Autonomous Driving in Urban Environments: Boss and the Urban Challenge

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CMU, GM, Caterpillar, Continental, Intel

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OUTLINE

- Introduction
- Moving Obstacle Detection and Tracking
- Curb Detection Algorithm
- Intersections and Yielding
- Distance Keeping and Merge Planning
- Lessons learned
- Conclusion

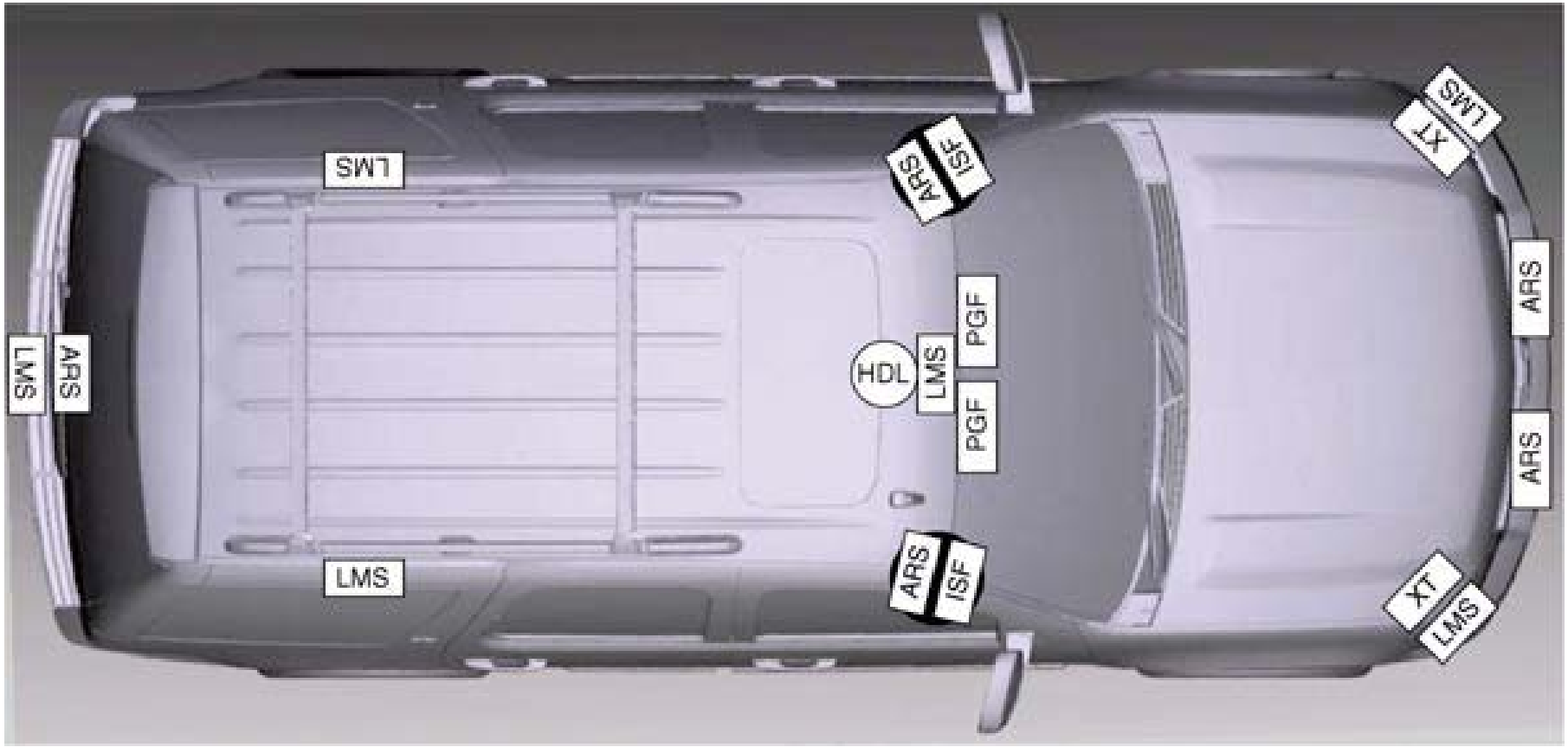
Urban Challenge

- Launched by DARPA(Defense Advance Research Project Agency)
- Develop Autonomous vehicles
- Target: US military ground vehicles be unmanned by 2015

