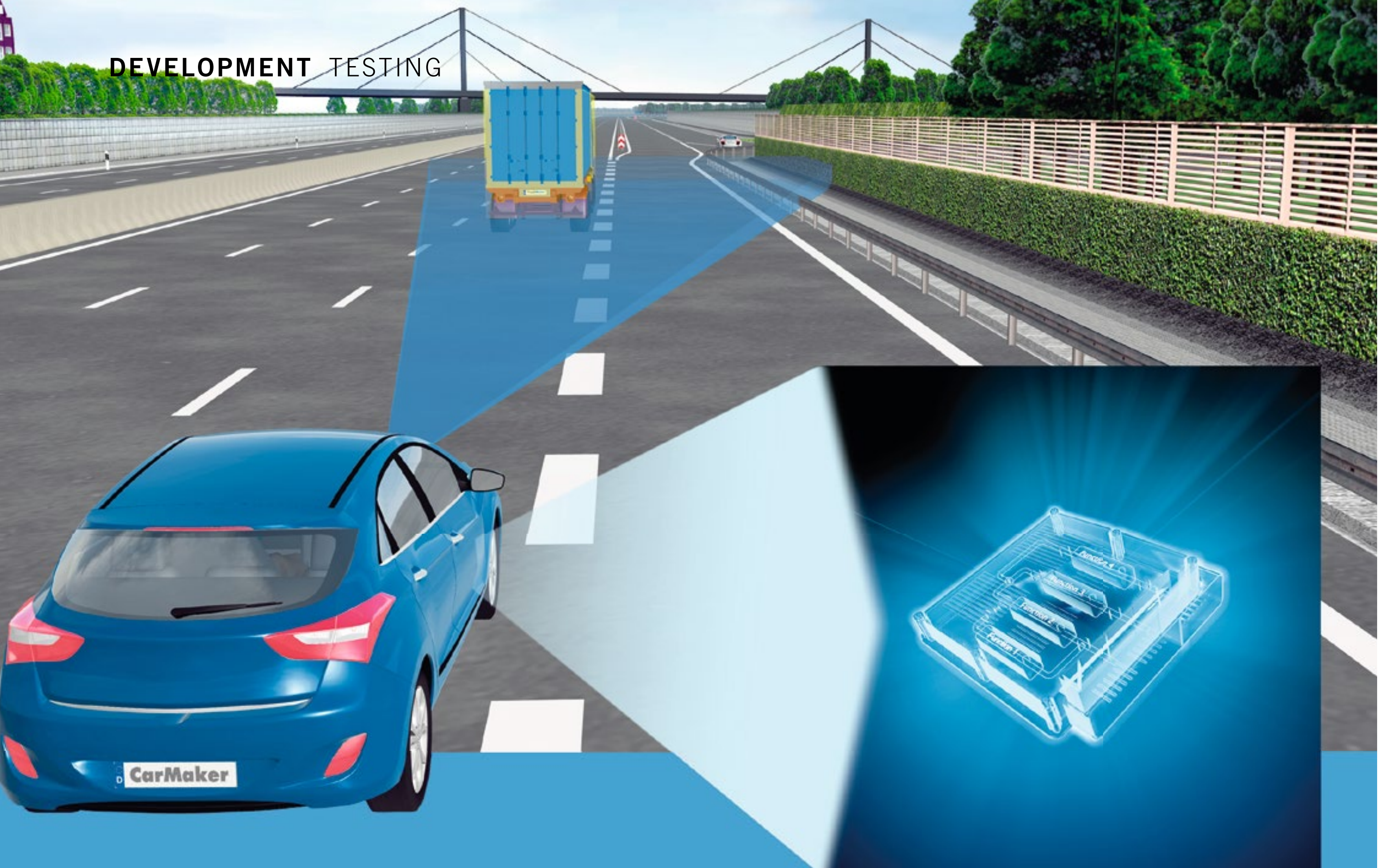

Early PC-based Validation of ECU Software Using Virtual Test Driving

The growing trend towards piloted driving (aka autonomous vehicles) intensifies the challenges posed by testing even further. Another implication of this trend is that validation which is exclusively based on real-world road testing is no longer economical due to the number of possible test cases. The approach of Etas and IPG Automotive addresses these challenges and describes hardware-independent, realistic testing of ECU software via the integration of a virtual ECU into an open integration and test platform. Due to early software debugging this solution yields considerable savings potential in terms of cost and time.

