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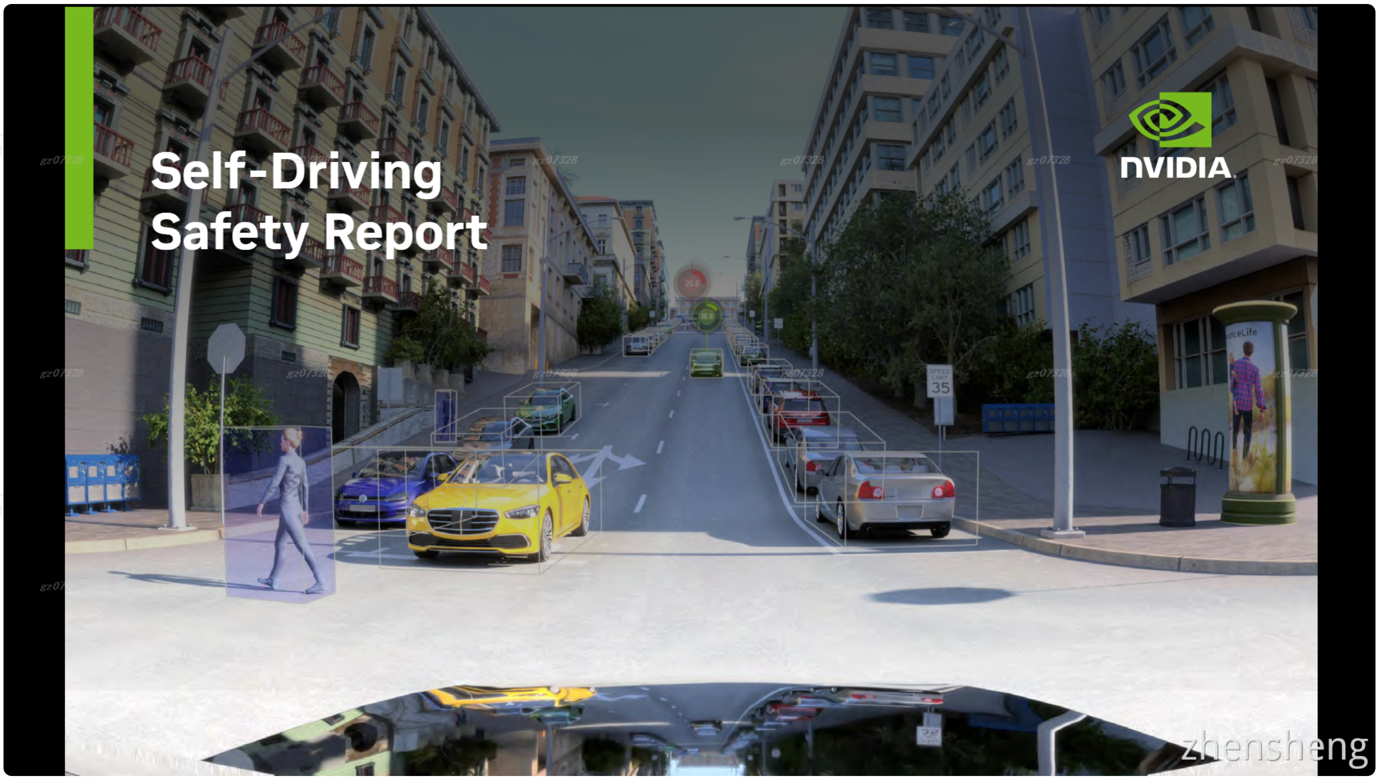

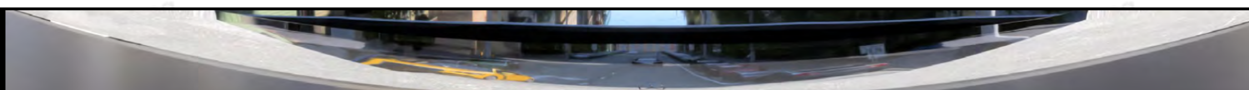

Our Mission

The next generation of transportation is autonomous. From shared and personal vehicles, to long- and short-distance travel, to delivery and logistics, autonomy will fundamentally improve the way the world moves. At NVIDIA, our automotive team's mission is to develop self-driving technology that enables safer, less congested roads, and mobility for all.

> "Safety is the most important aspect of a self-driving vehicle. NVIDIA's creation of a safe self-driving platform is one of our greatest endeavors, and provides a critical ingredient for automakers to bring autonomous vehicles to market."

Jensen Huang, NVIDIA founder and CEO

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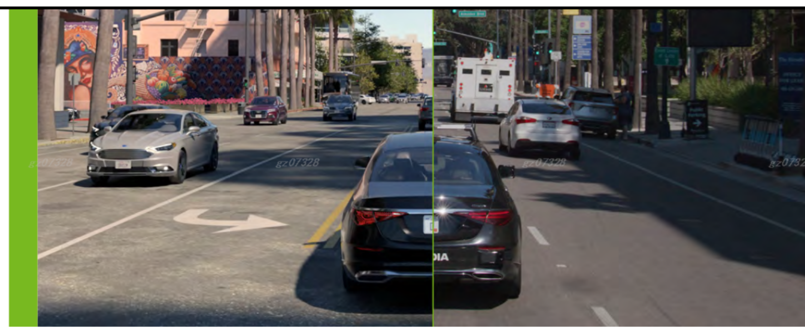
Introduction



NVIDIA pioneered accelerated computing to tackle challenges no one else can solve. Our work in AI and the metaverse is profoundly impacting society and transforming the world's largest industries—from gaming to robotics, to life-saving healthcare and climate change, to virtual worlds where we can all connect and create.

NVIDIA is also applying our technology-driven vision, computational performance, and energy efficiency to the transportation industry—helping vehicle makers around the world realize the dream of safe and reliable autonomous vehicles. From concept and design to engineering and production to sales and service, NVIDIA AI and DRIVE Omniverse™ are streamlining the entire automotive industry's workflow.

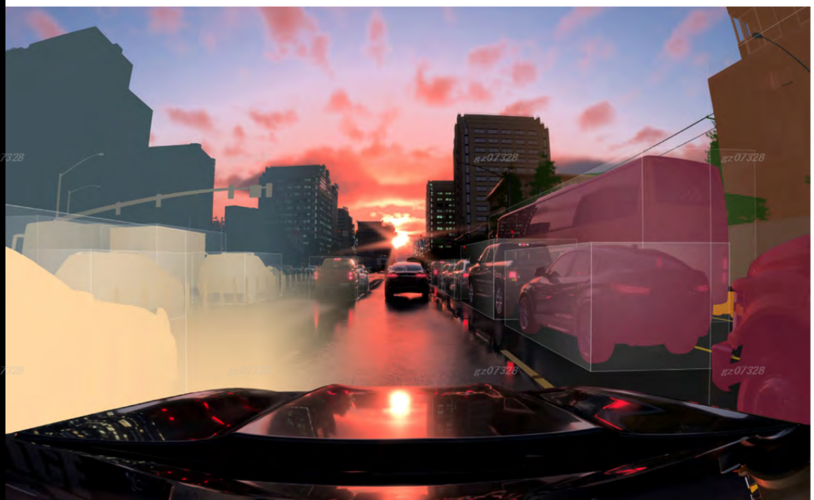
In particular, automated and autonomous vehicles are transforming the transportation industry. They have the potential to dramatically reduce injuries and fatalities from collisions, alleviate traffic congestion, increase productivity, and provide mobility to those who are unable to drive.

