Platforms and Algorithms for Autonomous Driving

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Brief introduction

- Ignacio (Nacho) Sañudo Olmedo
  - Postdoctoral researcher @ HiPeRT Lab
  - Computer science engineer degree 2014 @University of Cantabria
  - PhD thesis 2018 @ University of Modena and Reggio Emilia
- Research and teaching
  - Real-time (predictability, automotive, GPU architectures)
  - Research projects (Automotive)
    - Bosch
    - Ferrari
    - Many others...
  - Prof./collaborator in Platforms and Algorithms for Autonomous Driving
  - Prof. in Advanced informatics in Economy
    - Excel

Course structure

Structure

1. Introduction
2. Description of the use case
3. Description of the algorithm
4. Implementation

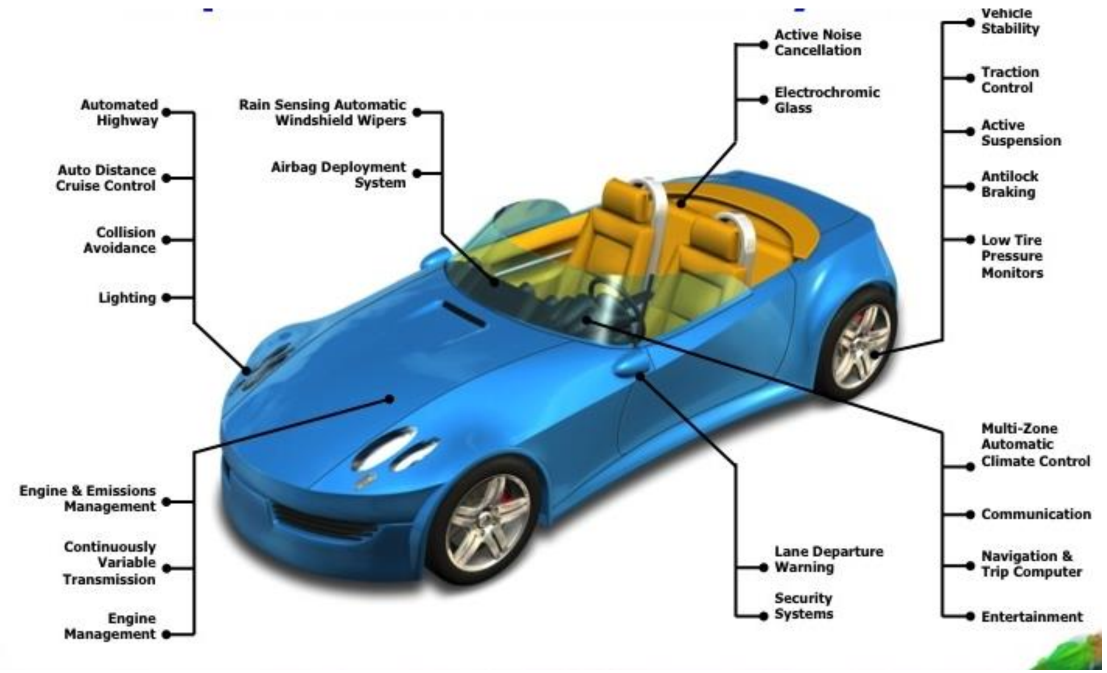
- Introduction Autonomous driving (20)
- Automotive ECU architectures (20)
- Perception
  - Sensors (20-21)
    - Object detection LiDAR - Euclidean Clustering
  - Computer vision & (maybe deep learning) (21-22)
    - Lane detection – Geometrical approach (Hough, Canny etc…)
  - Sensor fusion (22-11)
    - Car’s tracking – Extended Kalman Filter
  - Localization (11)
    - Ego vehicle localization - Particle Filter

Overview

- Perspective of the problem
- History
- Why study self-driving cars?
- SAE Levels
- Hardware stack
  - Sensors
  - Computing platforms
- Software stack
  - Perception
  - Planning
  - Control

Car’s architecture

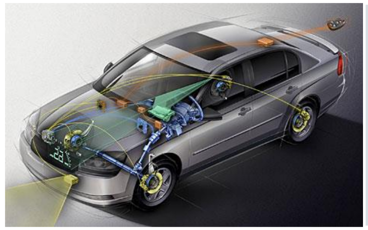
- Today, up to 2500 signals are exchanged through up to 70 electronic control units (ECUs) on five different types of networks
  - With the introduction of ADAS systems the complexity is even higher
- Car’s are becoming powerful computers
  - In charge of the decisions
  - It has to compute a large amount of data provided by the sensors



Automotive Embedded Systems Handbook (Industrial Information Technology). Nicolas Navet 2009

