August, 2020

Training A Spatial Graph With Expert Human Driver Log Data

Summer 2020 Intern Project - Planning Team, Motional

Intern: Tianyi Gu

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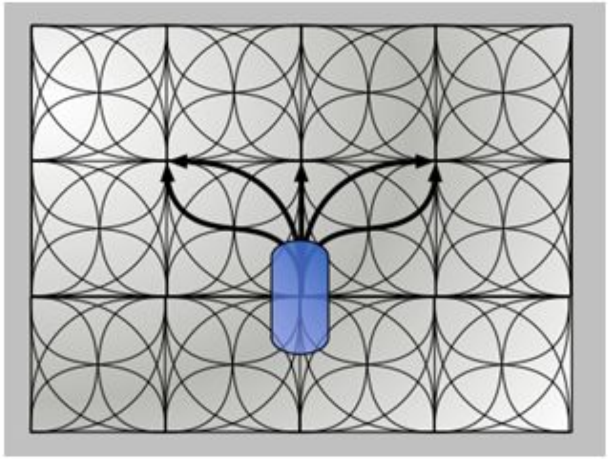
Content

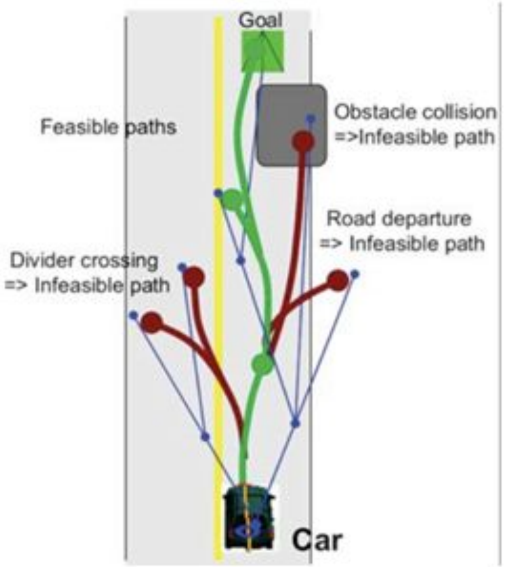
The Problem - Background

Lattice-based Planner



Pivtoraiko & Kelly 2005

Sampling-based Planner



Leonard et al. 2008

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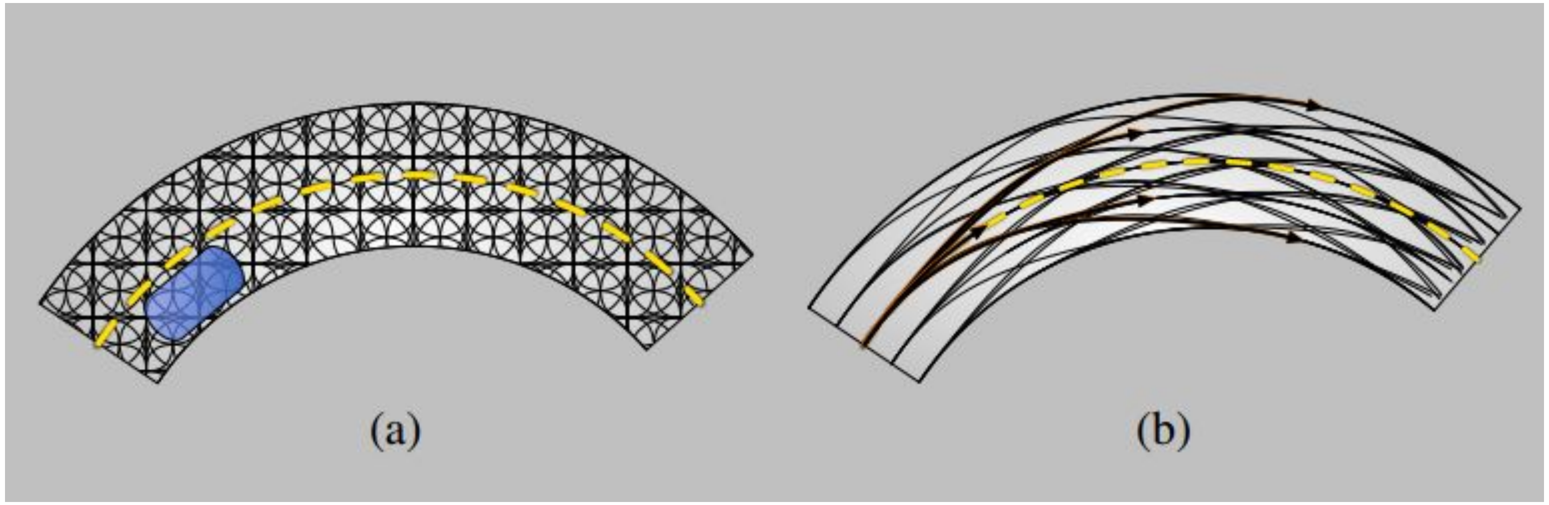
The Problem - Background

Lattice-based Planner

Spatial-Temporal Graph Search

SE(2) Graph Generation



Many edges in the left lattice are not useful !

The Problem - SE(2) Graph Generation

In this project, we want to find a principled way to generate SE(2) graph.

We want to answer following questions:

1. How dense should the SE(2) graph be?
2. Where should we put the vertices?
3. How to connect vertices?

Maximize

Diversity / Coverage

Minimize

Node count / Edge count

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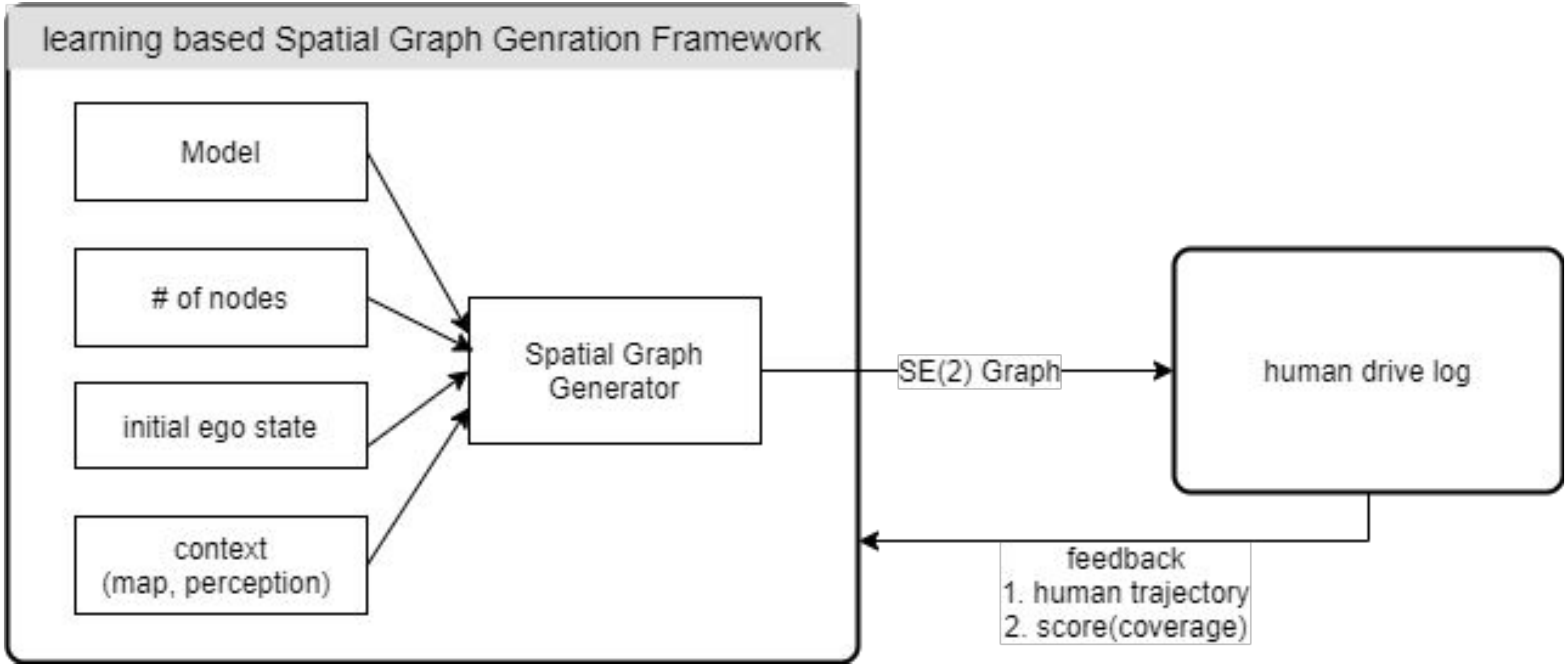
Our Approach - Learning A SE(2) Graph From Human Driver



