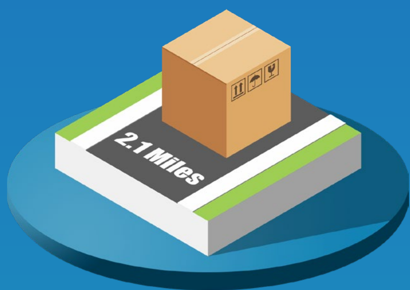
THE AUTOX
SAFETY FACTOR

PUBLISHED 2018

Democratizing Autonomy

Bringing Self-driving Technologies to Everyday Life



2.1 Miles

On average, every cubic meter of goods travels 2.1 miles to be delivered in the traditional B2B model[1].

107 Hours

In New York City, drivers on average spend 107 hours per year searching for parking spots[2].

60 Hours

The average person spends 60 hours per year shopping in grocery stores[3].

SERVING OUR COMMUNITY WITH AUTONOMOUS DELIVERY

Cars play a central role in our lives. Each year, we spend an increasing number of hours behind the wheel, a trend that may continue unless drastic changes are made. Yet when we consider how much time is spent driving to meet our needs, an unmistakable pattern emerges: **driving is rarely more than just a means to an end.**

> **AutoX envisions a world where self-driving cars take care of the means, freeing you up to enjoy the ends.**

In the world that AutoX envisions, autonomous vehicles connect us by allowing us to transport physical items to and from one place to another. Even today, lending a friend a salad bowl, a socket wrench, or an Xbox controller still means a visit to the purgatory of traffic. By handling the less pleasant part of the process, AutoX's autonomous vehicles can make the thought of sending a gift basket to your friend the warm, happy one that it always intended to be.

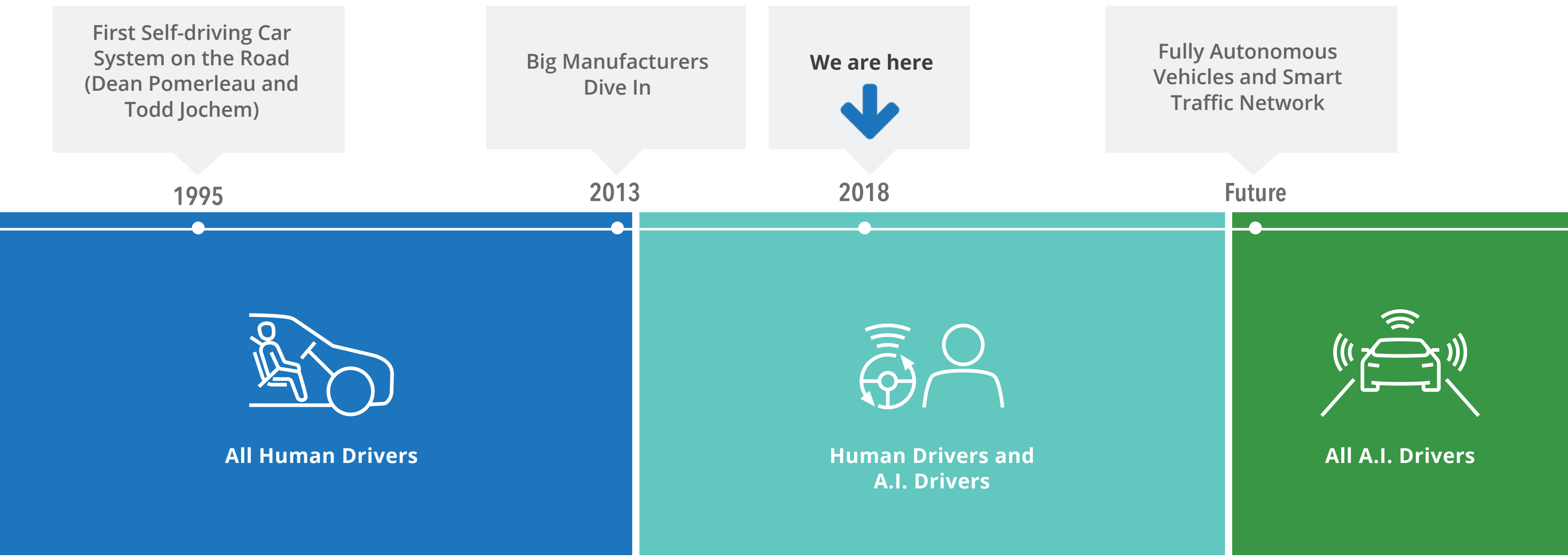
Communities are strengthened by passionate people who strive to share their works of love with others. The local artisanal baker who has been exploring new recipes will be overjoyed to send their regulars samples via autonomous vehicles as soon as the first batch is out of the oven. Florists, coffee shops, restaurants, and nearly every other business will benefit from our ability to share their products and creations with their communities in a safe, affordable, and pain-free way - and so will the communities that they serve. **With AutoX providing the means, the ends are truly limitless.**

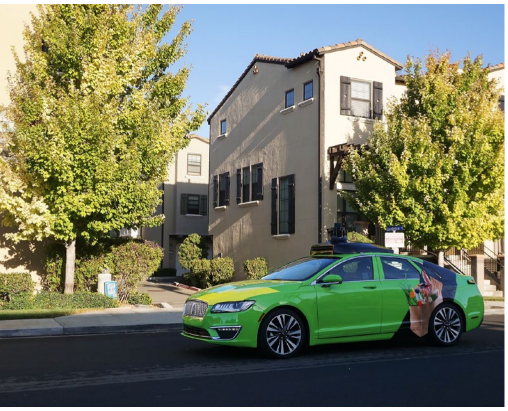
THE WORLD IN TRANSITION

Not long after the first motorcar was invented, human beings began to consider the possibility of making them autonomous. In 1925, inventor Francis P. Houdina publicly demonstrated his radio-controlled driverless car, American Wonder, in the streets of New York City, traveling up Broadway and down Fifth Avenue through heavy traffic[4]. This marked the beginning of humankind's aspiration for driverless vehicles. Since 2013, more and more pioneers have spearheaded the efforts of making self-driving cars a reality. Level 2 and Level 3 assistive-driving vehicles[5] are now being driven on the road. It seems inevitable that manual driving will someday be a thing of the past. Rather than driving to get the things we need, we have them come to us autonomously.

The next few decades will represent a transition period where humans and fully autonomous A.I. drivers are driving together, co-existing and sharing the road. The U.S. Department of Transportation has decreed that the freedom of the open road will be protected and enhanced. This includes the freedom for everyone to drive their own vehicles[6]. The unprecedented sharing of our roads between humans and computers is the reason AutoX is pushing the limits of cutting-edge A.I. technologies to ensure the safety of everyone involved. We have developed a smart hybrid system, which introduces a vital human element into the autonomous driving technology, so that we may better serve our community.

Autonomous driving technology, like most life-changing innovations, unleashes limitless possibilitites for the future. AutoX is pushing hard to build safe self-driving cars that will share the road with everyone.





THE VOLUNTARY SAFETY SELF-ASSESSMENT REPORT

We composed this voluntary safety self-assessment report to share our approach to achieving safe autonomous vehicle testing and future deployment based on the voluntary guidance of *A Vision for Safety, Automated Driving System 2.0* and *Preparing for the Future of Transportation, Automated Vehicles 3.0*. We open with a general introduction to AutoX's approach to building a safe and reliable self-driving delivery platform. Next, we highlight our redundancy-based system design for ensuring safety. Then, we introduce our testing and validation methods as well as our safety process and policy. Finally, we address considerations in public safety on the road, including our designed post-crash behavior and our engagement plan for first responders.

1. Statista. https://www.statista.com/statistics/781119/parcel-delivery-mileage-urban-commercial-transport/
2. Drivers spend an average of 17 hours a year searching for parking spots. https://www.usatoday.com/story/money/2017/07/12/parking-pain-causes-financial-and-personal-strain/467637001/
3. Who Does the Grocery Shopping, and When Do They Do It. Jack Goodman. The Time Use Institute. http://www.timeuseinstitute.org/Grocery16paper.pdf
4. Time Magazine. Science: Radio Auto. Aug 10, 1925. Retrieved 29 September 2013.
5. SAE autonomy scale. Level 2: Driver-assist systems that control both steering and acceleration/deceleration. These systems shift some of the workload away from the human driver, but still require that person to be attentive at all times. Level 3: Vehicles that can drive themselves in certain situations, such as in traffic on divided highways. When in autonomous mode, human intervention is not needed. But a human driver must be ready to take over when the vehicle encounters a situation that exceeds its limits.
6. U.S. Department of Transportation, Preparing for the Future of Transportation, Automated Vehicles 3.0

Safety Elements

In the guidance document *Automated Driving Systems 2.0: A Vision for Safety*, the National Highway Traffic Safety Administration (NHTSA) has outlined 12 topics that the self-driving system manufacturer should pay attention to for achieving safety. Below, we outline the sections in our report in which each of these topics is addressed.

System Safety

The key to achieving system safety is to establish a robust design process and follow a strict validation process. We are setting the highest standards in building our self-driving cars with design redundancies and safety strategies to handle autonomous driving system malfunctions and errors. AutoX's entire system features these strategies. In the **How Our Self-driving Car "Sees"** section, we share our methodology for designing and building our sensors and other equipment that enable our self-driving cars to "see". In the **Full Stack Redundancy** chapter, we discuss our design principle of providing redundancy for the entire self-driving system, from hardware to software to operations. In the **Testing and Validation** section, we share our data-driven development methods and our rigorous testing and validation process.

Operational Design Domain

A closed set of operational criteria and constraints, such as geographic area, weather condition, time of a day, etc., are defined as the Operational Design Domain (ODD). The ODD is extensively tested so that we are certain that our autonomous driving system is able to operate safety within it. Different testing or deployment stages have different ODDs. In the **Operational Design Domain** section, we define the ODD for our self-driving fleet.

Object and Event Detection and Response

Object and event detection and response refers to the detection by the autonomous driving system of circumstances that are relevant to the immediate driving task, as well as the implementation of the appropriate system response. In the **Algorithm Redundancy** and **A.I. Redundancy** sections, we introduce our unique way of safely handling and responding to immediate driving tasks. In the **The Brain of Our Cars** section, we present selected highlights of our A.I. technology that build a better and safer self-driving platform.

Fallback (Minimal Risk Condition)

Fallback is the transition to the minimal risk condition when a problem is encountered. In the **Fallback (Minimal Risk Condition)** section, we discuss our implementation of the minimal risk condition transition process.

Human Machine Interface

Human Machine Interface (HMI) describes a series of software and hardware user interfaces that help first responders, customers, and other road users to obtain necessary information about our self-driving car, as well as a way for them to safely engage with it. We address this topic in depth in the **Human Machine Interface (HMI)** section. The HMI also covers the interaction between the vehicle and the remote operator, and is extensively covered in the **Human Remote Operator** section.

