Foundations of Artificial Intelligence

F1. Automated Planning: Introduction

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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)

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

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 $\mathcal{S} = \langle S, A, cost, T, s_\mathsf{I}, S_\mathsf{G} \rangle$ with

- finite set of states S
- finite set of actions A
- action costs $cost : A \to \mathbb{R}^+_0$
- transition relation $T \subseteq S \times A \times S$ that is deterministic in $\langle s, a \rangle$ (see next slide)
- initial state $s_\mathsf{I} \in S$
- set of goal states $S_\mathsf{G} \subseteq S$

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

State Spaces: Terminology & Notation

Definition (transition, deterministic)

Let $\mathcal{S} = \langle S, A, cost, T, s_{\mathsf{I}}, S_{\mathsf{G}} \rangle$ 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 $s \to s'$ 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 $s_1 \neq s_2$.

Graph Interpretation

state spaces are often depicted as directed, labeled graphs

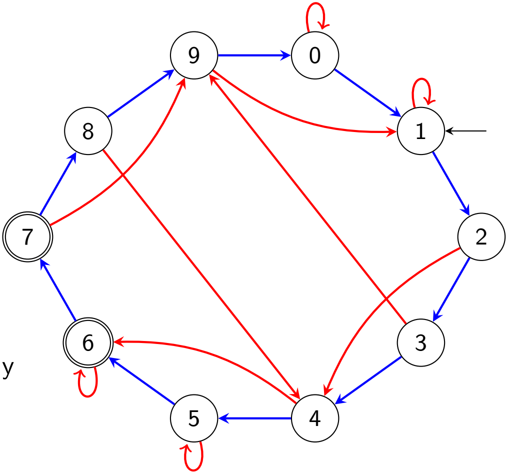
- states: graph vertices
- transitions: labeled arcs

- initial state: incoming arrow
- goal states: double circles
- actions: the arc labels
- action costs: described separately (or implicitly $= 1$)

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

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

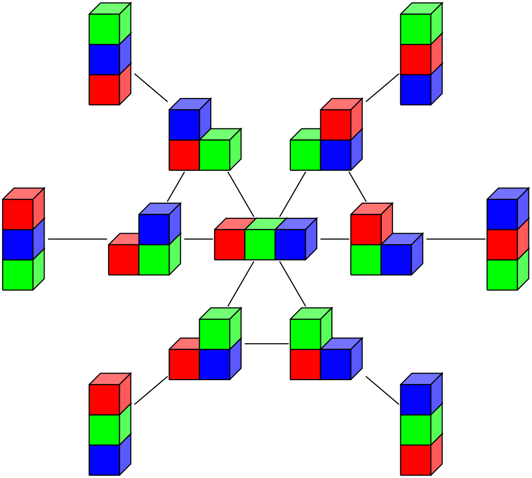
State Spaces with Declarative Representations

represent state spaces declaratively:

- compact description of state space as input to algorithms
  ⇝ 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

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

Summary

Summary

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