Breakthroughs in AI and accelerated computing are also opening future fleets to dramatic new functionality, fundamentally transforming the vehicle architecture for the first time in decades into a truly software-defined architecture. Like all modern computing devices, these intelligent vehicles are supported by a large team of AI experts and software engineers, dedicated to improving the performance and capability of the car as technology advances. Capabilities and services can be added using over-the-air updates throughout the entire life of the car.

NVIDIA works with vehicle makers, suppliers, sensor manufacturers, mapping companies, and startups around the world to develop end-to-end mobility solutions. We provide the systems architecture, AI supercomputing hardware, and full software stack required to build all types of vehicles—from AI-assisted cars and trucks to fully autonomous shuttles and robotaxis. With an open, modular architecture that spans from the cloud to the car, manufacturers can use select solutions or the entire development pipeline.

It all starts with NVIDIA DRIVE®, our highly scalable platform that can enable all levels of autonomous driving as defined by the Society of Automotive Engineers (SAE). These range from advanced driver-assistance system features (SAE Level 2: driver-assisted) through robotaxis (SAE Level 5: full automation).

The computational requirements of fully autonomous driving are enormous—easily up to 100 times higher than advanced vehicles in production today. With NVIDIA DRIVE, our partners can achieve the highest levels of safety with an architecture featuring diversity and redundancy in the computing hardware, sensor suites, and software stack.



To streamline development, we've created a single software-defined scalable architecture that advances each level of autonomy with additional hardware and software while preserving the core architecture. The same strategy holds for safety. With additional modular hardware and software, the level of safety achieved scales to match the more rigorous requirements of advanced levels of autonomy.

NVIDIA has created essential technologies for building robust, end-to-end systems for the research, development, and deployment of self-driving vehicles, spanning from the data center to the car. We offer a range of hardware and software solutions, from powerful GPUs and servers to a complete AI training infrastructure and in-vehicle autonomous driving supercomputers. We also support academic research and early-stage developers, partnering with dozens of universities worldwide and teaching courses on AI development at our Deep Learning Institute. As we identify challenges, we turn them into opportunities and build solutions.

This report provides an overview of NVIDIA autonomous vehicle technologies and how our unique contributions in safety architecture, co-designed hardware and software, design tools, methodologies, and best practices enable the highest possible levels of reliability and safety.

The Four Pillars of Safe Autonomous Driving

NVIDIA offers a unified hardware and software architecture throughout its autonomous vehicle research, design, and deployment infrastructure. We deliver the technology to address the four major pillars essential to making safe self-driving vehicles a reality.

> Pillar 1: Artificial Intelligence Design and Implementation Platform

> Pillar 2: Development Infrastructure For Deep Learning

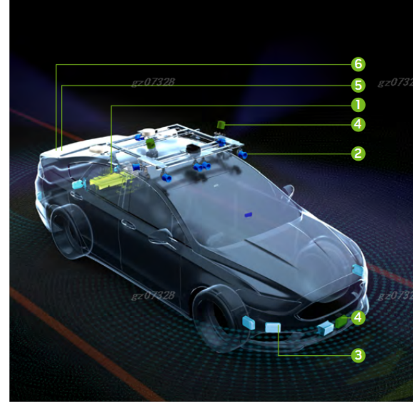
> Pillar 3: Data Center Solution for Robust Simulation and Testing

> Pillar 4: Best-In-Class Pervasive Safety and Cybersecurity Program

How Does An Autonomous Vehicle Work?

1. NVIDIA DRIVE AGX™ Platform: Sensor processing, AI computation, path planning, vehicle control
2. Camera: Detection and classification of static (signs, lanes, boundaries, etc.) and dynamic objects (pedestrians, cyclists, collision-free space, hazards, etc.)
3. Radar: Additional diversity and redundancy to both perception and localization functions
4. Lidar: High-resolution 3D perception, as well as an additional degree of diversity and redundancy
5. GNSS: Rough positioning
6. IMU: Motion compensation and localization

A fully autonomous vehicle (AV) can drive on its own through a combination of functionalities: perception, sensor fusion, localization to a high-definition map, path planning, and actuation. Cameras, radar, and lidar sensors enable the vehicle to see the 360-degree world around it, detecting traffic signals, pedestrians, vehicles, infrastructure, and other vital information. An on-board AI supercomputer interprets that data in real-time and combines it with cloud-based, high-definition mapping systems to safely navigate an optimal route.



This self-driving system allows the vehicle to detect and anticipate how objects and people along its path are moving, and then automatically controls the vehicle's steering, acceleration, and braking systems. The AI systems are capable of superhuman levels of perception and performance. They track all activity around the vehicle and never get tired, distracted, or impaired. The result is increased safety on our roads.

Pillar 1: Artificial Intelligence Design and Implementation Platform

NVIDIA DRIVE is the world's first scalable AI platform that spans the entire range of autonomous driving, from AI-assisted driving to robotaxis. The platform consists of hardware, software, and firmware that work together to enable the production of automated and self-driving vehicles.

Our platform combines deep learning with traditional software to enable a safe driving experience. With high-performance computing, the vehicle can understand in real-time what's happening around it, precisely localize itself on a high-definition map, and plan a safe path forward.

Our unified architecture extends from the data center to the vehicle and provides an end-to-end solution addressing the requirements of national and international safety standards.

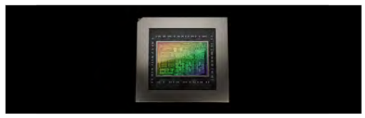
Deep neural networks (DNNs) are trained on NVIDIA DGX, a GPU-based server in the data center, then tested and validated in simulation on NVIDIA OVX before being seamlessly deployed to run on our AI computer in the vehicle. NVIDIA OVX is a computing system designed to power large-scale Omniverse digital twins. To operate safely, self-driving vehicles require on-board supercomputers capable of processing all the sensor data in real time.

NVIDIA DRIVE Hardware

Our underlying hardware solutions include:

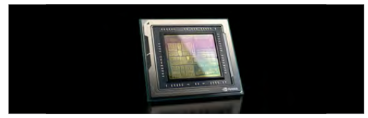
NVIDIA DRIVE Hyperion

DRIVE Hyperion™ is an end-to-end, modular development platform and reference architecture for designing autonomous vehicles (AVs). The latest generation includes the NVIDIA DRIVE AGX Orin™.



NVIDIA DRIVE Thor

Our next-generation centralized car computer combines advanced driver assistance and in-vehicle infotainment on a single safe and secure system. The DRIVE Thor superchip leverages our latest CPU and GPU advances to deliver an unprecedented 2,000 TFLOPS of performance, while reducing overall system cost, targeting 2025 vehicles.



NVIDIA DRIVE Orin

The DRIVE Orin SoC (system-on-a-chip) delivers 254 TOPS (trillion operations per second) and is the central computer for intelligent vehicles. It's the ideal solution for powering autonomous driving capabilities, confidence views, digital clusters, and AI cockpits. The scalable DRIVE Orin product family lets developers build, scale, and leverage one development investment across an entire fleet, from Level 2+ systems all the way to Level 5 fully autonomous vehicles.

NVIDIA DRIVE Software Development Kits

Software is what turns a vehicle into an intelligent machine. The open NVIDIA DRIVE® SDK gives developers all the building blocks and algorithmic stacks needed for autonomous driving. It empowers developers to efficiently build and deploy a variety of state-of-the-art AV applications more efficiently, including perception, localization and mapping, planning and control, driver monitoring, and natural language processing.

