

Foundations of Artificial Intelligence

F1. Automated Planning: Introduction

Malte Helmert

University of Basel

April 30, 2025

Foundations of Artificial Intelligence

April 30, 2025 — F1. Automated Planning: Introduction

F1.1 Introduction

F1.2 Repetition: State Spaces

F1.3 Compact Descriptions

F1.4 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

Classification

classification:

Automated Planning

environment:

- ▶ static vs. dynamic
- ▶ deterministic vs. nondeterministic vs. stochastic
- ▶ fully observable vs. partially observable
- ▶ discrete vs. continuous
- ▶ single-agent vs. multi-agent

problem solving method:

- ▶ problem-specific vs. general vs. learning

(applications also in more complex environments)

F1.1 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** (Part B)
- ▶ **classical** = static, deterministic, fully observable
- ▶ **variants**: probabilistic planning, planning under partial observability, online planning, ...

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

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

F1.2 Repetition: State Spaces

Formal Models for State-Space Search

To cleanly study search problems we need a **formal model**.

Nothing New Here!

This section is a **repetition** of Section B1.2 of the chapter “State-Space Search: State Spaces”.

State Spaces

Definition (state space)

A **state space** or **transition system** is a 6-tuple $\mathcal{S} = \langle S, A, cost, T, s_1, S_G \rangle$ with

- ▶ finite set of **states** S
- ▶ finite set of **actions** A
- ▶ **action costs** $cost : A \rightarrow \mathbb{R}_0^+$
- ▶ **transition relation** $T \subseteq S \times A \times S$ that is **deterministic in $\langle s, a \rangle$** (see next slide)
- ▶ **initial state** $s_1 \in S$
- ▶ set of **goal states** $S_G \subseteq S$

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

State Spaces: Terminology & Notation

Definition (transition, deterministic)

Let $\mathcal{S} = \langle S, A, cost, T, s_I, S_G \rangle$ 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 $\langle s, a, s' \rangle \in T$.

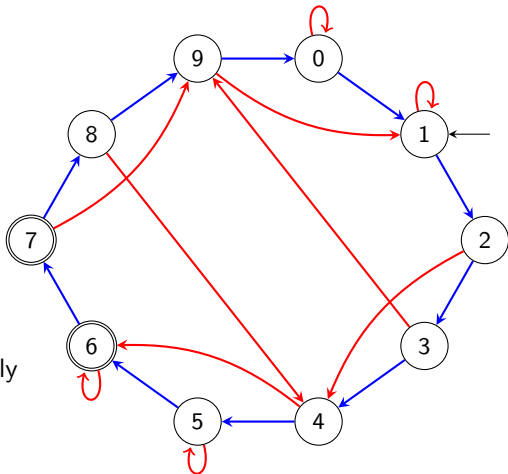
We write this as $s \xrightarrow{a} s'$, or $s \rightarrow s'$ when a does not matter.

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 $s_1 \neq s_2$.

Graph Interpretation

state spaces are often depicted as **directed, labeled graphs**

- ▶ **states**: graph vertices
- ▶ **transitions**: labeled arcs
(here: colors instead of labels)
- ▶ **initial state**: incoming arrow
- ▶ **goal states**: double circles
- ▶ **actions**: the arc labels
- ▶ **action costs**: described separately
(or implicitly = 1)



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

F1.3 Compact Descriptions

State Spaces with Declarative Representations

How do we represent state spaces in the computer?

previously: as black box

now: as declarative description

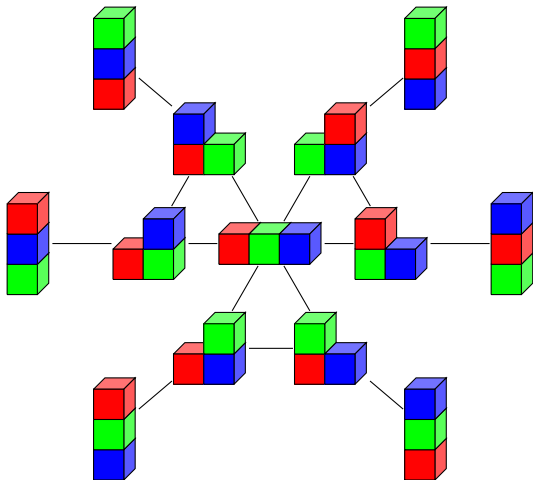
reminder: Chapter B2

State Spaces with Declarative Representations

represent state spaces **declaratively**:

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

Reminder: Blocks World



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

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 states** are compactly described with a logic-based formalism

different variants: different **planning formalisms**

F1.4 Summary

Summary

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