AIPlan4EU: Planning and Scheduling for Space Applications

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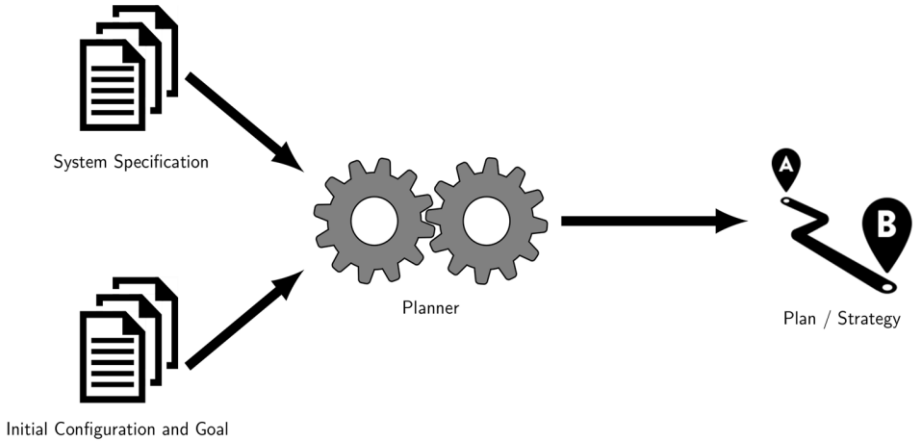
Introduction

- The **European AI On-Demand Platform** (AIoD - ai4europe.eu) is a platform for centralizing and experimenting with AI technologies; the platform aims at creating synergies between all the AI stakeholders

- **Planning** is one of the founding fields of AI not represented in the AI4EU platform



- The main **AIPlan4EU objective** is to provide a simple and streamlined **access to the planning technology** to allow for the creation of more and more planning-based applications

AIPlan4EU objectives

- ***O1**: Making **planning accessible to practitioners** and innovators*
  - Fragmented landscape, hard to experiment with different tools
- ***O2**: **Facilitate the integration** of planning and other ICT technologies*
  - No common API, different formal languages
- ***O3**: Making planning relevant in **diverse application** sectors*
  - Some planners are general purpose, others are specialized but few application sectors considered
- ***O4**: Seamlessly integrate planning within the AI4Europe platform*
  - Planning is currently missing, despite being a foundational AI sub-field
- ***O5**: **Facilitate learning of planning** for reskilling and lower the access barrier*
  - Planning material has a steep learning curve and requires specialized background knowledge
- ***O6**: Standardize and drive academic **research towards applications***
  - Planning research mostly focused on theoretical aspects or limited to few specific applications

AIPlan4EU Partners

Research Institutions

- ***FBK (Italy)***
- LAAS-CNRS (France)
- DFKI (Germany)
- Örebro University (Sweden)
- Basel University (Switzerland)
- University of Brescia (Italy)
- "La Sapienza" University (Italy)

Companies / SMEs

- Airbus SAS (France)
- Agrotech Valley Forum (Germany)
- EasyMile (France)
- F6S (Ireland)
- Magazino (Germany)
- Meritor (Sweden)
- Procter & Gamble Services (Belgium)
- Saipem (Italy)
- ***Trasys International (Belgium)***

