CPSC 322: Introduction to Artificial Intelligence

Search: Introduction

Textbook reference: 3.1–3.4

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Credit: These slides are adapted from the slides of previous offerings of the course. Thanks to all instructors for creating and improving the teaching material and making it available!

Lecture outline

- **Recap from last lecture** (~5 mins) 👈
- Search motivation (~5 mins)
- Simple search agents and examples (~30 mins)
- Break (~5 mins)
- General search procedure (~25 mins)
- Summary and wrap-up (~5 mins)

A rough CPSC 322 overview

Representation and reasoning

Environment

	Problem	Deterministic	Stochastic
Static	Constraint satisfaction	Arc consistency Variables + constraints Search	
	Query	Logics Search	Belief networks Variable elimination
Sequential	Planning	STRIPS Search	Decision networks Variable elimination Markov decision processes Value iteration

Recap: Choose the best answer

A deterministic agent

A. knows what state it is in

B. could predict the next state if it knew its current state and the action to be taken

C. is determined to get to its goal

D. does not know exactly what state it is in

Recap: How many states?

Mars explorer

Weather: {Sunny, Cloudy}

Temperature: [-40, +40]

Longitude: [0, 359]

Latitude: [1, 179]

A possible state:
{Sunny, -28, 320, 100}

How many total number of mutually exclusive states?

Questions?

Today's class: Learning outcomes

By the end of the class you will be able to

- Define a directed graph.
- Represent a problem as a state-space graph.
- Assess the size of the search space of a given search problem.
- Trace through/implement a generic search algorithm.

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Many problems can be solved by search

Deepmind's AlphaGo wins 2nd game against Chinese Go champion

Ke Jie lost despite playing what Google's AlphaGo indicated was the best game any opponent has played against it.

More examples

Peg solitaire

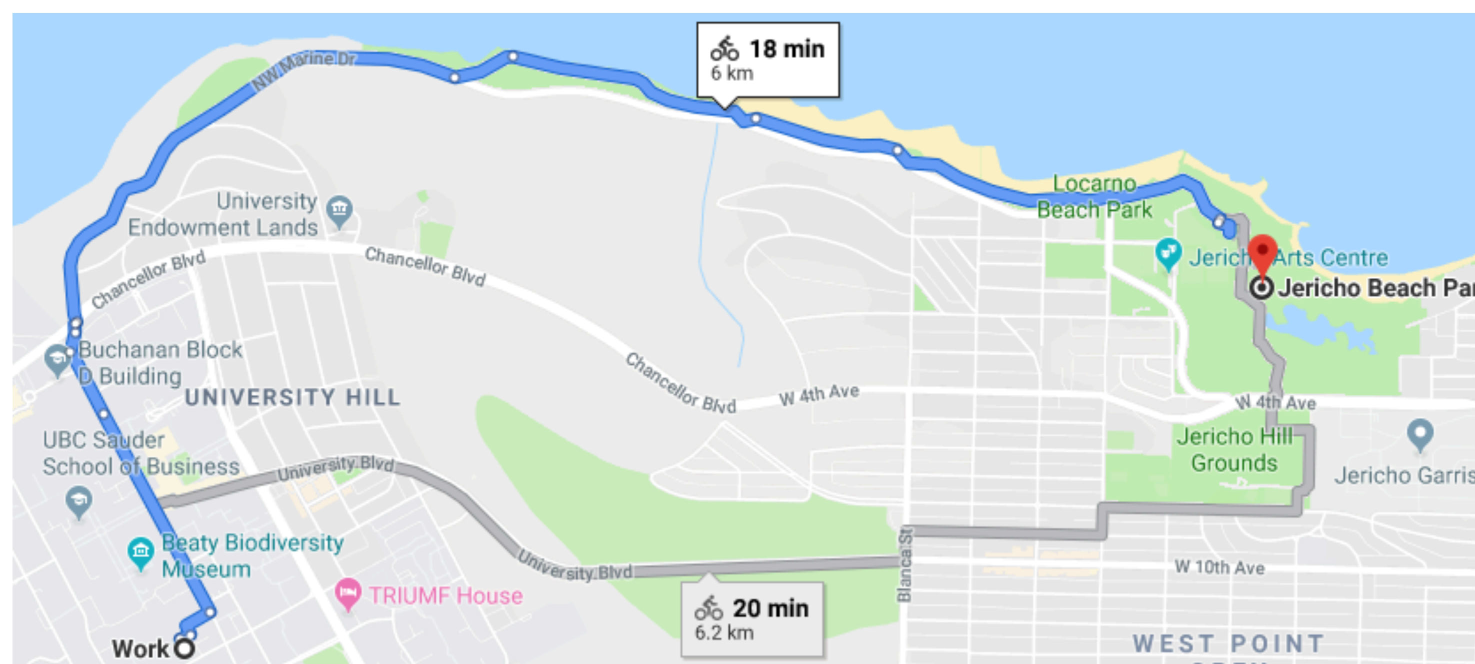
1	2	3
4	5	6
7	8	

8-puzzle

5	3			7				
6			1	9	5			
	9	8					6	
8				6				3
4			8		3			1
7				2				6
	6					2	8	
			4	1	9			5
				8			7	9

Sudoku

Path finding



Formulating a problem as search

- Often we are given a specification of what a solution is, but do not know how we would go about finding one.
- In that case we have to **search** for a solution.
  - Enumerate a set of potential partial solutions.
  - Check to see if they are solutions or could lead to one.
  - We can recognize a solution once we see one.

"Generate [potential [partial] solution] and test."

Why search?

- One of the most fundamental techniques in AI
  - Part of many AI systems
- Can solve problems that humans are not so good at solving
- Can achieve super-human performance on problems such as Chess and go
- A useful problem solving technique in AI as well in other areas
- Planning can be cast as a search problem

Planning ahead as a search problem

- We want to build good agents that make good decisions
- In order to make good decisions we need to plan ahead
- What it means to have an agent that plans ahead?
  - Build an agent that thinks about the consequences of its actions so that we can use those consequences to make good decisions in the first place.
- Formalize this idea of planning ahead as a search problem

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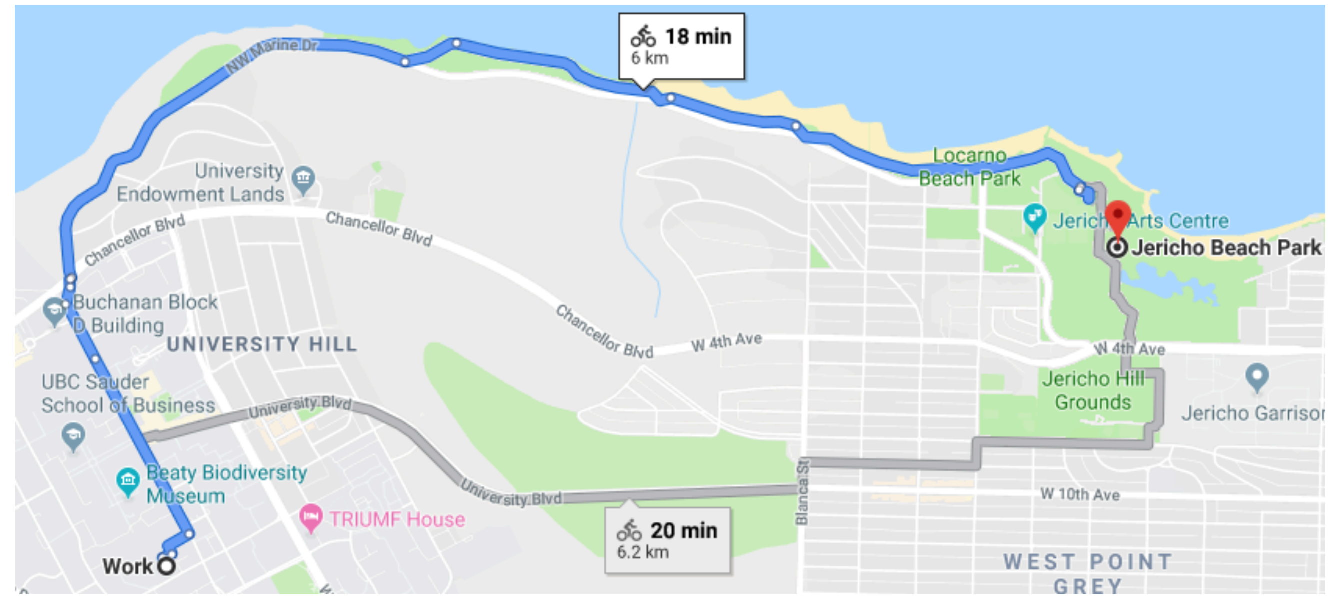
Simple deterministic agent