Cybersecurity

AutoX has followed a thorough process to minimize the risks of cybersecurity threats. This is especially important since AutoX has built a teleoperation system which allows human operators to control the vehicles remotely. In the **Cybersecurity** section, we have introduced our methods to ensure the cybersecurity of the vehicle and the remote command center.

Crashworthiness

Crashworthiness is the consideration and practice of how to best protect vehicle occupants in a collision. AutoX integrates its self-driving technology with Lincoln MKZs and Chrysler Pacificas, which meet applicable requirements of the Federal Motor Vehicle Safety Standards (FMVSS) as issued by the National Highway Traffic Safety Administration (NHTSA).

Post-Crash ADS Behavior

A well-designed post-crash behavior ensures that the autonomous driving system returns to a safe state immediately after being involved in a crash. AutoX has standardized the behavior of the vehicle after a crash, which minimizes the risk to first responders and other road users. In the Post Crash Behavior section, we provide a brief introduction to the desired post-crash behavior of our self-driving cars.

Data Recording

Learning from crash data is a central component to the safety potential of the autonomous driving system. In the Data Recording section, we present our strategies to ensure the recording, security, and proper usages of testing data from crashes.

Customer Education and Training

Education and training are imperative for increased safety during the deployment of the autonomous driving system. It is beneficial to develop, document, and maintain employee and customer education and training to address the anticipated differences in the use and operation of the autonomous driving system from those of the conventional vehicles that the public owns and operates today. In the Public Engagement section, we take a deeper dive into our practices of conducting customer education and training for safe self-driving testing and future self-driving deliveries.

Federal, State, and Local Laws

AutoX ensures that our autonomous driving system adheres to all applicable Federal, State, and local laws. We will promptly update our system to reflect changes to the laws. We discuss this in the Federal, State, and Local Laws section.

CONTENTS

CHAPTER 1

OUR SELF-DRIVING TECHNOLOGY

Safety in Design

Safety has been at the forefront of our minds from the very beginning. We believe that a safe autonomous driving system can be engineered through comprehensive design, reliable implementation, and extensive stress testing. By combining selected sensors with cutting-edge A.I., the systems we build have a high-resolution perception of their surroundings and are capable of making safe decisions in all kinds of circumstances. AutoX has strict testing and vehicle deployment protocols, ensuring that every AutoX self-driving car on the road is in excellent operating condition and ready to provide safe and reliable transportation.

HOW OUR SELF-DRIVING CAR “SEES“

Camera Vision

AutoX’s innovative camera perception module provides a robust, highly accurate object detection and classification system of the surrounding environment. The combination of high frame rates, high resolution, and rich color information makes cameras the ideal backbone for our sensor suite. Our cameras are critical for mapping, lane detection, the recognition of traffic lights and traffic signs, and many other tasks.

LiDAR

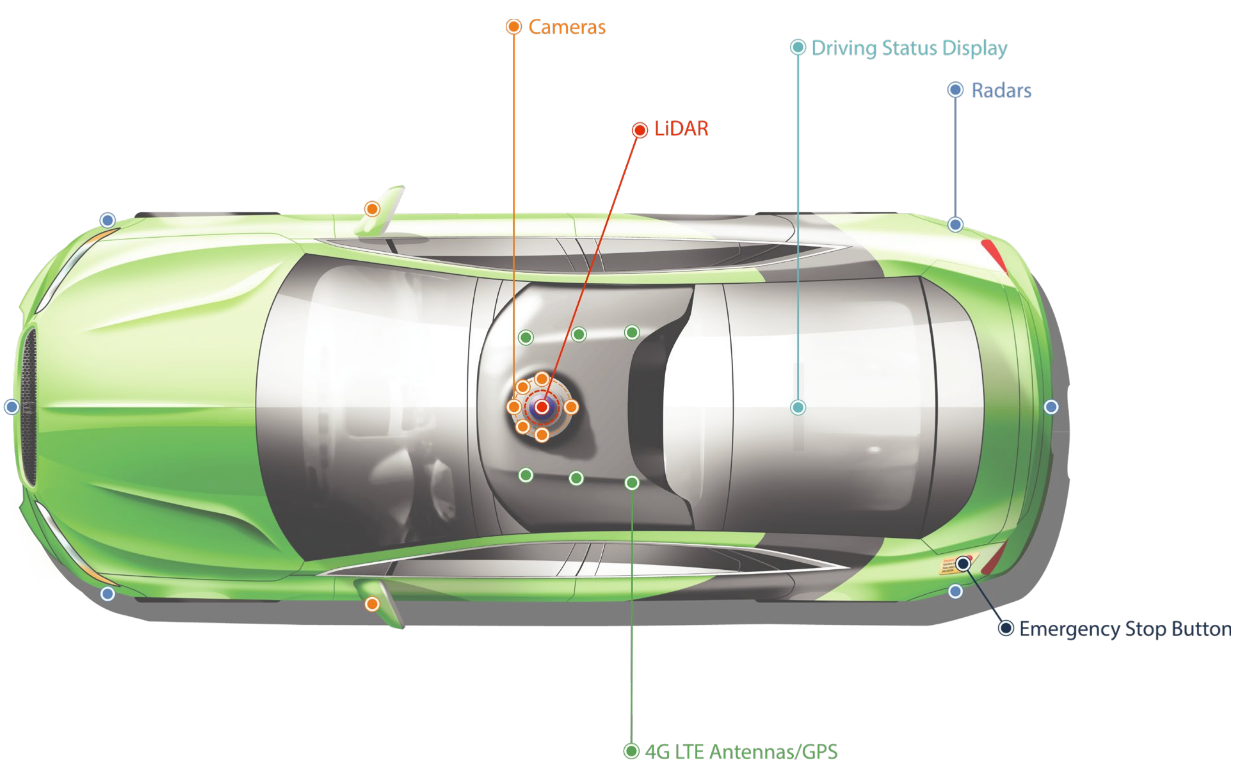
Light Detection and Ranging (LiDAR) is an active sensor that emits laser beams. A 3D point cloud is generated by tracing the reflection of laser beams that strike objects. This is combined with the information provided by the camera perception system, which creates a layer of redundancy for our self-driving systems. For instance, pedestrians, bicyclists, and others on the road are detected with the combination of LiDAR and camera perception.

Radar

The Radar system adds another layer of redundancy onto the perception module. Radar utilizes electromagnetic waves to detect the position and speed of objects and provides us with an effective method of providing better coverage.

Network Antenna and GPS

Having a well-designed fleet management system and stable communication with our vehicles is essential as it allows AutoX to monitor and remote control every one of our cars. The vehicles will maintain both data and radio communication links to our fleet command center.



Driving Status Display and Emergency Stop Button

AutoX has designed a human-machine interface that allows other road users to interact with the vehicle. A driving status display screen at the back of the vehicle informs the public at all times whether or not the vehicle is currently in self-driving mode. While our company's ethos is to ensure the safety of everyone that our vehicles share the road with, emergencies and unexpected issues are a possible reality that we must be prepared for. We have implemented an emergency stop button that enables law enforcement to bring the vehicle to a complete stop in a safe manner. The officer or responder may contact the vehicle's remote operators and take control of the vehicle if needed.

> **AutoX puts safety in the hands of the public by allowing them to safely disengage the autonomous mode if necessary.**

The Brain of Our Cars

The world's most talented experts in computer vision, autonomous driving, and robotics come together at AutoX to develop the brain of our cars. We have developed numerous innovative methods in the fields of visual perception, robotics, deep learning, and other key areas of artificial intelligence. The AutoX team strives to find ground-breaking solutions to unprecedented problems and share an unwavering pursuit of technological excellence. The result has been a unique combination of independent research and safety-oriented engineering. With our passion and dedication leading us, we will continue to maintain our rapid progress as we take driverless vehicles from concept to reality.

We are building the brain of a reliable autonomous vehicle to serve our community safely

Inside the Self-Driving Car's Brain

Localization	The localization module pinpoints the vehicle's exact location. AutoX creates its in-house HD 3D mapping and localization technology and uses real-time sensing to ensure that the maps are up to date.
Perception	The perception module allows the vehicle to be informed about its dynamic surroundings. Accurate object recognition and scene understanding are some of the keys to achieving safety. AutoX uses multi-sensor fusion to accomplish this.
Prediction	The prediction module anticipates other road users' behaviors and trajectories. This information is then provided to the decision and planning module.
Decision & Planning	AutoX's self-driving car is analyzing and optimizing every second to make the safest decision.
Control	The control module takes consideration of the kinematics and dynamics of the vehicle and calculates how much brake, throttle, and steering should be applied.

We have Created a High Resolution Perception Module

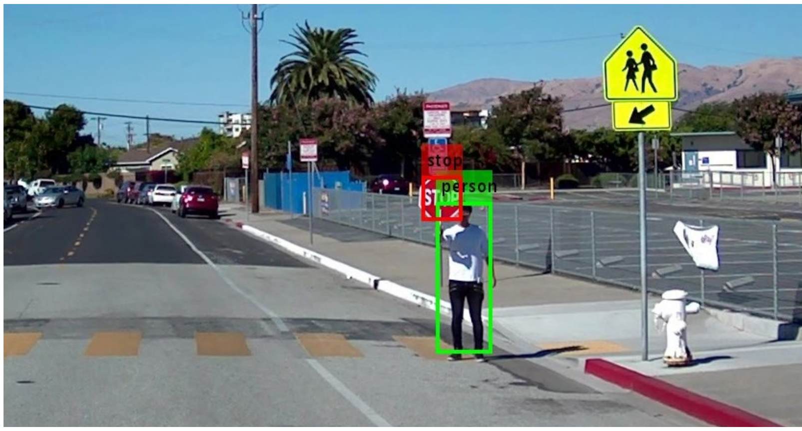
Perception is one of the most challenging tasks for a self-driving vehicle. Our roads are shared by human drivers, cyclists, pedestrians and others, so it is imperative that autonomous vehicles be able to identify, characterize, and react appropriately to them. Road users and other objects are frequently located close to or in front/behind one another - a typical situation is a person standing next to a tree by the side of the road. The eyes of a human driver can easily identify that the pedestrian and the tree are separate objects, and our minds can prepare for the possibility of the pedestrian crossing the road. One major challenge for the autonomous vehicle is to distinguish and recognize each individual object. We leverage our extensive research and development in multi-sensor fusion technology, which provides high precision perception for the A.I. to "see" reliably and accurately.

Our high resolution sensing goes beyond merely identifying objects. The perception module provides detailed information regarding an object's orientation, speed, and motion trajectory. This is invaluable information for the prediction module to forecast future motion and informs the next move of the vehicle accordingly. This ability to understand our current environment and predict its state in the immediate future using our perception module's high resolution sensing greatly enhances the safety of our vehicles.

Dual main sensors for redundancy

At AutoX, we use a variety of carefully selected sensors to provide us with a holisitic and complete picture of our vehicles' surroundings. We combine the high resolution and rich color information of cameras with the ability of LiDAR to accurately measure distance and speed. Coupled with other sensors such as radar, we have identified a complementary set of sensors, effectively giving our autonomous cars multiple "senses".

