Autonomous Control architectures

Dra. Mª Dolores Rodríguez Moreno

Universidad de Alcalá ISG

Objectives

Specific Objectives

- What is an autonomous control architecture (ACC)
- To know main ACC

Source

- Stuart Russell & Peter Norvig (2009). Artificial Intelligence: A Modern Approach. (3rd Edition). Ed. Pearsons
- Dana Nau's slides for Automated Planning. Licensed under License https://creativecommons.org/licenses/by-nc-sa/2.0/
- M. D. R-Moreno and James Kurien. What is next in Autonomous Control Techniques? ISAIRAS'08.

Outline

- **Introduction**
- Definition
- Classification
- Conclusions

Introduction (I)

- Robots without Planning Capabilities
  - Requires hand-coding the environment model and the robot's skills and strategies into a reactive controller
  - The hand-coding needs to be inexpensive and reliable enough for the application at hand
  - Well-structured, stable environment
  - Robot's tasks are restricted in scope and diversity
  - Only a limited human-robot interaction
- Developing the reactive controller
  - Devices to memorize motion of a pantomime
  - Graphical programming interfaces

Introduction (II)

- Robots with Planning Capabilities
  - Online input from sensors and communication channels
  - Heterogeneous partial models of the environment and of the robot
  - Noisy and partial knowledge of the state from information acquired through sensors and communication channels
  - Direct integration of planning with acting, sensing, and learning

Introduction: Types of Planning

- Domain-independent planning is not widely used in robotics
  - Classical planning framework too restrictive
- Instead, several specialized types of planning
  - Path and motion planning
    - Computational geometry and probabilistic algorithms
    - Mature; deployed in areas such as CAD and computer animation
  - Perception planning
    - Younger, much more open area
  - Navigation planning
  - Manipulation planning

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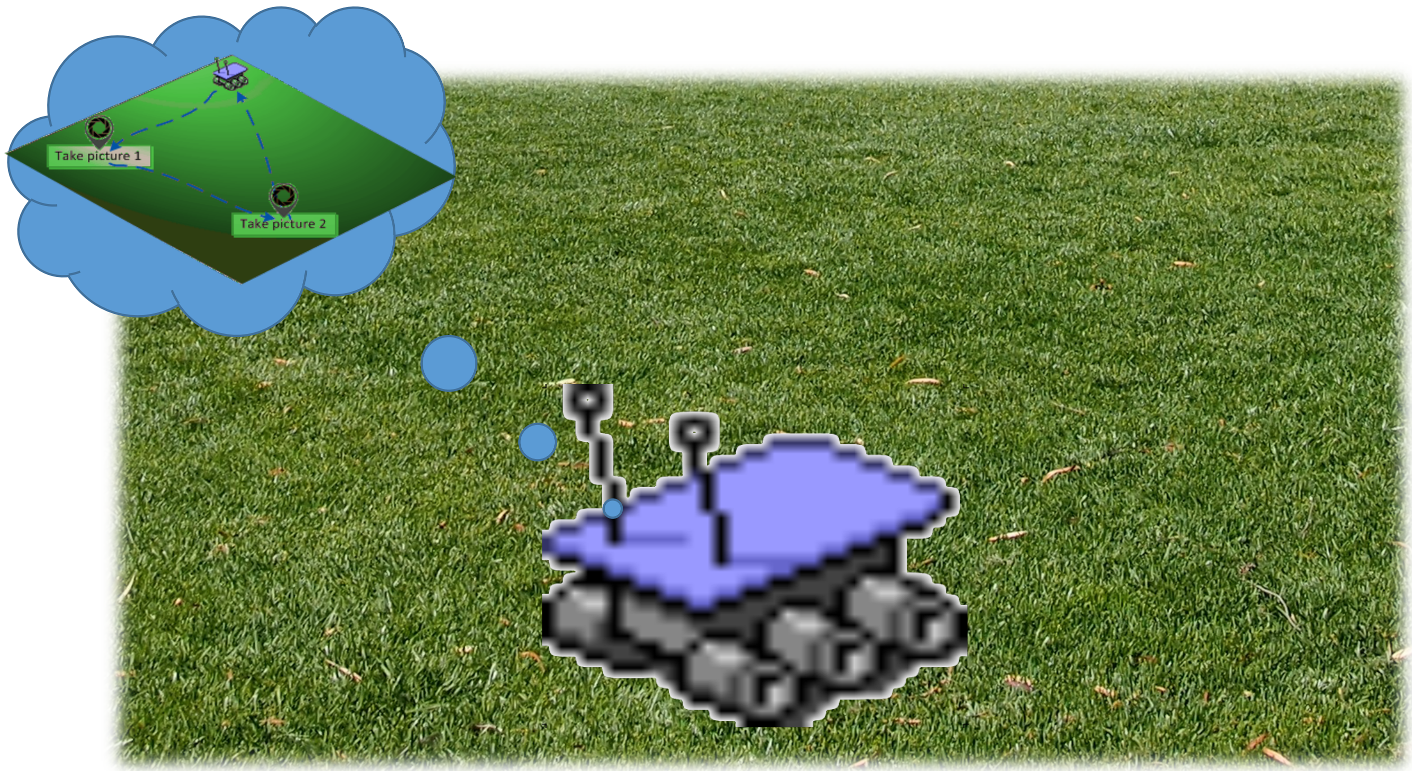
Definition (I)