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CHALLENGES OF VALIDATING ECU SOFTWARE

Hardware in the form of ECU or vehicle prototypes is frequently used for functional tests of ECU software. However, this is problematic with respect to the aforementioned time and cost pressures in the development process, as prototypes are typically available only in late stages of the development cycle. Furthermore, the relatively high costs associated with the creation of prototypes must be considered. Consequently, for cost reasons, only a small number of prototypes are typically produced, which further limits their availability for testing by development engineers. These issues can be supported by statistics: in approximately 60 % of the development cycle no prototypes are available for testing and less than 10 % of the engineers are afforded the possibility of running tests in the real-world vehicle [1].

This condition represents a considerable constraint whenever several teams work together. This is the case in so-called co-development processes used by automotive OEMs and suppliers. Geographic distances often make the coordination and design of the testing procedures as well as the utilisation of the available hardware more difficult. Prototype-based tests typically require costly transports, which may also lead to considerable time delays (for instance due to waiting periods to clear customs). In addition, the risk of unforeseeable hazards occurring in real-world road tests and the emergence of safety-relevant issues for both the driver and the vehicle in the validation of ADAS (such as emergency brake assist) must be taken into account. Last but not least, the required reproducibility, which can hardly be achieved in view of the complexity of environmental conditions, poses a problem. The need to make this process more efficient for all the parties involved calls for an approach that enables early and realistic ECU software validation.

VIRTUAL TESTING AND VALIDATION OF ECU SOFTWARE

The joint solution by Etas and IPG Automotive meets the challenges outlined above. This approach is based on the virtual electronic control unit EVE (Etas Virtual ECU) and the open integration and test platform CarMaker by IPG Automotive. To do so, the virtual ECU is integrated into the simulated environment and tested in various scenarios according to the relevant requirements **FIGURE 1**.

EVE represents a platform for PC-based software integration and validation and enables the virtualisation of complete individual ECUs or an entire array. Unlike previous solutions, EVE offers the possibility to integrate functional mock-up units (FMUs), application software components and basic software modules from different sources into virtual electronic control units. The application software is integrated on the PC with the RTA-OS embedded operating system, the Autosar [2] Runtime Environment (RTE) and the basic software to be used, and is validated and calibrated independent of the ECU hardware under largely realistic conditions. The integration into a test environment can be done either in real-time or non-real-time mode and supports a large number of different use cases.

CarMaker functions as a simulation environment for virtual test driving in this solution, allowing either the use of models which have been supplied or embedding proprietary models from different modelling tools. Precise non-linear vehicle and trailer models provide the basis for high-grade simula-

