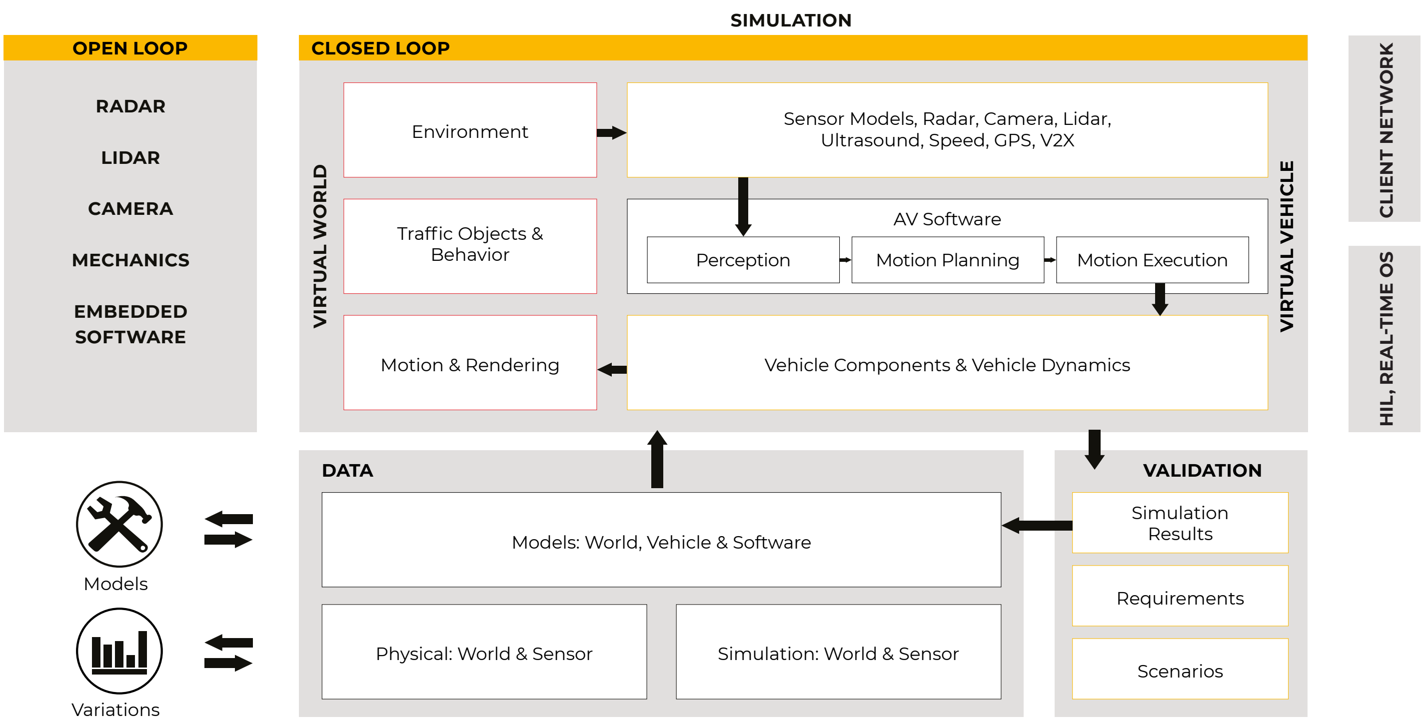
WHITE PAPER

An Integrated Simulation Platform to Validate Autonomous Vehicle Safety

Autonomous driving systems rely upon sensors and embedded software for localization, perception, motion planning and execution. Autonomous driving systems can only be released to the public after developers have demonstrated their ability to achieve extremely high levels of safety. Today's hands-off autonomous driving systems are largely built with deep learning algorithms that can be trained to make the right decision for nearly every driving situation. These systems, however, lack the detailed requirements and architecture that have been used up to now to validate safety-critical software, such as that which controls commercial airliners. Road testing is clearly an essential part of the development process, but billions of miles of road testing would be required to validate the safety of autonomous driving systems and software.

/ Ansys autonomous vehicle simulation environment

The Ansys autonomous vehicle open simulation platform addresses this challenge by integrating physics, electronics, and embedded systems and software to accurately simulate complete autonomous driving systems in a fraction of the time and cost required for road testing. Ansys capabilities span the simulation of all sensors, including lidars, cameras, radars and ultrasonic sensors; the multiphysics simulation of physical and electronic components; the analysis of system functional safety; as well as the design and automatic code generation of safety-certified embedded software. Sensor simulation can be integrated into a closed-loop simulation environment that interacts with traffic simulators, enabling thousands of driving scenarios to be executed virtually.



https://newsroom.intel.com/newsroom/wp-content/uploads/sites/11/2017/05/passenger-economy.pdf?cid=em-elq-26916&utm_source=elq&utm_medium=email&utm_campaign=26916&elq_cid=1494219

The Ansys autonomous vehicle open simulation platform addresses this challenge by integrating physics, electronics, and embedded systems and software to accurately simulate complete autonomous driving systems in a fraction of the time and cost required for road testing. Ansys capabilities span the simulation of all sensors, including lidars, cameras, radars and ultrasonic sensors; the multiphysics simulation of physical and electronic components; the analysis of system functional safety; as well as the design and automatic code generation of safety-certified embedded software. Sensor simulation can be integrated into a closed-loop simulation environment that interacts with traffic simulators, enabling thousands of driving scenarios to be executed virtually.

