Planning-based Controllers for Increased Levels of Autonomous Operations

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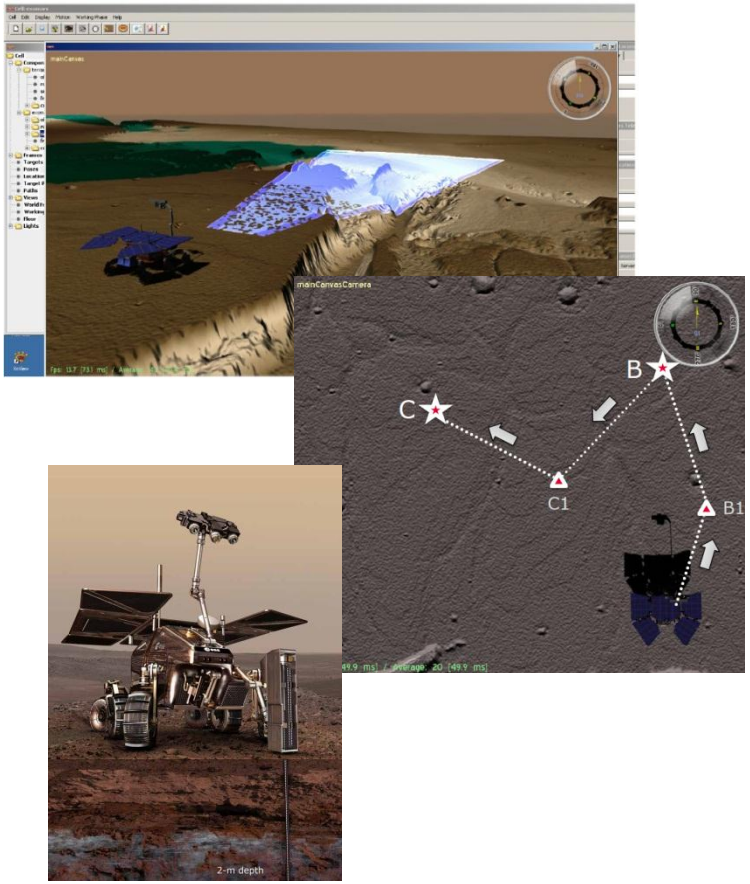
Motivation

- Upcoming missions will require a higher degree of remote operations to increase quality and quantity of science return
- Remote operations are a challenging scenario, mainly because communication delays and errors
- Autonomy can entail opportunistic science, provide contingency recovery procedures and allow fast reaction to tracked events
- AI planning-based control layers have demonstrated to be able to entail autonomy, but modeling still constitute a bottleneck for the use of these technologies



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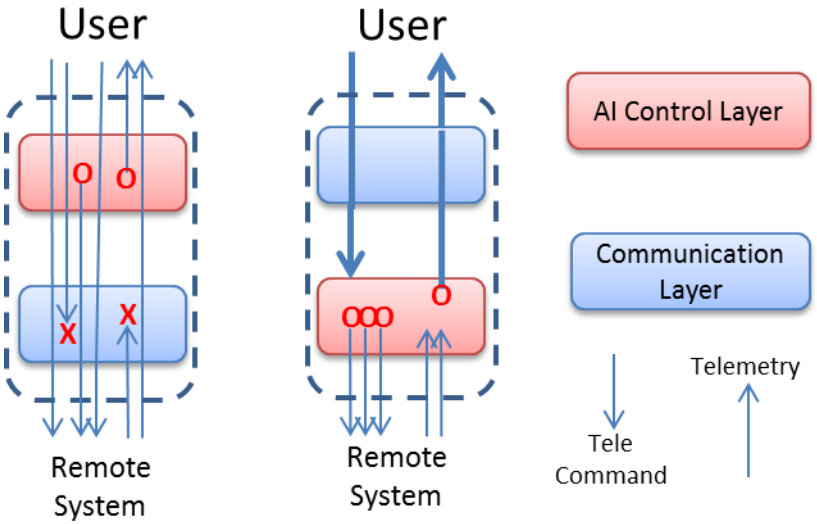
Approach

Use of a domain independent, model-based control layer between the operator and the system to be operated



At the remote system side:

- Rise the abstraction level of the platform commanding
- Provides to the operator the view of a goal oriented system
- Reduces the need of fine grained synchronization of commands

At the user side:

- Reduce the impact of delay and errors introduced by the channel

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Methodology

An executive agent:

- Re-Use of the the ESA GOAC (Goal Oriented Autonomous Controller) platform:
  - choice of the number and hierarchy of the reactors for the specific problem

One (or more) deliberative agents:

- Re-Use of the the ESA APSI (Advanced P&S Initiative) framework:
  - design and test of the model for each reactor

A functional layer:

- ESA METERON (Multi-purpose End-To-End Robotic Op. Network) infrastructure:
  - implementation a command dispatcher to connect GOAC with the system to be controlled

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The GOAC Project

1. **Objective**: : A 2 years ESA study (2009-2011) to design and test **robust onboard goal-oriented autonomous* software**. The Goal Oriented Autonomous Controller (GOAC) is designed to generate plans in-situ, to deterministically dispatch activities for execution and to recover from off-nominal conditions.

2. **Approach**: The project aims at using state-of-the-art technologies deployed by different research centers to build a **control architecture suitable for challenging real-world scenarios at ESA**. Goal is to integrate recent AI and robotics research to cope with challenging requirements from space.

3. **Support**: The ESA P&S Architecture supports the GOAC architecture providing **fast planning and re-planning capabilities, plan dispatch and plan execution monitoring**

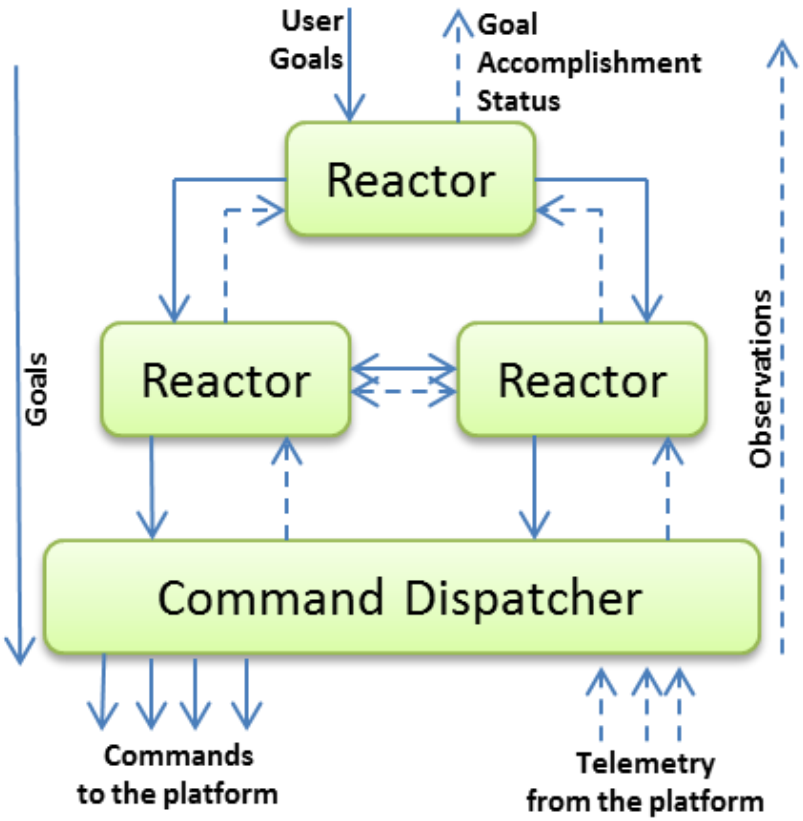
4. **Partners:**

5. **Project: ESA-ESTEC** ITTAO/1-5961/08/NL/RA

(*) Autonomy in this context is defined as "the ability to react to a wide variety of situations and circumstances, either nominal and exceptional, without the need of human supervision"