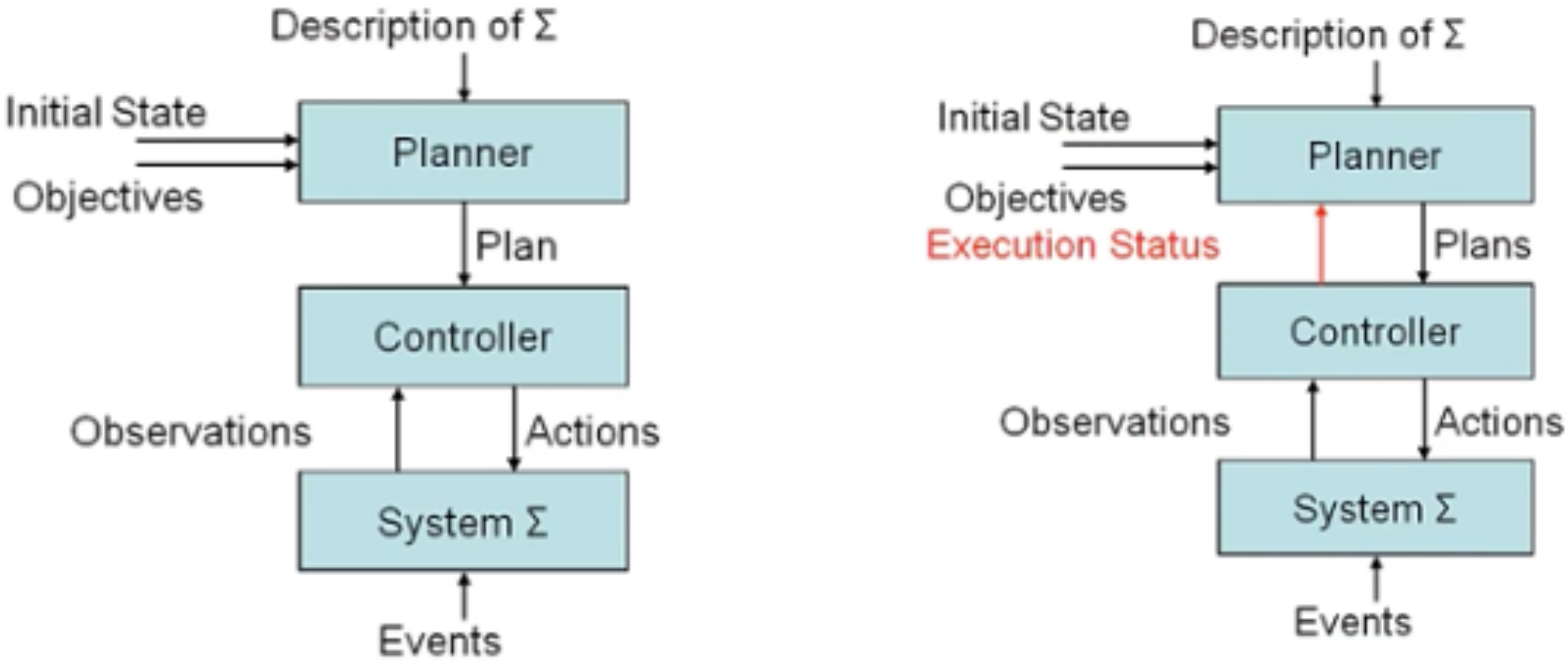
- Autonomous control architectures use models:
  - To reason about the system that control
  - The environment where they act
- They achieve a set of extended goals over a period of time, and are able to reason about faults with little or no human
- Given the initial state and external goals: they generate a set of actions
- If an action is not executed as expected: "recover"