- **Goal-driven deterministic** agent with
  - **Perfect knowledge** of the world
    - Using state-based world representation
    - Environment changes only when the agent acts, and in known ways
  - **Deterministic actions**
    - Agent perfectly knows actions that can be applied in any given state and the state it is going to end up in when an action is applied in a given state

Simple deterministic agent



We assume that

- Agent is in a **start** state
- Agent is given a **goal** (subset of all states)
- A sequence of actions taking the agent from the start state to a goal state is a **solution** (a plan)

Choose the correct answer

Our simple deterministic search agent has …

A. Perfect knowledge of its environment

B. Perfect knowledge of the effect that its actions can have on the environment

C. Both of the above

D. None of the above

Definition of a search problem

- **State space**: set of all possible states
  - Not necessarily given explicitly (state space might be infinite)
- **Initial state(s)**
- **Set of actions (operators)** available to the agent: for each state and each operator, if operator applicable, defines the successor state: the state the agent would end up in
- **Goal state(s)**: explicit set of states or predicate on states
- **Path cost** (we ignore this for now)

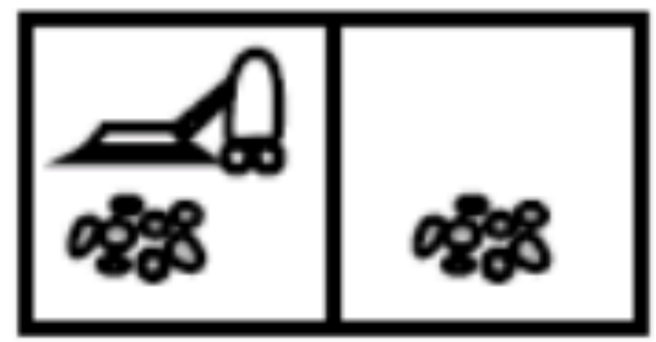
Three examples

- Vacuum cleaner world
- Solving an 8-puzzle
- The delivery robot planning the route it will take in a bldg. to get from one room to another (Text: Section 1.6)

Example 1: Vacuum cleaner world

- Two rooms: r1, r2
- Operators: left, right, suck
- Each room can be either dirty or clean
- Vacuuming agent can be in either r1 or r2
- **How many total states?**

Possible start state

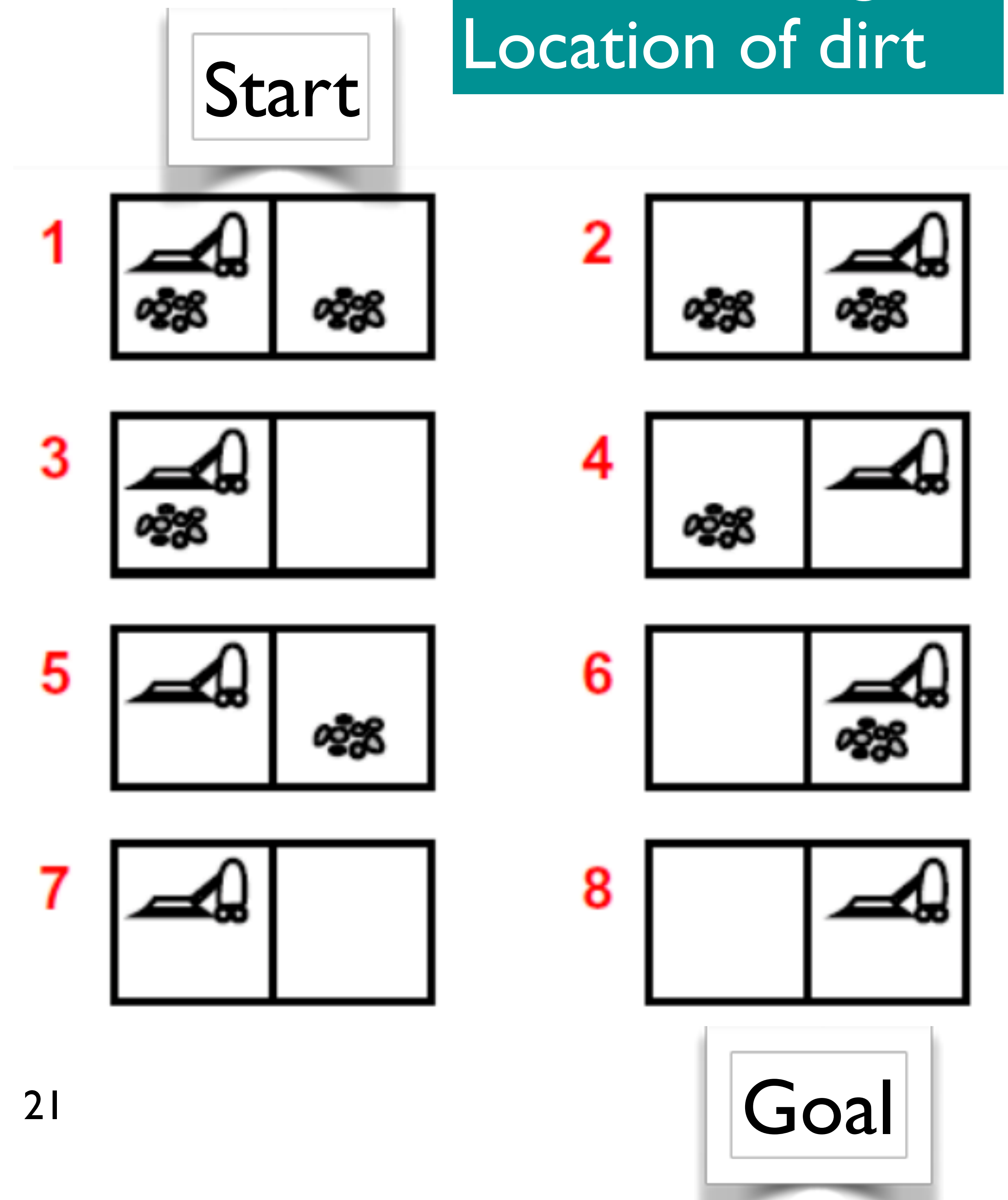


Possible goal state

Example 1: Vacuum cleaner world

- Two rooms: r1, r2
- Operators: left, right, suck
- Each room can be either dirty or clean
- Vacuuming agent can be in either r1 or r2
- **How many total states?**

Location of agent
Location of dirt



How many states?

