AI Agents and Search

Lara J. Martin (she/they)

https://laramartin.net/interactive-fiction-class

Slides adapted from Chris Callison-Burch and Cynthia Matuszek

Learning Objectives

Understand the difference between traditional AI agents and agentic AI

List the components of a search problem

Review basic types of tree search algorithms

Define & implement a search problem (for Action Castle)

Review: Story Cloze Test

Predict/select the most likely story *ending*

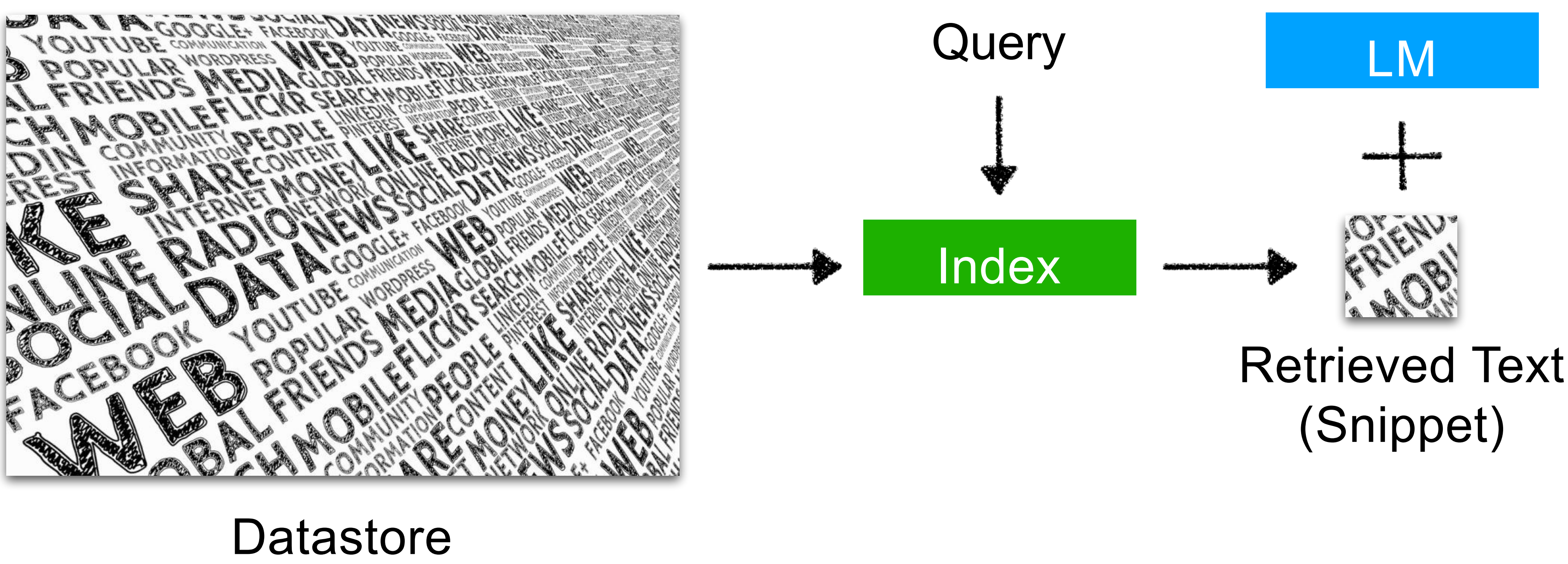
- Given the first 4 sentences of the story

Full sentences

Multiple choice evaluation

Mostafazadeh, N., Chambers, N., He, X., Parikh, D., Batra, D., Vanderwende, L., Kohli, P., & Allen, J. (2016). A Corpus and Cloze Evaluation for Deeper Understanding of Commonsense Stories. *Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies (NAACL-HLT)*, 839–849. http://www.aclweb.org/anthology/N16-1098

Review: RAG



AI Agents

AI Agent Definition

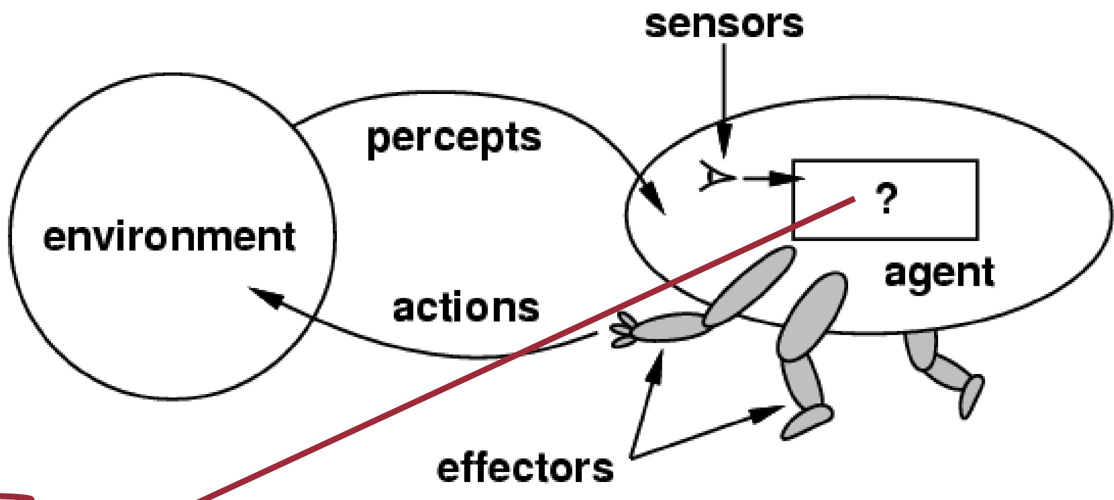
Agent: anything that perceives its environment through sensors, and acts on its environment through actuators

Percept: input at an instant

Percept sequence: history of inputs

Agent function: mapping of percept sequence to action

Agent program: (concise) implementation of an agent function



Picture from Dr. Cynthia Matuszek, source unknown

“Agentic AI”

Term coined around 2023 but has become popular as of early 2025

Using a *language model* to behave like an “agent” – the intersection of AI & NLP beyond chatbots

“autonomous systems designed to pursue complex goals with *minimal human intervention*” [1]

[1] D. B. Acharya, K. Kuppan and B. Divya, "Agentic AI: Autonomous Intelligence for Complex Goals—A Comprehensive Survey," in *IEEE Access*, vol. 13, pp. 18912-18936, 2025, doi: 10.1109/ACCESS.2025.3532853.