BOSS

- Team from CMU, GM, Caterpillar, Continental, Intel
- Modified from 2007 Chevrolet Tahoe to provide computer control
- Equipped by drive-by-wire system
- Controlled by CompactPCI with 10 2.16GHz Core2Duo CPU
- Won 2007 urban challenge

Sensors


LMS
ARS
LMS
ARS
ISF
HDL
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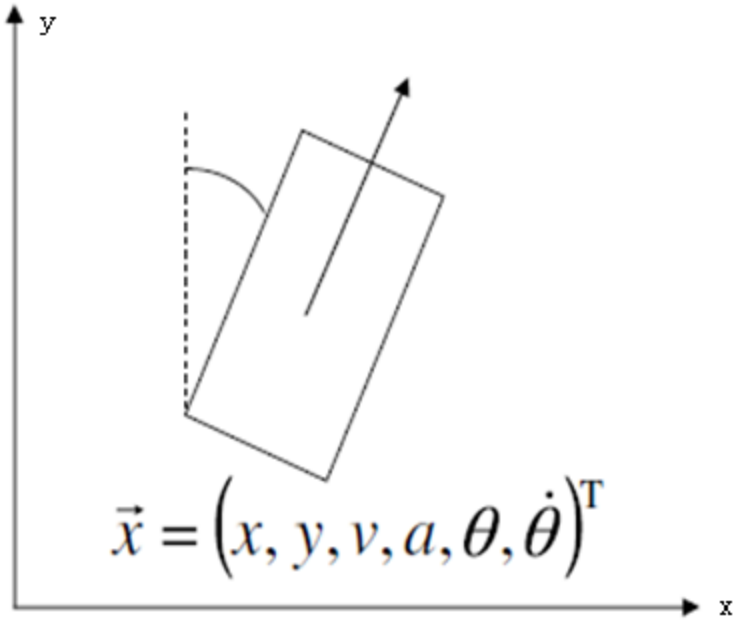
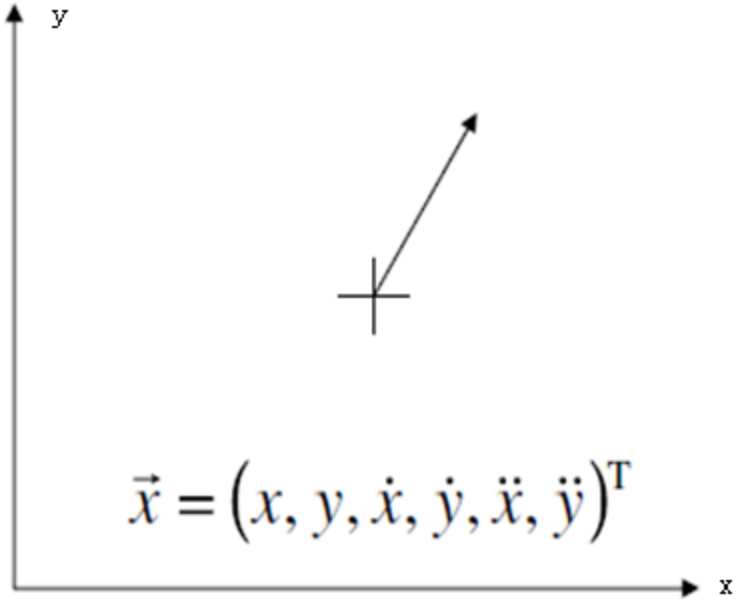
Moving Obstacle Detection and Tracking