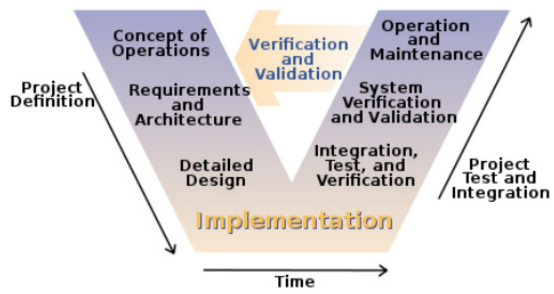
Ansys medini analyze helps to manage the safety validation process by implementing key safety analysis methods such as failure modes and effects analysis (FMEA) while supporting safety analysis and design according to ISO 26262 for electrical/electronic systems and software-controlled safety-related functions. This integrated solution can achieve end-to-end safety in deep-learning-based and other autonomous driving systems.

/ Challenges to large scale autonomous driving adoption

A study prepared by Strategy Analytics predicts that autonomous vehicles will generate a $7 trillion revenue stream by 2050 while saving an estimated 585,000 lives per decade and freeing more than 250 million hours of commuting time per year. But while autonomous test vehicles are already prowling streets around the world, there is a huge difference between building a few vehicles to run in benign conditions in a constrained environment versus building fleets of millions of vehicles that need to be able to operate safely anywhere at any time.

The greatest obstacle that needs to be overcome prior to the large-scale rollout of hands-off fully autonomous vehicles is developing software capable of safely handling every possible driving scenario without intervention from the operator. For example, consider the challenge of identifying any imaginable pedestrian, animal, vehicle or other object that might suddenly appear on the road ahead along with the endless number of scenarios that might affect the information received by the automated driving system's sensors such as weather, lighting, haze, obstructed views, etc.

Today's autonomous driving systems address this challenge with machine learning/deep learning software that can be trained to recognize patterns without having to be specifically programmed for every possible situation that could arise. The Society of Automotive Engineers (SAE) Automotive Industry Survey found that "public confidence and adoption" is the number one barrier to widespread adoption of fully autonomous vehicles. Autonomous driving systems based on deep learning can only be released to the public after automobile manufacturers have proven that they meet today's high safety standards. How should this software be validated?



V model defined in ISO 26262.

/ Traditional safety validation methods are no longer valid

Automobile safety software that has been used up to now, such as the software controlling advanced driver assistance systems (ADAS), are validated using the system and embedded software lifecycle V-model defined in ISO 26262. With this approach, engineers specify the detailed requirements of the systems, define a software architecture and create subsystems in parallel to address each of these requirements. The left side of the V shows how the system is broken down into smaller and smaller subsystems. The right side of the V shows the process of validating this software, starting with the smallest subsystems and climbing the V to a system-level validation.

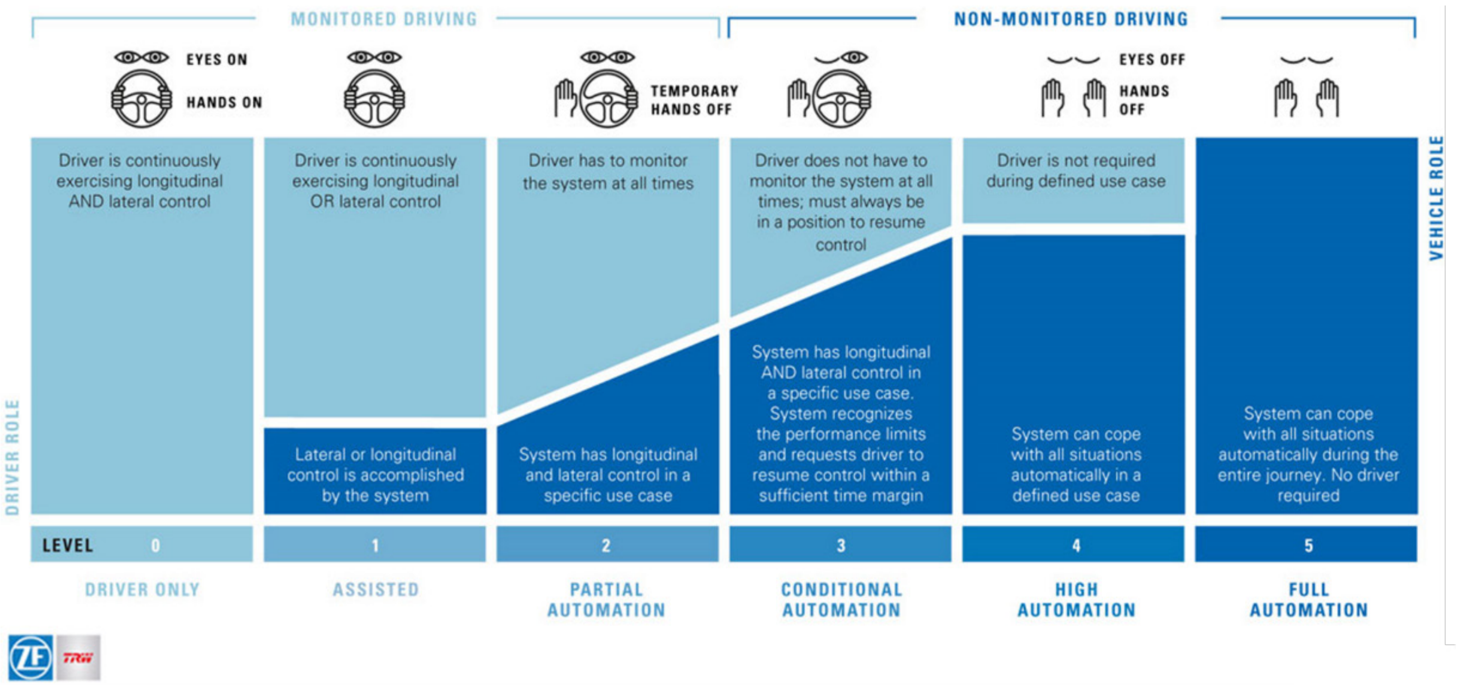
The SAE International's standard J3016 defines six levels of automation from 0 to 5 for automakers, suppliers and policymakers to classify a system's sophistication, and they are explained in detail in the image above. At level 0, the driver controls the car without any support from an automated system. As the level of automation increases, the responsibility for monitoring the driving environment progressively shifts from the driver to the system. At level 5, the highest level of automation, the autonomous driving system takes complete responsibility for handling any driving situation without the option of handing control back to the driver.