DRIVE OS is the first safe operating system for in-vehicle accelerated computing. It includes NvMedia for sensor input processing, NVIDIA CUDA® libraries for efficient parallel computing implementations, NVIDIA TensorRT™ for real-time AI inference, and other developer tools and modules to access hardware engines.

DriveWorks provides middleware functions–as part of DRIVE OS–that are fundamental to autonomous vehicle development. These consist of the sensor abstraction layer (SAL) and sensor plug-ins, data recorder, vehicle I/O support, and a deep neural network (DNN) framework.

DRIVE Chauffeur is built on the DRIVE Orin SoC and DRIVE SDK. It features the perception, mapping, and planning layers to handle both highway and urban traffic scenarios.

DRIVE Concierge is built on the DRIVE Orin SoC and DRIVE SDK. The platform extends beyond the cockpit, delivering infotainment and gaming, as well as acting as every passenger's digital assistant.

DRIVE Map is a multi-modal mapping platform that combines ground-truth and fleet-sourced map engines to achieve accuracy and scale. It serves as a foundational dataset for labeling, training, validation, and 3D environment reconstruction for simulation.

Pillar 2: Development Infrastructure For Deep Learning

In addition to in-vehicle supercomputing hardware, NVIDIA designs and develops the supercomputers used to solve critical challenges faced in the development and deployment of safe AVs. A single test vehicle can generate petabytes of data each year. Capturing, managing, and processing this massive amount of data for an entire fleet of vehicles requires a fundamentally new computing architecture and infrastructure.

NVIDIA DRIVE Infrastructure encompasses the complete data center hardware, software, and workflows needed to develop autonomous driving technology—from raw data collection through validation. It provides the end-to-end building blocks required for neural network development, training and validation, and testing in simulation.

> NVIDIA DGX SuperPOD™ delivers a turnkey AI data center solution for organizations that want to focus on insights instead of infrastructure. It includes best-of-breed computing, software tools, expertise, and continuous innovation delivered seamlessly.

> NVIDIA LaunchPad gives enterprises immediate access to NVIDIA AI running on private accelerated compute infrastructure to power critical AI initiatives. Speed the development and deployment of modern, data-driven applications and quickly test and prototype your entire AI workflow on the same complete stack you can purchase and deploy.

Our AI infrastructure helps developers create and train DNN models to enable highly accurate perception systems for autonomous vehicles. For example, we used DRIVE Infrastructure to create dozens of neural networks that separately cover perception of lanes and road boundaries, road markings, signs, vehicles, wait conditions, free space, and more. Because of the safety-critical nature of these networks, DRIVE Infrastructure also includes purpose-built deep learning compilers and runtime engines that have been specially qualified to fulfill automotive-grade requirements.

DRIVE Infrastructure is a solution for the entire industry. Today, leading automakers are each using more than 50 DGX SuperPODS—over 8,000 GPUs—to advance their AV development and testing.

Pillar 3: Data Center Solution For Robust Simulation and Testing

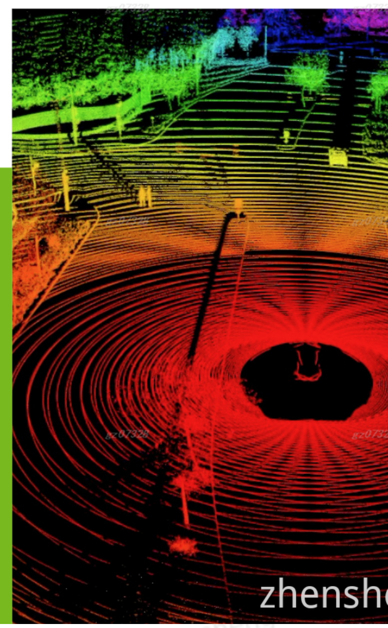
Before any autonomous vehicle can safely navigate on the road, engineers must first test and validate the AI algorithms and other software that enable the vehicle to drive itself. AI-powered autonomous vehicles must be able to respond properly to the incredibly diverse situations they could experience, such as emergency vehicles, pedestrians, animals, and a virtually infinite number of other obstacles—including scenarios that are too dangerous to test in the real world.

In addition, AVs must perform regardless of weather, road, or lighting conditions. There's no feasible way to physically road test vehicles in all these situations, nor is road testing sufficiently controllable, repeatable, exhaustive, or fast enough. The ability to test in a realistic simulation environment is essential to providing safe self-driving vehicles. Coupling actual road miles with simulated miles in the data center is the key to developing and validating AVs.

NVIDIA DRIVE Sim™ uses high-fidelity and physically based simulation to create a safe, scalable, and cost-effective way to bring self-driving vehicles to public roads. It taps into NVIDIA's core technologies, including NVIDIA RTX™, Omniverse™, and AI, to deliver a powerful computing platform capable of simulating a wide range of real-world scenarios for AV development and validation. DRIVE Sim can be connected to the AV stack in software-in-the-loop (SIL) or hardware-in-the-loop (HIL) configurations. In addition to development and testing, DRIVE Sim can generate synthetic data with associated ground truth data via Omniverse Replicator to train the vehicle's perception system by augmenting data captured in the real world.

NVIDIA Omniverse provides the core simulation and rendering engines for DRIVE Sim. Autonomous vehicle simulation requires extremely tight timing, repeatability, and real-time performance, and must be able to operate at scale. Additionally, generating data from AV sensor sets in physically based virtual worlds requires tremendous compute loads. NVIDIA Omniverse is architected from the ground up with multi-GPU support for large-scale, multi-sensor simulation used in autonomous vehicles. It also enables physically based, real-time sensor simulation using ray-tracing provided by NVIDIA RTX.

DRIVE Sim can be accessed through NVIDIA Omniverse Cloud or a local workstation, or scale to numerous GPUs across nodes. For HIL, NVIDIA DRIVE Constellation provides a dedicated hardware



platform, designed to run at scale in a data center. This ensures bit and timing accuracy. DRIVE Constellation is fully compatible with the NVIDIA DRIVE AGX platform or can be customized with third-party hardware.

NVIDIA Omniverse™ Replicator is an SDK that enables researchers, developers, and enterprises to build custom synthetic data generation (SDG) tools to accelerate the training and accuracy of perception networks.

NVIDIA Omniverse™ Cloud is an infrastructure-as-a-service that makes accessing and running Omniverse applications, such as DRIVE Sim, simple for individuals and teams. In addition, Omniverse Cloud provides many services that can be accessed via APIs for integration with existing workflows and infrastructure.

The neural reconstruction engine is a new AI toolset for the NVIDIA DRIVE Sim simulation platform that uses multiple AI networks to turn recorded video data into simulation. The new pipeline uses AI to automatically extract the key components needed for simulation, including the environment, 3D assets and scenarios. These pieces are then reconstructed into simulation scenes that have the realism of data recordings, but are fully reactive and can be manipulated as needed. Achieving this level of detail and diversity by hand is costly, time consuming and not scalable.

Pillar 4: Best-In-Class Pervasive Safety and Cybersecurity Program

Safety

Safety is our highest priority at every step of the AV research, development, and deployment process. It begins with a safety methodology that emphasizes diversity and redundancy in the design, validation, verification, and lifetime support of the entire autonomous system. We follow and develop best-in-class solutions in our processes, products, and safety architecture. NVIDIA safety is designed for software-defined autonomy because it accepts, tackles, and leverages the complexity of autonomous vehicles.