Fix shape rectangular model

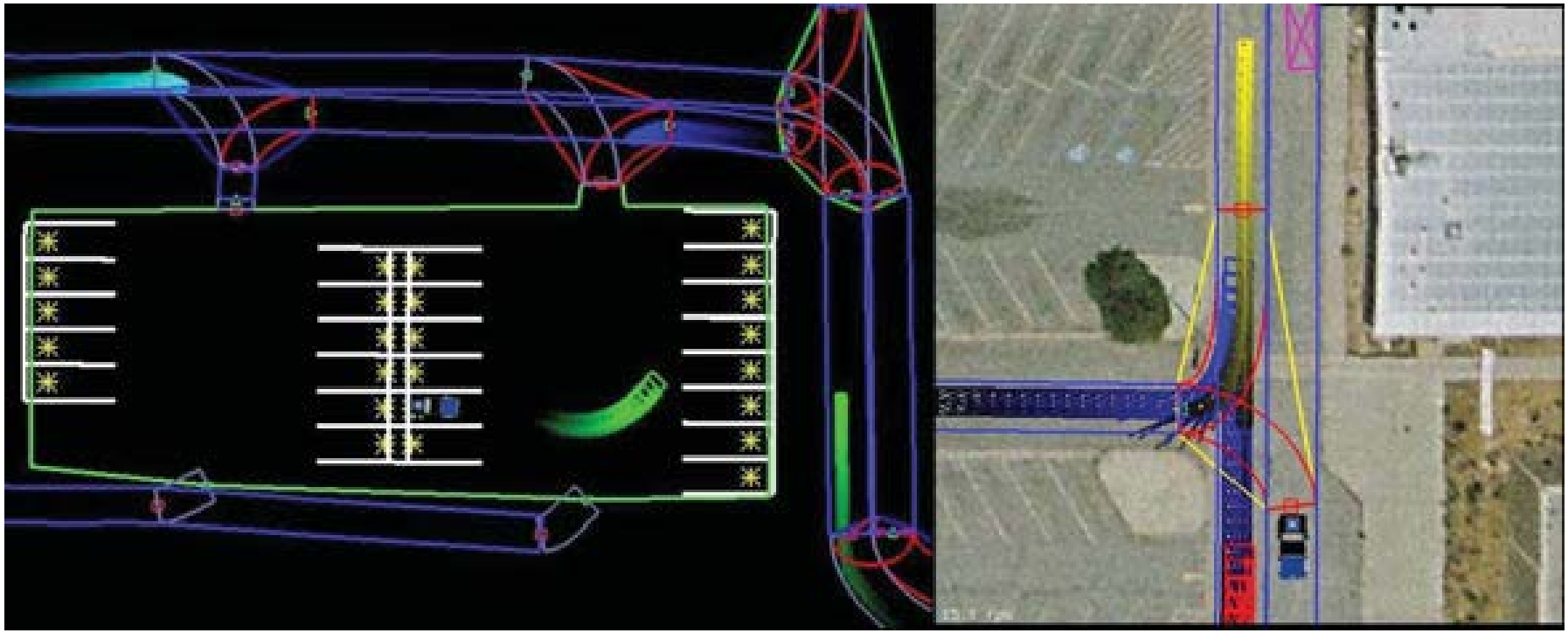


Point model

Object classification

- moving or not moving
  - Moving flag is set when a speed is detected
- Observed moving or not observed moving
  - Observed moving flag is set when keep moving more than a period of time

