Cooperative vs Non-Cooperative Autonomous Driving

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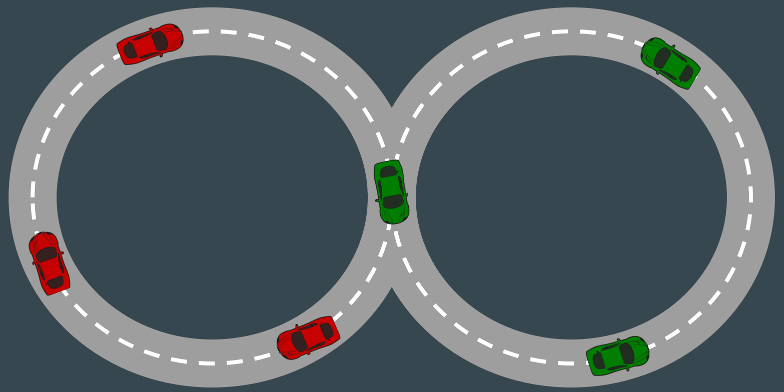
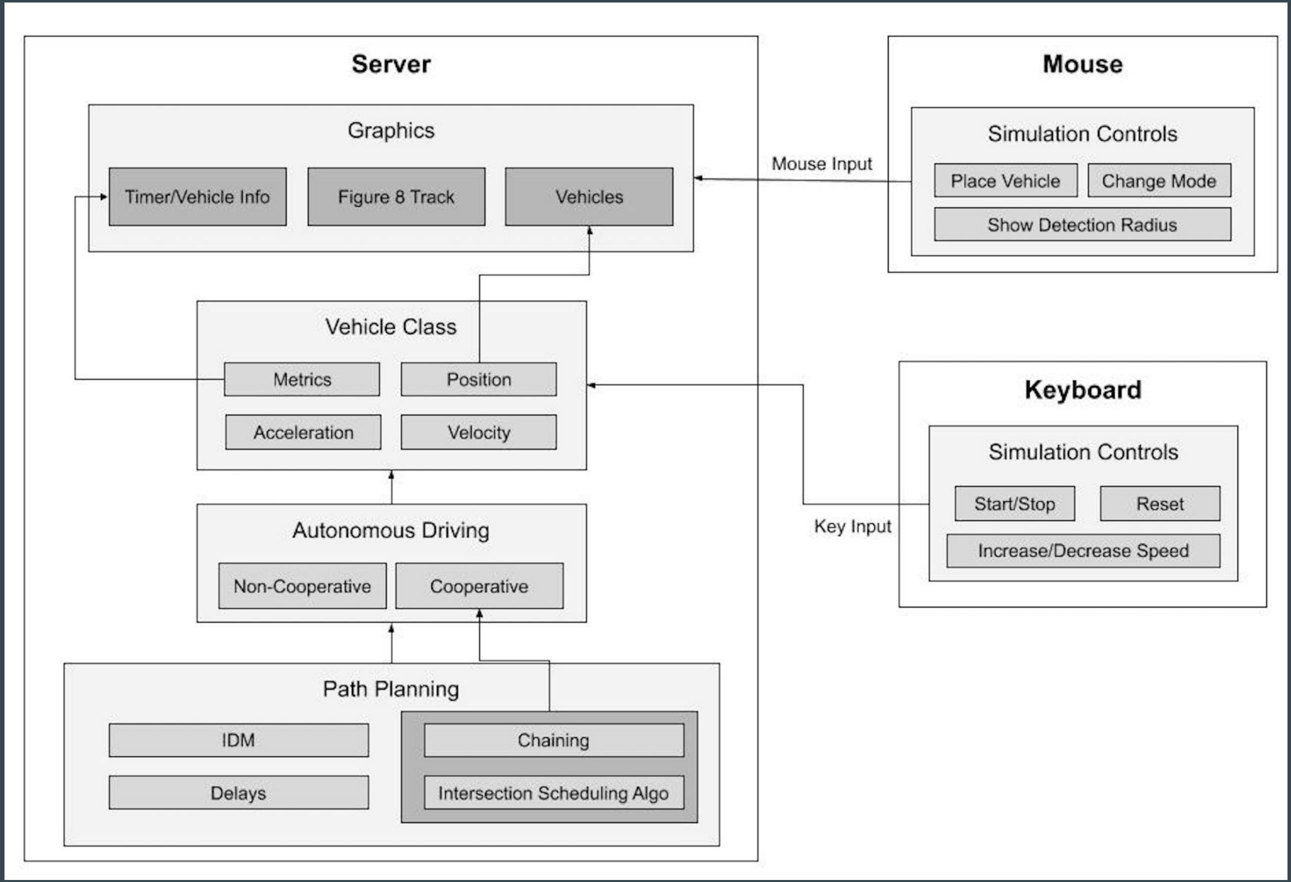
Problem

