Lecture

Control and Perception in Networked and Autonomous Vehicles

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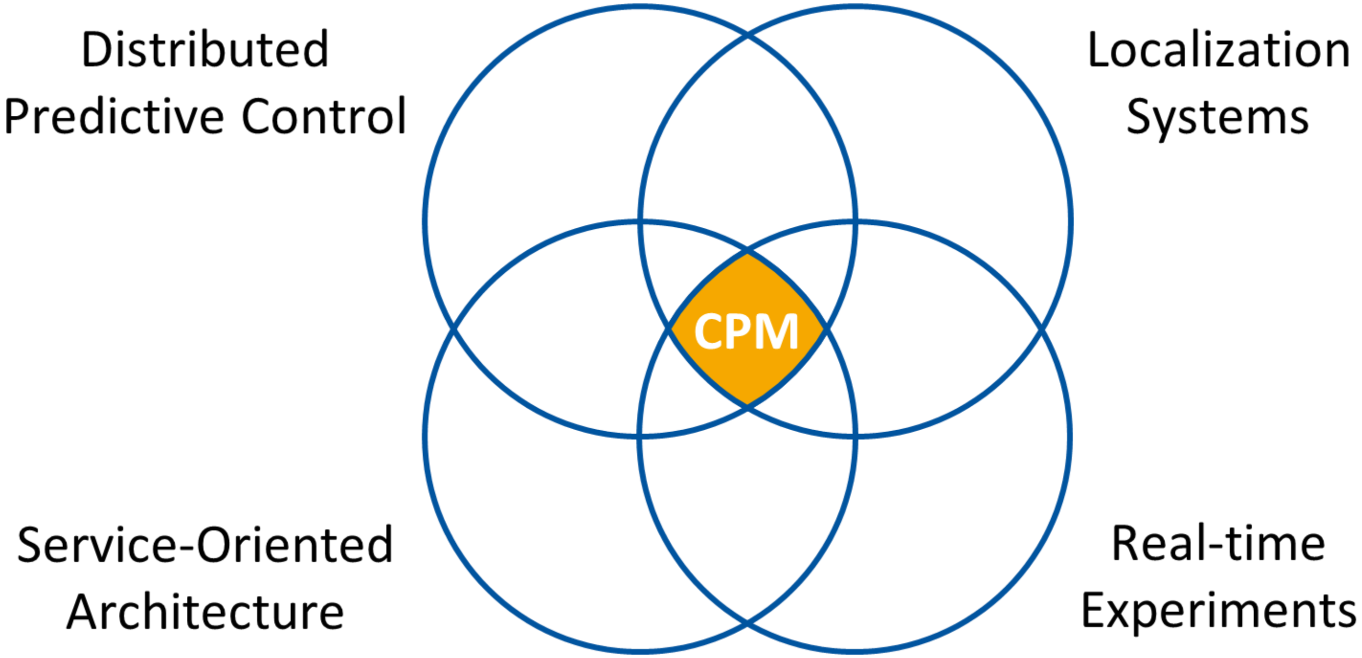
Winter Semester 2023/2024

Part 6

Software Architectures and Testing Concepts

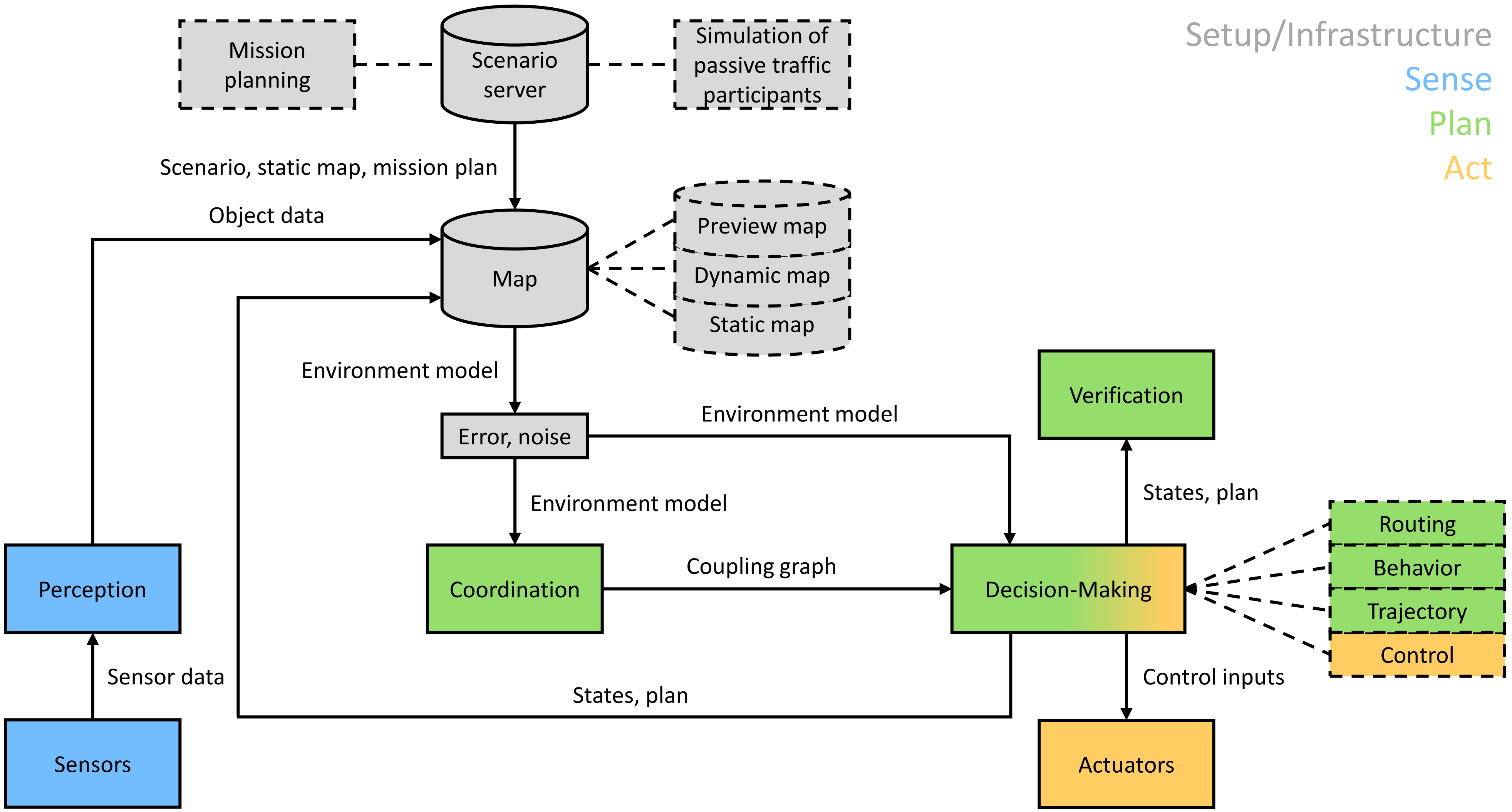
Course contents (CPM group course)

- Vehicle models
- Control and optimization
- Network and distribution
- Machine perception
- Software architectures and testing concepts
- Case study



*CPM: Cyber-Physical Mobility

CPM Lab architecture



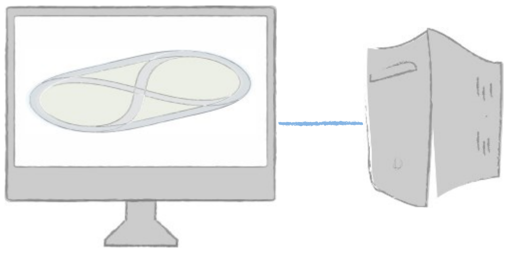
Further literature (1)

- B. Alrifaee. Networked Model Predictive Control for Vehicle Collision Avoidance. PhD thesis, RWTH Aachen University, 2017.
- K. Beck. Extreme Programming Explained. Addison-Wesley, 1999.

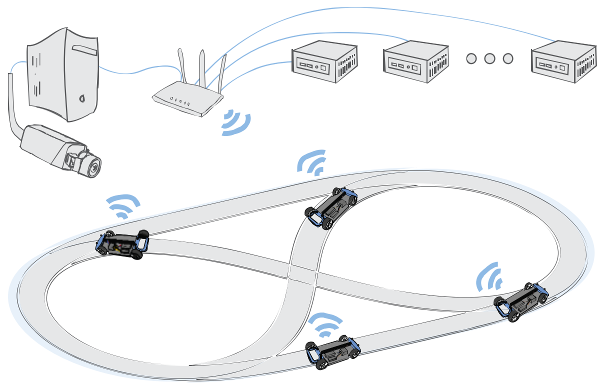
Further literature (2)

- Check out the CPM Lab website

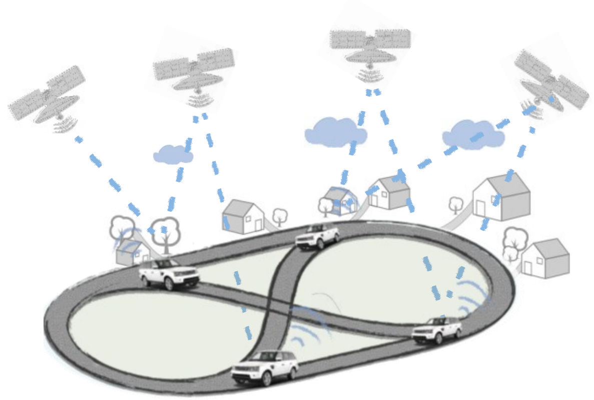
CPM Lab motivation



Simulation:
abstracts from
real-world behavior



Lab:
rapid functional
prototyping, cost
and time efficient

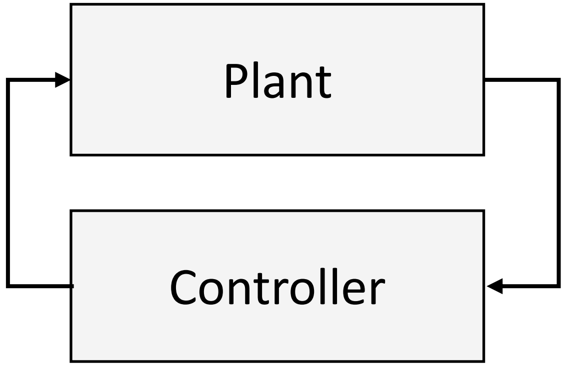


Real-world:
expensive and
time-consuming

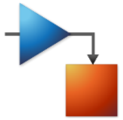
CPM Lab motivation

- Dynamics
- Network
  - Delays
  - Packet drop
- Hardware / software
  - Sensors
  - Actuators
- Isolate effects – control uncertainties
- Goal
  - Determinism and reproducibility
  - In-the-loop testing for networked systems

In-the-loop testing (XIL)

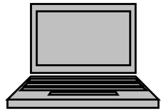


Software


Model

C
Generated Code

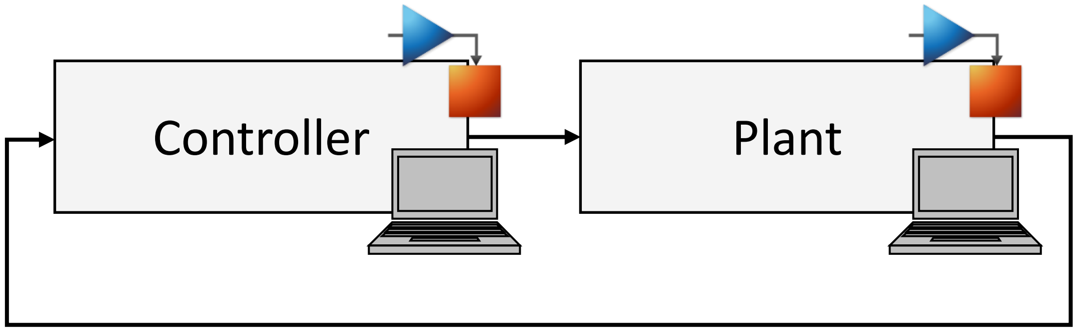
Hardware


Desktop PC

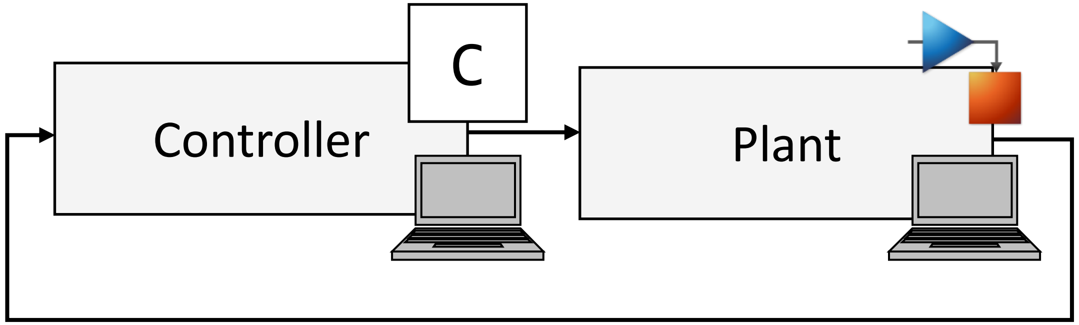

HIL simulator platform
(Real-time capable)