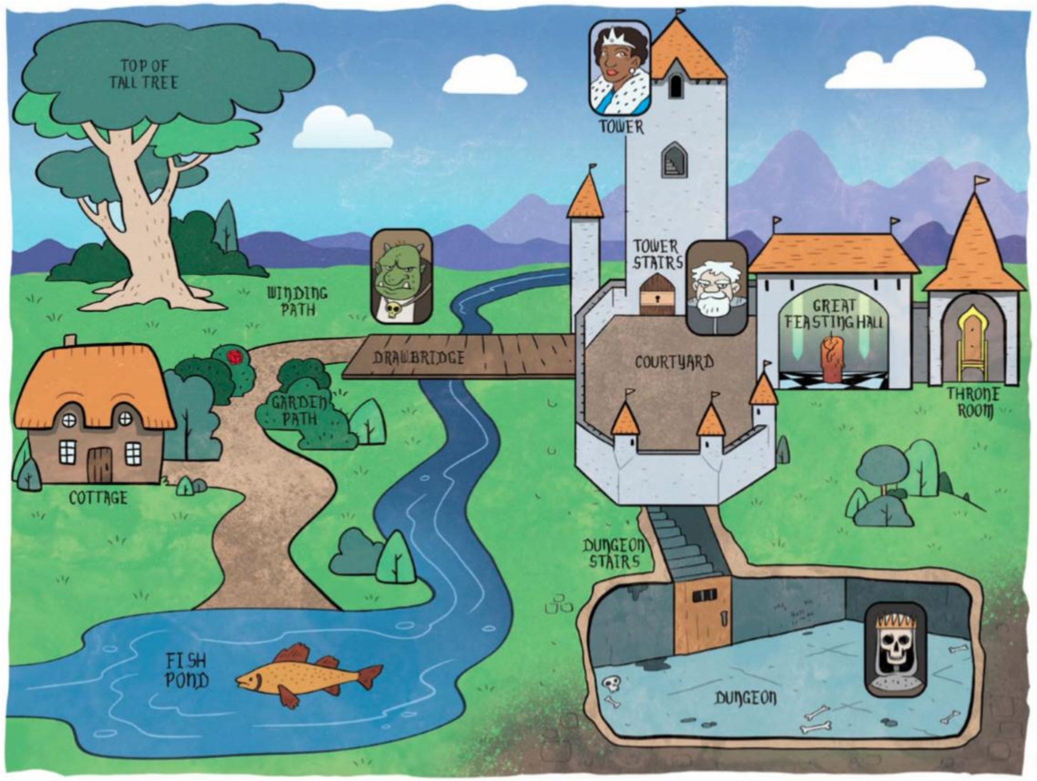
Problem-Solving Agents

A problem-solving agent must plan.

The computational process that it undertakes is called **search**.

It will consider a sequence of actions that form a path to a **goal state**.

Such a sequence is called a **solution** or **plan**.



1. take pole
2. go out
3. go south
4. catch fish with pole
5. go north
6. pick rose
7. go north
8. go up
9. get branch
10. go down
11. go east
12. give the troll the fish
13. go east
14. hit guard with branch
15. get key
16. go east
17. get candle
18. go west
19. go down
20. light lamp
21. go down
22. light candle
23. read runes
24. get crown
25. go up
26. go up
27. go up
28. unlock door
29. go up
30. give rose to the princess
31. propose to the princess
32. down
33. down
34. east
35. east
36. wear crown
37. sit on throne

Formal Definition of a Search Problem

1. **States:** a set **S**
2. An **initial state** $s_i \in S$
3. **Actions:** a set **A**

   ∀ s **Actions(s)** = the set of actions that can be executed in **s**.

4. **Transition Model:** ∀ s∀ a∈Actions(s)

   Result(s, a) → s_r

   s_r is called a successor of **s**

   $\{s_i\} \cup$ **Successors**$(s_i)^*$ = state space

5. **Path cost** (Performance Measure): Must be additive, e.g. sum of distances, number of actions executed, …

   c(x,a,y) is the step cost, assumed ≥ 0

   - (where action **a** goes from state **x** to state **y**)

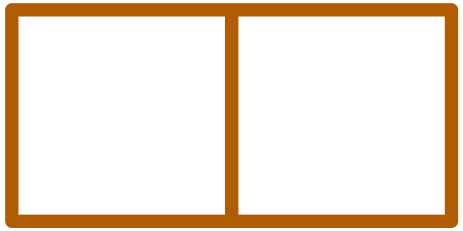
6. **Goal test: Goal(s)**

   s is a goal state if **Goal(s)** is true.
   Can be implicit, e.g. **checkmate(s)**

Vacuum World

States: A state of the world says which objects are in which cells.

In a simple two cell version,



Only need the things relevant to the agent's decision making

Vacuum World

States: A state of the world says which objects are in which cells.

In a simple two cell version,

- each cell can have dirt or not

Vacuum World

States: A state of the world says which objects are in which cells.

