Planning Representation

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Objectives

Specific Objectives

- Understand what Planning is
- Understand Planning as a search process
- Know main representation languages

Source

- Stuart Russell & Peter Norvig (2009). Chapter 10 (7, 8, 9) Artificial Intelligence: A Modern Approach. (3rd Edition). Ed. Pearsons
- Ghallab, Nau &Traverso (2004). Automated Planning: Theory & Practice. The Morgan Kaufmann Series in Artificial Intelligence

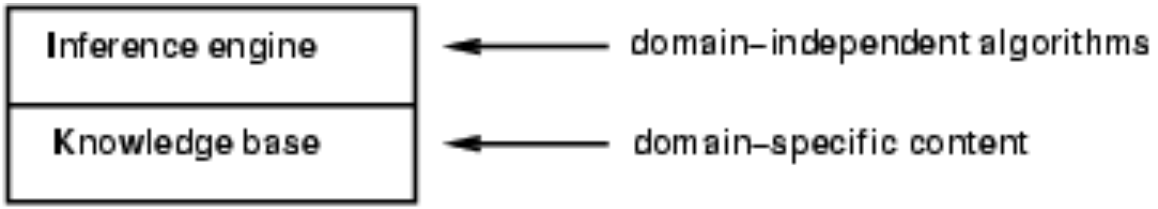
Outline

- **Introduction**
- Logics
- Application domains
- Modelling in planning
- STRIPS
- PDDL
- IPC
- Conclusions

Introduction (I)

- Knowledge representation and associated processes are central to the AI
- They play an important role when dealing with partially observable environments
  - Combining general knowledge with real perceptions to infer hidden aspects of the world before selecting any action
  - The natural understanding needs also to infer hidden states
  - We need techniques to inference things
  - Search the solution

Introduction (II)



- Knowledge base = set of sentences in a formal language
- Follow declarative approach to build an agent (or other system):
  - Tell it what it needs to know
  - Then it can ask itself what to do - answers should follow from the KB

Introduction (III)

- Planning: selects a sequence of activities that meet one or more goals and a set of constraints imposed by the domain

- Scheduling: resource allocation and start times of activities, obeying the temporal restrictions on the activities and the capacity limitations of shared resources
  - An optimization task where limited resources are available throughout the time between activities
  - Activities can be run in serial or in parallel according to different objectives

Introduction (IV)

- Planning
  - Based on predicates and objects
  - It uses a first-order language (FOL) containing predicates and functions to describe the domain
  - The functions are a set of parametrized operators of the available transitions domain
- Scheduling
  - Not use of predicate or specific language
  - Represents activities and resources by numbers in an input file

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Logic

- Logics are formal languages for representing information such that conclusions can be drawn
- Syntax defines the sentences in the language
- Semantics define the "meaning" of sentences (i.e., define truth of a sentence in a world)
- E.g., the language of arithmetic
  - $x+2 \geq y$ is a sentence; $x2+y > \{\}$ is not a sentence
  - $x+2 \geq y$ is true iff the number $x+2$ is no less than the number y
  - $x+2 \geq y$ is true in a world where $x = 7, y = 1$
  - $x+2 \geq y$ is false in a world where $x = 0, y = 6$

Logic: types (I)

- Propositional: is the simplest logic and assumes the world contains facts
  - Representation elements: proposition and connectivity ($\wedge$, $\vee$, $\Rightarrow$, $\Leftrightarrow$, $\neg$)
  - Inference: deductions with rules, facts & Modus-Ponens, Modus Tollen
  - Advantage: general representation and decidable in finite time if CNF (DPLL or WalkSAT)
  - Disadvantage: low expressivity and not able to reason about sets of things (i.e. graphs or hierarchies)
- First Order Logic:
  - Based on predicates:
    - Objects: people, houses, numbers, colours, baseball games, wars, …
    - Relations: red, round, prime, brother of, bigger than, part of, comes between, …
    - Functions: father of, best friend, one more than, plus, …
  - Representation elements: predicates, connectivity ($\wedge$, $\vee$, $\Rightarrow$, $\Leftrightarrow$, $\neg$) and quantifiers ($\forall$, $\exists$)
  - Inference and Unification

Logic: types (II)

- Second order (or higher order) logic
  - They have two (or three) defined types: objects and sets; or functions on them (or both)
  - It is equivalent to saying that predicates can take other predicates as arguments
- Modal and temporal logic
  - It deals with statements affected by necessarily and possibly
- Diffuse logic
  - Quantify the uncertainty
- Others: multi-valued, non-monotonous, quantic

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Example I: Satellites operations (I)

