The Technology Behind Self-Driving Cars

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Jeremy Berchtold

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Report

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Introduction

Self-driving cars rely on advanced computers. The technology behind self-driving cars can be broken down into two areas, the information flow within the cars and the machine learning that powers them. After understanding these concepts, one can better understand the safety of these cars.

The flow of information goes from input data, to machine learning, to mechanical outputs. This general flow applies to all self-driving cars. The machine-learning section of these cars is able to use the input data to determine positions of surrounding objects such as pedestrians and drive the car accordingly. The safety of the cars depends on the accuracy of the machine-learning section.

The safety of self-driving cars is largely unknown because of the small number of cars being tested. However, researches are finding ways to test cars under different conditions to prevent potential errors. This report will examine research simulating the effect of rain and other weather on the accuracy of these cars.

Overall, self-driving cars rely on complex technology. For someone outside the field, it is difficult to make informed decisions about the safety of these cars. This report will explain the technology that powers self-driving cars and how it relates to their safety.

Overview of Machine Learning

Self-driving cars use machine learning to accomplish tasks that cannot be done with traditional programming. Traditional programming is good for well-defined tasks, like numerical computations in a spreadsheet. Contrarily, machine learning is good for abstract tasks, such as recognizing what objects are in an image.

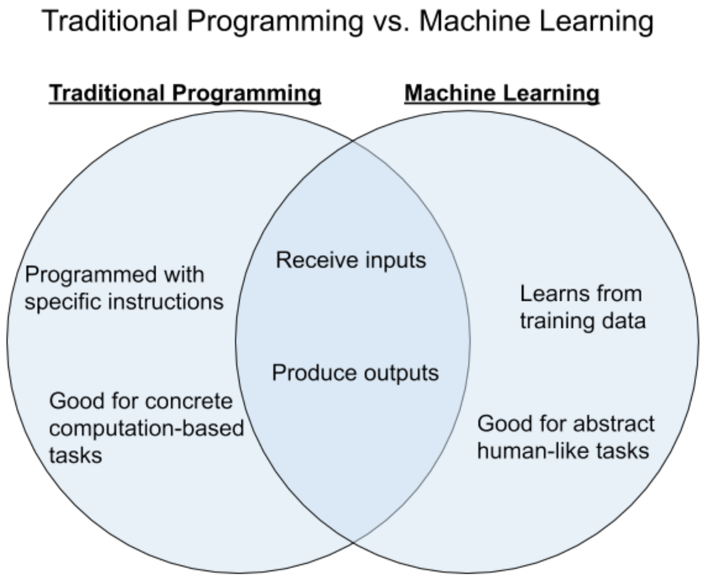

Figure 1: Comparison of traditional programming and machine learning

Drawbacks of Traditional Programming

In traditional programming, someone creates a program with a specific set of instructions for the computer. These instructions are very precise and can only break down inputs into a specific set of well-defined cases such as determining if a number is even or odd. This does not work well for abstract tasks like driving. For example, identifying a pedestrian is difficult for computers because there is too much variability in the input image data. It is like trying to find a mathematical formula for a function with a million variables. It is not possible to code explicit cases for all images that could or could not contain pedestrians. It would be impossible to make sure every case is covered.

Benefits of Machine Learning

Machine learning provides an excellent fix for the drawbacks of traditional programming. Instead of coding a traditional program, a structure called a neural network is created. This neural network takes inputs such as images and produces outputs like locations of pedestrians. Then programmers use training data to train network and the network is able to learn. The training data includes some correct inputs and outputs. After the training, the network is then able to infer correct results for inputs it has not seen before. This is similar to how we as humans learn from studying. We see examples, learn the concepts, and then apply it to new cases. Machine learning allows computers to give correct results for abstract tasks that would not be achievable with traditional programming. Machine learning, in combination with the flow of information, will give a basis for understanding the machine learning specific to self-driving cars.

Information Flow

The flow of information in self-driving cars is important because it explains how data moves from one part of the car to another. Information flow shows how all pieces of a self-driving car connect, which gives an overall understanding of the technology.