Different sensors provide layers of redundancy to one another. We frequently cross-check their readings to ensure that no object is left undetected and to eliminate false positives. We are also able to lean more heavily on just one of them when the other is rendered less effective, allowing our system to be robust to changing conditions.

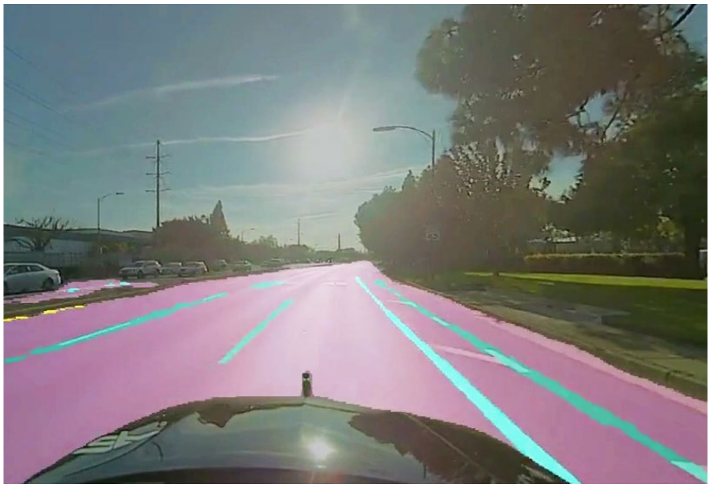


Using our perception module with multi-sensor fusion technology, our A.I. is able to distinguish the flagger and the dynamic traffic sign he is holding. Our system can also detect if the sign is flipped to read "SLOW" insead of "STOP".

Realtime object recognition

Camera image segmentation is the process of analyzing and detecting different objects from camera inputs and segmenting the image by finding out what object each pixel of the image belongs to, such as trees, sky, different types of vehicles, roads, and road markings. AutoX's system is able to analyze and segment camera inputs in real time.

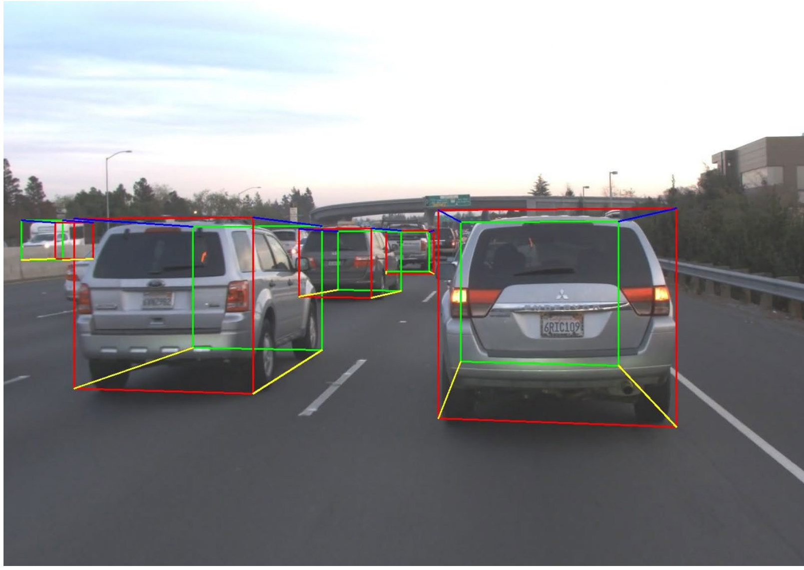
Testing of our real-time segmentation algorithm in highly occluded scenarios in downtown San Francisco.



Segmentation results: the driveable area is shown in pink and the lane detection is shown in cyan. The lane marking detection result is stable under direct sunlight and other lighting conditions.

Where? Which way? How fast?

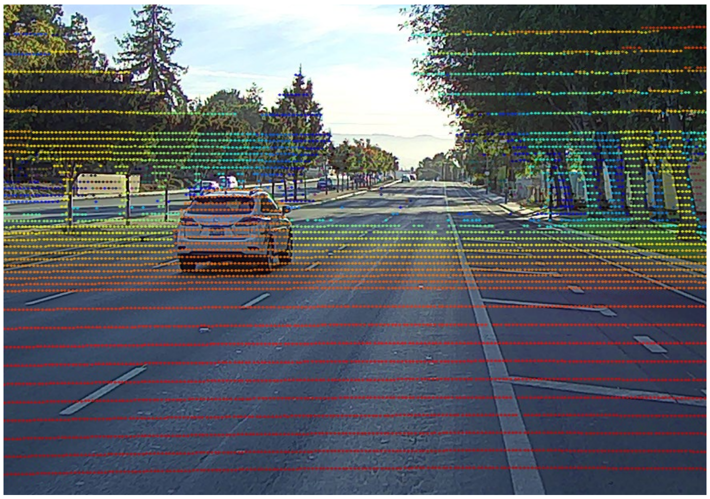
3D object information is critical in the perception module of autonomous vehicles. We use 3D information to calculate the dimensions, orientations, and velocities of surrounding objects. The AutoX approach leverages color information provided by cameras, 3D information from LiDAR, and information from other sensors to provide the decision-engine with enough data to make safe decisions.



Based on the camera image, we are able to recognize the heading of the car which helps us to obtain more accurate orientation and velocity information of other cars. The rear of each vehicle is encased by a red square and the front in a green square.

Sensor Fusion

We have created systematic methods for multi-sensor calibration and synchronization. By synchronizing data from multiple sensors such as cameras and LiDARs, our self-driving cars are able to see the world in 3D point clouds with rich semantic information.



Camera + LiDAR fused image

Large-scale High Definition 3D Maps

HD 3D maps provide detailed road information for the autonomous vehicle. AutoX combines the data from multiple sensors including cameras, LiDARs, GPS, and IMU (Inertial Measurement Unit) to build large scale HD 3D maps with multi-channel information. The larger the map is, the more challenging it is for the map construction to be fully autonomous. For example, when the same intersection is scanned twice by the mapping vehicle, the algorithm must recognize that the two scan results are for the same intersection; the map will otherwise contain an error. We've been tirelessly working to solve such technical challenges. Over the past two years, we've built an automated loop closure system that is more robust and efficient for large scale HD map building.

AutoX team built the HD 3D map for North San Jose near our home

FALLBACK (MINIMAL RISK CONDITION)

AutoX's autonomous driving system has a fallback strategy that is triggered if the testing vehicle is operating outside the operational design domain (ODD). A series of reacting plans will be executed when such situations are detected. AutoX's system features a reliable out-of-ODD detection and is designed to ensure that the minimal risk fallback is always enabled.

Out-of-Operational-Design-Domain Detection

There are two aspects of the out-of-ODD detection in AutoX's system. First, our team has developed a comprehensive vehicle health monitor that runs alongside the A.I. software. The health monitor is able to detect errors in the message flow amongst the various software and hardware modules of the autonomous vehicle system. If errors are detected, the health monitor will notify the A.I. system and provide an audible notification to the safety driver or a remote takeover request to the remote operator. Second, every AutoX testing vehicle is constantly alerted of the change of environment by the A.I., a safety driver, or a trained remote control operator. If any environmental condition changes are detected (e.g. a sudden heavy rain), the safety driver and/or remote operator will be able to take over the testing vehicle or activate a pre-programmed automatic minimal risk condition fallback.

Minimal Risk Condition Fallback

AutoX's minimal risk condition fallback strategy consists of three parts: autonomously attempting to pull the vehicle over, notifying the safety driver and/or remote operator, which allows vehicle takeover. When an out-of-ODD situation is detected or an out-of-ODD status is received by a remote operator, the minimal risk condition fallback process will be activated, commencing the process of autonomously pulling the vehicle over. This relies on minimal sensors and software components to come to a safe stop, and should therefore be operational even if some part of the A.I. system is not functional. AutoX's system will then notify the safety driver or the remote operator immediately when beginning the process of pulling over. The safety driver or the remote operator can take over the testing vehicle at any time.

DATA RECORDING

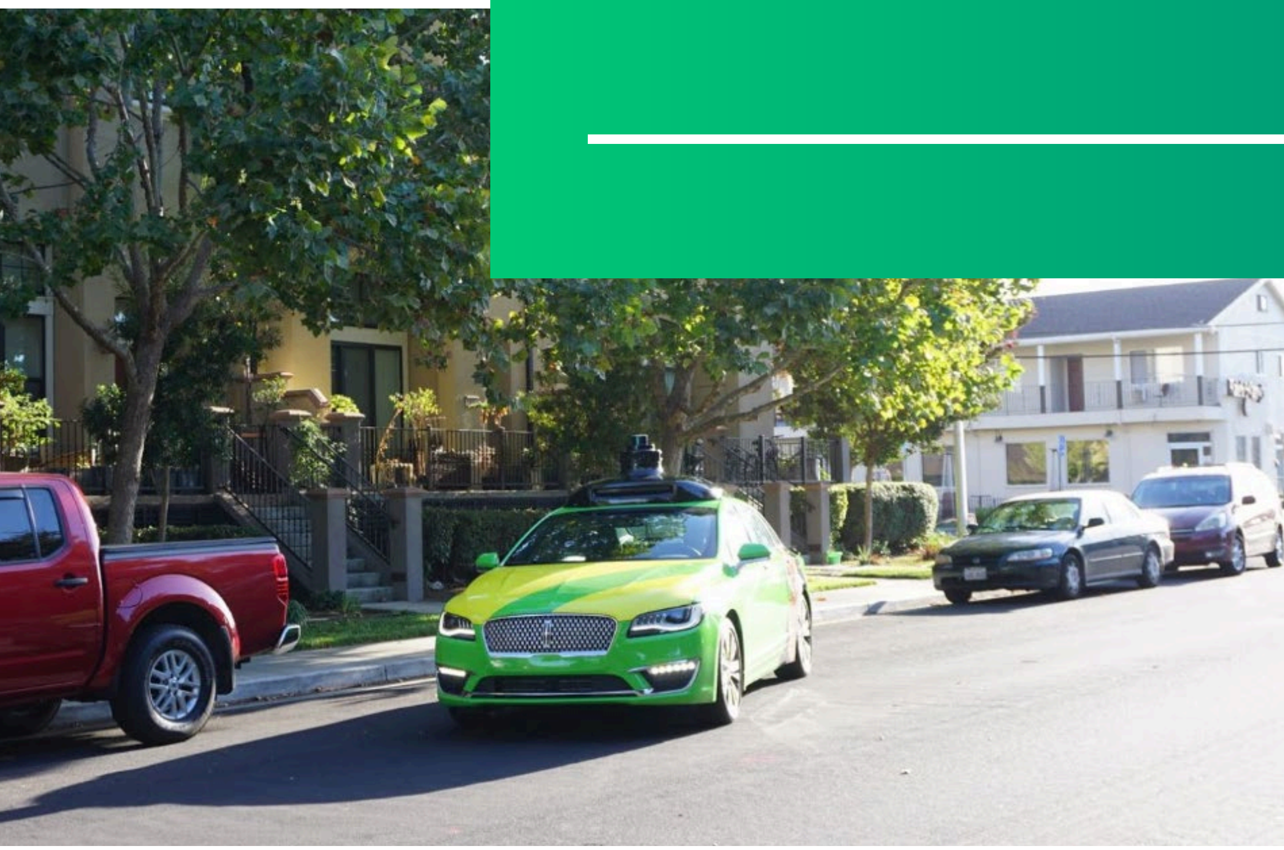
AutoX has developed a powerful black box system for data recording during autonomous vehicle testing. The black box system is able to generate detailed datasets of a whole test drive, or span three minutes before and after triggering events. The black box system can be triggered manually by a safety driver or automatically by the A.I. system. The data recorded by the black box system includes vehicle position, velocity, raw sensor input from the LiDAR, cameras, radars, and GPS along with the corresponding perception outcome, vehicle decision, planning, control data, and other vehicle logged data. AutoX uses this information to reconstruct test scenarios in our simulator, so our self-driving cars are constantly learning from every mile of driving data collected by our fleet vehicles. In the event of collisions or accidents, AutoX will keep the corresponding driving data for crash reconstruction.

