Embedded Systems Engineering
Self-Driving Cars - challenges and opportunities

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Introduction

A self-driving car is a vehicle controlled by a computer, which requires minimal or no human input, in order to move safely through its environment, these autonomous vehicles are classed under multiple levels of automation.

- **Level 0:** No Automation (Everyday cars)
  - No additional features, standard cruise control
- **Level 1:** Driver Assistance (Most cars from 2018+)
  - Adaptive cruise control, lane keep assist
- **Level 2:** Partial Automation (Tesla Autopilot)
  - Automated speed (stop-go) and steering control (centering the car in the lane)
- **Level 3:** Conditional Automation (2019 Audi A8 came close but not quite)
  - Autonomous vehicles only capable of full autonomy in ideal conditions
- **Level 4:** High Automation (Waymo currently attempting development)
  - Full driving automation requiring only destination input, but restricted to specific use cases
- **Level 5:** Full Automation (Future Tech)
  - Full driving automation, capable of navigating all road conditions, requiring no human intervention.

Currently, the level of automation that can be seen in commercial self-driving cars, goes as far as partial automation, we can see driver assistance functions in almost all modern cars, these mechanisms range from the lane, speed control, emergency braking, despite the vehicle containing these mechanisms they are not sufficient replacements from a human driver.

In an attempt to reach full automation, we can begin to see partial automation features in a select portion of modern cars, such as Tesla vehicles with the Tesla Autopilot system, this system allows the driver to be 'hands-off' in certain situations as the system can take full control of the vehicle's acceleration, steering, and braking mechanisms, the driver acts as as a safety net in the event that the automated system fails or makes an incorrect decision.

Challenges

There have been significant advances in technology that have aided the advancement of self-driving cars, however, there is still a wide range of challenges between our current state and full automation.

Artificial Intelligence Processing Power

A driving force behind the current state of self-driving cars is artificial intelligence, a subfield of computer science that explores the simulation of human intelligence.

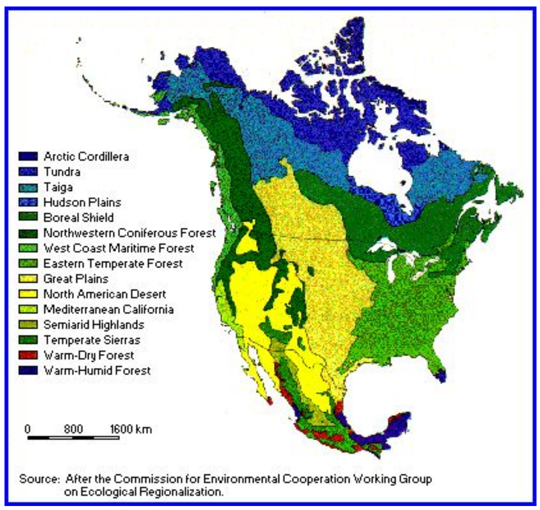
Using advanced AI techniques we are able to give inanimate vehicles vision, and also understanding of the contents in their view, this allows for entity recognition which can be seen in partially automated systems such as Tesla's system, where the on-board computer controlling the vehicle is able to detect other vehicles, obstacles, various road signs, pedestrians, even animals.

An important challenge to overcome when looking at fully autonomous self-driving cars is the large processing power required when processing the huge quantity of entities that need to be examined in order for the vehicle to make the safest driving decision.

This issue can be highlighted in large extremely busy cities, reducing the performance of self-driving cars due to uncertainty, long processing times, and missed information, all of which could lead the vehicle to make a decision that may ultimately cause an accident.

Environmental Variation

Humans can travel between vastly different environments, for example looking at mainland United States, there are nine distinct regional climates, this could be interpreted as nine variations of the environment, however, we also need to consider all variations of possible weather conditions, and how these will affect the sensors and navigation systems.



Not only are there the concrete changes in the environment as mentioned above, but also differences between city, inner-city, suburban, rural environments all of which will include their own subtle or blatant variations, therefore it’s a herculean task to concretely program the self-driving car to react to these different environments.

Using AI we can create complex navigation systems, consisting of computer vision and sensors, geo-location, and much more, allowing a self-driving car to successfully navigate a specific environment, however, we lack the capability to account for all possible driving conditions, and all possible environments.

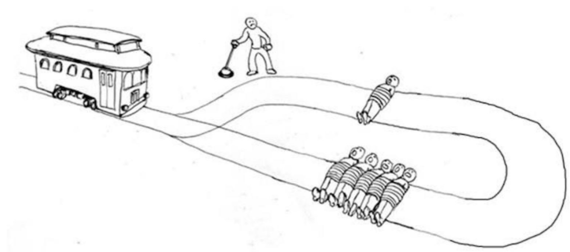
An additional concern is that these environments are not stagnant, they are constantly evolving, therefore self-driving car manufacturers are unable to solely gather the concrete environment data over time, as it will likely be outdated at the end of the data collection.

Moral Challenges

Possibly one of the most frequently asked questions for self-driving cars, “is who lives and who dies ?” This question raises a huge range of ethical and moral considerations.

The challenge behind this question stems from identifying the ‘correct’ choice a car should make in the final moments before a fatal accident, known commonly as the trolley problem.

The trolley problem consists of an ethical dilemma which is whether or not to sacrifice one person to save a larger number of people, however, the complexity of this problem increases vastly as there can be multiple factors that need to be examined, thus rendering this question much more than the initial binary decision that it may seem.



