Presentation 'Benchmarking Autonomous Robotics Controllers' by Pablo Muñoz (University of Alcalá)

Introduction by TO (M. van Winnendael, TEC-MMA)

Title of the contract: Cooperative Systems for Autonomous Exploration Missions
Budget + Program: 90 k€, NPI (Networking/Partnering Initiative)
Duration: 3 years
Contractor: University of Alcalá, UAH (Spain)
Subject of the activity: On-board autonomy of space robotics systems, in the first place planetary rovers
Main Objectives:

- Metrics for measuring planning and execution performance
- Path planning algorithms to define navigation routes
- Algorithms for controlling the reactive behavior of ESA's Goal-Oriented Autonomous Controller (GOAC) in uncertain situations

07/12/2016

Benchmarking Autonomous Robotics Controllers

Pablo Muñoz Martínez

TEC-ED & TEC-SW Final Presentation Days

ESA/ESTEC December 7, 2016

Universidad de Alcalá

PhD funded by ESA NPI

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PhD program on space research

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Dr. Amedeo Cesta

Dr. Andrea Orlandini

Planning & Scheduling Team

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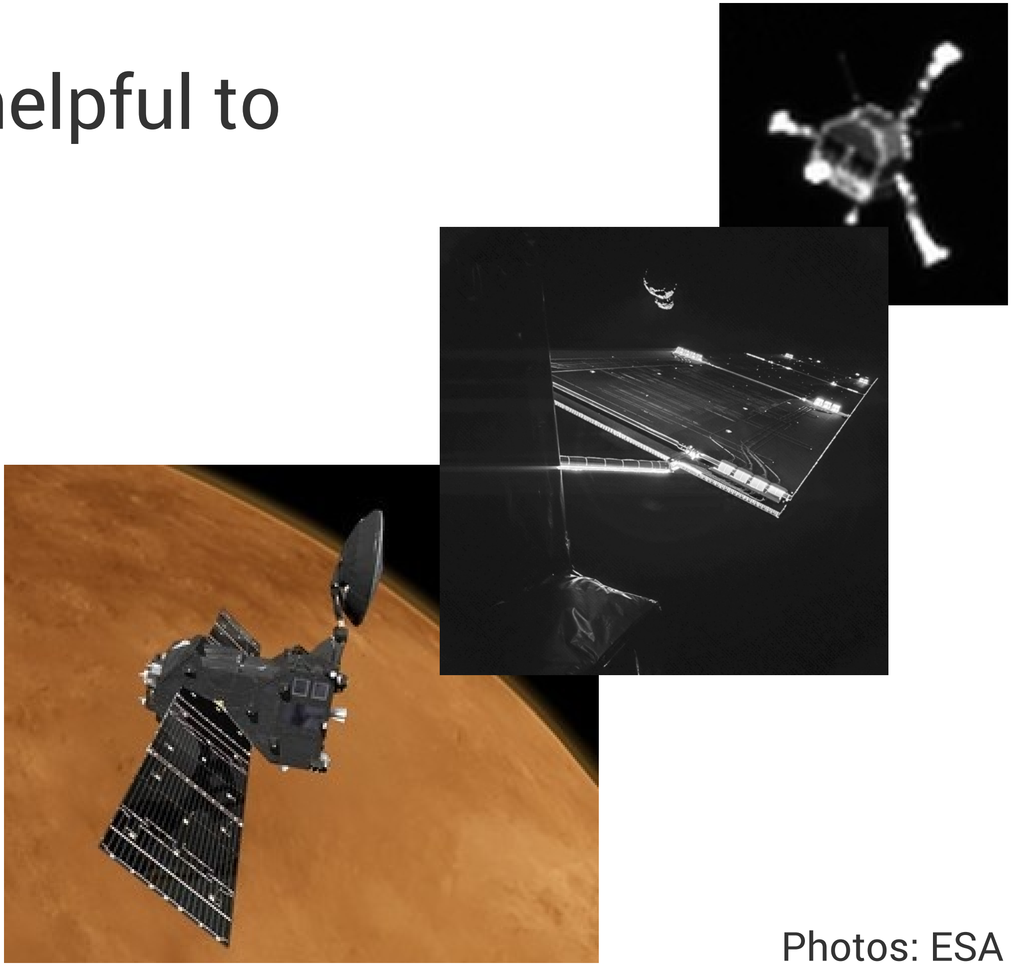
Motivation

- Space exploration is a challenge
- New missions carry more science instruments
- Go deeper into the space
- On-board autonomy can be helpful to
  - Maximize science return
  - Minimize risks
  - Reduce operators workload



Photos: ESA

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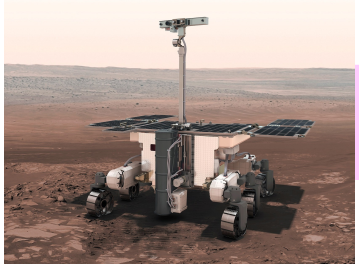
Autonomy levels

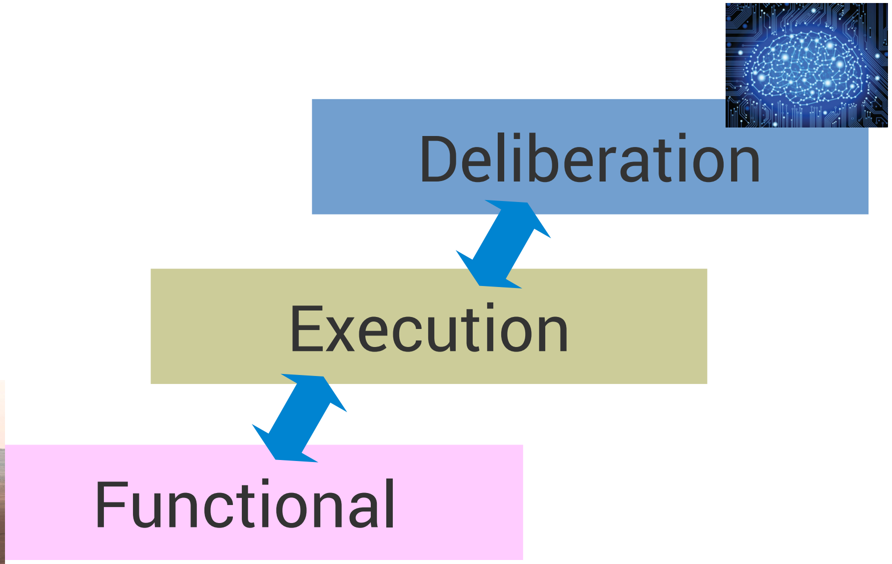
- Decision making capability (AI)
- According to ESA standards

E1	On-ground control (teleoperation)
E2	On-board scheduler for on-ground commands
E3	Event based autonomous operation
E4	Goal oriented and mission replanning

Autonomous controllers

- Integration of P&S (Planning & Scheduling) in robotics
- P&S is used for on-ground operations
- Most common schema: 3T (3-Tired)
- Wide research field
  - ESA: GOAC
  - NASA: IDEA, RA
  - UAH: MoBAr





Open issues

- No appropriate software to facilitate operation
- Lack of experimentation
- Hard to extract meaningful data
- Approaches are validated with few scenarios
- Difficult to generate reproducible experiments

→ Tests can be seen as *proof of concept*

→ Difficult to compare approaches

→ Hard to trust in autonomy

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Objectives

- Create a framework for autonomous controllers characterization and evaluation
  - Testbench methodology
  - Performance metrics
  - Compare at least two controllers
  - Ease deployment and operation
  - Improve trust in autonomy for robotics