Taking the driver out of the control loop creates major challenges in validating the capabilities of the sensors that are now responsible for perception of the driving environment. The deep learning systems used do not possess the requirements, architecture and detailed subsystems used to validate conventional safety software. Another challenge is that machine learning/deep learning systems are probabilistic so that they may at times behave differently even when given the same inputs.

Road testing is clearly an essential part of development but does not provide a viable solution to the question of how to validate autonomous driving systems. The problem is that road testing primarily consists of routine situations that are not difficult for either human or automated drivers. Akio Toyoda, President of Toyota Motors, said that fully autonomous vehicles would have to be driven 8.8 billion miles to ensure their safety. Furthermore, this enormous test driving program would only serve to validate a single autonomous driving system. If you change your code or experience a failure, you must reset your mileage count to zero and start over again.

The autonomous driving industry needs closed-loop simulation in which a virtual vehicle is driven in a realistic virtual world by real autonomous vehicle software. Simulating every detail of autonomous driving is an enormous challenge that requires accurate simulation of a wide range of elements:

- Obstacles such as pedestrians and other vehicles.
- The road and its state, such as being drenched in rain.
- The vehicle including its mechanical characteristics, state, location and behavior.
- The environment: level of visibility, material properties, weather conditions and road signs.



Six levels of automation.

https://www.forbes.com/sites/alanohnsman/2016/10/03/toyotas-robot-car-line-in-the-sand-8-8-billion-test-miles-to-ensure-safety/#20144c716f01

How simulation addresses the safety validation challenge

Ansys provides the first complete closed loop simulation environment which includes virtual world model and driving scenarios, physically accurate sensor models, AV embedded software and vehicle dynamics. This closed loop allows virtual testing with Software-in-the-Loop (SIL) and Hardware-in-the-Loop (HIL). Ansys offers the broadest toolset for validating the safety and reliability of autonomous vehicles — speeding time to market for these vehicles by mitigating the need for billions of miles of road testing. The Ansys platform simulates driving scenarios including modeling the virtual world in which the autonomous car is operating and the virtual vehicle itself with accurate sensor simulation as well as vehicle dynamics.

The Ansys ADAS/autonomous vehicle simulation platform can verify the safety of complex autonomous driving systems by integrating physics, electronics, embedded systems and software simulation. The driving scenario model animates the motion of the test car and other vehicles and objects in a test drive. Sensor models observe the surroundings in the virtual world and output sensor signals. Signal processing models and deep learning identify objects, autonomous vehicle position and driving conditions from sensor data. Control algorithms make control decisions, generate actuator inputs and display information and decisions to the passenger/operator. Vehicle component models use actuator inputs such as steering, braking and acceleration. The vehicle dynamics model computes the position, velocity and orientation of the test vehicle. These integrated systems make it possible to quickly and economically simulate any vehicle, with any combination of sensors with any control system in any driving scenario.