Target HW
(e.g., Microcontroller)

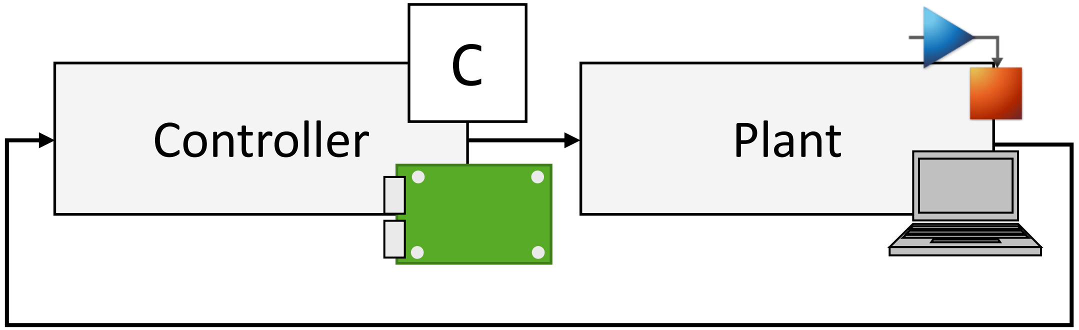
In-the-loop testing (XIL)



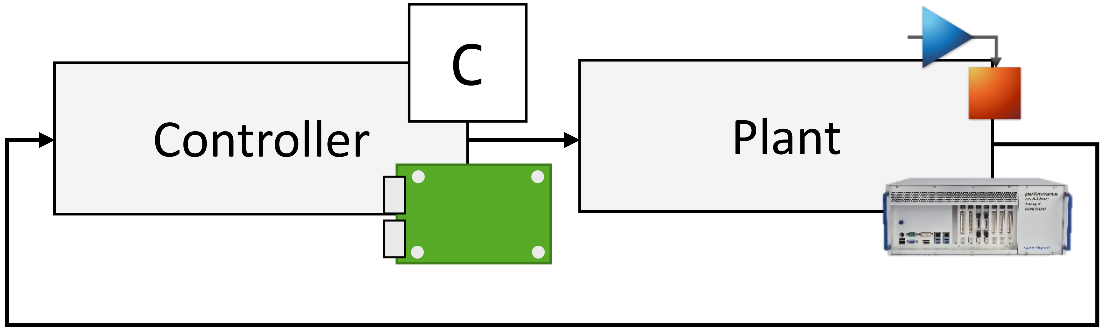
Model in the loop (MIL)



Software in the loop (SIL)

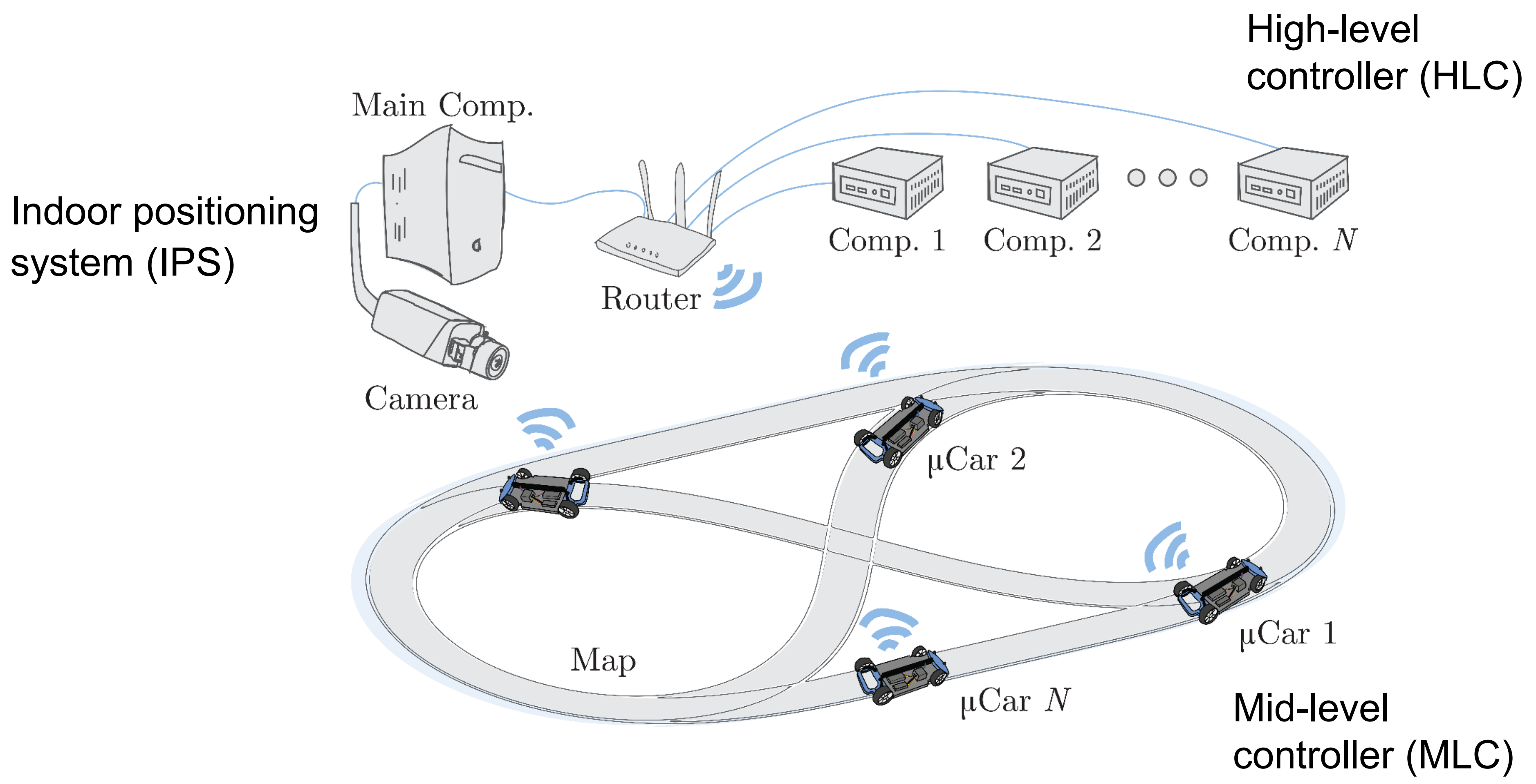


Processor in the loop (PIL)

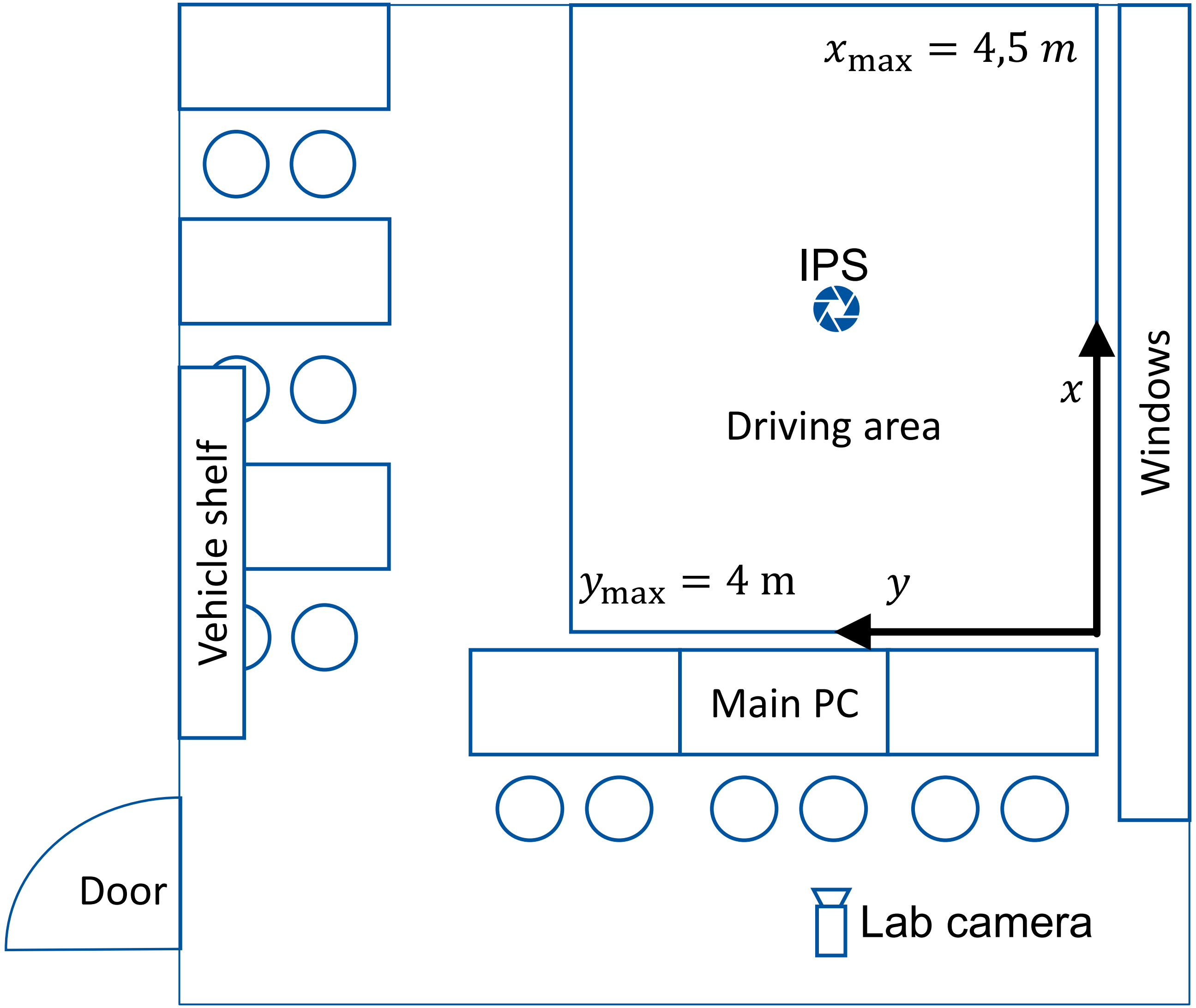


Hardware in the loop (HIL)