The GOAC Approach

- A goal-oriented system
- Interleaved sense-plan-act cycles (reactors)
- Reactors embed a domain independent, model driven, timeline-based planning technology
- Well defined interaction protocol:
  - Goals (up to down)
  - Observations (down to up)
- Increased depth allows HTN and planning at different temporal scopes
- Increased width allows planning with different functional scopes



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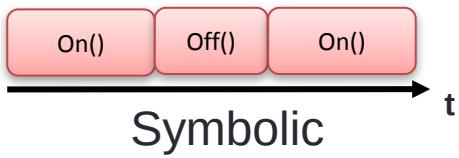
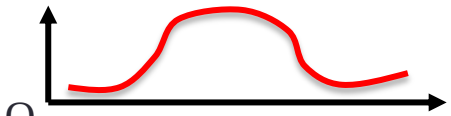
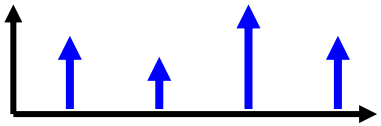
Timeline-Based Planning



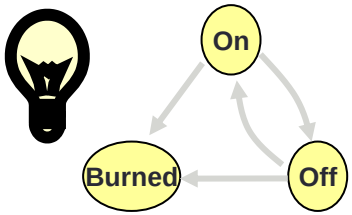
Symbolic



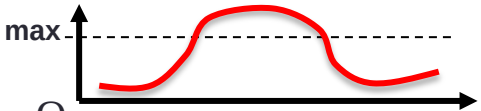
Numeric



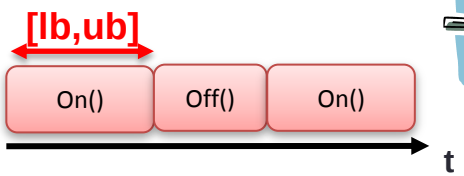
Pulses



Transitions



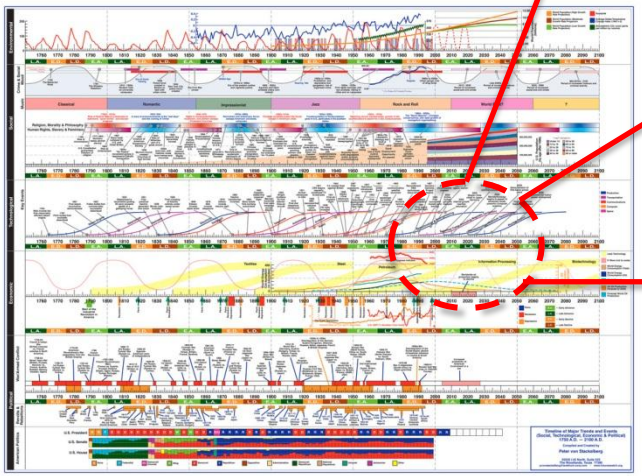
Value Constraints



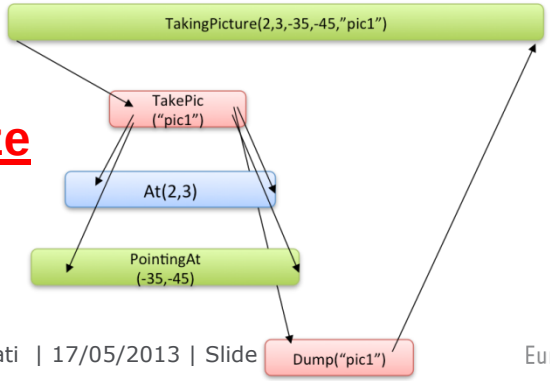
Temporal Constraints

1 - Represent Features

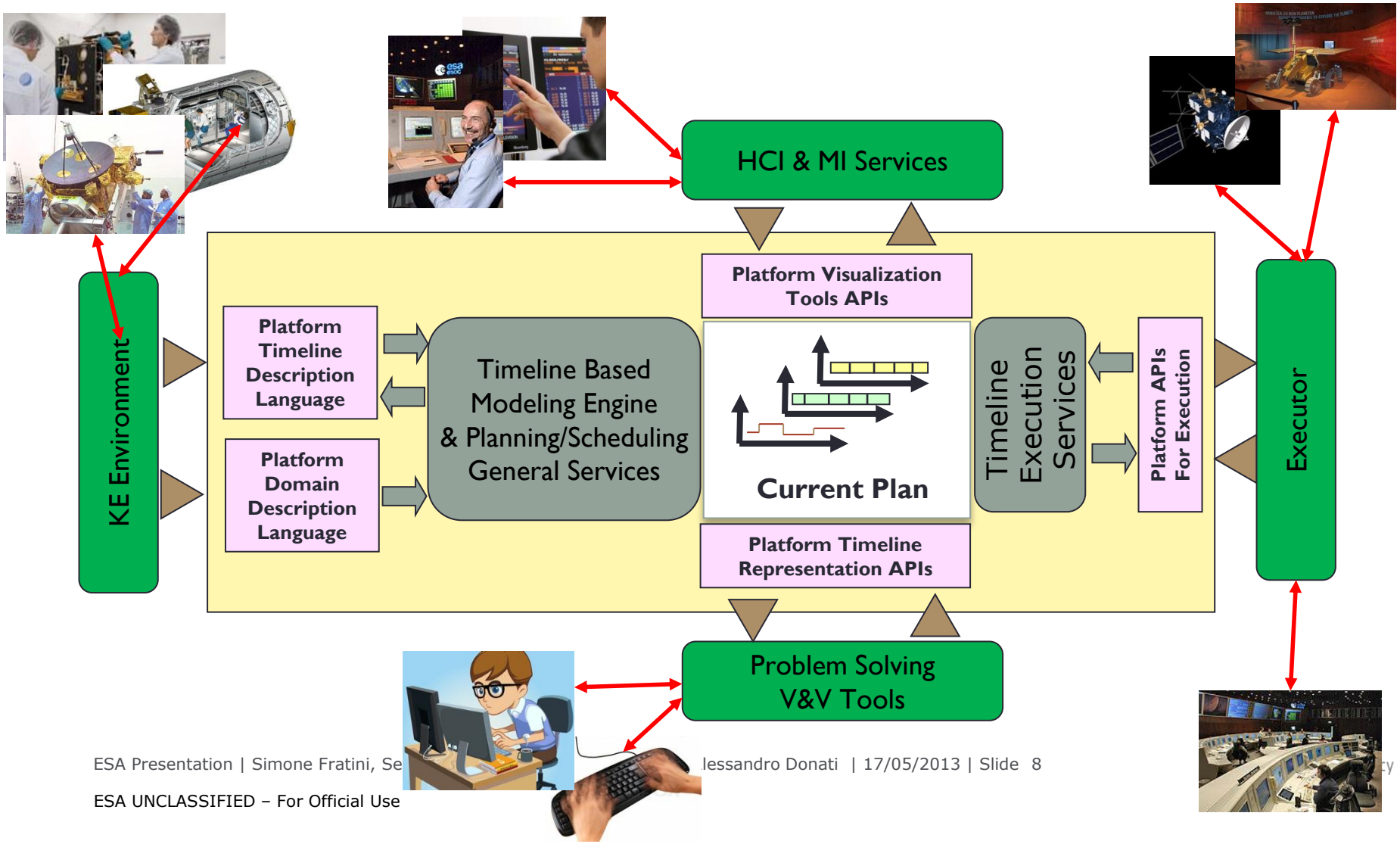
2 – Describe Features



3 – Synchronize Features



The ESA-APSI Framework



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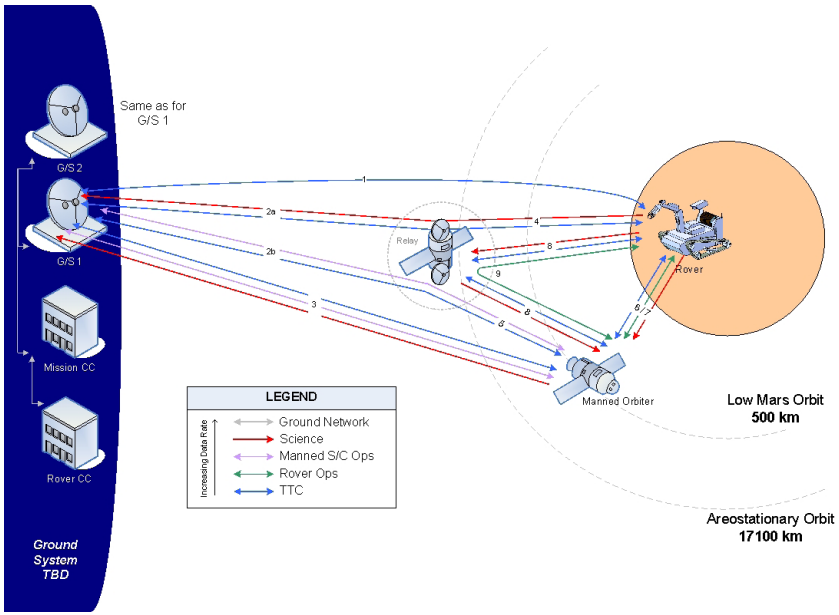
METERON: Multi-purpose End-To-End Robotic Operations Network