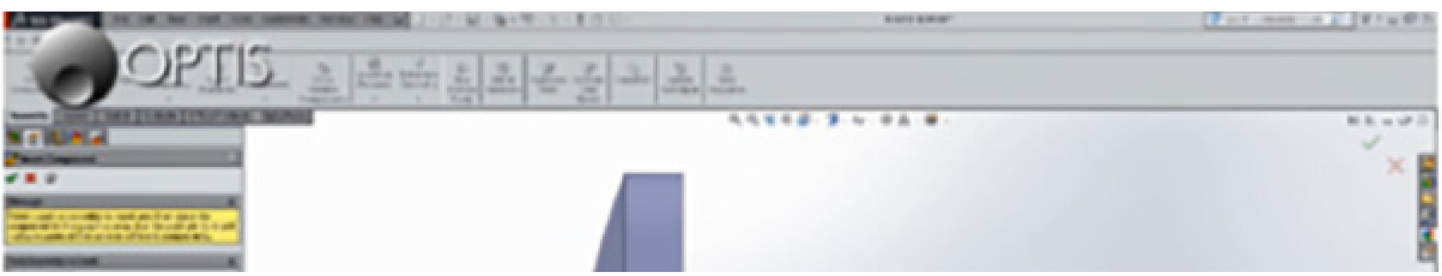
The Ansys interactive driving simulator considers all the interactions of the autonomous vehicle, the environment, the obstacles and road's state, and provides guidance on how to engineer the vehicle to ensure its compliance with safety regulations and customer expectations. Based on realistic driving conditions, this autonomous vehicle simulator makes the same reliable decisions as the future real-world connected vehicle.

Simulating the sensors

By providing a realistic physics-based sensor response in real time for cameras, lidars, radars and ultrasonic sensors, the Ansys simulation platform provides engineers with all the information needed to create the safest autonomous driving systems. Autonomous vehicles require increasing numbers of optical sensors, including cameras for visible and infrared detection and lidars for a 360-degree 3D view of the driving environment.

As an example, Ansys SPEOS optical simulation software validates the performance of the optical sensors through physics-based simulation that accurately represents their real-world performance. SPEOS enables engineers to perform a detailed physics simulation of optical cameras and lidars, taking optical lenses, mechanics, sensors, materials and light properties into account and merging images obtained by multiple cameras.

Next, SPEOS simulates the in-vehicle installation to determine the impact of the installation on images produced by the cameras and lidars. Finally, a reduced order model (ROM) of the camera and lidar models is integrated into a driving scenario that provides the performance needed for real-time simulation. The simulation accurately duplicates the images generated by the cameras and lidar, tracing rays of light as they enter the sensors to identify factors such as sun glare and reflections on the road or glass buildings while validating the perception of the sensors. A similar process applies with Ansys HFSS for radars.

