Lehrstuhl für Fahrzeugtechnik
Fakultät für Maschinenwesen
Technische Universität München

Roborace @ TUM – Autonomous Driving at the Racetrack

Technical University of Munich
Department of Mechanical Engineering
Chair of Automotive Technology

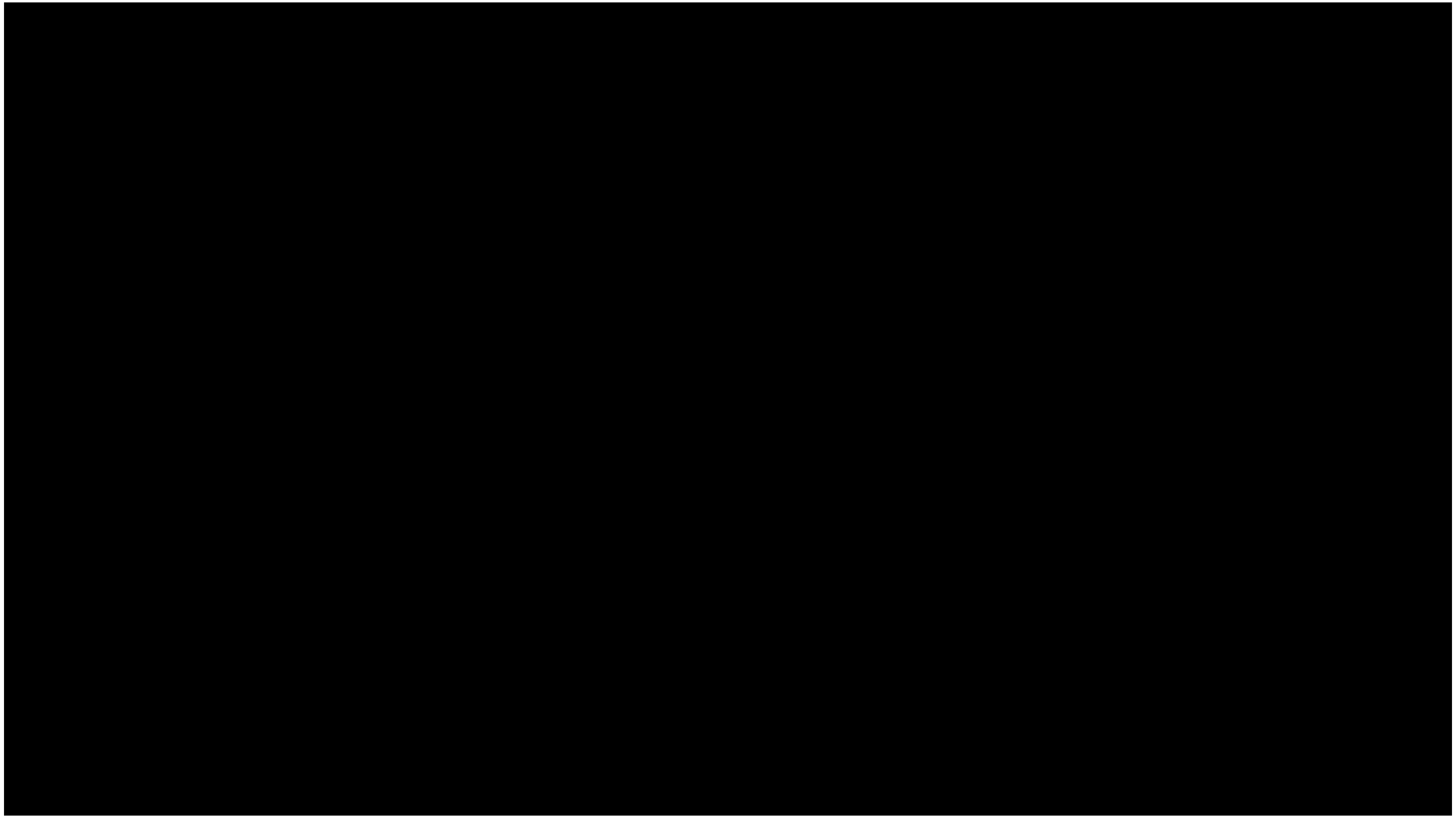
Munich, 02.07.

About Roborace - Background

- First full-scale racing series for autonomous vehicles
- Teams focus on software development based on the provided platform
- Several trial races for minimum lap-time in 2017 and 2018

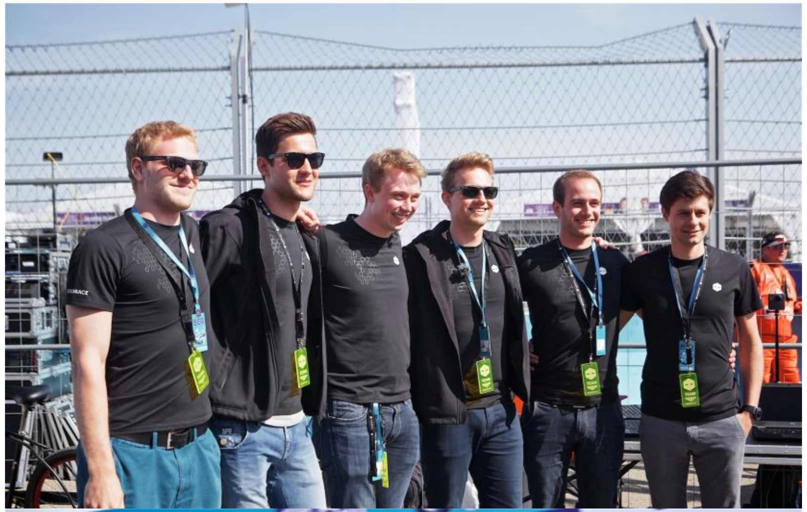
- Roborace Championship started in 2019
  - Monteblanco in April
  - Modena in May