CYBERSECURITY

AutoX implements security solutions and infrastructure based on the cybersecurity principles published by NHTSA. Our vehicles are equipped with a load balancing engine that uses Quality of Service (QoS) to control bandwidth usage, providing reliable and stable traffic to communicate over bonded network links. We share real-time telematics with the vehicle during all autonomous testing. The data communications between each vehicle and the command center are carried out via secure Virtual Private Network (VPN) tunnels and only our command center can decrypt and reassemble packets back into their original order. To further improve our security practices, we have established a fleet management program to discover new incidents and vulnerabilities by monitoring and identifying usage and behavior, thereby ensuring that the transmission of data is secure and fully controlled.

CHAPTER 2

FULL STACK REDUNDANCY



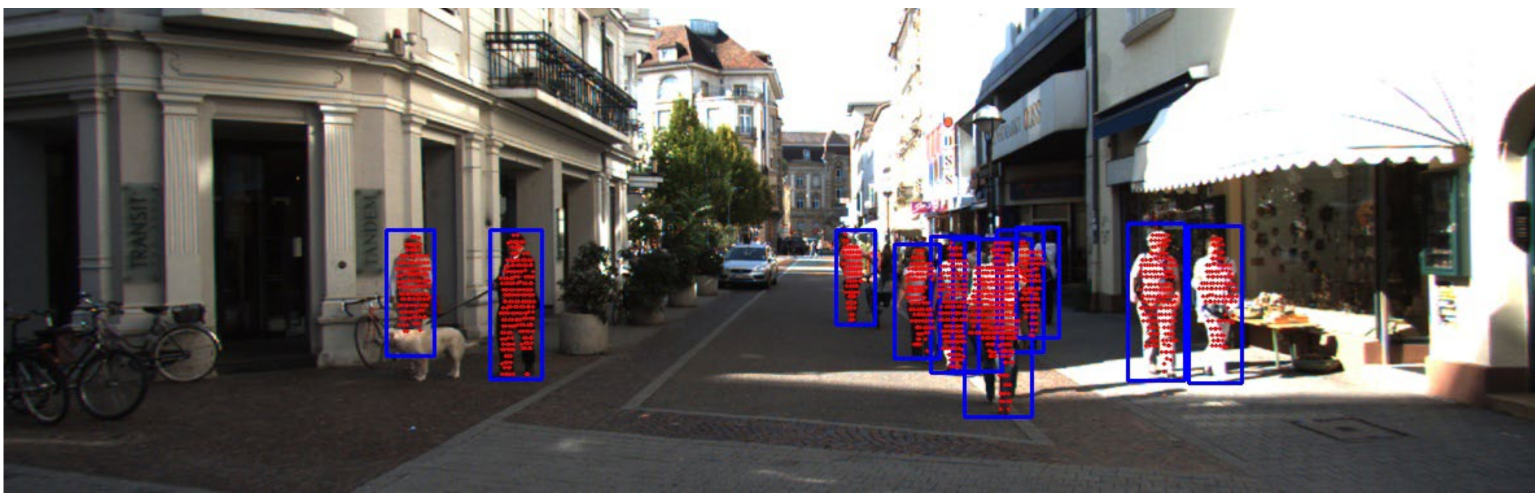
Redundancy Is Safety

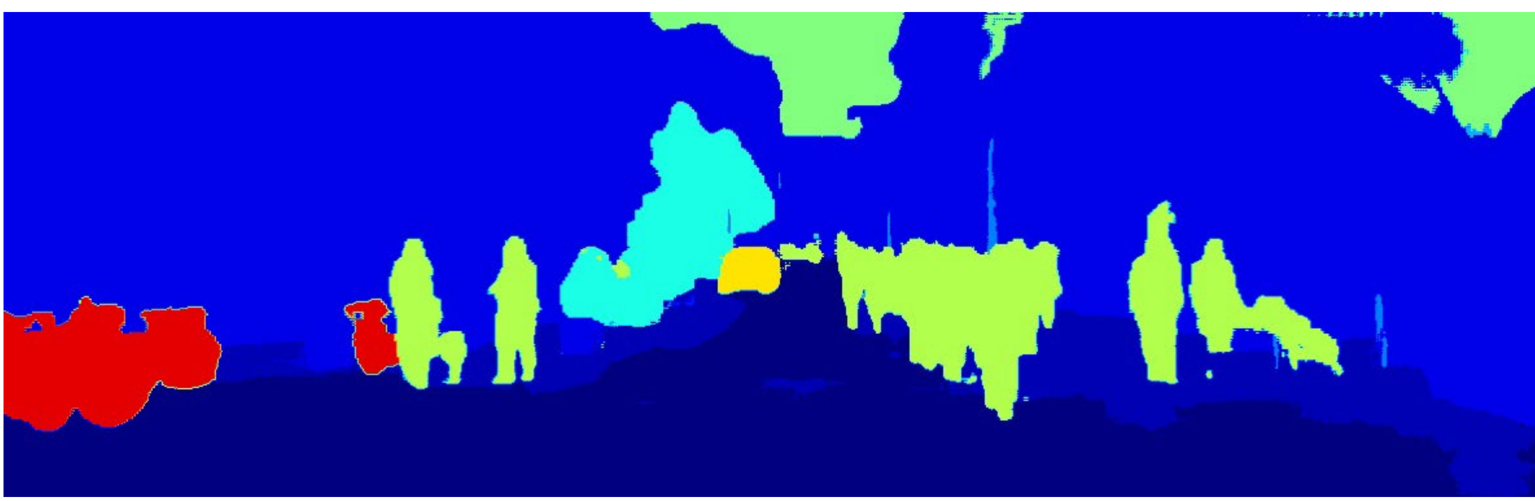
To ensure safety, it is essential to think a step ahead and always have a backup plan. AutoX has designed a multi-layer architecture for redundancy in both software and hardware. We have also introduced the “highest safety redundancy” - human remote operators - into the self-driving car testing loop. We believe that by designing a highly redundant system, we can minimize the possibility of failures occurring.

SENSOR REDUNDANCY

Perceiving the world with multiple senses

The world that self-driving cars navigate in is complex and dynamic; for instance, smaller vehicles are frequently hidden behind large trucks, and it is difficult to distinguish between joggers and bushes by the roadside. It is therefore critical to design a perception module with multiple sensors and perception methods. AutoX has developed a customized sensor fusion technology that includes automatic multi-sensor calibration and hardware-level synchronization. AutoX's sensor fusion technology is able to combine the sensing capabilities of our multiple sensors, resulting in reliable and robust perception with a broad sensing scope.



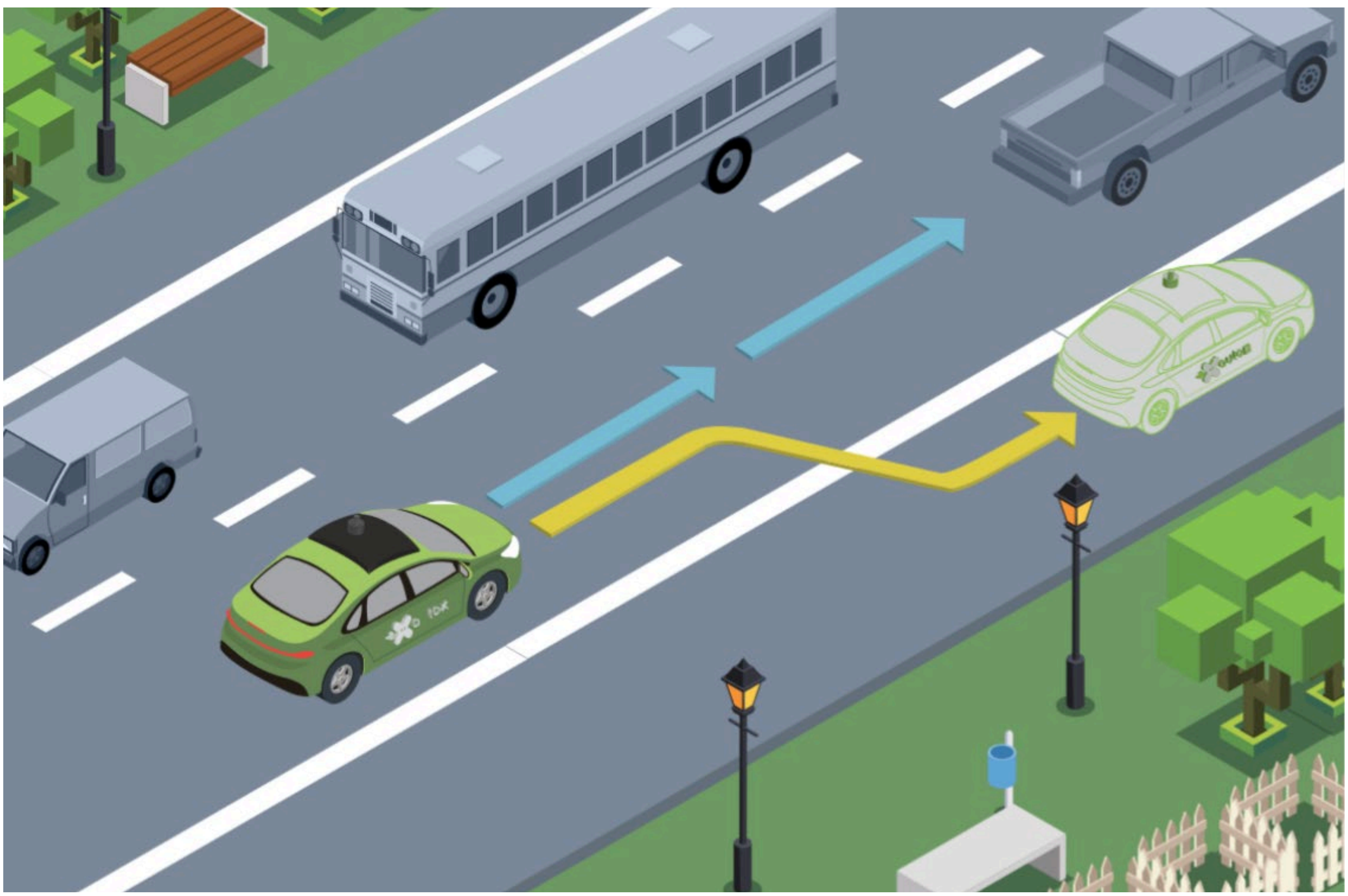


We are able to precisely filter out the LiDAR points corresponding to pedestrians based on the camera segmentation image, which allows us to build a highly safe autonomous driving technology.