Suppose we have the same problem with k rooms. The number of states is

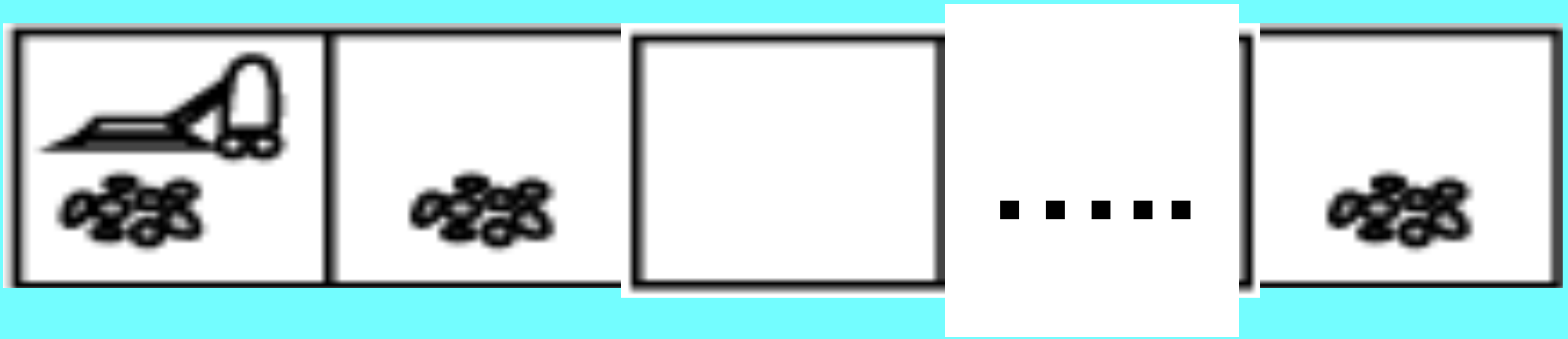
A. k^3

B. $k \times 2^k$

C. $k \times 2k$

D. $2 \times k^k$

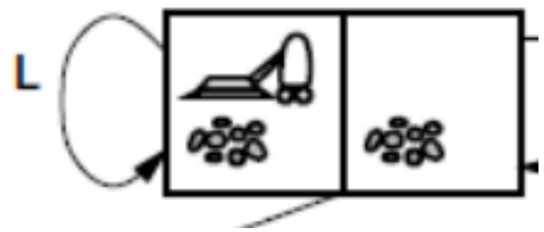
E. Never mind, I'll clean up the rooms myself.



ASIDE: Think at leisure

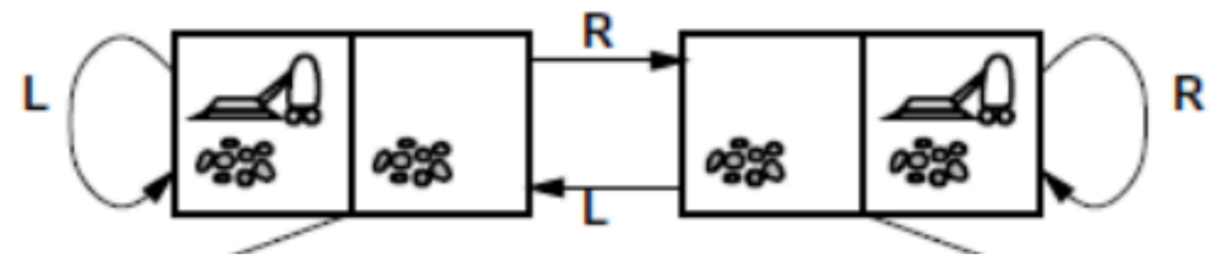
How many states if we had k rooms and a room can be either be dirty or swept or wiped (3 possible feature values instead of 2)?

Search space



- Operators: left (L), right (R), suck (S)
- Successor states in the graph describe the effect of each action applied to a given state
- Possible Goal: no dirt

Search space



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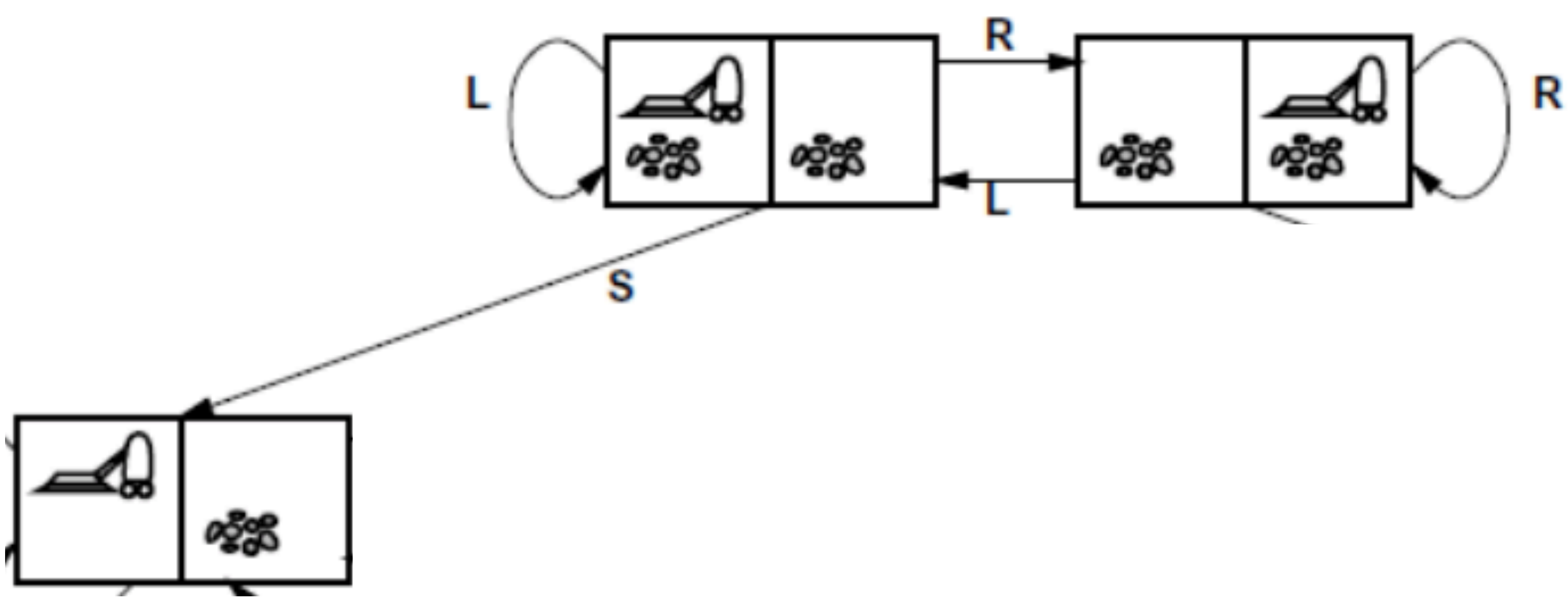

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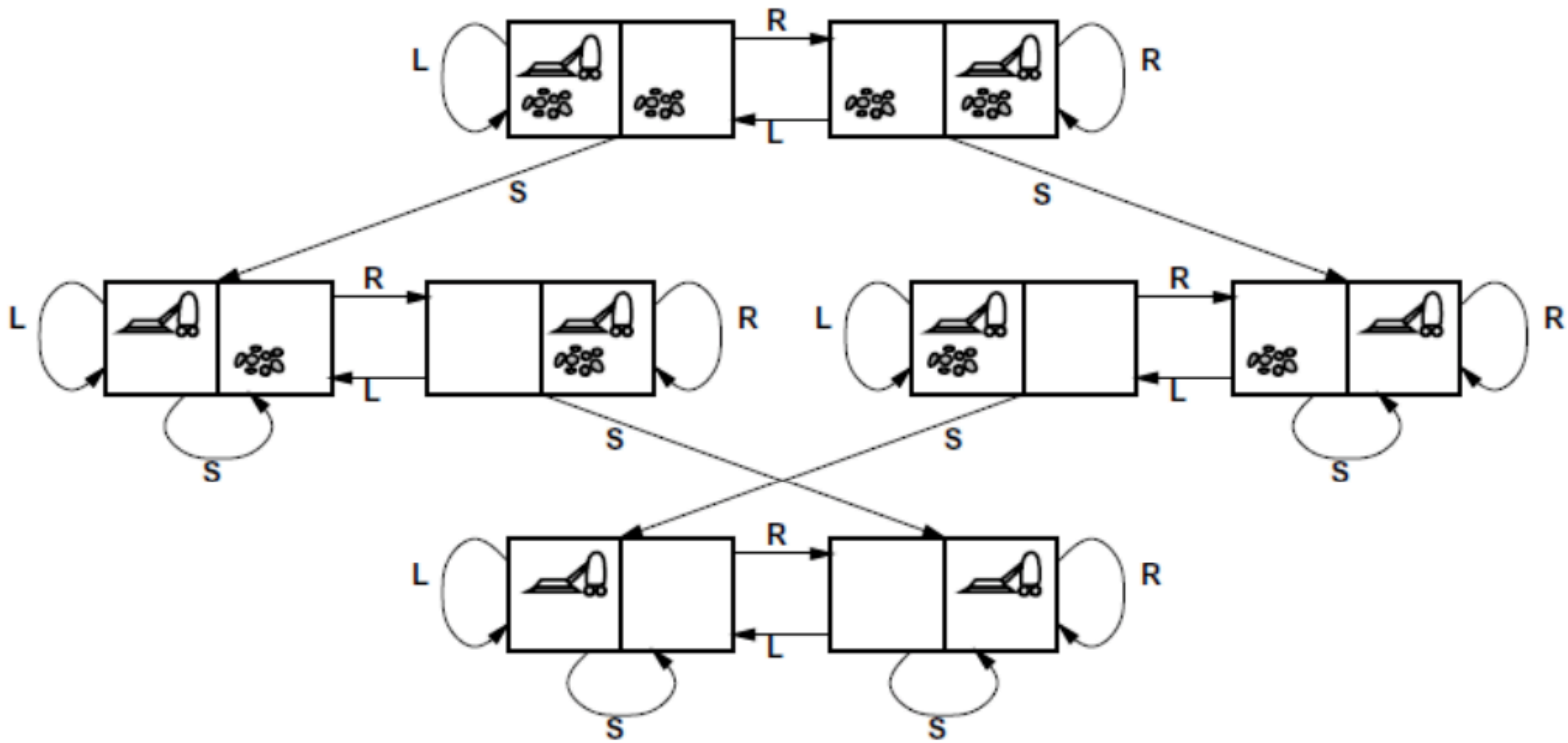
Search space



