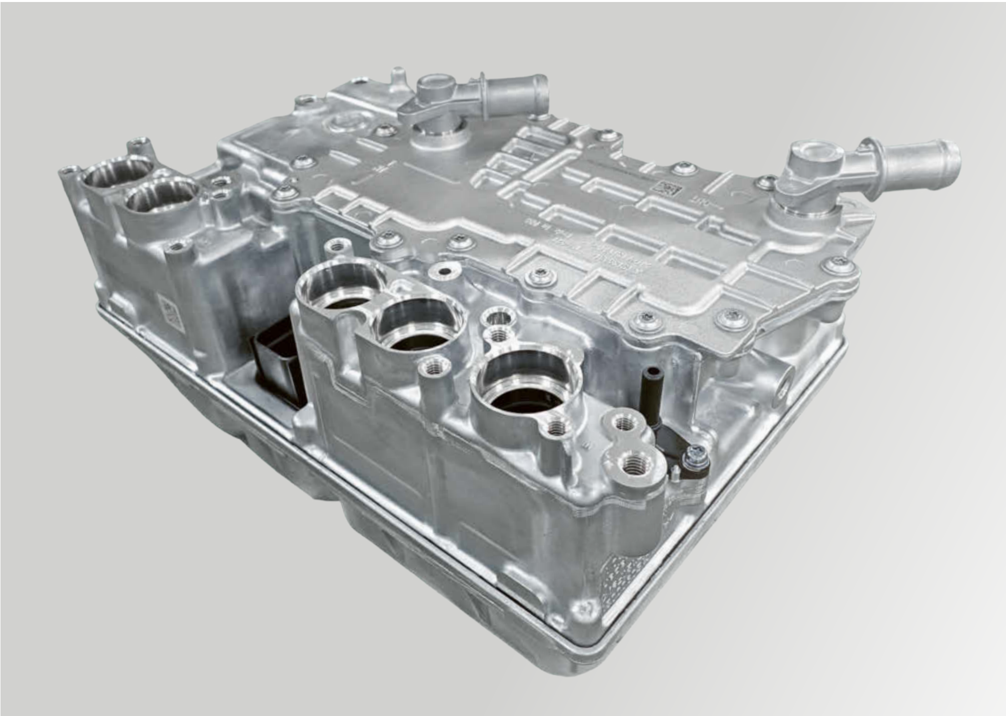
88 kW

of deceleration power is what the new Cayenne can deliver during recuperative braking. This is 30 percent more than its predecessors.

"Porsche Engineering always provided the required resources right when we needed them."

Fabian Heitkamp
Development Engineer at Porsche

PULSE INVERTER
WHISPER QUIET WITH OPTIMIZED EFFICIENCY



Generation of training data

The **pulse inverter** supplies the electric motor with energy depending on the driver's power requirements. To do so, the DC voltage of the high-voltage battery is switched on and off at a high frequency. The ratio of on to off time determines the power of the engine. Reducing this frequency increases the efficiency of the electronics—but at the same time irritating sounds can also occur. To avoid this, it is randomly varied by noise, which means that no single frequency is perceptible.

"Basically, our goal is to use recuperative braking as much as possible, thereby increasing the electric range of the vehicle."

Lisa Helbig
Development Engineer at Porsche Engineering

NOISE SUPPRESSES NOISE

In addition to the new damper system and the hybrid brake, Porsche Engineering was also involved in the development, testing and validation of the pulse inverter (PWR) for the new Cayenne from the very beginning. In this case, the main thing was to make the transition from the combustion engine to the electric motor imperceptible to the driver while at the same time enhancing the vehicle's performance. Among other characteristics, the newly developed pulse inverter is characterized by a variable switching frequency and different modulation methods, which are optimized according to the current operating point. "Reducing the pulse frequency of the pulse inverter increases its efficiency, enabling a ten percent boost in the power output of the motor—only through intelligent control via software," explains Pascal Heusler, Senior Manager Pulse Inverter Software and Calibration at Porsche. "This has a drawback in terms of noise. However, because this approach produces noise. The solution to this is to generate an artificial noise around the carrier frequency, which dilutes this motor noise." However, this approach cannot be applied to every operating point. The idea: The controller

“The driver does not perceive any interaction during the transition between recuperative and hydraulic braking.”

Alexandros Athanasiadis
Development Engineer at Porsche

must react within a few milliseconds and adjust the switching frequency if necessary. “It’s a very innovative solution,” says Heusler. “We improve the system efficiency and at the same time ensure that with the sophisticated sound composition, the driver doesn’t hear a thing.”

The pulse inverter in the new Cayenne is used as a modular system throughout the VW Group—the same control unit is used in almost 100 different vehicle variants that use five different electric motors and three different transmissions. In addition, they are based on different platforms—either the new Volkswagen E^3 electronics architecture or MLBevo. So system integration in this case also meant integration across different brands and vehicle classes, which the developers succeeded in doing. “From the outside, the variants can only be distinguished by their different connectors, the inner parts are always the same,” as Frank Deckert reports, Project Manager for Pulse Inverter Integration at Porsche Engineering. “We covered the entire variance with a single piece of hardware.”

BALANCING ACT WITH THE CALIBRATION

In order to reduce the work involved in the calibration, out of the roughly 100 vehicles developers formed 11 groups with comparable characteristics, for example in terms of their performance and powertrains. All vehicles in a group receive the same data input, which poses a major challenge. The thermal model for the rotor and stator, for example, has a major influence on torque accuracy and component protection, but in turn depends heavily on the installation position in the vehicles. The configuration therefore requires a balancing act between the different models. The standardization of the calibration brings great advantages for future updates: By limiting the variance, the software maintenance effort is reduced (cost efficiency by concept). “Overall, we have developed a top-notch system with state-of-the-art control,” says Heusler. “We were only able to achieve this because we worked closely with Porsche Engineering and our colleagues did a great job.”

The new Cayenne has been on the market since July 2023. Porsche and Porsche Engineering are currently working together on system integration for the variants of the luxury SUV. Another important success factor was the high level of trust between the contractor and the client. “At the beginning of such a project, not everything is defined to the last detail. There are situations in which you have to step in from one day to the next and temporarily expand the team with additional experts,” says Porsche project manager Becker. The approach of bringing hardware and software experts together at an early stage has proven fruitful. “The Cayenne project shows how important systematic system integration is,” says Ziegahn. “And it illustrates the important role simulation plays in development today. With them, we can do a lot of the preparation work for integration outside of the vehicle and later focus on the fine tuning. This is the only way to keep pace with the ever-increasing complexity of recent years.”

SUMMARY

Porsche Engineering handled both the team management of the chassis series development team, including FAS/HAF, and large parts of the development of the propulsion system and chassis for the new Porsche Cayenne. The focus was on the characteristic Porsche driving experience, which requires optimal interaction of the hardware and software. A key factor in the project’s success was the successful system integration of all components.

“We covered the entire variance with a single piece of hardware.”

Frank Deckert
Project Manager for Pulse Inverter Integration at Porsche Engineering

ANY QUESTIONS?

Some questions just have to be asked. We have the answers—delivered with an amusing twist. This time:

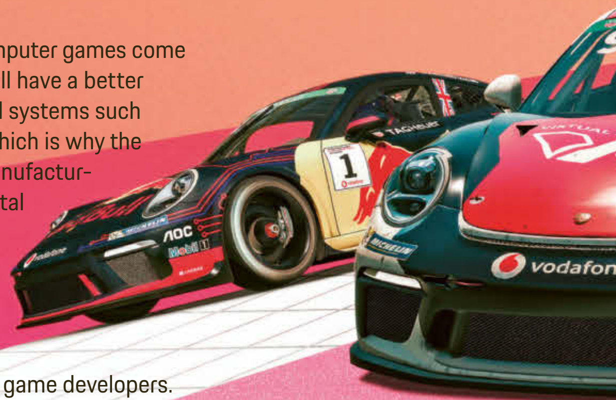
Who is closer to reality: Vehicle developers or gamers?

Text: Christian Buck
Illustration: Julien Pacaud

Many are sure to remember the early days of racing games, when the graphics of 'Gran Turismo' or 'World Racing', revolutionary by standards of the time, caused a sensation.. From today's perspective, the enthusiasm at the time is somewhat baffling. The reaction today is more likely along the lines of: "That's what it looked like? That's not how I remember it!" Today, instead of pixelated roads we find razor-sharp landscapes that are so lifelike that they are even used for automotive development.

After all, there's one thing gamers and automotive developers have in common: They want to transfer reality into the virtual world in as much detail as possible—some to feel like they're in a real car while gaming, and others to test new vehicle functions with the aid of simulations. But who's leading the way here?

The answer to this question is: It depends. Even though today's computer games come very close to the driving performance of real racing cars, engineers still have a better understanding of the physics of driving and the properties of standard systems such as ABS or ESP. Even the behavior of the tires is difficult to replicate, which is why the game manufacturers tend to use more general tire models. "Some manufacturers of computer games do, however, go to great lengths to create digital likenesses of the originals," says Sebastian Hornung, CEO of Porsche subsidiary OverTake. "For example, a company from Italy searched through racing protocols from the 1970s in order to recreate the Porsche 917 and the Porsche 956 in the computer over months of painstaking work."



