Comp 790-058 Lecture 06: Overview of Autonomous Driving

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Sahil Narang

University of North Carolina, Chapel Hill

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Autonomous Driving

- Autonomous vehicle: a motor vehicle that uses artificial intelligence, sensors and global positioning system coordinates to drive itself without the active intervention of a human operator
- Focus of enormous investment [$1b+ in 2015]

Tesla

Waymo

Nutonomy

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Autonomous Driving: Motivation

- Cars are ubiquitous
  - ~ 1 bn vehicles for a global population of ~7 bn [est. 2010]
- Car accidents can result in catastrophic costs
  - 300 bn USD in car crashes in 2009
  - 160 bn USD congestion related costs in 2014
  - Health costs
    - 33k fatalities, 2 million+ injuries in 5.4 million crashes in 2010
    - Premature deaths due to pollution inhalation

Autonomous Driving: Levels of Autonomy

- 0: Standard Car
- 1: Assist in some part of driving
  - Cruise control
- 2: Perform some part of driving
  - Adaptive CC + lane keeping
- 3: Self-driving under ideal conditions
  - Human must remain fully aware
- 4: Self-driving under near-ideal conditions
  - Human need not remain constantly aware
- 5: Outperforms human in all circumstances

Structure

- History of Autonomous Driving
- Main Components
- Other Approaches
- Other Issues

Structure

- History of Autonomous Driving
  - Through the years (1958-2007)
  - Current State of the Art
- Main Components
- Other Approaches
- Other Issues

Autonomous Driving: Levels of Autonomy

- https://www.youtube.com/watch?v=E8xg5I7hAx4

Autonomous Driving: Through the years

- Magic Highway (1958)
  - https://www.youtube.com/watch?v=L3funFSRAbU

Autonomous Driving: Through the years

- CMU NavLab (1986)
  - https://www.youtube.com/watch?v=ntIczNQKfjQ

Autonomous Driving: Through the years

- DARPA Grand Challenge 2004
  - https://www.youtube.com/watch?v=wTDG5gjwPGo

Autonomous Driving: Through the years

- DARPA Grand Challenge 2005
  - https://www.youtube.com/watch?v=7a6GrKqOxeU

Autonomous Driving: Through the years

- DARPA Grand Challenge 2007
  - Focus on urban driving
  - https://www.youtube.com/watch?v=8NIx7Y4EgQg

Autonomous Driving

- Urban driving is particularly challenging

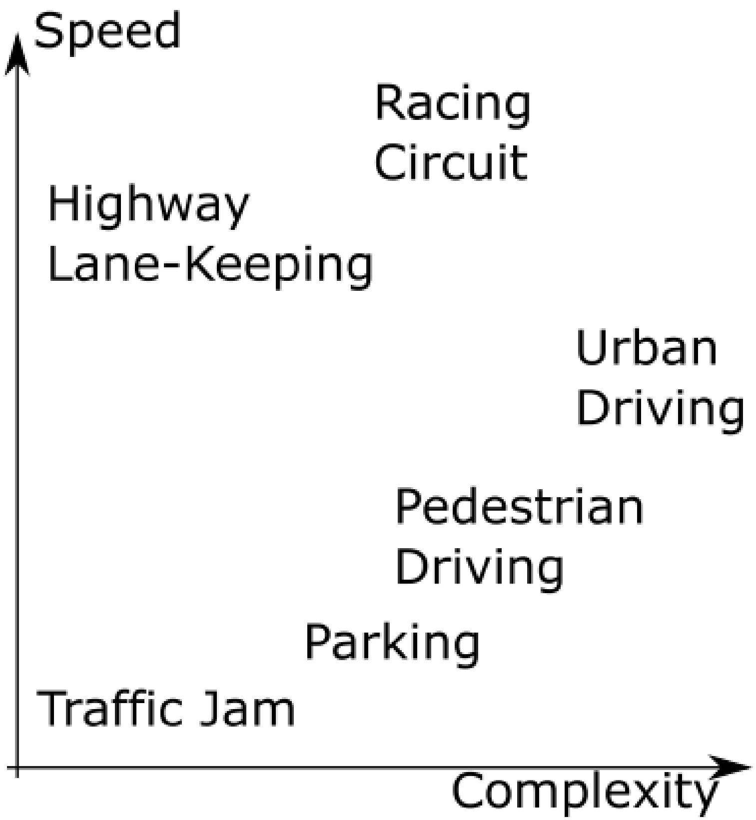

Figure 1. Complexity and operating velocity for various driving scenarios.

Structure

- History of Autonomous Driving
  - Through the years (1958-2007)
  - Current State of the Art
- Main Components

- Other Approaches

- Other Issues

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Autonomous Driving: State of the Art Today

- Automated road shuttles
  - Vehicles operate in segregated spaces
  - Simple car-following strategies
  - https://www.youtube.com/watch?v=Byk8LcPovOQ

Autonomous Driving: State of the Art Today

- Google's Waymo
  - https://www.youtube.com/watch?v=TsaES--OTzM

Structure

- History of Autonomous Driving
- Main Components
    - Perception
    - Planning
    - Control
- Other Approaches
- Other Issues

Autonomous Driving: Main Components

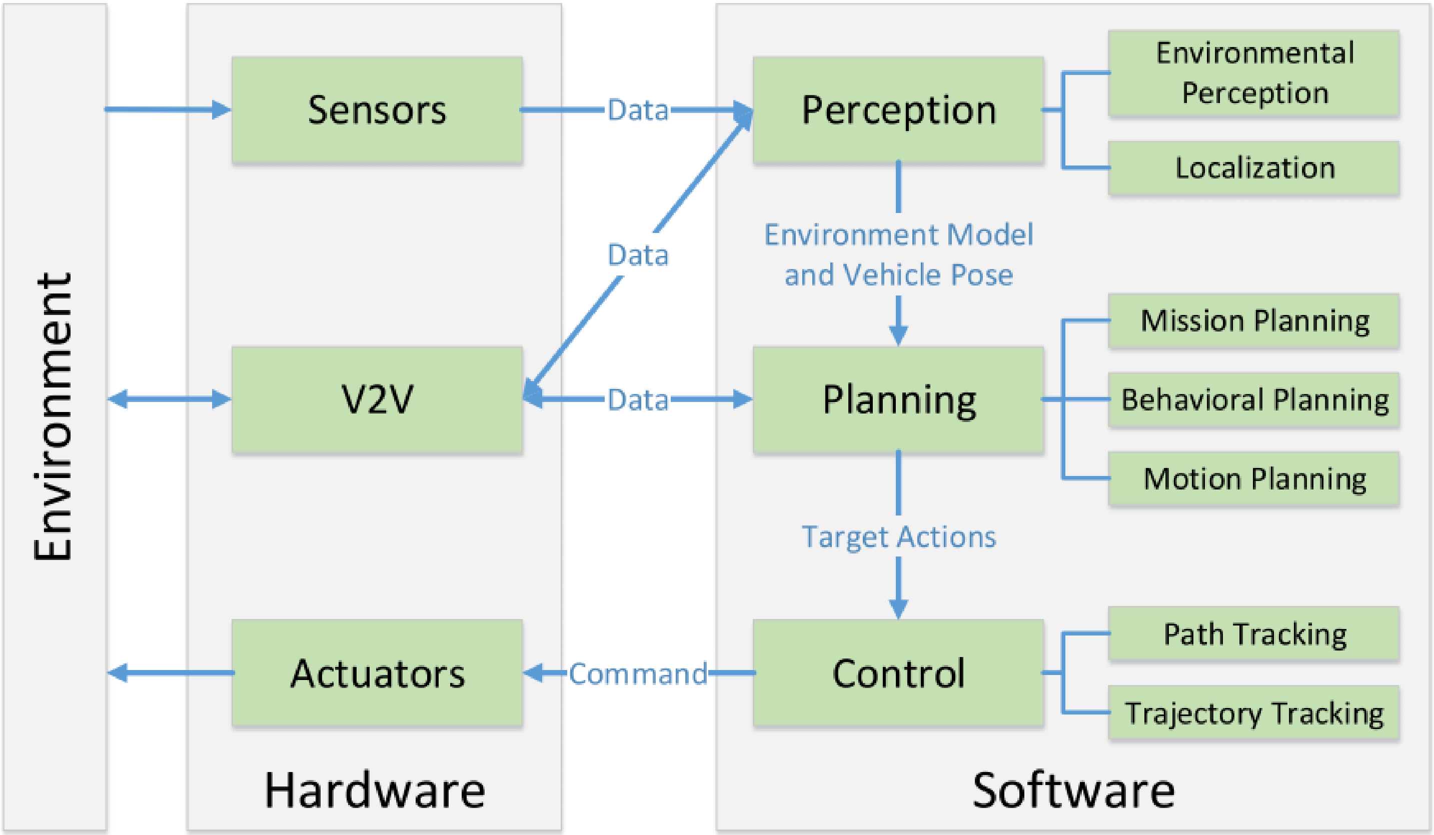
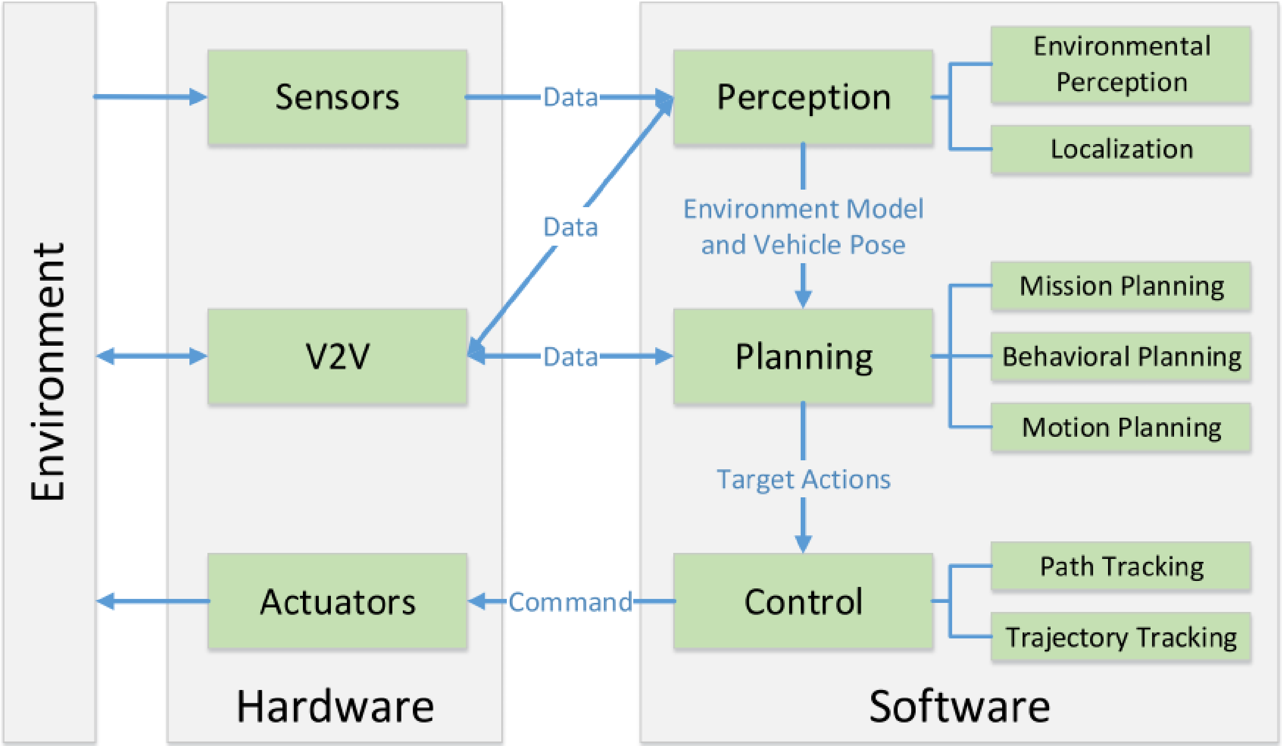


Figure 2. A typical autonomous vehicle system overview, highlighting core competencies.

Autonomous Driving: Main Components

- Perception
  - collect information and extract relevant knowledge from the environment.



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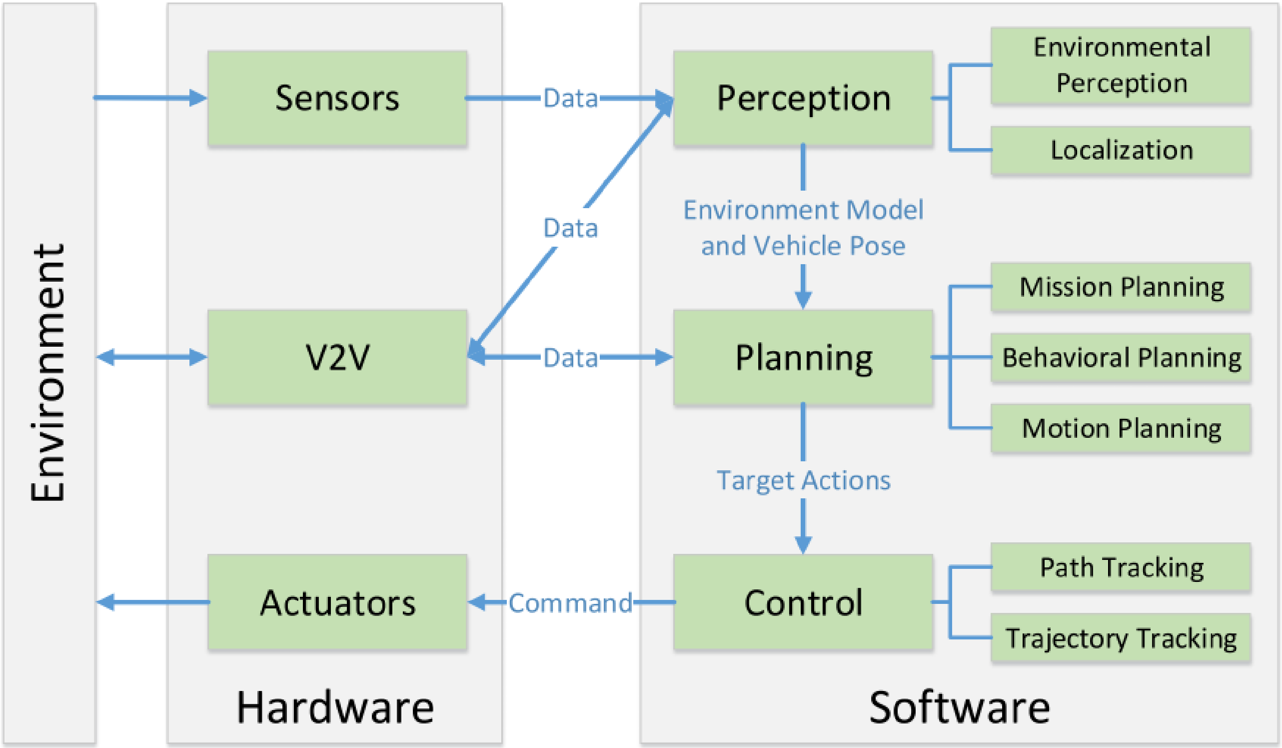
Autonomous Driving: Main Components

- Planning
  - Making purposeful decisions in order to achieve the robot's higher order goals



