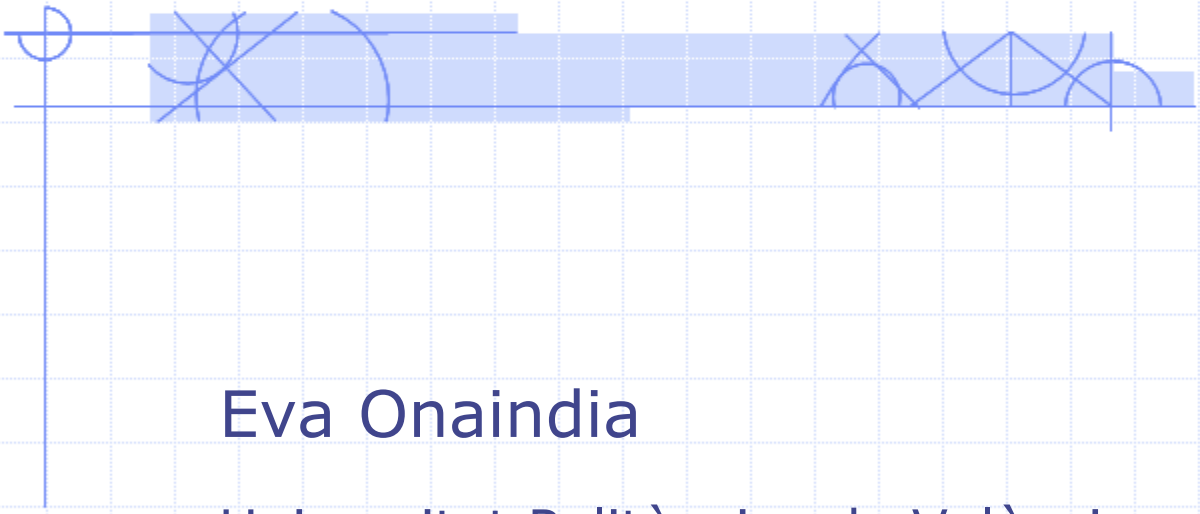
AI Planning

Introduction. Planning architecture.



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Acknowledgements

Most of the slides used in this course are taken from Dana Nau's lecture slides for the textbook *Automated Planning,* licensed under the Creative Commons Attribution-NonCommercial-ShareAlike License:

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I would like to gratefully acknowledge Dana Nau's contributions and thank him for generously permitting me to use aspects of his presentation material.

Introduction: some Dictionary Definitions of "Plan"

plan *n.*

1. A scheme, program, or method worked out beforehand for the accomplishment of an objective: *a plan of attack.*
2. A proposed or tentative project or course of action: *had no plans for the evening.*
3. A systematic arrangement of elements or important parts; a configuration or outline: *a seating plan; the plan of a story.*
4. A drawing or diagram made to scale showing the structure or arrangement of something.
5. A program or policy stipulating a service or benefit: *a pension plan.*

- These two are closest to the meaning used in AI

[a representation] of future behavior … usually a set of actions, with temporal and other constraints on them, for execution by some agent or agents. - Austin Tate

[*MIT Encyclopedia of the Cognitive Sciences*, 1999]

				.10	0.34	03 Establish datum point at
						01 Install 0.15-diameter sic
						02 Rough side-mill pocket at length 0.40, width 0.30,
						03 Finish side-mill pocket a length 0.40, width 0.30,
						04 Rough side-mill pocket at length 0.40, width 0.30,
						05 Finish side-mill pocket a length 0.40, width 0.30,
				.10	1.54	01 Install 0.08-diameter enc
						[...]
004	T	VMC1	2.50		4.87	01 Total time on VMC1
005	A	EC1	0.00		32.29	01 Pre-clean board (scrub ar
						02 Dry board in oven at 85 (
005	B	EC1	30.00		0.48	01 Setup
						02 Spread photoresist from 1
005	C	EC1	30.00		2.00	01 Setup
						02 Photolithography of photo using phototool in "real
005	D	EC1	30.00		20.00	01 Setup
						02 Etching of copper
005	T	EC1	90.00		54.77	01 Total time on EC1
006	A	MC1	30.00		4.57	01 Setup
						02 Prepare board for solderi
006	B					
006	C	MC1	30.00		7.50	01 Setup

A portion of a manufacturing process plan

Screenprint solder stop (

Introduction. Generating Plans of Action.

- Computer programs to aid human planners
  - Project management (consumer software)
  - Plan storage and retrieval
    - e.g., ***variant process planning*** in manufacturing
  - Automatic schedule generation
    - various OR and AI techniques
- For some problems, we would like generate plans (or pieces of plans) automatically
  - Much more difficult
  - Automated-planning research is starting to pay off

Processes:

