# Achievements and contributions

# Halmstad University

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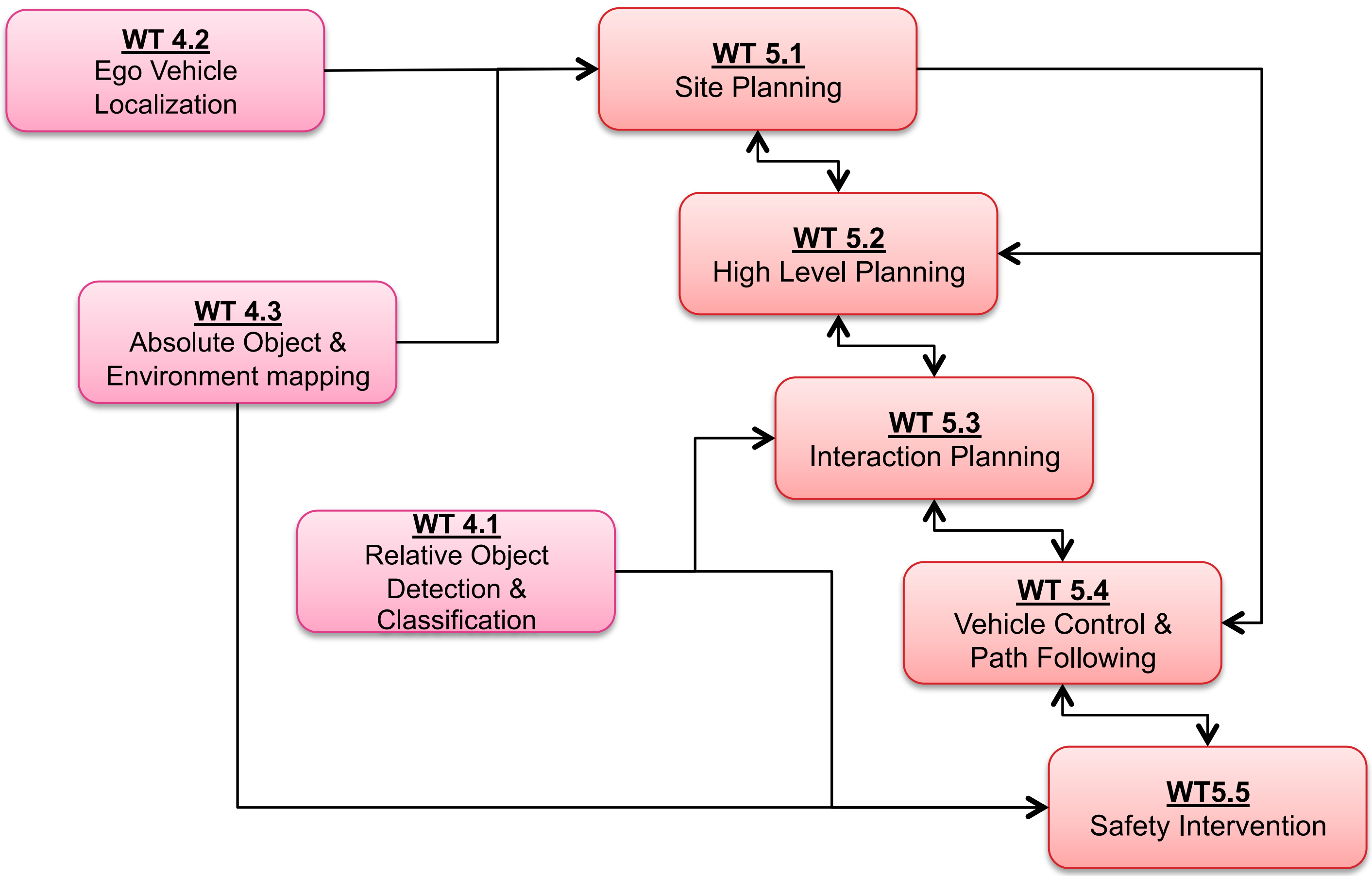
Final meeting – Gothenburg, Sweden – August 2016

# Objectives

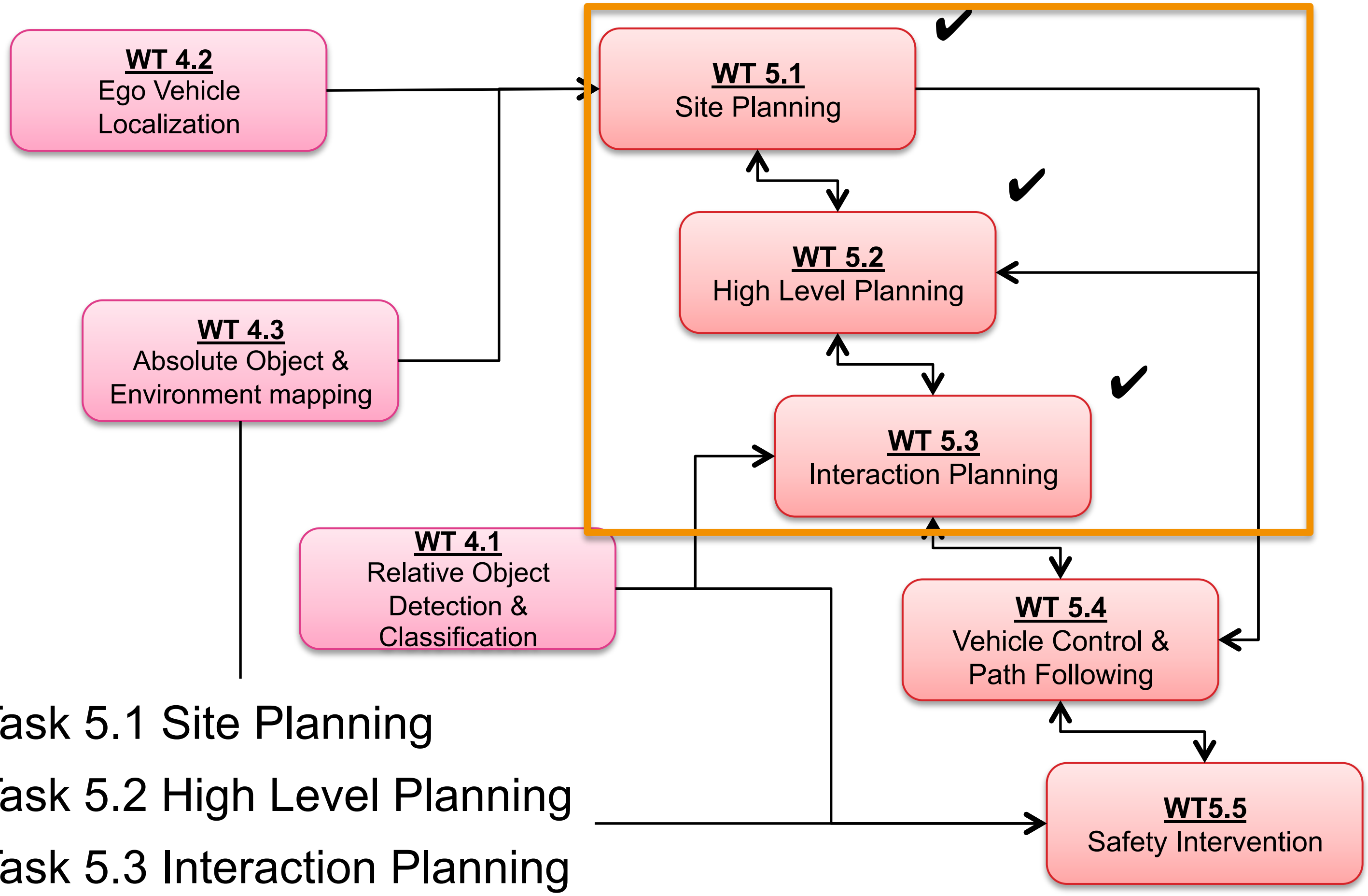
Our main objectives are part of WP5 & WP6 :

- Develop global and local path planning sub-systems.
- Task allocation: build a mock-up high-level Site Planning control.
- Integrate the map, communication and localization inputs from WP4 into the planning algorithms.