Automotive - Brain

Lines of Code (LoC)

2015

100M

2013


25M

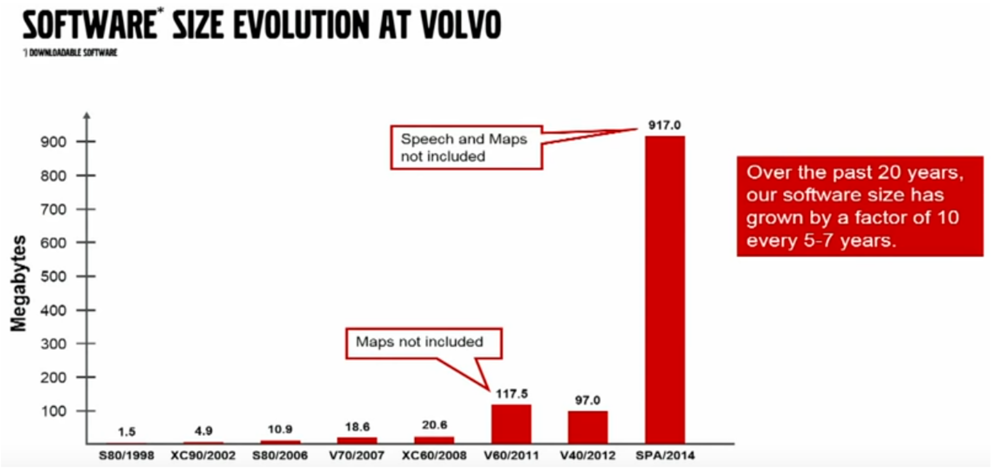
1981

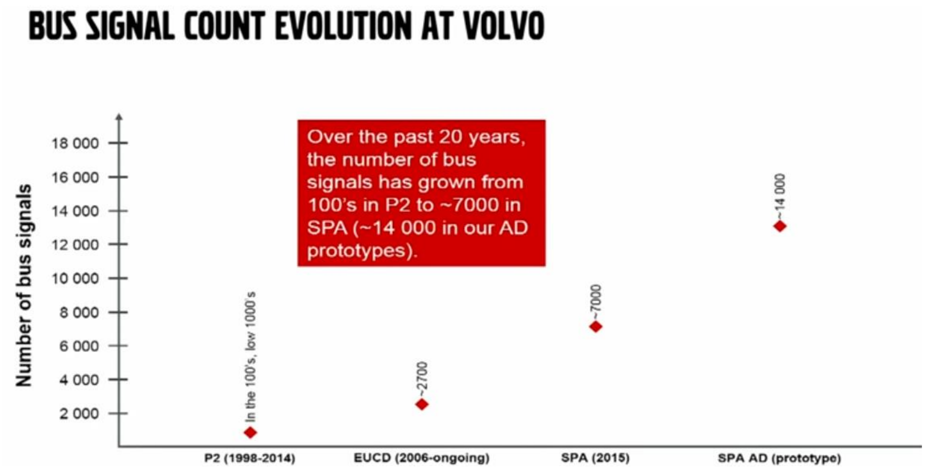
400k

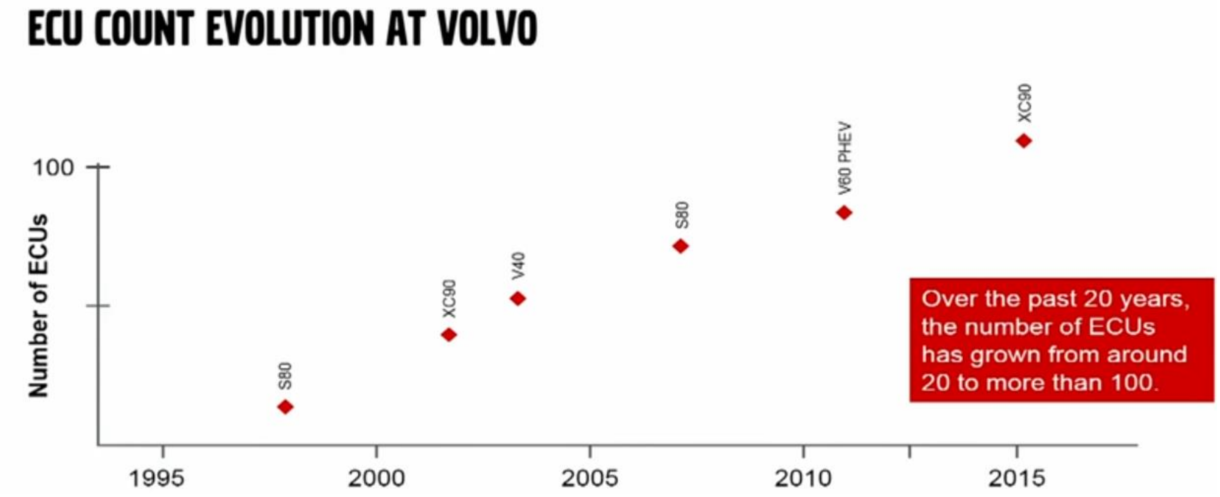
- A million lines of code, if printed, would be about 18,000 pages of text

