Autonomous Road Vehicles

“Autonomous Driving in Urban Environments: Boss and the Urban Challenge.” Chris Urmson et al. (Carnegie Mellon, GM Research)
Motivation

- Millions of reported Accidents
  - ~90% due to some degree of human error
  - Over 32,000 deaths in 2010 (in the US)

- Military
- Accessibility
- Efficiency
History

- DARPA Grand Challenges
  - Desert roads in 2004-05
  - Urban Challenge introduced in 2006
- Boss (GM & Carnegie Mellon)
  - Junior (Stanford)
- Google
  - 300,000 miles without (computer caused) incident
Sensors
Sensors

- LIDAR – Light Detection and Ranging
  - 64 Lasers and receivers
  - 360 deg. Movement
What the Car Sees
Autonomous Components

- Perception
  - Environment data from sensors

- Motion Planning
  - Vehicle Movement

- Mission Planning
  - Dealing with blockages and rerouting

- Behavioral Reasoning
  - Executing actions determined by Mission Planning
Perception

- Sensor Layer / Fusion Layer
  - Sensors send observations to Fusion Layer
  - Fusion Layer produces Object Hypothesis Set

- Object hypotheses
  - Moving / Static
  - Observed Moving / Not Observed Moving

- Prediction for moving objects
  - Based on road constraints or estimated states
Position Errors

- Applannix POS-LV uses GPS and inertial and wheel encoder data

- Discontinuous Errors (Position Jumps)
  - Is the change in position expected

- Continuous Errors (Drift, Road model errors)
  - Adjusts position based on lane center
  - After 5.7km without GPS, 2.5m of error accumulated
Motion Planning

- Road Navigation
Motion Planning

- Zone Navigation
Mission Planning

- Uses prior knowledge of roadways and their connectivity
- Detects blockages in routes
  - High cost for maneuvering around blockage
  - Favors U-turns and reroutes car
  - Decays over time to allow revisit
  - One way streets – Zone Error recovery
Figure 14. High-level behaviors architecture.
Boss Behavior Architecture

- Intersections
  - Precedence Estimator

- Yielding to moving vehicles
  - Time to.. Cross intersection, reach velocity,
Boss Behavior Architecture

- Distance Keeping, Merge Planning
  - Merge Distance, Minimum Gap, Velocity in merge-to lane
  - N+1 Possible Slots analyzed

![Diagram of two-lane merging](image)

**Figure 17.** Two-lane merging.
Error Recovery

- Generation of nonrepeating, novel recovery goals in the face of repeated failures
- Multiple sets of recovery goals depending on failure context
- Simple recovery state logic to avoid multiple maneuver recovery schemes
On-Road Failure

- **Causes**
  - Small obstacles (traffic cones)
  - Large obstacles (Barrels) detected too late
  - Infeasible Lanes

- **Solution**
  - Forward Goals in small increments
  - Reverse and try forward with a new perspective
  - Turn around

*Figure 19.* Example shimmy error recovery goal sequence.
Intersection Failure

- **Solution**
  - Increase Motion Planning ‘workspace’ (tight turns)
  - Mark path as blocked, check feasibility of other exit paths
  - Reattempt original goal with loose restrictions

*Figure 20. Example jimmy recovery goal sequence.*
Zone Failure

- ‘Shake’ recovery sequence
  - Transient blockage or sensor failure
  - Selects goals in a triangular pattern

*Figure 21.* Example shake recovery goal sequence.
Worst-case Scenario

- **Cause**
  - System has not moved 1m in 5min

- **Solution**
  - Psuedo-random, approximately feasible goals
  - Restart once a recovery goal is met

*Figure 22.* Example wiggle recovery goals.
Conclusions

- **Key Features**
  - Robust Design
  - Static / Moving object models
  - Behavioral Engine that can throw out rules of the road

- **Further Areas**
  - DARPA 2007 did not include traffic lights, pedestrians
  - Non-ideal Weather
  - Interaction with human drivers
  - Legal aspects of Autonomous Cars (NV,CA,FL)
Sources
