Acting is the Purpose of Planning

or

The Actor's view of Deliberation

Malik Ghallab

LAAS-CNRS

Rome, June 2013

A change of focus

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- Not a novel research path

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- Focus Automated Planning research on the ***actor's perspective***

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    A Survey on Deliberation Functions for Autonomous Robots

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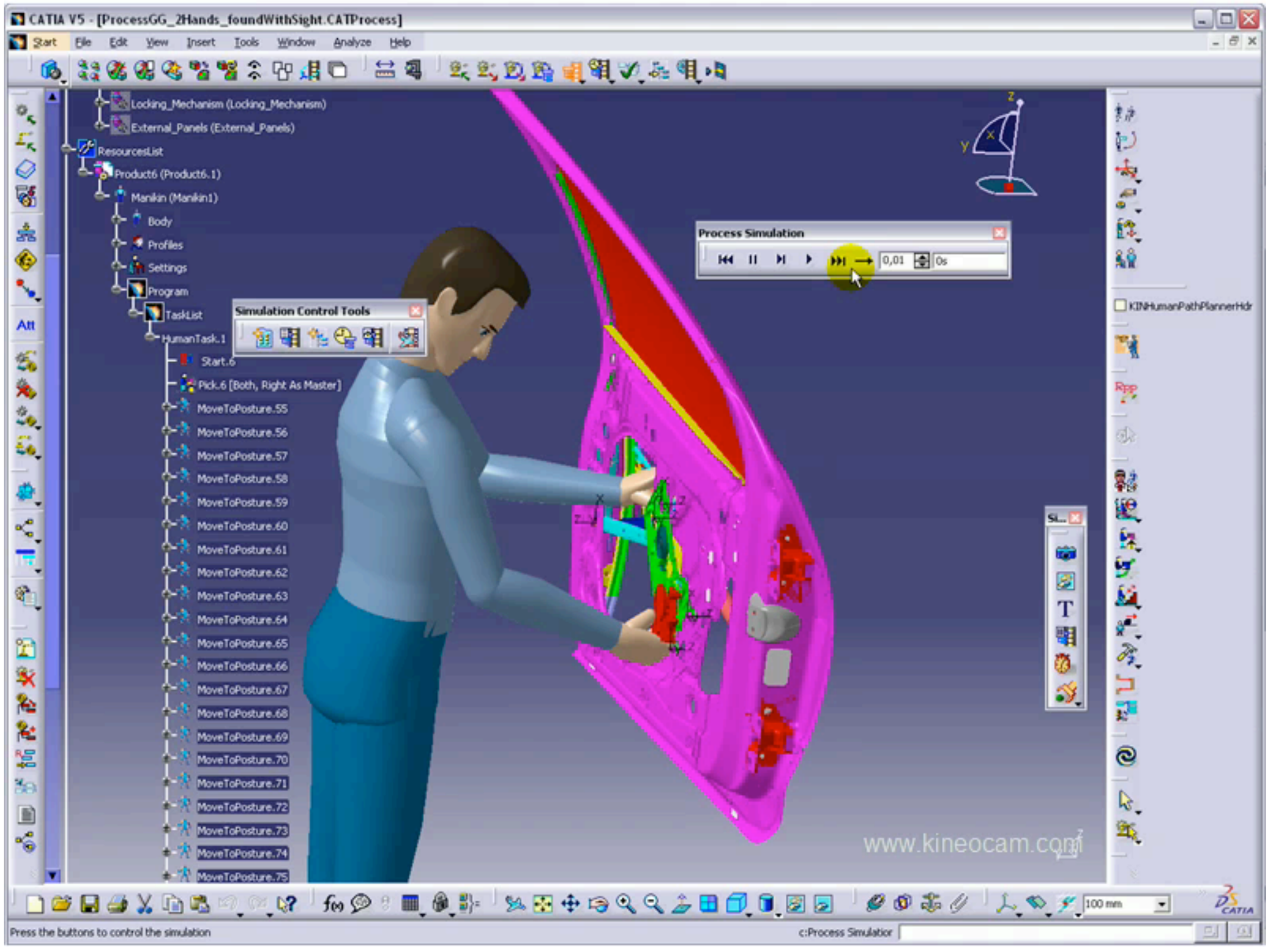
    A Survey on Deliberation Functions for Autonomous Robots
  - Collaboration with Dana Nau and Paolo Traverso

    A Position Paper on Automated Planning and Acting

Premises

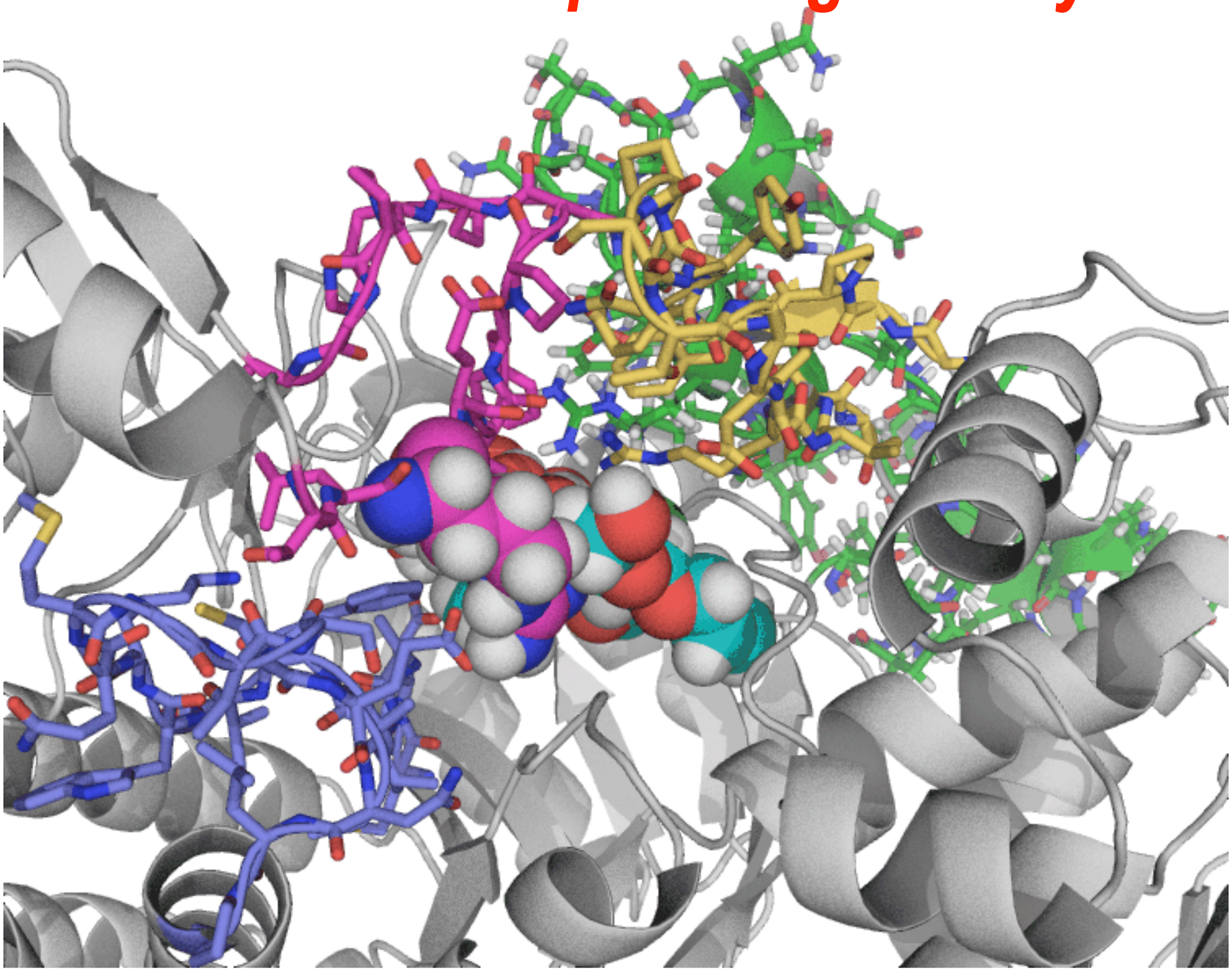
- Planning is a deliberation function
- Main purpose of planning is acting
  - Planning is valuable for other uses than acting
    - *Design* of tools, assembly, molecules permitting actions
    - Video games

Motion planning in car design



[Kineo]

Motion planning in enzyme design



[J.Cortes, LAAS]

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  Deliberate action:
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- Automated Planning research *does not*

  focus on actual challenges of deliberate action

Critical view of current main stream

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- Automated Planning literature

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  - Numerous "*Planners*"

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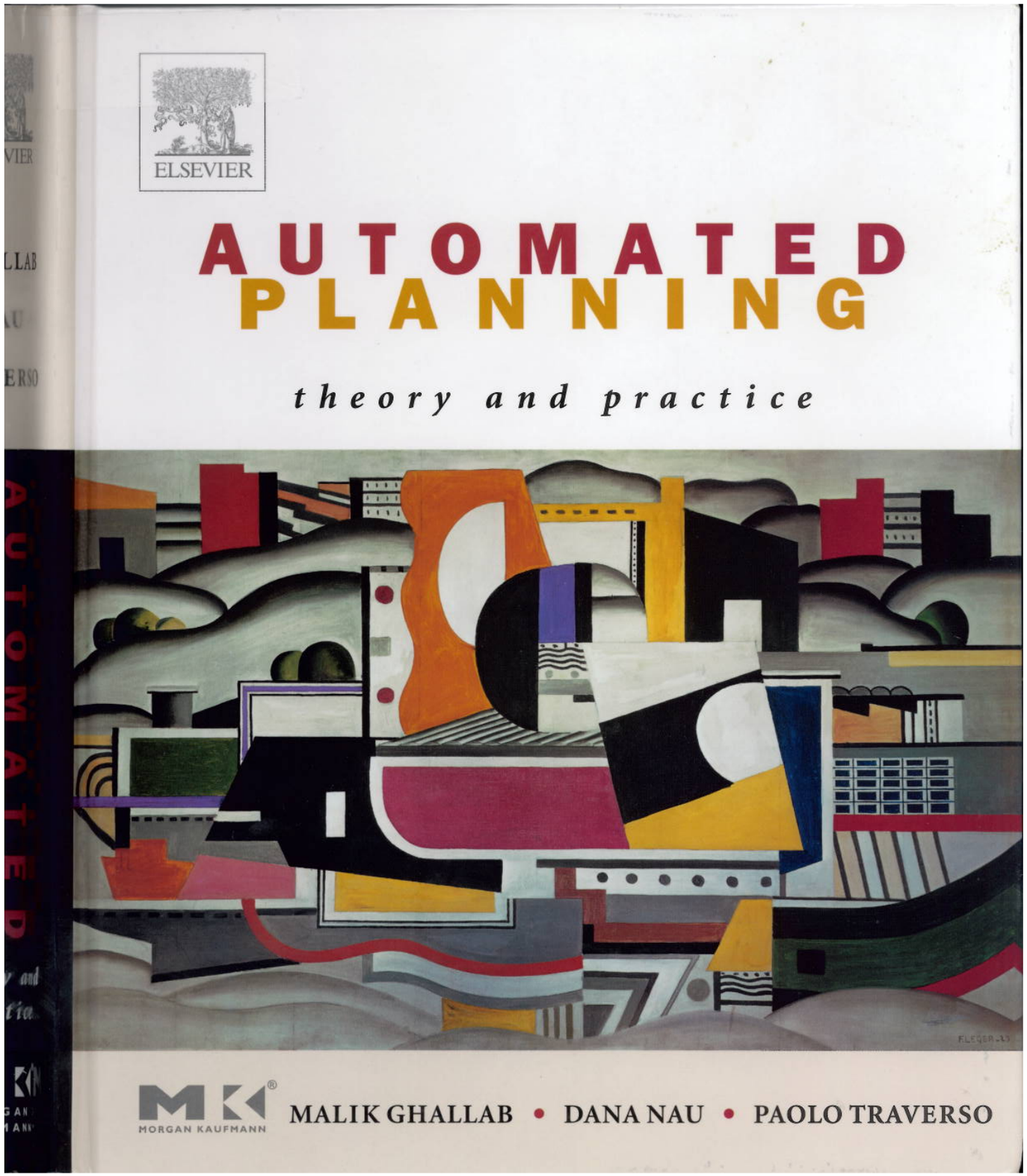
  - Search problems: over-explored
  - Acting problems: insufficiently investigated

A typical textbook of the field



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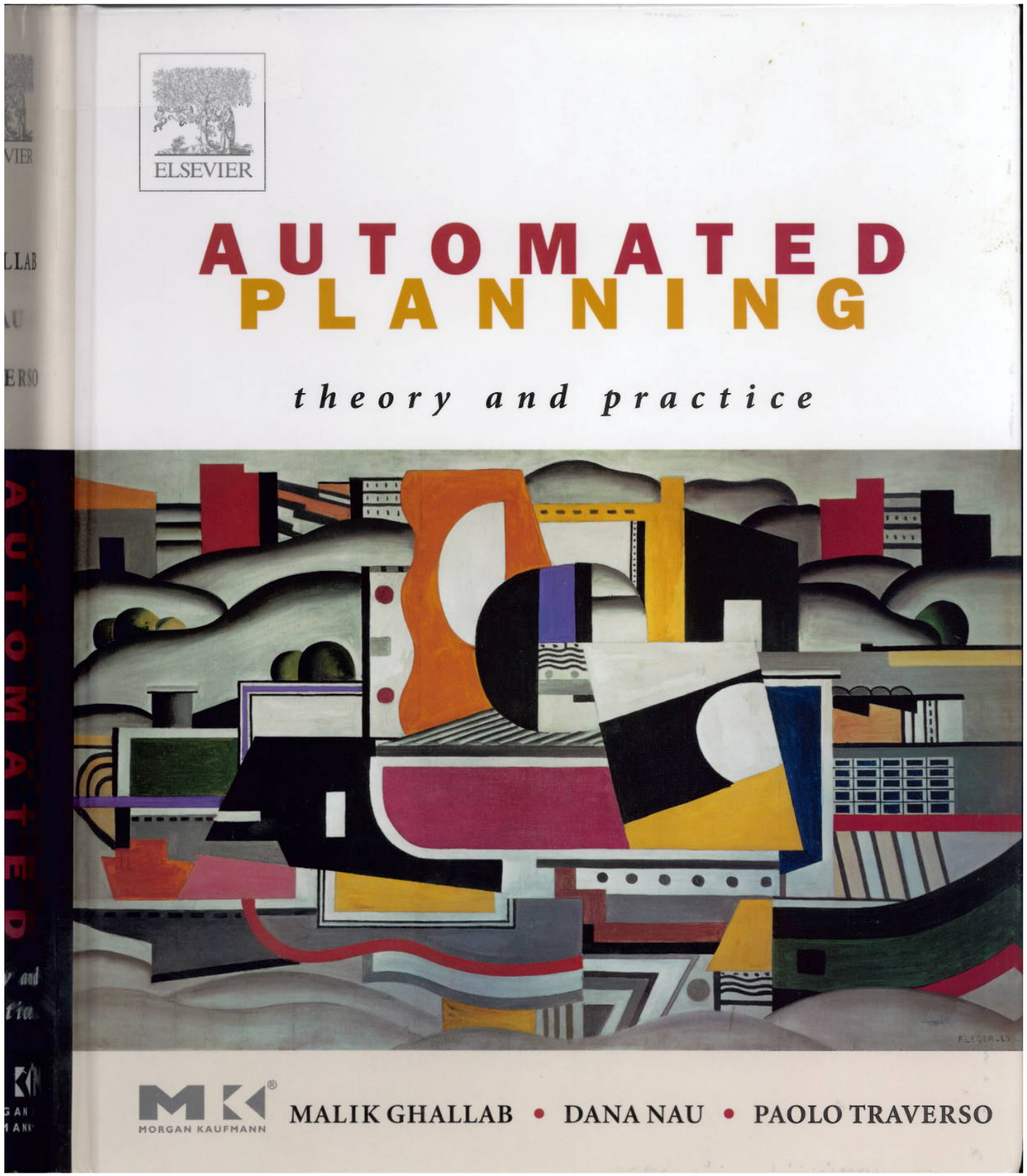

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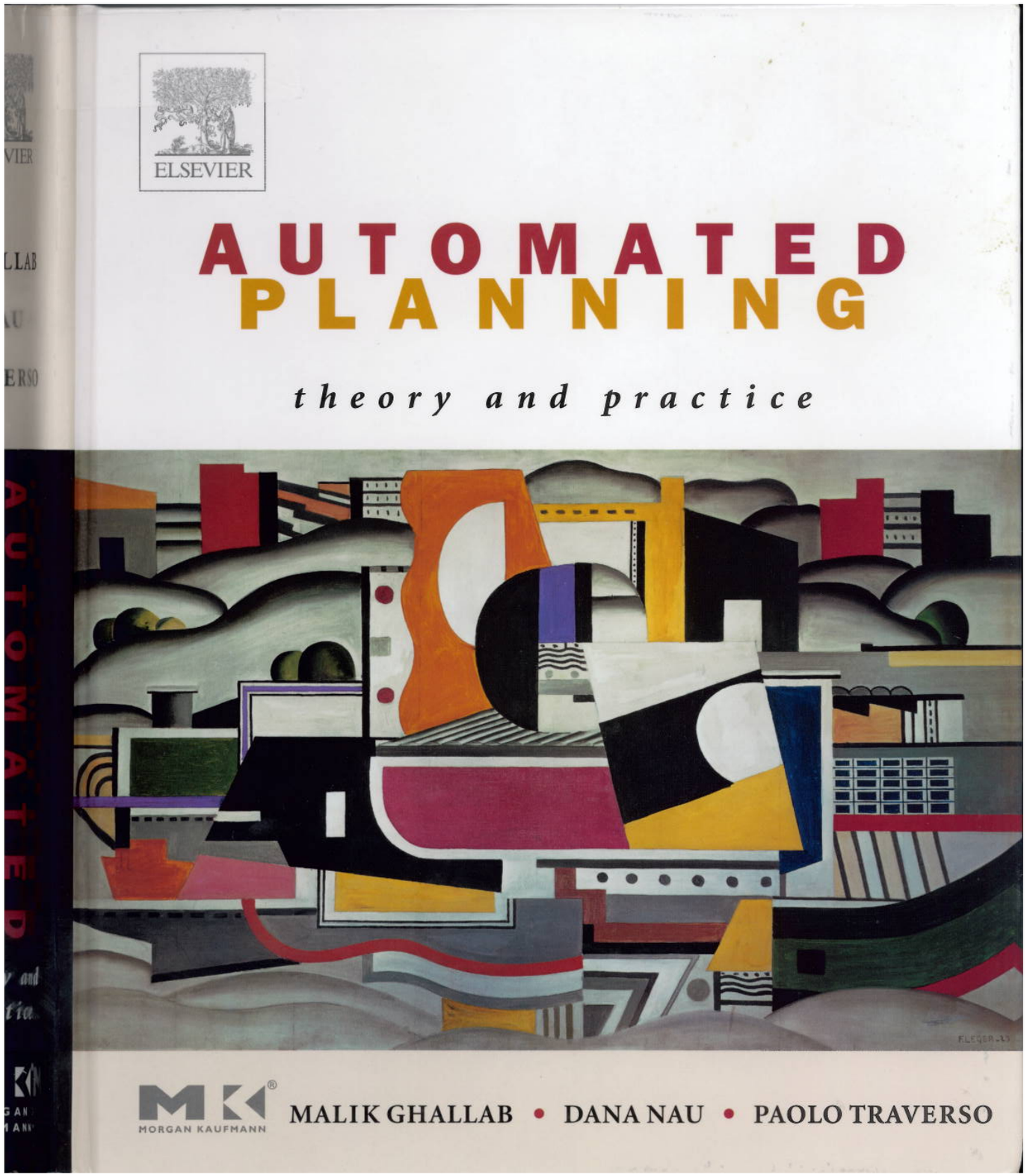

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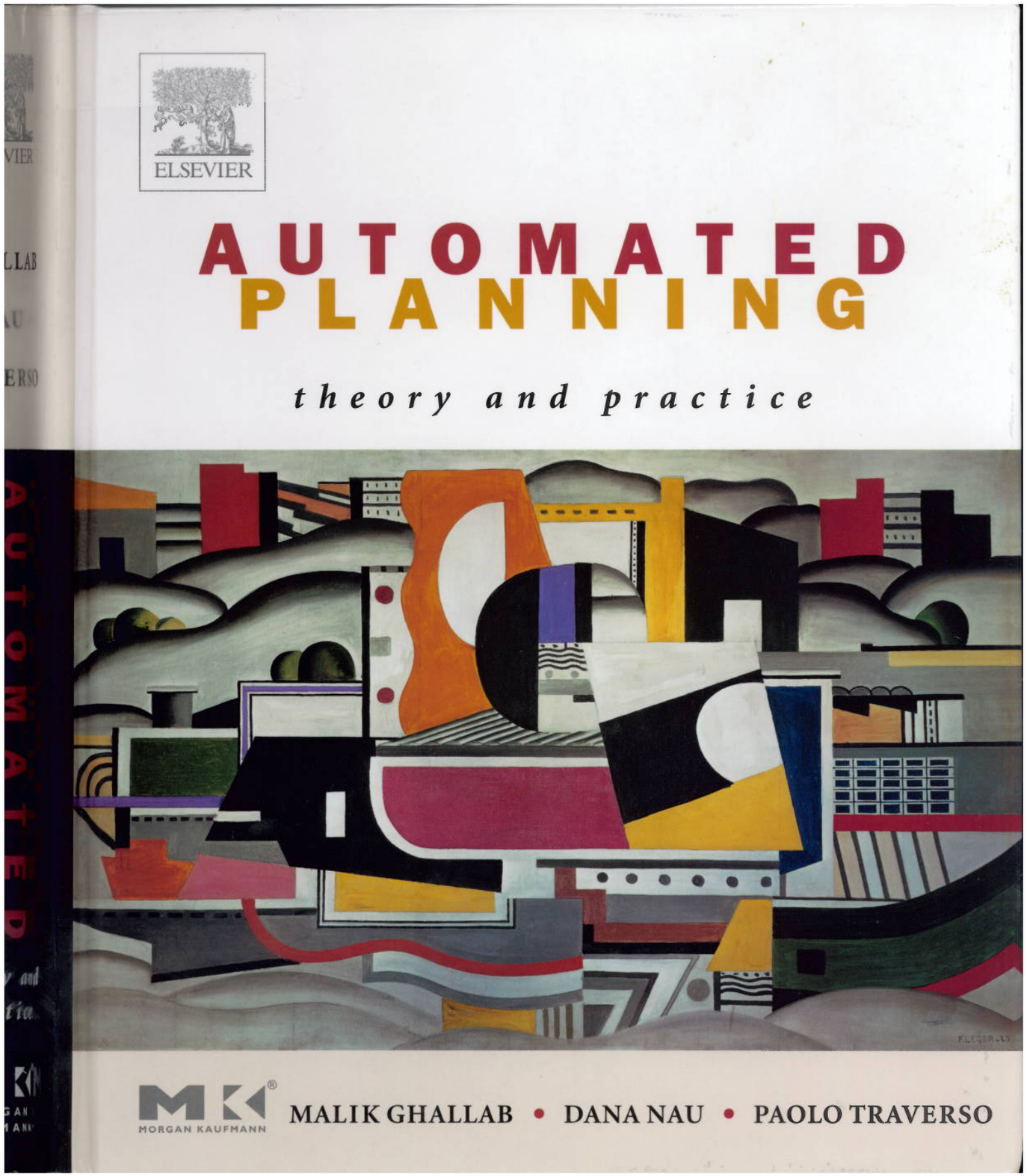

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  - 1.2 page / 630p.

