

Foundations of Artificial Intelligence

33. Automated Planning: Introduction

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Classification

classification:

Automated Planning

environment:

- ▶ **static** vs. dynamic
- ▶ **deterministic** vs. non-deterministic vs. stochastic
- ▶ **fully** vs. partially vs. not **observable**
- ▶ **discrete** vs. continuous
- ▶ **single-agent** vs. multi-agent

problem solving method:

- ▶ problem-specific vs. **general** vs. learning

33.1 Introduction

Automated Planning

What is Automated Planning?

“Planning is the art and practice of thinking before acting.”

— P. Haslum

~ finding **plans** (sequences of actions) that lead from an initial state to a goal state

our topic in this course: **classical planning**

- ▶ **general** approach to finding solutions for **state-space search problems** (Chapters 5–19)
- ▶ **classical** = static, deterministic, fully observable
- ▶ **variants**: probabilistic planning, planning under partial observability, online planning, ...

What is New?

Many previously encountered problems are planning tasks:

- ▶ blocks world
- ▶ missionaries and cannibals
- ▶ 15-puzzle

New: we are now interested in **general** algorithms, i.e., the developer of the search algorithm **does not know** the tasks that the algorithm needs to solve.

- ~ no problem-specific heuristics!
- ~ **input language** to model the planning task

Planning: Informally

given:

- ▶ state space description in terms of suitable problem description language (**planning formalism**)

required:

- ▶ a **plan**, i.e., a solution for the described state space (sequence of actions from initial state to goal)
- ▶ or a proof that no plan exists

distinguish between

- ▶ **optimal planning**: guarantee that returned plans are optimal, i.e., have minimal overall cost
- ▶ **suboptimal planning (satisficing)**: suboptimal plans are allowed

Automated Planning: Overview

Chapter overview: automated planning

- ▶ 33. Introduction
- ▶ 34. Planning Formalisms
- ▶ 35.–36. Planning Heuristics: Delete Relaxation
- ▶ 37. Planning Heuristics: Abstraction
- ▶ 38.–39. Planning Heuristics: Landmarks

33.2 Repetition: State Spaces

About This Section

Nothing New Here!

This section is a **repetition** of Section 5.2 of the chapter “State-Space Search: State Spaces”.

Formalization of State Spaces

preliminary remarks:

- ▶ to cleanly study search problems we need a **formal model**
- ▶ fundamental concept: **state spaces**
- ▶ state spaces are (labeled, directed) **graphs**
- ▶ **paths** to goal states represent **solutions**
- ▶ **shortest paths** correspond to **optimal solutions**

State Spaces

Definition (state space)

A **state space** or **transition system** is a 6-tuple $\mathcal{S} = \langle S, A, \text{cost}, T, s_0, S_* \rangle$ with

- ▶ S : finite set of **states**
- ▶ A : finite set of **actions**
- ▶ $\text{cost} : A \rightarrow \mathbb{R}_0^+$ **action costs**
- ▶ $T \subseteq S \times A \times S$ **transition relation**; deterministic in $\langle s, a \rangle$ (see next slide)
- ▶ $s_0 \in S$ **initial state**
- ▶ $S_* \subseteq S$ **set of goal states**

German: Zustandsraum, Transitionssystem, Zustände, Aktionen, Aktionskosten, Transitions-/Übergangsrelation, deterministisch, Anfangszustand, Zielzustände

State Spaces: Transitions, Determinism

Definition (transition, deterministic)

Let $\mathcal{S} = \langle S, A, \text{cost}, T, s_0, S_* \rangle$ be a state space.

The triples $\langle s, a, s' \rangle \in T$ are called **(state) transitions**.

We say \mathcal{S} **has the transition** $\langle s, a, s' \rangle$ if $\langle s, a, s' \rangle \in T$.

We write this as $s \xrightarrow{a} s'$, or $s \rightarrow s'$ when a does not matter.

Transitions are **deterministic** in $\langle s, a \rangle$: it is forbidden to have both $s \xrightarrow{a} s_1$ and $s \xrightarrow{a} s_2$ with $s_1 \neq s_2$.

State Spaces: Terminology

terminology:

- ▶ predecessor, successor
- ▶ applicable action
- ▶ path, length, costs
- ▶ reachable
- ▶ solution, optimal solution

German: Vorgänger, Nachfolger, anwendbare Aktion, Pfad, Länge, Kosten, erreichbar, Lösung, optimale Lösung

33.3 Compact Descriptions

State Spaces with Declarative Representations

How do we represent state spaces in the computer?

previously: as black box

now: as **declarative description**

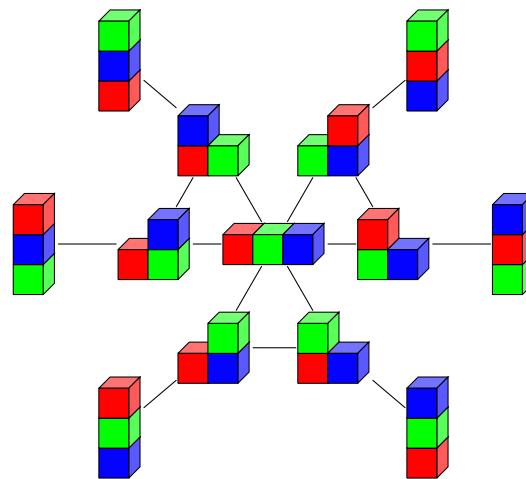
reminder: Chapter 6

State Spaces with Declarative Representations

represent state spaces **declaratively**:

- ▶ **compact** description of state space as input to algorithms
 - ~~ state spaces **exponentially larger** than the input
- ▶ algorithms directly operate on compact description
 - ~~ allows automatic reasoning about problem: reformulation, simplification, abstraction, etc.

Reminder: Blocks World



problem: n blocks \rightsquigarrow more than $n!$ states

33.4 Summary

Compact Description of State Spaces

How to describe state spaces compactly?

Compact Description of Several States

- ▶ introduce **state variables**
- ▶ states: assignments to state variables
- ↪ e.g., n binary state variables can describe 2^n states
- ▶ **transitions and goal** are compactly described with a logic-based formalism

different variants: different **planning formalisms**

Summary

- ▶ **planning**: search in **general** state spaces
- ▶ **input**: compact, declarative description of state space