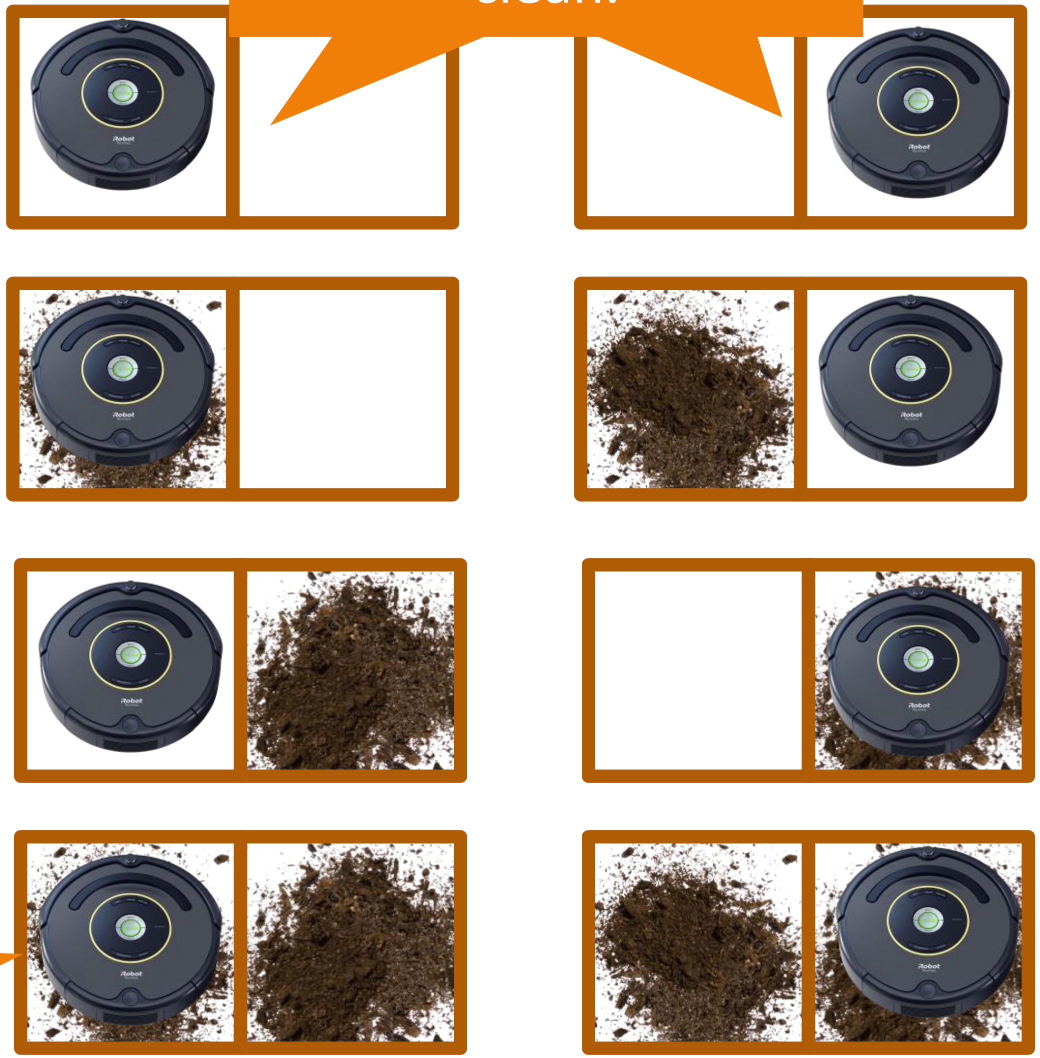
In a simple two cell version,

- each cell can have dirt or not
- the agent can be in one cell at a time

2 positions for agent * 2^2 possibilities for dirt = 8 states.

With n cells, there are $n*2^n$ states.

Goal states: States where everything is clean.



One state is designated as the **initial state**

Vacuum World

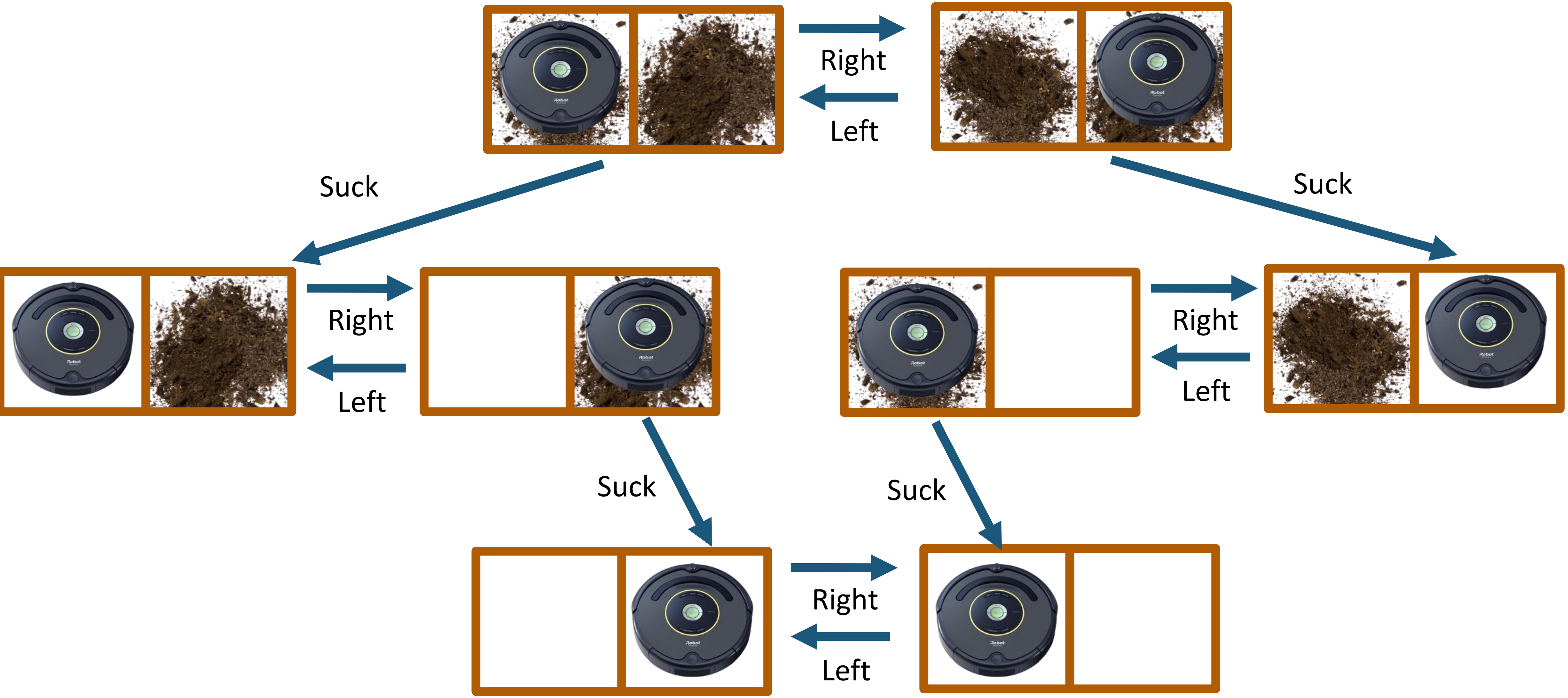
Actions: Anything the agent can do to affect the environment

