Foundations of Artificial Intelligence

7. State-Space Search: Examples of State Spaces

Malte Helmert and Thomas Keller

University of Basel

February 26, 2020

State-Space Search: Overview

Chapter overview: state-space search

- 5.–7. Foundations
  - 5. State Spaces
  - 6. Representation of State Spaces
  - 7. Examples of State Spaces
- 8.–12. Basic Algorithms
- 13.–19. Heuristic Algorithms

Three Examples

In this chapter we introduce three state spaces that we will use as illustrating examples:

1. blocks world
2. route planning in Romania
3. missionaries and cannibals

7.1 Blocks World

Blocks World

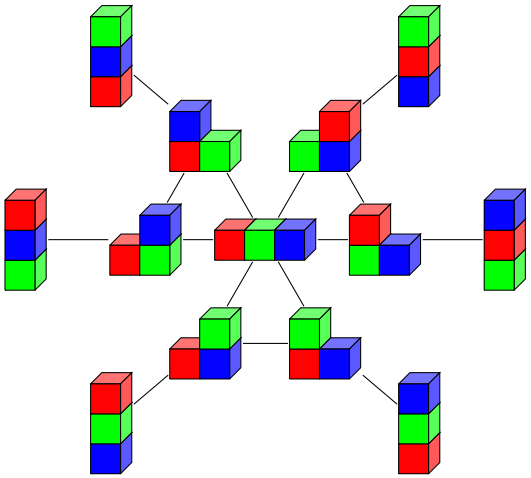
Blocks world is a traditional example problem in AI.

Setting: Blocks World

- Colored blocks lie on a table.
- They can be stacked into towers, moving one block at a time.
- Our task is to create a given goal configuration.

Example: Blocks World with Three Blocks

(action names omitted for readability;
initial state and goal can be arbitrary)



Blocks World: Formal Definition

state space $\langle S, A, cost, T, s_0, S_\star \rangle$ for blocks world with n blocks

State Space Blocks World

states S:

partitions of $\{1, 2, \ldots, n\}$ into nonempty ordered lists

example $n = 3$:

- $\{\langle 1,2,3\rangle\}$, $\{\langle 1,3,2\rangle\}$, $\{\langle 2,1,3\rangle\}$, $\{\langle 2,3,1\rangle\}$, $\{\langle 3,1,2\rangle\}$, $\{\langle 3,2,1\rangle\}$
- $\{\langle 1,2\rangle, \langle 3\rangle\}$, $\{\langle 2,1\rangle, \langle 3\rangle\}$, $\{\langle 1,3\rangle, \langle 2\rangle\}$, $\{\langle 3,1\rangle, \langle 2\rangle\}$, $\{\langle 2,3\rangle, \langle 1\rangle\}$, $\{\langle 3,2\rangle, \langle 1\rangle\}$
- $\{\langle 1\rangle, \langle 2\rangle, \langle 3\rangle\}$

Blocks World: Formal Definition

state space $\langle S, A, cost, T, s_0, S_\star \rangle$ for blocks world with n blocks

State Space Blocks World

actions A:

- $\{move_{b,b'} \mid b, b' \in \{1, \ldots, n\}$ with $b \neq b'\}$
  - move block b onto block b'.
  - both must be uppermost blocks in their towers
- $\{totable_b \mid b \in \{1, \ldots, n\}\}$
  - move block b onto the table ($\rightsquigarrow$ forming a new tower)
  - must be uppermost block in its tower

action costs $cost$:

$cost(a) = 1$ for all actions a

Blocks World: Formal Definition

state space $\langle S, A, cost, T, s_0, S_\star \rangle$ for blocks world with n blocks

State Space Blocks World

transitions:

example for $a = move_{2,3}$:

transition $s \xrightarrow{a} s'$ exists iff

- $s = \{\langle b_1, \ldots, b_k, 2\rangle, \langle c_1, \ldots, c_m, 3\rangle\} \cup X$ and
- if $k > 0$: $s' = \{\langle b_1, \ldots, b_k\rangle, \langle c_1, \ldots, c_m, 3, 2\rangle\} \cup X$
- if $k = 0$: $s' = \{\langle c_1, \ldots, c_m, 3, 2\rangle\} \cup X$