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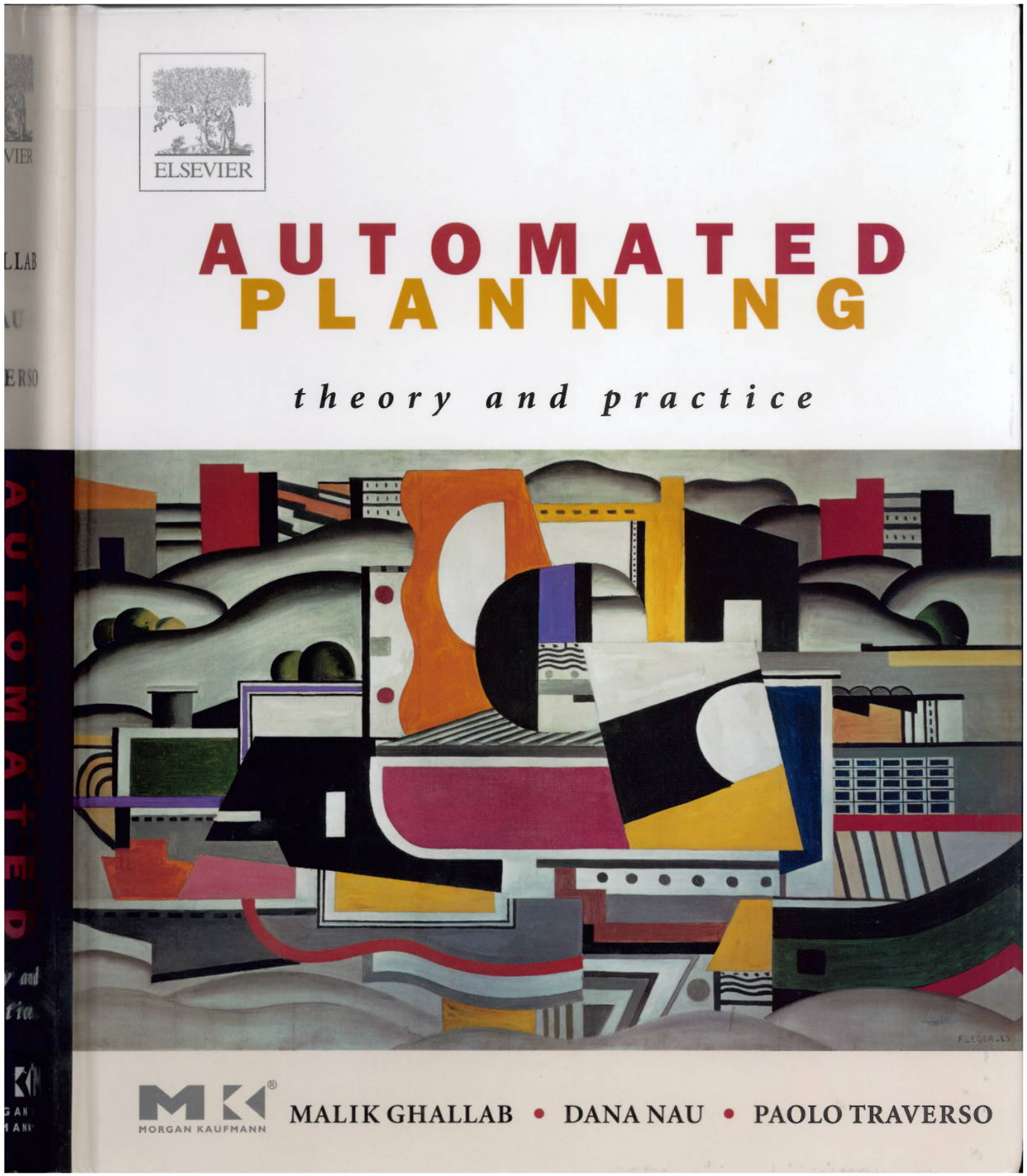

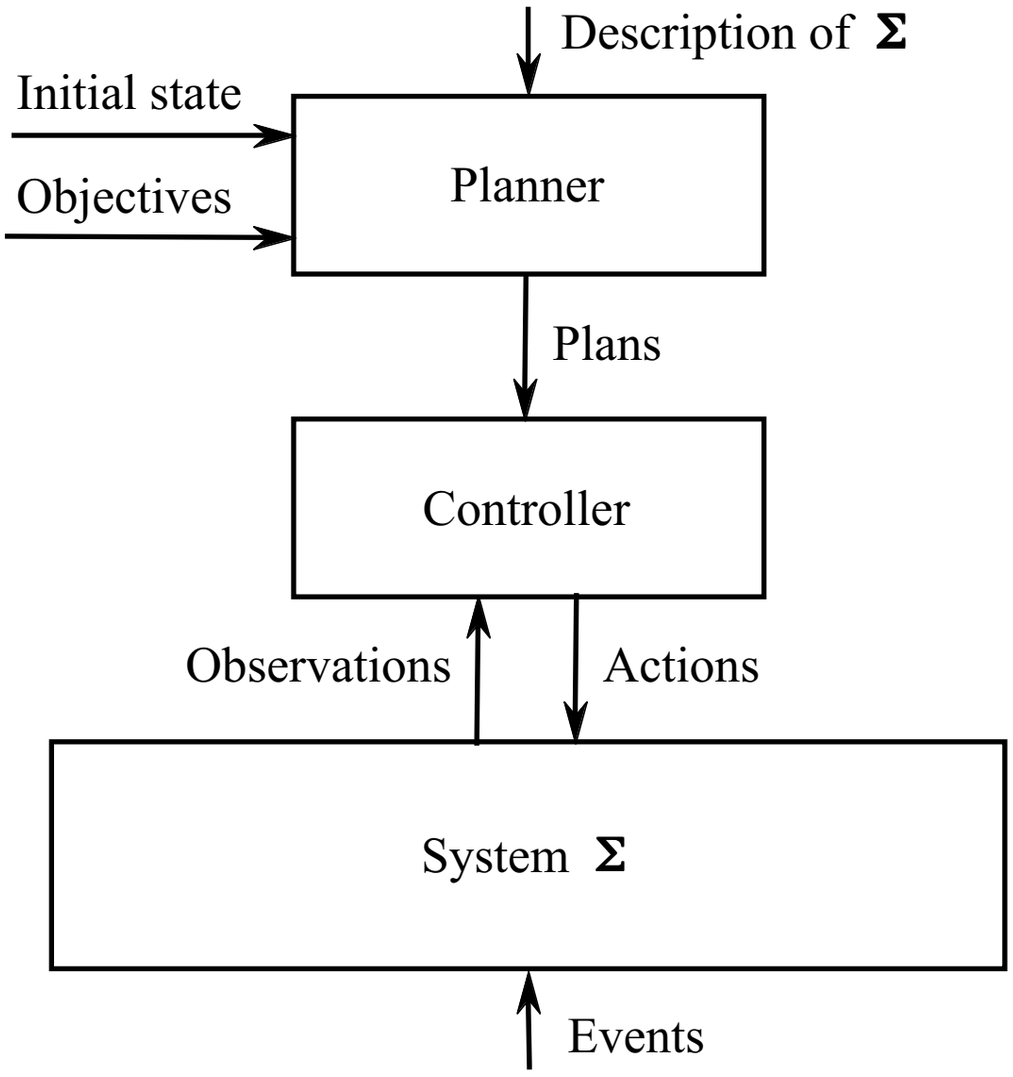

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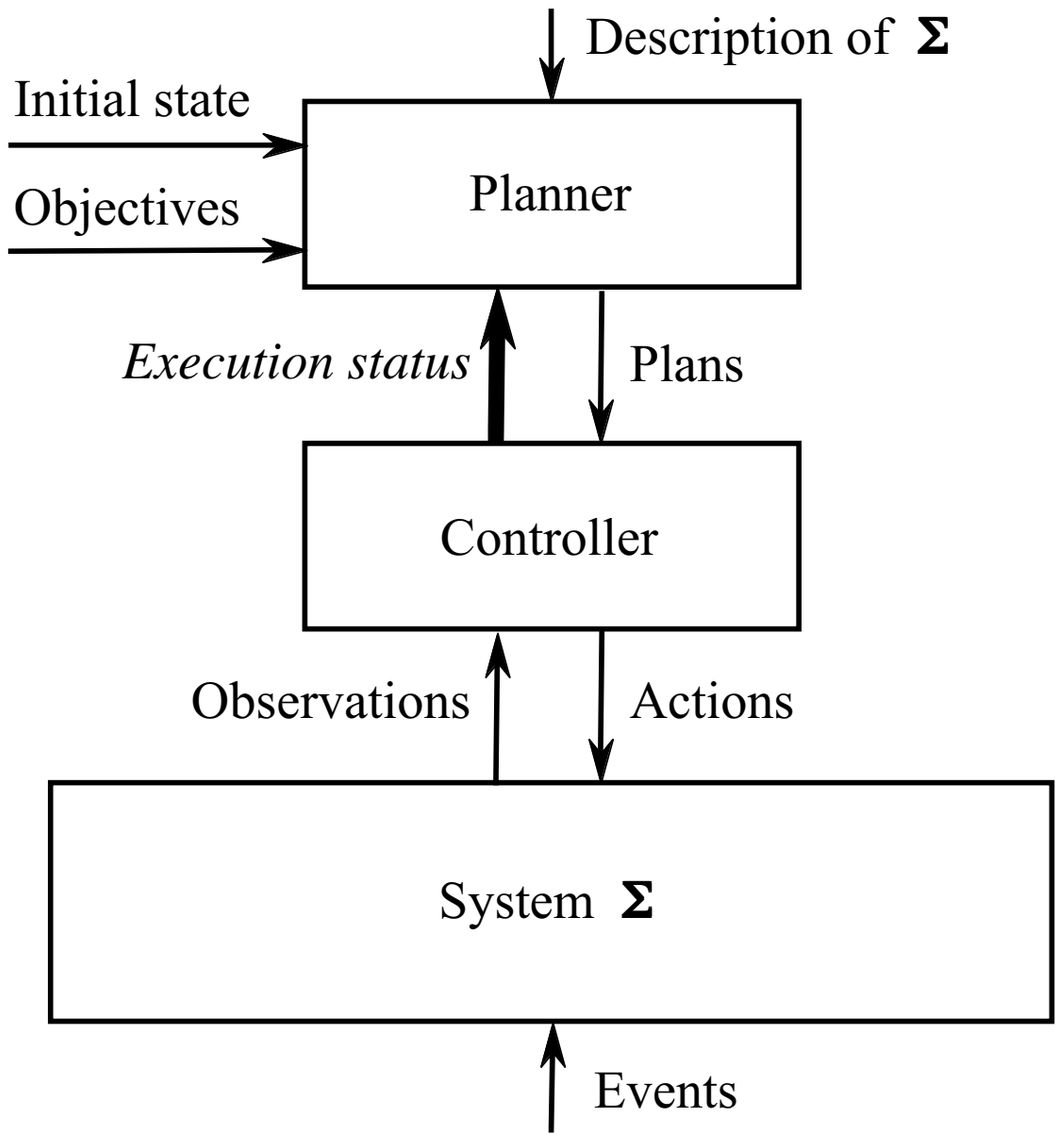

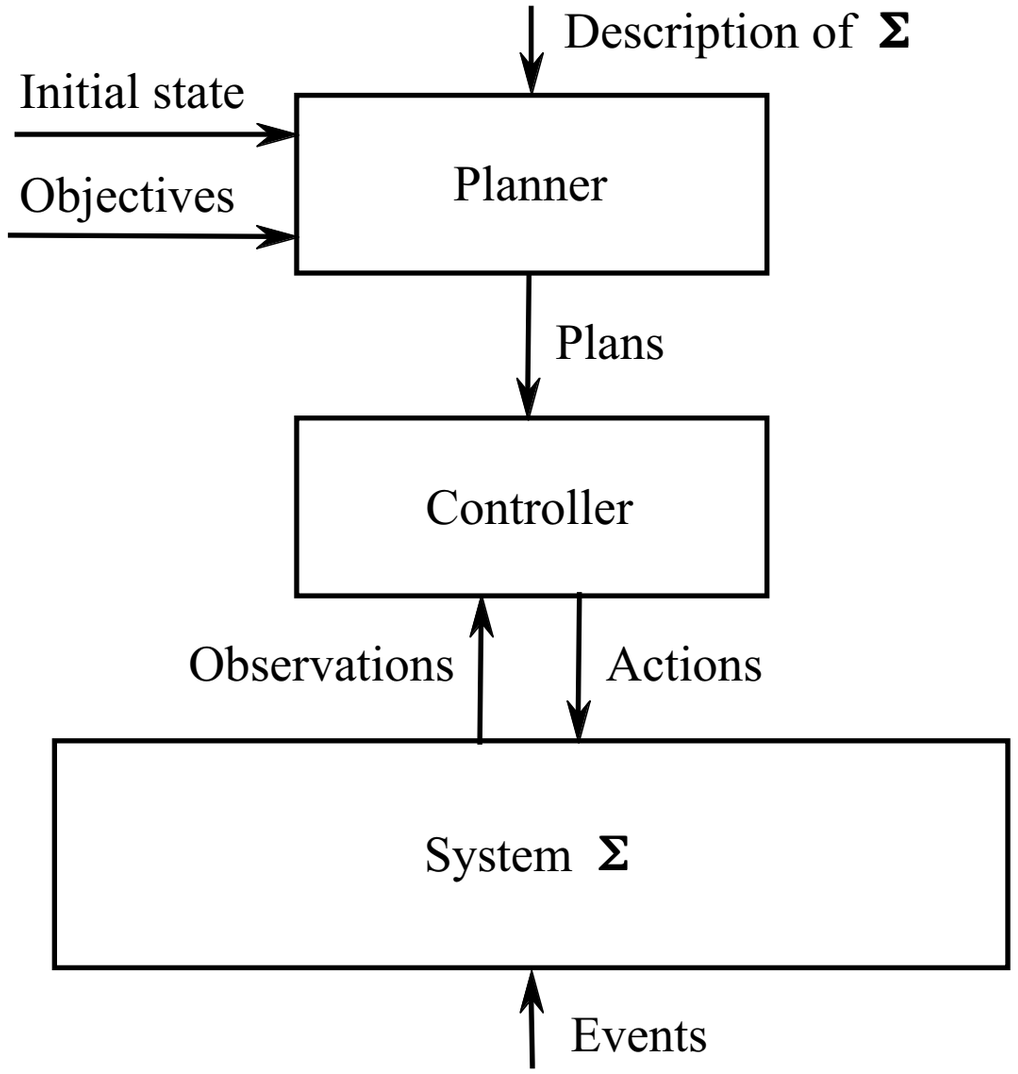

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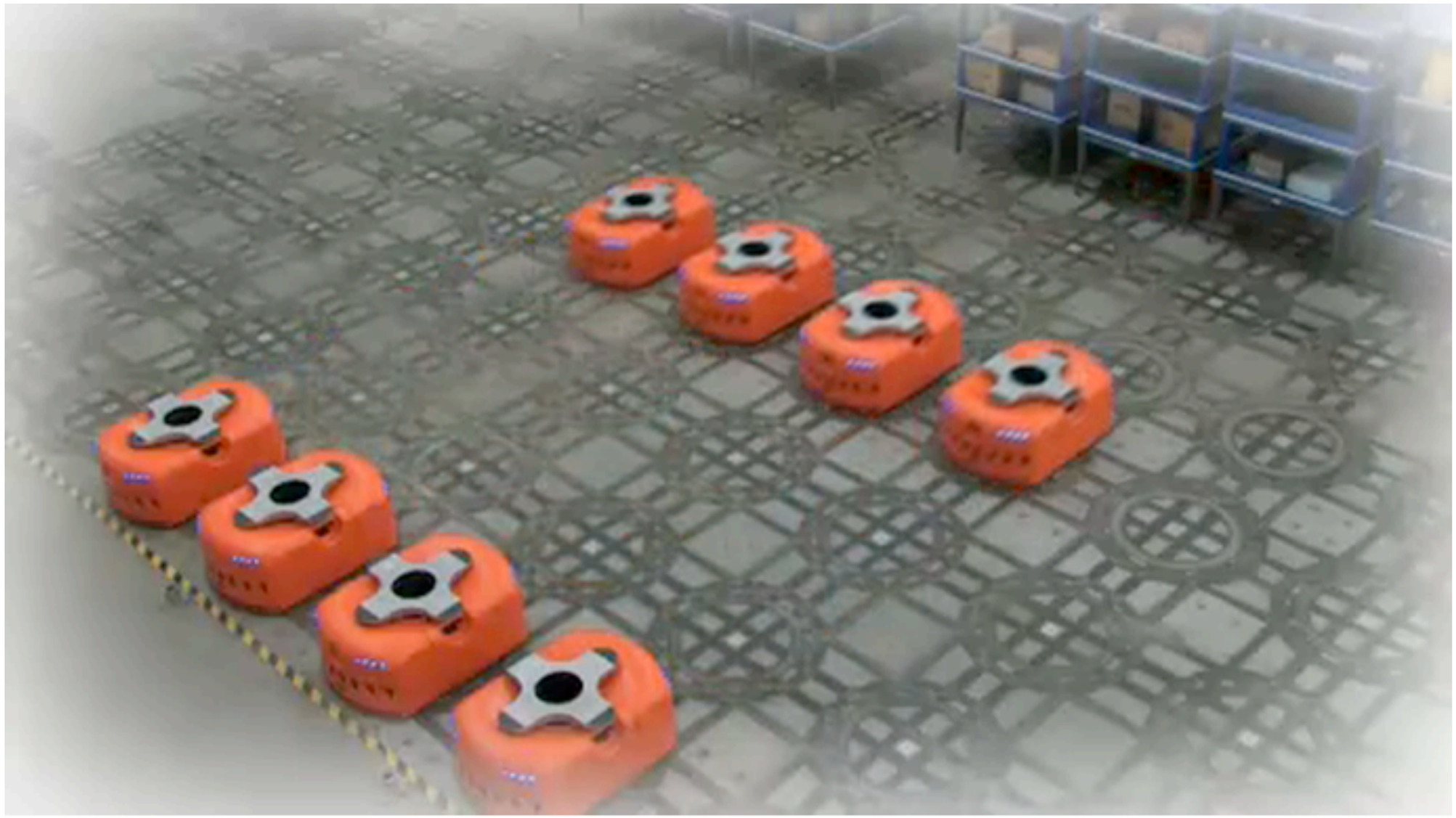
  - Robot manufacturers focus on
    - Programmable systems and ease of programming
    - Not much on autonomous deliberation through planning

Example of Warehouse automation



Kiva Systems

Household robot factotum

[LAAS, Toulouse]

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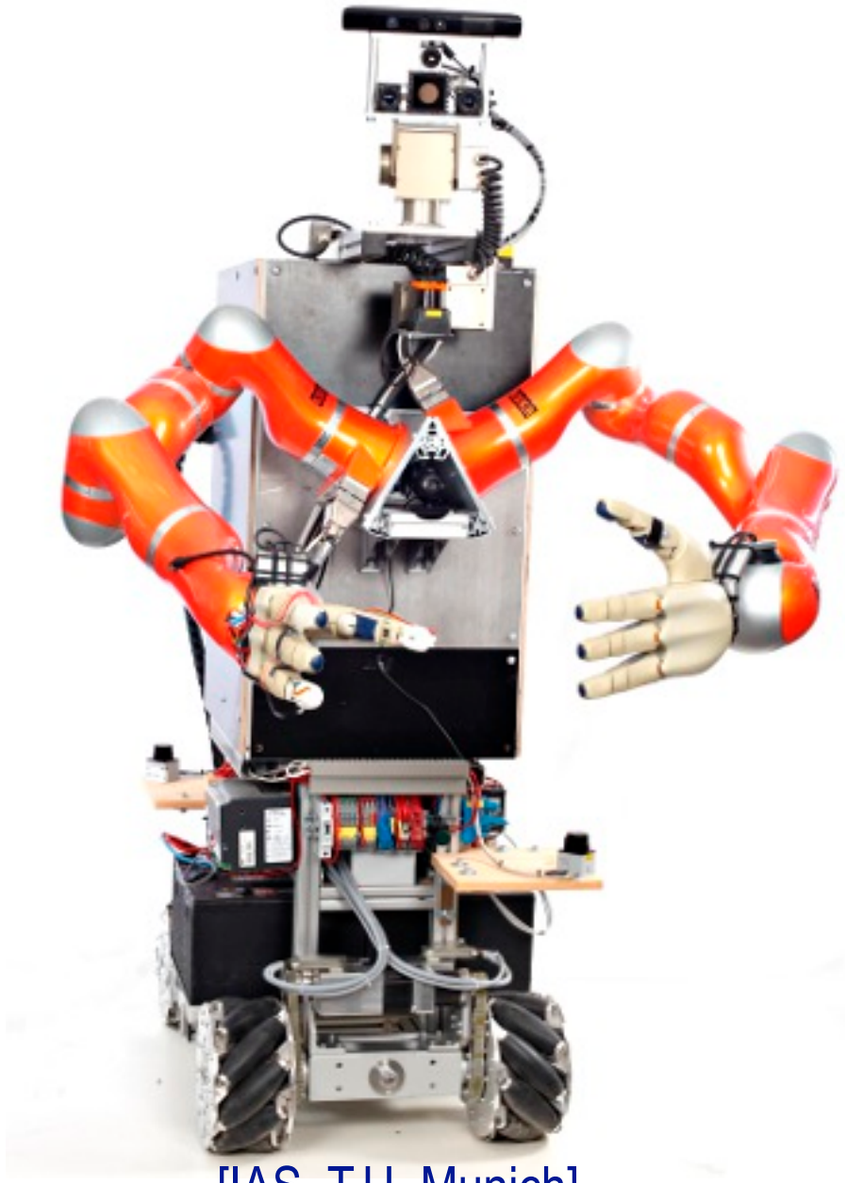
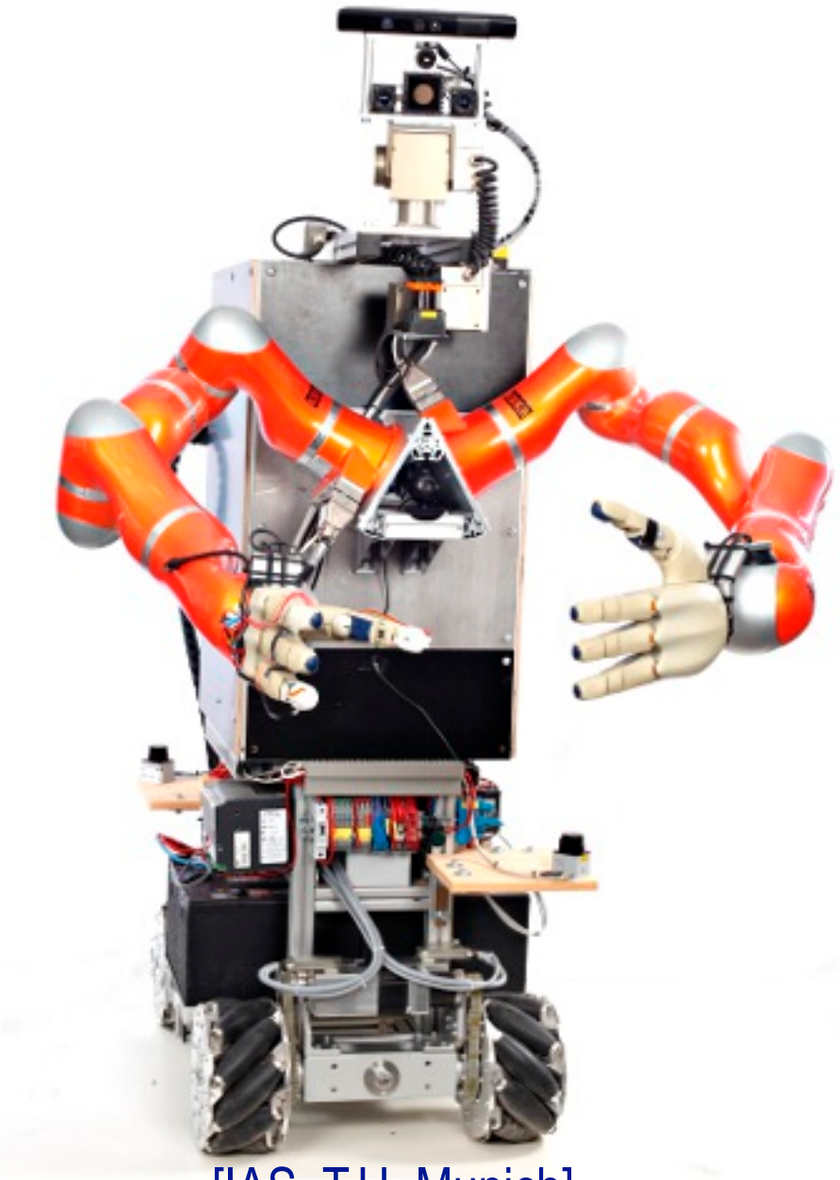


[IAS, T.U. Munich]

Household robot factotum

- Mission
  - Household services: pick, bring, maintain, sort, clean, cook
  - Support users: help, remind, monitor
- Main features
  - Wide *variety* of environments and tasks
  - Complex interactions with users

[LAAS, Toulouse]



[IAS, T.U. Munich]

Basic skills for a factotum robot

- ***Localize*** itself in the environment map
- ***Map*** the environment: extend or update the map
- ***Move*** to a target position
- ***Detect*** and ***avoid*** obstacle
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Mapping: dynamic & context-dependent

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```
(:action move
    :parameters (?r - robot ?from ?to - location)
    :precondition (and (adjacent ?from ?to)
            (at ?r ?from) (not (occupied ?to)))
    :effect (and (at ?r ?to) (not (occupied ?from))
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$$\mathsf{move}(r, l, l')@[t_s, t_e)$$

$$\begin{aligned}
\text{precond:}\quad & \mathsf{at}(r, l)@[t_1, t_s),\ \mathsf{free}(l')@[t_2, t_e) \\
\text{effects:}\quad & \mathsf{at}(r,\ \mathsf{routes})@[t_s, t_e) \\
& \mathsf{at}(r, l')@[t_e, t_3) \\
& \mathsf{free}(l)@[t_4, t_5) \\
\text{const:}\quad & t_s < t_4 < t_2,\ \mathsf{adjacent}(l, l')
\end{aligned}$$

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not enough addressed in planning

Why actor's view not enough addressed in planning

- Emphasis bias issue
  - Planning: Choice and organization of actions
  - Ingredients: Prediction + Search
  - *Precond-Effects* models
    - Focus on search
    - Trivialized prediction

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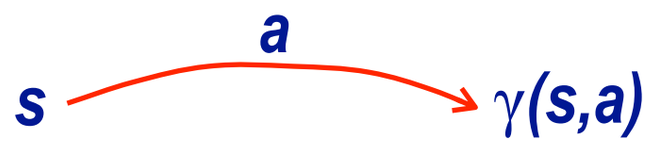

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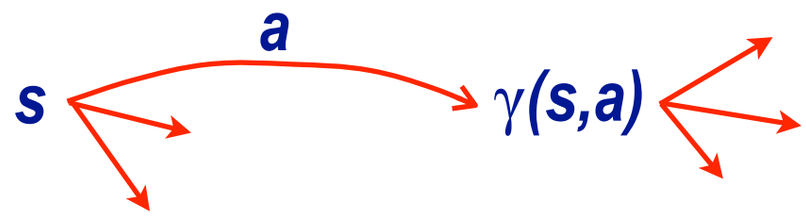

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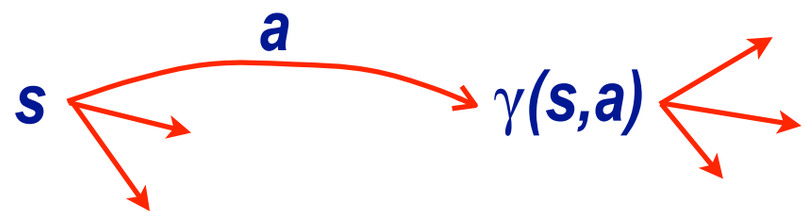

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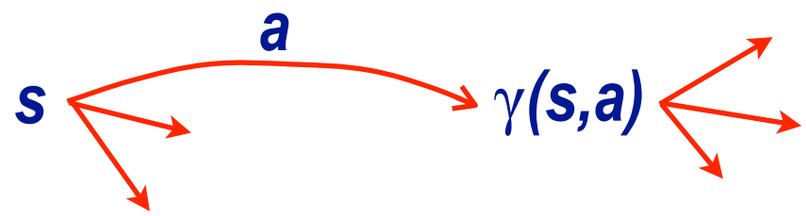