Source: http://www.visualcapitalist.com/millions-lines-of-code/

Automotive evolution





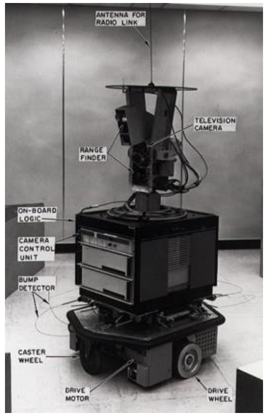


Self driving car

- A self-driving car, also known as an autonomous vehicle (AV), is a vehicle that is capable of **sensing** its environment and **moving** safely with little or no human input
- SDC are robots that acts considering the environment
  - It’s hard to model/interpret the world and be able to act intelligently

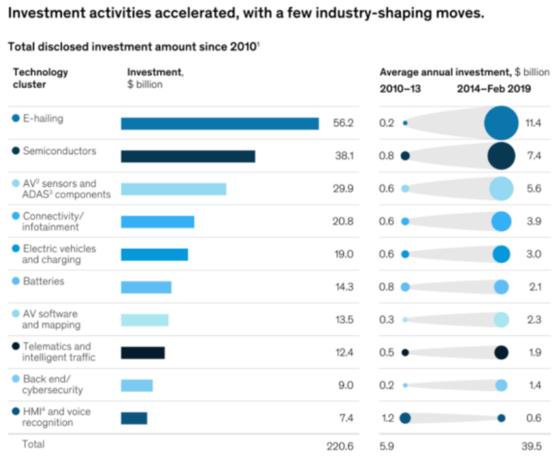
Self driving car history

- These research projects changed the course of the modern mobility
  - Shakey (1966-1972)
    - The first general-purpose mobile robot
      - A* search algorithm, the Hough transform, and the visibility graph method
  - VaMoRs Mercedes project (1983-2002)
    - One of the first autonomous car
      - More than 2000km semi-autonomous
      - Use of advanced computer vision techniques
  - DARPA Challenge (2005-2007)
    - The rebirth of the autonomous hype
      - The engine that pushed the industry to acknowledge the readiness of the technology