To conceptualize our autonomous vehicle safety program, we follow recommendations by the U.S. Department of Transportation's National Highway Traffic Safety Administration in its 2017, 2018, and 2020 publications.[1]

Throughout our program, we follow the automotive industry's safety standards from the International Organization for Standardization. These include:

Functional Safety (ISO 26262)

Autonomous vehicles must operate safely when a system fails. For L2/L2+, we must detect and mitigate failures (returning control to the driver), and for L3/L4 we must continue to operate safely and reach a minimal risk condition. We apply functional safety at all levels of hardware, software, and the system–from the application, through middleware through the operating system, to the board and to the chips on the board, and to the system providing the autonomous driving functionality.

Safety of the Intended Function (ISO 21448, aka SOTIF)

A system designed to be functionally safe (ISO 26262)[2] must also be designed and tested to be performant on all safety-critical metrics related to the intended functionality (ISO 21448).[3]

Safety hazards can be present even if the system is functioning as designed, without a malfunction. SOTIF focuses on ensuring the absence of unreasonable risk due to hazards resulting from insufficiencies in the intended functionality or from reasonably foreseeable misuse. For example, perception failures must be ensured sufficiently rare so that the autonomous vehicle rarely fails to detect a pedestrian in its path.

Safety and Artificial Intelligence

We actively contribute to ongoing standardization initiatives related to Safety of Artificial Intelligence, such as the ISO PAS 8800[4] and ISO/IEC TR 5469,[5] both currently in development.

Federal and International Regulations and Standardization

We adhere to federal and international regulations, including global NCAP (New Car Assessment Program), Euro NCAP, and the United Nations Economic Commission for Europe. We influence, co-create, and follow standards of the International Standards Organization, the New Vehicle Assessment Program, and the Society of Automotive Engineers International, as well as standards from other industries.

We contribute to standardization initiatives of the Institute of Electrical and Electronics Engineers (IEEE), such as IEEE 2846-2022 (on Assumptions for Models in Safety-Related Automated Vehicle Behavior)[6] and IEEE P2851 (on Exchange/Interoperability Format for Safety Analysis and Safety Verification of IP, SoC, and Mixed Signal ICs)[7].

Beyond complying with federal and industry guidelines, we practice open disclosure and collaboration with industry experts to ensure that we remain up-to-date on all current and future safety issues. We also hold leadership positions in multiple safety working groups to drive the state-of-the-art and explore new research areas, such as safety for AI systems and explainable AI.

Meeting the Highest Standards

To make transportation safer, autonomous vehicles must have processes and underlying systems that meet the highest standards.

NVIDIA uses TÜV SÜD — an independent, accredited assessor — to ensure compliance with the International Organization for Standardization (ISO) 26262:2018 Functional Safety Standard for Road Vehicles.

NVIDIA DRIVE platforms and processes have recently been certified and assessed by TÜV SÜD:

- NVIDIA DRIVE core development processes are certified as ISO 26262 Automotive Safety Integrity Level (ASIL) D compliant.

TÜV SÜD ISO 26262

- The NVIDIA DRIVE Orin system-on-a-chip (SoC) completed concept and product assessments, and is deemed to meet ISO 26262 ASIL D systematic requirements and ASIL B random fault management requirements.
- The NVIDIA DRIVE AGX Orin board completed concept assessment and is deemed to meet ISO 26262 ASIL D requirements.
- The NVIDIA DRIVE Orin-based system, which unifies the Orin SoC and DRIVE AGX Orin board, completed concept assessment and is deemed to meet ISO 26262 ASIL D requirements.
- Development of NVIDIA DRIVE OS 6.x is in progress and will be assessed by TÜV SÜD. This follows the recent certification of DRIVE OS 5.2, which includes NVIDIA CUDA libraries and the NVIDIA TensorRT software development kit for real-time AI inferencing

Cybersecurity

An autonomous vehicle platform can't be considered safe without cybersecurity. Comprehensive security engineering practices and development are essential to deliver on the functional and overall safety required for the automotive industry.

Security breaches can compromise a system's ability to deliver on fundamental safety goals. To deliver a best-in-class automotive security platform with high consumer confidence, we've built a world-class security team and aligned with government and international standards and regulations. We've also built strong partner relationships to remediate security incidents and serve as a good steward in protecting customer data privacy.

NVIDIA follows international and national standards for hardware and software implementations of security functionality, including cryptographic principles. We adhere to standards set by NIST (National Institute of Standards and Technology) [8] and GDPR (General Data Protection Regulations) [9] to protect the data and privacy of all individuals.

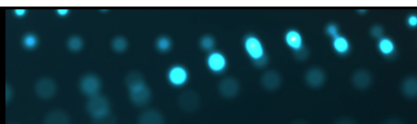
Our cybersecurity team works with the Automotive Information Sharing and Analysis Center (Auto-ISAC), NHTSA, SAE, and the Bureau of Industry and Security (Department of Commerce). We also contribute to the Automatic Identification System (Department of Homeland Security), Federal Information Processing Standards (Federal Information Security Management Act), and Common Criteria standards or specifications.

We follow and maintain a cybersecurity management system as defined in UNECE Regulation No. 155 [10]. In addition, we use the ISO/SAE 21434 cybersecurity process as a guiding principle and leverage processes and practices from other cybersecurity-sensitive industries with ISA/IEC 62443.

We participate in the SAE J3101 standard development, which ensures the necessary building blocks for cybersecurity are implemented at the hardware and system software levels. We review platform code for security conformance and use static and dynamic code analysis techniques for early detection, and perform penetration and other offensive security techniques for validation.

NVIDIA employs a rigorous security development lifecycle into our system design and hazard analysis processes, including threat models that cover the entire autonomous driving system—hardware, software, manufacturing, and IT infrastructure. The DRIVE platform has multiple layers of defense that provide resiliency against a sustained attack.

NVIDIA also maintains a dedicated Product Security Incident Response Team that manages, investigates, and coordinates security vulnerability information



internally and with our partners. This allows us to contain and remediate any immediate threats while openly working with our partners to recover from security incidents.

We also work closely with our suppliers to ensure the components that make up the whole of an autonomous driving platform provide the necessary security features. Proper cybersecurity of complex platforms becomes assured when all the links in the chain from raw data to processed input to control actions meet security requirements. In addition, NVIDIA works with our vendors to ensure they have a cybersecurity reaction capability for new or unfound threats.

Finally, as vehicle systems have a longer in-use lifespan than many other types of computing systems, we use advanced machine learning techniques to detect anomalies in the vehicle communications and behaviors and provide additional monitoring capabilities for zero-day attacks.

Architected for Safety

NVIDIA designed the DRIVE AGX platform to ensure that the autonomous vehicle can operate safely within the intended operational design domain (ODD). In situations where the vehicle is outside its defined ODD or conditions dynamically change to fall outside it, our products enable the vehicle to return to a minimal risk condition (also known as a safe fallback state). For example, if an automated system detects a sudden change such as a heavy rainfall that affects the sensors and, therefore, the driving capability within its operational design domain, the system is designed to hand off control to the driver. If significant danger is detected, the system is designed to come to a safe stop.

NVIDIA follows the V-model (including verification and validation) at every stage of DRIVE development. We also perform detailed analyses of our products' functionality and related hazards to develop safety goals for the product. For each identified hazard, we create safety goals to mitigate risk, each rated with an Automotive Safety Integrity Level (ASIL). ASIL levels of A, B, C, or D indicate the level of risk mitigation needed, with ASIL D representing the highest level. Meeting these safety goals is the top-level requirement for our design. By applying the safety goals to a functional design description, we create more detailed functional safety requirements.

