Autonomous Motion Planning for an Automotive System

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Autonomous Driving in Urban Environments: Boss and the Urban Challenge

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Boss

Getting from Start to Goal

- Mission Planning
- Behavioral Reasoning
- Motion Planning

Mission Planning

- Graph Search

- Blockage Detection

Behavioral Reasoning

- Intersection and Yielding
- Distance Keeping and Merge Planning
- Zone Planning
- Error Recovery

Motion Planning

- Structured

- Unstructured

Mission Planning

- Graph Search
  - Precomputed Graph
  - Vertices represent goal locations
  - Edges represent things like lanes

Edge Weights

- Combination of several factors:
  - Expected time of traversal
  - Edge length
  - Complexity of environment
- Updated in real time
  - Blockages
  - Replan

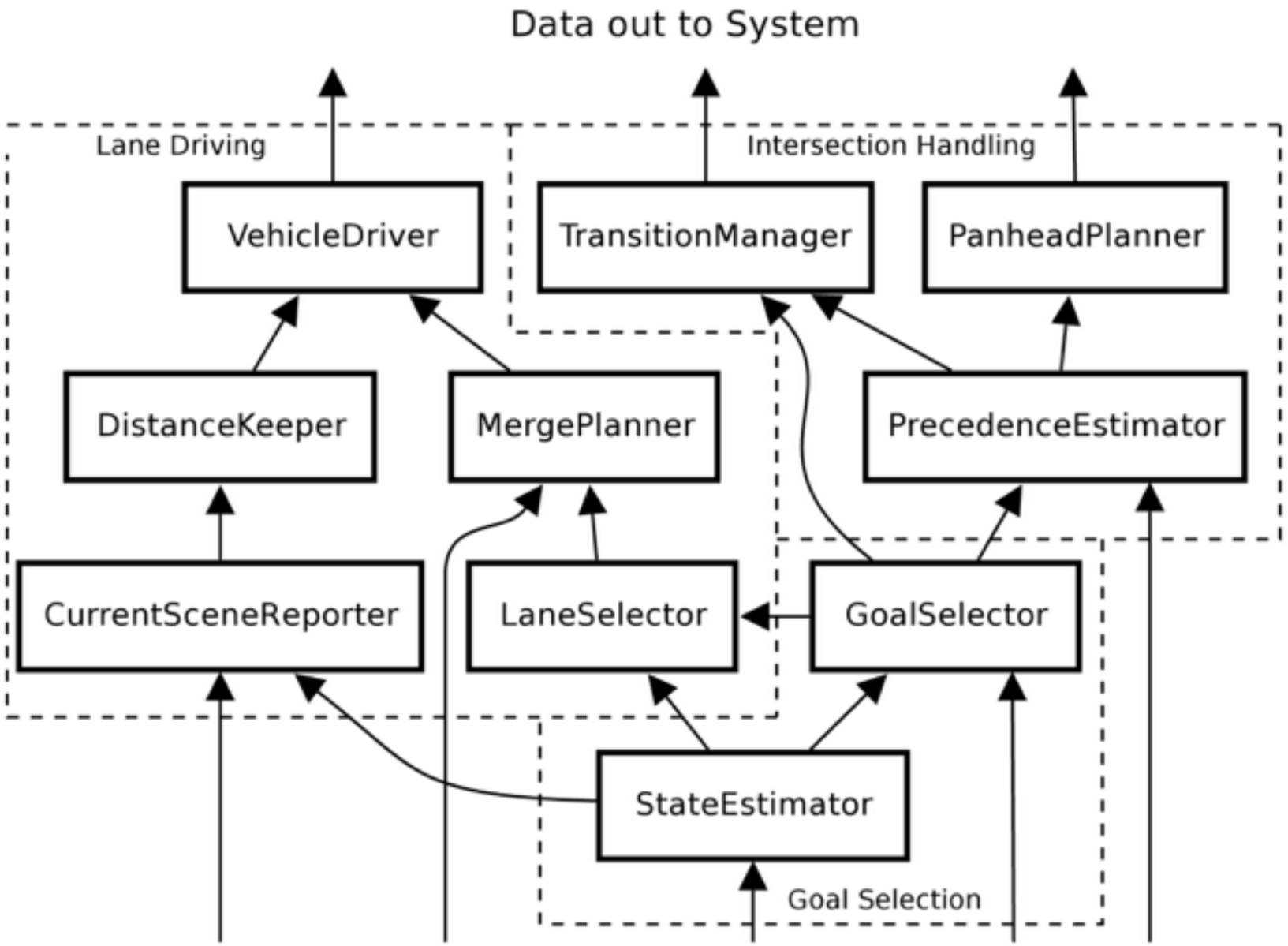
Blockages

- Detected Blockages
  - Sensed static obstacles
  - Knowledge decays over time
- Virtual Blockages
  - Motion planner fails
  - Forgotten at each checkpoint

Mission Planning

- Feeds navigation information to Behavioral Reasoning unit including:
  - Intersection information
  - Lane information

Behavioral Reasoning



Behavioral Reasoning

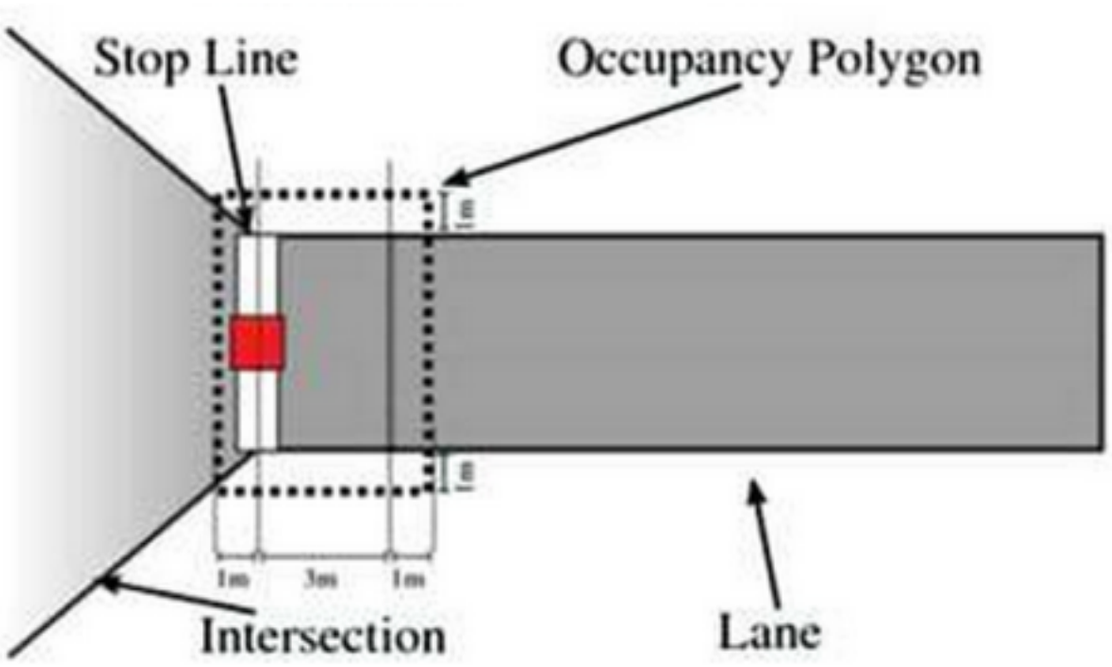
Table III. Components of the behavioral subsystem.