When it comes to the look of digital racing cars, Porsche helps the game developers. They receive 3D models of the current vehicles from the sports car manufacturer. If necessary, they can measure the dimensions of historic racing cars in the Porsche Museum by laser scan, and even record their sound. "Because the game manufacturers always use the latest graphics engines, the models they create are likely to look a little better," Hornung suspects.

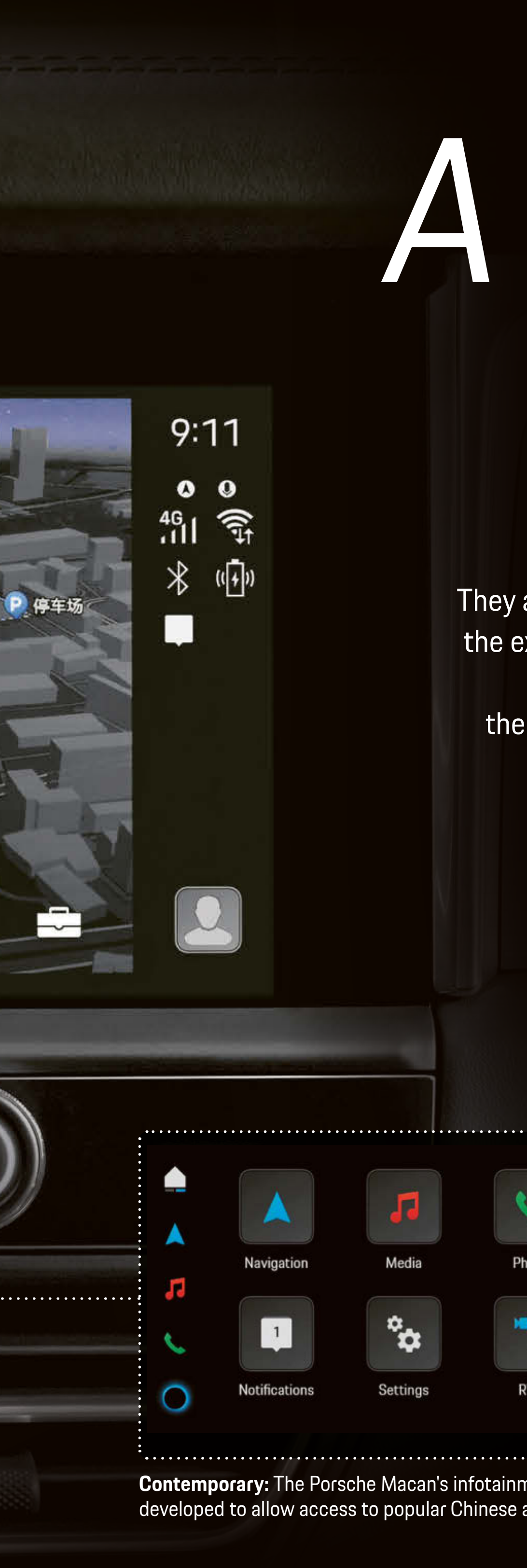
On the track, they're neck and neck. This is because both game manufacturers and engineers use service providers that can use laser scans to detect even the smallest unevenness on the road surface. The vehicle developers also work with the same high level of precision on ordinary roads, such as freeways, which are measured exact to the millimeter for route modeling article. Data like this is generally not available to the game manufacturers.

In the meantime, Porsche is working on automating the digitalization of roads with the help of the 'Virtual Roads' app, thereby opening up new use cases. In doing so, video recordings—recorded on smartphone through the windshield—are expected to serve as the starting point for the creation of a route model. In the future, the app could, for example, be used at events.

Battling it out: Realistic models are important both for computer games and vehicle development. When it comes to driving performance, manufacturers have a leg up.

PERFORMANCE AND EXPERTISE

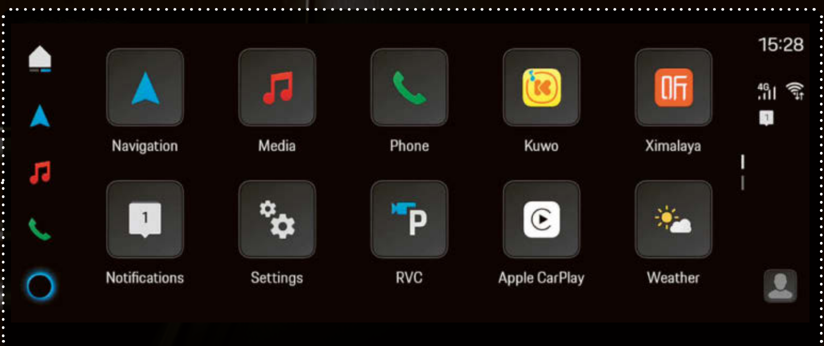
DEVELOPMENT AND VALIDATION



A PLATFORM FOR CHINA

Digital ecosystems have grown at a rapid rate in China over the last few years. They are now an integral feature of everyday life. This has a corresponding impact on the expectations placed on vehicle infotainment systems. As part of model updates, Porsche and Porsche Engineering, in conjunction with a Chinese supplier, have therefore developed a new control unit for the infotainment system in the Boxster, Cayman, and Macan—in record time and 'in China for China'.

Text: Christian Buck



Contemporary: The Porsche Macan's infotainment system has been developed to allow access to popular Chinese apps.

The infotainment system plays a particularly important role for Chinese customers when it comes to purchasing a vehicle. They expect features such as convenient, dialog-oriented voice control and the availability of popular country-specific apps, for example for mobile access to music, podcasts, videos, messaging services, and the provision of real-time information using cloud-networked map and navigation functions. Many local traffic guidance systems are cloud-integrated, meaning that the waiting time at a red light, for example, is available as real-time information and, if the driver has the appropriate apps, can be displayed in the form of a countdown. "For that to work, a vehicle has to be equipped with the right hardware and software, as well as an appealing user interface. That's why we regularly perform model updates on our vehicles: So that they can keep pace with rapidly evolving customer expectations," reports Michael Ackermann, Senior Expert Digital Product Line Macan at Porsche AG. "In 2022, we decided to

Expectations met: The 718 is one of the models offering Chinese customers the latest Internet services.

"In Germany, a lot of the tests wouldn't have even been possible, because the map material installed, for example, was intentionally limited to China."

Stefanie Ebert
Project Manager
at Porsche Engineering

develop a new Android-based infotainment platform for the 718 and the Macan that would be suitable for China's current Internet services and which would offer customers what they expect from us."

DEMANDING SCHEDULE

This meant that the new infotainment system needed to offer access to popular apps such as Ximalaya for news and podcasts, WeChat for messaging, iQIYI for video streams, and Kuwo Music, a streaming service comparable to Spotify. Improvements to the navigation system were also planned; it is expected to make use of maps and traffic guidance information from the Chinese provider Amap in the future. Voice control was also set to be raised to the next level, allowing colloquial commands such as "I wanna go to the station and get gas on the way" to be processed with ease.

In addition to the technology, there was another challenge: The demanding schedule. The project needed to be completed as soon as possible due to the rapid pace of technical development in the world of infotainment. "That's how we came up with the idea of looking for a supplier in China who could take care of development in China for China," Ackermann explains. That was where Porsche Engineering got involved: The company has a large development site in Shanghai, many local engineers, and numerous on-site testing options. "In spring 2022, we put together an international team of colleagues from Germany and China," says Thomas Pretsch, Director Infotainment at Porsche Engineering. "Our first task was to determine current customer expectations and to evaluate different Chinese suppliers. We also compiled all the specifications for the hardware, software, and user interface."

The job faced by the future supplier was just as clear as it was demanding: A new, state-of-the-art infotainment system was needed—but without changes having to be made to the two vehicle models to accommodate the new solution. "Factors such as the size, the installation points, and the ventilation had to remain the same," Pretsch explains. After an extensive market analysis and a proof of concept submission from two suppliers, Porsche Engineering recommended one of the two companies as the manufacturer of the new infotainment system. Among other things, the company produces head units, complete screens, and solutions for rear seat entertainment. "This supplier had a suitable platform in its range that could form the basis for a new development," says Stefanie Ebert, who is responsible for managing the project at Porsche Engineering. "The company had also previously worked for Volkswagen, which meant that it was already familiar with the Group's processes and was already connected to several systems."

Porsche accepted the recommendation and, once the supplier had been selected, the project needed to start as soon as possible. To ensure efficient and rapid collaboration, Porsche Engineering set up its own development team in Shanghai, which included several

Arriving in comfort: Customers and China benefit from features such as an improved navigation system based on data from map provider Amap.

"The collaboration was excellent—and meant that we could give our customers a lot of new features in a short time."

Michael Ackermann
Senior Expert Digital Product Line Macan at Porsche

Macan
Fuel consumption (combined): 10.7–10.1 l/100 km;
CO_2 emissions (combined): 243–228 g/km

Boxster
Fuel consumption (combined): 9.7–10.1 l/100 km;
CO_2 emissions (combined): 247–201 g/km

All consumption figures according to WLTP; as of 11/2023

function managers—including those for the navigation system and the Digital Assist voice control system. The developers' tasks included managing the supplier and deciding on the functional definitions. They also oversaw and coordinated all modifications to the user interface, without neglecting the characteristic Porsche look that customers expect.