Definition (II)



ToDo Example

- What is needed to build an Autonomous Architecture?
- Can you design using blocks the different elements?
  - Inputs
  - Outputs
  - Think in abstract
  - Then use several example to see if fits your design
  - See how can you integrate the explanation of the TEDEx video for robots


Description of Σ
Initial State
Objectives
Planner
Plan
Controller
Observations
Actions
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Description of Σ
Initial State
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Source

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- **Classification**
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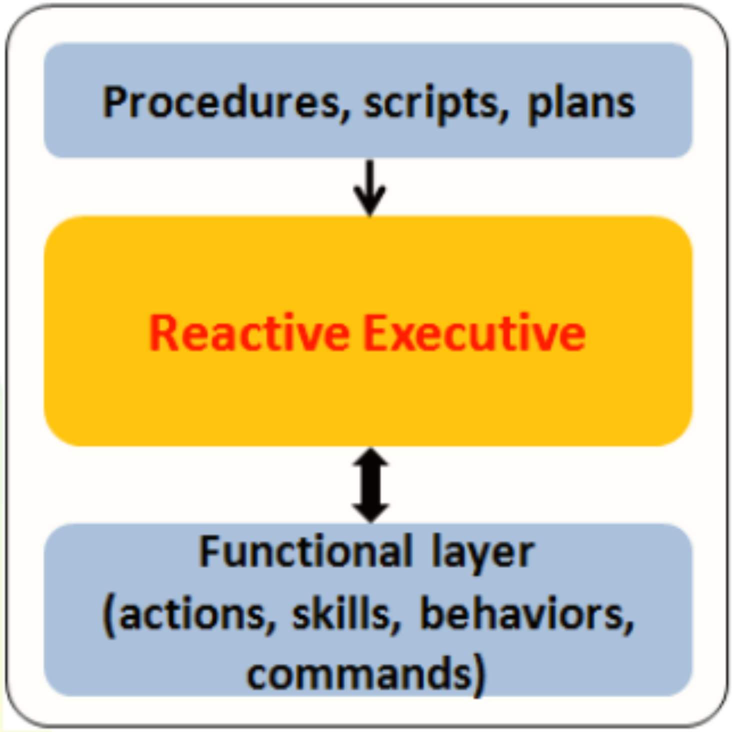
Classification

- Attending to the "reactivity/deliberativeness" of the system, the main architectural approaches are:
  - Reactive, procedural approach (non-deliberative)
    - Purely reactive controllers
    - Symbolic reactive controllers
  - Hybrid approach
    - Three-tiered controllers
    - Model-based, planning centric methods

Reactive (non-deliberative)

- Purely reactive controllers: motor action as response to the collected data by sensors without reasoning about them (no internal state is contained)
- Symbolic reactive controllers: an intermediate "decision-making" step that infers an action output from the sensor input and a symbolic representation is introduced (based on behaviours)
- Suitable when:
  - Real world cannot be accurately modeled
  - Uncertainty is quite delimited
  - Real-time warranty is a safety-critical concern

Reactive (non-deliberative)



Reactive (non-deliberative)