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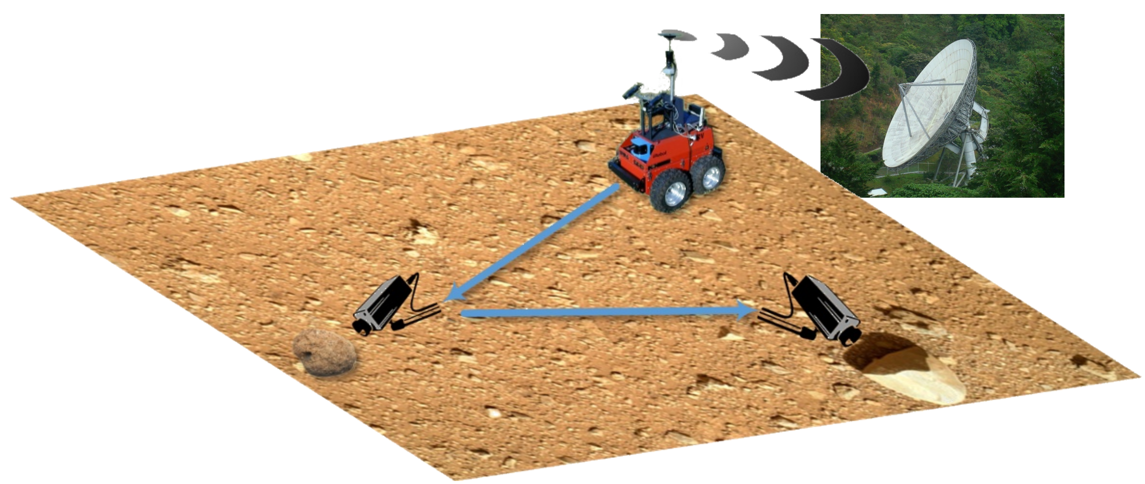
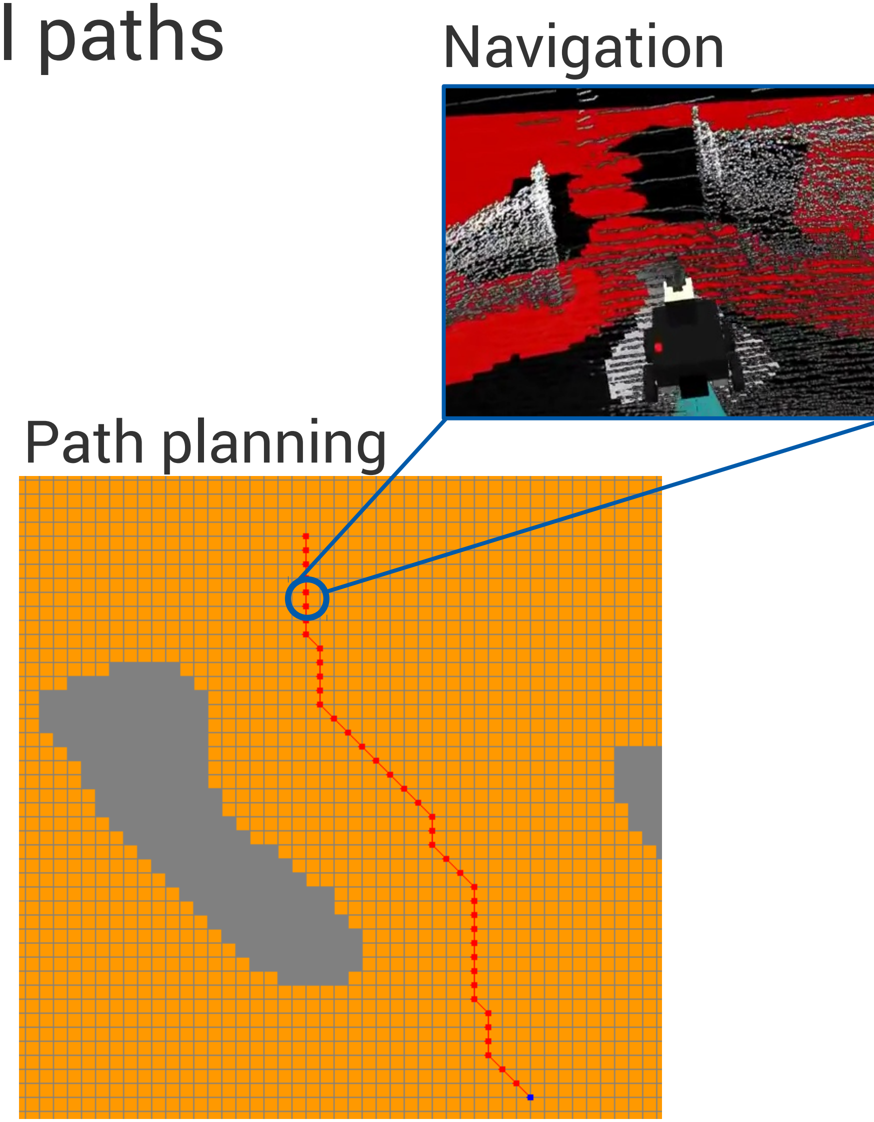
Planetary exploration case study

- Perform scientific tasks in different locations
- Limited communication opportunities
- E4 autonomy: user provides initial goals
- Common scenario for autonomous controllers testing
- Requires
  - Task planning
  - Path planning



Path planning

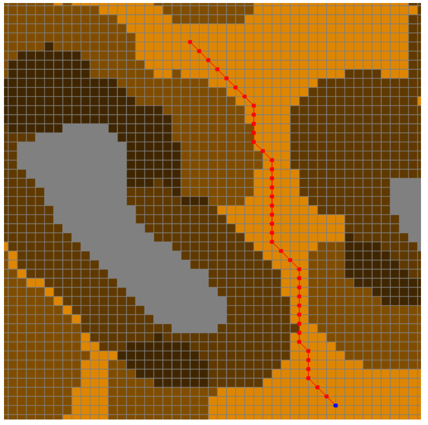
- Obtain feasible and optimal paths
- 2D binary grid map
  - Used in real missions
  - Deterministic algorithms
    - A*
    - A*PS
    - Theta*

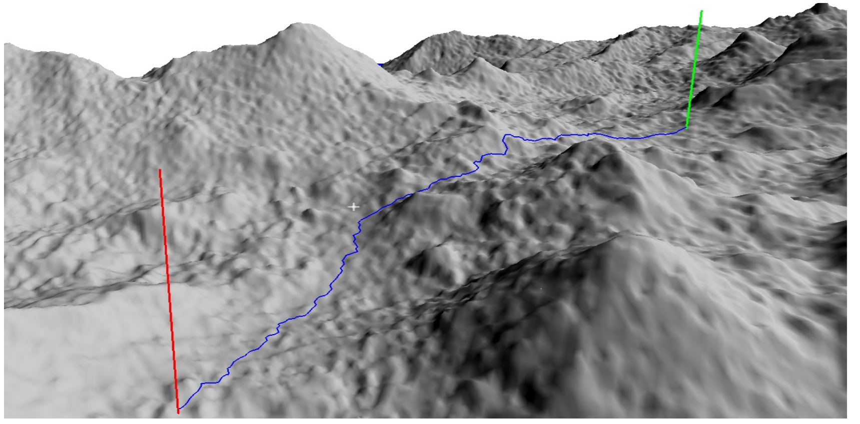


More about 2D path planning:
P. Muñoz and M.D. R-Moreno. On Heading Change Measurement: Improvements for Any Angle Path Planning. *Novel Applications of Intelligent Systems*, ch. 6 (2015)

Path planning

- Planetary robotics require more realistic terrains with
  - Terrain characteristics (cost maps)
  - Altitude (DTM)





- Field D* (MER/MSL operations) exploits cost maps
- Modified A* can use different DTM representations

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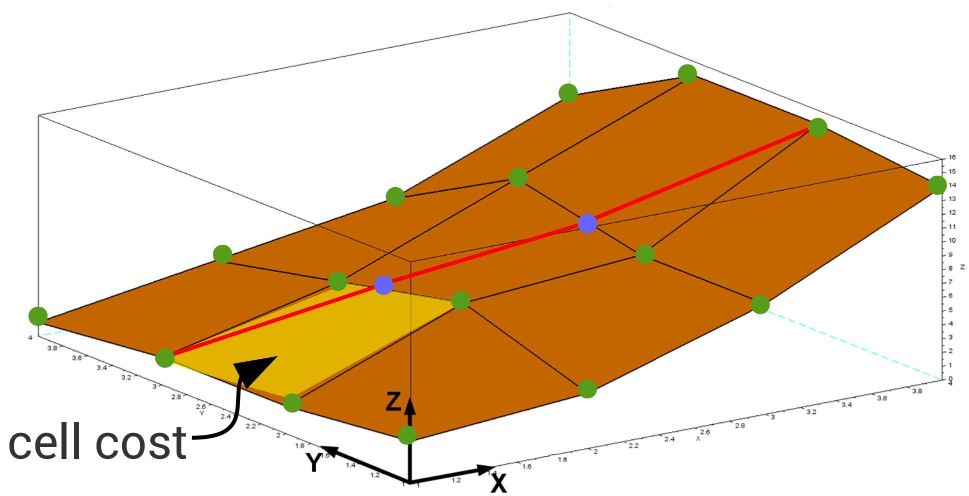
Path planning – 3Dana

- 3Dana: path planning on realistic surfaces
  - Accurate lineal interpolation
  - Allow DTM and/or cost map
  - Path cost = path length × cell cost
  - Heading changes heuristic
  - Terrain slope