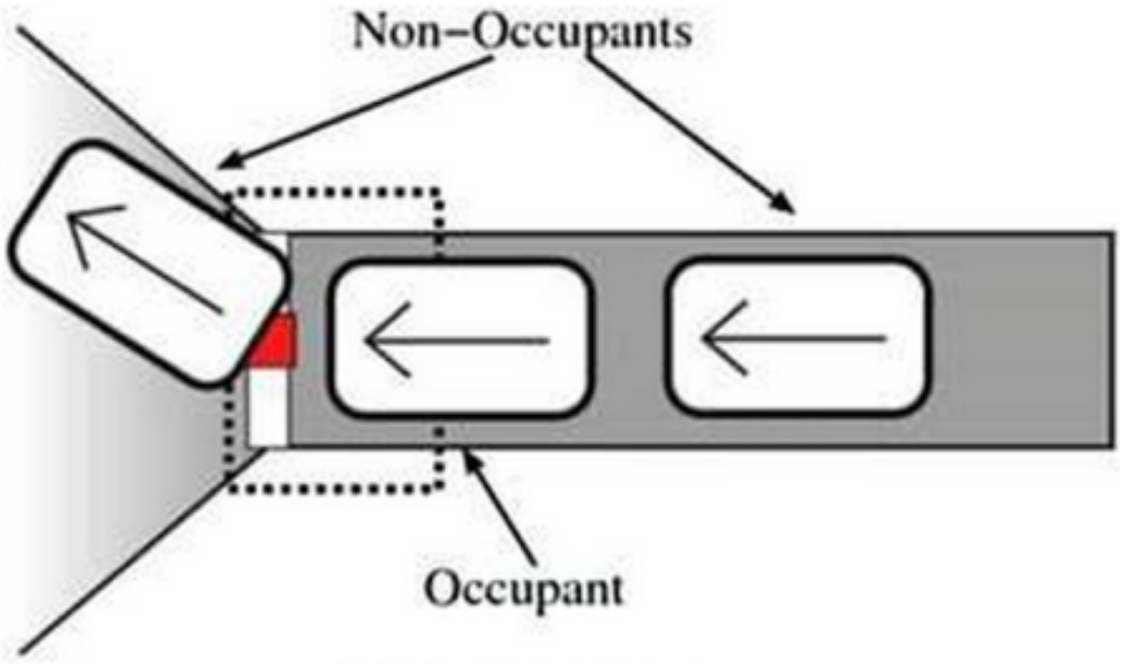
Goal selection components	Drive down road	Handle intersection
State estimator: combines the vehicle's position with the world model to produce a discrete and semantically rich representation of the vehicle's logical position with the RNDF. ***Goal selector***: uses the current logical location as reported by state estimator to generate the next series of local goals for execution by the motion planner; these will be either lane goals or zone goals.	***Lane selector***: uses the surrounding traffic conditions to determine the optimal lane to be in at any instant and executes a merge into that lane if it is feasible. ***Merge planner***: determines the feasibility of a merge into a lane proposed by lane selector. ***Current scene reporter***: the current scene reporter distills the list of known vehicles and discrete obstacles into a few discrete data elements, most notably the distance to and velocity of the nearest vehicle in front of Boss in the current lane. ***Distance keeper***: uses the surrounding traffic conditions to determine the necessary in-lane vehicle safety gaps and govern the vehicle's speed accordingly. ***Vehicle driver***: combines the outputs of distance keeper and lane selector with its own internal rules to generate a so-called "motion parameters" message, which governs details such as the vehicle's speed, acceleration, and desired tracking lane.	***Precedence estimator***: uses the list of known other vehicles and their state information to determine precedence at an intersection. ***Pan-head planner***: aims the pan-head sensors to gain the most relevant information for intersection precedence decisions. ***Transition manager***: manages the discrete-goal interface between the behavioral executive and the motion planner, using the goals from goal selector and the gating function from precedence estimator to determine when to transmit the next sequence of goals.