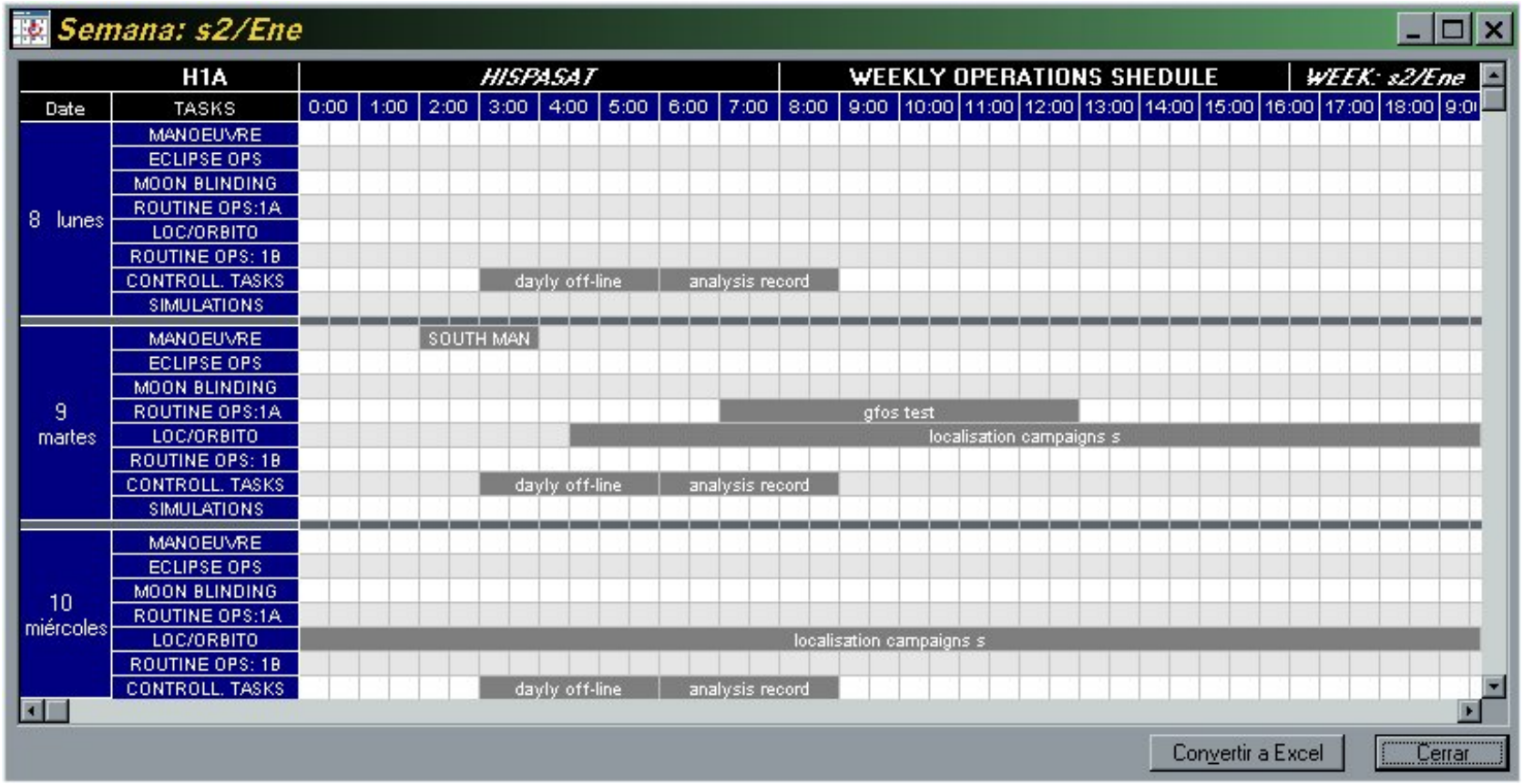
- Scheduling ground operations in HISPASAT
- Spanish satellite communications operator, leader in the distribution of content in Spanish and Portuguese
- 25 years of experience, with an important presence on Spain & in Latin America (4th satellite operator), is in charge of:
  - National communications needs
  - Capacity for digital TV in Europe, America & North Africa
  - TV image
  - Defence purposes
- Operations follow engineering instructions: work to accomplish

Example I: Satellites operations (II)