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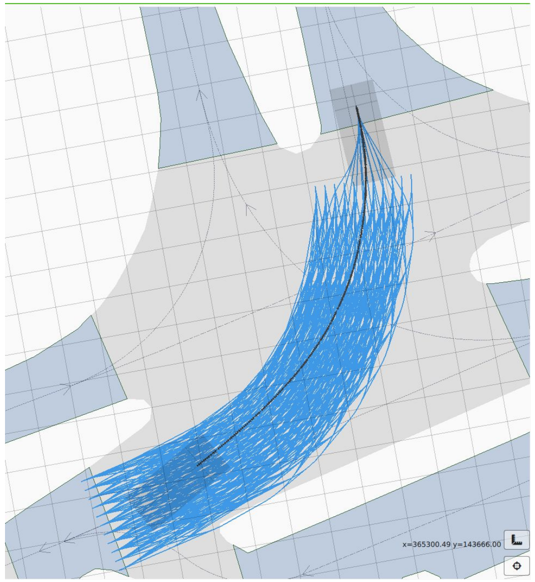
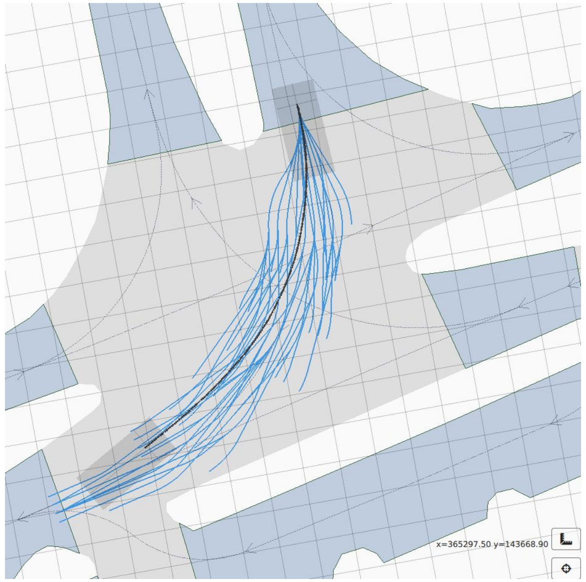
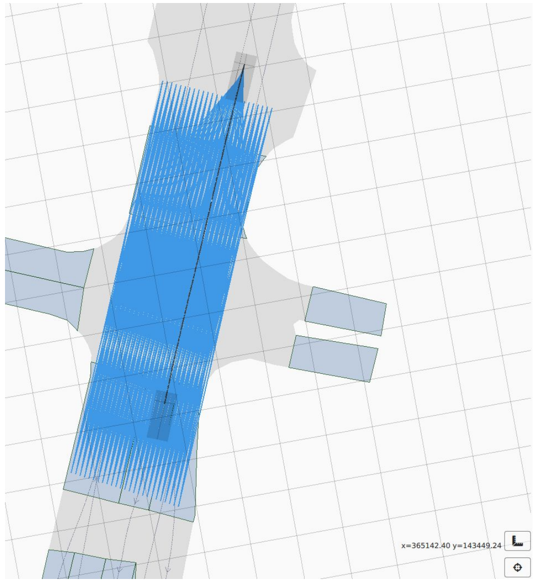
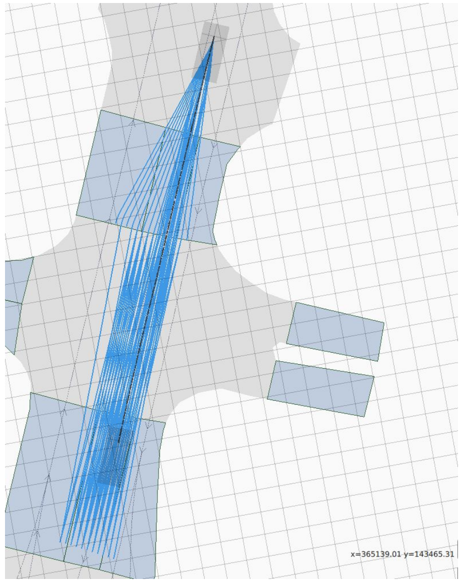
The Problem - SE(2) Graph Generation

- Less nodes, less edges
- High coverage on expert human trajectories

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Our Approach - Learning A SE(2) Graph From Human Driver

- Initial Graph Generation
- Training Data Preparation
- Train a SE(2) Graph with Human Drive Data

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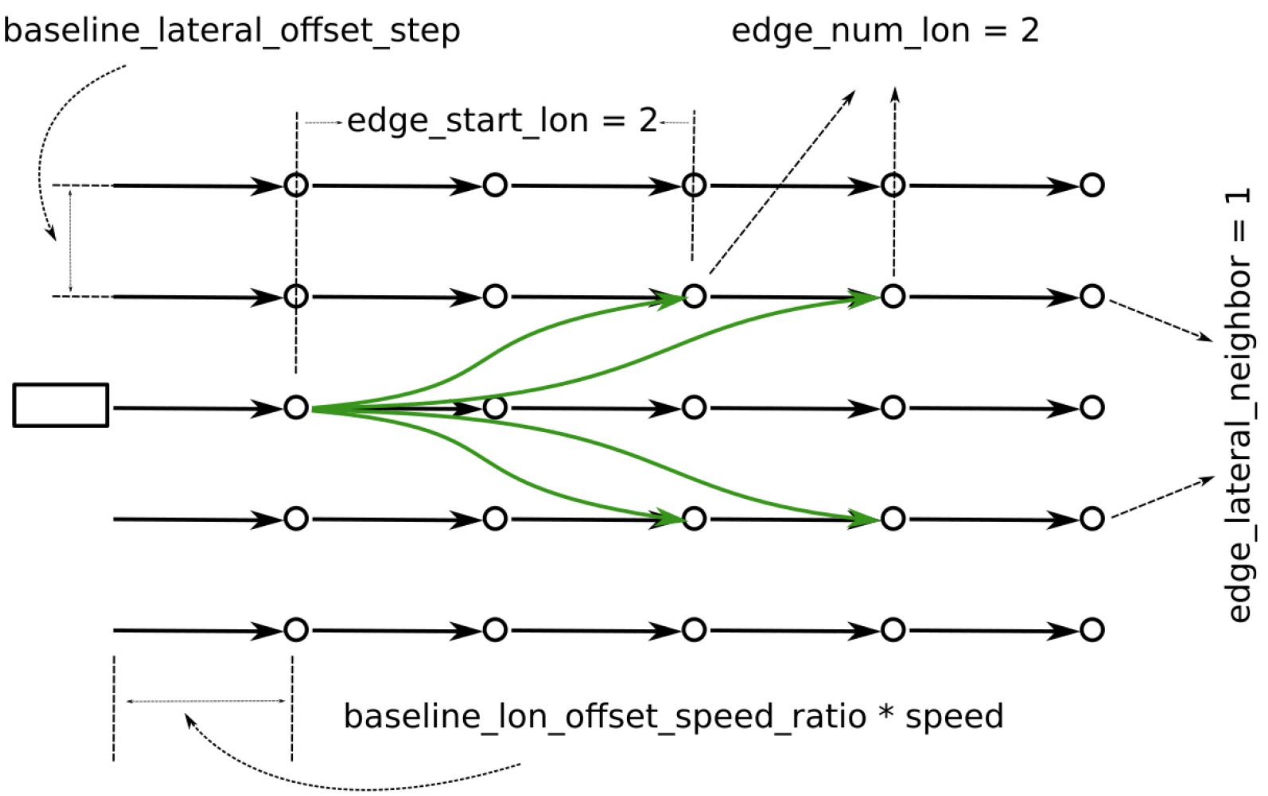
Our Approach - Learning A SE(2) Graph From Human Driver

- Initial Graph Generation - structured connection



parameter	value	unit
baseline_lon_offset_speed_ratio	4	-
baseline_lateral_offset_step	0.5	m
edge_start_lon	2	vertices
edge_number_lon	2	vertices
edge_lateral_neighbor	1	neighbor lines each direction

