Planning Representation

Planning & Scheduling

Computer Sciences Degree

Computer Engineering Department

Dra. Mª Dolores Rodríguez Moreno

Objectives

Specific Objectives

- Role of logics
- Role of search
- Know main languages

Source

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

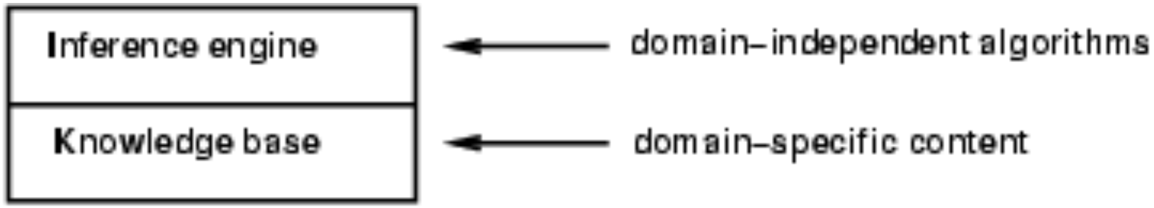
Outline

- **Introduction**
- Logics
- Type of problems
- Modelling in planning
- STRIPS
- PDDL
- IPC
- Conclusions

Introduction

- 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

Introduction



- 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

Outline

- Introduction
- **Logic**
- Type of problems
- Modelling in planning
- STRIPS
- PDDL
- IPC
- Conclusions

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,

Outline

- Introduction
- Logic
- **Type of problems**
- Modelling in planning
- STRIPS
- PDDL
- IPC
- Conclusions

Type of problems

- **Fully observable** (vs. partially observable): an agent's sensors give it access to the complete state of the environment at each point in time
- **Deterministic** (vs. non-deterministic): the next state of the environment is completely determined by the current state and the action executed by the agent
- **Episodic** (vs. sequential): the agent's experience is divided into atomic "episodes" (each episode consists of the agent perceiving and then performing a single action), and the choice of action in each episode depends only on the episode itself
- **Discrete** (vs. continuous): A limited number of distinct, clearly defined percepts and actions
- **Single agent** (vs. multiagent): an agent operating by itself in an environment

Outline

- Introduction
- Logic
- Type of problems
- **Modelling in planning**
- STRIPS
- PDDL
- IPC
- Conclusions

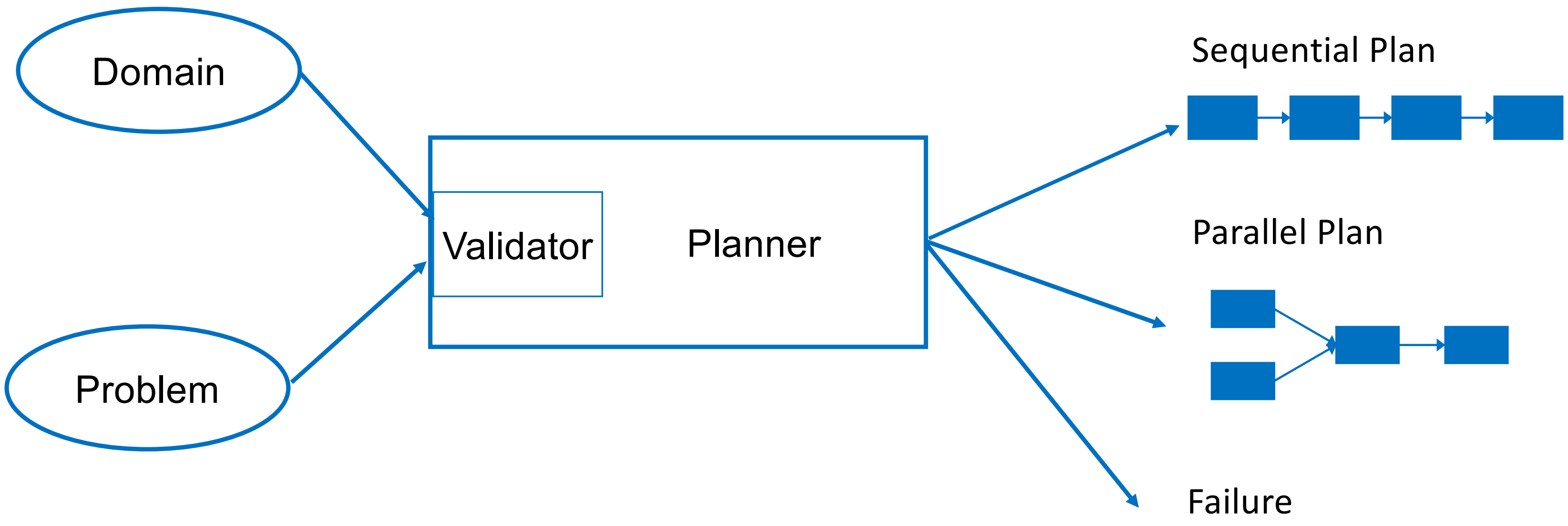
Modelling in planning (I)

- Planners decompose the world in terms of logical conditions and represent a state as a sequence of connected positive literals
  - Propositions: Fast ∧ AirbusA380
  - FOL: At(Plane1,Madrid) ∧ 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