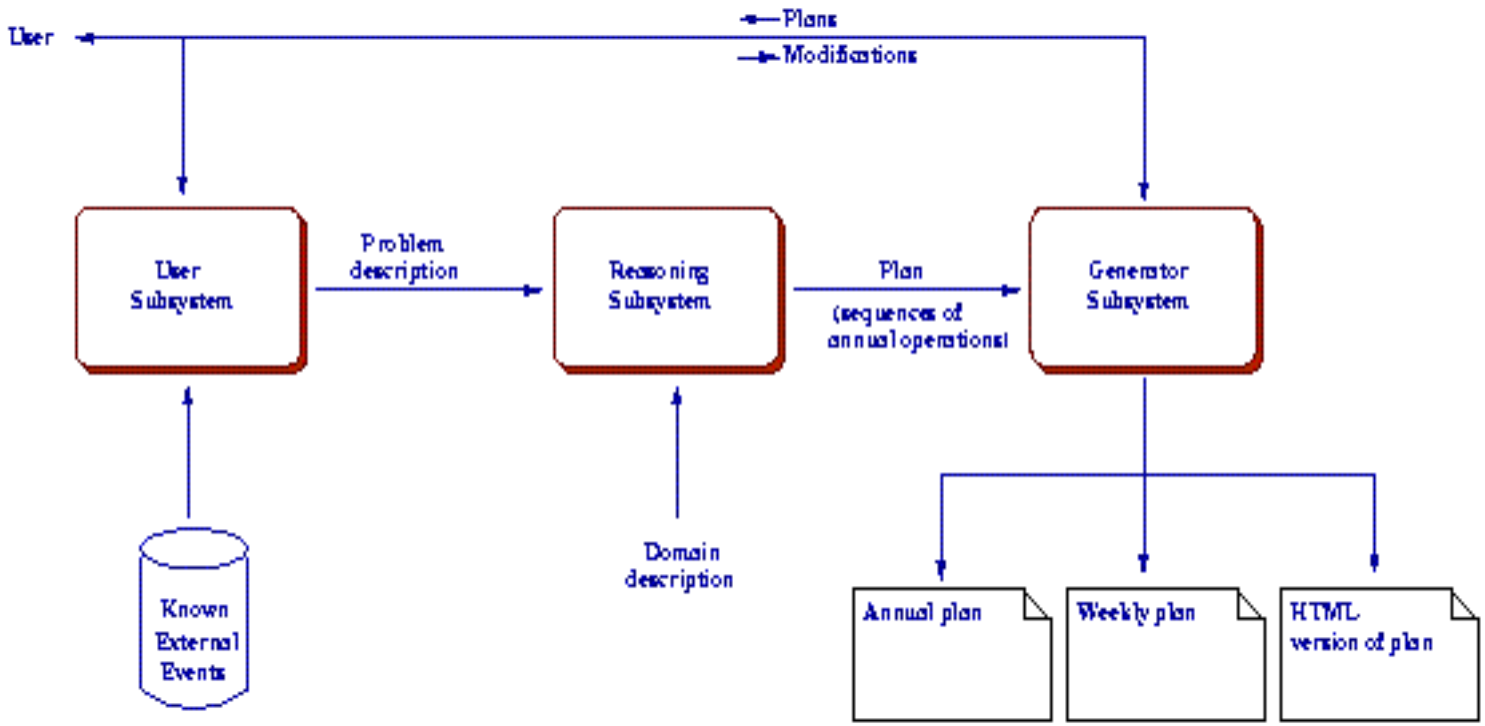
- Operations
  - Follow engineering instructions:

    By Hand & On Paper
  - Depend on external factors (Moon blindings)
  - Scheduled around Manoeuver
  - Related to the use of batteries & tanks
  - Maintenance (i.e. Antennas)

Example I: Satellites operations (III)



Example I: Satellites operations (IV)



Example II: Workflow Systems (I)

- Business Process Management (BPM): a discipline that view business as a set of processes
- Examples:
  - A bank manager rejecting a loan application is a step in a business process
  - A manager approving a purchase order is is an activity in a process
- Involves combination of modelling, execution, control, measurement and optimization of business activity flows
- There are tools to help in defining & simulating models (manually generated)