- To act as a test-bed, providing end-to-end in-orbit demonstration of potential future exploration operations scenarios involving robots and humans;
- To validate the concept of real-time bi-lateral control of a robot on a planetary surface, from a manned orbiter, by human operators in fully immersed telepresence;
- To perform further in-orbit testing and validation of novel communication techniques, such as Delay Tolerant Network (DTN) concepts and technologies.



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METERON Preparation: Operational Readiness Implementation/Demonstration

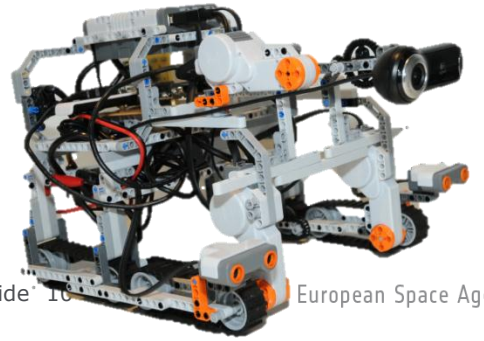
Quickstart-a: Establish ESA DTN connectivity to Columbus module in collaboration with University of Colorado

Quickstart-b: Enable basic real-time telerobotics communication between Columbus and Ground via KONTUR-2 link

Quickstart-c: Demonstrate full end-to-end connectivity between facilities integrating both previous phases

→ Quickstart-a verified with OPSCOM-1 experiment of October 2012

Demonstrated simple robotics telecontrol running over a DTN network, where a crewmember on the ISS interacted with a simple rover on Earth.



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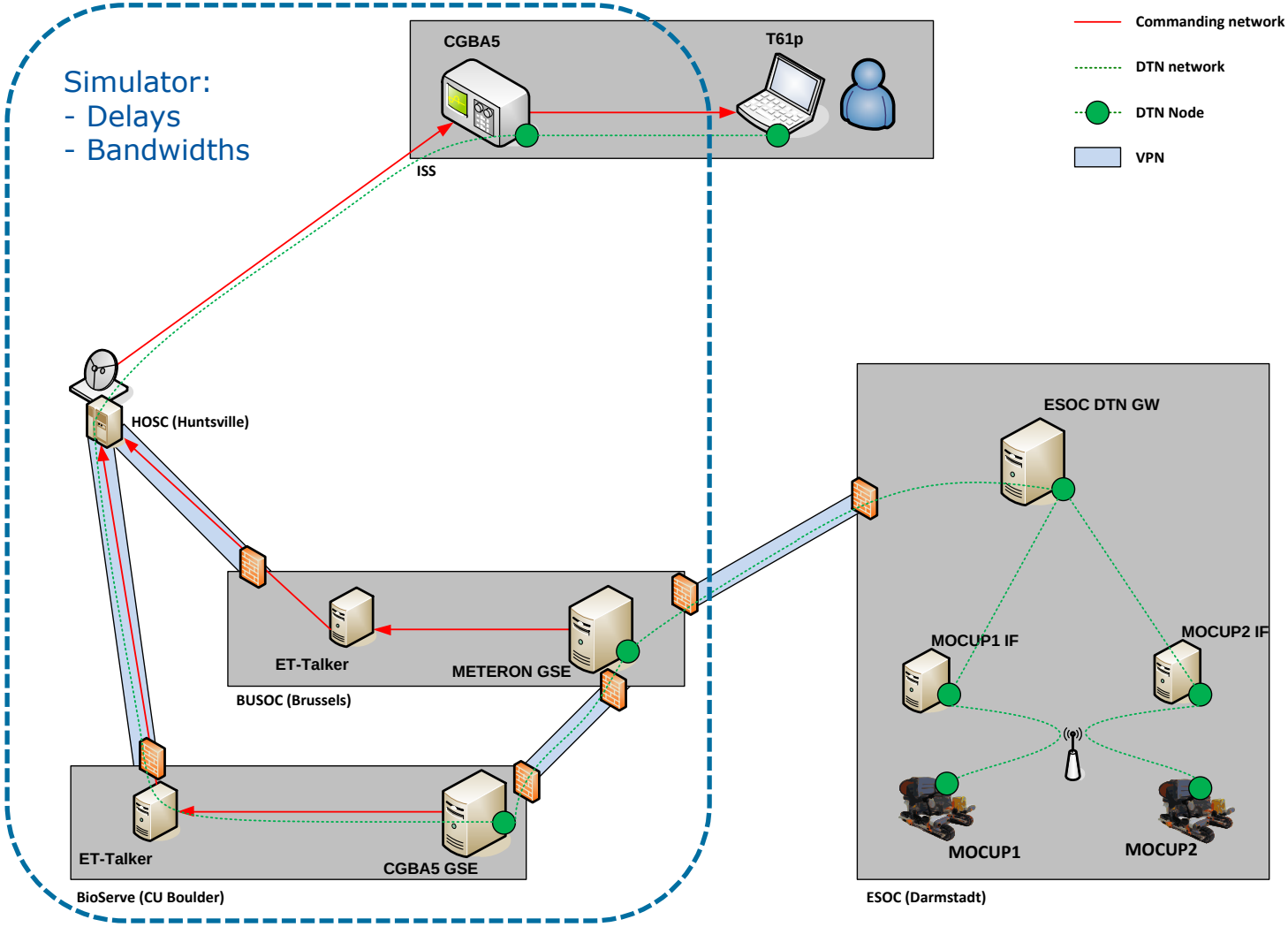
METERON OPSCOM1 Architecture Overview