- Examples:
  - Subsumption architecture [Brooks, R.A., 1986]
    - System decomposed into concurrent (hierarchically arranged) behaviors: higher layers represent more abstract behaviors, and have lower priorities than the lowers
    - Behavior: sense-act function which maps perceptual inputs to actions
  - Agent Network Architecture (ANA) [Maes, P., 1991]
    - Similar system decomposition
    - Behaviors modules defined by their pre-conditions and post-conditions (interfaces), and by a (dynamic-valued) activation level

Classification

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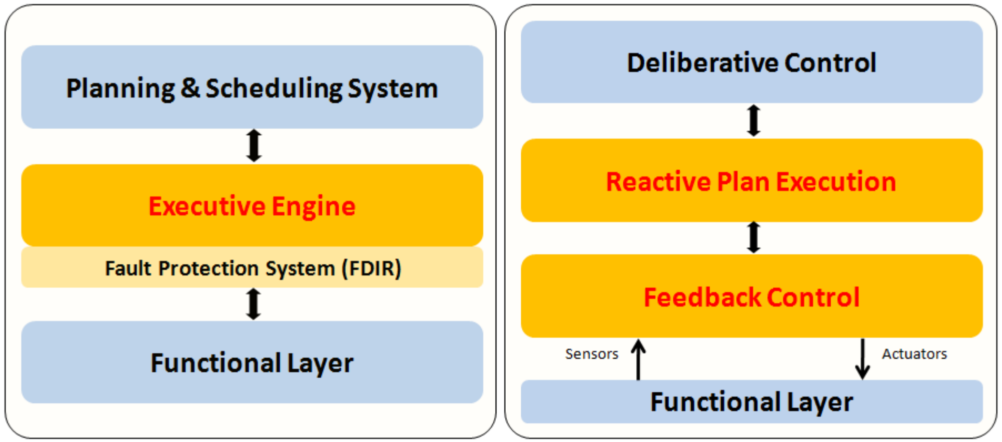
  - **Hybrid approach**
    - **Three-tiered controllers**
    - Model-based, planning centric methods

Three-tiered controllers

- Interleave a planning step using a model of the world
- Implement Sense-Plan-Act cycle
- Limitations:
  - Monolithic planning cycle
  - Slow reactivity when deliberation is needed
  - Hard scalability and robustness decreasing



Three-tiered controllers: examples

- 3T [Bonasso et al., 1997]
  - 3 layers

- Tripodal Control Architecture [Kim, G. and Chung, W., 2006]
  - Consist of a deliberative, a sequencing and a reactive layer.
  - The deliberative layer is the interface with the user and with the planning process execution

- ATLANTIS [Gat, E., 1992]
  - Consists of a reactive controller, a sequencer and a deliberator
  - Includes monitor capabilities to re-planning/plan-repairing

Classification

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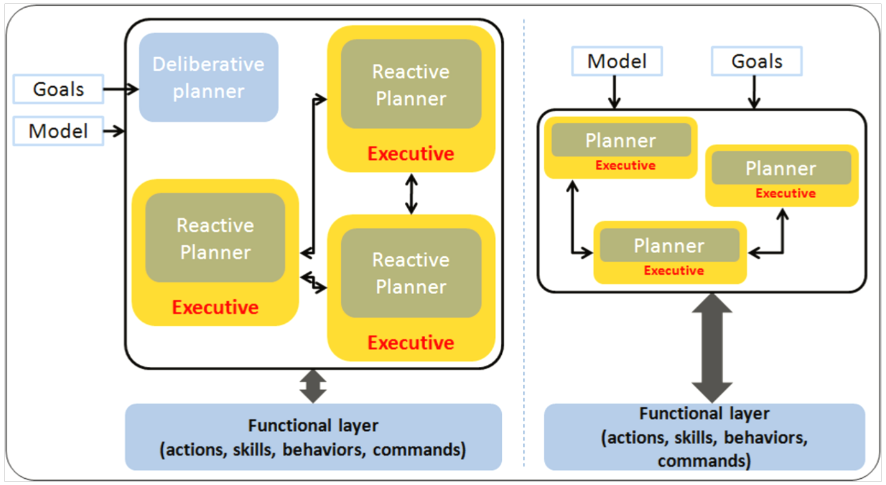
    - **Model-based, planning centric methods**