Opn	A	RC/VM	Setup	Runtime	IN	Description
000	A	VMC1	0.00	0.00	01	Orient board
					02	Clamp board
					03	Establish datum point at bullseye (0.2
001	B	VMC1	0.10	0.43	01	Install 0.20-diameter drill bit
					02	Rough drill at (1.25, -0.50) to depth
					03	Finish drill at (1.25, -0.50) to depth
001	C	VMC1	0.10	0.77	01	Install 0.20-diameter drill bit
					02	Rough drill at (0.00, 4.88) to depth 1
					03	Finish drill at (0.00, 4.88) to depth
[...]						
001	T	VMC1	2.20	1.20	01	Total time on VMC1
004	A	VMC1	2.00	0.00	01	Orient board
					02	Clamp board
					03	Establish datum point at bullseye (0.2
004	B	VMC1	0.10	0.34	01	Install 0.15-diameter side-milling too
					02	Rough sidemill pocket at (-0.25, 4.65
						length 0.40, width 0.30, depth 0.50
					03	Finish side-mill pocket at (-0.25, 4.2
						length 0.40, width 0.30, depth 0.50
					04	Rough side-mill pocket at (0.25, -3.0
						length 0.40, width 0.30, depth 0.50
					05	Finish side-mill pocket at (0.25, -3.0
						length 0.40, width 0.30, depth 0.50
004	C	VMC1	0.10	1.54	01	Install 0.08-diameter end-milling tool
[...]						
004	T	VMC1	2.50	4.87	01	Total time on VMC1
005	A	EC1	0.00	32.29	01	Pre-clean board (scrub and wash)
					02	Dry board in oven at 85 deg. F
005	B	EC1	30.00	0.48	01	Setup
					02	Spread photoresist from 18000 RPM spin
005	C	EC1	30.00	2.00	01	Setup
					02	Photolithography of photoresist
						using photomask in "test.tges"
005	D	EC1	30.00	20.00	01	Setup
005	T	EC1	90.00	54.77	02	Etching of copper
					01	Total time on EC1
006	A	MC1	30.00	4.57	01	Setup
					02	Prepare board for soldering
006	B	MC1	30.00	0.29	01	Setup
006	C	MC1	30.00	7.50	01	Setup
					02	Deposit solder paste at (3.35,1.23) on
[...]						
					31	Deposit solder paste at (3.52,4.00) on
006	D	MC1	0.00	5.71	01	Dry board in oven at 85 deg. F to sol
006	T	MC1	90.00	18.07	01	Total time on MC1
[...]						
011	A	TC1	0.00	35.00	01	Perform post-cap testing on board
011	B	TC1	0.00	29.67	01	Perform final inspection of board
011	T	TC1	0.00	64.67	01	Total time on TC1
999	T		319.70	403.37	01	Total time to manufacture

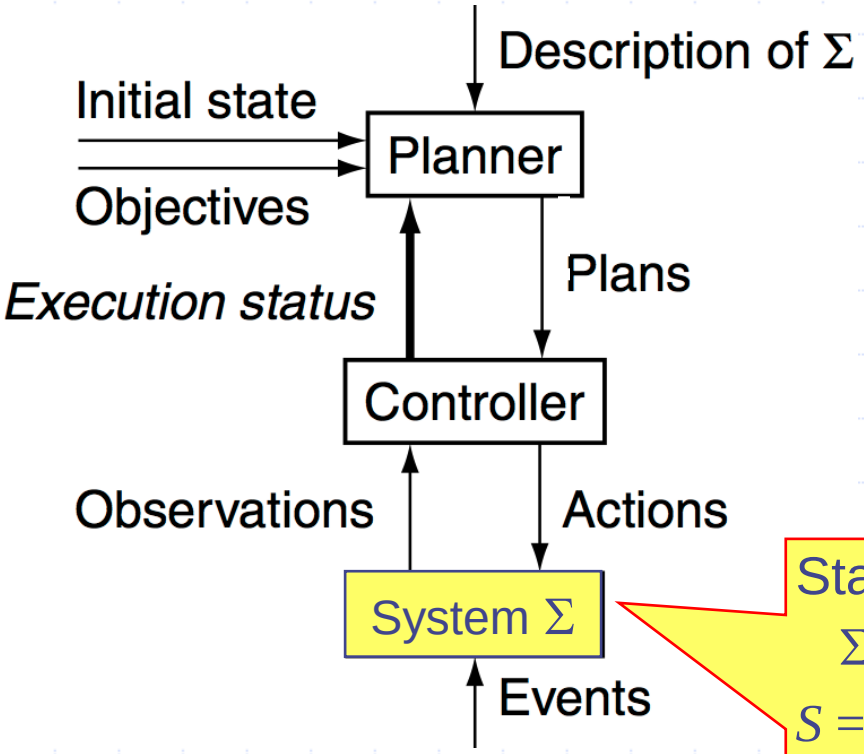
Introduction. Space Exploration.

- Autonomous planning, scheduling, control
  - NASA: JPL and Ames
- Remote Agent Experiment (RAX)
  - Deep Space 1
- Mars Exploration Rover (MER)

Introduction. Manufacturing.

- Sheet-metal bending machines - Amada Corporation
  - Software to plan the sequence of bends [Gupta and Bourne, *J. Manufacturing Sci. and Engr.*, 1999]

Introduction:
Conceptual Model. Environment.