CPM Lab components

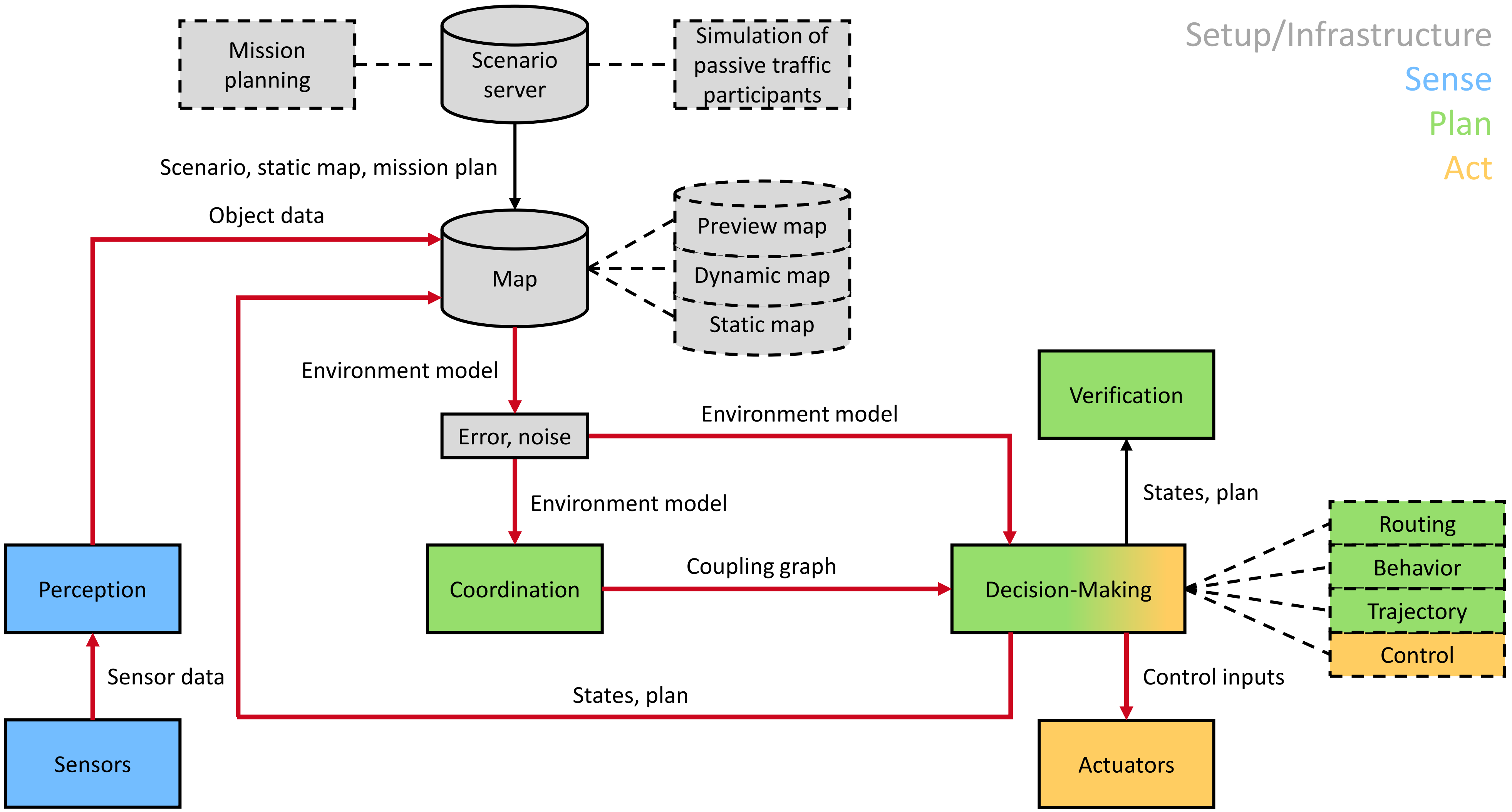


CPM Lab room

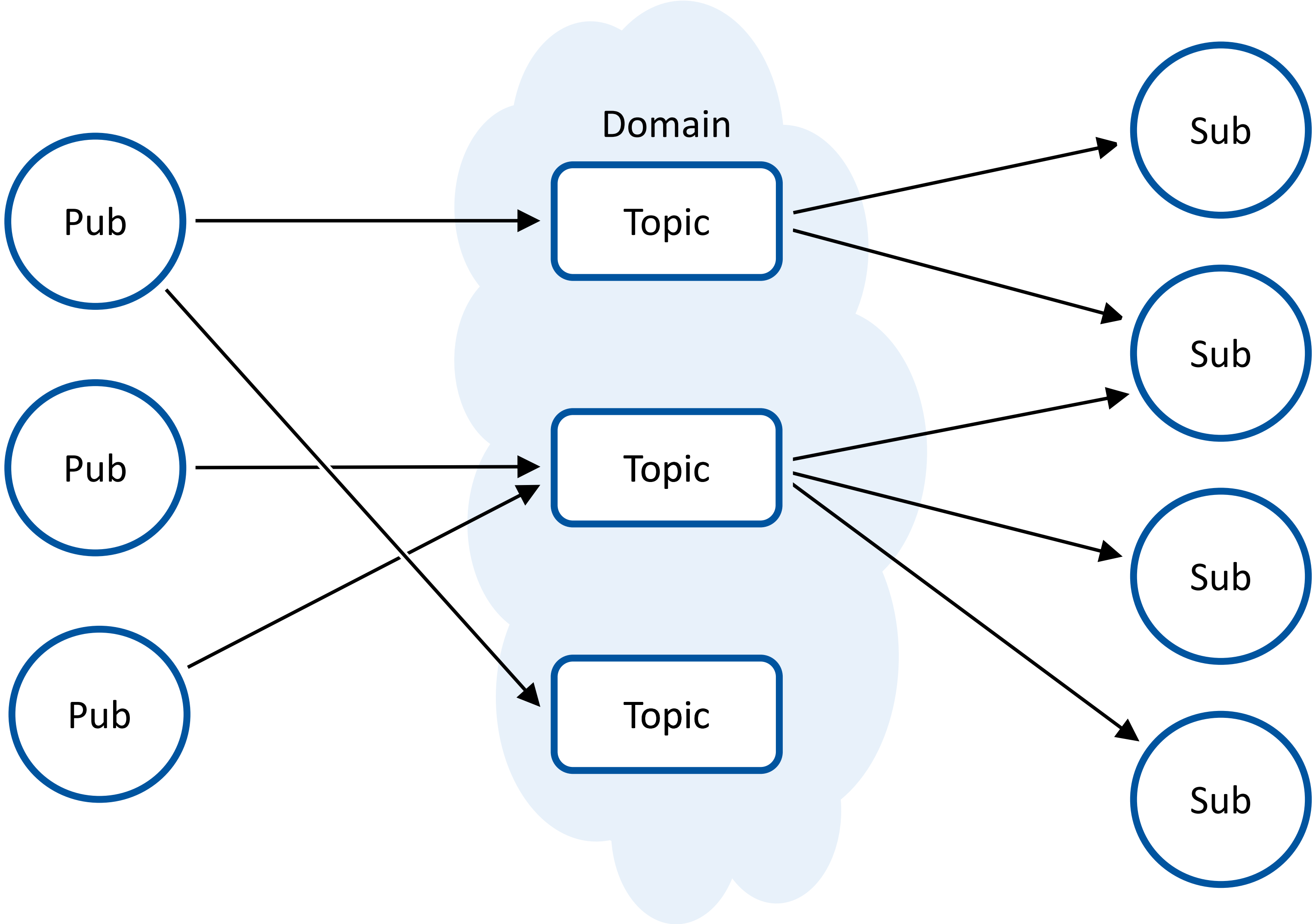


$x_{\max} = 4{,}5\ m$
IPS
Driving area
x
Windows
Vehicle shelf
$y_{\max} = 4$ m
y
Main PC
Door
Lab camera