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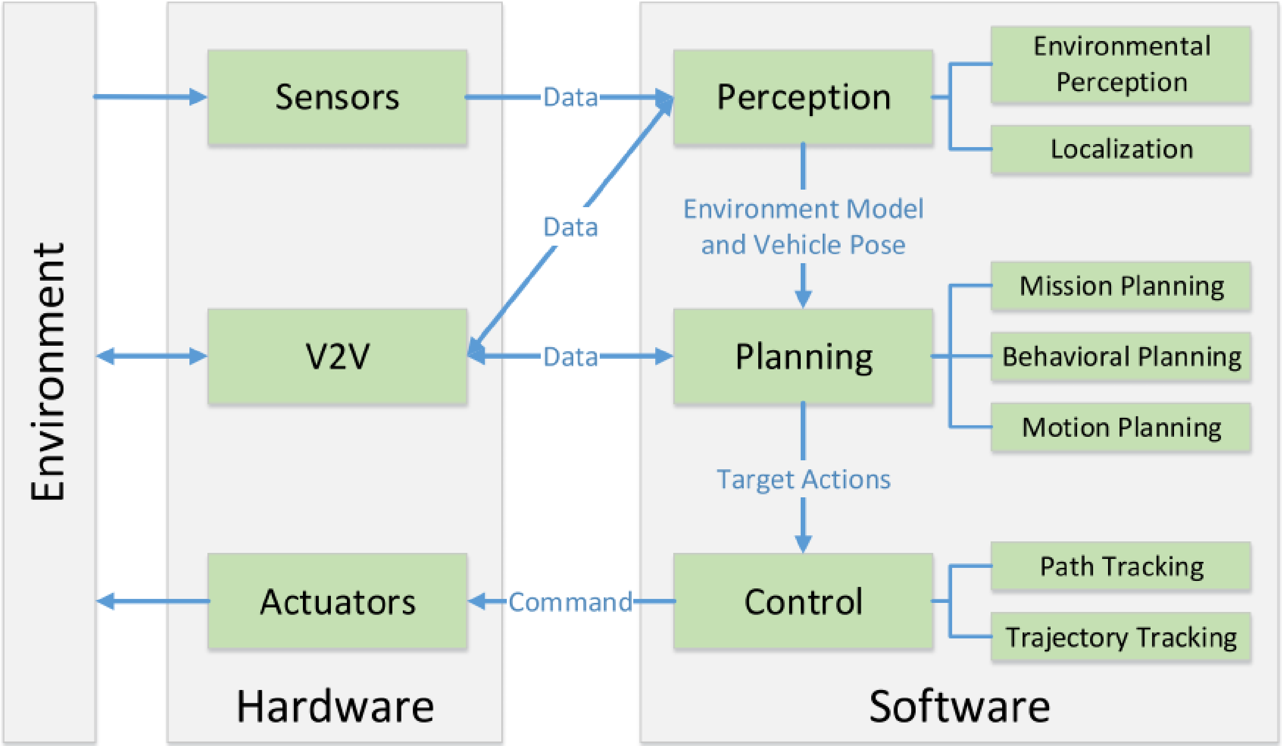
Autonomous Driving: Main Components

- Control
  - Executing planned actions



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Structure

- History of Autonomous Driving
- Main Components
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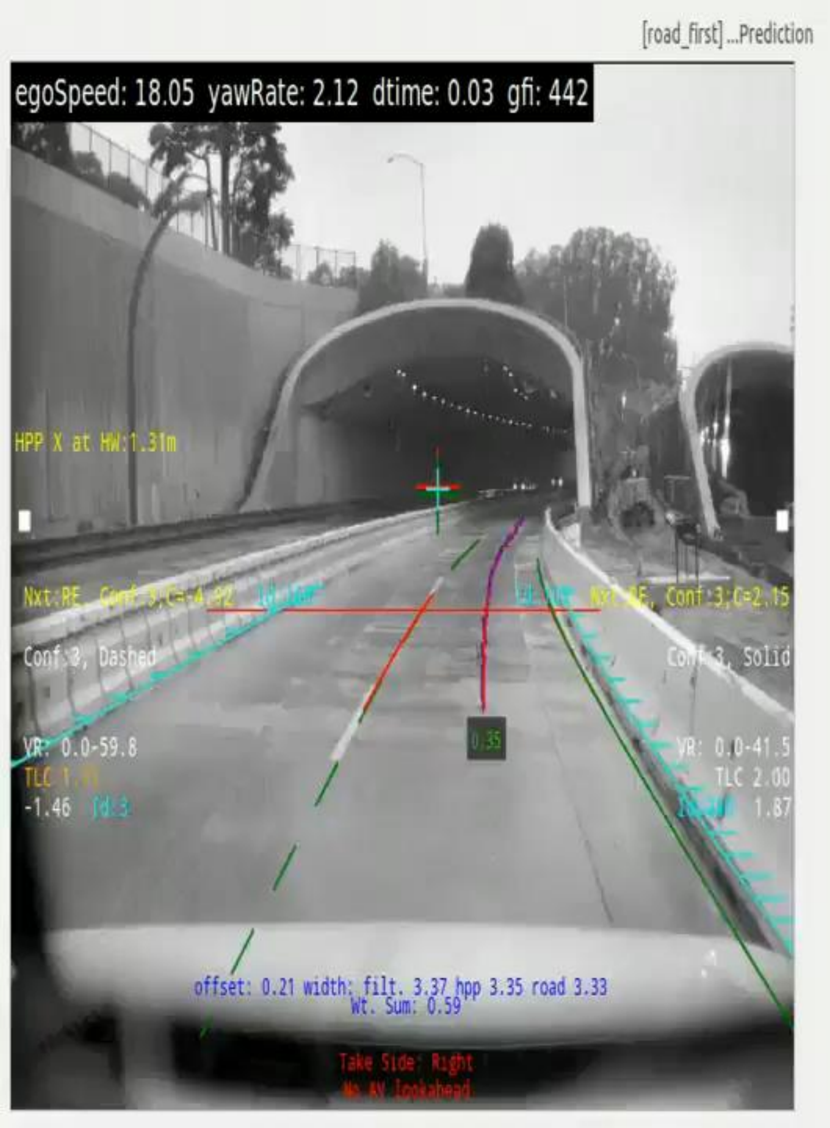
- Other Issues

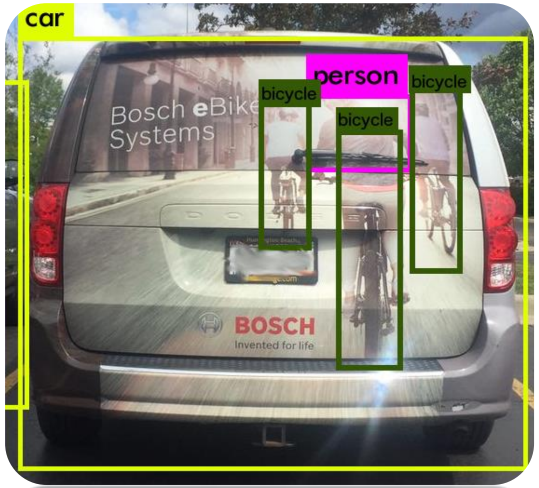
Autonomous Driving: Perception

- Sensing Challenges
  - Sensor Uncertainty
  - Sensor Configuration
  - Weather / Environment



Autonomous Driving: Challenges in Perception

- Sensor Misclassification
  - “When is a cyclist not a cyclist?”
  - When is a sign a stop sign?
  - Whether a semi or a cloud?



Autonomous Driving: Perception

- Environmental Perception
  - LIDAR
  - Cameras
  - Fusion
  - Other approaches
    - RADAR, Ultrasonic sensors

Autonomous Driving: Perception

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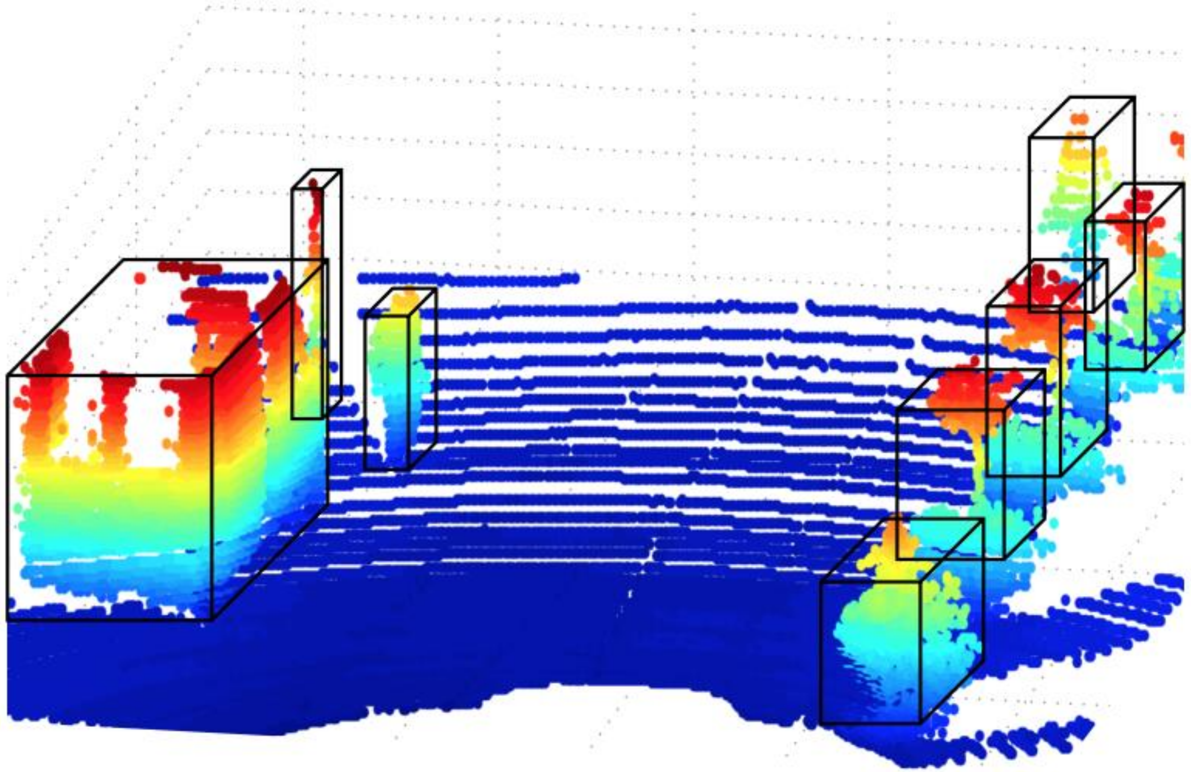
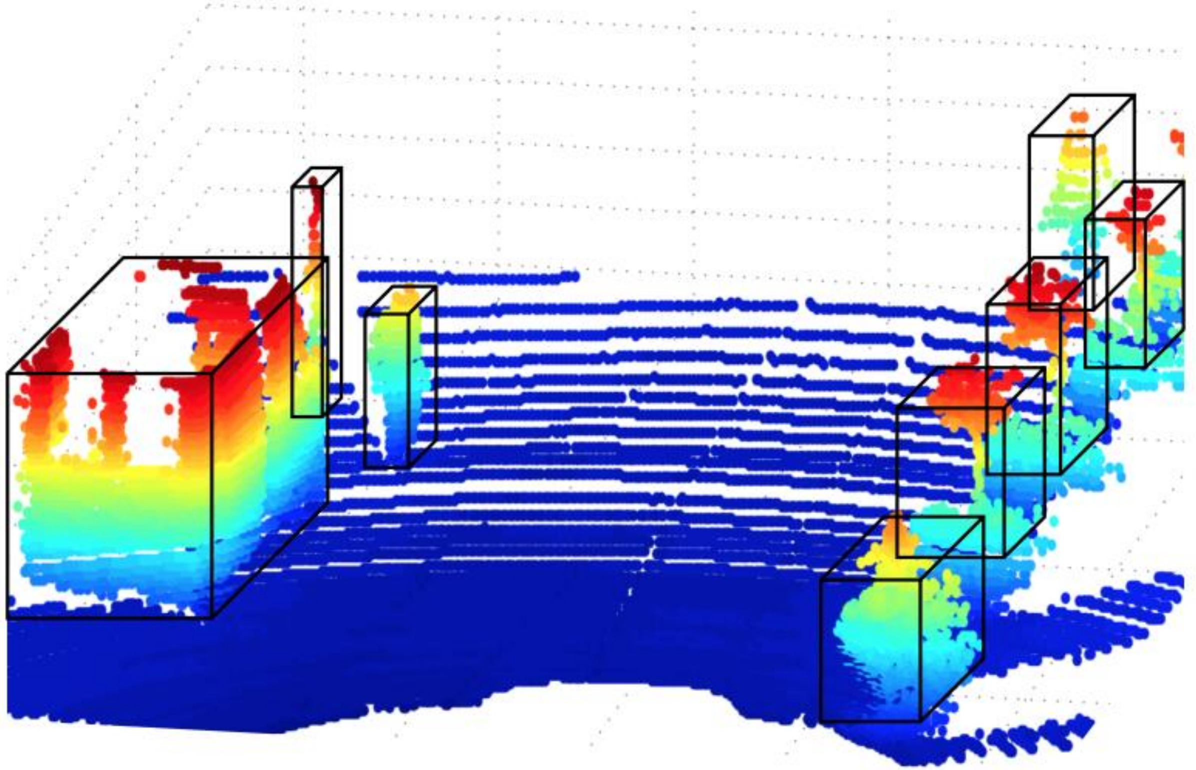
Autonomous Driving: Perception using LIDAR

- Light Detection and Ranging
  - Illuminate target using pulsed laser lights, and measure reflected pulses using a sensor



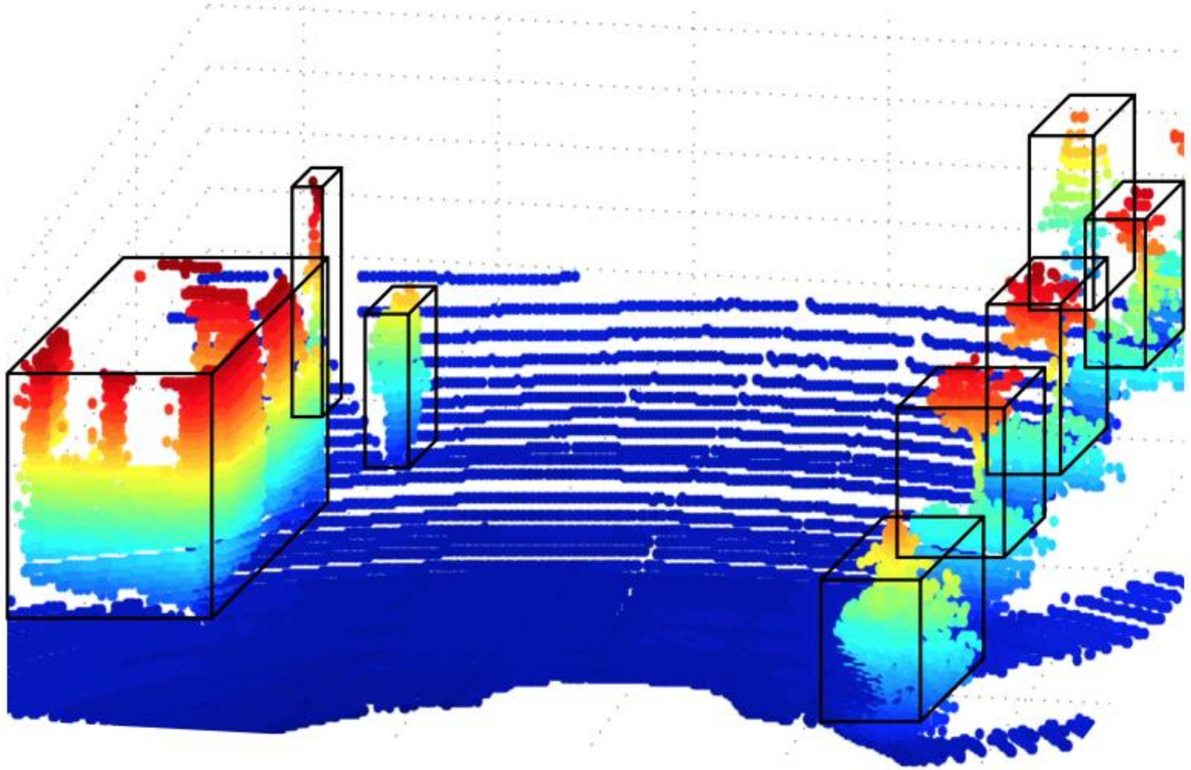
Autonomous Driving: Perception using LIDAR