The standard answer for this question is saving multiple people, however, this is not always the case as seen in an experiment done by MIT, which consists of a website called ‘The Moral Machine’ which generates potential situations and asks the user which moral decision they would take.

The results of this experiment varied widely depending on the different category of person, for example, a single baby’s life could be valued more than several elderly people, this is somewhat of a basic consideration, however, when put into a real-life context, we see huge probability calculations in order to mimic these moral considerations.

The ability to make these probabilistic choices under immense time pressure, is the first issue, but also the self-driving car manufacturer or specifically the software engineer who programs this software needs to define these moral choices, and this presents a huge ethical grey area, as the question being asked is that of ‘whose life is worth more?’

And a final consideration is should the self-driving car value the lives of its passengers more than that of a pedestrian, there is a paradox created here, where naturally a person will want their own vehicle to prioritize their lives, but the vehicle of another to prioritize the lives of some people outside of the vehicle.

Social Challenges

As with most future technology, there always is a prominent amount of skepticism around it, and self-driving cars are not excluded from this.

One of the more prominent social considerations around self-driving cars is the absence of eye contact or hand gestures in situations such as a pedestrian crossing, in an attempt to provide similar functionality, LED systems are currently being tested, where a specific light color or pattern will signal the pedestrian to cross.

A further social consideration for self-driving cars is a vital one, and that is the level of safety that the technology is able to provide to both the passenger and the external people.

In order for self-driving cars to be adopted and for governments to allow them on roads, all the people who are involved need to consider the technology safe, the level of safety is somewhat ambiguous and grazes our previous challenge of ethical and moral choices in life or death situations, for example in the question of safety, the life of a cat may not come into question for a certain percentage of the population, however, a different percentage of the population may value the life of a cat hugely in their decision.

We must also consider the legal challenges, such as insurance, taxing.

Opportunities

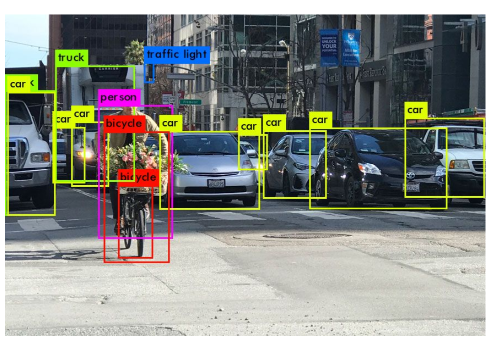
Computer Vision

As explored in the challenges section, computer vision, specifically in the form of entity recognition is vastly important for self-driving cars, however, this is not the only usage, we also see computer vision in lane detection.

Whilst there have been significant improvements in computer vision, this is still a field that can be considered a prominent research opportunity when it comes to improving self-driving cars. A troublesome challenge is processing the sheer quantity of entities that need to be detected and analyzed in certain environments such as chaotic cities.

The opportunity for research here is immense, by developing faster or more efficient entity recognition models from a machine learning or deep learning point of view this could mean using convolutional neural networks over typical machine learning or neural network models, or by developing smarter recognition systems that parse the initial data, so that we use contextual information in order to reduce the data that needs processing into a succinct portion of data that highlights only the vital information, this would allow much faster processing.

Improvements in the neural network field, such as an algorithm called 'you only look once' (YOLO) provide immensely fast entity detection (155 frames per second), the main benefit behind YOLO other than it's speed is its capability to use multiple bounding boxes, and multiple classes, this provides a much clearer view of the entire list of entities in the frame, instead of missing several entities due to a larger bounding box overlapping smaller ones, advances such as these paired with overall faster processing will bring us closer to fully self-driving cars.



Cyber-Security Measures

Fully self-driving cars provide a dangerous tool, that can be exploited by a malicious attacker, such attacks have already been seen in partially autonomous vehicles, such as in the Tesla Model S and Jeep Cherokee, both of which were exploited by security experts, an important consideration here is that in a partially autonomous vehicle the driver can take control, and mitigate the actions of the attacker, but in the case of a fully autonomous car they may not.

It's a safe assumption to assume that future self-driving cars will feature a wide range of networking systems, in order to communicate with each other and therefore provide malicious attackers with potential points of attack.

A vital challenge that provides a huge research opportunity is reducing the possibility of attackers taking control of the vehicle, this may involve real-time protection methods capable of dealing with threats the second they occur, measures such as this require constant upkeep as the nature of threats is ever-evolving.

Luckily there are companies such as Argus that are working on integrated intrusion detection and prevention systems (IDPS) linked to a cloud-based security system.

This creates a single entry point, through secure protocols, acting as a gateway to the vehicle's system.

Conclusion

Despite multiple claims of achieved of self-driving cars, there are currently no commercially available level 5 (fully autonomous) self-driving cars.

The partially autonomous vehicles are a great step in getting closer to our goal, however, we still have a wide range of challenges left to overcome, ranging from software challenges found in image recognition, cybersecurity, or processing performance.

There are also the vast social, moral, and ethical challenges and their solutions, that must be questioned thoroughly, as their implementation is vital to the future of self-driving cars, but could prove detrimental if done poorly.

Self-driving cars provide a huge opportunity for jobs and research, from adaptability to the variety of environments worldwide, overcoming potential security threats, sensor and computer vision performance, all of which describe areas of self-driving cars that need thorough research.