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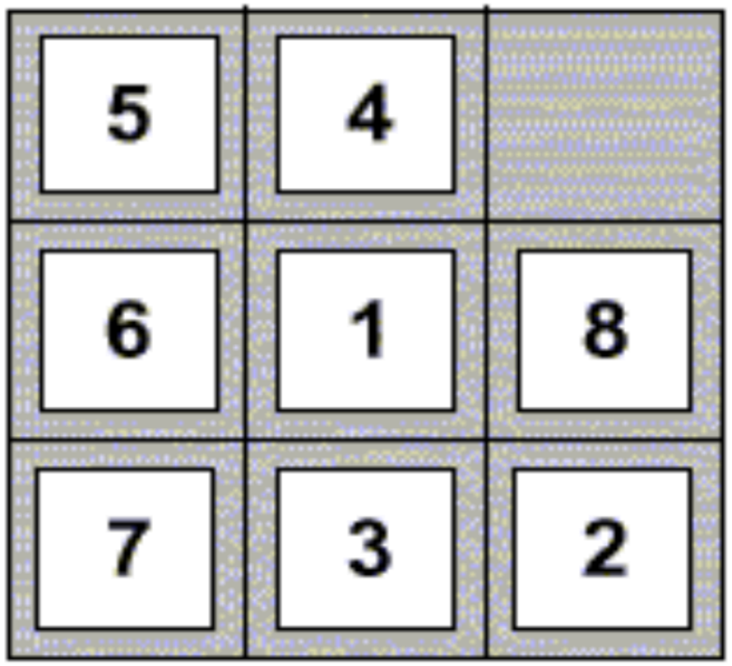
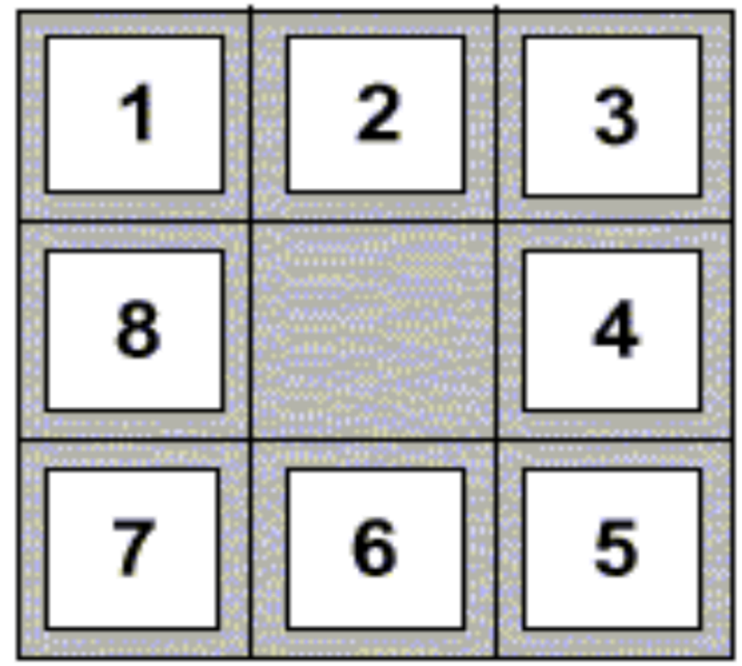
- Possible Goal: no dirt

Example 2: 8-puzzle



Start



Goal

States: each state specifies which number/blank occupies each of the 9 tiles

Actions: blank moves left, right, up down

Possible Goal: configuration with numbers in right sequence

Example 2: 8-puzzle

How many states?

