

# Foundations of Artificial Intelligence

## F2. Automated Planning: Planning Formalisms

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## F2.1 Four Formalisms

## F2.2 STRIPS

## F2.3 ADL, SAS<sup>+</sup> and PDDL

## F2.4 Summary

# Automated Planning: Overview

## Chapter overview: automated planning

- ▶ F1. Introduction
- ▶ F2. Planning Formalisms
- ▶ F3. Delete Relaxation
- ▶ F4. Delete Relaxation Heuristics
- ▶ F5. Abstraction
- ▶ F6. Abstraction Heuristics

## F2.1 Four Formalisms

# Four Planning Formalisms

- ▶ A description language for state spaces (**planning tasks**) is called a **planning formalism**.
- ▶ We introduce four planning formalisms:
  - ① STRIPS (Stanford Research Institute Problem Solver)
  - ② ADL (Action Description Language)
  - ③ SAS<sup>+</sup> (Simplified Action Structures)
  - ④ PDDL (Planning Domain Definition Language)
- ▶ STRIPS and SAS<sup>+</sup> are the most simple formalisms; in the next chapters, we only consider these.

## F2.2 STRIPS

# STRIPS: Basic Concepts

## basic concepts of STRIPS:

- ▶ STRIPS is the **most simple** common planning formalism.
  - ▶ state variables are **binary** (true or false)
  - ▶ **states**  $s$  (based on a given set of state variables  $V$ ) can be represented in two equivalent ways:
    - ▶ as **assignments**  $s : V \rightarrow \{\mathbf{F}, \mathbf{T}\}$
    - ▶ as **sets**  $s \subseteq V$ ,  
where  $s$  encodes the set of state variables that are **true** in  $s$
- We will use the set representation.
- ▶ **goals** and **preconditions of actions** are given as sets of variables that must be **true** (values of other variables do not matter)
  - ▶ **effects of actions** are given as sets of variables that are **set to true** and **set to false**, respectively

# STRIPS Planning Task

## Definition (STRIPS Planning Task)

A **STRIPS** planning task is a 4 tuple  $\Pi = \langle V, I, G, A \rangle$  with

- ▶  $V$ : finite set of **state variables**
- ▶  $I \subseteq V$ : the **initial state**
- ▶  $G \subseteq V$ : the set of **goals**
- ▶  $A$ : finite set of **actions**,  
where for all actions  $a \in A$ , the following is defined:
  - ▶  $pre(a) \subseteq V$ : the **preconditions** of  $a$
  - ▶  $add(a) \subseteq V$ : the **add effects** of  $a$
  - ▶  $del(a) \subseteq V$ : the **delete effects** of  $a$
  - ▶  $cost(a) \in \mathbb{N}_0$ : the **costs** of  $a$

**German:** STRIPS-Planungsaufgabe, Zustandsvariablen, Anfangszustand, Ziele, Aktionen, Add-/Delete-Effekte, Kosten

**remark:** action costs are an extension of “traditional” STRIPS



# State Space for STRIPS Planning Task

## Definition (state space induced by STRIPS planning task)

Let  $\Pi = \langle V, I, G, A \rangle$  be a STRIPS planning task.

Then  $\Pi$  **induces** the **state space**  $\mathcal{S}(\Pi) = \langle S, A, cost, T, s_I, S_G \rangle$ :

- ▶ **set of states:**  $S = 2^V$  (= power set of  $V$ )
- ▶ **actions:** actions  $A$  as defined in  $\Pi$
- ▶ **action costs:**  $cost$  as defined in  $\Pi$
- ▶ **transitions:**  $s \xrightarrow{a} s'$  for states  $s, s' \in S$  and action  $a \in A$  iff
  - ▶  $pre(a) \subseteq s$  (preconditions satisfied)
  - ▶  $s' = (s \setminus del(a)) \cup add(a)$  (effects are applied)
- ▶ **initial state:**  $s_I = I$
- ▶ **goal states:**  $s \in S_G$  for state  $s$  iff  $G \subseteq s$  (goals reached)

**German:** induziert den Zustandsraum

# Example: Blocks World in STRIPS

## Example (A Blocks World Planning Task in STRIPS)

$\Pi = \langle V, I, G, A \rangle$  with:

- ▶  $V = \{on_{R,B}, on_{R,G}, on_{B,R}, on_{B,G}, on_{G,R}, on_{G,B},$   
 $on-table_R, on-table_B, on-table_G,$   
 $clear_R, clear_B, clear_G\}$
- ▶  $I = \{on_{G,R}, on-table_R, on-table_B, clear_G, clear_B\}$
- ▶  $G = \{on_{R,B}, on_{B,G}\}$
- ▶  $A = \{move_{R,B,G}, move_{R,G,B}, move_{B,R,G},$   
 $move_{B,G,R}, move_{G,R,B}, move_{G,B,R},$   
 $to-table_{R,B}, to-table_{R,G}, to-table_{B,R},$   
 $to-table_{B,G}, to-table_{G,R}, to-table_{G,B},$   
 $from-table_{R,B}, from-table_{R,G}, from-table_{B,R},$   
 $from-table_{B,G}, from-table_{G,R}, from-table_{G,B}\}$

...

