TESLA AND ARTIFICIAL INTELLIGENCE

~TEHNICAL RAPORT~

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Summary

Tesla is an American electric vehicle and clean energy company based in Palo Alto, California. Tesla's current products include electric cars, battery energy storage from home to grid-scale, solar panels and solar roof tiles, as well as other related products and services.

Tesla offers four electric car models: Model S, Model 3, Model X and Model Y.

Tesla is the first car manufactory that developed full self-driving (FSD), extension of Autopilot to enable fully autonomous driving by creating a computer chip that has been installed in its cars.

Autopilot enables your car to steer, accelerate and brake automatically within its lane.

There are core algorithms that drive the car by creating a high-fidelity representation of the world and planning trajectories in that space. In order to train the neural networks to predict such representations, algorithmically accurate and large-scale ground truth data is created, by combining information from the car's sensors across space and time. State-of-the-art techniques are used to build a robust planning and decision-making system that operates in complicated real-world situations under uncertainty.

Cutting-edge research is applied to train deep neural networks on problems ranging from perception to control. Tesla’s per-camera networks analyze raw images to perform semantic segmentation, object detection and monocular depth estimation. Tesla’s birds-eye-view networks take video from all cameras to output the road layout, static infrastructure and 3D objects directly in the top-down view. Tesla’s networks learn from the most complicated and diverse scenarios in the world, iteratively sourced from our fleet of nearly 1M vehicles in real time. A full build of Autopilot neural networks involves 48 networks that take 70,000 GPU hours to train. Together, they output 1,000 distinct tensors (predictions) at each timestep.

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Introduction

Tesla was founded on the principle that electric cars are superior, faster, and more enjoyable than gasoline cars. It has not only become a leading name in the world of electric vehicles but also a source of inspiration for the passionate, automobile enthusiasts. Tesla has made use of the customer datasets for data analytics to predict and gather information about customer requirements and used it to improve the features of its vehicles. The current AI technologies that Tesla is using in its cars are based on unsupervised machine learning.

On one hand, Tesla makes two kinds of electric motors. Their oldest currently-produced design is a three-phase four-pole AC induction motor with a copper rotor (which inspired the Tesla logo), which is used as the rear motor in the Model S and Model X. Newer, higher-efficiency, permanent magnet motors are used in the Model 3, Model Y, the front motor of 2019-onward versions of the Model S and X, and is expected to be used in the Tesla Semi Class 8 semi-truck. The permanent magnet motors increase efficiency, especially in stop-start driving.

On the other hand, their autopilot is an advanced driver-assistance system also developed by Tesla. Nonetheless, the system requires active driver supervision at all times.

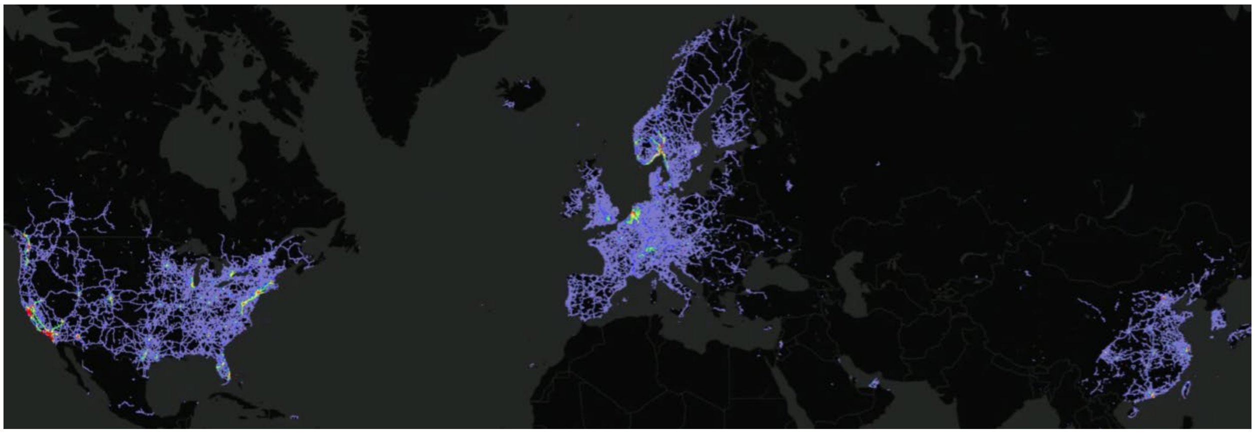
Additionally, since September 2014, all Tesla cars have been shipped with sensors and software to support Autopilot. Autopilot software is defined as just Traffic-Aware Cruise Control and Autosteer (Beta), as a standard feature. Full self-driving software (Autopark, Navigate on Autopilot (Beta), Auto Lane Change (Beta), Summon (Beta), Smart Summon (Beta) and future abilities) is an extra cost option.

Tesla's approach to achieve full autonomy is different from that of other companies. Whereas Waymo, Cruise, and other companies are relying on highly detailed (centimeter-scale) three-dimensional maps, lidar, and cameras, as well as radar and ultrasonic sensors in their autonomous vehicles, Tesla's approach is to use coarse-grained two-dimensional maps and cameras (no lidar) as well as radar and ultrasonic sensors. Tesla claims that although its approach is much more difficult, it will ultimately be more useful, because its vehicles will be able to self-drive without geofencing concerns. Tesla's self-driving software is being trained on over 20 billion miles driven by Tesla vehicles as of January 2021. In terms of computing hardware, Tesla designed a self-driving computer chip that has been installed in its cars since March 2019.