Predicts the motion of tracked vehicles

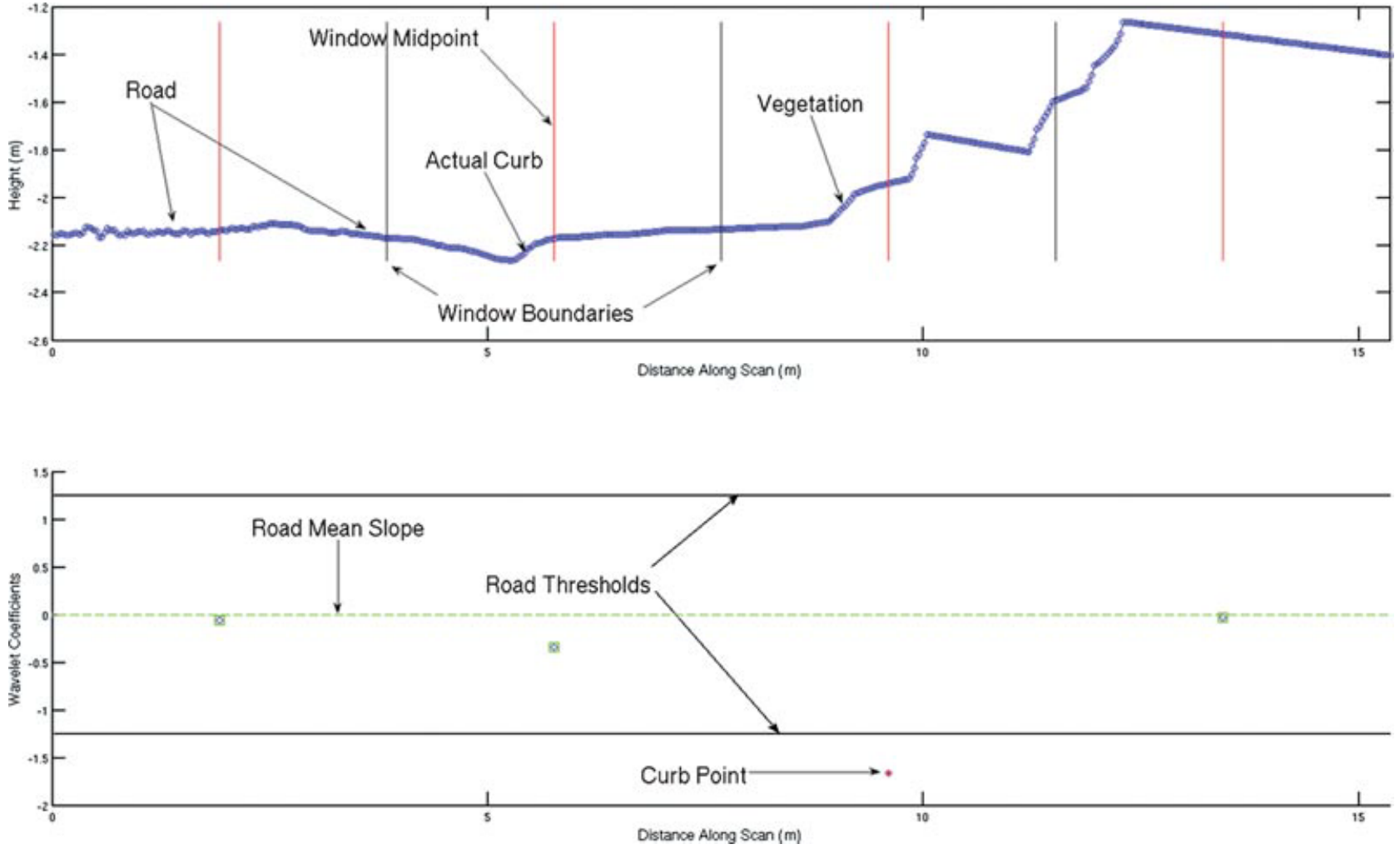


Curb detection algorithm

Wavelet-based feature extraction

- $$\Psi(t) = \begin{cases} 1 & \text{if } 0 \le t < \frac{1}{2}, \\ -1 & \text{if } \frac{1}{2} < t < 1, \\ 0 & \text{otherwise,} \end{cases}$$
- $$\varphi(2^j t - i) = \begin{cases} 1 \text{ if } 0 \le t < 1, \\ 0 \text{ otherwise,} \end{cases} \quad j > 0 \wedge 0 \le i \le 2^j - 1.$$