- LIDAR Challenges
  - Scanning sparsity
  - Missing points
  - Unorganized patterns
  - Knowledge gathering can be difficult



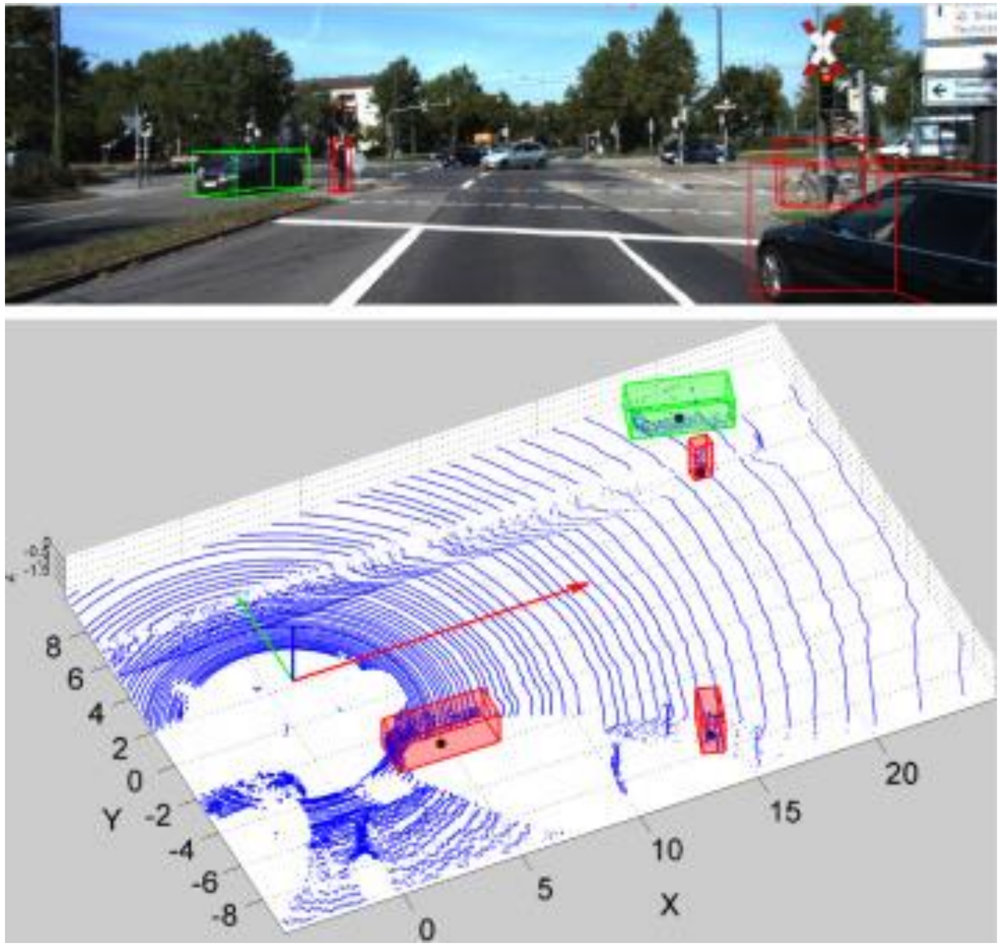
Autonomous Driving: Perception using LIDAR

- Data Representation
  - Point clouds
  - Features: lines, surfaces etc
  - Grid based approaches



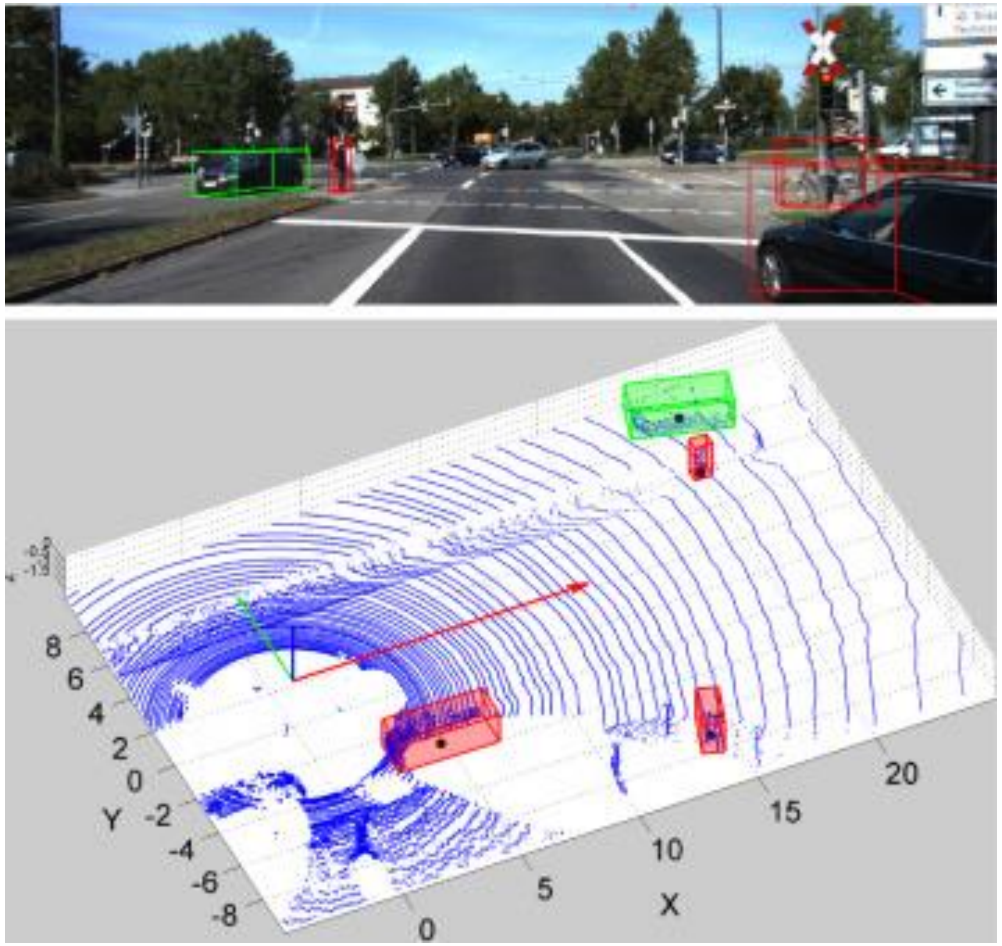
Autonomous Driving: Perception using LIDAR

- Knowledge Extraction
  - 3D point cloud segmentation
  - Classification



Autonomous Driving: Perception using LIDAR

- Knowledge Extraction
  - 3D point cloud segmentation
    - Edge based
    - Region based
    - Model based
    - Attribute based
    - Graph based
  - Classification



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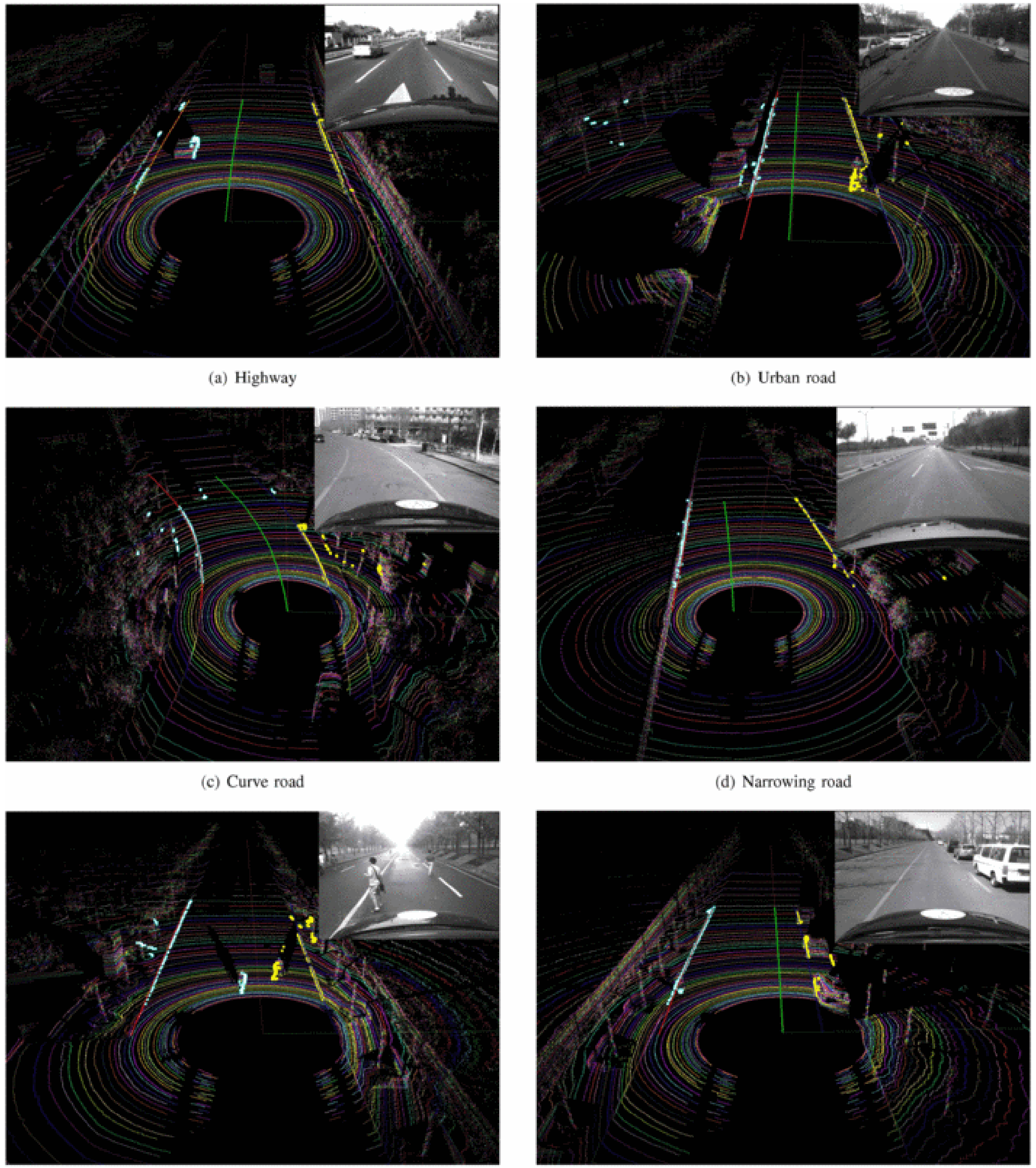

(a) Highway (b) Urban road (c) Curve road (d) Narrowing road (e) Obstructed by objects and water (f) Parked cars at roadside

Autonomous Driving: Perception using LIDAR

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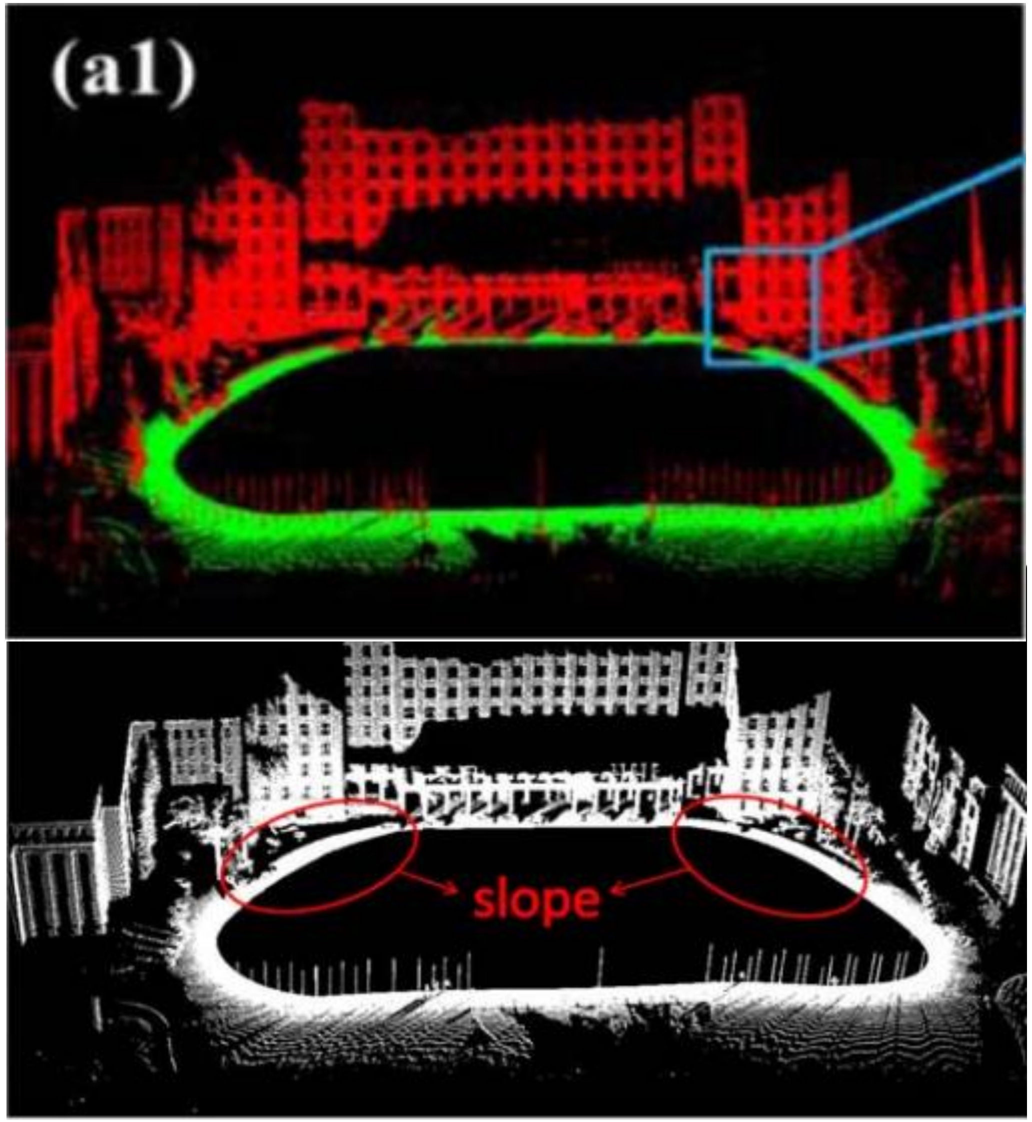