Nevertheless, most experts believe that Tesla's approach of trying to achieve full self-driving by eschewing lidar and high-definition maps is not feasible. In a March 2020 study by Navigant Research, Tesla was ranked last for both strategy and execution in the autonomous driving sector. In March 2021, according to a letter that Tesla sent to the California DMV about FSD's capability, acquired by PlainSite via a public records request, Tesla stated that FSD is not capable of autonomous driving and is SAE Level 2 automation.

Tesla's Deep Learning at Scale

Training data is one of the fundamental factors that determine how well deep neural networks perform. (The other two are the network architecture and optimization algorithm.) As a general principle, more training data leads to better performance. This is why Tesla is believed to be the most promising autonomous vehicles program in the world.



Visualization of Tesla's fleet. Image courtesy of Tesla.

With a fleet of approximately 500,000 vehicles on the road equipped with what Tesla claims is full self-driving hardware. Tesla's fleet is not only driving about as many miles each day – around 15 million but is also growing by approximately 5,000 cars per week.

There are three key areas where data makes a difference:

- **Computer vision**
- **Prediction**
- **Path planning/driving policy**

Computer vision

One important computer vision task is object detection. Some objects, such as horses, only appear on the road rarely. Whenever a Tesla encounters what the neural network thinks might be a horse (or perhaps just an unrecognized object obstructing a patch of road), the cameras will take a snapshot, which will be uploaded later over wifi. It helps to have vehicles driving billions of miles per year because you can source many examples of rare objects. It stands to reason that, over time, Tesla will become better at recognizing rare objects than other competing vehicles.

For common objects, the bottleneck for Tesla is most likely paying people to manually label the images. It's easy to capture more images than you can pay people to label. But for rare objects, the bottleneck for other companies is likely collecting images in the first place, whereas for Tesla is just labelling and developing the software to trigger snapshots at the right time. This is a much better position to be in.

Prediction

Prediction is the ability to anticipate the movements and actions of cars, pedestrians, and cyclists a few seconds ahead of time. Anthony Levandowski, who for years was one of the top engineers at Waymo, recently wrote that "the reason why nobody has achieved" full autonomy "is because today's software is not good enough to predict the future." Levandowski claims the main category of failures for autonomous vehicles is incorrectly predicting the behaviour of nearby cars and pedestrians.

However, Tesla cars are getting closer and closer to this goal. Any time a Tesla makes an incorrect prediction about a car or pedestrian, the Tesla can save a data snapshot to later upload and add to Tesla's training set. Tesla may be able to upload an abstract representation of the scene (wherein objects are visualized as colour-coded cuboid shapes and their pixel-level information is thrown away) produced by its computer vision neural networks, rather than upload video. This would radically reduce the bandwidth and storage requirements of uploading this data.

Images used to train object detection require human labelling, a prediction neural network can learn correlations between past and future just from temporal sequences of events.

Since there is no need for humans to label the data, Tesla can train its neural networks on as much useful data as it can collect. This means the size of its training dataset will correlate with its overall mileage.

Path planning/driving policy

Path planning and driving policy refer to the actions that a car takes: staying centred in its lane at the speed limit, changing lanes, passing a slow car, making a left turn on a green light, nudging around a parked car, stopping for a jaywalker, and so on. It seems fiendishly difficult to specify a set of rules that encompass every action a car might ever need to take under any circumstance. One way around this problem is to get a neural network to copy what humans do. This is known as imitation learning (also sometimes called apprenticeship learning, or learning from demonstration).

The training process is similar to how a neural network learns to predict the behaviour of other road users by drawing correlations between past and future. In imitation learning, a neural network learns to predict what a human driver would do by drawing correlations between what it sees (via the computer vision neural networks) and the actions taken by human drivers.

Still frame from Tesla’s autonomous driving demo. Courtesy of Tesla.

Tesla is applying imitation learning to driving tasks, such as how to handle the steep curves of a highway cloverleaf, or how to make a left turn at an intersection. It sounds like Tesla plans to extend imitation learning to more tasks over time, like how and when to change lanes on the highway.

As with prediction, it may be sufficient to upload an abstract representation of the scene surrounding the car, rather than upload video. This would imply much lower bandwidth and storage requirements.

Also as with prediction, no human labelling is needed once the data is uploaded. Since the neural network is predicting what a human driver would do given a world state, all it needs are the world state and the driver’s actions. Imitation learning is, in essence, predicting Tesla drivers’ behaviour, rather than predicting the behaviour of other road users that Teslas see around them.

Elon Musk has alluded to this capability (or something similar) in the past, although it’s not clear if it’s currently running in Tesla cars.

The inverse would be when a Tesla is on Autopilot or in the upcoming coming urban semi-autonomous mode and the human driver takes over. This could be a rich source of examples where the system does something incorrectly, and then the human driver promptly demonstrates how to do it correctly.

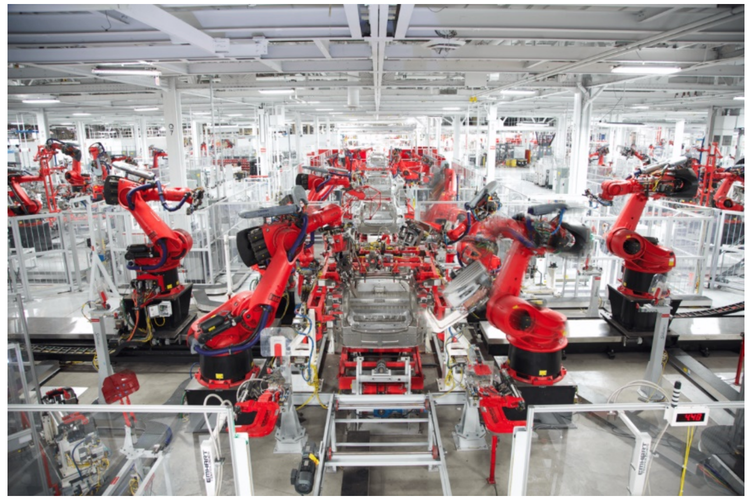
Some ways to capture interesting replays (namely, specific moments when the car did something wrong) include: sudden braking or swerving, automatic emergency braking, crashes or collision warnings, and more sophisticated techniques in machine learning known as anomaly detection and novelty detection. (These same conditions could be also used to trigger replay captures for prediction or camera snapshots for object detection). If Tesla already knows what it wants to capture, such as left turns at intersections, it can set up a trigger to capture a replay whenever the vision neural networks see a traffic light and the left turn signal is activated, or the steering wheel turns left.