About Roborace – Season Alpha



About Roborace – Milestones

- **01/2018:** Software development started
- **05/2018:** 150kph at 80% of maximum friction level
- **01/2019:** HiL – Simulator finished in cooperation with Speedgoat
- **03/2019:** Faster than an Amateur Racing Driver with speed limits of 100kph
- **04/2019:** Successful overtaking with 2 fully autonomous race cars (blue flag scenario)
- **05/2019:** First autonomous race at speeds up to 160 kph and 80% of the maximum friction
- **05/2019:** Gap between Human and Software: 0.005%



TUM Team Structure

Prof. Dr.-Ing.
Markus Lienkamp
Chair of Automotive Technology

Prof. Dr.-Ing.
Boris Lohmann
Chair of Automatic Control

Johannes Betz

Alexander Heilmeier

Tim Stahl

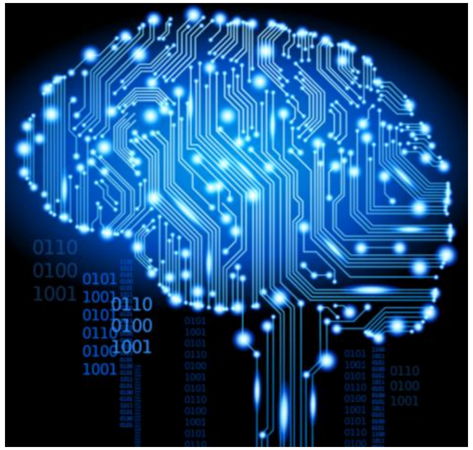
Leonhard Hermansdorfer

Thomas Herrmann

Felix Nobis

Alexander Wischnewski

Team Structure – Motivation for universities



Know-How:
- Artifical Intelligence (AI)-Algorithms
- Sensorfusion
- Control
- Automotive Technology

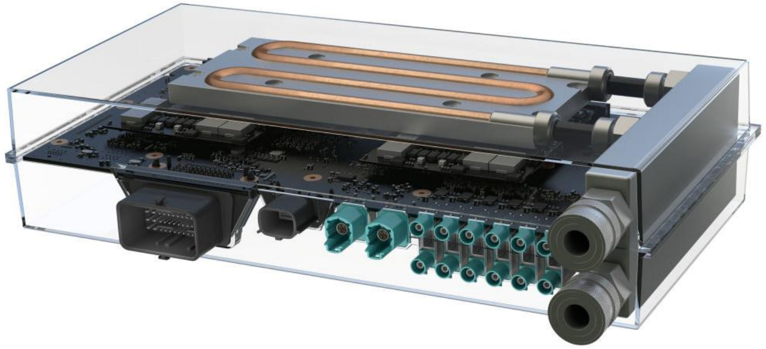
Research:
- PHD thesis
- Publications
- Student thesis

Road relevant Research:
- Real traffic scenarios
- Static and dynamic objects
- Different road quality and road surfaces