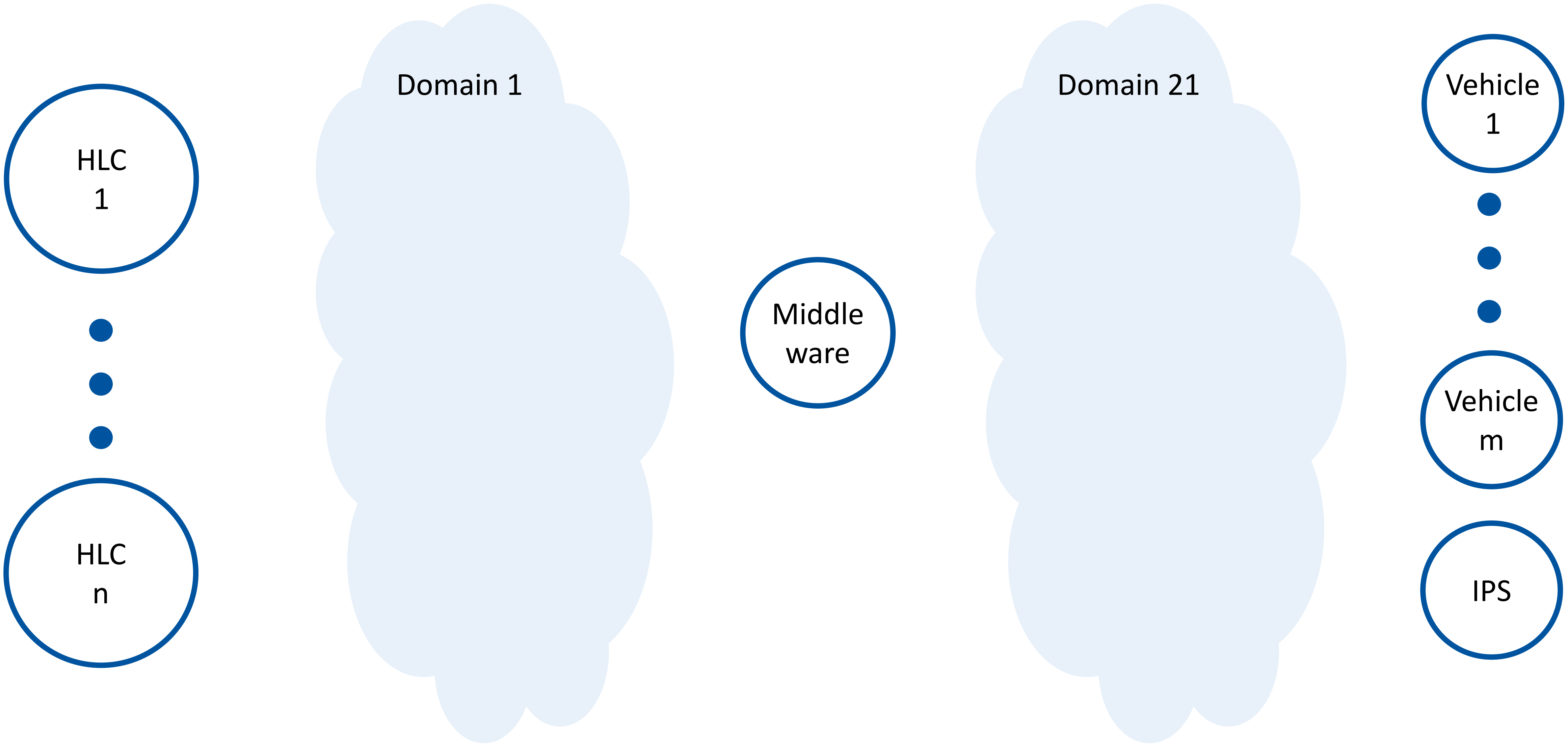
CPM Lab architecture: communication



Data Distribution Service



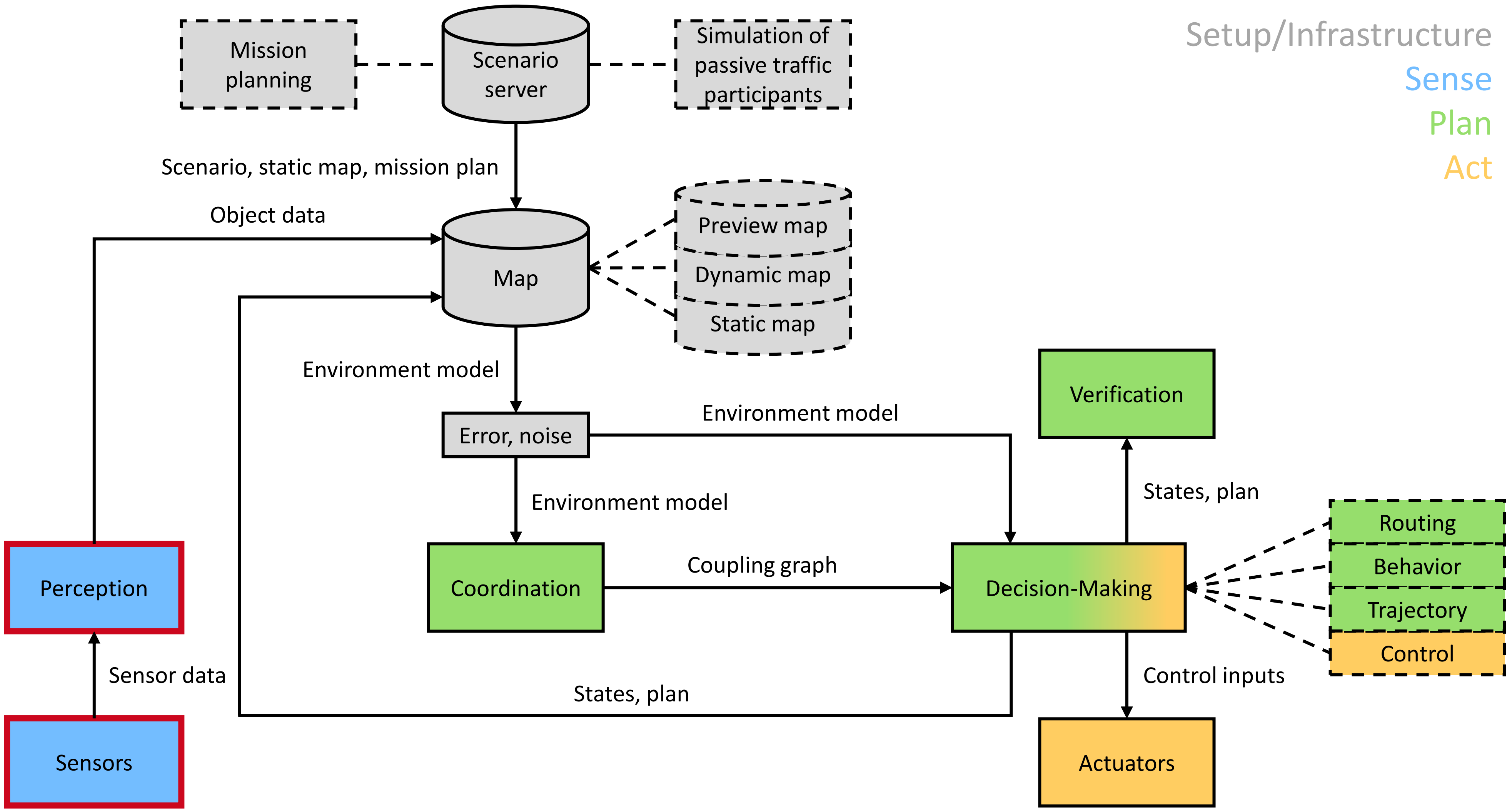
Data Distribution Service – CPM Lab



Data Distribution Service – message format

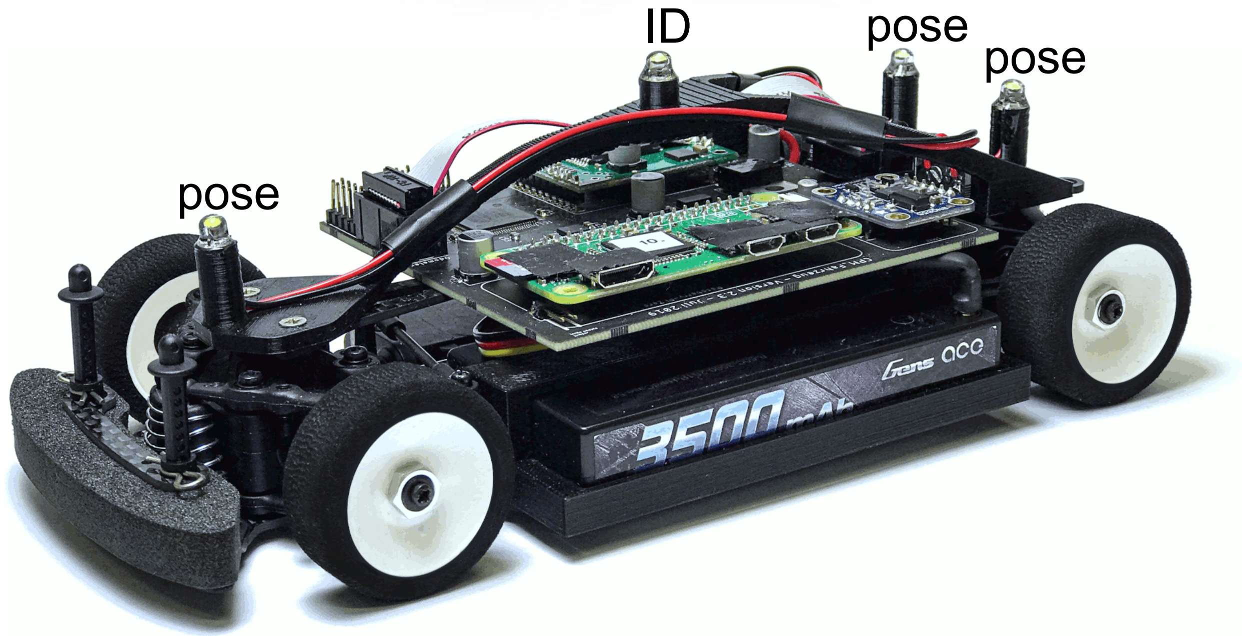
- Message datatype on topic defined with Interactive Data Language (IDL)
- Examples
  - Pose ID, Header, $x(t), y(t), \psi(t)$
  - State ID, Header, $x(t), y(t), \psi(t), s(t), v(t), a(t), \ldots$
  - DirectControl ID, Header, motor_throttle, steering_servo
- Header
  - create_stamp
  - valid_after_stamp

CPM Lab architecture: indoor positioning system



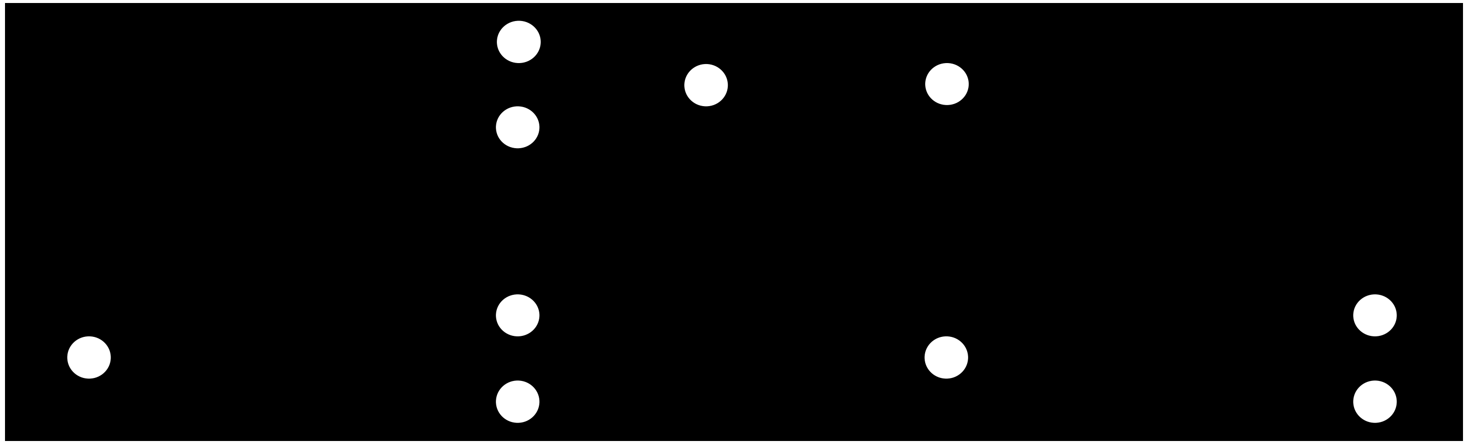
Indoor positioning system

- Camera mounted on the ceiling
  - Top-down view on the field
  - Streams images with 50 Hz
- Vehicles are equipped with LEDs
  - 3 LEDs to encode pose
    - Non-equilateral triangle
  - 1 LED to encode ID
    - Frequency

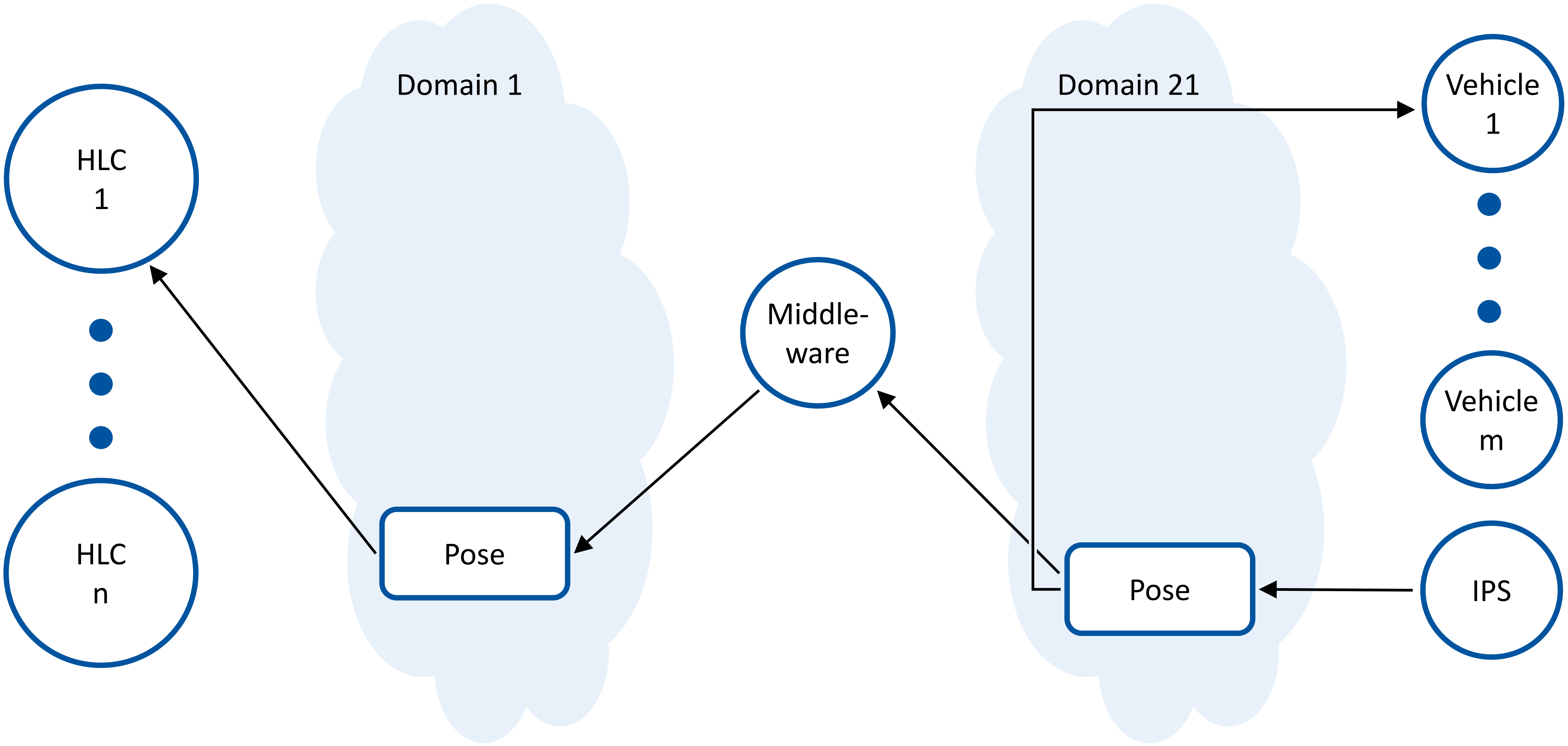


Indoor positioning system

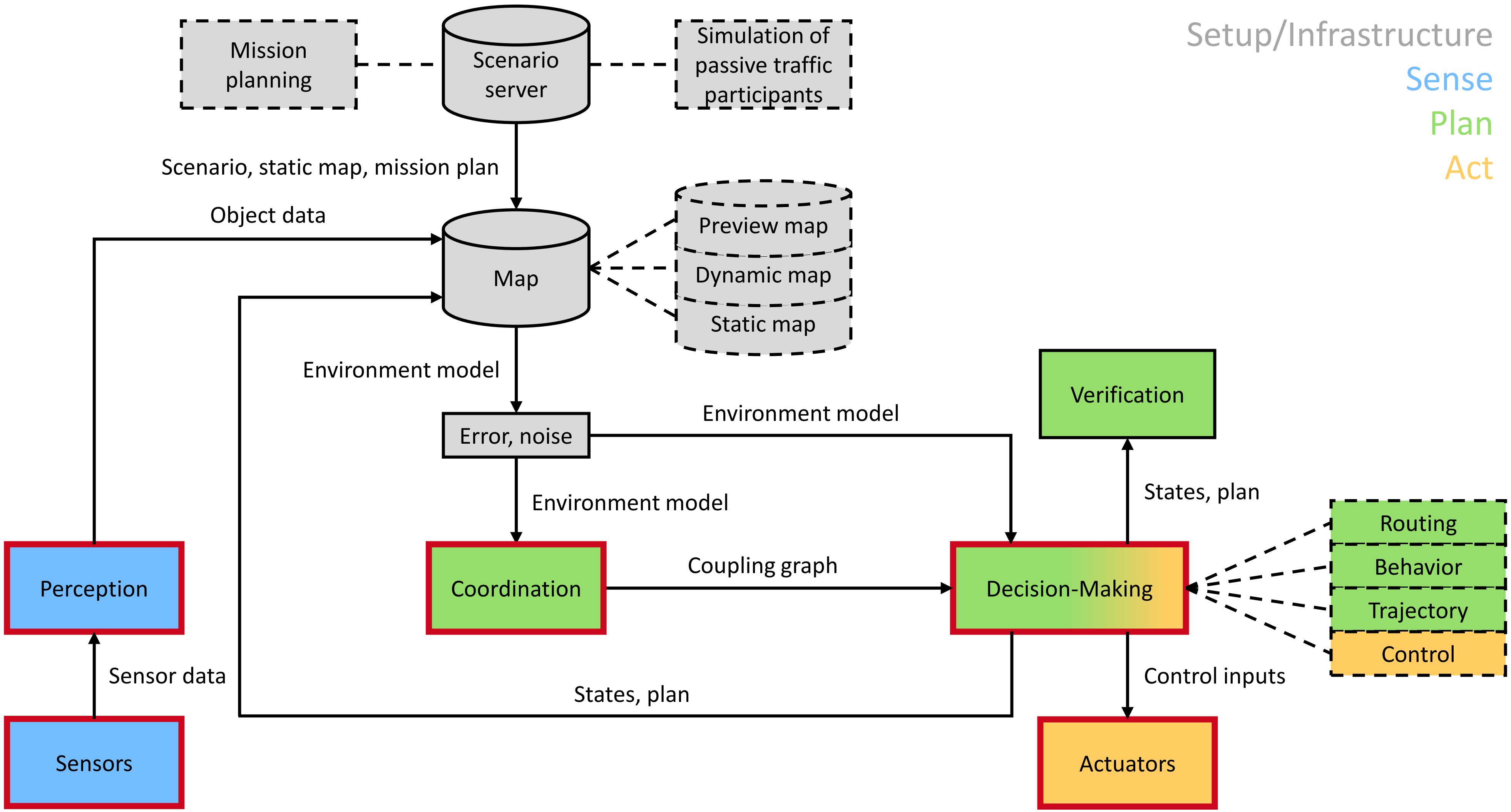
- Low exposure time leads to high contrast of LEDs to background
- IPS pipeline:
  1. Extract LED points of camera image
  2. Transform image coordinates to world coordinates
  3. Find vehicles
  4. Map found vehicles to past vehicles
  5. Extract position, orientation, and ID