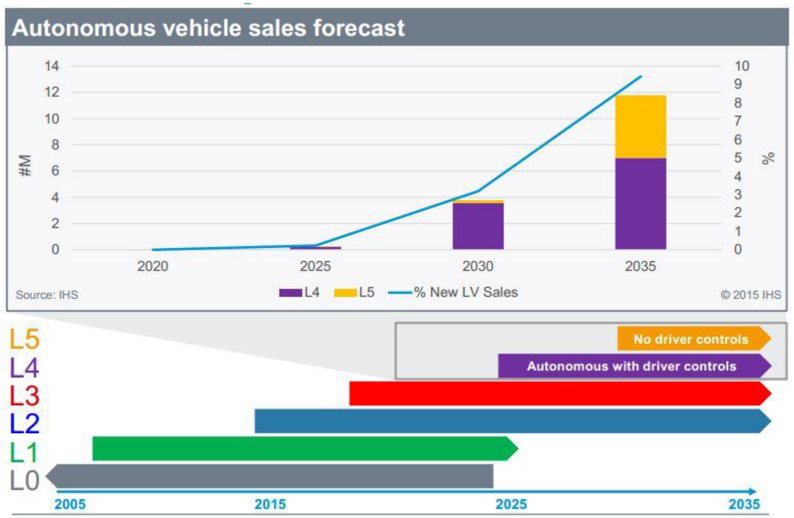


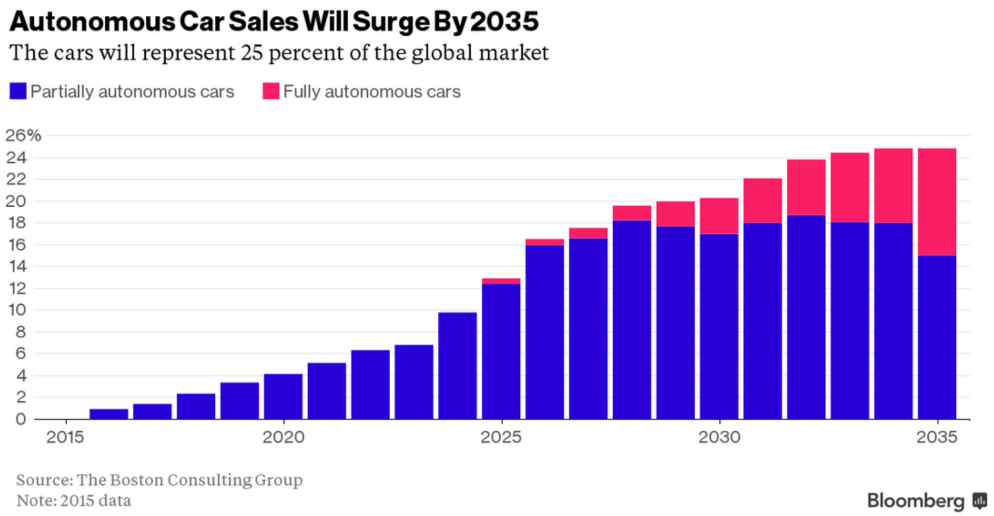
Source: IEEE Talk James Gowers May 12 2020

Why study self-driving cars?



- Exponentially growing market
  - $42B in 2025 to $77B in 2035 (Source: The Boston Consulting Group)
- Western Europe and Japan will be fastest adopters
- Huge financial interest and impressive buyouts…





Why study self-driving cars?

Most Deadly Occupation: Truck Driver

By MARK BAUMGARTNER • Aug. 15

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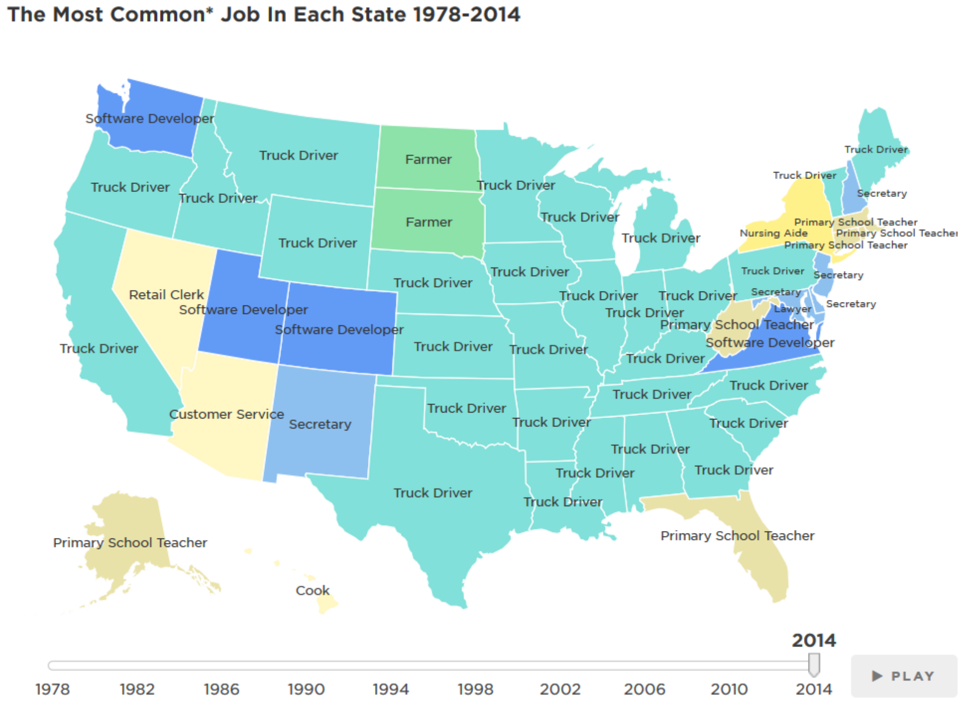
Driving a truck was the most hazardous occupation in the United States last year, according to the government's latest workplace fatality census, which also said highway accidents were the leading cause of deaths of workers in all lines of work.

More truck drivers were fatally injured on the job, 852, than workers in any other single occupation, the Labor Department said, although the fatal injuries among truck drivers declined 5 percent in 2000.