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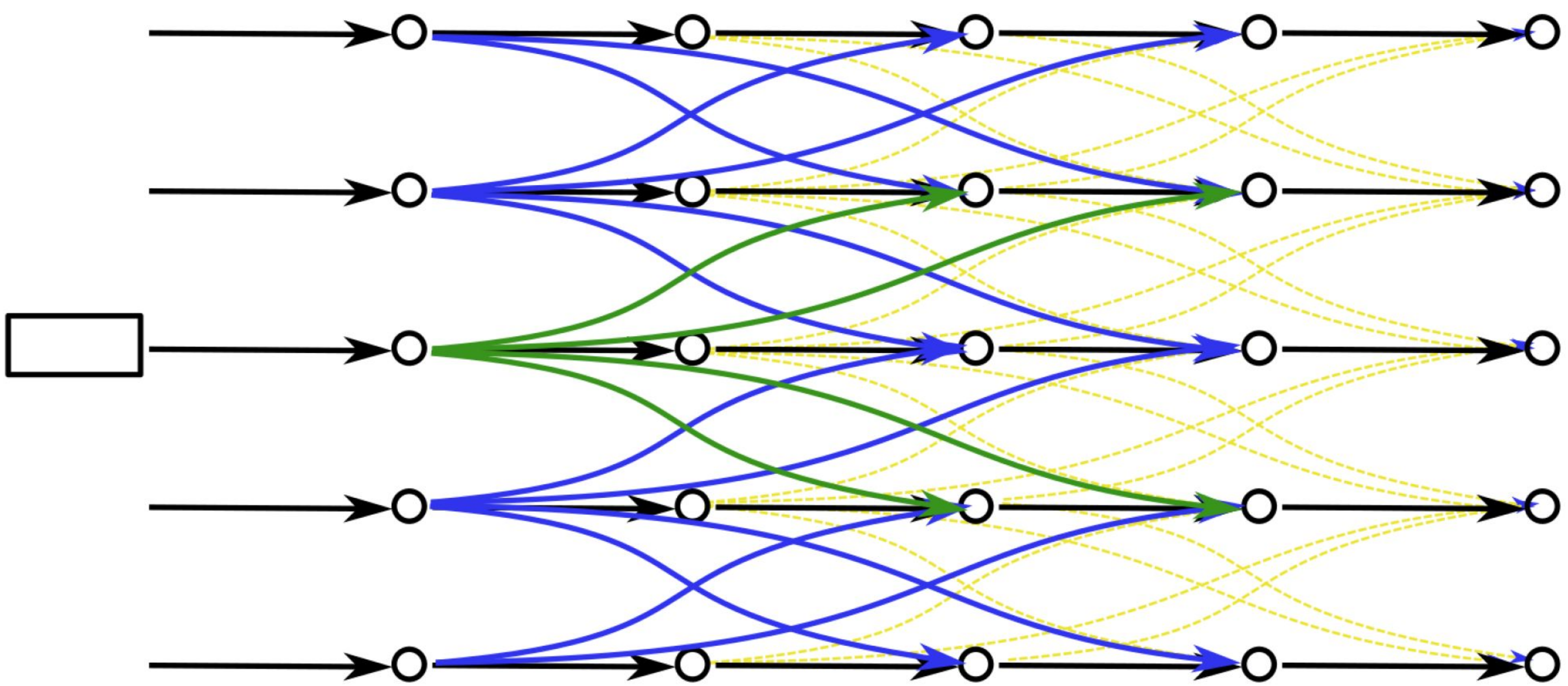
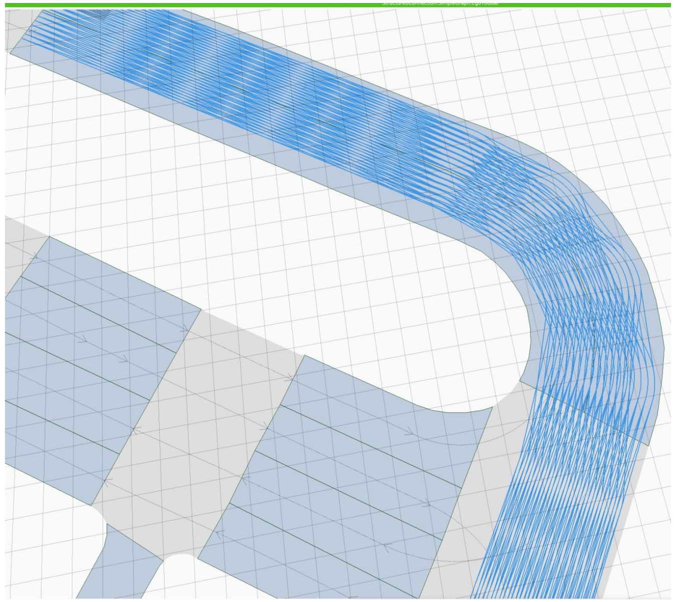
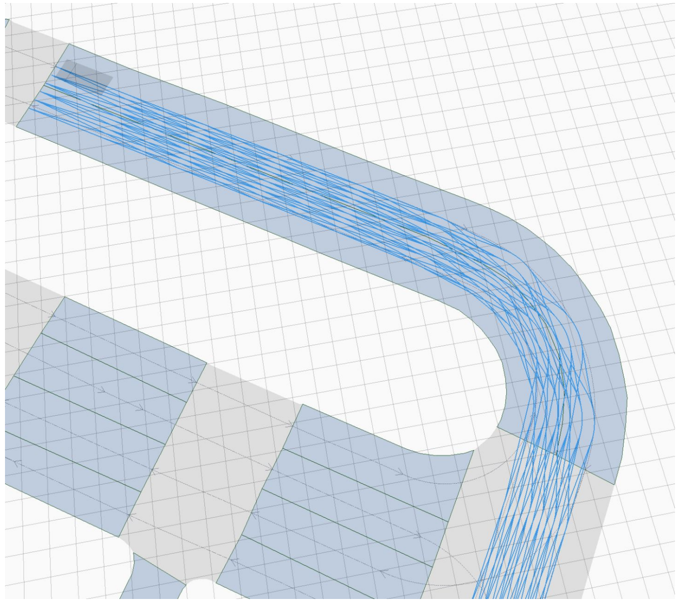
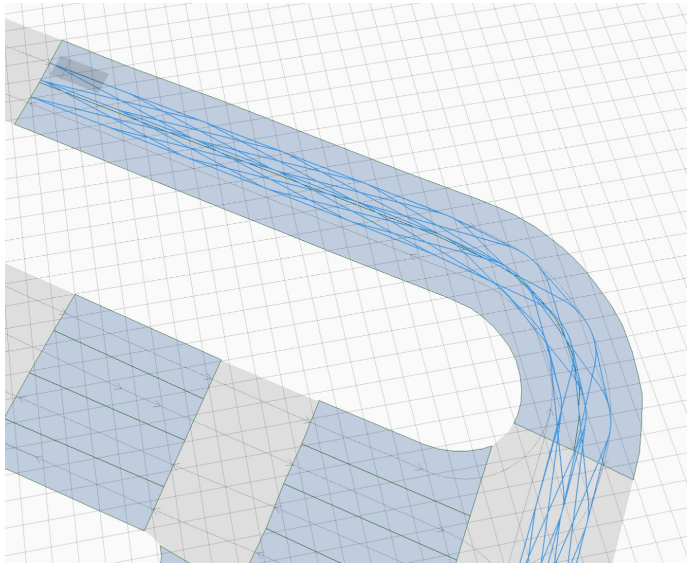
Our Approach - Learning A SE(2) Graph From Human Driver

- Initial Graph Generation - structured connection



Our Approach - Learning A SE(2) Graph From Human Driver

- Initial Graph Generation - How to choose candidate graph?