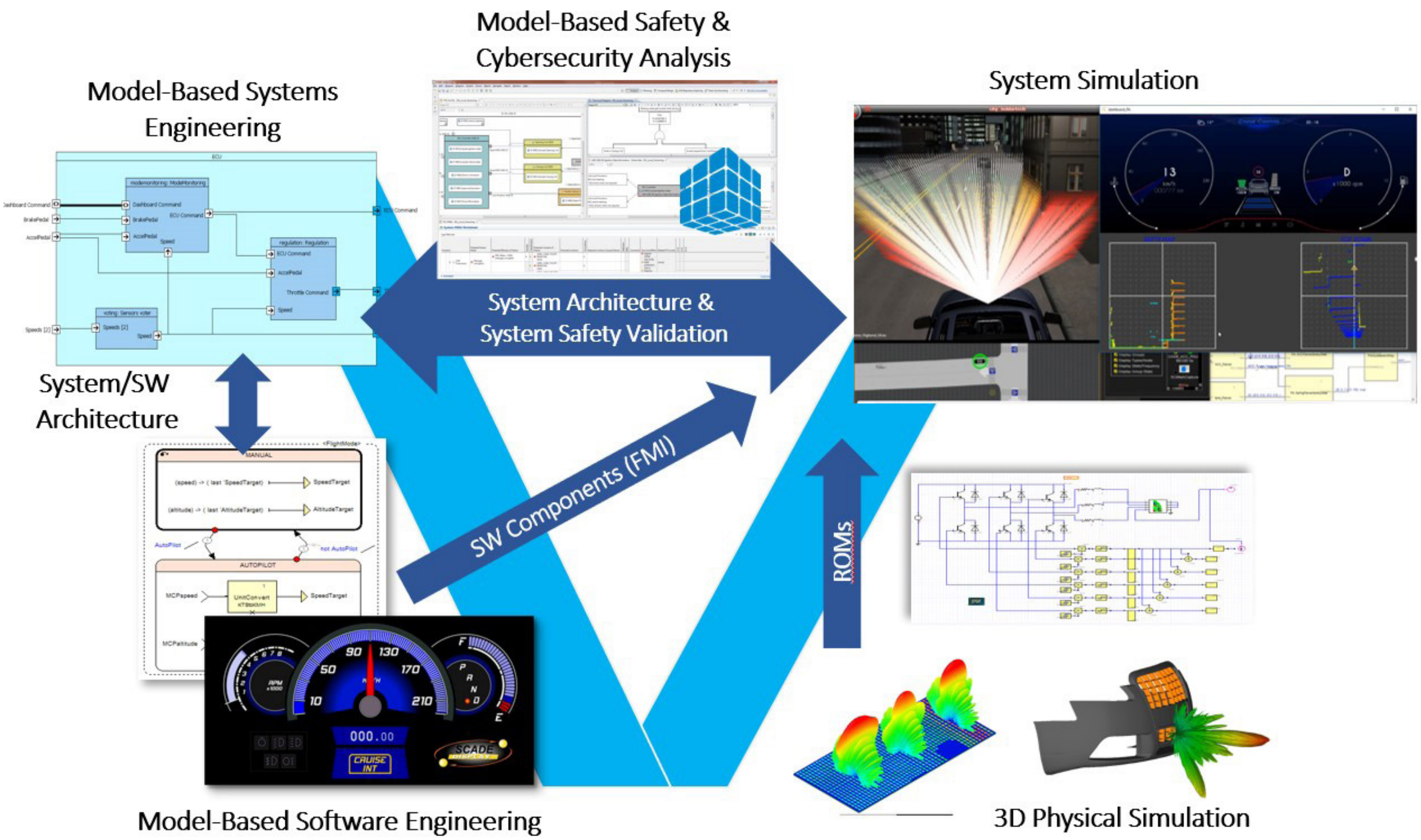


From left: 1) Detailed component simulation with SPEOS; 2) Simulation of in-car installation with SPEOS 3) Simulation of sensor performance in driving with VRXPERIENCE.

Managing the safety validation process

ISO 26262 requires that automotive systems engineers evaluate and assess the safety of autonomous driving systems by identifying relevant hazards and failure modes for electronic components. The question of how to develop autonomous vehicles will be more comprehensively addressed in a new standard to follow the second ISO 26262 release, commonly referred to as Safety of the Intended Functionality (SOTIF). The SOTIF standard will provide guidelines for documenting driving scenarios, safety analysis of those scenarios, the verification of both safety scenarios and triggering events, and the validation of the vehicle in the environment with applied safe systems.

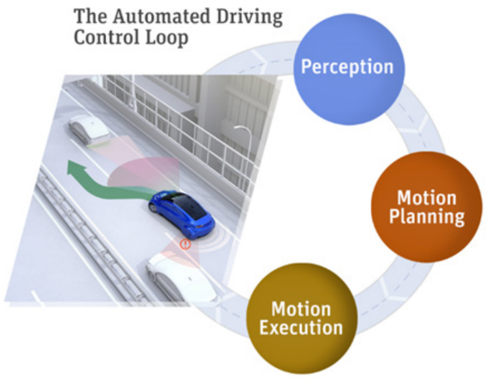
Automotive systems engineers need to validate the functional safety of automotive electronics down to the chip level to achieve a high level of confidence in the safety of their designs when autonomous vehicles are placed on the road. The problem is that many engineering teams are taking on this incredibly sophisticated task with outdated processes that rely heavily on consumer-grade software tools, notably Excel™, that were not designed to organize and facilitate the analysis of highly complex electrical systems or large volumes of functional safety analysis data.



Ansys medini analyze is closely integrated with the Ansys simulation platform.

Overhauling the control loop

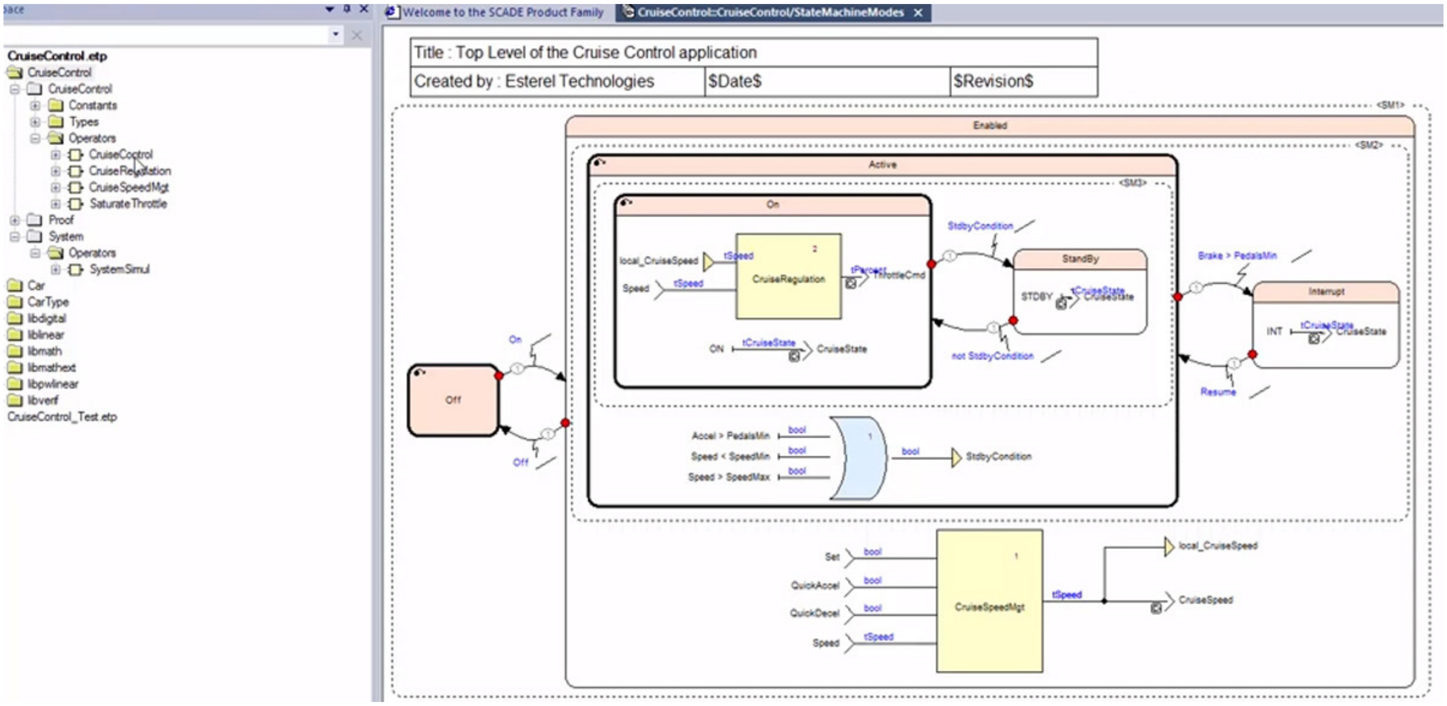
A combination of machine learning/deep learning and control logic is being used by today's cutting edge automotive engineers to implement a fully autonomous vehicle control loop. The control loop is composed of perception (what the car observes), motion planning (what behavior the car is planning) and motion execution (how the car will complete the plan). This control loop is executed in cyclic fashion so that the vehicle can respond to constant environmental changes.