- Simulate non-cooperative vs cooperative autonomous driving
- Experiment with different scenarios of cars moving in circles on a figure-8 track
- Compare performance between approaches
- **Our solution:** Software-based simulation
  - Customizable setup mode
  - Testing mode
    - Average velocity
    - Average acceleration/deceleration
    - Waiting time
    - Total throughput



Solution Design



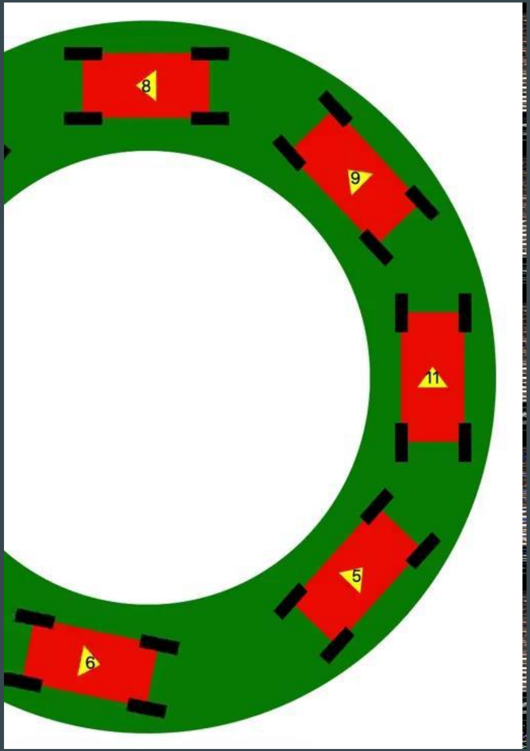
Intelligent Driver Model (IDM)

- Defines a vehicle's acceleration based on distance to nearest obstacle, difference in velocity, etc.
- Chose realistic numbers for parameters and converted to pixels using scale

$$s^\star(v, \Delta v) = s_0 + Tv + \frac{v \Delta v}{2\sqrt{\alpha\beta}}.$$

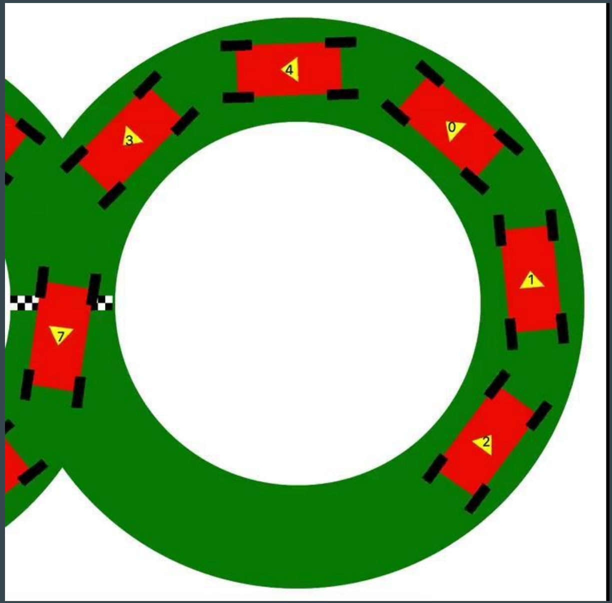
$$a_{\mathrm{IDM}} = \alpha \left[1 - \left(\frac{v}{v_0} \right)^{\delta} - \left(\frac{s^\star(v, \Delta v)}{s} \right)^2 \right]$$