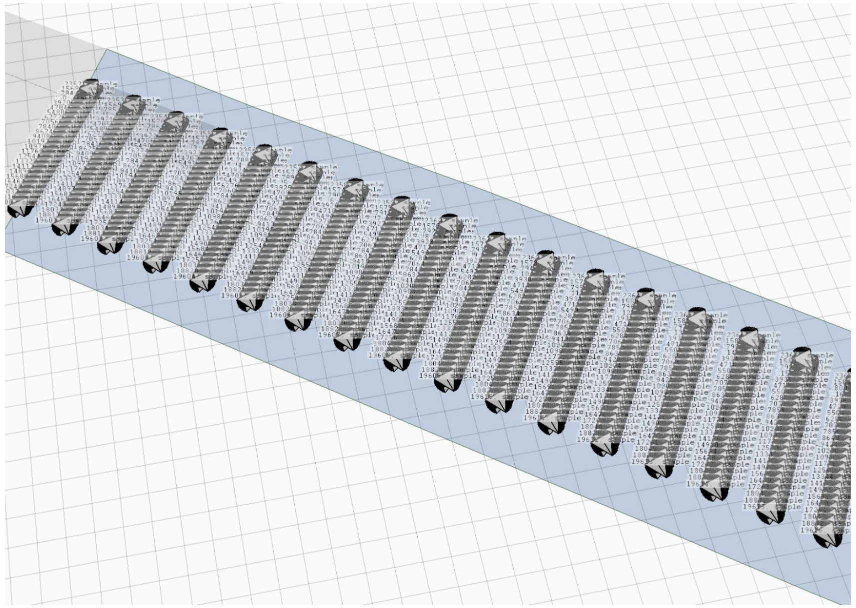
density = high	density = median	density = low
		

Our Approach - Learning A SE(2) Graph From Human Driver

- Initial Graph Generation - How to choose candidate graph?

  uniform sample-based evaluator

  cover samples as much as possible but still keep the graph size small



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Our Approach - Learning A SE(2) Graph From Human Driver

- Initial Graph Generation - How to choose candidate graph?

uniform sample-based evaluator

SE2 distance function: Weighted SE2 distance

$$d(s, g) = w1 \cdot \|s_{linear} - g_{linear}\|_{L_2} + w2 \cdot \|s_{angular} - g_{angular}\|_{L_1}$$

We set w1 = 1, w2 =2.

This means 3 degree off on heading is about equally important as 10 cm off on 2D map.

(0.05 rad is as important as 0.1 m)

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Our Approach - Learning A SE(2) Graph From Human Driver

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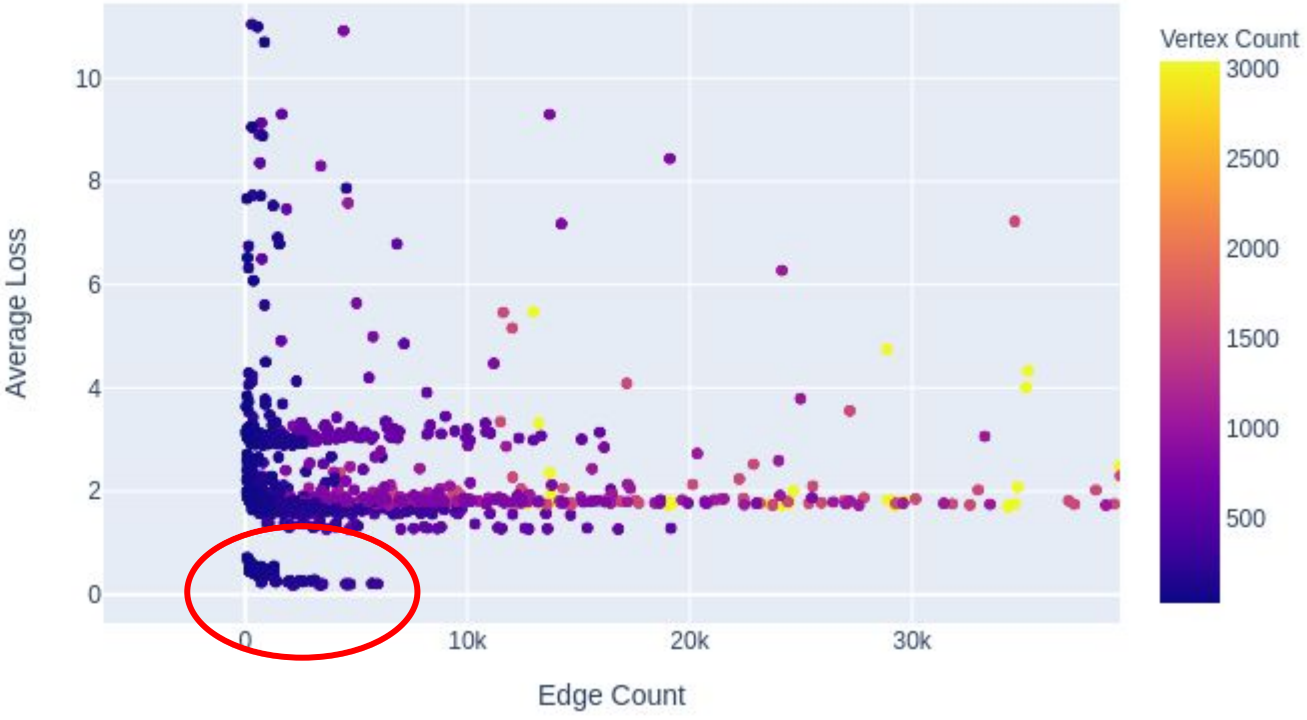

parameter	tested value	unit
baseline_lon_offset_speed_ratio	*1, 2, 3, 4, 5*	-
baseline_lateral_offset_step	*0.1, 0.5, 1, 2*	m
edge_start_lon	*1, 2, 3*	vertices
edge_number_lon	*1,2,3,4,5*	vertices
edge_lateral_neighbor	*1,2,3,4,5*	neighbor lines each direction

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Our Approach - Learning A SE(2) Graph From Human Driver

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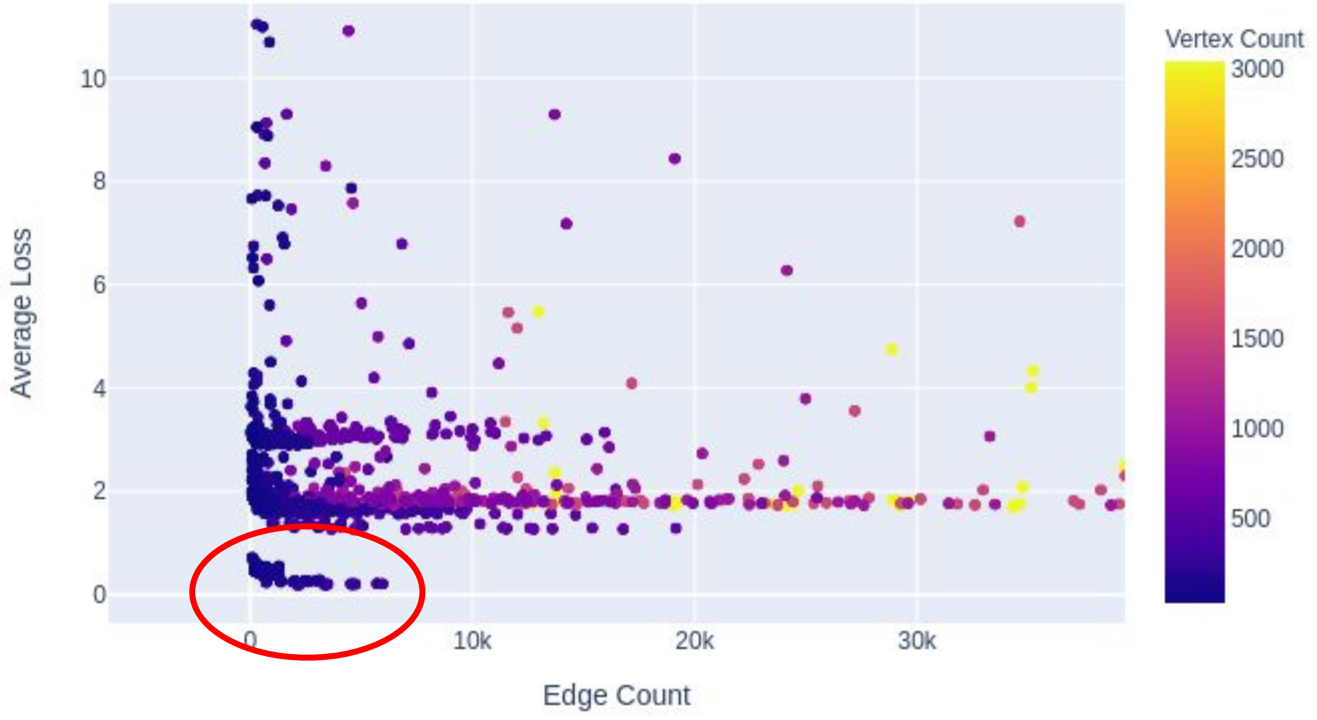

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edge_lateral_neighbor	2	neighbor lines each direction

Our Approach - Learning A SE(2) Graph From Human Driver

- Initial Graph Generation
- Training Data Preparation
- Train a SE(2) Graph with Human Drive Data

