Motional

IROS October 2022

# Leveraging ML for Vehicle Control in Academia and Industry

Nathan Spielberg, PhD

Senior Engineer, Motional

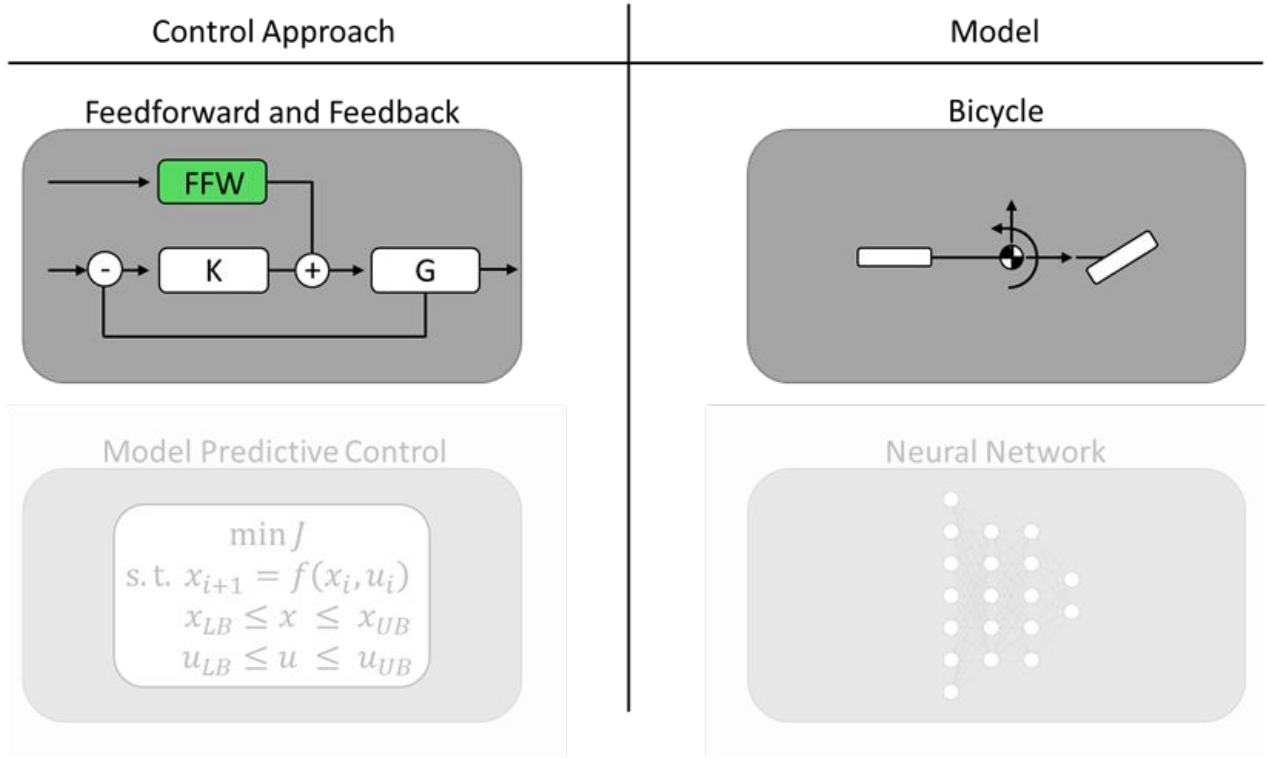
# Stanford Dynamic Design Lab

- MS 2017, PhD 2021 (Prof. J. Christian Gerdes)
- Vehicle dynamics and control
- Automation near the vehicle's handling limits
- **Leveraging Data for Vehicle Control Near the Limits**

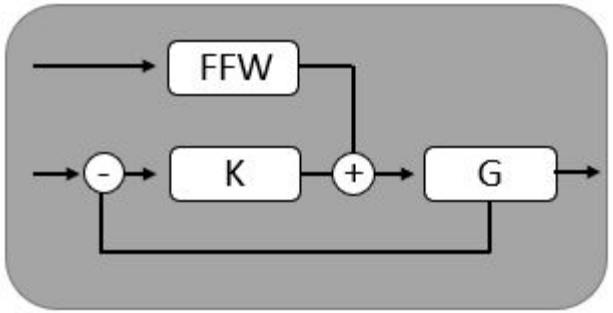
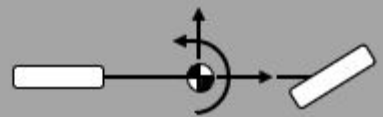
# How Can We Leverage Data to Allow Self-Driving Cars to Operate Near The Limits?

# Contribution Roadmap

1. **Learning Feedforward Controls  for Racing**
2. Learning Neural Network Vehicle Models
3. Using Neural Network Models in Model Predictive Control



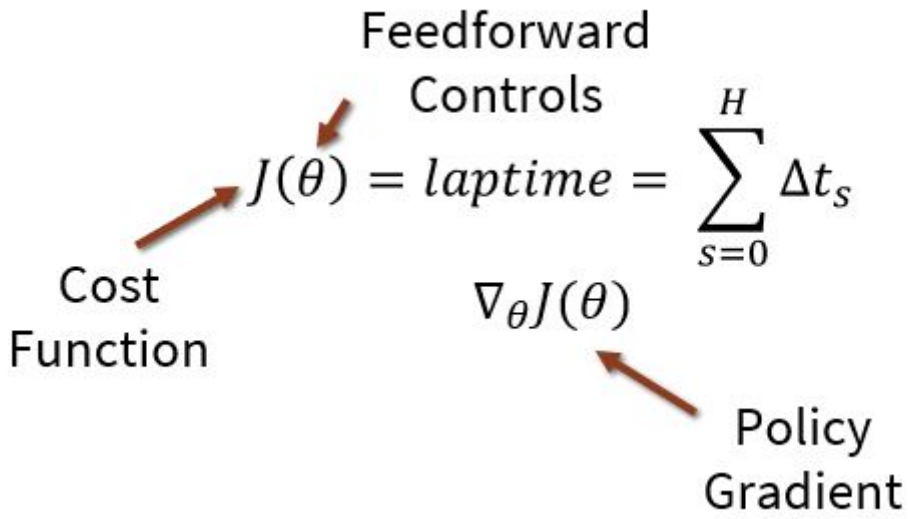
# FFW + FB Approach Comparable to Skilled Amatuer

| Control Approach | Model |
| --- | --- |
| Feedforward and Feedback | Bicycle |
|   |  |
| Model Predictive Control | Neural Network |
| $\min J$<br>$\text{s.t. } x_{i+1} = f(x_i, u_i)$<br>$x_{LB} \leq x \leq x_{UB}$<br>$u_{LB} \leq u \leq u_{UB}$ |  |