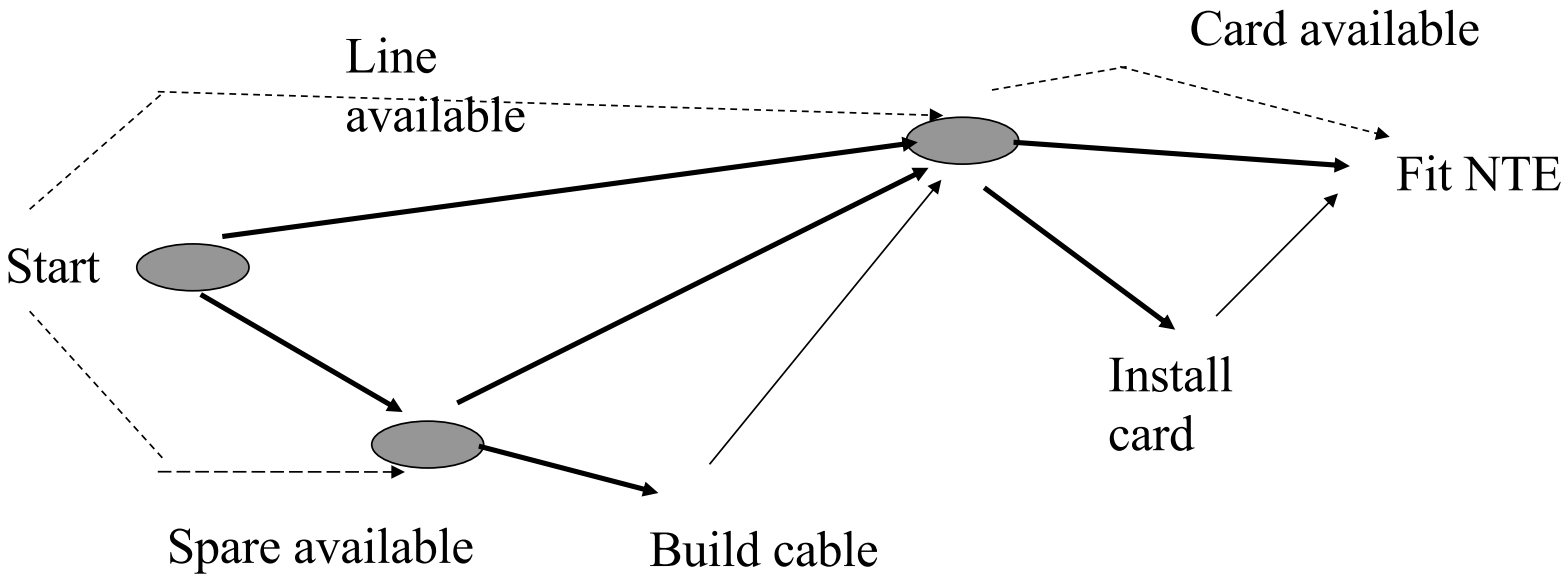
Example II: Workflow Systems (II)

- BPM at BT in UK for lines provision
- COMOSS
  - BP starts when the user calls
  - Gather information and passed to COSMOSS as a job
  - Job is decomposed into activities (Target time)
  - Activities have conditions to be met: questions to be answered
  - The SW will construct a schedule
  - Job & Activities are assigned to agents

Example II: Workflow Systems (III)

- A customer contacts BT for a line and it could:
  - She has already one line (spare pair of wires is available from the house to make a connection from the DP).
  - She is asking for a line for the 1st time (if not new cable must be build)
- Check there is a spare line card available in the exchange (if not, installation may be arranged)
- Contact the customer to fit a new NTE
- Test the line end to end and install NTE
- Allocate the telephone number to the new line an update the exchange, line and customer records

Example II: Workflow Systems (IV)