State transition system

$\Sigma = (S, A, E, \gamma)$

S = {states}

A = {actions}

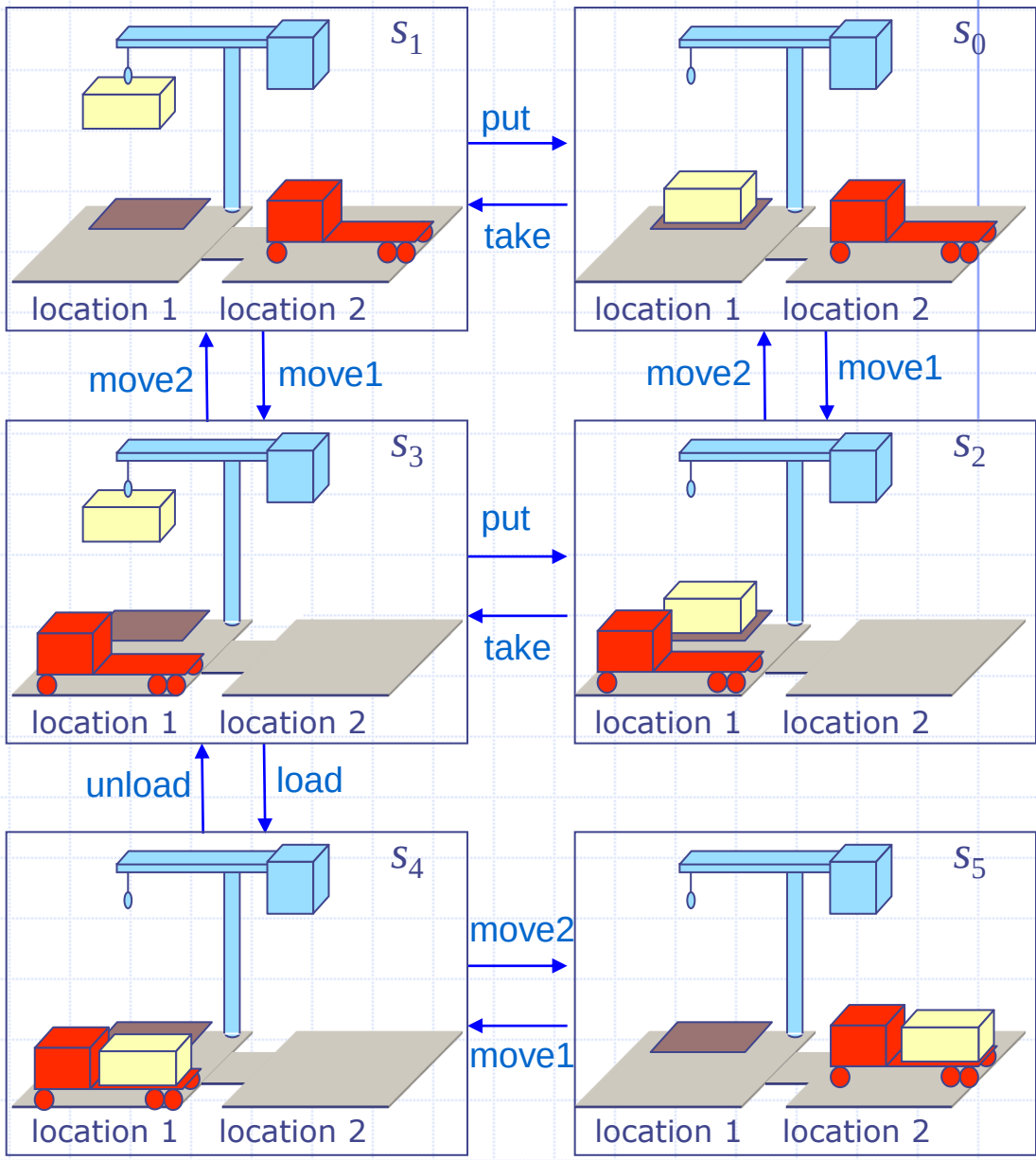
E = {exogenous events}

γ = state-transition function

State Transition System

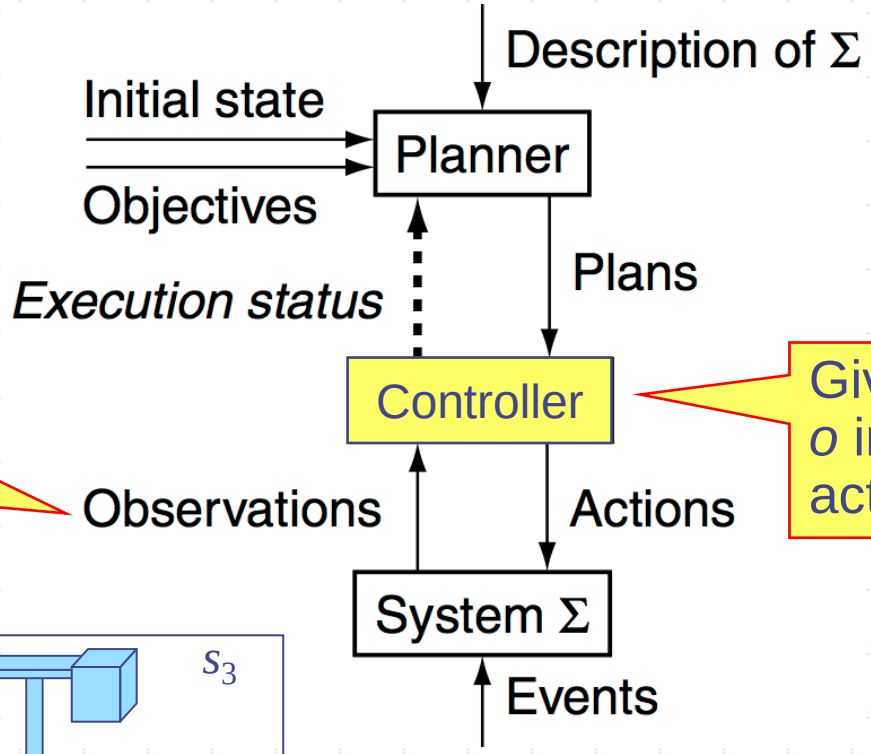
$\Sigma = (S,A,E,\gamma)$

- S = {states}
- A = {actions}
- E = {exogenous events}
- State-transition function
  $\gamma: S \times (A \cup E) \rightarrow S$
  - $S = \{s_0, \ldots, s_5\}$
  - A = {move1, move2, put, take, load, unload}
  - $E = \{\}$
  - γ: see the arrows



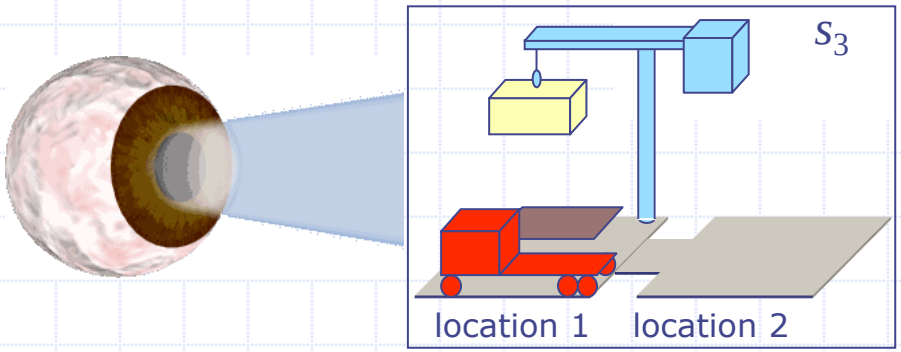
The Dock Worker Robots (DWR) domain

Introduction.
Conceptual Model. Controller.