Path planning – 3Dana

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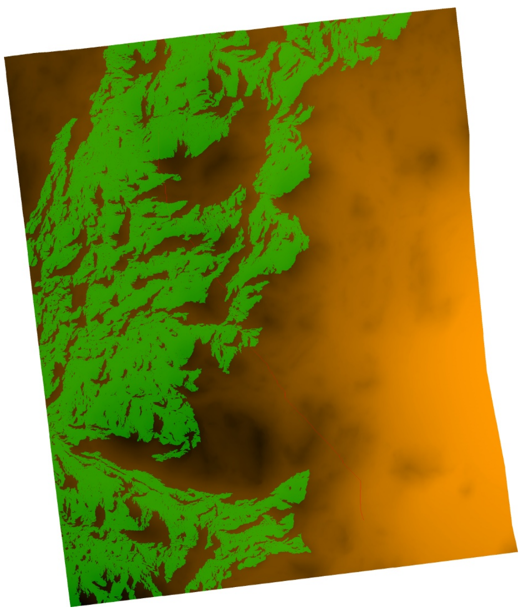
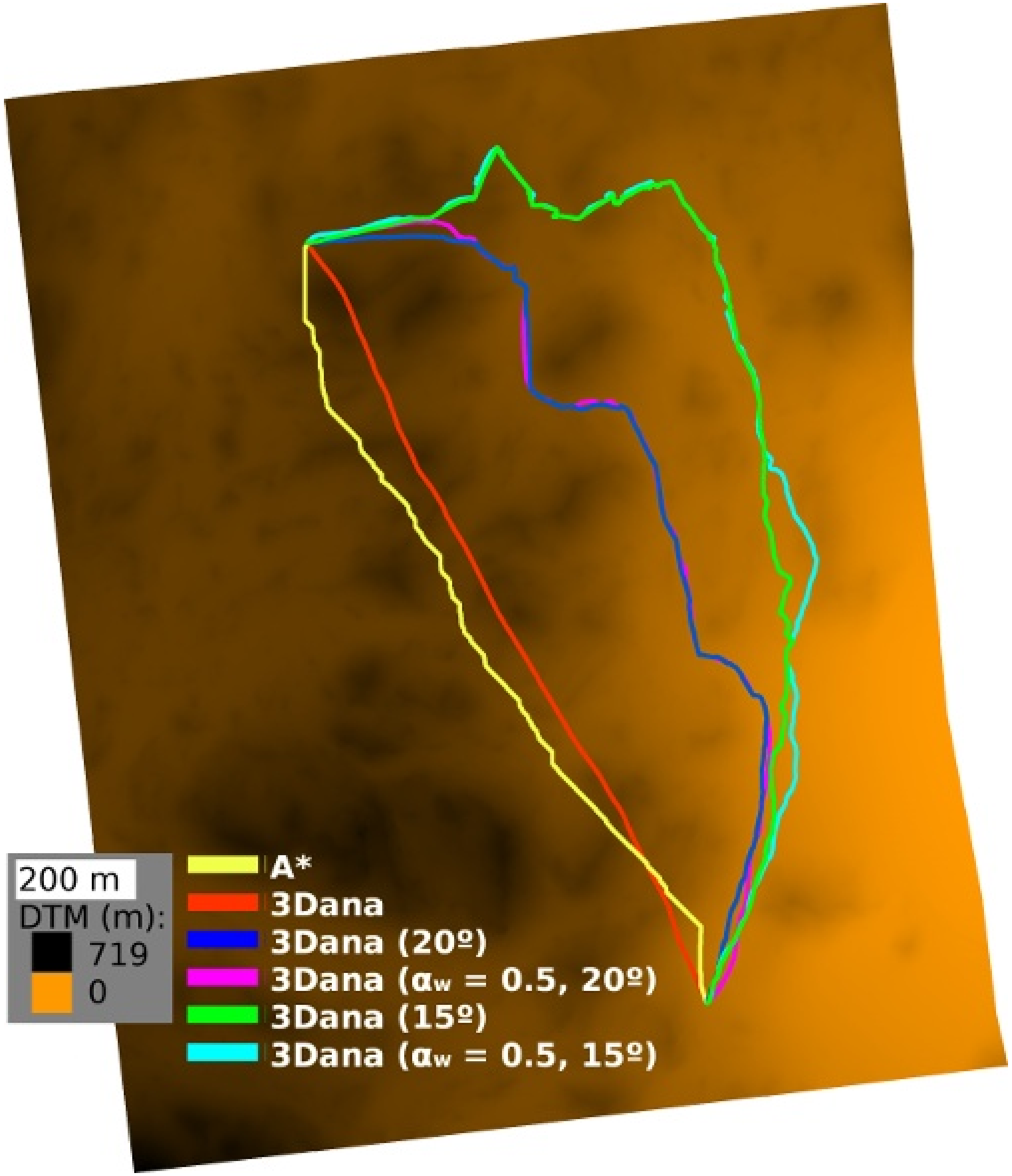
- Evaluation on Mars DTM
  - 3Dana provides safer paths
  - Slope limitation
  - Reachability map





More results:
P. Muñoz, M.D. R-Moreno and Bonifacio Castaño. 3Dana: Path Planning on 3D Surfaces.
In procs. of the 36th SGAI International Conference on Artificial Intelligence (2016)

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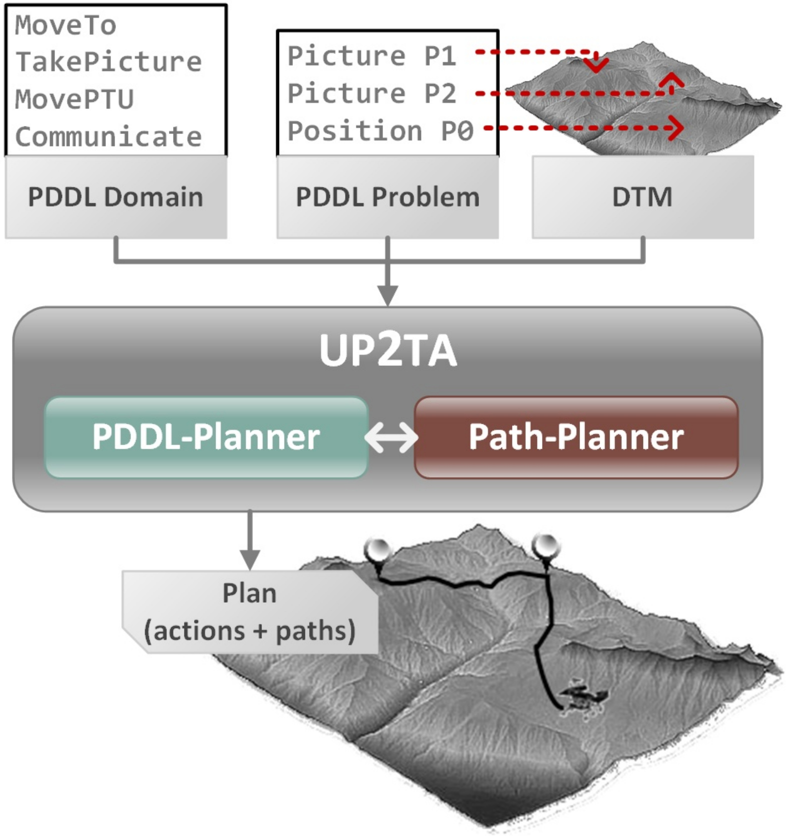
Task planning – The UP2TA planner

- Exploration requires to achieve multiple goals
- UP2TA (Unified Path planning & Task planning Architecture)
  - PDDL planner: FF
  - Path planner: 3Dana
- Objective: optimize the plan
  - Minimize travelled distance
  - Best task ordering