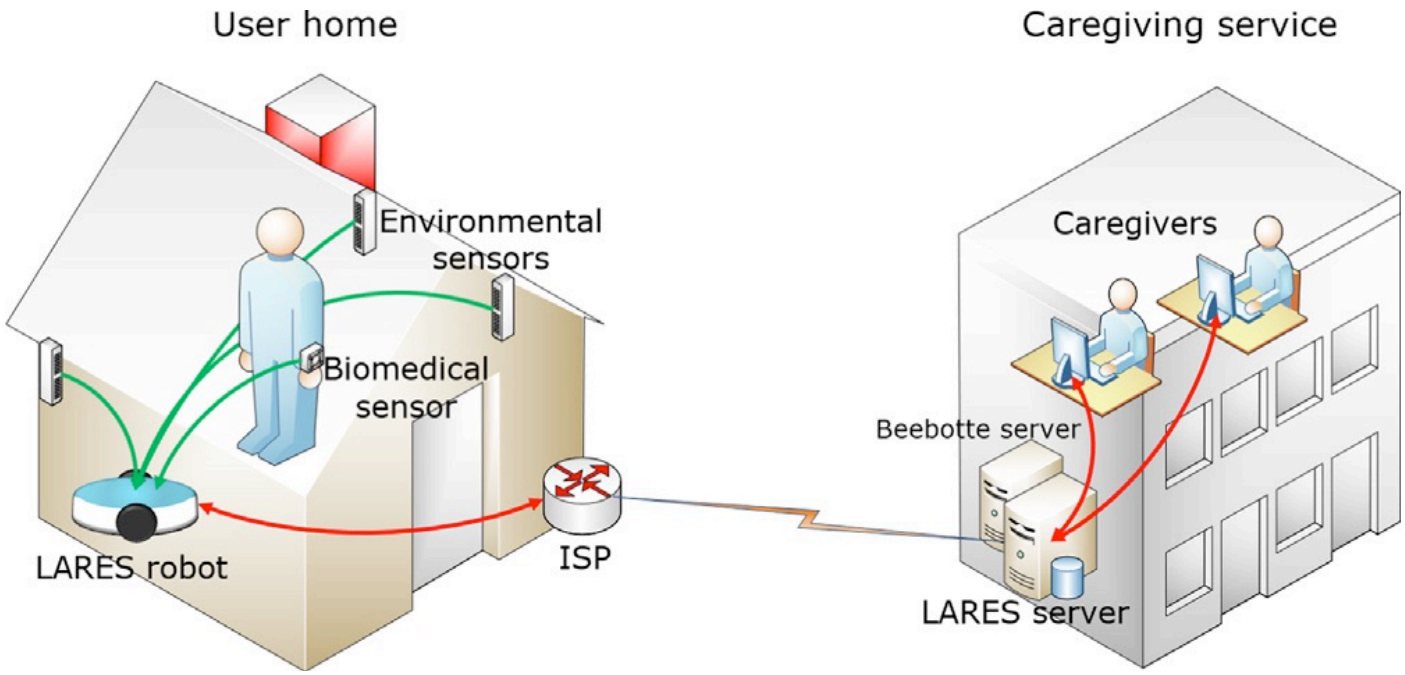


Example III: Robotics (I)

- Robots to support ageing people: LARES system
- Ageing often reduces:
  - Mobility
  - Mental capabilities
- Older and handicap adults often require caregiving:
  - Family cares
  - Nursing homes
  - Teleassistance

Example III: Robotics (II)

Components



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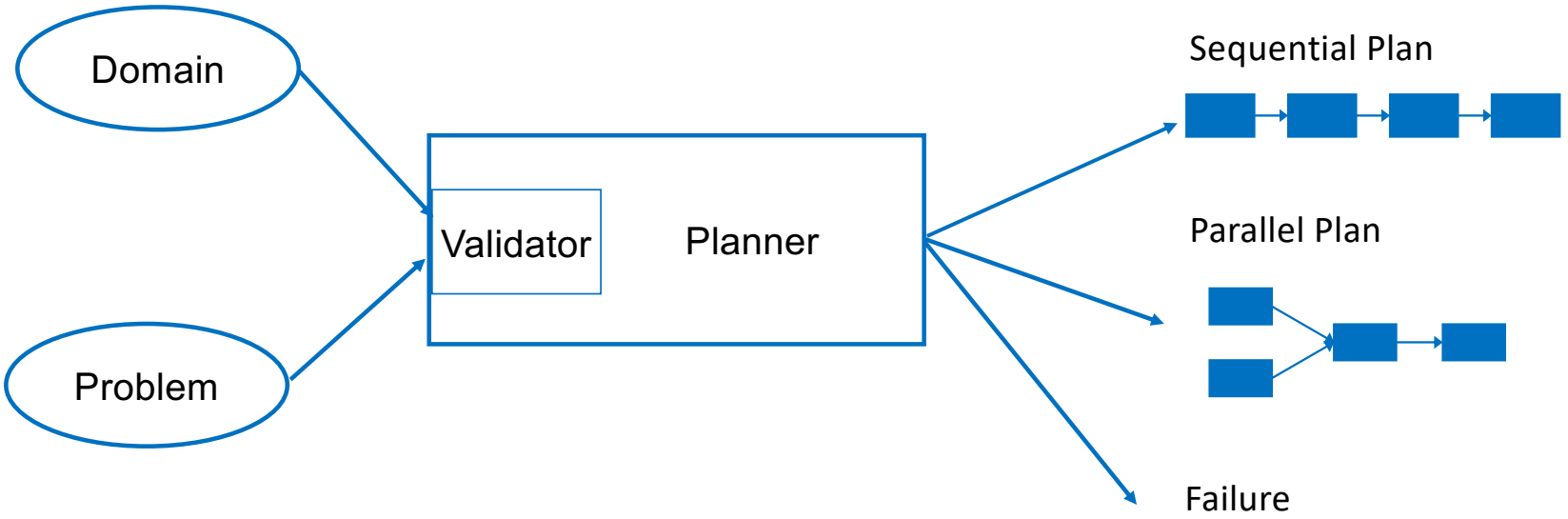
Modelling in planning (I)

- Planners decompose the world in terms of logical conditions and represent a state as a sequence of connected positive literals
  - Propositions: Fast $\wedge$ AirbusA380
  - FOL: At(Plane1,Madrid) $\wedge$ At(Plane2,Paris)
  - Not allowed: At(Padre(Ana),Madrid)
- Representations are based on predicates and objects
- Each domain has a specific FOL containing predicates and functions
- We define a set of operators that are a parametrized representation of the available transitions domain
- It is assumed that all conditions that are not mentioned in a state are FALSE (**closed world assumption**)