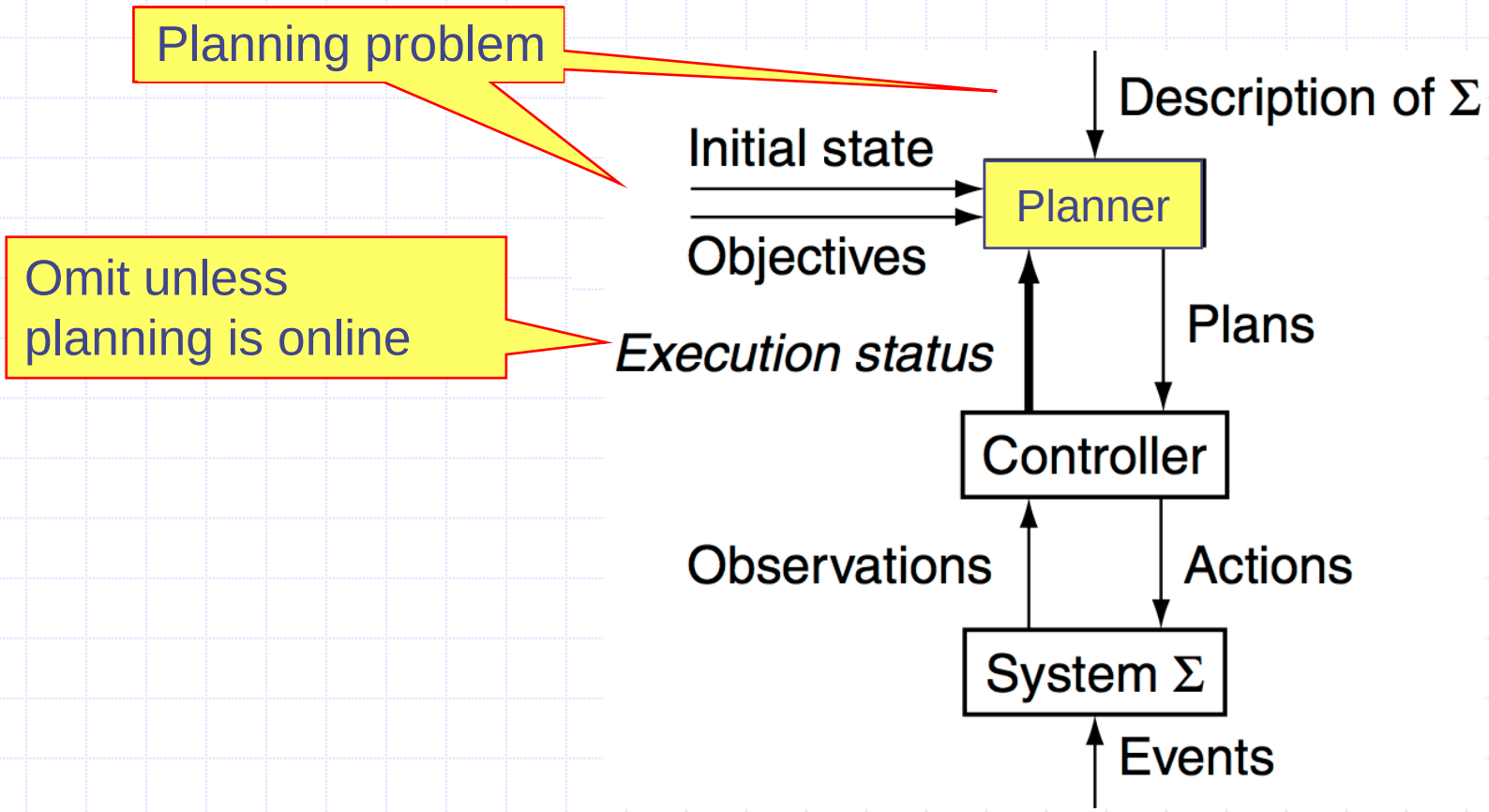


Given observation *o* in *O*, produces action *a* in *A*

Observation function
$h: S \rightarrow O$



Introduction.
Conceptual model. Planners input.