# Task Inter-Relation

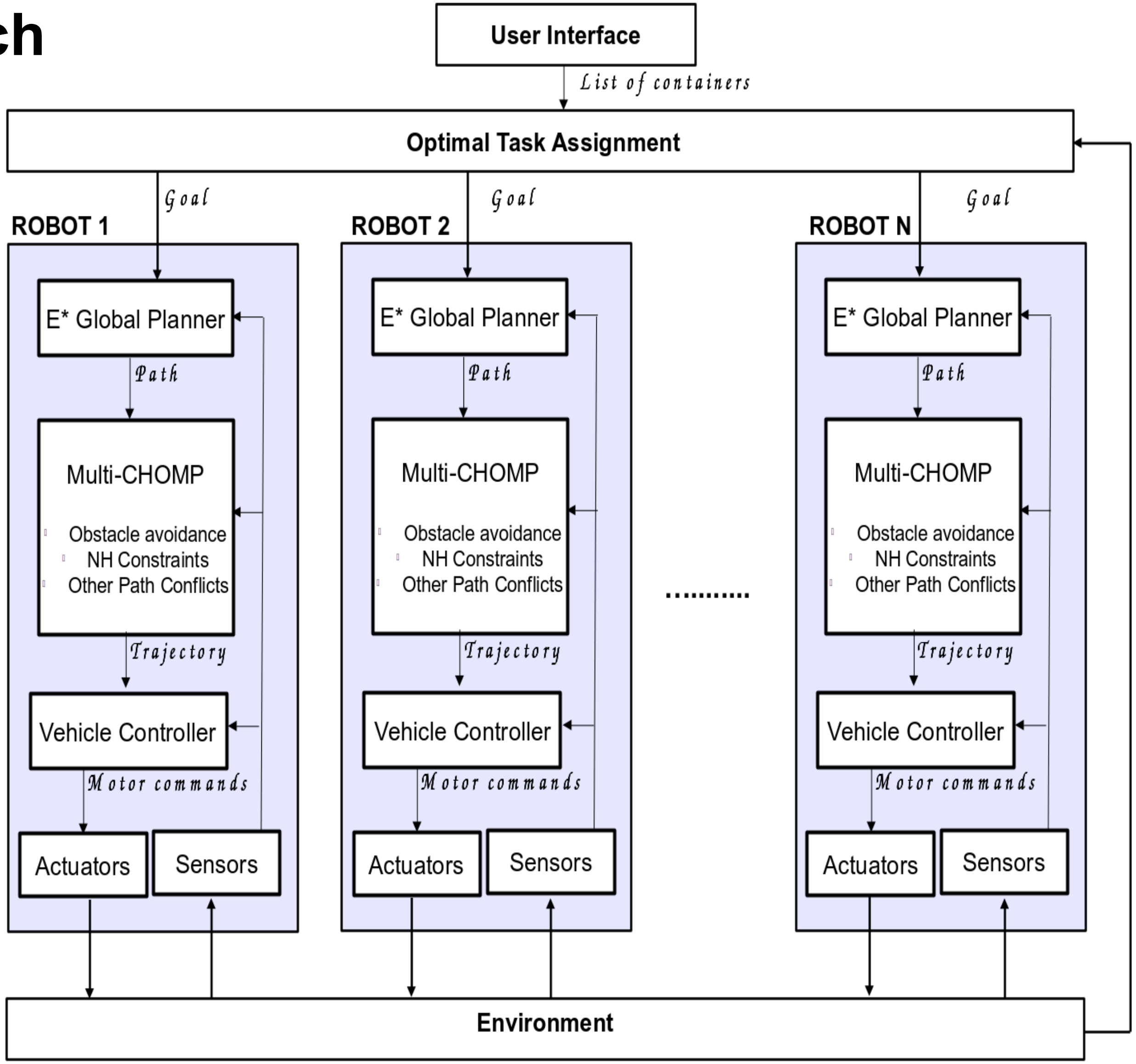


# Independent software modules finished



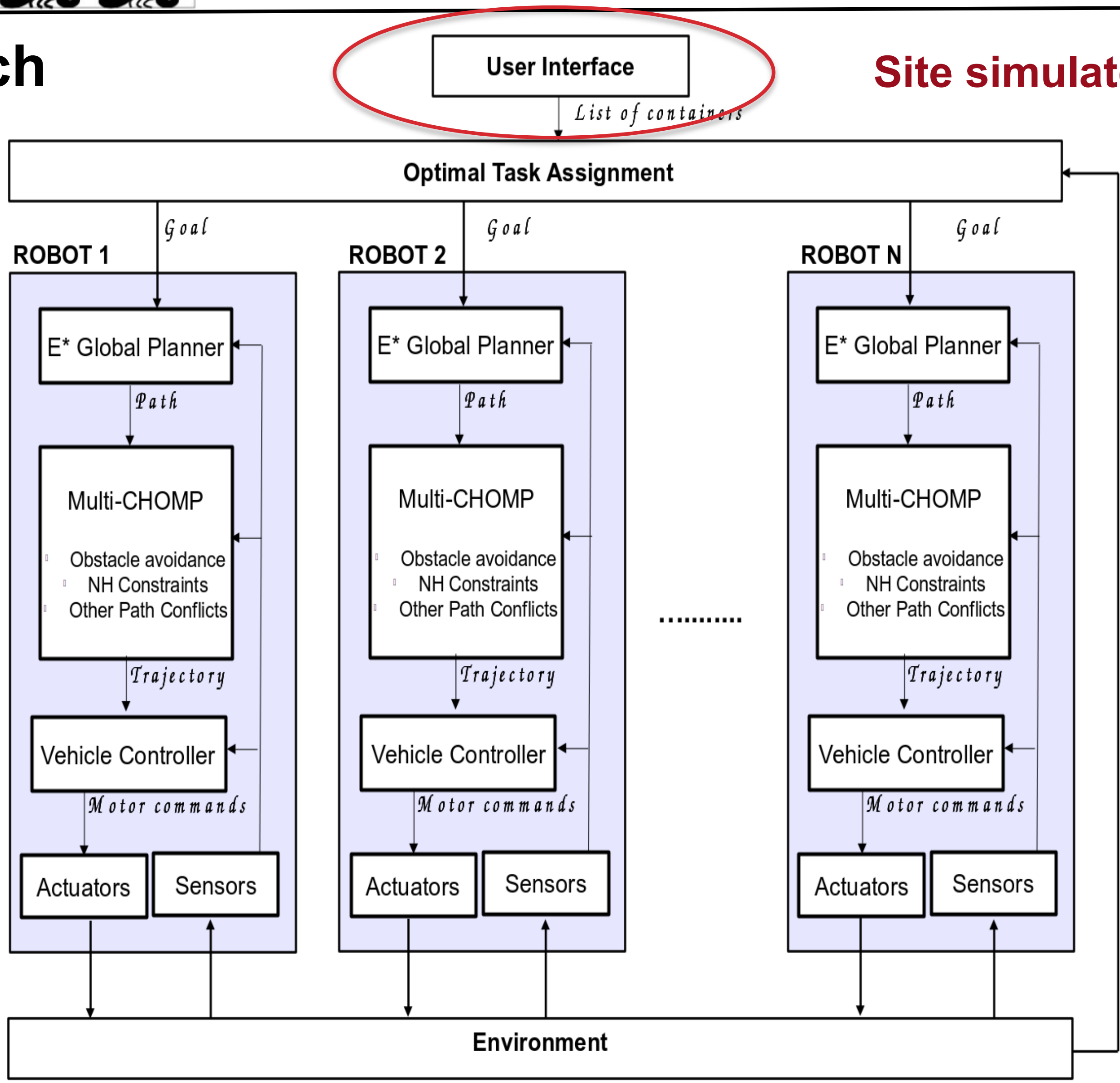

- Task 5.1 Site Planning
- Task 5.2 High Level Planning
- Task 5.3 Interaction Planning
- WP6: Integration

# Approach


User Interface
List of containers
Optimal Task Assignment
Goal
ROBOT 1
ROBOT 2
ROBOT N
E* Global Planner
Path
Multi-CHOMP
Obstacle avoidance
NH Constraints
Other Path Conflicts
Trajectory
Vehicle Controller
Motor commands
Actuators
Sensors
..........
Environment