"In addition to the day-to-day cooperation with the supplier's resident engineers who were seconded to Porsche Engineering China, there was at least one meeting a week in China about new software releases," Ebert reports. The developers at Porsche Engineering in Shanghai also made sure they consistently coordinated with their colleagues in Germany. The Germany-based colleagues, in turn, formed the interface with Porsche AG and its managers, such as those in the infotainment and user interaction development departments. Axel Huber, project manager for infotainment and user interaction at Porsche: "It was important for us to have an expert partner familiar with the processes at Porsche and able to act independently and on their own initiative, without forgetting to consult with us on important decisions. Collaboration with Porsche Engineering and the system supplier was always very constructive." Other interfaces with Porsche AG were the Macan and 982 model series, the quality assurance department, procurement, and sales.

Systematic testing of hardware and software was carried out by Porsche Engineering in Shanghai. "This meant that we benefited from the local expertise and market knowledge of our Chinese colleagues," reports Ebert. "What's more: In Germany, a lot of the tests wouldn't have even been possible, because the map material installed, for example, was intentionally limited to China."

EXPRESS ROUTE TO SUCCESS

In addition to the strict installation space requirements and the need to adapt the user interface to the Porsche design, the electrical compatibility of the new infotainment system with existing components such as the operating elements, instrument cluster, and reversing camera also proved to be a technical challenge. As most customers choose a Bose amplifier for their new Macan or 718, there also needed to be a way to connect it to the new hardware by means of a fiber-optic cable. "We usually use MOST as the interface for this, but the supplier did not yet have any experience with that kind of bus," as Pretsch notes. "The Chinese engineers worked on this new aspect with great dedication, and were also able to successfully integrate this interface into the new hardware platform." Once it had been ensured that the development satisfied the extensive requirements, Porsche Engineering issued its approval recommendation for the new infotainment system.

Porsche and Porsche Engineering, together with the supplier, were able to put this challenging project on an express route to success: Production of the new infotainment system started in China at the end of September 2023, and installation in Macan, Boxster, and Cayman vehicles began in Germany at the end of November. The first of these vehicles was delivered to customers at the beginning of 2024. As was the original plan, no changes needed to be made to the vehicles—even the wiring harness and its many connections to the infotainment hardware remained exactly the same. "Only the label tells our production colleagues that they are installing different hardware in the vehicles for China," says Ackermann approvingly.

"Despite the very tight schedule of just 18 months, we completed the project on time and within budget," concludes Ackermann. "We would normally have needed three years, and it was only possible because we truncated our internal processes and reduced them to the bare necessities—without, of course, sacrificing quality or adherence to legal requirements." Ackermann added that the supplier showed great diligence and quickly solved any challenges that arose. He also praised the exemplary collaboration with Porsche Engineering: "We maintained an intensive dialog throughout the project, and our colleagues were always very well prepared. Overall, the collaboration was excellent—and meant that we could give our customers a lot of new features in a short time." ●

“COURAGE IS THE FUEL THAT DRIVES INNOVATION”

Artificial intelligence (AI) and autonomous driving: Automotive development has never been so exciting. Federico Magno (Member of the Executive Board of Porsche Consulting) and Dirk Lappe (Chief Technology Officer of Porsche Engineering) discuss the major future trends and the role played by courage in development in our expert interview.

Text: Porsche Engineering
Photos: Nói Crew

Visionary thinkers: Federico Magno (left) and Dirk Lappe talk about the opportunities offered by artificial intelligence.

TRENDS AND TECHNOLOGIES

INTERVIEW

“The human ability to learn from experience and to apply intuition and emotional intelligence remains unique.”

Dirk Lappe

How far do you think AI development will go and what role will it play in our society? Are there specific limits or end goals to AI development?

— **LAPPE:** Artificial intelligence (AI) has made impressive progress, however, it does have limits compared to human inventiveness. AI is very strong when it comes to detecting patterns, analyzing data, and executing specific, learned tasks. But the types of creativity and innovation that humans exhibit are difficult for AI. AI can process data based on previous information, but—unlike humans—it can't come up with completely new ideas or concepts. The human ability to learn from experience and to apply intuition and emotional intelligence remains unique. The intelligence associated with conscious perception, i.e. the awareness of one's own existence and the ability to process experiences subjectively, is a major challenge in the context of AI. Current AI systems can process data based on algorithms and machine learning, and can even make decisions. But they do not have any awareness in the sense that humans do.

— **MAGNO:** Our awareness also comprises emotions—something that I, as an Italian, know all about! Emotions include things like self-assurance, subjective experiences, and our understanding of ourselves in the context of the world. These aspects are deeply rooted in human psychology and are embedded in our brains. AI systems have no personal experiences; in other words, they don't know what they're doing or, to be more precise, what they've done. They act without feeling. This self-referential intelligence of humans, as it is known, is another fascinating characteristic. It refers to how humans think about themselves, how they develop self-awareness, and how they understand and reflect on their own mental processes.

What's special about that?

— **MAGNO:** It has been said that self-understanding is the first step towards improvement. And, if you take that literally, it describes quite neatly what differentiates us from artificial intelligence—at least for now. Our self-knowledge means that we are able to learn from our mistakes. This type of intelligence is uniquely complex as it includes not only cognitive abilities, but also emotional and social aspects. Machines are scarcely able to emulate this kind of intelligence. AI systems can be programmed to analyze their performance and to adapt to certain tasks. And yet that is nothing other than cold self-optimization, an anemic, emotionless process. The systems have no awareness of themselves the way humans do.

And what does that mean for the vehicles of the future?

— **LAPPE:** With regard to future developments, such as the vehicle of the future, it is easy to speculate that AI could achieve or even surpass human-like capabilities in certain areas. Nevertheless, aspects such as creative thinking, empathy, and general problem-solving skills are likely to be limits that AI will find difficult to overcome. The future of automated driving looks promising, all the same. Impressive developments are being made outside of AI, such as ones to sensor systems. These advances could make traffic safer and more efficient. Automated vehicles could also improve mobility for people who can't drive themselves, or don't want to. However, along with technical complexity, there are also challenges, such as legal issues, data protection and social acceptance.

What role is played by the self-referential intelligence that Mr. Magno just described?

— **LAPPE:** Self-referential intelligence of the kind that humans are endowed with is not necessarily crucial to autonomous driving. Autonomous vehicles use AI systems that process and react to information about their surroundings as a basis, but need no self-awareness or understanding of their own existence to do so. For autonomous driving, other aspects of AI are more important, such as the ability to register its surroundings—other vehicles, pedestrians, traffic signs, and the road conditions—with accuracy. Its ability to use sensor data and programmed algorithms to make safe and efficient decisions is also relevant, as is, ultimately, its capacity to adapt to different traffic conditions and unpredictable events. These capabilities allow autonomous vehicles to navigate and operate safely without the need for self-referential intelligence. If, during autonomous driving, not all perception data is available, this brings several challenges, to which there are also several possible solutions. Autonomous vehicles are often equipped with redundant systems such as multiple sensors and cameras. If one sensor fails, others can compensate for the missing data. If there is insufficient data, autonomous systems tend to drive more carefully by slowing down, for example, or even stopping until more information is available. Experience can teach vehicles how to handle incomplete data better. Connectivity with other vehicles or with the road infrastructure can provide additional information. Safety is always the top priority.

And what about completely driverless mobility?

— **LAPPE:** Let's first have a quick look at what that means. We know that there are five levels of automated driving. Each level introduces more automation and less need for human intervention. Level 1—driver assistance: There are systems in place such as cruise control and lane keeping assist, but the driver needs to constantly intervene and maintain control. Level 2—partial automation: The vehicle can perform certain tasks such as steering, accelerating, and braking, but the driver still has to monitor the surroundings and be ready to step in. Level 3—conditional automation: Under certain

Dirk Lappe
has been Chief Technology Officer (CTO) of Porsche Engineering since 2009. Before that, he was its Director of Electrics/Electronics Development. After studying in Braunschweig, the graduate engineer—who specialized in electrical engineering, electronics, and communications technology—worked as a development engineer, project leader, group manager, advisor, and Head of UMTS predevelopment at Bosch.

"Courageous developers and businesses have the power to inspire others. They show that it's possible to put visionary ideas into practice."

Federico Magno

conditions, the vehicle can drive itself, but the driver needs to be ready to take control if needed. Level 4—high degree of automation: The vehicle can drive autonomously in most situations without the driver needing to take action. There does remain, however, an option for manual driving.

— **MAGNO:** And then we get to the cream of the crop, level 5—fully automated driving. In this case, the vehicle is responsible for all driving tasks under all conditions. There is no need for a driver or even a steering wheel. This is the level that will prove to be very difficult to achieve in the coming years due to the amount of data and processing power required, as well as the very expensive sensor technology needed. Autonomous vehicles are highly dependent on the available and learned dataset, and on that dataset being up to date. Most of the data needs to be continuously collected by the vehicle itself. To analyze the data, however, an autonomous vehicle drives millions of kilometers virtually in simulations, where it learns to make the right decisions.