Intersection Handling

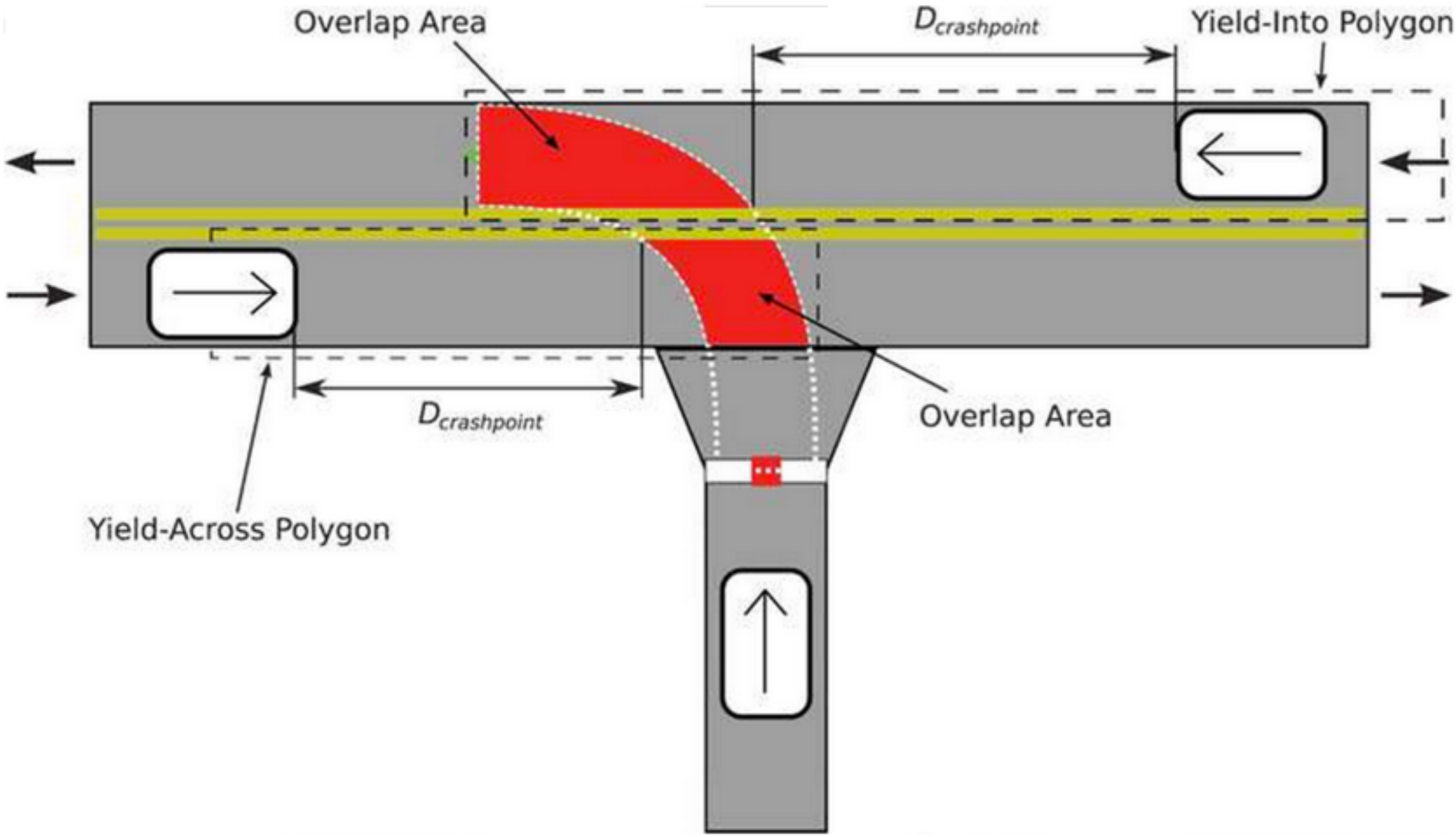
- Observes model of intersection
- Computes vehicle precedence
- Actively gathers data (movable sensors)
- Acts when has highest precedence