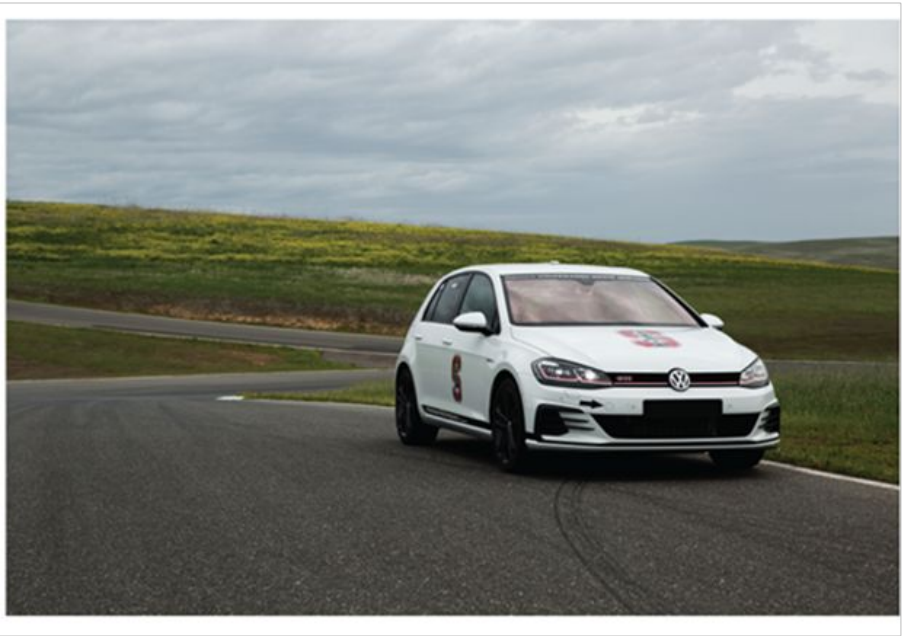
Spielberg et al. Science Robotics 2019

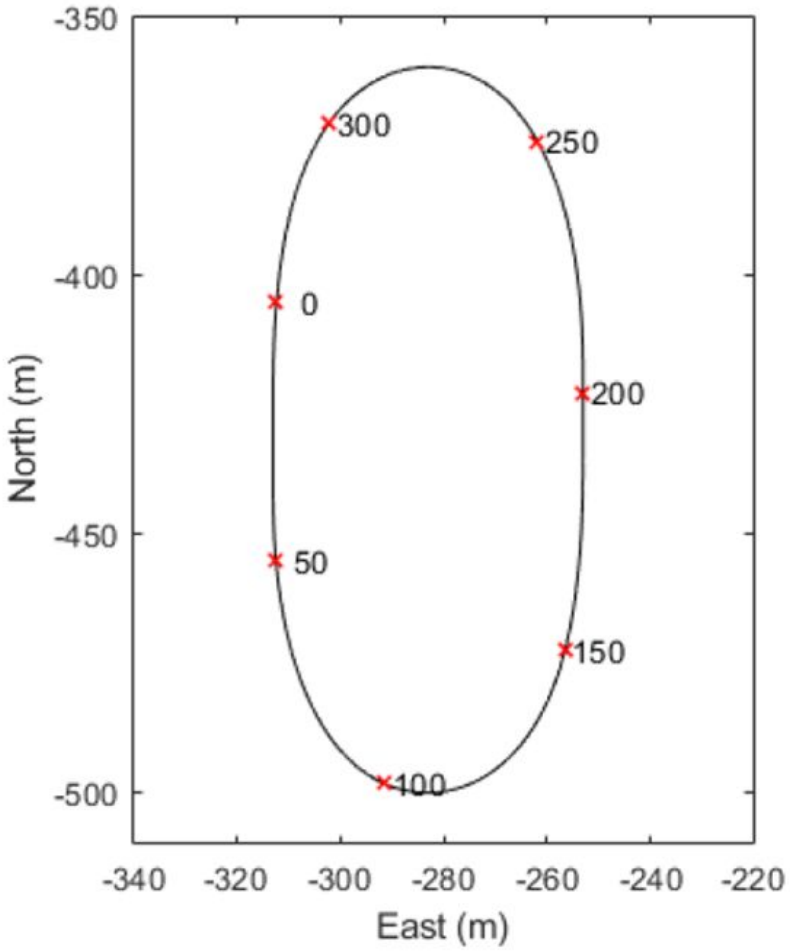
# Model-Based Policy Search

- Skilled drivers are incredibly data efficient
- Have an idea of the vehicle's model
- Optimize for lap time
- Use data to improve lap after lap