Federico Magno has been Member of the Executive Board of Porsche Consulting since 2017. He heads the company's Operations, Brand & Sales and Development & Technology units. He also leads the Automotive, Aerospace and Transportation units. Federico Magno studied economics at Bocconi University in Milan.

What exactly distinguishes the system from a human?

— **MAGNO:** In principle, not much, at least to begin with. Humans also use their senses to register their surroundings, traffic, road conditions, signs, and the dimensions of their vehicle. They generally have only limited data at hand, such as knowing where a certain road is or where to turn. And this data is easy to expand with an old-fashioned road map, for example. Humans, however, don't need to drive millions of kilometers to pass the driving test. The requirements to obtain a driver's license usually include a certain number of driving lessons and theoretical instruction, followed by a practical and a theoretical test. After that, humans can use their self-referential intelligence to make up for the rest: They don't need to have been in every possible situation before in order to know which action to take. It doesn't matter if it's a green ball or a red one that rolls onto the road; humans still know to stop because a child might well be running after it. An autonomous vehicle first needs to be taught both situations. And that's just one basic example. From today's perspective, it remains uncertain whether fully autonomous vehicles will ever be able to find all the necessary answers for level 5 in simulations and tests.

Mr. Lappe, how does Porsche Engineering intend to influence progress in mobility in the future?

— **LAPPE:** With courage! As in recent years, we will continue to show courage in development in the future—because that is consistently the fuel of innovation, progress, and positive change. Developments, whether they be of a technological, scientific, or social nature, often require courage. Courage in development is more than just a personal quality. There are many reasons why courage in development is of crucial importance. It's the engine of innovation. It empowers developers to explore new ideas and create innovative solutions that cross the boundaries of what is already known. Without courage, a lot of groundbreaking discoveries and inventions would never become reality.

Mr. Magno, what is Porsche Consulting's view of the future of mobility?

— **MAGNO:** The development of mobility has always been characterized by many uncertainties and risks that should not be underestimated. However, the risk of failure is, today, a financial one and fortu-

Taycan Turbo S Sport Turismo

Power consumption (combined): 24.0–22.6 kWh/100 km
CO_2 emissions (combined): 0 g/km
Range (combined): 430–456 km
Electric range (urban): 518–562 km

All consumption figures according to WLTP; as of 11/2023

nately no longer a life threatening one, as it was, for example, in the first few years of aviation. This is another area where AI helps us to better find rare errors that potentially would have ended disastrously in the past. Businesses that exhibit courage do not consider errors insurmountable obstacles or signs of failure. Instead, they see errors as valuable opportunities to learn and improve, and to develop a product that will serve everyone.

It sounds like you both consider courage to be the central enabler when it comes to developments and innovations, including ones in mobility…

— **LAPPE:** That's right. Developments can run into many obstacles and challenges. Courage means that developers can overcome these obstacles, find creative solutions, and face up to great difficulties. In a constantly changing world, courage is required to adapt to new technologies, trends, and customer needs. Courageous developers are open to change and are ready to rethink existing concepts and business models.

— **MAGNO:** I'd go even further and say that courageous developers and businesses have the power to inspire others. They show that it's possible to take risks and to put visionary ideas into practice. Their actions encourage others to be courageous and to blaze innovative trails. Courageous development can bring about far-reaching social change by offering solutions for pressing social problems. Examples range from breakthroughs in the medical field to sustainable environmental initiatives.

— **LAPPE:** Courage is, not least, a key to promoting personal and professional growth. At the same, it drives progress in development as well as overall social progress.

— **MAGNO:** Having a competitive edge like that can be crucial in an increasingly globalized world. Courageous businesses are often able to distinguish themselves from their competition by opening up new markets and offering innovative products and services. Their courage promotes a positive working environment where people are ready to share their creative ideas and pursue pioneering projects.

— **LAPPE:** To sum up, courage in development is a driving factor for change and progress towards the mobility of the future. It helps us to overcome challenges, and shape the world with innovative ideas and solutions. Courageous development is a

“AI has the power to revolutionize business processes— at least if it’s used right. And that, too, will take a certain amount of courage.”

Federico Magno

“AI will revolutionize automobile development by making vehicles safer, more efficient, and more user friendly.”

Dirk Lappe

driver of positive change and should therefore be promoted and valued at every phase of a development project. It's the key to a better future.

And what about the future of AI?

— **LAPPE:** The future of AI in automobile development is promising and diverse, and not just when it comes to autonomous driving. AI has the potential to contribute to improving vehicle safety systems by spotting dangerous situations faster and initiating preventive measures. Vehicles can be individualized based on requirements, resulting in a whole new driving experience. For development and production, AI systems can optimize processes, save resources, and increase product quality. AI is able to forecast maintenance needs, which is already reducing downtime and increasing the service life of vehicle components. We will also begin to experience more advanced connectivity functions in the car, including a connection to big data and IoT applications. AI enables us to make vehicles more environmentally friendly by optimizing their fuel consumption and supporting the development of electric vehicles. Overall, AI will revolutionize automobile development by making vehicles safer, more efficient, and more user friendly.

— **MAGNO:** Over the long term, additional big leaps in innovation are already in sight. Neuromorphic systems that mimic the structures and functions of the human brain could play a key role in the ongoing development of AI technologies in the future. These chip-based systems could be more efficient and faster than conventional processors, especially when processing sensory data. They could make decisions in real time—thereby rivaling even the decisiveness of humans. Systems of this nature are designed to better process complex and unstructured data of the kind found in the real world. That will shape the future of mobility, and not just in the form of fully autonomous, level 5 vehicles, but also in the way mobility will be organized and the new business models that will emerge as a result. At Porsche Consulting, we already use AI in a wide range of areas such as sales, development, production, and even marketing. And we know that it has the power to revolutionize business processes— at least if it's used right. And that, too, will take a certain amount of courage.

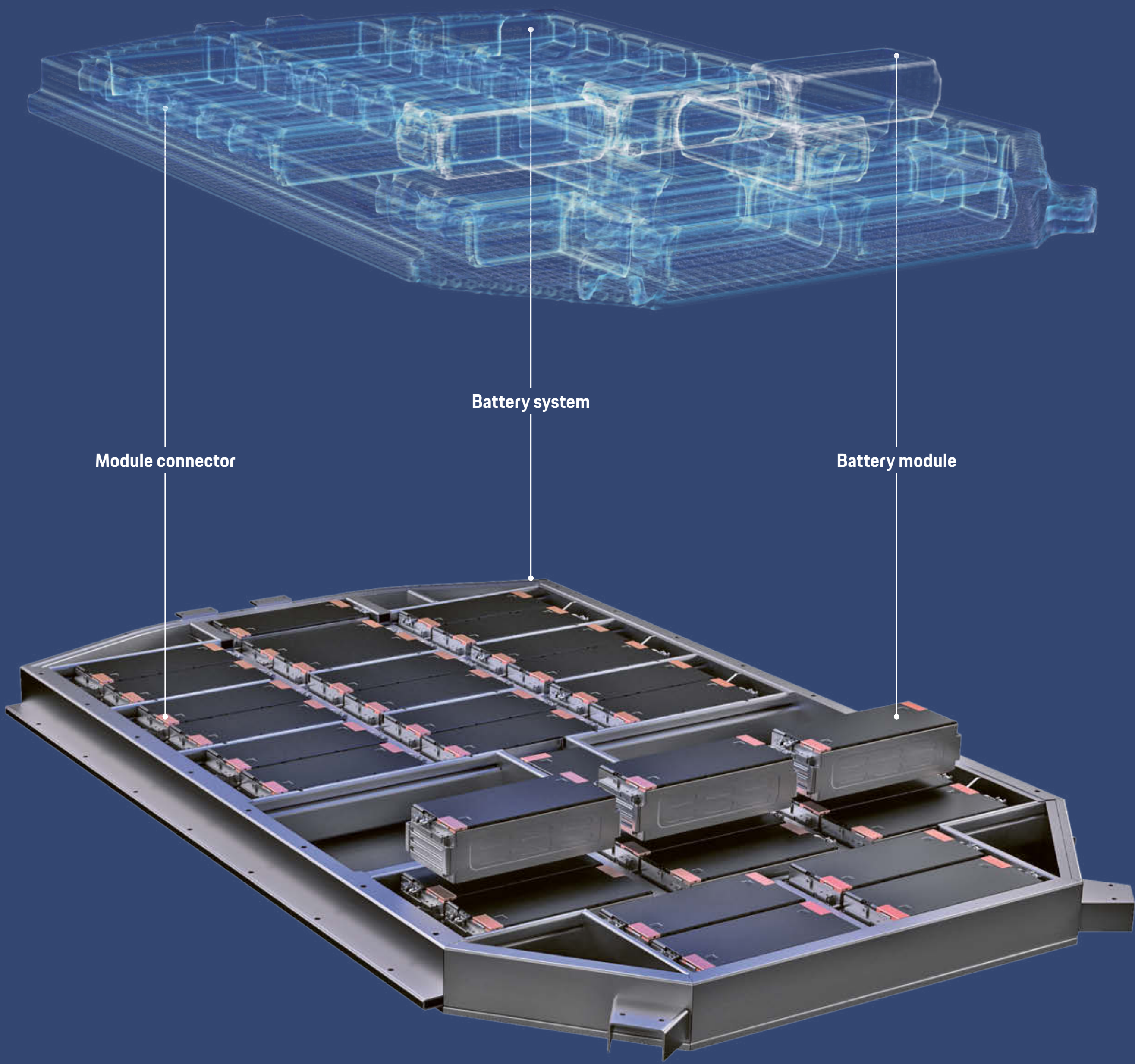
— **LAPPE:** Physical computing models that mimic natural processes can also help to develop more efficient and more robust AI systems. These kinds of models could be able to handle uncertainties and incomplete information better, something that is crucial to autonomous driving. Such technologies are promising, but are still in an early stage of development. They could lead to significant breakthroughs in AI, particularly with regard to flexibility, learning capacity, and adaptability.