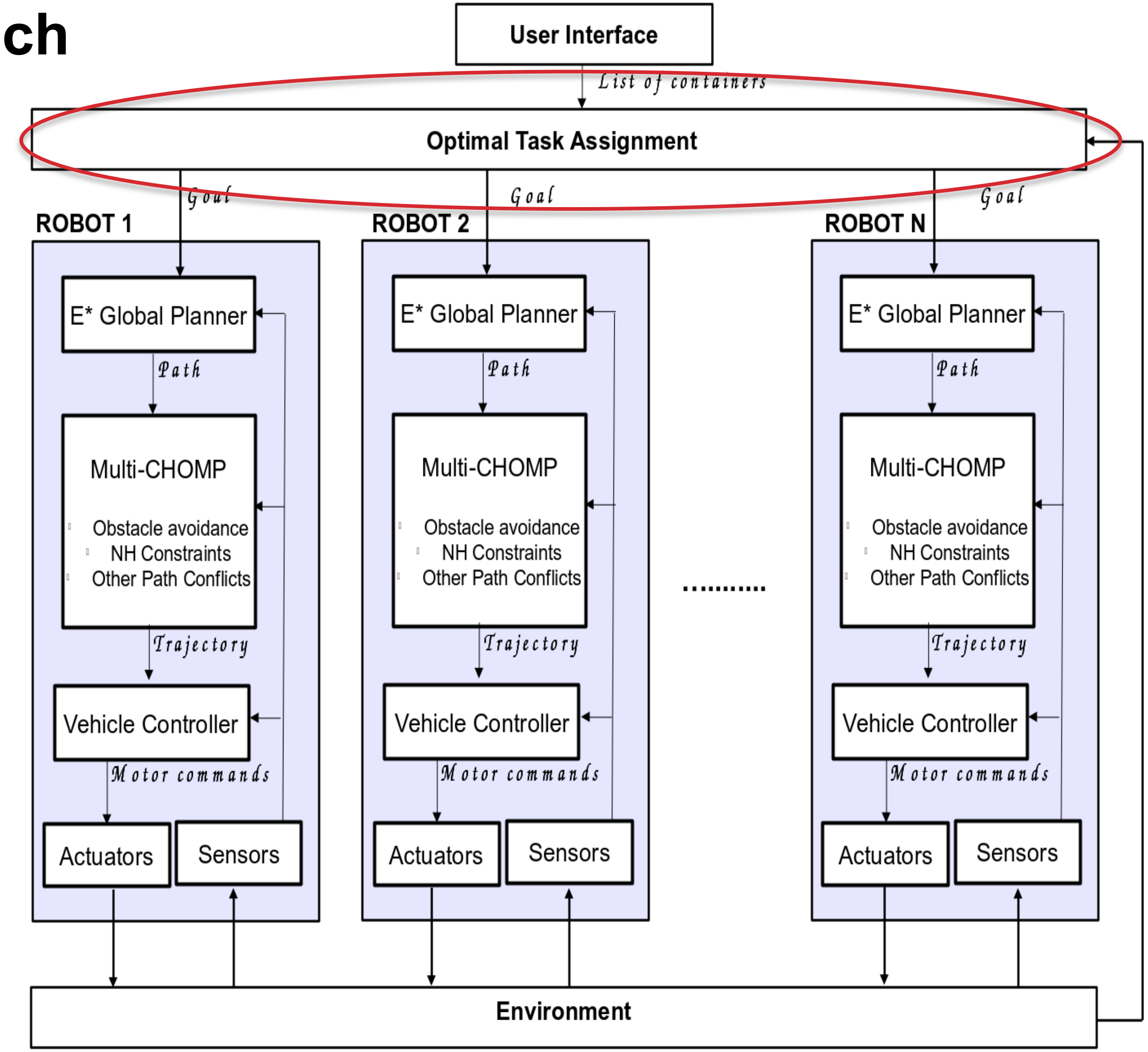
# Approach

**Site simulator**



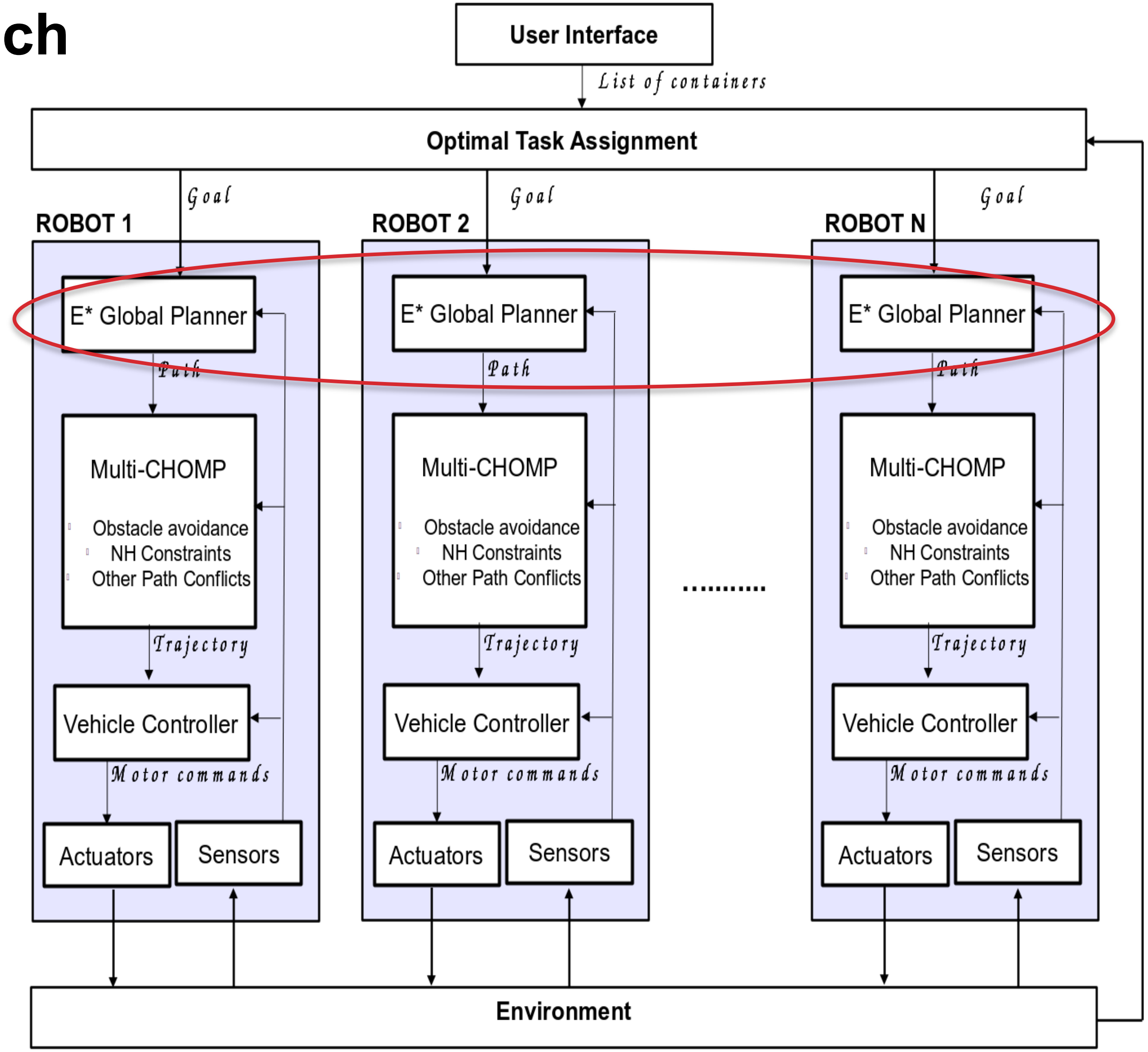
# Approach

## Task 5.1



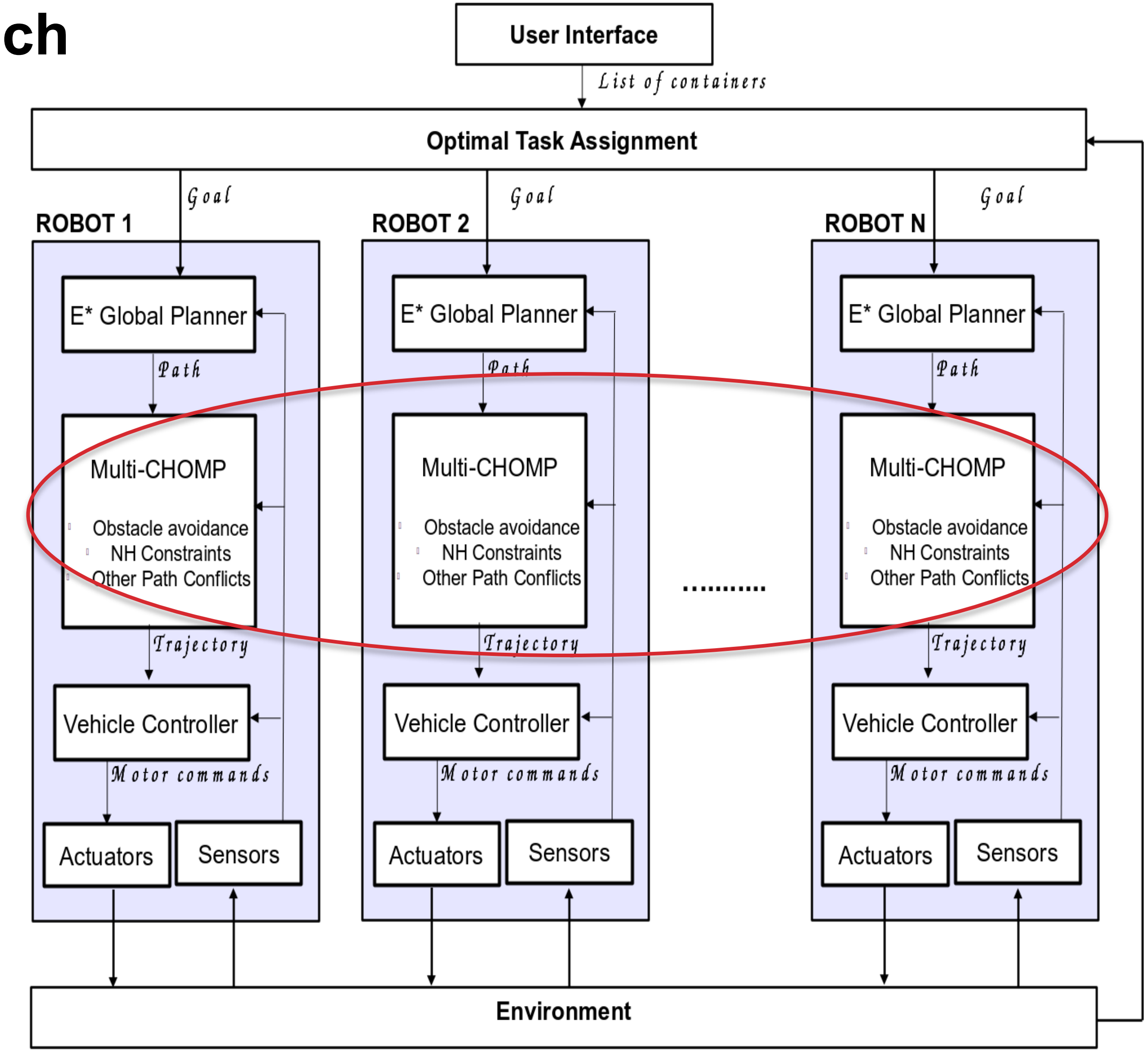
# Approach

Task 5.2



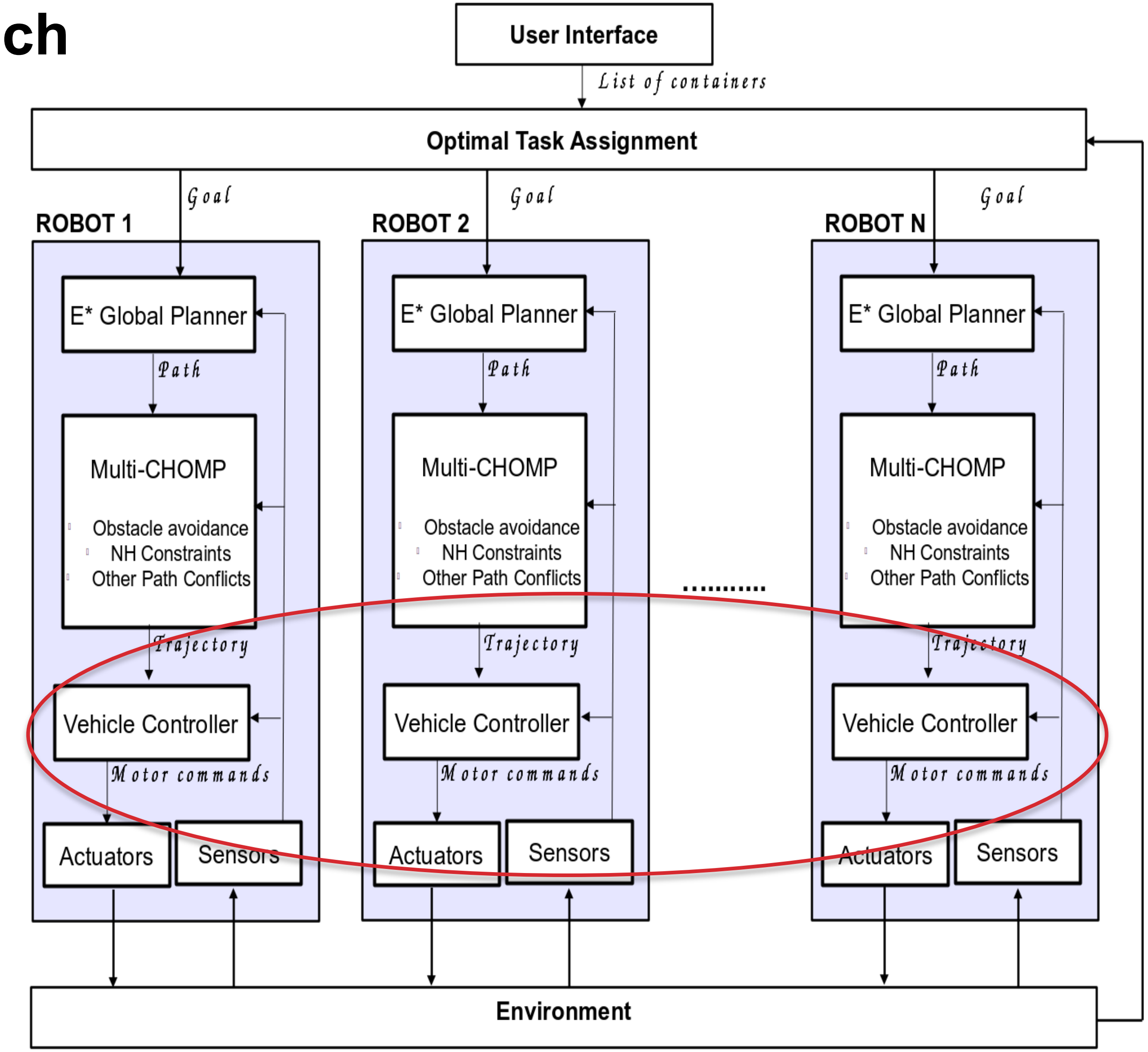
# Approach

Task 5.3



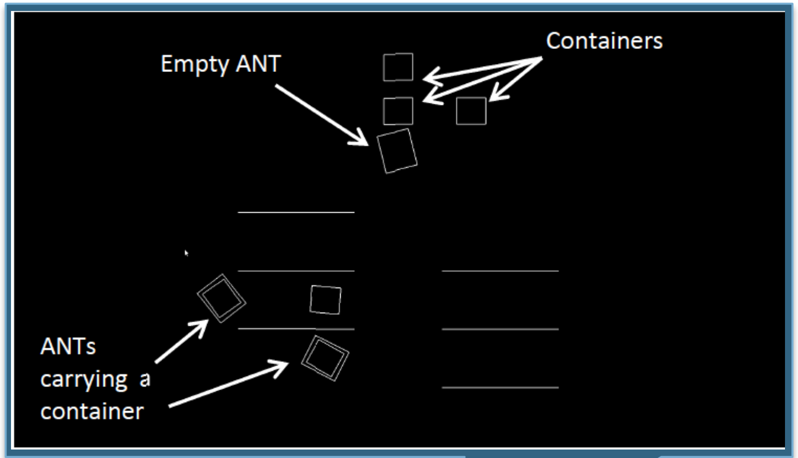
# Approach

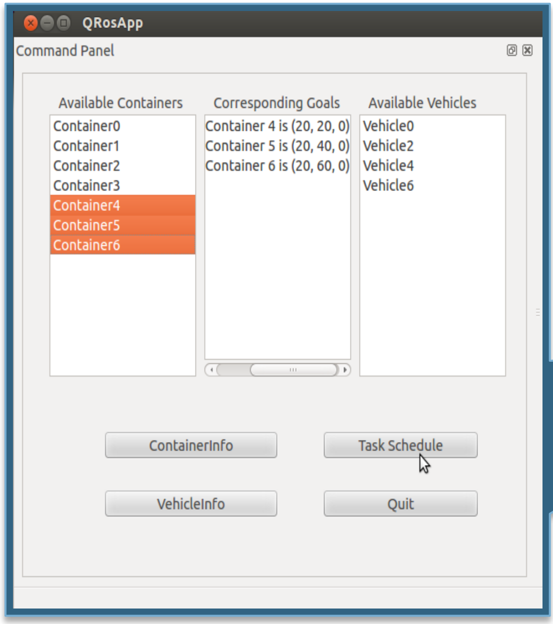
Task 5.4

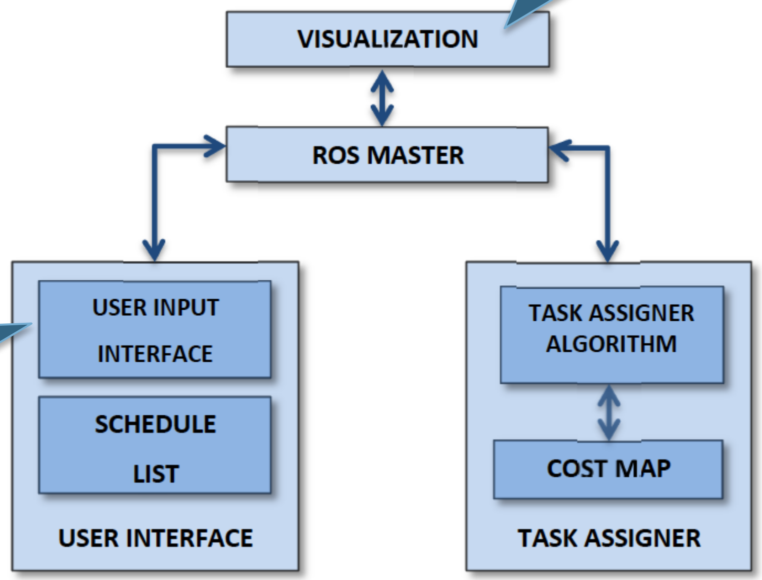


# Site simulator

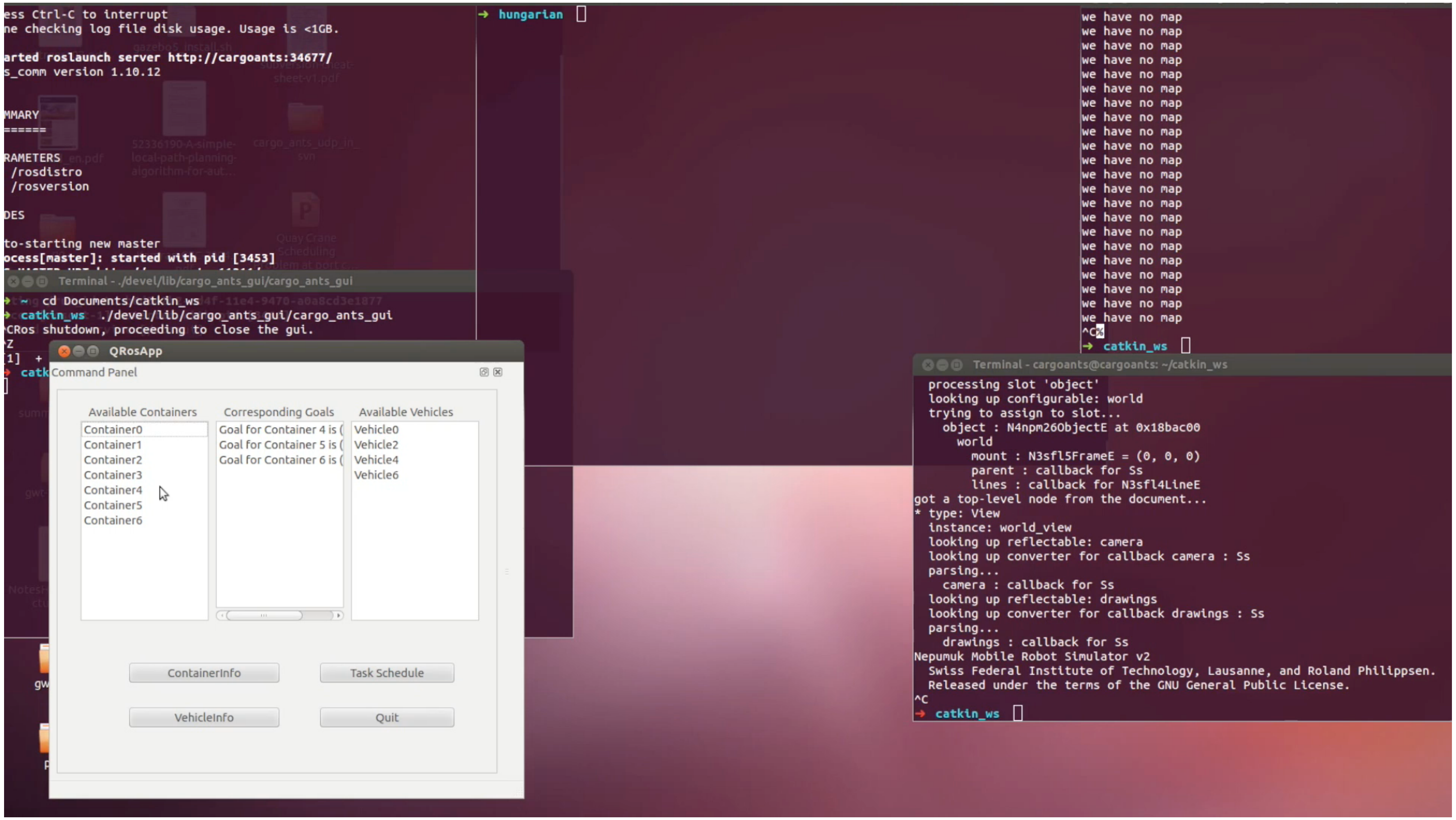
- User interface
- Visualization of ANTs and Containers
- Task assigner module



# Site simulator



# Task 5.1: Site planning (task assignment)

- **Goal**: Assign containers to available vehicles.
- Two approaches implemented and compared.
- We minimize total path length of assignments.

***Cij***: cost of assigning
*ith*-container to *jth*-ANT

$$
\begin{aligned}
\text{minimize } & f = \sum_{i,j} c_{ij} x_{ij}, \\