- *Suck*
- *Move Left*
- *Move Right*
- *(Move Up)*
- *(Move Down)*

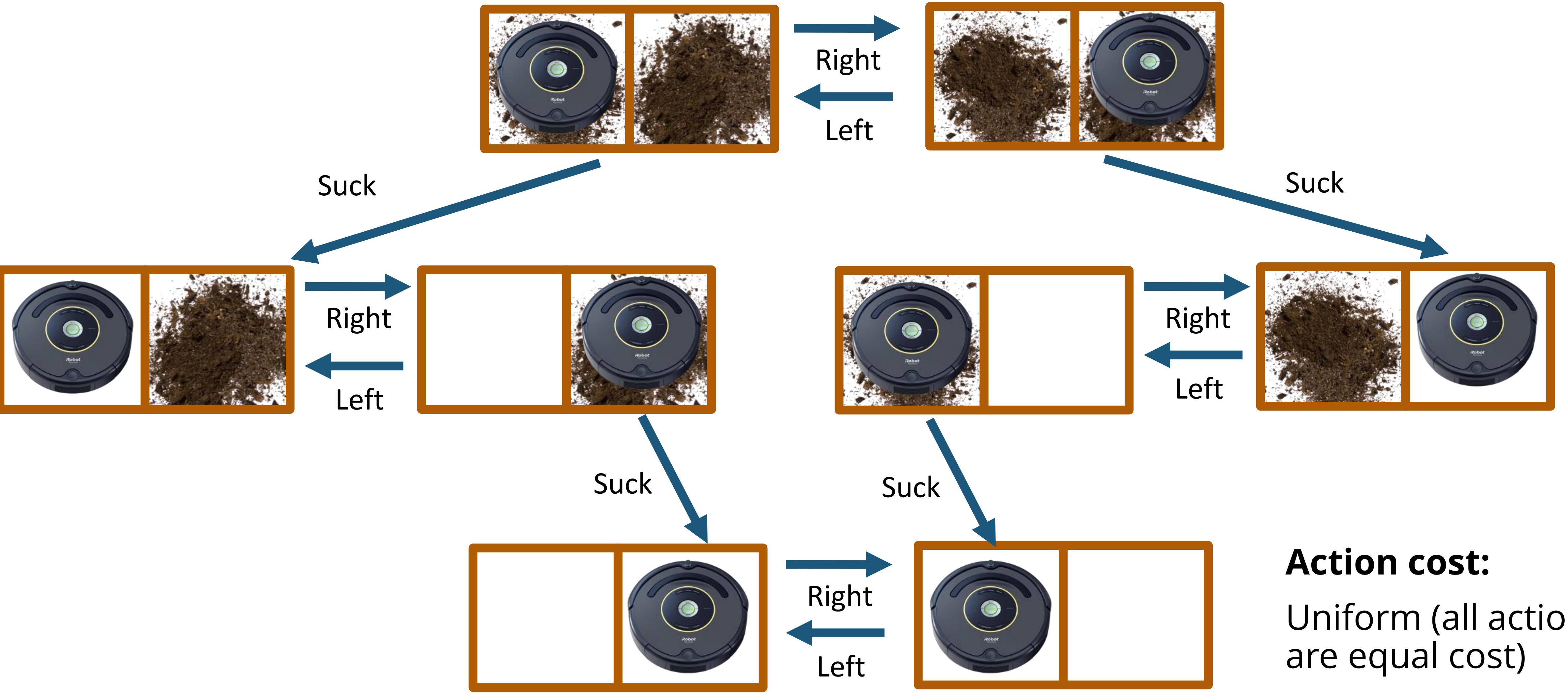
Transition: How actions affect what current state the world is in

- Suck – removes dirt
- Move – moves in that direction, unless agent hits a wall, in which case it stays put

Vacuum World Transition Model



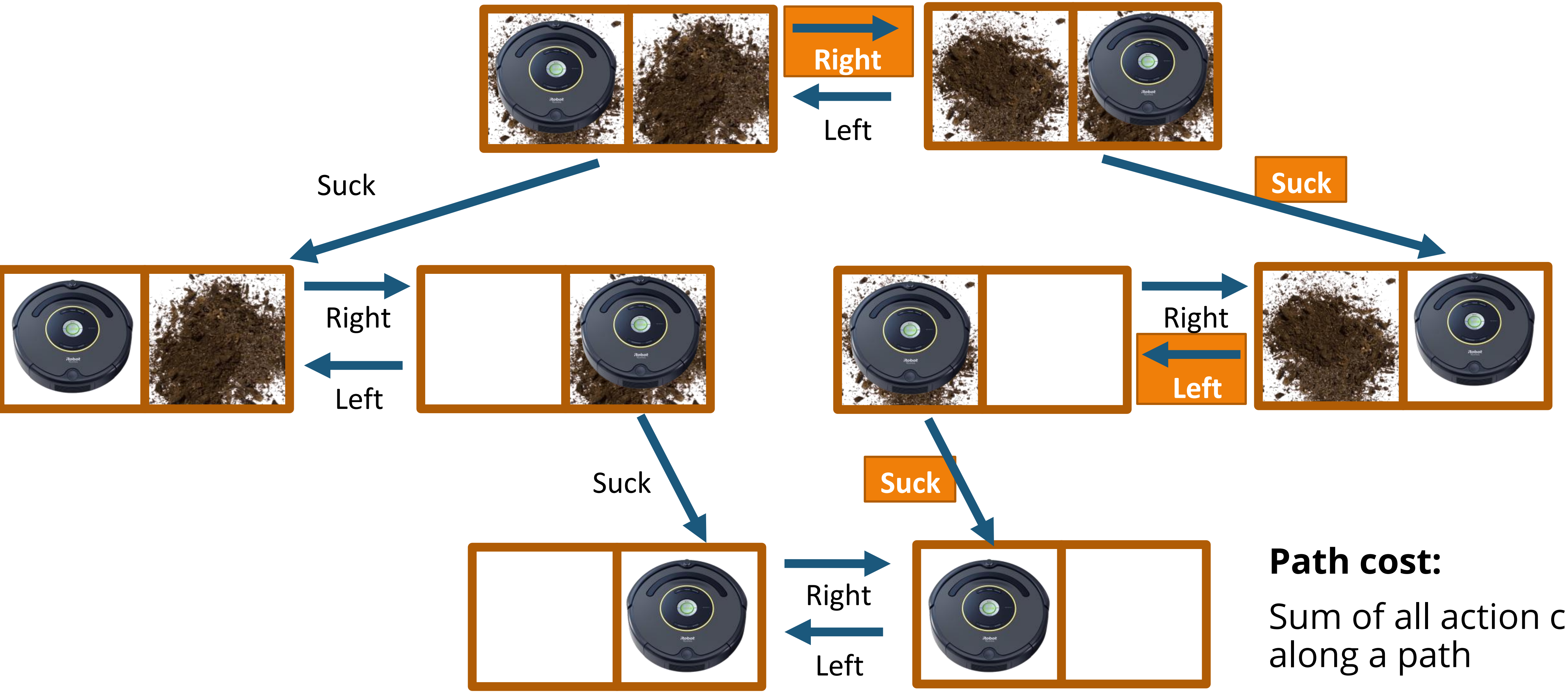
Vacuum World Transition Model



Action cost:

