**Robustly-Safe Automated Driving (ROAD) Systems**

Changliu Liu, Graduate Student Researcher; Masayoshi Tomizuka, Professor

---

### Layer 2: Learning and Decision Making

**The ROAD System**

- **Vision camera**
- **LiDAR**
- **Radar**

**Identification of moving objects / motion trajectories / signal etc.**

- **Layer 1: Sensor Fusion & Perception & Knowledge Representation**
  - Inertia sensor
  - GPS

- **Object dynamics (offline-learned)**

- **Logical / Computational**

- **Motor sensors**

<table>
<thead>
<tr>
<th>Physical</th>
<th>Layer 3: Vehicle Regulations &amp; Low Level Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS signal</td>
<td>Steering angle/brake/acceleration</td>
</tr>
</tbody>
</table>

**Layer 2: Learning & Decision Making**

- **Kinematic vehicle model**

- **Driving strategy / desired vehicle trajectory for collision avoidance**

- **Layer 3: Vehicle Regulations & Low Level Control**

**Efficiency:** Navigate to the destination in minimum time

- Moving Agents

**Road Condition Info**

- Reachable area under the baseline controller
- Safe region in real time
- Predicted course for the yellow car
- Predicted course for the blue car
- Predicted course for the pink car

**Safety:** Interact with surrounding vehicles properly

- Predict the future course for each surrounding vehicle (learning and prediction);
- Find a trajectory in the safe region (decision making).

---

### The Multi-Agent System

- **Decision Maker & Controller**

- **Motor Dynamics**

- **Automated Vehicle**

- **Stationary Obstacles and Road Condition**

**Steady State Behavior**

- Behavior 1 (B1): Lane Following
- Behavior 2 (B2): Lane Changing to the Left
- Behavior 3 (B3): Lane Changing to the Right
- Behavior 4 (B4): Lane Merging
- Behavior 5 (B5): Lane Exiting

**Exiting Behavior**

**Learning and Prediction**

- **Classifier (From offline learning)**

- **Model Selection**
  - Model 1: Features 1, Coefficients 1
  - Model 2: Features 2, Coefficients 2
  - Model N: Features N, Coefficients N

**Update coefficients**

**Prediction**

**The transition model**

**Steady State**

- Behavior 1 (B1): Lane Following
- Behavior 2 (B2): Lane Changing to the Left
- Behavior 3 (B3): Lane Changing to the Right
- Behavior 4 (B4): Lane Merging
- Behavior 5 (B5): Lane Exiting

**The probability of lane changing rises since the lateral speed is nonzero.**

**After observing lane changing, the probability of lane following rises.**

---

### The Optimization Problem in Decision Making

1. **Solve the optimal control problem without the safety constraint**
2. **Check if the resulting trajectory violates the safety constraint**
3. **If no, execute the resulting trajectory**
4. **If yes, modify the trajectory to make it safe**

---

### Procedures in solving the optimization problem:

1. Solve the optimal control problem without the safety constraint
2. Check if the resulting trajectory violates the safety constraint
3. If no, execute the resulting trajectory
4. If yes, modify the trajectory to make it safe

---

### Case Study

#### Case 1: A stationary obstacle

- The vehicle starts to decelerate and change lane.
- Lane following with constant speed

#### Case 2: A slow front vehicle

- The vehicle starts to change lane when it encounters a slow vehicle.

#### Case 3: Overtaken by a fast vehicle

- The vehicle slows down to let the fast vehicle cut in.
- The vehicle keeps a safe distance from the fast vehicle.

**Objectives:** speed tracking and lane following, e.g., the cost function penalizes 1) the deviation from the desired speed and 2) the deviation from the lane center (the target lane center is subject to change according to different strategies).

**Safety constraint:** the distance \( d \) between the automated vehicle and the front and rear vehicles on the same lane should be greater than \( d_{\text{min}} \).

\[
\hat{\phi} = r_{\text{min}} - d
\]