Extending the autonomy envelope of space applications: a research path

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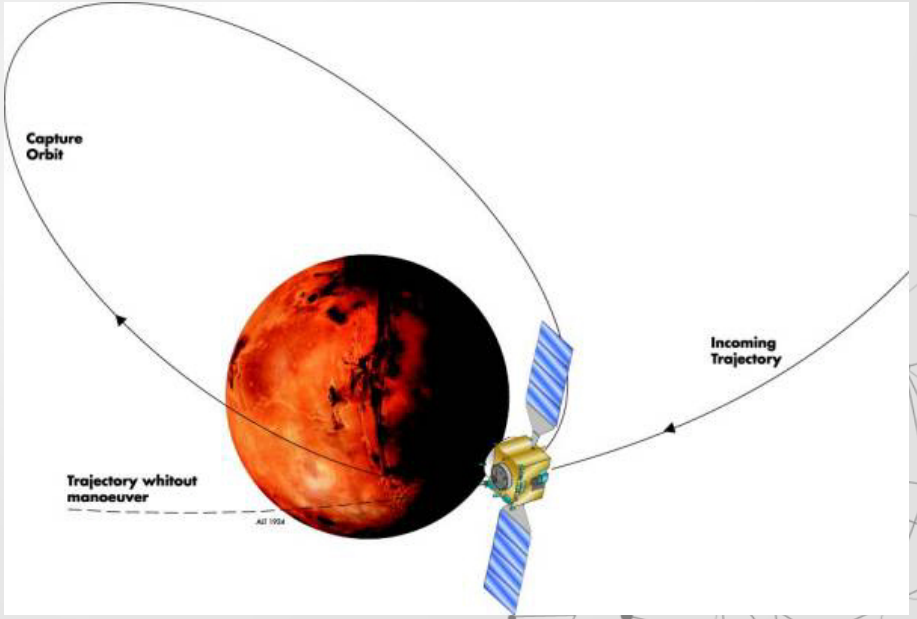
LEVELS OF AUTONOMY

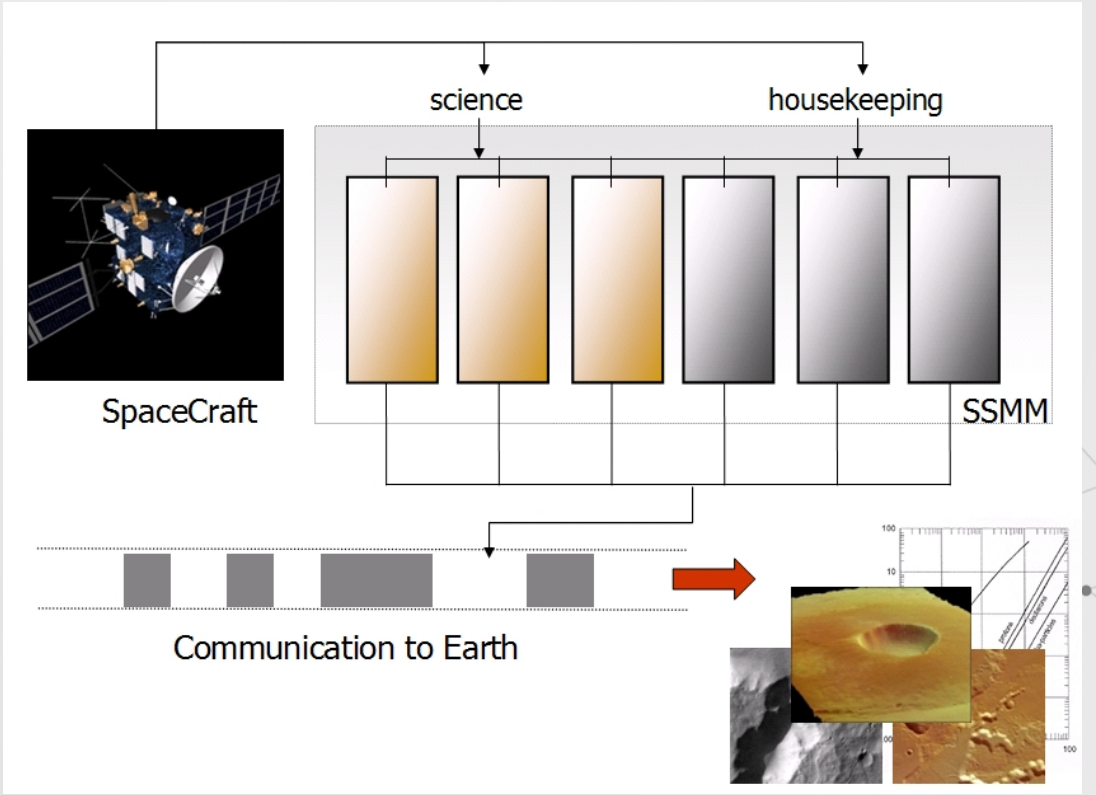
- Current levels of autonomy defined by European Cooperation for Space Standardization (ECSS) for Mission Nominal Operations Execution:
  - Level E1: tele-operation
  - Level E2: execution of pre-planned mission operations onboard, i.e. automatic operation
  - Level E3: automatic selection of pre-filled plans, i.e. semi-autonomy
  - Level E4: autonomous planning based on *exogenously provided goals*, and execution of the synthesized plans according to the **Sense-Plan-Act** paradigm, i.e. fully autonomous operation