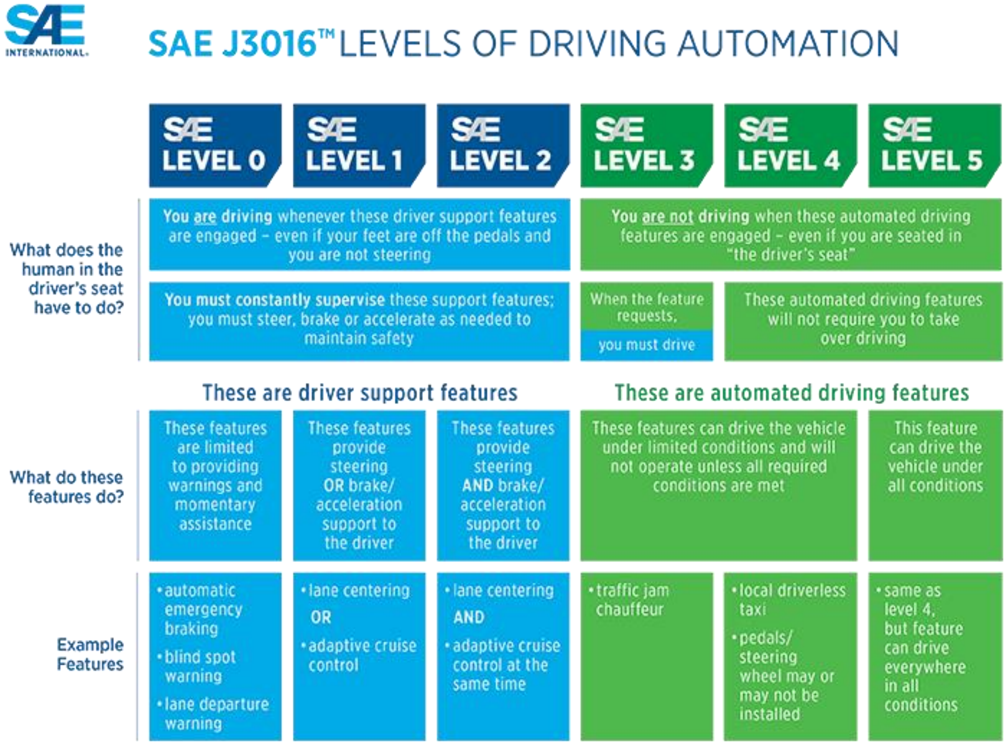
That trend bolsters statistics showing that truck accidents per million miles traveled have declined in each of the past three years, said Duane Acklie, chairman of the American Truckers Association.



SAE Levels

Level	Name	Who is Driving?	Who is Monitoring?	Who Intervenes?
0	No Automation	😀	😀	😀
1	Driver Assist	😀🤖	😀	😀
2	Partial Automation	🤖😀	😀	😀
3	Conditional Automation	🤖	🤖	😀
4	High Automation	🤖	🤖	🤖😀
5	Full Automation	🤖	🤖	🤖

- The Society of Automotive Engineers defines Different levels of automation (SAE J30169)
  - It provides a taxonomy with detailed definitions for six levels of *driving automation,* ranging from *no driving automation* (level 0) to *full driving automation* (level 5)



Source: Wikipedia & SAE

Classic Players

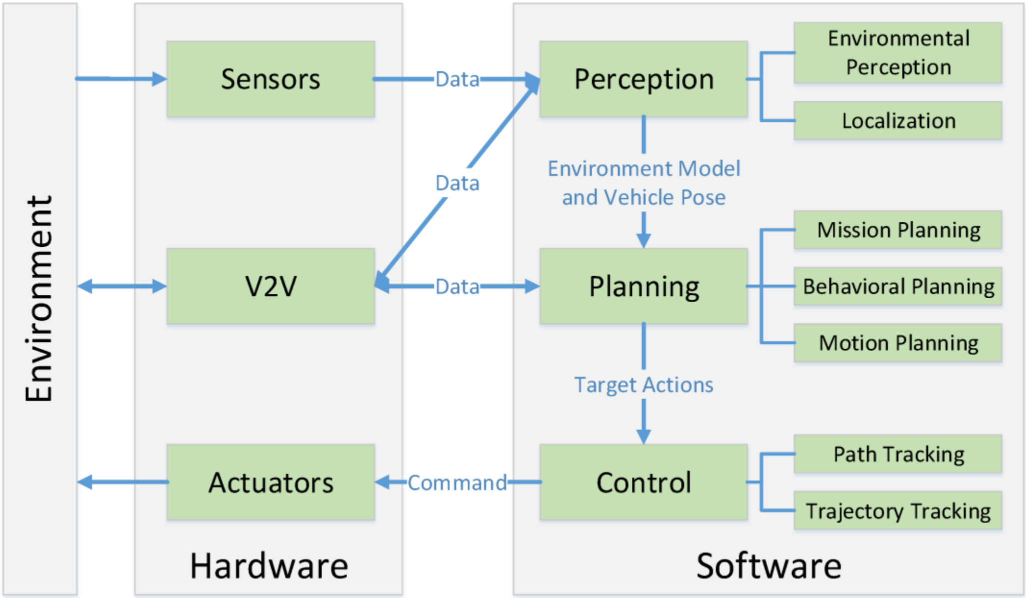
New players

https://www.bloomberg.com/features/2020-self-driving-car-race/

AV stack

- Feature extraction
- Object classification
- Obstruction identification
- Mapping and Localization
- Dynamics modeling
- Traffic signal detection
- Sign detection and classification
- Path planning and decision making