\text{subject to } & \sum_{j} x_{ij} = 1, \quad \forall i, \\
& \sum_{i} x_{ij} = 1, \quad \forall j, \\
& x_{ij} \geq 0, \quad \forall (i, j),
\end{aligned}
$$

$\boldsymbol{x_{ij}}$: assignment of
*ith*-container to *jth*-ANT

# Task 5.1: Site planning (task assignment)

- Comparison with a heuristic approach (first comes first served basis)

| Number of ANTs and Number of Containers (CNTs) | Feedback Controller Assignment | Hungarian Algorithm Assignment | Total Path Length (meters) | |
|---|---|---|---|---|
| | | | Feedback controller | Hungarian Algorithm |
| 1 ANT – 4 CNTs | $C_1 \to A_1$ $C_2 \to A_1$ $C_3 \to A_1$ $C_4 \to A_1$ | $C_4 \to A_1$ $C_3 \to A_1$ $C_2 \to A_1$ $C_1 \to A_1$ | 24.08 | 24.08 |
| 2 ANTs – 4 CNTs | $C_1 \to A_1$ $C_2 \to A_2$ $C_3 \to A_1$ $C_4 \to A_2$ | $C_4 \to A_1$ $C_3 \to A_2$ $C_2 \to A_1$ $C_1 \to A_2$ | 85.12 | 45.17 |