Mars-Express Mission

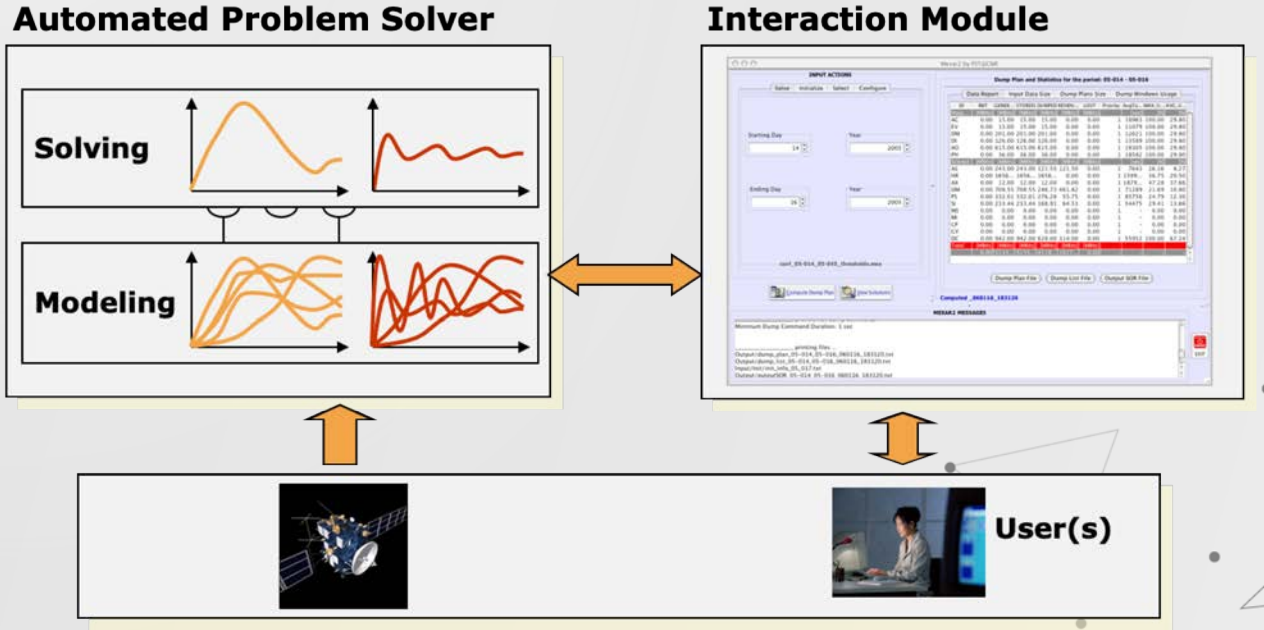
- Launched on June 2003
- The space probe is orbiting around Mars since January 2004 (very successful mission)
- Seven scientific payloads which collect data to study the Martian atmosphere and the planet's structure and geology
- 2-3 Gb of data generated on a daily basis



MEX: relevant subsystems



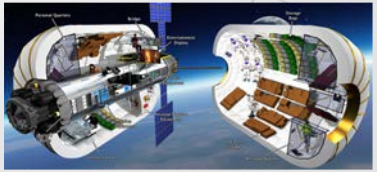
Mexar2*: Model-based interactive problem solving



(*) ESA Contract No. 4000112300/14/D/MRP "Mars Express Data Planning Tool MEXAR2 Maintenance"

Pushing forward the level of Autonomy

- Unknown and unstructured environments
- How can robot deal with uncertainty?
- How can autonomous robots acquire knowledge and skills to solve problems that are unforeseeable at design time?