› Autonomous vehicles feature a technology that “deals” with the environment
  – Different sensor and software components are involved



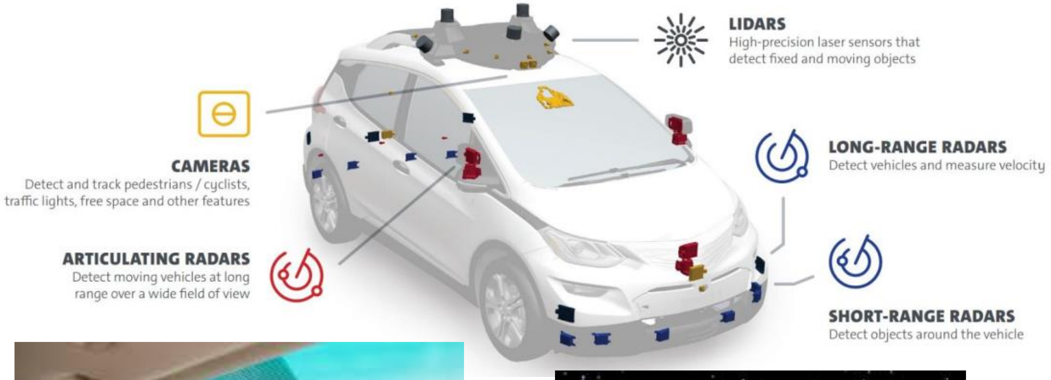
Hardware stack

Camera: is an electronic device that uses lenses to capture images. It is used used to detect and track objects or detect lane boundaries

RADAR: is a technology system that uses radio waves to detect objects, their **distance, angle and speed** in relation to the ego-vehicle

LiDARs:- Light Detection And Ranging (LiDAR) is a technology used to scan objects, **measure distances and height**. A lidar sensor transmits laser beams that bounce off objects and return to the sensor

GPS: is a satellite-based radio navigation system which is used to provide a position, the GPS satellites broadcast two pieces of information: their **location and time**



Sensor war

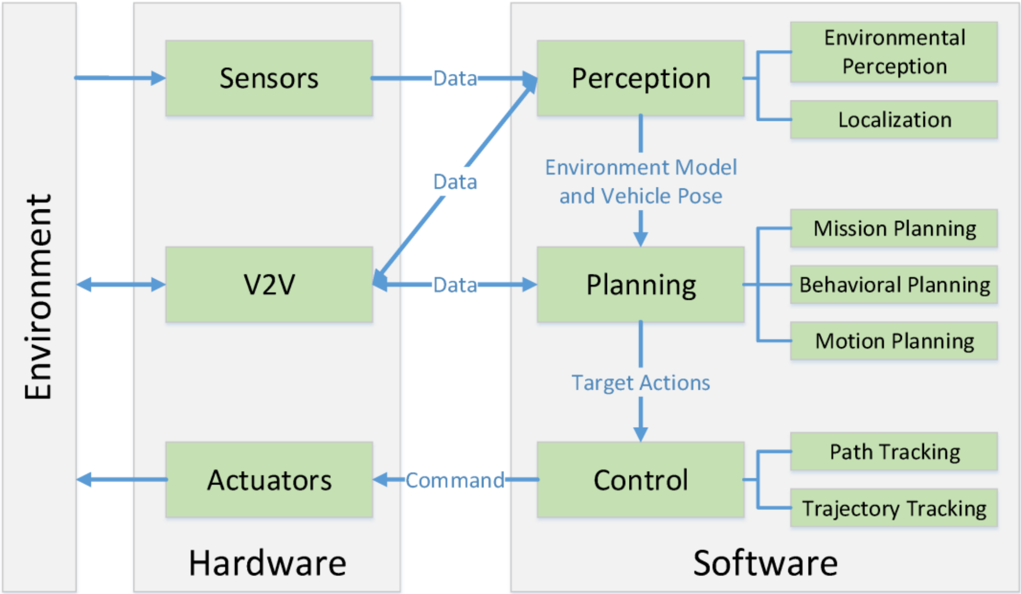
- There’s an ongoing battle between LiDAR and Cameras for the title of the self-driving car’s “eyes”
- Tesla
  - Camera+Radar
- The rest of the world
  - Full sensor stack
- Elon Musk statements about LiDARs
  - “LiDAR is a fool’s errand”
  - “Anyone relying on lidar is doomed. Doomed! [They are] expensive sensors that are unnecessary. It’s like having a whole bunch of expensive appendices. Like, one appendix is bad, well now you have a whole bunch of them, it’s ridiculous, you’ll see”
  - "You were not shooting lasers out of your eyes to get here”