At the system-development level, we refine the safety design by applying the functional safety requirements to a specific system architecture. Technical analyses–such as Failure Mode and Effects Analysis (FMEA), fault tree analysis (FTA), and dependent failure analysis (DFA)–are applied iteratively to identify weak points and improve the design. Resulting technical safety requirements are delivered to the hardware and software teams for development at the next level. We've also designed redundant and diverse functionality into our autonomous vehicle system to make it as resilient as possible. This ensures that the vehicle will continue to operate safely when a fault is detected or reconfigure itself to compensate for a fault.

At the hardware-development level, we refine the overall design by applying technical safety requirements to the hardware designs of the board and the system-on-a-chip (SoC). Technical analyses are used to identify any weak points and improve the hardware design. Analysis of the final hardware design is used to verify that hardware failure related risks are sufficiently mitigated.

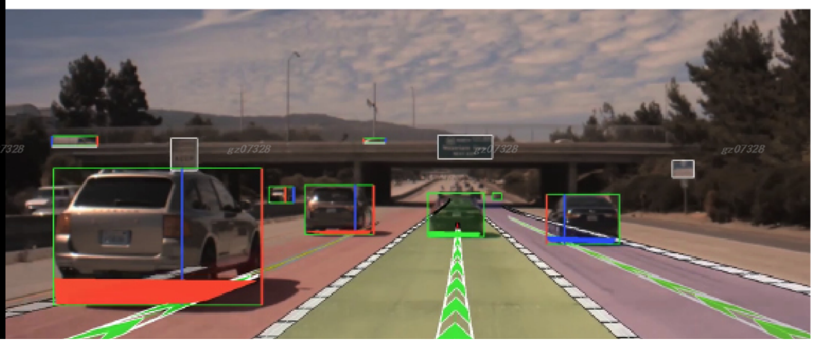
At the software-development level, we consider all software including firmware. We refine the overall design by applying technical safety requirements to the software architecture. We also perform code inspection, reviews, automated code structural testing, and code functional testing at both unit and integration levels. Software-specific FMEA is used to design better software. In addition, we design test cases for interface, requirements-based, fault-injection, and resource-usage validation methods.

When we have all necessary hardware and software components complete, we integrate and start our verification and validation processes at the system level. In addition to the autonomous vehicle simulation, we also perform end-to-end system testing and validation.

Safety For Software-Defined Autonomy

Our safety approach is architected for software-defined autonomy. Compared to safety approaches for traditional systems, NVIDIA's safety strategy is:

- Designed for dynamic system configurations
- A flexible platform for hardware and software richness
- Optimized for a growing number of functions
- Ecosystem-friendly with open system boundaries
- Designed for AI hardware, software, and tools
- Expandable with new algorithms
- Supportive of decomposable safety concepts
- Designed to handle millions of lines of code
- Easily updatable over-the-air
- Function aware, data-oriented, and validated end-to-end
- Hardware-Firmware-Software harmonized



All In One: AI Training, Simulation, and Testing

NVIDIA's infrastructure platform includes a data factory to label millions of images, an NVIDIA DGX SATURNV supercomputer for training DNNs, DRIVE Constellation for hardware-in-the-loop simulation, and other tools to complete our end-to-end system.

Autonomous vehicle software development begins with collecting huge amounts of data from vehicles in globally diverse environments and situations. Multiple teams across many geographies access this data for labeling, indexing, archiving, and management before it can be used for AI model training and validation. In addition, real data can be augmented with synthetic data from simulation for scenes that are rare or difficult to label. We call this first step of the autonomous vehicle workflow the "data factory."

AI model training starts when the labeled data is used to train the models for perception and other self-driving functions. This is an iterative process; the initial models are used by the data factory to select the next set of data to be labeled. Deep learning

engineers adjust model parameters as needed, and then re-train the DNN, at which point the next set of labeled data is added to the training set. This process continues until the desired model performance and accuracy is achieved.

Self-driving technology must be evaluated again and again during development in a vast array of driving conditions to ensure that the vehicles are far safer than human-driven vehicles. Simulation runs test-drive scenarios in a virtual world, providing rendered sensor data to the driving stack and carrying out driving commands from the driving stack. Re-simulation plays back previously recorded sensor data from the real world to the driving stack. The AI model is then validated against a large and growing collection of test data.

Hardware

The DRIVE AGX hardware architecture is scalable, covering everything from entry-level advanced driver assistance systems to fully autonomous robotaxis. The current generation DRIVE Orin SoC's safety architecture was developed over several years by hundreds of architects, designers, and safety experts based on analysis of hundreds of safety-related modules.

Built as a software-defined platform, DRIVE Orin is developed to enable architecturally compatible platforms that scale from a Level 2 to a full self-driving Level 5 vehicle, enabling OEMs to develop large-scale and complex families of software products. All DRIVE SoCs are programmable through open CUDA and TensorRT APIs and libraries, so developers can leverage their investments across multiple product generations.

In 2022, NVIDIA introduced DRIVE Thor, our next-generation centralized computer for safe and secure autonomous vehicles.

DRIVE Thor, which is designed to achieve up to 2,000 teraflops of performance, unifies intelligent functions — including automated and assisted driving, parking, driver and occupant monitoring, digital instrument cluster, in-vehicle infotainment (IVI) and rear-seat entertainment — into a single architecture for greater efficiency and lower overall system cost.

The next-generation superchip comes packed with the cutting-edge AI capabilities first introduced in the NVIDIA Hopper™ Multi-Instance GPU (MIG) architecture, along with the NVIDIA Grace™ CPU and NVIDIA Ada Lovelace GPU. DRIVE Thor with MIG support for graphics and compute uniquely enables IVI and advanced driver-assistance systems to run domain isolation, which allows concurrent time-critical processes to run without interruption.

Available for automakers' 2025 models, it will accelerate production roadmaps by bringing higher performance and advanced features to market in the same timeline.

Software

The Perception module in the DRIVE SDK takes sensor data and uses a combination of deep learning and traditional signal processing to determine an understanding of the vehicle's environment, referred to as the World Model. Once the environment is understood, the Planning module uses this information to determine and score a set of trajectories and determine the best route. The Vehicle Dynamics Control module can then transform the chosen path into vehicle actuation.

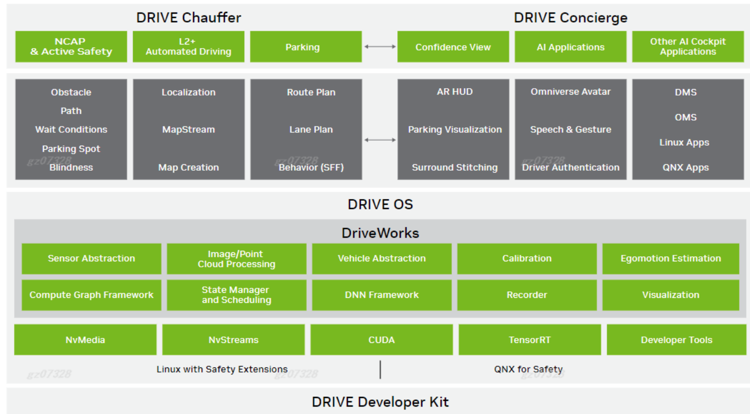
DRIVE SDK currently uses more than 20 DNN models running simultaneously, in addition to a large suite of computer vision and robotics algorithms. However, the number of DNNs and the capabilities they cover are continually growing.

