Urban Challenge 07

AnnieWAY

Annie Lien
Benjamin Pitzer

German Research Foundation

University of Karlsruhe (TH)
Institute for Measurement and Control

TU Munich

Universitaet der Bundeswehr

Fraunhofer IITB

Urban Challenge Requirements

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Basic Navigation

- Vehicle is ready in 5 minutes after receiving the mission file
- Checkpoints are hit, vehicle stays in lane, speed limits and safety distances are obeyed...
- “Passing” of static obstacle
- U-turn and K-turn

Basic Traffic

- Correct order of precedence at 4 way stop
- Vehicle following

Advanced Navigation

- Obstacle field navigation
- Parking lot navigation
- Dynamic rerouting
- Lane following in areas with sparse waypoints
- Correct handling of GPS outages

Advanced Traffic

- Merging into moving traffic
- Left turn across a lane with oncoming traffic
- Zone (parking lot and obstacle field) navigation in the presence of oncoming traffic
- Emergency braking
- “Recovery” mode for congested intersections

Urban Challenge Requirements

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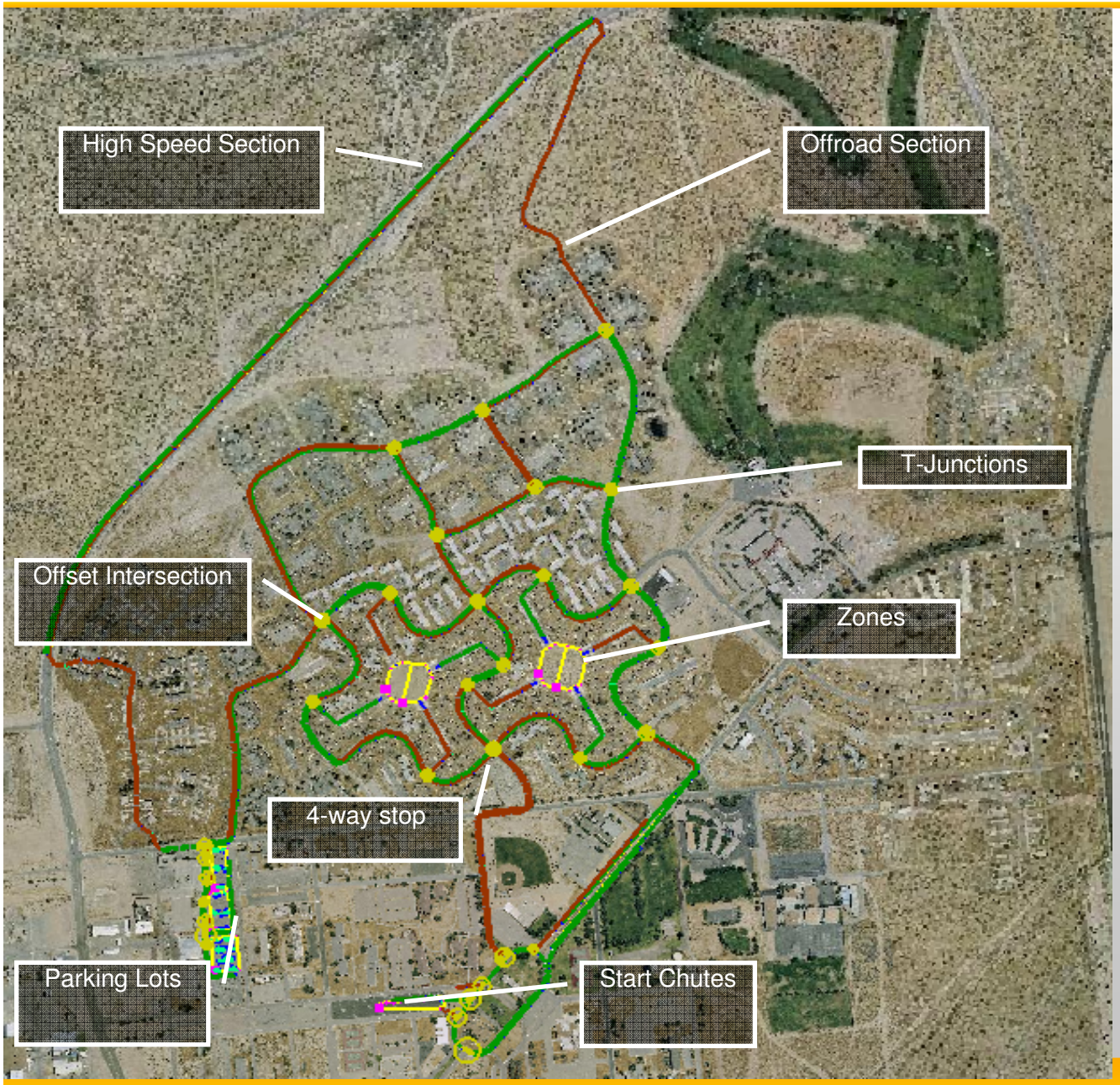

Project Timeline

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Jan 30:	received vehicle
Feb 06:	first version of longitudinal control is working
Feb 16:	received Velodyne LIDAR (main sensor)
Apr 12:	e-stop is working
Apr 12:	first odometry based run
Apr 13:	received GPS/INU components
Apr 13:	video demonstration
May 20:	transport of the car to California; opening of AnnieWAY HQ
Jun 01:	finished and submitted technical report
Jun 21:	complete reengineering of AI: introduction of finite state machine
Jun 26:	site visit
Oct 21:	beginning of NQE
Nov 1:	first off-road tests
Nov 3:	finished and tested lane change and passing
Nov 4:	final event

Hardware Setup

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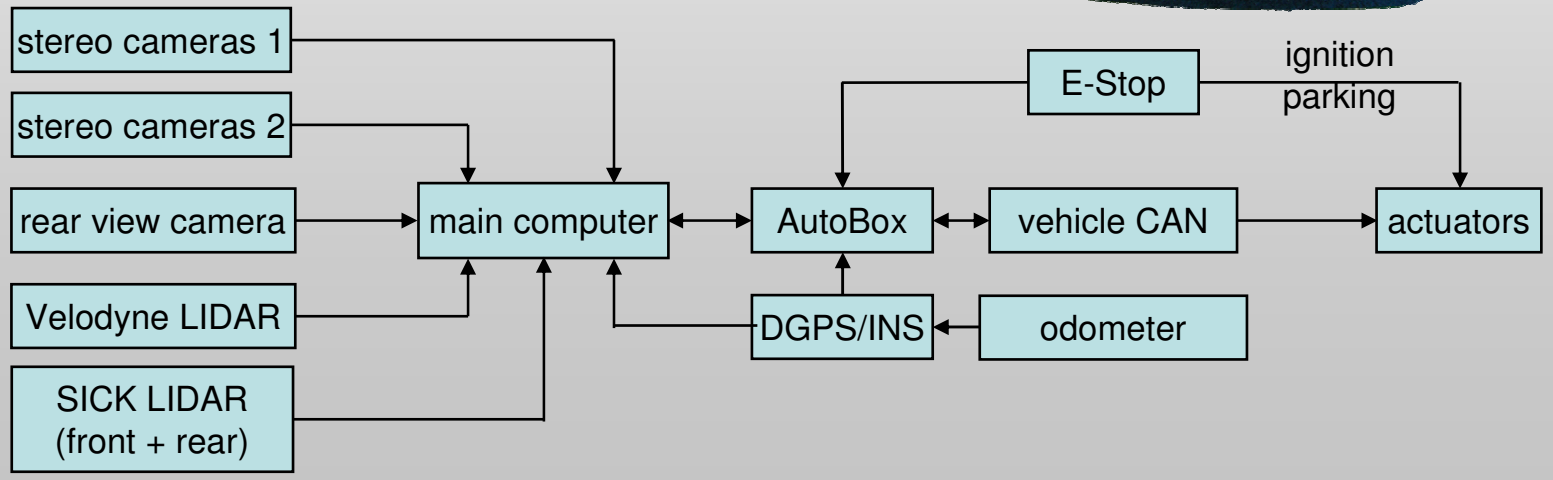

Velodyne HDL-64 Lidar

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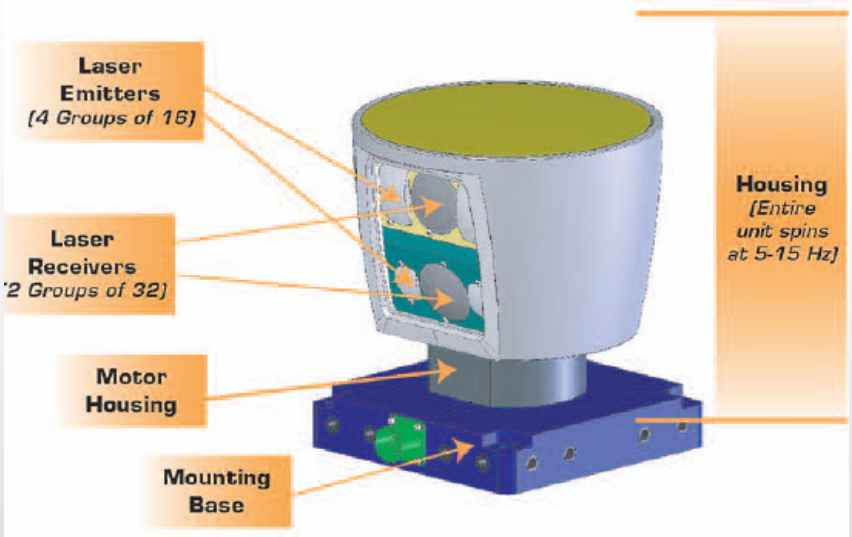
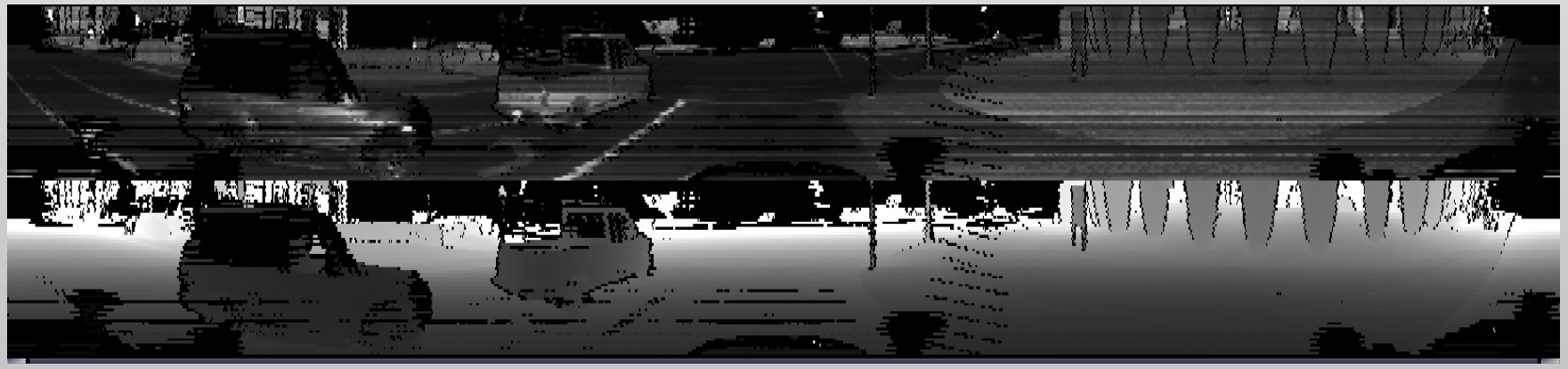
- High definition lidar scanner
- 360° horizontal/ 26.8° vertical FOV
- 120m range
- 5cm distance accuracy
- 15Hz update rate
- 1M points per second
- Distance and reflectivity