Introduction. Planning Problem

Description of Σ

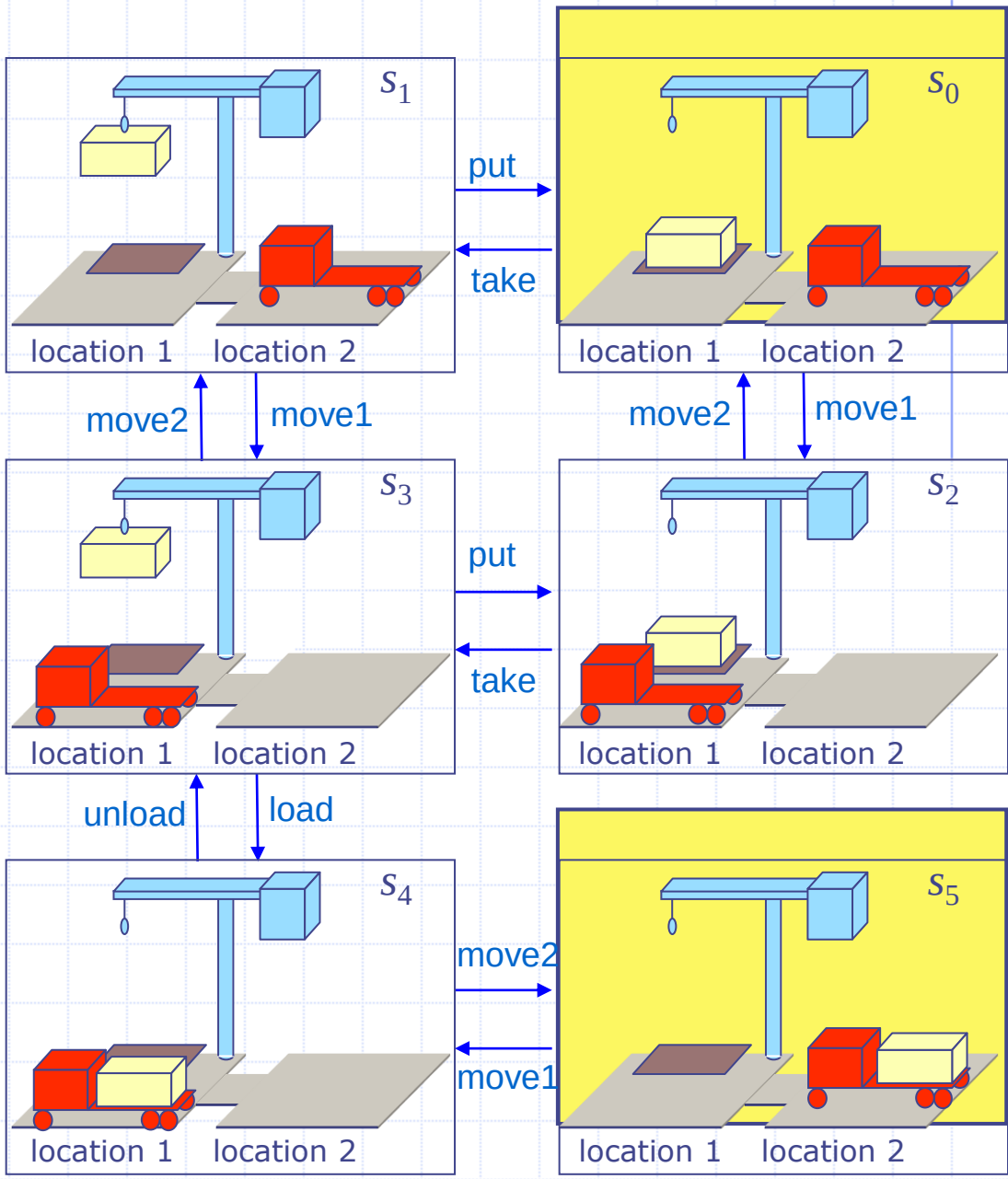
Initial state or set of states

Initial state = s_0

Objective

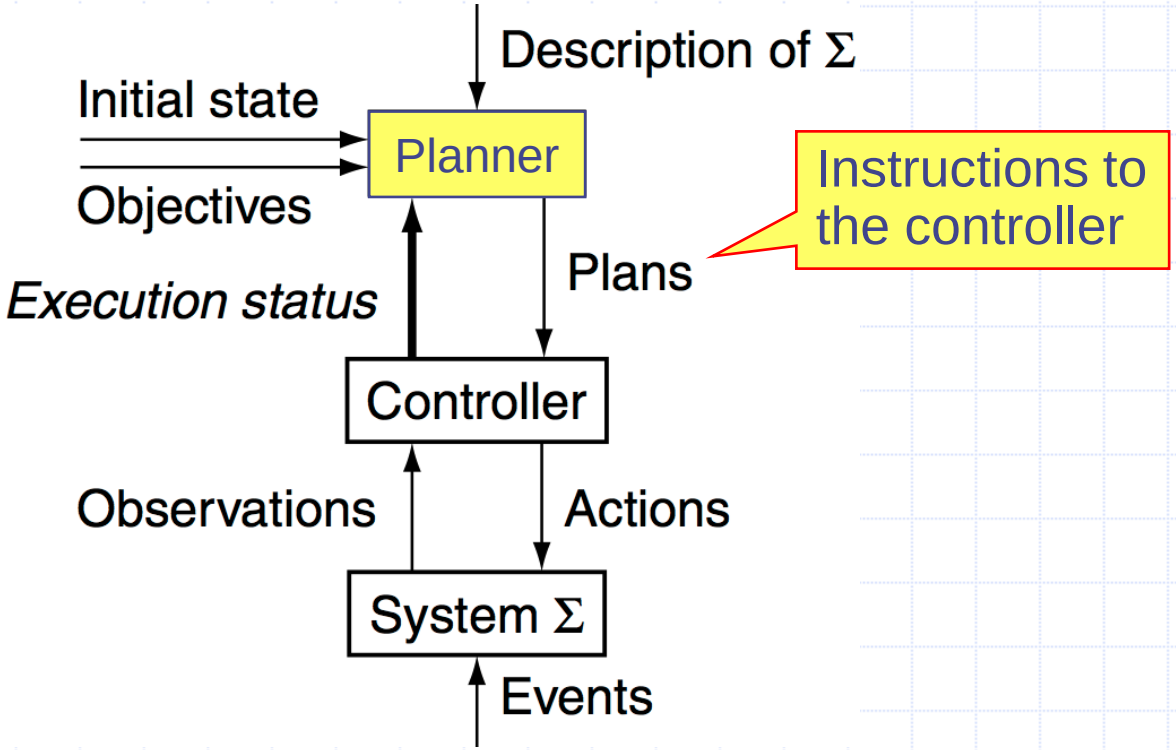
Goal state, set of goal states, set of tasks, "trajectory" of states, objective function, …

Goal state = s_5



The Dock Worker Robots (DWR) domain

Introduction.
Conceptual Model. Planner's Output.