Each major function—such as sensor processing, AI-based perception, localization, trajectory planning, and mapping—is performed with multiple redundant and diverse methods to achieve the highest level of safety. For example, DRIVE SDK uses embedded modules for detecting and handling obstacles and drivable space. For wait conditions, we detect traffic lights, stop signs, intersections, and stop lines. For paths, we detect lane edges and drivable paths. This detection is happening over multiple frames, and objects are tracked over time. We also layer diversity by using multiple sensor types (radar, camera, and lidar). The triple combination of diverse DNNs, tracking of objects over multiple frames, and presence of different sensor types ensures safe operation within the operational design domain. Additionally, the integrated functional safety mechanisms enable safe operation in the event of a system fault.

Vehicles and Sensors

DRIVE Hyperion is a reference vehicle implementation of the DRIVE platform to enable self-driving development, data collection and ingestion, verification, and validation across automation levels. The platform leverages multiple sensor modalities—including cameras, radars, IMUs, and ultrasonic sensors—and is deployable to a variety of vehicle types.

DRIVE Software Architecture

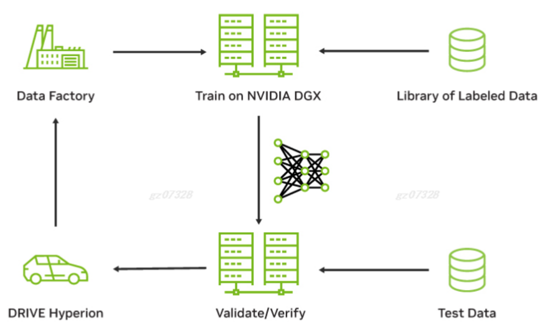


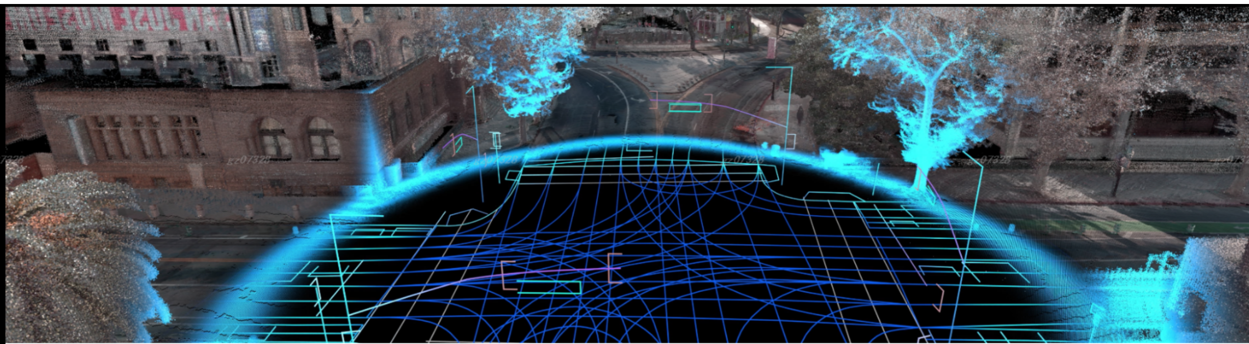
Data Center

After collecting sensor data, we process it and, in the case of camera data, select images to be labeled for training the AI. The entire process is continuously validated. We label not only objects and images within captured frames, but also scenarios and conditions in video sequences. The more diverse and unbiased data we have, the safer the DNNs become. We also define key performance metrics to measure the collected data quality and add synthetic data into our training datasets via NVIDIA Omniverse Replicator. Using Replicator, developers can generate pre-labeled ground-truth data to bootstrap algorithm development. The ultimate goal is to continuously add training data to build a comprehensive matrix of locations, conditions, and scenarios. Performance of neural network models is validated against the data and retested as new data is collected.

In addition to labeling the objects in an image, we label the conditions under which data was collected. This provides a matrix of conditions we can use as a test dataset to test the performance of our DNN models against a wide range of scenarios, weather conditions, and times of day.

GPUs in the data center are used extensively to investigate new DNNs with diverse datasets, continually train neural network models, analyze the results of workflows, and test and validate outcomes using large-scale systems for simulation in virtual worlds and replay of collected data.





Mapping

DRIVE Map is a multi-modal mapping platform that combines ground-truth and fleet-sourced map engines to achieve accuracy and scale. It serves as a foundational dataset for labeling, training, validation, and 3D environment reconstruction for simulation. DRIVE Map also includes four localization layers, giving developers the flexibility to integrate into any autonomous vehicle system.

This unique approach combines the best of both worlds, achieving high precision with dedicated survey vehicles, as well as the freshness and scale that can only be achieved with millions of passenger vehicles continuously updating and expanding the map.

The ground truth engine is based on the DeepMap survey map engine, which achieves centimeter-level accuracy and delivers ultra-accurate real-time localization for autonomous vehicles.

The AI-based crowdsource engine is designed to gather map updates from cars on the road, constantly uploading new data to the cloud as the vehicles drive. The data is then aggregated and used to update the map, providing the real-world fleet fresh over-the-air map updates.

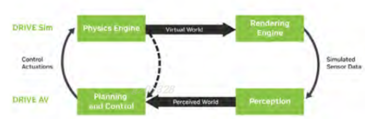
DRIVE Map also provides a data interface, DRIVE MapStream, to allow any passenger car that meets the DRIVE Map requirements to continuously update the map using camera, radar, and lidar data.

Simulation

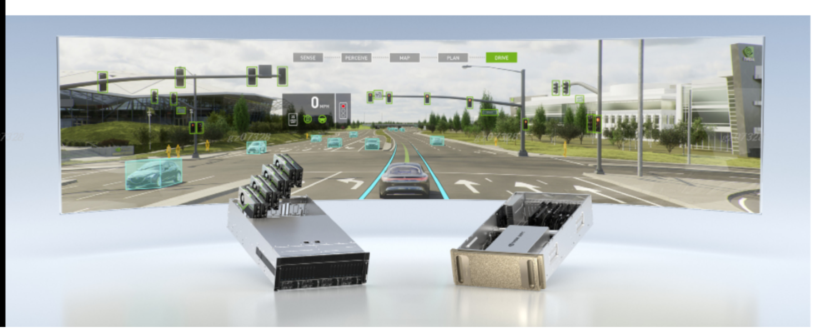
While traffic accident rates have been increasing, occurrences of dangerous incidents experienced by a single test vehicle are extremely rare, making it hard to accurately assess safety or compare different designs. To statistically demonstrate that a self-driving system has a lower collision rate than human drivers requires a sizable test fleet driving hundreds of millions of miles. As a result, it's difficult to verify and validate vehicle self-driving capabilities solely using on-road testing.

DRIVE Sim and DRIVE Constellation bridge this verification and validation gap. These solutions are designed for maximum flexibility, throughput, and risk elimination by relying on high-fidelity simulation. To ensure the simulation data is accurate, correlation to simulation is done in both lab and on-road environments. For even higher levels of fidelity, HIL testing on DRIVE Constellation uses actual vehicle hardware, ensuring bit and timing accuracy. The complete system can be robustly tested with the same data processing and communications protocols used in the actual car.

Simulation at scale makes it possible for dangerous events and rare corner cases to be tested repeatedly. It also enables testing under a wide range of conditions including harsh lighting conditions, different times of day, and different weather conditions.



DRIVE AV and DRIVE Sim Interaction.