ALGORITHM REDUNDANCY

We always have a backup plan

By designing a sophisticated planning and decision algorithm architecture, we ensure that the brain inside the AutoX self-driving cars always has a backup plan in mind, creating an algorithm-level redundancy for safety. There are two aspects to this. First, given a specific planning task, the decision and planning modules will check various planning inputs based on multiple criteria simultaneously. The self-driving software will always choose the safest solution that has minimal risks. For example, the planning software will constantly monitor all traffic around the testing vehicle, even if it is in a protected left turn, minimizing the risks caused by red light runners. Secondly, no matter what the current task is, the planning and decision module will always calculate a safe pullover route, rendering it ever-ready to respond to an emergency.

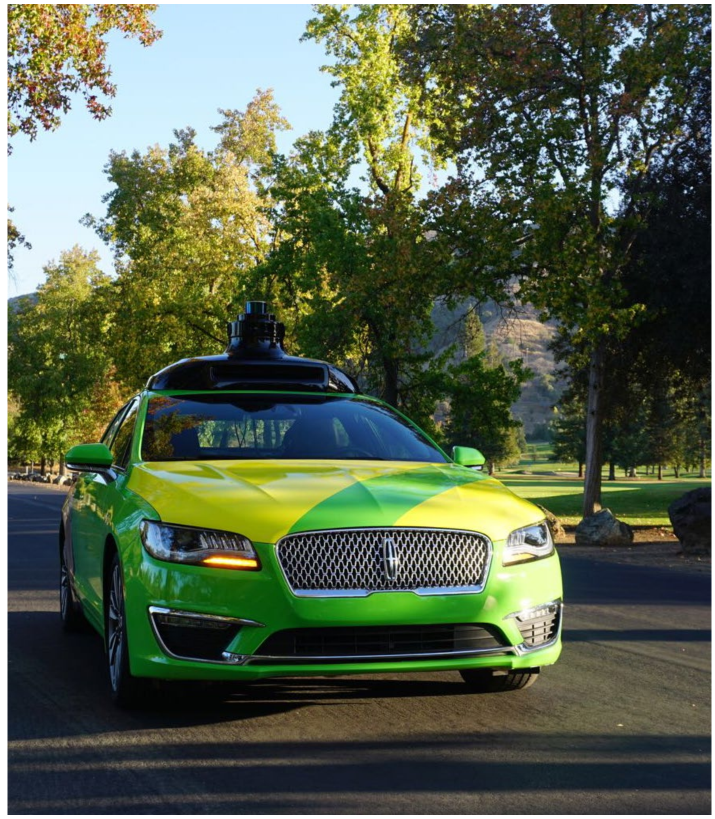


A Tale of Two Approaches:

HD 3D Map-Based and Real-time Sensing

The HD 3D Map-Based Approach
HD 3D maps are high definition pre-mappings of the driving environment. They provide important details about static road signatures, such as the location of stop signs, trees, and lane markings. During self-driving, this pre-collected data will be compared to the current sensor input and the self-driving car can precisely discern its own location. At the same time, all of the detailed semantic information from the HD 3D maps are utilized by the A.I. However, it is difficult to guarantee the accuracy of the HD 3D map on a large scale. Thus, we need the real-time sensing approach.

The Real-time Sensing Approach
The high-resolution real-time sensing approach is more similar to a human driving. In the same way we use our senses to locate lane markings and other cars, this approach uses fused data from multiple sensors and feeds it into the perception algorithm, which is running lane detection and other perception tasks in real time. This approach has a high technological barrier because it requires cutting-edge computer vision and A.I., however it provides AutoX with accurate and up-to-date information, helping the self-driving car respond to sudden unexpected situations. Furthermore, the approach is more robust to transient events such as road construction, which is out of the realm of the map-based approach.



A.I. REDUNDANCY

Running two A.I. systems simultaneously

At AutoX, we believe that achieving safe and reliable Level 4 self-driving requires our system to fully utilize the information provided by our HD 3D maps while constantly sensing the environment in real time to correct mistakes and out-of-date maps. When the results from these two A.I. approaches are properly fused together, they improve and correct each other's errors. This dual A.I. design also ensures that AutoX's vehicles will not rely exclusively on one type of sensor or self-driving method, creating an A.I.-level of redundancy.

SYSTEM REDUNDANCY

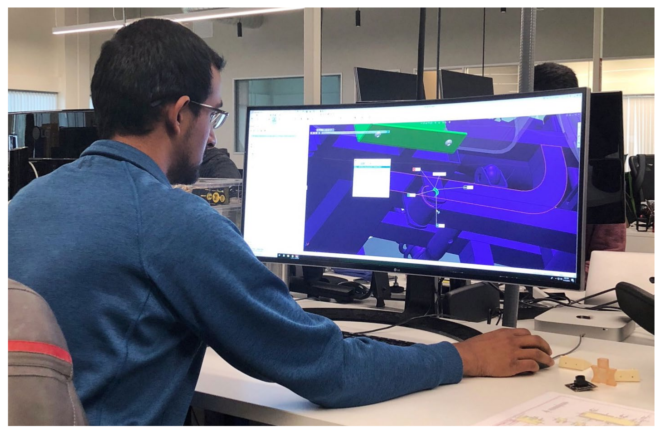
Decentralized Dual Computing and Drive-by-Wire Control Unit

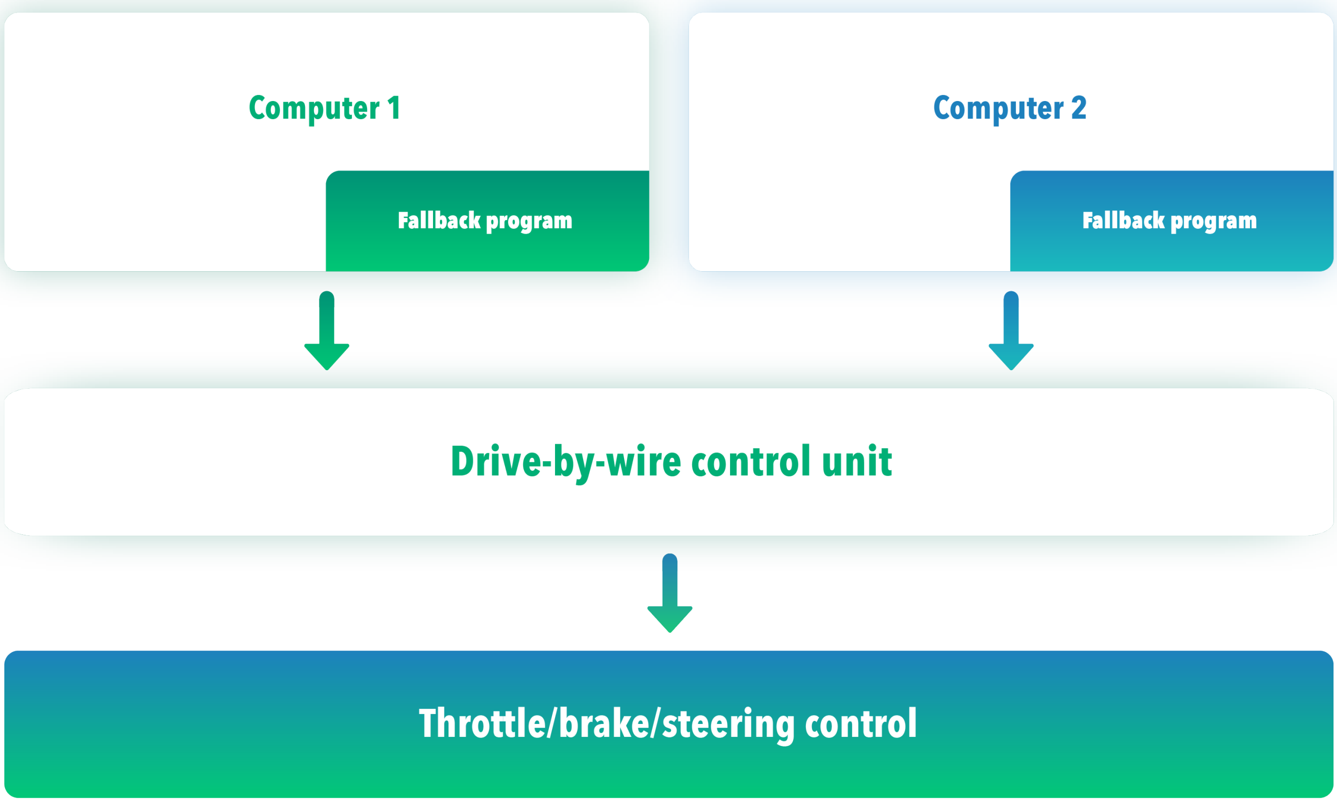
AutoX vehicles feature two main computers. Should one computer experience a failure, the second computer will immediately take over the vehicle, pull over, and make a safe stop. This decentralized dual computing system utilizes two reliable computing platforms with the same computing capability. While this ensures computational redundancy, we also equip each vehicle with redundant Drive-by-wire control unit that allows the A.I. to drive the vehicle. This redundant system approach also accounts for potential failures in the main system. There is a fallback system available to take control of the vehicle if a hardware or software discrepancy is detected.

HARDWARE REDUNDANCY

Double Infrastructure for Safety

AutoX has designed a fully redundant hardware infrastructure in our vehicles to handle hardware issues such as power failures. It includes redundant backup power, a redundant emergency stop button, and redundant connectivity devices.



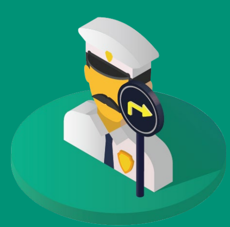


HUMAN REMOTE OPERATORS

The “Highest Safety Redundancy”

A remote human operator is the “Highest Safety Redundancy” for the fully autonmous vehicle. AutoX has developed a powerful and reliable A.I., though there still exist extreme situations that are difficult for any A.I. to handle. These are called “edge cases.” We have built a remote monitoring and teleoperating system to enable human remote operators to help and assist the self-driving car at anytime during testing and deployment.

Road Construction in Progress



Traffic Guard on Duty

Car Accident

Defective Traffic Light

Emergency Vehicles Need to Get By

Bad Weather

Force Detour

Road Obstruction

There are two ways a human remote operator could help: "remote takeover" and "remote hybrid support."