Parameter	**Value**
Optimal Velocity	0.3 m/s
Max. Accel.	0.3 m/s^2
Max. Decel.	0.2 m/s^2
Buffer Distance	7 m

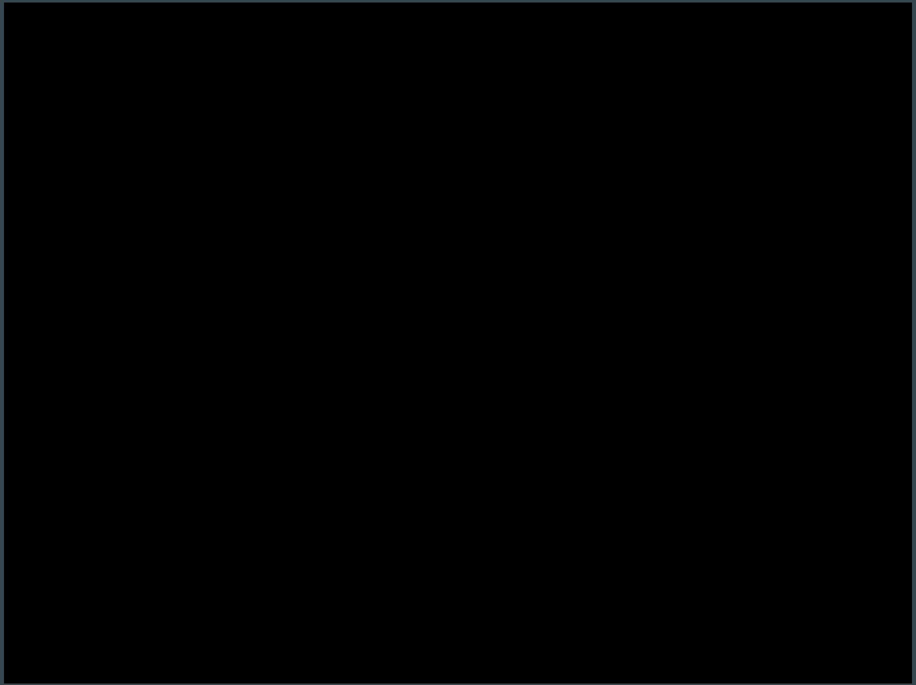


Cooperative Framework

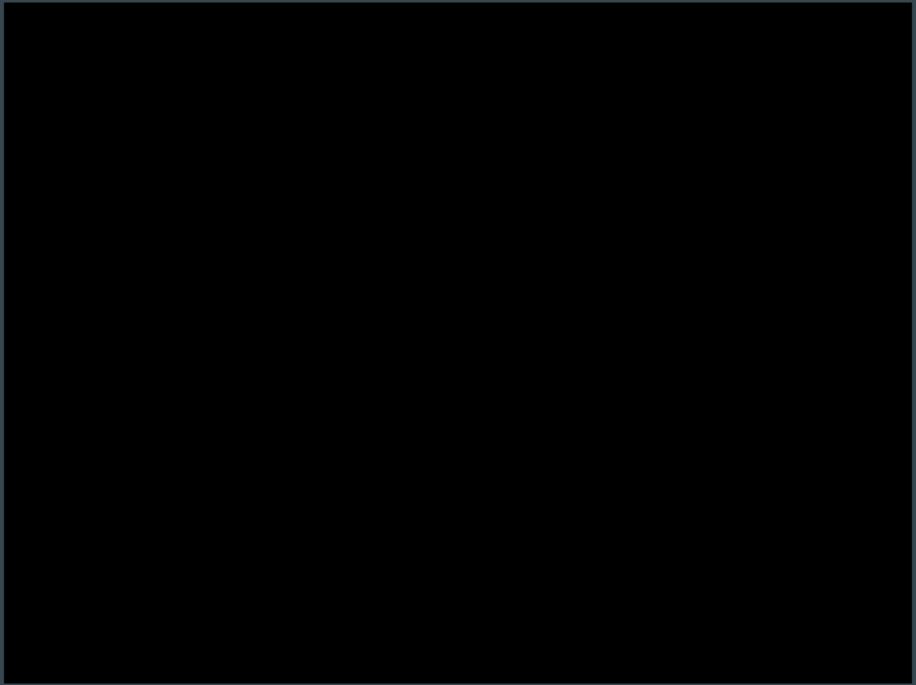
- Car Chaining
  - Communication allows for closer following distance
  - Accelerate/decelerate at same rate as lead vehicle
- Intersection Scheduling Algorithm
  - Vehicles communicate length of queue
  - Priority is assigned to each lane based on a weighted combination of features
  - Aims to allow multiple cars from one lane to pass the intersection



Cooperative



Non-Cooperative



Design Trade-Offs

- Figure 8 Demo vs 2-Lane Track
  - Focus on optimizing, only using start/stop
- Central scheduler
  - Avoids the need for distributed consensus/decision making
  - Requires Roadside Units (RSUs) when scaling to real world usage
- Multi-vehicle passage
  - Reduces delays from acceleration/deceleration
  - Tradeoff between fairness and throughput

Testing

- 50 test cases were randomly generated (9 - 13 vehicles per test, 40 seconds each)
- Internal simulation time was decoupled from system time
  - Simulation graphics were turned off
  - Testing ran much faster and results outputted to a .csv file
- Metrics
  - Throughput was measured by checking every time vehicles passed the intersection line
  - Velocity was recorded at every iteration and averaged
  - Acceleration/deceleration were also recorded at every iteration and averaged