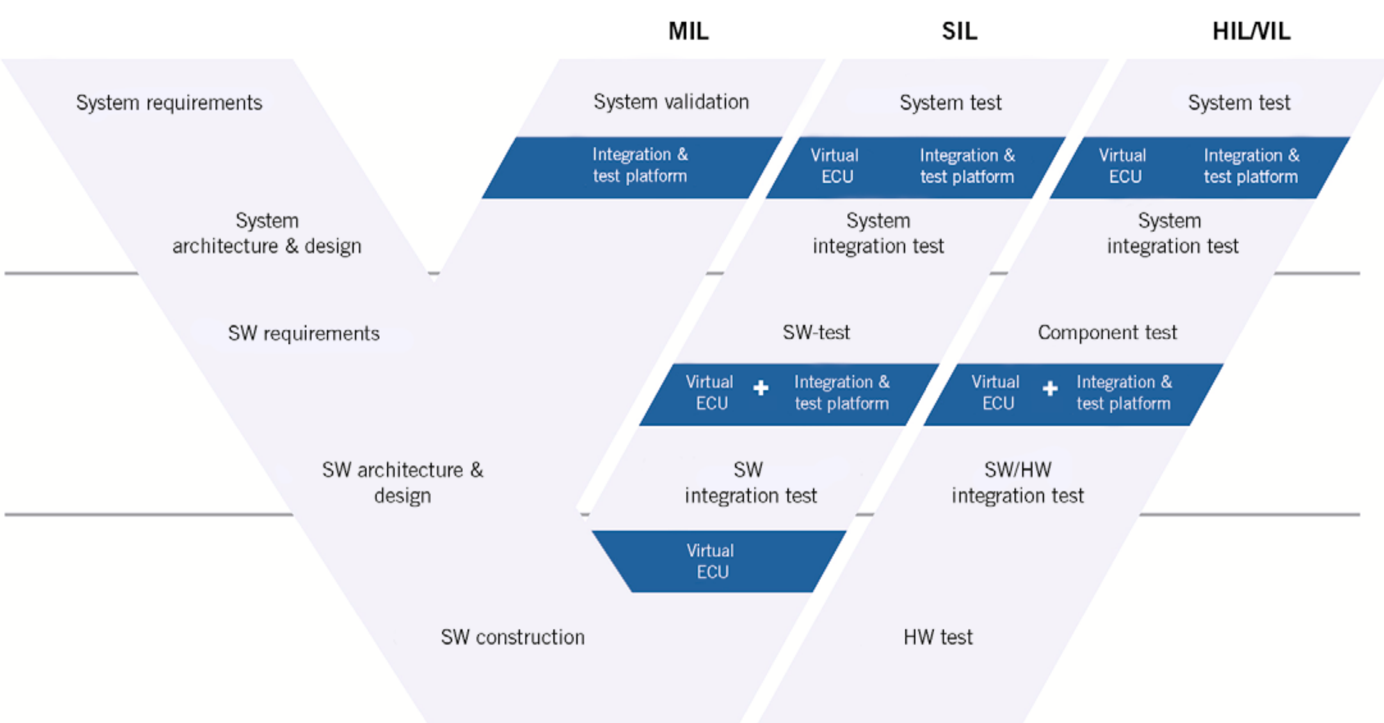

FIGURE 1 Visualisation of the use of virtual ECU testing in an integration and test platform for the various development stages of a full vehicle (V-process)

tions and allow complex driving manoeuvres to be performed in a wide variety of situations in a reproducible manner. For example, the performance of advanced driver assistance systems can be tested in scenarios involving a large number of other road users, various environments such as motorways, secondary roads or urban traffic, embedding of traffic objects, activation of sensors and much more.

According to this approach the software to be tested is initially integrated into the virtual EVE. Afterwards, the virtual EVE can be exported as a functional mock-up unit (FMU) [3] and integrated into CarMaker via the standardised functional mock-up interface (FMI). This is followed by virtual testing and approval of this software as part of virtual test driving with CarMaker.

EMBEDDING OF VIRTUAL ECUS IN THE INTEGRATION AND TEST PLATFORM

Virtual ECUs offer the advantage of hardware-independent availability. They can be created at an early stage of the development. In contrast to ECU prototypes ("A samples"), virtual ECUs are very cost-efficient and can be easily integrated into existing development processes. In addition, virtual ECUs make it possible to evaluate their functionality and interaction with environmental and component models long before using hardware prototypes. This assures the usability of the ECU software in the system context.

To implement this solution, a virtual ECU is embedded into a virtual vehicle [4]. Like a real-world vehicle, the virtual vehicle has various components (e.g. engine, powertrain or different advanced driver assistance systems). The electronic control units of these components can be virtually modelled as part of the ECU software validation and thus be tested in a virtual traffic scenario as a component of the total virtual system, **FIGURE 2**.

The possibility of running reusable manoeuvres is a core element of this solution. The manoeuvre- and event-based approach in CarMaker allows specific manoeuvres to be defined once and subsequently be used again in different test scenarios or at a later stage of the development process. The approach of event-based testing allows the functionality of the virtual ECU (EVE) in CarMaker to be tested by defining an event. This approach ensures consist-