Remote Takeover

Remote takeover allows a human remote operator to drive the car remotely as if the remote operator is in the car. Remote operators will have a steering wheel and brake and throttle pedals that he or she can use to control the vehicle, much like conventional driving. We use a minimum of four cameras to get a surrounding view of the car. In situations such as a emergency vehicle passing by, the remote operator is able to take control of the car and "drive" it to the side of the road and prevent slowdowns and accidents. There is also a continuous two-way communication link maintained between the testing vehicle and the AutoX command center. The human remote operator can react to law enforcement and other first responders immediately.

Remote Hybrid Support

Our self-driving system senses the environment in many ways. Our vehicles are equipped with sensors such as LiDARs and radars that perceive the world in a way that humans cannot. However, in some cases, the A.I. may still struggle with making decisions since there are so many challenging situations to handle. With this in mind, AutoX has designed a remote hybrid support system, which allows the self-driving car to "ask for help" with certain decisions that it finds challenging. The human remote operator can also check the A.I. decision results and correct or overwrite them when unexpected errors occur.

Building a reliable remote teleoperating system

AutoX's remote control system is a part of the remote teleoperating system. It provides us with a unique layer of redundancy and the ability to help our A.I. handle edge cases. At the same time, a great deal hinges on the human remote operator. AutoX ensures that each of our operators completes a rigorous training program, and we provide a remote control system that closely mimics the process of operating a normal car. The operator's controls consist of a steering wheel, accelerator, and brake pedal, much like a conventional vehicle. The controls are carefully calibrated to mimic the sense of realistic driving feedback, and the ergonomics of the entire setup are close to that of a real car.

Remote control

Remote hybrid support

Due to the importance of the remote control system, a great deal of care has been devoted to its development. The remote control system and the remote hybrid supporting system have a strict real-time constraint. We cannot tolerate even a half-second delay or glitches in video streaming or vehicle control. AutoX engineers have ensured that all the test vehicles are always connected to AutoX command center reliably through innovations in both hardware and software.

In terms of hardware, we use multiple high speed modem bonding and bandwidth aggregation technology. Multiple channels of high speed internet from different carriers are used together to share the bandwidth, so that we can get a much higher data uploading speed compared to other applications. If one modem fails, the payload can seamlessly be transferred to other modems.

High resolution video can place a burden upon the network connection, and network failures are a possibility that we must contend with. As constant connectivity is a must, we execute a series of strategies to ensure that the remote operator never loses contact with the vehicle. For instance, in the event of poor network connection, we adjust the camera video to fit the network conditions.

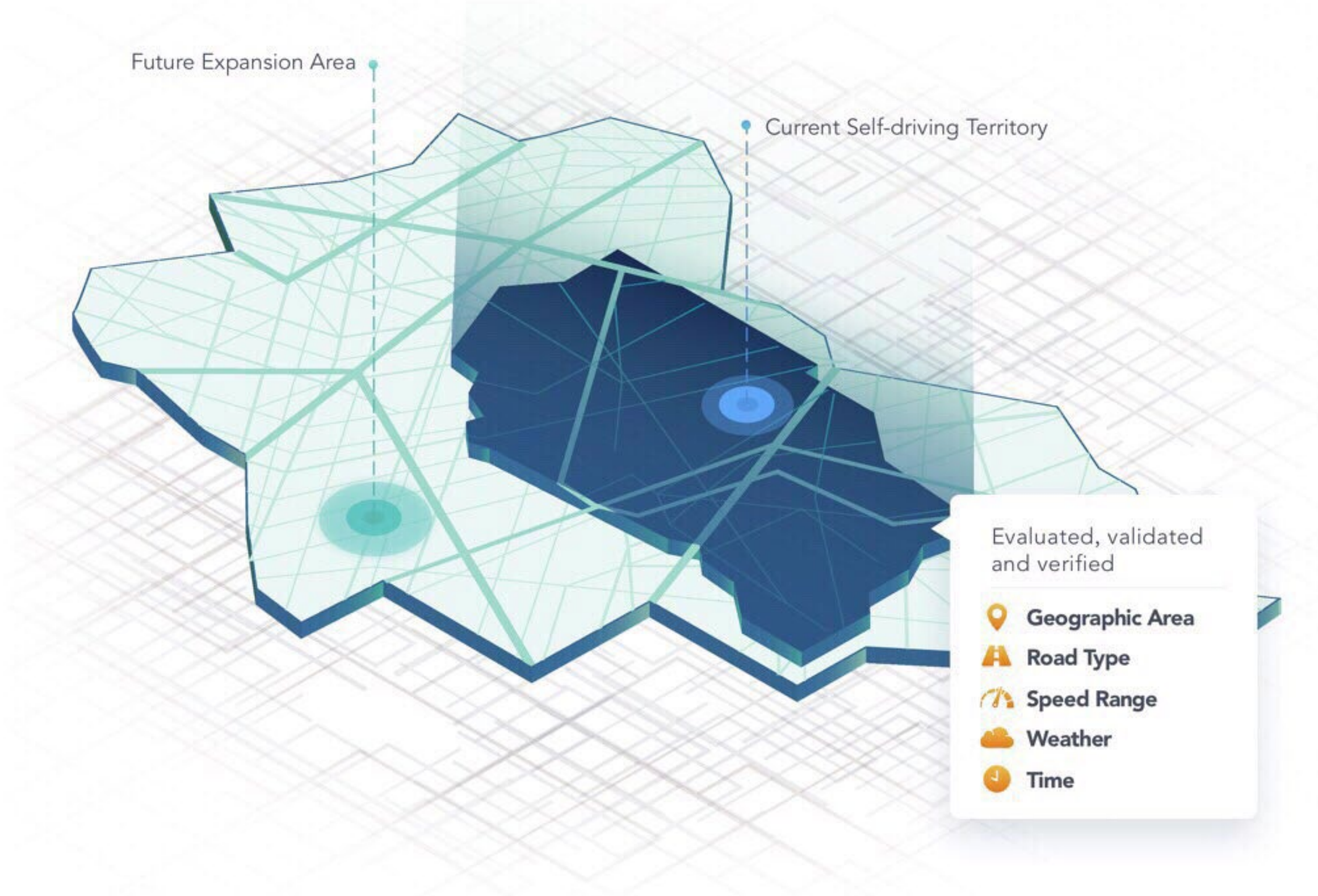
We are always watching our vehicles and are ready for human engagement during testing, even if there is no one physically inside the vehicle.

CHAPTER 3

TESTING AND VALIDATION

AutoX's Policy and Methods for Ensuring Safe Self-driving Vehicle Testing

By establishing strict testing and validation procedures, AutoX ensures that its self-driving car tests are conducted safely. We have created a virtual world for the testing of our self-driving system. Every self-driving feature is first tested in the powerful simulated environment. Afterwards, well-trained AutoX safety drivers and remote operators are constantly making sure that our on-road testing is safe for all road users, the surrounding environment, and ourselves.



OPERATIONAL DESIGN DOMAIN

At AutoX, we are developing full-stack Level 4 self-driving technology, achieving a driving mode-specific performance by an automated driving task[1]. It is therefore extremely important to understand the capability of the self-driving car and standardize the operational design domain.

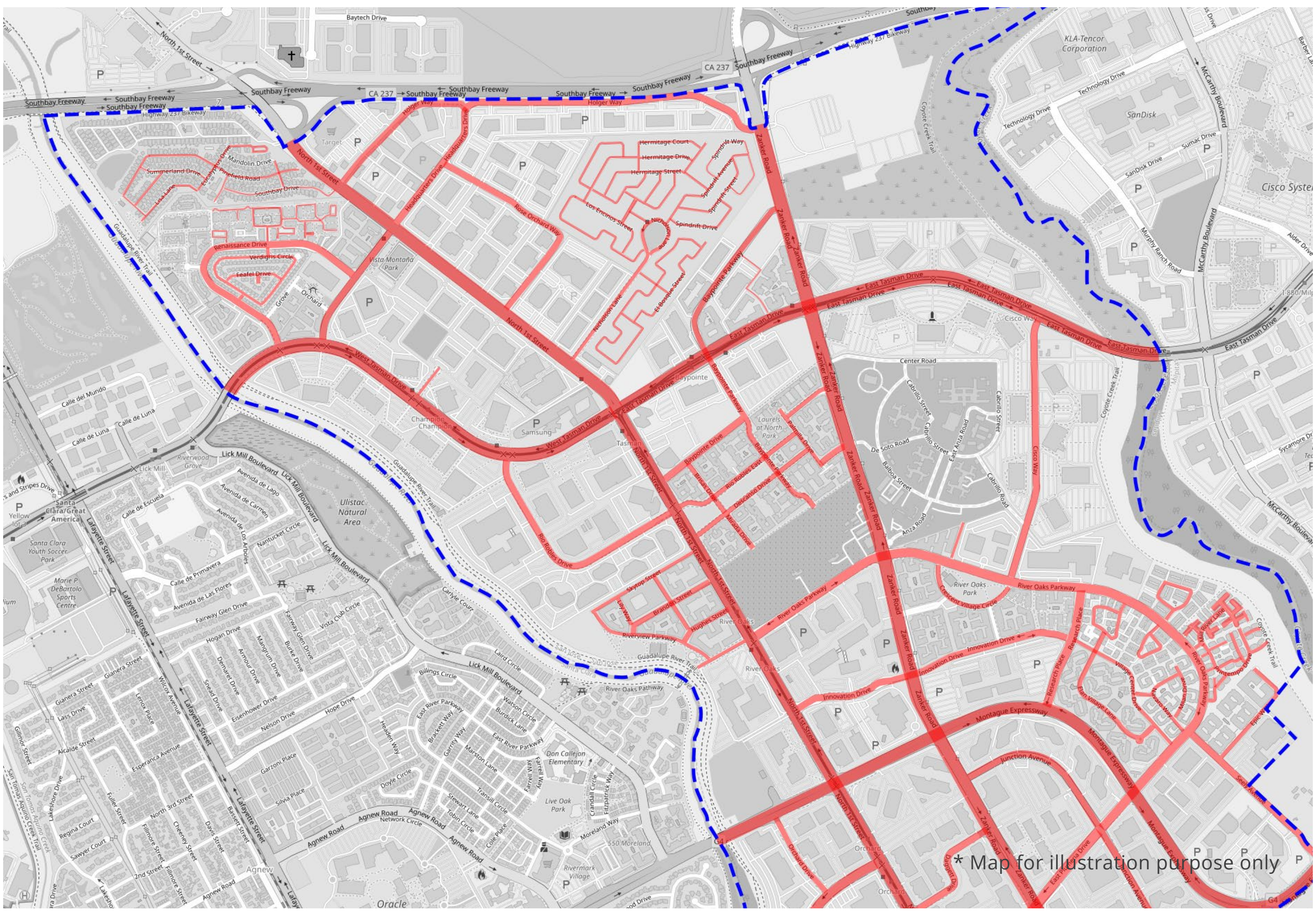
We will only test our self-driving car within the range of its capability

The operational design domain is a closed set of conditions in which AutoX driverless vehicles will safely operate only if all conditional constraints are met. The operational design domain consists of six elements: the geographic area of testing, road type, speed range, weather conditions, time of day and types of passengers. AutoX will not perform Level 4 autonomous testing if any of the conditions listed above are not fulfilled in the testing scenario. The software and hardware systems that the AutoX driverless vehicles carry on board, as well as

1. SAE International, J3016_201806: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles

related systems installed in the AutoX fleet management and control center, are designed to perform dynamic driving tasks in the predefined operational design domain. The dynamic driving tasks are characterized by the fact that, during the driverless vehicle test, the driving assignments can be assigned and changed on the fly, including vehicle destination re-routing, vehicle behavior changing from city road driving to pulling over, and other driving behaviors. However, all the driving assignments given to AutoX driverless vehicles are assured to meet the predefined operational design domain described in this section.