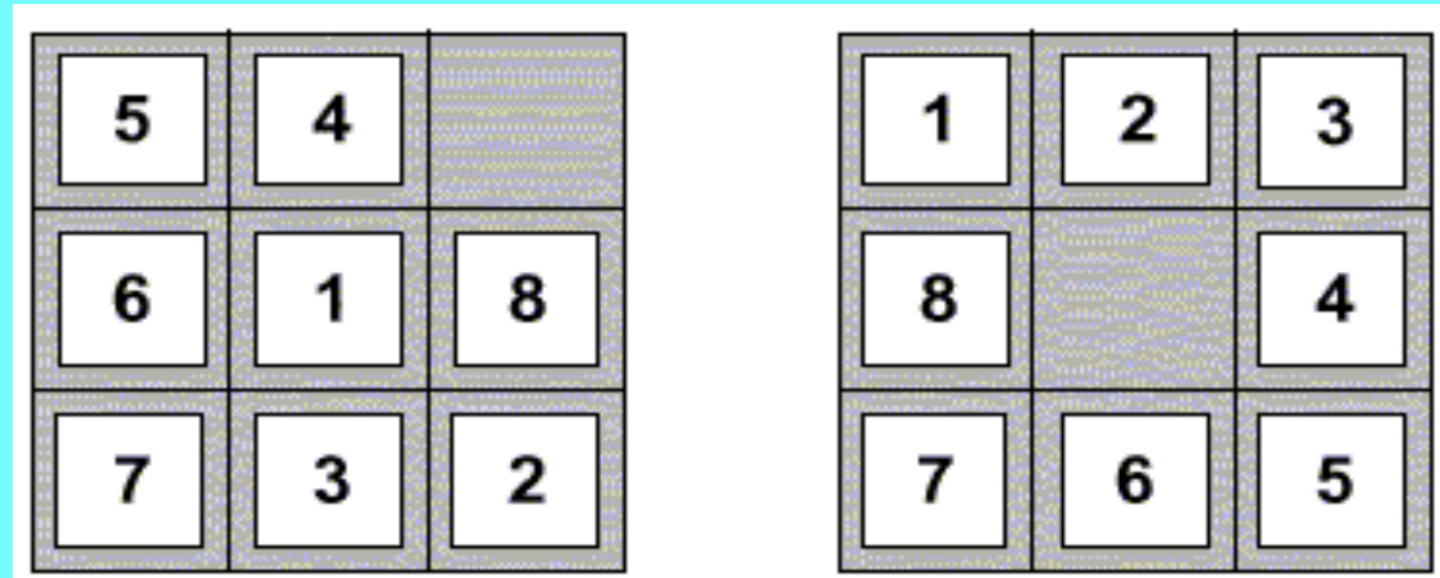
A. 8^9

B. 2^9

C. 9^9

D. $9!$

E. 42

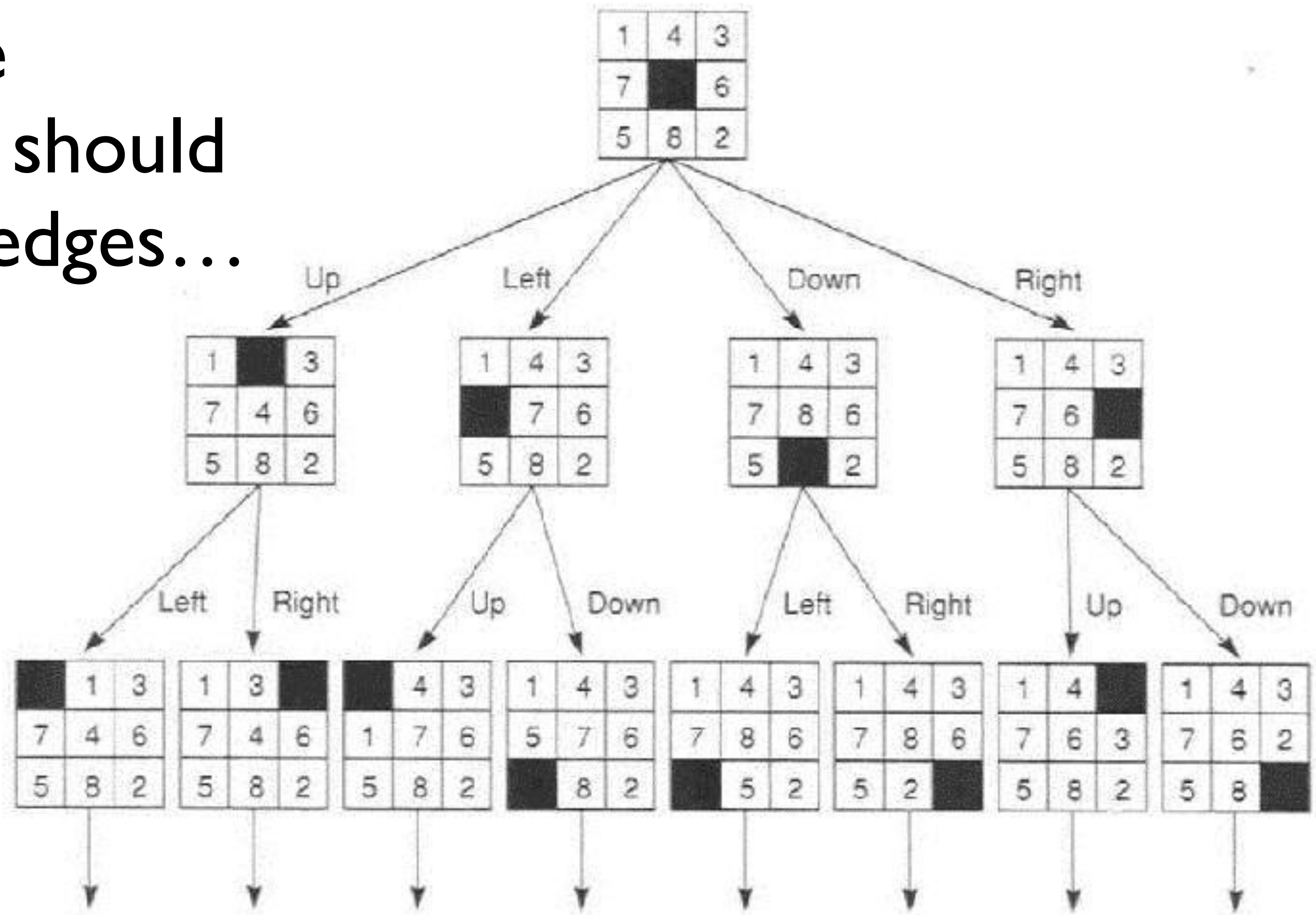


Start Goal

Each state specifies which number/blank occupies each of the 9 tiles

Search space for 8-puzzle

- Only a tiny fraction of the search space
- Each action can be reversed, so there should be twice as many edges…

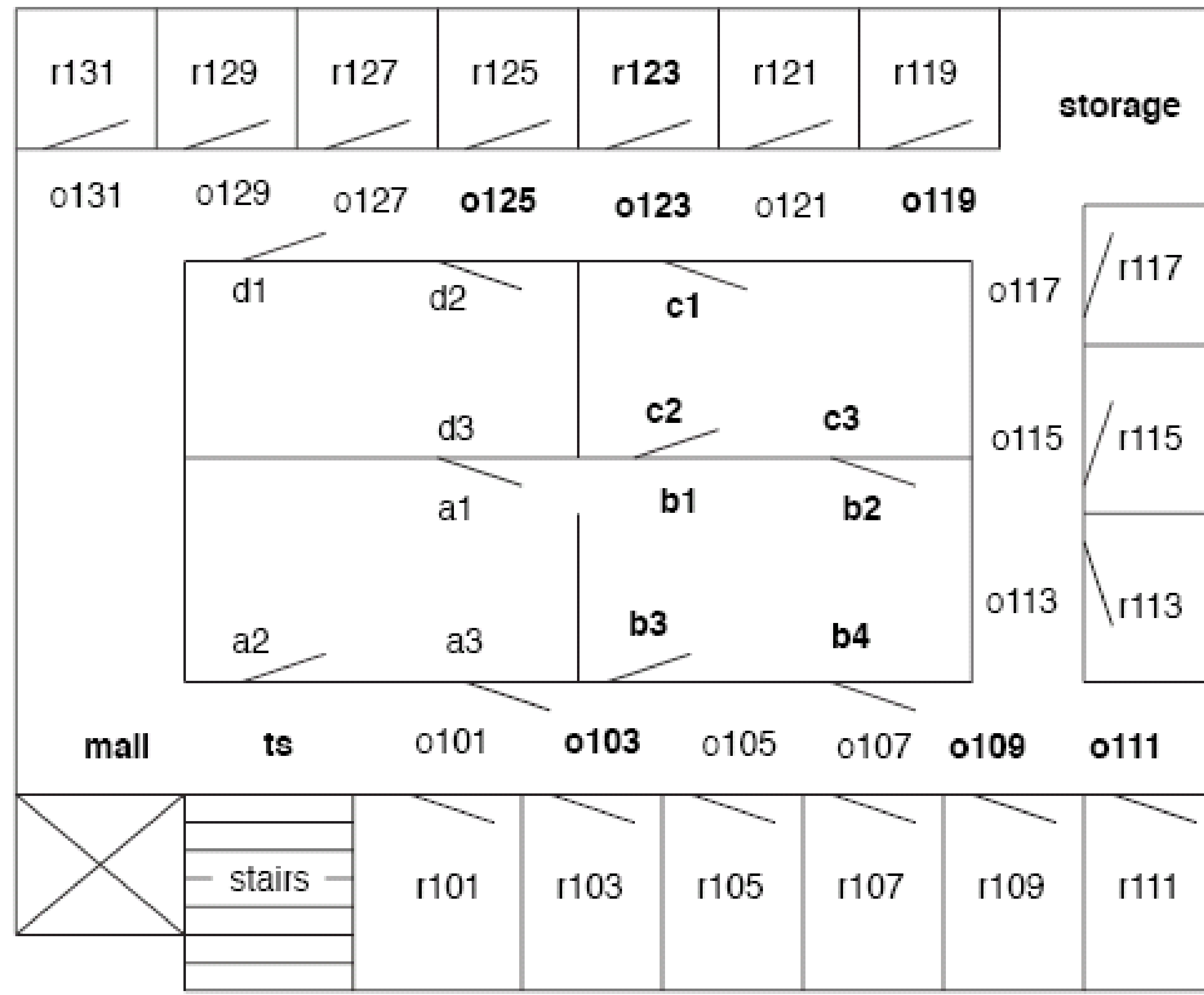


Example 3: Delivery robot

Simplified version

- Consider only bold locations

- Limits in direction of movement (can move only in the direction doors open)