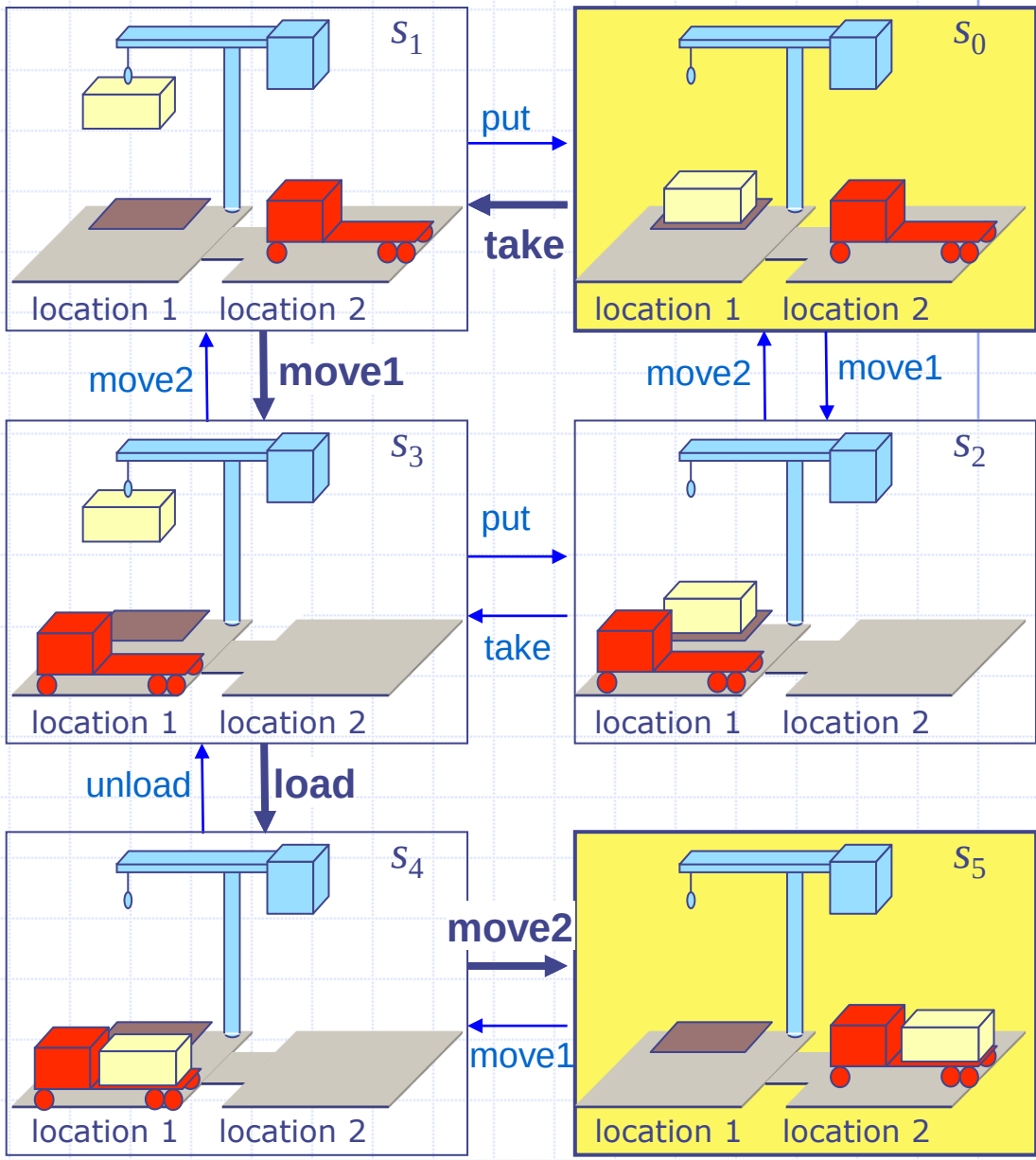
Introduction. Plans

Classical plan: a sequence of actions

⟨take, move1, load, move2⟩

Policy: partial function from *S* into *A*

{(s_0, take),
(s_1, move1),
(s_3, load),
(s_4, move2)}



The Dock Worker Robots (DWR) domain

Introduction.
Planning versus Scheduling

- Scheduling
  - Decide when and how to perform a given set of actions
    - Time constraints
    - Resource constraints
    - Objective functions
  - Typically NP-complete
- Planning
  - Decide what actions to use to achieve some set of objectives
  - Can be much worse than NP-complete; worst case is undecidable