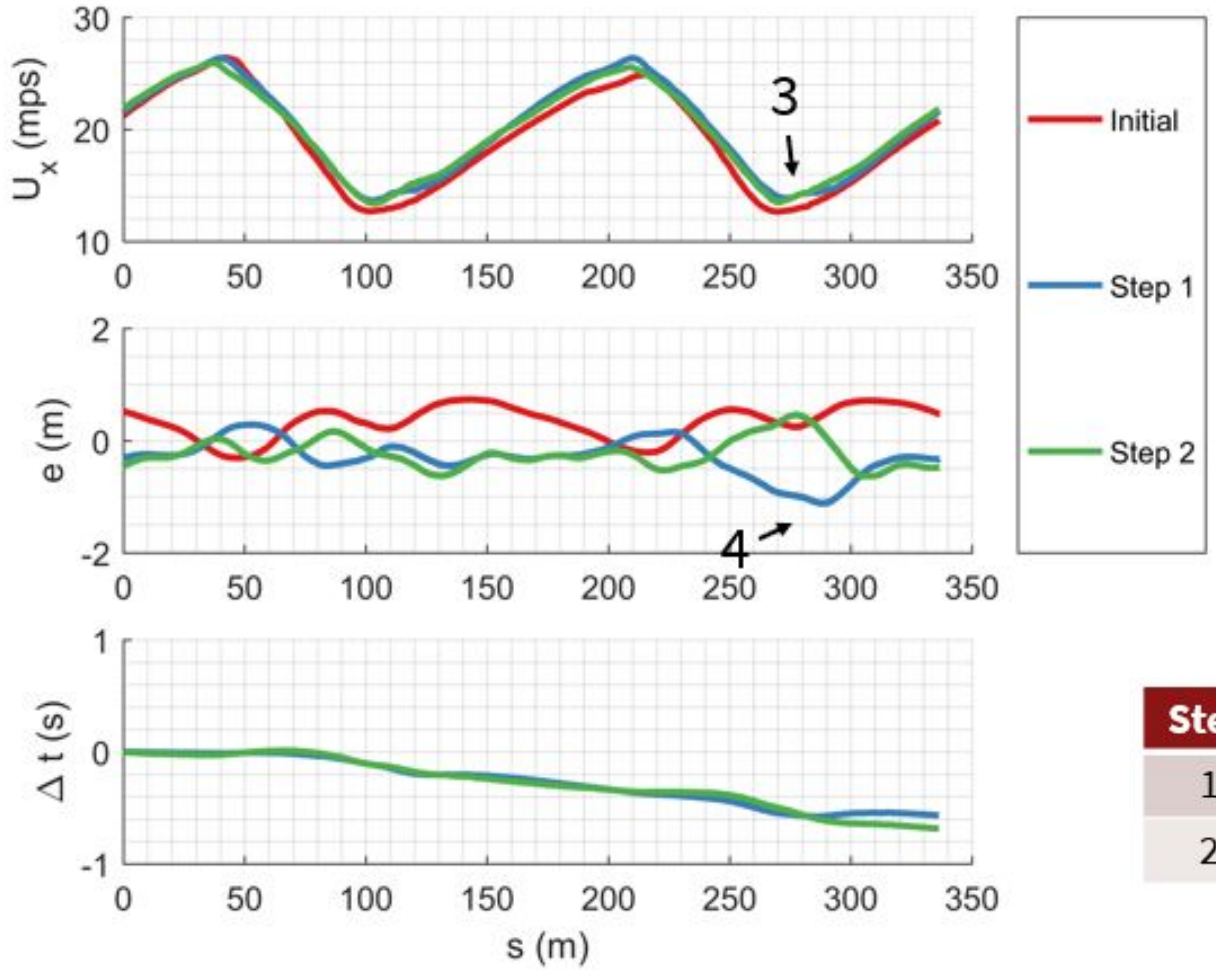



# Experimental Setup





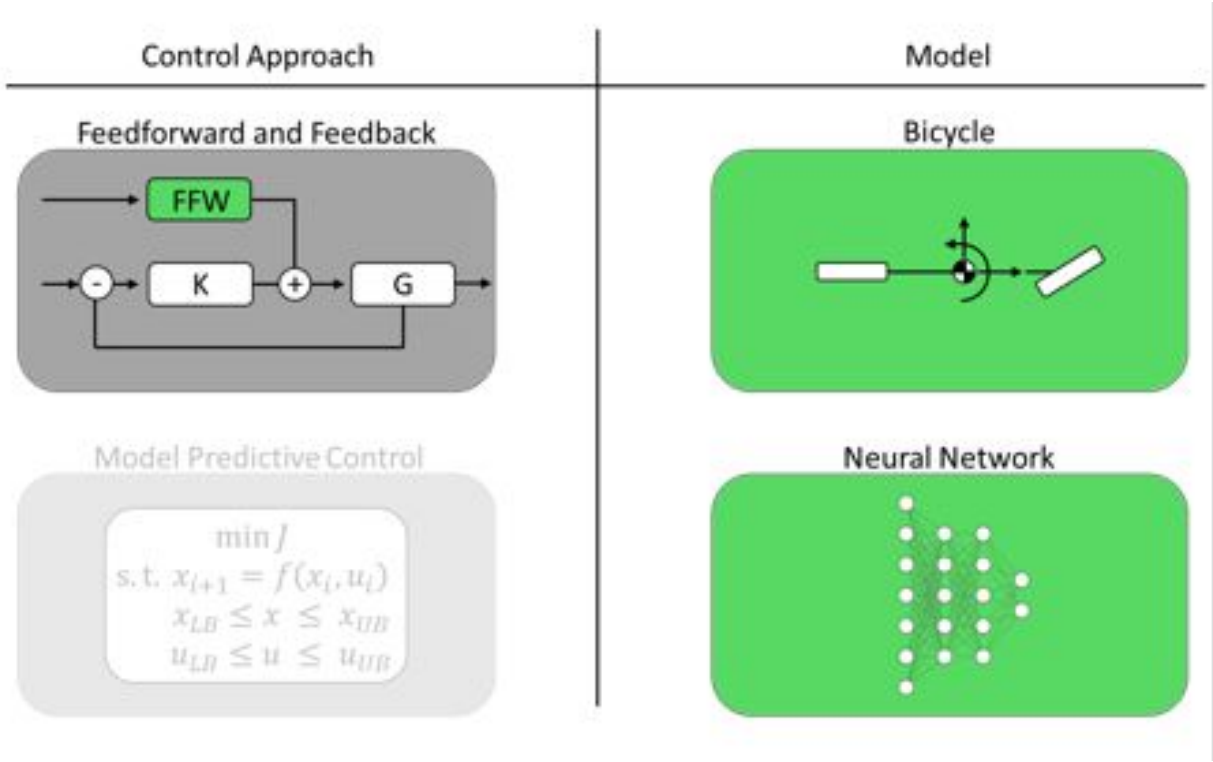
# Both Updates Improve Lap Time




| Step | Δt (s) |
|---|---|
| 1 | 0.57 |
| 2 | 0.69 |