Precedence


Stop Line
Occupancy Polygon
1m
3m
1m
Intersection
Lane


Non-Occupants
Occupant

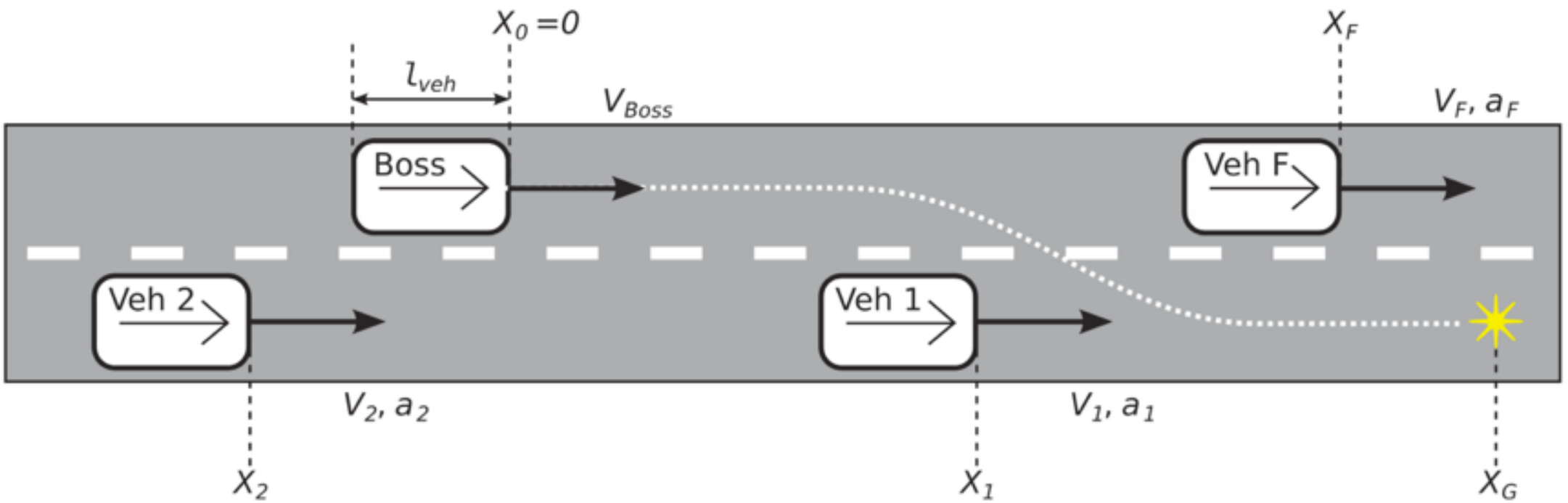
Precedence for Yielding



Distance Keeping

- Attempts to match the velocity of the vehicle in front of it
  - Positive acceleration proportional to velocity difference
  - Negative acceleration fixed parameter
- Maintain a desired vehicle gap
  - One car length per 10 mph, or minimum gap