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- Frontier issue
  - Planning easily separated from sensory-motor functions
  - "*Acting" vs "Executing"* more blurred frontier

Actor's view of deliberation

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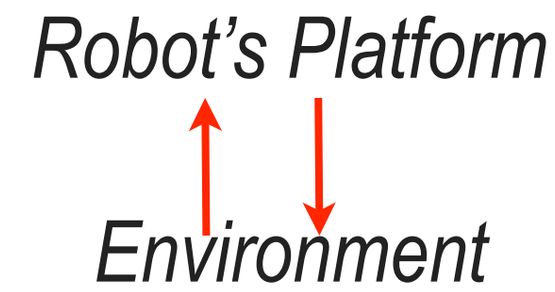
Robot's Platform

Actor's view of deliberation



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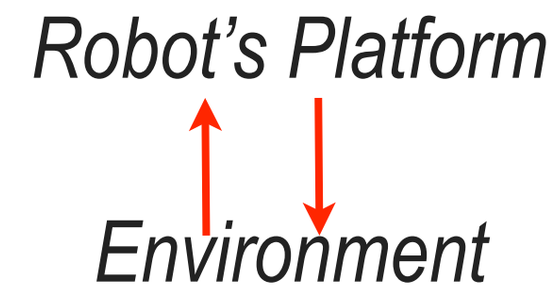
Planning

Task ⟶ ⟨ ..., abstract step, ... ⟩



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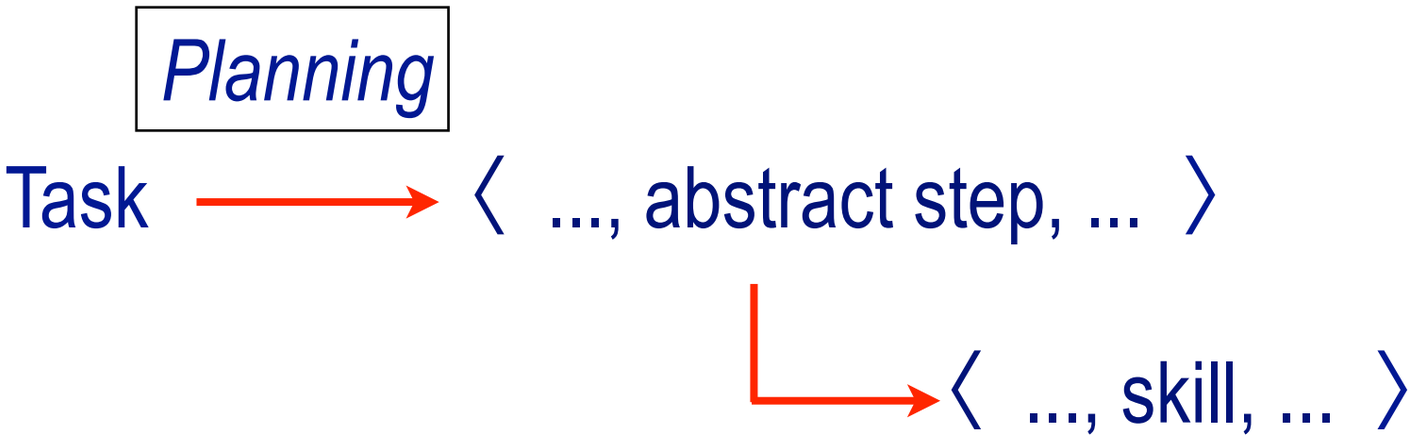

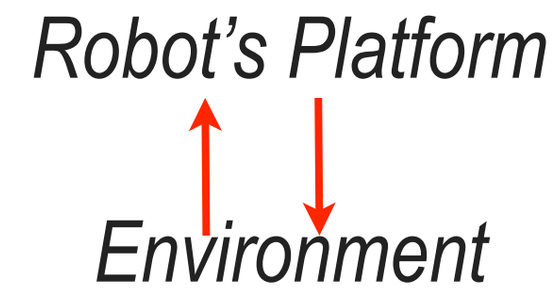

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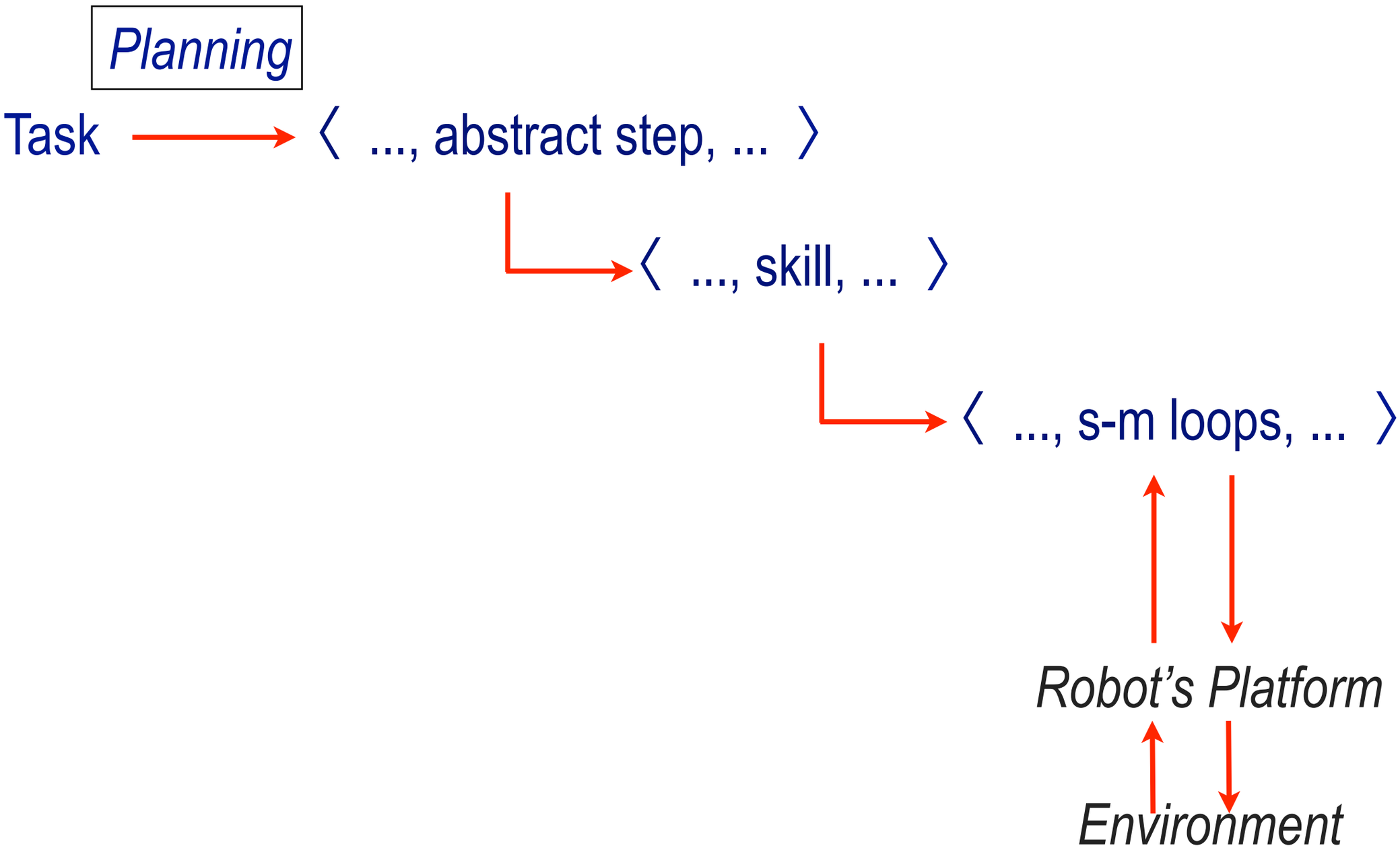

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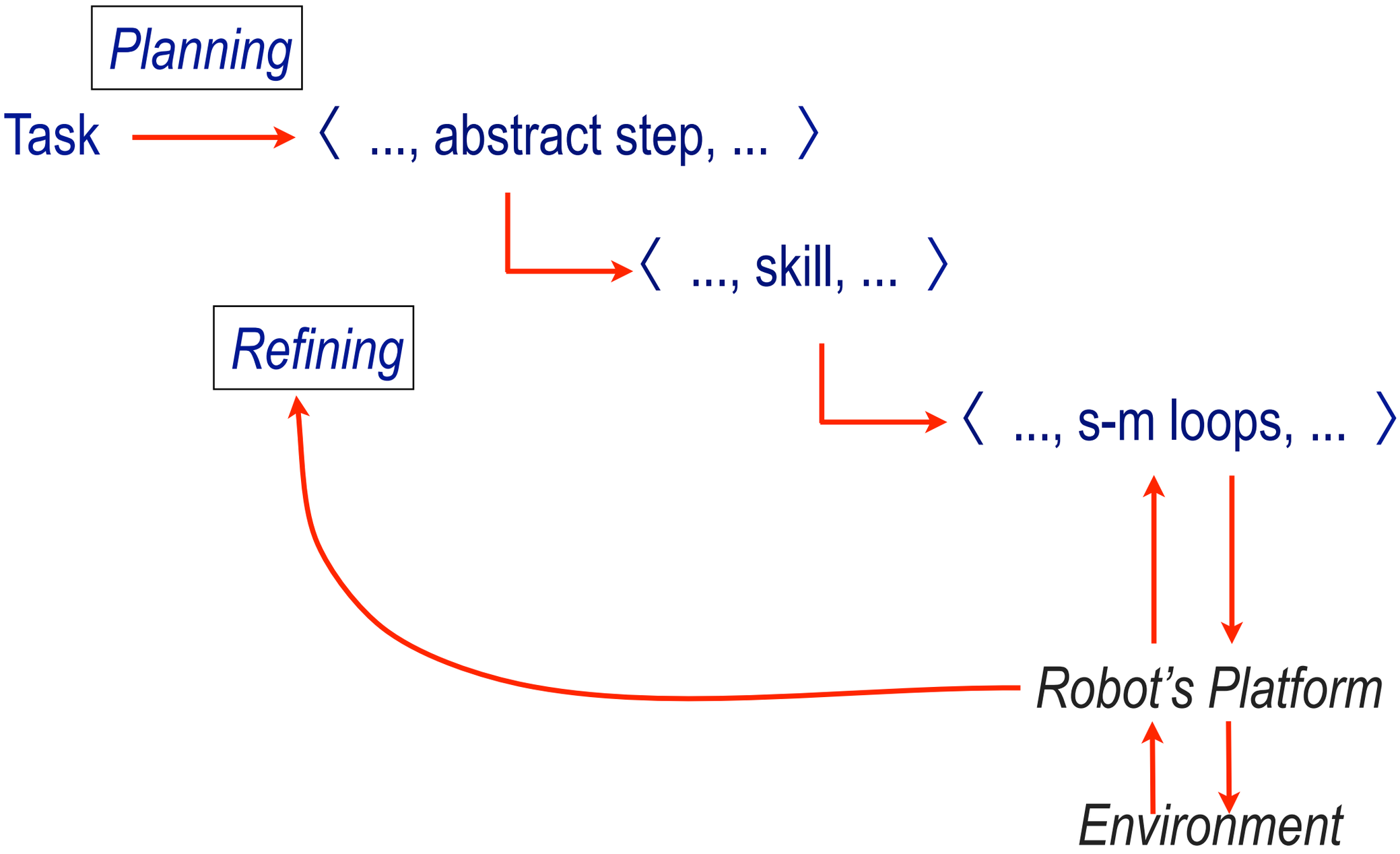

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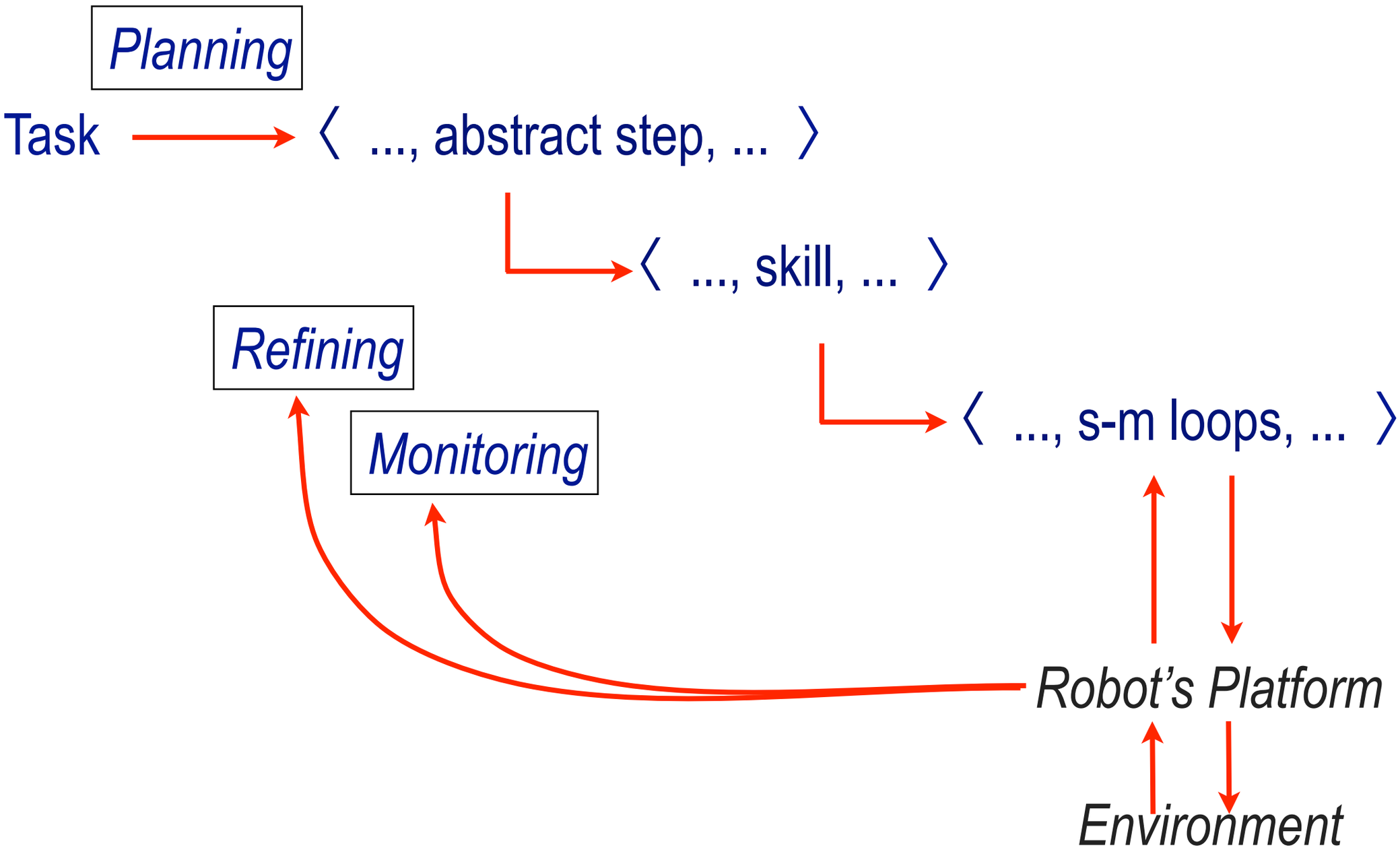

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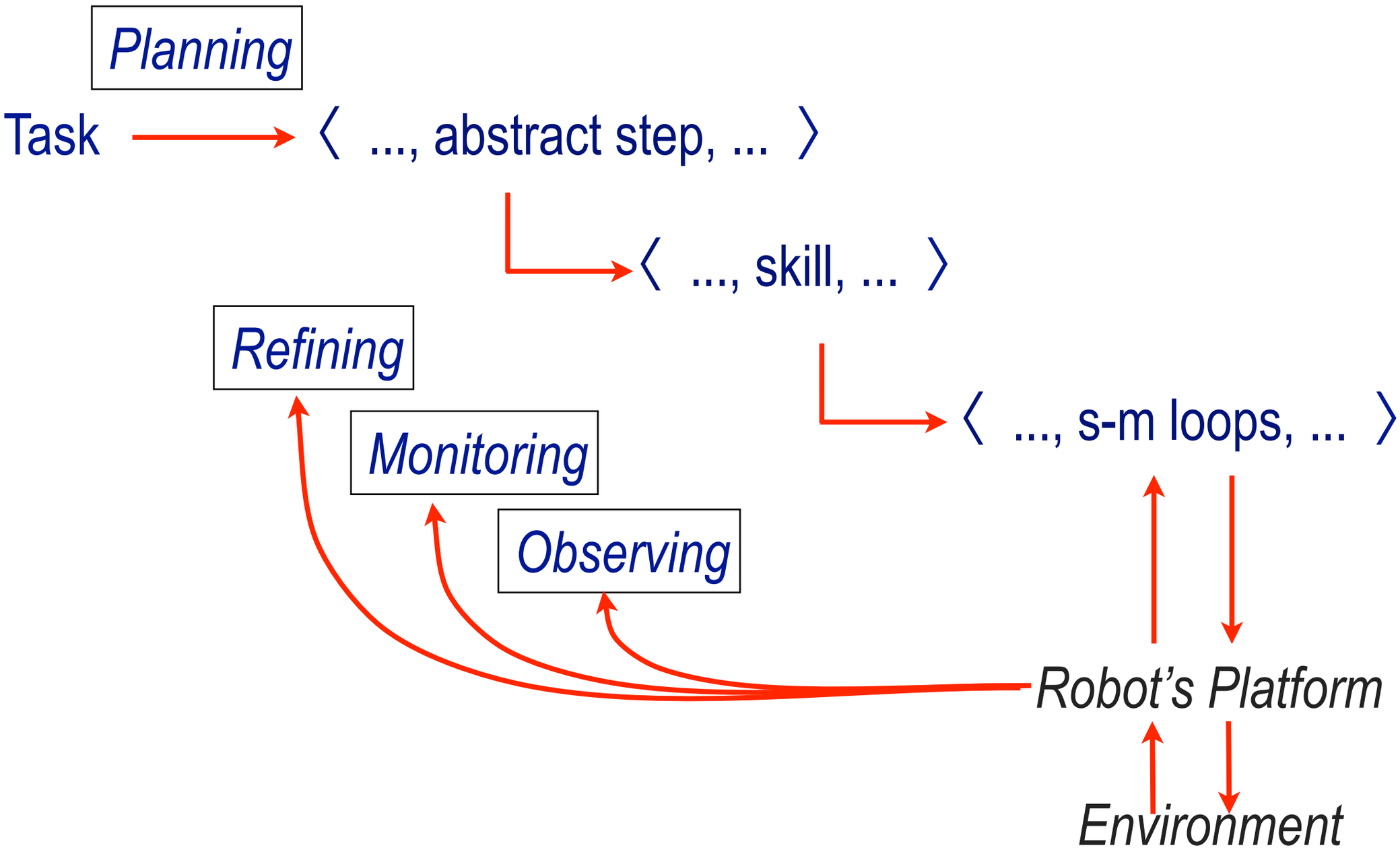

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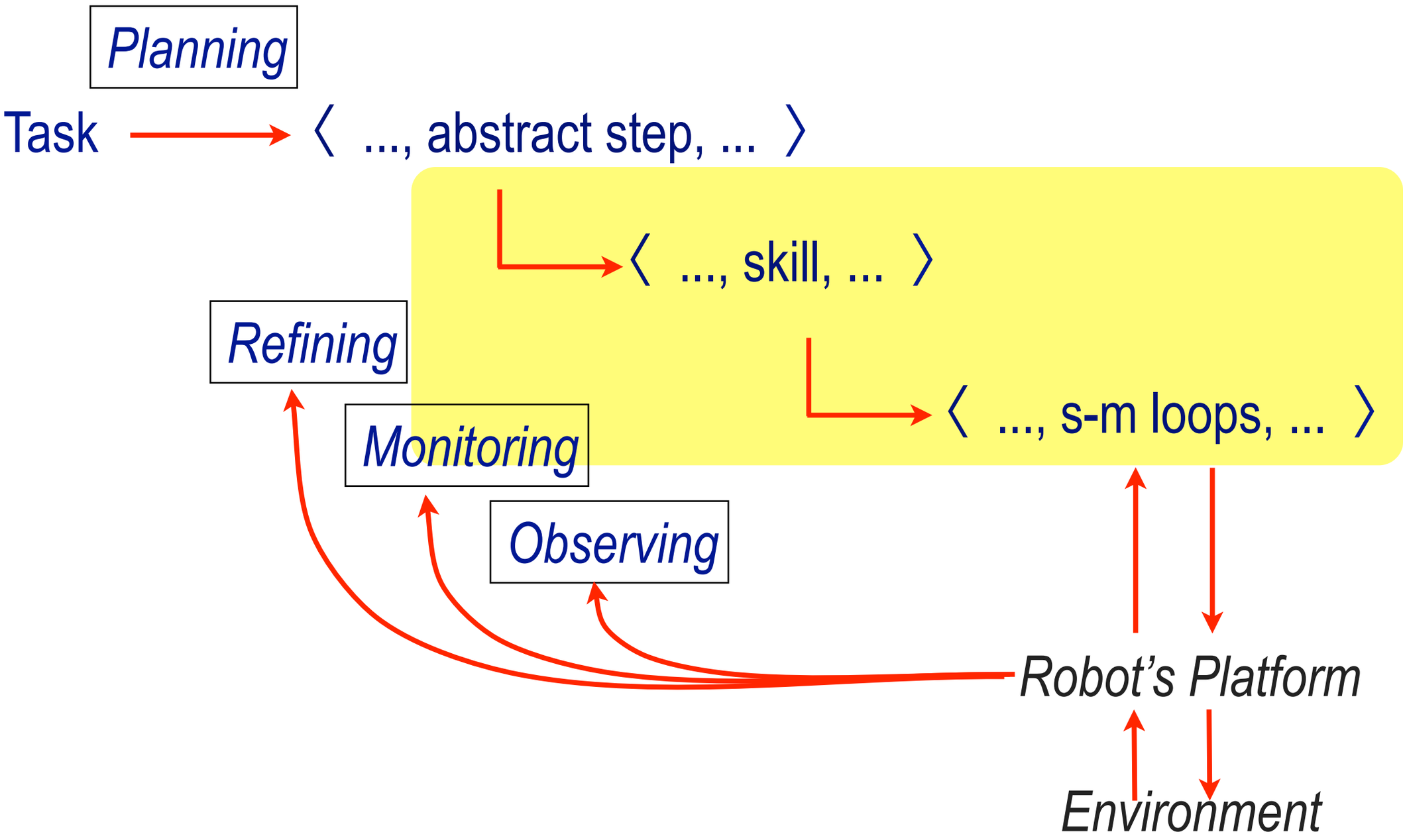

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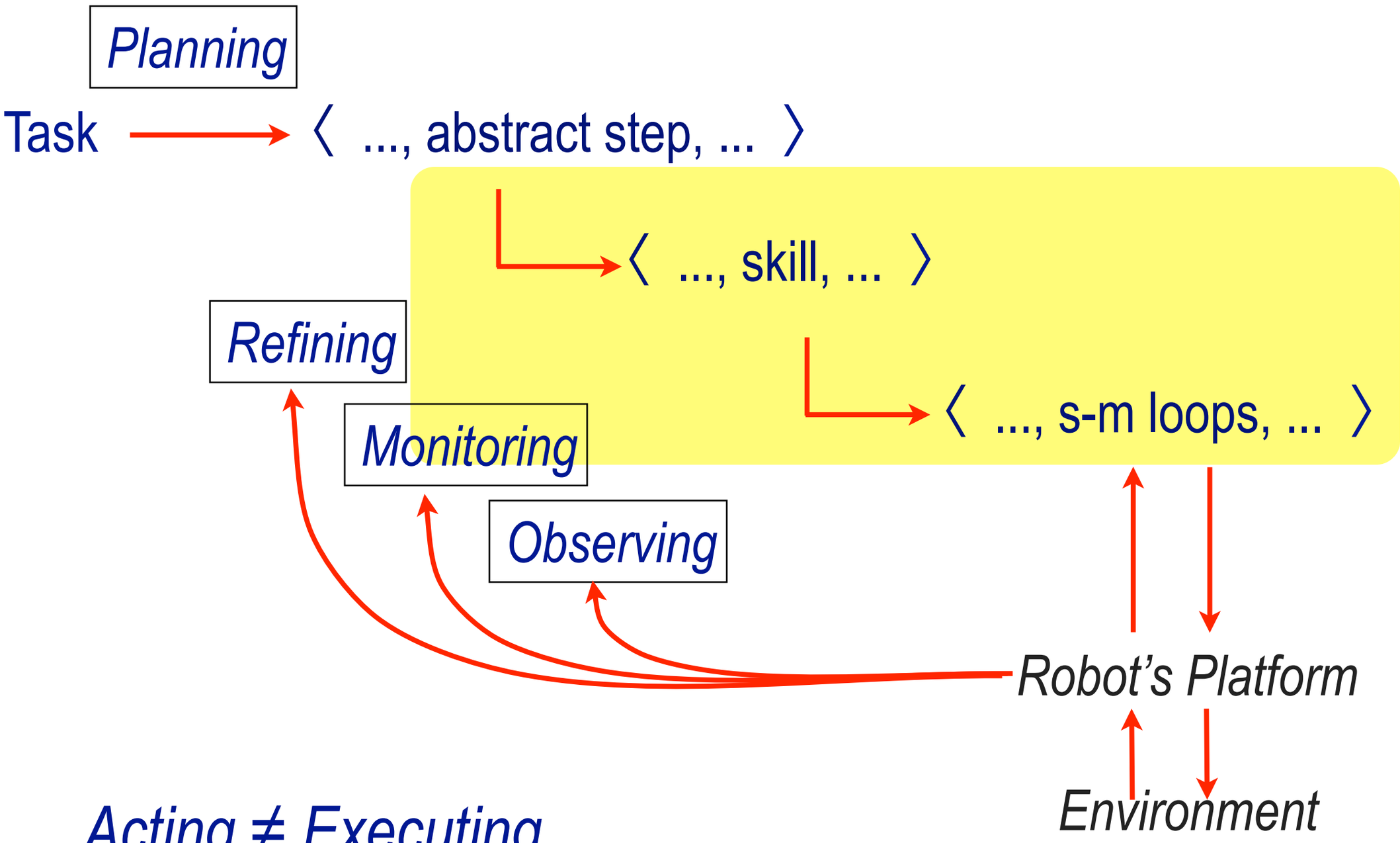

