Universidad de Alcalá

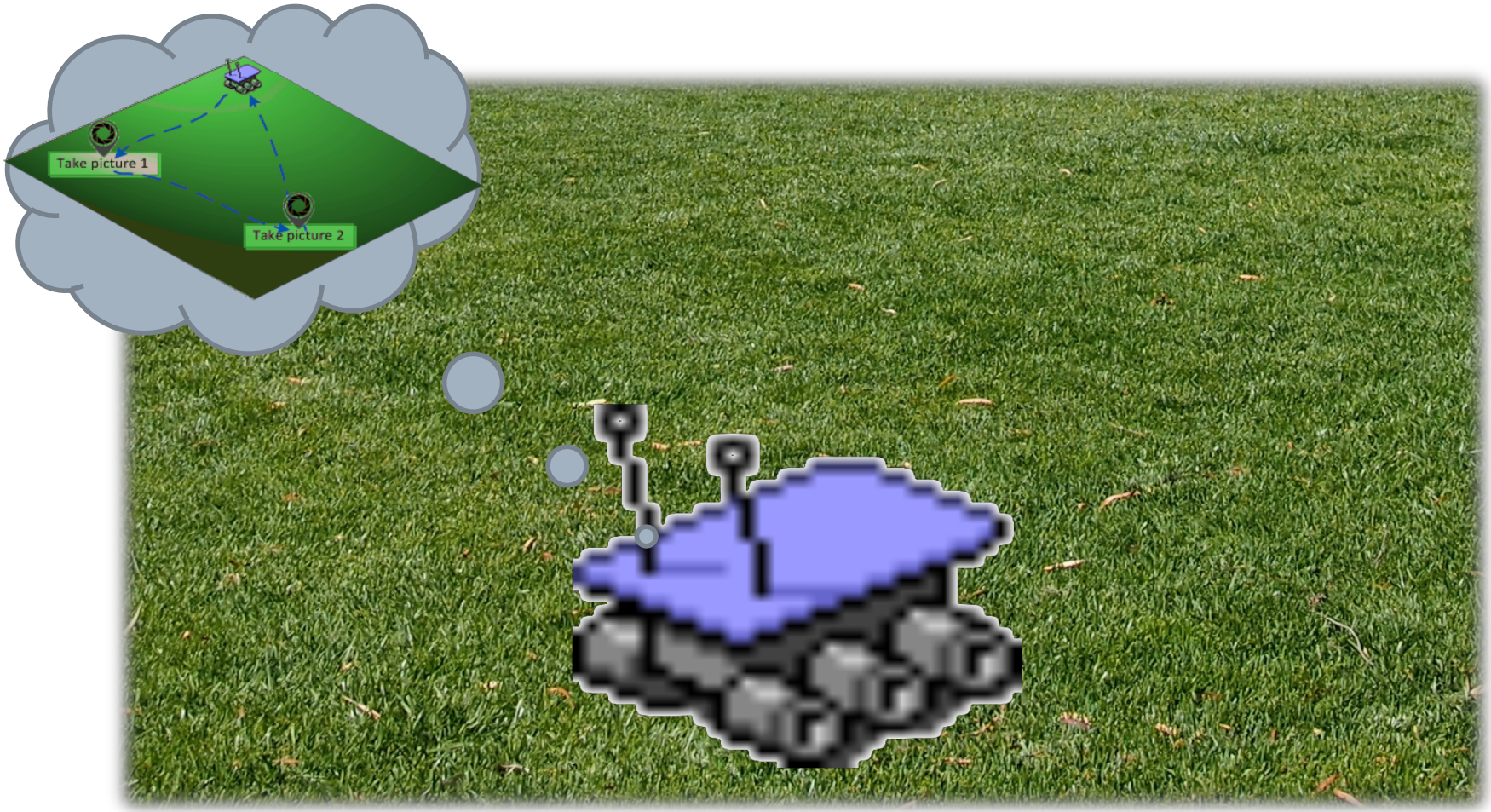
Autonomous Control Architectures

ISG
Intelligent Systems Group

Outline

- **Introduction**
- Autonomous Control Architecture
- Conclusions

Introduction



Introduction

- 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”

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- **Autonomous architectures**
- Conclusions