Environmental Impact

As pollution is constantly increasing and damaging our planet, it is one of the main concerns of Tesla's engineers to find ways to make an environmentally friendly car.

We know Elon Musk's Tesla vehicles create less pollution out of the tailpipe, but the batteries are a different matter. The truth is, direct comparisons are difficult to make due to the endless variables to take into account. But as more information about batteries and manufacturing becomes available, it is important to consider all of the factors to make the most sustainable decision when it comes to car ownership.

Running a factory is resource-intensive. Reports vary regarding the carbon footprint of the actual product though. While the parts are different, it's generally accepted that Tesla vehicle production is equivalent or less-consumptive than standard vehicle builds.



From the beginning, Musk has spouted claims about the efficiency of Tesla plants, with the use of high-tech robots for precision and LED lighting to save energy as well as reliance on local renewable energy. The company claims to have earned a zero-waste certification at the Fremont plant, although there have been reports showcasing the company's waste at this plant. As new plants are constructed from the ground up, they are built to rely on renewable energy sources. In addition, the company's water reduction efforts are seen across the sales, service and delivery facilities. It has even implemented waterless car washes in some areas.

While the company goal is to lead the way in sustainable practices, it is still hovering around progress rather than perfection. By comparison to standard manufacturing practices, however, Tesla's conservation methods are welcome environmentally.

One of the prevalent arguments regarding EVs is the fact that they charge using electrical power. That power is most often sourced from the local power grid, which can be composed of a variety of sources including the very fossil fuels electric cars aim to eliminate. While Musk has repeatedly claimed that Tesla charging stations are 100% powered by renewable energy, this statement from a company spokesperson is likely closer to the truth. “We aim for carbon neutrality, and where the market allows via wholesale power purchase, we source renewable energy, even though it is slightly more expensive. In Europe, the power for all our Supercharger stations is sourced by renewable energy. Continuing to convert our superchargers to solar power will push us further down that road.”

To some degree, it’s out of Tesla’s hands when it comes to public electricity, including what the consumer uses once they get their car home. It’s up to each Tesla owner to invest in solar panels or subscribe to renewable energy sources through their utility provider.

While Tesla may not be able to count on complete reliance on renewable energy, it does own a solar power production company. This adds up to a carbon offset, which is a good thing. However, it shouldn’t be considered when measuring the carbon footprint from Tesla cars as a whole.