Acting ≠ Executing

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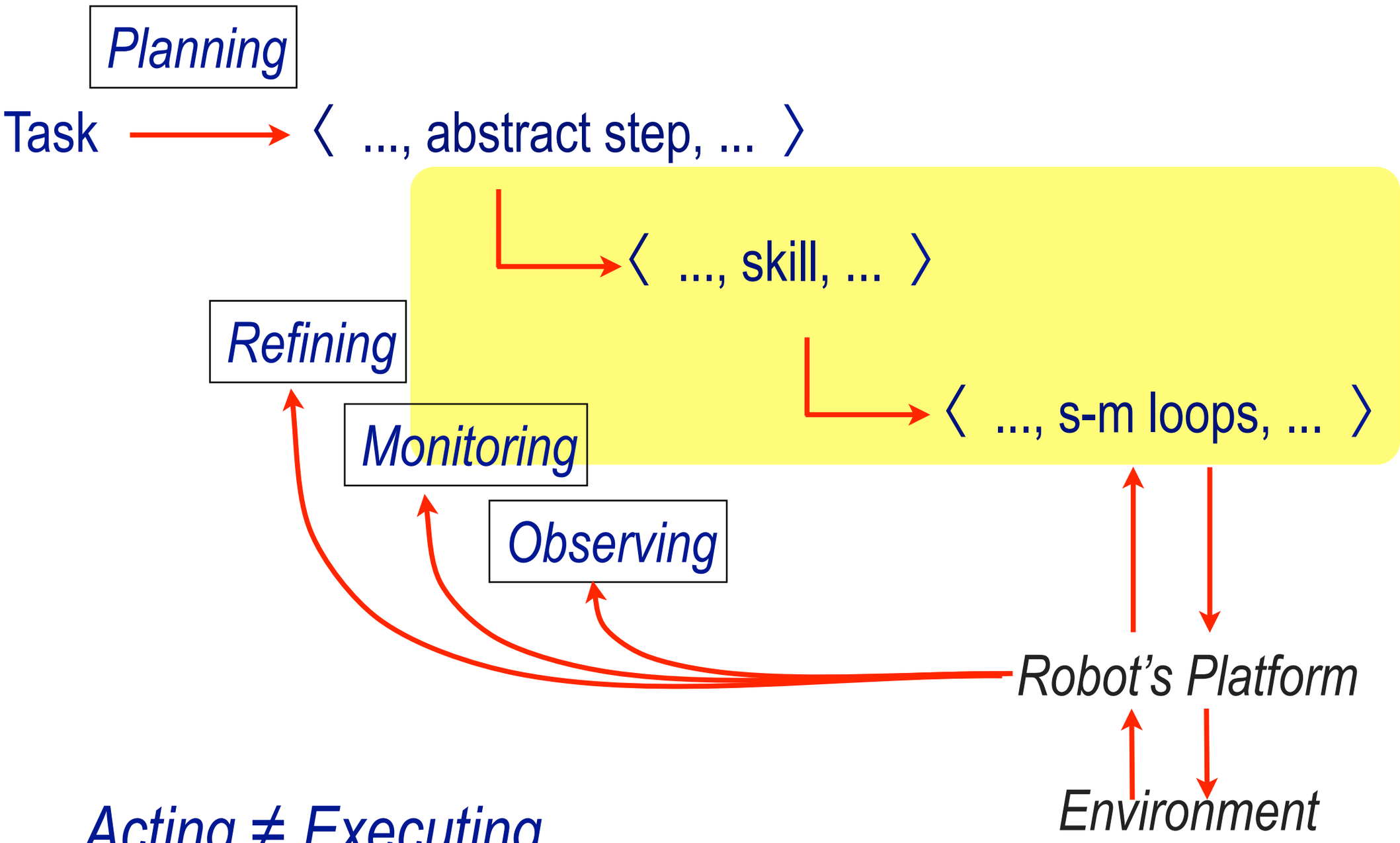


Acting ≠ Executing

Actor ≠ Executor

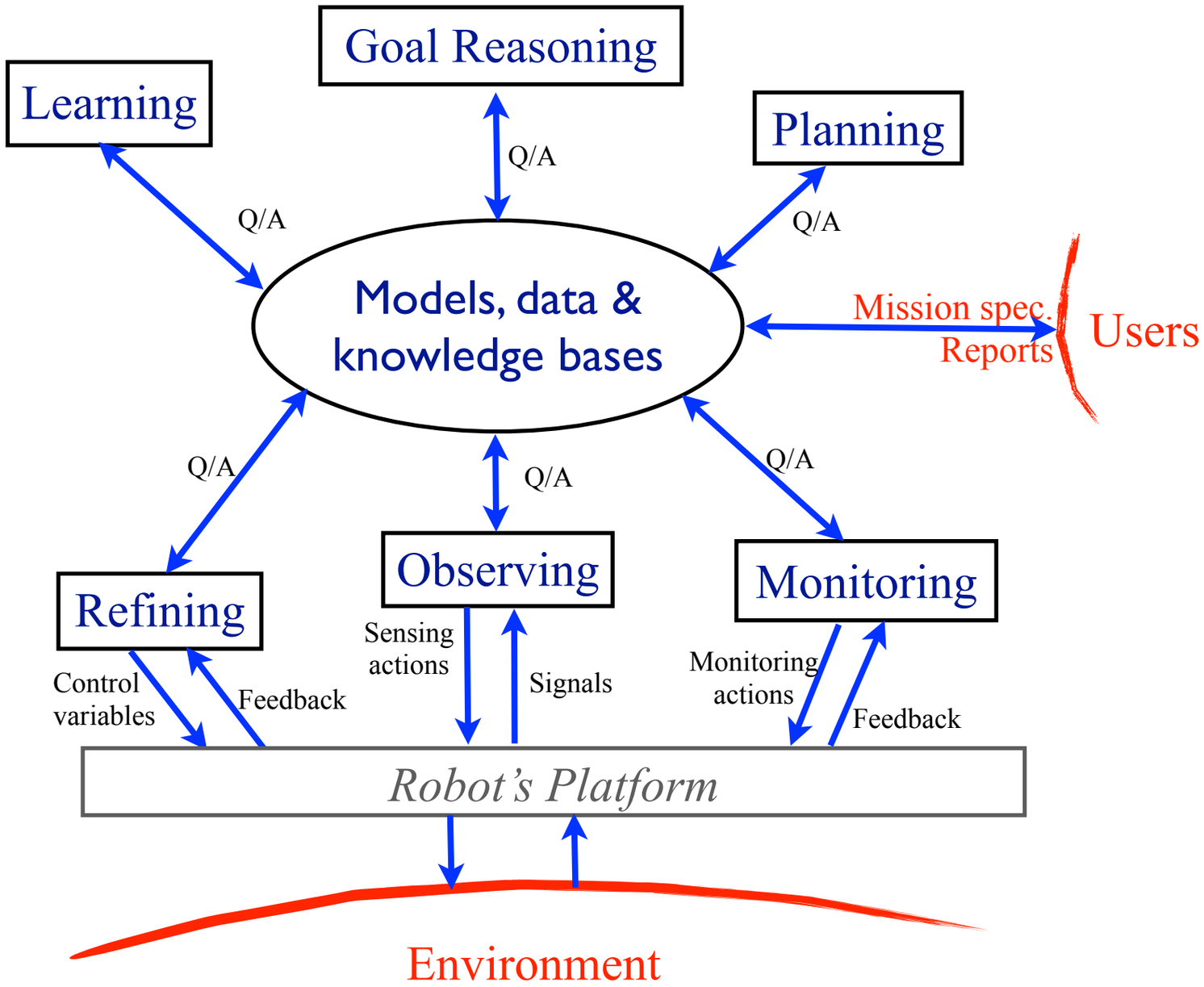
Outline

✓Motivations

- Deliberation functions
  - Planning
  - Refining
  - Monitoring
  - Perceiving
  - Goal reasoning
  - Learning
  - Integration

- Research Challenges
  - Representation
  - Model acquisition & Verification
  - Synthesis
  - Monitoring and Goal reasoning
  - Integration

Actor's deliberation functions



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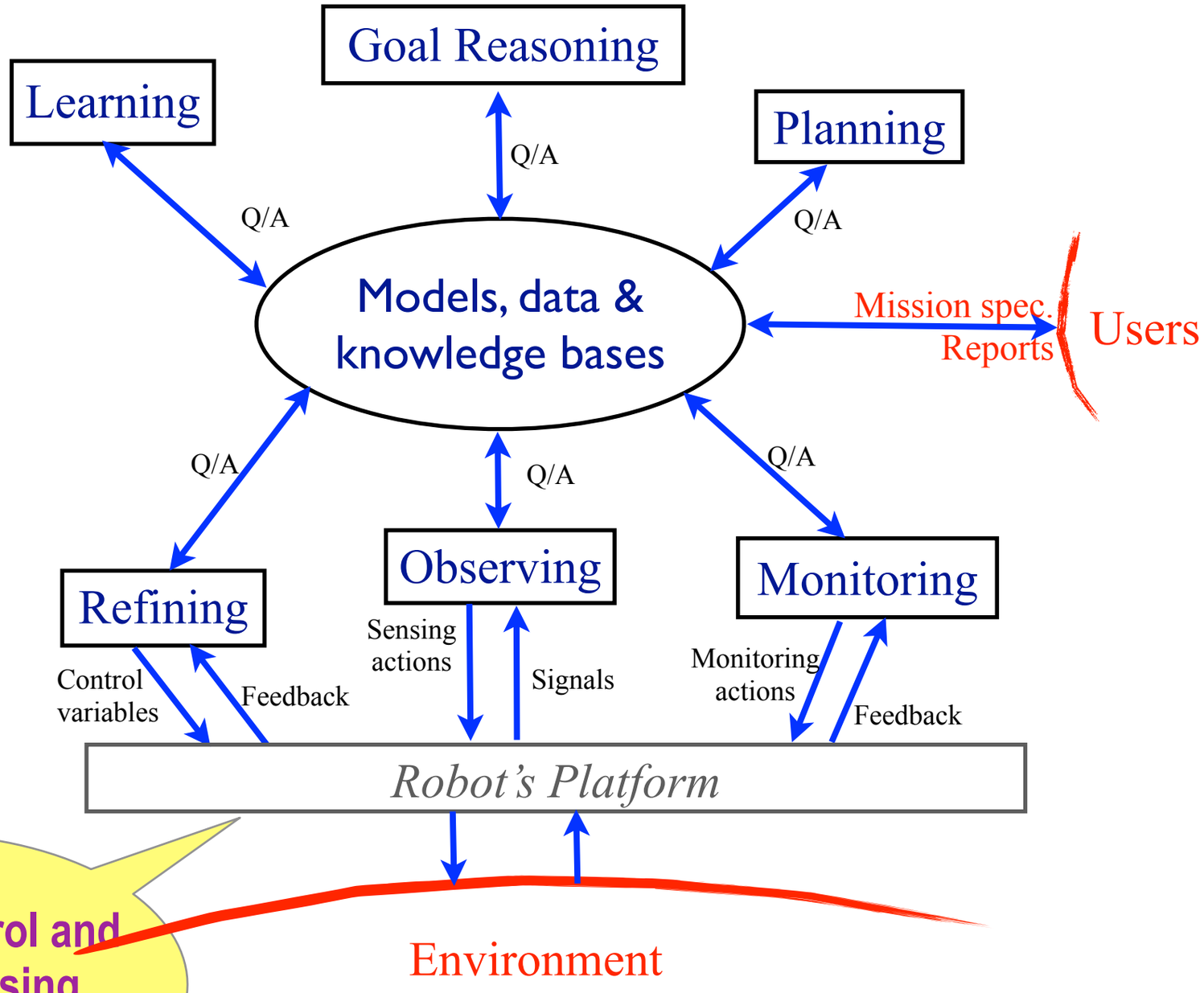

Low-level control and signal processing, *no deliberation*

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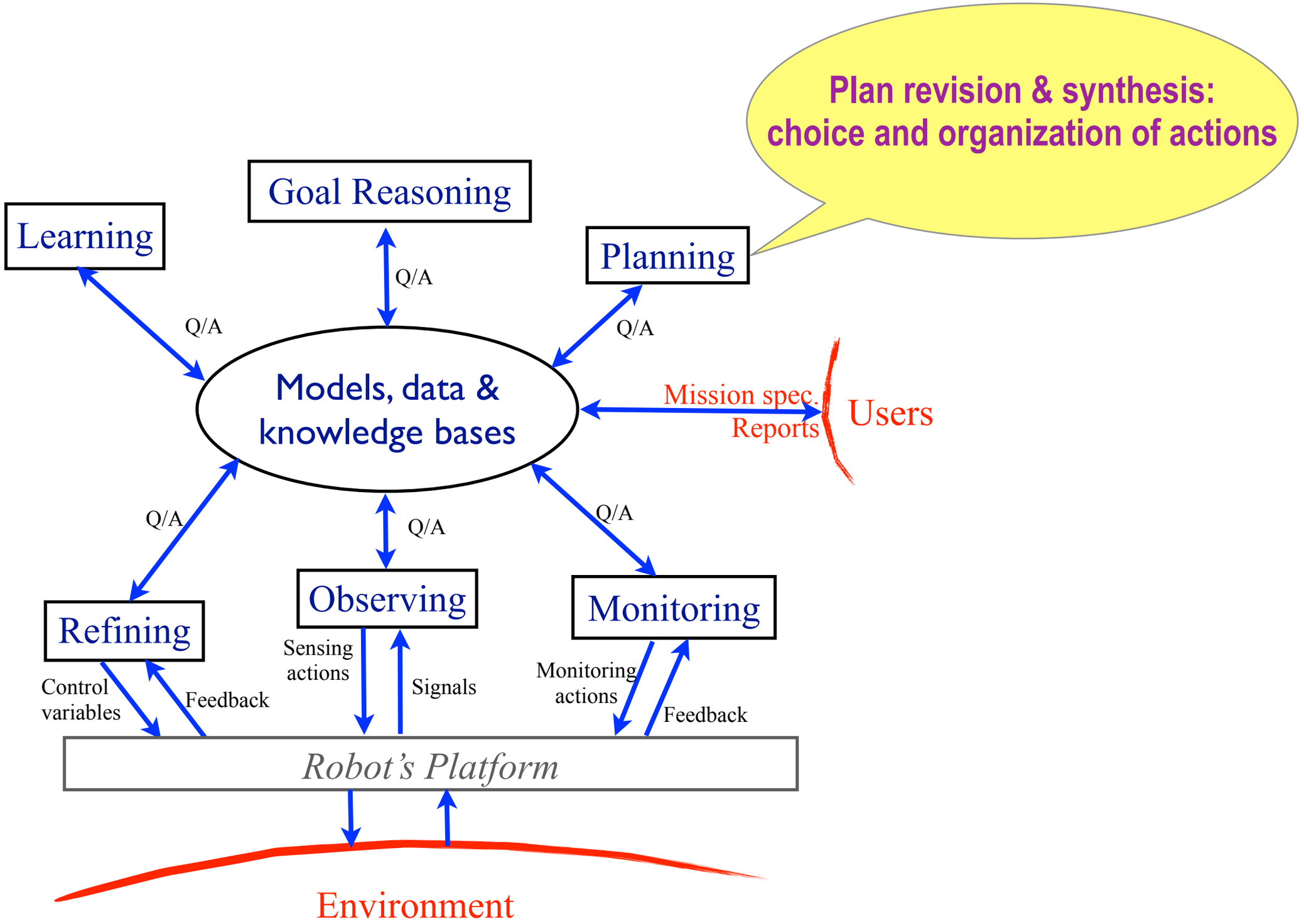

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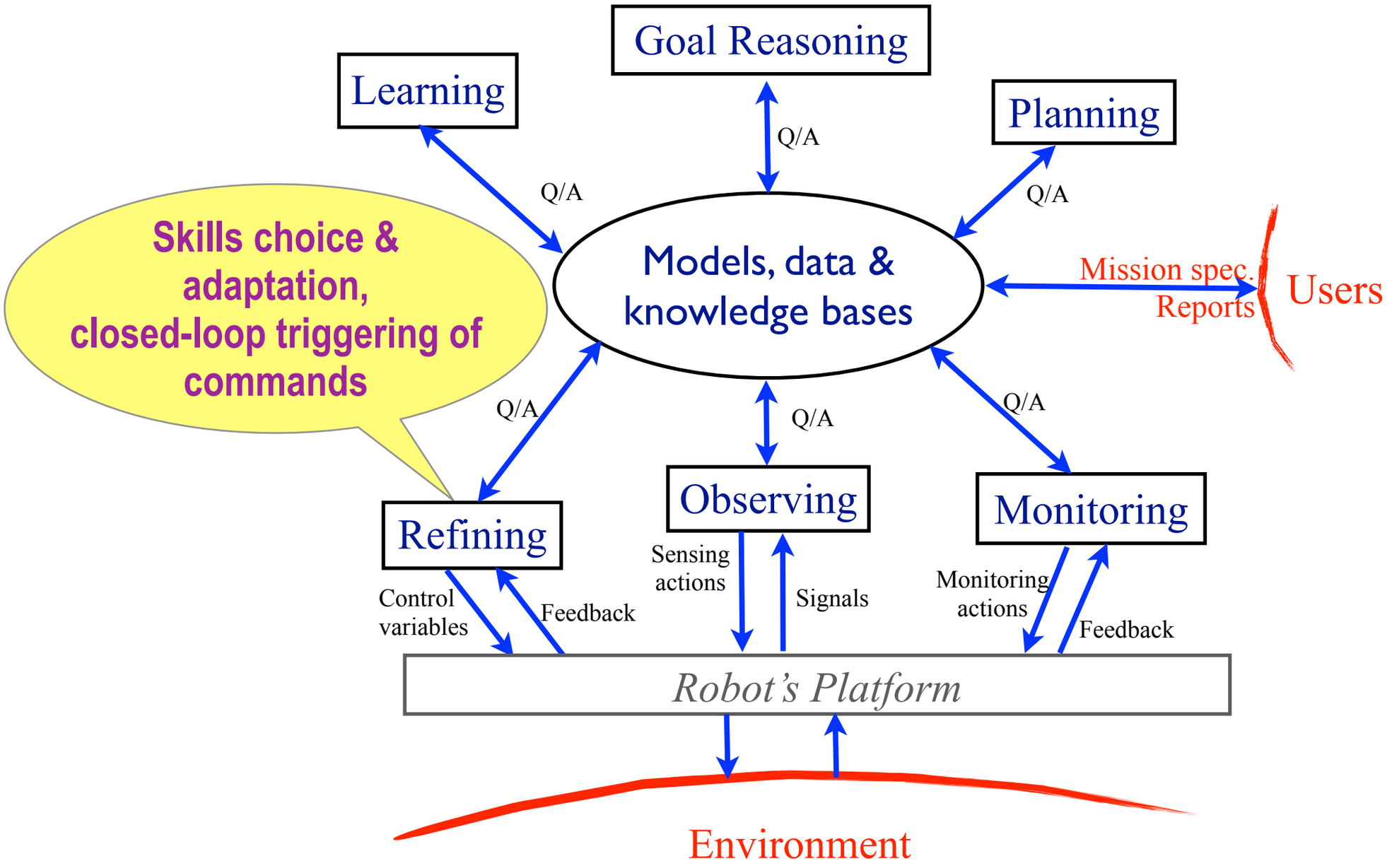

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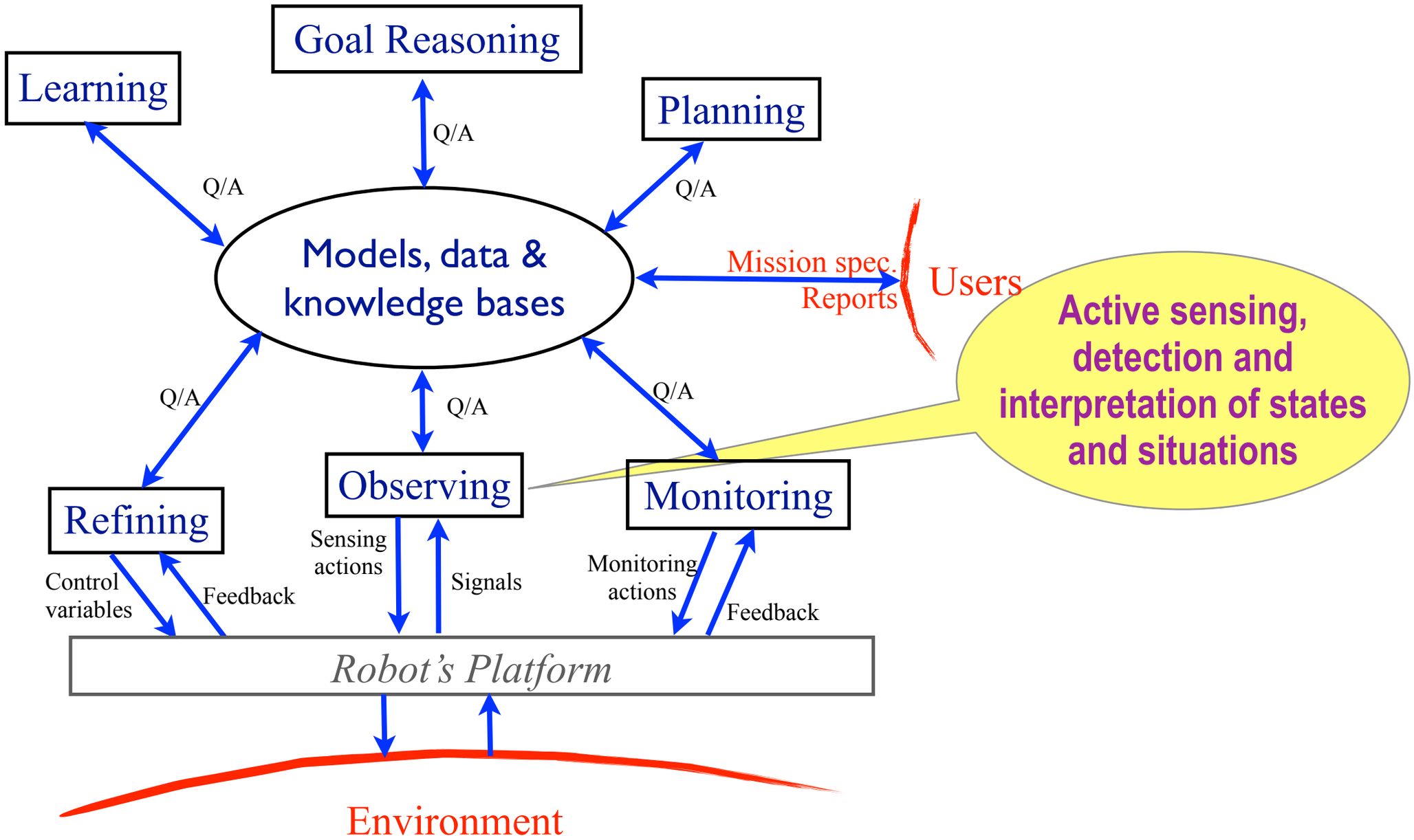

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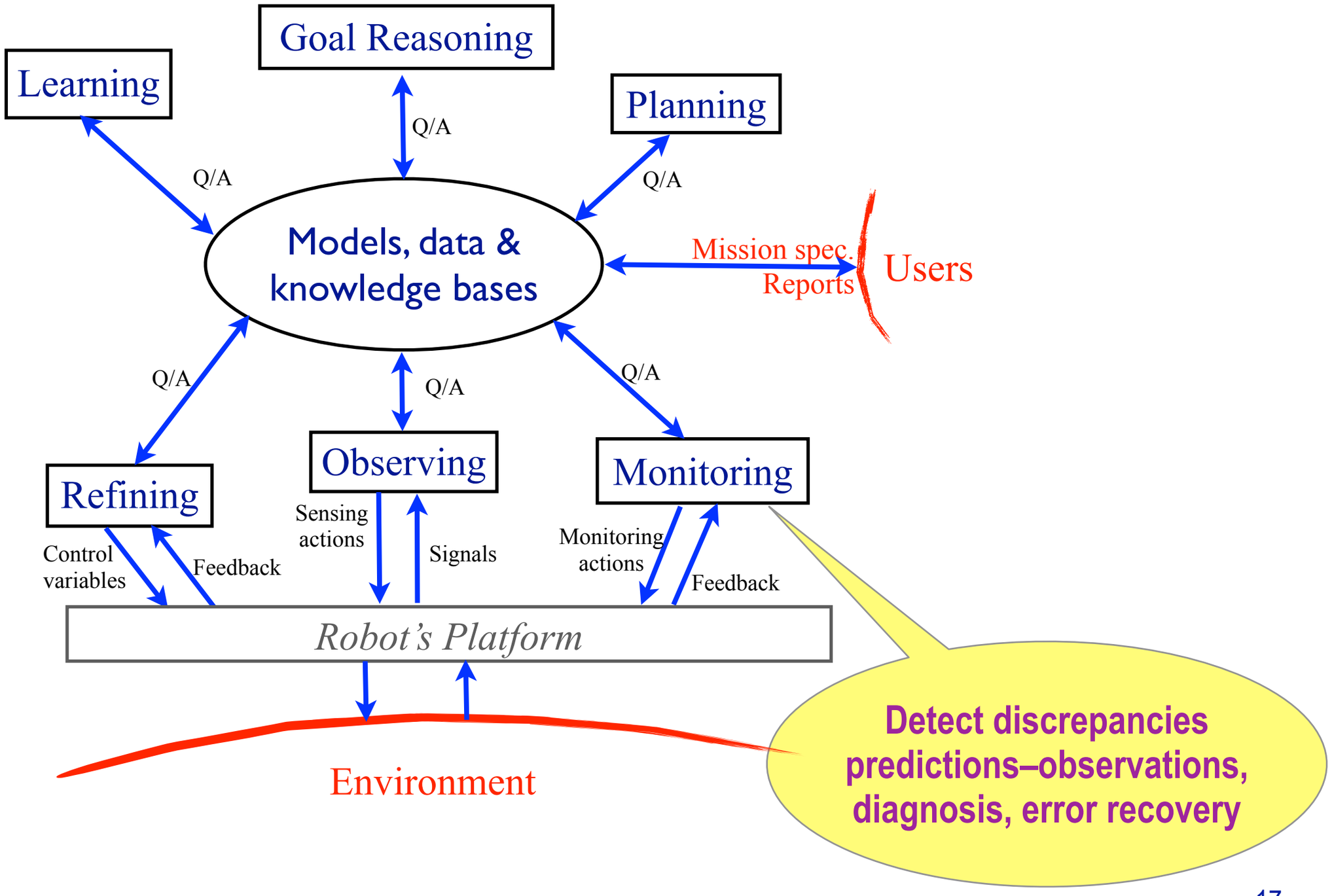