Uniform (all actions are equal cost)

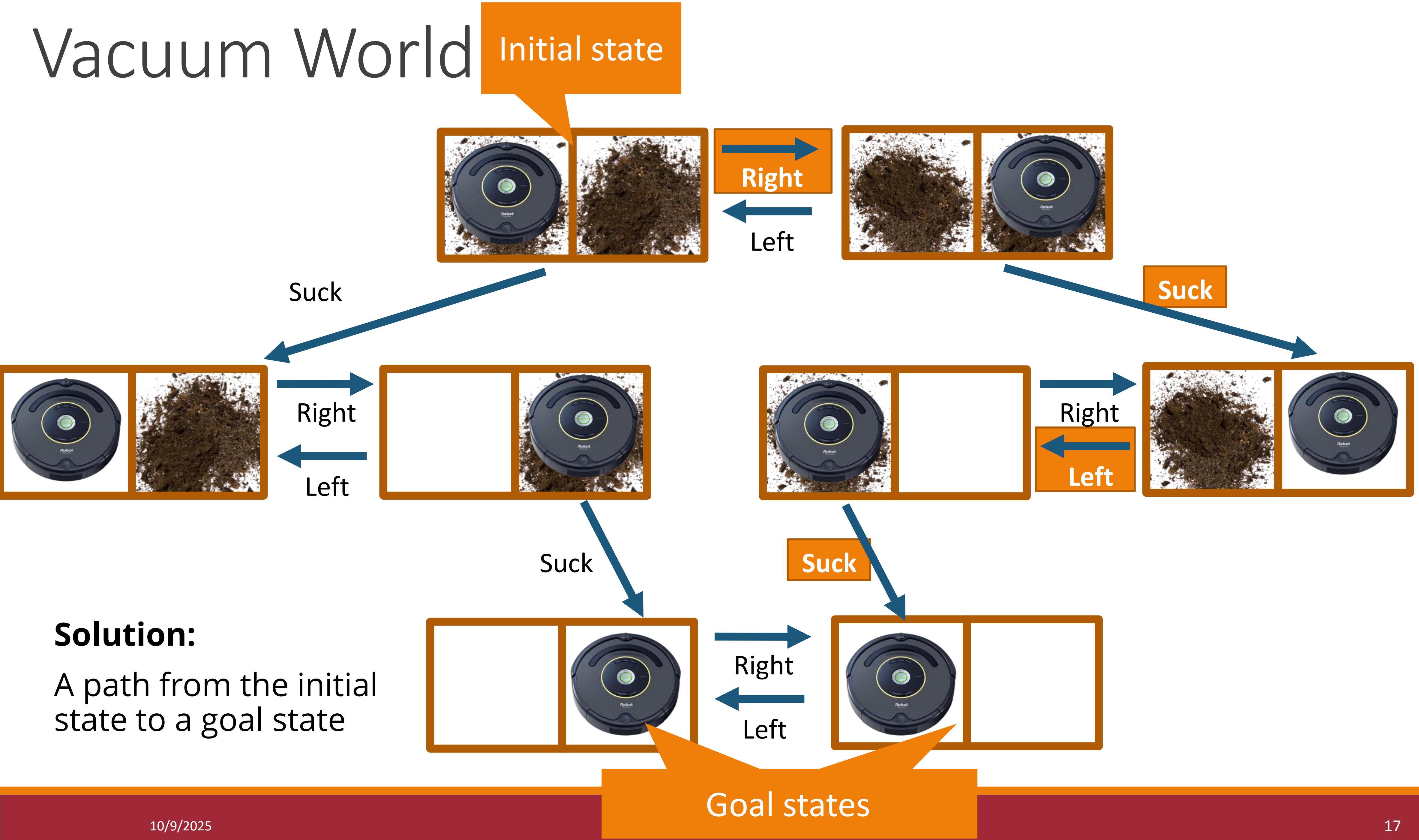
Vacuum World Transition Model



Path cost:

Sum of all action costs along a path

Vacuum World



Solution:

A path from the initial state to a goal state

Search Algorithms

Useful Concepts

State space: the set of all states reachable from the initial state by *any* sequence of actions

- When several operators can apply to each state, this gets large very quickly
- Might be a proper subset of the set of configurations

Path: a sequence of actions leading from one state s_j to another state s_k

Solution: a path from the initial state s_i to a state s_f that satisfies the goal test

Search tree: a way of representing the paths that a search algorithm has explored. The root is the initial state, leaves of the tree are successor states.

Frontier: those states that are available for *expanding* (for applying legal actions to)

Solutions and *Optimal* Solutions

A **solution** is a sequence of actions from the initial state to a goal state.

Optimal Solution: A solution is optimal if no solution has a lower path cost.