  - Acceleration/deceleration counts frequency of vehicle acceleration/deceleration
  - Waiting time was measured when a vehicle’s velocity was 0 and averaged amongst vehicles

Results

- **30.33%** increase in throughput in cooperative vs non-cooperative case

	Non-Cooperative	Cooperative	% Change
Avg Velocity	0.094 m/s	0.121 m/s	↑ 28.23%
Avg Acceleration	0.0024 m/s^2	0.0032 m/s^2	↑ 31.25%
Avg Deceleration	0.024 m/s^2	0.043 m/s^2	↑ 77.08%
Avg Acceleration Counts	515.77	195.22	↓ 62.15%
Avg Deceleration Counts	1497.5	1463.3	↓ 1.29%
Avg Waiting Time	8.79 s	4.93 s	↓ 43.88%
Total Loops	2305	3004	↑30.33%

Requirements

- 30% increase in throughput ✔️
- 30% increase in average velocity ❌ *(28.23% increase)*
- 30% decrease in waiting time ✔️
- 15% decrease in acceleration ❌ *(31.25% increase)*
- 15% decrease in deceleration ❌ *(77.08% increase)*

But we observed decreases in acceleration/deceleration counts

Takeaways

- More advantageous with denser tracks
    - Not much contention for the intersection with a sparse car population
- Higher acceleration/deceleration
    - Vehicles reach optimal velocity more often (higher change in velocity)
- Lower waiting time
    - Chaining removes intermediate delays between vehicles in a chain
    - Multiple vehicles allowed to pass intersection at a time
    - Lane with longer queue is prioritized

Project Management

Task breakdown

- Graphic simulation
- Intelligent Driver Model
- Cooperative Framework

Remaining tasks

- Create video
- Final Report