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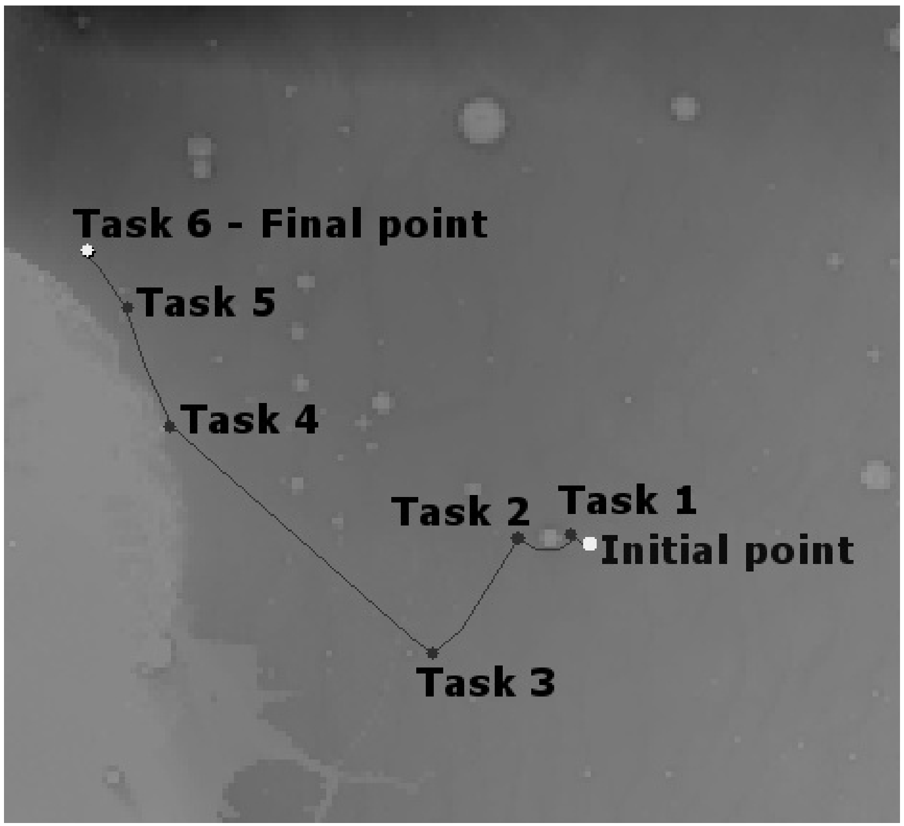
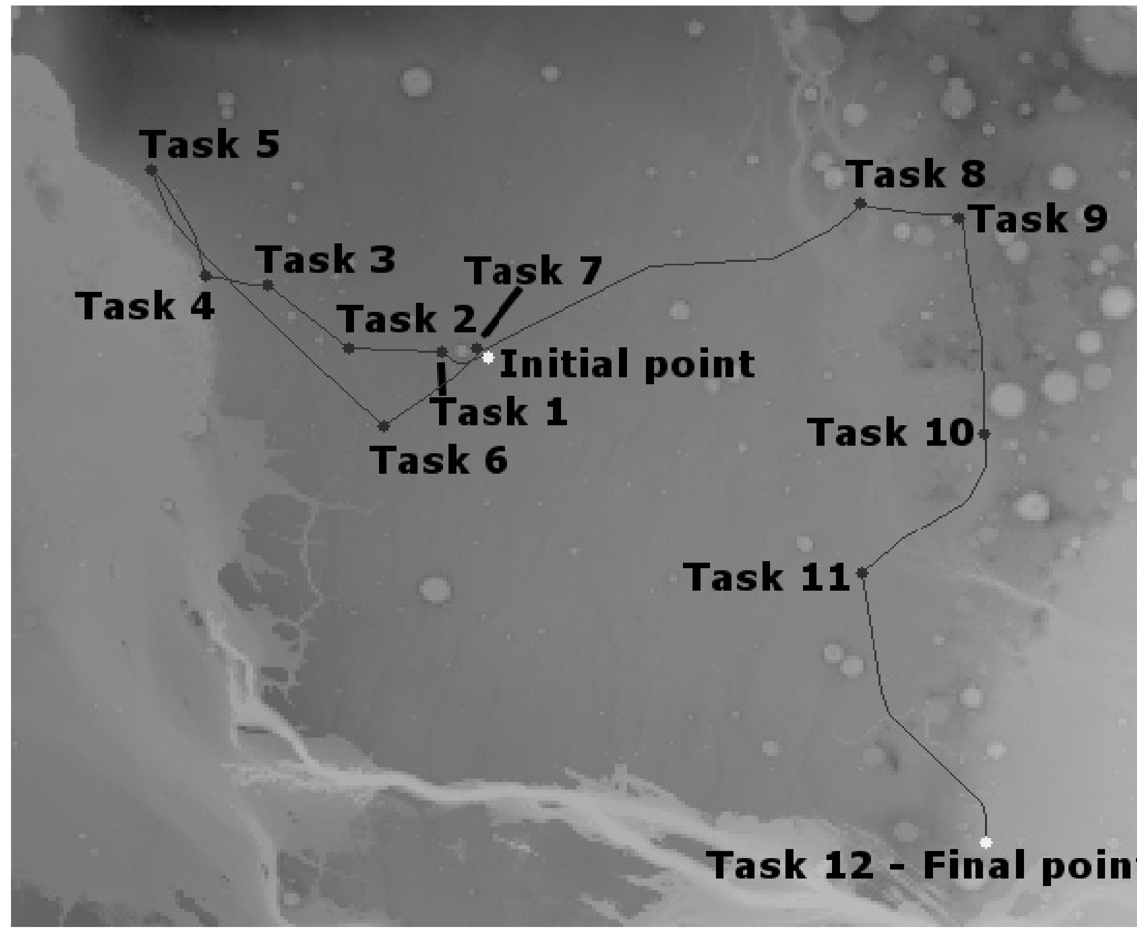
Task planning – The UP2TA planner





More results:
P. Muñoz, M.D. R-Moreno and D. F. Barrero. Unified Framework for Path Planning and Task Planning for Autonomous Robots. *In Robotics and Autonomous Systems*, vol. 82, pp. 1—14 (2016)

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An evaluation framework

- Hard to compare autonomous controllers
- Objective
  - Generation of meaningful execution data
  - Analysis integration of P&S in robotics
  - Generation of reproducible/comparable testbenchs
- Based on
  - A **methodology** to guide the testing phase
  - A set of **metrics** to assess P&S integration
  - A **software** tool to
    - Automate testbenchs
    - Improve autonomy support for users

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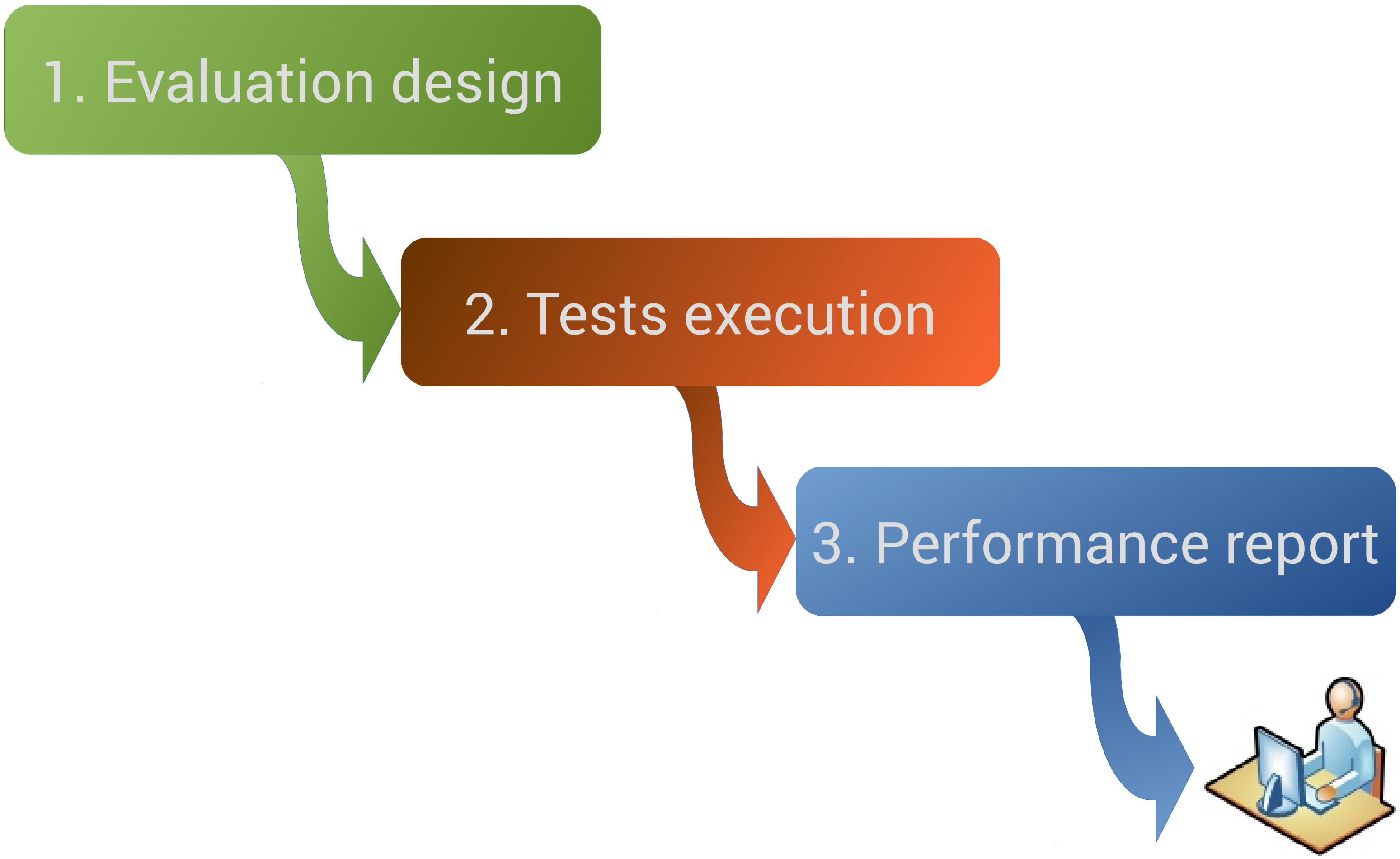
Methodology