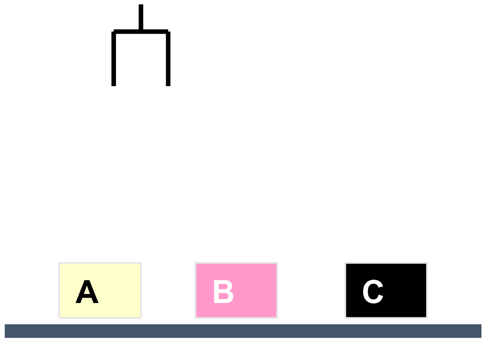
Outline

- Introduction
- Logic
- Type of problems
- Modelling in planning
- **STRIPS**
- PDDL
- IPC
- Conclusions

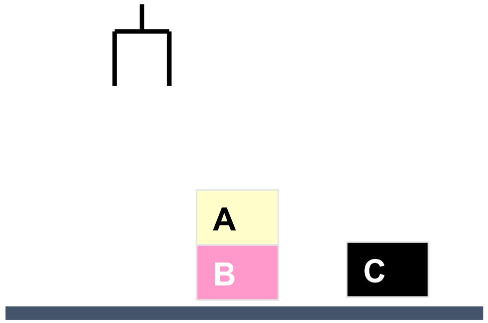
STRIPS

- **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))
  (add (holding ?x))
  (del (handempty) (clear ?x) (ontable ?x)))
```

List of predicates that must be true in the current state for aplying the action

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

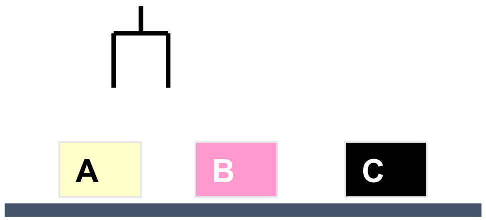
handempty
clear(A)
ontable(A)
clear(B)
ontable(B)
clear(C)
ontable(C)

pickup(A)

~~handempty~~
~~clear(A)~~
~~ontable(A)~~
holding(A)
clear(B)
ontable(B)
clear(C)
ontable(C)

pickup(B)

~~handempty~~
clear(A)
ontable(A)
~~clear(B)~~
~~ontable(B)~~
holding(B)
clear(C)
ontable(C)



Initial State

Outline

- Introduction
- Logic
- Type of problems
- Modelling in planning
- STRIPS
- **PDDL**
- IPC
- Conclusions

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

- **PDDL+:** provides a more flexible model of continuous changes through the use of autonomous processes and events
- **MAPL** (Multi-Agent Planning Language, pronounced "maple”)
  - Non-propositional state-variables (which may be n-ary: true, false, unknown, or anything else)
  - Temporal model given with modal operators (before, after, etc.).
  - 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

- **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

- **RDDL** (Relational Dynamic influence Diagram Language): the 7th IPC in 2011
  - Based on PPDL1.0 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

Outline

- Introduction
- Logic
- Type of problems
- Modelling in planning
- STRIPS
- PDDL
- **IPC**
- Conclusions

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

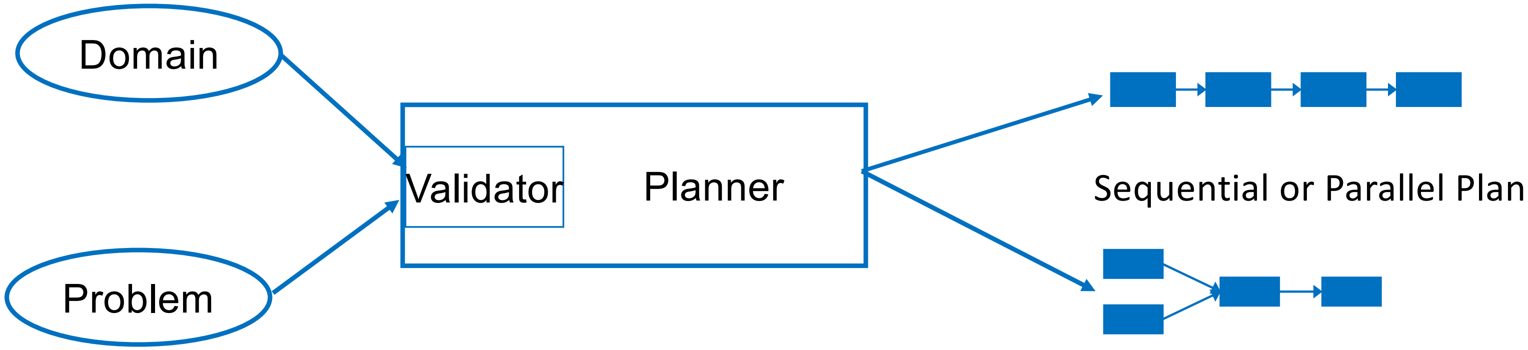
- 1st IPC in 1998 (1 track: Deterministic)
- 2nd IPC in 2000 (1 track: Deterministic)
- 3rd IPC in 2002 (1 track: Deterministic)
- 4th IPC in 2004, University of Freiburg, Germany (2 tracks: Deterministic & Probabilistic)
- 5th IPC in 2006, Universita di Brescia, Italy (2 tracks: Deterministic & Probabilistic)
- 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)

Outline

- Introduction
- Logic
- Type of problems
- Modelling in planning
- STRIPS
- PDDL
- IPC
- **Conclusions**

Conclusions

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



Conclusions