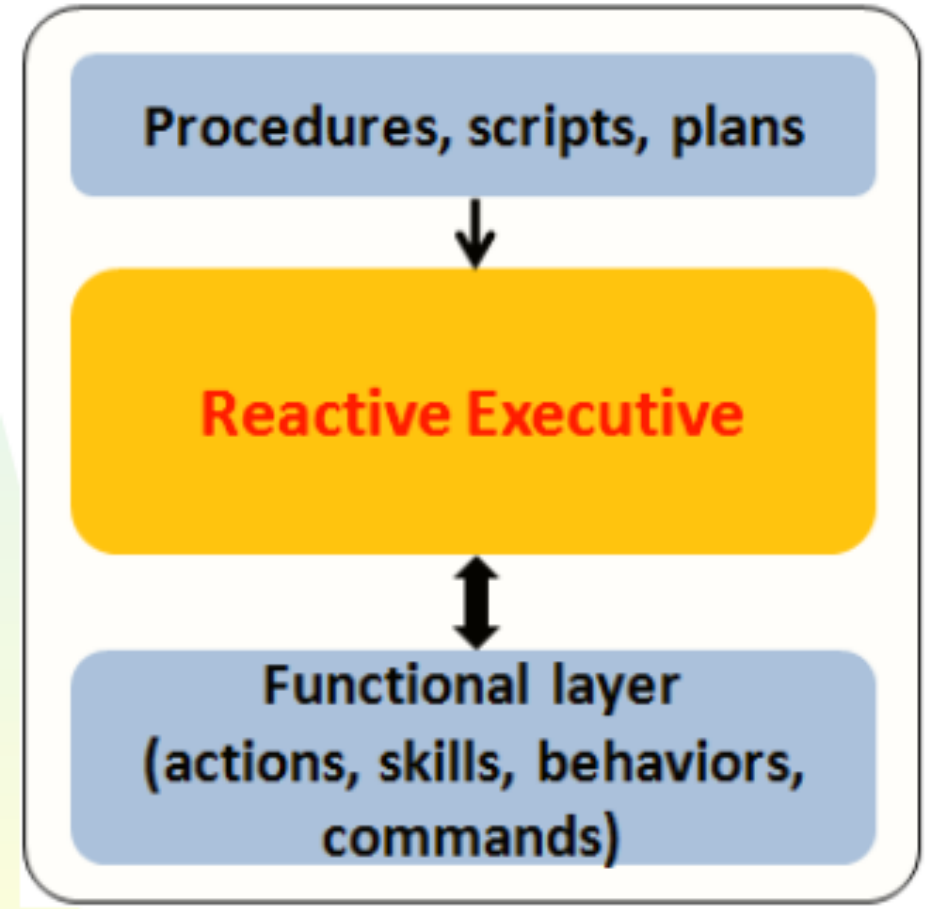
Classification

- 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)

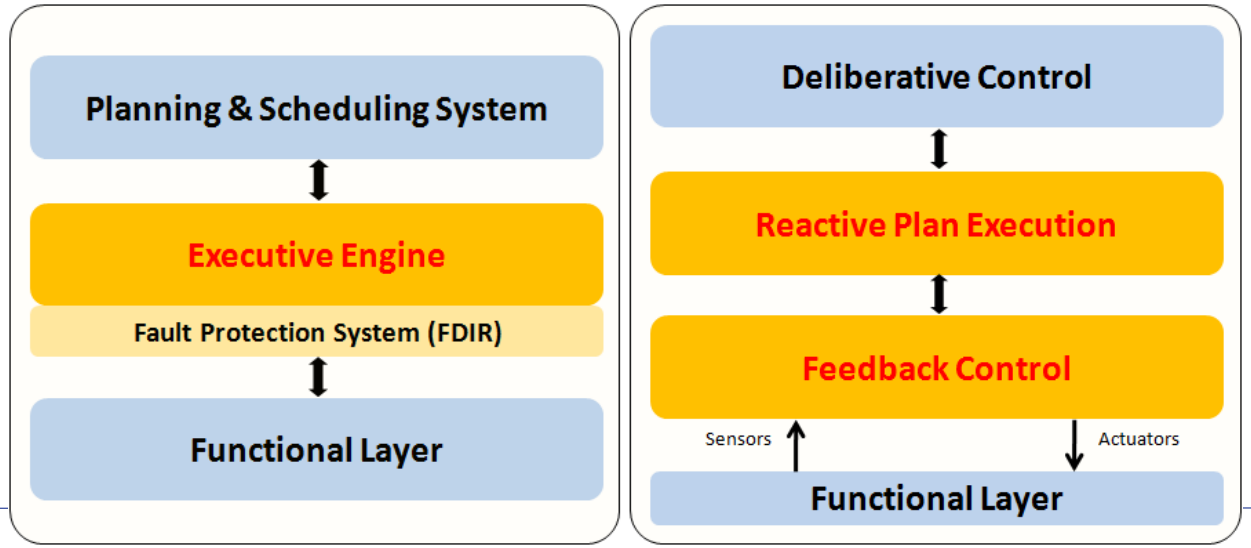


Reactive (non-deliberative)