Our Approach - Learning A SE(2) Graph From Human Driver

- Training Data Preparation
  - OneNorth Expert Driver_Log
  - contain 30 hours of AV data in Singapore
  - convert from legacy coordinates to UTM coordinates, so it can work with avmap and avtest
  - split log into planning problem instances
  - planning instances are saved as JOSN files


```
{
    "init_ego_pose": [
      1151.808874255592,
      393.9706090933266З,
      1.2096617576737891
    ],
    "init_ego_velocity": 3.3481582460510673,
    "goal_ego_pose": [
      1170.8830955458552,
      414.6584417187234,
      0.9328866715163339
    ],
    "log_name": "n013-2019-06-17-14-19-46+0800",
    "init_timestamp": 1560752396183863,
    "duration": 5,
    "ego_path": [
      [
        1151.808874255592,
        393.97060909332663,
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      ],
      [
        1151.8681950012576,
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        1.199778708367397
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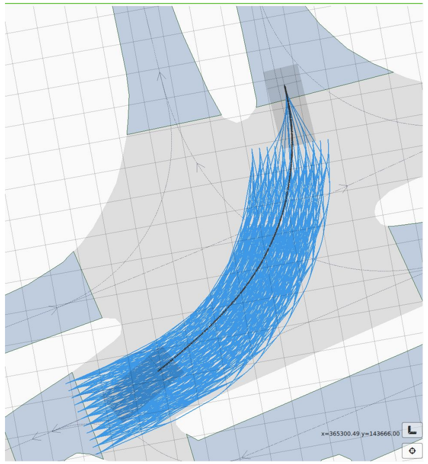
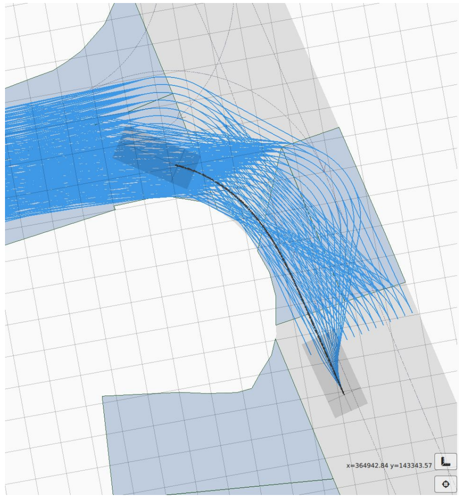
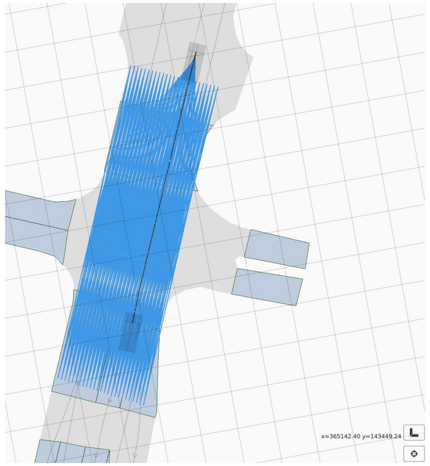


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Our Approach - Learning A SE(2) Graph From Human Driver

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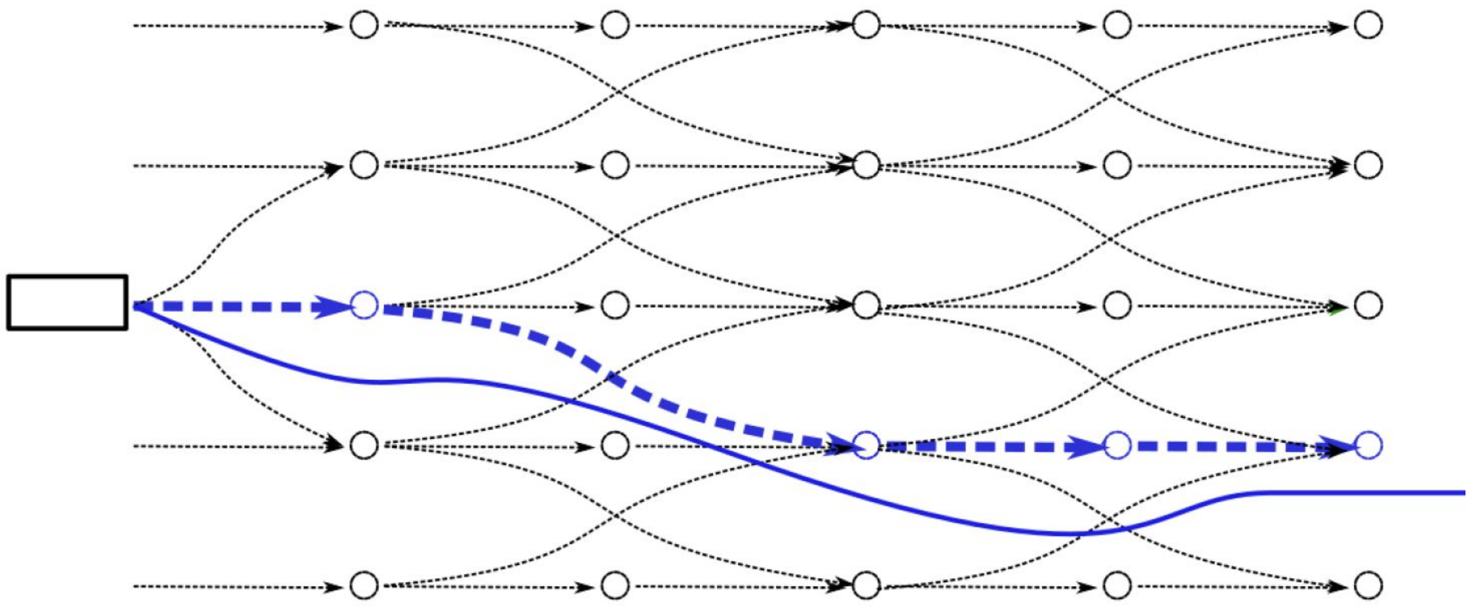
Our Approach - Learning A SE(2) Graph From Human Driver

- Train a SE(2) Graph with Human Drive Data
  - Loss computator : given a graph and a human trajectory, what is the loss between the best reproduced trajectory and the human trajectory?



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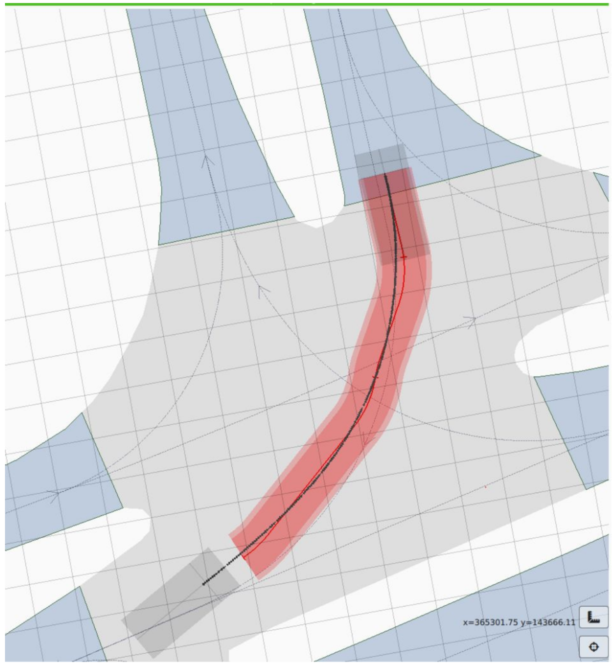

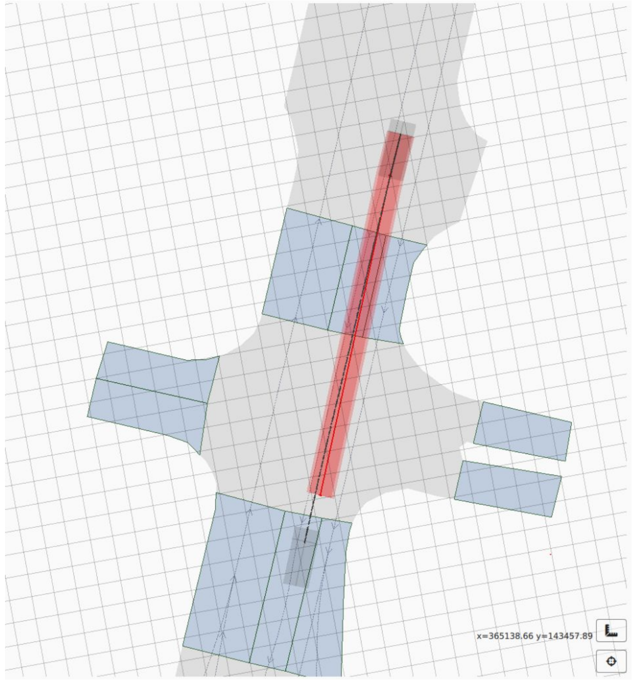

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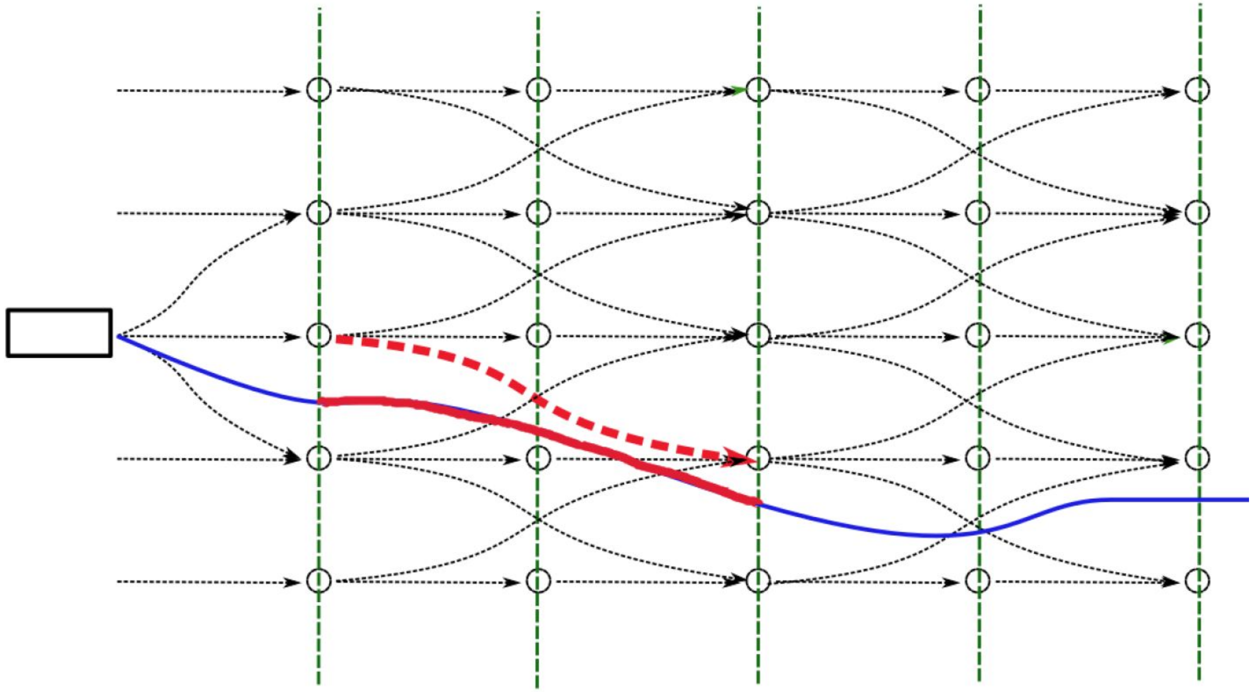
Our Approach - Learning A SE(2) Graph From Human Driver

- Train a SE(2) Graph with Human Drive Data
  - Loss computator : Dijkstra with edge loss as cost