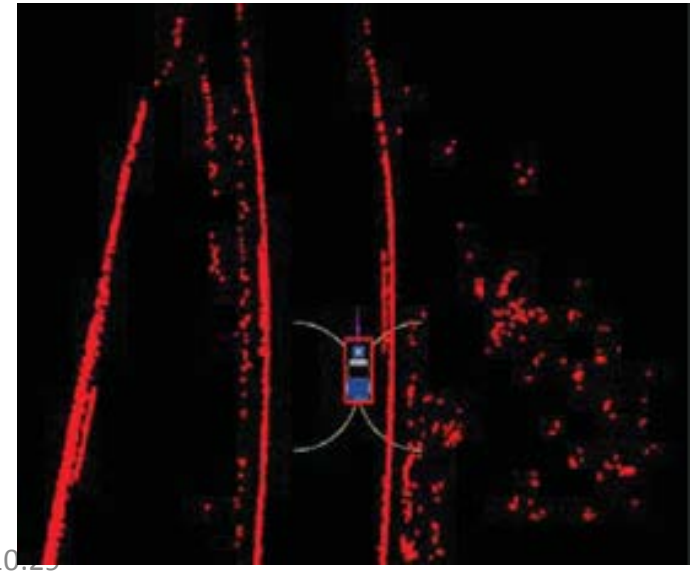
Wavelet-based feature extraction



Wavelet-based feature extraction

- Collect coefficients for the current level i
- Label each coefficient with label of level i-1
- Compute $\hat{y}_{\text{road}}$ using these labels
- Class(y[n], i)= $\begin{cases} 1 & \text{if } y[n] - \hat{y}_{\text{road}} >= d_i \\ 0 & \text{otherwise} \end{cases}$