- 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

Three layer architectures (hybrid)

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

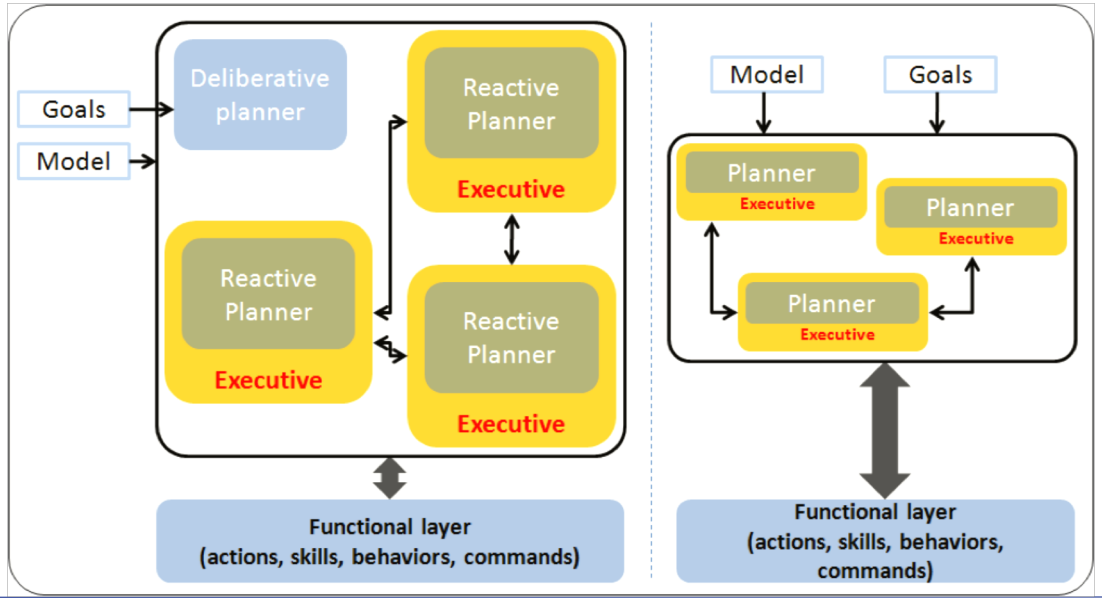


Three layer architectures (hybrid)

- 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

Model-based, planning centric methods (hybrid)

- 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 (hybrid)

- Why aren't simple execution systems enough?
  - Controllers are developed *ad hoc* for each application
  - Control rules are implicit, hard-coded and distributed throughout software
  - Scripted execution is too brittle to operate in unpredictable domains
  - Explicitly representing the full set of contingencies is intractable
  - Rule representation language and semantics are often different between planning systems and execution systems
  - Integrating multiple high-level controllers is too difficult
- IDEA is an architecture that enables high-level control by tightly integrating planning and execution

IDEA Approach

- 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

IDEA Approach

- Common framework
  - Identical core control and communications architecture over all IDEA controllers
  - Each application defines system models and communications interfaces
  - Common infrastructure simplifies integration of multiple controllers

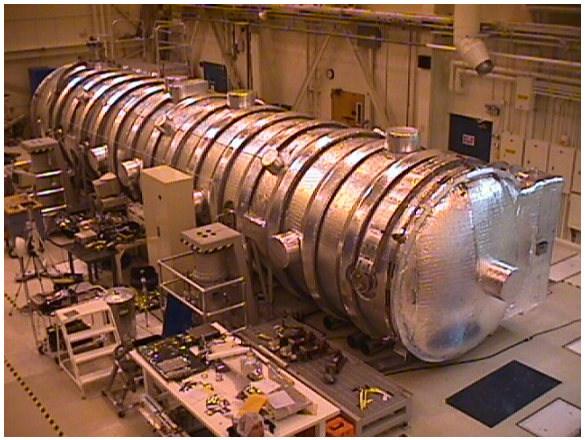
Unified Planning and Execution

- Planning and execution rules defined and enforced by a single model
- Planning and execution processes access a common database
- No hardcoded behaviors buried in code
- Advantage:
  - Removes inconsistencies associated with hard-coded controllers and separate planning and execution systems