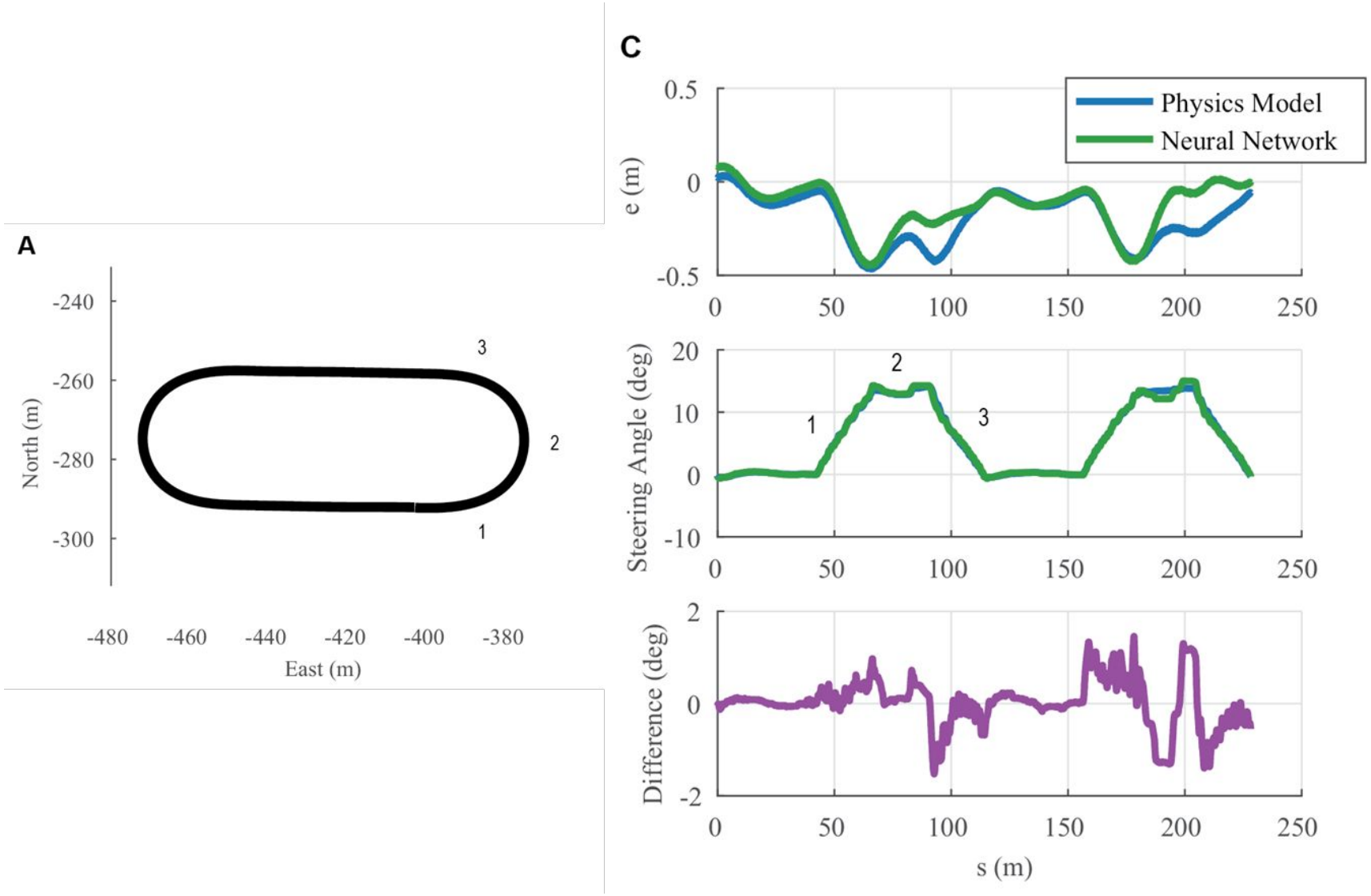
# Contribution Roadmap

1. Learning Feedforward Controls  for Racing
2. **Learning Neural Network Vehicle Models**
3. Using Neural Network Models in Model Predictive Control