Model-based, planning centric methods

- Exploits automated planning and model-based reasoning at the core
- Divide-and-conquer scheme: system functionality is distributed
- Theoretically meets:
  - The efficiency/robustness of the reactive controllers
  - The high-level reasoning capabilities of the (purely) model-based approach

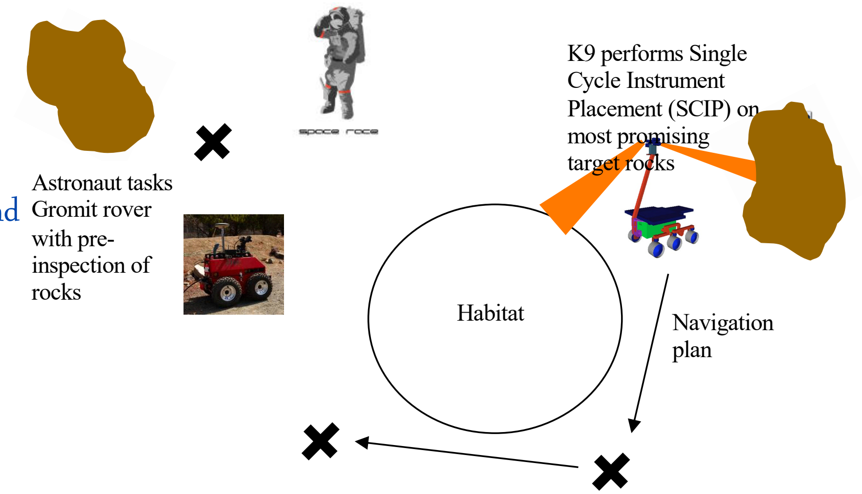


Model-based, planning centric methods: IDEA

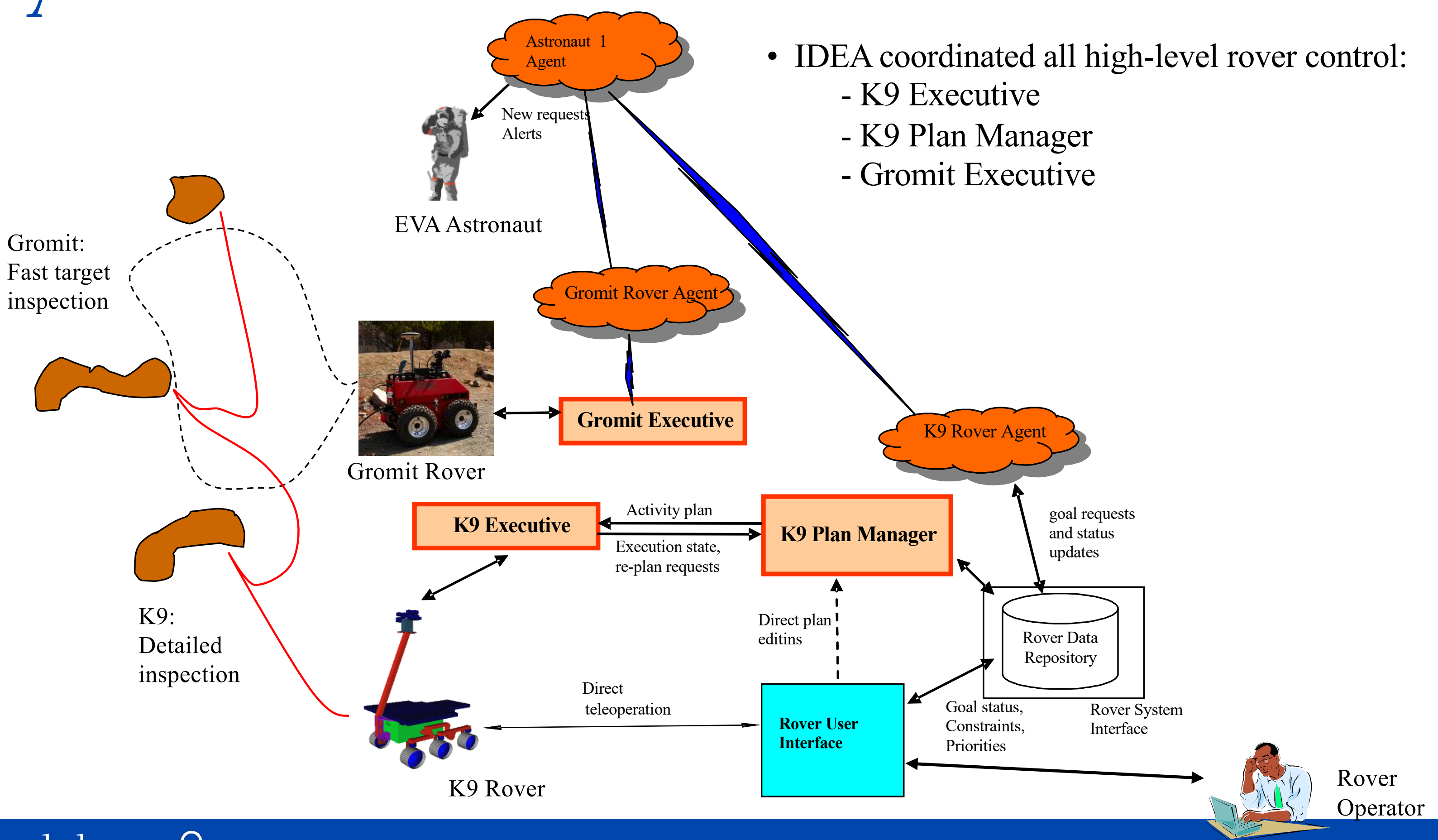
- IDEA is an architecture that enables high-level control by tightly integrating planning and execution
- Interleaved planning and execution
  - AI planning and scheduling is the core reasoning approach for execution
  - Planning over different horizons enables deliberation and reaction in a single framework
- Model-based control
  - Declarative models define system behavior and interactions with other systems
  - Models restrict plan search to legal behavior