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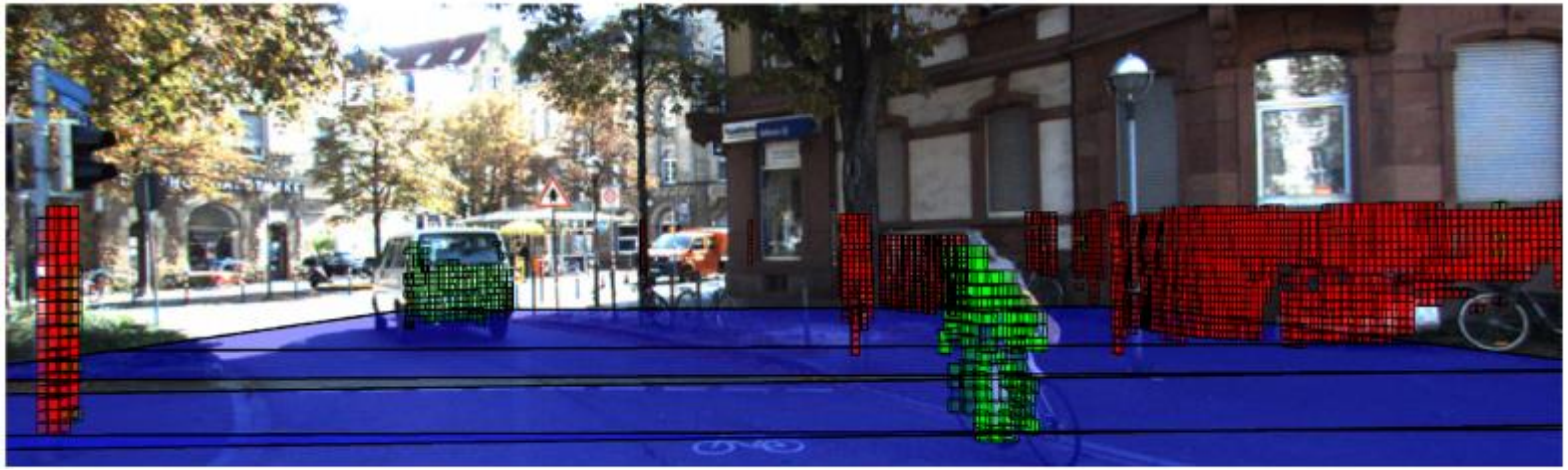

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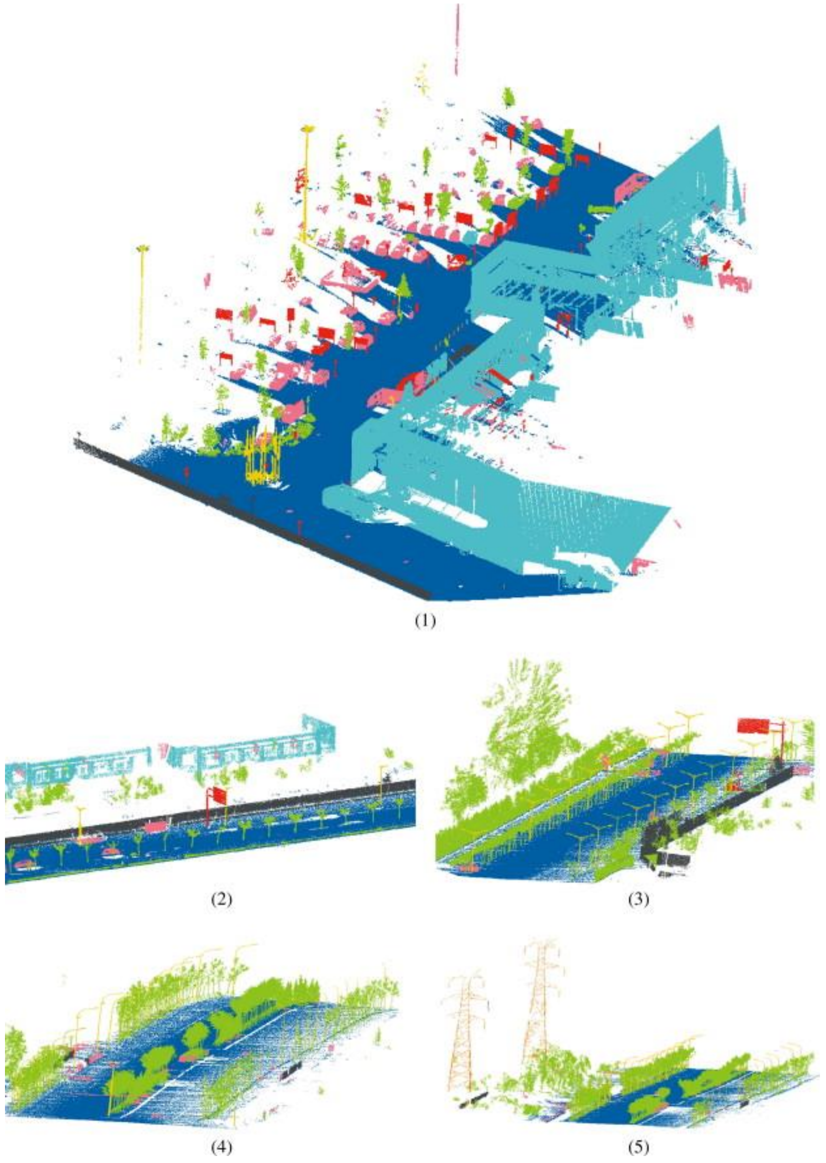

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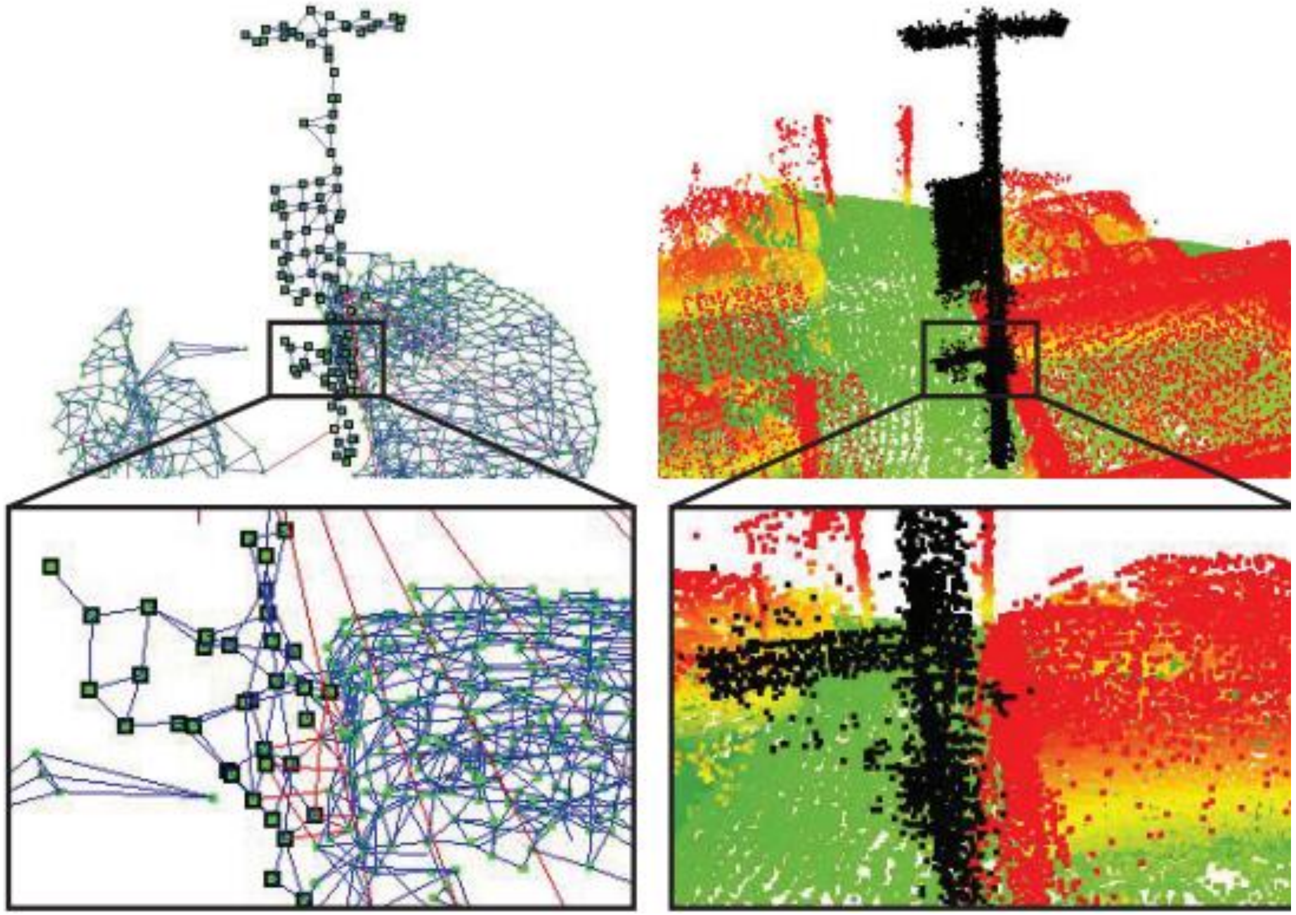
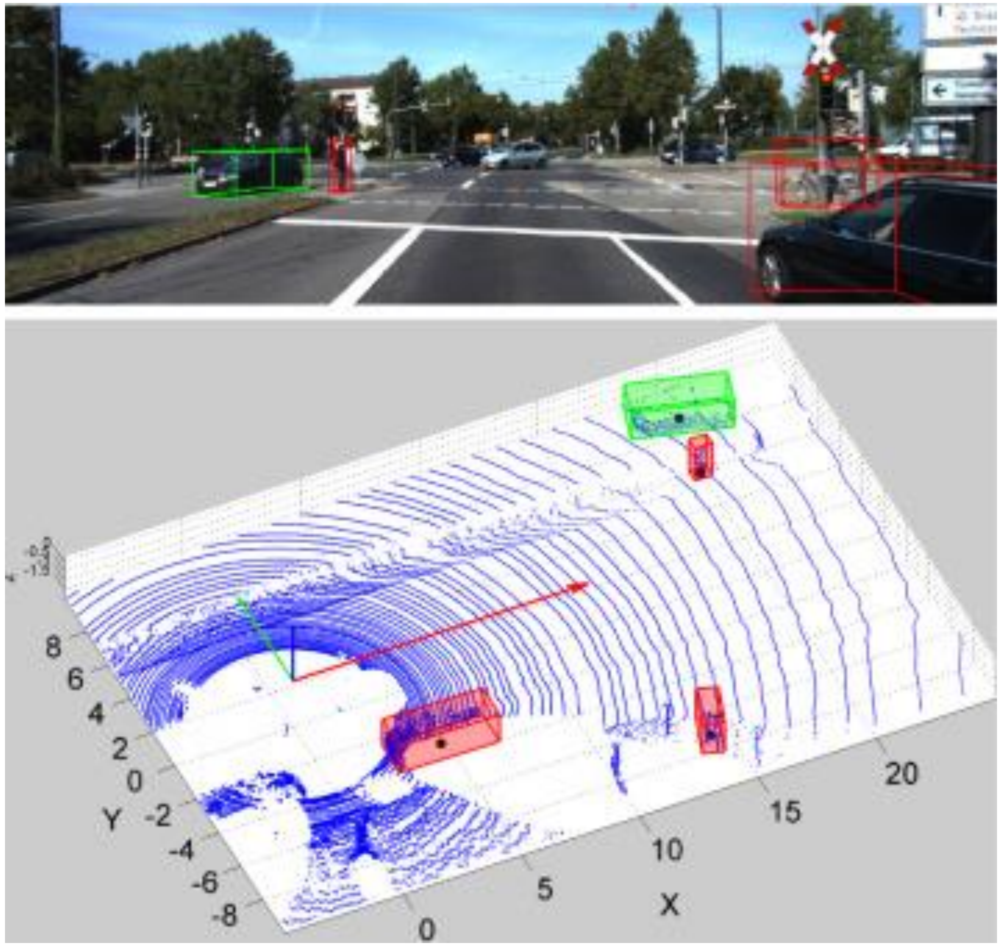


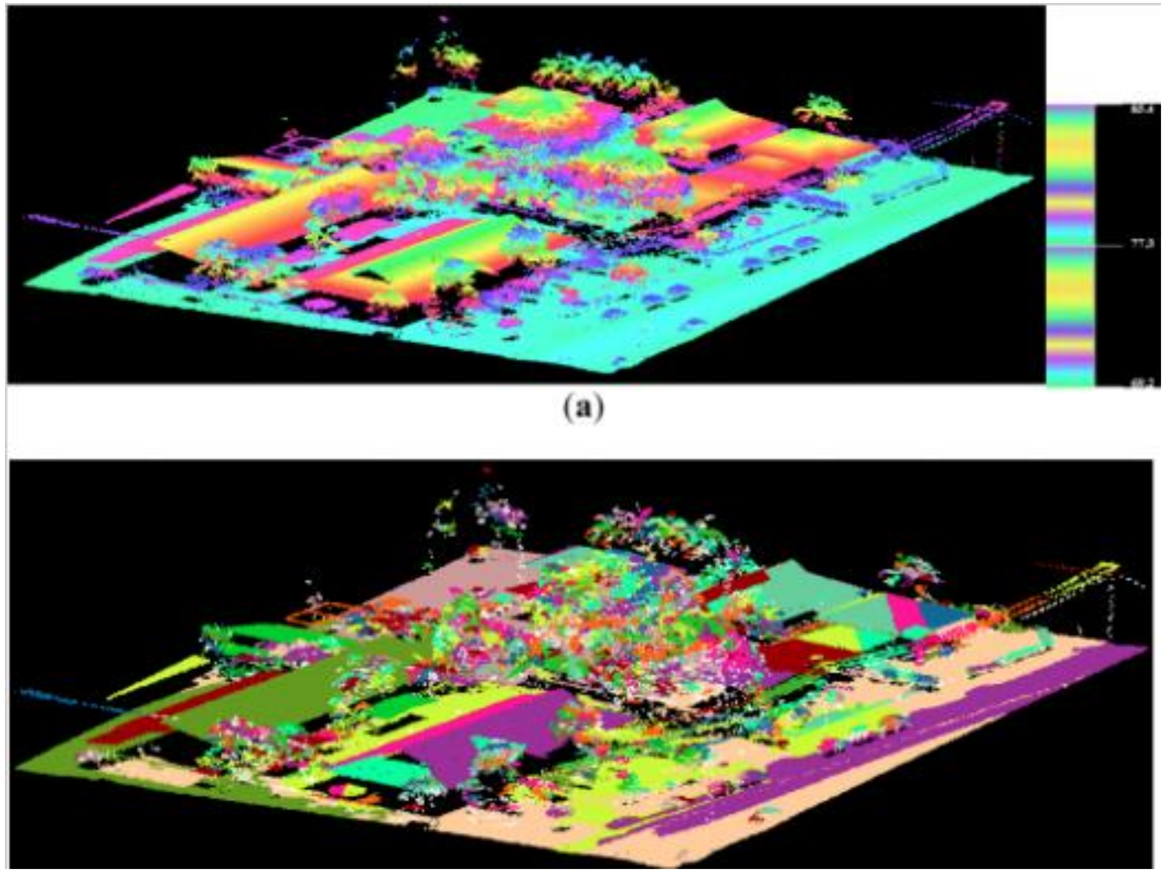
Autonomous Driving: Perception using LIDAR

- Knowledge Extraction
  - 3D point cloud segmentation
  - Classification
    - Few methods use point clouds directly
    - High memory and computational costs
    - Less robust



Autonomous Driving: Perception using LIDAR

- Knowledge Extraction
  - 3D point cloud segmentation
  - Classification
    - Multi-class labelling using SVM
    - VoxNet: 3D CNN