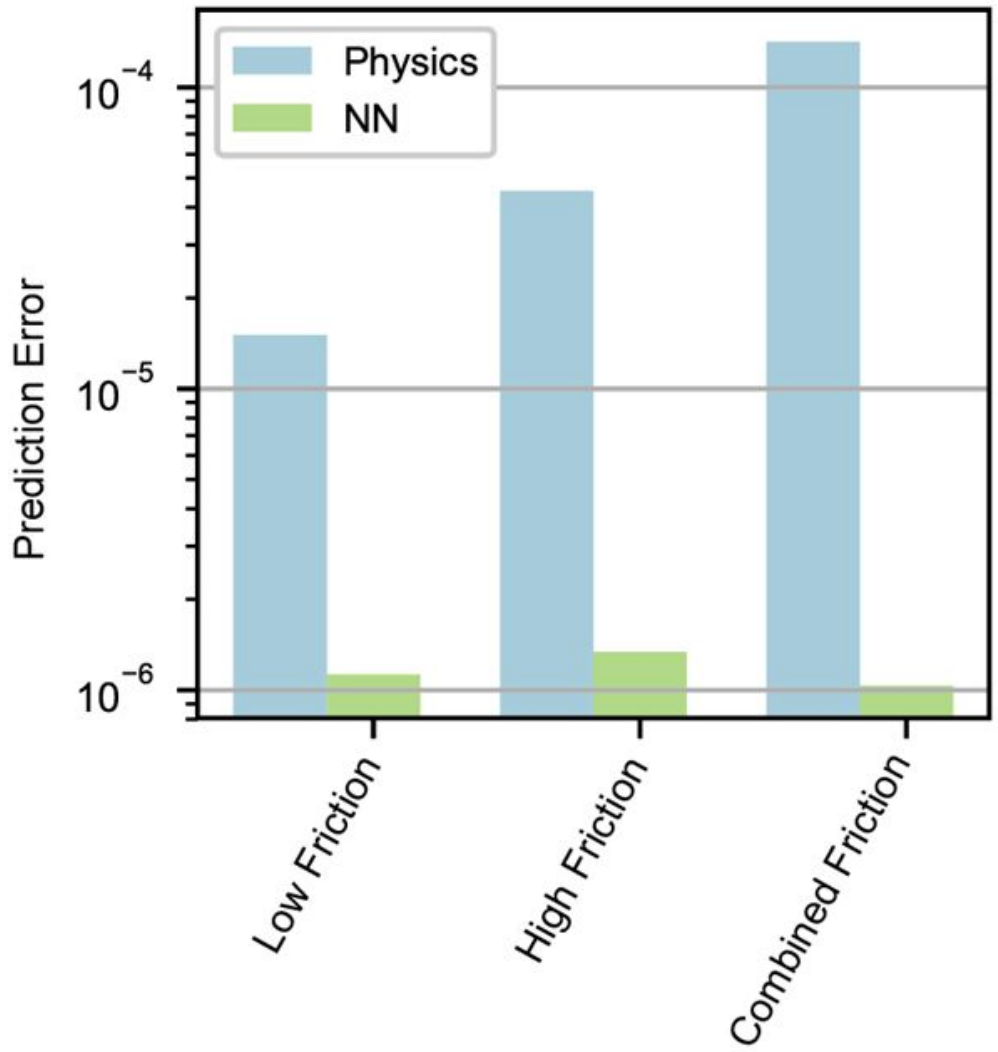


# Experimental Results

# Neural Network Tracks Better Than Bicycle Model



# Network Learns From High- and Low-Friction Data

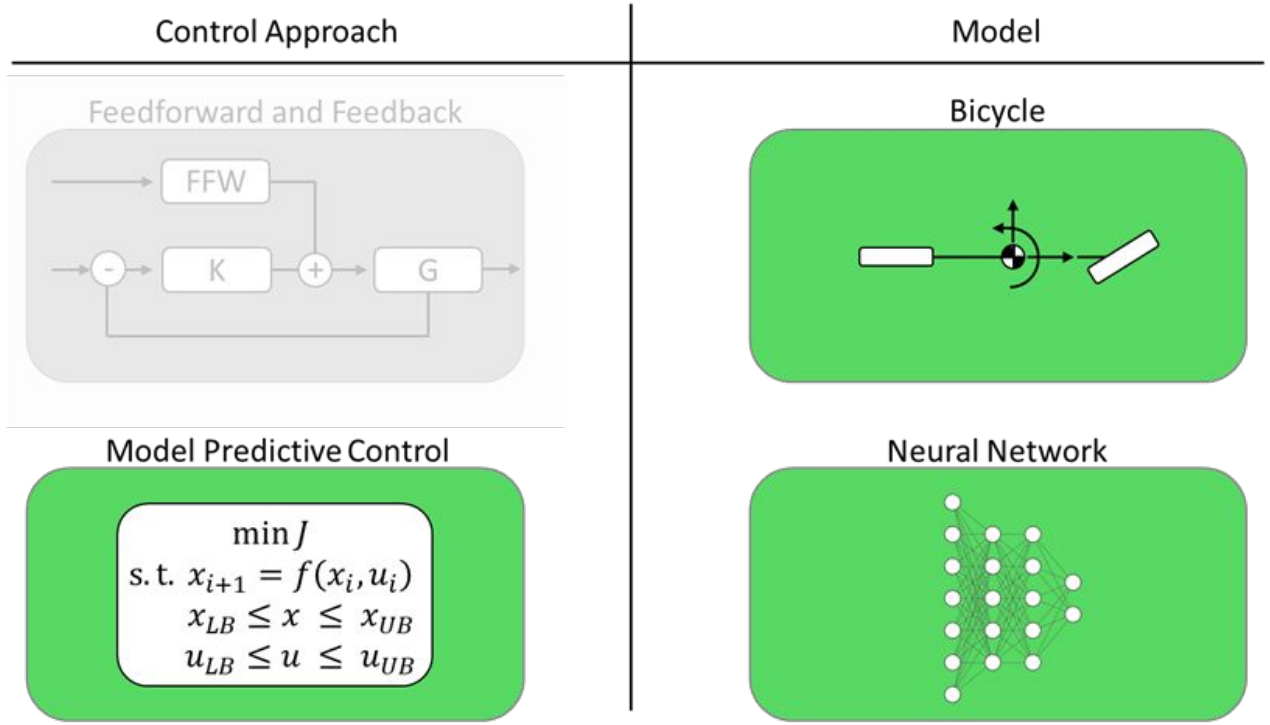



- High friction data from Thunderhill Raceway
- Low friction data from Arctic Circle test facility
- Network Predicts motion better in each case
- Physics worst performance on Combine
- Average parameter set