The automated driving control loop.

Defining the control logic

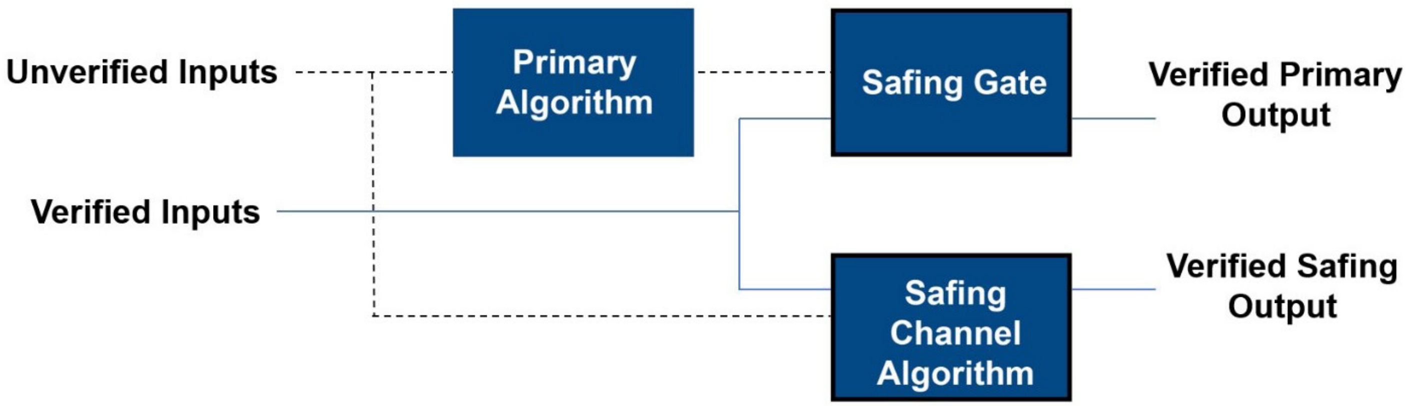
In order to design and generate code for the control logic, Ansys developed the only comprehensive solution capable of automatically generating qualified code from software models for autonomous vehicles. The Ansys SCADE Suite KCG code generator used together with SCADE Test will ensure that your embedded code meets the safety standards. It will also help you get your product to the market faster than ever before. The SCADE Suite KCG code generator takes as input a SCADE model made of a combination of state machines and data flows and produces as output an equivalent C program.



Designing control logic with Ansys SCADE.

Architecture safe autonomous vehicle control software

To verify the safety of the complex algorithms used for perception, motion planning and execution, engineers must break down the overall autonomous vehicle architecture into a meaningful set of components. A Carnegie Mellon University research team proposed an architecture that will guarantee safety for each of these components based on a DOER-CHECKER principle. The detailed architecture is composed of a primary algorithm (DOER) that may be extremely complex, undergo frequent updates and be difficult to verify. This primary algorithm is paired with a corresponding safing gate (CHECKER) that verifies that the outputs of the primary algorithm are correct. If the safing gate detects a problem, it transfers control to a safing channel algorithm that produces a short-duration mission, such as pulling the car to the side of the road.



The primary channel produces a long-duration mission with no defined end state, while the safing channel produces a short-duration mission that ends in a safe state.