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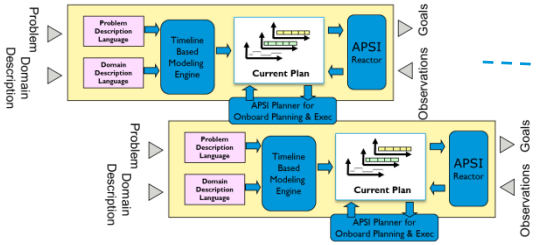
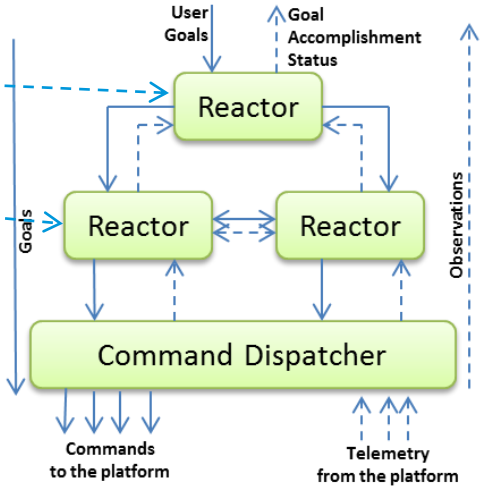
Integration Schema

Deliberative Layer - APSI

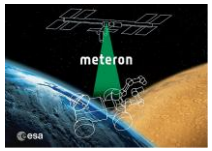


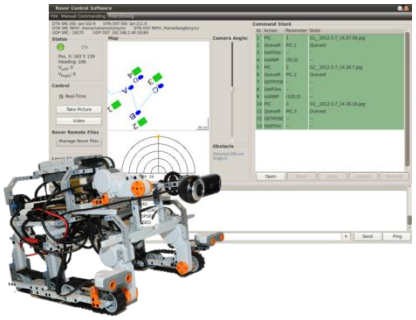
Executive Agent - GOAC

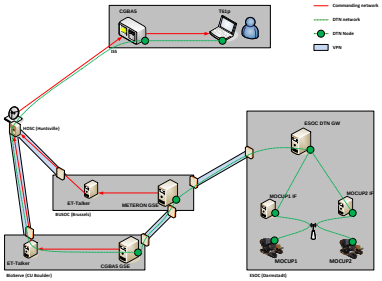
GOAL ORIENTED AUTONOMOUS CONTROLLER



Functional Layer – METERON Infrastructure







Tele Commands

Telemetry

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Methodology

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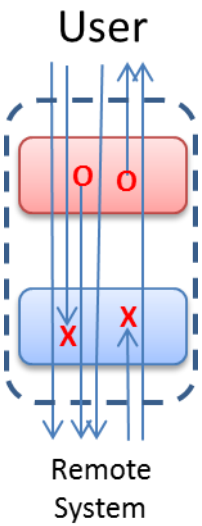
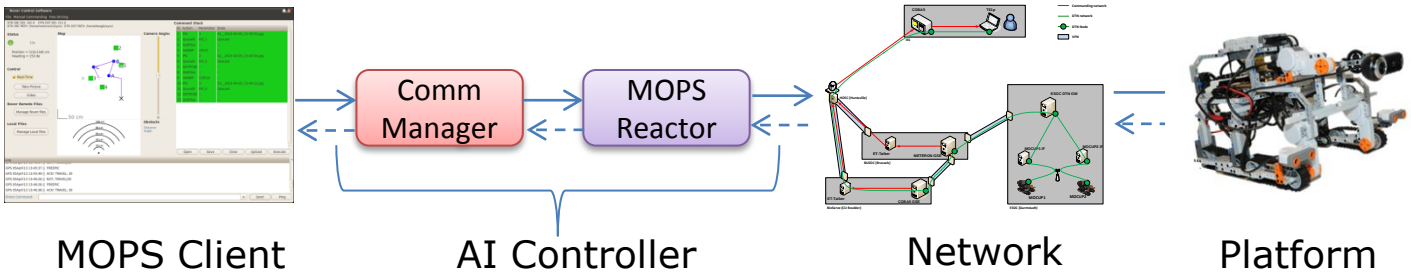
Upstream Configuration

GOAL: providing a unified view of the communication layer plus remote system that allows the operator to reduce the impact of the delay and errors introduced by the communication channel



REACTORS: 1 deliberative + 1 command dispatcher

1. The communication repair reactor is designed to robustify the communication between the operator and the remote system (deliberative reactor)
2. The MOPS reactor encapsulates the connection with the rover trough the network and constitute the logical interface with the platform.



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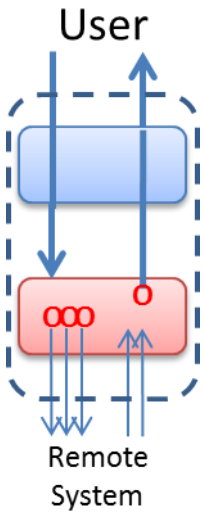
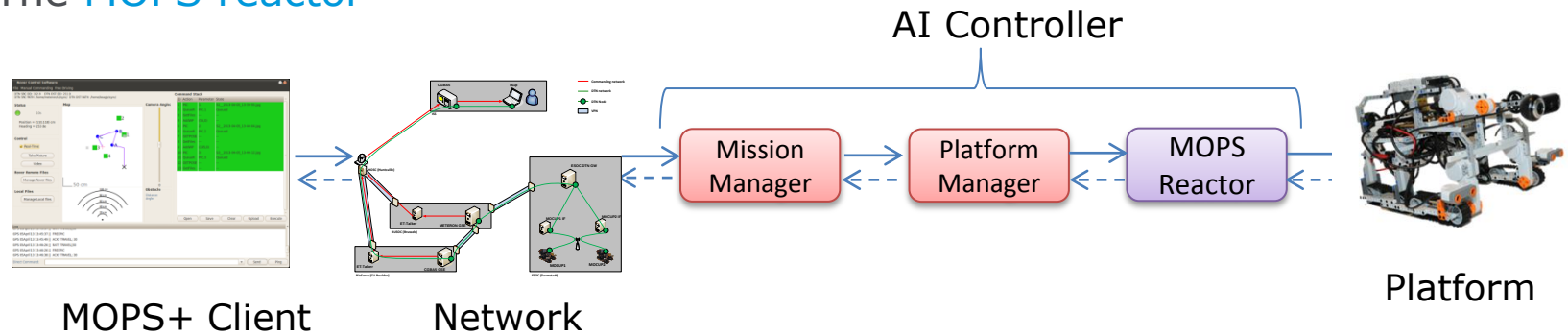
Downstream Configuration

GOAL: providing to the operator the view of a more robust autonomous, goal oriented system, to reduces the amount of controls and the need of fine grained synchronization of commands



REACTORS: 2 deliberative + 1 command dispatcher

1. The platform manager reactor aims at modeling a "virtual platform" able to perform simple navigation tasks in a robust manner
2. The mission manager reactor is designed to plan for complex user tasks
3. The MOPS reactor



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Model-Based is very nice but…

"Timeline-based planners embed complexity in the planning model…. In some cases, the complexity of the definition model … takes a significant development effort. "

"Currently, modeling can be undertaken by experts only."