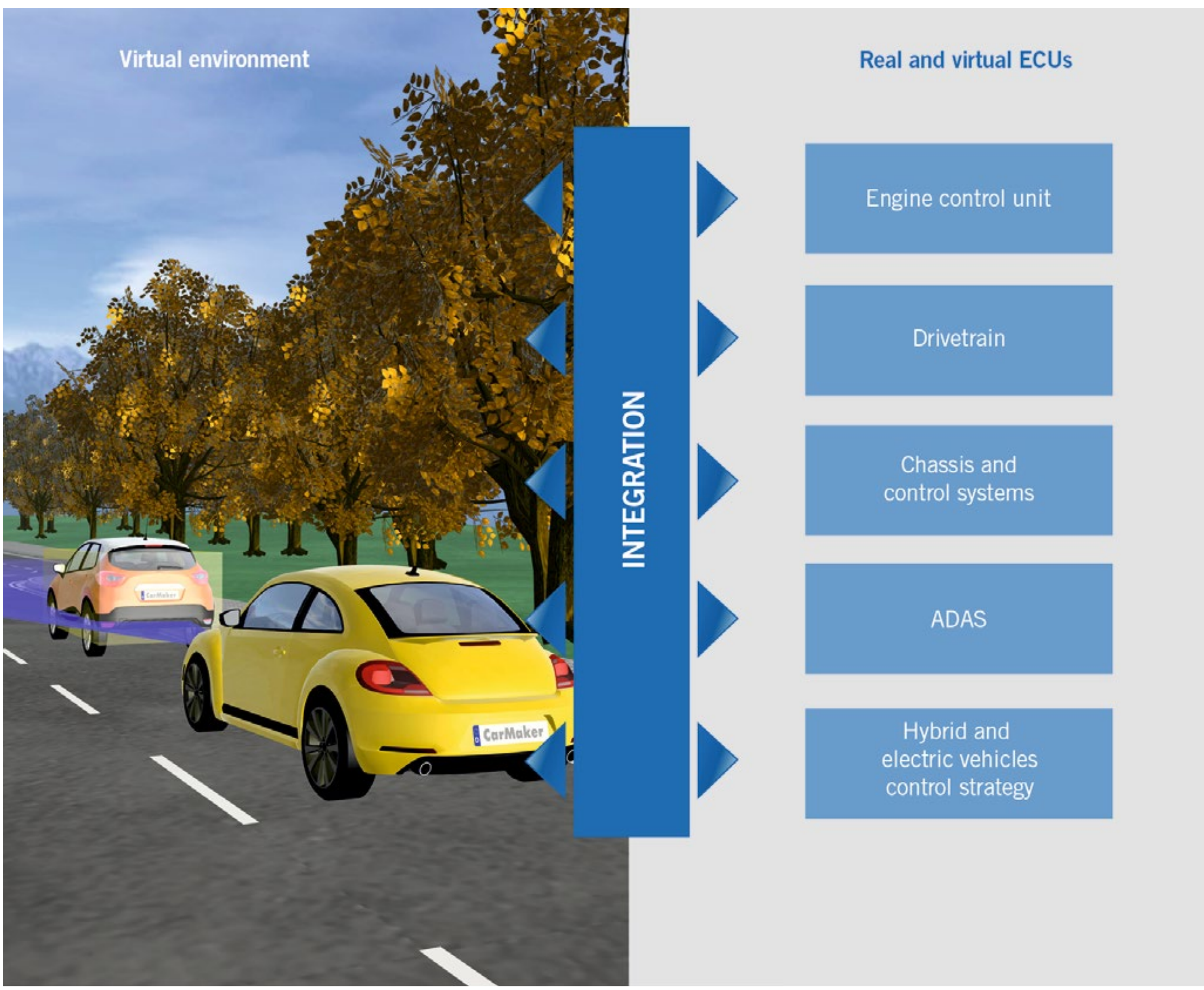

FIGURE 2 Integration of various virtual and real-world components into the virtual environment

FIGURE 3 Mapping of the debugging process of the virtual ISOLAR-EVE control unit in CarMaker

ency across the Model- (MiL), Software- (SiL) and Hardware- (HiL) or Vehicle-in-the-Loop (ViL) process and thus yields high efficiency improvement potential compared with today's solutions. The parameters of the ECUs are calibrated throughout the process in a closed-loop simulation. With respect to the requirements described above this approach makes virtual testing of hazardous situations possible without endangering the driver or the vehicle. Furthermore, this approach guarantees the reproducibility of the test results required in the validation process. In operation, the ECU software can be debugged while the test is being run. After successful debugging, the virtual ECU is re-generated and can immediately be tested in CarMaker without having to be reconfigured. **FIGURE 3** shows that the faults, by means of comparing the ego and the ghost vehicle, can be visualised in IPGMovie after the restart. The reproducibility of the test conditions, and thus the faults, is another advantage.

EFFICIENT TESTING OF VIRTUAL ECUS

The usability of ECU software in the system context can be investigated and tested at an early stage of the development process and provides an ideal basis for its further development. The approach presented here allows hardware-independent PC-based software validation. Furthermore, the synergy effects between the automotive OEM and the supplier are strengthened by enabling them to jointly work with the same artefacts. Through frontloading, i.e. the early validation of discrete sub-functions, the quality of the ECU software significantly increases and the development process becomes more efficient. As the approach includes the compatibility with standards, the challenges posed by heterogeneous tool landscapes are taken into account as well. Last but not least, the realistic visualisation enables high ease of use and facilitates the acceptance of the validation results between the different users. In addition to the time and cost savings gained, this approach, on the one hand, allows the manufacturer to invest more time in the development of new functions while, on the other, the ECU software achieves a higher level of maturity.

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