"The development of an AI with conscious perception or even self-referential intelligence would be an enormous leap ahead. It would, however, also present a lot of legal, ethical, philosophical, and technical questions that we would have to address."

Federico Magno

— **MAGNO:** The development of an AI with conscious perception or even self-referential intelligence would be an enormous leap ahead. It would, however, also present a lot of legal, ethical, philosophical and technnical questions that we would have to address.

— **Lappe:** We will see major advances in autonomous vehicles up to level 4 and will be able to produce high-quality and safe products. However, we will continue to see relatively few level 5 vehicles on the roads for many decades to come due to a dearth of complete data. Even in the foreseeable future, most vehicles will continue to have a steering wheel that intelligent humans will be able to use to override artificial intelligence and assume control of the vehicle.



Precise replica: The digital twin of a battery operates exactly like the original and provides information on the expected aging process.

Glimpse into the future

Batteries are crucial components of electric vehicles—not least because they significantly influence the residual value. OEMs and suppliers are therefore keen to understand the details of how battery cells and systems age and the impact that driving behavior / handling have on their service life. For this purpose, Porsche Engineering is developing a digital twin of a high-voltage battery.

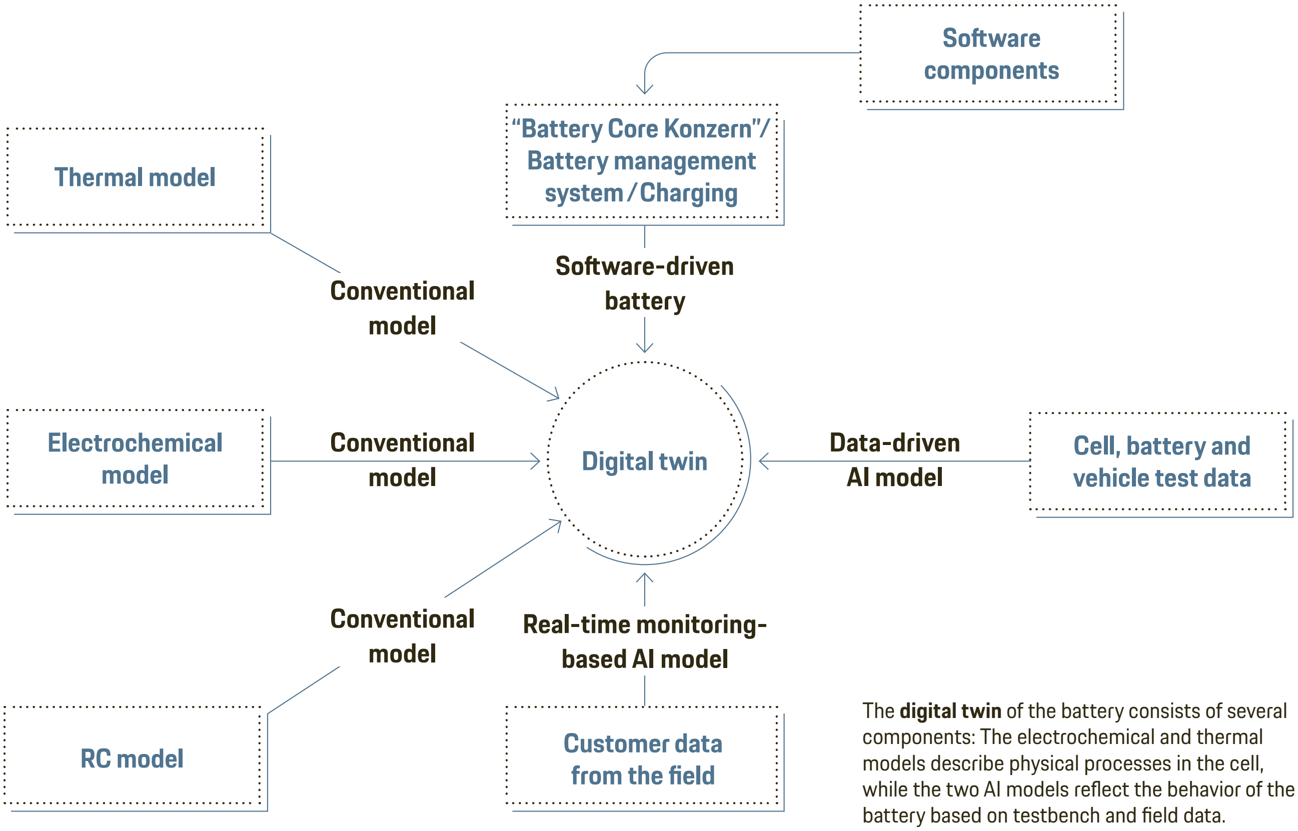
Text: Constantin Gillies

How will a system for which there is no long-term track record behave in the future? The space agency NASA has grappled with this question for decades. Their probes, after all, frequently embark into unknown environments equipped with the latest technology. To better assess the life cycle of spacecraft, NASA researchers developed the concept of a 'digital twin' in the early 2000s: The real aircraft was replicated down to the most minute detail as a model in the computer, and was then used to play out the unknown scenarios—decades of travel, for example.

Porsche Engineering takes the same approach to optimizing the high-voltage battery of electric vehicles. "We need to understand how the cells will behave in the field over the long term—without being able to draw on many years of experience, as is the case for the combustion engine," explains Joachim Schaper, Senior Manager AI and Big Data at Porsche Engineering. The Battery Digital Twin is intended to provide a glimpse into the future: The digital representation of the battery operates exactly like the original and provides information on the expected aging process. It can also be used to improve the service life and performance of the battery. AI experts from Porsche Engineering in Germany and the Czech Republic are therefore working flat out on the Battery Digital Twin.

With ever-rising demands on the durability of batteries, not least in the legal realm, the topic is very much front of mind. From August this year, anyone who puts batteries into circulation in the European Union has had to provide information on performance and durability in accordance with the new EU Battery Regulation (BATT2). The US state of California has already set minimum standards: From the 2030 model year, electric vehicles must still achieve at least 80 percent of their original range after ten years or 150,000 miles (241,000 km) of mileage. This is

THE DIGITAL TWIN
A COMBINATION OF PHYSICAL AND AI MODELS



The **digital twin** of the battery consists of several components: The electrochemical and thermal models describe physical processes in the cell, while the two AI models reflect the behavior of the battery based on testbench and field data.

"We need to understand how the cells will behave in the field over the long term— without being able to draw on many years of experience."

Joachim Schaper
Senior Manager AI and Big Data at Porsche Engineering

stipulated by the California Air Resources Board in its "Advanced Clean Cars II" regulation of November 2022. A similar regulation could apply in the EU in the future. It is therefore essential for OEMs to be able to provide precise information on the durability of vehicle batteries.

DETECTING PATTERNS OF BEHAVIOR

To create a digital twin of the battery, the engineers provide a modular, scalable framework for integrating existing and future model components. The basis for this is a performance module that describes the electrical capability of the battery in a simplified manner and can build on established approaches such as the resistor-capacitor model. In addition, there is a more complex electrochemical model that simulates the processes in the battery cell at the level of individual particles—the interaction between anode, cathode and electrolyte. Another facet is the thermal model, which can be used to predict how the battery will react to cold or heat.

The models are mainly based on laboratory tests with individual cells or cell modules and their ability to predict how the battery will behave in the vehicle is limited. The experts at Porsche Engineering therefore use real field data taken from test vehicles or test benches on which cells are tested. They are supplemented with data from the fleet, provided that customers participate in a data exchange program.

With the help of the field data, AI algorithms are trained to recognize patterns in customer driving behavior. Temperature or voltage deviations in individual cells, for example, can indicate premature wear and abnormalities. However, AI can only recognize aspects for which there is an existing data basis in the field. It can't make predictions about long-term aging effects, as there's hardly an e-vehicle on the road that is more than four years old. This is why the engineers at Porsche Engineering are bringing the two worlds together: "The success lies in combining existing model-based components with AI methods," explains Adrian Eisenmann, Development Engineer at Porsche Engineering.

Some start-ups are already directing their exclusive focus on the analysis of battery data. However, just looking at cells and modules is not enough, Schaper emphasizes: "You also need comprehensive knowledge of the processes in the vehicle." Porsche Engineering is at home in both worlds: For example, the engineers have developed large parts of the battery management system for Porsche electric vehicles as well as pulse inverters for the powertrain. At the same time, Porsche Engineering also employs highly specialized battery data scientists.