…modeling is one of the most challenging tasks when implementing an instance of GOAC…

"In order to support the modeling process and to make it feasible to non-experts, it will be useful in the future to develop a more detailed methodology and to create development tools. This is a future task, of paramount importance for its evolution and acceptance by the developer's community."

Excerpts from the report "LESSONS LEARNED AND CONCLUSIONS"
TN10, AUTONOMOUS CONTROLLER PROJECT
GMV, 8/11/2011

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Pattern-Based Modelling

"In software engineering, a design pattern is a general reusable solution to a commonly occurring problem within a given context in software design.

A design pattern is not a finished design that can be transformed directly into source or machine code. It is a description or template for how to solve a problem that can be used in many different situations."

Methodological Approach to pattern-based modelling:

a) Identify "common occurring problems" in P&S and Execution
b) Design and test of modelling patterns for these problems
c) Classify an instance of a real problem as one of the "common occurring problems" identified at point a)
d) Instantiate the pattern into a real model for the real problem

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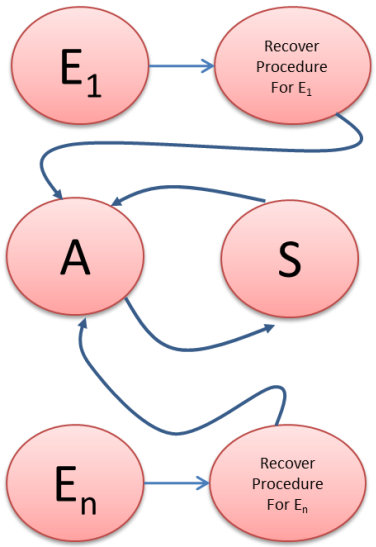
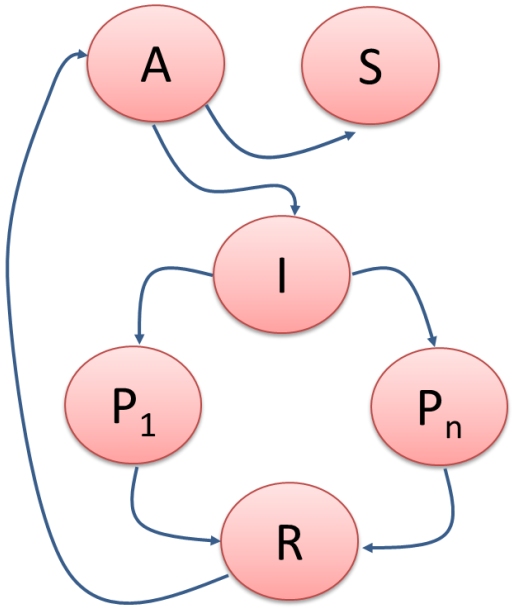
The Platform Manager Reactor

Commonly occurring problems:

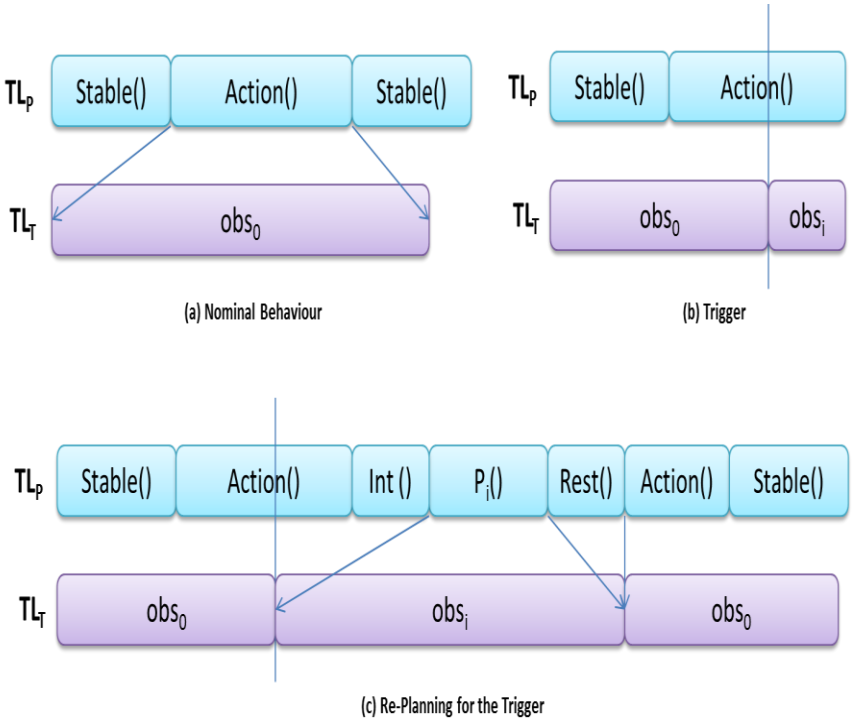
1. recover from a set of predefined not nominal conditions
2. plan on-board activities to achieve unexpected sub-goals triggered by the status of the platform



(a) Failure Recover Pattern



(b) Trigger Reaction Pattern



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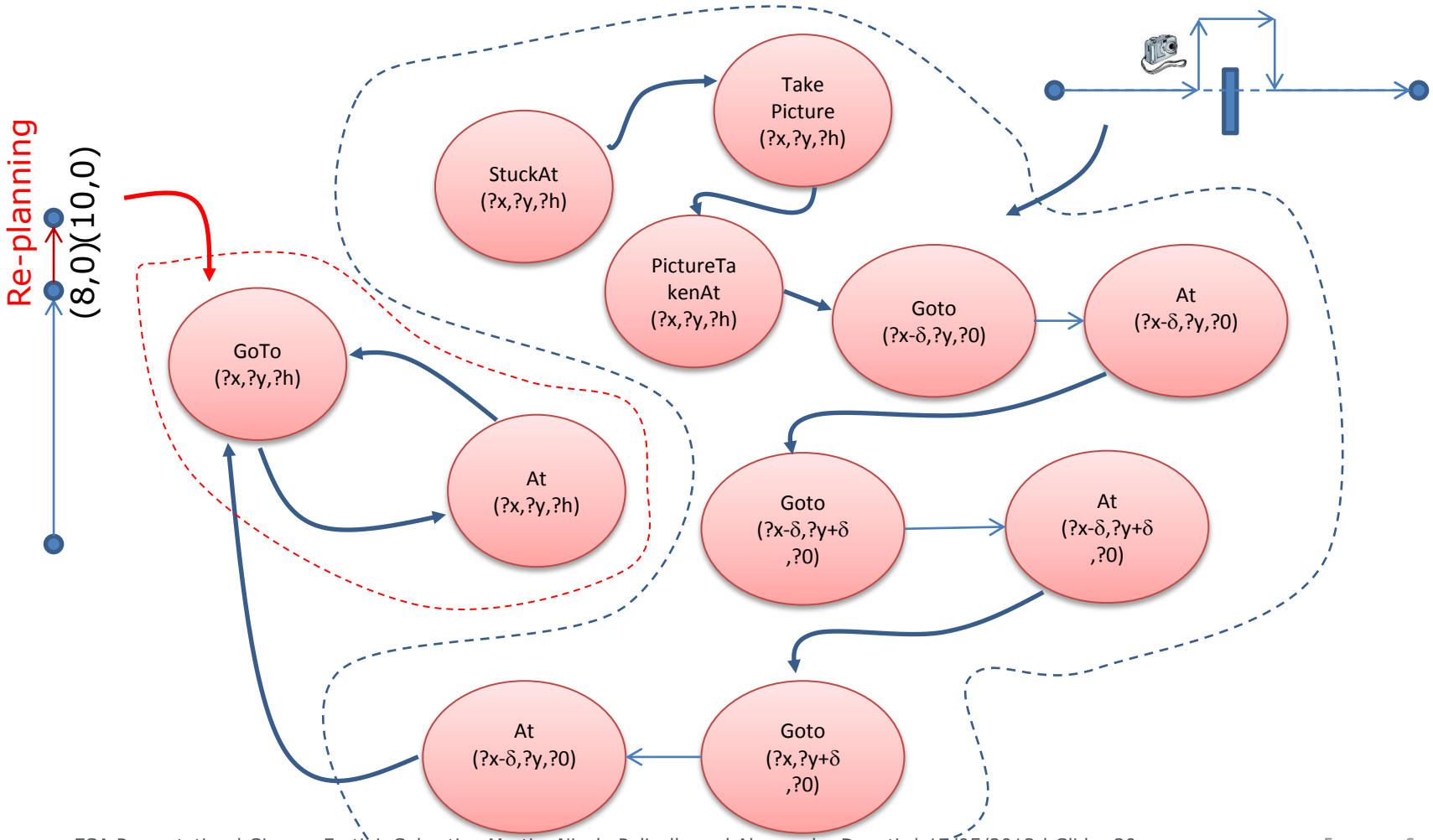
Obstacle Avoidance