Modelling in planning (II)

- Given a classical planning problem
  - Inputs
    - Problem: Initial State and Goal(s)
    - Domain
  - Output
    - A sequence of actions that transform the initial state to a state that satisfies the goals
- State space
  - All states reachable by applying a sequence of actions to the initial state
  - Actions are operators with its parameters instantiated by constants of the initial state

Modelling in planning (III)



Modelling in planning: Domain (I)

- Operators specify the possible transactions in a domain
- For each problem, use the initial state and the specification of operators to determine possible transactions for the particular problem
- To be problem independent, operators use parameters
- Composed of:
  - Preconditions: conditions that must be met before execution
  - Effects: conditions that we achieve when the action is executed
- What is not mentioned, remains unchanged

Modelling in planning: Domain (II)

- We say that an action is applicable in any state that satisfies its preconditions, otherwise the action has no effect
- The application consists of replacing the variables by constants
- Instantiated operator is called an action

Modelling in planning: Problem

- Composed of Initial State and Goal(s)
- To represent initial state
  - It can be any logical description
  - What is not mentioned is FALSE
- To represent a goal
  - A set of literals (*ground literals*)
  - A goal is satisfied if **all** literals are satisfied

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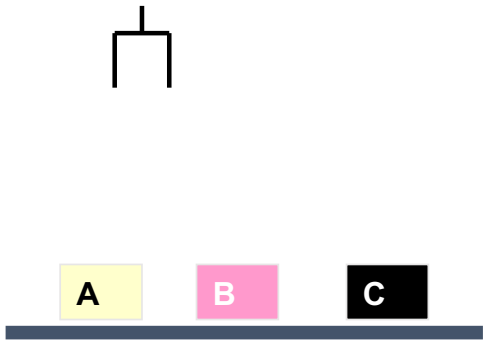
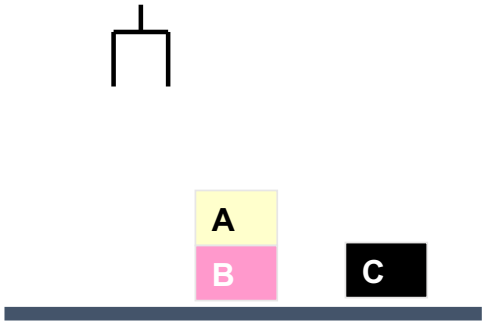
STRIPS

- **St**anford **R**esearch **I**nstitute **P**roblem **S**olver
- It is an automated planner and a formal language
- Simplest and oldest representation of operators in AI (1971)
- The initial state is represented by a DB of positive facts
- It can be seen as a simple way to specify updates to the DB
- Little expressiveness for real domains so that other languages have emerged: ADL, Prodigy language (PDL), UCPOP language , SIPE-2 language ,..., PDDL (standard)

STRIPS (I)



Initial State



Goal

STRIPS (II)

```
(def-strips-operator (pickup ?x)
   (pre (handempty) (clear ?x) (ontable ?x))
   (add (holding ?x))
   (del (handempty) (clear ?x) (ontable ?x)))
```

STRIPS (II)

```
(def-strips-operator (pickup ?x)
    (pre (handempty) (clear ?x) (ontable ?x))
    (add (holding ?x))
    (del (handempty) (clear ?x) (ontable ?x)))
```

Operator name & parameters

STRIPS (II)

```
(def-strips-operator (pickup ?x)
   (pre (handempty) (clear ?x) (ontable ?x))
   List of predicates that must be true
   in the current state for aplying the
   action
   (add (holding ?x))
   (del (handempty) (clear ?x) (ontable ?x)))
```

STRIPS (II)

```
(def-strips-operator (pickup ?x)
   (pre (handempty) (clear ?x) (ontable ?x))
   (add (holding ?x))
   List of predicates that must be true
   in the next state

   (del (handempty) (clear ?x) (ontable ?x)))
```

STRIPS (II)

```
(def-strips-operator (pickup ?x)
   (pre (handempty) (clear ?x) (ontable ?x))
   (add (holding ?x))
   (del (handempty) (clear ?x) (ontable ?x)))
   List of predicates that must be false
   in the next state
```

STRIPS (III)

- Given the initial state
  - All instantiations of the `?x` parameter that satisfy the precondition