To achieve absolute safety, if an unexpected situation occurs during a driverless vehicle test that is outside the operational design domain, the test will terminate immediately and a minimal risk condition fallback will be triggered. A human operator can take control of the testing vehicle based on different situations. This is known as a human operator takeover, and can refer to either remote operator takeover or in-vehicle operator takeover. The software and hardware systems of the AutoX driverless vehicles are designed to ensure remote operator takeover shortly after triggering. The remote operator will operate the testing vehicle and transition it to a safe status as soon as possible, resume the test if the failing conditions are recovered, or wait for in-vehicle human takeover or law enforcement takeover depending on the circumstance. Note that the event that triggers human operator takeover may not necessarily indicate a failure in the testing vehicle's A.I. system. For example, if the remote operator notices that there is an accident in the adjacent lane, he or she may make take control of the vehicle as a precaution.



* Map for illustration purpose only

TESTING AND VALIDATION

Whenever new features are added to the AutoX full stack self-driving system, we conduct tens of thousands of tests to make sure that the new features meet all our safety requirements. The first step of testing and validation takes place in a virtual world: the AutoX 3D simulator.

The AutoX 3D simulator is a multifunctional simulation and verification platform for autonomous vehicles. It is able to simulate various scenarios, each of which can be tailored to the particular circumstances that the team wish to test. The simulator can accomplish five major tasks: infrastructure building, sensor and perception simulation, motion planning and control simulation, traffic and decision simulation, and full stack verification.

START FROM THE VIRTUAL WORLD

Scenario Editing and Unit Tests

Simulated vehicles interact with virtual environments called scenarios. The quality of the virtual environments affects not only the visual appearance of the simulation, but also the quality of the sensor simulation and performance of the simulated vehicles.

> **In the AutoX 3D simulator, scenarios can be created using real HD 3D map collected in the real world or new virtual cities that do not exist by a powerful “world editor.”**

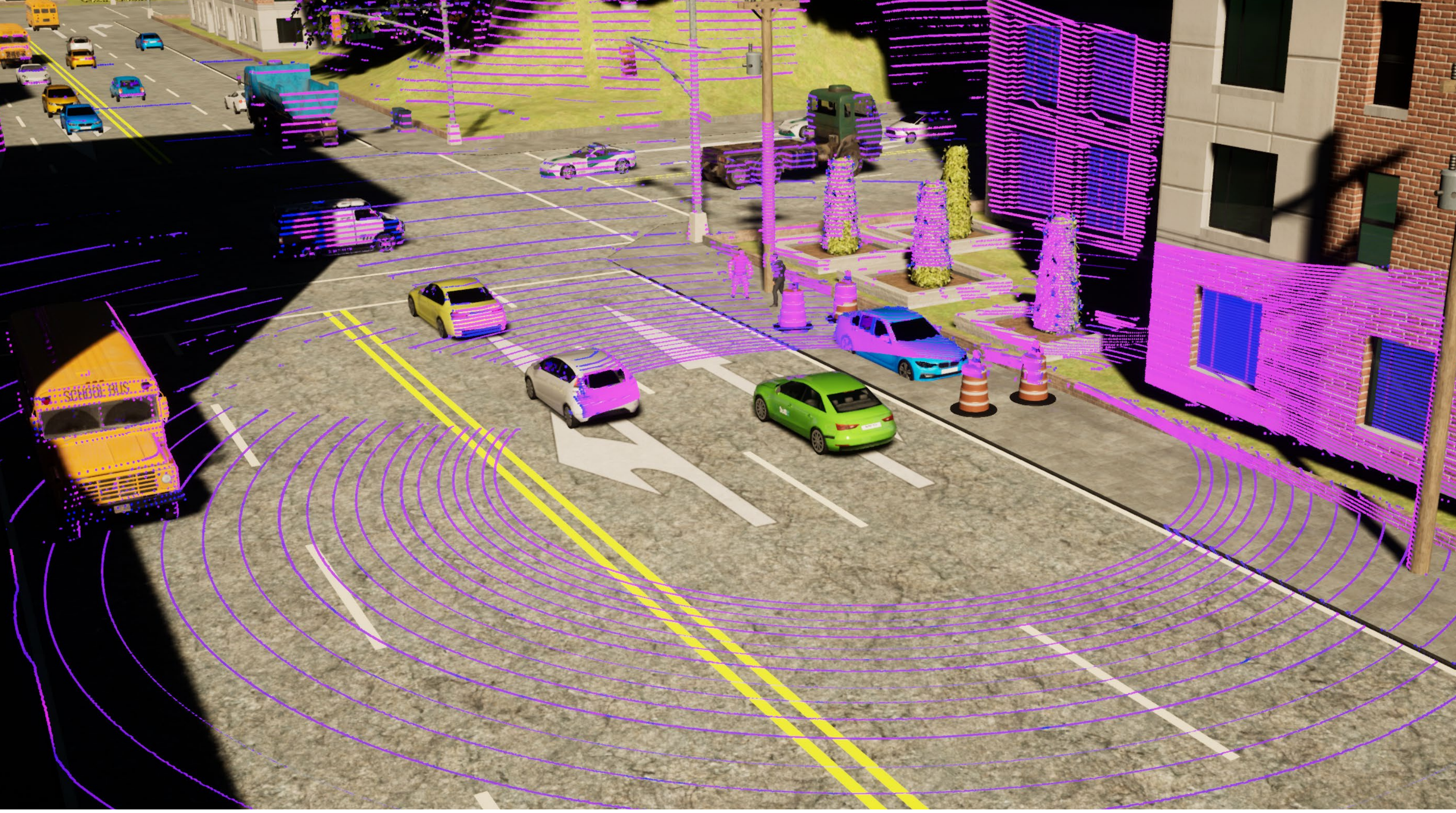
The AutoX 3D simulator scenarios are diverse, with a variety of road types, buildings, traffic signs, and landscapes. The scenarios are designed to have a certain level of complexity and realism for the sensor simulation and localization simulation, which gives an intuitive visual feedback to our team as well, helping them to gauge the performance of the A.I. algorithms in the virtual world.

3D scenarios can be easily transformed to HD 3D maps that can be used directly in the A.I. system, and vice versa. It can also provide multi-sensor perception results which can be used for control and motion planning. AutoX engineers have tuned parameters carefully to obtain a realistic vehicle dynamic model that simulates engine RPM and torque output based on different throttle and brake inputs. Different road conditions and tire friction conditions are simulated as well, providing a wide range of realistic unit test scenarios for control algorithm and motion planning algorithm development and refinement.

Creating Scenarios and Edge Cases

Decision making is one of the most challenging tasks in the A.I. development of an autonomous vehicle. There are infinite edge cases that may be difficult or dangerous to reproduce in reality, such as illegal driving behaviors or sudden traffic accidents. The AutoX 3D simulator provides a systematic tool to define and produce those traffic scenarios in the virtual world. Other vehicles and pedestrians are simulated, and their behaviors can be defined or controlled using descriptive languages and other human-machine interfaces.

The simulated agents in the AutoX 3D simulator can interact with each other and the simulated self-driving car. They too have “minds“ of their own and are able to follow (or not follow!) the traffic rules like a real driver, including waiting or running red lights and reacting to stop signs. Users can ascertain how the self-driving car should behave, for instance when a reckless driver suddenly cuts in, by reproducing and testing under this situation many times in the virtual world. In addition to the unit feature development, we can also create more complex traffic scenarios in the AutoX 3D simulator and have the whole prediction, decision, planning, and control A.I. in the loop. Algorithms are tested inside the virtual world with many of other vehicles and pedestrians simulated.



Closed Loop Simulation: Adding Sensor Perception to the Simulation

The virtual world is the ideal ground for initial testing and verification of new features. For this to be effective, however, it is essential that the perception, planning and decision making modules of the virtual vehicles closely resemble that of the real ones. In the AutoX 3D simulator, the entire Level 4 self-driving system is run in the virtual world. The 3D simulator is able to produce simulated camera, LiDAR, and other sensor outputs for the virtual vehicle, ensuring that our perception system is effectively replicated in the simulation. This way, we can test the ability of the system to see and classify various objects. This is especially beneficial in testing the system performance in challenging circumstances, such as situations where a vehicle is obscured behind a larger one, or pedestrians are standing near trees. Our team can then optimize the system's performance and test in these scenarios as many times as is necessary - all in the safety of the virtual world. By the time a new perception module feature is ready to be tested in a closed environment in the real world, it has already undergone many cycles of optimization in the virtual world.

BEFORE WE GO: VEHICLE MAINTENANCE AND PREFLIGHT CHECK

Pre-flight Safety Checks

Every one of our testing vehicles goes through extensive pre-flight safety checks before getting on the road. These consist of an inspection performed by our technicians as well as pre-flight checklists performed by our autonomous vehicle testers.

Mechanical inspections

Mechanical inspections are performed on each car to ensure that they are safe for testing on public roads. Technicians thoroughly inspect all safety-related measures such as tire tread, pressure, headlights, tail lights, windshield, mirrors, etc. Cars that do not pass this inspection are made unavailable for testing until the issues are resolved.

Pre-flight checklists

Pre-flight checklists are completed every time before the car leaves the garage for a test on public roads. We standardize the procedure to ensure all layers of components associated with getting an autonomous vehicle online are tested in the accurate sequence to ensure the holistic system is in proper conditions. The entire procedure includes sensor suit function checks, loading of the proper software version, localization checks, object detection checks, etc.