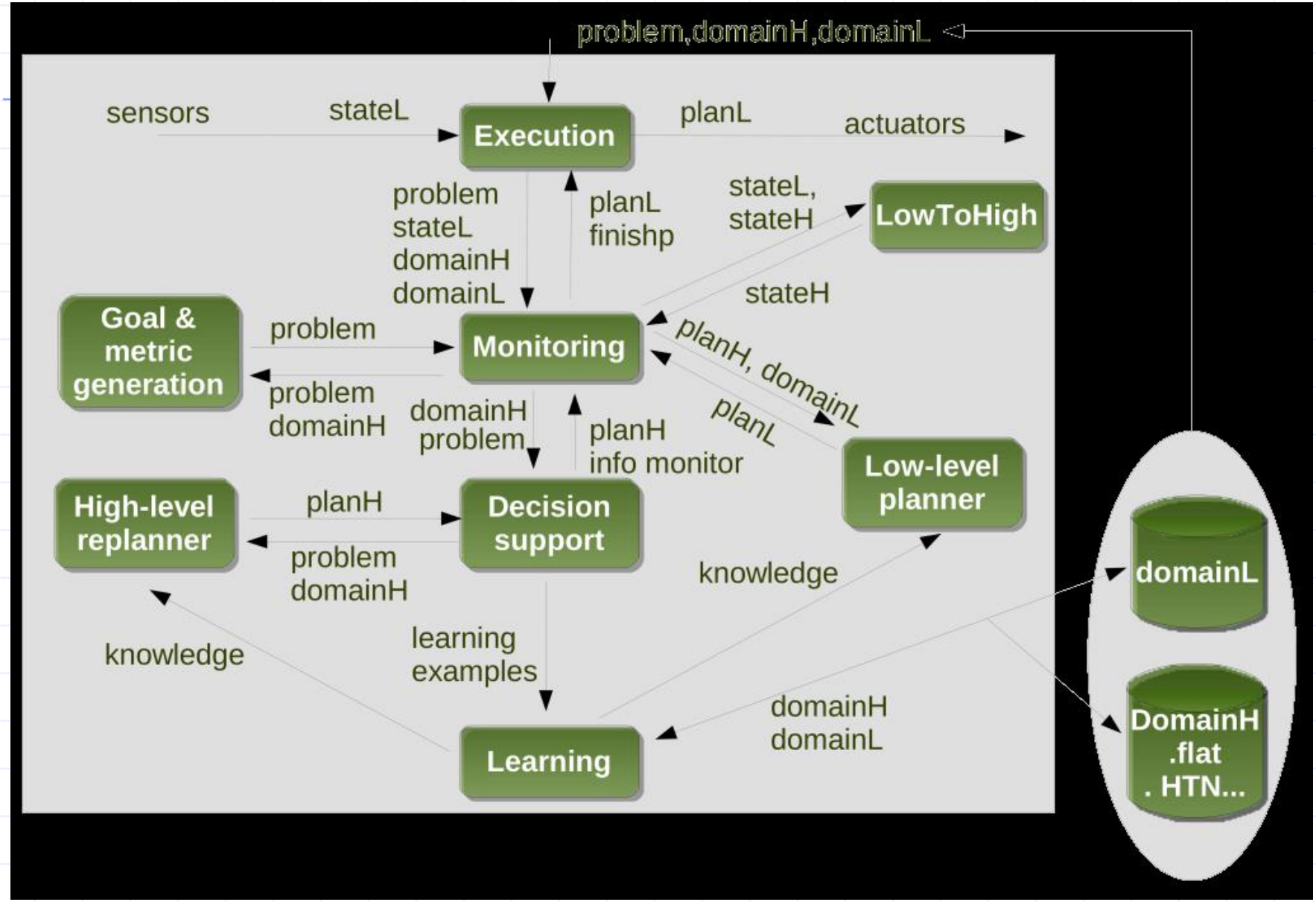
Planning architecture: PELEA project

- Integration of the full spectrum of planning-related technologies (sensing, planning, executing, monitoring, replanning and even learning from past experiences).

- PELEA (Planning, Execution and LEarning Architecture) is a general-purpose architecture.

- Control flow, connections among the main PELEA components.

Planning architecture: PELEA project

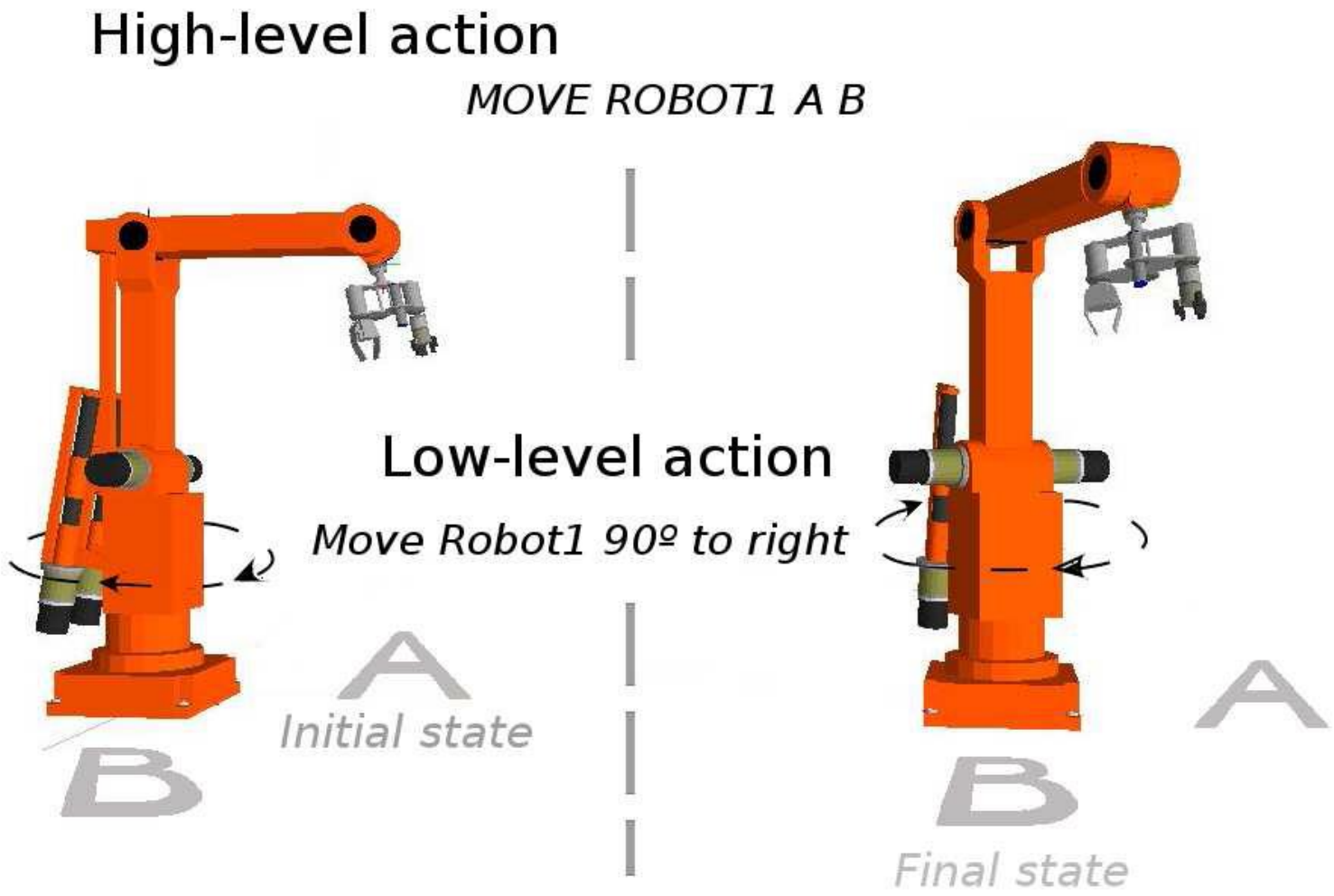


PELEA: the Execution Module (EM)

- EM acts as a wrapper over anything external to PELEA (a software simulator, application, a hardware device like a robot or a user)

- The tasks of the EM are:
  - to initiate PELEA by receiving a particular domain and problem to be solved
  - to observe the current world information by reading the sensors
  - to send the low-level actions to the actuators (for example, move the robot 90 degrees to the right)

PELEA: low-level



PELEA: the Monitoring Module (MM)

- Check whether the observed state coming from the Execution is a correct state according to the planning process.
- With the info monitor parameter the MM knows which aspects (variables) of the plan need to be monitored during the execution.
- The MM acts as a plan dispatcher sending the Execution Module the actions to execute.