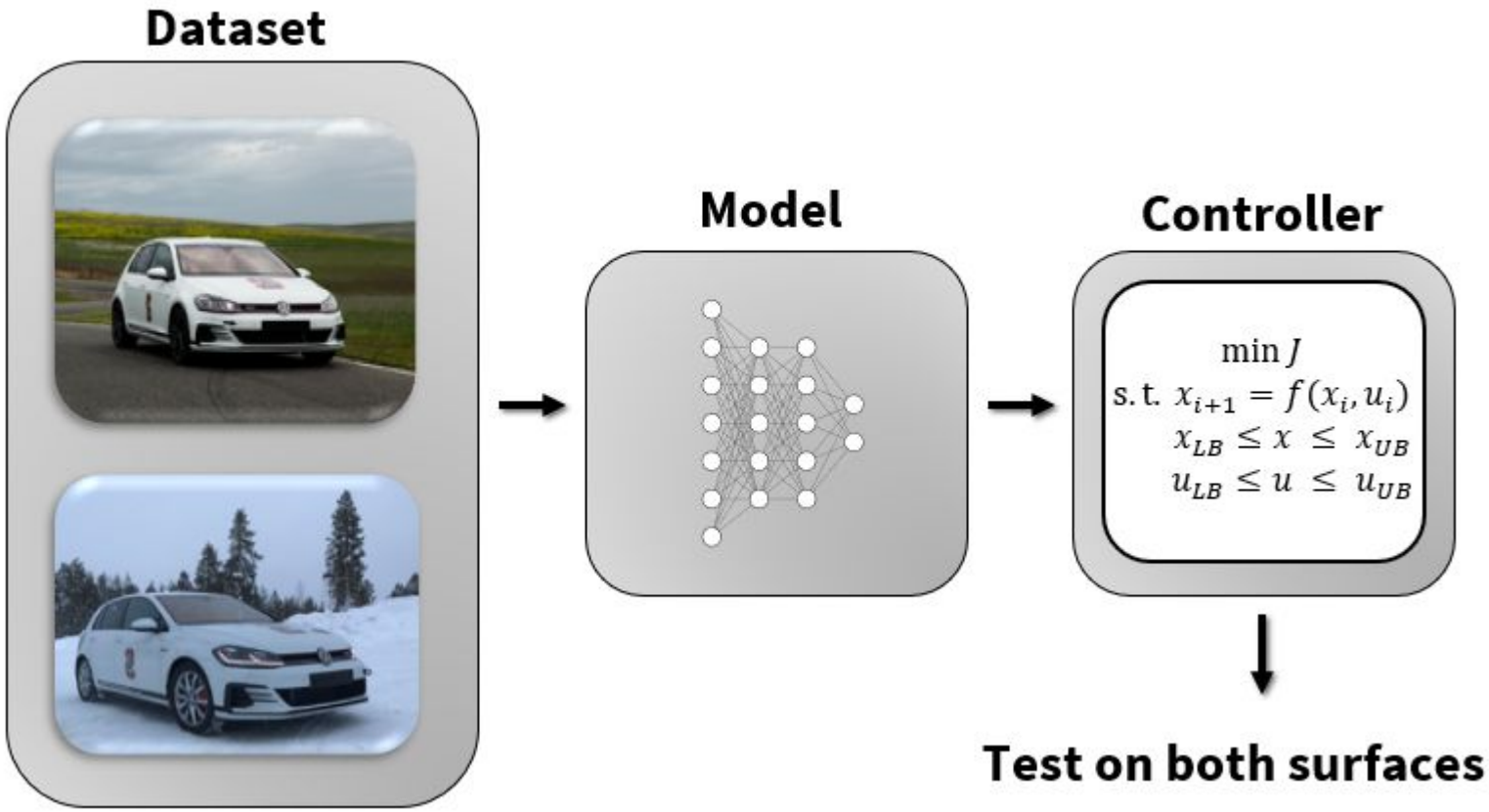
Spielberg et al. Science Robotics 2019

# Contribution Roadmap

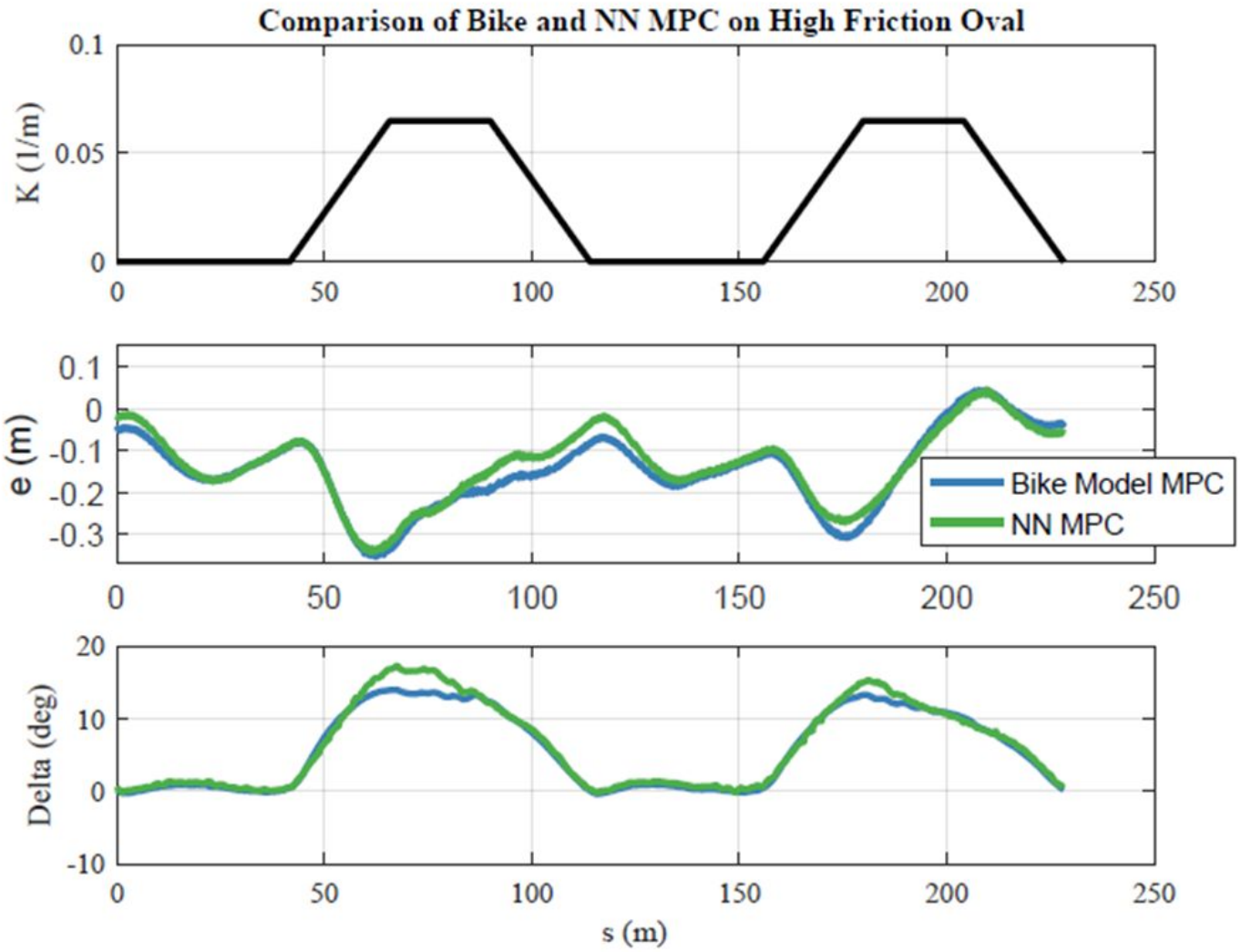
1. Learning Feedforward Controls  for Racing
2. Learning Neural Network Vehicle Models
3. **Using Neural Network Models in Model Predictive Control**