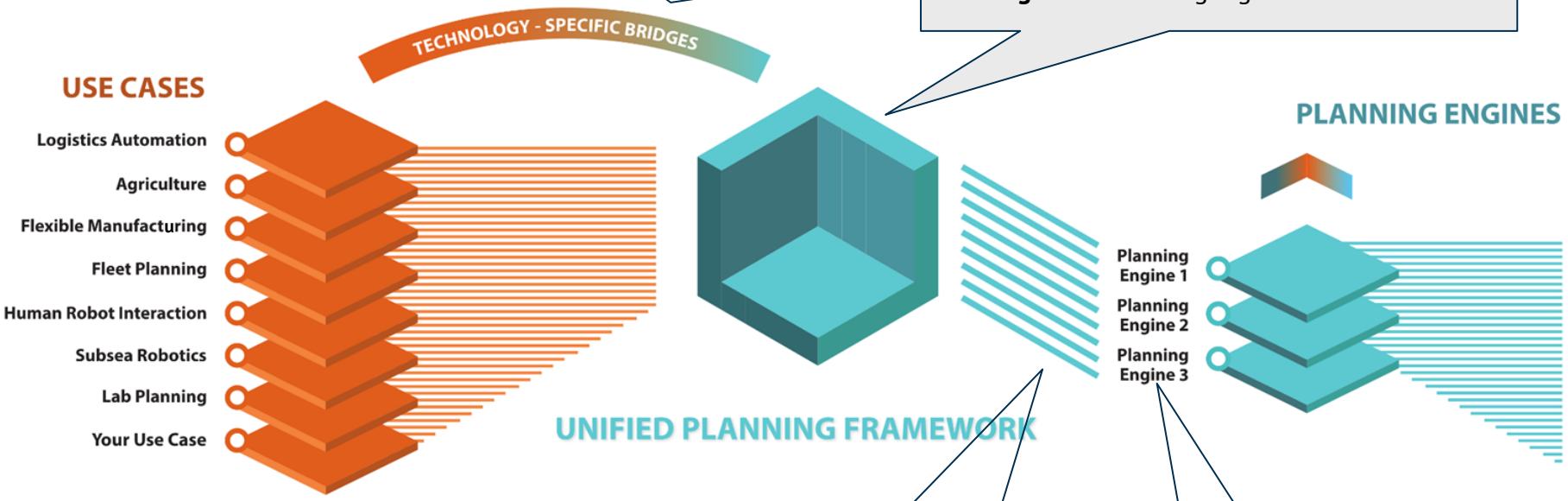
Plan

- Introduction
- AIPlan4EU architecture
- Unified Planning framework
- Use Cases & Technology Specific Bridges (TSB)
- Space use case
- Integration into the RVP of ROCS
- Conclusions

AIPlan4EU Architecture

The API offered by the UPF is integrated by a **collection of reusable components** that are specific to a certain technology (not use-case specific). E.g. Integration in ROS, Integration in a WMS, …

The UPF is a **reusable, planner-agnostic** Python library, offering an **abstraction layer** for diverse planning engines and **interoperability with existing tools** and languages



The UPF has a notion of "**Operation Mode**" (OM):

- OM examples include "**OneshotPlanning**", "**PlanValidation**" and "**PlanRepair**"
- Each engine declares which operation modes it supports

"Planning Engines" is a general word: plan **generators**, plan **validators**, **visualizations**…

Unified Planning

- The Unified Planning framework (UPF) is a library that seamlessly invokes a portfolio of planning techniques
  - Written in python with a focus on usability and expressiveness
  - Permissively open source
  - Development under completion (12/2023)
  - https://github.com/aiplan4eu/upf
  - Not only plan generation

```
from unified_planning.shortcuts import *

x = Fluent("x")

a = InstantaneousAction("a")
a.add_precondition(Not(x))
a.add_effect(x, True)

problem = Problem("basic")
problem.add_fluent(x)
problem.add_action(a)
problem.set_initial_value(x, False)
problem.add_goal(x)

with OneshotPlanner(problem_kind=problem.kind) as
planner:
    result = planner.solve(problem)
    print(f"{planner.name} found this plan: {result.plan}")
```

Unified Planning Services

- ***OneshotPlanner:*** single call to a planning engine that given a problem returns a plan (or a failure response)
- ***PlanValidator:*** given a planning problem and a plan, checks if the plan is valid
- ***SequentialSimulator:*** given a problem provides an interactive way to explore the reachable states
- ***Compiler:*** transforms a given problem into an equivalent one performing some kind of rewriting
- ***AnytimePlanner:*** iteratively generates solutions to a planning problem (e.g., incrementally better plans)
- ***Replanner:*** interactively generate new plans given a problem and subsequent changes to it
- ***PlanRepairer:*** given a planning problem and a (possibly invalid) plan, returns a valid plan
- ***PortfolioSelector:*** given a planning problem selects the best engines to solve the problem