Experimental Systems

Personal Satellite Assistant (ARC)

Collaborative Decision Systems (ARC)



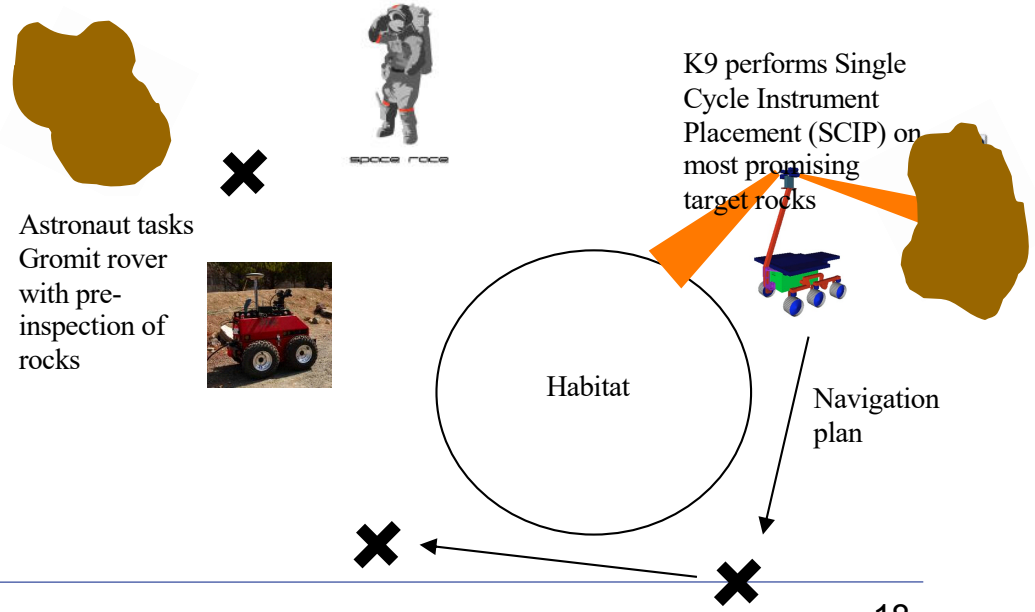
MAM Interferometry Testbed (JPL)

DARPA HURT (Honeywell/ARC)