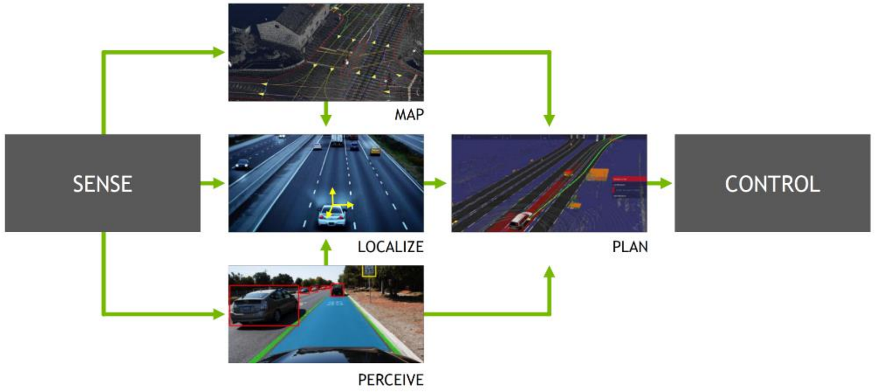
Silicon war

- To implement image processing, object detection, mapping, planning and control different computing platforms can be adopted
  - Safety design
  - Different computing platforms
    - CPU
    - Graphic Processing Unit (GPU)
    - Field Programmable Gate Array (FPGA)
    - Application Specified Integrated Chip (ASIC)
    - In today’s world of self-driving-car prototypes, most cars are built using a combination of CPUs and GPUs
  - Trends (BMW, NVIDIA...)

Software stack

- The "brain" of the car is composed of three main components
  - Perception, Planning and control





Source: Perception, Planning, Control, and Coordination for Autonomous Vehicles. Scott Drew Pendleton et al.

Perception

- **Environmental perception:** ability to extract meaningful information from the environment by using sensors (Computer vision/AI)
  - Predominantly, the camera is the sensor used to perform object detection
    - Dynamic objects: Object classification, object tracking, motion prediction…
    - Static objects: traffic lights, signs, lanes….
- **Localization**: Is the capacity of the car to determine it's position in the world with low error
  - Different sensors can be used: GPS, IMU, radar, LiDAR, camera….

Source: Udacity

Object detection/tracking

- **Moving Objects Tracker** (MOT) subsystem is responsible for detecting and tracking the pose of moving obstacles in the environment around the self-driving car
  - essential for avoid collision with potentially moving objects like vehicles or pedestrians
    - LIDAR and RADAR, or stereo and monocular camera
- Computer vision techniques
  - Canny edge, hough transform...
- Deep learning techniques

https://www.youtube.com/watch?v=xAAz3Zgkmy8

Object detection

- "tkDNN is a Deep Neural Network library built with cuDNN and tensorRT primitives, specifically thought to work on NVIDIA Jetson Boards. It has been tested on TK1 (branch cudnn2), TX1, TX2, AGX Xavier, Nano and several discrete GPUs. The main goal of this project is to exploit NVIDIA boards as much as possible to obtain the best inference performance"
- https://www.youtube.com/watch?v=2WbtJBN6gzs

https://github.com/ceccocats/tkDNN

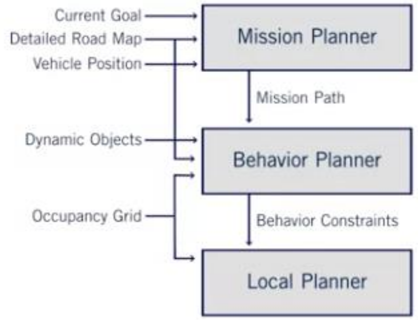
Localization

- The localization software component is in charge of estimating the ego vehicle pose (position and orientation) relative to a map or road
  - LiDAR-Based Localization
    - Compares currently extracted features with features marked in a map
    - We will implement [1]
  - Camera-Based Localization
    - Based on extracting visual odometry and road maps
  - LiDAR plus Camera-Based Localization
    - LiDAR data is used to build a map, and LiDAR /camera data to estimate the localization of the self-driving car relative to the map
    - Most of these methods matches stereo images to 3D point-cloud maps