An initial function at Porsche Engineering China called 'Repair Prediction' has already emerged from the work on the digital battery twin. It is based on a machine learning algorithm that monitors the battery data and warns of signs of wear or abnormalities. "This allows the customer to be notified proactively," says Lars Marstaller, Product Owner Battery Analytics at Porsche Engineering. The predictive function also shortens any workshop visits, as necessary spare parts can be ordered at an early stage.

INDIVIDUAL BATTERY TWIN

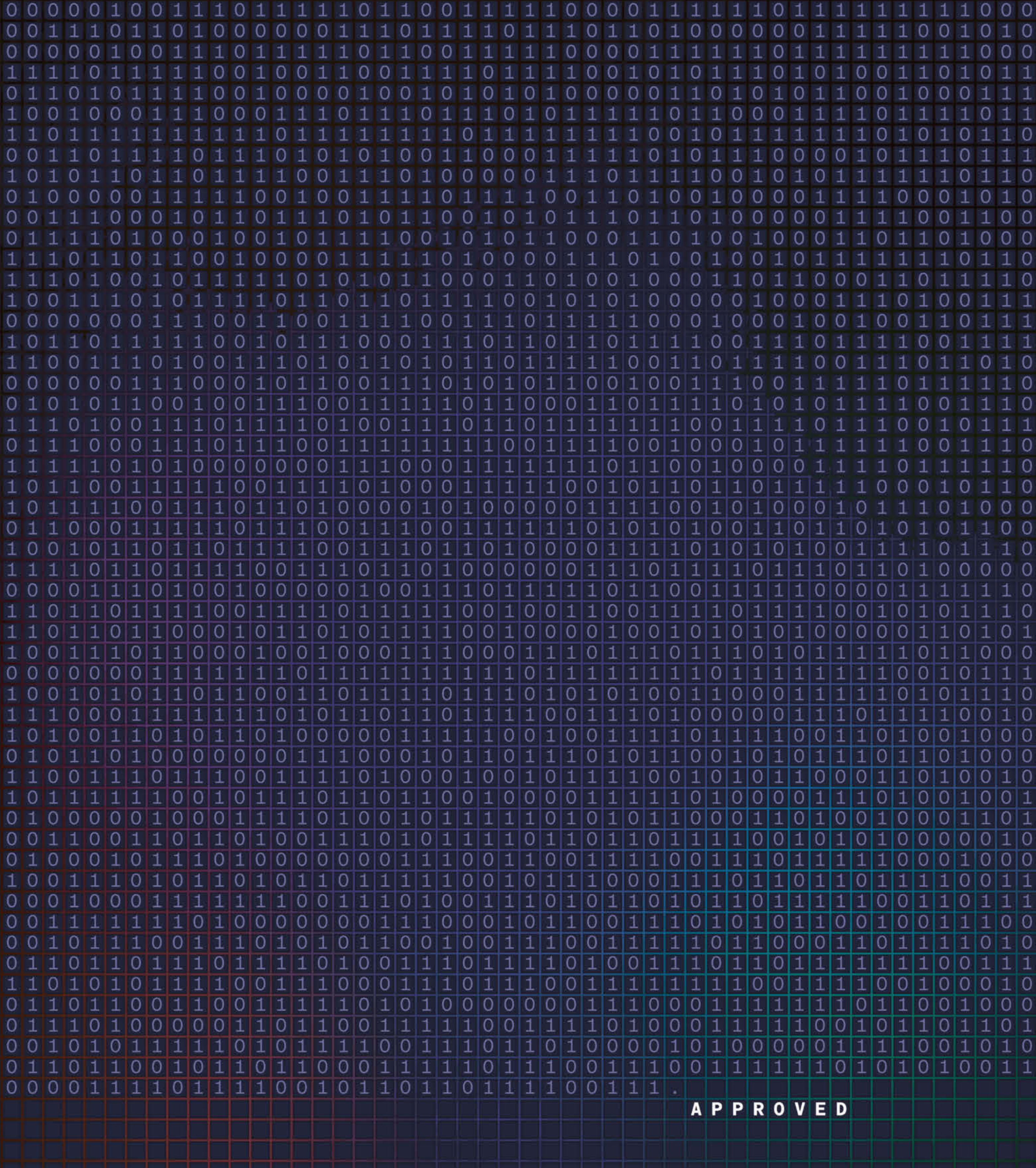
The work on the Battery Digital Twin started last year and is making good progress. Porsche Engineering has already created prototypes of the electrochemical and thermal models, which are now combined with AI analyses. But the work is challenging: Data from vehicles with different thermal and charging systems must be merged, and the laboratory models are often complex and need a lot of computing power. The simulation models are gradually parameterized with field data in order to make them even more realistic. Prototype applications are expected this year.

"Its success lies in combining existing model-based components with AI methods."

Adrian Eisenmann
Development Engineer at Porsche Engineering

The long-term goal is not only to create a general Battery Digital Twin, but also a digital representation of individual vehicle batteries. It could run in the cloud and, if desired, give the customer instructions on how to extend the life of the battery without compromising the drive performance. Some factors that have a positive effect on durability are known: The state of charge (SoC) should be kept constant between 30 and 70 percent and extreme outside temperatures should be avoided. These, however, are just a few of many factors. "Battery aging is a complex interplay of many factors that are difficult to separate, especially in the field," says Eisenmann.

Eventually, it may even be possible to customize the vehicle with the help of the digital doppelganger. "In the future, you could analyze the customer's driving style on request and change the parameters in the battery management system in a way that minimizes wear," expert Marsteller can imagine. In addition, digital twins could provide important insights for the development of new batteries—potentially even beyond the automotive industry. "Knowledge about the cells could also be applied to trucks, e-bikes and boats," Schaper offers as an example.



Guaranteed error-free: Software verification involves comparing the code with precise specifications that could potentially be generated automatically by AI in the future.

Putting code to the test

Software plays a key role in modern life, but also in vehicles. For this reason, OEMs and suppliers use proven methods and tools to identify errors in programs as early as possible. Researchers are already working on new approaches, including ones based on artificial intelligence.

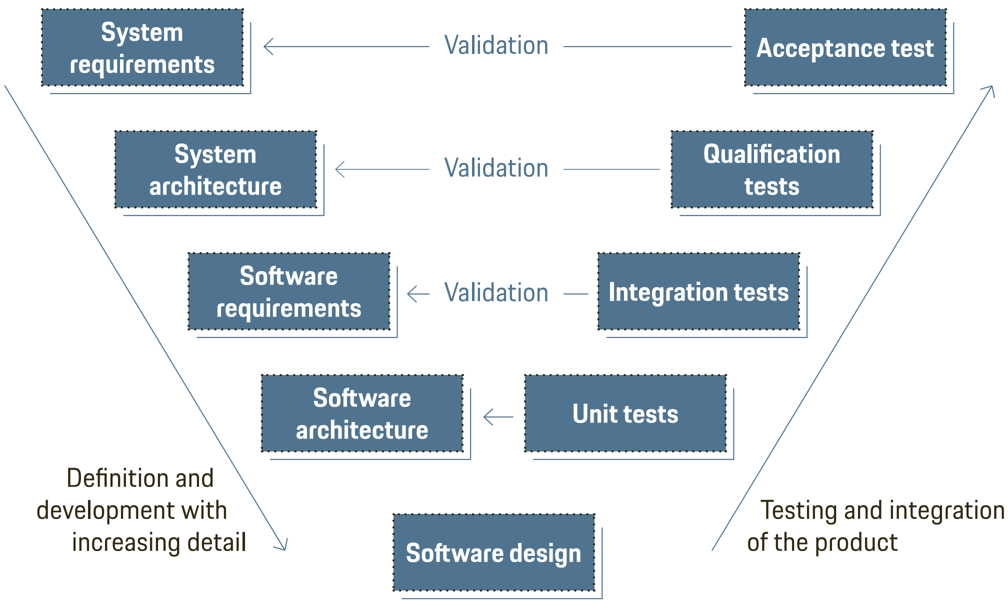
Text: Christian Buck

Today, vehicles are mobile computers with a network of up to 100 electronic control units that control the engine and battery functions, monitor the air conditioning system, and control the infotainment system. And more and more intelligent features such as adaptive cruise control and automated driving functions are being added. All this is only possible with the help of complex software.

As the complexity of the software increases, so too does the work required by OEMs and suppliers to avoid errors and thus ensure high software quality. On the one hand, they use the industry's standard processes for orientation—particularly Automotive SPICE (ASPICE) and ISO 26262—as well as in-house coding and quality guidelines that, for example, prohibit the use of error-prone functions in certain programming languages. With its development processes, Porsche Engineering reliably and reproducibly achieves ASPICE Level 2. This not only corresponds to the current state of the art and constitutes the essential basis for approval in the vehicle, but also assures customers that errors and non-conformities can be detected and remedied at an early stage.