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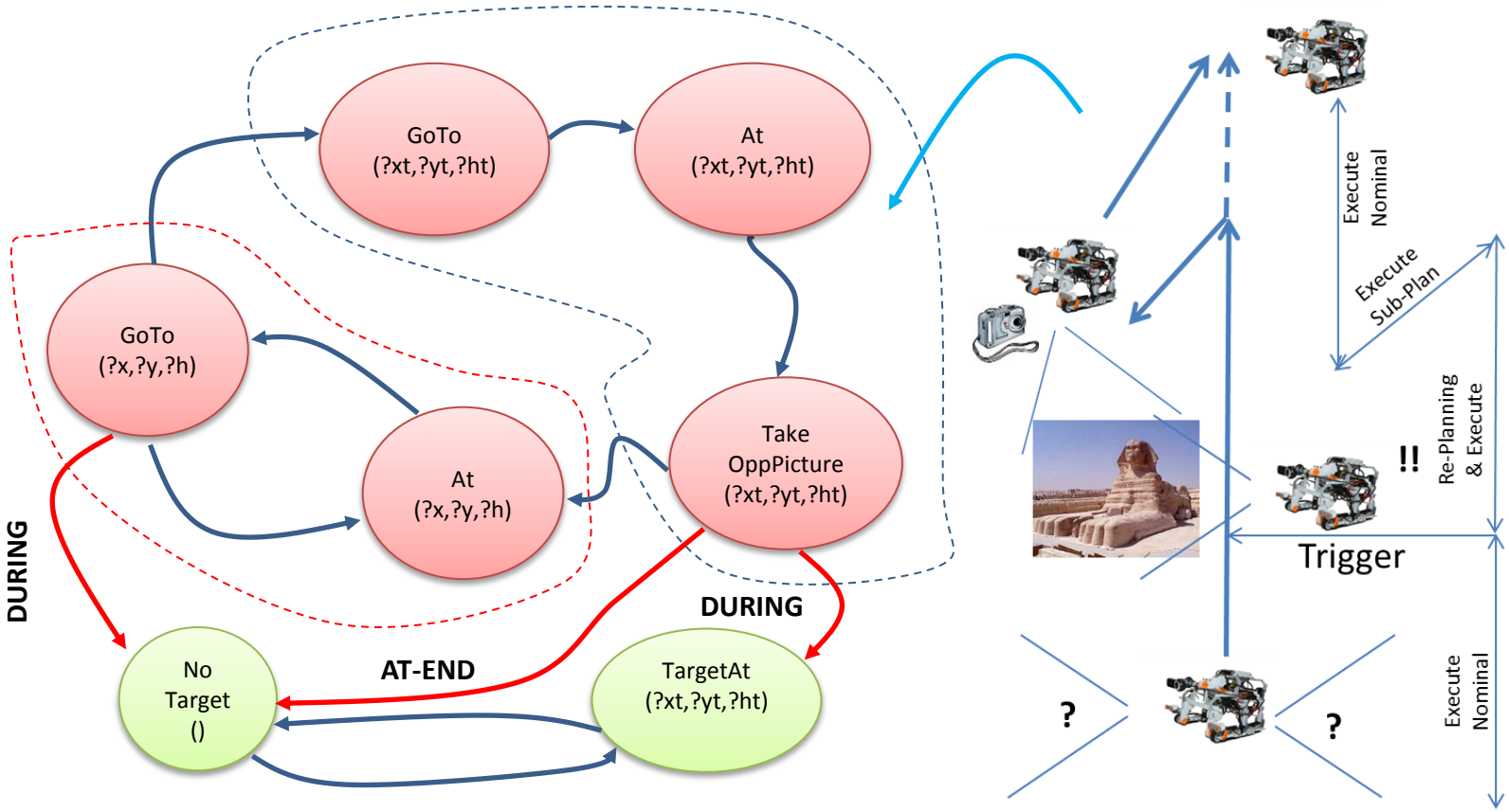
Opportunistic Science



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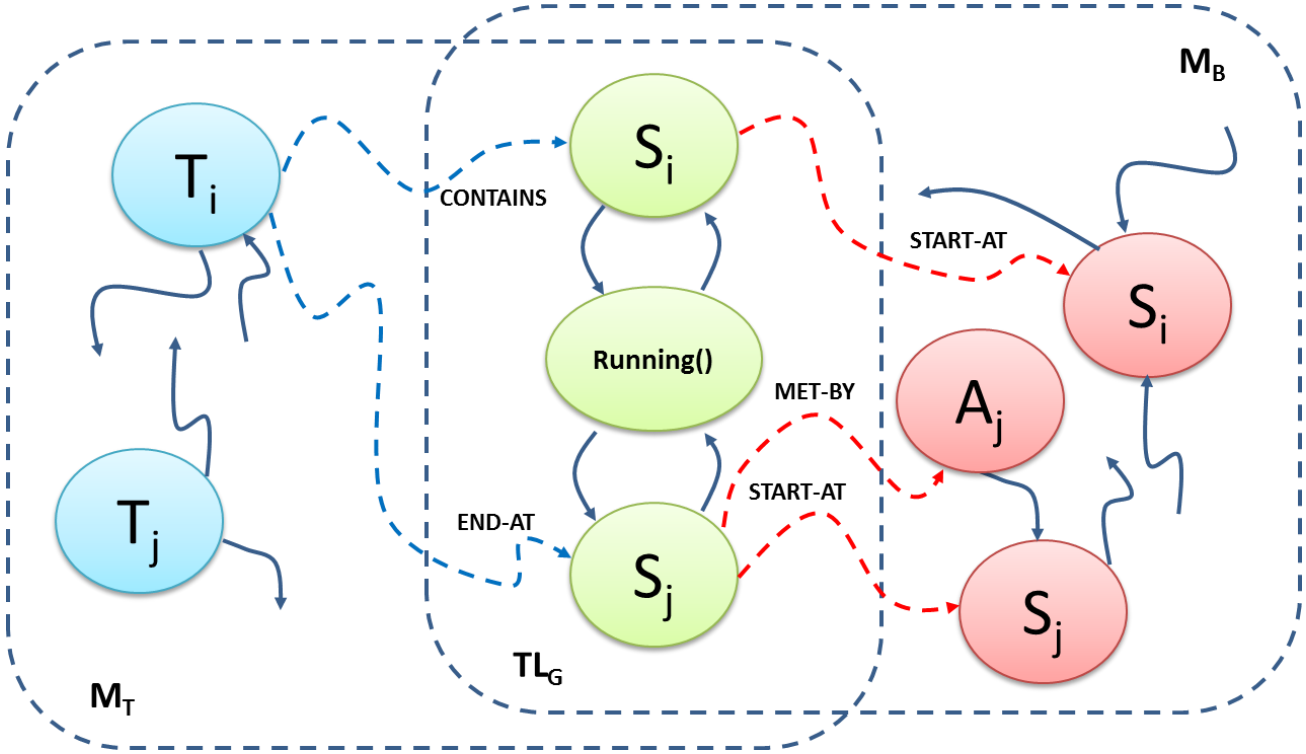
The Mission Manager Reactor