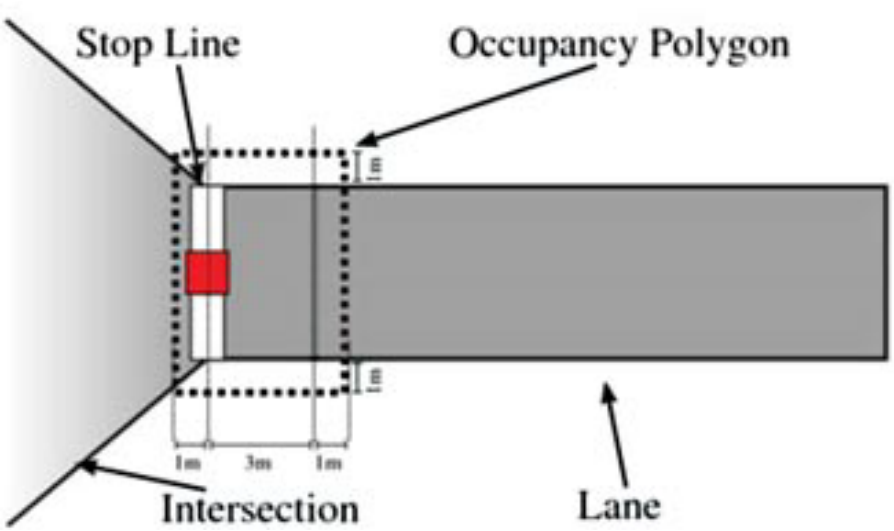
Performance of the algorithm

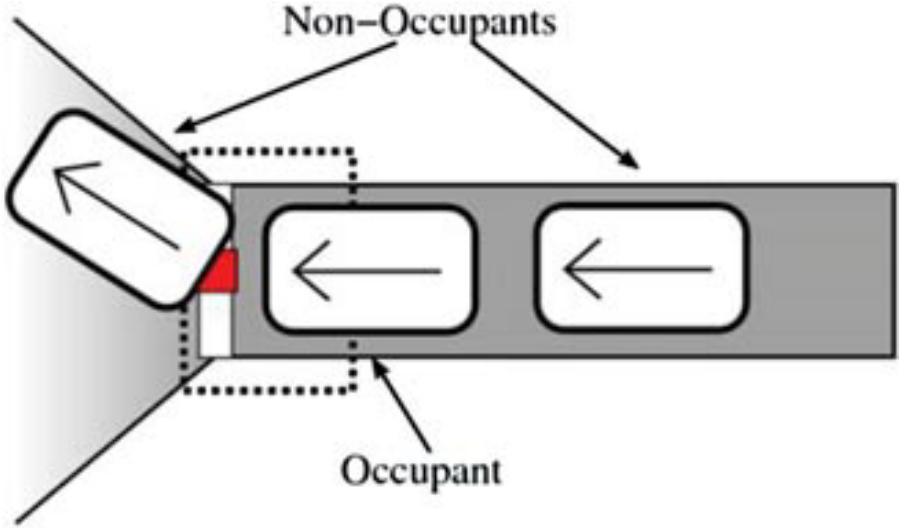


Intersections and Yielding

- Intersection-Centric Precedence Estimation
- Yielding

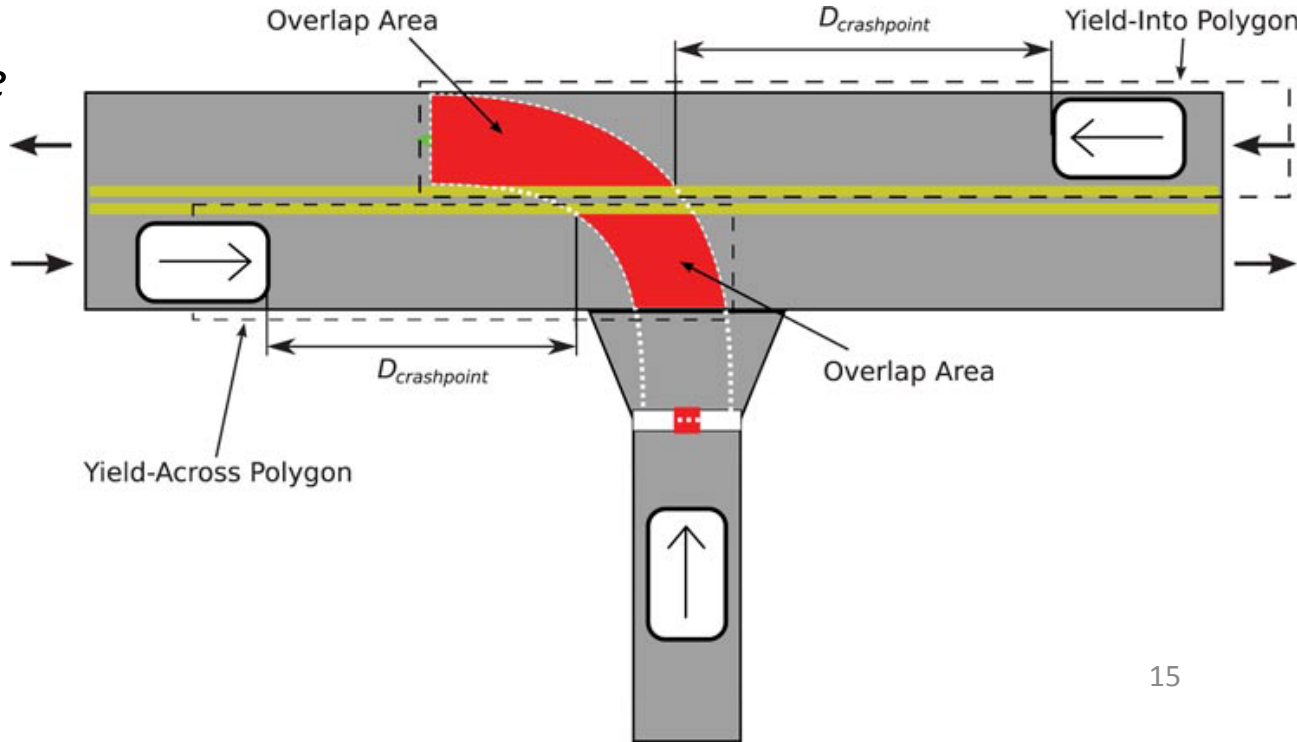
Intersection-Centric Precedence Estimation





Yielding

- $T_{required} = T_{act} + T_{delay} + T_{space}$
- $L_{yeild\ polygon} = V_{maxlane} \cdot T_{required} + d_{safety}$
- $T_{arrival} = d_{crash} / v_{obstacle}$
- $T_{arrival} > T_{require}$