  - Edge Loss:



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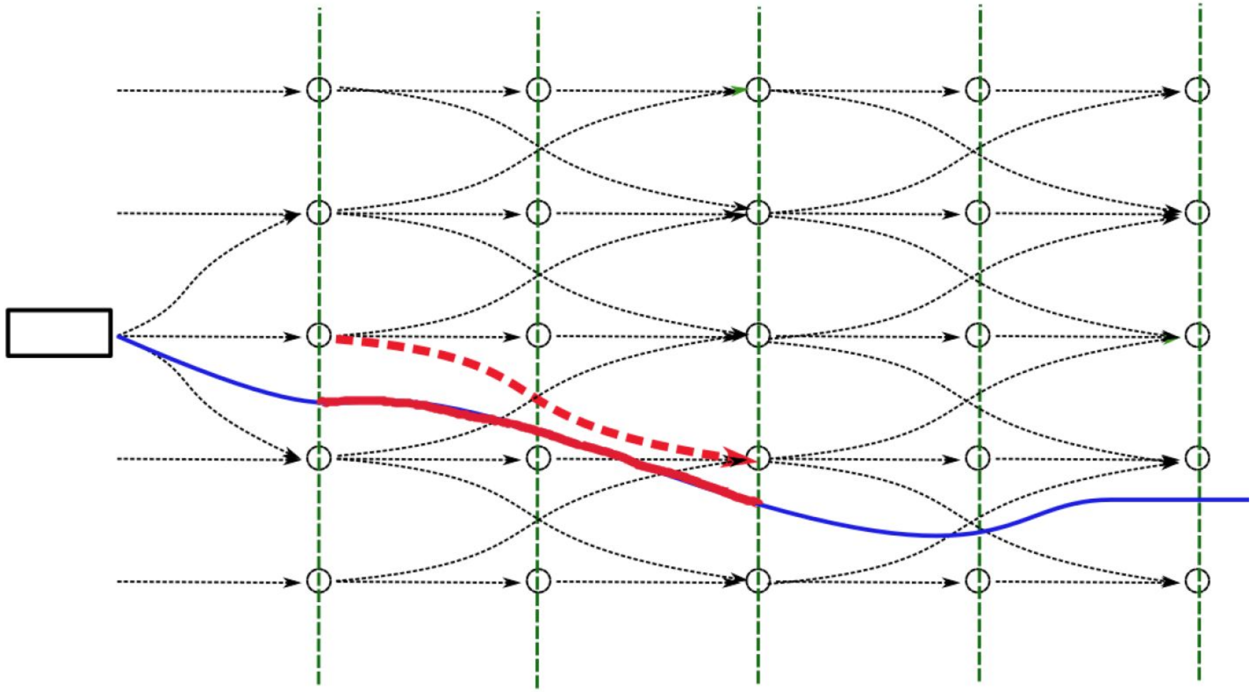

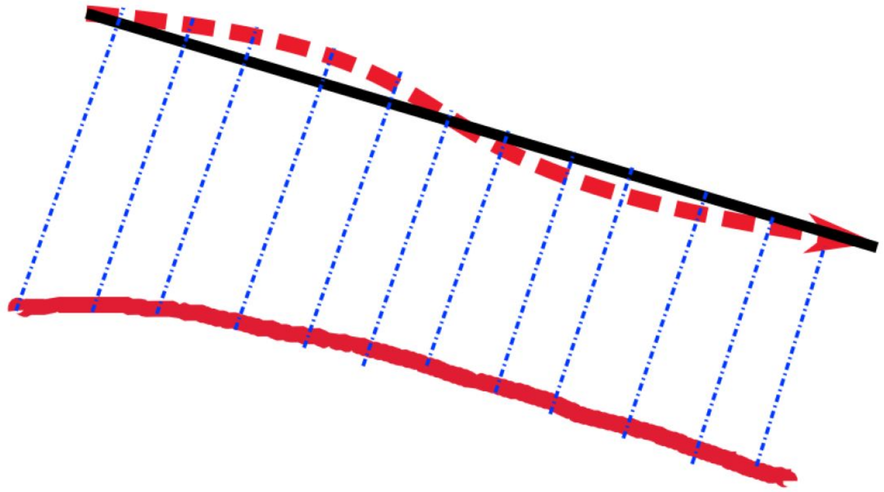

Our Approach - Learning A SE(2) Graph From Human Driver

- Train a SE(2) Graph with Human Drive Data
    - Loss computator : Dijkstra with edge loss as cost
    - Edge Loss
    - Score of the graph, Score of each edge

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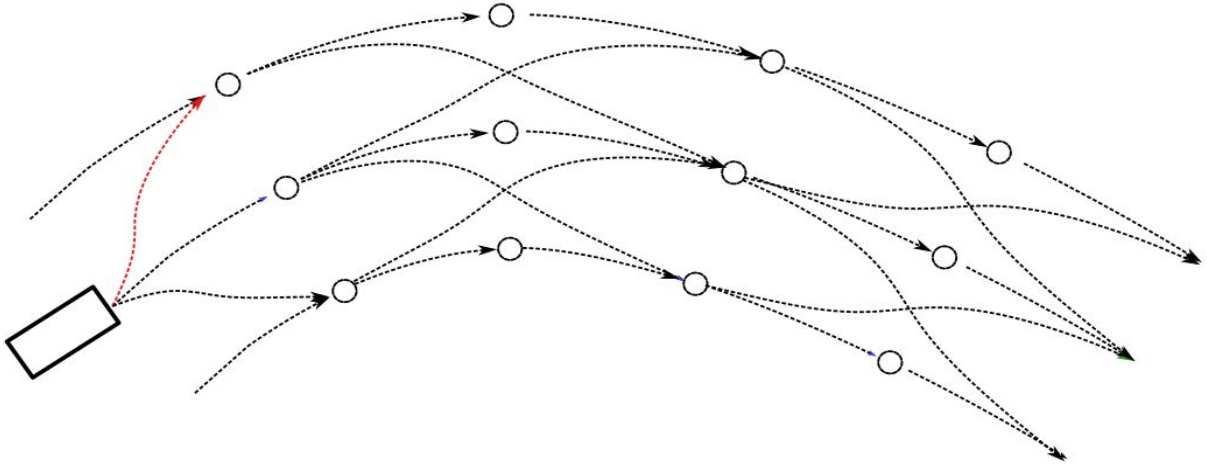
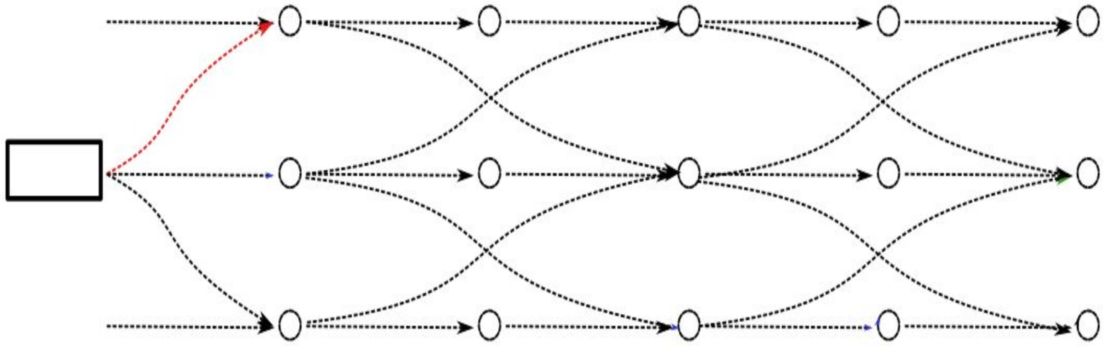
Our Approach - Learning A SE(2) Graph From Human Driver

- Train a SE(2) Graph with Human Drive Data
  - Loss computator : Dijkstra with edge loss as cost
  - Edge Loss
  - Score of the graph, Score of each edge
  - Abstract graph





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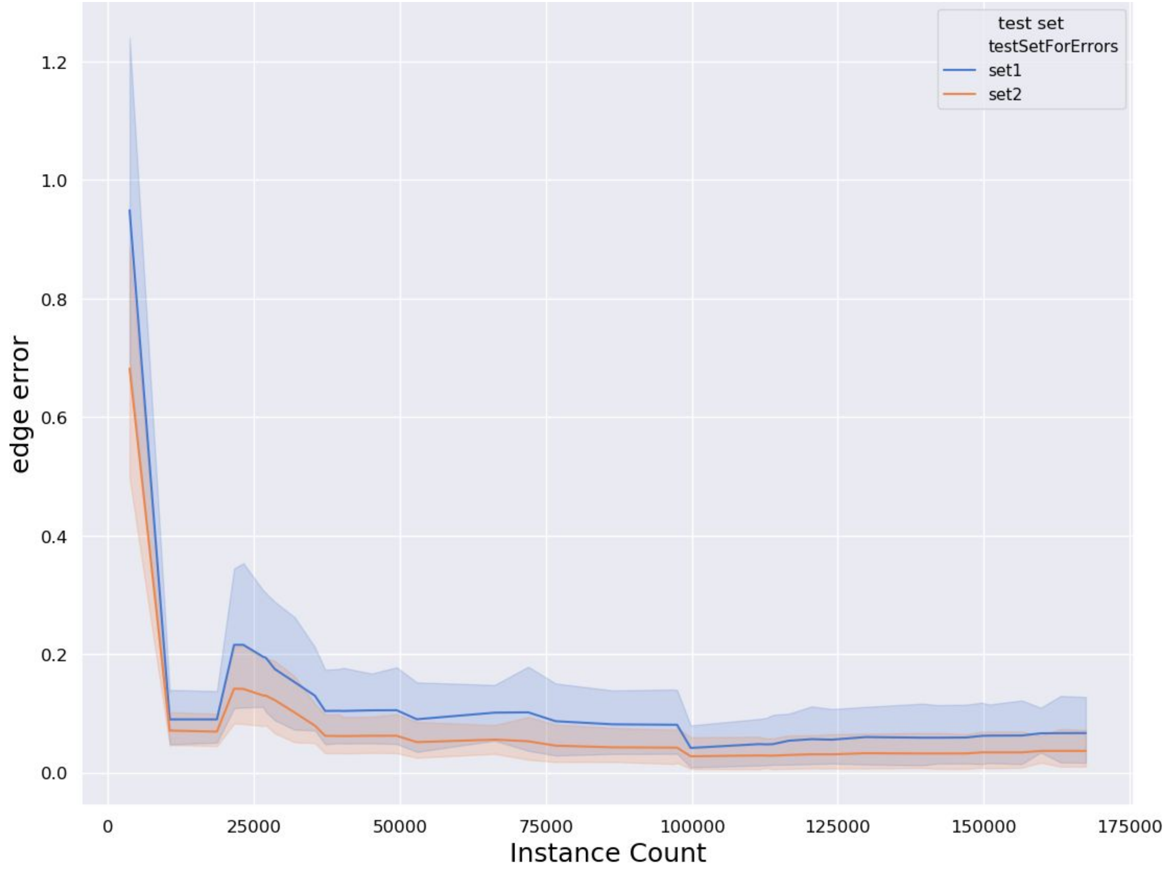
Results and Discussion

- Results
- Takeaways
- Limitations

Results - Edge Loss Prediction



Metrics:

- **mean**
- median
- min
- 95 percentile