Battery disposal is another hot topic with concerns over massive, and potentially toxic, waste. However, the newest generation of batteries, especially Tesla batteries aimed at eliminating cobalt altogether, are highly recyclable. Not only can 90% of the battery be recycled, but even after its usable life in a Tesla, the battery can be used for energy storage for another 20 years or so. In addition, batteries can be refurbished by replacing bad cells or removing good cells to use in another battery.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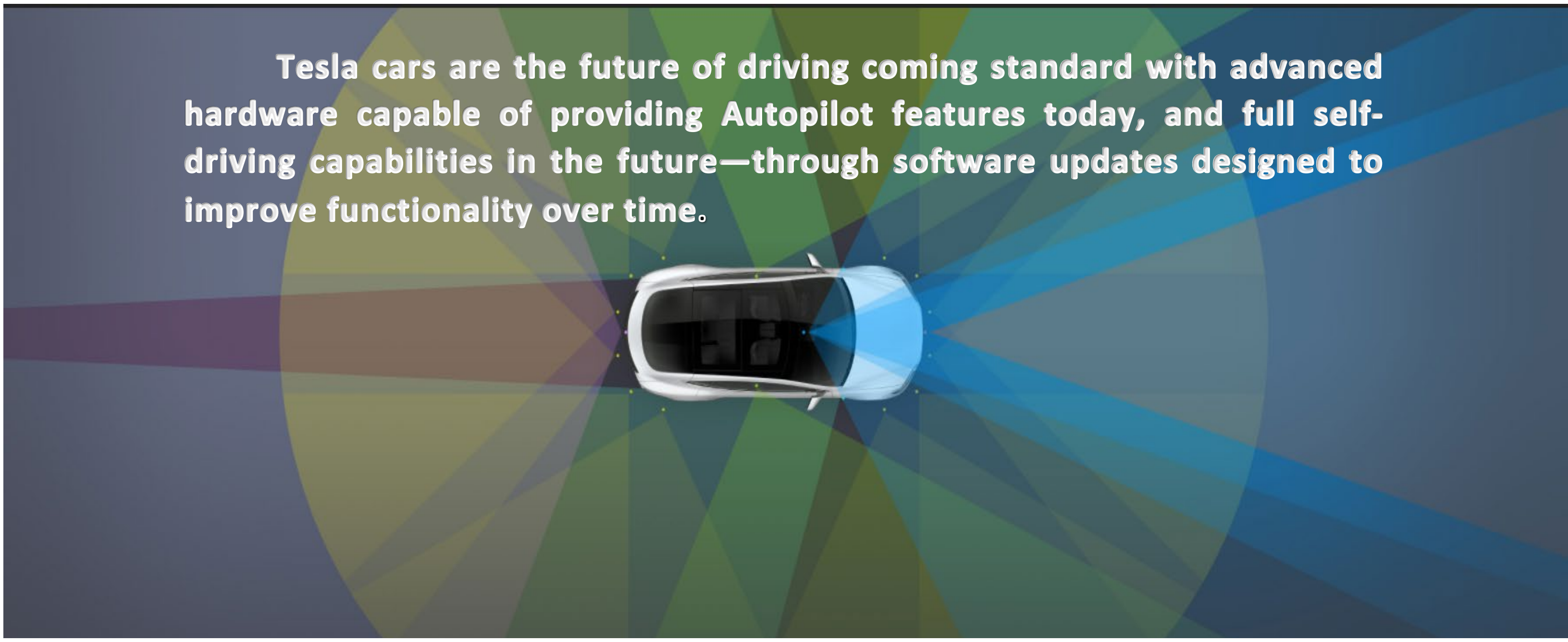
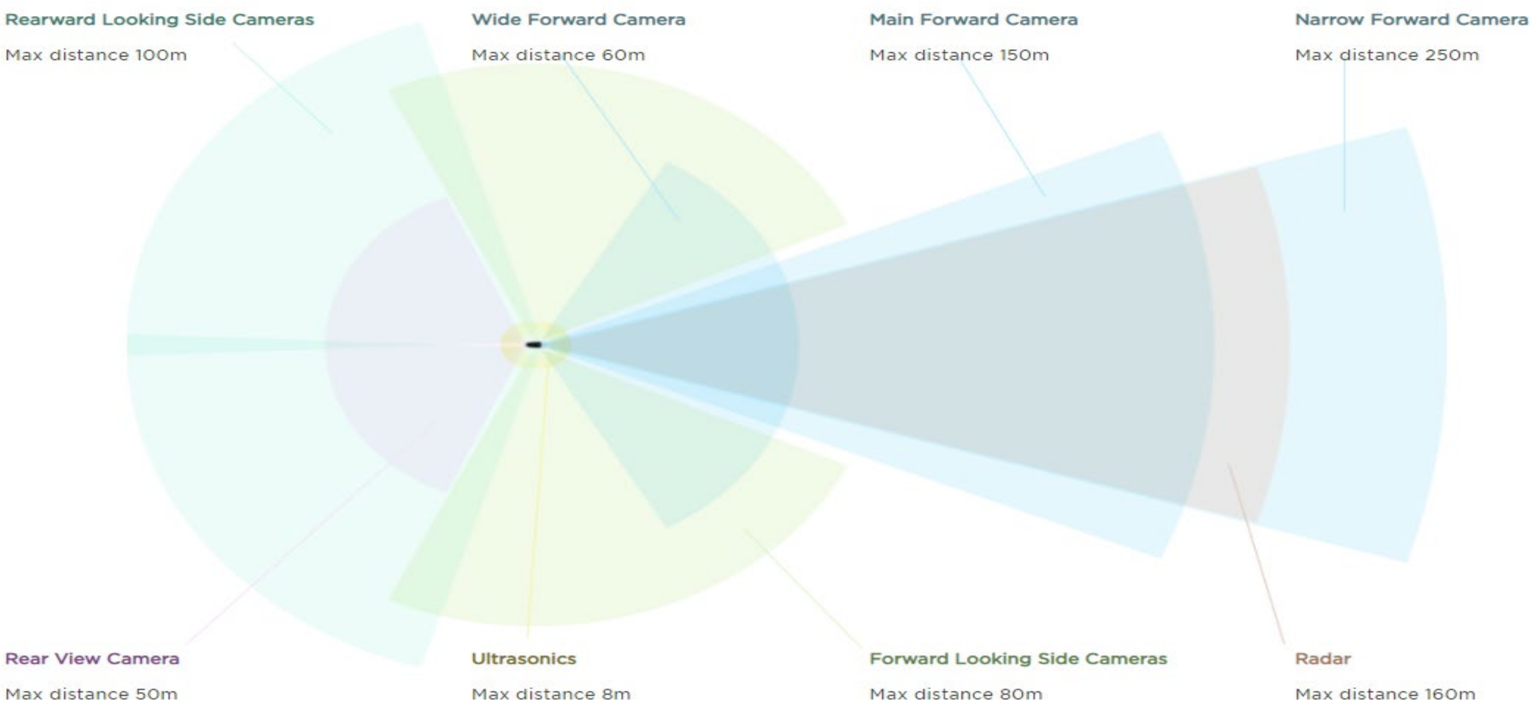
Procedure