Distance Keeping and Merge Planning

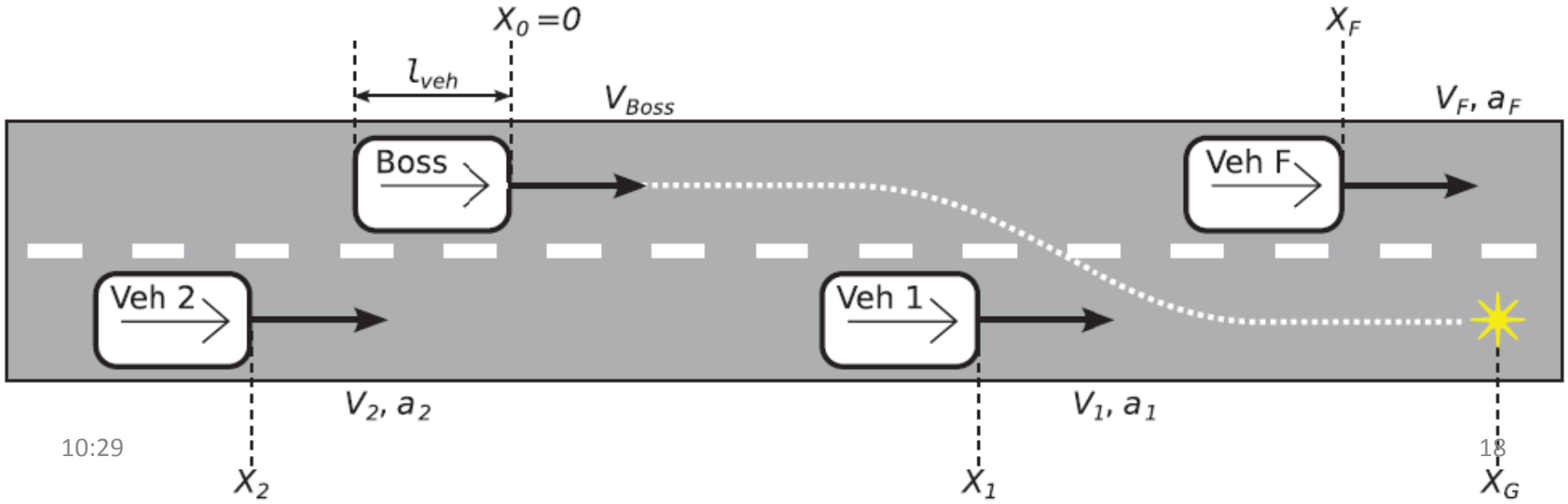
- Distance Keeping
- Merge Planning

Distance Keeping

- $v_{cmd}=K_{gap}\cdot(d_{target}-d_{desired})$
- $d_{desired}=\max(v_{target}\cdot l_{vehicle}/10, d_{mingap})$
- $a_{cmd}=a_{min}+K_{acc}v_{cmd}\cdot(a_{max}-a_{min})$

Merge Planning

- $d_{merge}=12m$
- $d_{obst}=v_0 \cdot d_{init}/(v_0-v_1)$
- $X_0-l_{vehicle}-X_1>=max(v_1 \cdot l_{vehicle}/10, d_{mingap})$
- $X_1-l_{vehicle}-X_0>=max(v_1 \cdot l_{vehicle}/10, d_{mingap})$



Lessons Learned

- Sensors are insufficient for urban driving
- Road shape estimation maybe replaced by estimating position relative to the road
- Human level driving require a rich representation
- Validation and verification of the system is an unsolved problem
- Driving is a social activity

Conclusion

- A moving obstacle and static obstacle detection and tracking system
- A road navigation system that combines road localization and road shape estimation where road geometry is not available
- A mixed-mode planning system that is able to both efficiently navigate on roads and safely maneuver through open areas and parking lots
- A behavioral engine that is capable of both following the rules of the road and violating them when necessary
- A development and testing methodology that enables rapid development and testing of highly capable autonomous vehicles

Questions?