Lane Merging



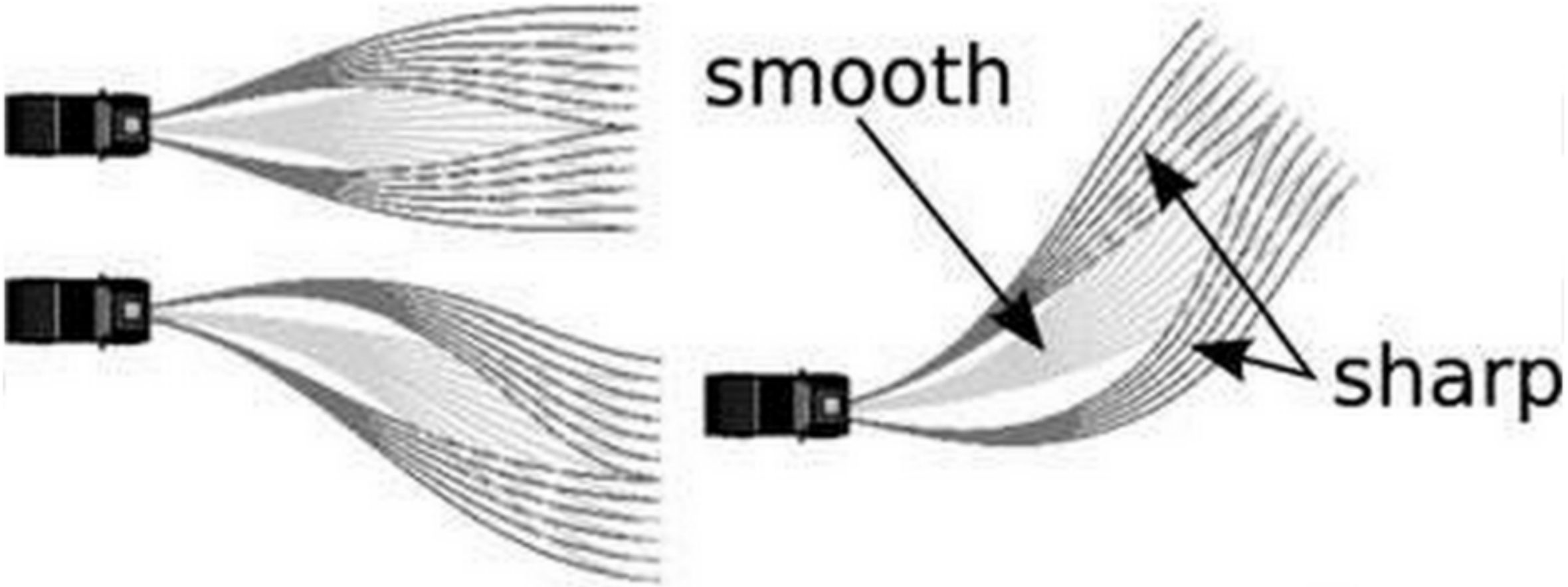
Motion Planning

- Structured
  - Lane following
  - Merging
  - Intersection handling
- Unstructured
  - Parking lot navigation
  - Error recovery (dead vehicle, fallen tree, etc)

Structured Motion Planning

- First a trajectory is constructed
  - Center line of lane
  - Virtual lane
  - Merging path
- Perturbations of trajectory planned
  - Smooth
  - Sharp

Perturbations of Trajectory



Trajectory Generation

- Howard, T.M., and Kelly, A. (2007). Optimal rough terrain trajectory generation for wheeled mobile robots. International Journal of Robotics Research, 26(2), 141–166.

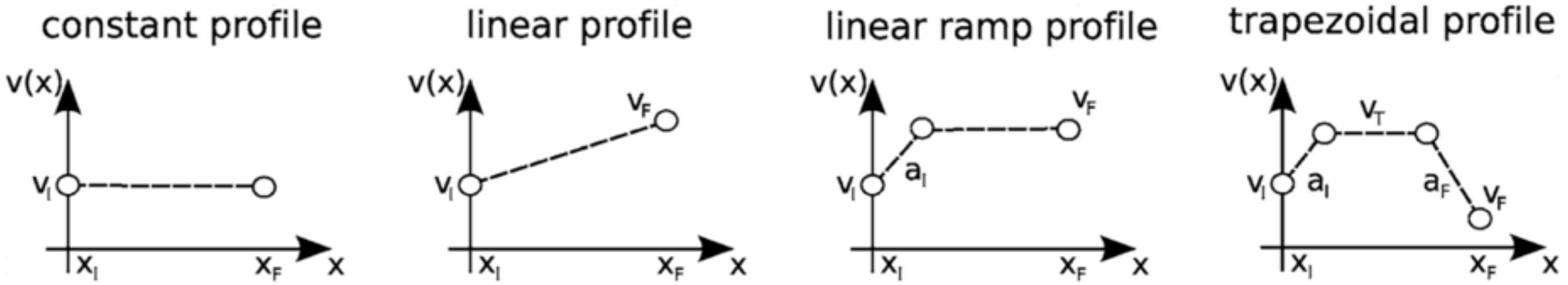
Trajectory Generation

- Vehicle model:
  - Curvature limit (minimum turning radius)
  - Curvature rate of change limit (how quickly the steering wheel can be turned)
  - Maximum acceleration and deceleration
  - Control input latency model

Trajectory Generation

- Boundary Value Problem
- Control parameterized
  - Velocity profiles
  - Spline parameters

Trajectory Generation



Trajectory Generation

- Initial trajectory is iteratively improved
  - Jacobian numerically evaluated in parameter space
  - Gradient decent
- Iterates until boundary constraints within threshold or divergence