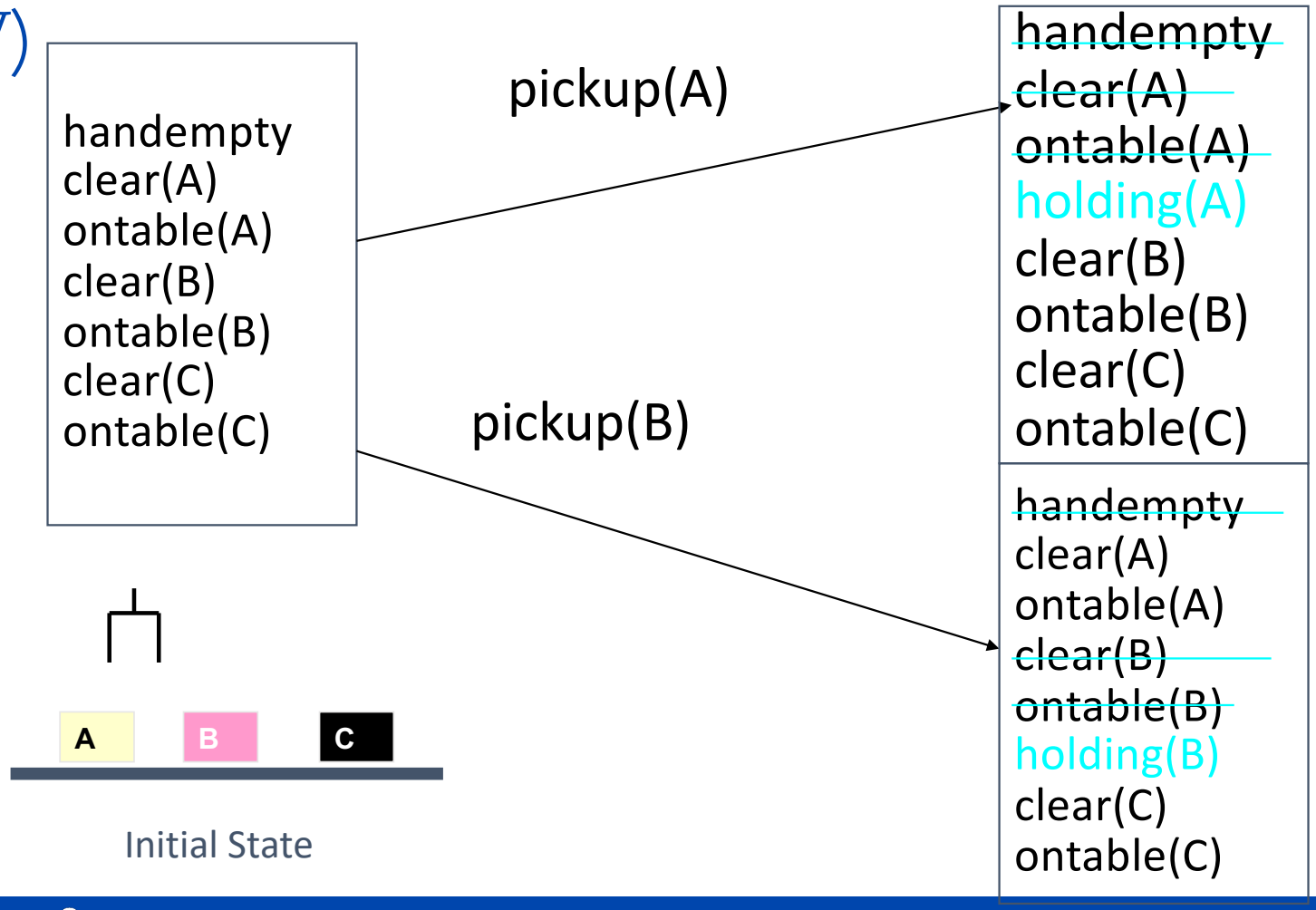
```
(and (handempty) (clear ?x) (ontable ?x))
```

  produced a different action (transition) that can be applied to the initial state
  - Actions whose preconditions are not met are illegal transitions

STRIPS (IV)

- Actions are deterministic
- Nothing else changes more! (This often has algorithmic consequences)
- From the properties of the initial state and the set of operators is possible to determine:
  - The finite set of actions that can be applied to the initial state
  - In each successor state generated by these actions, you can evaluate all logical formulas, and determine the set of available actions

STRIPS (V)



Initial State

Outline

- Introduction
- Logic
- Type of problems
- STRIPS
- **PDDL**
- IPC
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PDDL

- **P**lanning **D**omain **D**efinition **L**anguage
- Emerges as an attempt to unify previous formalisms and to compare the efficiency of planners
- AIPS-98 Planning Competition Committee
- Intended to represent the physics of a domain: what predicates there are, what actions are possible, the structure of such actions and their effects
- Based on ADL, Prodigy language (PDL), UCPOP language, among others
- Versions: 1.2, 2.1, 3.0 and actually in the 3.1

PDDL2.1 Variants (I)