Data Distribution Service – CPM Lab

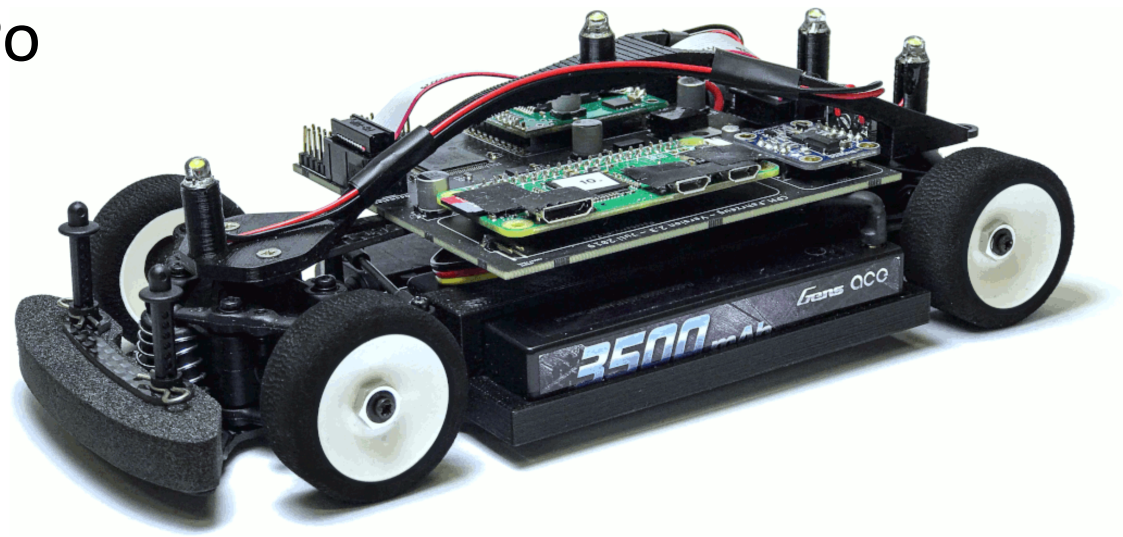


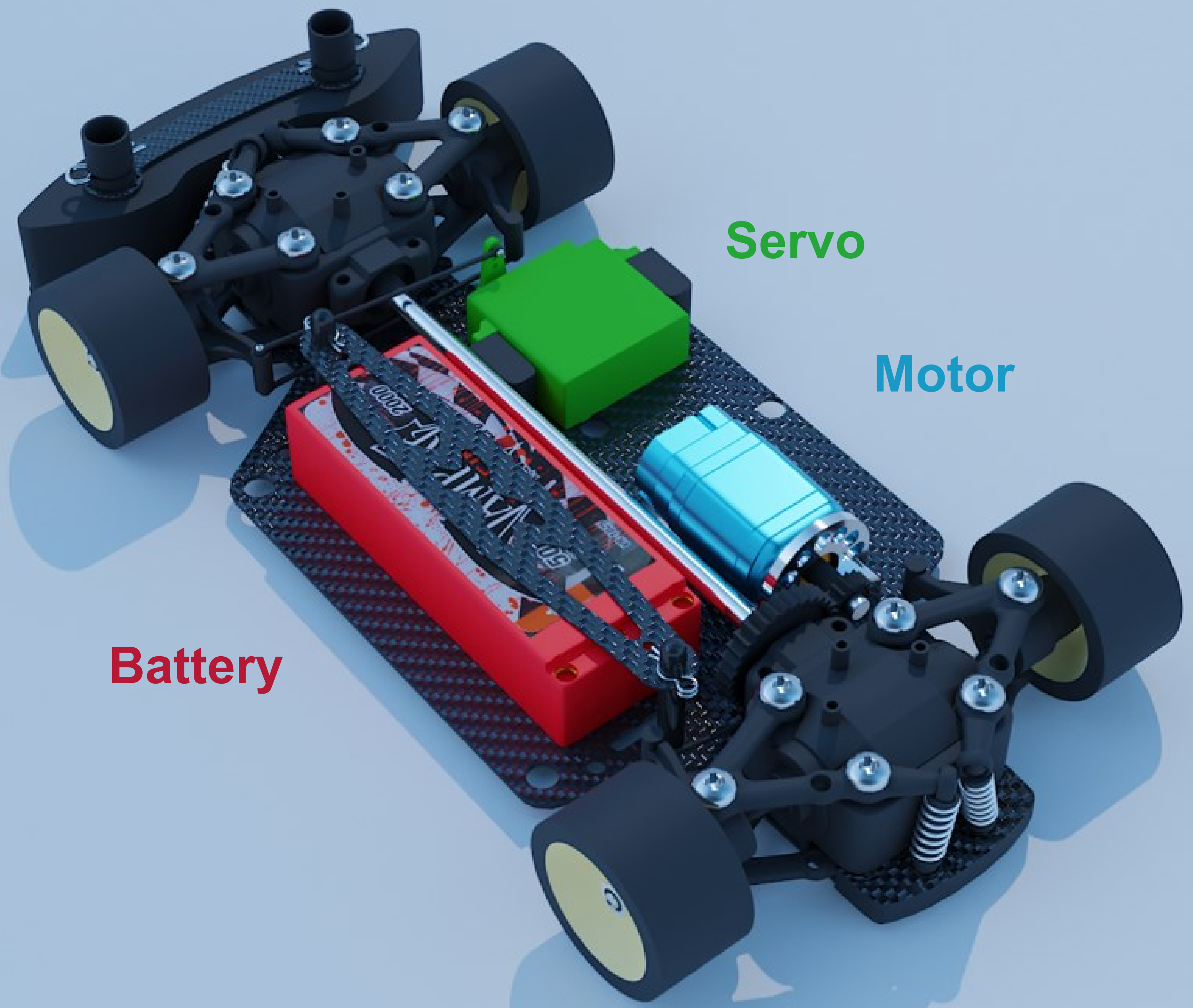
CPM Lab architecture: high level controller and vehicle