Trajectory Evaluation

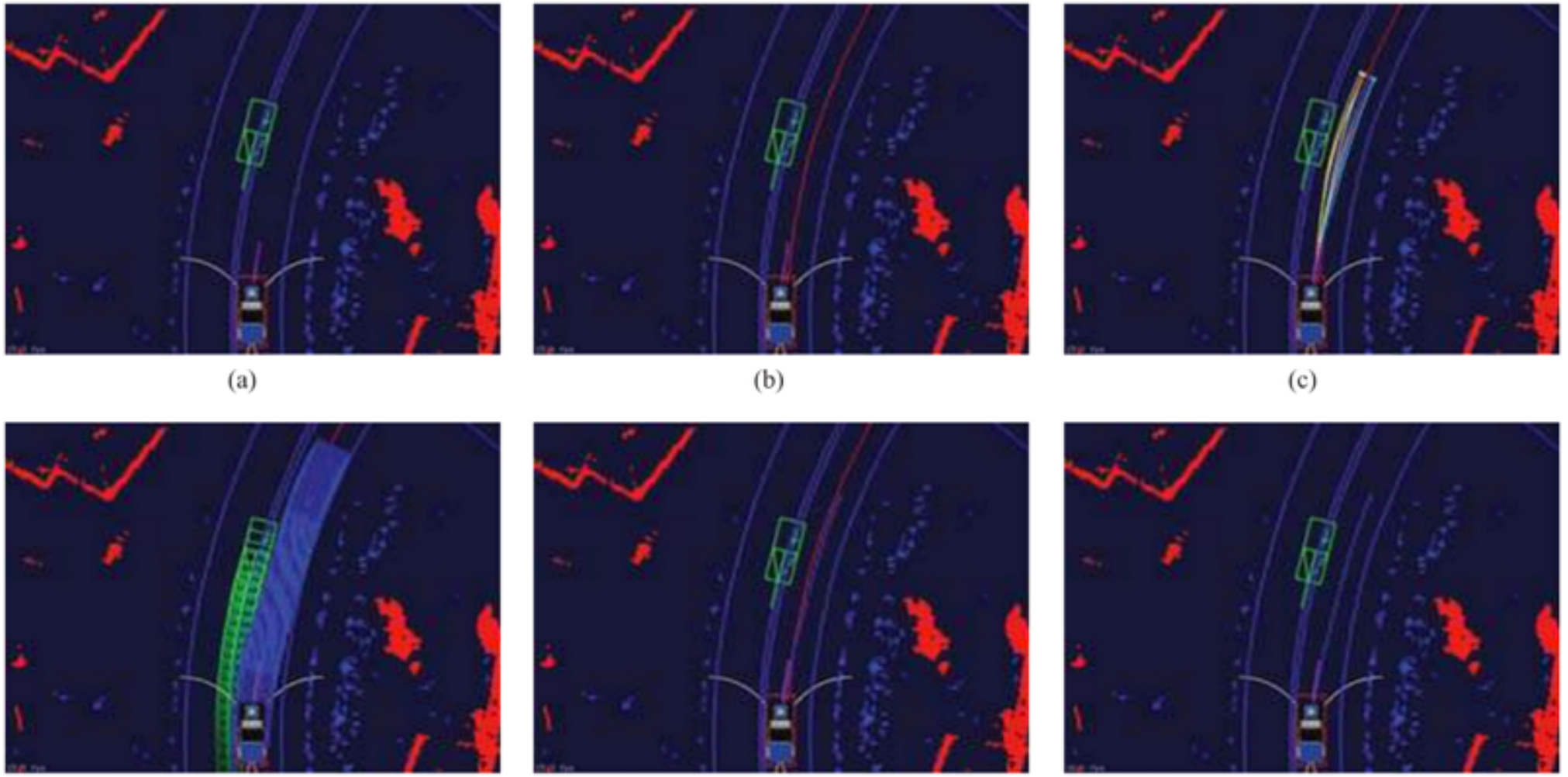


Figure 5. A single timeframe following a road lane from the DARPA Urban Challenge. Shown is the centerline path extracted from the lane (b), the trajectories generated to track this path (c), and the evaluation of one of these trajectories against both static and dynamic obstacles (d and e).