- Evaluation consists on 3 sequential phases



Methodology

1. Evaluation design

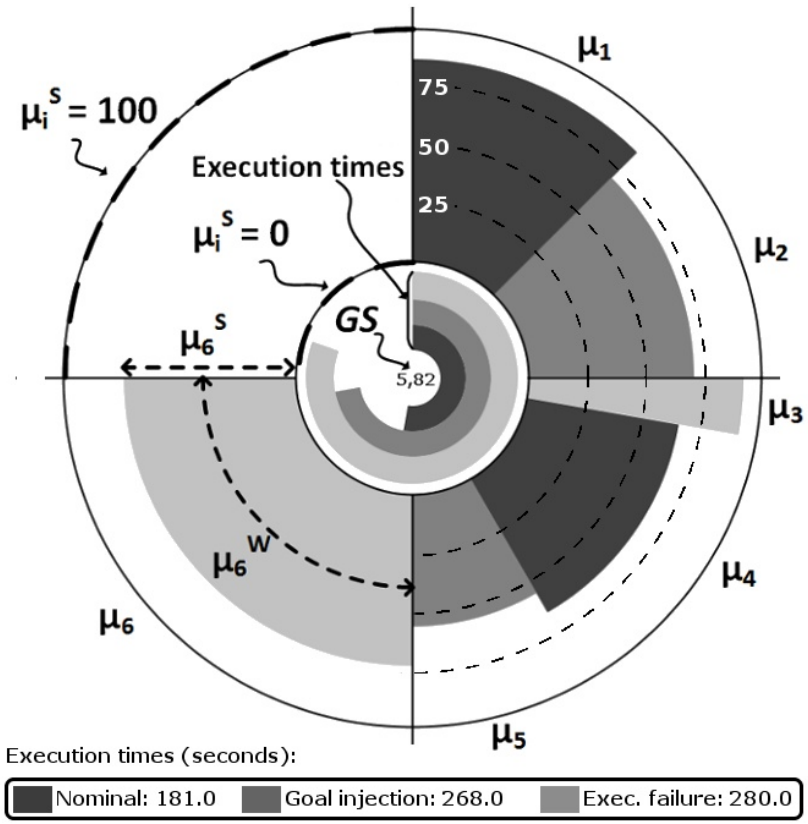
- Objective of the test
- Application scenario and robotic platform
- Controllers configurations
- Operative conditions
  - Nominal
  - Contingency
  - Goal injection
- Normalized performance metrics

Methodology

2. Tests execution

- Scenario and controller instantiation
- Controllers execution
- Monitoring of metrics data
- Collection of average behaviours

Methodology



- Data synthesis
- Generation of objective evaluations
- Meaningful data representation

3. Performance report

General metrics

- Characterize autonomous behaviours
- Enable different controllers comparison
- Four groups
  - Plan accuracy
  - Planner model adequacy
  - Planner performance
  - Planning & Execution (P&E) integration

Model (Plan accuracy, Planner model adequacy)

Controller (Planner performance, Planning & Execution (P&E) integration)

- These groups fit in the graphical report
- Easy to focus on particular characteristics

General metrics

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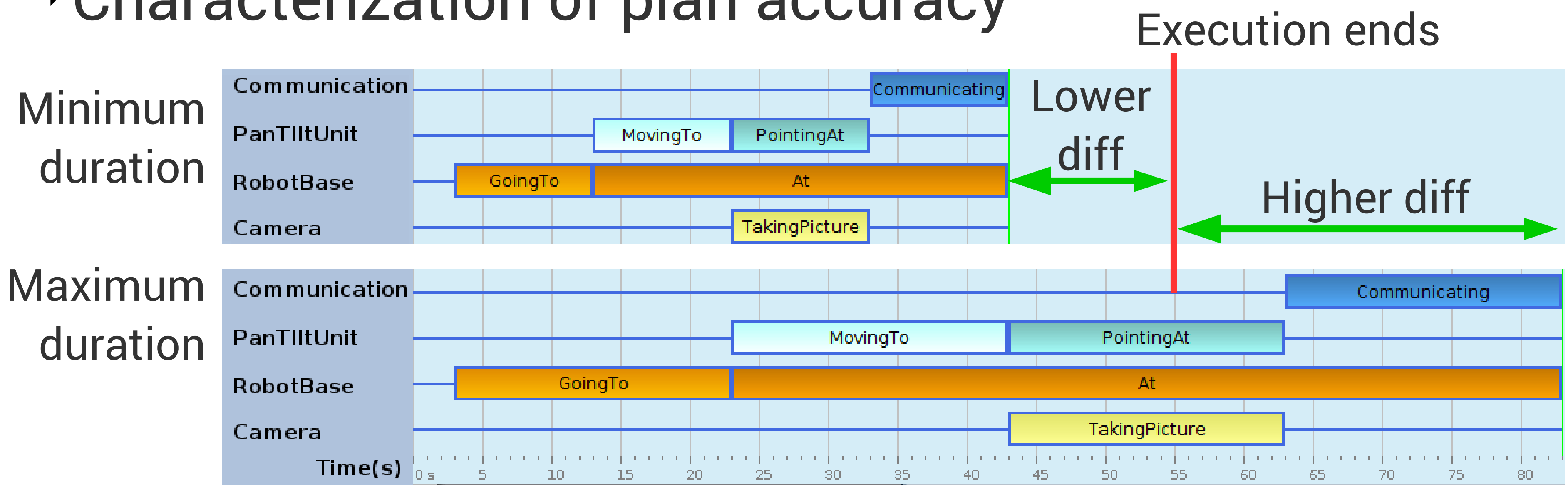
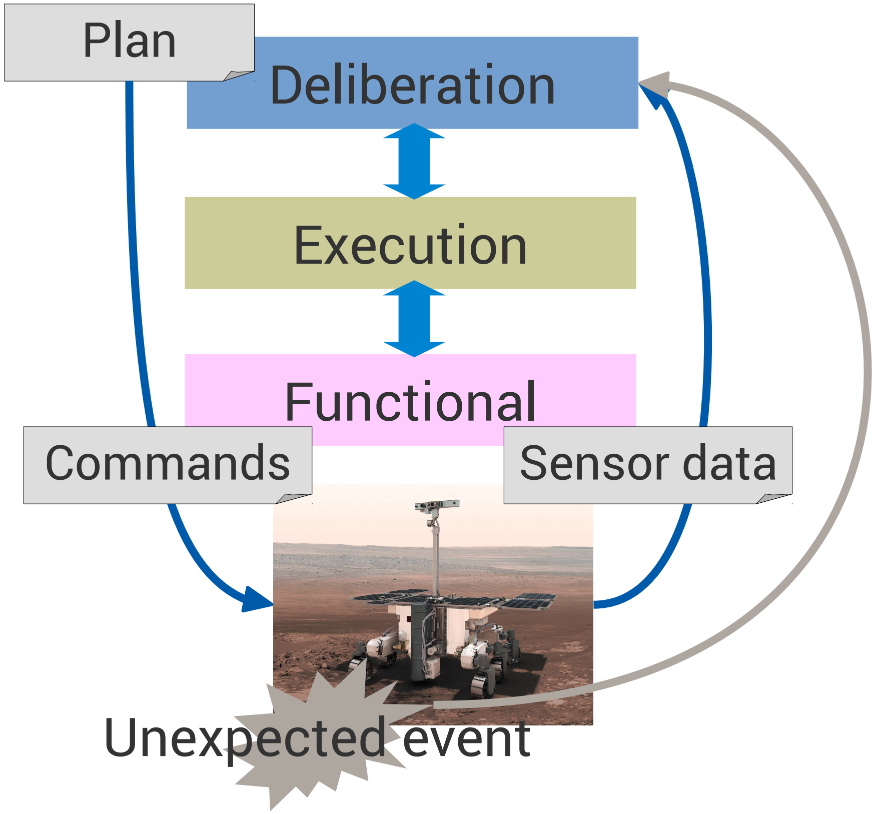
- Characterization of plan accuracy



- Planning performance
  - Time
  - Memory

General metrics

- Integration of P&S with underlying layers of the controller
- Analysis of information flow
- Characterization of reaction time to unexpected events