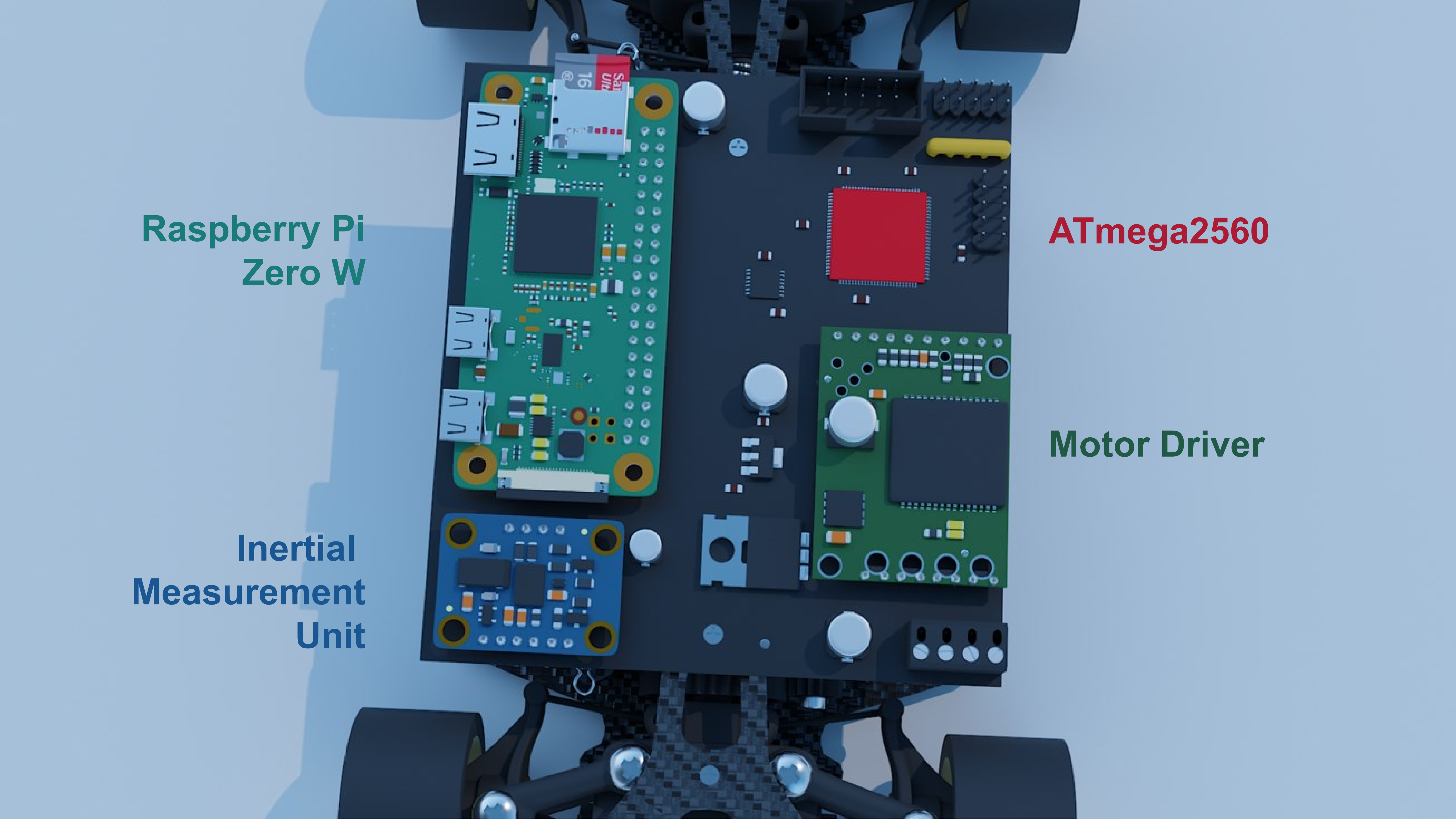


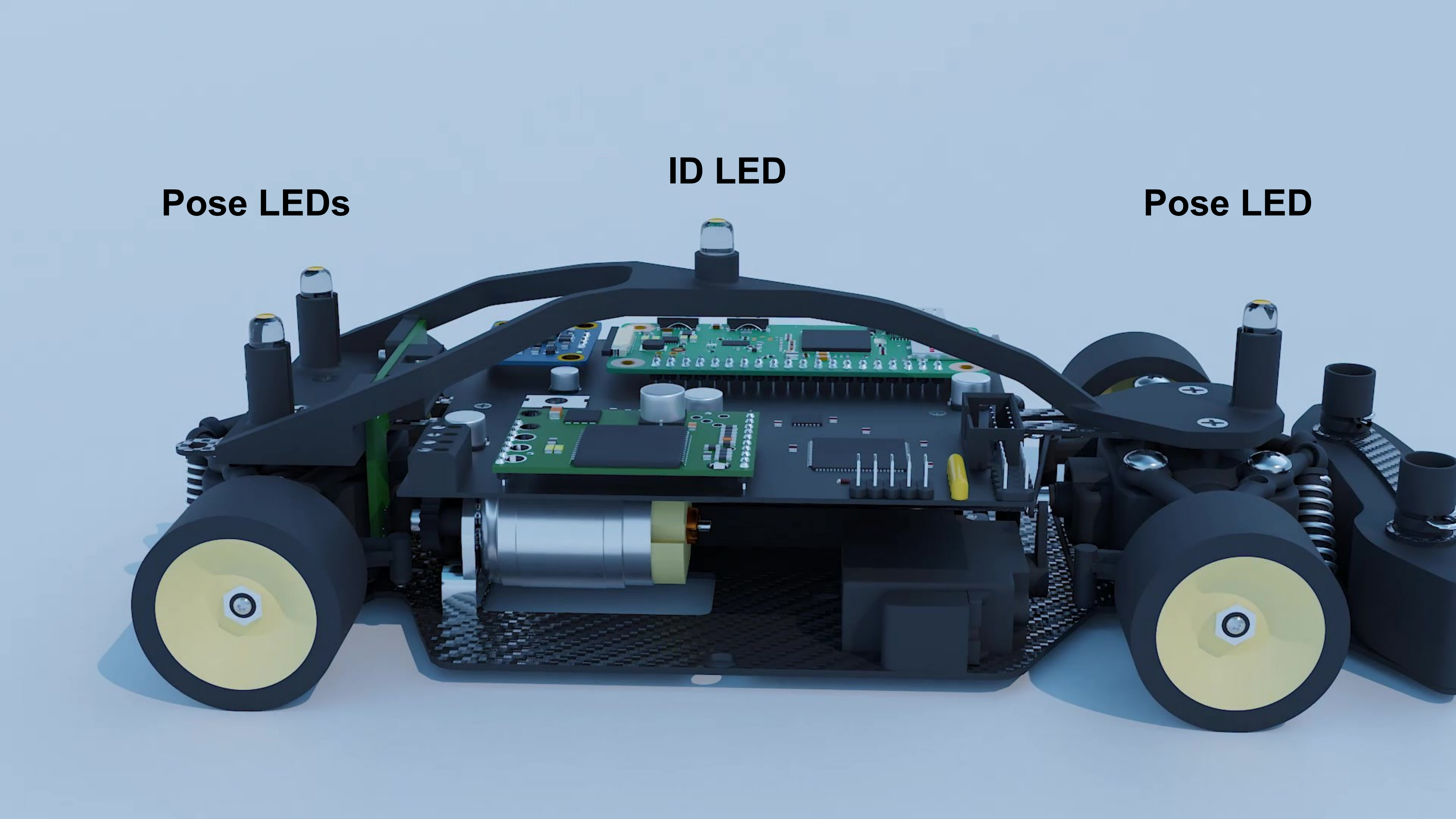
Vehicle – µCar

- Mechanical platform XRAY M18 PRO LiPo
- Sensors
  - IMU (DeboSens BNO055)
  - Odometer (3 Hall-effect sensors + magnet)
- Actuators
  - Servo motor (Hitec D89MW) for steering
  - Brushless DC Motor (Pololu VNH5019) for propulsion
- Computation
  - Mid-level controller (Raspberry Pi Zero W) for WLAN, clock synchronization, sensor fusion, trajectory following control and path tracking
  - Low-level controller (ATmega2560) for reading sensor data and actuation