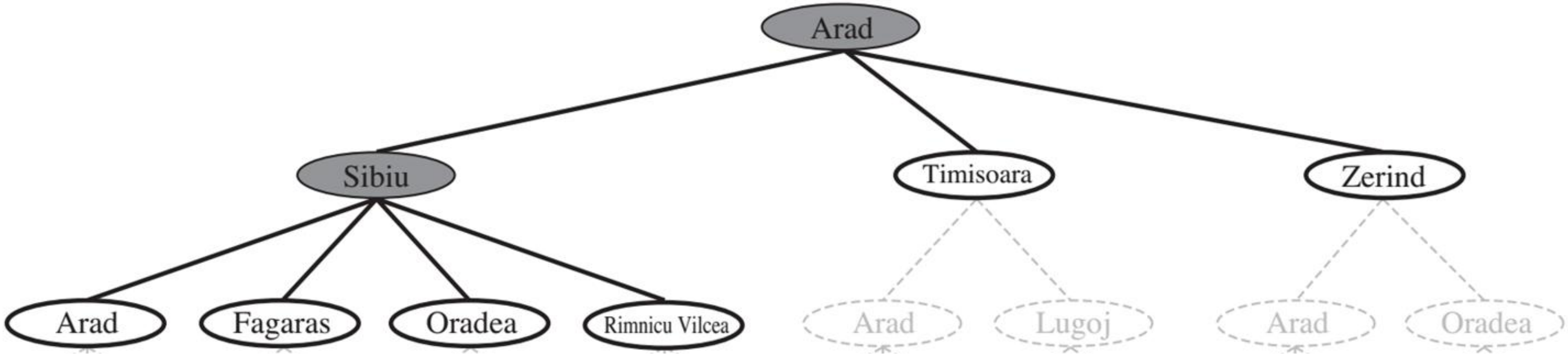
Basic search algorithms: Tree Search

Generalized algorithm to solve search problems

Enumerate in some order all possible paths from the initial state

- Here: search through ***explicit tree generation***
  - ROOT= initial state
  - Nodes in search tree generated through transition model
  - Tree search treats different paths to the same node as distinct

Generalized tree search



function TREE-SEARCH(*problem, strategy*) return a solution or failure

Initialize frontier to the *initial state* of the *problem*

do

if the frontier is empty then return *failure*

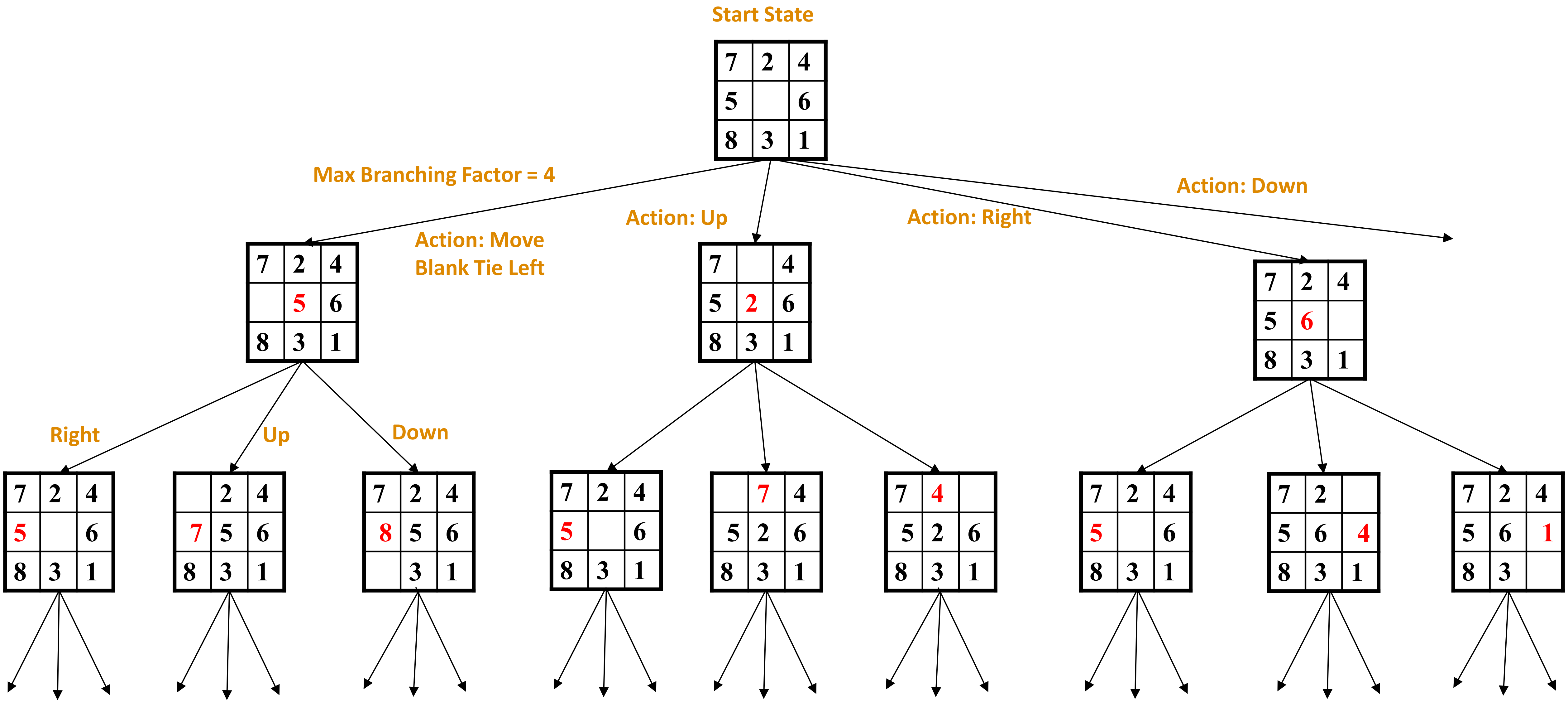
choose leaf node for expansion according to strategy & remove from frontier