| 2 ANTs – 8 CNTs | $C_1 \to A_1$ $C_2 \to A_2$ $C_3 \to A_1$ $C_4 \to A_2$ $C_5 \to A_1$ $C_6 \to A_2$ $C_7 \to A_1$ $C_8 \to A_2$ | $C_8 \to A_1$ $C_7 \to A_2$ $C_6 \to A_1$ $C_5 \to A_2$ $C_4 \to A_1$ $C_3 \to A_2$ $C_2 \to A_1$ $C_1 \to A_2$ | 112.2 | 51.73 |
| 3 ANTs – 6 CNTs | $C_1 \to A_1$ $C_2 \to A_2$ $C_3 \to A_3$ $C_4 \to A_1$ $C_5 \to A_2$ $C_6 \to A_3$ | $C_6 \to A_1$ $C_5 \to A_2$ $C_4 \to A_3$ $C_3 \to A_1$ $C_2 \to A_2$ $C_1 \to A_3$ | 182.36 | 72.33 |
| 3 ANTs – 3 CNTs | $C_1 \to A_1$ $C_2 \to A_2$ $C_3 \to A_3$ | $C_3 \to A_1$ $C_2 \to A_2$ $C_1 \to A_3$ | 142.42 | 64.24 |
| 4 ANTs – 8 CNTs | $C_1 \to A_1$ $C_2 \to A_2$ $C_3 \to A_3$ $C_4 \to A_4$ $C_5 \to A_1$ $C_6 \to A_2$ $C_7 \to A_3$ $C_8 \to A_4$ | $C_8 \to A_1$ $C_7 \to A_2$ $C_6 \to A_3$ $C_5 \to A_4$ $C_4 \to A_1$ $C_3 \to A_2$ $C_2 \to A_3$ $C_1 \to A_4$ | 202.11 | 92.55 |

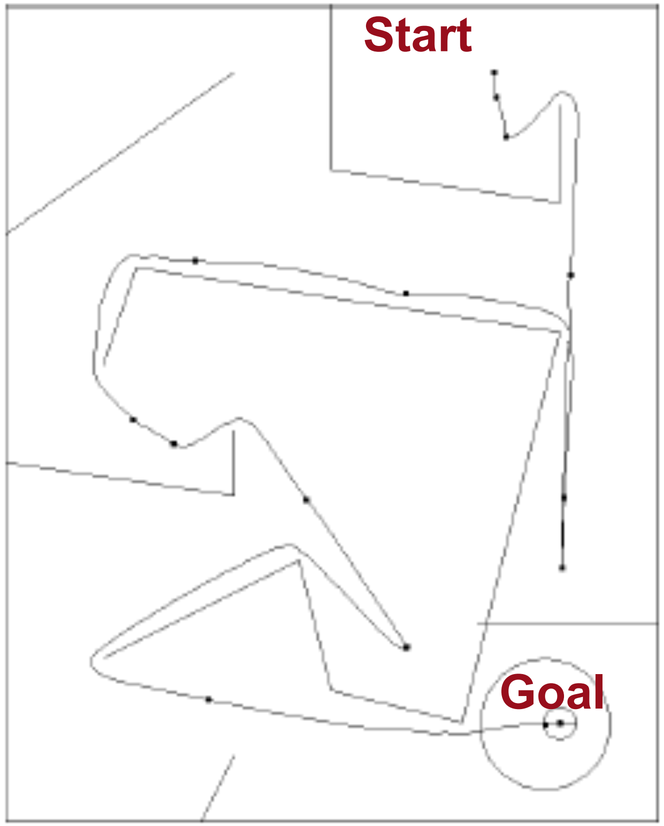
Table 1: Simulation results of comparing a feedback controller [5] and the Hungarian (Kuhn-Munkres) Algorithm [6].