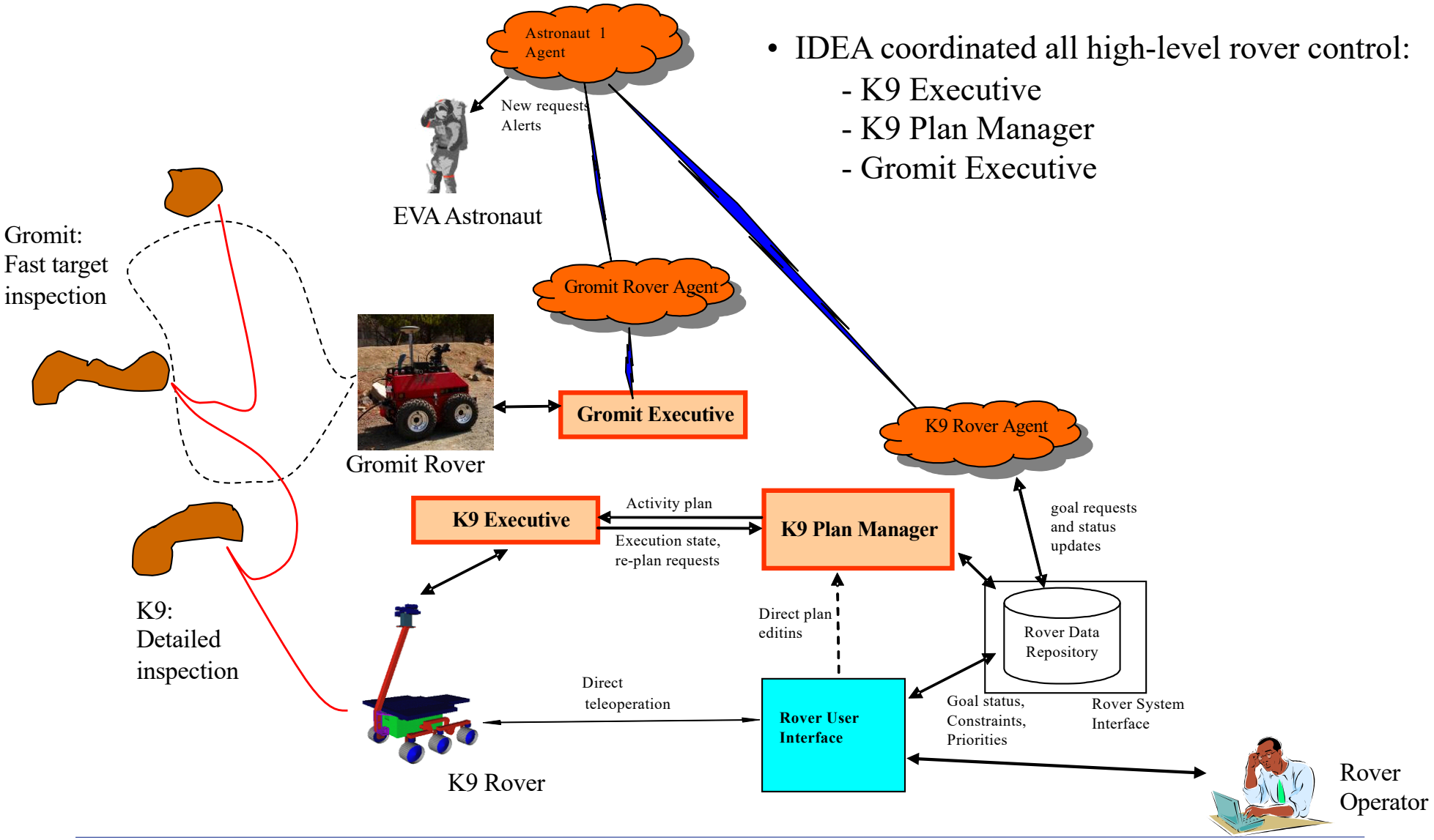
Life in the Atacama (CMU/ARC)