The information flow in self-driving cars can be divided into three sections [1]:

- Inputs
- Machine Learning
- Mechanical Outputs

Overall, the flow of information can be broken down into the following steps [1]:

1. Car receives inputs
2. Inputs are given to the machine-learning section
3. Machine-learning section generates mechanical outputs

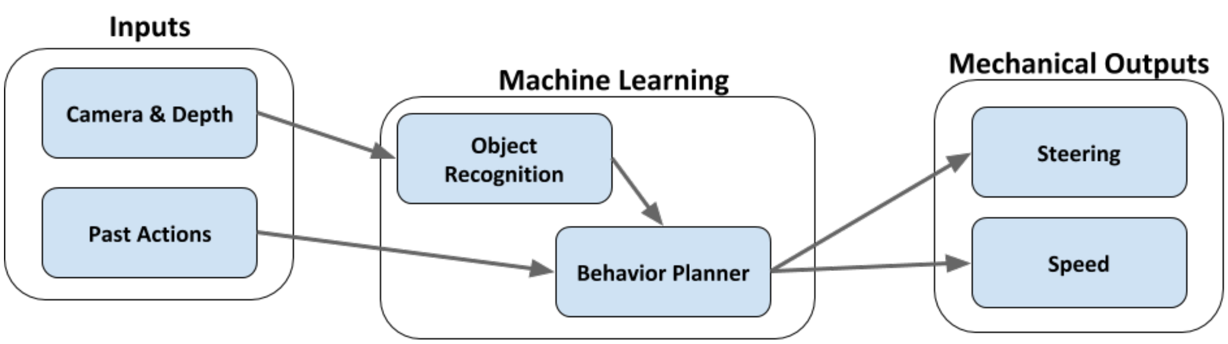

Figure 2: The flow of information within self-driving cars [1]

Inputs

The inputs contain images from the camera and depth data from the sensors [1,2]. This provides the car with three-dimensional data about its surroundings [1]. Additionally, the car records a history of its past actions. For example, if a car is turning it will know how much it has turned so far in order to predict at what angle to keep turning. All this information is then passed to section of the car that uses machine learning.

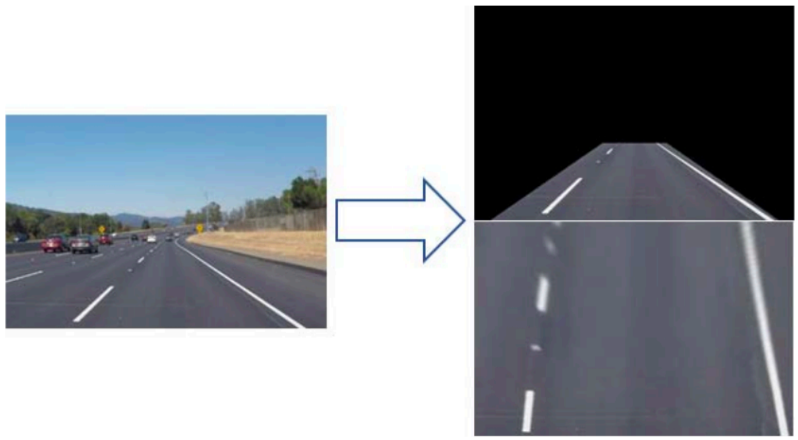

Figure 3: An example of the car detecting the road in an input camera image [3]

Machine Learning

Next, the machine-learning section of the car is divided into two main parts:

- Object Detection
- Behavior Planning

Object detection processes the camera and depth data. It converts the raw data to positions of surrounding objects such as pedestrians, roads, and signs. [1]

Behavior planning uses the past actions and the positions of surrounding objects generated by the object detection. It then decides on what actions to perform, such as turning, speeding up, or slowing down.

Object detection and behavior planning both use machine learning because they are trying to accomplish a complex abstract task with no one correct answer. Instead of coding the logic themselves, people train these sections of the car using example driving data. The cars can then extrapolate and apply this learning to new driving situations. This process is explained further in the "Machine Learning in Self-Driving Cars" section of the report.

Mechanical Outputs

Then the output of the machine-learning section is converted into mechanical actions. The machine-learning section sends data to motors which trigger different mechanical actions. For example, if there is not pedestrian to the left, the car can turn the steering wheel to the left. This general three-step process, inputs to machine learning to mechanical outputs, applies to all self-driving cars [1].

Machine Learning in Self-Driving Cars

Object Detection

Self-driving cars mainly use machine learning within object detection. Object detection identifies surrounding objects and determines their positive relative to the car. This task needs machine learning because it involves image recognition. The input images and depth data contain too much variability so it would be impossible to divide it into cases for traditional programming. The neural network used for object detection receives camera images and depth data as inputs and produces object types and locations [3]. However, the network needs training data to learn.

The training data for the object detection network consists of correctly identified objects in images. The data is stored in pairs of inputs and outputs. Programmers will go through the training inputs and manually determine where the objects are.

Training Data

The neural network then goes through the training phase where it learns from these input and output pairs. The network attempts to reproduce the outputs when given the inputs. If too few training pairs are used, the network won't be able to learn what to do in cases it hasn't seen before. Imagine if a student had a biology test on all animals, but they only studied horses. The student wouldn't do very well when they encountered birds on the test. If the network only sees pedestrians who are tall, it will fail when identifying a shorter pedestrian. The training dataset must be large and diverse.