Teaching:
- New lectures

Roborace – ECU Setup

Nvidia Drive PX2



Speedgoat

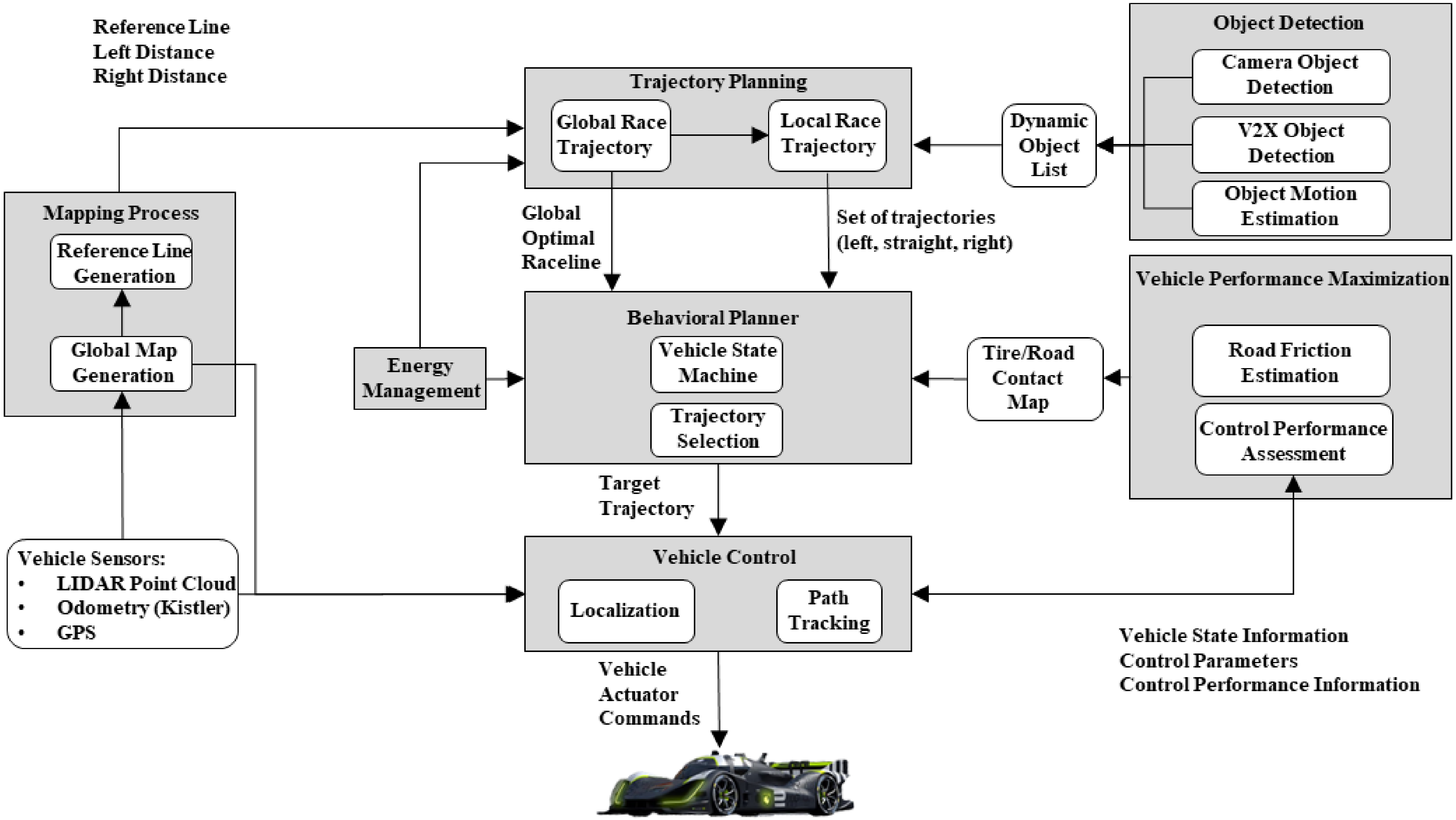
Hardware

Software: Perception → Planning → Control

Software Language: C++, ROS | python | MATLAB SIMULINK

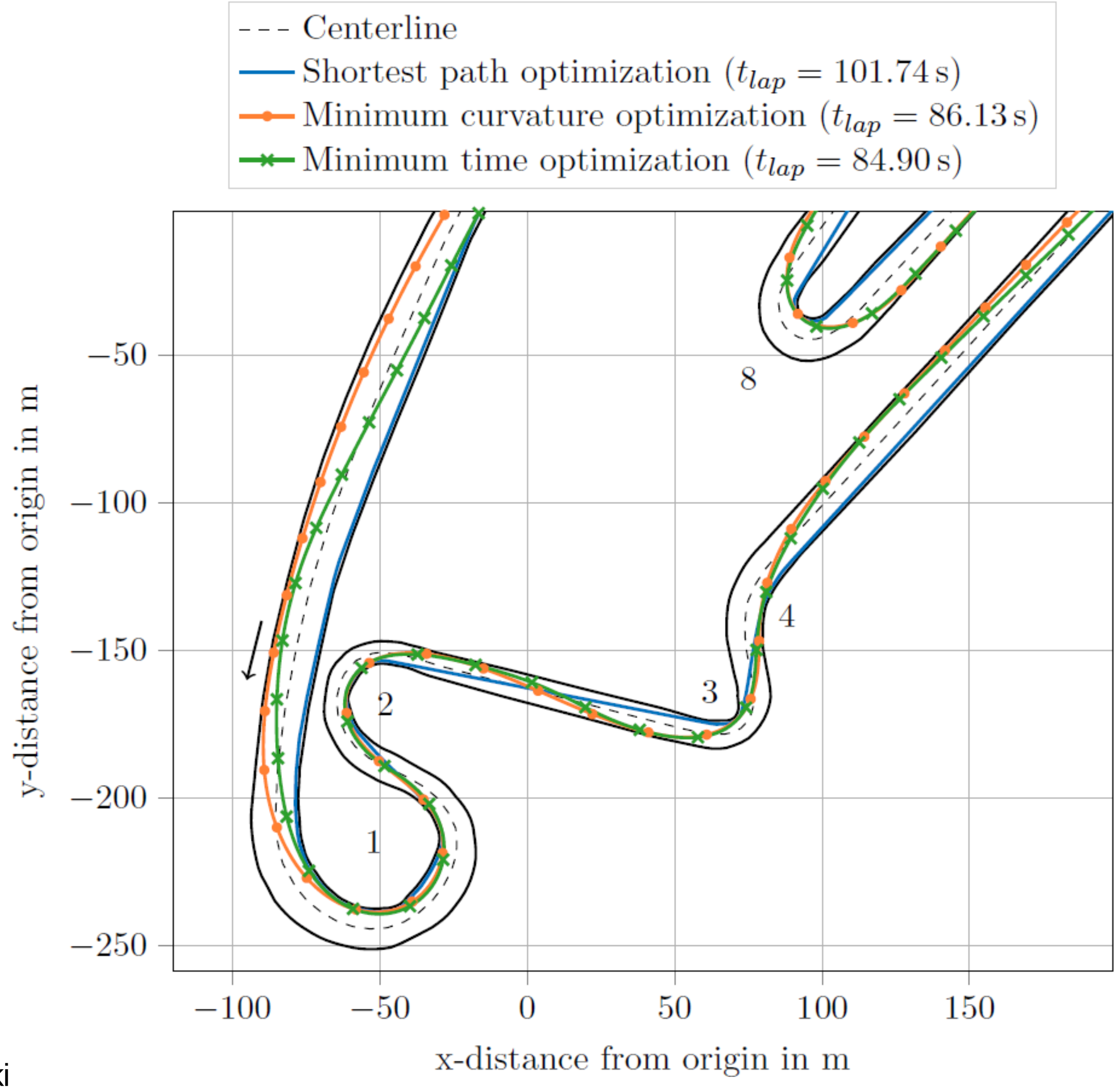
Interface: ØMQ | UDP, Ethernet

Software – Architecture



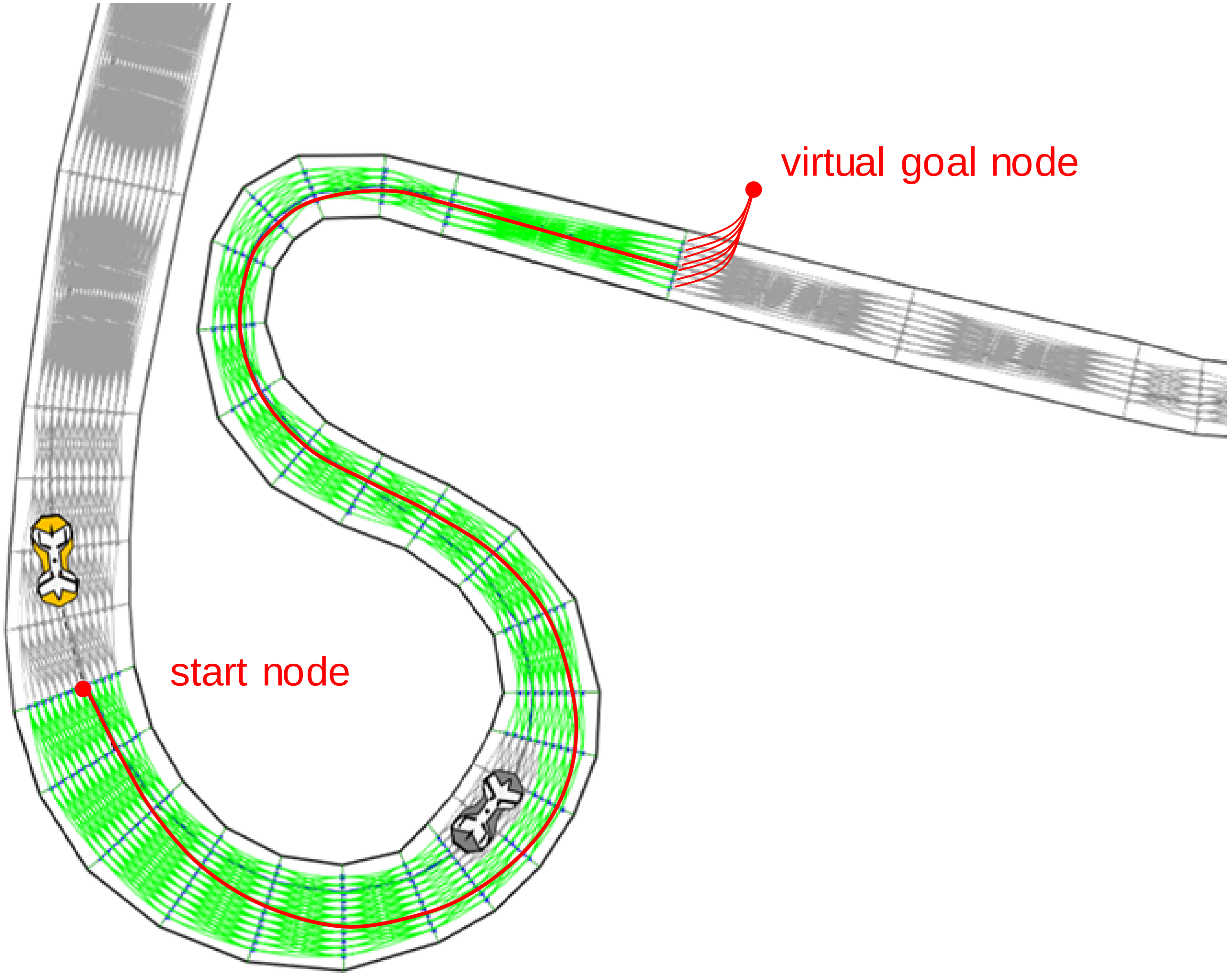
Software – Global Trajectory Planning

- Detailed comparison between shortest path, minimum curvature and minimum time trajectories
- Minimum time optimization using a nonlinear dual track model
  - CasADi Optimization Framework
  - Wheel dependent friction coefficients based on a friction map
  - Significant differences to a nonlinear single track model