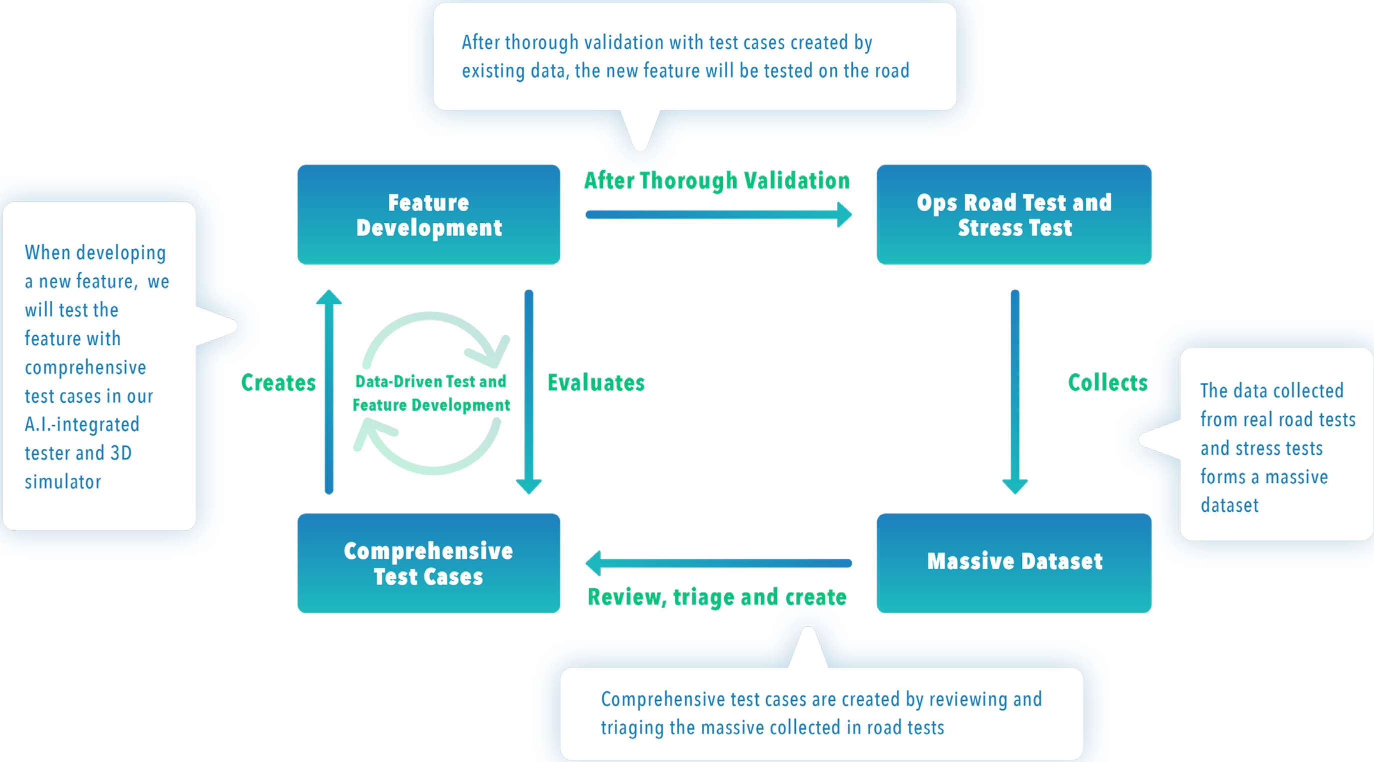
Vehicle Maintenance

We constantly monitor the components and the overall system of each vehicle. We analyze and test our system at multiple layers, including inspections on the vehicle itself: vehicle serviced for tire rotation, alignment, oil & air filter changes, brakes, and other car related inspections, as well as sensor suit checking, computers and Drive-by-wire (DBW) hardware checking. Some of these services are carried out by external professionals and are strictly monitored by our technicians.

FROM CLOSED TESTING SITES TO PUBLIC ROADS

Data-driven Development Approach

After extensive testing and validation in simulation, AutoX engineers will rigorously test the integration of the system into a test vehicle. We initially conduct unit tests in closed testing facilities. Well-trained AutoX employees will create a series of different scenarios mimicking real driving situations. Various regression tests from speed control and steering control to the performance of the A.I. components will be arranged and carried out in a systematic fashion. With these tests, we can ensure that the vehicle operates safely within our ODD. Only then will we conduct public road tests. A strict safety protocol will be followed for both manned and unmanned testing of our self-driving cars. All of the self-driving testing vehicles will be constantly monitored by a well-trained safety driver and a human remote operator.



SAFETY DRIVER AND REMOTE OPERATOR TRAINING

Safety drivers and remote operators are the last line of defense in autonomous vehicle safety. AutoX requires its safety drivers and remote operators to complete a training program tailored to ensuring proficiency in identifying problems and controlling the vehicle in a safe manner. This formal process takes 3 weeks for each remote operator and 2 weeks for California DMV-certified autonomous vehicle testers to complete. Remote operator candidates must also complete this process, along with additional training specific to remote teleoperation tasks.

FEDERAL, STATE, AND LOCAL LAWS

AutoX designs its vehicles to meet all Federal, State, local laws, and any other government standards. Our vehicles meet the Federal Motor Vehicle Safety Standards and other relevant requirements. We also actively communicate with local authorities, local law enforcement agencies, and local communities to ensure that we follow all the government laws and instructions in terms of our operational and business practices.

AutoX safety drivers and remote operators understand that safety is our number one priority, and will follow our safety policy at all times while operating our autonomous vehicles. The operator is required to be attentive and take control of the vehicle in the event of an emergency and bring it to safety. Operators shall not text, talk on the phone, eat, smoke, or do anything that they would not do when driving an actual vehicle. Their attention must be focused on the road, and they should be in position to take control of the vehicle at any moment. AutoX Assistance Operators shall obey all provisions of the Vehicle Code and local regulation applicable to the operation of motor vehicles. Test drivers are trained and required to record field data and create daily reports. These reports should reflect events completely and truthfully.

We have designed a systematic training program for AutoX safety drivers and remote operators. The program primarily consists of five parts: understanding the operational design domain, the autonomous system, the remote control system, fleet management system user interface training, and field training. We have also designed an examination with both written tests and field tests to make sure that every AutoX safety driver and remote operator is qualified to ensure the safety of the public and of our self-driving cars.

CHAPTER 4

EVERYONE'S SAFETY IS OUR PRIORITY

Designing a standardized protocol for public safety

AutoX is preparing for driverless vehicle testing. We have devoted a great deal of effort to building a stable, reliable, and failure proof self-driving software and hardware system. We are also actively communicating with local law enforcement agencies and local communities to standardize a series of communication protocols and implementations. We will specifically address public safety and the safety of the law enforcement during their engagement with our self-driving cars.

HUMAN-MACHINE INTERFACE (HMI)

AutoX's self-driving cars will become part of the communities that they serve, and their presence on the roads calls for a means for other road users to communicate with them. Our approach to this is three-fold:

1 We clearly communicate the status of the vehicle at all times, via a screen at the back of the vehicle. This allows bystanders to be aware of the state of the self-driving system.

2 We enable law enforcement and other first responders to bring the vehicle to a safe stop and disengage from autonomous driving mode in the event of an emergency. This is accomplished by using either of the emergency vehicles inside or outside the vehicle.

3 We provide an on-board radio as well a cellular phone to enable contact with vehicle's remote operator, who can offer information and support to first responders. We can also operate the vehicle remotely as required by the situation.

Exterior emergency button and A.I. control disengagement switch

SHOWING THE DRIVING STATUS OF THE VEHICLE

There are three possible driving statuses of AutoX self-driving vehicles: Auto-drive mode, Remote Control mode, and Manual Drive mode.

In Auto-drive mode, the vehicle is controlled by the self-driving software. This indicates that the system is healthy; there are mechanisms in place to detect any anomalies in the self-driving system that can trigger a remote takeover. This mode indicates that AutoX's level 4 autonomous driving technology is in full control.

In Remote Control mode, the AutoX self-driving car is remotely controlled by a human remote operator. The remote operator is able to bypass the self-driving software and control the vehicle from the command center. The remote control mode is designed as a fallback mode for edge case handling and emergency takeover.

In Manual Drive mode, the testing vehicle is fully controlled by a human driver inside the vehicle. The autonomous vehicle is effectively a normal motor vehicle; no self-driving is taking place.

We have designed a driving status display located on the rear side of the vehicle, helping first responders and other road users to identify the driving status of the vehicle.

FORCED A.I. DISENGAGEMENT AND FORCED DRIVE-BY-WIRE DISENGAGEMENT

In the event of a collision or accident, the self-driving system may no longer function as expected due to hardware damage. AutoX has designed an emergency Human Machine Interface (HMI) to protect law enforcement officers and other first responders who may engage with the autonomous vehicle. These consist of interior and exterior emergency stop buttons and emergency drive-by-wire disengagement switches. When conducting a drive-by-wire disengagement, the testing vehicle will no longer be controlled by any self-driving software, including the remote control system. This way, the law enforcement officers and other first responders can safely interact with the self-driving car, and move it out of an accident scene to prevent any further collisions.

POST-CRASH BEHAVIOR

AutoX has designed an emergency protocol defining the post-crash behavior of our self-driving testing vehicles. We are also publishing an AutoX driverless vehicle law enforcement engagement plan for the reference of law enforcement agencies and the general public. AutoX believes that a clear, transparent, and standardized interaction protocol for any emergency scenarios can prevent secondary accidents caused by miscommunication and misunderstandings.

All AutoX driverless test vehicles will be constantly being monitored by an AutoX remote control operator during the self-driving car testing. If an AutoX self-driving test vehicle is in an accident or if a collision is imminent, the Absolute Emergency Braking (AEB) system will be activated and the vehicle will come to a full stop. The remote operator will assess the collision. If there is a need to move the vehicle to the side of the road, and the vehicle is in a condition to do so, the remote operator will do so via remote control. If there is an accident involving other road users or if there is damage to public properties, the remote operator will call 911 to report the accident. The AutoX fleet management team will arrive at the collision scene as soon as possible to provide on-site support for law enforcement.

It is of upmost importance to us that our vehicles be safe, courteous users of the roads. We will closely cooperate with law enforcement as we continuously test and perfect our technology.

PUBLIC ENGAGEMENT

AutoX prioritizes above all the safety of everyone we share the road with. In order to achieve this, we communicate transparently with our users about our technology and how we handle emergencies. In the AutoX app, we will provide a detailed description of the vehicle systems and how the customer should approach and interact with them. The vehicle itself provides addition instruction through clear, concise instructions posted near its emergency button.

This safety report is meant to serve as an introduction to the operation of our vehicle and provide a deeper dive into our safety systems. AutoX will continue to produce such content to share with the public.

All AutoX operators are ambassadors and representatives of our vehicles. They are well-trained and up-to-date with the operation protocol and our technology. They are ready to interact with the public to address any questions about our autonomous vehicles.

CONCLUSION

AutoX has a vision to connect people using our autonomous vehicle technology. The ability to autonomously transport physical objects opens a whole new world of possibilities. It promises to save more time that will no longer be lost to traffic and errands. As we strive to accomplish this, we are cognizant of the fact that our vehicles will become part of the communities that they serve. As such, the safety of our customers, of other drivers, pedestrians, and all other road users is the highest priority. This calls for a system that has safety and reliability engineered into its very fabric - a product that is engineered from the very beginning with safety in mind. In this report, we have sketched out the myriad of strategies we have undertaken to ensure the safety our vehicles, from having high resolution sensing systems to redundancy in both software and hardware to human oversight via our remote teleoperating system. We have made significant headway in creating robust, reliable self-driving cars, and we will strive for perfection in every detail. The road ahead is full of promise, and safe AutoX autonomous vehicles are the best way to reach the future.

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