Velodyne HDL-64 Lidar

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Software Architecture

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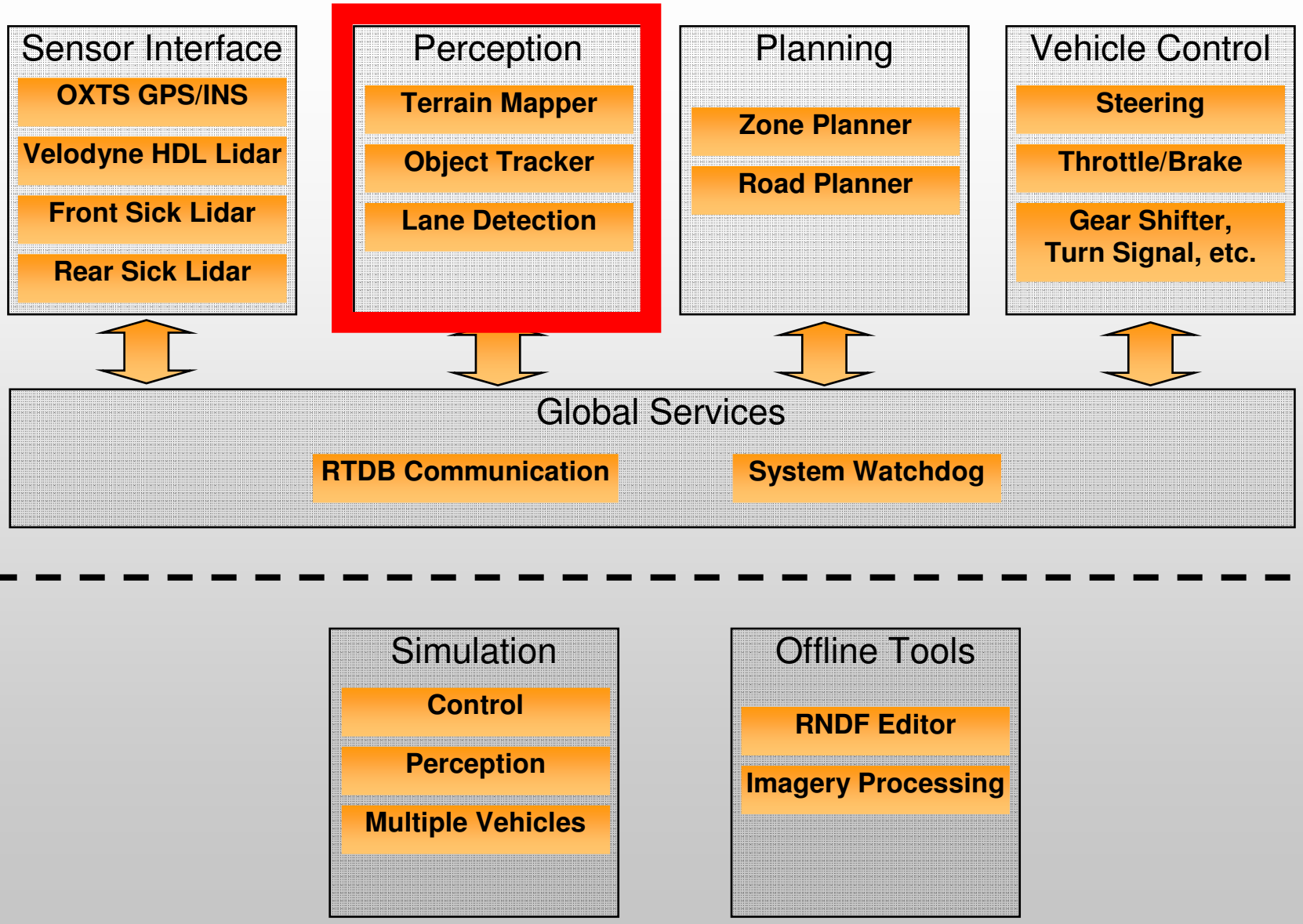
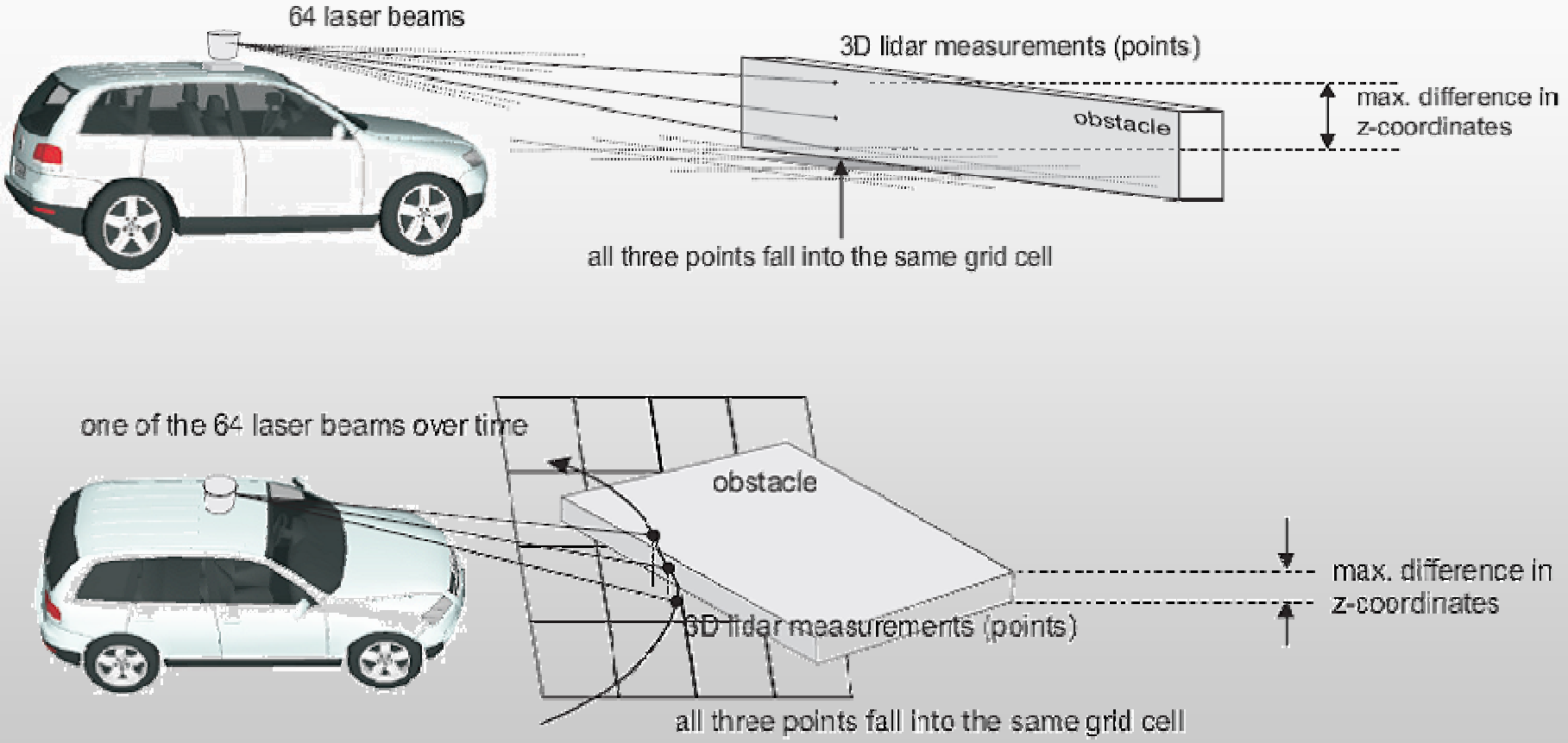


Perception – Grid Mapping



Perception – Grid Mapping

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Perception – Grid Mapping

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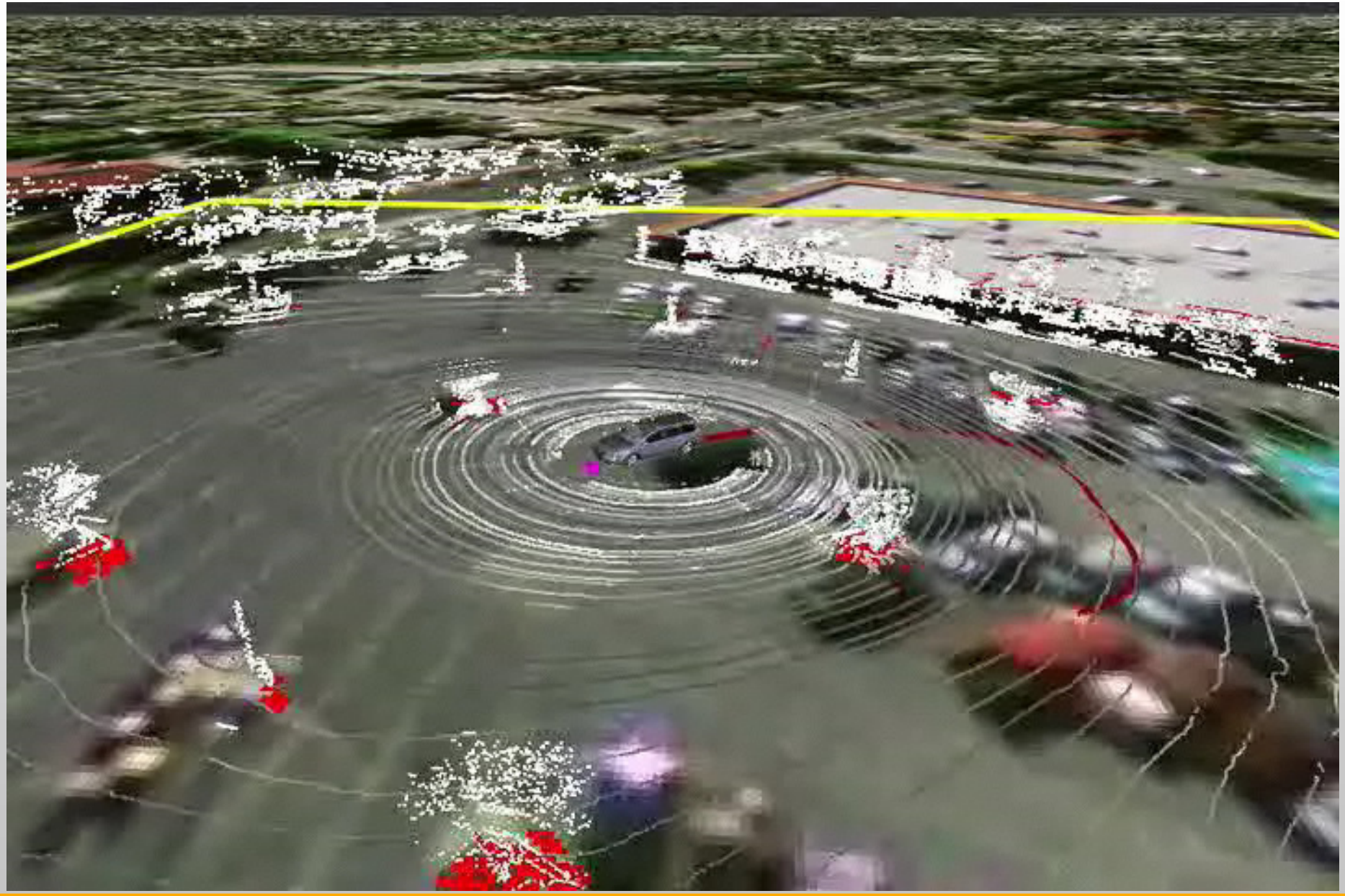