# Task 5.2: High Level Planning (Path planning)

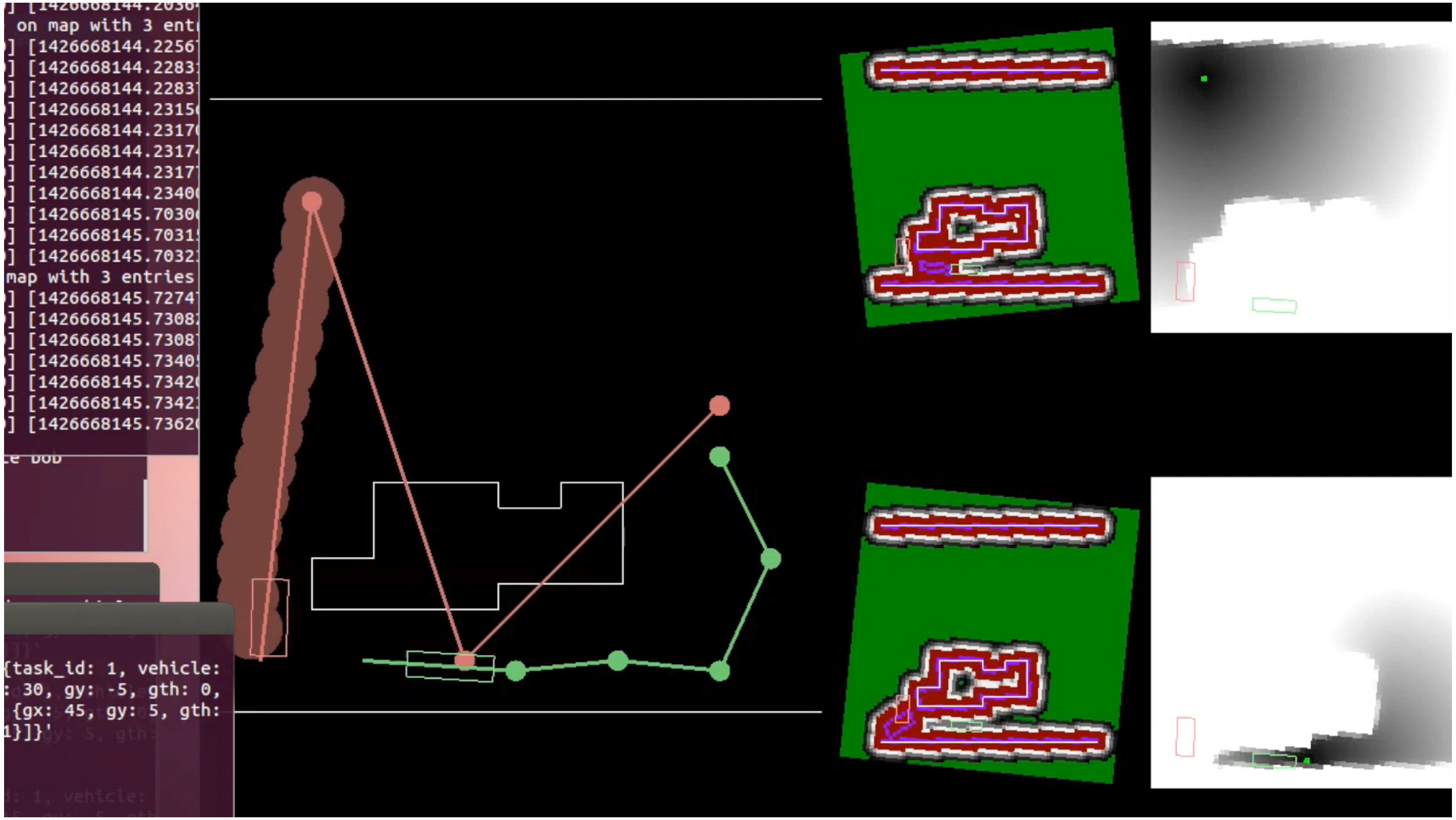
- **Goal**: Compute feasible paths
- **E-star** allows Dynamic re-planning:

Changes in the environment model can be repaired to avoid the expenses of complete re-planning.

[Philippsen & Siegwart 2005]