Autonomous Driving: Perception using LIDAR

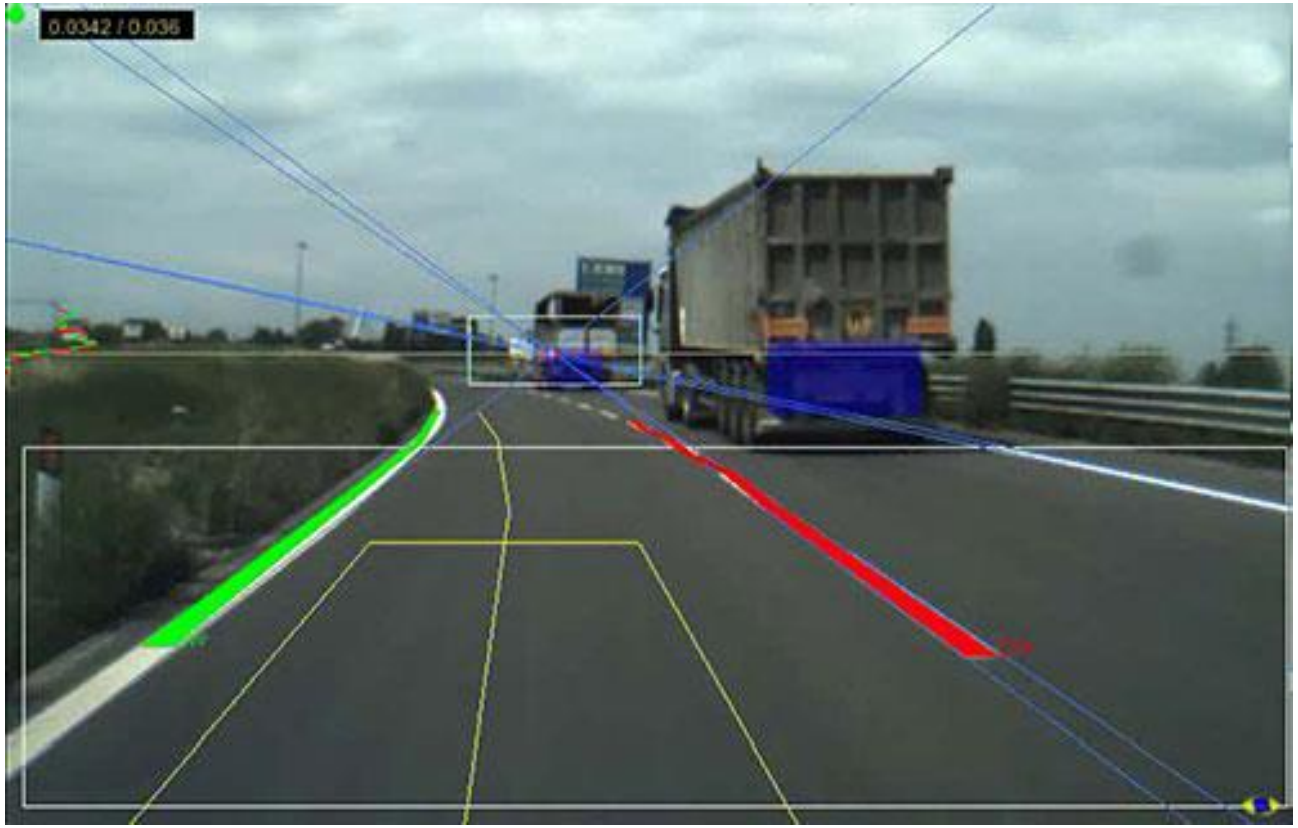
- LIDAR in practice
  - Velodyne 64HD lidar
    - https://www.youtube.com/watch?v=nXlqv_k4P8Q

Autonomous Driving: Perception

- Environmental Perception
  - LIDAR
  - Cameras
  - Fusion
  - Other approaches
    - RADAR, Ultrasonic sensors

Autonomous Driving: Perception using Cameras

- Camera based vision
  - Road detection
    - Lane marking detection
    - Road surface detection
  - On-road object detection



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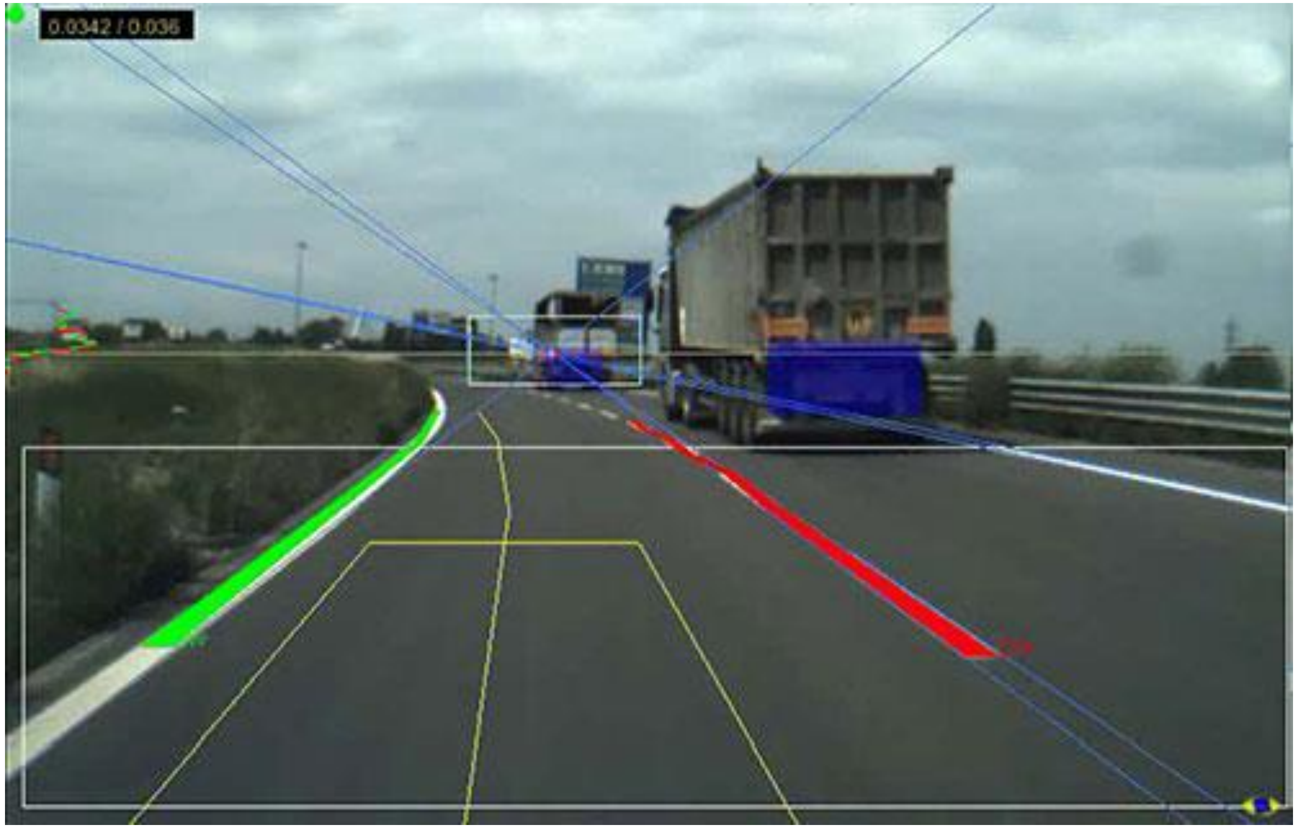
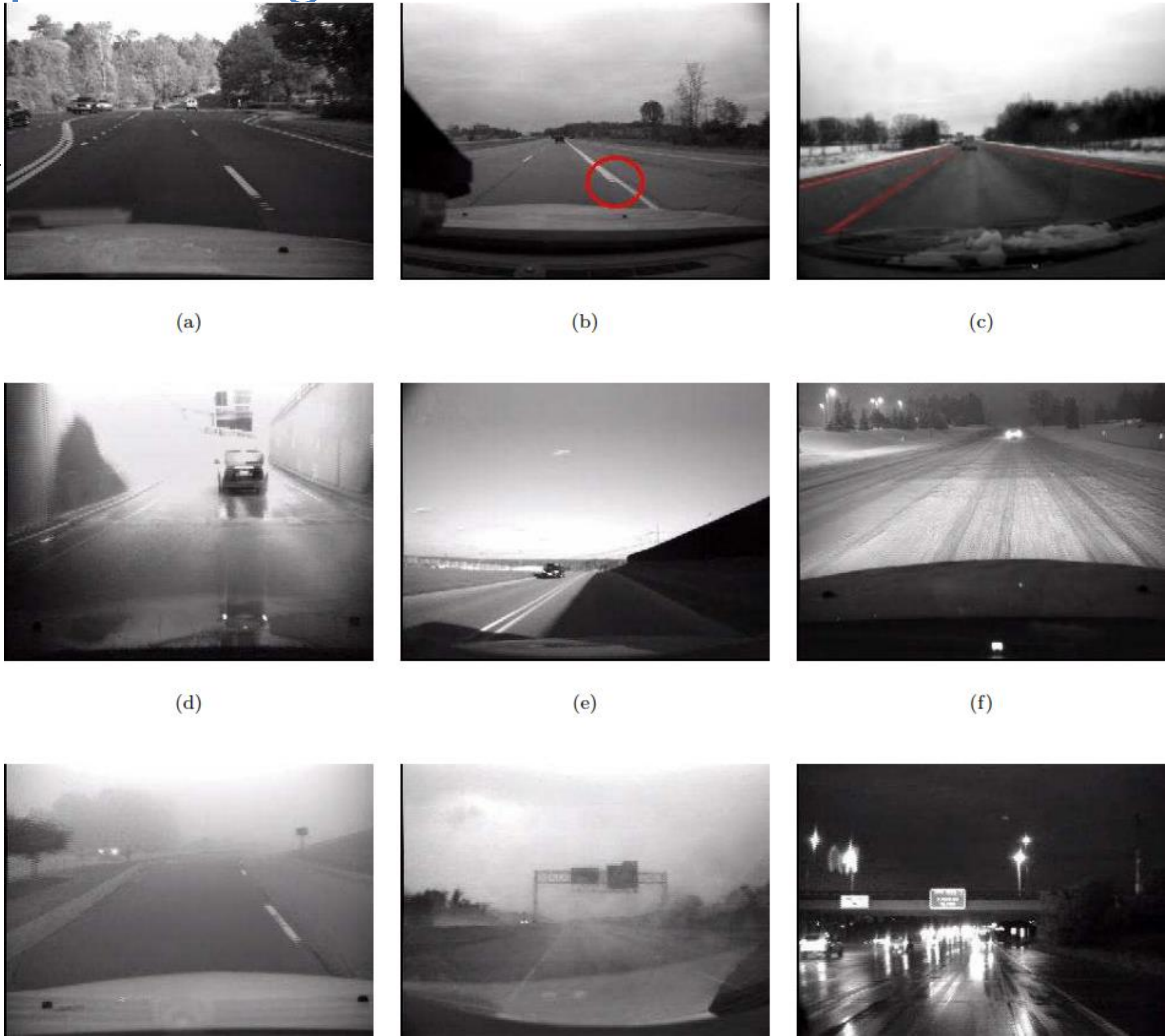


Autonomous Driving: Perception using Cameras

- Challenges in Lane Detection
  - Road conditions
    - Singularities
    - Worn-out markings
    - Directional arrows
    - Warning text
    - Zebra crossing
  - Environment conditions
    - Shadows from cars and trees
    - Weather effects

Autonomous Driving: Perception using Cameras

- Challenges in Lane Detection



(a) (b) (c)

(d) (e) (f)

Autonomous Driving: Perception using Cameras

- General approach to lane detection
  - Lane line feature extraction
  - Model fitting
  - Vehicle pose estimation

Autonomous Driving: Perception using Cameras

- General approach to lane detection
  - Lane line feature extraction
    - Gradient based methods
    - Pattern finding
  - Model fitting
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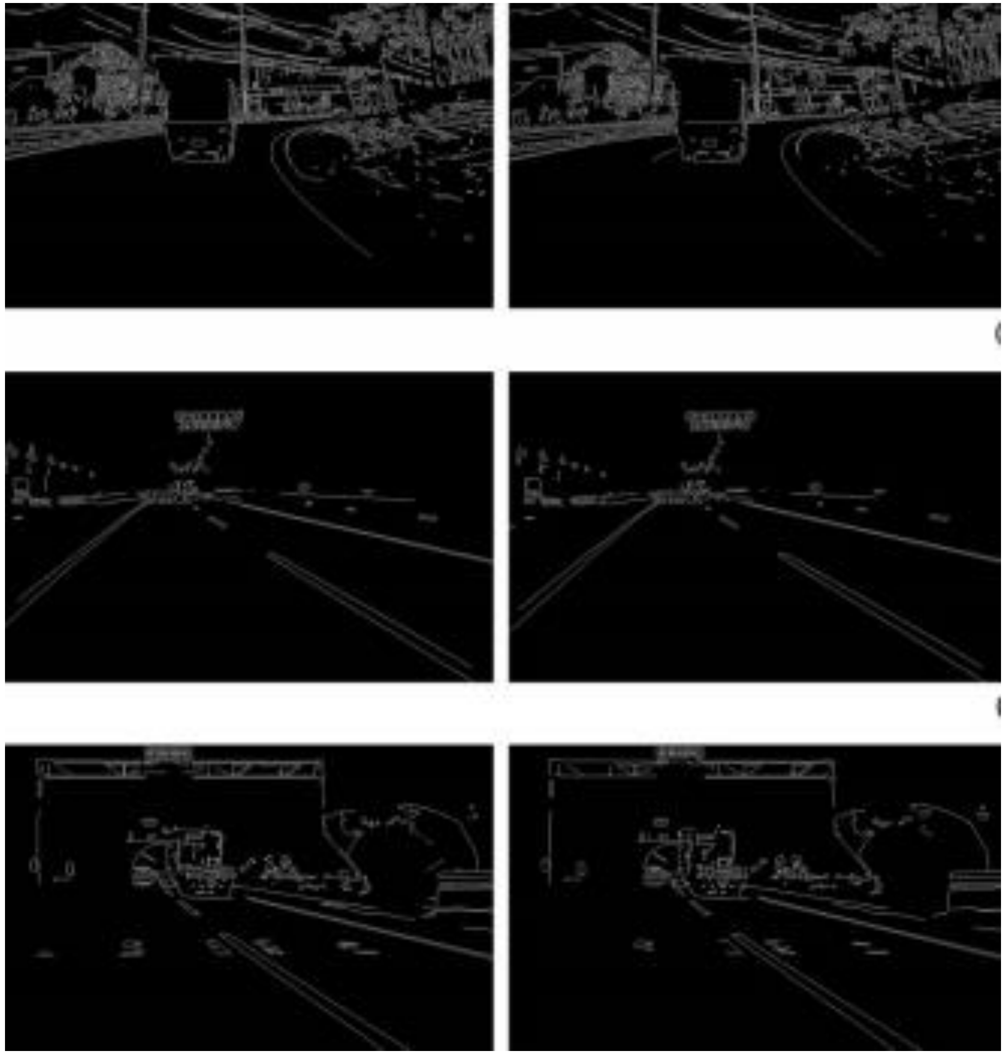