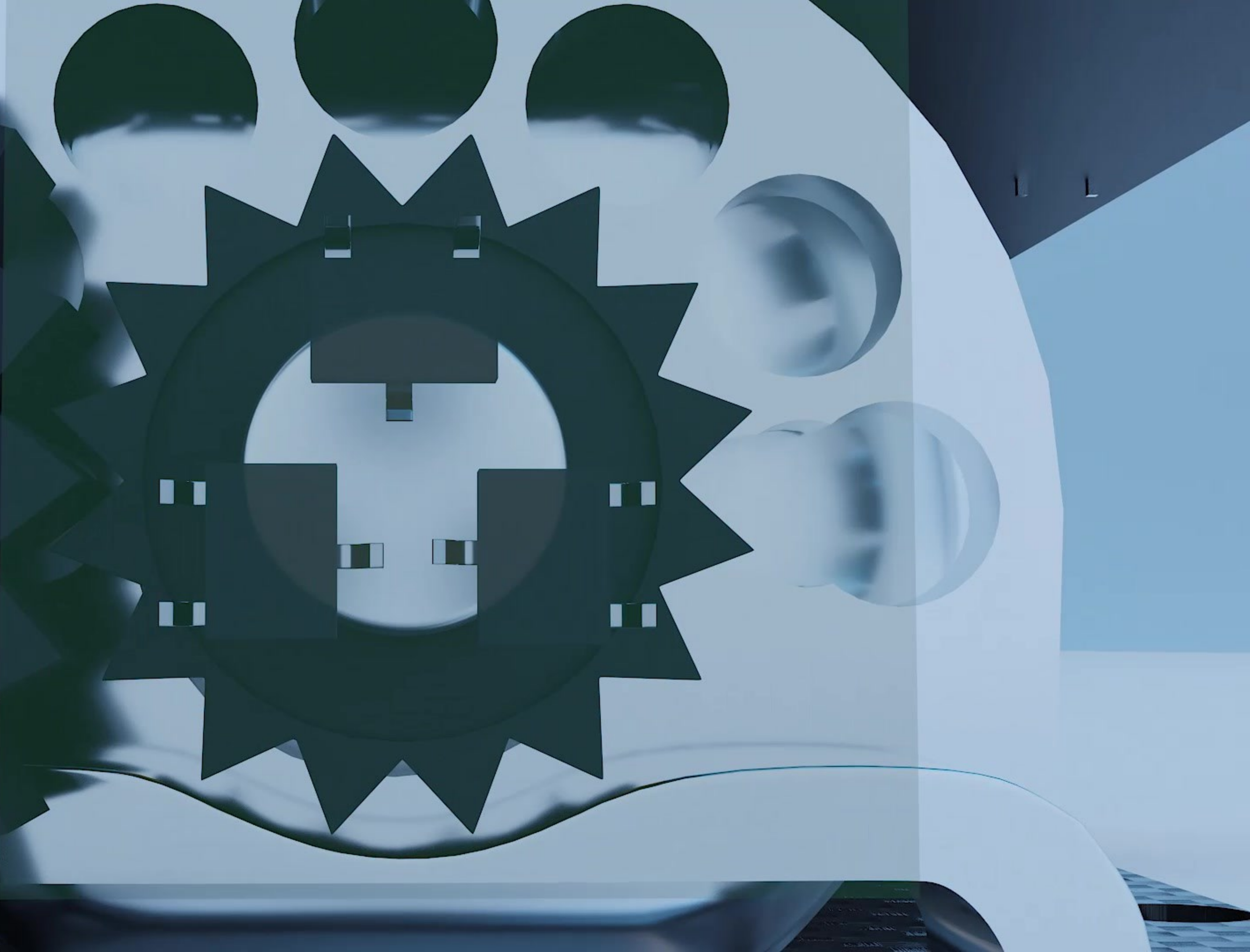



Servo
Motor
Battery

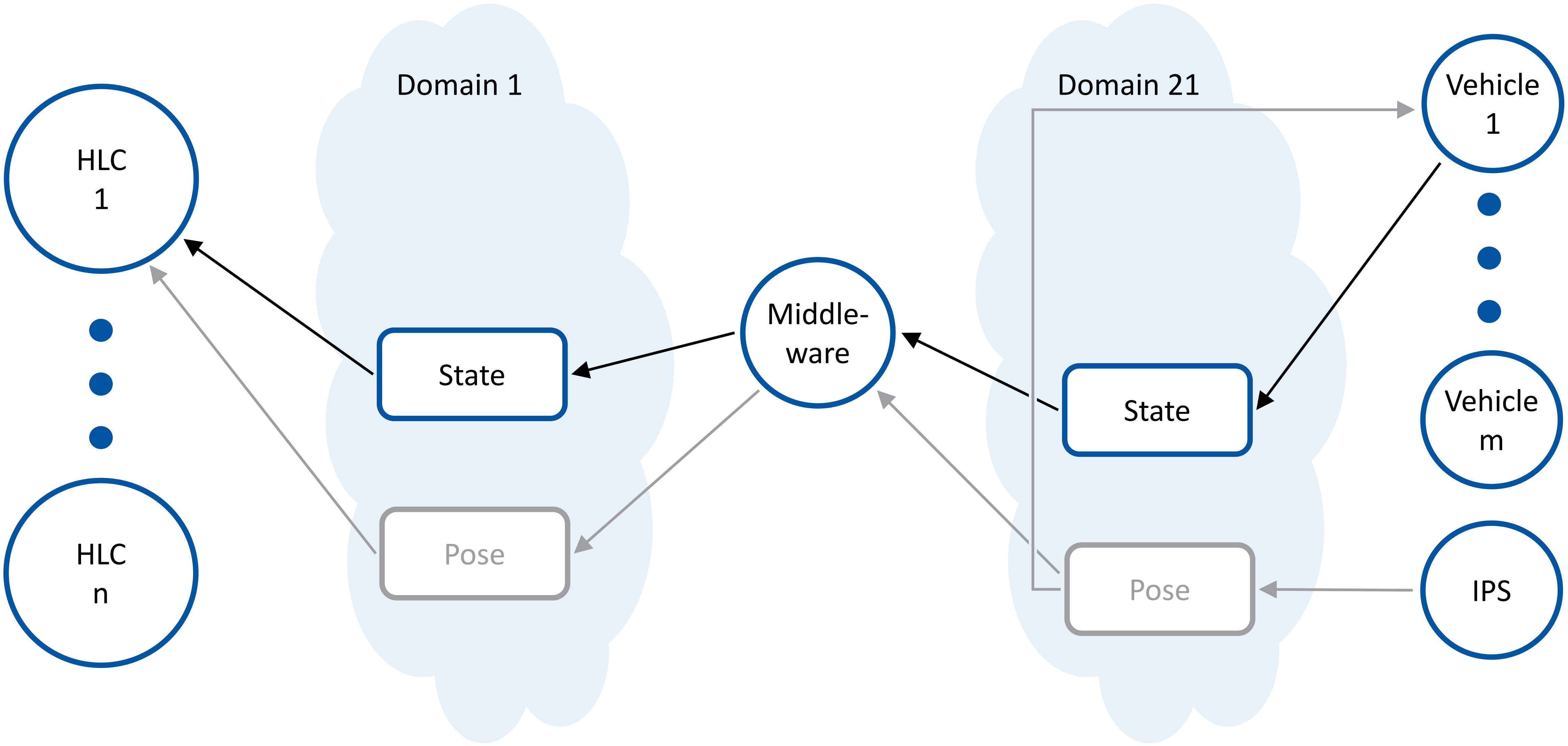

Raspberry Pi
Zero W
ATmega2560
Motor Driver
Inertial
Measurement
Unit


Pose LEDs
ID LED
Pose LED

Hall Effect Sensors and Magnet



Data Distribution Service – CPM Lab

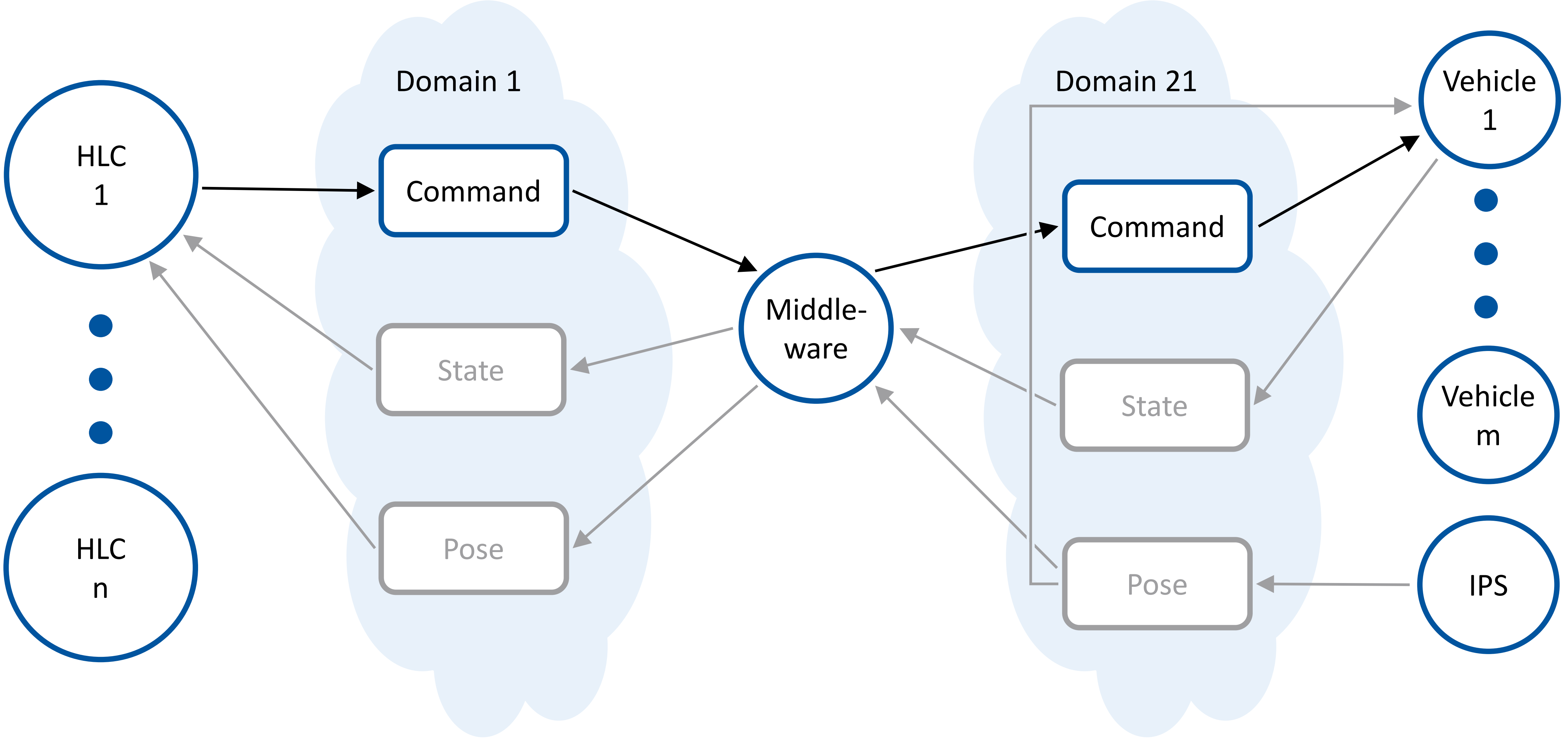


High-level controller

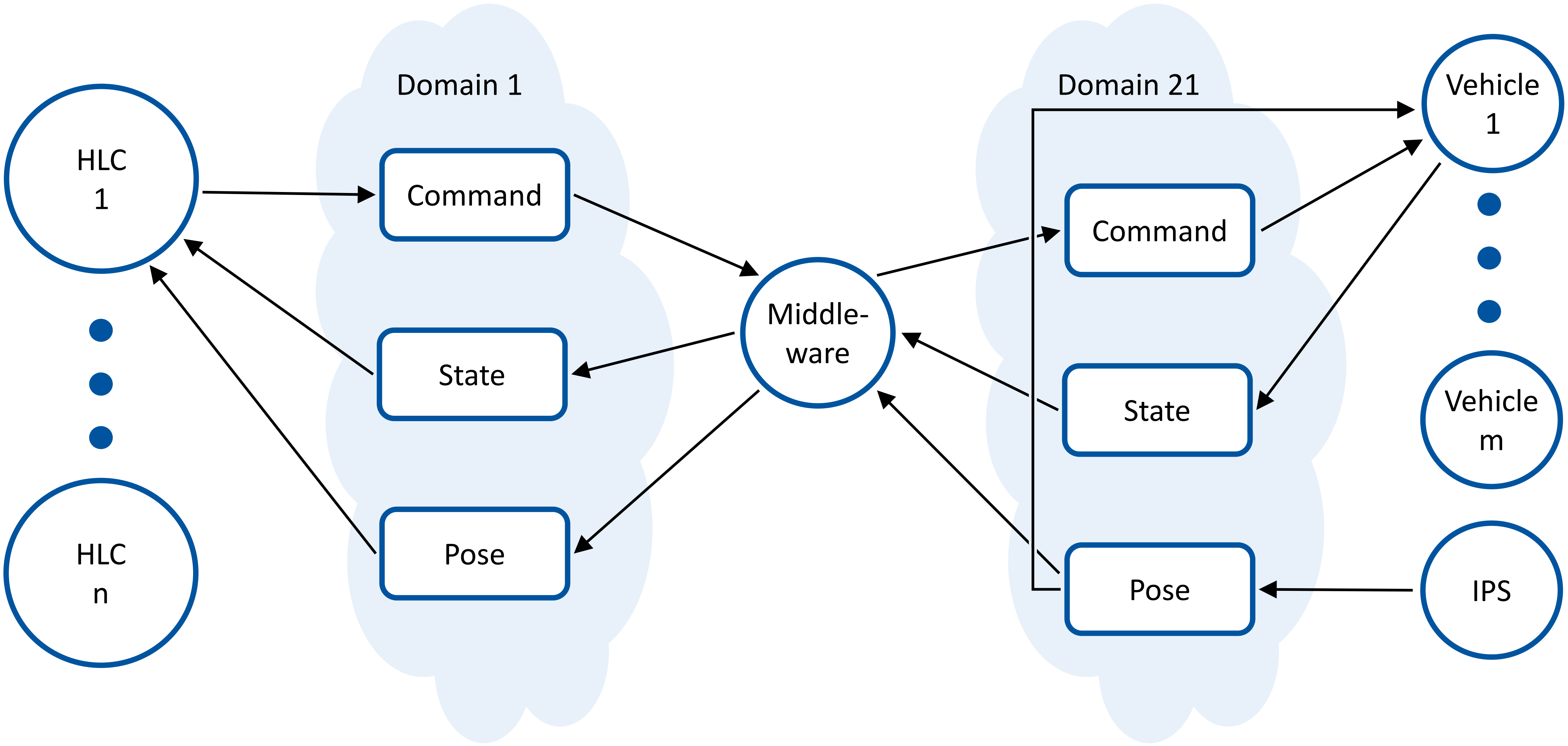
- Direct control
  - Motor as input
  - Steering servo as input
- Path tracking
  - Path and speed as inputs
  - Stanley controller [1]
- Trajectory following
  - Trajectory as input
  - Model predictive controller on Raspberry Pi Zero W using a simplified bicycle model [2]
- HLC in any programming language, only interface to DDS necessary

[1] Hoffmann, Gabriel M., et al. "Autonomous automobile trajectory tracking for off-road driving: Controller design, experimental validation and racing." 2007 American control conference
[2] Scheffe, Patrick, et al. „Networked and Autonomous Model-scale Vehicles for Experiments in Research and Education“ 2020 IFAC World Congress

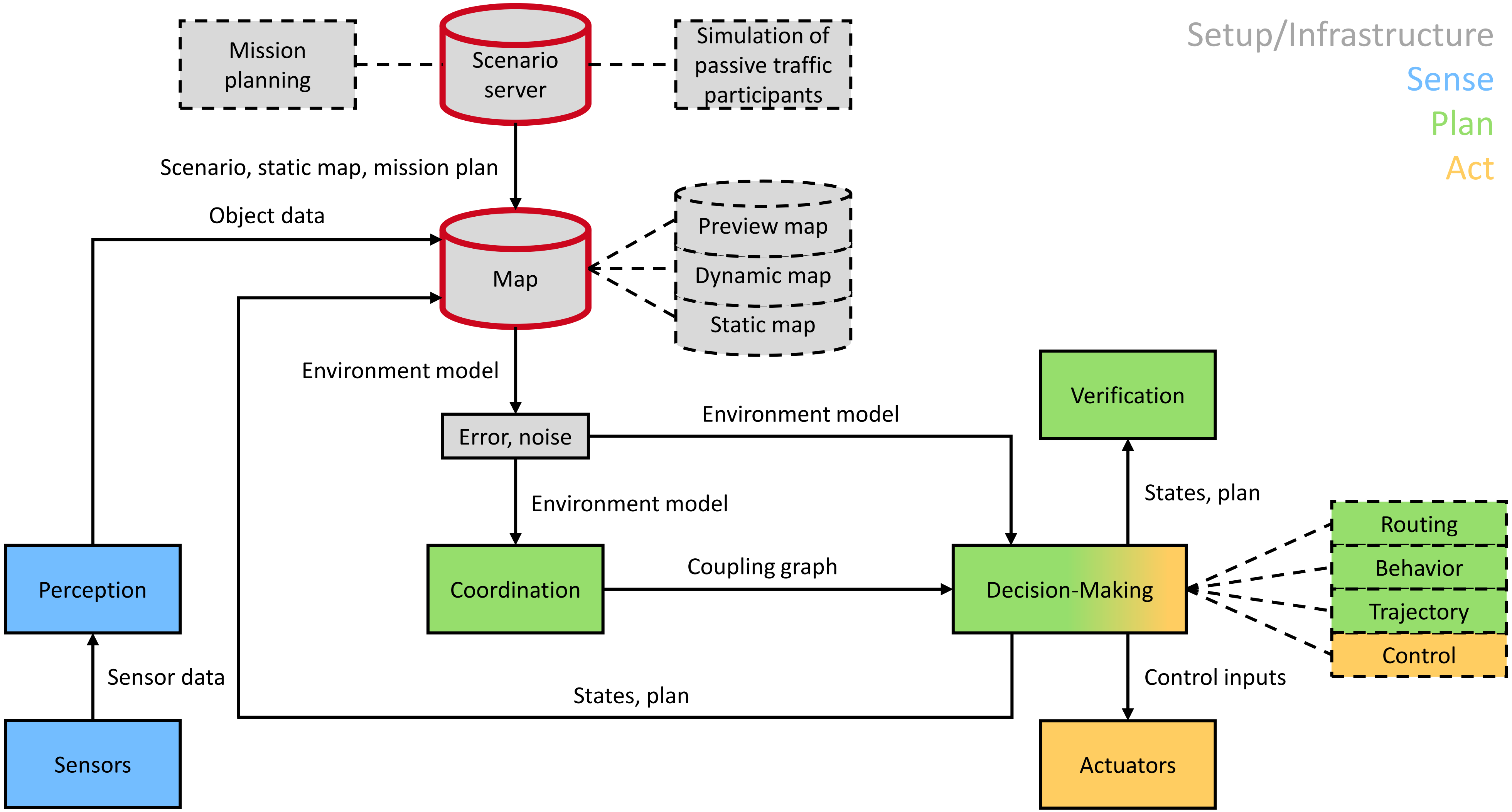
Data Distribution Service – CPM Lab



Data Distribution Service – CPM Lab



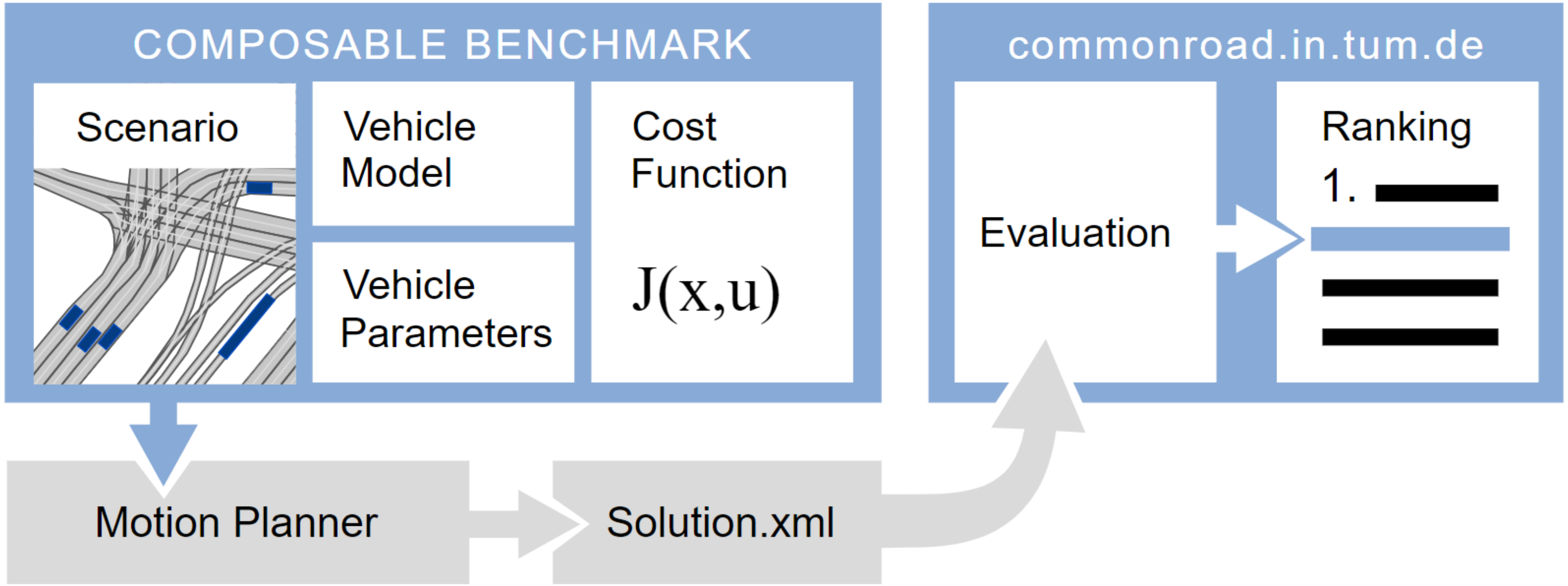
CPM Lab architecture: Scenario definition