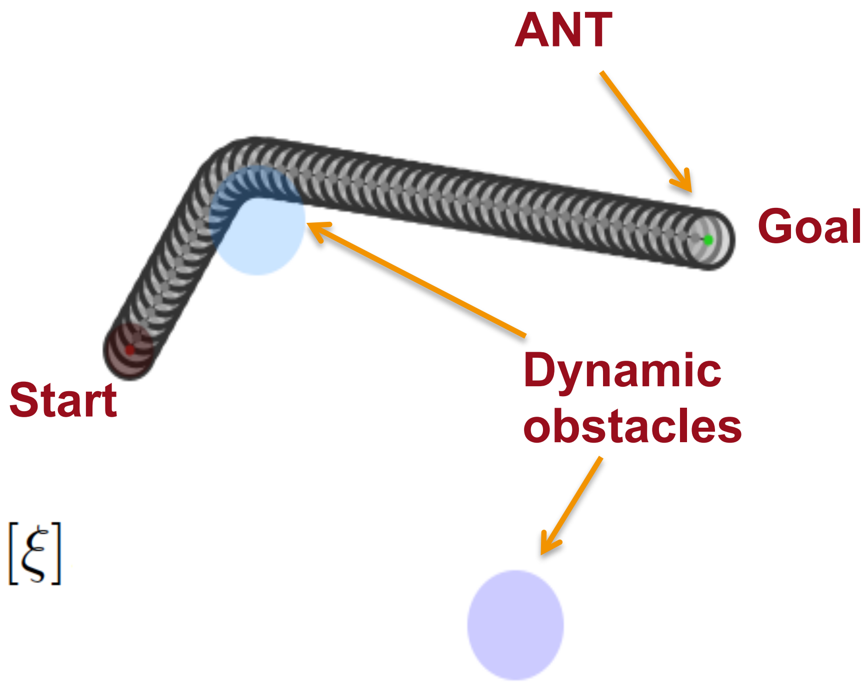


# Task 5.2: High Level Planning (Path planning)



# Task 5.3: Interaction Planning (Path adaptation)

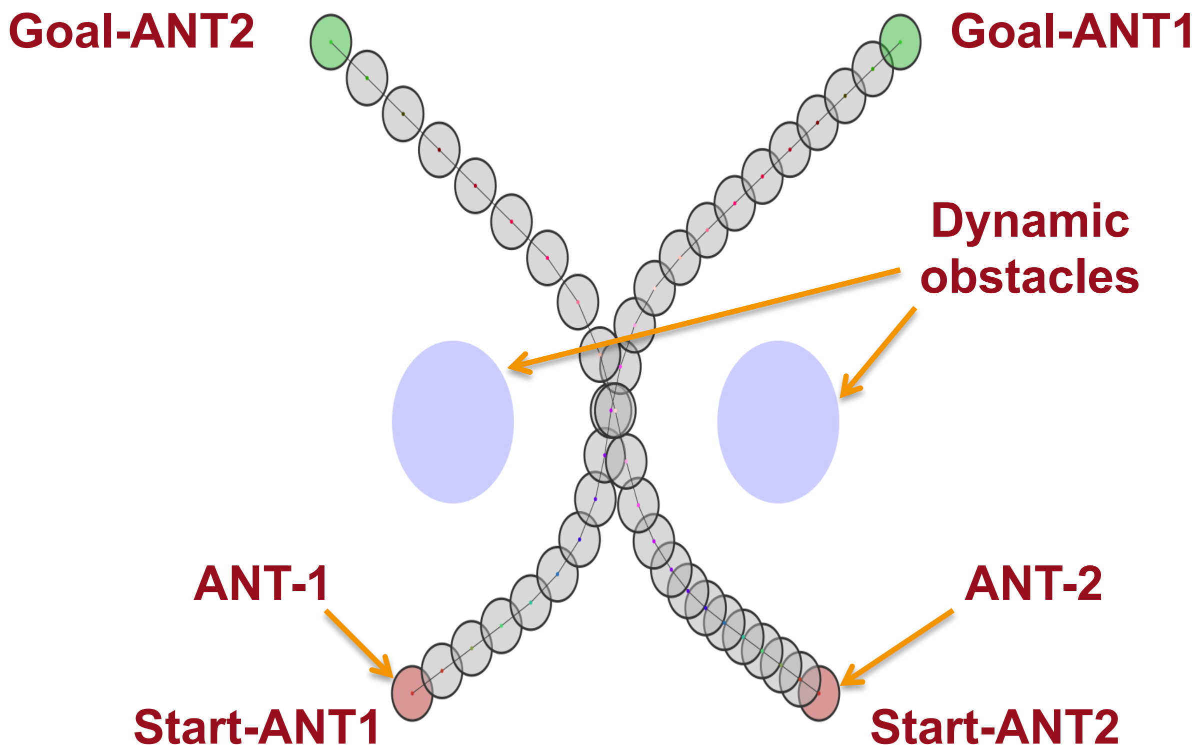
- **Goal**: Adapt trajectories to account for collisions.
- **Approach**: CHOMP: Covariant Hamiltonian Optimization for Motion Planning. [Zucker et al. 2012]
- **CHOMP**:
  - Obstacle avoidance
  - Smoothness



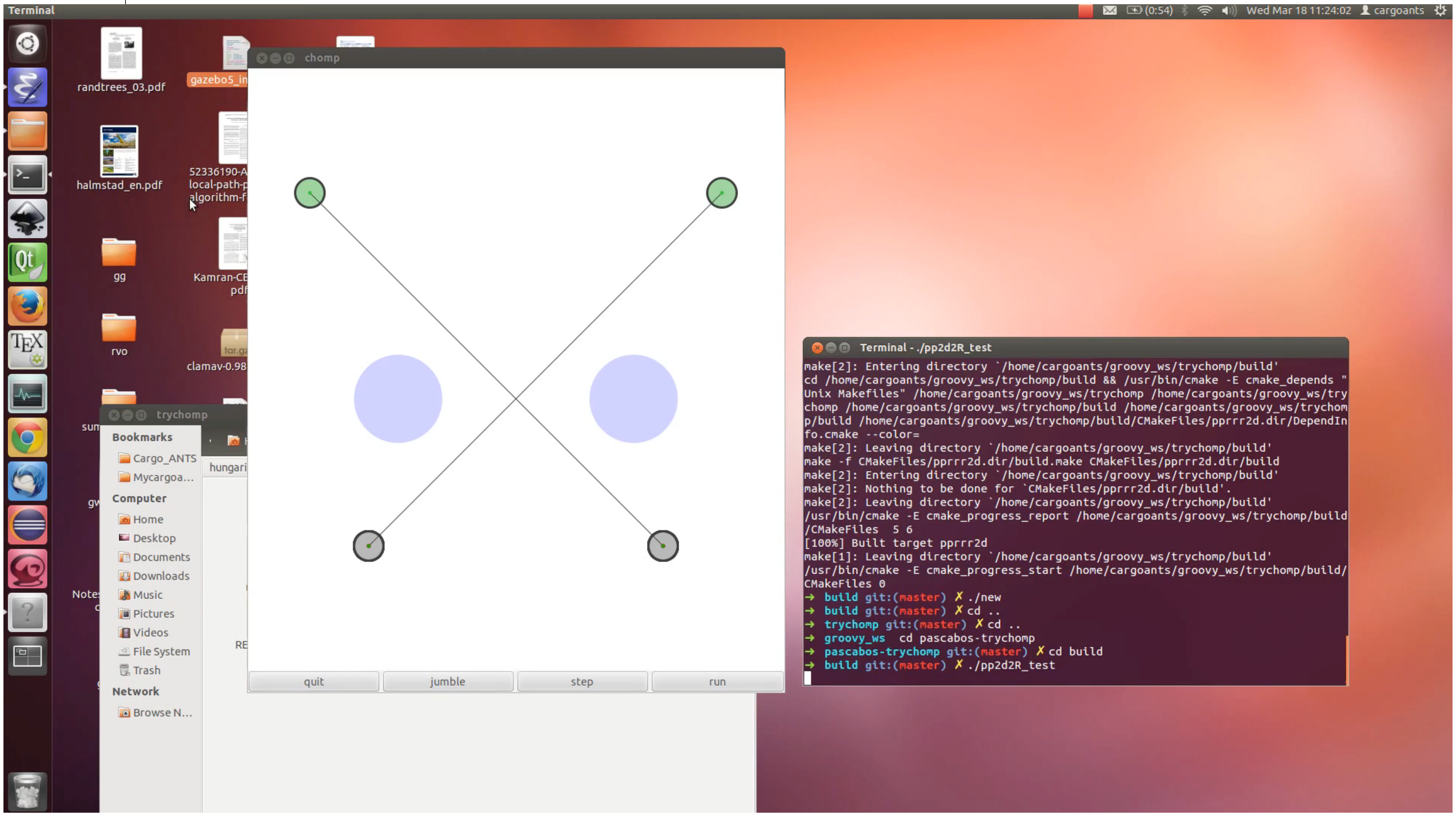

$$\mathcal{U}[\xi] = \mathcal{F}_{obs}[\xi] + \lambda \mathcal{F}_{smooth}[\xi]$$

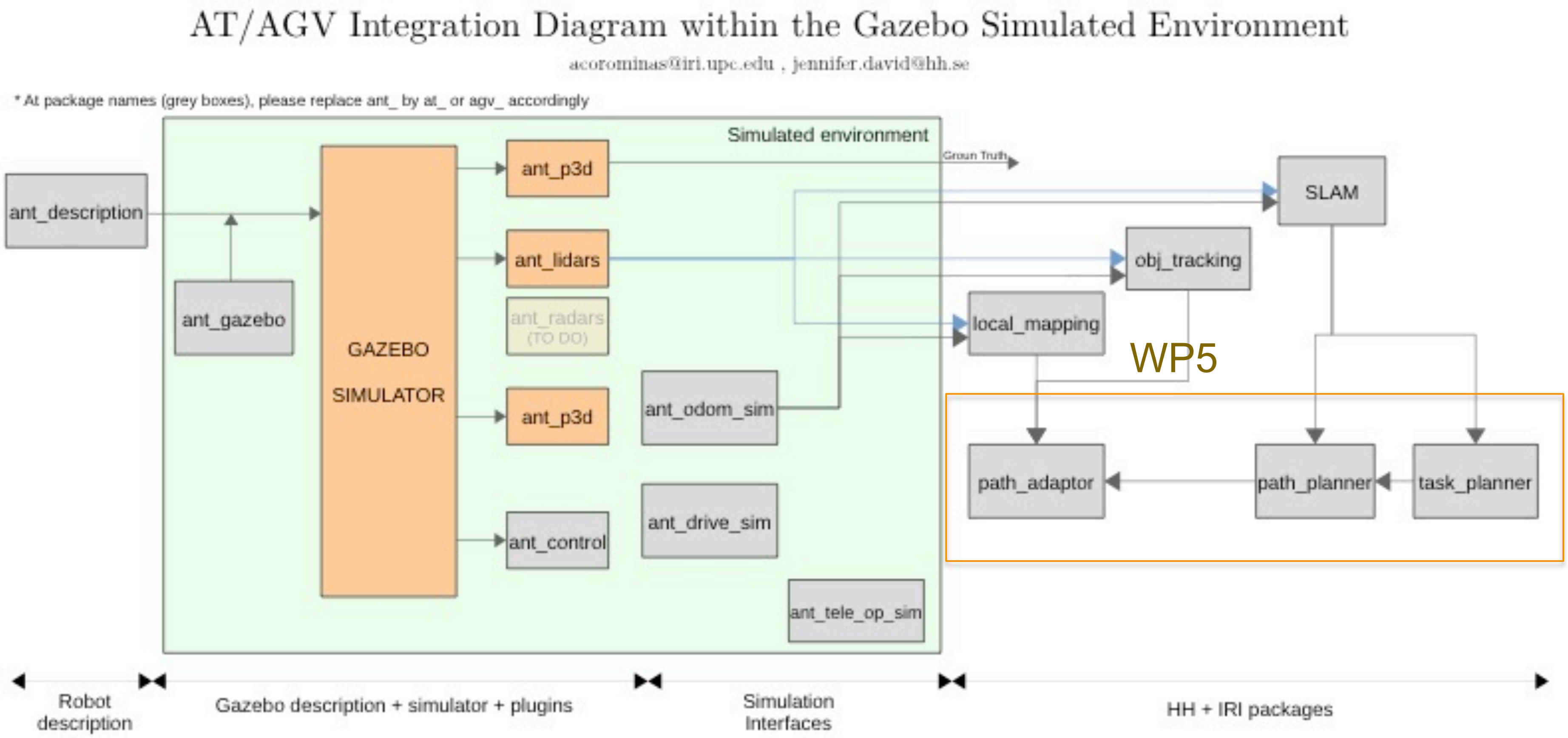
# Task 5.3: Interaction Planning (Path adaptation)