Collaborative Decision Systems (CDS)

- Human-robot collaboration for planetary surface operations
  - Gromit rover (rock pre-inspection)
  - K9 Rover (detailed science sampling)
  - EVA astronaut (directing geology)
  - RoverOperator (oversees rover ops)
- Project Goals:
  - Demonstrate coordinated human-robot surface operations near human habitat
  - Coordinated field geology
  - Tightly integrate and test existing technologies
- IDEA K9 Exec and PlanManager
  - PlanManager: turns goal requests from RoverOperator into plans for K9
  - K9 Exec: using plans, oversees mobility, target tracking, instrument placement and measurements
- IDEA Gromit Exec
  - Coordinated mobility and panoramic image taking
- Results Synopsis
  - Successful demonstration of coordinated operations
  - IDEA greatly eased system integration



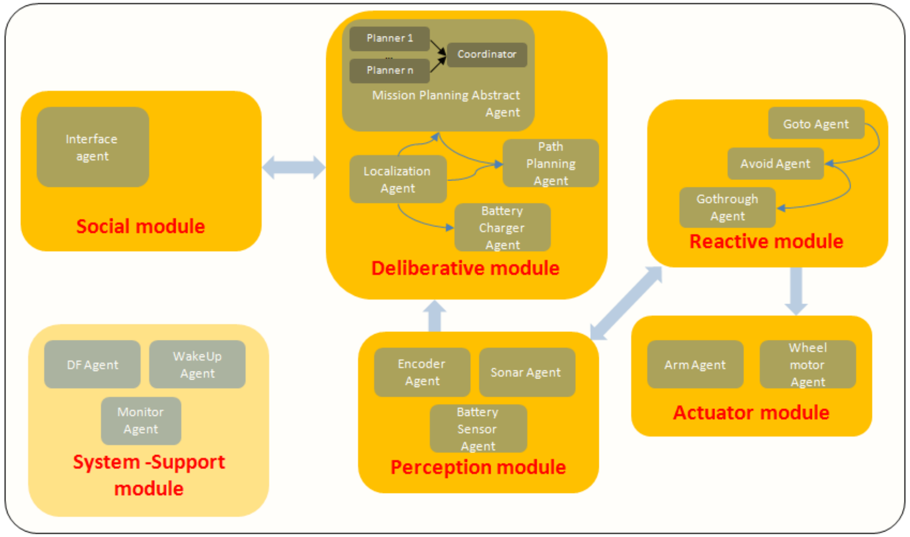
CDS System Architecture



- IDEA coordinated all high-level rover control:
  - K9 Executive
  - K9 Plan Manager
  - Gromit Executive