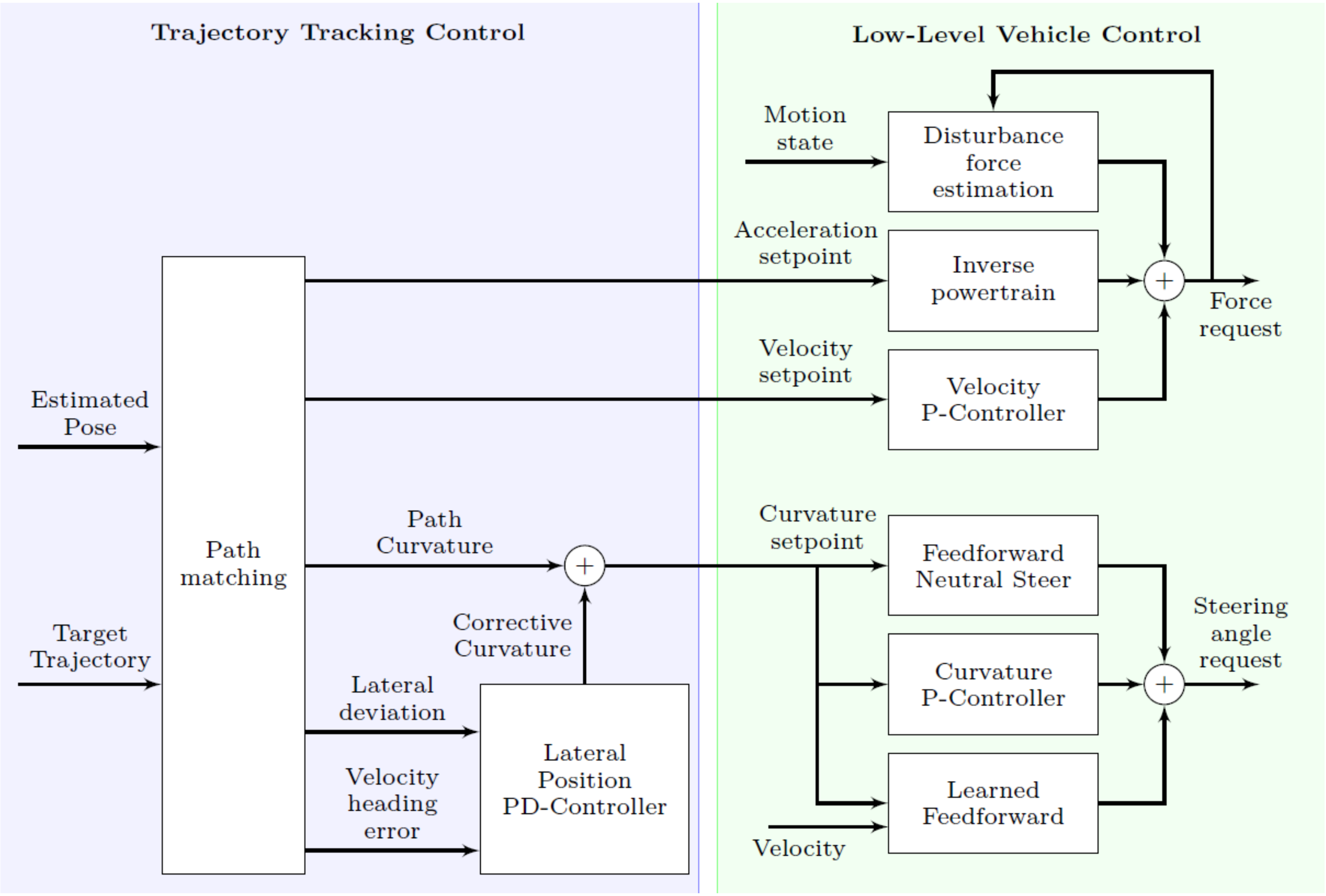
Software – Local Trajectory Planning

- Generate three action sets:
  - Straight → Remove obstacles and only consider them in velocity plan
  - Overtake Right/Left → Remove nodes which are blocked by opponent vehicle and its prediction
- Velocity planner considers friction map for all action sets



Software – Control

- Path Tracking
  - Curvature based feedforward
  - PD-Control
  - Gain-Scheduling
- Velocity Tracking
  - Acceleration based feedforward
  - P-Control
  - Disturbance estimation
- Curvature Tracking
  - P-Control
  - Data driven under-/oversteer compensation



Software – Future Challenges

- Dynamic trajectory planning poses severe computational demands
- Split between planning and control leads to difficulties once the limits are pushed
  - Feedback loop between planning and control required
  - Timing issues when trajectory changes significantly
- Removal of restrictions in terms of overtaking regulations
  - More advanced trajectory prediction for opponent vehicles
  - Planning has to consider potential reactions of opponents

Software – Research Topics

Object Tracking and Prediction

- Make the car aware of ist surroundings
- Estimate movement options for different objects classes

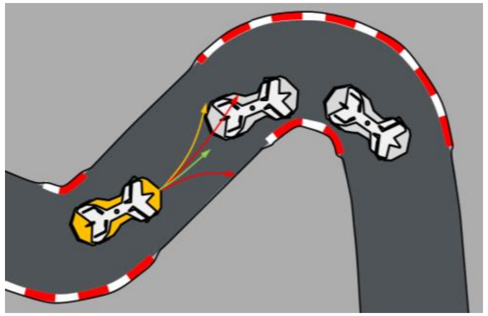
https://blogs.nvidia.com/wp-content/uploads/2016/01/ces-computer-vision-example-web.gif