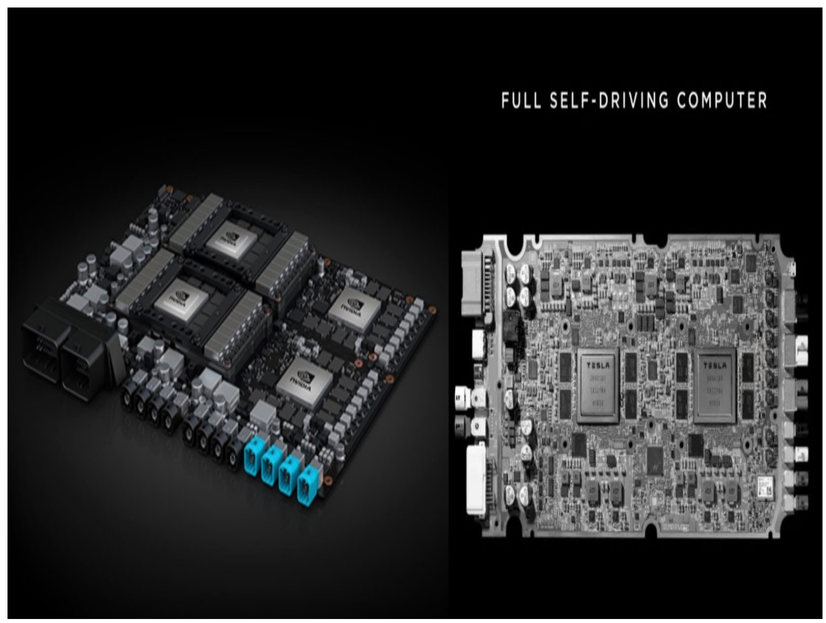




Tesla artificial intelligence is designed to adapt and evolve every second.

Hardware

Build silicon chips that power tesla’s full self-driving software from the ground up, taking every small architectural and micro-architectural improvement into account while pushing hard to squeeze maximum silicon performance-per-watt. Perform floor-planning, timing and power analyses on the design. Write robust, randomized tests and scoreboards to verify functionality and performance. Implement compilers and drivers to program and communicate with the chip, with a strong focus on performance optimization and power savings. Finally, validate the silicon chip and bring it to mass production.

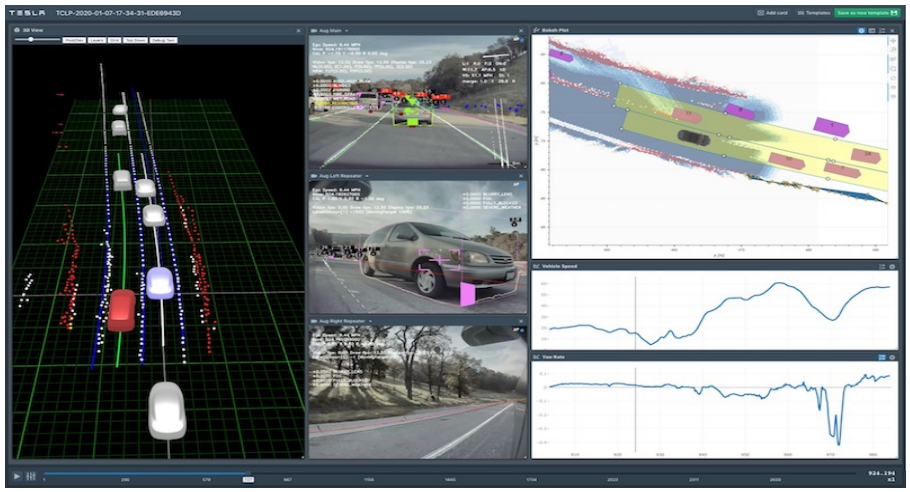


Neural Networks

Apply cutting-edge research to train deep neural networks on problems ranging from perception to control. Tesla's per-camera networks analyze raw images to perform semantic segmentation, object detection and monocular depth estimation. Tesla birds-eye-view networks take video from all cameras to output the road layout, static infrastructure and 3D objects directly in the top-down view. Tesla networks learn from the most complicated and diverse scenarios in the world, iteratively sourced from their fleet of nearly 1M vehicles in real time. A full build of Autopilot neural networks involves 48 networks that take 70,000 GPU hours to train. Together, they output 1,000 distinct tensors (predictions) at each timestep.

Autonomy Algorithms

Develop the core algorithms that drive the car by creating a high-fidelity representation of the world and planning trajectories in that space. In order to train the neural networks to predict such representations, algorithmically create accurate and large-scale ground truth data by combining information from the car's sensors across space and time. Use state-of-the-art techniques to build a robust planning and decision-making system that operates in complicated real-world situations under uncertainty.
Tesla can save a data snapshot to later upload and add to Tesla’s training set.



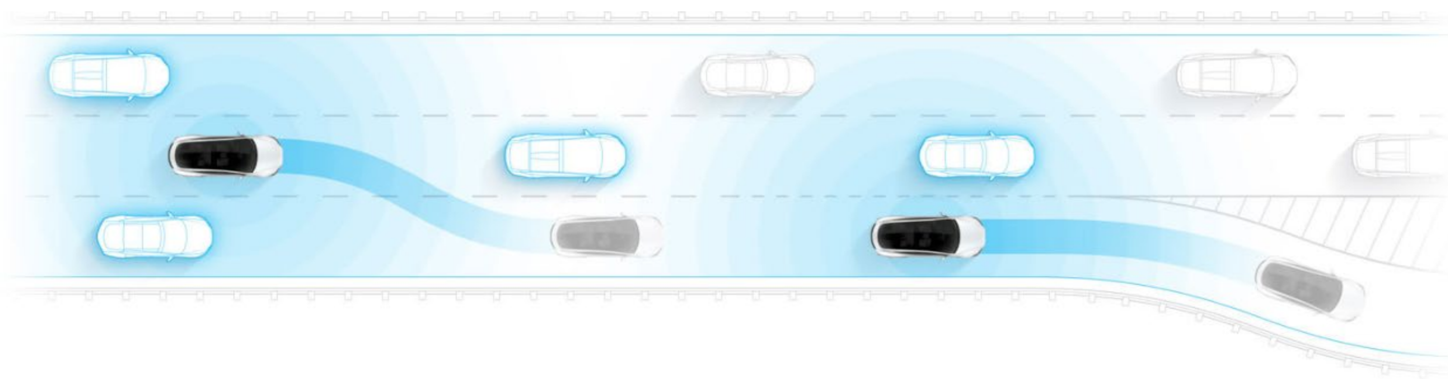
Evaluation Infrastructure

Build open- and closed-loop, hardware-in-the-loop evaluation tools and infrastructure at scale, to accelerate the pace of innovation, track performance improvements and prevent regressions. Leverage anonymized characteristic clips from our fleet and integrate them into large suites of test cases. Write code simulating our real-world environment, producing highly realistic graphics and other sensor data that feed our Autopilot software for live debugging or automated testing.