Perception - Dynamic Obstacle Tracking

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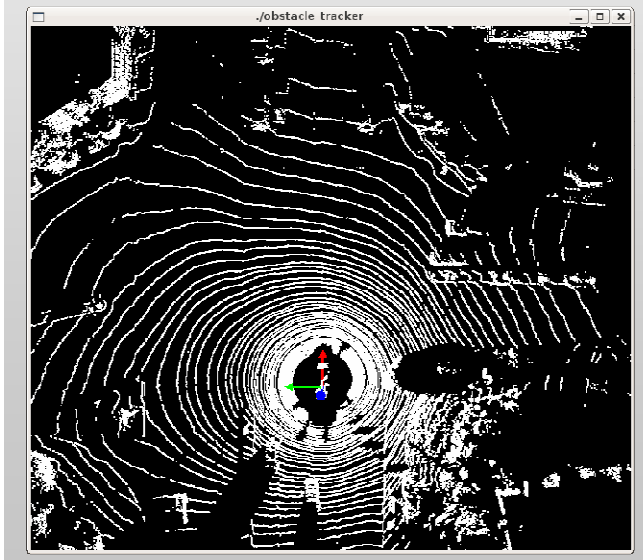
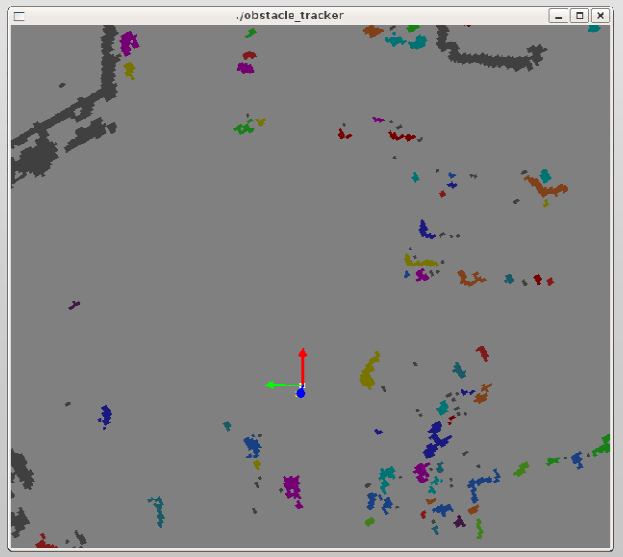
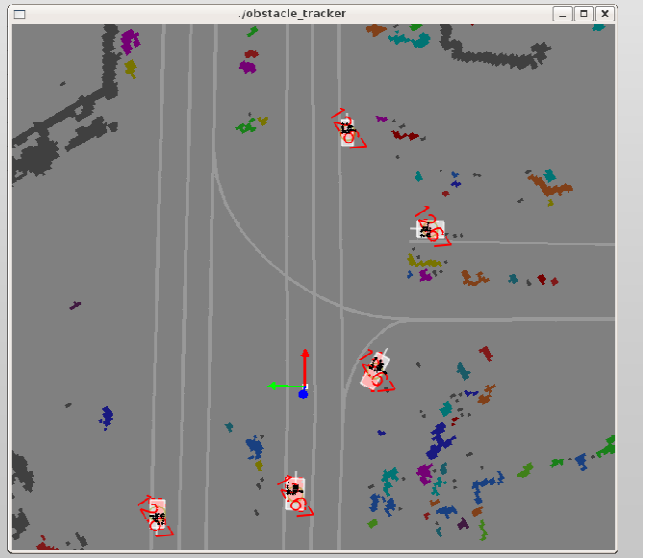
- Dynamic Obstacle Tracking
  - Data preprocessing
  - Obstacle detection
  - Obstacle tracking (pose and velocity)
  - Obstacle post processing and publishing



Lidar Data



Clustered Obstacle Map



Tracked Obstacles

Perception - Dynamic Obstacle Tracking

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Perception – Lane Detection

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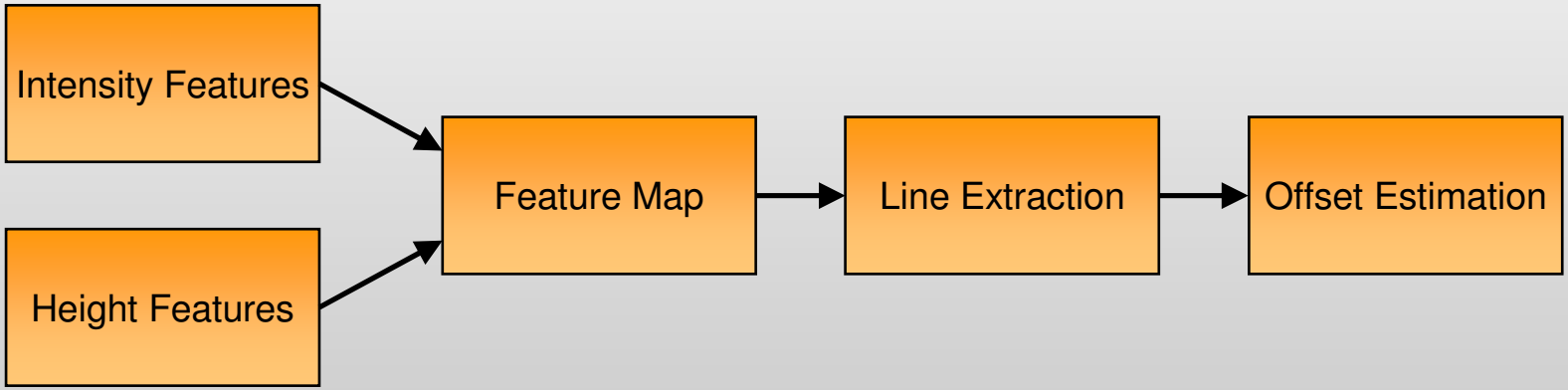
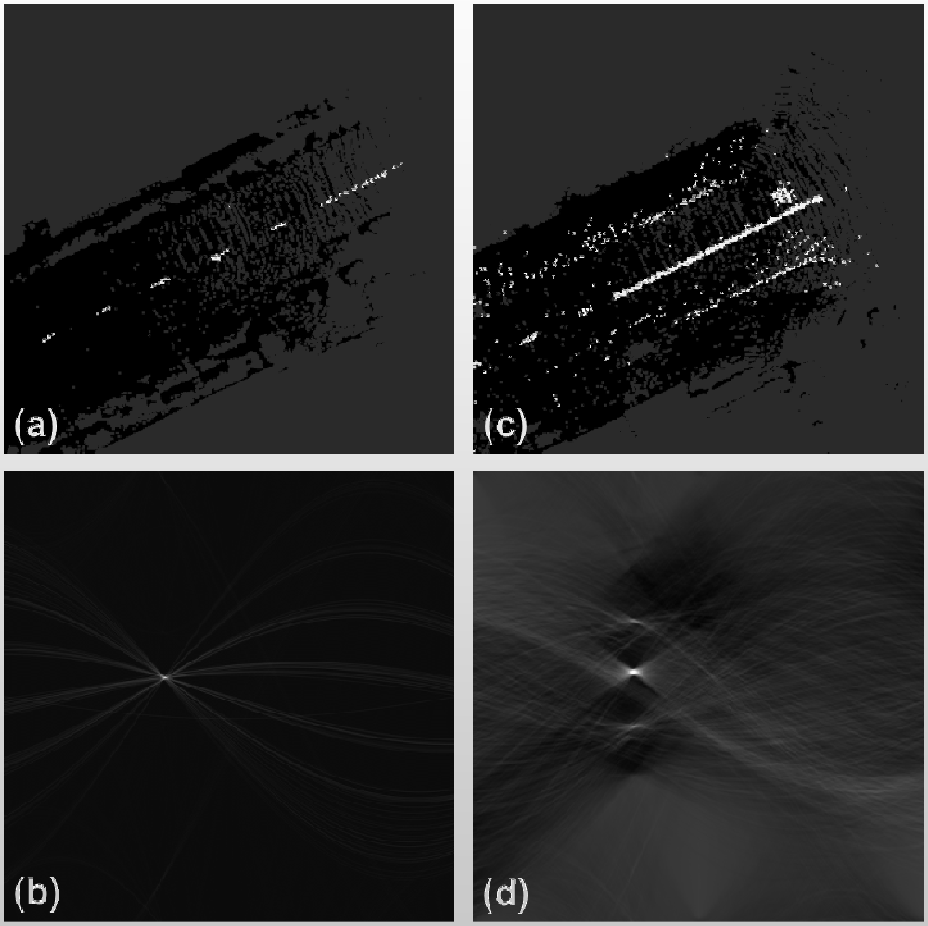
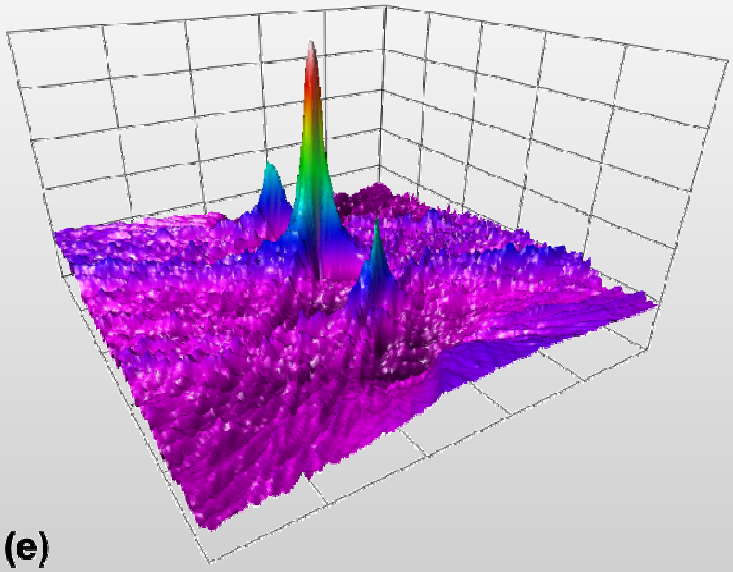
- Lane Detection
  - Feature mapping (intensity and height)
  - Line extraction (radon transform)
  - Localization offset calculation



Perception – Lane Detection





Software Architecture

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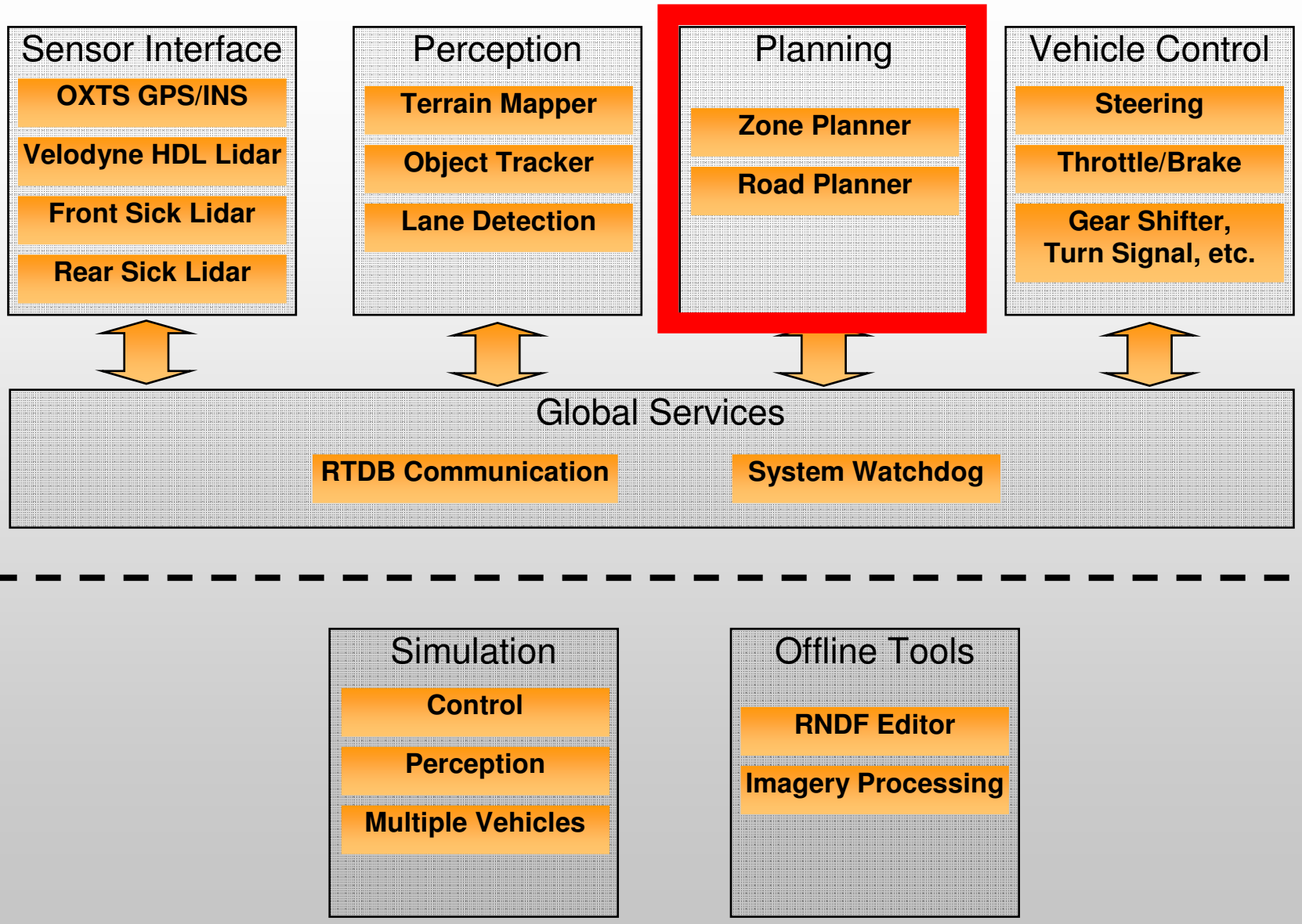