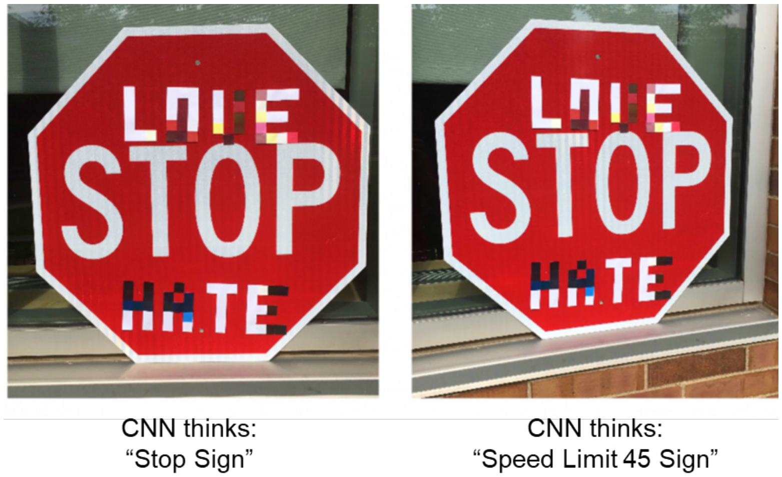
The detailed safety requirements of the safing gates can be established so that their implementation satisfies the highest-level safety requirements of ASIL D in ISO 26262, avoiding the need for the DOER to meet these requirements. The DOER can fail arbitrarily, do wrong things in the worst possible way, because the CHECKER turns the DOER into a fail silent component that shuts down whenever it does not produce correct data. For example, if the safing gate (CHECKER) detects a planning failure – such as the planned path intersects with a parked car -- it shuts down the planning algorithm (DOER).

Validating perception

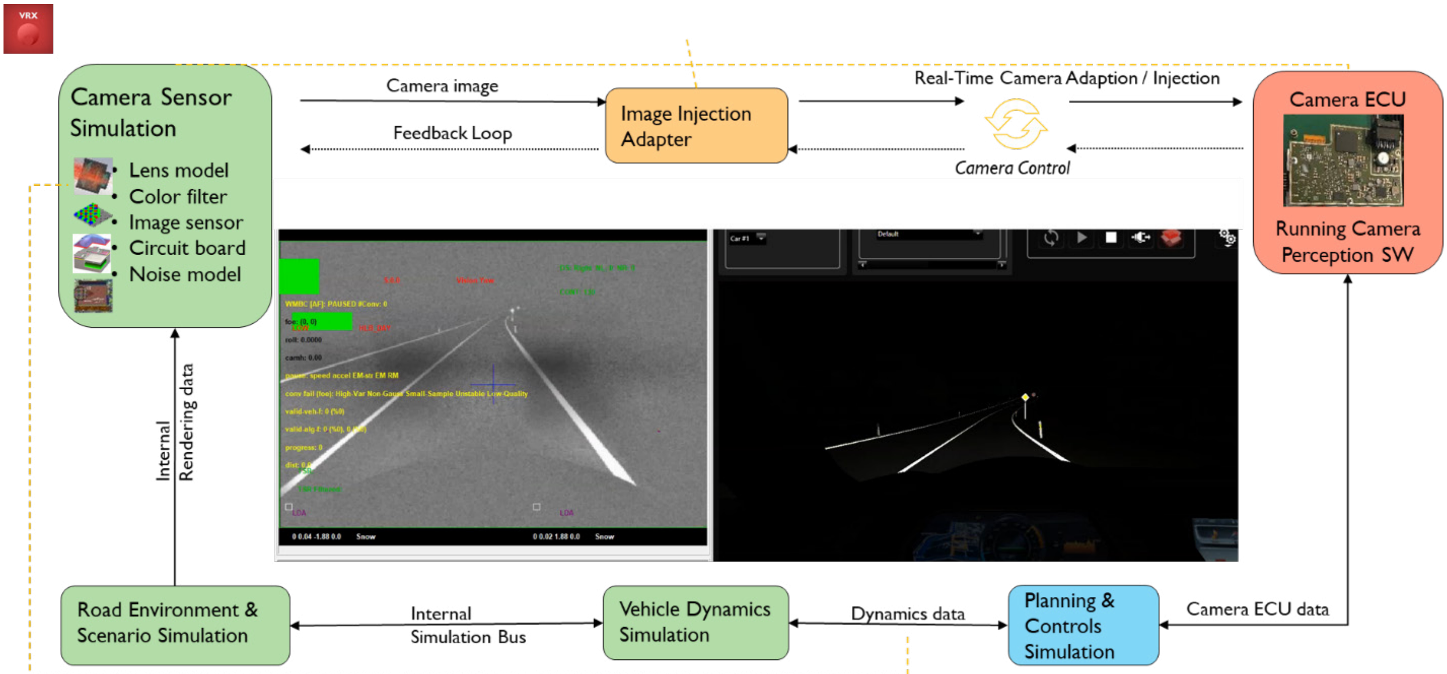
Autonomous driving systems rely on sensors to make decisions about the environment. However, it is not possible to create a safing gate to check that perception outputs are correct. The examples shown here demonstrate how signal noise can challenge the robustness of the function to correctly comprehend the situation and behave safely. The Safety of the Intended Functionality (SOTIF) section of ISO 26262 addresses hazardous behavior in systems with these types of limitations.

Strong detection can become extremely weak after barely perceptible environmental changes.

Simulation enables engineers to intentionally arrange objects and events in the simulation, simulate sensor readings, determine whether perception properly detected the objects and events, and whether the autonomous driving system responded properly. What is needed to prove the safety of the perception function is large-scale exposure to the difficult cases that challenge autonomous driving systems as well as human drivers.



