# Foundations of Artificial Intelligence

## 33. Automated Planning: Introduction

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April 27, 2020

# 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

# Introduction

# Automated Planning

**What is Automated Planning?**

"Planning is the art and practice of thinking before acting."

— P. Haslum

$\rightsquigarrow$ 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, . . .

# 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

# 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

# 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 $\mathcal{S} = \langle S, A, cost, T, s_0, S_\star \rangle$ with

- $S$: finite set of states
- $A$: finite set of actions
- $cost : A \to \mathbb{R}_0^+$ 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
- $S_\star \subseteq S$ set of goal states

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

# State Spaces: Transitions, Determinism

**Definition (transition, deterministic)**

Let $\mathcal{S} = \langle S, A, cost, T, s_0, S_\star \rangle$ 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 $s \to s'$ 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

# 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

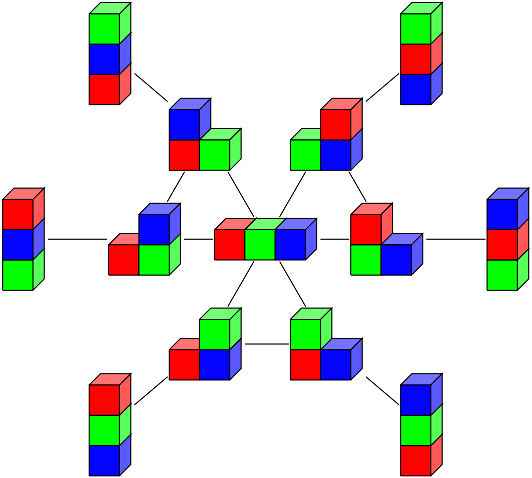
## State Spaces with Declarative Representations

represent state spaces declaratively:

- compact description of state space as input to algorithms
  $\rightsquigarrow$ 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 are compactly described with a logic-based formalism

different variants: different planning formalisms

# Summary

# Summary

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