Planning on the road

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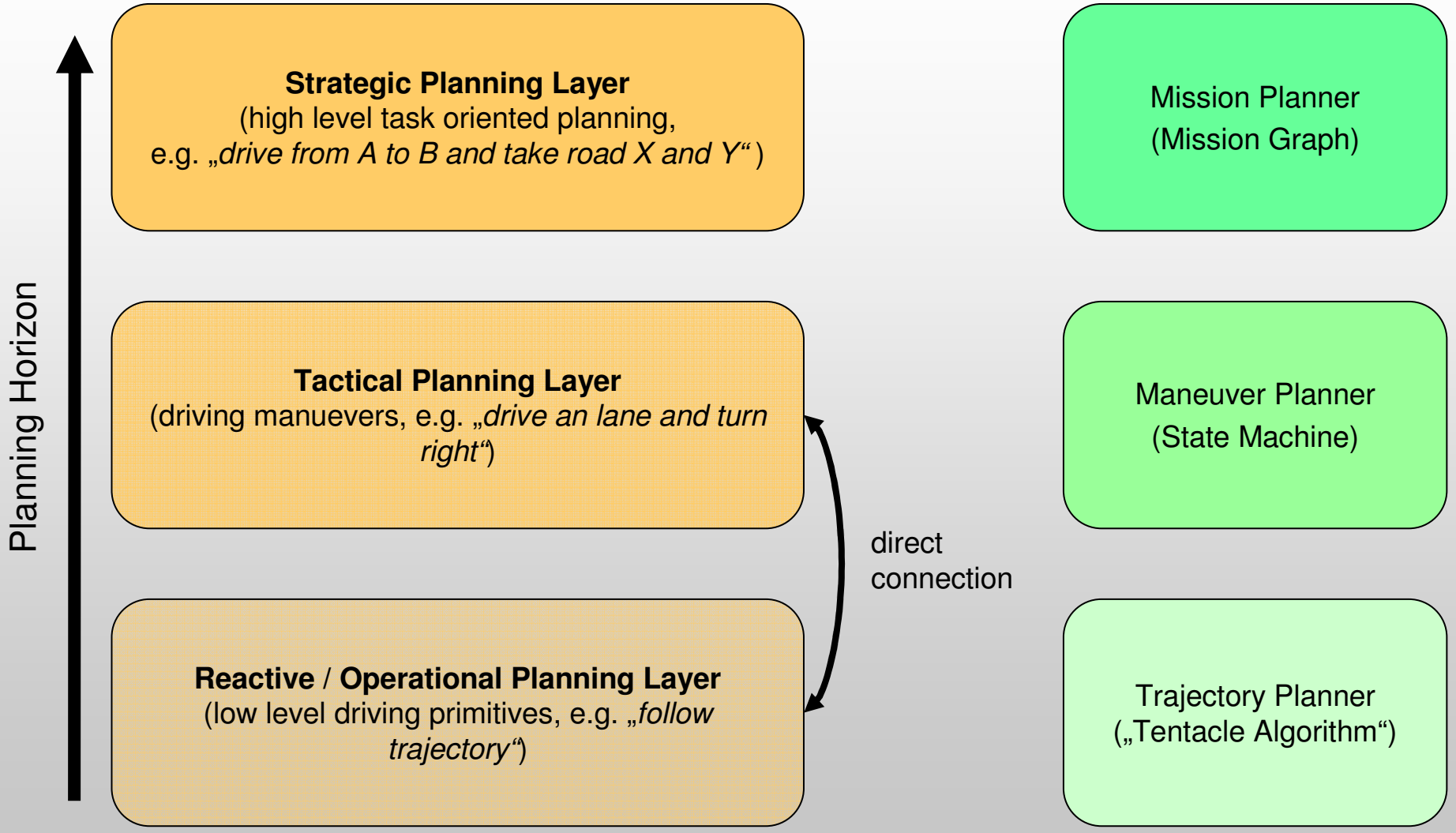

Planning – Mission Planner

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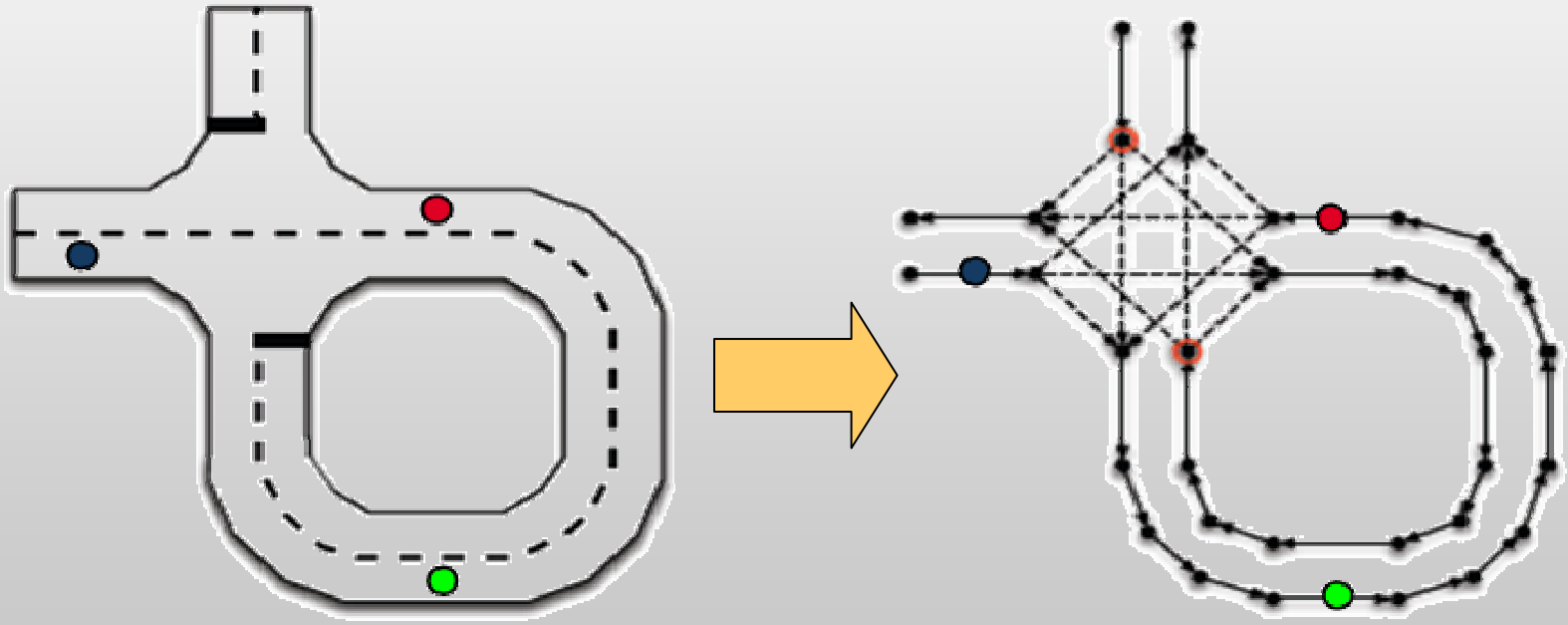
- Mission planner
  - Computes a strategic plan to accomplish mission once
  - Traverses all checkpoints
  - Mission re-planned on the fly



Road Network

Mission Graph

Planning – Mission Planner

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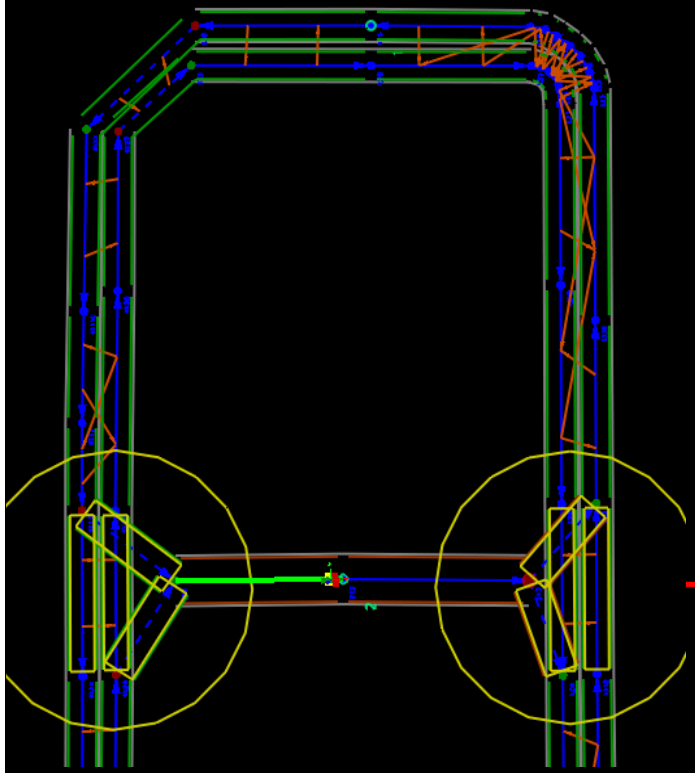
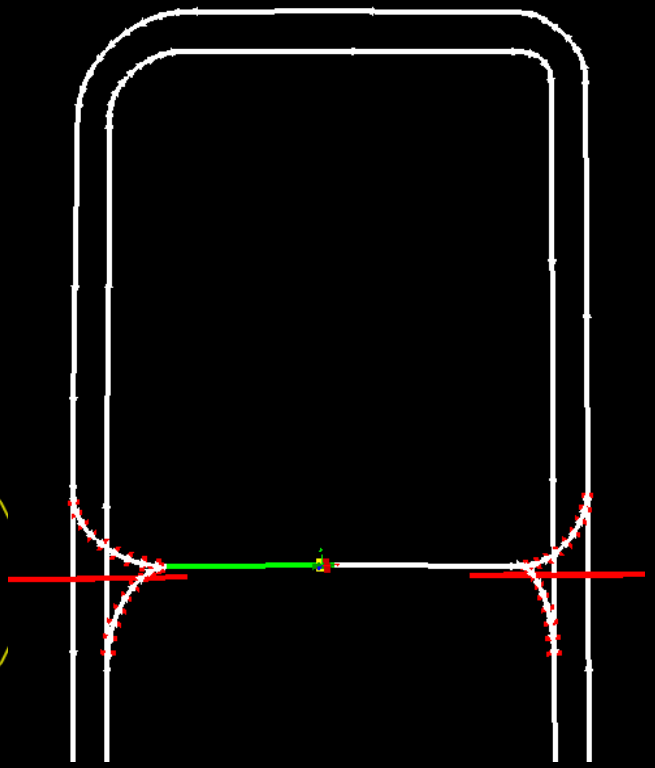
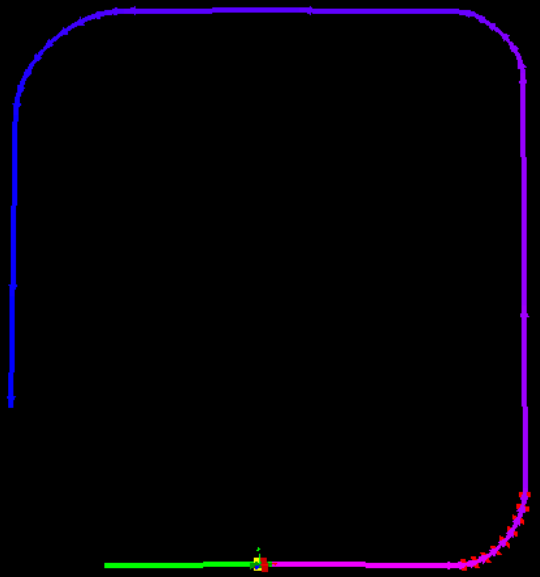