Problem: how to define complex high level tasks in terms of simple, low level tasks?



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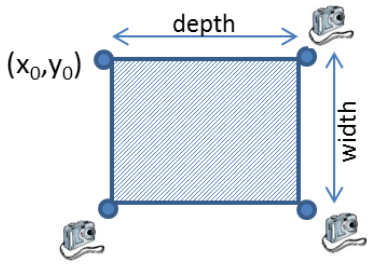
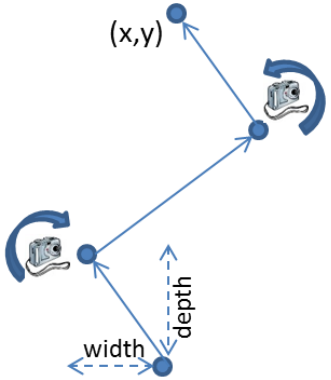
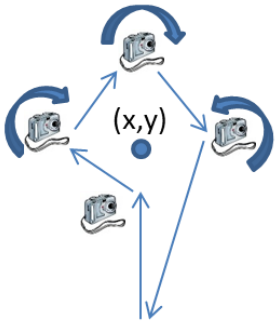
Example of Modeling



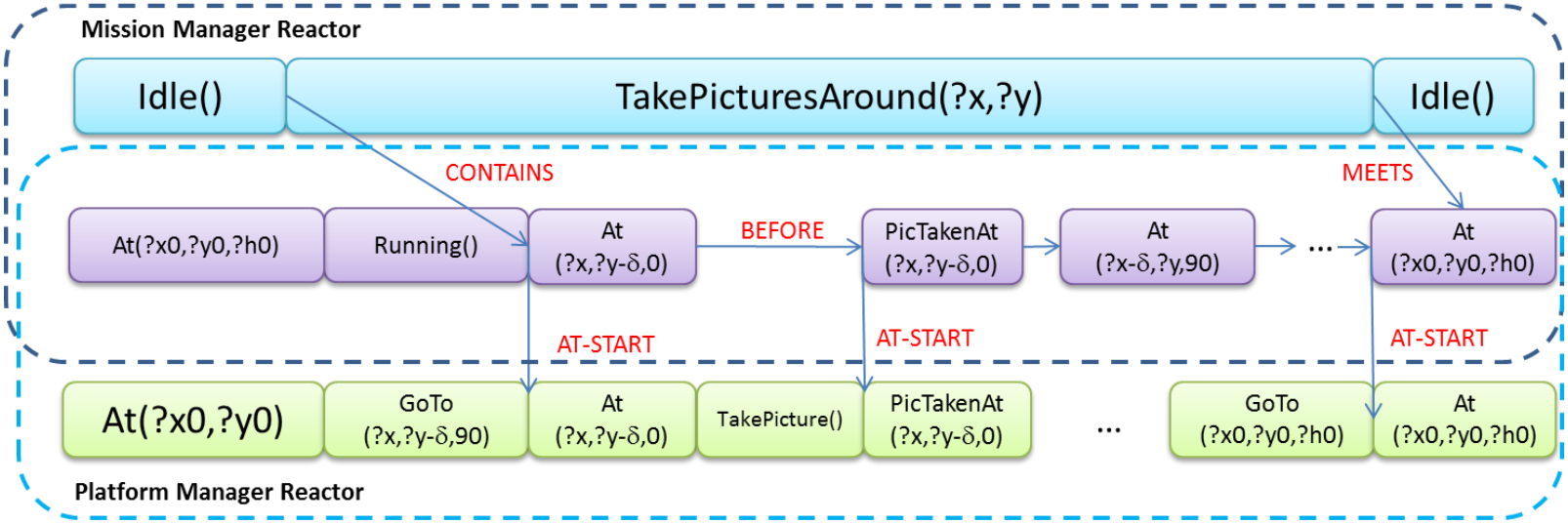
(a) Monitor(?depth,?width)



(b) ZigZag(?x,?y,?depth,?width)



(c) TakePicturesAround(?x,?y)



(d) Synchronizations for TakePicturesAround(?x,?y)

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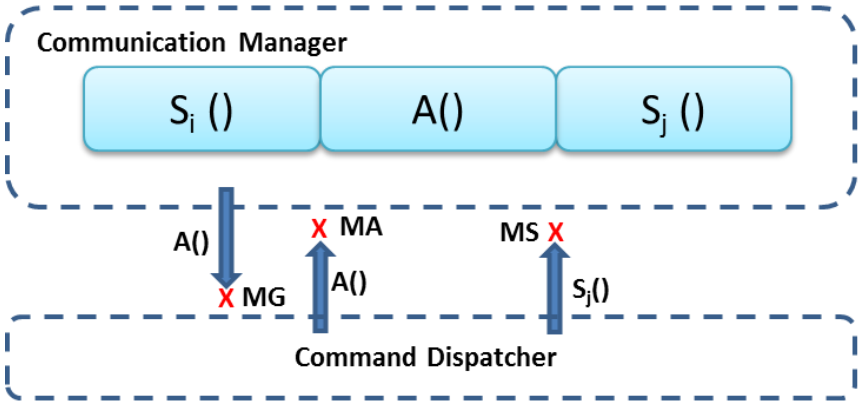
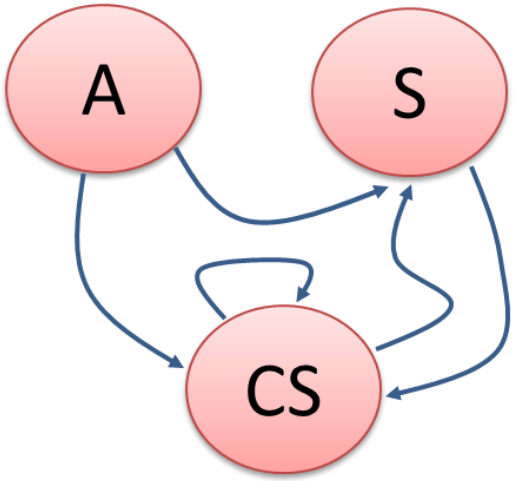
The Communication Manager Reactor

Many reasons for discrepancy among planned and executed timelines (interpreted as failures during execution):