PELEA: the Decision Support (DS) module

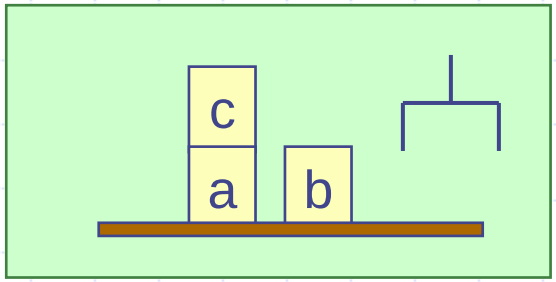
- The DS is responsible for calculating the info monitor parameter.
- When the MM reports a discrepancy between the observed state and the expected planning state, the DS makes the following tasks:
  - to check whether the discrepancy is relevant to the planvalidity or not
  - to make a decision about applying a plan-repair method or replanning from scratch (try to minimizing the number of changes in the original plan)

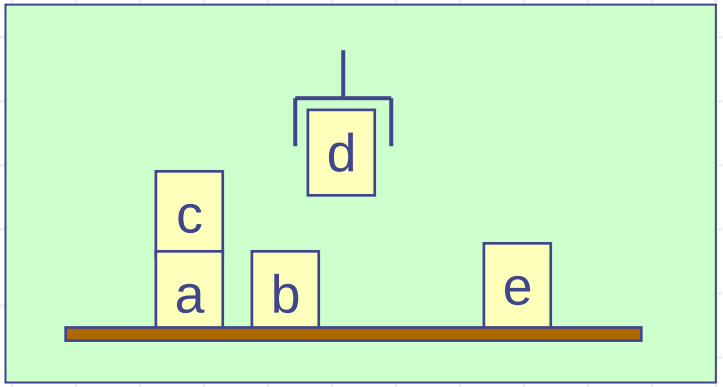
PELEA: the Planner

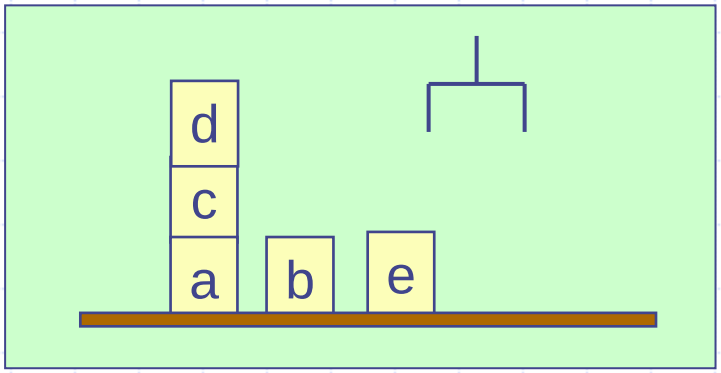
- Planning, repairing and replanning
- We can use any type of planner:
  - State-space planners (plan as a sequence of actions)
  - Plan-space planners (plan as a set of parallel actions)
  - Temporal planners
  - Other type of planners

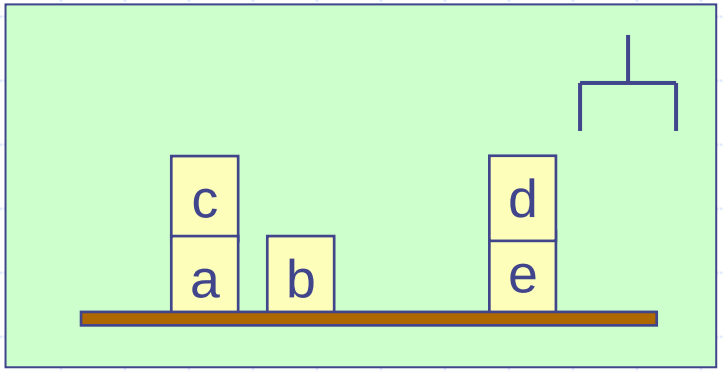
PELEA: Demo of the PELEA architecture (I)

Blocks-world domain

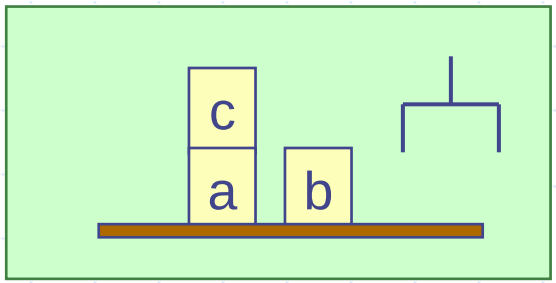




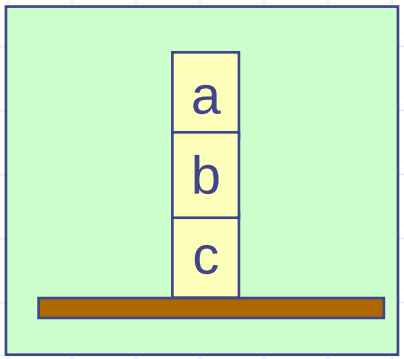




PELEA: Demo of the PELEA architecture (II)



Initial state



Goal state

PELEA: Demo of the PELEA architecture (III)

OPERATORS:

unstack <block> <block>
stack <block><block>
pickup <block>
drop <block>

INSTANTIATED OPERATORS (actions):

1. **unstack C A**
2. **drop C**
3. **pickup B**
4. **stack B C**
5. **pickup A**
6. **stack A B**

plan of actions

https://www.dropbox.com/s/lza9y8pon99q62m/blocksworld_low-level_pfile0_with_failure_fast.avi?dl=0