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



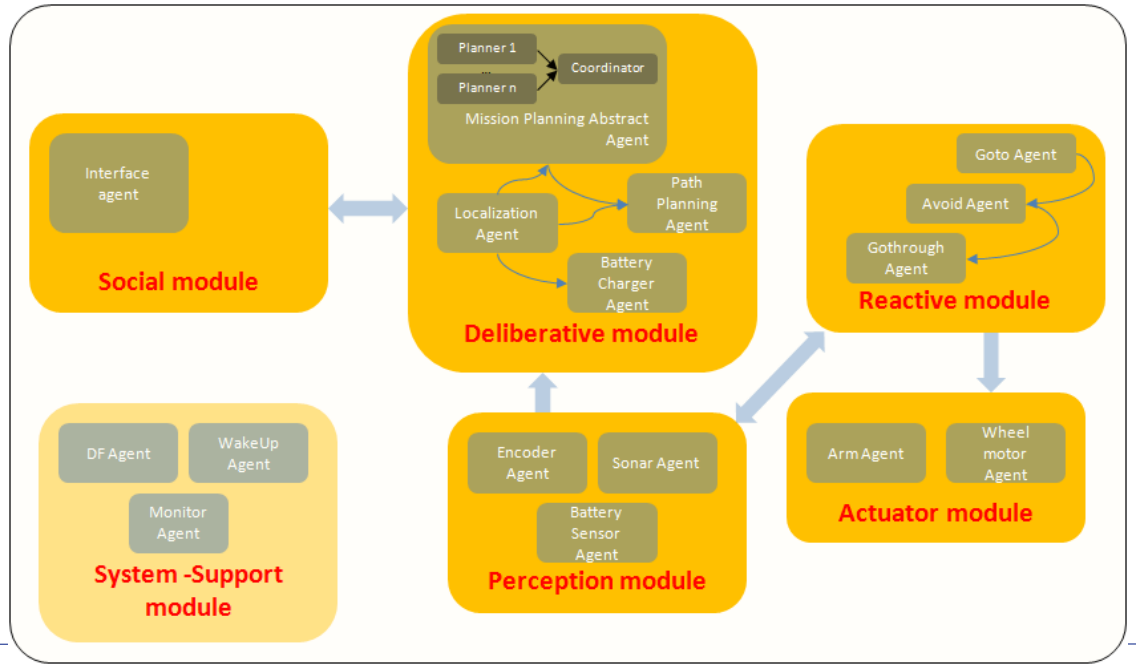
CDS System Architecture



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

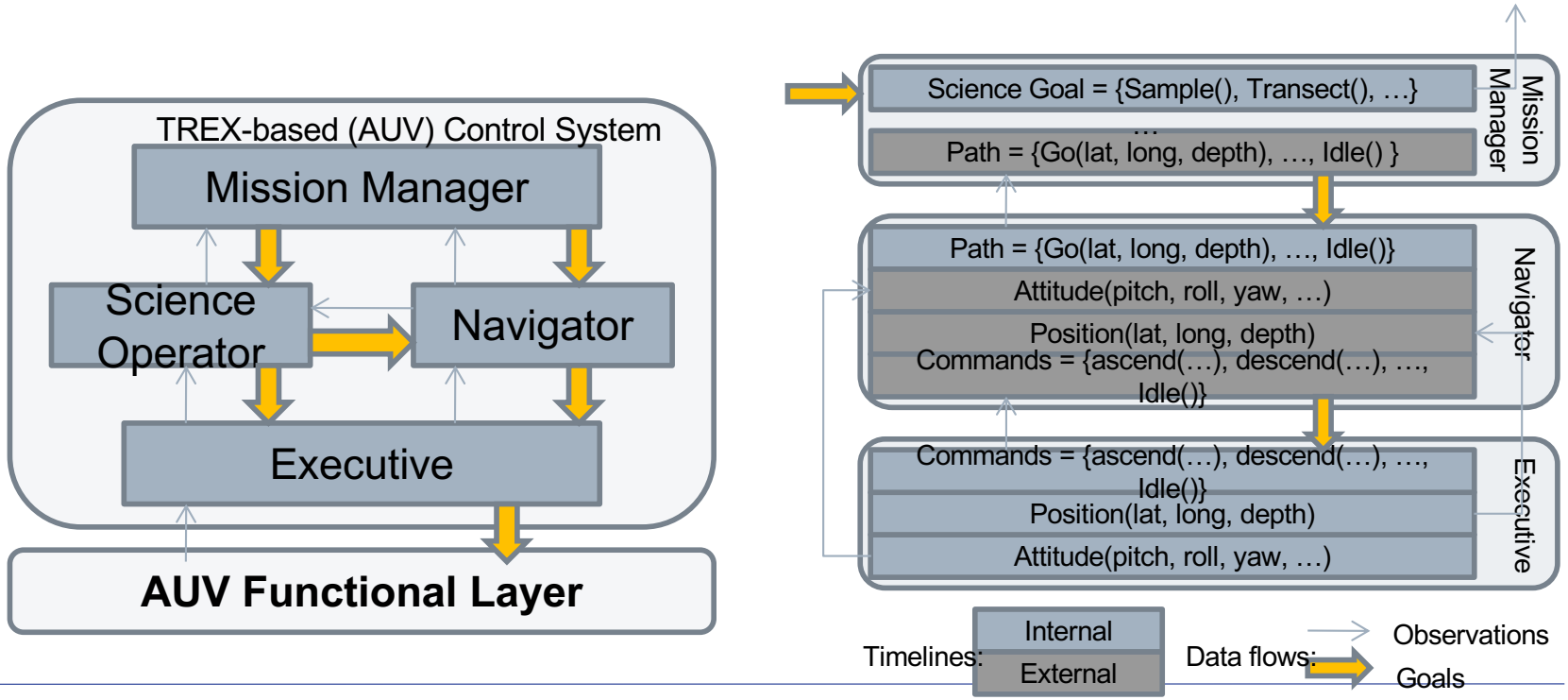
Model-based, planning centric methods (hybrid)

- Examples
  - 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 (hybrid)

- Examples
  - 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

- 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

Conclusions

- Is the scope the same in Planetary Exploration and Orbit?
  - In Orbitary missions (Earth or Space Observations) are different from Planetary Exploration
  - Why? Surface on the planets present special challenges for autonomous robots
  - The robot must navigate in these environments avoiding obstacles where it can collide or fall in a hole

Conclusions

- Where can we apply AI in robotic systems?

  - Diagnosis and reconfiguration
  - Navigation and Path Planning (depends on the mission)
  - Planning/Scheduling and Intelligent Execution
  - Command sequence generation
  - Data processing and validation
  - Vision

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 controller