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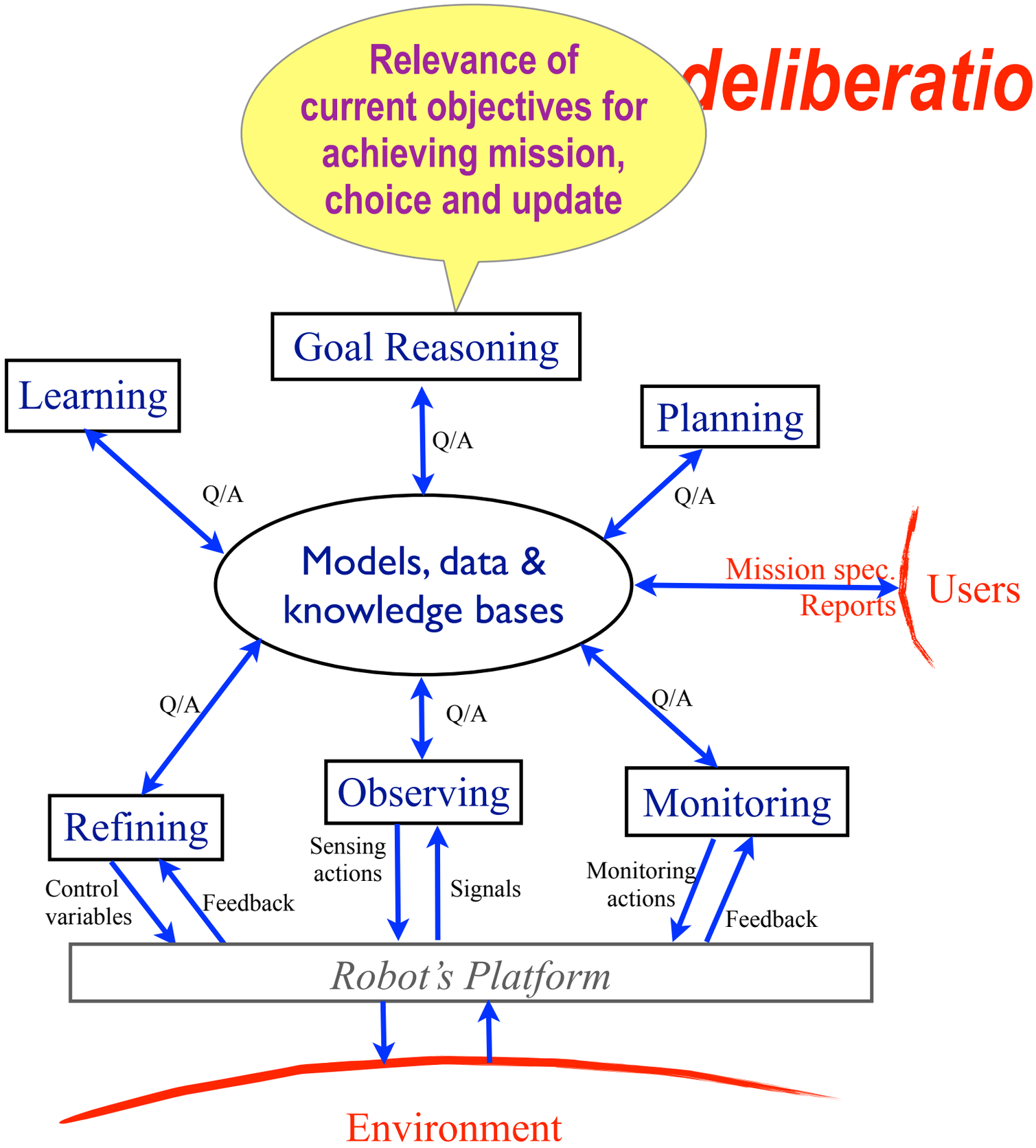
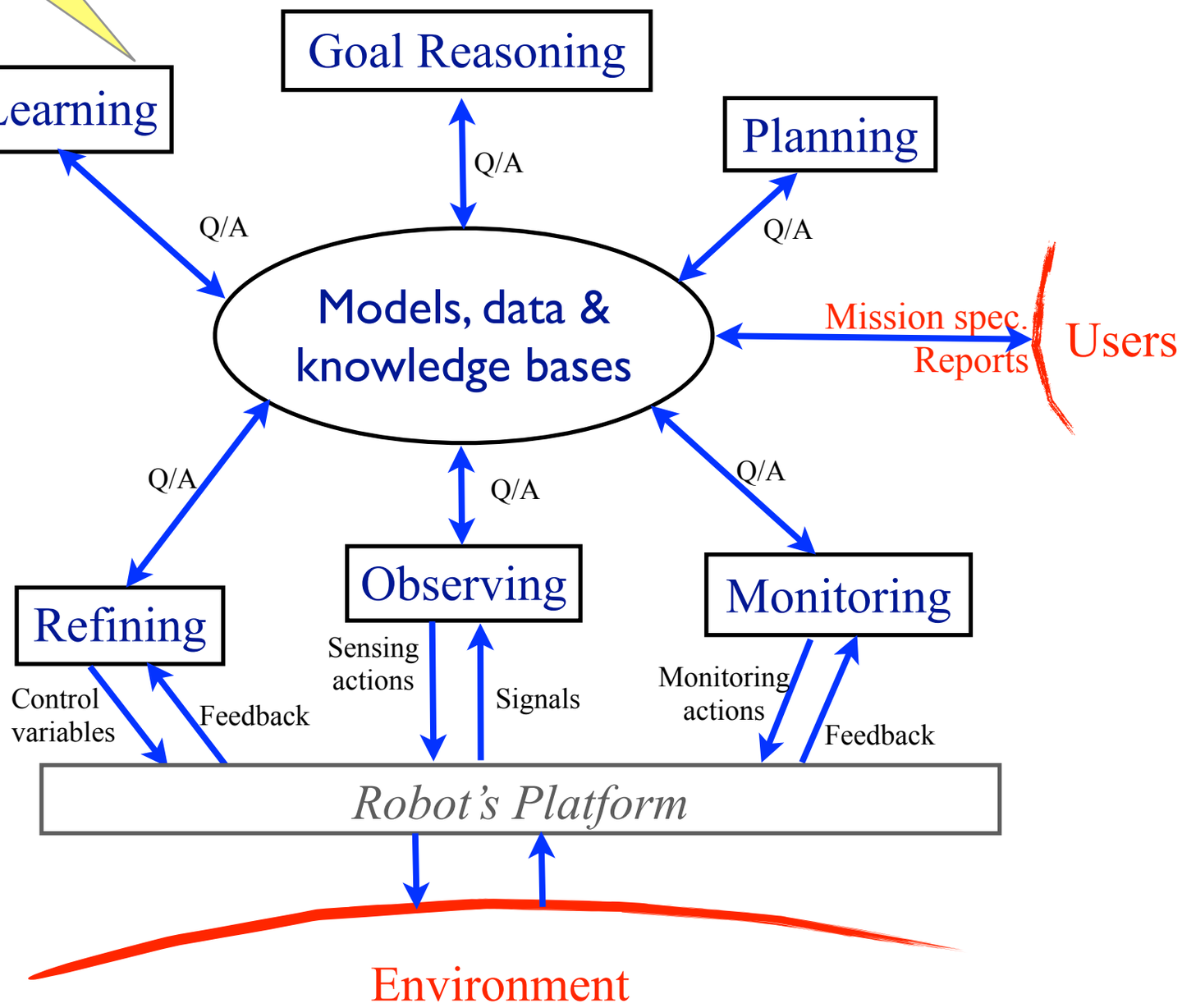


Actor's deliberation functions

Active learning to acquire and improve models and behaviors



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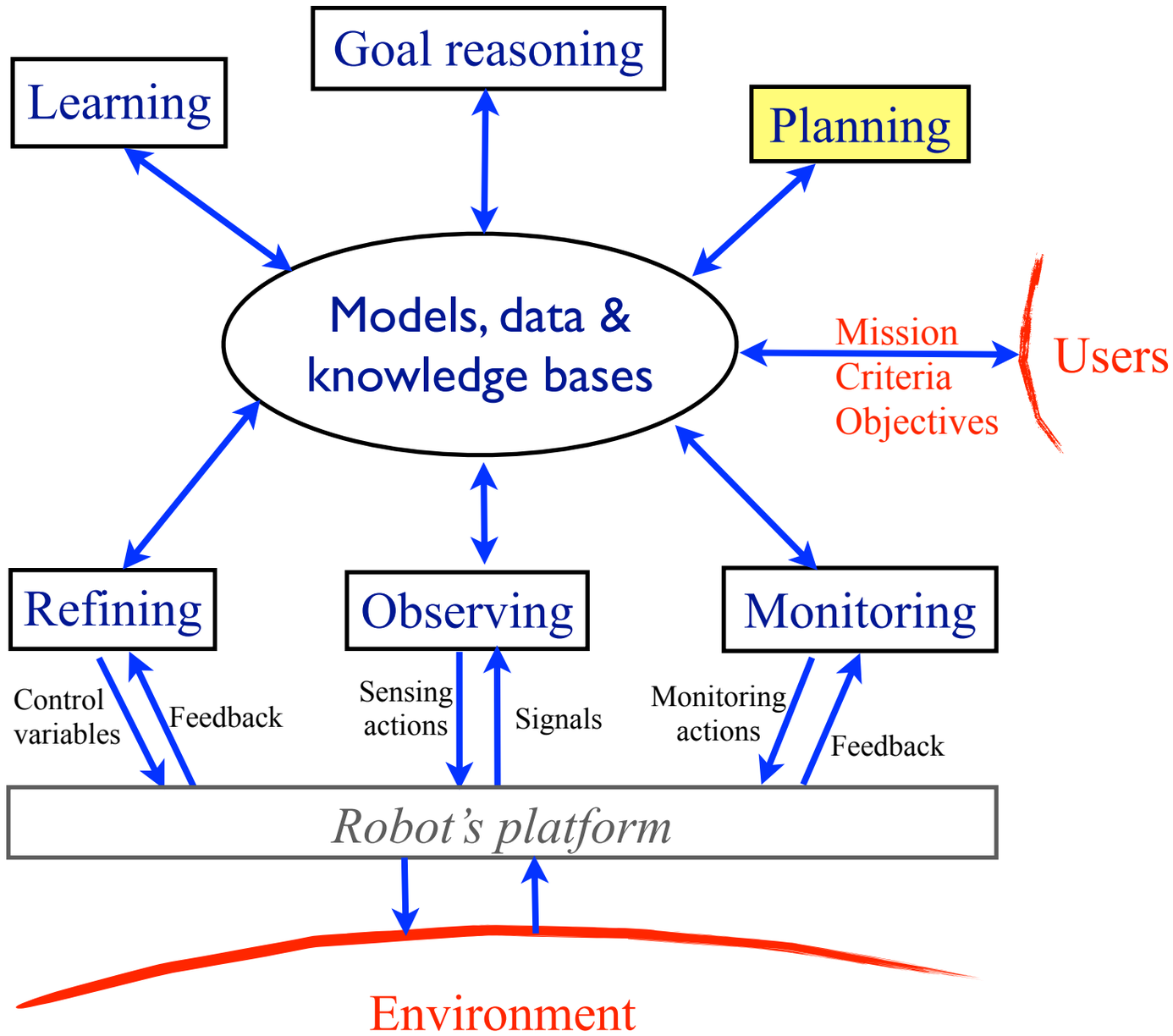

Planning in Robotics

- ***Different types of actions***

  => Different predictive models

  => Different planning problems and techniques

  - Motion and manipulation planning
  - Perception planning
  - Navigation planning
  - Communication planning
  - Task planning

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  ➡ Integration of planners with distinct state and action spaces

Planning in Robotics

- *Usual context*
  - Open, dynamic environment
  - Interaction with users
  - Online, interleaved with acting
- *Desirable features*
  - Access to external domain knowledge
  - Manage concurrency
  - Reason on uncertainty
- *Approaches*
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  - Temporal
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} ANML

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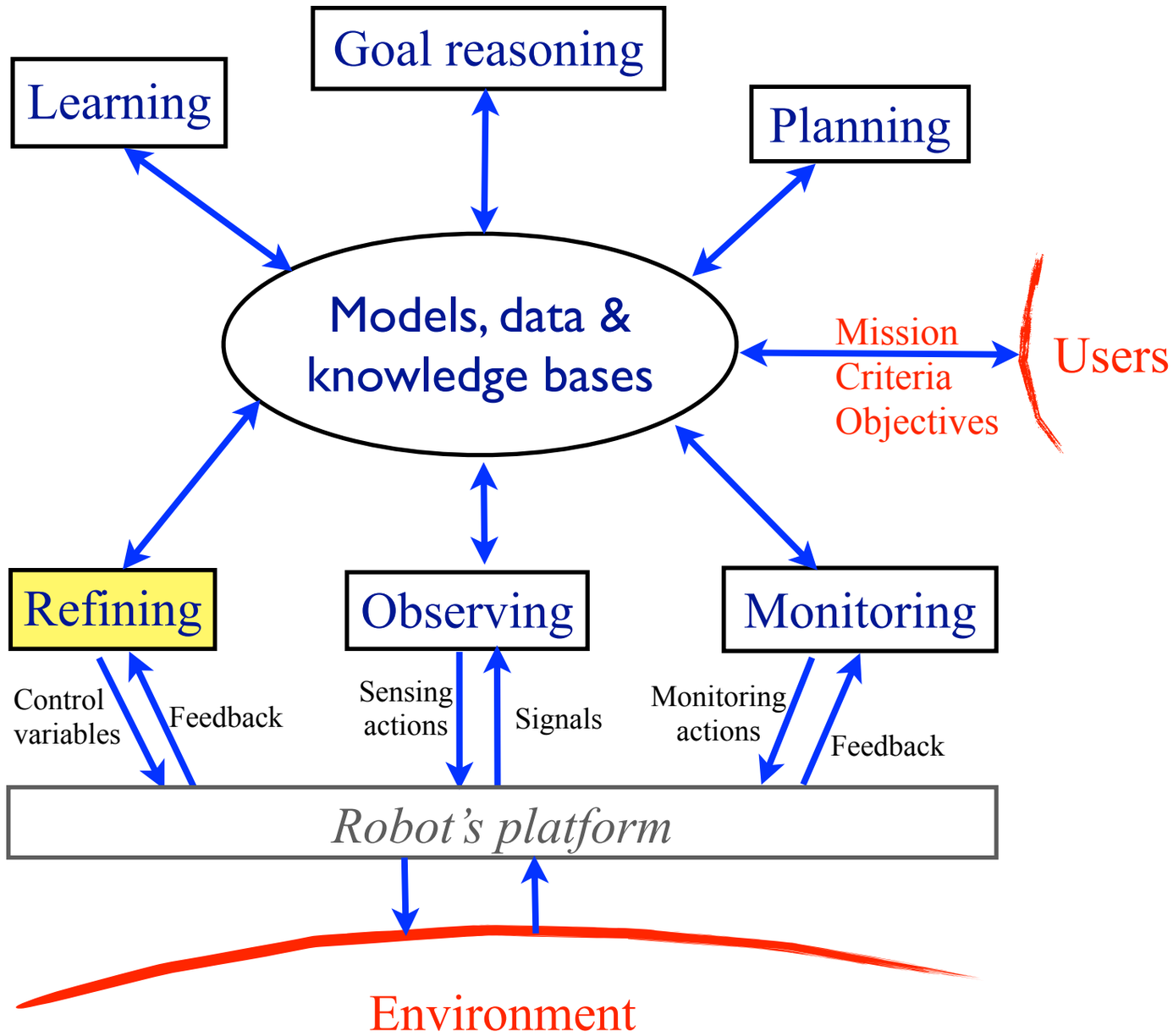
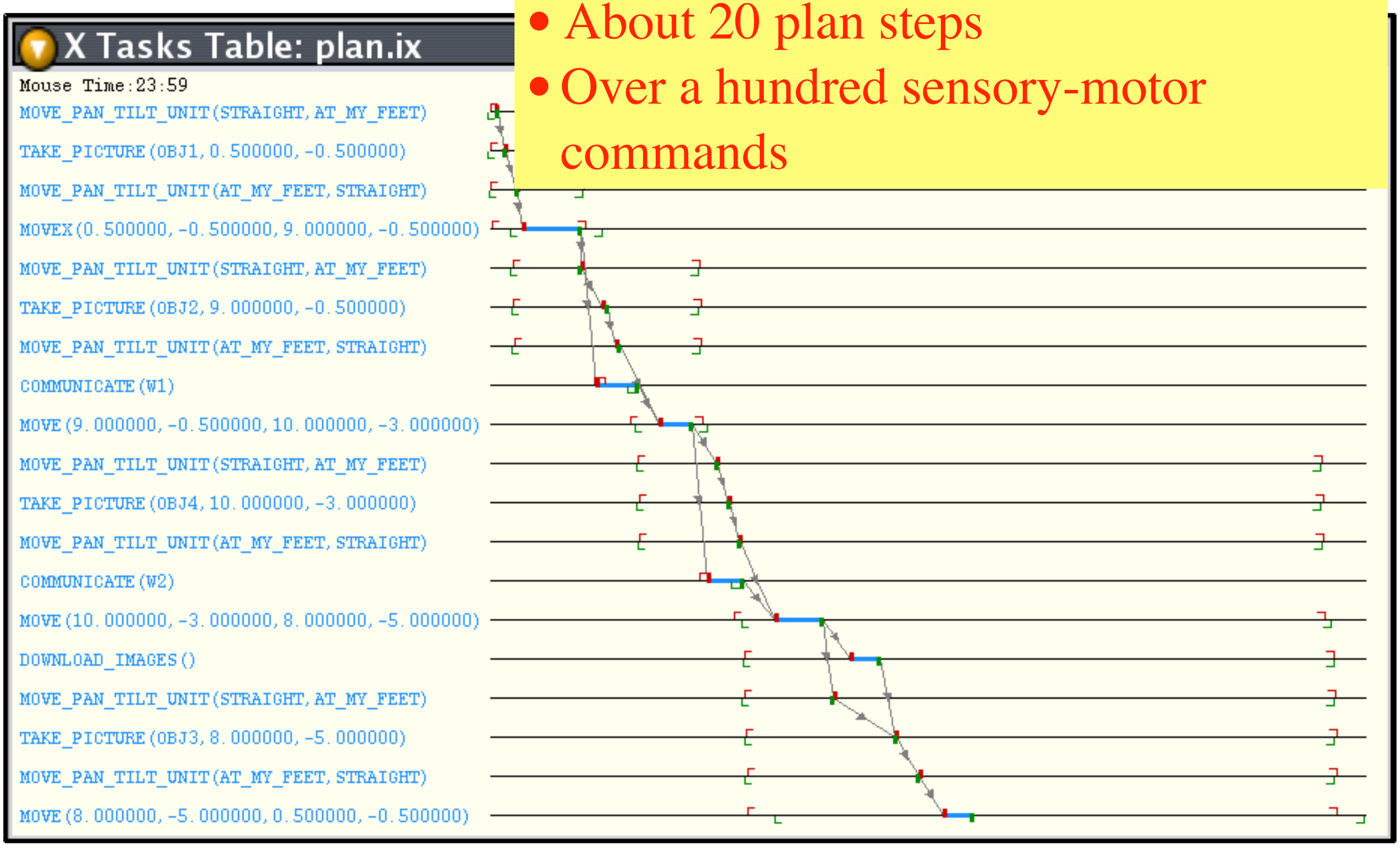
=> Sparse probabilistic models

Actor's deliberation functions



Refining abstract steps into skills

- About 20 plan steps
- Over a hundred sensory-motor commands



Refining abstract steps into skills

20 abstract steps:
Descriptive models
What, When, Why

Refinement

100 s-m commands:
Operational models
Modus operandi
How

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Refining abstract steps into skills

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What, When, Why

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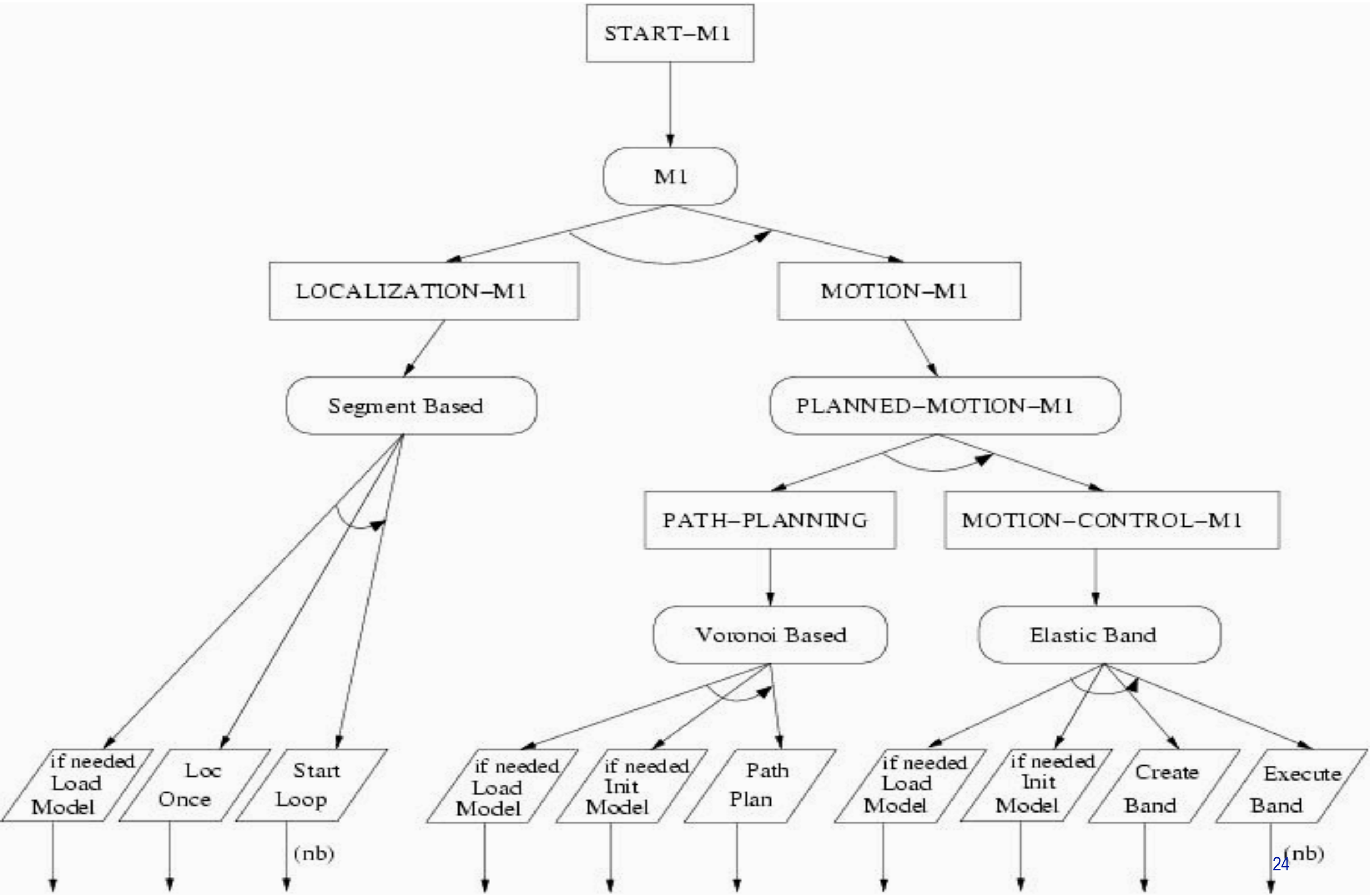
How to get the operational models ?