Unstructured Motion Planning

- Motion goal is pose within a zone

- No predefined paths

Lattice Planner

- 4D state space (x, y, θ, v)
- Anytime D*
- Likhachev, M., Ferguson, D., Gordon, G., Stentz, A., & Thrun, S. (2005). Anytime dynamic A*: An anytime,replanning algorithm. In Proceedings of the Fifteenth International Conference on Automated Planning andScheduling (ICAPS 2005), Monterey, CA. AAAI.

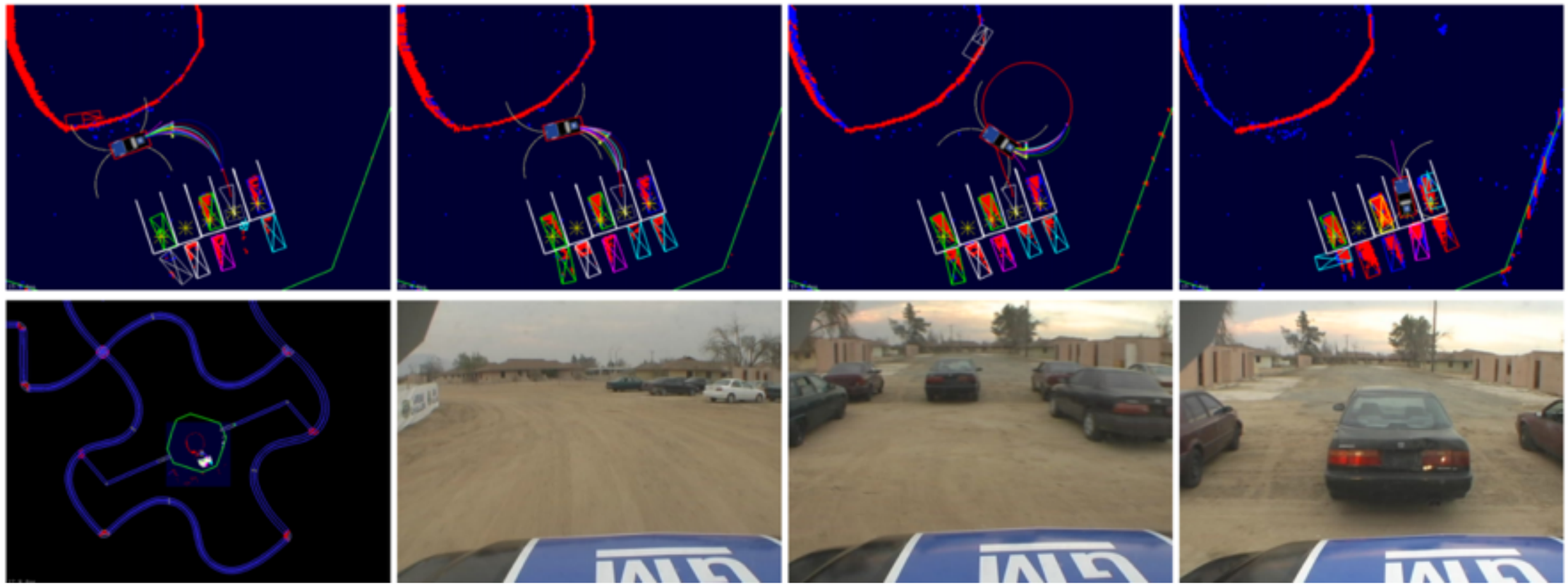
Anytime D*

- Uses a discretized (multi resolution) state/control space
- Heuristic search from goal pose to current pose
- Initial trajectory, improved over time with extra computation (bounds on sub optimality)
- Able to adapt to sensor input

Anytime D*

- Plans around static obstacles
- Bias paths away from dynamic obstacles
- Paths are followed using a similar local planner as structured motion planning presented earlier
- Leverage preplanning

Anytime D*



Anytime D*

- Also see:
  - http://www.cs.cmu.edu/~maxim/files/motplaninurbanenv_part2_iros08.pdf

Getting from Start to Goal

- Mission Planning
  - Adaptive high level graph search
- Behavioral Reasoning
  - State based reasoning system
- Motion Planning
  - Optimization or graph based, depending on environment

Thank You