## Example: Blocks World in STRIPS

### Example (A Blocks World Planning Task in STRIPS)

*move* actions encode moving a block  
from one block to another

example:

- ▶  $pre(move_{R,B,G}) = \{on_{R,B}, clear_{R}, clear_{G}\}$
- ▶  $add(move_{R,B,G}) = \{on_{R,G}, clear_{B}\}$
- ▶  $del(move_{R,B,G}) = \{on_{R,B}, clear_{G}\}$
- ▶  $cost(move_{R,B,G}) = 1$

## Example: Blocks World in STRIPS

### Example (A Blocks World Planning Task in STRIPS)

*to-table* actions encode moving a block from a block to the table

example:

- ▶  $pre(to-table_{R,B}) = \{on_{R,B}, clear_R\}$
- ▶  $add(to-table_{R,B}) = \{on-table_R, clear_B\}$
- ▶  $del(to-table_{R,B}) = \{on_{R,B}\}$
- ▶  $cost(to-table_{R,B}) = 1$

## Example: Blocks World in STRIPS

### Example (A Blocks World Planning Task in STRIPS)

*from-table* actions encode moving a block  
from the table to a block

example:

- ▶  $pre(\text{from-table}_{R,B}) = \{on\text{-table}_R, clear_R, clear_B\}$
- ▶  $add(\text{from-table}_{R,B}) = \{on_{R,B}\}$
- ▶  $del(\text{from-table}_{R,B}) = \{on\text{-table}_R, clear_B\}$
- ▶  $cost(\text{from-table}_{R,B}) = 1$

# Why STRIPS?

- ▶ STRIPS is **particularly simple**.
- ~> simplifies the design and implementation of planning algorithms
- ▶ often cumbersome for the user to model tasks directly in STRIPS
- ▶ **but:** STRIPS is equally “powerful” to much more complex planning formalisms
- ~> automatic “compilers” exist that translate more complex formalisms (like ADL and SAS<sup>+</sup>) to STRIPS

## F2.3 ADL, SAS<sup>+</sup> and PDDL

# Basic Concepts of ADL

## basic concepts of ADL:

- ▶ Like STRIPS, ADL uses propositional variables (true/false) as state variables.
- ▶ preconditions of actions and goal are **arbitrary logic formulas** (action applicable/goal reached in states that satisfy the formula)
- ▶ in addition to STRIPS effects, there are **conditional effects**: variable  $v$  is only set to true/false if a given logical formula is true in the current state



# Basic Concepts of SAS<sup>+</sup>

## basic concepts of SAS<sup>+</sup>:

- ▶ very similar to STRIPS: state variables not necessarily binary, but with given **finite domain** (cf. CSPs)
- ▶ states are **assignments** to these variables (cf. CSPs)
- ▶ preconditions and goals given as **partial assignments**  
**example:**  $\{v_1 \mapsto a, v_3 \mapsto b\}$  as preconditions (or goals)
  - ▶ If  $s(v_1) = a$  and  $s(v_3) = b$ ,  
then the action is applicable in  $s$  (or goal is reached)
  - ▶ values of other variables do not matter
- ▶ effects are **assignments to subset** of variables  
**example:** effect  $\{v_1 \mapsto b, v_2 \mapsto c\}$  means
  - ▶ In the successor state  $s'$ ,  $s'(v_1) = b$  and  $s'(v_2) = c$ .
  - ▶ All other variables retain their values.

# Basic Concept of PDDL

- ▶ PDDL is the standard language used in practice to describe planning tasks.
- ▶ descriptions in (restricted) predicate logic instead of propositional logic ( $\rightsquigarrow$  even more compact)
- ▶ other features like **numeric variables** and **derived variables** (**axioms**) for defining complex logical conditions (formulas that are automatically evaluated in every state and can, e.g., be used in preconditions)
- ▶ There exist defined PDDL fragments for STRIPS and ADL; many planners only support the STRIPS fragment.

**example:** blocks world in PDDL

## F2.4 Summary

# Summary

## planning formalisms:

- ▶ **STRIPS**: particularly simple, easy to handle for algorithms
  - ▶ binary state variables
  - ▶ preconditions, add and delete effects, goals:  
sets of variables
- ▶ **ADL**: extension of STRIPS
  - ▶ **logic formulas** for complex preconditions and goals
  - ▶ **conditional effects**
- ▶ **SAS<sup>+</sup>**: extension of STRIPS
  - ▶ state variables with **arbitrary finite domains**
- ▶ **PDDL**: input language used in practice
  - ▶ based on predicate logic  
(more compact than propositional logic)
  - ▶ only partly supported by most algorithms  
(e.g., STRIPS or ADL fragment)