- CHOMP with multiple ANTs (conflict resolution)



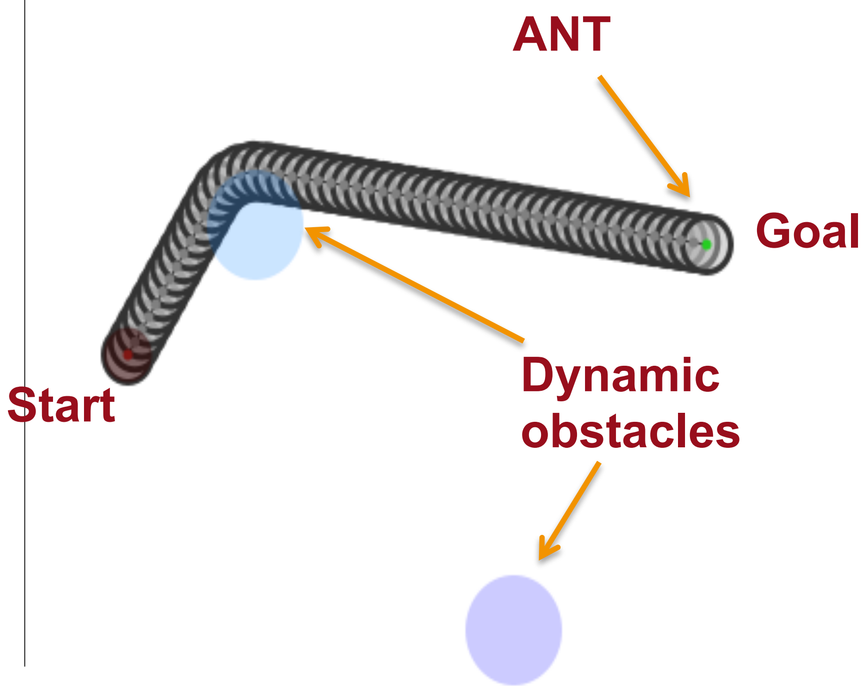
# Task 5.3: Interaction Planning (Path adaptation)




AT/AGV Integration Diagram within the Gazebo Simulated Environment
acorominas@iri.upc.edu , jennifer.david@hh.se
* At package names (grey boxes), please replace ant_ by at_ or agv_ accordingly
Simulated environment
ant_description
ant_gazebo
GAZEBO
SIMULATOR
ant_p3d
ant_lidars
ant_radars
(TO DO)
ant_p3d
ant_control
ant_odom_sim
ant_drive_sim
ant_tele_op_sim
Groun Truth
SLAM
obj_tracking
local_mapping
WP5
path_adaptor
path_planner
task_planner
Robot
description
Gazebo description + simulator + plugins
Simulation
Interfaces
HH + IRI packages

# WP4-WP5 software integration (local planning)

- INPUTS
  - Path adaptor (HH)
  - Local mapping (CSIC)



# WP4-WP5 software integration (local planning)

- < VIDEO >

# WP4-WP5 software integration (global planning)

- INPUTS:
  - Global map/SLAM (CSIC)
  - Global planner (HH)

# WP4-WP5 software integration (global planning)

- < VIDEO >

# AT-WP5 software integration (communication)

- INTEGRATION
  - Trajectory sender (HH)
  - Trajectory receiver (VOLVO)

- Installation of basic setup in AT's Navigation PC (ROS packages).

- UDP communication with AutoBox:
  - **ROS2UDP**:
    - sending local trajectory to AT.

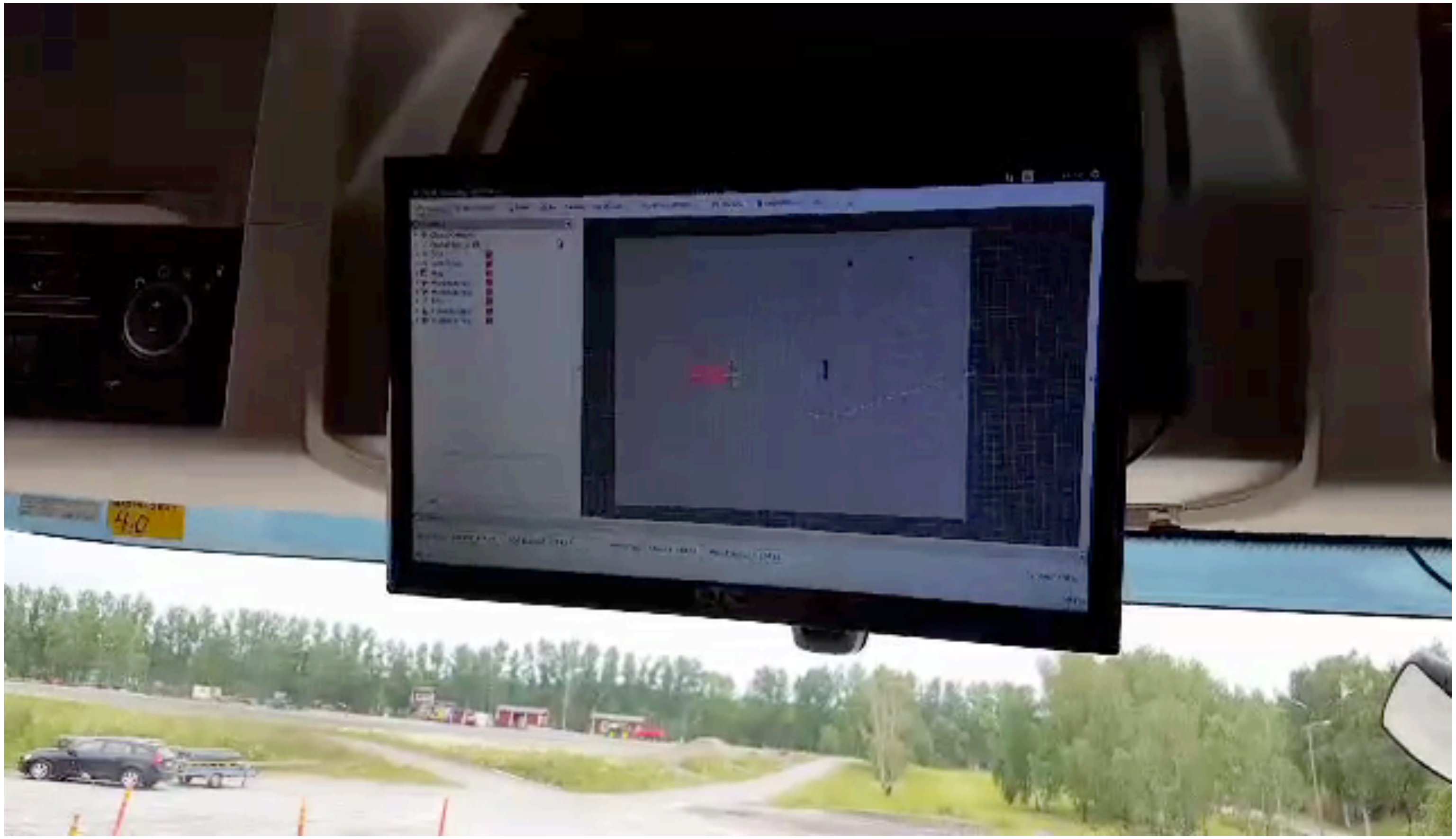
# AT-WP5 software integration (local planning)

- INTEGRATION:
  - UDP Communication (CSIC, HH, Volvo).
  - Local mapping (CSIC).
  - AT Controller (Volvo).
  - Path adaptor (HH).



# AT-WP5 software integration (local planning)

# AT-WP5 software integration (local planning)



# Summary

- **T5.1:**
  - Working on additional constraints for Task Assignment
- **T5.2:**
  - E-star algorithm is employed for this task.
- **T5.3:**
  - Interaction planning planned with CHOMP
- **WP6 :**
  - Integration of software modules with WP5.
  - Integration of software modules in AT & simulated AGV.
- **MAIN DELIVERABLES (AS LEAD BENEFICIARY):**
  - D2.7 (Project description in presentation and poster).
  - D5.1 (Description of modules).
  - D5.2 (Final version of subsystems).
  - D5.4 (Report on planning, decision and action phase in the vehicle).

# Thank you