Tesla vision

To make use of a camera suite this powerful, the new hardware introduces an entirely new and powerful set of vision processing tools developed by Tesla. Built on a deep neural network, Tesla Vision deconstructs the car's environment at greater levels of reliability than those achievable with classical vision processing techniques.

Autopilot



Autopilot advanced safety and convenience features are designed to assist you with the most burdensome parts of driving. Autopilot introduces new features and improves existing functionality to make your Tesla safer and more capable over time.

Autopilot enables your car to steer, accelerate and brake automatically within its lane.

Navigate on Autopilot suggests lane changes to optimize your route, and makes adjustments so you don't get stuck behind slow cars or trucks. When active, Navigate on Autopilot will also automatically steer your vehicle toward highway interchanges and exits based on your destination.

With the new Tesla Vision cameras, sensors and computing power, your Tesla will navigate tighter, more complex roads.

Smart Summon

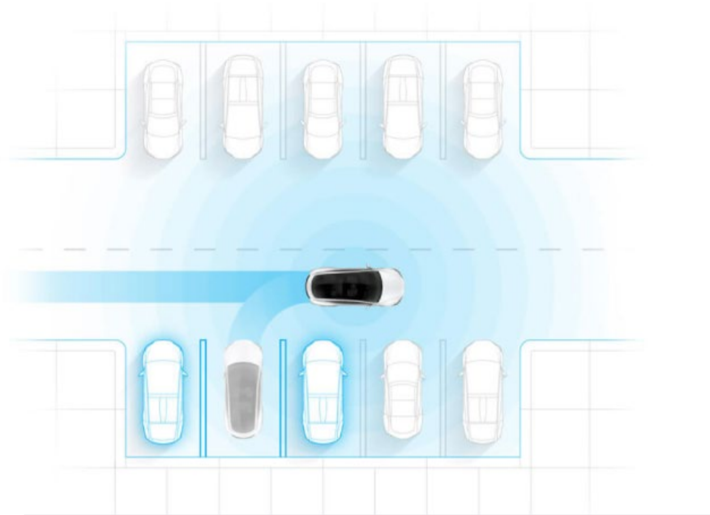
Smart Summon is the new name for Tesla’s autonomous parking feature, which enables a Tesla vehicle to leave a parking space and navigate around obstacles to its owner who’s using the tesla key or the tesla app.

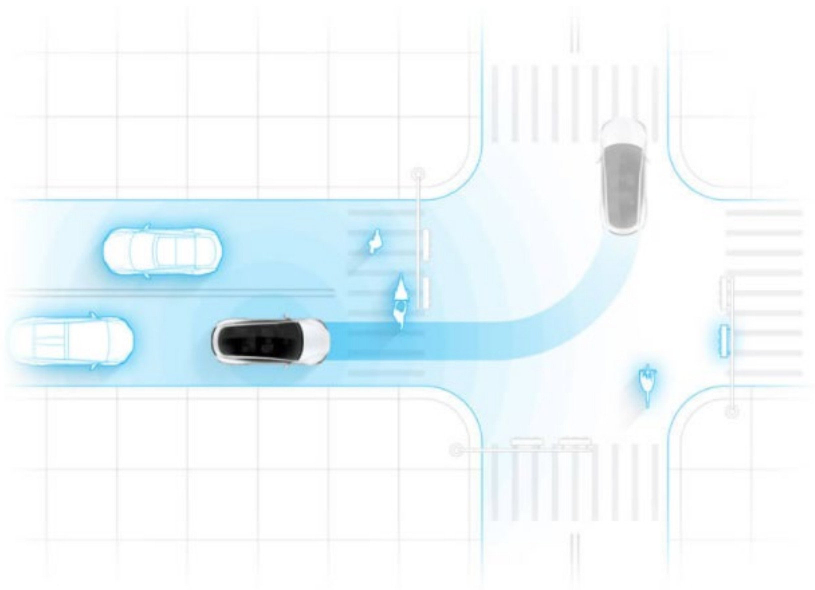
With Smart Summon, your car will navigate more complex environments and parking spaces, maneuvering around objects as necessary to come find you in a parking lot.

Full Self-Driving Capability

All new Tesla cars have the hardware needed in the future for full self-driving in almost all circumstances. The system is designed to be able to conduct short and long distance trips with no action required by the person in the driver’s seat.
All you will need to do is get in and tell your car where to go. If you don’t say anything, the car will look at your calendar and take you there as the assumed destination or just home if nothing is on the calendar. Your Tesla will figure out the optimal route, navigate urban streets (even without lane markings), manage complex intersections with traffic lights, stop signs and roundabouts, and handle densely packed freeways with cars moving at high speed. When you arrive at your destination, simply step out at the entrance and your car will enter park seek mode, automatically search for a spot and park itself. A tap on your phone summons it back to you.
Some features require turn signals and are limited in range. The future use of these features without supervision is dependent on achieving reliability far in excess of human drivers as demonstrated by billions of miles of experience, as well as regulatory approval, which may take longer in some jurisdictions. As these self-driving capabilities are introduced, your car will be continuously upgraded through over-the-air software updates.