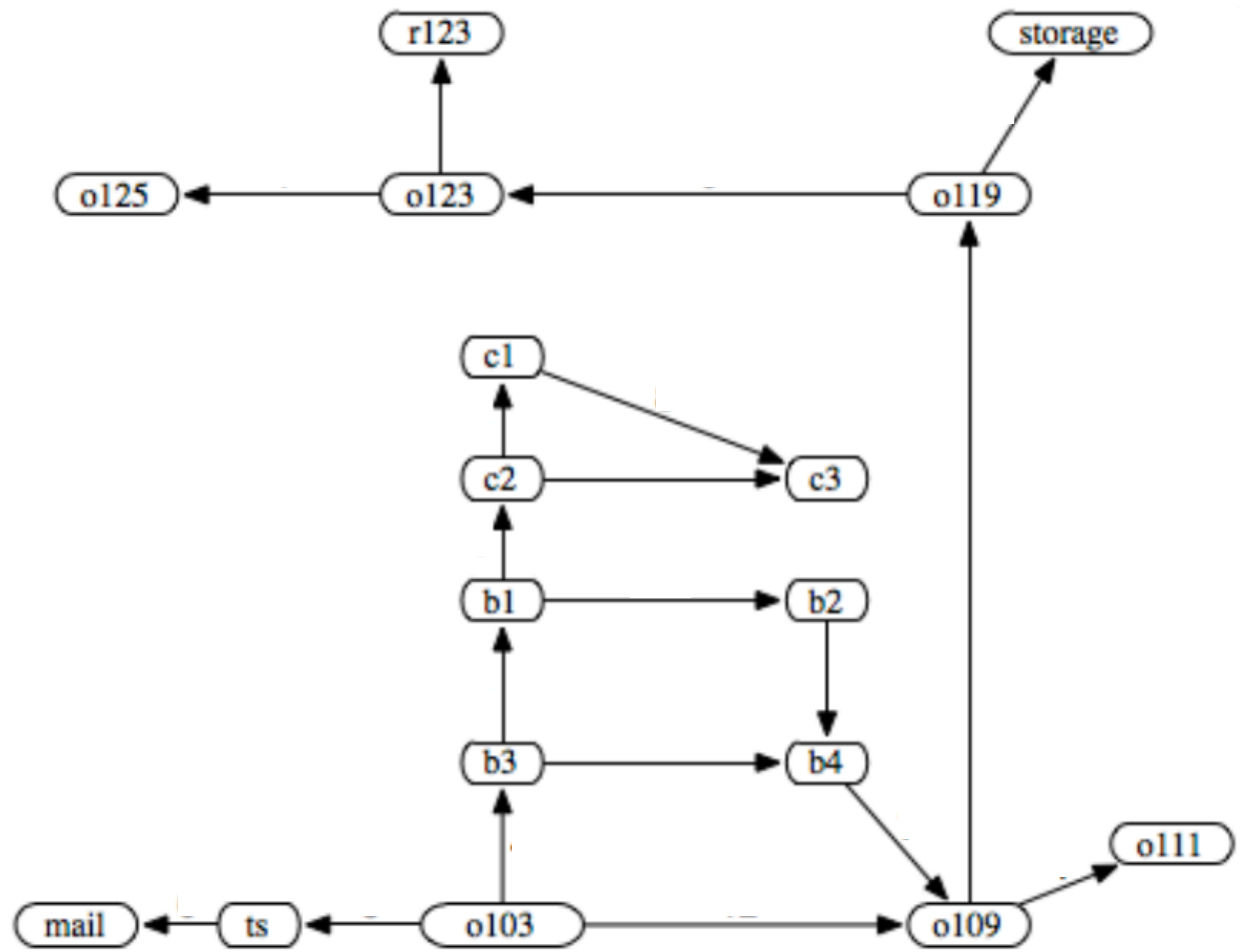
Example 3: Delivery robot

- How can we find a sequence of actions and their appropriate ordering that lead to the goal?
- Define underlying search space graph where nodes are states and edges are actions.

Example 3: Delivery robot

Simplified version

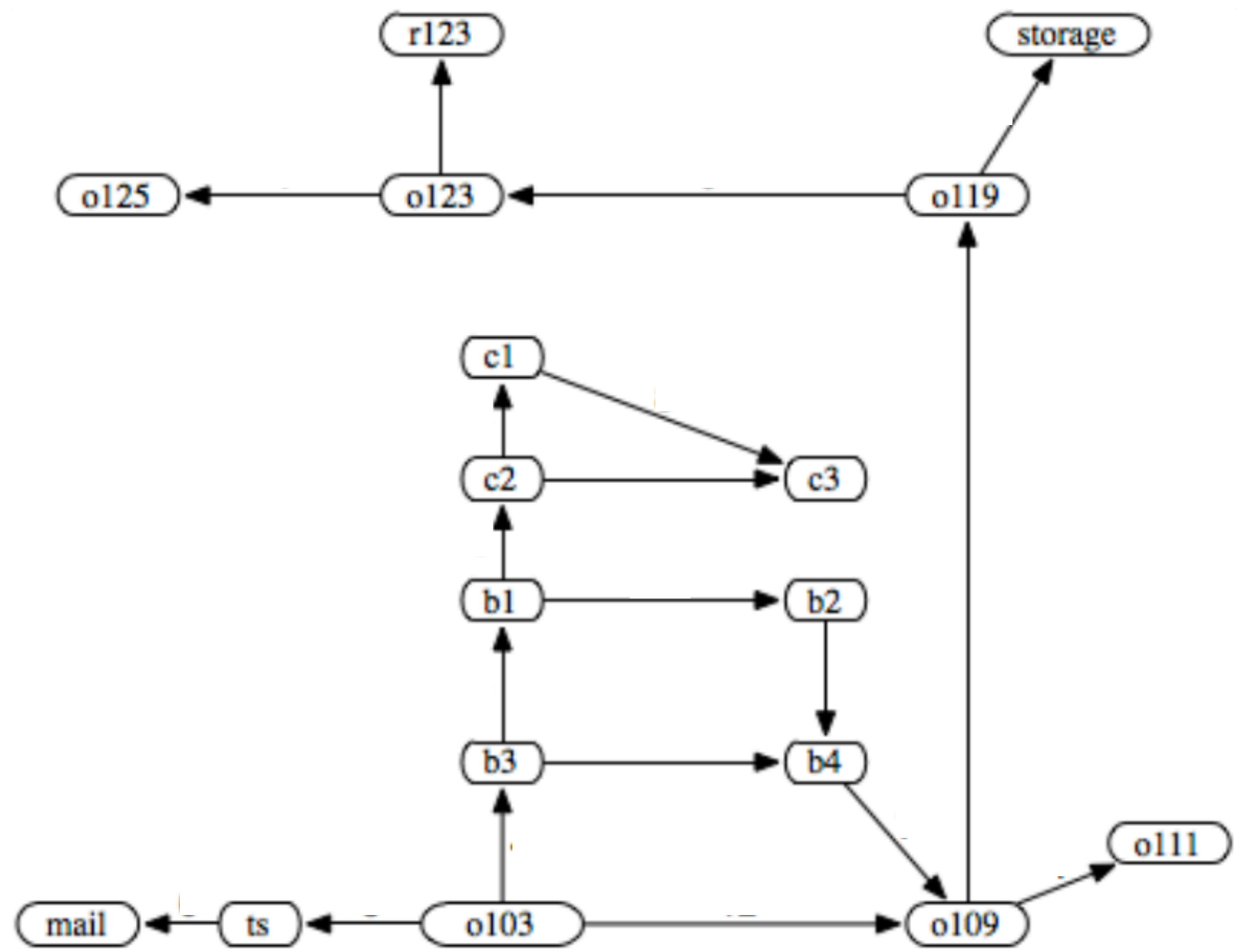
- Start: o103
- Goal: r123
- Solution: ?