RNDF



RNDF Graph



Mission Graph

Planning – Mission Planner

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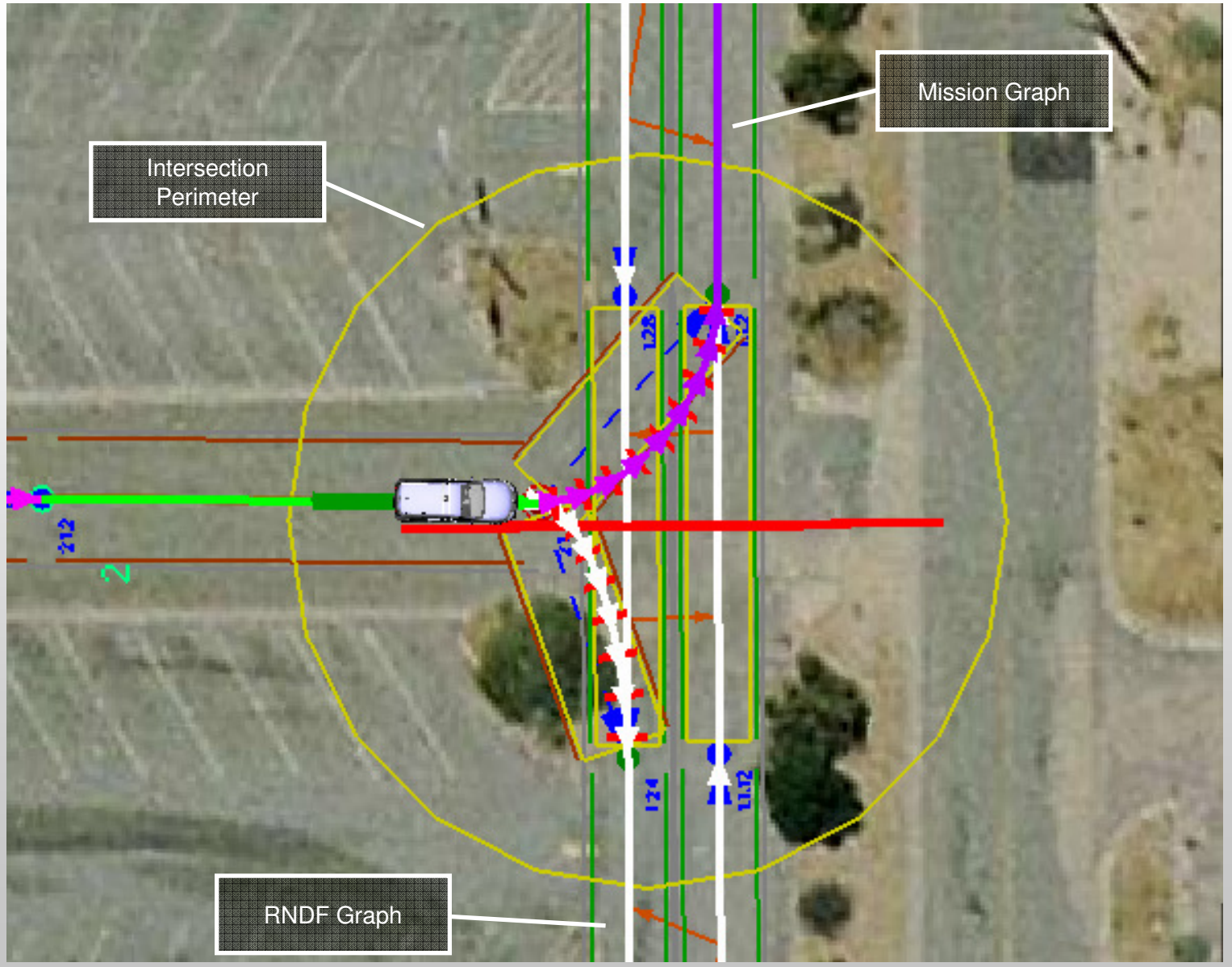

- **Maneuver planner**
  - Plans actual driving maneuvers depending on situation
  - Applies California traffic rules
    - Passing static and dynamic obstacles
    - Handling intersection (precedence, merging)
    - Performing u-turns
    - Following of other vehicles
  - Implements most recovery strategies
  - Concurrent Hierarchical State Machines (CHSM)
    - Easy to maintain and extend
    - Input: world state (pose, static grid, dynamic obstacles)
    - Output: trajectory, desired velocity

Planning – Maneuver Planner

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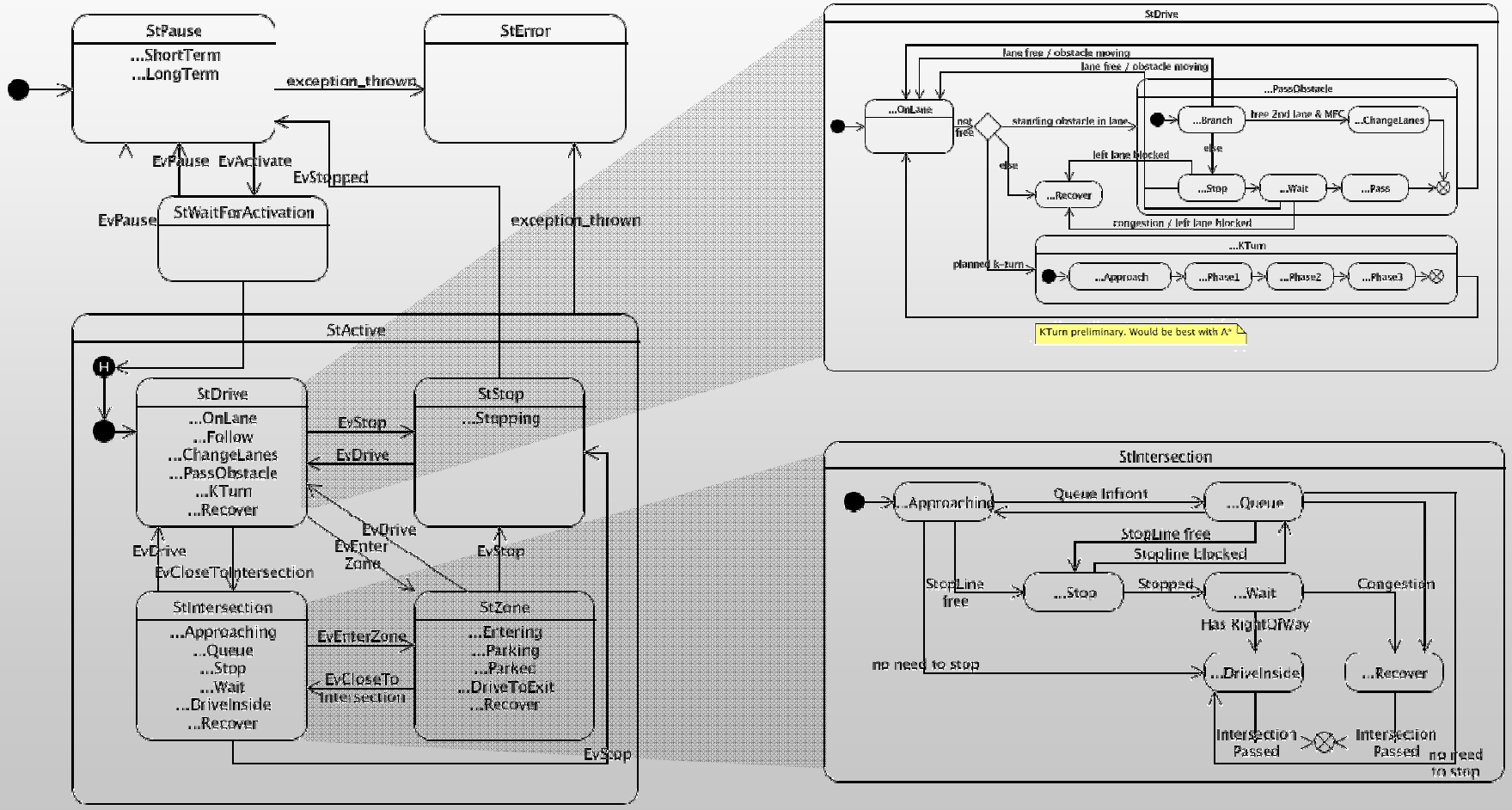
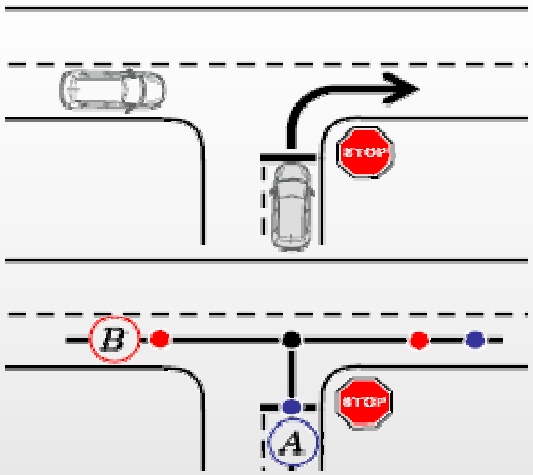
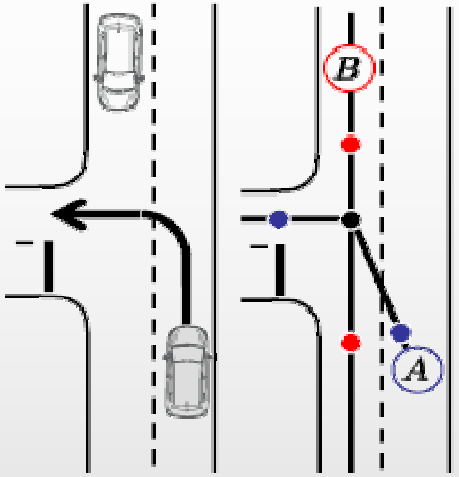
- Maneuver Planning with Concurrent Hierarchical State Machines (CHSM)