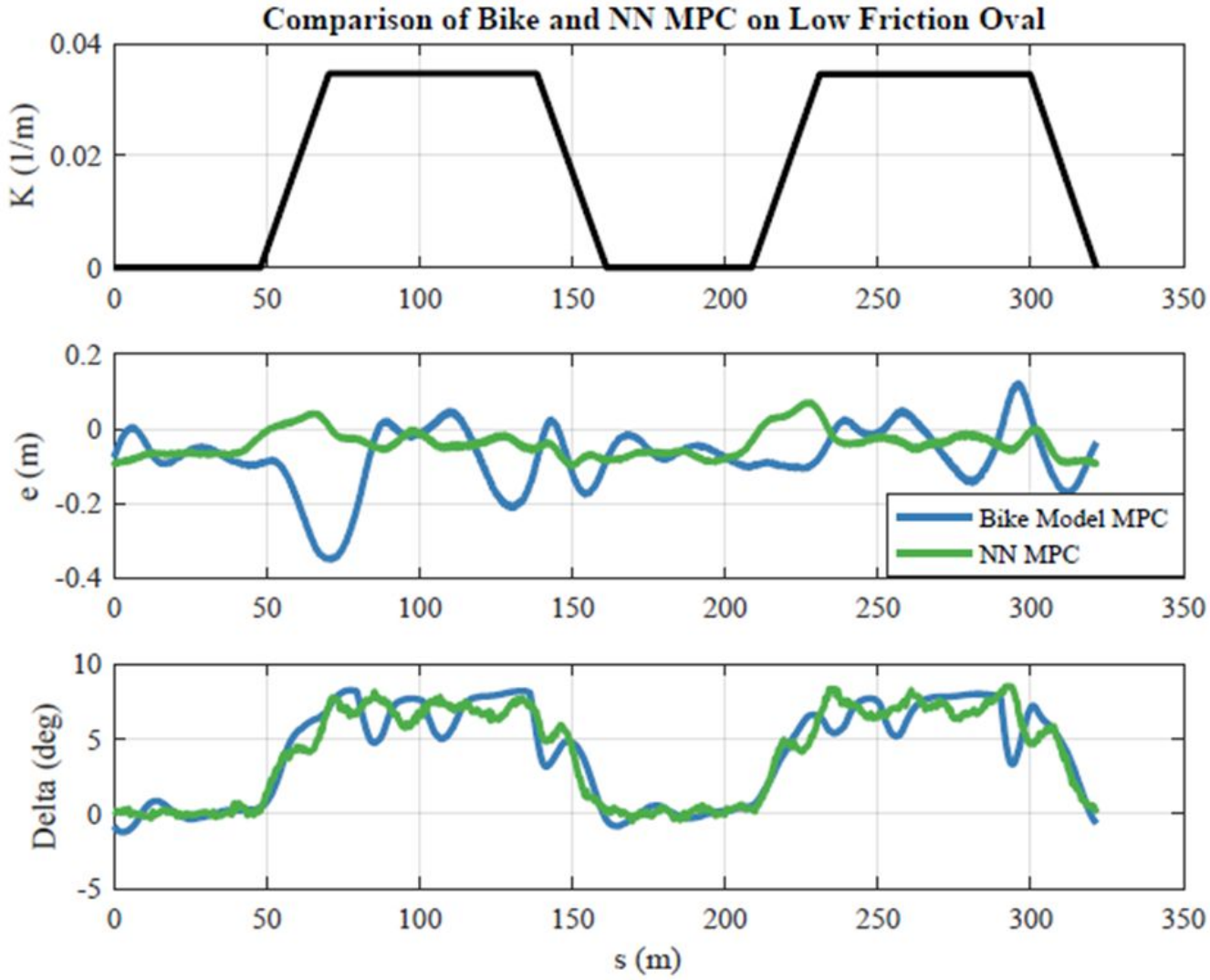
# Idea: Leverage Learned Network Dynamics on High-Low-Friction