All you will need to do is get in and tell your car where to go. If you don't say anything, your car will look at your calendar and take you there as the assumed destination. Your Tesla will figure out the optimal route, navigating urban streets, complex intersections and freeways.





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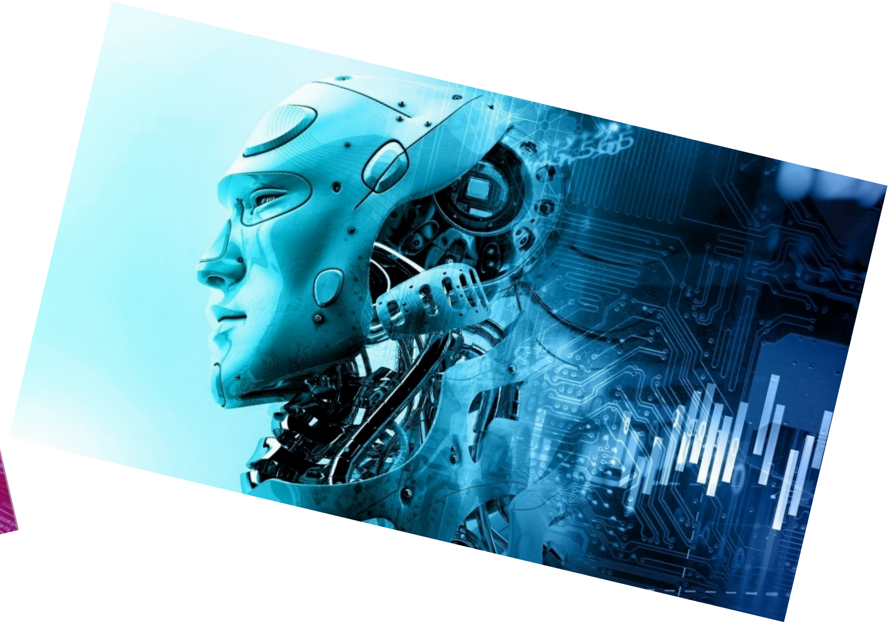
Artificial intelligence morality (ethical decisions or all calculated?)



Creating an artificial intelligence was hard enough but making it think as a human would be nearly impossible. Tesla's AI is based on a neuronal network learning connection where people were asking some questions about decision making and the AI converts their answers into decisional code. Tesla's AI morality is based on a variety of human thoughts and answers so it can reproduce the best decision as fast as it can.

When a driver slams on the brakes to avoid hitting a pedestrian crossing the road illegally, she is making a moral decision that shifts risk from the pedestrian to the people in the car. Self-driving cars might soon have to make such ethical judgments on their own — but settling on a universal moral code for the vehicles could be a thorny task, suggests a survey of 2.3 million people from around the world.

The survey, called the Moral Machine, laid out 13 scenarios in which someone's death was inevitable. Respondents were asked to choose who to spare in situations that involved a mix of variables: young or old, rich or poor, more people or fewer.

People rarely encounter such stark moral dilemmas, and some critics question whether the scenarios posed in the quiz are relevant to the ethical and practical questions surrounding driverless cars. But the study's authors say that the scenarios stand in for the subtle moral decisions that drivers make every day.

The problem is that creating an AI who can take moral decisions based on a learning curve is the global protocol of protecting the life and taking as few casualties as possible. The AI of the car can think that the life of owner and integrity of car is more important in a critical situation than to hit another car or producing an accident so it won't take any risk. Let-s think about a freeway drive where your car moves straight and suddenly a big obstacle appears in the front of car, the AI will see and analyze the object, trying to break but if Is to close and it knows can't break fast enough it will calculate the best way of escaping without any damage, if it can't find the good way it will hit the other car near you in order to avoid the obstacle who could create more damage or even death of owner.

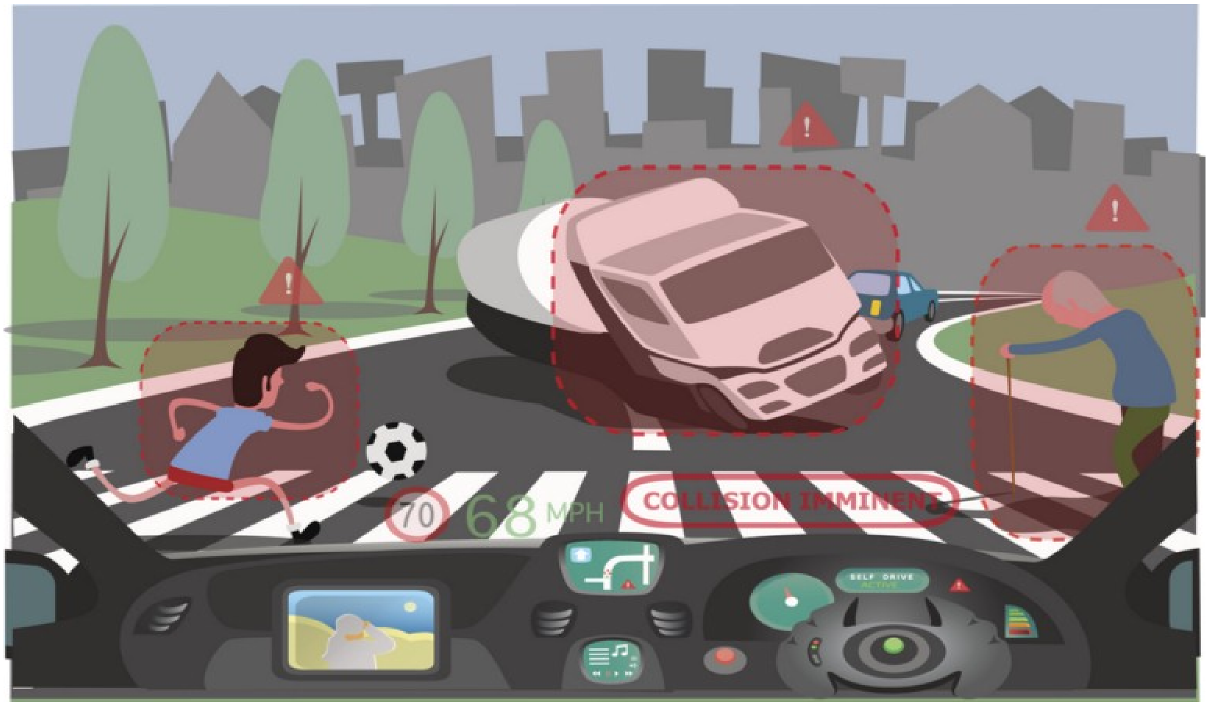
How do they think about choosing the criterion that should govern how a self-driving car engages with the Trolley Problem?