- Specification
- Synthesis

Synthesis of skills achieving an action



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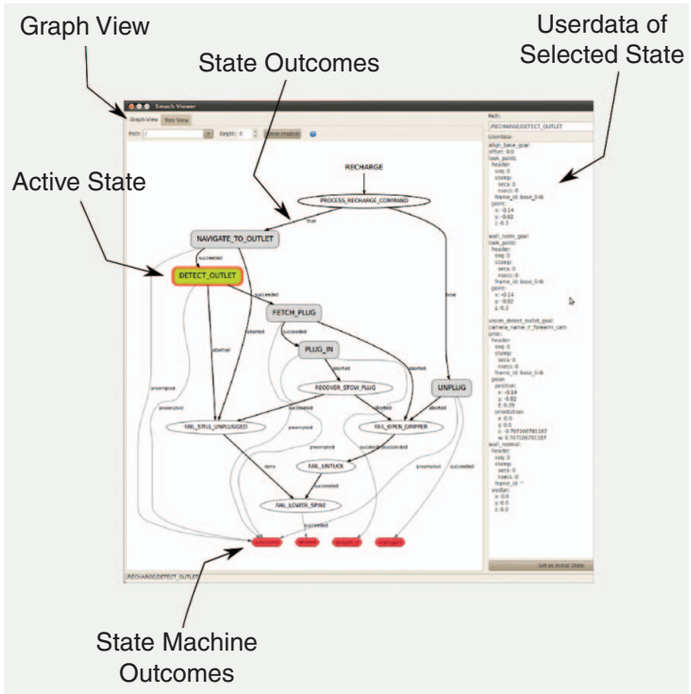

[Smach (ROS)]

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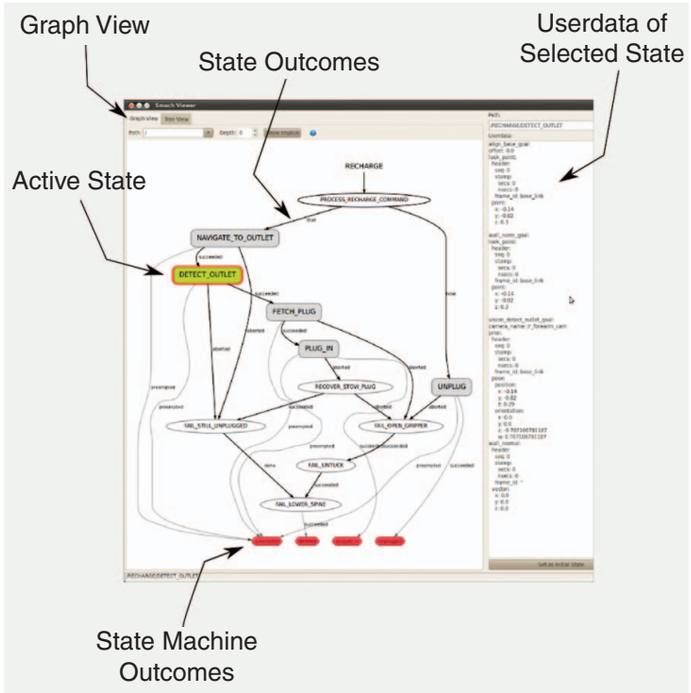

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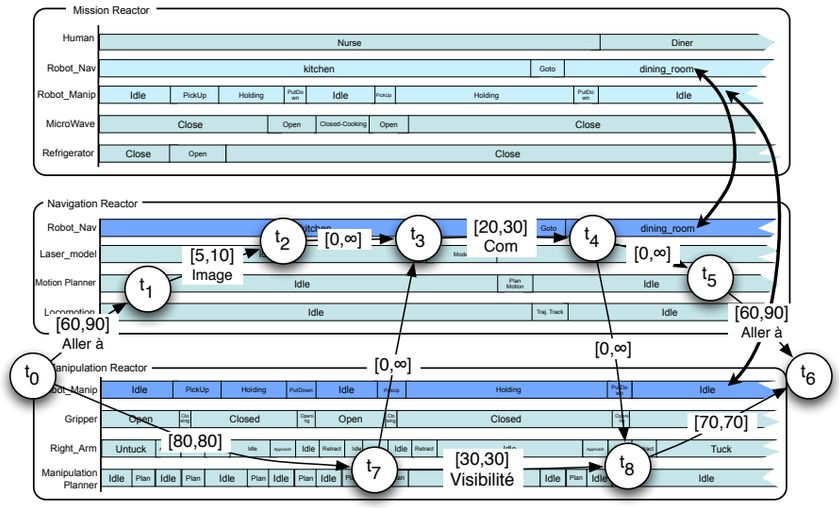


[T-Rex / IDEA]

Approaches

Approaches	Systems
Direct	STRIPS/Planex
Procedure	RAP
	PRS
	Cypress/CPEF
	TCA/TDL
	XFRM/RPL/SRP
Petri-Net	IMRS
	Procosa
	Petri-Net Plans
Automata Graph	FSA
	PLEXIL
	RMPL
	SMACH
Logic	Golex
	ReadyLog
CSP	IxTeT
	RMPL
	IDEA/T-ReX
	Casper
MDP	PEARL
	K9 MDP
	Robel
	Ressac

Approaches

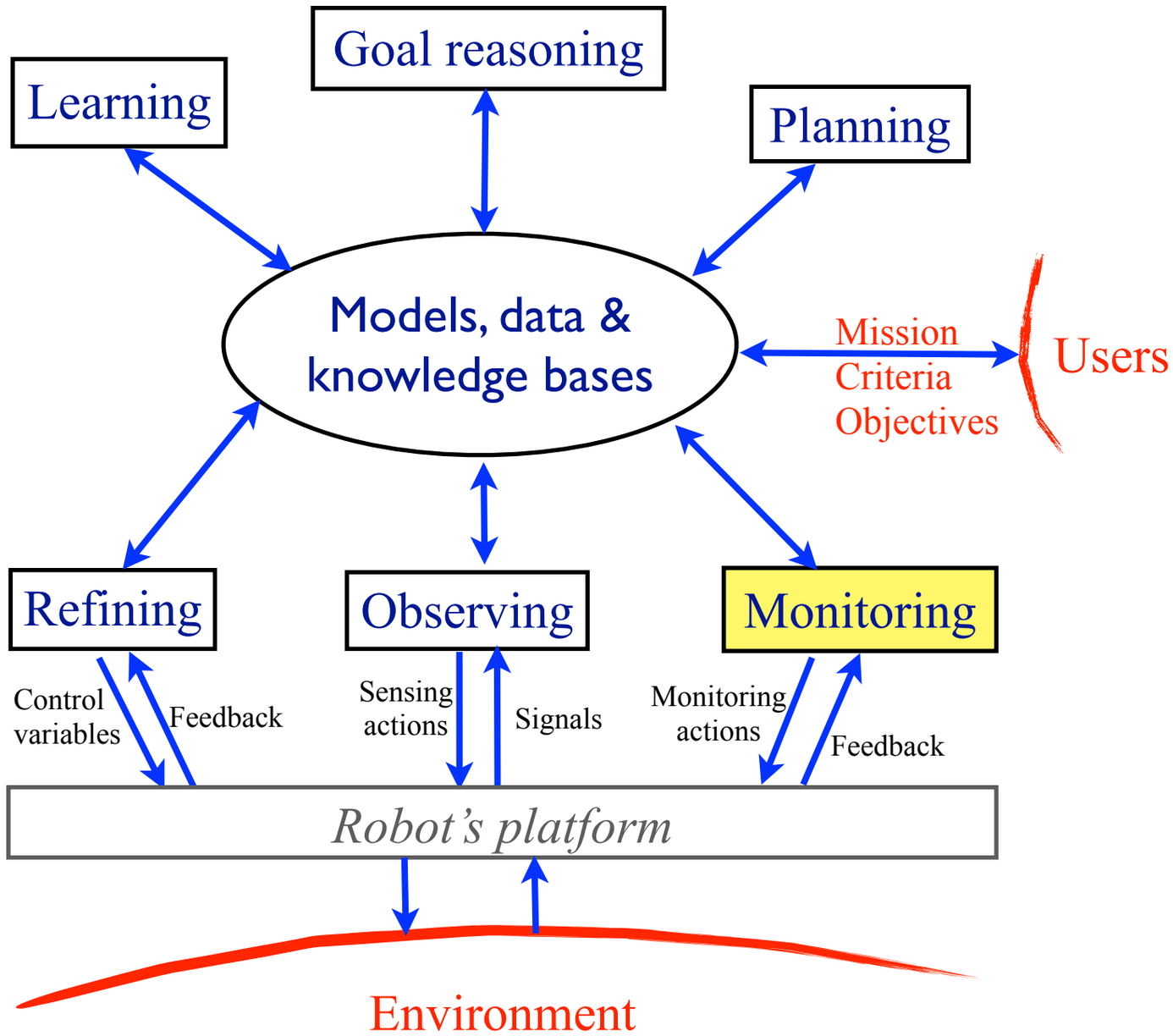
		Functions					Knowledge Representation			
Approaches	**Systems**	***Refinement***	***Instantiation***	***Time handling***	***Nondeterminism***	***Repair***	***Hand-Written***	***Model Based***	***V&V***	***Similar to Planning KR***
Direct	STRIPS/Planex					X	X			
Procedure	RAP	X	X				X			
	PRS	X	X				X			
	Cypress/CPEF	X	X				X			ACT
	TCA/TDL	X	X	X			X			
	XFRM/RPL/SRP	X	X			X	X			X
Petri-Net	IMRS	X		coordination			X	X	X	
	Procosa	X		coordination			X	X	X	
	Petri-Net Plans	X		coordination			X	X	X	
Automata Graph	FSA	X	X	X			X	X		Link
	PLEXIL	X	X	X			X	X		
	RMPL	X	X	X			X	X		
	SMACH	X	X	X			X	X		
Logic	Golex	X	X				X		X	Same lang. not same model
	ReadyLog	X	X				X		X	
CSP	IxTeT	X	X	X		X		X		X
	RMPL	X	X	X	X	X		X		X
	IDEA/T-ReX	X	X	X		X		X		X
	Casper	X	X	X		X		X		X
MDP	PEARL				X					
	K9 MDP				X					
	Robel				X					
	Ressac				X					

Refining abstract steps into skills

Descriptive models
Know-What

Operational models
Know-How

Actor's deliberation functions



Monitoring

- Functions
  - Survey actor's predictions

    in plans, skills and environment models
  - Detect discrepancies = predictions - observations
  - Explain and diagnose discrepancies
  - Recover: trigger first reactions and repair actions

Approaches

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  more proprioceptive then exteroceptive

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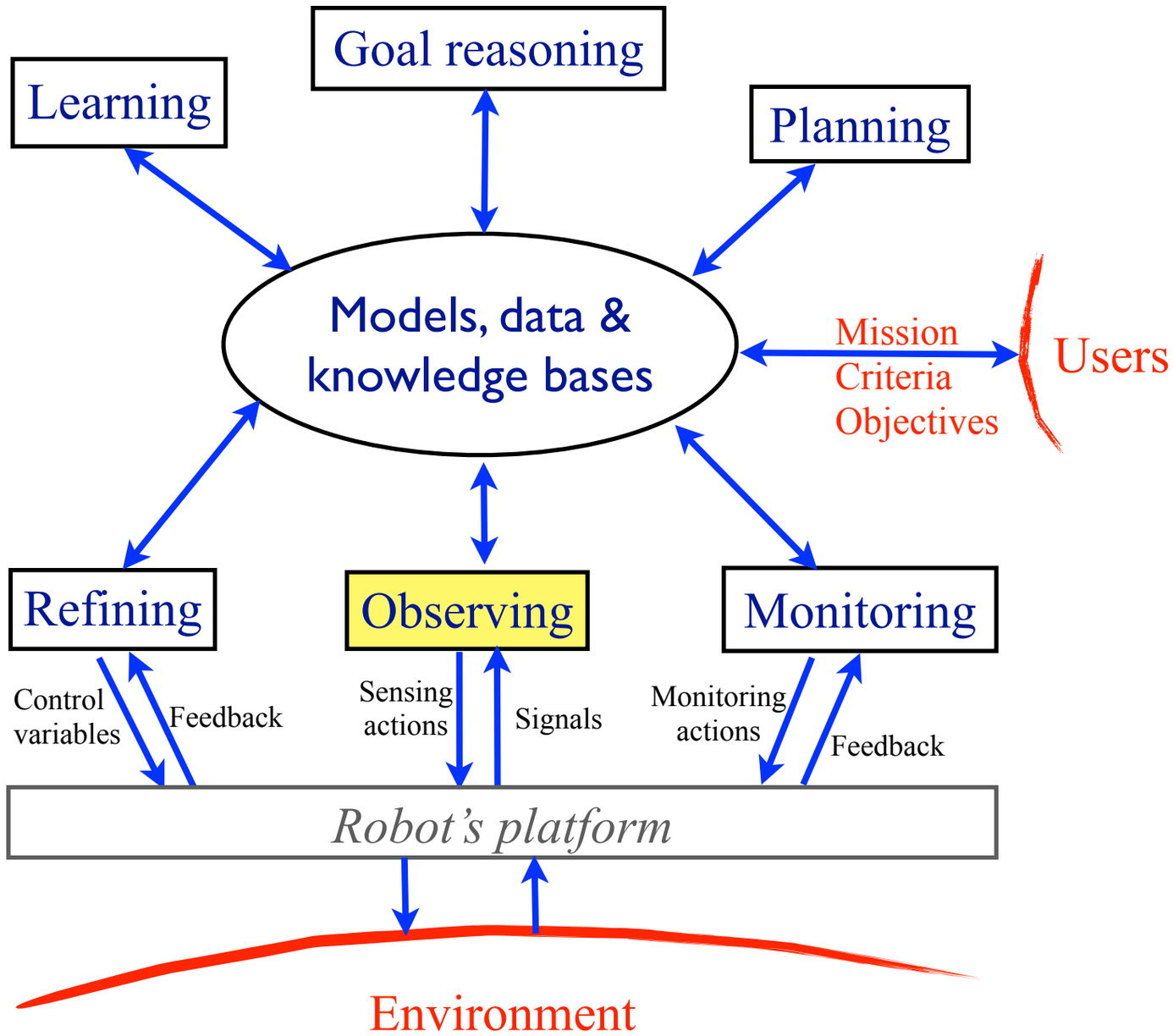
- Synthesize additional invariants from extended planning problems which guarantees the plan execution, e.g., TALPlan
- Model checking execution traces with LTL
- Constraint Based Automata + Control programs, e.g., RMPL

Approaches

	Knowledge Representation	*Search & Algorithm*	*Link with other Deliberative Functions*
Planex	Triangular table		with planning and exec
Livingstone	Qualitative model Transition automata with probabilities and costs	ITMS with conflict directed best-first search	
RMPL	Hierarchical constraint-based automata	Reactive programming	with planning
[Fraser et al., 2005]	Logical invariant	Logical satisfiability	with planning
[Fichtner et al., 2003]	Fluent Calculus	Prioritized non monotonic default logic	
[Lamine and Kabanza, 2002]	Linear Temporal Logic	Delayed formula progression	same technique used for planning
[Petterssonetal.,2003]	Neural net		
SKEMon	Description Logic & Bayesian Belief		
TALplanner	Temporal Action Logics	Formula progression	with planning and observing

Actor's deliberation functions



Observing

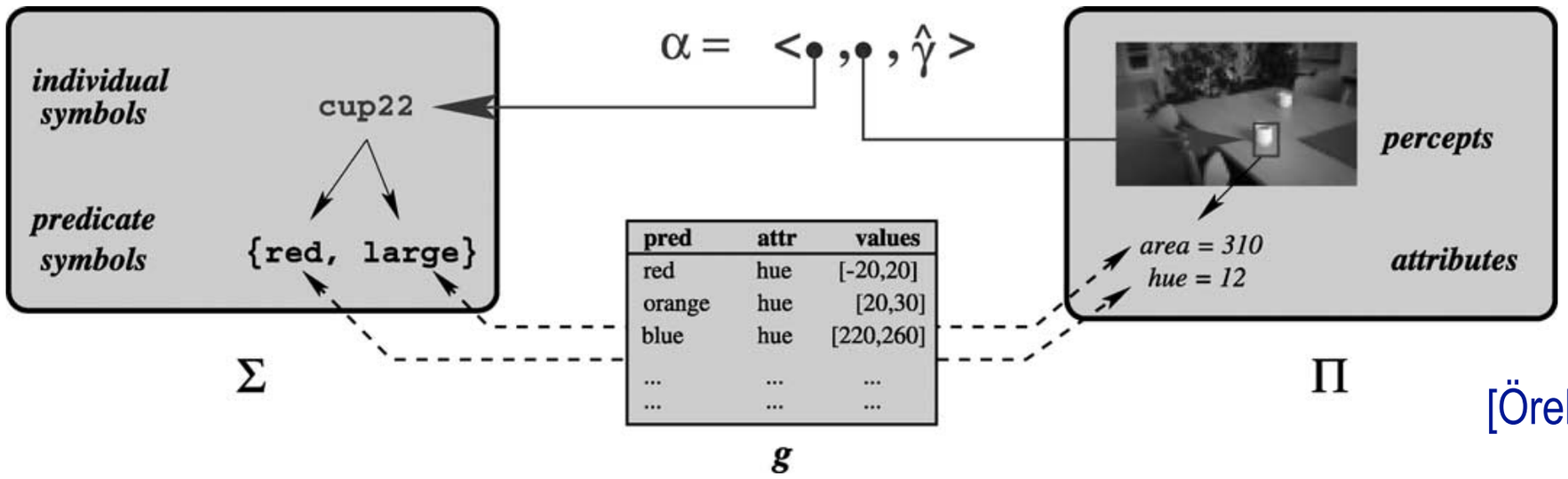
- Role
  - Process signals needed in closed loop servoing
  - Detect and structure environment features

    Recognize, categorize,

    Link signals to symbols: anchoring
    - Recognize situations and plans in observed sequences of events
- Bottom-up to from signal to symbols
- Top-down to focus attention and trigger observation actions

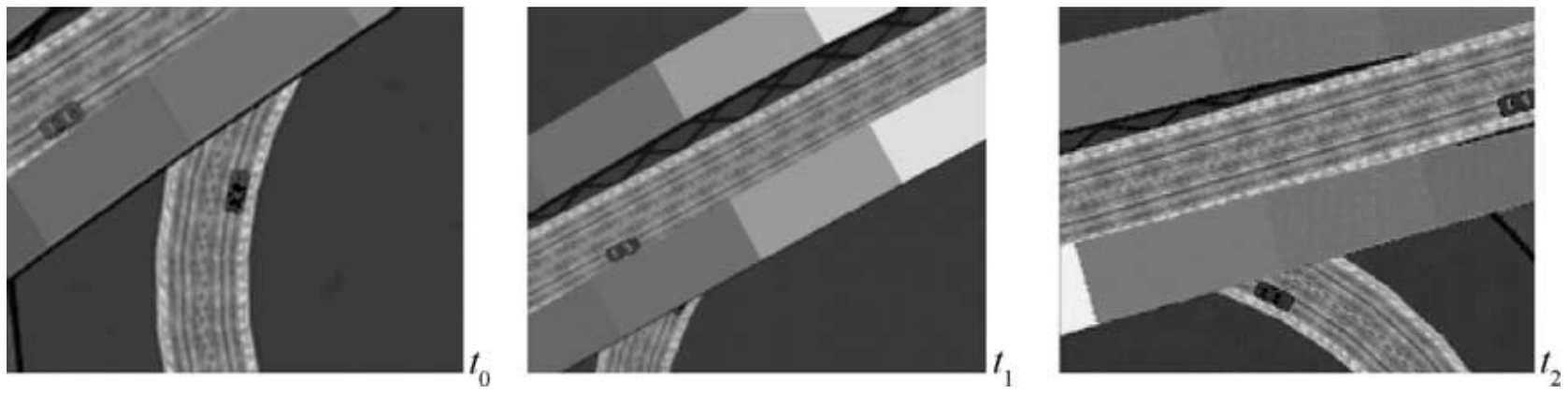
Observing

- Anchoring problem
  - Relate perceptual data and symbolic attribute corresponding to the same physical object



[Örebro Univ.]

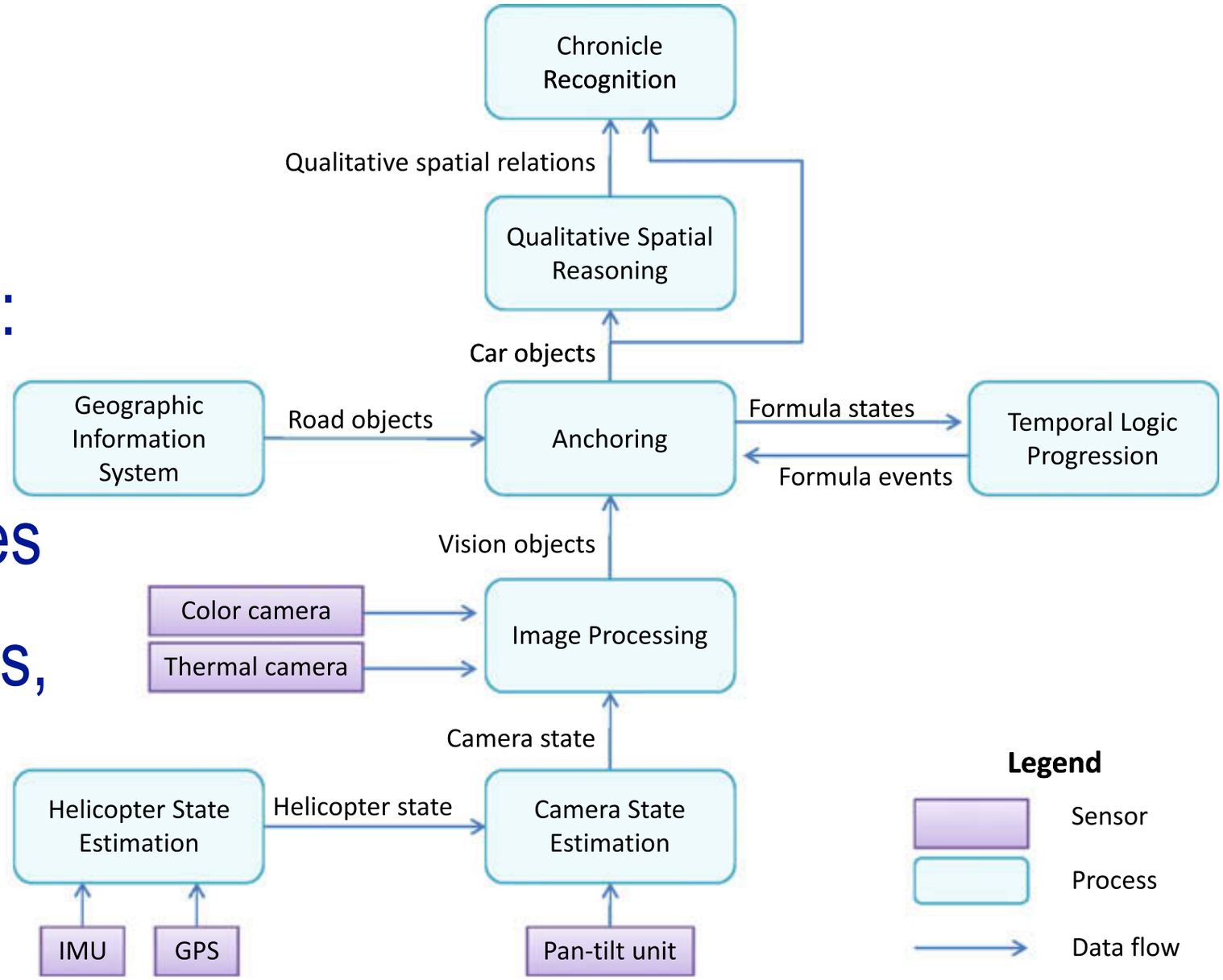
- Track anchors overtime and refine/revise hypothesis



[Linköping Univ.]

Perception Engine

- Comprehensive and coherent approach for observing
- Data flow architecture
- Stream-based formalism on perception processes:
  - primitive, refinement, configuration processes
  - policies over processes, temporal constraints
- Integration to planning and monitoring,
- Opens V&V perspectives



[Dyknow, Linköping U.]