- **PDDL+:** provides a more flexible model of continuous changes through the use of autonomous processes and events
- **MAPL** (Multi-Agent Planning Language, pronounced "maple")
  - Temporal model given with modal operators (before, after, etc.)
  - Non-propositional state-variables
  - Actions whose duration will be determined in runtime and explicit plan synchronization which is realized through speech act based communication among agents

(Source)

PDDL2.1 Variants (II)

- **OPT** (Ontology with Polymorphic Types):
  - An attempt to create a general-purpose notation for creating ontologies, defined as formalized conceptual frameworks for planning domains
  - Efficient type inference and other compatibilities with the semantic web
- **PPDDL** (Probabilistic PDDL):
  - Probabilistic effects (discrete, general probability distributions over possible effects of an action)
  - Reward fluents (for incrementing or decrementing the total reward of a plan in the effects of the actions)
  - Goal rewards (for rewarding a state-trajectory, which incorporates at least one goal-state)
  - Goal-achieved fluents (which were true, if the state-trajectory incorporated at least one goal-state)

Variants (III)

- **RDDL** (Relational Dynamic influence Diagram Language): the 7th IPC in 2011
  - Based on PPDDL1.0 and PDDL3.0, is a completely different language both syntactically and semantically
  - Introduces partial observability (allows efficient description of MDPs and POMDPs by representing everything with variables
- **NDDL** (New Domain Definition Language) is NASA's planning language
  - Use variable representation (timelines/activities) rather than a propositional/first-order logic, and
  - No concept of states or actions, only of intervals (activities) and constraints between activities

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- **IPC**
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IPC

- **I**nternational **P**lanning **C**ompetition
- Organized in the context of the International Conference on Planning and Scheduling (ICAPS)
- Aims to evaluate SoA planning systems on a number of benchmark problems
- Goals:
  - Promote planning research
  - Highlight challenges in the planning community
  - Provide new and interesting problems as benchmarks for future research

IPC: competitions

- 1st IPC in 1998 (1 track: Deterministic)
- 2nd IPC in 2000 (1 track: Deterministic)
- 3rd IPC in 2002 (1 track: Deterministic)
- 4th IPC in 2004, University of Freiburg, Germany (2 tracks: Deterministic & Probabilistic)
- 5th IPC in 2006, Universita di Brescia, Italy (2 tracks: Deterministic & Probabilistic)
- 6th IPC in 2008 (3 tracks: Deterministic, Uncertainty & Learning)
- 7th IPC in 2011 (3 tracks: Deterministic, Uncertainty & Learning)
- 8th IPC in 2014, University of Huddersfield (4 tracks: Deterministic, Uncertainty & Learning)
- 9th IPC in 2018 (3 tracks: Deterministic, Probabilistic & Temporal)

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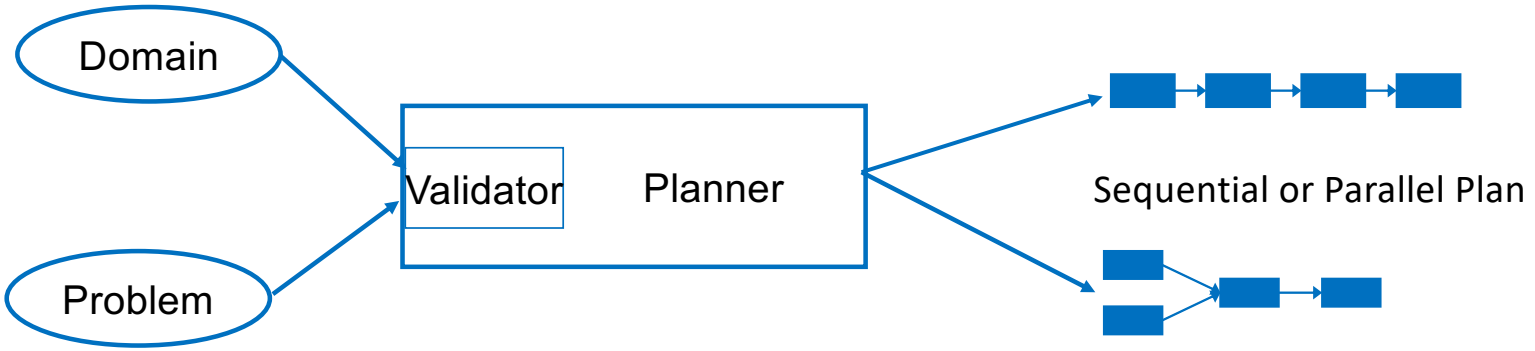
Conclusions

- Knowledge representation in FOL
- Languages: STRIPS and PDDL (standard)
- Competitions: IPC
- Inputs & outputs of a planner



Conclusions