Option 1 is to keep it simple — the only criterion would be to minimize the *number* of lives lost. This likely won't work for two reasons: (1) the majority of the time this would lead to a death verdict for the single passenger which would cause a severe adverse impact on ridership. Why get into a self driving car if when an accident occurs, you bear the majority risk? (2) This schema disregards all other relevant context — we would obviously save 1 cancer researcher over 100 terrorists.

Option 2 is more complex and where we may strive to maximize utility. The challenge comes in defining both "maximize" and "utility." The choice between cancer researchers and terrorists is easy. But if we dive into more nuanced examples, the choice point will be informed by a combination of weighted value criterion and this is where it gets tricky.

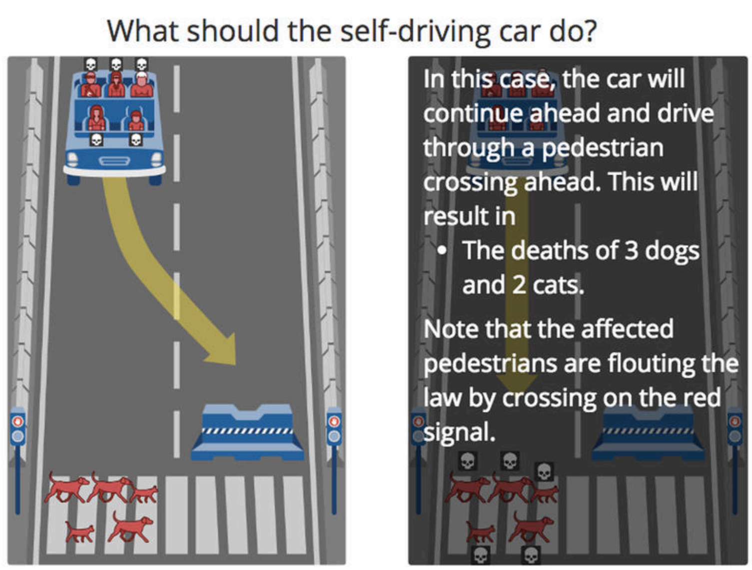
Some number of criterion to consider: (1) age, (2) health, (3) demographics, (4) income. What about (5) cost of the accident, i.e. what taxpayers would have to subsidize in rebuilding roads and other infrastructure? How does the split of where these dollars come from — state, federal or private — affect the decision? How about (6) the dynamics of the actual accident — should we factor in who was wearing a seatbelt? How about the more subjective variables like (7) "current contribution to society" or (8) "future potential.

Ethical decision making



Another exemple of ethical decision making

Here we can see one case of decision the AI could have to take. By thinking about the global protocol that says to protect the life of human it will try to break fast enough to be able to hit the wall at a minimum speed that won't create any damage to the people inside the car. If it calculates that it is impossible to hit the wall without any life risk then it will decide to kill as fewer animals as it can.



Findings

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Conclusions

Tesla has an advantage over other competitors thanks to its ingenuity and its customers.

Firstly, concerns about collecting the right data, paying people to label it, or paying for bandwidth and storage don't obviate these advantages. These problems are addressed not only by designing good triggers, but also by using data that doesn't need human labelling, and using abstracted representations (replays) instead of raw video.

The majority view among business analysts, journalists, and the general public appears to be that Tesla is behind its competition however when taking into account the first principles of neural networks, Tesla is actually more evolved.

Tesla's hardware architecture — a flat pack of batteries at the base, two electric engines (front and rear), no transmission, etc. —also gives it an advantage over competing electric vehicles built on traditional vehicle architectures, such as a lower center of gravity, greater energy density, and more efficient battery management. This means that pound-for-pound, Tesla tends to beat out competitors who try to leverage parts of the old internal combustion vehicle architecture, for example, by putting batteries in the trunk rather than in a flat pack at the bottom.

On the surface, building a new architecture may seem an easy strategy to imitate, but prior research shows it can be very difficult: it can take time and effort for incumbents since it often requires abandoning old ways of doing things and developing new capabilities.

Secondly, Tesla's ecosystem strategy also considers the level of individual components for its products. It is known from past research that the profits in an industry tend to flow to the bottlenecks — the components that limit the performance of the system. In the case of electric cars, even though batteries are made of commodity materials, because their power capacity limits the performance of most applications, especially cars, they are a bottleneck to the performance of the whole system. By investing in batteries —producing them at scale and in better ways — Tesla is betting that they will control the bottleneck, and thus the profit center, for the future of the industry.

In conclusion, Tesla always takes decisions based on the impact they will have in the distant future. This type of thinking is usually correlated to great success and achievements.

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