Setup/Infrastructure
Sense
Plan
Act

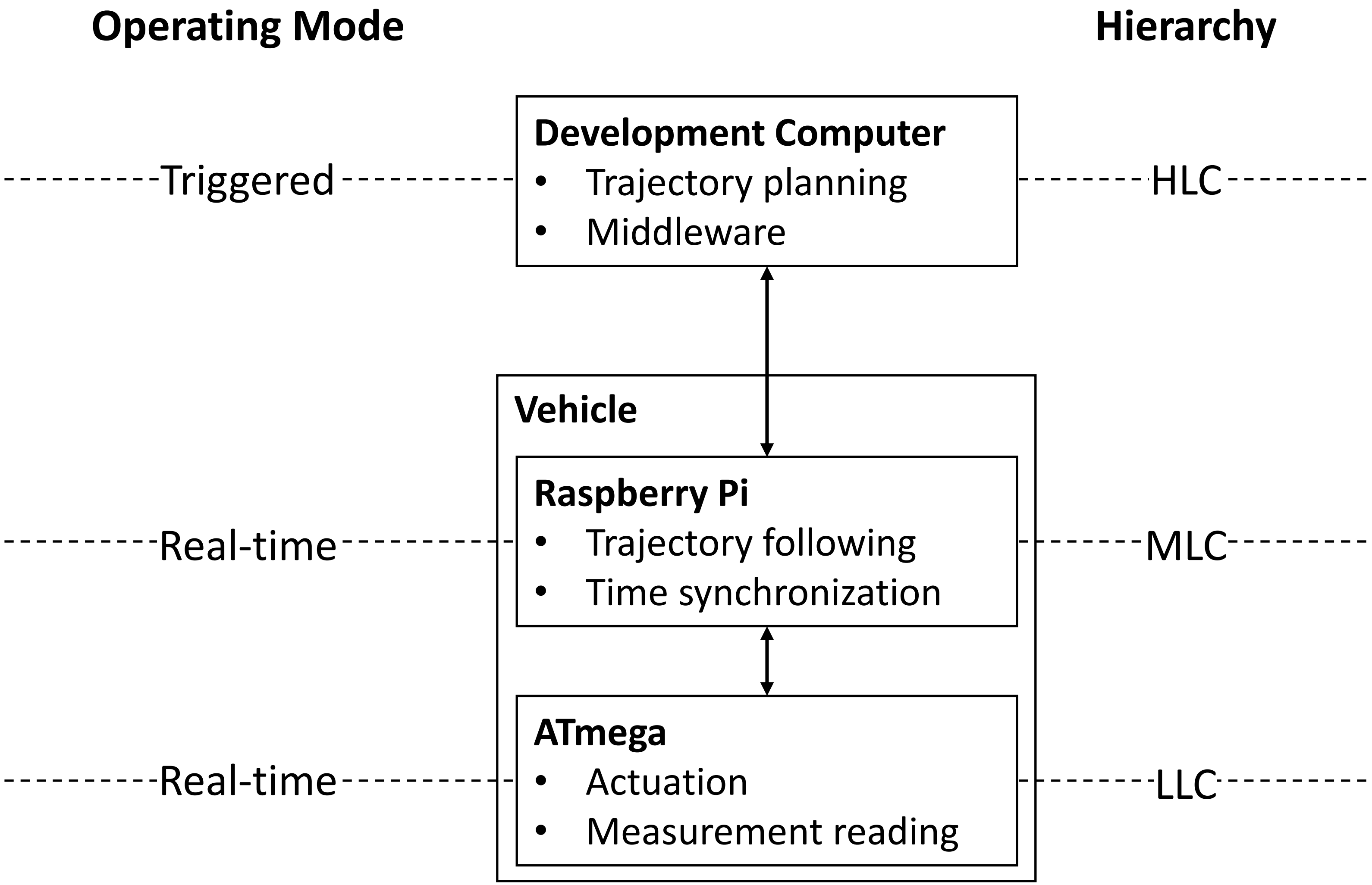
Scenario definition: CommonRoad [1]

- Lanelets
  - Left and right bounds
  - Connections
- Static obstacles
  - Dimensions
- Dynamic obstacles
  - Dimensions
  - Trajectory
- Planning problem
  - Initial state
  - Goal state

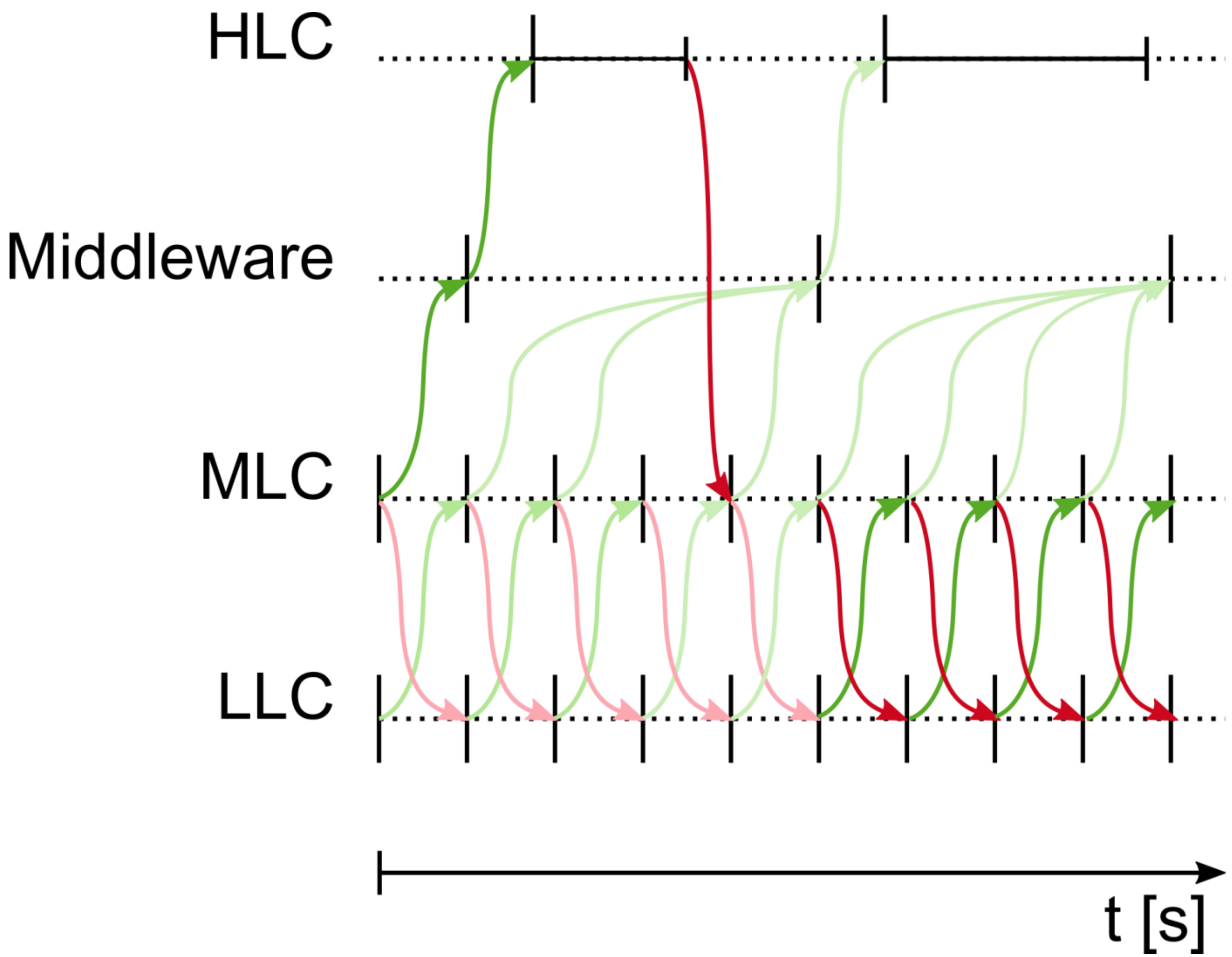


[1] Althoff, Matthias, Markus Koschi, and Stefanie Manzinger. "CommonRoad: Composable benchmarks for motion planning on roads." 2017 IEEE Intelligent Vehicles Symposium (IV)

Experimental concept



Experimental concept



Process model – eXtreme Programming

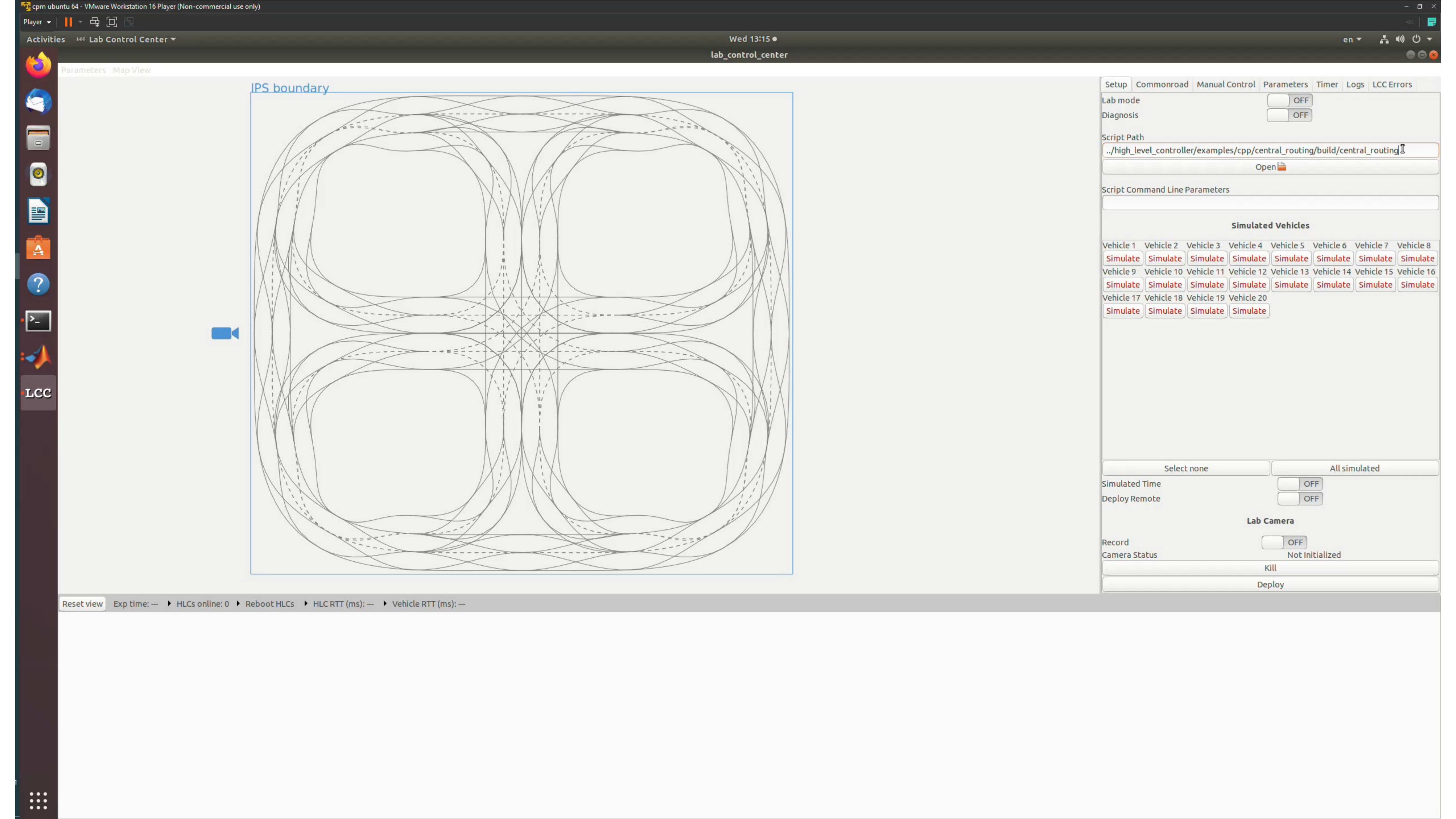
- Evolutionary development in small increments
- Most important features first
- Test-first, automated testing
- Have working code
- Pair programming

- No explicit design, documentation, review → suitable for small projects

Git commands

1. **git clone**
   To copy a git repository from remote source
2. **git status**
   To check the status of files you've changed in your working directory
3. **git add**
   Adds changes to stage/index in your working directory
4. **git commit**
   Commits your changes and sets it to new commit object for your remote
5. **git push**
   Push your changes to remote
6. **git pull**
   Pull changes from the remote

You can find a more elaborate introduction to git in the moodle room.


cpm ubuntu 64 - VMware Workstation 16 Player (Non-commercial use only)
Player
Activities
Lab Control Center
Wed 13:15
en
lab_control_center
Parameters
Map View
IPS boundary
Setup
Commonroad
Manual Control
Parameters
Timer
Logs
LCC Errors
Lab mode
OFF
Diagnosis
OFF
Script Path
../high_level_controller/examples/cpp/central_routing/build/central_routing
Open
Script Command Line Parameters
Simulated Vehicles
Vehicle 1
Vehicle 2
Vehicle 3
Vehicle 4
Vehicle 5
Vehicle 6
Vehicle 7
Vehicle 8
Vehicle 9
Vehicle 10
Vehicle 11
Vehicle 12
Vehicle 13
Vehicle 14
Vehicle 15
Vehicle 16
Vehicle 17
Vehicle 18
Vehicle 19
Vehicle 20
Simulate
Select none
All simulated
Simulated Time
OFF
Deploy Remote
OFF
Lab Camera
Record
OFF
Camera Status
Not Initialized
Kill
Deploy
Reset view
Exp time: —
HLCs online: 0
Reboot HLCs
HLC RTT (ms): —
Vehicle RTT (ms): —
LCC