Replay

In addition to simulation, NVIDIA utilizes replay—playing back previously recorded sensor data, rather than synthetic data—to test and study the driving software stack. For example, we incorporate actual sensor data from automatic emergency braking scenarios using replay to help understand and eliminate false positives.

On-Road Testing

NVIDIA created the DRIVE Road Test Operating Handbook to ensure a safe, standardized on-road testing process. This document specifies what must be done before, during, and upon completion of every road test. As recommended in the U.S. DOT report Preparing for the Future of Transportation: Automated Vehicles 4.0,[11] NVIDIA's process is modeled on the FAA-certified Pilot's Operating Handbook that must be carried in-flight with every general aviation aircraft in the U.S.

On-road testing is always performed with a highly trained safety driver continuously monitoring the vehicle's behavior and ready to immediately intervene when necessary. A co-pilot monitors the self-driving software—for instance, checking that the objects detected by the car correspond to those viewed live—and that the vehicle's path is valid for current road conditions.

We can also modify our processes when it's not possible to test in-person. The NVIDIA DRIVE RC (remote control) teleoperation system enables the human co-pilot to remotely monitor the vehicle, while the DRIVE Sim virtual testing platform makes it possible to safely and securely test vehicles virtually.

Prior to allowing software to be tested on-road, it's extensively tested using unit tests and system simulation.

Developer Training and Education

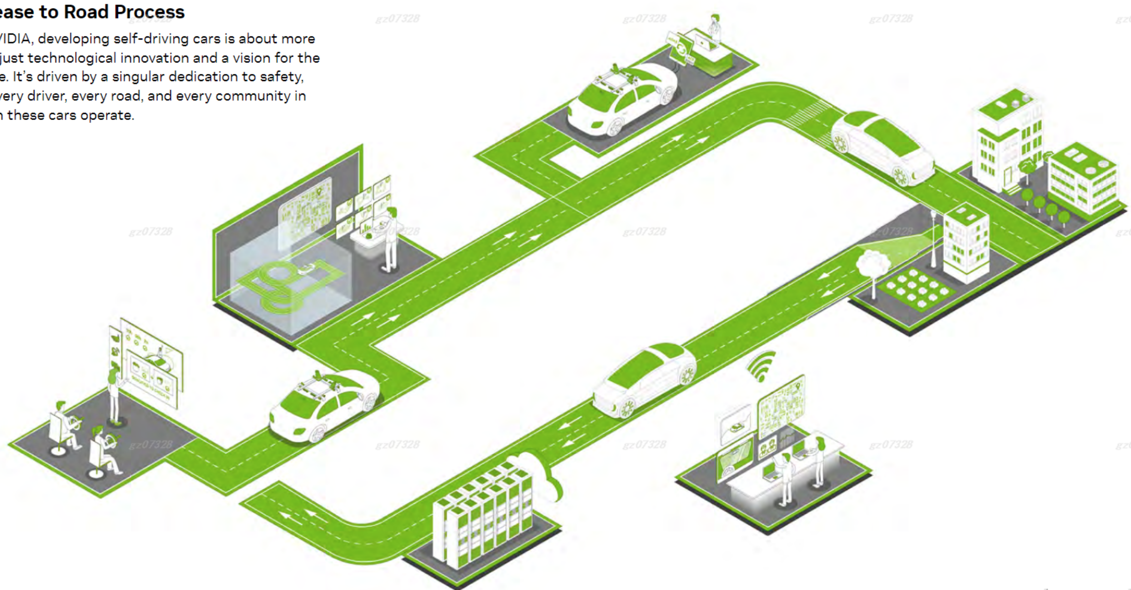
NVIDIA is committed to making developer education easily accessible, helping both experts and students learn more about these breakthrough technologies. The NVIDIA Deep Learning Institute offers multiple courses on how to design, train, and deploy DNNs for autonomous vehicles, and we produce a wide range of content to answer common questions. We now have over two million registered developers across eight different domains, such as deep learning, accelerated computing, autonomous machines, and self-driving cars.

In addition, NVIDIA hosts the GPU Technology Conference (GTC) to help educate students, developers, and executives on accelerated computing, AI, and autonomous vehicles. Each conference features hundreds of sessions, panels, and hands-on courses.

The Drive for Autonomous Vehicle Safety

Release to Road Process

At NVIDIA, developing self-driving cars is about more than just technological innovation and a vision for the future. It's driven by a singular dedication to safety, for every driver, every road, and every community in which these cars operate.



Summary

NVIDIA is unique in providing foundational technologies for the design, development, and manufacture of safe and reliable software-defined autonomous vehicles. Our ability to combine the power of visual and high-performance computing with artificial intelligence and proven software development makes us an invaluable partner to vehicle manufacturers and transportation companies around the world.

We adhere to the industry's most rigorous safety standards in the design and implementation of the powerful NVIDIA DRIVE platform, and we collaborate with industry experts to address current and future safety issues. Our platform aligns with and supports the safety goals of the major autonomous vehicle manufacturers and robotaxi companies.

Building safe autonomous vehicle technology is one of the largest, most complex endeavors our company has ever undertaken. We've invested billions of dollars in research and development, and many thousands of engineers throughout the company are dedicated to this goal. As of now, more than 1,500 engineer-years have been invested in our automotive safety process.

There are currently more than 50 AV companies who have over 800 test vehicles on the road powered by NVIDIA technology. They recognize that greater compute in the vehicle enables redundant and diverse software algorithms to deliver increased safety on the road.

We fundamentally believe that self-driving vehicles will bring transformative benefits to society. By eventually removing human error from the driving equation, we can prevent the vast majority of accidents and minimize the impact of those that do occur. We can also increase roadway efficiencies and curtail vehicle emissions. Finally, people who may not have the ability to drive a car will gain the freedom of mobility when they can easily summon a self-driving vehicle.

NVIDIA holds a key role in the development of AVs that will revolutionize the transportation industry over the next several decades. Nothing is more exciting to us than overcoming technology challenges and making people's lives better and our roads safer.

Appendices

Appendix A: NVIDIA Activity in Expert Groups

NVIDIA is respected as an organization of experts in relevant fields as demonstrated by the active leadership role that our experts have in international standardization working groups. Working groups benefiting from our expertise include:

> ISO TC 22/SC 32/WG 8, ISO 26262, Functional Safety" and ISO 21448 "Safety of the intended functionality"

> ISO TC 22/SC 32/WG 13, ISO TS 5083, "Safety and cybersecurity for automated driving systems — Design, verification and validation methods"

> ISO TC 22/SC 32/WG 14, ISO PAS 8800, "Safety and Artificial Intelligence"

> ISO TC 22/SC 32 and SAE TEVEES 18A, ISO/SAE 21434, "Cybersecurity engineering"

> ISO/TR 9839, "Application of Predictive Maintenance with ISO 26262-5"

> IEC 61508, "Functional safety of electrical/electronic/programmable electronic safety-related systems"

> IEEE 2846-2022, "A Formal Model for Safety Considerations in Automated Vehicle Decision Making"

> IEEE P2851, "Standard for functional safety data format for interoperability within the dependability lifecycle"

> IEEE Computer Society Functional Safety Standards Committee (FSSC)

> ISO/IEC JTC1 SC42 WG3, ISO TR 5469, "Artificial intelligence — Functional safety and AI systems"

> Euro NCAP, through the European Association of Automotive Suppliers

> Comité de Liaison de la Construction d'Equipements et de Pièces d'Automobiles

> UNECE Working Groups on Functional Requirements for Automated Vehicles (FRAV) and Validation Methods for Automated Driving (VMAD)

> UNECE Working Groups on Dynamic Control Assistance System (DCAS)

> SAE Automotive Functional Safety Committee

> Multiple worldwide R&D consortia, technical review committees, and R&D chair roles

Appendix B: National and International Safety Regulations and Recommendations

NVIDIA adheres to national and international safety recommendations, some of them outlined here.