- used in best trajectory

prediction error converge on test set

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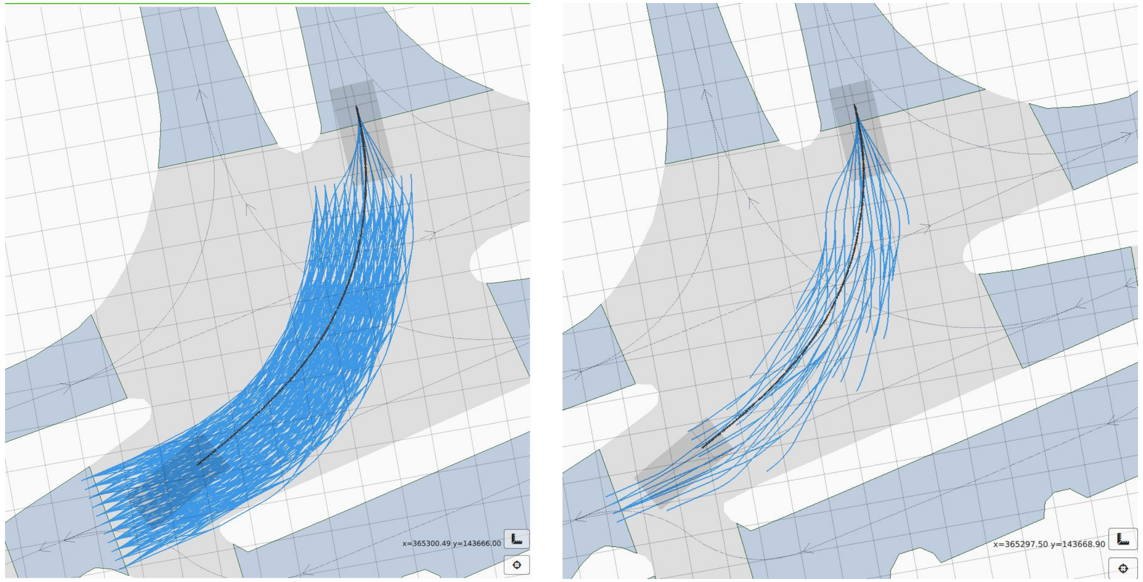
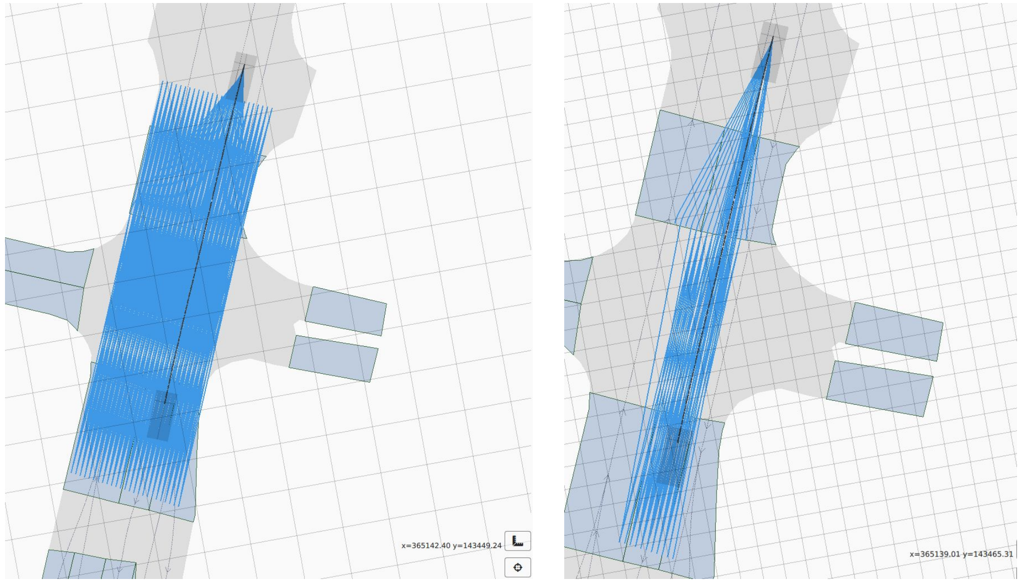
Results - Graph Pruning



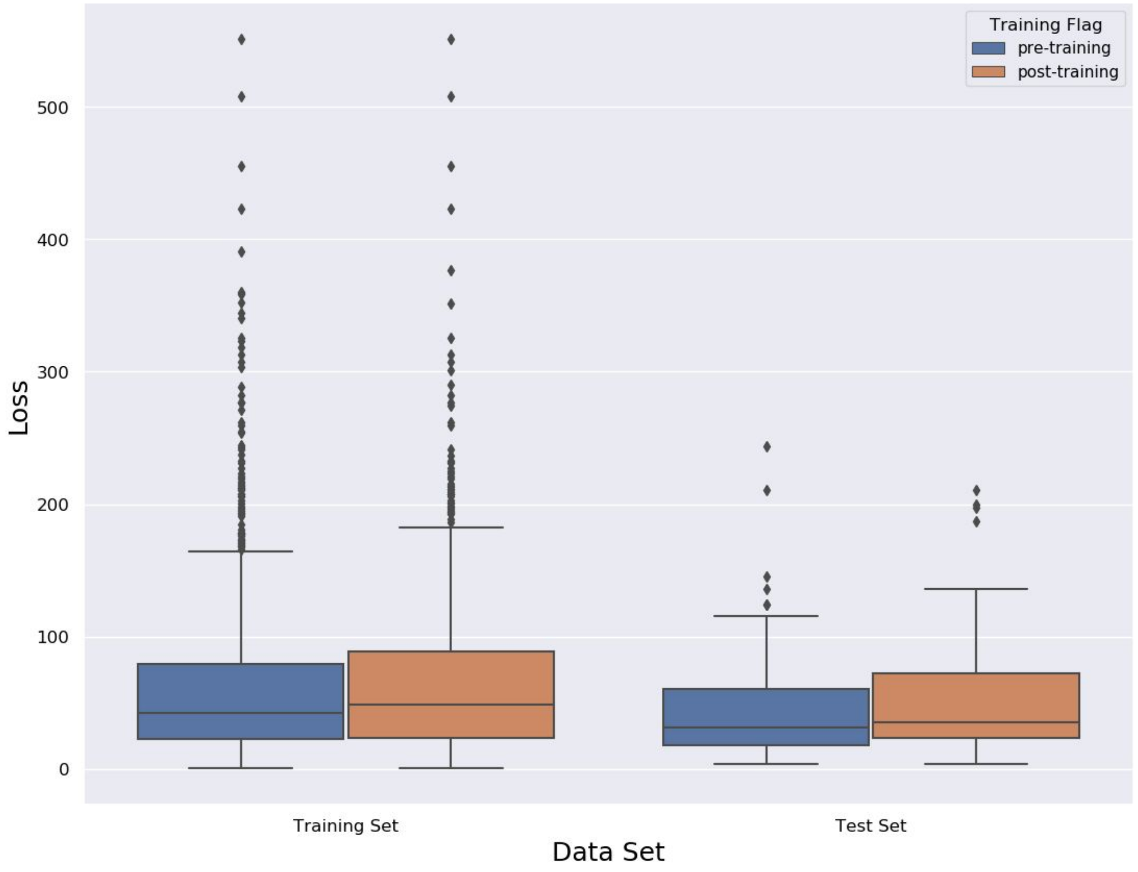
90.5% pruned



79.6% pruned

Many useless edges are pruned

Results - Overhead on Loss



Not much overhead on loss

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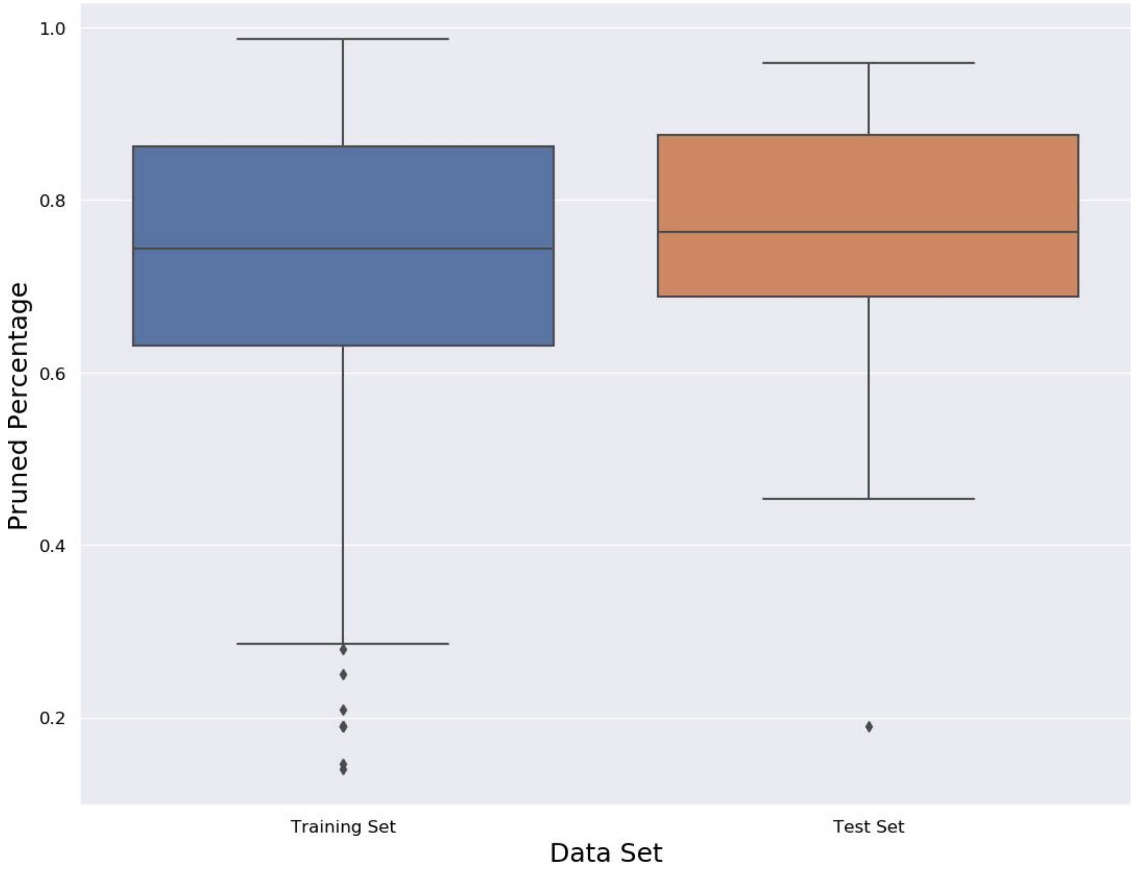
Results - Graph Pruning



~78% of the edges are pruned

Results - Takeaways

- This approach enable the graph size reduction without compromising the performance
- Utilizing drive logs has the potential to inform the planner

Results - Limitations

- Low speed and stop scenarios are not supported
- The graph coverage is limited by the dataset
- Temporal dimension of the drivers' decision is learned implicitly

What’s Next

- Test the graph generator with a S-T planner
- Write a patent/paper about the discovery