if node contains goal state then return *solution*

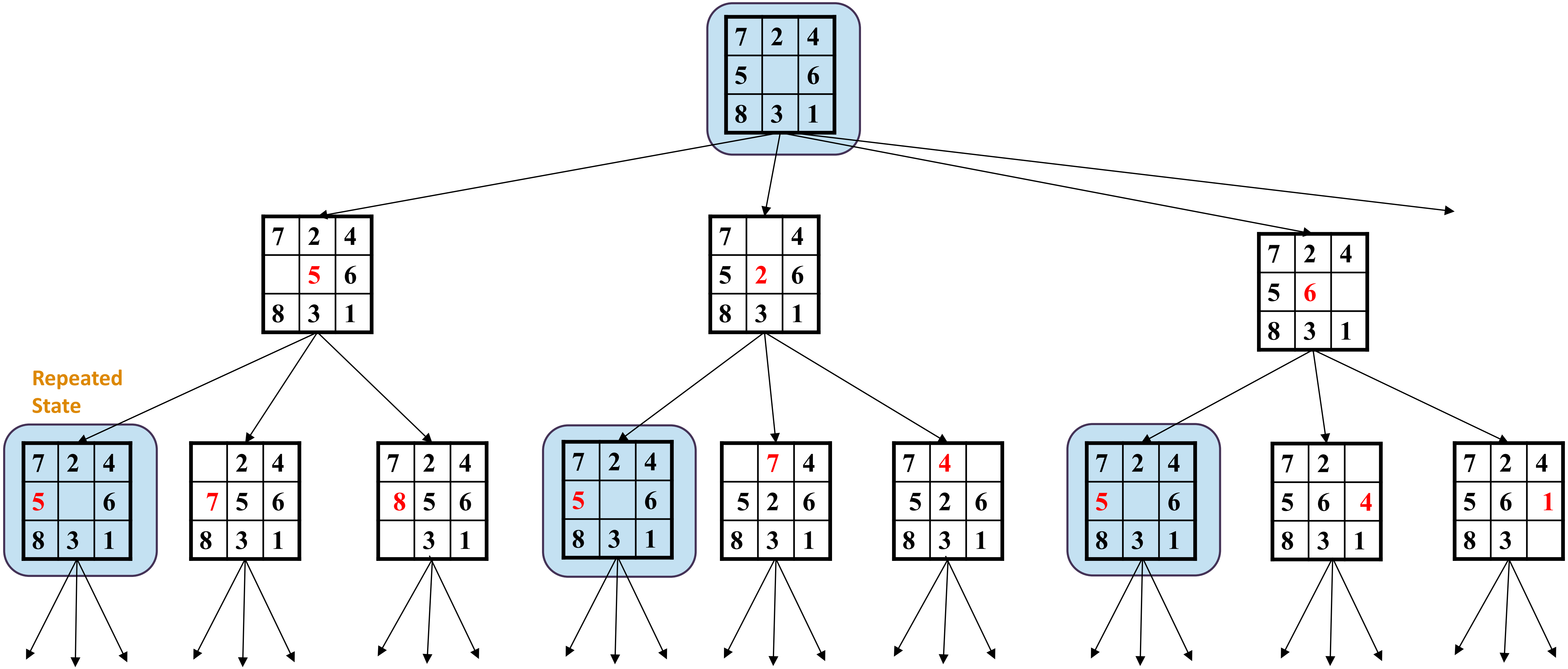
else expand the node and add resulting nodes to the frontier

The strategy determines search process!

8-Puzzle *Search Tree*



8-Puzzle *Search Tree*



Graph Search vs Tree Search

```
function TREE-SEARCH(problem) returns a solution, or failure
    initialize the frontier using the initial state of problem
    loop do
    if the frontier is empty then return failure
    choose a leaf nose and remove it from the frontier
    if the node contains a goal state then return the corresponding solution
    expand the chosen node, adding the resulting nodes to the frontier

function GRAPH-SEARCH(problem) returns a solution, or failure
    initialize the frontier using the initial state of problem
    initialize the explored set to be empty
    loop do
        if the frontier is empty then return failure
        choose a leaf node and remove it from the frontier
        if the node contains a goal state then return the corresponding solution
        add node to the explored set
        expand the chosen node, adding the resulting nodes to the frontier
            only if not in the frontier of explored set
```

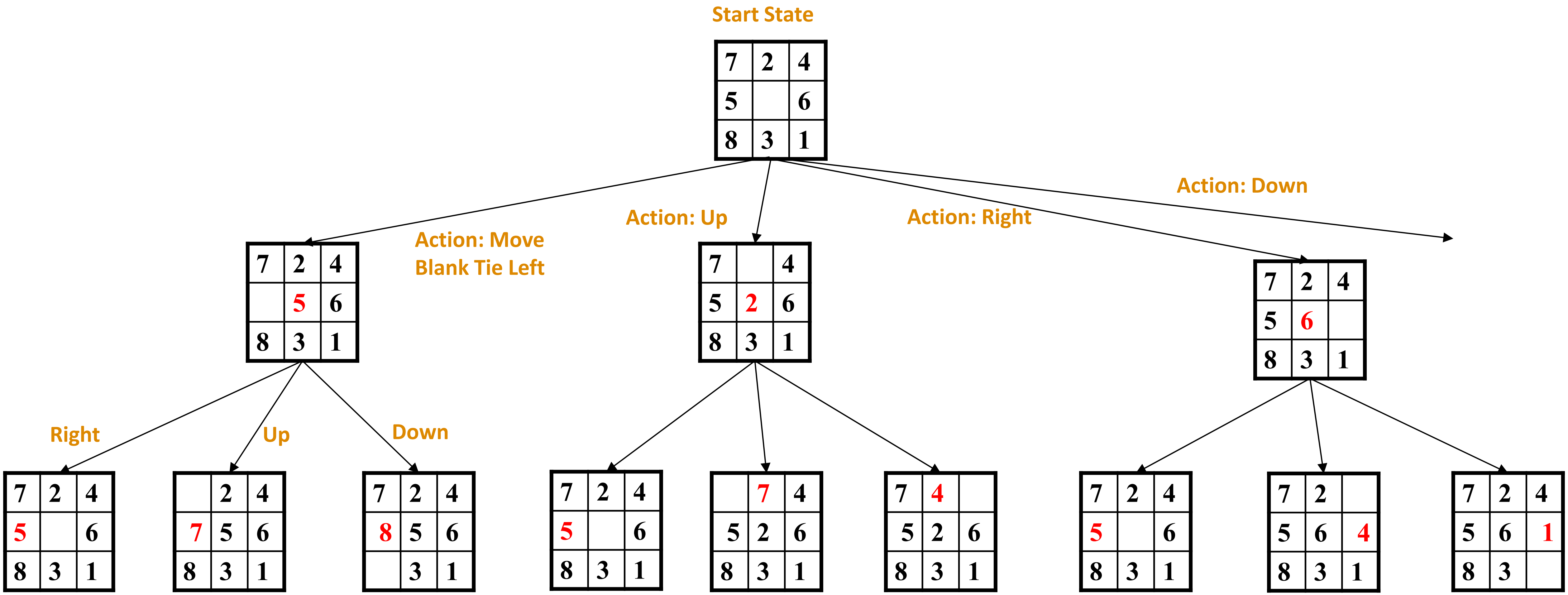
Search Strategies

Several classic search algorithms differ only by the order of how they expand their search trees

You can implement them by using different queue data structures

- **Depth-first search** = LIFO queue
- **Breadth-first search** = FIFO queue
- **Greedy best-first search** or **A* search** = Priority queue

8-Puzzle Breadth-first Search



Search Algorithms

Dimensions for evaluation

- **Completeness** - always find the solution?
- **Optimality** - finds a least cost solution (lowest path cost) first?
- **Time complexity** - # of nodes generated *(worst case)*
- **Space complexity** - # of nodes simultaneously in memory *(worst case)*