International Organization for Standardization (ISO)

We adhere to ISO 26262 and ISO 21448 (SOTIF). ISO 2626210 addresses functional safety in road vehicles. We apply ISO 26262 to the application, middleware, operating system, board, and chip levels. ISO 2144811 addresses safety of the intended functionality in road vehicles. It reuses and extends the ISO 26262 development process to address SOTIF concerns.

National Highway Traffic Safety Administration (NHTSA)

Safety guidelines for autonomous driving are covered in a publication by NHTSA titled Voluntary Guidance for Automated Driving Systems. Of the 12 safety elements representing industry consensus on safety for the use of automated driving systems on public roadways, 10 are the most relevant to NVIDIA.

Global NCAP (New Car Assessment Program)

Regional NCAPs adjust safety practices to their particular markets, and NVIDIA will evaluate performance with all local NCAPs. The European New Vehicle Assessment Program (Euro NCAP) provides consumers with an independent safety assessment of vehicles sold in Europe. Euro NCAP published its 2025 Roadmap, which presents a vision and strategy to emphasize primary, secondary, and tertiary vehicle safety. We are currently addressing these Euro NCAP recommendations:

> Automatic Emergency Steering

> Pedestrian and Cyclist Safety

> Assisted Driving Testing

> Simulation and Assessment

> Child Presence Detection

> Autonomous Emergency Braking

> Cybersecurity

> V2X

> Driver Monitoring

> Human-Machine Interface (HMI)

> Pedestrian and Cyclist Safety

> Simulation and Assessment

> Child Presence Detection

> Cybersecurity

Appendices

Appendix C: NHTSA Elements of Safety

The National Highway Traffic Safety Administration outlined key topics for self-driving safety in its **Automated Driving Systems 2.0: A Vision for Safety.** Of the 12 safety elements representing industry consensus on safety for the use of automated driving systems on public roadways, 10 are relevant to NVIDIA.

A. System Safety
NVIDIA has created a system safety program that integrates robust design and validation processes based on a systems-engineering approach with the goal of designing automated driving systems with the highest level of safety and free of unreasonable safety risks.

B. Object And Event Detection And Response
Object and event detection and response refers to the detection of any circumstance that's relevant to the immediate driving task, and the appropriate driver or system response to this circumstance. The NVIDIA DRIVE AV module is responsible for detecting and responding to environmental stimuli, both on and off the road. The NVIDIA DRIVE IX module helps monitor the driver and take mitigation actions when they're required.

C. Operational Design Domain
NVIDIA has developed an extensive set of operational design domains for individual driving automation systems or features, as recommended by NHTSA. Each operational design domain includes the following information at a minimum to define the product's capability boundaries: roadway types, geographic area and geo-region conditions, speed range, environmental conditions (weather, time of day, etc.), and other constraints.

D. Fallback (Minimal Risk Condition)
Our products enable the vehicle to detect a system malfunction or breach of the operational design domain, and then transition the system to a safe or degraded mode of operation based on a warning and degradation strategy. Every NVIDIA autonomous driving system includes a fallback strategy that enables the driver to regain proper control of the vehicle or allows the autonomous vehicle to return to a minimal risk condition independently. Our HMI products can be used to notify the driver of a potentially dangerous event and return the vehicle to a minimal risk condition independently, or alert the driver to regain proper control. The minimal risk conditions vary according to the type and extent of a given failure.

E. Validation Methods
Validation methods establish confidence that the autonomous system can accomplish its expected functionalities. Our development process contains rigorous methods to verify and validate our products' behavioral functionality and deployment. To demonstrate the expected performance of an autonomous vehicle for deployment on public roads, our test approaches include a combination of simulation, test track, and on-road testing. These methods expose the performance under widely variable conditions, such as when deploying fallback strategies.

F. Human-Machine Interface
DRIVE IX provides an open software stack for cockpit solution providers to build and deploy features that will turn personal vehicles into interactive environments, enabling intelligent assistants, graphic user interfaces and immersive media and entertainment.

G. Vehicle Cybersecurity
NVIDIA employs a rigorous security development lifecycle into our system design and hazard analysis processes, including threat models that cover the entire autonomous driving system—hardware, software, manufacturing, and IT infrastructure. The NVIDIA DRIVE platform has multiple layers of defense that provide resiliency against a sustained attack.
NVIDIA also maintains a dedicated Product Security Incident Response Team that manages, investigates, and coordinates security vulnerability information internally and with our partners. This allows us to contain and remediate any immediate threats while openly working with our partners to recover from security incidents.

H. Data Recording
NVIDIA replay enables real data from sensors placed on test vehicles that are driving on the public roads to be fed into the simulation. To maximize the safety of self-driving vehicles, NVIDIA offers a combination of simulated data to test dangerous road scenarios coupled with real-world data from replay.

I. Consumer Education And Training
We continually develop, document, and maintain material to educate our employees, suppliers, customers, and end consumers. We offer multiple AI courses under our Deep Learning Institute and we report about new knowledge and developments at the NVIDIA GPU Technology Conferences around the world. We also collaborate with the research organizations to invent improved approaches to autonomy and maintain the highest integrity level to co-create world-class thought leadership in the autonomous vehicle domain.

J. Federal, State, And Local Laws
We operate under the principle that safety is the first priority and comply with international, federal, state, and local regulations, and safety and functional safety standards. We also frequently communicate with regulators to ensure that our technology exceeds all safety standards and expectations. We are active in standardization organizations to advance the future of autonomous driving.

Appendix D: References

1. NHTSA Automated Driving Systems: https://www.nhtsa.gov/vehicle-manufacturers/automated-driving-systems
2. ISO 26262: Road Vehicles – Functional Safety. The International Organization for Standardization (ISO), 2018. Part 1: Vocabulary: Terms and Definitions: https://www.iso.org/standard/68383.html
3. ISO 21448, Road vehicles – Safety of the intended functionality, 2022: https://www.iso.org/standard/77490.html
4. ISO PAS 8800: ISO - ISO/AWI PAS 8800 - Road Vehicles — Safety and artificial intelligence
5. ISO/IEC TR 5469: ISO - ISO/IEC CD TR 5469 - Artificial intelligence — Functional safety and AI systems
6. IEEE 2846-2022 web page: IEEE SA - IEEE 2846-2022
7. IEEE P2851 web page: https://sagroups.ieee.org/2851/
8. NIST Cybersecurity: https://www.nist.gov/topics/cybersecurity
9. GDPR: https://gdpr.eu/
10. UNECE Regulation 155: https://unece.org/transport/documents/2021/03/standards/un-regulation-no-155-cyber-security-and-cyber-security
11. Preparing for the Future of Transportation: Automated Vehicles 4.0 (AV 4.0), 2020: https://www.transportation.gov/av/4

参考

https://blogs.nvidia.com/blog/2023/04/20/nvidia-drive-safety-milestones/

https://blogs.nvidia.com/blog/2018/10/23/introducing-self-driving-safety-report/

https://resources.nvidia.com/en-us-auto-safety?fm=dnd&_pfses=6BWPsvsmUwZN5PpvdfD7M43N

2018报告

📎NVIDIA-Self-Driving-Safety-Report-2018.pdf