Unified Planning – Planning Engines

- **Downward:** is a state-of-the-art domain-independent classical planning system based on heuristic forward search
- **Pyperplan:** a lightweight STRIPS planner
- **ENHSP:** heuristic forward state space search planner that looks for a plan in the transition system induced by a numeric planning problem definition
- **LPG:** planner based on stochastic local search and action graphs
- **TAMER:** *temporal planner* for the ANML planning specification language
- **FMAP:** multi-agent planner
- **Aries:** constraint-based planner and scheduler
- **SpiderPlan:** constraint-based planner supporting also motion planning

Technology specific bridges

- Agriculture Domain: Organize agricultural activities for silage maize harvesting.
- Flexible Manufacturing: organization of the factory activities to achieve a desired production. The use-case scenario involves the operations to construct truck axles.
- Logistics Automation: realization of an offline design aid tool for the automatic debugging of Behavior Trees used to control an autonomous robot capable of intra-logistics tasks. Moreover, we tackled the problem of runtime reactive planning for Behavior Trees.
- Shuttle Fleet Management: mission assignment for a fleet of Automated Guided Vehicles to fulfill transportation demands and use the recharging stations optimally.
- Automated Experiment Design: automation of consumer goods testing by means of a robotic arm controlled by an automated planner.
- Subsea Robotics: realization of an on-line planner and a re-planner for underwater autonomous inspection missions.

- Space Domain: Generation and Consolidation of Activity Plans for a remote exploration rover

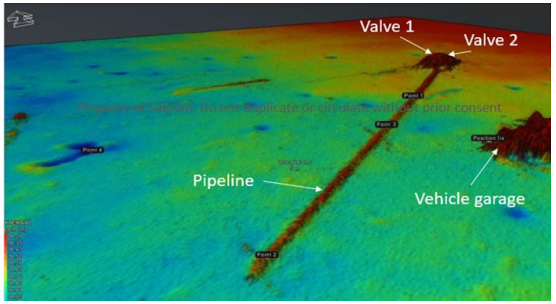
Use Cases & Technology specific bridges

Agriculture Domain

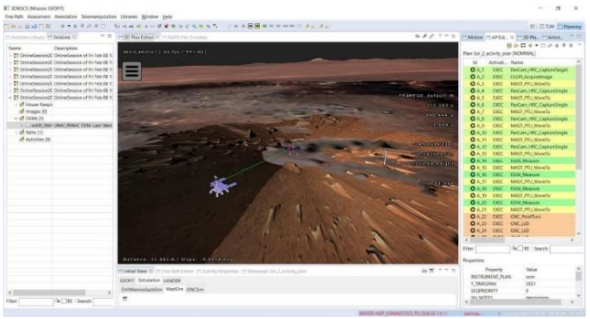
Logistics Automation

Flexible Manufacturing

Automated Experiment Design



Subsea Robotics



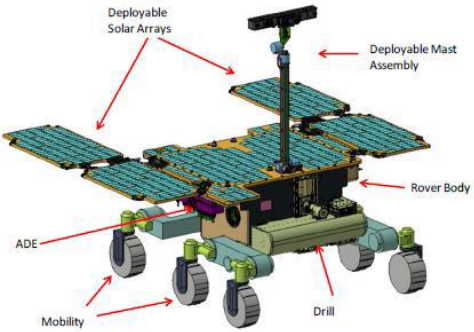
Space Exploration

Space Use Case: ExoMars Rover operations planning

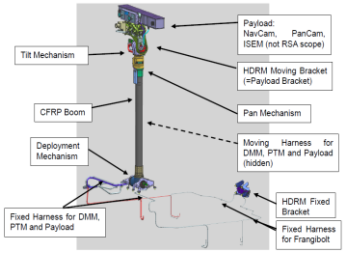
- The ExoMars Rover is designed to implement E3 level of autonomy allowing the "Execution of adaptive missions operations on-board":
  - An **Action** represents elementary rover Activities
  - The **Tasks** are logical and temporal composition of Actions; the Tasks, as composition of Actions control several subsystems in parallel
  - **Activity Plans** is a composition of Activities (Actions & Tasks) following the semantics of a specific Rover Activity Plan Description language (RAPD) and are interpreted on-board