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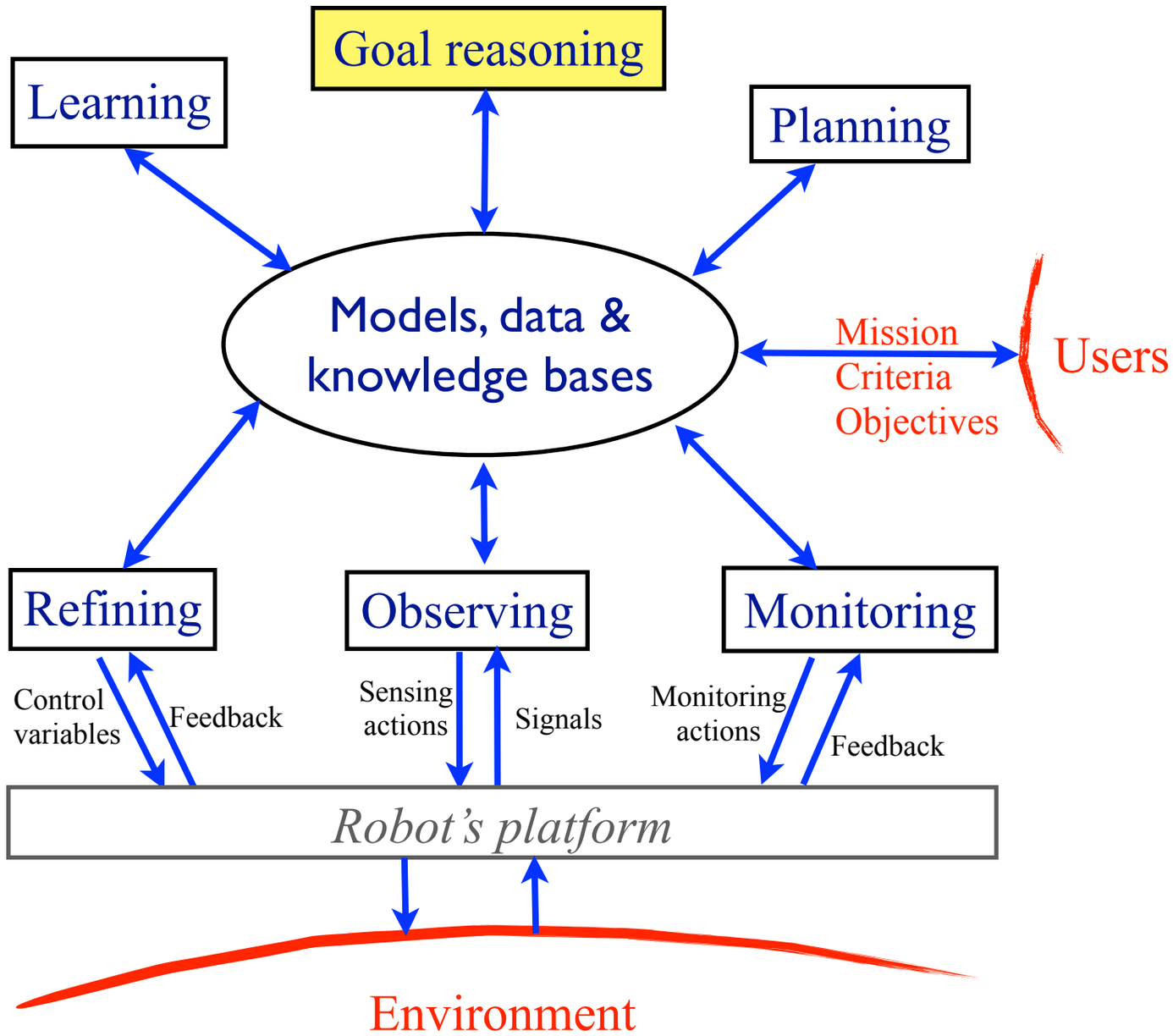

Goal Reasoning

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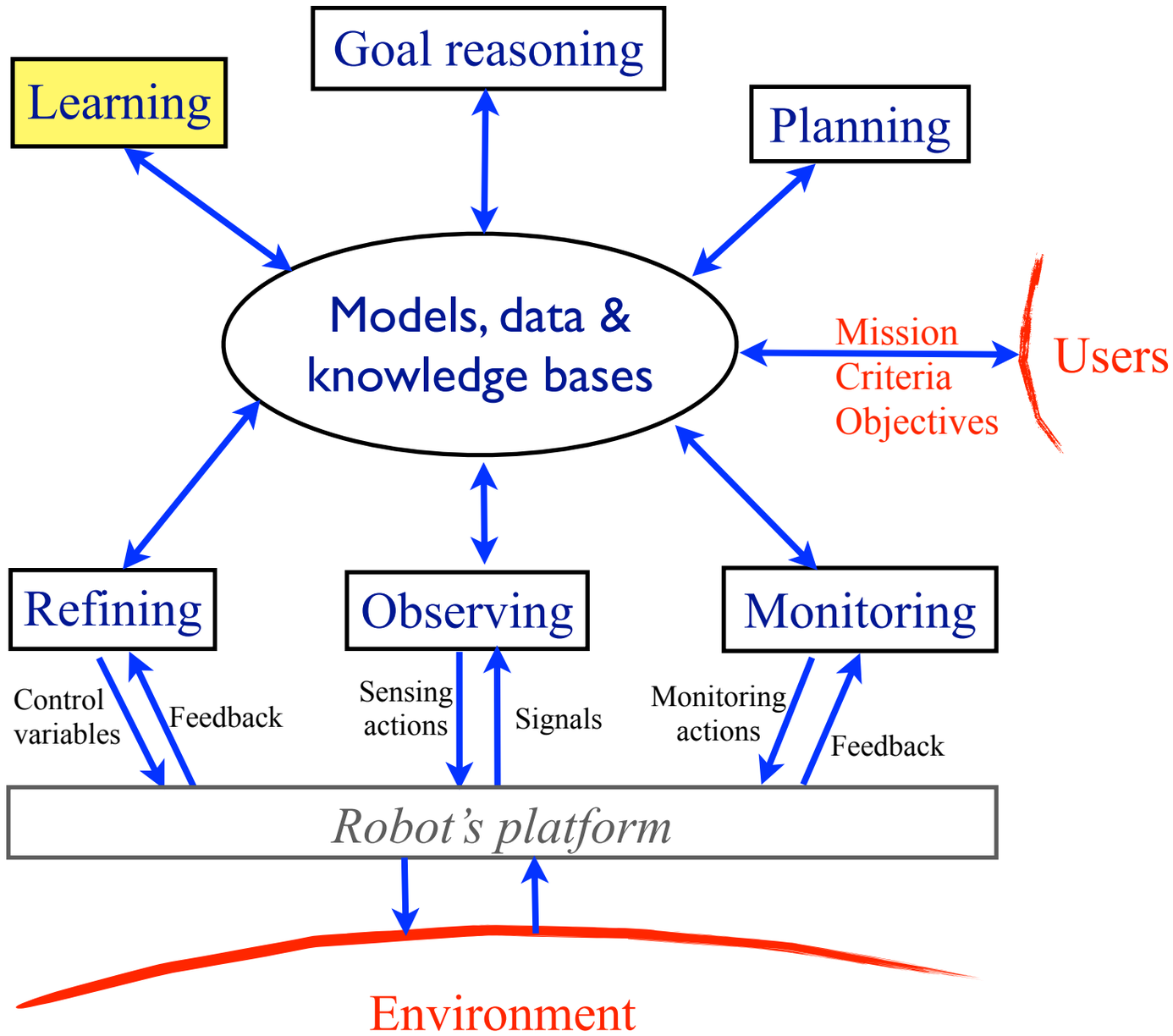
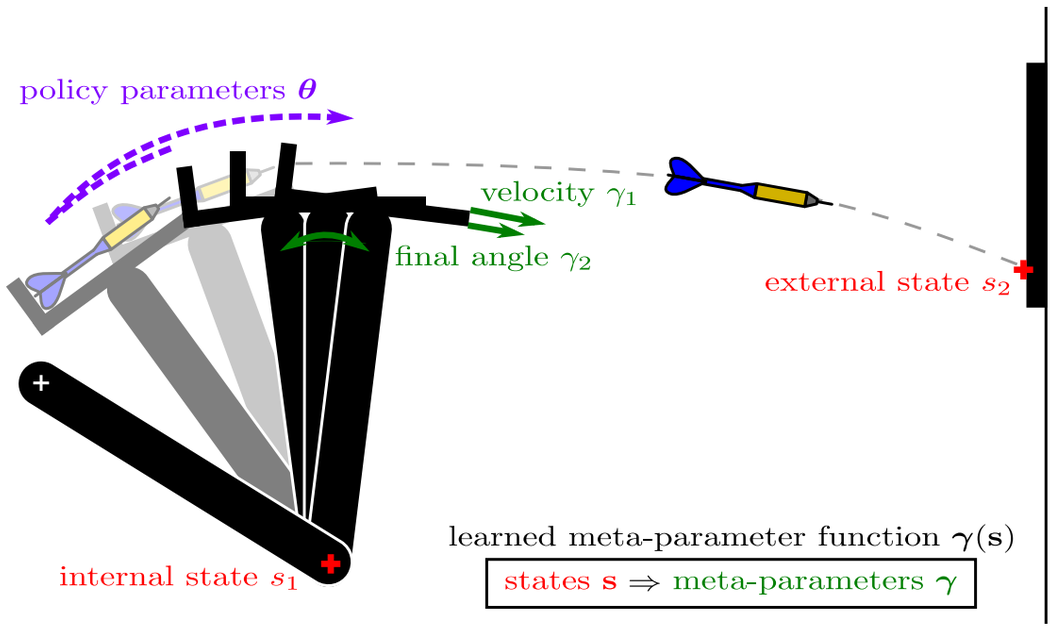
    - Explicit choice
- Found in large systems, e.g., CPEF, DS1

  Function often embedded in acting/monitoring/planning

Actor's deliberation functions



Reinforcement Learning of sensory motor functions



[MPI Bio-Cybernetics, Tübingen]

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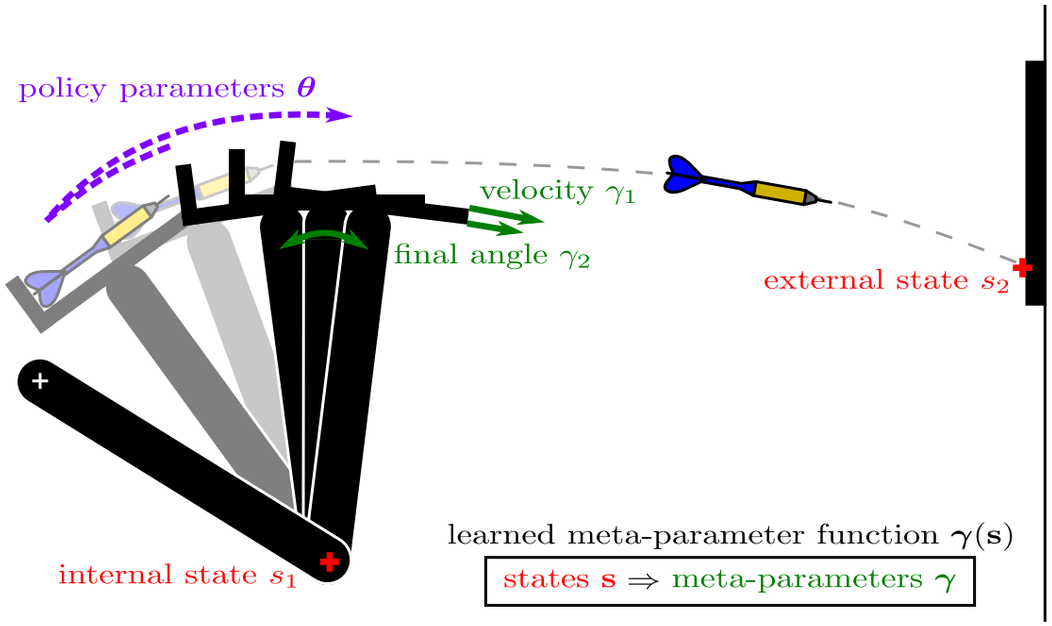

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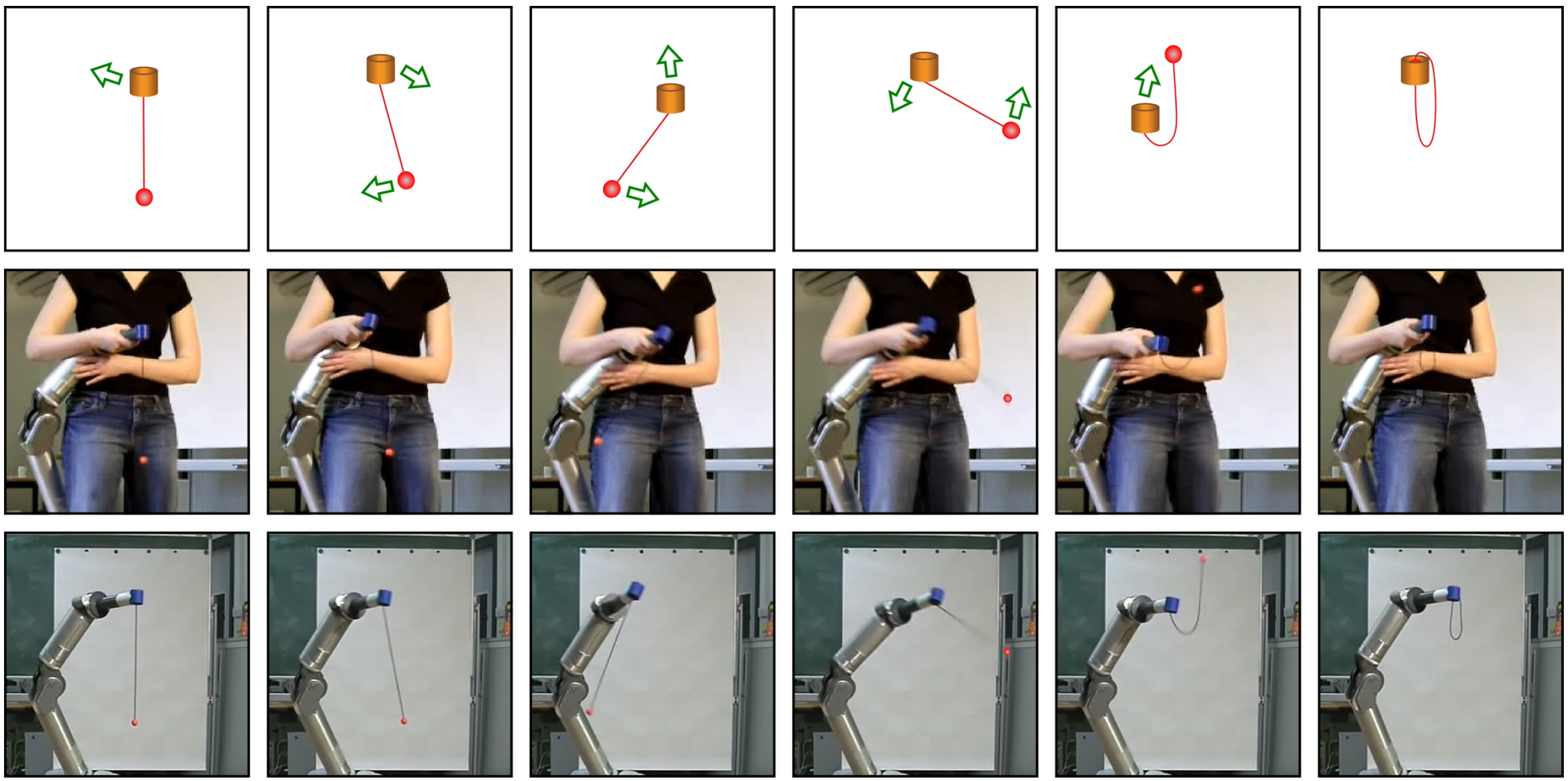

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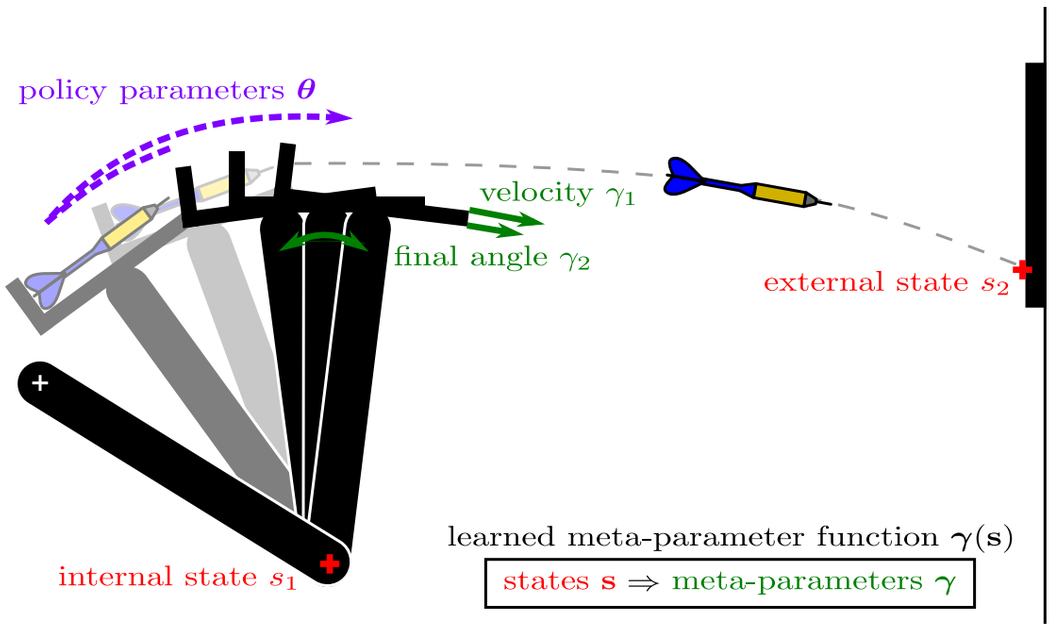

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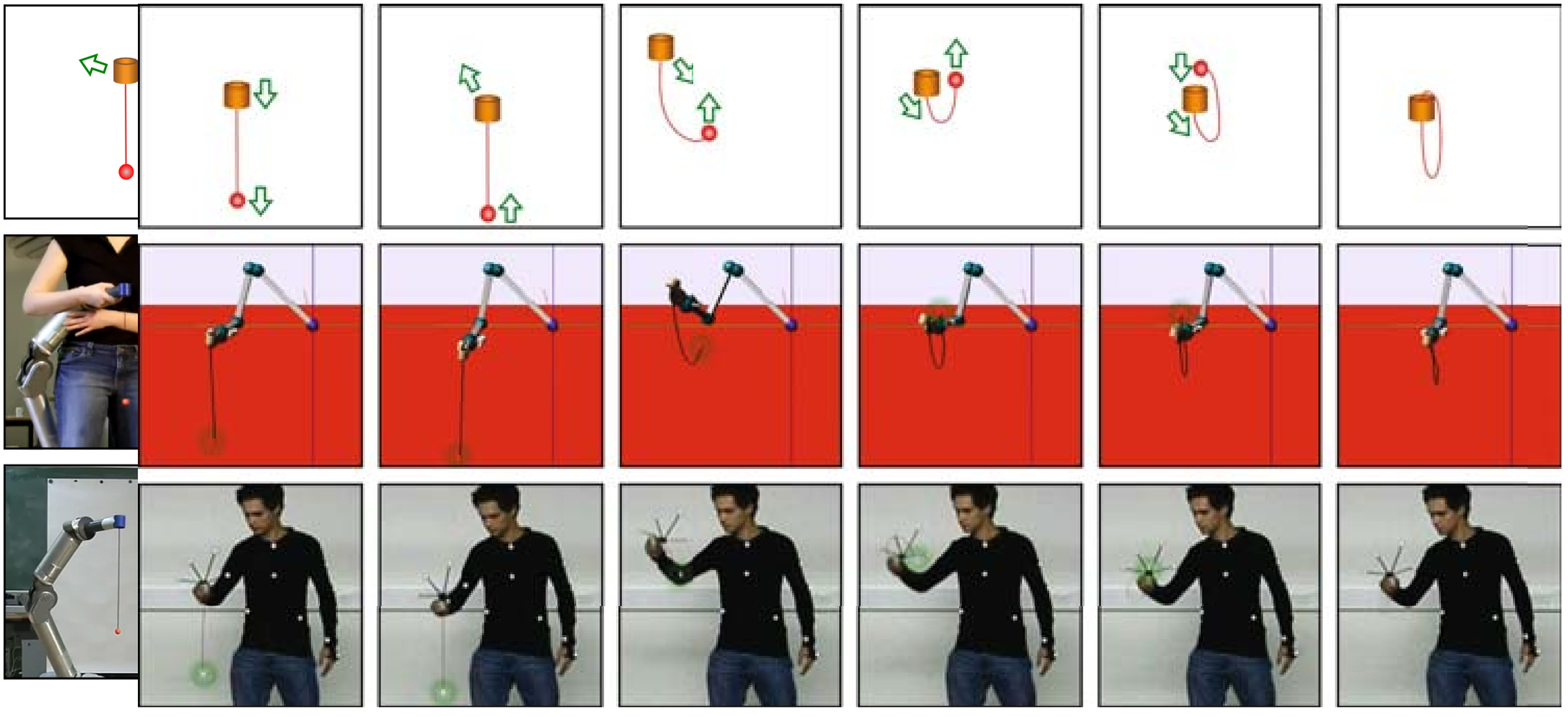


Helicopter Aerobatics Apprenticeship Learning

[U. Stanford]

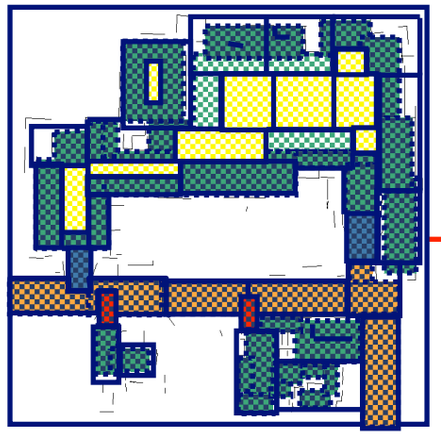
Aerobatics Apprenticeship Learning

Simple linear rigid dynamic models of helicopter

- Learn dynamic models, *one for each type of maneuver*
  - Regression from teacher's demonstrations
  - Improvement by reinforcement learning in autonomous flight
- Learn reference trajectories, one for each aerobatic figure
  - *Expectation-Maximization* on teacher's demonstrations
  - Temporal alignment and optimization
- Learn controllers, one for each aerobatic figure
  - *Differential dynamic programming* continuous MDPs solved by iterative approximation of receding horizon LQR problems

Skill selection learning

Navigation goal



Reports

Markov Decision Process

- Optimal plan
- Receding Horizon Control

S2

Query resource

Resource allocation

Resource Manager

Suspend
Resume

Start

Stop

Extensible set of skills

Skill 1

Skill 2

Skill 3

Skill 4

. . .