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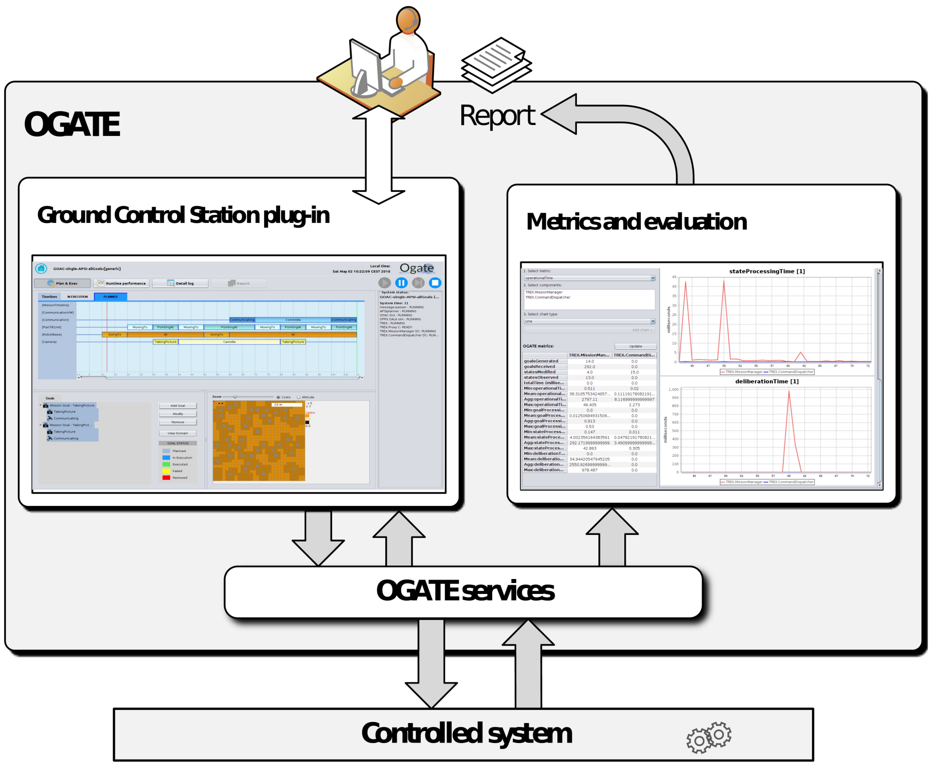
The OGATE software

- OGATE (On-Ground Autonomy Test Environment)
- Designed to support autonomy
  - Simplify controllers deployment/operation
  - Monitor P&S features
  - Perform automatic testbenchs
  - Plug-ins
- Implements the methodology and metrics collection
- Allows user-defined metrics



More info:

P. Muñoz, A. Cesta, A. Orlandini and M.D. R-Moreno. First Steps on an On-Ground Autonomy Test Environment. *In procs. of the 5th IEEE Conference on Space Mission Challenges for Information Technology* (2014)

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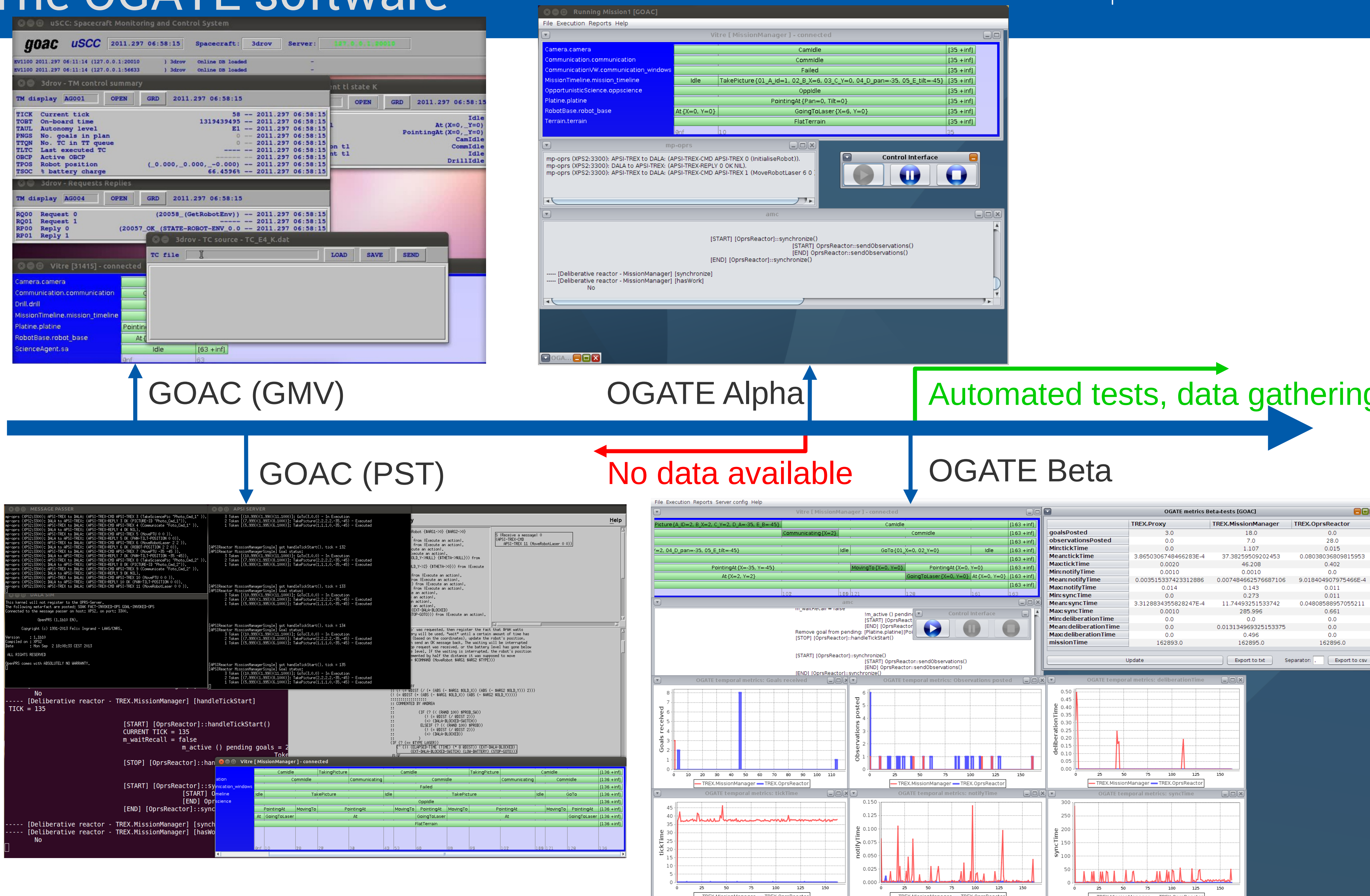
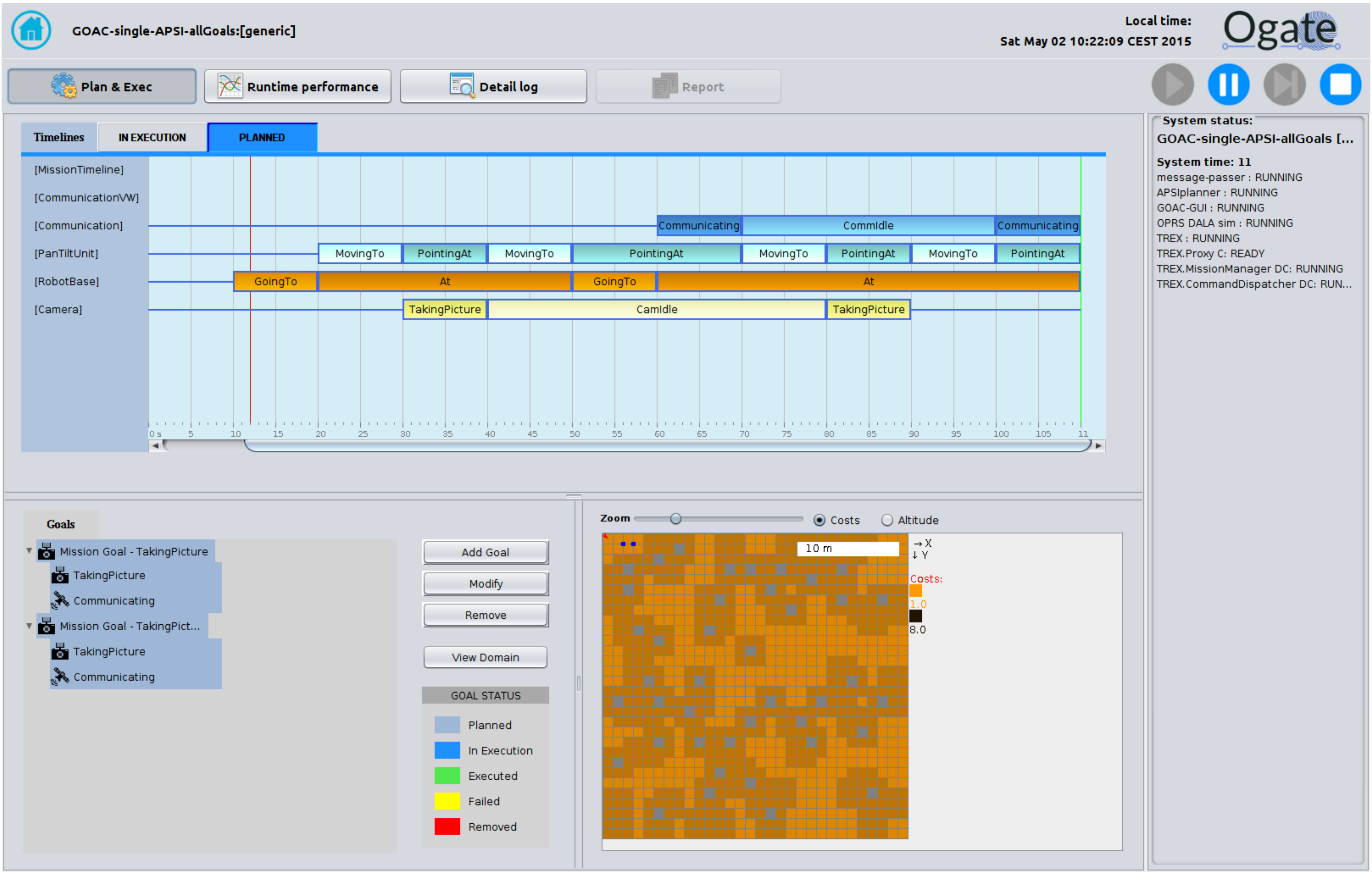
The OGATE software