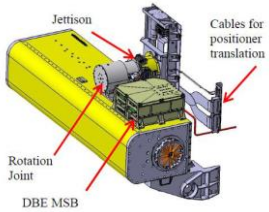
Space Use Case: Modelling

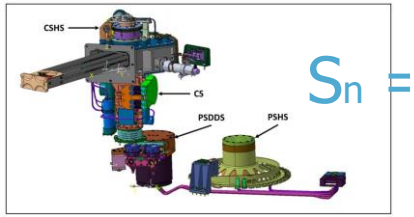
System



Subsystems







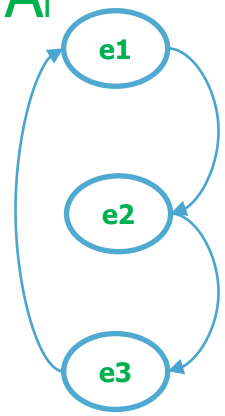
States

$S_1 = \{ X_1, X_2, \ldots, X_n \}$

$S_2 = \{ X_1, X_2, \ldots, X_n \}$

$S_n = \{ X_1, X_2, \ldots, X_n \}$

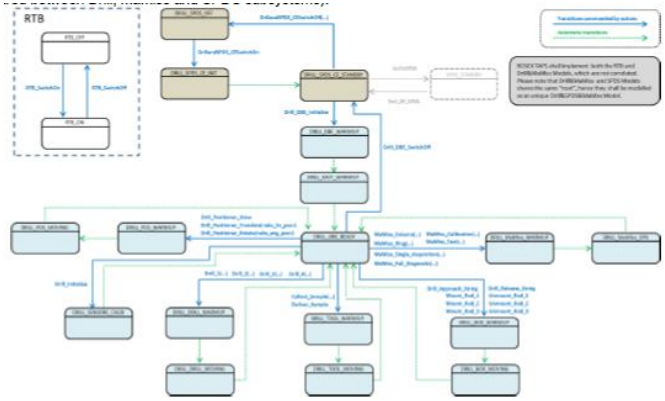
Activities



Resources

e_i ->

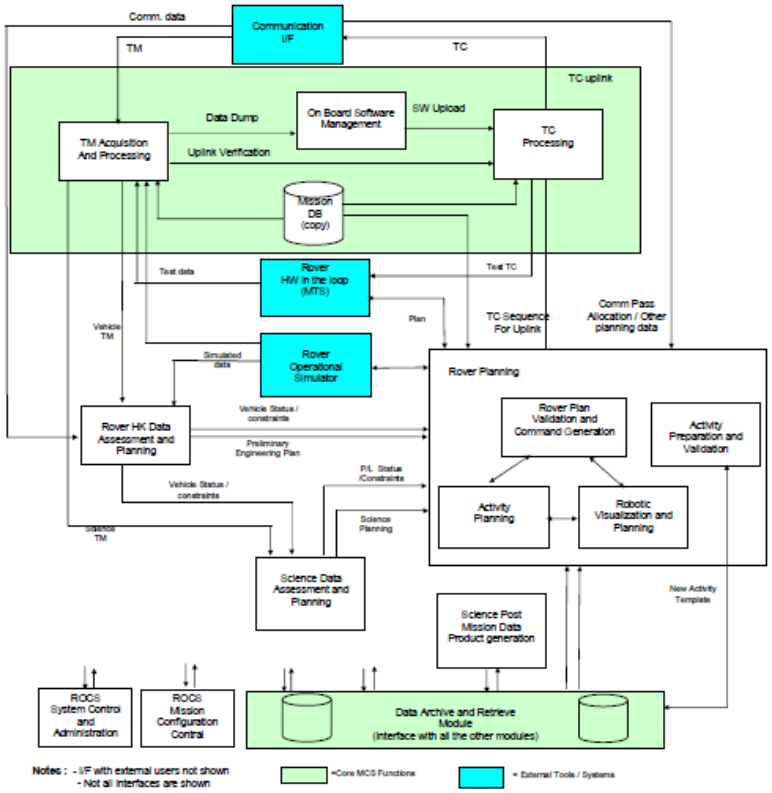
{ Dur., Power, Mem mass }



(*) X and Resources may depend on external conditions

Space Use Case: Operations Planning Workflow

- The typical rover Activity Planning workflow (tactical planning) in ExoMars involves the following steps:
  - Telemetry Acquisition and Processing
  - Engineering and Science Data Assessment
  - **Engineering and Science Planning**
    - *Partial Engineering and Science Activity Plans are manually created* by composing Activities using dedicated MMIs. The prepared Partial Plans are submitted to a central Activity Planning tool for further consolidation.
  - **Activity Plan Consolidation**
    - An Activity Planner integrates all the submitted Partial Science and Engineering Activity Plans and schedules them in a Consolidated Activity Plan so that constraints and resources are respected.
  - Activity Plan Validation and Uplink