action

action

action

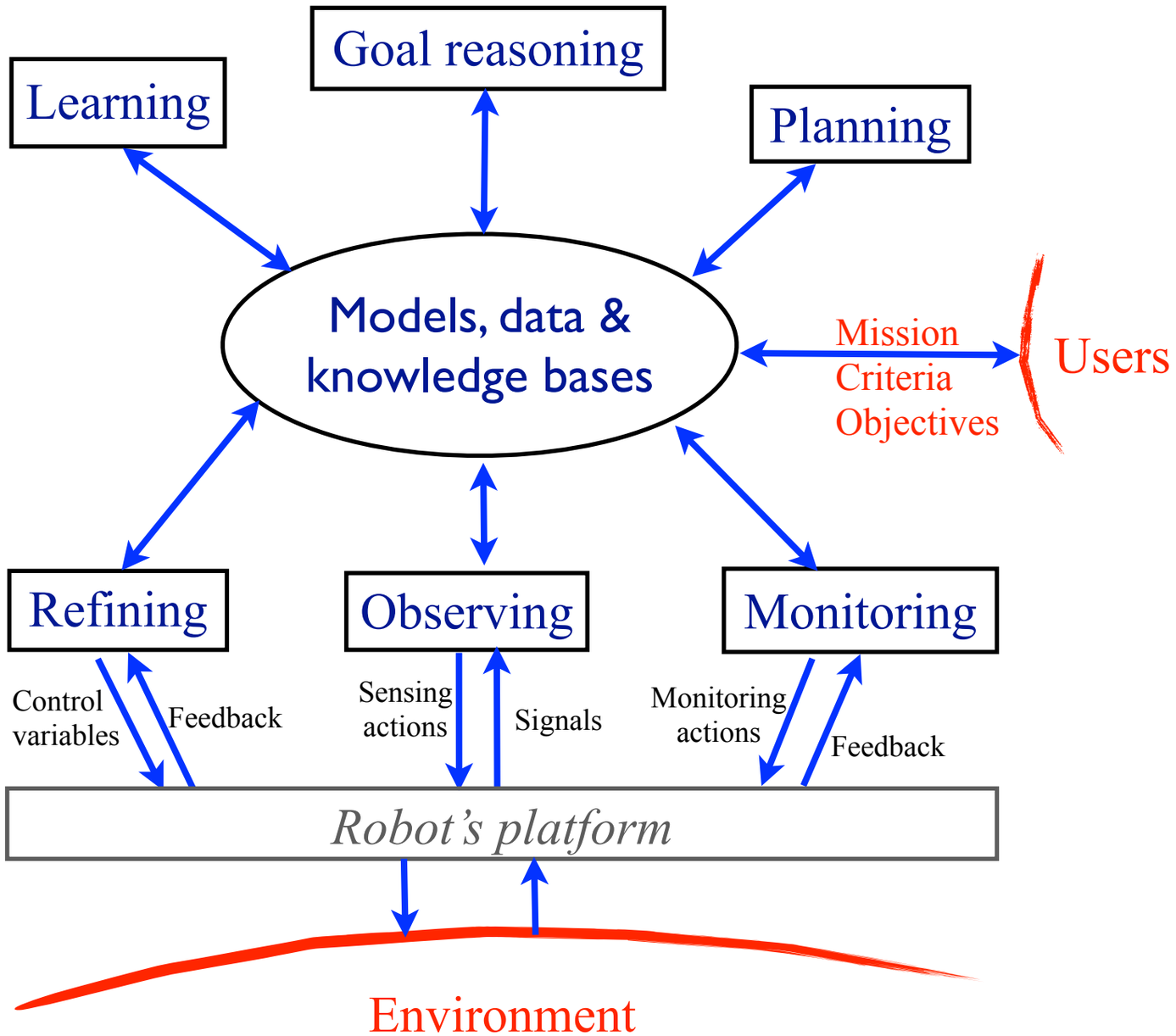
action

Reactive Control System

Reports

Sensory-motor commands

Actor's deliberation functions



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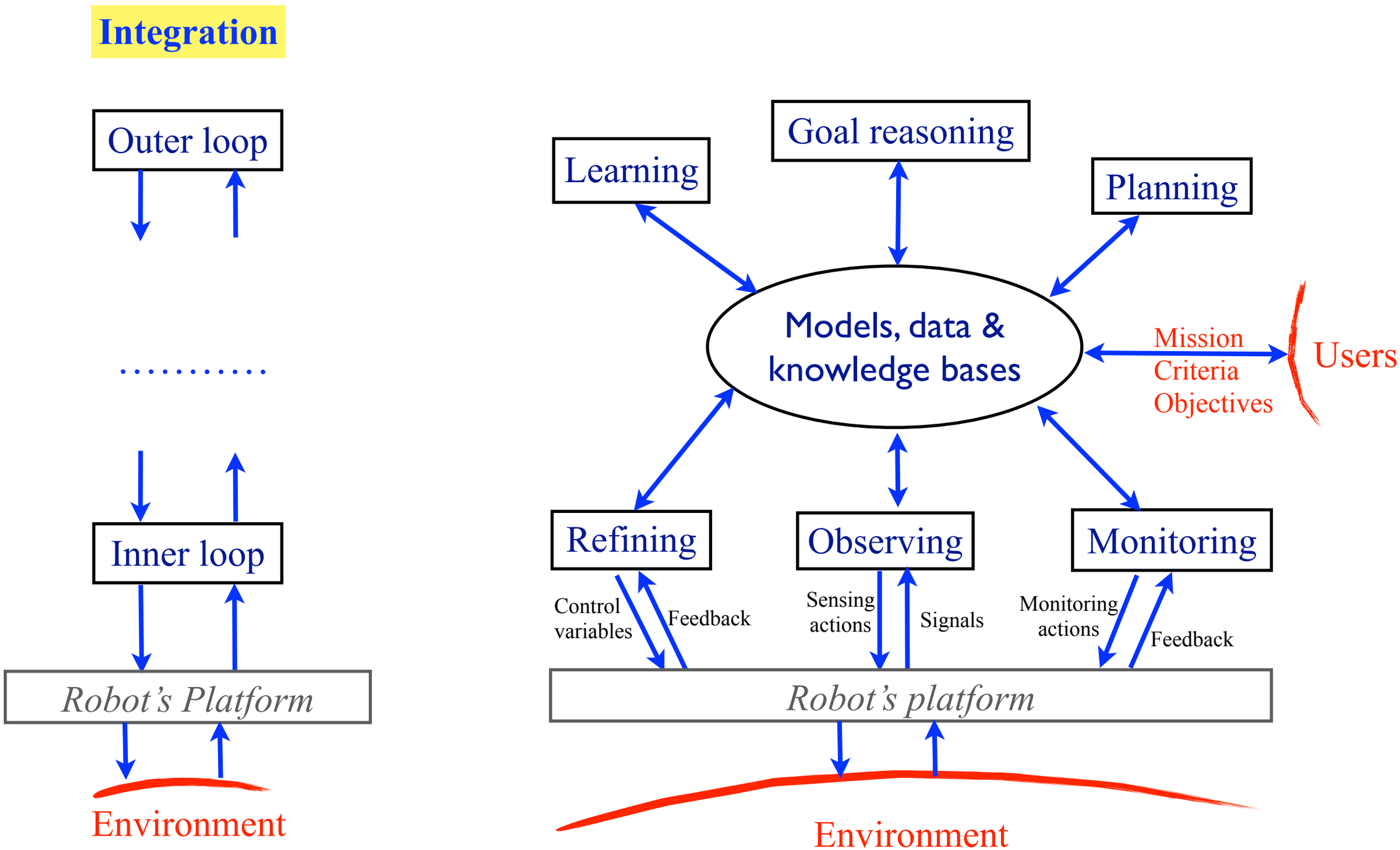
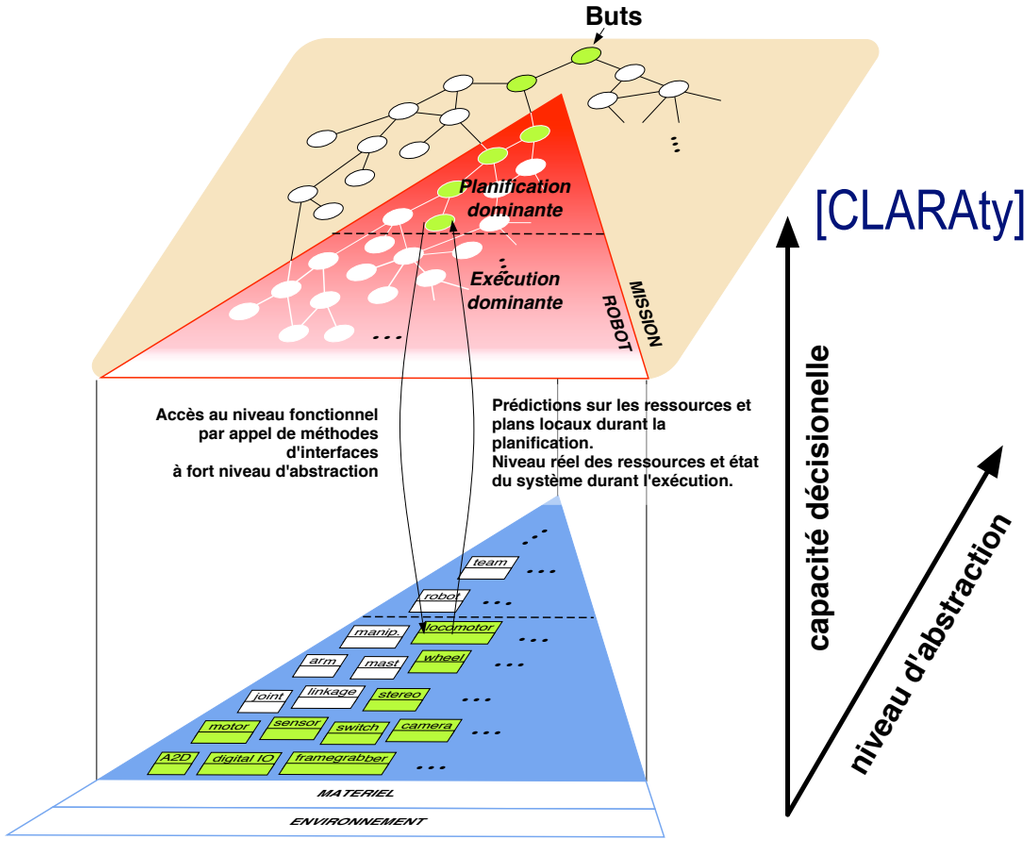


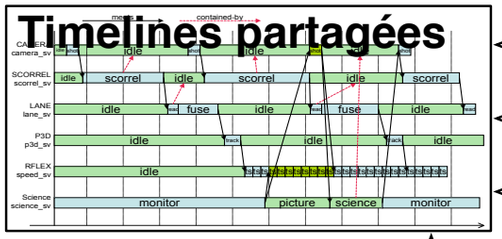
Integration



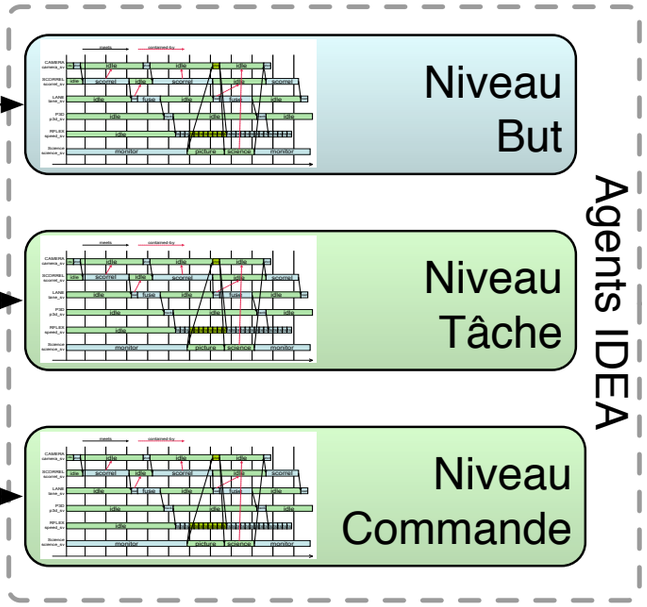
[CLARAty]

capacité décisionelle

niveau d'abstraction

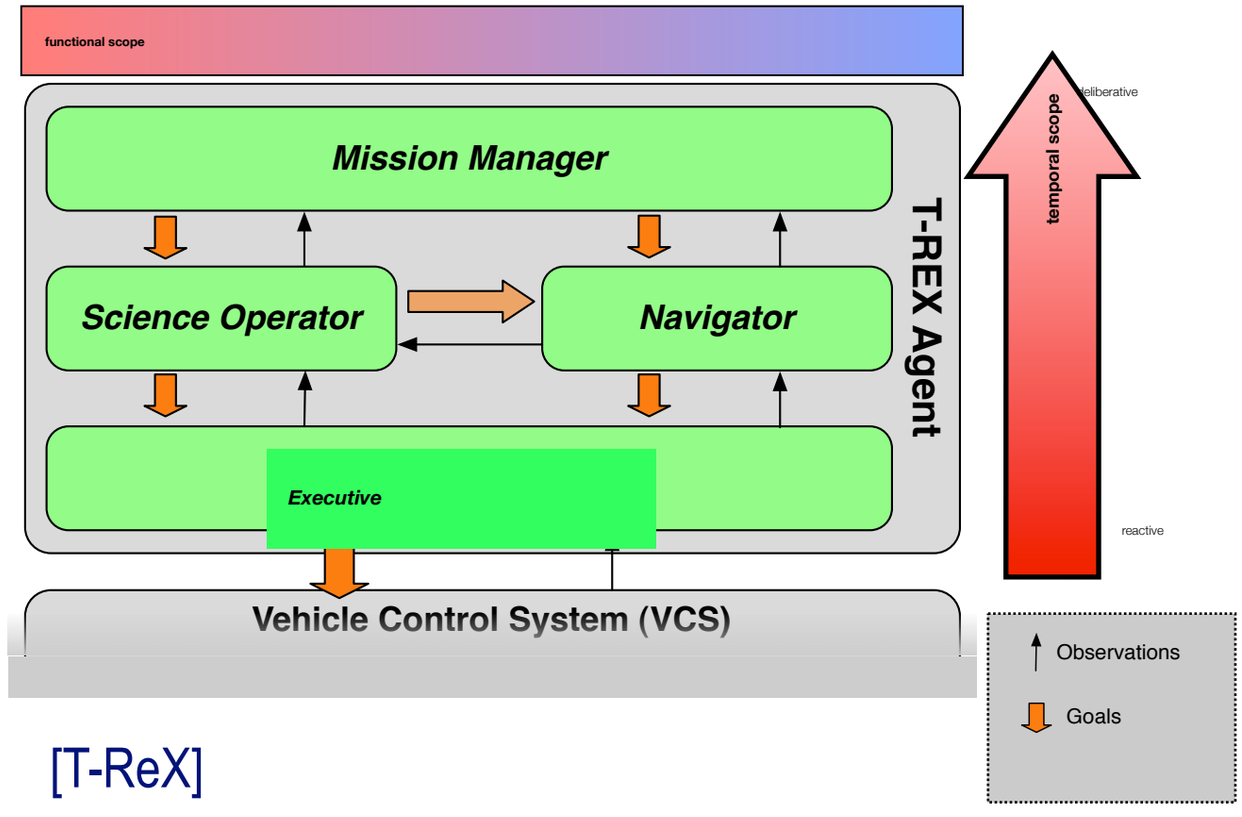


[IDEA]

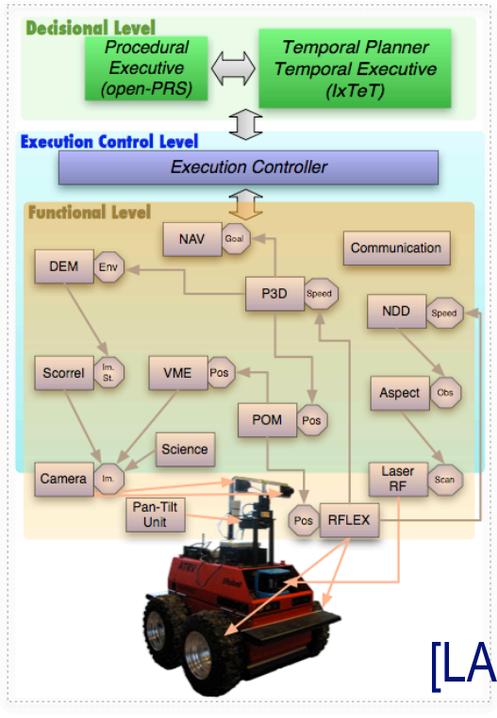


encapsulation IDEA

Flight Software

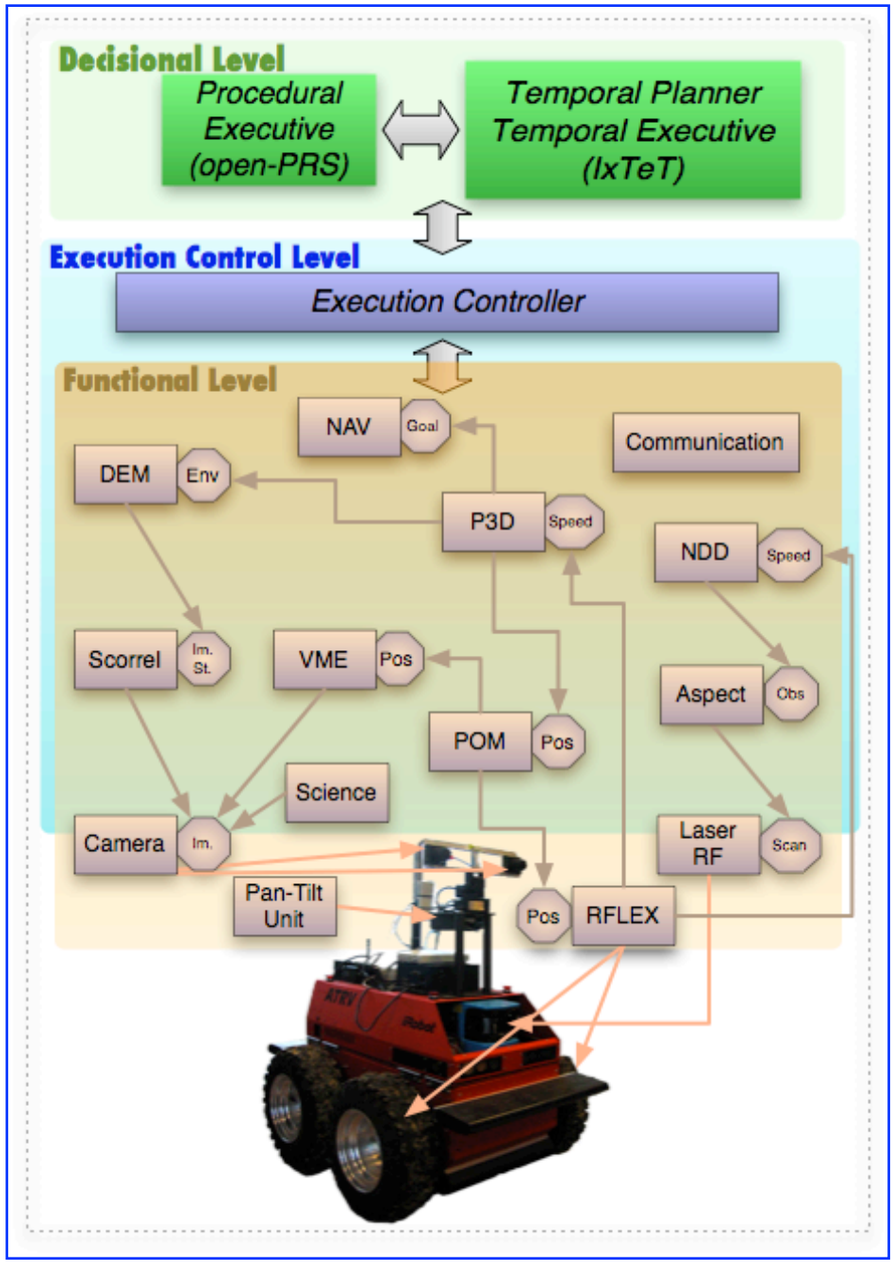


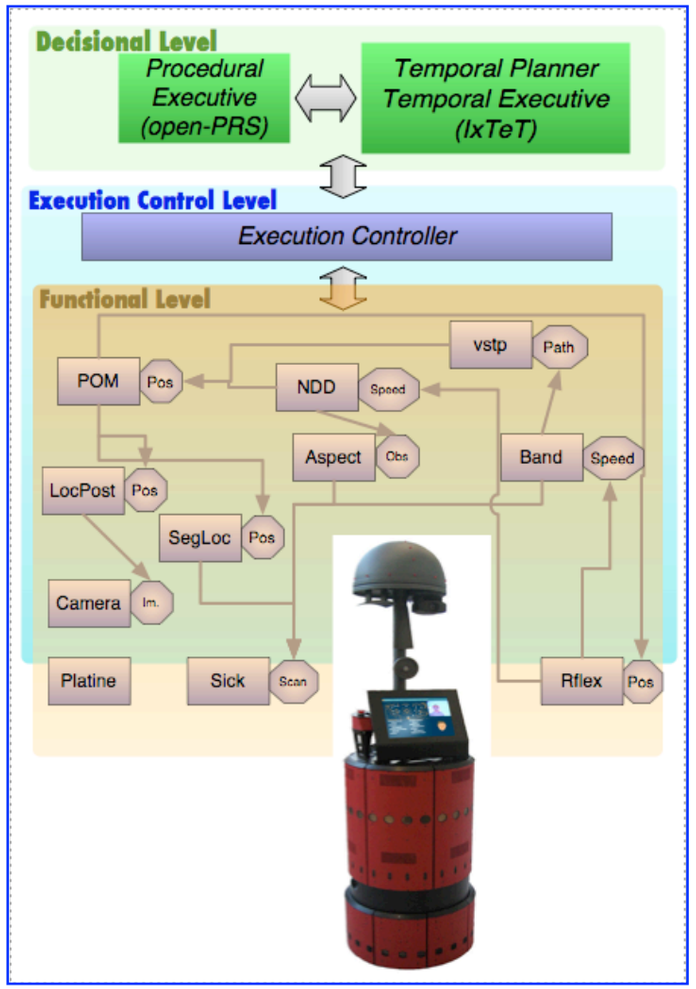
[T-ReX]

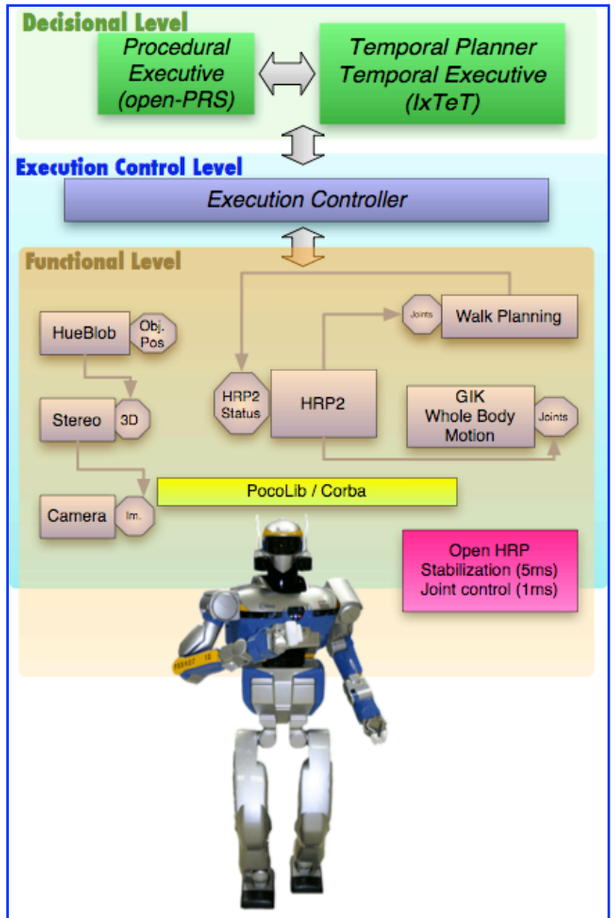


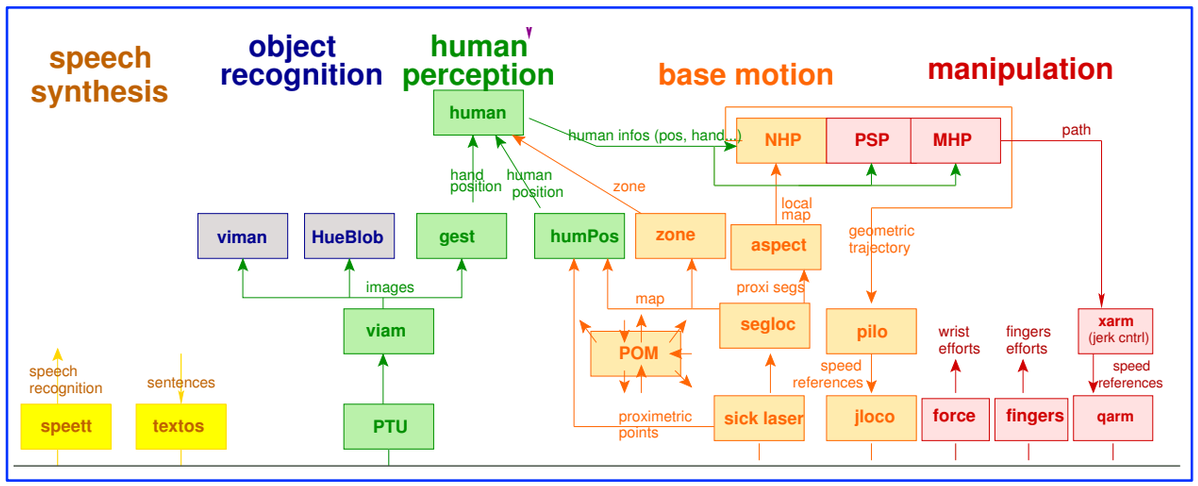
[LAAS]

Integration



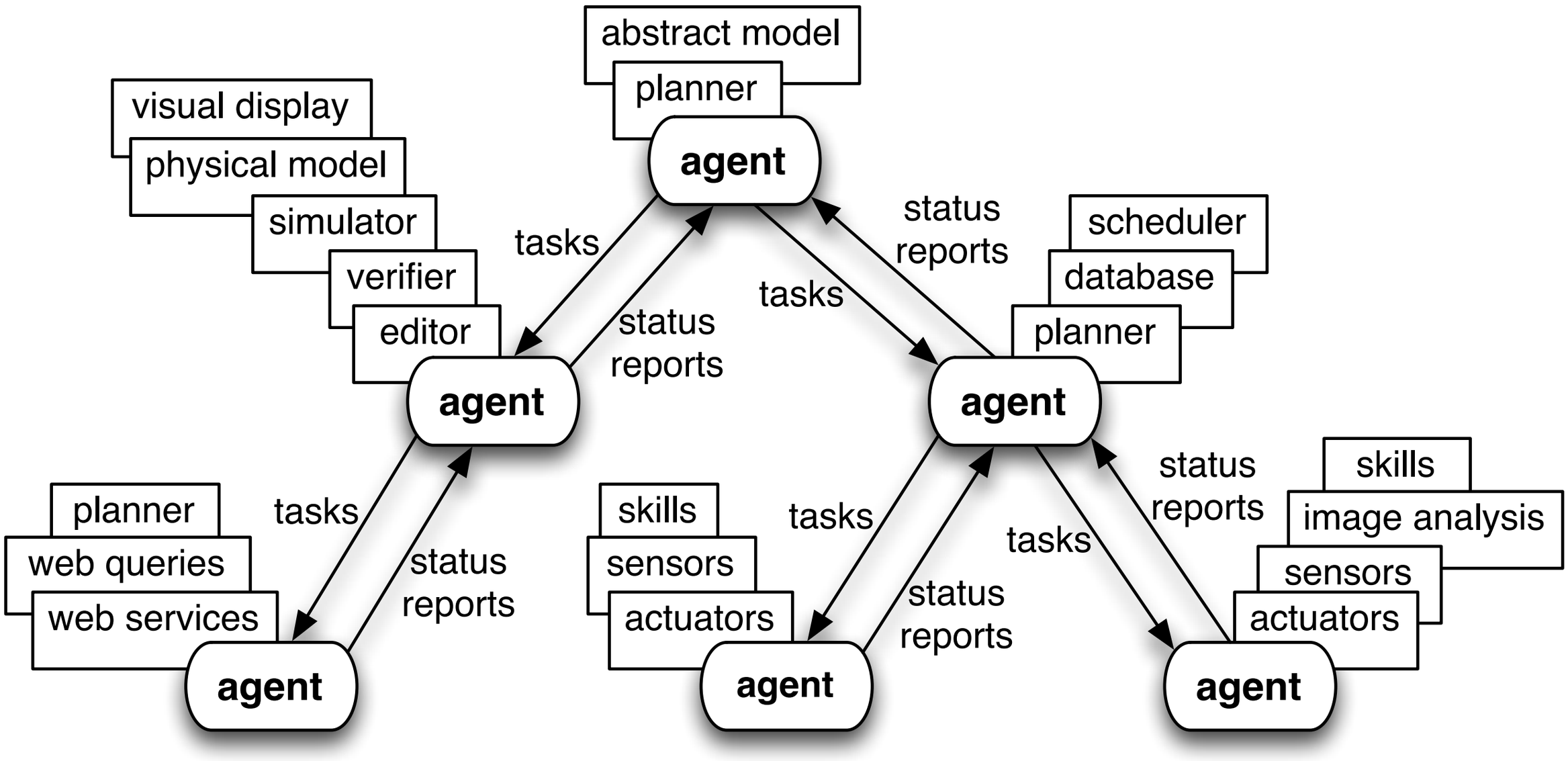






Integration

- Organizational principle: ***actor as a hierarchy of agents***



Outline

✓Motivations

✓Deliberation functions

- Planning
- Refining
- Monitoring
- Perceiving
- Goal reasoning
- Learning
- Integration

- Research Challenges
  - Representation
  - Model acquisition & Verification
  - Synthesis & Refinement
  - Monitoring and Goal reasoning
  - Integration

Representation Challenges

- ***Descriptive models***
  - Map known representations: PDDLx, ANML, RDDL, $\mathcal{K}$
    - Where in the actors hierarchy
    - Link to monitoring, sensing, control
    - Suitability for online plan repair
    - Criticality issues
  - Link to open domain representations: ontologies/DL, e.g.,RoboEarth, OMRKF, ORO, RACE
- ***Operational models***: procedural, automata and graphical
- Relationships between descriptive and operational models
- Simulation and sampling techniques

Model Acquisition, Learning and Verification

- Tools for the specification of descriptive and operational models
- Learning to acquire or improve these models
  - Reinforcement Learning: hierarchical, relation RL, factored MDP
  - Learning from demonstration: teleoperation, external observation
- Verification
  - Hierarchy of actors: of the consistency of their models
  - Heterogeneity of representations
  - Program verification techniques
  - Model checking

Synthesis and refinement

- Online plan synthesis, extension and repair, while acting
- Online skill selection and adaptation
- Integrate temporal dimensions:
  - Time in reasoning about a peculiar resource
  - Time as a computational resource for reasoning
  - Real-time constraints on acting and deliberation
- Planning with sensing and information gathering actions
- Integrate risk and criticality considerations to plan horizon and optimization issues

Monitoring and goal reasoning

- Derive monitoring conditions from descriptive and operational models
- Focus of attention mechanism and link to perceiving for acquiring information needed for monitoring
- Model-based diagnosis for the robot-environment interactions
- Recovery actions and link to criticality analysis issues
- Qualify current goals with respect of longer term objectives and motivations, express reservations and conditions to be monitored
- How to synthesize new goals for current mission
- Map monitoring functions to the actor's hierarchy

Integration

- How to organize actors hierarchy
- Static, i.e., mapped to the robot architecture, or dynamic
- Actor’s enablers, including executors
- Concurrency of actors
- Temporal constraints

Other Deliberation challenges in robotics

- Observing the environment semantics
- Interacting
- Learning
  - Models of the robot and the environment
  - Categories
  - Functions, skills and behaviors
- Architecture
  - Specification
  - Robust adaptation

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Actor's view of deliberation: numerous challenges
Planning is just the tip of the iceberg