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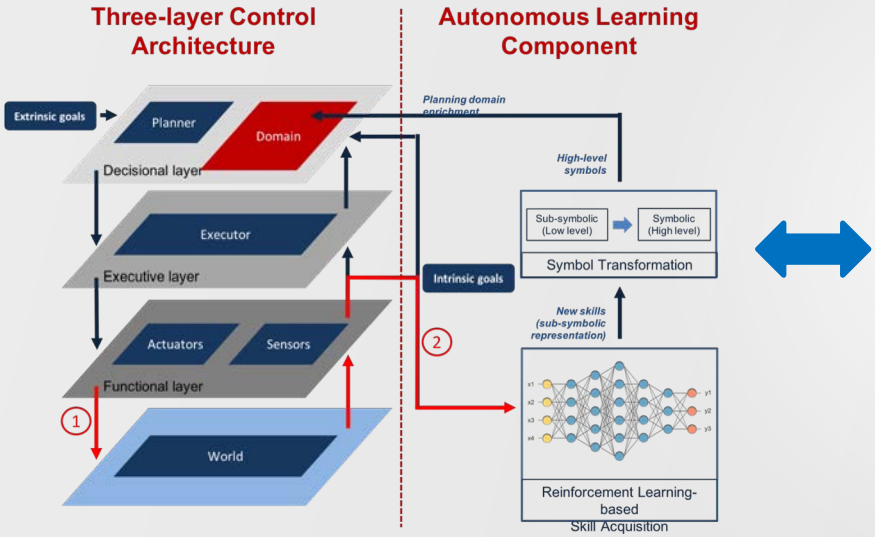
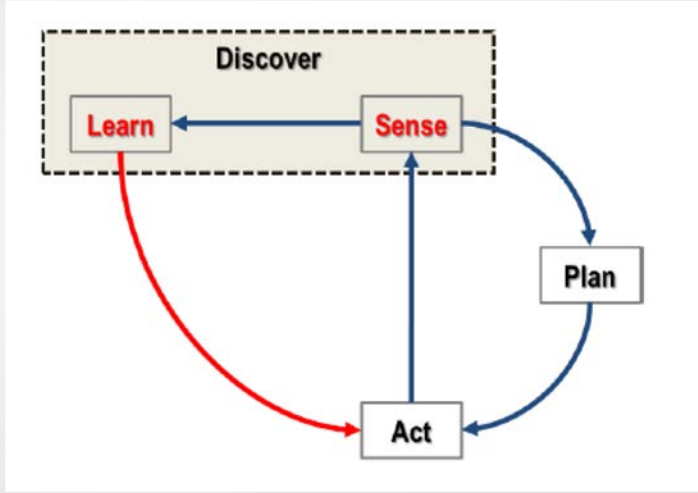
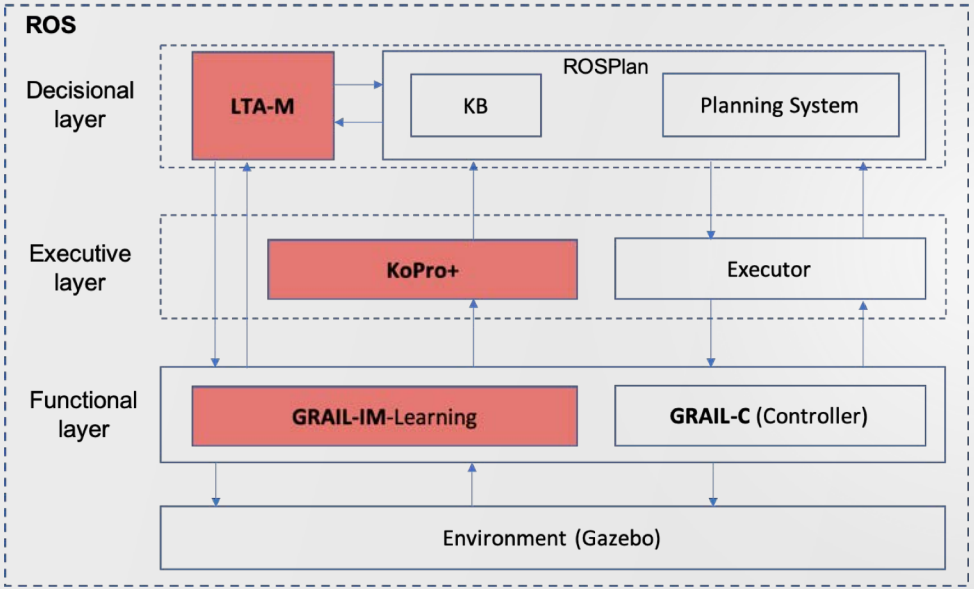
- **Pushing the envelope of autonomy one step farther**
  - "Level E5": self-generation of **goals** and autonomous learning of the skills necessary to achieve them: goals are autonomously generated, planned for, and executed to the aim of increasing the knowledge of the mission environment

From Sense-Plan-Act to Discover-Plan-Act





IMPACT* architecture



Main features implemented by IMPACT:

- Implementation of high-level policies to control the interleaving of all phases of the agent's life: reasoning, execution, learning;
- Automatic abstraction of the newly acquired skills from a sub-symbolic level to a high-level symbolic representation (e.g., Planning Domain Definition Language), and autonomous enrichment of the planning domain by adding symbolic knowledge on new states and operators;
- Autonomous learning of new skills based on self-generated goals driven by intrinsic motivations.