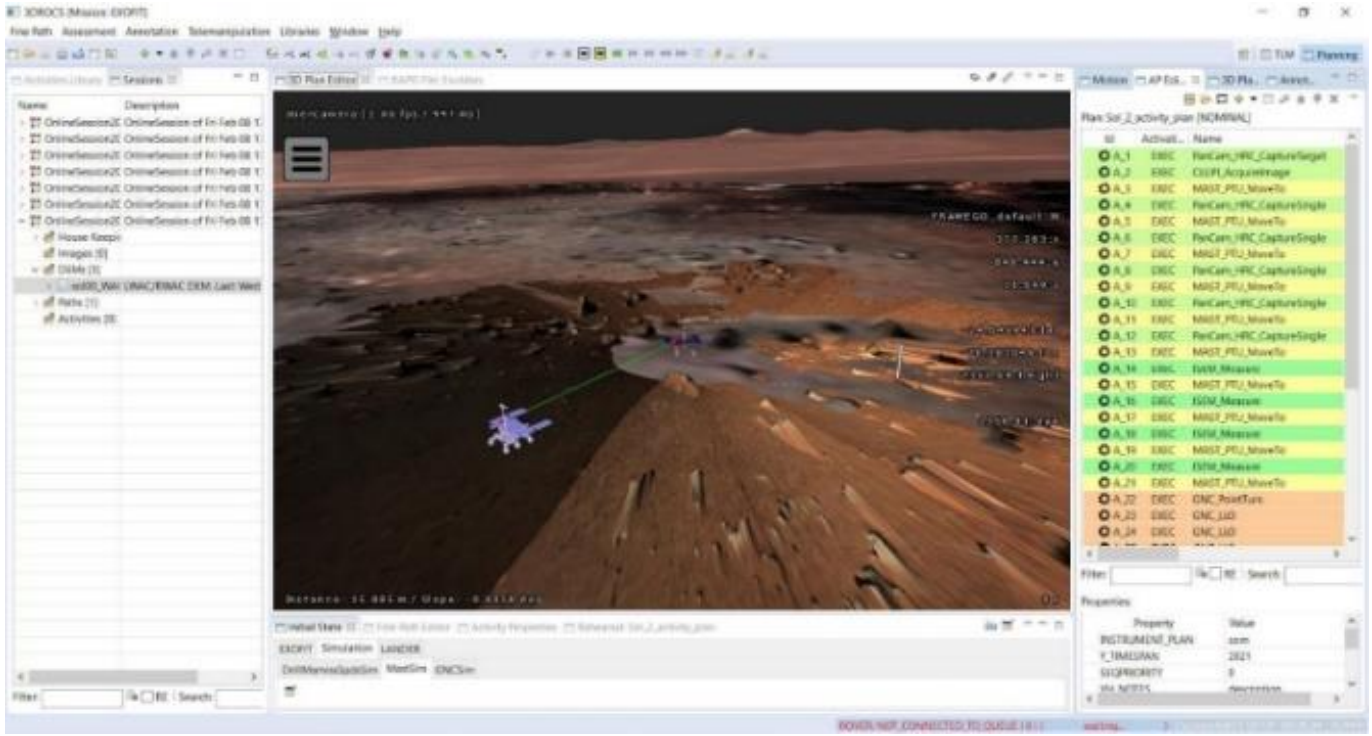


Space Use Case: Operations Planning

- Automated planning is expected to improve several aspects/steps of the Activity Planning workflow
  - The manual generation of Partial Engineering and the Science Activity Plans **requires from the operators (engineers and scientists) to be aware of several engineering low level constraints** (e.g., set the robotic system to a state compliant to their objectives, avoid the use of subsystems that create conflicts during operations, be aware about the resource consumption of their objectives). As a result**, the Partial Planning step requires a significant amount of time** to be completed and very often provides invalid Partial Plans that are later rejected.
  - In the current Activity Planning workflow the **consolidation of the Partial Activity Plans to a final valid Consolidated Activity Plan to be uploaded for execution is performed manually**. Filling the gaps between the partial plans to construct a valid complete plan is time consuming and error-prone.
  - The proposed Partial Engineering and Science Activity Plans, generally, over subscribe the available resources (time, power and memory). **Automated planning may generate optimal plans with respect to the available