Attacks disguised as graffiti can cause confusion and brittleness in convolutional neural network (CNN). Evtimov et al., “Robust Physical-World Attacks on Deep Learning Models”, arXiv:1707.08945.



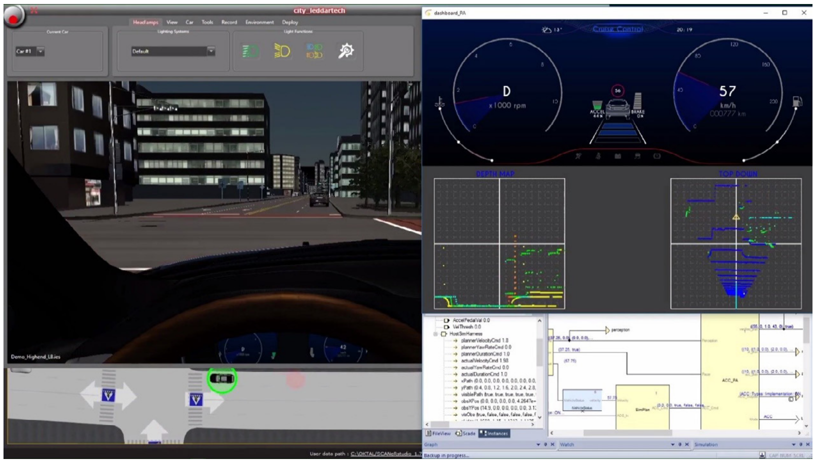
Perception validation based on Hardware-in-the-Loop (HIL) testing.

Ansys addresses this challenge with its VRXPERIENCE closed loop simulation solution that executes driving scenarios while using reduced order models derived from physics-based simulations of any combination of sensors. The camera sensor simulation can be connected to the camera electronic control unit (ECU) for a hardware in the loop (HIL) simulation in which the perception software on the ECU chip interprets the image generated by the camera sensor simulation. This simulation can be used to validate the autonomous driving simulation, and engineers can view the camera's image and driver's image in real time to quickly identify and understand problems. VRXPERIENCE enables automotive companies to virtually test and integrate their next-generation autonomous driving sensors before the actual release of the product. By replicating a real-world physical environment in 3D and creating a real-time, virtual-reality–based driving experience, VRXPERIENCE allows product developers to experience an autonomous vehicle under many daytime and nighttime driving scenarios with different road and weather conditions.

A major challenge for engineers responsible for simulating automated driving systems is developing virtual environments needed to train autonomous driving systems. Ansys addresses this challenge with extensive content libraries that enable the creation of unlimited driving scenarios with virtual roads including lanes, intersections, signs, signals, traffic, pedestrians and other objects. Human avatars guarantee the ultimate level of realism.

The VRXPERIENCE autonomous vehicle simulator makes the same decisions as a real-world connected vehicle, helping to eliminate costly and risky real-world tests of sensor systems and reducing time-to-market. Engineers can be confident that the vehicle is accurately "seeing" traffic, pedestrians, road signs and markings — as well as observing safe driving regulations and standards. These unique capabilities enable you to speed up the engineering process by driving your autonomous vehicle at an early stage of development on digital test tracks with realistic traffic conditions, including various weather conditions, oncoming vehicles and pedestrian scenarios to anticipate your vehicle's reaction to any critical situation.

Conclusion



Automatic cruise control and pedestrian detection simulation. The pundits keep telling us that full scale deployment of autonomous vehicles is just around the corner. However, the automobile industry knows that it is much easier to build a few vehicles to run in limited conditions than it is to build fleets of hundreds of thousands of vehicles and deploy them to run anywhere anytime. It is difficult to see how any practical amount of road testing alone is enough to ensure the safety of such as fleet. Thus, the greatest challenge remaining in the large-scale deployment of autonomous driving systems is testing and debugging machine learning and deep learning algorithms that work without defined requirements and design to ensure their robustness and safety.

Ansys has leveraged its vast experience in multiphysics simulation and safety-critical embedded software to deliver a complete closed loop simulation platform for virtual testing of autonomous driving systems that includes physically accurate sensor models, a virtual environment and scenarios, and virtual SIL and HIL testing. These unique capabilities enable you to drive your future autonomous vehicle on virtual test tracks with realistic traffic conditions, including weather, oncoming vehicles and pedestrian scenarios, to train your machine learning software and validate its response to any driving scenario. By providing realistic physics-based simulation in real time, Ansys enables automotive systems engineers to create the safest autonomous driving systems.

ANSYS, Inc.
Southpointe
2600 Ansys Drive
Canonsburg, PA 15317
U.S.A.
724.746.3304
ansysinfo@ansys.com

If you've ever seen a rocket launch, flown on an airplane, driven a car, used a computer, touched a mobile device, crossed a bridge or put on wearable technology, chances are you've used a product where Ansys software played a critical role in its creation. Ansys is the global leader in engineering simulation. We help the world's most innovative companies deliver radically better products to their customers. By offering the best and broadest portfolio of engineering simulation software, we help them solve the most complex design challenges and engineer products limited only by imagination.

Visit www.ansys.com for more information.