- errors in the models of the deliberative reactors
- errors in the implementation of the command dispatcher
- errors in communication among the reactors (lost goals or observations)



(a) Communication Failures



(b) Modelling Pattern

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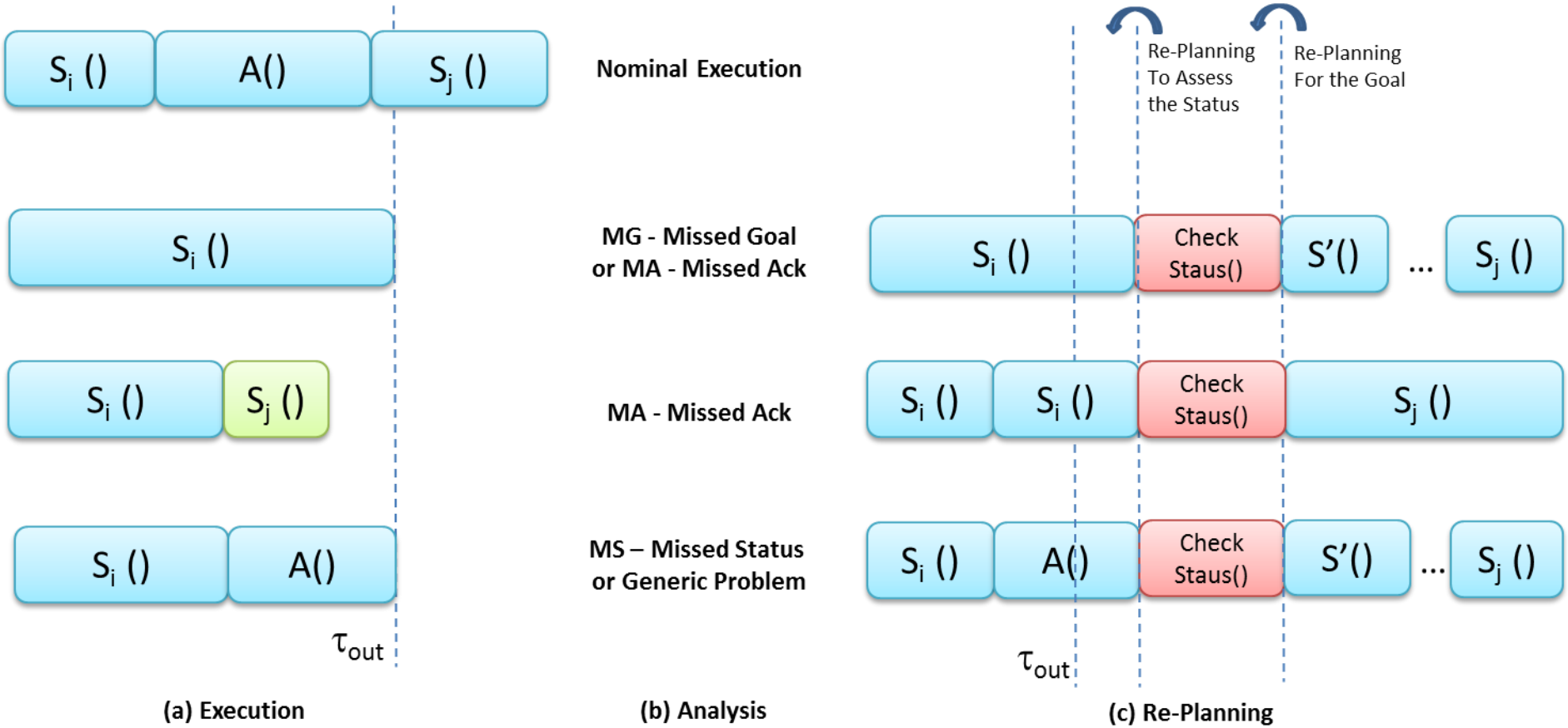
Communication Repair



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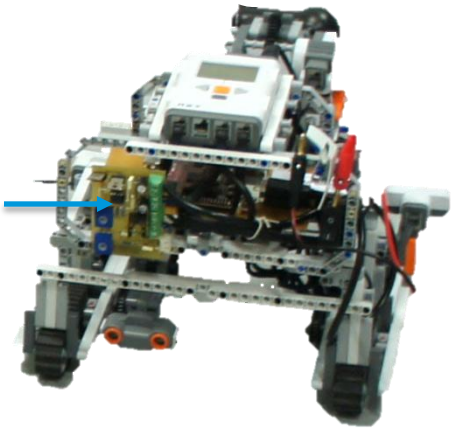
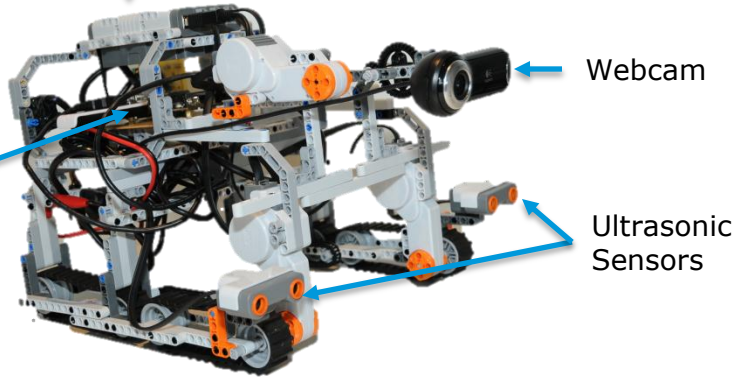
MOPS/MOCUP Software

2. METERON Operations and Communications Prototype (MOCUP)

- **Lego Mockup Rover –** NXT 2.0 Mindstorms kit
  - Add LiPo battery (4h autonomy)
  - Wireless dongle
  - Built powerboard to keep battery from depleting

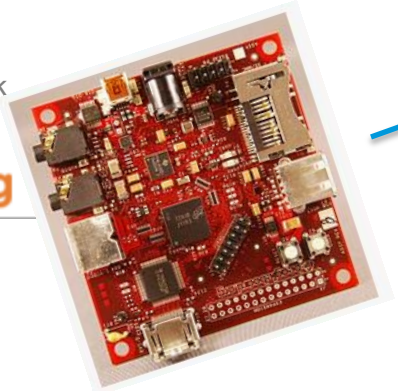


- **NXT Board** -> lejos NXJ (Not eXactly Java)
  - Obstacle detection algorithm (Rover stops moving < 15cm)
  - Position information from wheel odometry
  - 3 Ultrasonic Sensors (30deg FOV)
  - Web cam for video and pictures (adjustable angle)



- **Beagleboard** with built in ARM-Linux
  - 1 GHz CPU core
  - RAM 512 MB
  - onboard Ethernet jack
  - 4 port USB hub

beagleboard.org



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Short Video

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Conclusions

1. Role of autonomy in supporting rover tele-operations:
    a. Mitigate Communication Failures
    b. Extend Controlling Capabilities (high level commands)
    c. Local Reaction and Failure Recovery

2. Current solution:
    a. Integration of all ESA sw
    b. Framework Approach: about 1 week of coding for tailoring the GOAC platform

3. Model-Based approach:
    a. brings flexibility and reusability
    b. but also additional burden on not-so-standard capabilities

4. Future work:
    a. Considering resources, i.e. on board memory, battery, etc..
    b. Collaborative environment for supporting goal oriented operations
    c. Extended migration of tele-operation failures

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