resources and therefore maximize the science return**. As a particular case of interest is to **automatically identify and propose to the operator the values of well-defined parameters that allow to fit the automatically generated plan in the range of the available resources**.

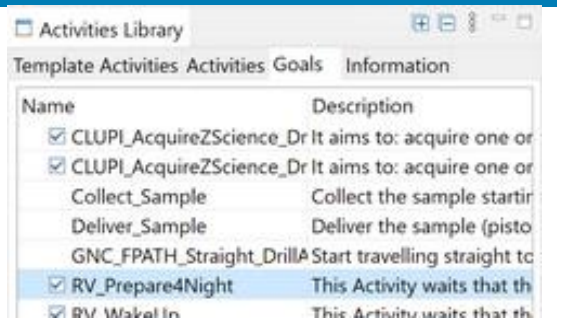
Space Use Case: Software Integration

- The AIPlan4EU framework has been integrated into the ExoMars ROCS – RVP component that is at the center of the Tactical Planning process

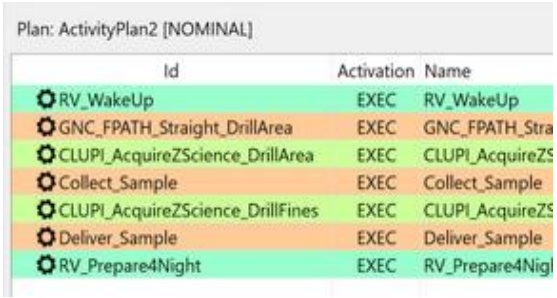


Space Use Case: Software Integration

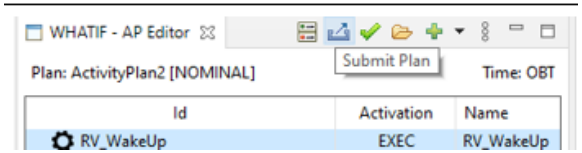
- The data model is enhanced to integrate the concept of the Goal; the available **Goals are included in the ATL** and visualized in the ‘Activities Library’ view



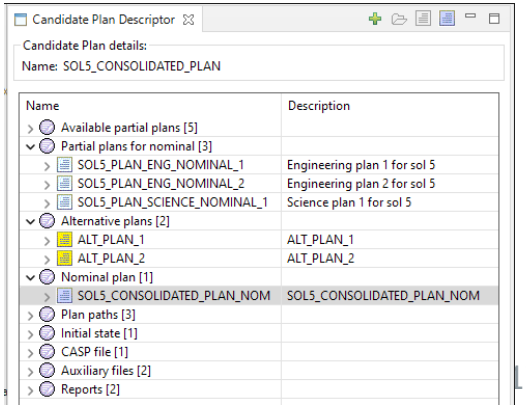
- **The ‘Activity Plans Editor’ view accepts as inputs user selected goals** and allows the operator to request the automatic generation of an Activity Plan. In case a valid Plan cannot be generated the UPF provides the reason in terms of Goals/States that cannot be reached



- The operator may also request by the UPF the **validation of user defined Activity Plans**; the provided feedback allows him to progressively construct a valid Plan