Programmers create training data by recording images from the self-driving cars cameras while a human is driving it. Then the programmers label all objects in the images, like pedestrians, signs, and roads. They then pack the data into a format the neural network can process. Lastly, the programmers train the neural network with this training data.

If there is not enough training data, or it is incorrectly labeled, the neural network can give incorrect outputs. The safety of the car relies on a large amount of accurate training data.

Safety

Causes of Errors

If the training data for the self-driving car doesn't contain enough examples, there can be safety issues. The neural networks that power self-driving cars sometimes produce incorrect results. Weather conditions such as rain and fog can lead the network to incorrectly predict the road location [1]. This is dangerous because if the car thinks the road is somewhere else, it will drive outside of its lane, potentially crashing. The neural network produces an incorrect result because it has not seen rain or fog before and hasn't learned what to do.

One solution to this problem is to train the network with data containing rain and fog. However, this is expensive because the training dataset needs to be much bigger, meaning programmers need to spend more time creating correct sample outputs for the inputs. There is a better solution to this problem. Weather conditions can be simulated using image transformations, such as rotation and scaling. These transformations simulate the effects of rainwater on the cameras of a self-driving car. The simulated images can help catch errors in the neural network. [1]

Statistics

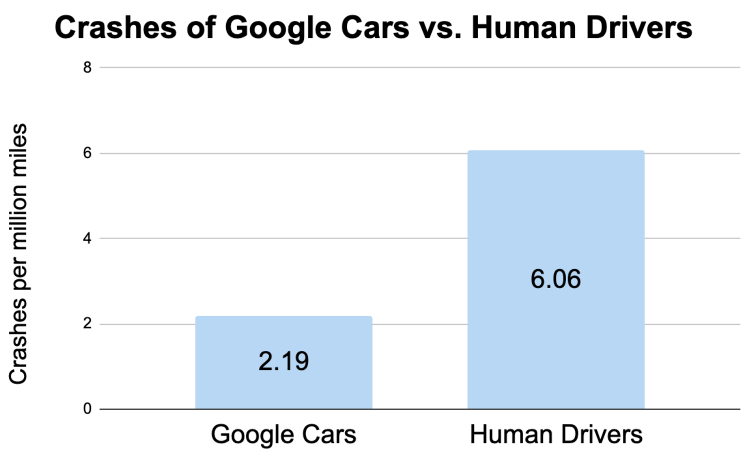

Figure 4: Crash data comparing Google self-driving cars to human drivers [4]

In short, we don't yet know if self-driving cars are safe. Google's self-driving cars have a lower crashes per million miles than human drivers with 2.19 and 6.02, respectively. However, this information is not statistically significantly. Since there are not many self-driving cars and crashes are uncommon, it is difficult to determine the safety with statistically significant results. There were only three police-reportable crashes from Google cars during the measured timeframe of 2009 - 2015. With this small of a sample size, statistically significant results cannot be determined. [4]

Figure 5: Correct road identification [1]

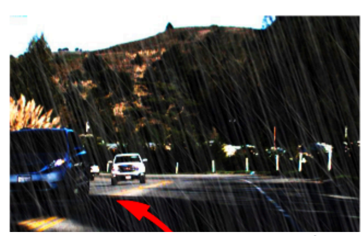

Figure 6: Rain causing incorrect road identification [1]

Conclusion

In summary, the self-driving cars rely on machine learning to process inputs and generate mechanical outputs. The technology behind self-driving cars is complex and still developing. However, the main concepts are the flow of information and machine learning. After understanding these concepts, one can better understand the safety concerns about self-driving cars.

The flow of information in self-driving cars is broken down into the following steps: input, machine learning, and mechanical outputs. The input consists of camera images, depth data, and past actions. The machine-learning section processes these inputs and produces mechanical outputs such as steering or braking.

Self-driving cars use machine learning because driving involves many complex abstract tasks. From identifying pedestrians to determining how to brake smoothly, sample data is used to train neural networks for the car. The networks are then able to infer correct actions in new situations they have not encountered yet.

The safety of self-driving cars is still largely unknown. Researches have attempted to determine the crash rate relative to human drivers. However, crash rates for both self-driving and human-driven cars are low. As a result, there are no statistically significant findings. However, there have been attempts to help catch errors. Using transformations on the input images can help account for errors due to weather conditions such as rain and fog.

Self-driving cars provide an excellent display of the advancements in the field of Computer Science because of their complex technology. These cars will continue to drive improvements in the field for years to come.

Works Cited

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