# NN Performs Comparably on High Friction Racing

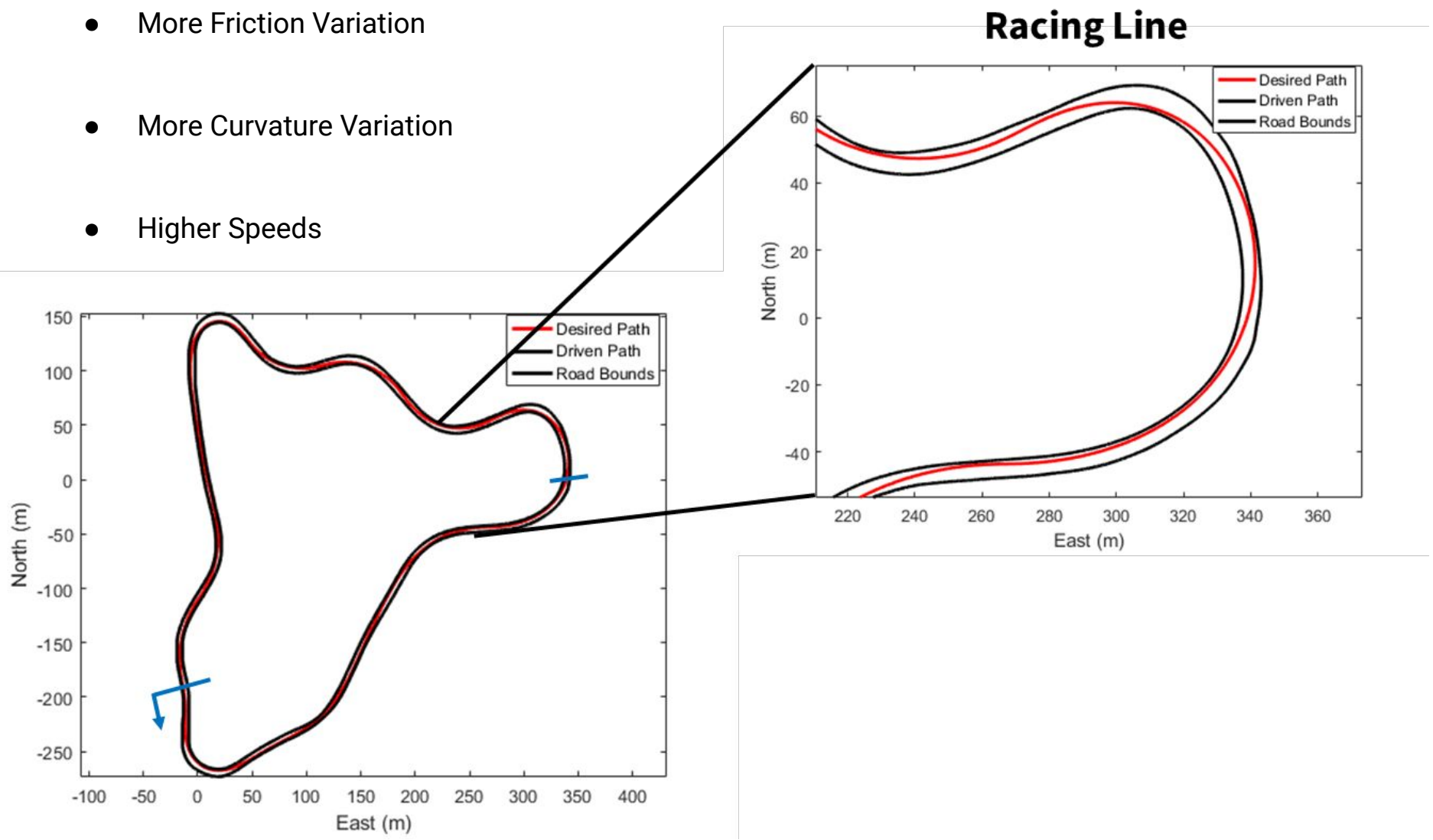


# NN Outperforms in Low-Friction Racing



# Ultimate Generalization Test: Ice Racing

- More Friction Variation
- More Curvature Variation
- Higher Speeds



# Ice Racing Using NNMPC Within 20cm

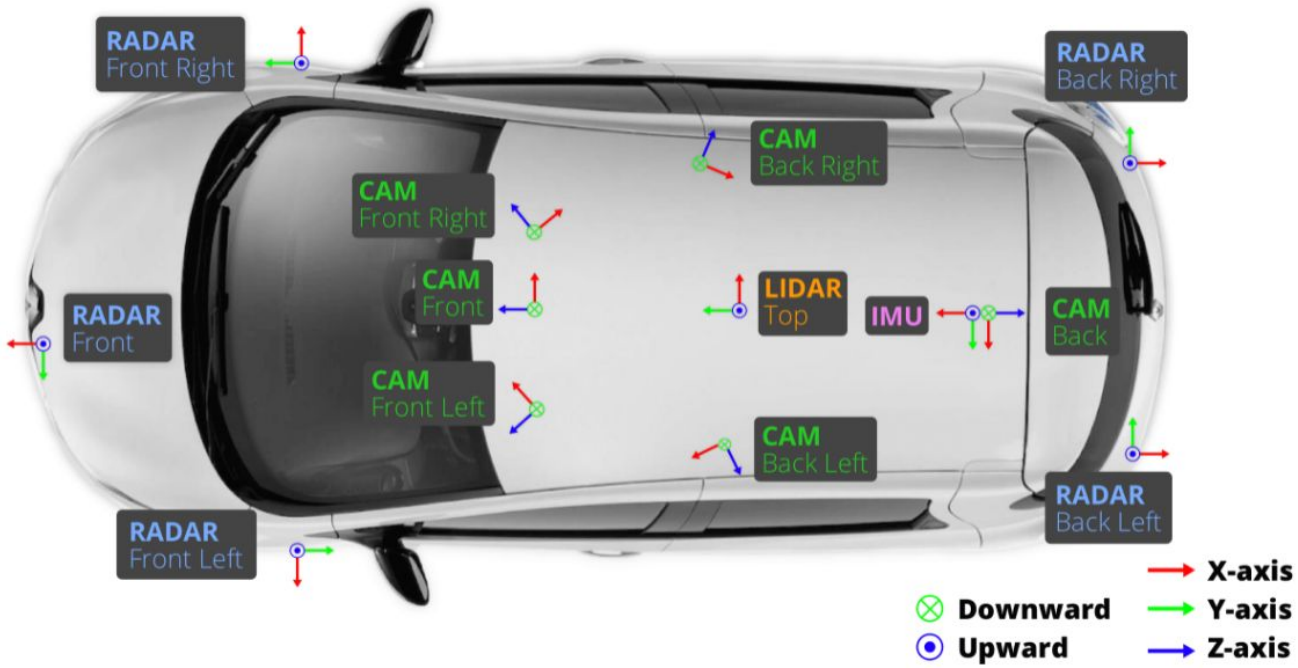
Replayed experimental data

Spielberg, Nathan A., Matthew Brown, and J. Christian Gerdes. “Neural Network Model Predictive Control for Automated Driving on Multiple Surfaces ." *IEEE Transactions on Control Systems Technology* (2020):

# Leveraging Data at Motional

# nuScenes

- Public large-scale dataset for autonomous driving
- 1000 scenes (15hrs) of data between Boston and Singapore
- Ground truth labels for 23 object classes




https://www.nuscenes.org/nuscenes

# nuPlan

- World’s first large-scale planning benchmark for autonomous driving
- 1500 hrs of driving data from Boston, Pittsburgh, Las Vegas, Singapore
- Train model, simulate model, measure performance, visualize results


| Evaluation Type | Ego Simulation | Agent Simulation |
|---|---|---|
| Log replay | Open-loop | Open-loop |
| Simulation (non reactive agents) | Closed-loop | Open-loop |
| Simulation (reactive agents) | Closed-loop | Closed-loop |

https://www.nuscenes.org/nuplan

# Leveraging Learning For Vehicle Control

- Autonomous vehicles generate an abundance of data
- We should leverage it to perform as well or better than humans
- Allow predictive control approaches to understand dynamics
- Allow policies to learn updated control commands
- Ultimately, safe self-driving vehicles

Nathan Spielberg (Nathan.Spielberg@motional.com)