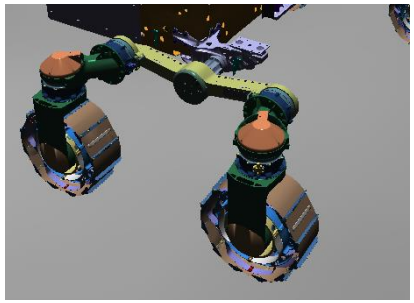


- The ‘Consolidated Plans’ view is also connected with the UPF allowing to **construct a complete plan** (Consolidated Activity Plans) from the set of the Partial Plans submitted by the science and engineering teams

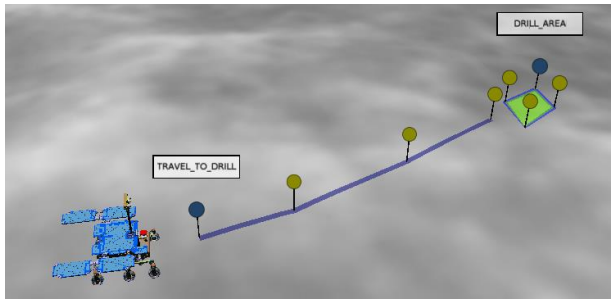


Benefits

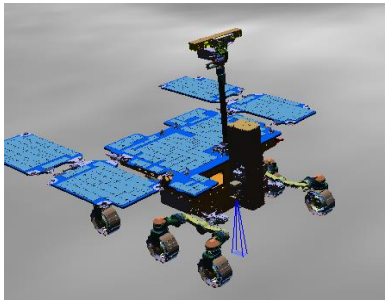
- Evaluation
  - The benefits of using automated planning in the Activities Planning Workflow has been evaluated and confirmed in the particular case of preparing the ExoMars nominal ‘sol 5’ operations for ‘subsurface sample collection



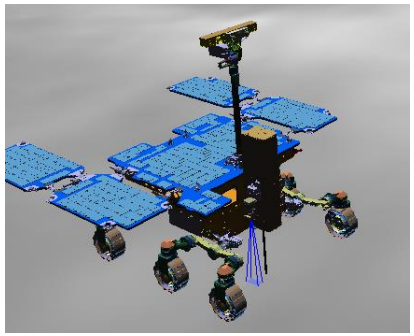
Rover configure for travel



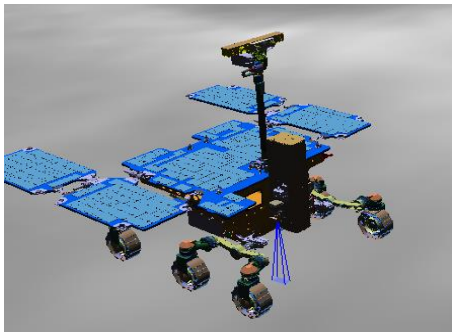
Travel to science of interest



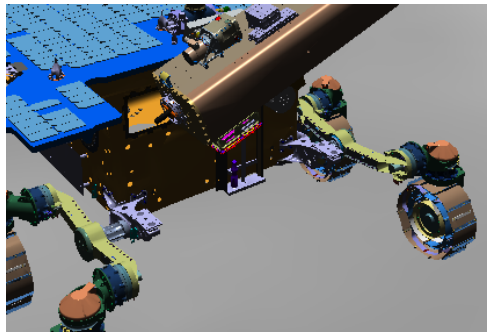
Science - reconfiguration



Drill – Sample collection



Science



Sample transfer

Conclusions

- We presented the AIPlan4EU European Horizon 2020 project
- Unified Planning: a single, easy-to-use access point to planning technology to model, manipulate, and solve different classes of planning problems with the support of a collection of planning engines
- Many ‘Technology Specific Bridges’ demonstrated the effectiveness of the approach in various domains
- In the Space domain, the UPF has been integrated into the ROCS – RVP component responsible for the operations tactical planning; the evaluation demonstrates the benefits on the minimization of the duration of the planning cycle
- The UPF has been used in ESA activities (ROBDT & VIVAS); the development continuous targeting optimized plans and it will be further demonstrated