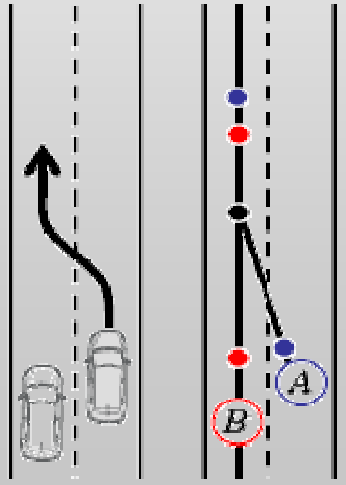




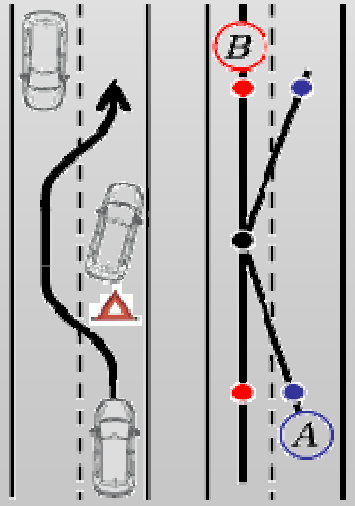
right-turn with stopping



left-turn without stopping



lane change



double lane change

Planning – Trajectory Planner

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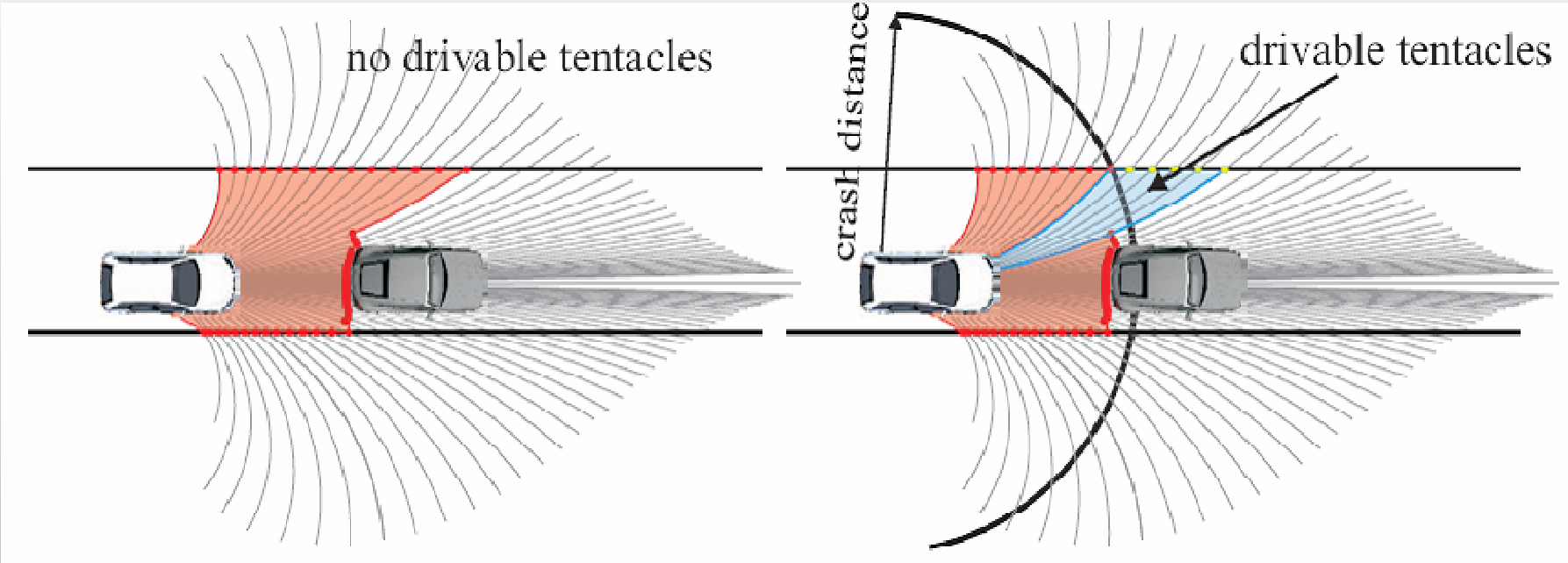
- Avoiding collisions is number one priority
- Ignore any traffic rules if necessary
- Precalculated “tentacle”-trajectories fan out with different curvatures
- Occupancy grid is analyzed for drivable areas



Planning – Trajectory Planner

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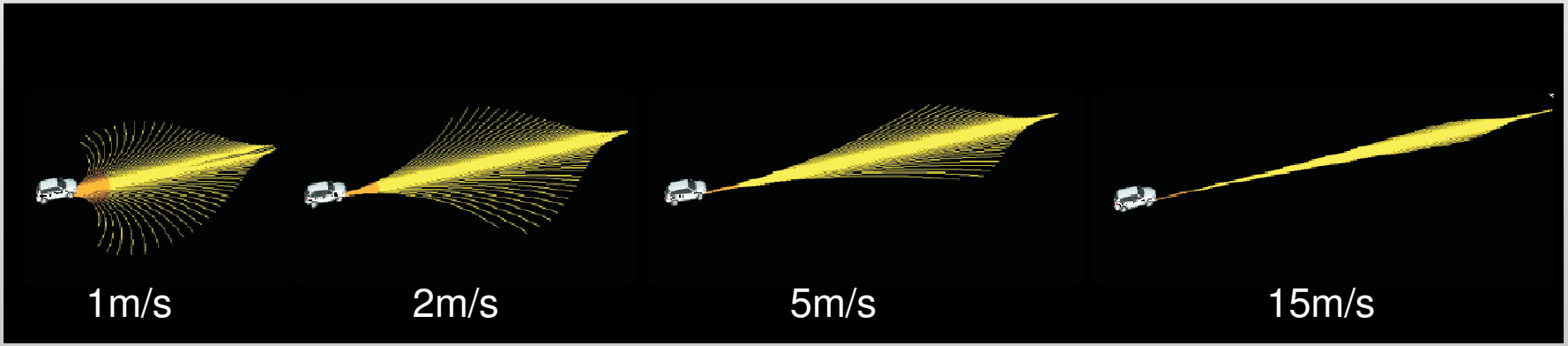
- Trajectory selection
  - Velocity sets
  - Distance to next obstacle
  - Terrain smoothness
  - Close to previous tentacle



Planning – Zone Planner

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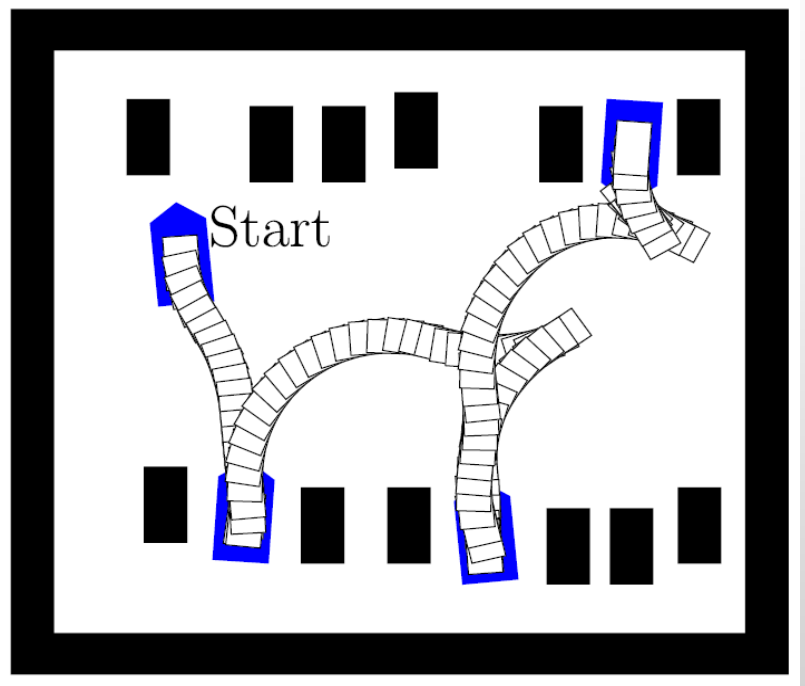
- Free form navigation
  - Unstructured environments
  - Recovery situations
  - U-turns
- Zone Planner
  - A* Best-First Algorithm
  - Two distance heuristics
    - Vorenoi/Dijkstra
    - Circle-Tangent-Circle



Planning – Zone Planner

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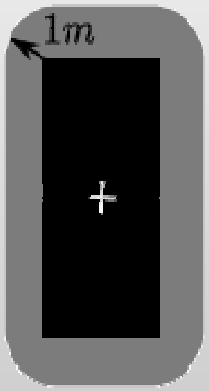
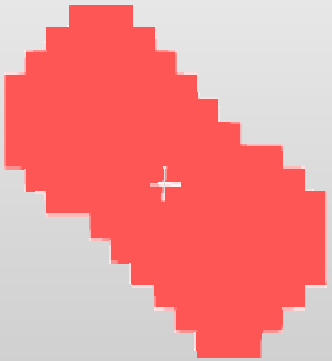
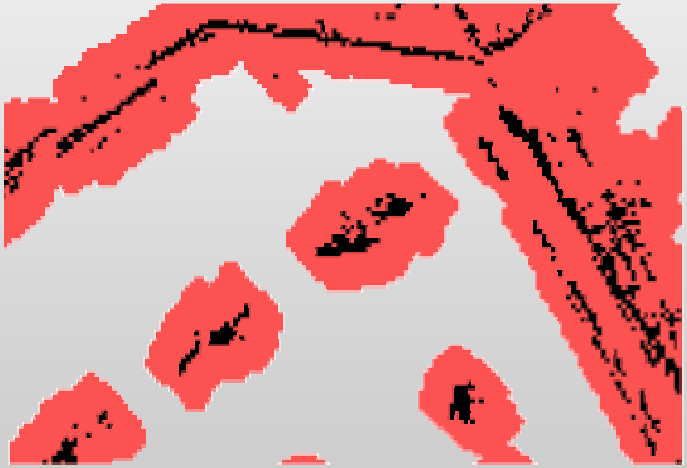
- Obstacle grid is transformed to configuration space
- Convolution of obstacles with car shaped kernel
- Discrete rotations (36) form configuration space layers
- GPU accelerated convolution



Car Model



Kernel



Configuration Space

Planning – Zone Planner

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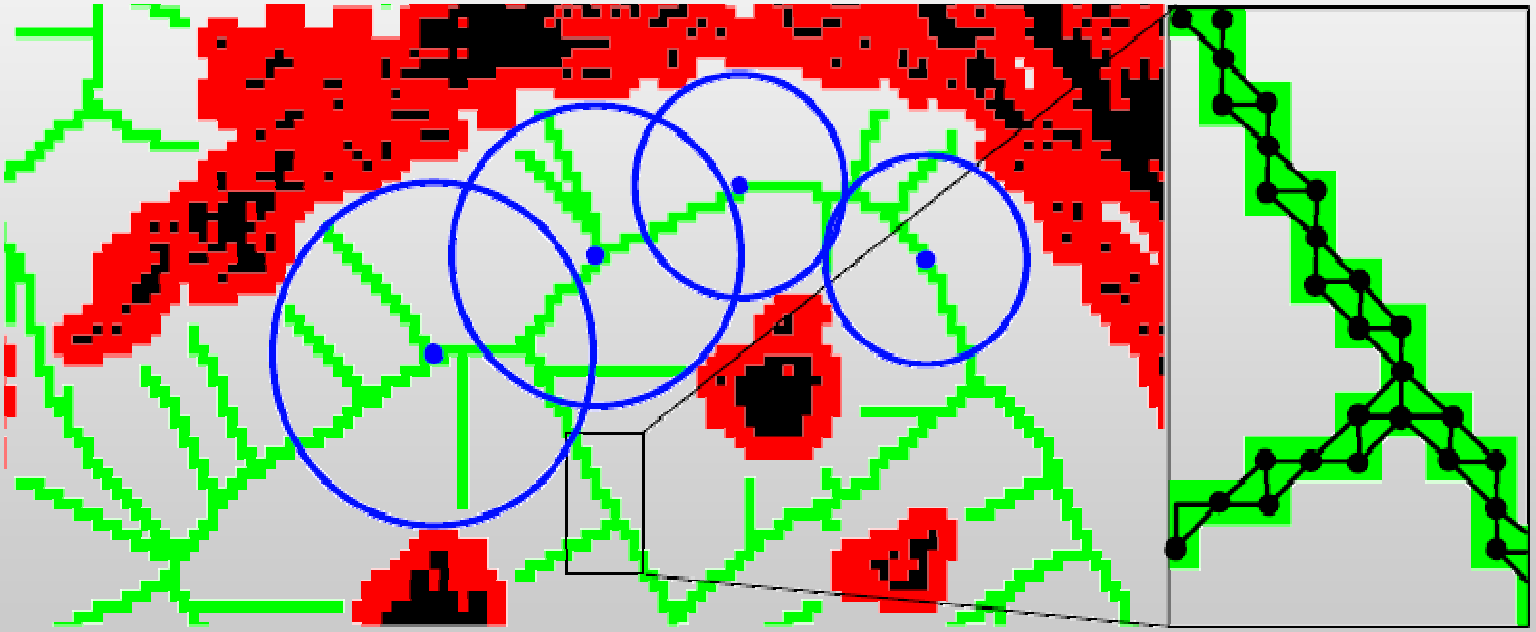
- Vorenoi lines for distance heuristic
- Maximal distance to obstacles