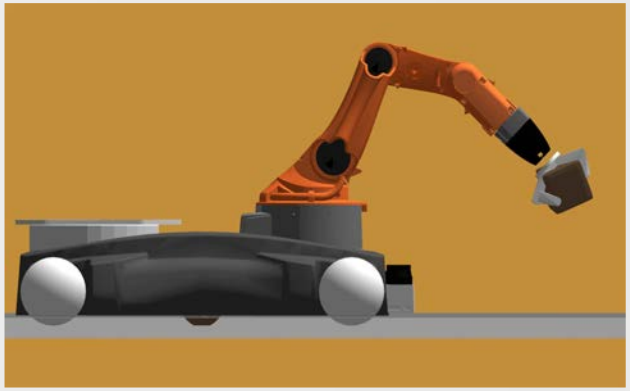
(*) A. Oddi, R. Rasconi, V.G. Santucci, G. Sartor, E. Cartoni, F. Mannella, G. Baldassarre. Integrating Open-Ended Learning in the Sense-Plan-Act Robot Control Paradigm", Proceedings of the 24th European Conference on Artificial Intelligence, ECAI 2020.

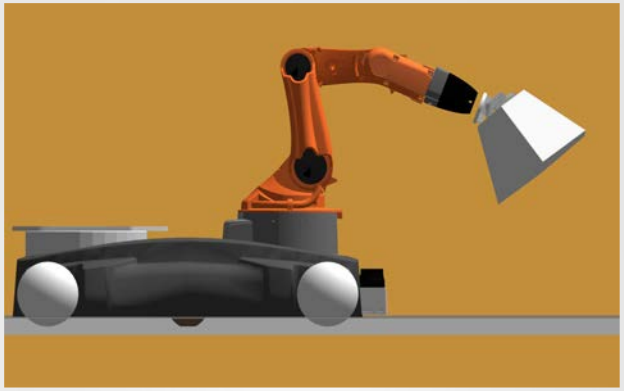
Long-Term Autonomy and Lifelong Learning agents

- In general Long Term Autonomy (LTA) is the ability of a robotic system to:
  - perform reliable operations for long periods of time under changing environmental conditions;
  - increase over time its knowledge about the environment.

- LTA module is intended to provide answers to the following questions:
  - When to calculate a new PDDL domain?
  - Which part of experience will you keep?
  - When should the system explore the environment?

Autonomous enrichment of high-level (PDDL) knowledge





- Learning to grasp a new object given previous knowledge and skills
- The system is endowed with a pre-programmed skill that can grasp a generic object in front of the rover
- The skill was designed to work with small objects (left). We want to demonstrate that the robot is autonomously able to recognize a new context (the big object, right), learn how to grasp it, and enrich its symbolic knowledge base accordingly.

Autonomous enrichment of high-level (PDDL) knowledge

Old cube-grasping operator

```
(:action opt_4
    :parameters ()
    :precondition (and (Symbol_0) (Symbol_7)
    (Symbol_9))
    :effect (and (Symbol_5) (not (Symbol_7)))
)
```

Symbol_0: Object in sight
Symbol_7: Object not grasped
Symbol_9: Object not stowed
Symbol_5: Object grasped

New autonomously synthesized operator

```
(:action opt_7
    :parameters ()
    :precondition (and (Symbol_0) (Symbol_10)
    (Symbol_7) (Symbol_9))
    :effect (and (Symbol_5) (not (Symbol_7)))
)
```

Symbol_0: Object in sight
Symbol_7: Object not grasped
Symbol_9: Object not stowed
Symbol_5: Object grasped

Symbol_10: Object is VASE

Conclusions

- Sense-Plan-Act is one of the core ideas to realize autonomous systems
- The integration of planning and learning is a promising approach experienced during the IMPACT* project to increase the level of autonomy for an intelligent controller
- **Challenge**: Long-Term Autonomy strategies based on the integration of symbolic planning and open-ended learning to foster new symbolic knowledge acquisition based on previously learned high-level models (bootstrap learning).

(*) Project: IMPACT - Intrinsically Motivated Planning Architecture for Curiosity-driven roboTs. Funded by the European Space Agency (ESA), ESA Innovation Triangle Initiative (ITI) 2017, contract N. 4000124068/18/NL/CRS. Contact: Angelo Oddi (angelo.oddi@istc.cnr.it)

THANKS

Does anyone have any questions?

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