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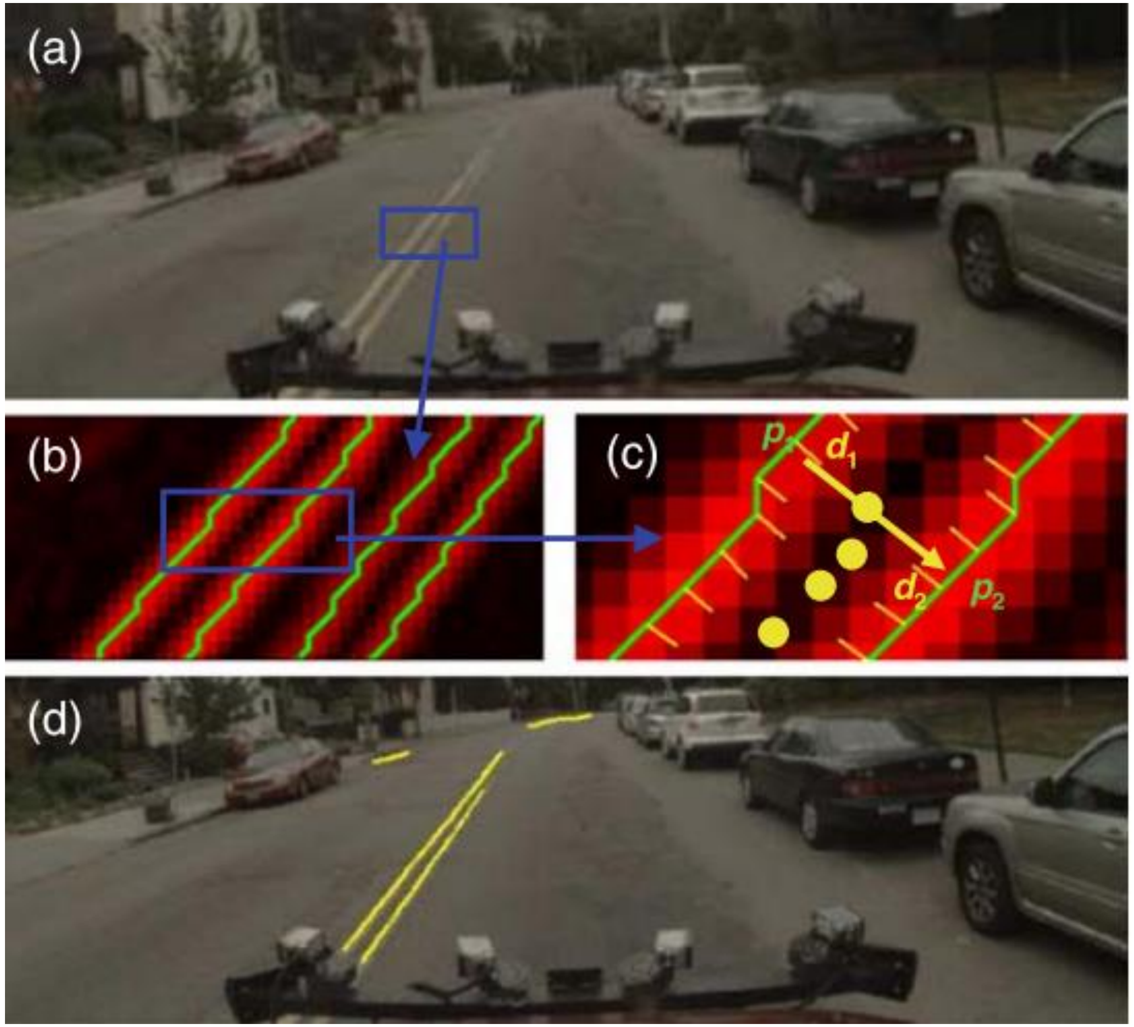

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Autonomous Driving: Perception using Cameras

- General approach to lane detection
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  - Model fitting
    - Parametric
    - Semi-parametric
    - Particle Filters
  - Vehicle pose estimation

Autonomous Driving: Perception using Cameras

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Autonomous Driving: Perception using Cameras

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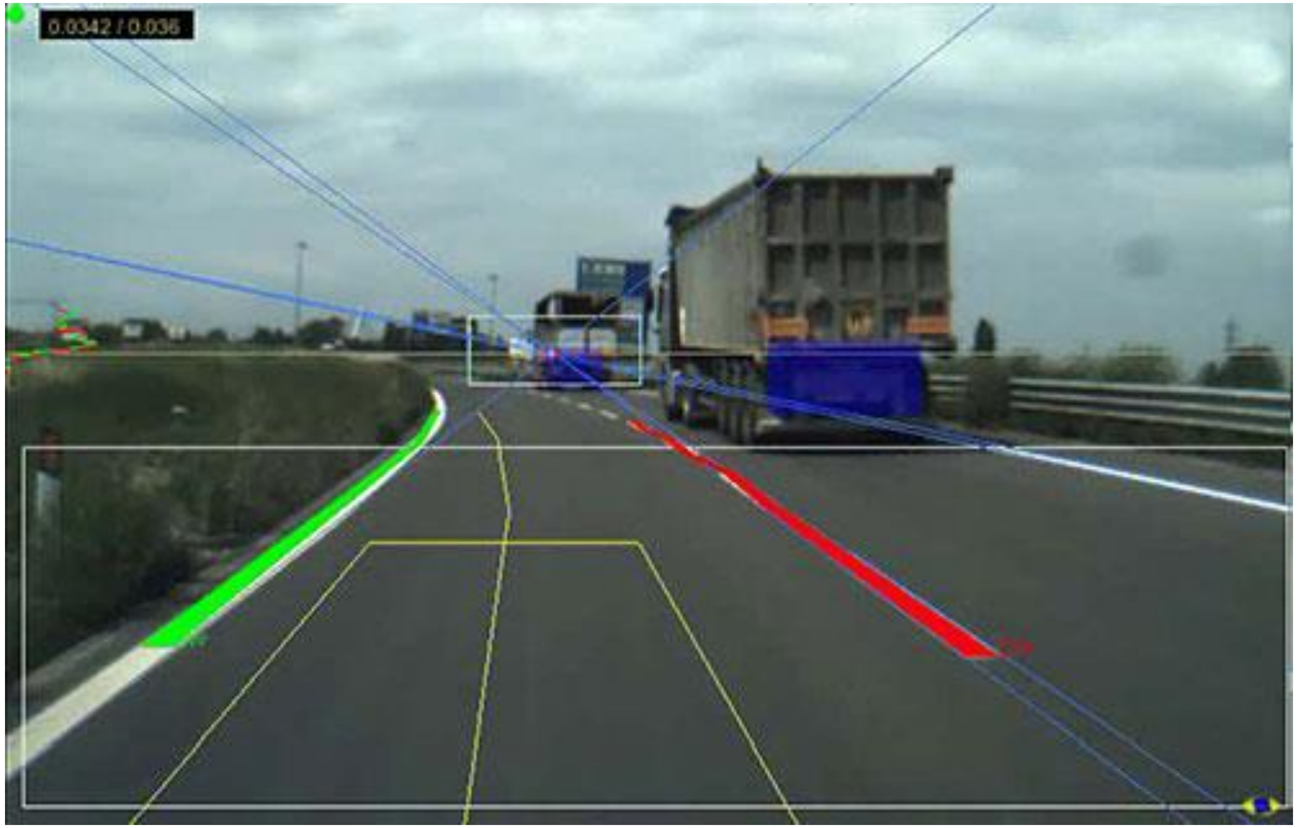
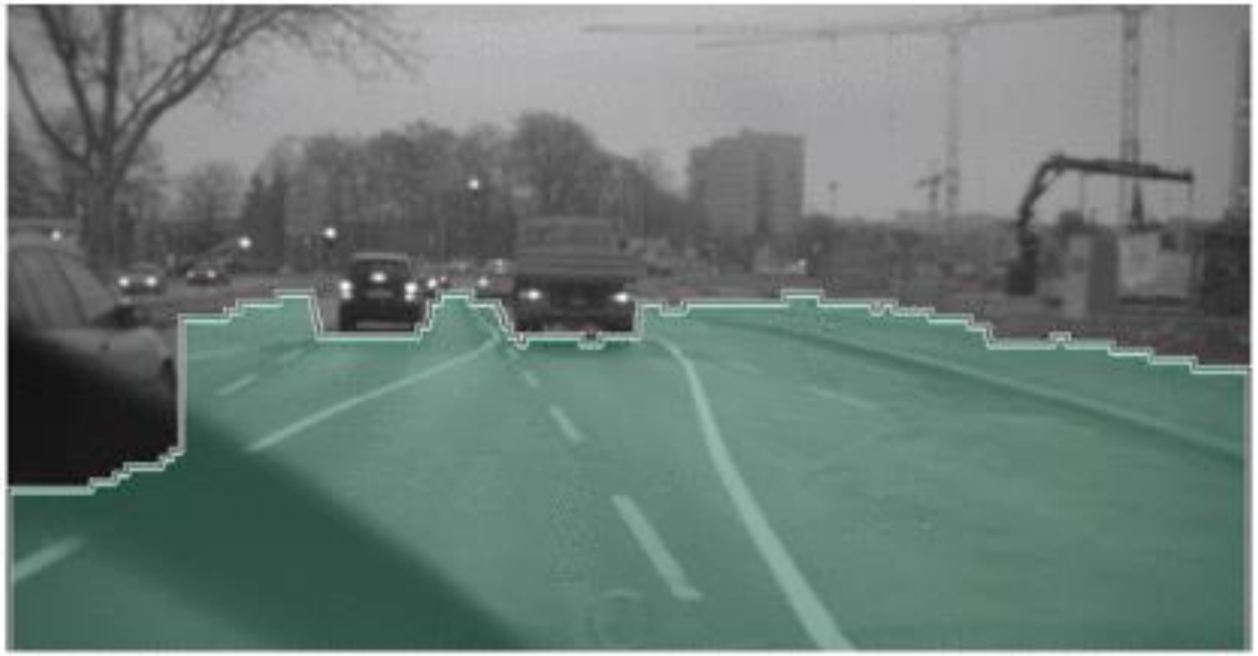


Autonomous Driving: Perception using Cameras

- Approaches to Road surface detection
  - Feature-based
  - Deep learning

Autonomous Driving: Perception using Cameras

- Approaches to road surface detection
  - Feature-based
    - Feature extraction
    - Segmentation
    - Classification
    - May not be robust
  - Deep learning



Autonomous Driving: Perception using Cameras

- Approaches to road surface detection
  - Feature-based
  - Deep learning
    - Direct pixel/block labelling
    - High memory and computation requirements
    - Annotated data
    - Black box

Autonomous Driving: Perception using Cameras

- Camera based vision
  - Road detection
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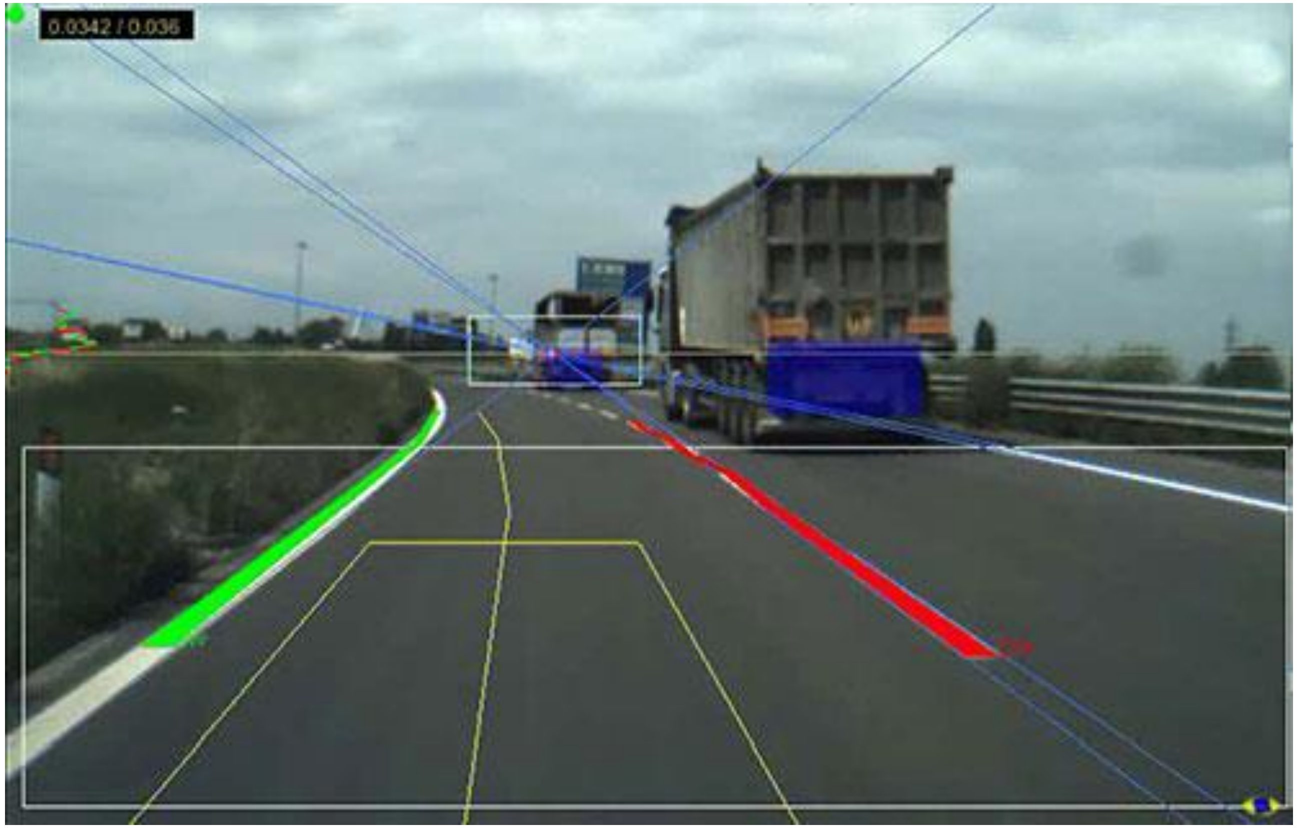
    - Road surface detection
  - On-road object detection



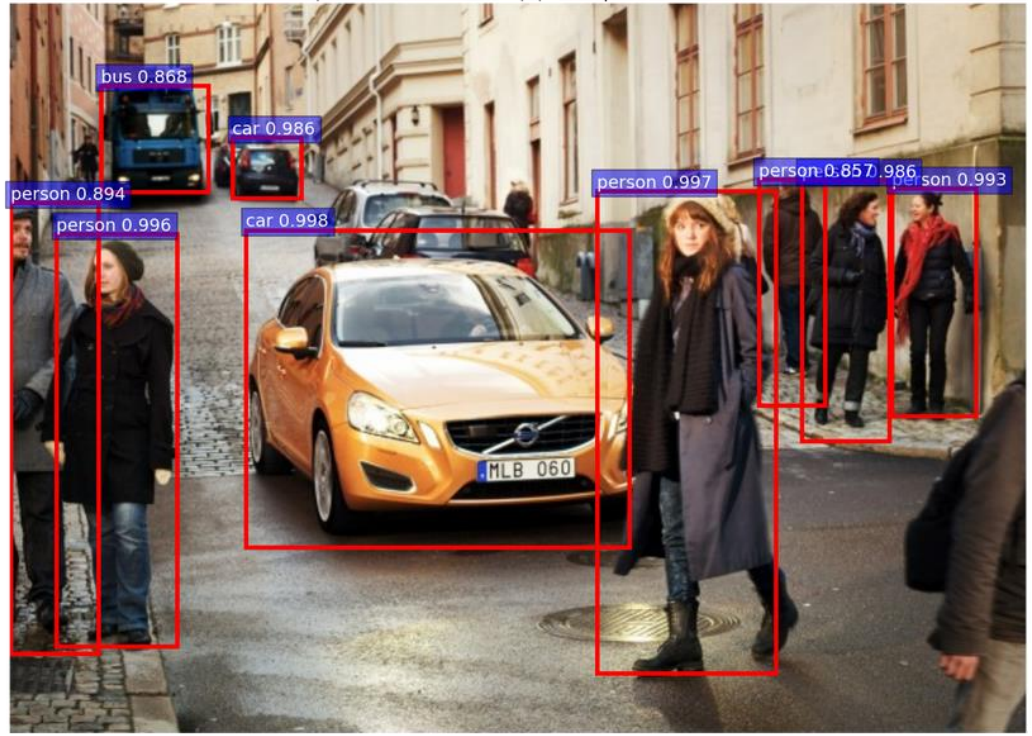
Autonomous Driving: Perception using Cameras