Example 3: Delivery robot

- Start: o103
- Goal: r123
- A solution:

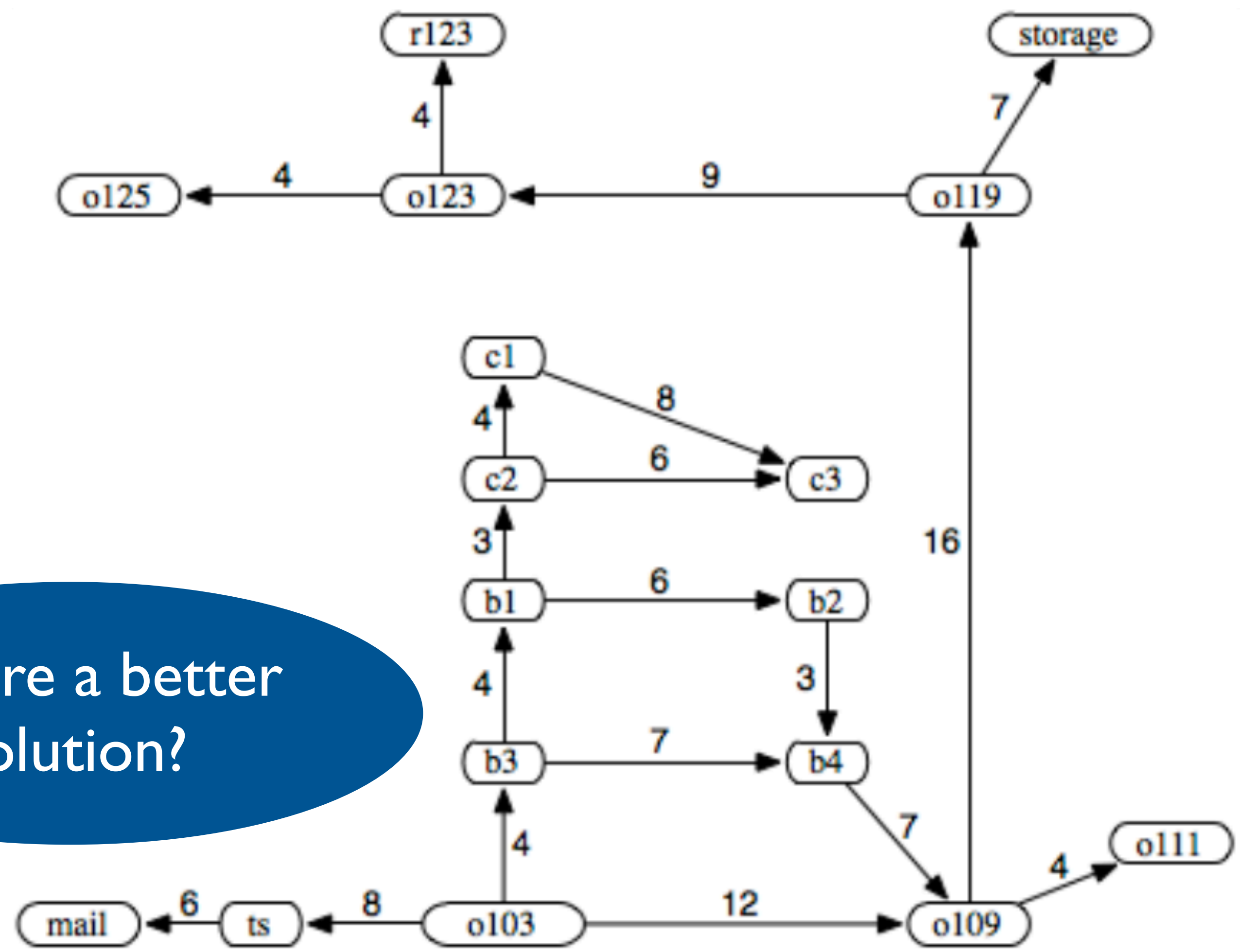
Simplified version



O103 → b3 → b4 → o109 → 0119 → 0123 → r123

Example 3: Delivery robot

Simplified version with costs



- Start: o103
- Goal: r123
- A solution:

Is there a better solution?

O103 → b3 → b4 → o109 → 0119 → 0123 → r123

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Search abstract definition

How to search

- Start at the start state
- Evaluate which actions can lead us from states that have been encountered in the search so far to new states
- Stop when a goal state is encountered

To make this more formal, we'll need to review the formal definition of a directed graph

Directed graphs

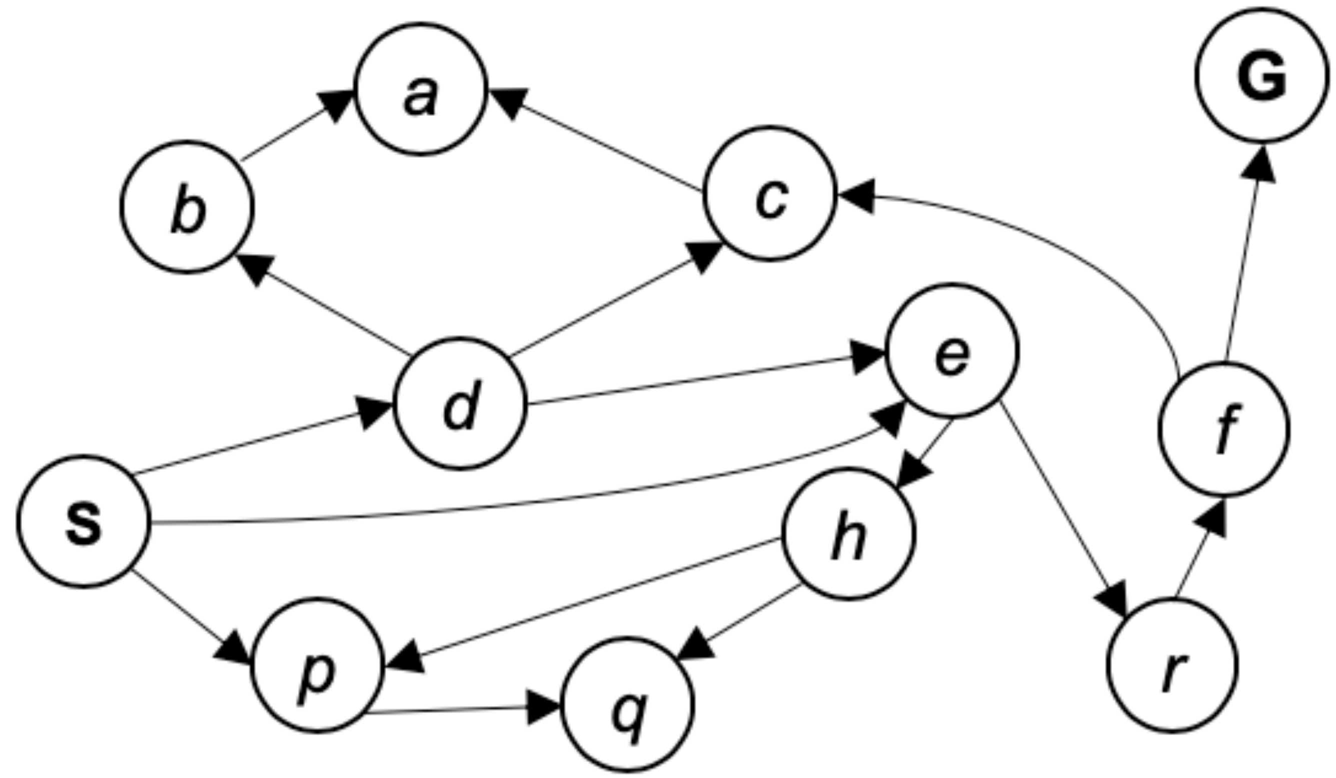
- A **directed graph** consists of
  - a set N of nodes (vertices)
  - a set A of ordered pairs of nodes, called edges (arcs).
- Node n_2 is a **neighbour** of n_1 if there is an arc from n_1 to n_2. That is, if $< n_1, n_2 > \in A$
- A **path** is a sequence of nodes $n_0, n_1, n_2, \ldots, n_k$ such that $< n_{i-1}, n_i > \in A$
  - Start node = n_0
  - End node = n_k
- A **cycle** is a non-empty path such that the start node is the same as the end node.

Directed graph

- A **path** is a sequence of nodes $n_0, n_1, n_2, \ldots, n_k$ such that $< n_{i-1}, n_i > \in A$
  - Start node = n_0
  - End node = n_k
- A **cycle** is a non-empty path such that the start node is the same as the end node.