Free Navigation in Unstructered Environment

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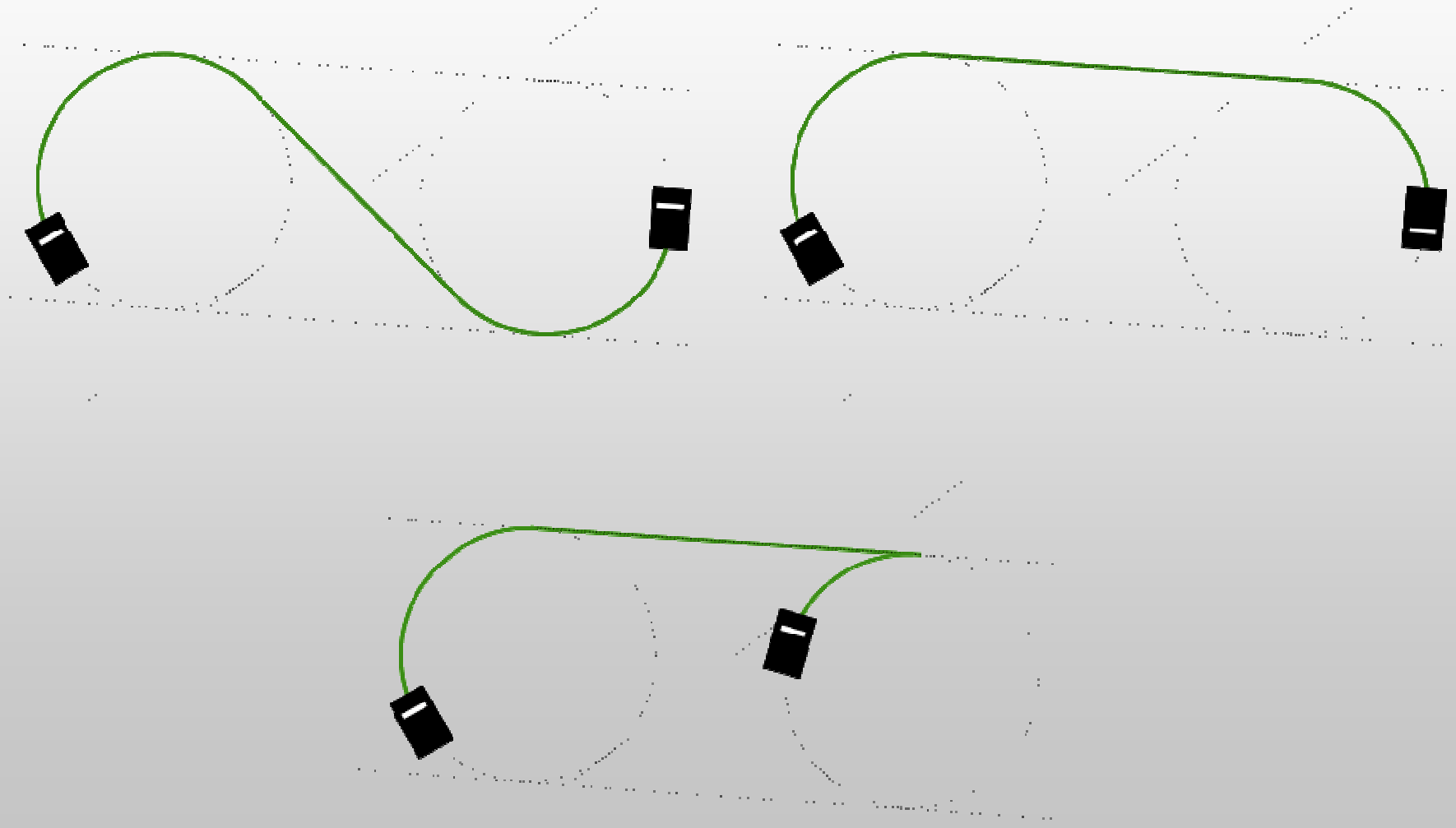
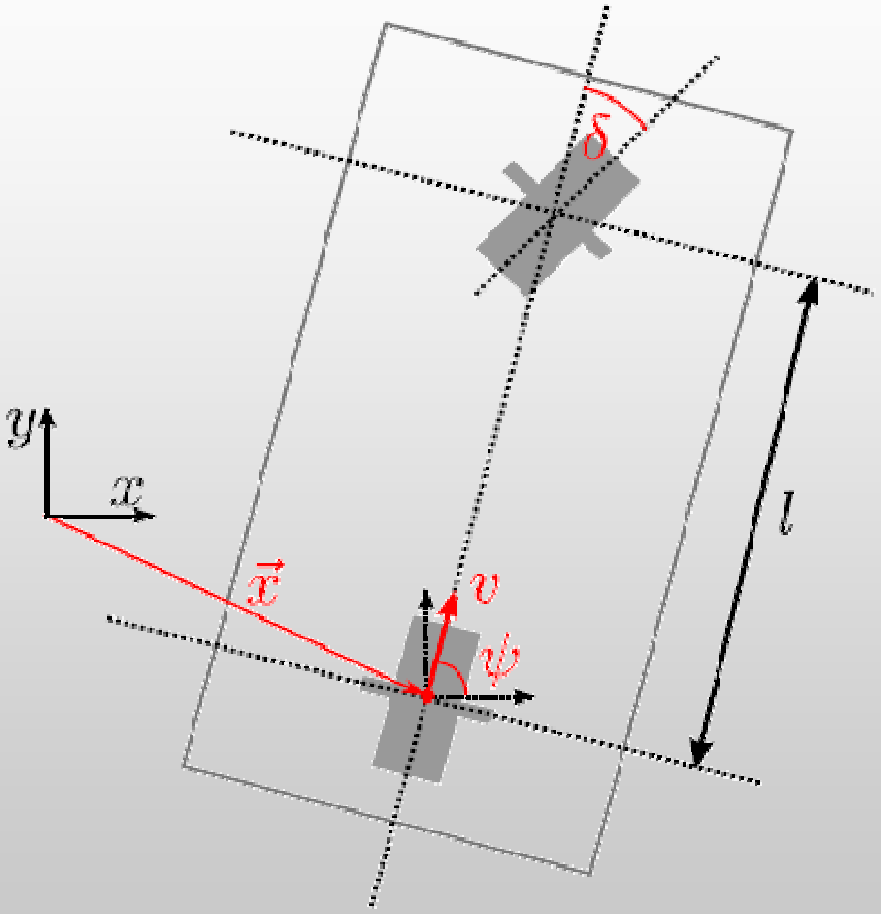
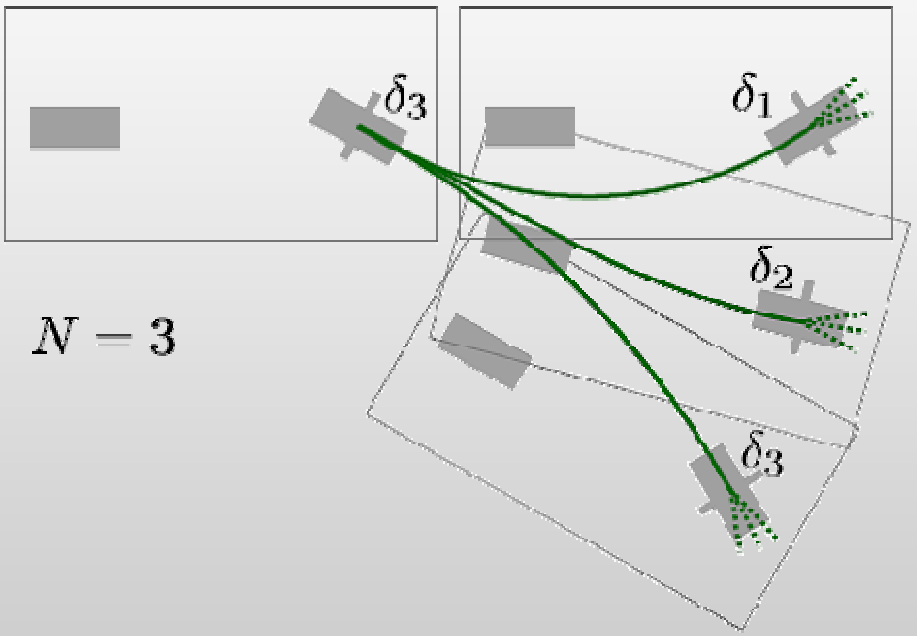
- Circle-Tangent-Circle for distance heuristic