- On-road object detection
  - Pedestrian, cyclists, other cars
- Challenging due to the various types, appearances, shapes, and sizes of the objects

Autonomous Driving: Perception using Cameras

- On-road object detection
  - Pedestrian, cyclists, other cars
- Challenging due to the various types, appearances, shapes, and sizes of the objects
- Deep learning methods are far superior

person detections with p(person | box) >= 0.8



Autonomous Driving: Perception using Cameras

- Mobileye
  - Country road: https://www.youtube.com/watch?v=ywvJqKVcnDA
  - Highway: https://www.youtube.com/watch?v=_ZH5Taq6mvw
  - Rain: https://www.youtube.com/watch?v=39QMYkx89j0
  - Pedestrians: https://www.youtube.com/watch?v=H_wMyUEeIzQ

Autonomous Driving: Perception using Sensor Fusion

- LIDAR
  - 3D measurements
  - Impervious to illumination changes
  - Prone to noise
  - Hard to extract knowledge
- Cameras
  - Provide rich appearance details in 2D
  - Affected by illumination/ weather

Autonomous Driving: Vehicle Localization

- Determining the pose of the ego vehicle and measuring its own motion
- Fusing data
  - Satellite-based navigation system
  - Inertial navigation system
- Map aided localization
  - SLAM

Structure

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Autonomous Driving: Main Components

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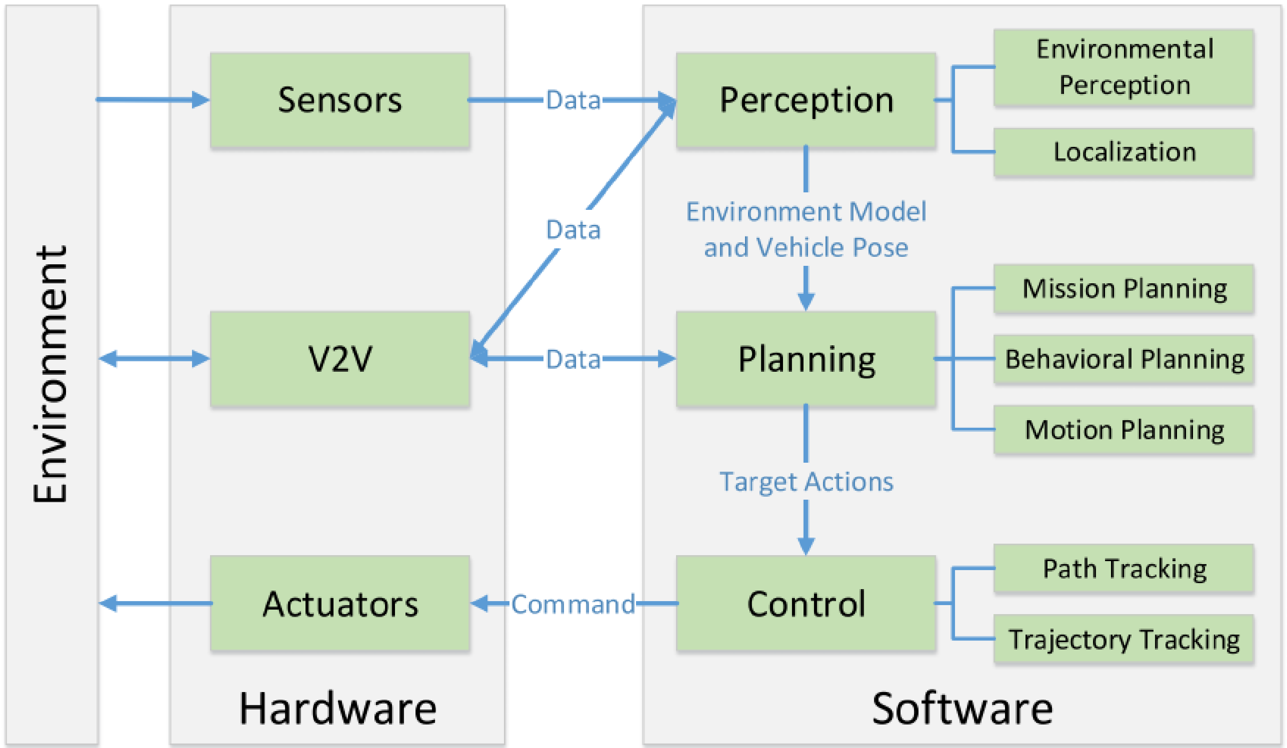


Figure 2. A typical autonomous vehicle system overview, highlighting core competencies.

Autonomous Driving: Planning

- Compare to Pedestrian Techniques:
  - Route Planning: road selection (global)
  - Path Planning: preferred lanes (global)
  - Maneuver-search: high level maneovers (local)
  - Trajectory planning: Lowest level of planning (local)

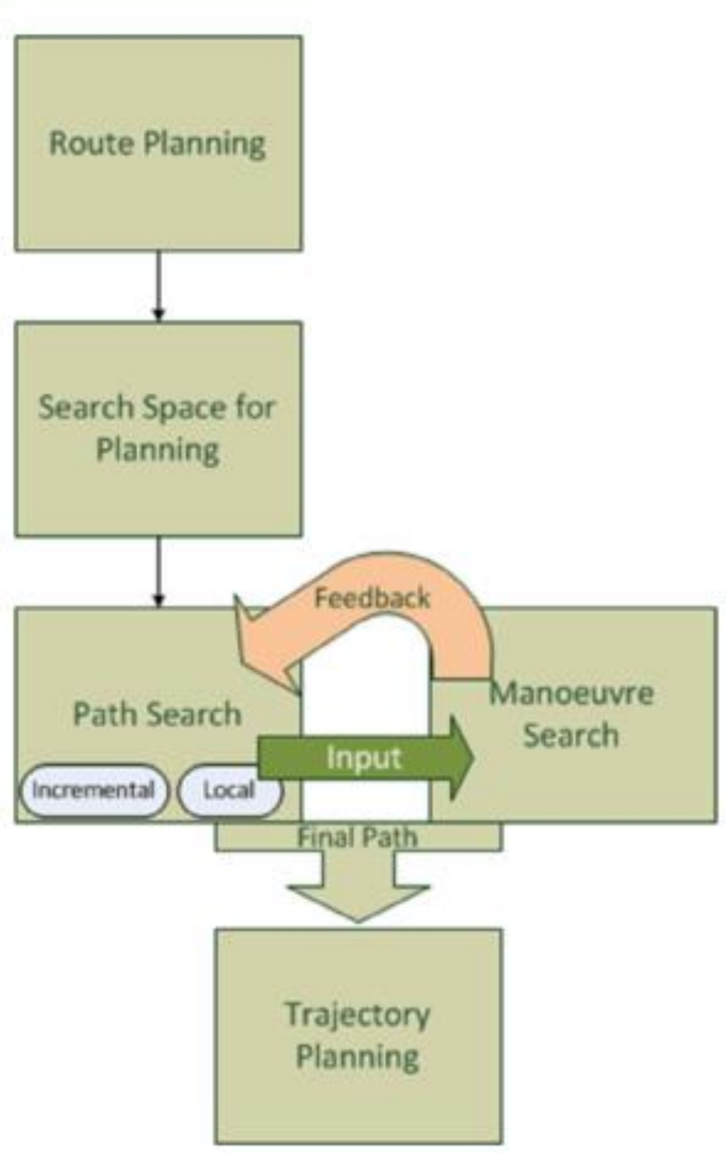
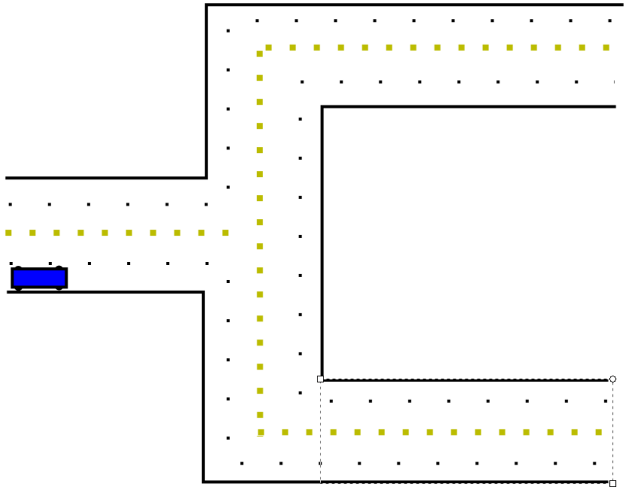
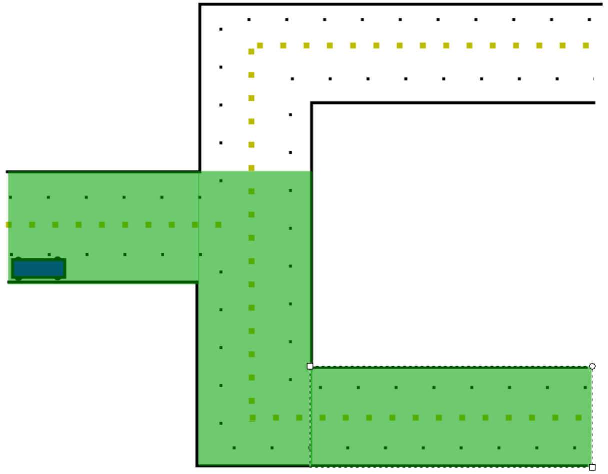


Fig. 2. A flow chart of planning modules.

Autonomous Driving: Route Planning

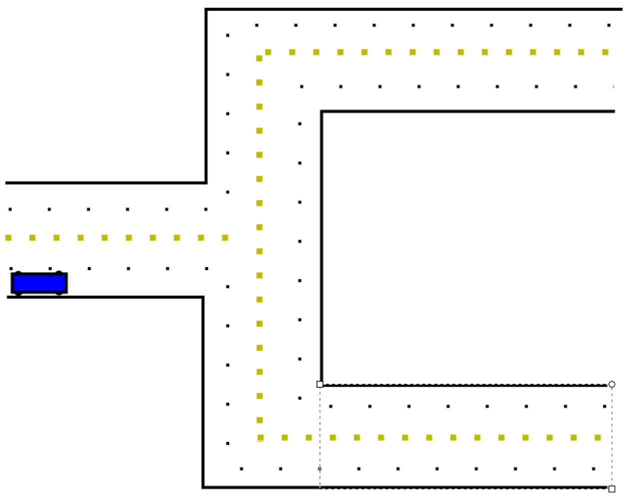
- Determine the appropriate macro-level route to take
- Typically road level i.e. which roads to take
- Katrakazas: "Route planning is concerned with finding the best global route from a given origin to a destination, supplemented occasionally with real-time traffic information"

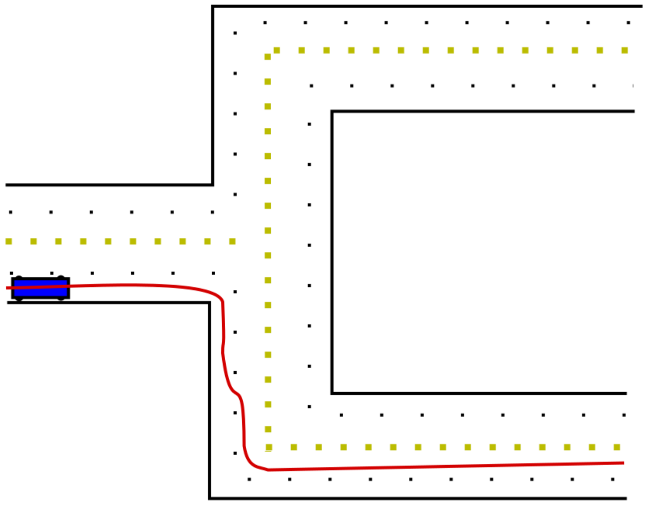




Autonomous Driving: Path Planning

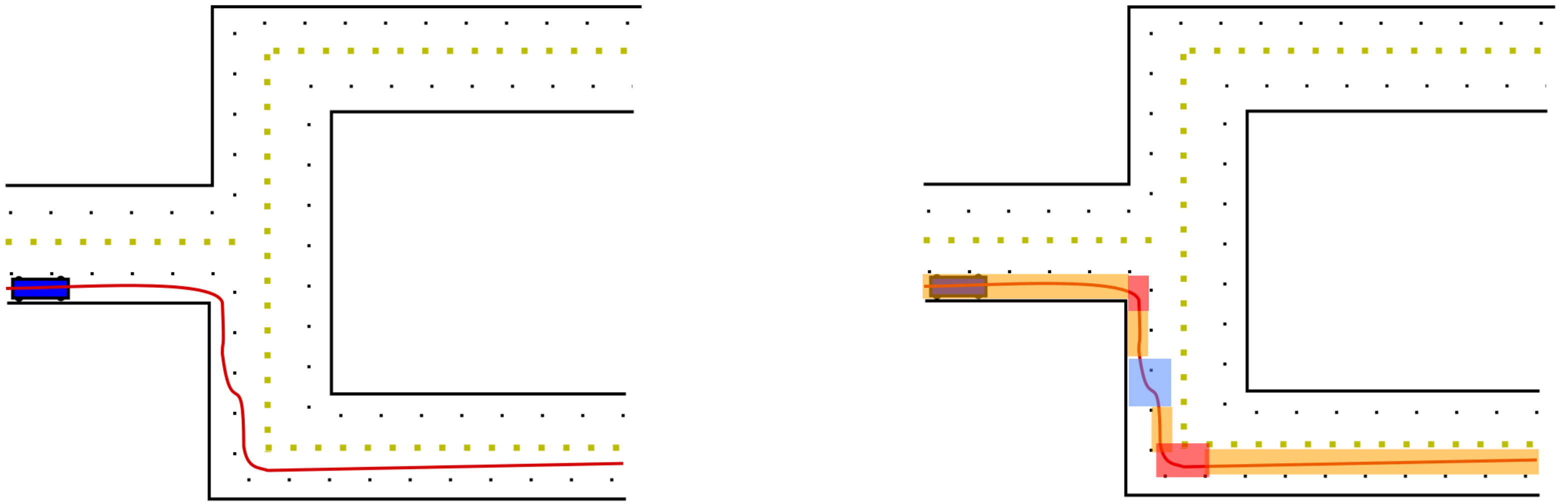
- Determine the appropriate geometric waypoints to follow when driving
- Katrakazas: “a path is a geometric trace that the vehicle should follow in order to reach its destination without colliding with obstacles. ”