In software development, Porsche Engineering applies the V model (see illustration): On the left, from top to bottom, you will find the steps System requirements, System architecture, Software requirements and Software architecture. At the base of the V is the software design, which is followed on the right-hand side from bottom to top by the steps of unit tests, integration tests and qualification tests as well as acceptance test and use. "Every step on the left matches a test step on the right," explains Stefan Rathgeber, Director Software High-Voltage Systems at Porsche Engineering. "In unit tests, for example, we test the smallest unit at the functional level,

VALIDATION ON EVERY LEVEL
RAISING SOFTWARE QUALITY WITH THE V MODEL



Porsche Engineering applies the proven V model in software development. The software is defined and developed in increasing detail along the left side, followed by the step-by-step validation of the results on the right side. There are test catalogs for all levels that factor in all variants.

component tests then follow one level above that." For all levels, there are test catalogs that factor in all variants.

A dedicated team of quality managers at Porsche Engineering checks whether all process steps are adhered to and documented during software development. They constantly conduct reviews to find problems as early as possible, because the effort required for troubleshooting and remediation rises sharply in

"The combinatorics of the individual system are further potentiated by the combinatorics of the variants."

Professor Ina Schaefer
Karlsruhe Institute of Technology

later development phases. The impossibility of testing every possible constellation, for example, means that certain unfortunate combinations can cause problems.

The numerous vehicle variants, equipment versions and software updates after delivery of the vehicles pose a special challenge. "Vehicle variants are a big topic at the moment," says Thomas Machauer, Lead Engineer at Porsche Engineering. "You try to test only the differences between the variants and thereby find the best compromise between effort and quality." Professor Ina Schaefer of the Karlsruhe Institute of Technology (KIT) studies the subject. She concentrates on the intelligent generation and prioritization of test cases, particularly for software variants. "The combinatorics of the individual system are further potentiated by the combinatorics of the variants," she explains. "We therefore ask ourselves the following questions: What do you need to test in order to cover the variant space well? In what order should the tests be carried out? If we succeed in only testing the differences, we will achieve a more efficient test process."

INTELLIGENT TEST SELECTION

A current doctoral dissertation in Schaefer's department deals with the intelligent testing of different vehicle variants when an update is transmitted over-the-air. "Updates make everything more complicated because the vehicles in the field have very different software versions," says Schaefer. "In the past, the software was only tested at the start

"Computer scientists want to show mathematically that a program does exactly what the specifications prescribe."

Professor Ralf Reussner
Karlsruhe Institute of Technology

of series production. In the future, you will have to re-test with every update, which will greatly increase the work involved." This also raises completely new questions: What do you need to test on an individual vehicle to make sure everything is safe? What effect does the update have on the vehicle's components? To answer these questions, Schaefer's team has developed a prototype tool that examines the variant space and provides a list of configurations to be tested. Other tools suggest the best test sequence.

But even the most intelligent test cannot cover all mathematically possible combinations of input and output values in a given software. That's why other scientists are working on the verification of code. "What computer scientists mean by that is proof," explains Professor Ralf Reussner of KIT. "They want to show mathematically that a program does exactly what the specifications prescribe. This approach is already being used in particularly safety-critical areas of aviation, and individual car manufacturers have already studied it as part of research projects."

What initially sounds promising, however, often reaches theoretical limits. There are mathematical problems, for example, whose truth or falsehood cannot be determined automatically—for example, true statements for which no proof exists. What that means for software: Certain properties cannot be tested for all computer programs with an algorithm—for example, whether a program stops or gets stuck in an endless loop. "In general, we will therefore never be able to build a verification tool that can take any given program code and fully automatically prove that it is error-free," says Reussner. However, the scientists are often lucky and do indeed automatically find proof of correctness. And if that is not possible, interactive tools are used in which the human intervenes in the process when necessary. "In practice, however, these tools do an astonishing amount automatically," says Reussner.

SPECIFICATION BY WAY OF SPECIFICATIONS

Another problem in software verification: If the specifications themselves are incorrect, the proof is also worthless. To prevent this, computer scientists have developed their own specification languages that resemble programming languages. "They can be used to describe logical relationships, but also temporal propositions," says Reussner's KIT colleague Professor Bernhard Beckert. "This involves a great deal of effort, however: The precise specification of software today takes about the same time as writing the code. However, the simple description that the software does not contain typical errors such as a division by zero is less complex." The easiest thing would be if the precise specification could be automatically derived from the software specifications, which, in Beckert's opinion, could be possible in the future with the help of artificial intelligence: "Large language models such as ChatGPT might be able to do that."

However, artificial intelligence could also independently search for program errors—for example, as a complementary step to formal verification. This approach, dubbed 'neural bug detection', is being studied by the working group of Professor Heike Wehrheim at the University of Oldenburg. "You can train an AI to find errors with the help of correct and incorrect programs," says Wehrheim. "It's still early days for the subject, but it's booming at the moment and is being studied by many researchers." So far, however, the approach is only suitable for small programs or simple, individual functions.

"Better software is definitely possible, even if it will never be 100 percent error-free," says KIT expert Schaefer, summing up the current situation. "But with good processes and innovative procedures, we can consistently improve the quality. I'll never run out of things to study in this field."

UNLIMITED DRIVING PLEASURE

The legendary 911 has turned 60. Porsche took the anniversary as an opportunity to develop a purist special-edition model. With its lightweight design, breathtaking GT high performance and a significant reduction in insulation, the 911 S/T exemplifies the 911 in its purest form.

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

Timeless design, reinterpreted for today: The new 911 S/T is unmistakably a descendant of the legendary original from 1963.

Exclusive: There are just 1,963 units of the special model for the anniversary of the 911.

Elegant: Cognac and Black dominate the interior of the Heritage Design package. The fabric seat center panels feature black pinstripes—an allusion to the history of the 911. Customers of the 911 S/T also have the exclusive opportunity to buy the Chronograph 1—911 S/T.

The new 911 S/T

Fuel consumption (combined): 13.8 l/100 km
CO_2 emissions (combined): 313 g/km

All consumption figures according to WLTP; as of 11/2023

Eye-catching style: The Porsche logo and the 911 S/T model designation on the rear of the car feature a finish in Gold in the Heritage Design Package.

Porsche is celebrating the 60th anniversary of the 911 with a special edition built for maximum driving enjoyment: In a limited run of 1,963 units, the Porsche 911 S/T offers lightweight design and a purist driving experience. For the first time, the high-speed engine in the 911 GT3 RS delivers its power to the road using a manual transmission and lightweight clutch.

To mark the milestone anniversary of the iconic 911 sports car, the engineers in Weissach have designed a highly puristic sports car dedicated to sheer driving pleasure: The 911 S/T. The exclusive anniversary model unites the strengths of the 911 GT3 with a Touring Package and the 911 GT3 RS, and delivers a unique combination of agility and driving dynamics. It combines the naturally aspirated, 386 kW (525 PS) four-liter boxer engine from the 911 GT3 RS with a short-ratio manual transmission. This is complemented by resolute lightweight construction and a running gear setup optimized for agility and drivability. The 911 S/T weighs just 1,380 kilograms (DIN curb weight, incl. all fluids), making it the lightest model in the 992 generation. The optional Heritage Design package draws inspiration from the race version of the 911 S from the late 1960s and early 1970s.

↓

The four-liter boxer engine delivers

386 kW (525 PS)

of power

Thanks to lightweight design, the special edition weighs just

1,380

kilograms

DYNAMIC RESPONSIVENESS

The design of the anniversary model incorporates GT and motorsport expertise from Porsche. This is reflected in its particularly nimble and agile handling, which is designed for maximum driving pleasure on winding country roads. The reduction of rotating masses both in the engine as well as the wheels and brakes ensures particularly dynamic responsiveness. The S/T responds

Ready for the track: The color Shore Blue Metallic is exclusive to the Heritage Design package. On the doors, a car number from 0 to 99 as well as a decorative foil can be applied.

to driver commands instantaneously. Every steering movement, every modicum of pressure on the accelerator or brake is implemented immediately and with pinpoint precision. Unlike the 911 GT3 RS, the focus of the development of the 911 S/T has not been placed on track use, but rather for journeys on public roads.

DIRECT DESCENDANT OF THE 911 S

The name marks out the new 911 S/T as the descendant of a particularly performance-focused version of the first 911 generation. From 1969, Porsche offered the 911 S with a special race version. Internally, these vehicles were called 911 ST. Modifications to the chassis, wheels, engine and body significantly improved their longitudinal and lateral dynamics. Large spoilers and other aerodynamic aids were not yet used in these models. The new 911 S/T embraces the spirit of the original 911 S (ST) and transfers it into the current model generation of the Porsche 911. The anniversary model combines elements of the 911 GT3 RS with the body of the 911 GT3 with the touring package, and supplements it with components

The 911 S/T needs just

3.7

seconds to reach 100 km/h

Its top speed is

300

km/h

specially developed for the 911 S/T. The result is a unique driving experience within the 911 GT portfolio.