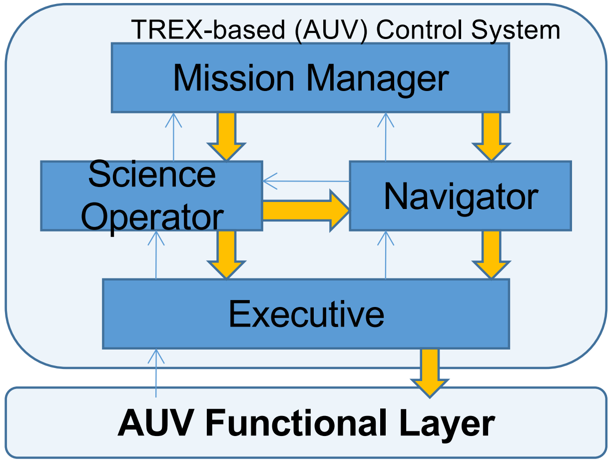
Model-based, planning centric methods: examples (I)

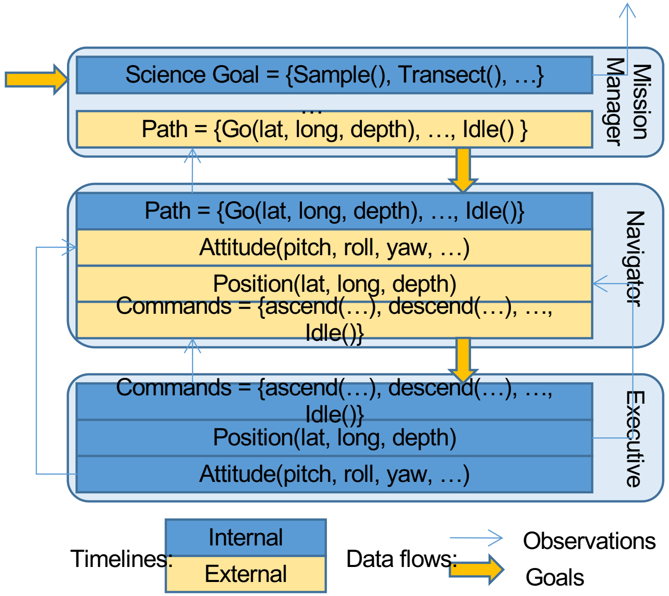
- ARMADiCo [Innocenti, B., 2008]
  - Multi-agent and general purpose architecture for mobile robots
  - Distributed communication scheme which allows agents compete for the available resources



Model-based, planning centric methods: examples (II)

- TREX [McGann, C. et al., 2008]
  - Combines goal- and event-driven behavior in a framework based on temporal reasoning & planning
  - Developed for Autonomous Underwater Vehicles





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Conclusions

- A system is autonomous if it is able to achieve their goals with little or no human supervision
- Traditional systems are based on 3T-arquitectures
- New approaches distribute the systems between different controllers

Conclusions

- Where can we apply AI in robotic systems?
  - Navigation and Path Planning (depends on the mission)
  - Planning/Scheduling and Intelligent Execution
  - Command sequence generation
  - Data processing and validation
  - Vision

Conclusions

- What is the desired autonomy level?

Level	**Description**	**Functions**
E1	Mission execution under ground control; limited onboard capability for safety issues	Real-time control for nominal operations. Execution of time-tagged commands for safety issues
E2	Execution of pre-planned, ground-defined, mission operations onboard	Capability to store time-based commands in an on-board scheduler
E3	Execution of adaptive mission operations onboard	Event-based autonomous operations. Execution of on-board operations control procedures
E4	Execution of goal-oriented mission operations onboard	Goal-oriented mission re-planning