Tire/Road Friction Prediction

- Autonomous Driving is a highly safety critical task
- Authorities require explainable solutions and valid risk assessments

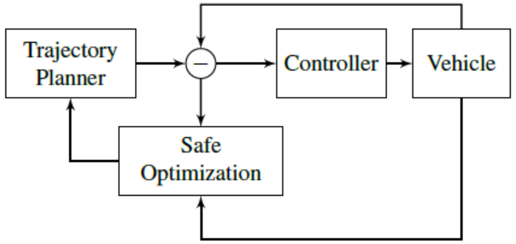
Safety Assessment of Trajectories

- Autonomous Driving is a highly safety critical task
- Authorities require explainable solutions and valid risk assessments



Safe Learning Control

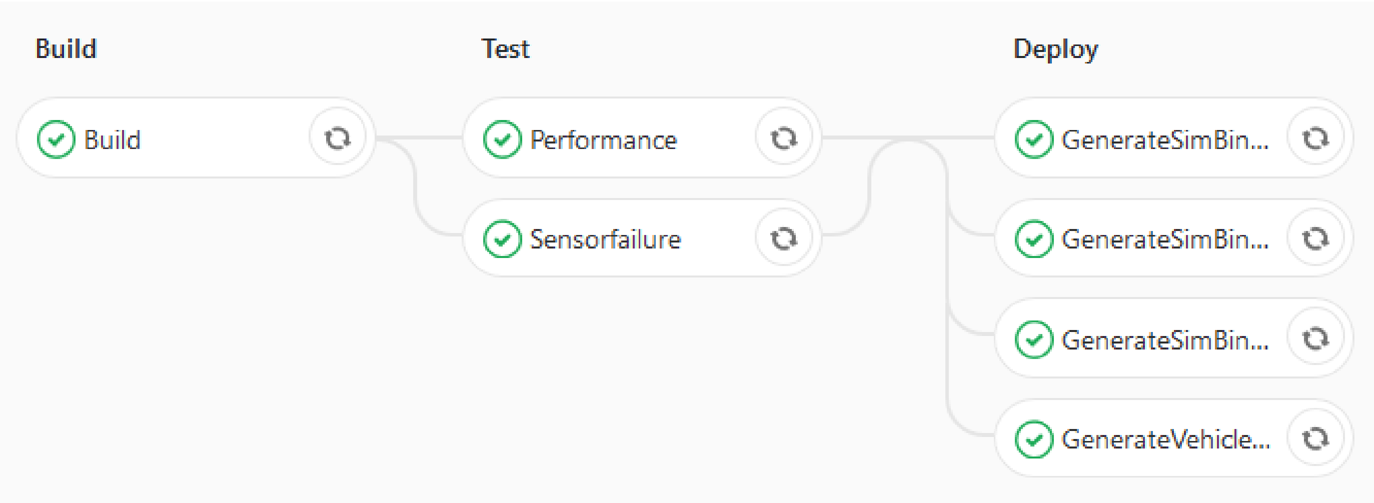
- Improve dynamic models online
- Adjust trajectory planning and control according to these information



Development Toolchain – Workflow

- Simulink Project allows to manage dependencies
- Control Simulink Model is split in ~40 submodels
- Main functionality placed in m-Files to allow text based merges

- Direct Integration of Simulink and Gitlab CI
- Simulation requires lots of computation power



Development Toolchain – Mathworks Software

- Function development in Simulink
  - Speed control
  - Path tracking control
  - Sensor fusion
  - Vehicle state machine
- Simulation in Simulink
  - Vehicle Dynamics Blockset
  - Real-Time Toolchain
- Project organization
  - Simulink Project
  - Referenced Models
  - Data Dictionaries
  - Data Analysis

Development Toolchain – Testing Workflow

Controller Simulation in Simulink

- Full system inluding Rest-Bus Simulation
- Realistic Sensor Noise
- Basic Trajectory Planner (Raceline Tracking)