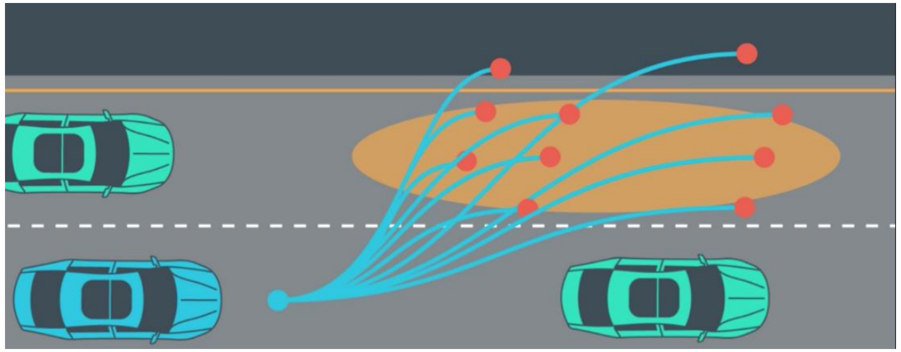
https://www.youtube.com/watch?v=qkWqRSgUFmw

[1] Levinson, J., & Thrun, S. (2010). Robust vehicle localization in urban environments using probabilistic maps. In 2010 IEEE International Conference on Robotics and Automation (pp. 4372–4378). IEEE.

Path planning



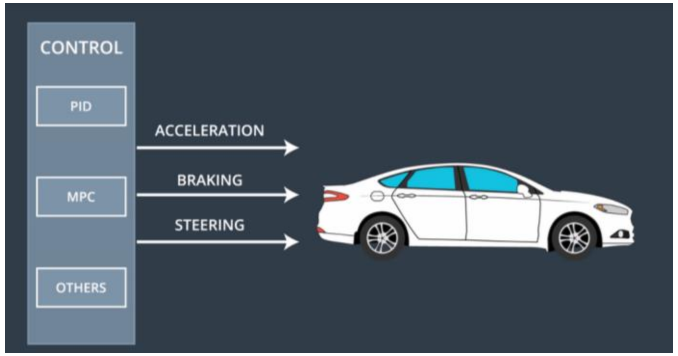
- **Path planning**: is computational problem to find a sequence of valid configurations or paths that moves the ego-vehicle from the source to destination
  - **Mission planning**: is the process of making the highest-level decisions with regard to the proposed destination, for instance, which road should we take if we would like to go from Modena to Bologna
  - **Behavioral planning**: responsible for decision making to ensure the vehicle follows any stipulated road rules and interacts with other agents in a safe manner
  - **Motion planning**: process of deciding on a sequence of actions to reach a specified goal, typically while avoiding collisions with obstacles (it defines the specific plan to drive)



Source: Perception, Planning, Control, and Coordination for Autonomous Vehicles. Scott Drew Pendleton et al.

Control

- **Control:** computes and sends commands to the actuators of the steering wheel, throttle and brakes
  - Path tracking: plan to move from a start pose to a goal pose (**pure pursuit**)
  - Trajectory tracking: plan to move from a start pose to a goal pose includes the velocity (and time) information of the motion (**MPC**)
- Controllers typically separates the problem in longitudinal and lateral control
  - Lateral control: steering angle
  - Longitudinal control: throttle and braking

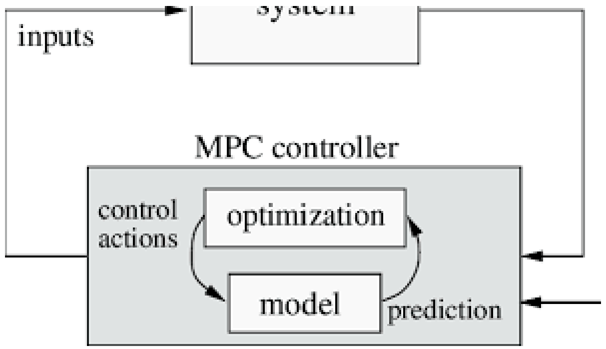


https://www.youtube.com/watch?v=vgEyvazwrU8

Source: Perception, Planning, Control, and Coordination for Autonomous Vehicles. Scott Drew Pendleton et al.

Model predictive control (MPC)

- MPC methods use models of how self-driving cars respond to efforts over time to predict future values of velocity and orientation
  - They use these predictions to try and decide which efforts should be sent to the car to better reduce current and future errors in velocity and orientation



https://www.youtube.com/watch?v=Mci4TPKXSlI