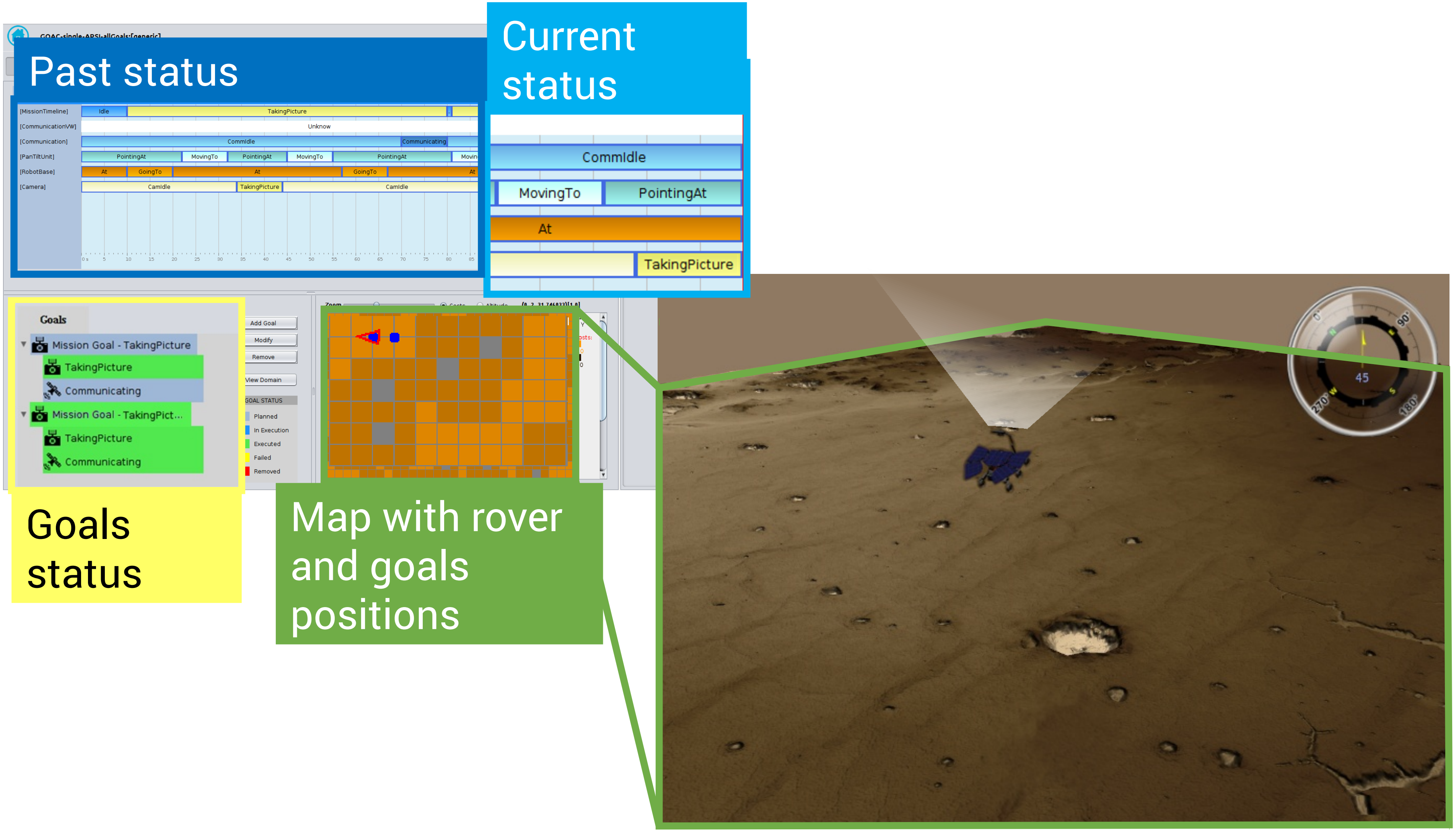
The OGATE software

- Current deployment: mission planning



The OGATE software

- Current deployment: mission monitoring



The OGATE software

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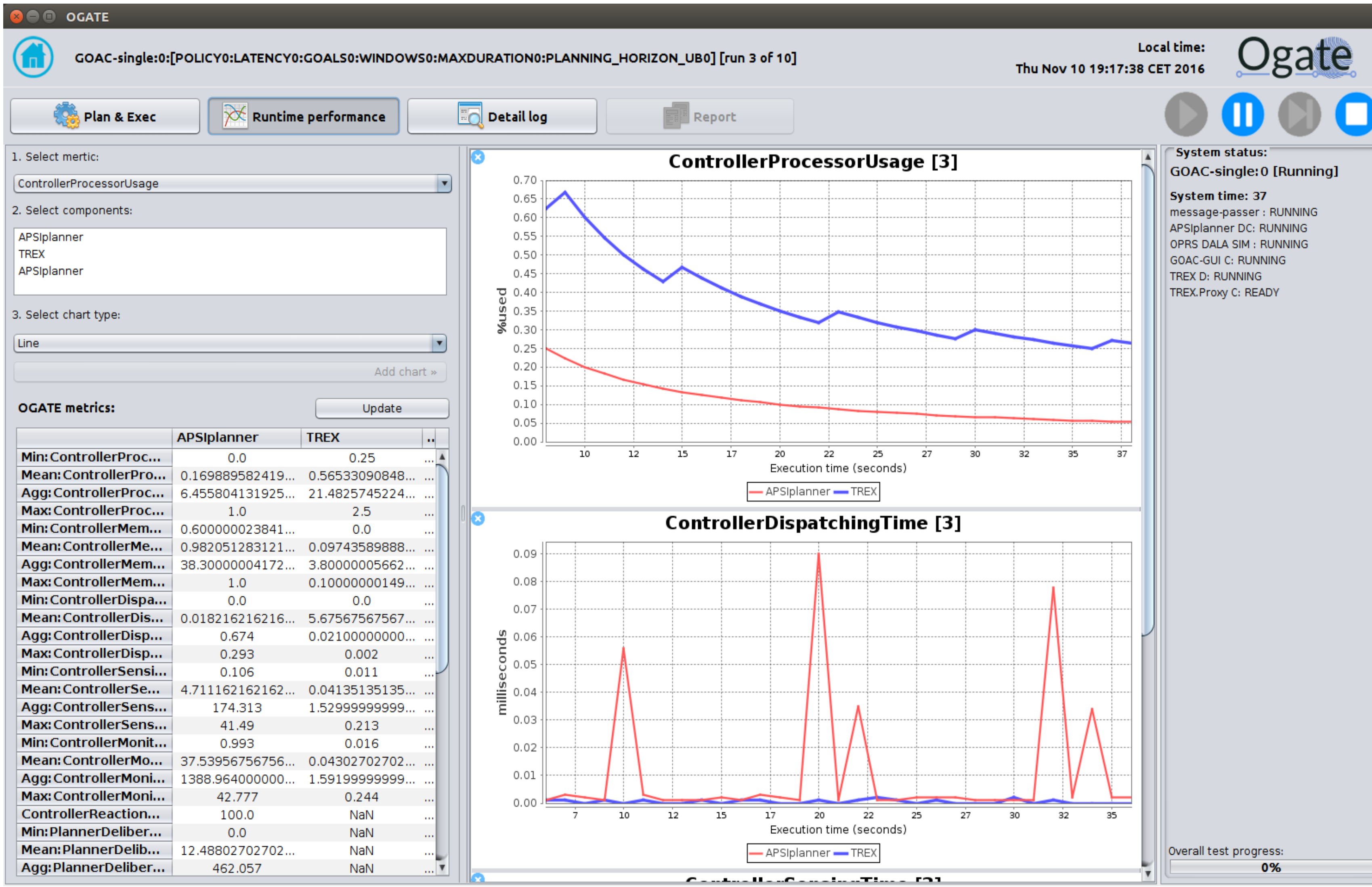
- Current deployment: performance assessment



A comparison testbench

- Two controllers
  - GOAC (Goal Oriented Autonomous Controller)
    - ESA effort for autonomy in space (E1-E4)
    - Timelines based planning (APSI-TRF)
  - MoBAr (Model Based Architecture)
    - UAH E4 controller
    - Predicate based planning (UP2TA)
- Exploration domain, simulated TurtleBot 2
- OGATE carries out automated tests
  - Nominal / Goal injection / Execution failure
  - Reports summarize average behaviours