Trajectory Planning Simulation

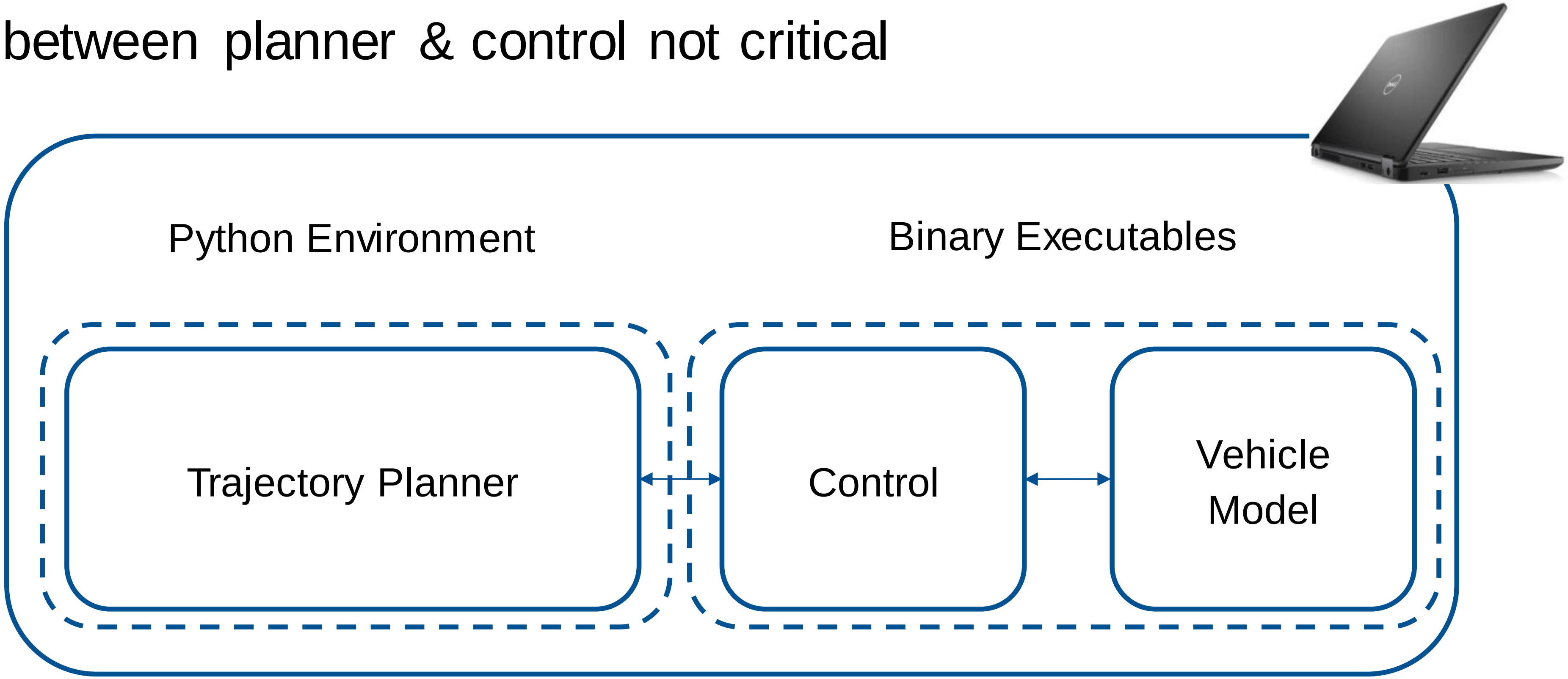
- Binary executable generated from Simulink based on vehicle dynamics and control model
- Trajectory planner running in Python
- Data exchange via UDP (localhost)

Full System Simulation on HiL System

- Vehicle Physics on a Speedgoat HiL System
- Controller on a Speedgoat ECU
- Trajectory Planner on a NVIDIA ECU

Development Toolchain – Testing Workflow

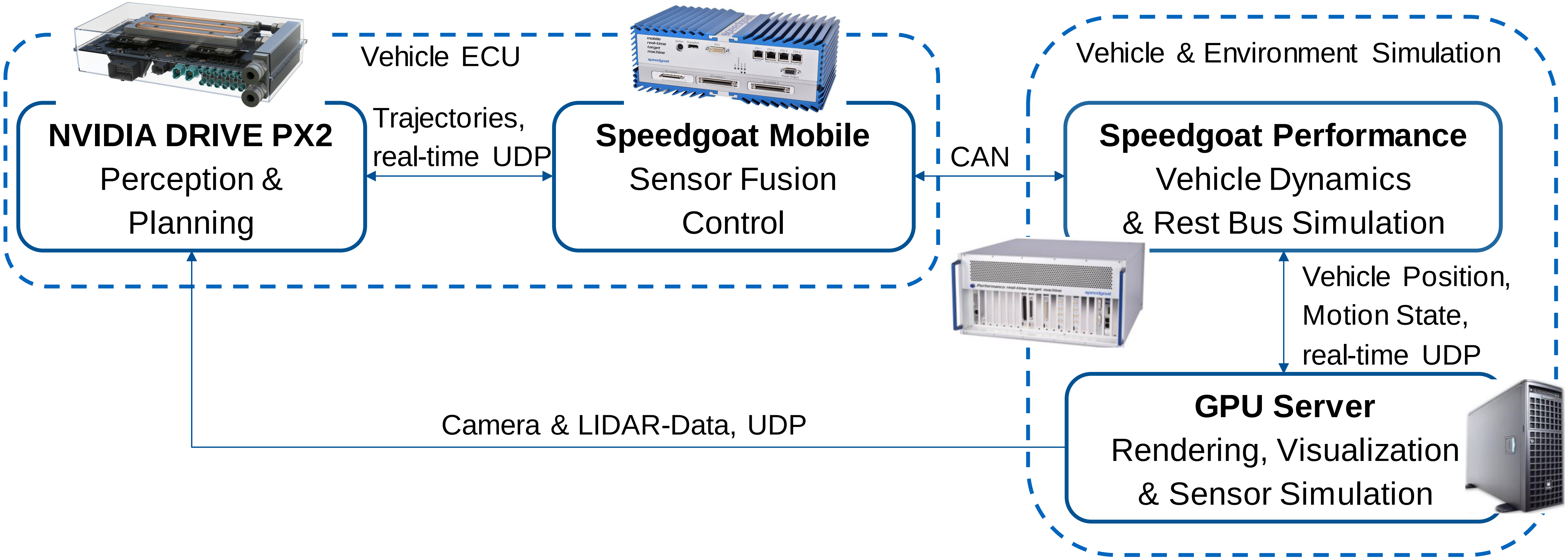
- Enables trajectory planning developers to test their software locally
- Fast dynamics incorporated within a single binary
- Timing between planner & control not critical