Blocks World: Formal Definition

state space $\langle S, A, cost, T, s_0, S_\star \rangle$ for blocks world with n blocks

State Space Blocks World

initial state s_0 and goal states $S_\star$:

one possible definition for $n = 3$:

- $s_0 = \{\langle 1, 3\rangle, \langle 2\rangle\}$
- $S_\star = \{\{\langle 3, 2, 1\rangle\}\}$

(in general arbitrarily choosable)

Blocks World: Properties

blocks	states	blocks	states
1	1	10	58941091
2	3	11	824073141
3	13	12	12470162233
4	73	13	202976401213
5	501	14	3535017524403
6	4051	15	65573803186921
7	37633	16	1290434218669921
8	394353	17	26846616451246353
9	4596553	18	588633468315403843

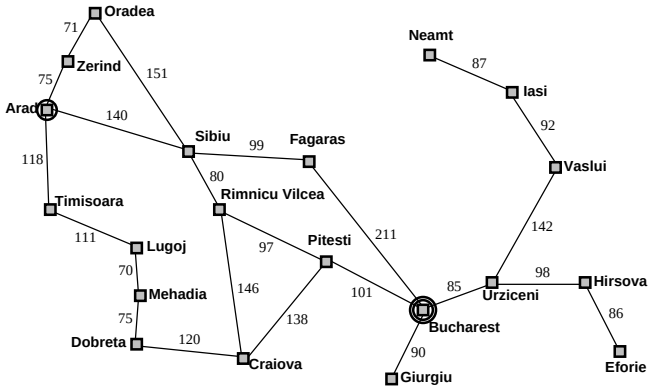
- For every given initial and goal state with n blocks, simple algorithms find a solution in time $O(n)$. (How?)
- Finding optimal solutions is NP-complete (with a compact problem description).

7.2 Route Planning in Romania

Route Planning in Romania

Setting: Route Planning in Romania

We are on holiday in Romania and are currently located in Arad.
Our flight home leaves from Bucharest. How to get there?



Romania Formally

State Space Route Planning in Romania

- states S: $\{\text{arad}, \text{bucharest}, \text{craiova}, \ldots, \text{zerind}\}$
- actions A: $move_{c,c'}$ for any two cities c and c' connected by a single road segment
- action costs $cost$: see figure, e.g., $cost(move_{\text{iasi,vaslui}}) = 92$
- transitions: $s \xrightarrow{a} s'$ iff $a = move_{s,s'}$
- initial state: $s_0 = \text{arad}$
- goal states: $S_\star = \{\text{bucharest}\}$

7.3 Missionaries and Cannibals

Missionaries and Cannibals

Setting: Missionaries and Cannibals

- Six people must cross a river.
- Their rowing boat can carry one or two people across the river at a time (it is too small for three).
- Three people are missionaries, three are cannibals.
- Missionaries may never stay with a majority of cannibals.

Missionaries and Cannibals Formally

State Space Missionaries and Cannibals

states S:

triples of numbers $\langle m, c, b \rangle \in \{0, 1, 2, 3\} \times \{0, 1, 2, 3\} \times \{0, 1\}$:

- number of missionaries m,
- cannibals c and
- boats b

on the left river bank

initial state: $s_0 = \langle 3, 3, 1 \rangle$

goal: $S_\star = \{\langle 0, 0, 0 \rangle, \langle 0, 0, 1 \rangle\}$

actions, action costs, transitions: ?

7.4 Summary

Summary

illustrating examples for state spaces:

- blocks world:
  - family of tasks where n blocks on a table must be rearranged
  - traditional example problem in AI
  - number of states explodes quickly as n grows
- route planning in Romania:
  - small example of explicitly representable state space
- missionaries and cannibals:
  - traditional brain teaser with small state space (32 states, of which many unreachable)