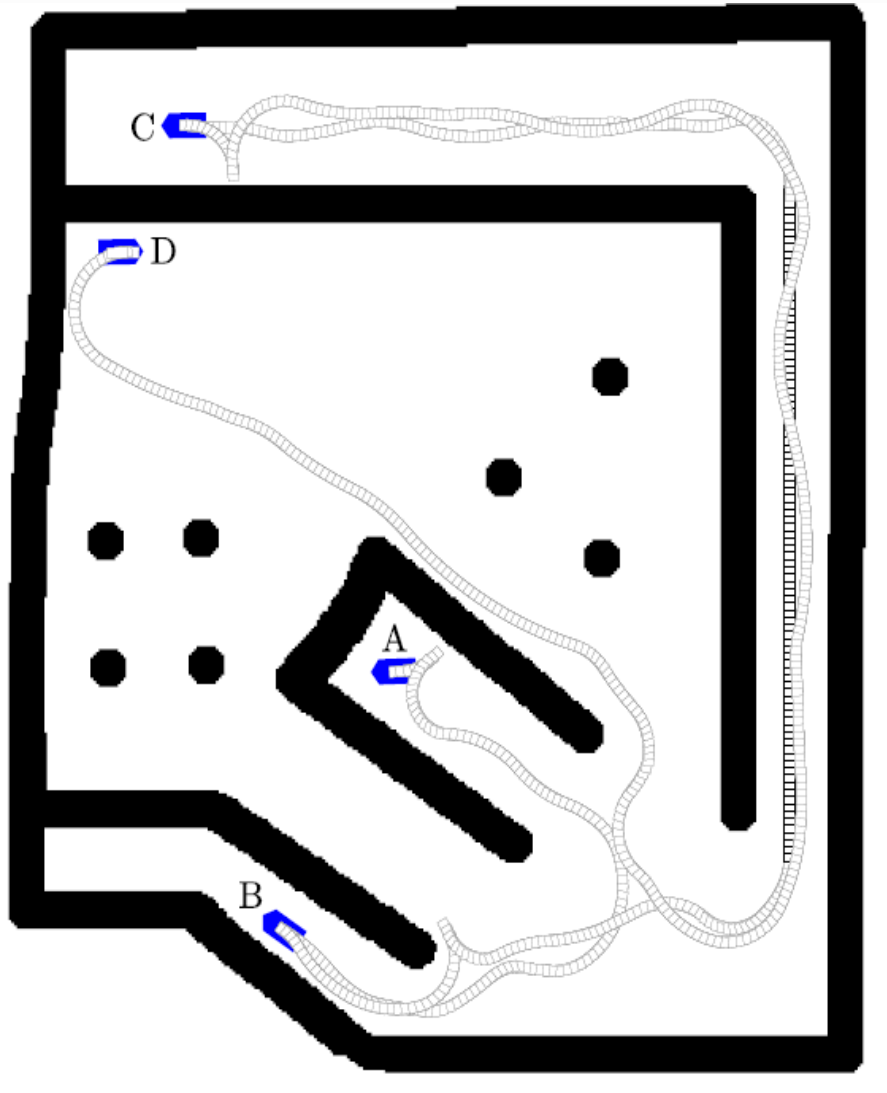


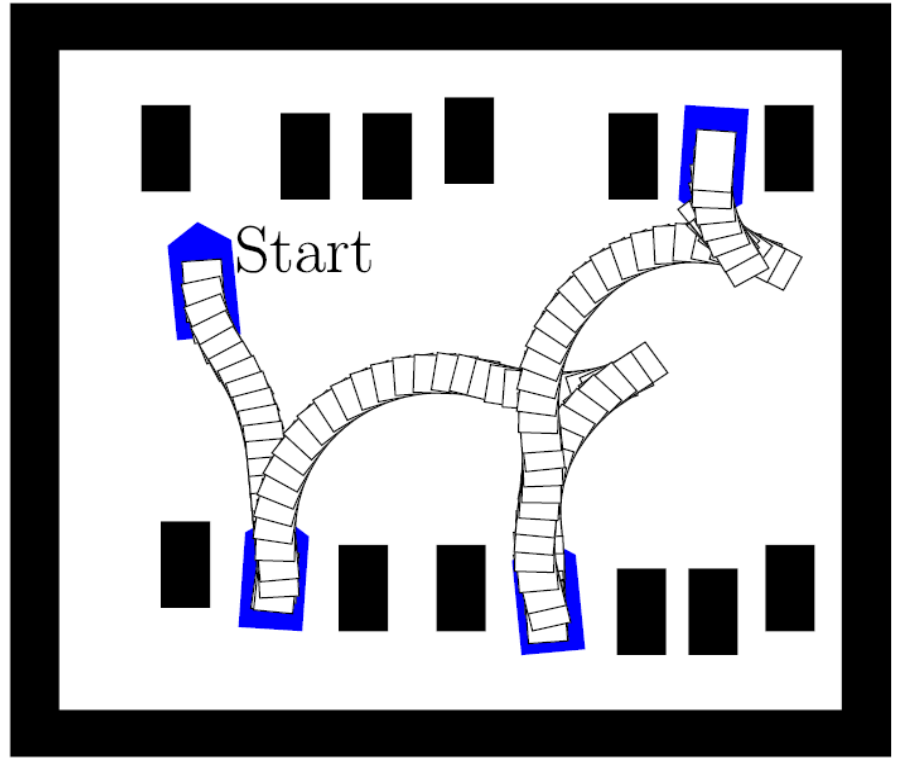
Dynamic Model



Search Graph

Planning – Zone Planner





Planning – Zone Planner

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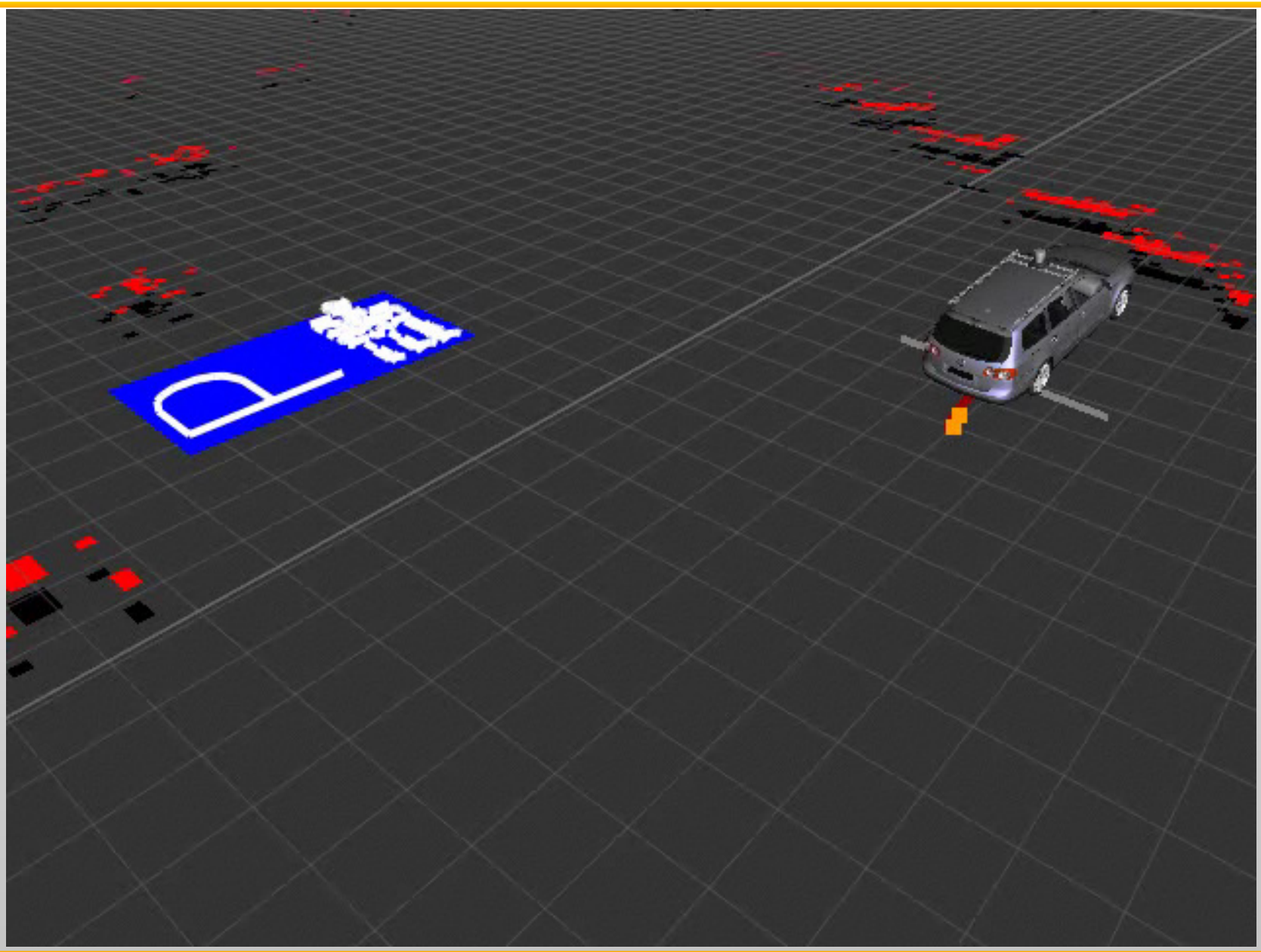
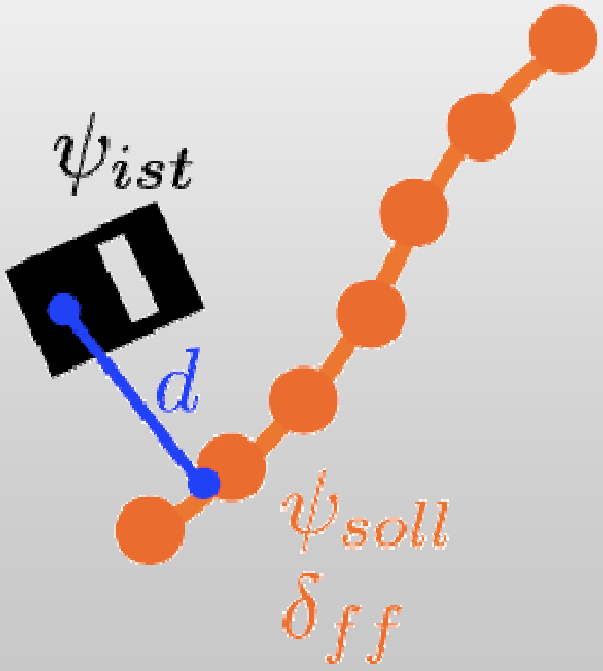


- Feed-forward control in state space description

$$\delta = \delta_{ff} + k_p d + k_d \Delta\psi$$



ψ: vehicle orientation
δ: steering angle
d: distance to ideal (wanted) trajectory

Longitudinal Control

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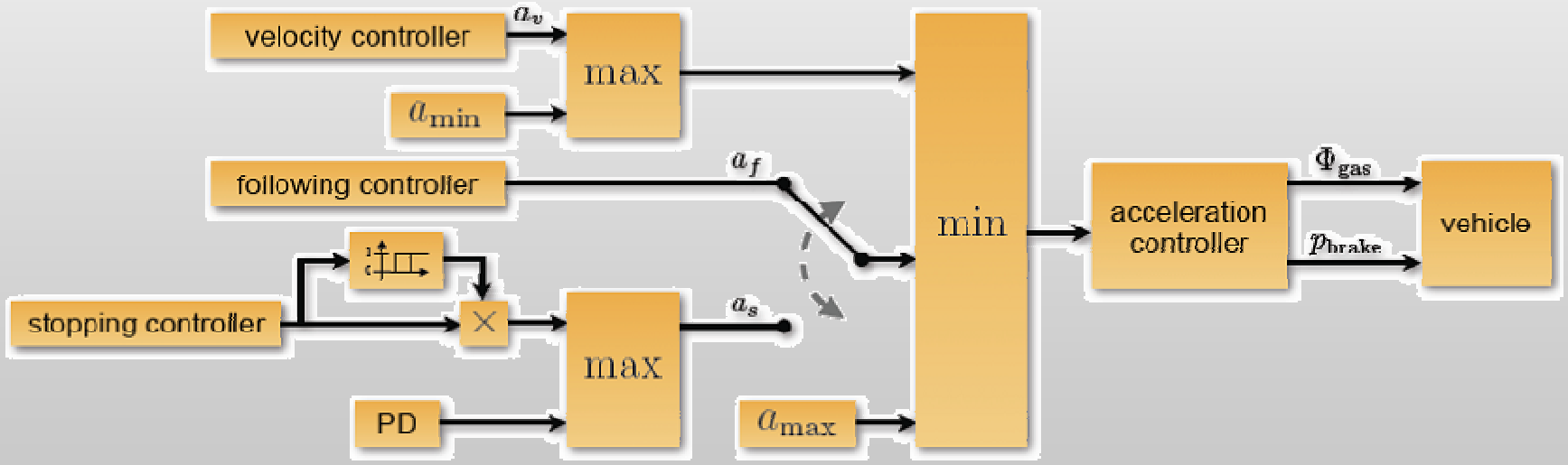
- Combines three control strategies:
  - Velocity controller
  - Following controller
  - Stopping controller



NQE – Test A

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Final Event

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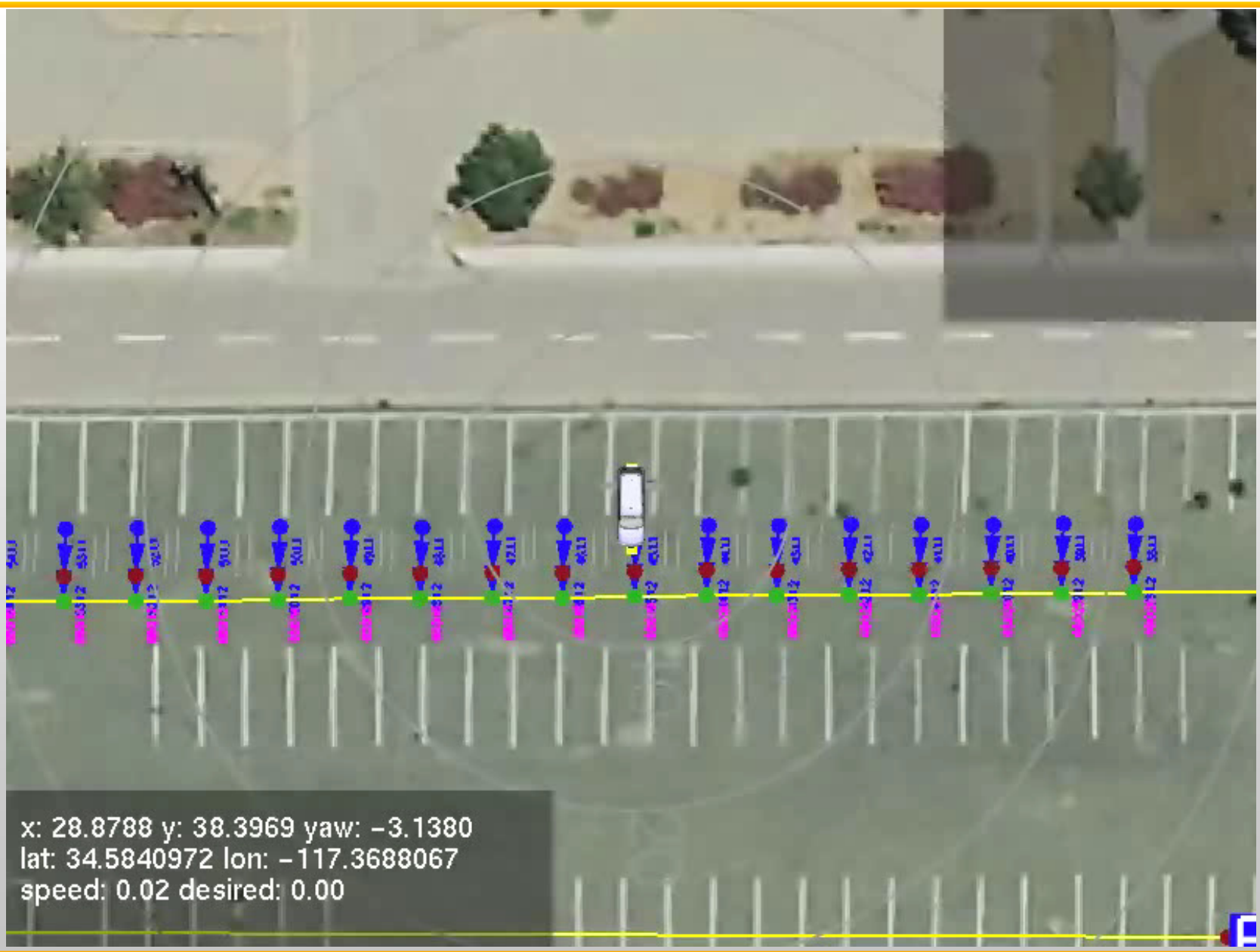

Lessons we learned

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Never use untested software!!!

Lessons we learned

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Simple is better!!!

Lessons we learned

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Never stop coding!!!

The Team

AnnieWAY

BOSCH

Bosch Research and Technology Center, Palo Alto
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