Development Toolchain – Testing Workflow

- Test software on vehicle hardware

  → Performance and Integration



Conclusion

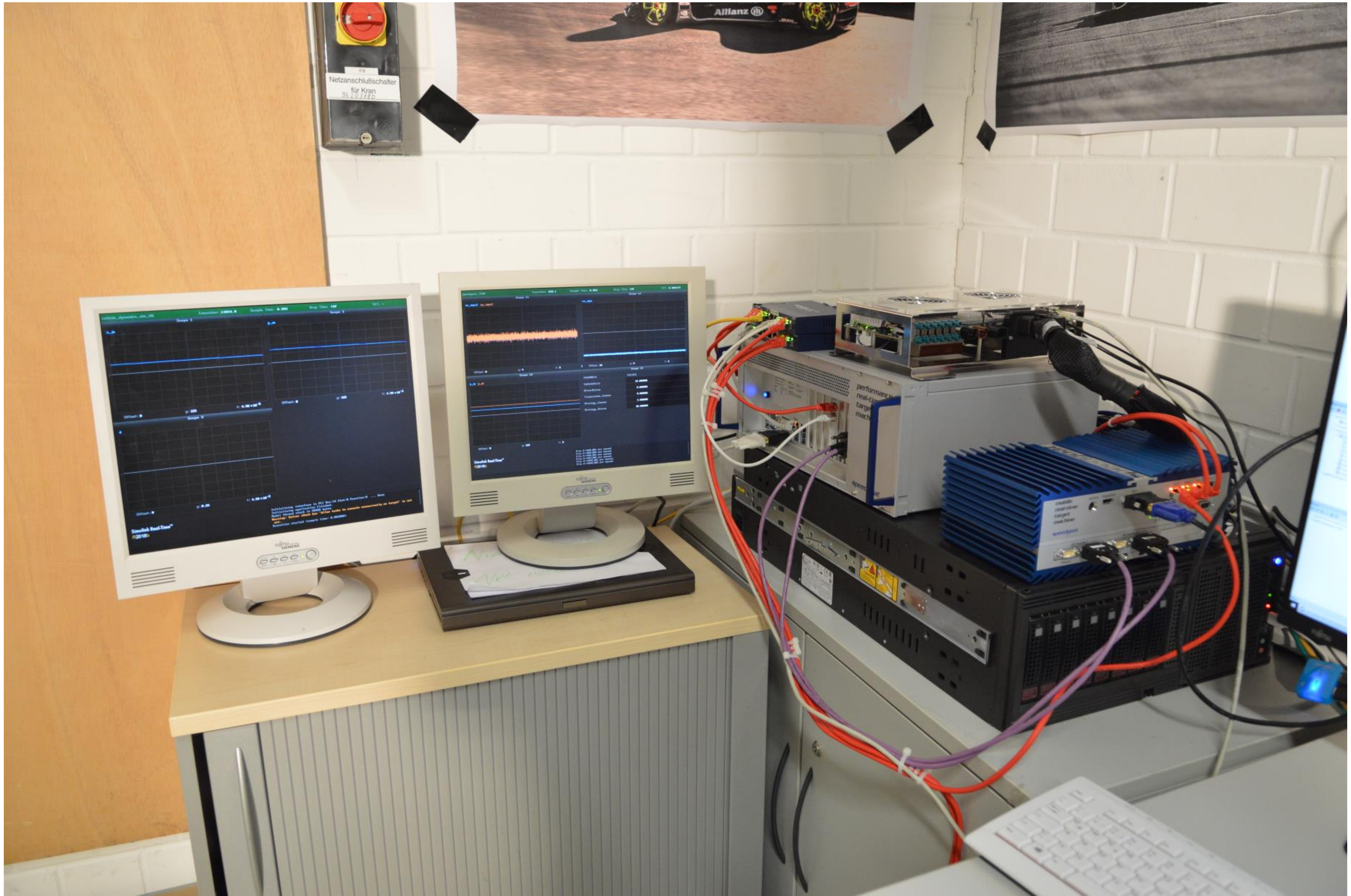
- Roborace@TUM Autonomous Driving Stack
  - Allows to utilize the full vehicle potential
  - Overtaking functionality for certain scenarios
  - Partially available at github: [TUMFTM/veh_passenger]
  - More modules will become available in the future
- Next Steps & Future:
  - Preparing for race events in locations all around the world
  - Create benchmarks for state-of-the-art algorithms for racetrack applications
  - Research on already identified shortcomings of available concepts

We are looking for Partners who want to team up to accelerate research on Autonomous Driving within the demanding environment of Motorsport!

Backup Slides

Autonomous Lap

Development Toolchain – HiL Setup



Development Toolchain – HiL Setup