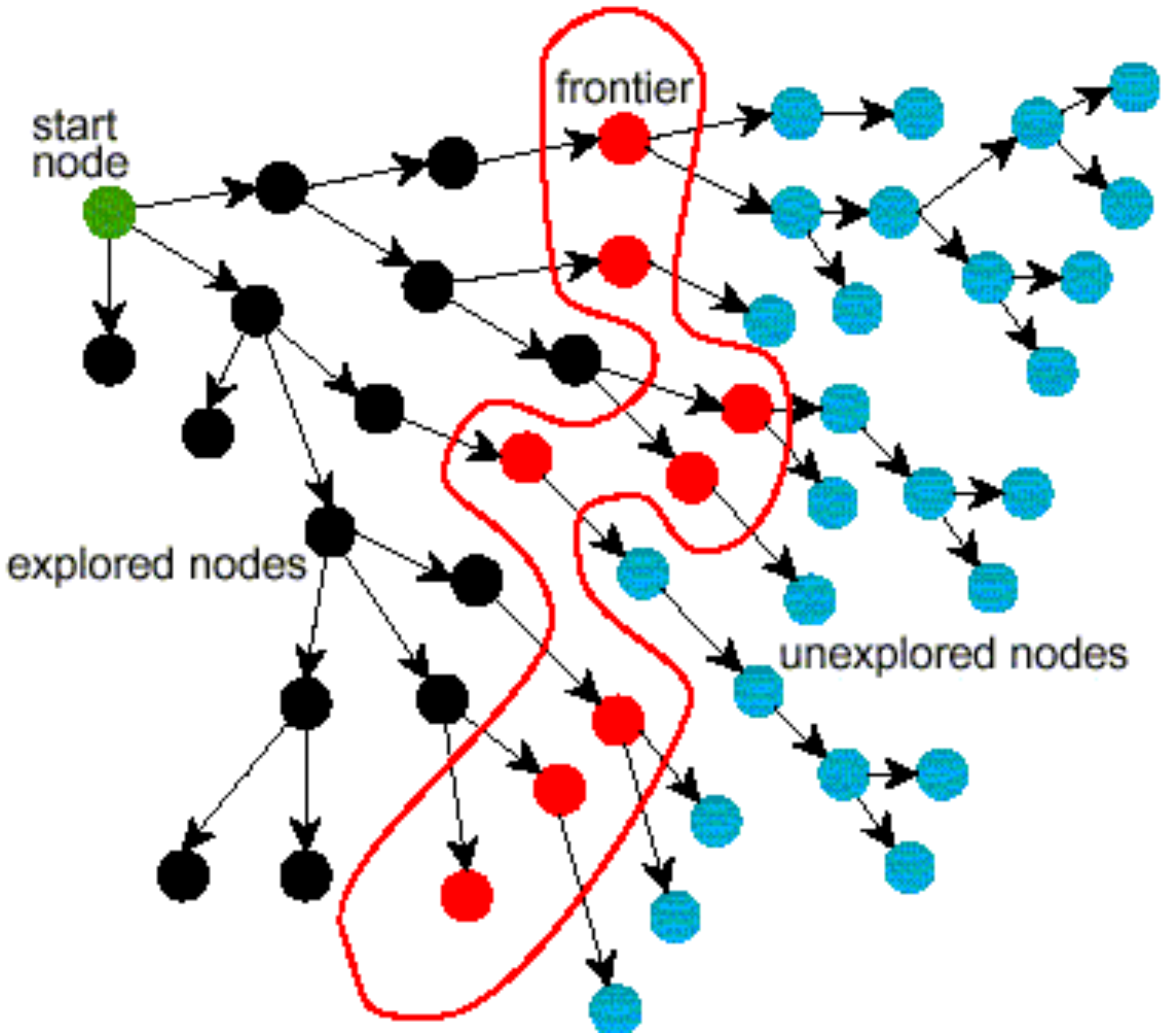
Search graphs

- Nodes are search states
- Edges correspond to actions
- Given a set of start nodes and goal nodes, a **solution** is a path from a start node to a goal node: a plan of actions



Credit: Graph picture from Berkeley AI course material

Problem solving by graph searching



Branching factor

- **The forward branching factor** of a node is the number of arcs going out of the node.
- **The backward branching factor** of a node is the number of arcs going into the node.
- If the forward branching factor of any node is $\underline{b}$ and the graph is a tree, how many nodes are $\underline{m}$ steps away from a node?

A. mb

B. m/b

C. b^m

D. m^b

Graph searching

- Generic search algorithm: given a graph, start nodes, and goal nodes, **incrementally explore paths** from the start nodes

- **Maintain a frontier** of paths from the start node that have been explored.

- As search proceeds, the **frontier expands into the unexplored nodes** until a goal node is encountered.

- **The way in which the frontier is expanded defines the *search strategy*.**

Generic search algorithm

Inputs: a graph,

a start node n_o

a boolean procedure *goal(n)* that tests if n is a goal node

frontier:= [$< n_0 >$: n_0 is a start node];

While frontier is not empty:

select and **remove** path $< n_0, n_1, \ldots, n_k >$ from frontier;

If *goal*(n_k)

return $< n_0, n_1, \ldots, n_k >$;

For every neighbour n of n_k

add $< n_0, n_1, \ldots, n_k, n >$ to frontier;

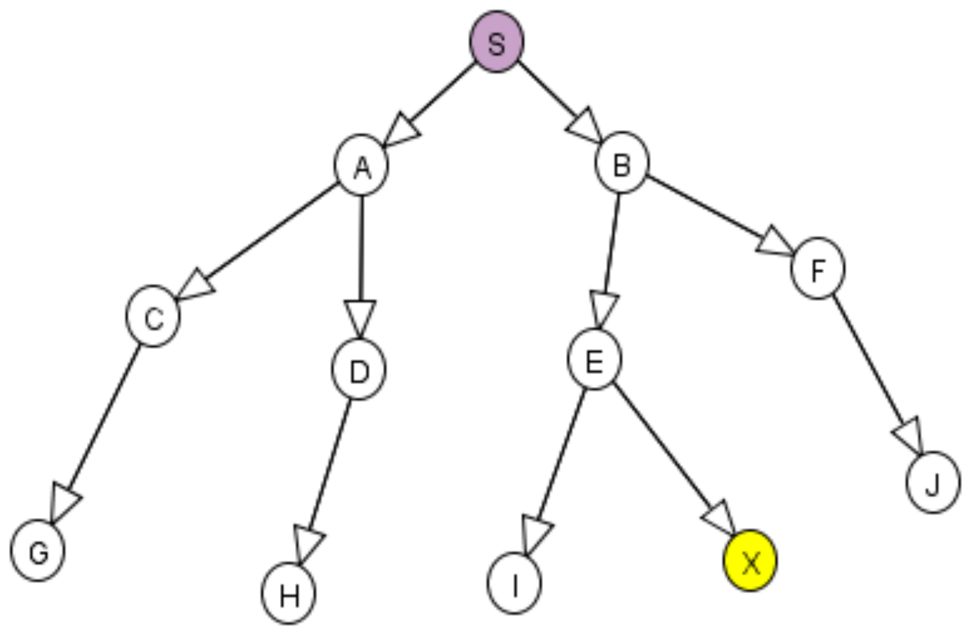
return NULL

Activity: Generic search algorithm

Trace the algorithm on the graph below
Start node: S
Goal: X

Inputs: a graph,
a start node n_0
a boolean procedure *goal(n)* that tests if *n* is a goal node

frontier:= [$< n_0 >$: n_0 is a start node];
While frontier is not empty:
select and **remove** path $< n_0, n_1, \ldots, n_k >$ from frontier;
If *goal(n_k)*
return $< n_0, n_1, \ldots, n_k >$;
For every neighbour n of n_k
add $< n_0, n_1, \ldots, n_k, n >$ to frontier;
return NULL



Summary

- Search is a key computational mechanism in many AI agents
- We will study the basic principles of search on the simple deterministic goal-driven search agent model in state-based world representation
- Generic search approach:
  - Define a search space graph
  - Initialize the frontier with an empty path
  - Incrementally expand frontier until goal state is reached
- **The way in which the frontier is expanded defines the search strategy**

Coming up

Uninformed search

- Depth-first search
- Breadth-first search

Textbook reference: [3.5.1, 3.5.2]