Among other measures, the 911 S/T achieves its particularly agile and direct handling through consistent lightweight design. The front hood, the roof, the front fenders and the doors with their striking inlets are made of lightweight carbon fiber-reinforced plastic (CFRP), as are the roll cage, rear axle anti-roll bar and shear panel (stiffening element on the rear axle). Porsche also fits out the anniversary model with magnesium wheels, the PCCB system, a lithium-ion starter battery and lightweight glass, all as standard. With reduced insulation, the omission of rear-axle steering and weight savings in the powertrain, the 911 S/T achieves a DIN curb weight of just 1,380 kilograms. This makes the road-ready speed machine a further 40 kilograms lighter than a manual 911 GT3 Touring.

Porsche engineers developed a new lightweight clutch exclusively for the 911 S/T. In conjunction with a single-mass flywheel, it reduces the weight of the rotating mass by 10.5 kilograms. This noticeably improves the responsiveness of the naturally aspirated boxer engine, which now revs up instantaneously with bracing speed. Coupled with a six-speed manual transmission with a shorter gear ratio than the 911 GT3, the high-speed engine in the 911 S/T delivers even more immediacy in its dynamics. It propels the 911 S/T to 100 km/h in just 3.7 seconds. Top speed, in turn, is an impressive 300 km/h or 192 mph. The exhilarating driving experience is heightened by the compelling soundscape of the standard lightweight sports exhaust system. The 911 S/T is the only 911 in the current generation to combine a double-wishbone front-axle design with a multi-link rear axle without rear-axle steering. The dampers and control systems were tuned accordingly.

STANDARD CFRP SEATS

The aerodynamic measures on the 911 S/T also focus on use on public roads. The anniversary model is equipped as standard with a Gurney flap on the retractable rear spoiler. Standard equipment also includes 20-inch (front) and 21-inch (rear) lightweight center-locking magnesium wheels. Ultra-high-performance 255/35 ZR 20 tires ensure a high level of mechanical grip on the front axle. On the rear axle, the 911 S/T features 315/30 ZR 21 tires. CFRP full bucket seats come standard. The four-way-adjustable Sports Seat Plus is available at no extra charge. The instrument cluster and the clock of the Sport Chrono package are finished in a classic green Porsche color scheme. The 911 S/T is offered with an optional exclusive Heritage Design Package. The new exterior color Shore Blue Metallic and the rim color Ceramica are available exclusively for this particularly elegant variant. On the doors, a car number from 0 to 99 as well as a decorative foil can be applied on request. The classic-design Porsche crest from the original 911 that adorns the front, the hub caps, the steering wheel, the headrests and the car key underscores the historic roots of the 911 S/T. In the interior, the fabric seat centers in Classic Cognac with pinstripes in Black represent a further nod to the car's lineage. Bi-color semi-aniline leather trim in Black/Classic Cognac leather with an extensive leather trim, a roof lining in perforated Dinamica, and other elements from the Porsche Exclusive Manufaktur round out the package. The Porsche logo and the 911 S/T model designation on the rear of the car feature a finish in Gold.

Porsche Design exclusively offers customers of the 911 S/T the Chronograph 1—911 S/T. Featuring a titanium case, uncoated and blasted for weight-saving reasons, this exclusive timepiece goes all in on the lightweight design principle of the new purist 911 special edition. The heart of the chronograph is the Porsche Design WERK 01.240 with its COSC certification and flyback function. It is operated with a rotor based on the design of the magnesium wheel of the 911 S/T.

911 GT3 RS

Fuel consumption (combined): 13.4 l/100 km
CO_2 emissions (combined): 305 g/km

911 GT3

Fuel consumption (combined): 13.0–12.9 l/100 km
CO_2 emissions (combined): 294–293 g/km

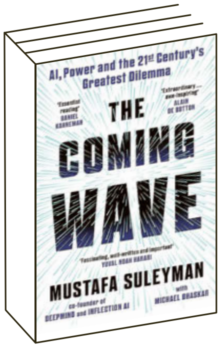
911 GT3 mit Touring-Paket

Fuel consumption (combined): 12.9 l/100 km
CO_2 emissions (combined): 293–292 g/km

All consumption figures according to WLTP; as of 11/2023

Sports car with motorsport genes: The 911 S/T offers maximum driving pleasure on winding country roads.

Deeper knowledge



BOOK

In with the new

Artificial intelligence, DNA printers and quantum computers are radically changing the world. The book poses the central question: How do we stay in control of these new technologies?

The Coming Wave
Mustafa Suleyman, Michael Bhaskar
Bodley Head

The big picture

PODCAST

Deep dives into AI applications

Whether it's wildlife biologists, astrophysicists or data scientists: In this podcast from NVIDIA, specialists report on the concrete implications of AI—one person, one interview, one story.

The AI Podcast
blogs.nvidia.com/ai-podcast

PODCAST

Spotlight on people and technologies

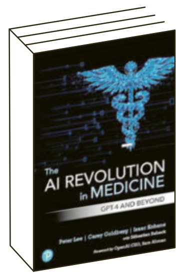
This podcast by host Brandon Bartneck focuses on the development and implementation of safe, sustainable and equitable mobility solutions.

Future of Mobility
brandonbartneck.com/futureofmobility

BOOK

Revolution in medicine

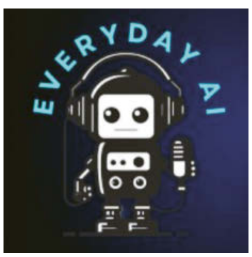
GPT-4 and its competitors are on the cusp of revolutionizing medicine. Now the question is: What can they do? And what can't they do—at least not yet? And what should AI systems never do?



The AI Revolution in Medicine
Peter Lee, Isaac Kohane, Carey Goldberg
Pearson

PODCAST

Getting ahead with AI

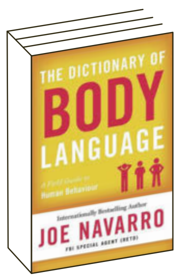


This daily livestream aims to help people advance their careers with AI. Among other things, it offers practical tips on how to integrate AI and machine learning into your everyday activities.

Everyday AI
youreverydayai.com

BOOK

Deciphering human behavior



Former FBI agent Joe Navarro explains the hidden meanings behind the many conscious and unconscious things we do with our bodies.

The Dictionary of Body Language
Joe Navarro
Thorsons Publishing Group

For the child in all of us

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↑

GAME

Strategy game for kids and adults

“GiiKER Smart Four” is an innovative 3D board game that stands out from conventional four-in-a-row games. And with built-in AI, you can compete with a smart computer adversary when no second person is available.

GiiKER Smart Four
www.amazon.com

↑

GAME

Fighting the chaos in your head

This game requires you to play cards and see through a confounding riot of colors and texts. It is based on the Stroop effect: Our brains have difficulty separating words and colors when they’re incongruent with each other.

Color Addict
www.amazon.com

Intelligent entertainment

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↑

FILM

Dune: Part Two

In the forthcoming new film Dune: Part Two by director Denis Villeneuve, Paul Atreides joins forces with the Fremen on the desert planet of Arrakis in a bid to defeat his enemies. As in the film Dune: Part One from 2021, viewers can look forward to extraordinary scenes showing the battle between good and evil.

Dune: Part Two
In theaters from February 29, 2024

↑

VIDEO GAME

Play the sleuth

The player assumes the role of a detective with memory loss, who is tasked with solving a murder. Over the course of the investigation, he starts remembering events from his own past and forces attempting to influence the city’s development.

Disco Elysium
discoelysium.com

1994

Flexible solution: The Flex7 seating concept, developed by Porsche, enabled the two seats in the rear to be fully lowered to the vehicle floor and the center row to be folded over and pushed forward. The compact MPV offered space for up to seven people and the storage area could be enlarged in no time to suit requirements.

An innovative seating concept

Opel Zafira Compact MPV

built

1995–2019

In the 1990s, Adam Opel AG decided to develop a seven-seater compact MPV based on the Opel Astra: The Opel Zafira. The contract was awarded to Porsche customer development in 1994, where engineers were involved in designing the body-in-white and developing the interior, among other things. The technical platform the car was based on also needed to be revised: In addition to adapting the engines and drivetrain, as well as the front and rear axles of the Opel Astra, it was also necessary to completely redevelop the engine peripherals and the vehicle electrical system.

Another element of the assignment was prototype construction and producing pilot series vehicles. Porsche Engineering also assumed responsibility for all the testing, including crash tests and test drives. In fact, the experts from Weissach also provided support with the production launch: In the run-up to the start of series production, they oversaw the production, quality and logistics management of the new Opel series.

In April 1999, it was finally time: Opel introduced the first generation of the Zafira, which became a major sales success. One of the special features of the compact MPV was the—at that time brand new—Flex7 seating concept, developed by Porsche Engineering: It enabled the two seats in the rear to be fully lowered to the vehicle floor and the center row to be folded over and pushed forward. This made the interior of the Opel Zafira very flexible and easy to reconfigure—from the full seven-seater formation to a 1.80-meter-long and 1.11-meter-wide flat storage space: Anything was possible, without even having to remove the seats.

The first generation of the Opel Zafira was built in Bochum between 1999 and 2005 with additional production sites in Thailand and Brazil. The Opel Zafira was available abroad as the Vauxhall Zefira, Chevrolet Zafira, Chevrolet Nabira, Holden Zafira and Subaru Traviq. After the third generation, its career as a compact MPV came to an end. Today, Opel offers a van under the name Zafira Life.

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