A comparison testbench

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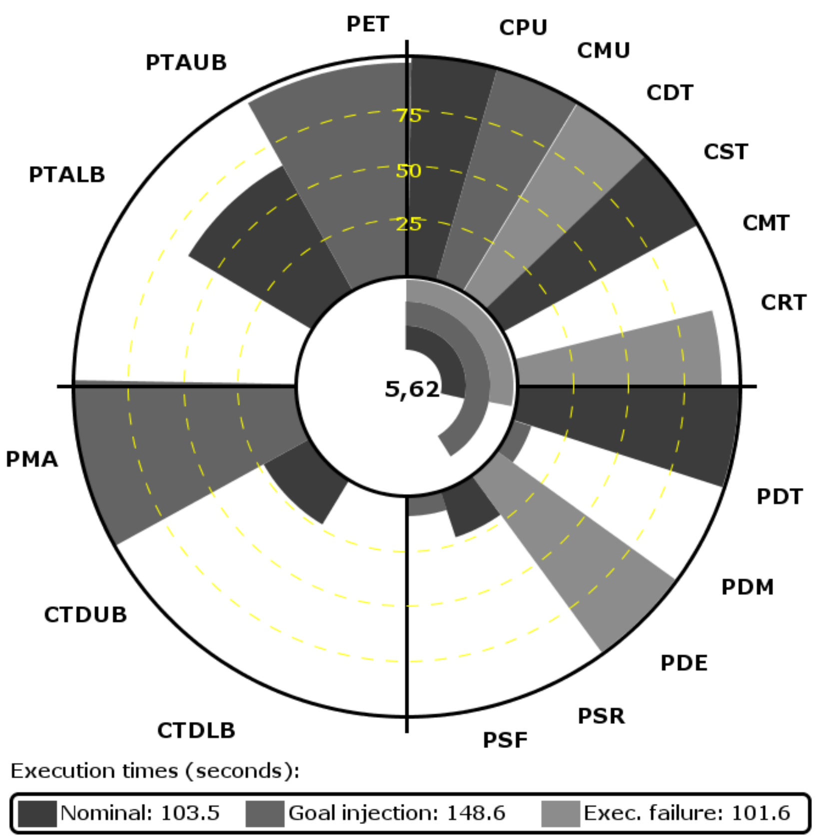
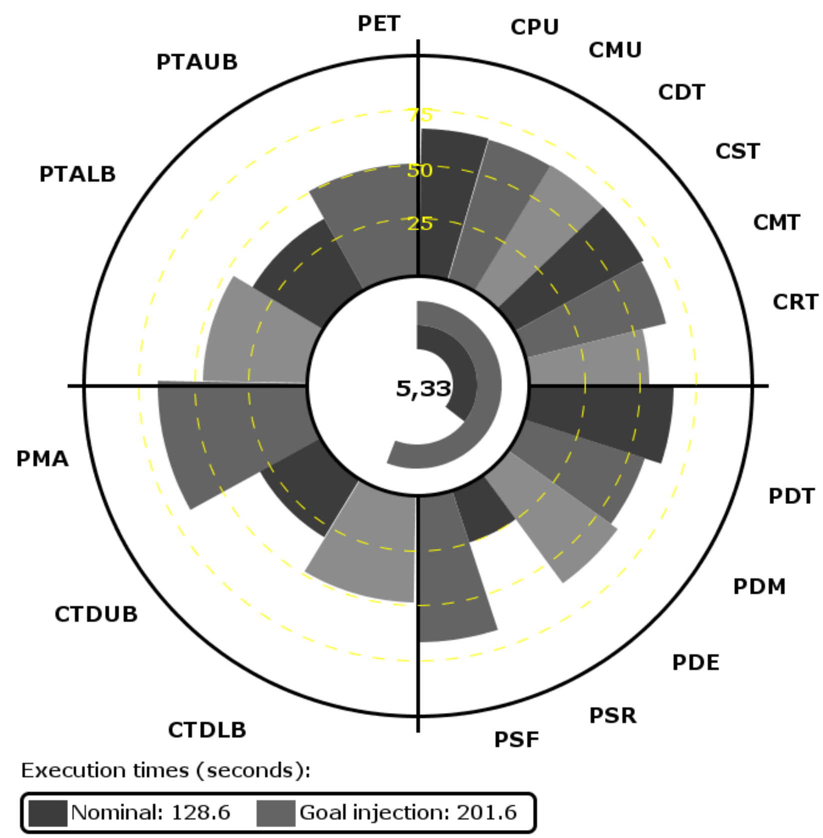
- Report after 30 executions

MoBAr



GOAC



More results:

P. Muñoz, A. Cesta, A. Orlandini and M.D. R-Moreno. A Framework for Performance Assessment of Autonomous Robotic Controllers. *In procs. of the 2nd Workshop on Planning and Robotics – ICAPS* (2015)

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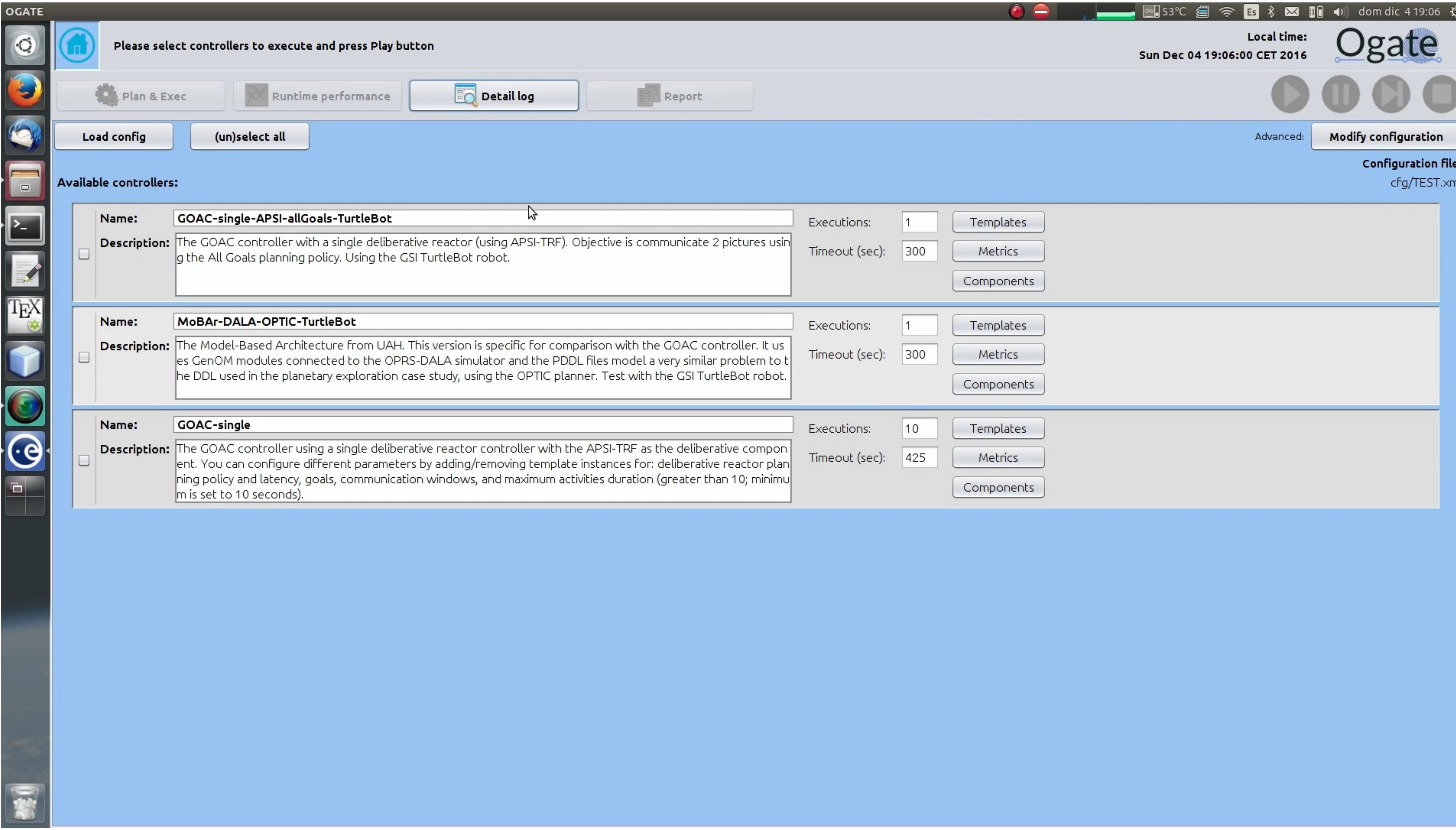
Demo



Thanks for your attention

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