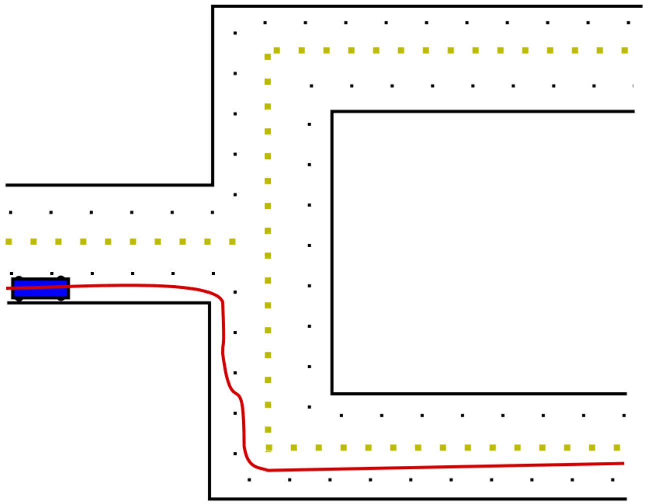
Autonomous Driving: Maneuver Planning

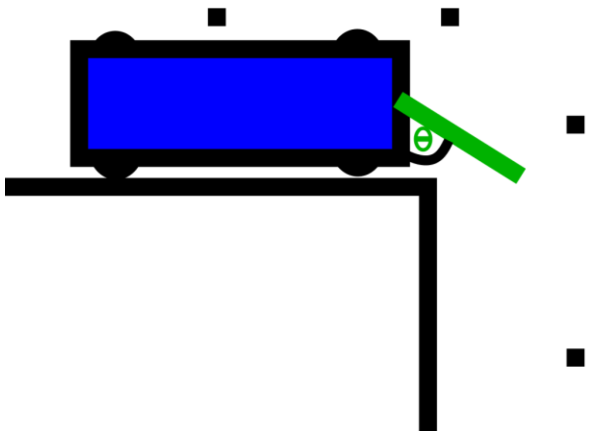
- Determine the appropriate ‘attitude’ or posture of the vehicle. Decides which behavior the vehicle is performing at any time
- Katrakazas: “high-level characterization of the motion of the vehicle, regarding the position and speed of the vehicle on the road. Examples of maneuvers include ‘going straight’, ‘turning’, ‘overtaking’ etc”



Autonomous Driving: Trajectory Planning

- Katrakazas: “Trajectory planning(also known as trajectory generation) is concerned with the real-time planning of the actual vehicle’s transition from one feasible state to the next, satisfying the vehicle’s kinematic limits based on vehicle dynamics and constrained by the navigation comfort, lane boundaries and traffic rules, while avoiding, at the same time, obstacles including other road users as well as ground roughness and ditches”





Autonomous Driving: Planning

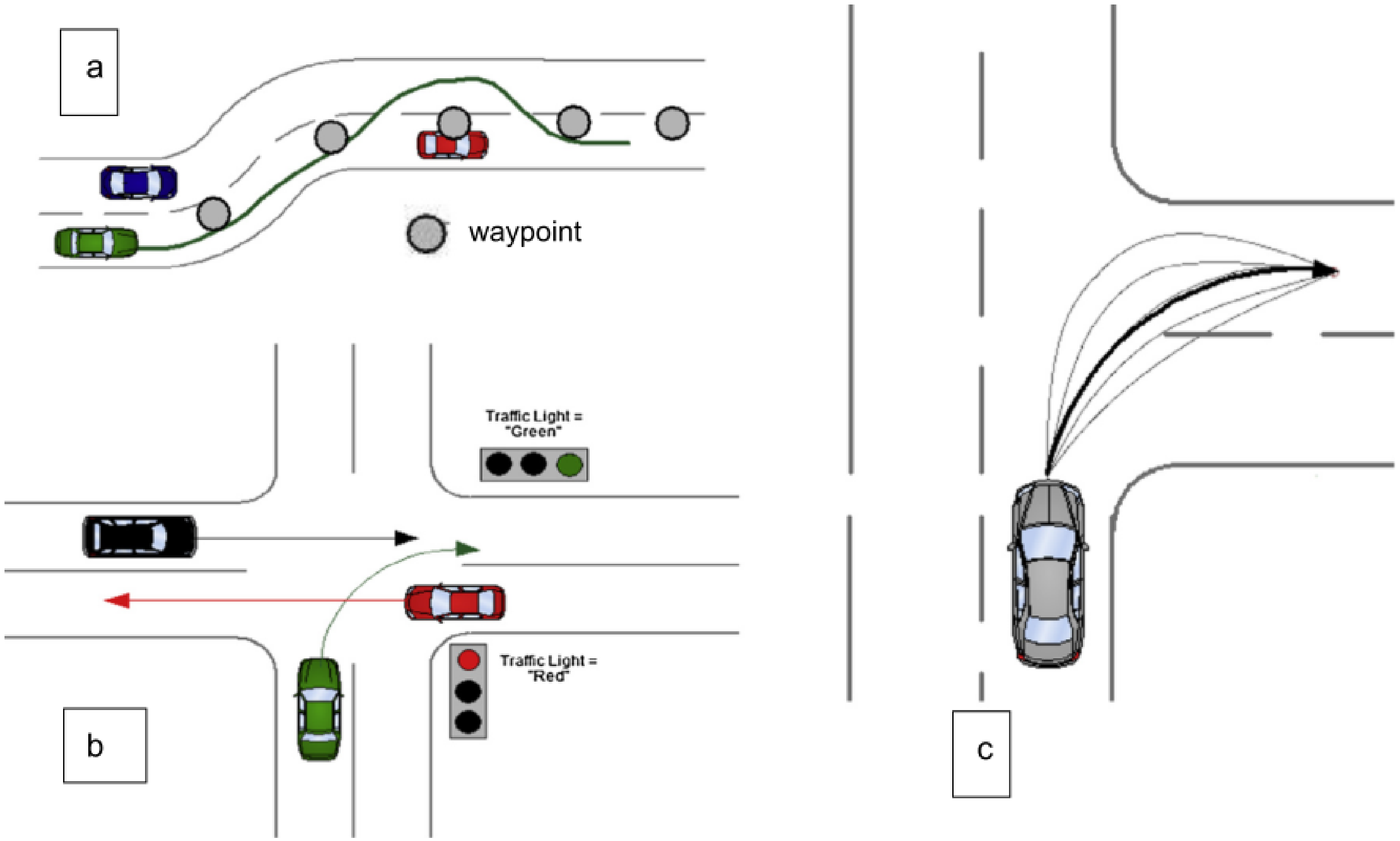


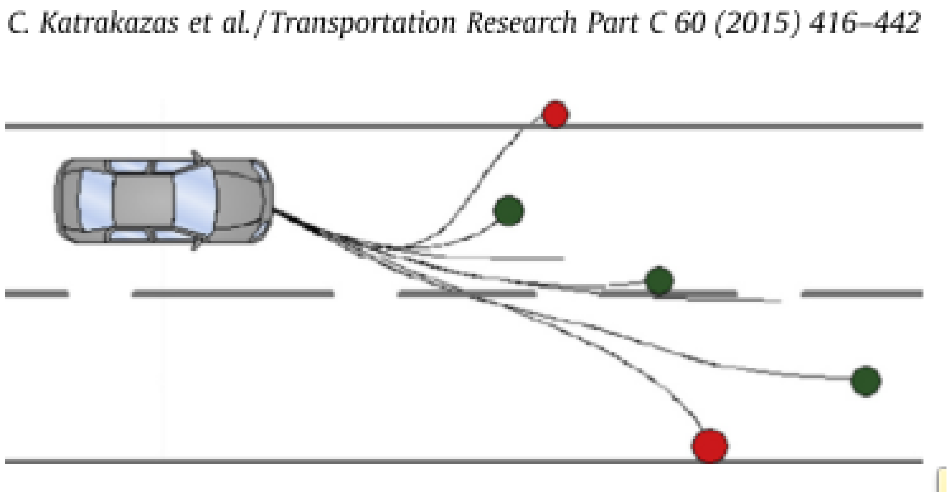
Fig. 3. (a) Path planning, (b) manoeuvre planning and (c) trajectory planning (adapted from Lee and Vasseur (2014)).

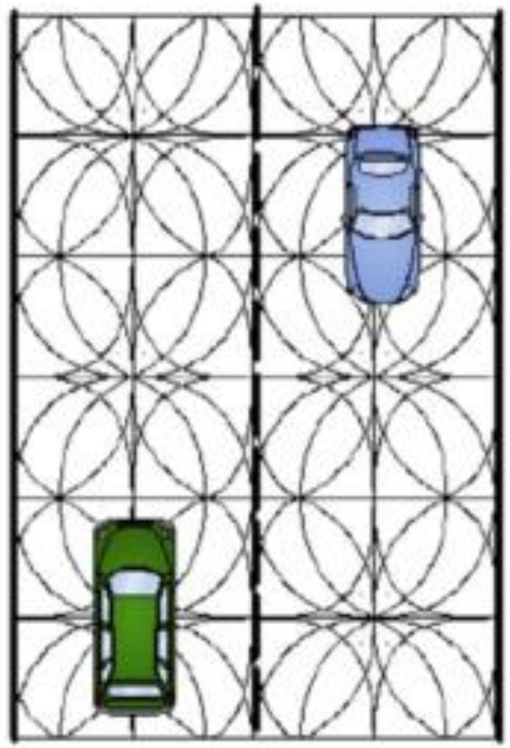
Autonomous Driving: Route Planning

- Extensive literature in traffic simulation and civil engineering domain
- In general, graph search (i.e. A-Star, Dijkstra)
  - Includes self-aware routing
  - Travel-network optimization
  - Dynamic Traffic Assignment
  - See: "Self-Aware Traffic Route Planning", David Wilkie, Jur Van den Berg, Ming Lin, Dinesh Manocha

Autonomous Driving: Path Planning

- RRT and Lattice methods are most-well represented





Autonomous Driving: Path Planning

Table 3
Comparison of RRTs and Lattice planners for incremental search planning.

RRTs	Lattice planners
Advantages • Kinematic and real-time feasibility • Quick search of free space • Advanced decision techniques are applied for collision checking • Optimality in the path is guaranteed in newer implementations such as RRT* *Disadvantages* • Jagged paths • Heavily dependent on the Nearest Neighbour heuristic to expand • Each node of the tree needs to be checked for collisions while the tree is expanding • Advanced techniques for collision checking pre-suppose perfect knowledge of the environment	*Advantages* • Low computational power needed • Smoothness and optimality of the path are guaranteed (within the given lattice) • Generally appropriate for dynamic environments • Paths comply with the dynamic and kinematic abilities of the vehicle *Disadvantages* • Time inefficiency with the calculation of a path for evasive manoeuvers • May lead to exhaustive sampling or oscillations • Transferability

Autonomous Driving: Maneuver Planning

- Decision making far more complex due to interactions with other traffic participants
  - Required to anticipate behavior of other participants
- Existing techniques
  - POMDPs
  - MCDM – Multi-Criteria Decision Making
  - DFA – Deterministic Finite Automata
  - Game theory approach (perfect information game, ends in crash)
  - Driving corridors

Autonomous Driving: Trajectory Planning

- Compute a trajectory, according to the chosen path and maneurver, which satisfies:
  - Kinematic constraints
  - Dynamic constraints
  - Collision-free constraints
  - Passenger comfort constraints
- Common approaches
  - Driving corridor optimization
  - Sampling-based planning

Structure

- History of Autonomous Driving
- Main Components
    - Perception
    - Planning
    - Control
- Other Approaches
- Other Issues

Autonomous Driving: Control Planning

- Convert plans into actions
  - Provide inputs to the hardware level to generate the desired motion
- Common Approaches
  - Proportional-Integral-Derivative (PID) controller
  - Model Predictive Control (MPC)

Structure

- History of Autonomous Driving
- Main Components
- Other Approaches
- Other Issues

Autonomous Driving: End-End Approaches

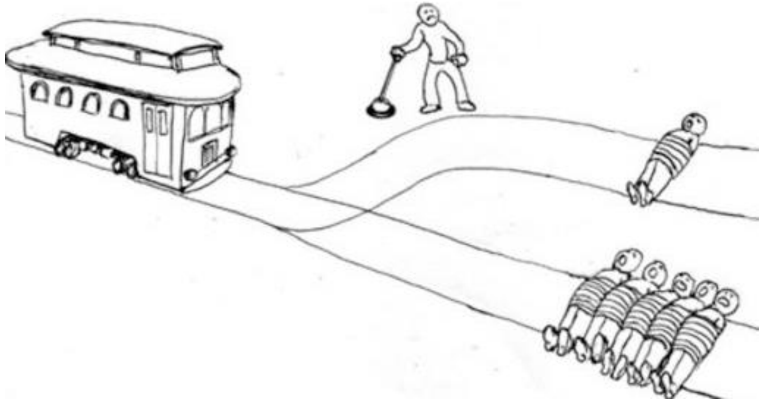
- Nvidia PilotNet
  - Deep learning to directly map video frames to control

Structure

- History of Autonomous Driving
- Main Components
- Other Approaches
- Other Issues

Autonomous Driving: Other Issues

- Other challenges:
  - Communication
  - Coordination
  - Ethical Issues
    - Trolley Problem



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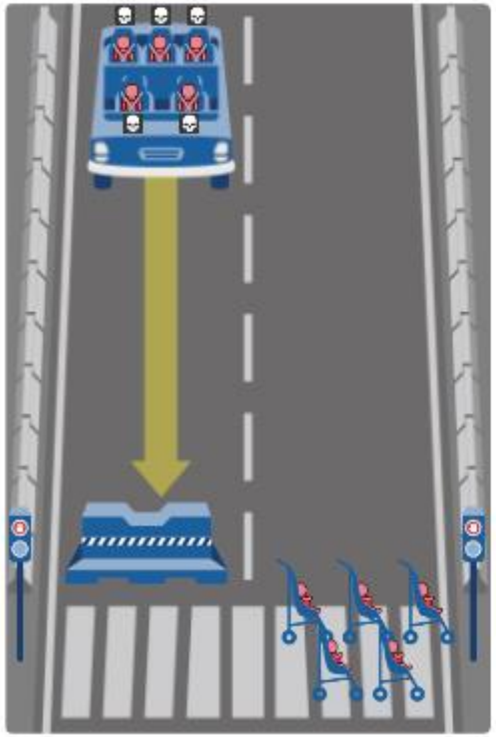
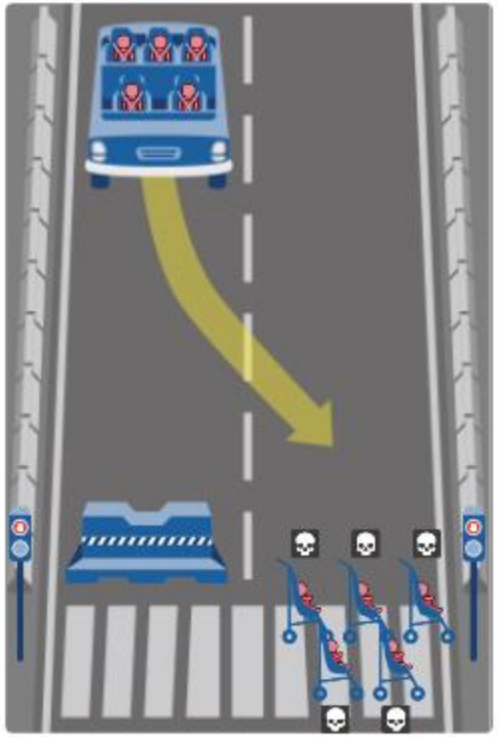
Autonomous Driving: Other Issues

- Other challenges:
  - ⑩ MIT “Moral Machine” [https://goo.gl/RL4pr5]





Autonomous Driving: Other Issues

- Civil Engineering / Ethics
  - Traffic impacts?
    - Pro: Vehicles should respond appropriately to traffic reducing jams
    - Con: Many more vehicles per person possible
  - People may not own cars?
    - Pro: Less emission? Less Traffic?
    - Con: Less access?