Time/space complexity variables

- b, maximum branching factor of search tree
- d, depth of the shallowest goal node
- m, maximum length of any path in the state space (potentially ∞)

Properties of Breadth-First Search (BFS)

Complete?	Yes (if b is finite)
Optimal?	Yes, if cost = 1 per step (not optimal in general)
Time Complexity?	$1+b+b^2+b^3+\ldots+b^d = O(b^d)$
Space Complexity?	$O(b^d)$ (keeps every node in memory)

Time/space complexity variables

- b, maximum branching factor of search tree
- d, depth of the shallowest goal node
- m, maximum length of any path in the state space (potentially ∞)

BFS versus DFS

Breadth-first

- ☑ Complete,
- ☑ Optimal
- ☒ *but* uses O(b^d) space

Time/space complexity variables

- *b, maximum branching factor* of search tree
- *d, depth* of the shallowest goal node
- *m*, *maximum length* of any path in the state space (potentially ∞)

Depth-first

- ☒ Not complete unless m is bounded
- ☒ Not optimal
- ☒ Uses O(b^m) time; terrible if m >> d
- ☑ but only uses O($b*m$) space

Exponential Space (and time) Is Not Good...

- Exponential complexity uninformed search problems *cannot* be solved for any but the smallest instances.
- *(Memory* requirements are a bigger problem than *execution* time.)

DEPTH	NODES	TIME	MEMORY
2	**110**	**0.11 milliseconds**	**107 kilobytes**
4	**11110**	**11 milliseconds**	**10.6 megabytes**
6	**10^6**	**1.1 seconds**	**1 gigabytes**
8	**10^8**	**2 minutes**	**103 gigabytes**
10	**10^{10}**	**3 hours**	**10 terabytes**
12	**10^{12}**	**13 days**	**1 petabytes**
14	**10^{14}**	**3.5 years**	**99 petabytles**

Assumes b=10, 1M nodes/sec, 1000 bytes/node

Action Castle

Art: Formulating a Search Problem

Decide:

Which properties matter & how to represent

- *Initial State, Goal State, Possible Intermediate States*

Which actions are possible & how to represent

- *Operator Set: Actions and Transition Model*

Which action is next

- *Path Cost Function*

Formulation greatly affects combinatorics of search space and therefore speed of search

Action Castle Map Navigation

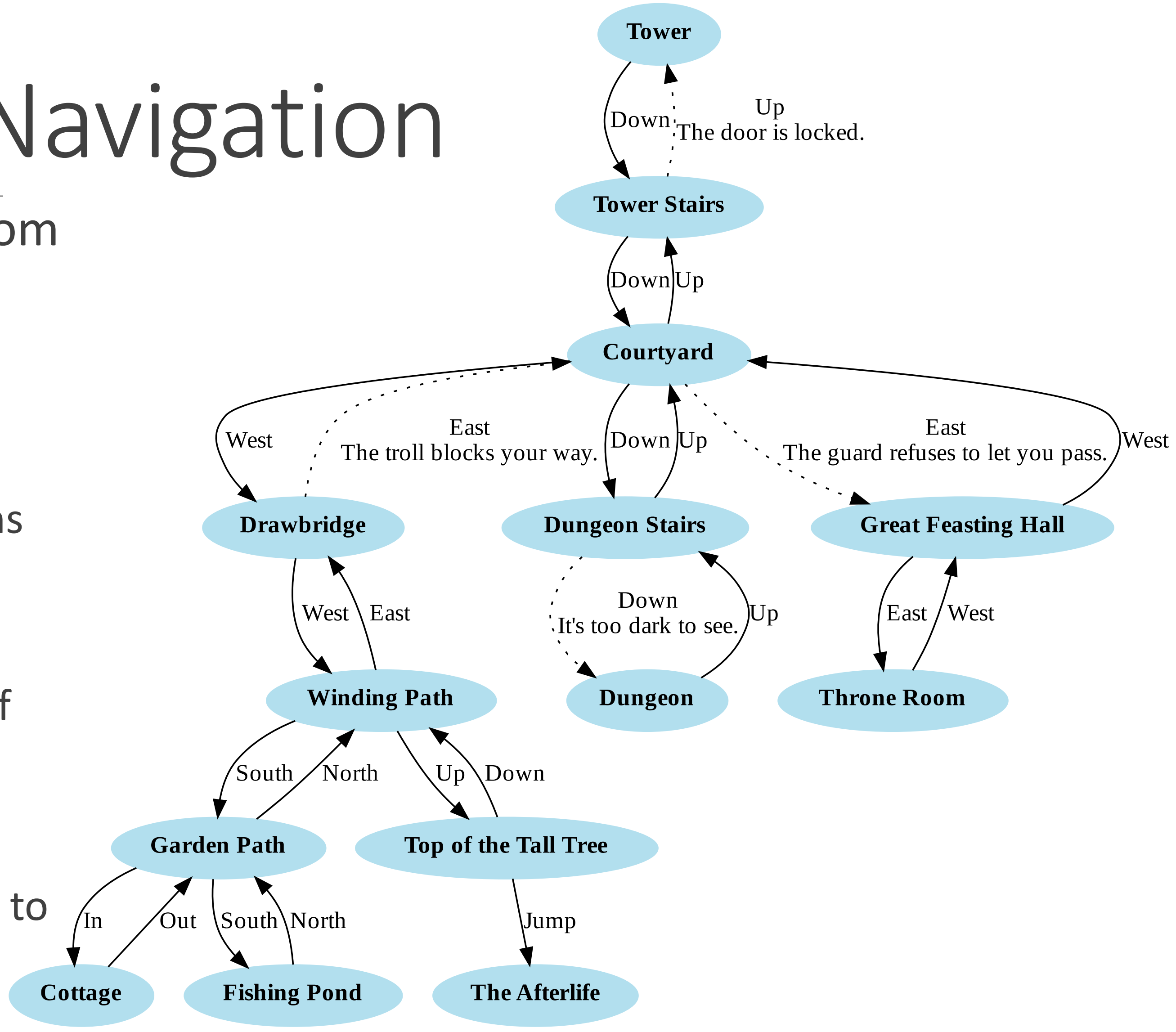
Let’s consider the sub-task of navigating from one location to another.

Formulate the ***search problem***

- States: locations in the game
- Actions: move between connected locations
- Goal: move to a particular location like the **Throne Room**
- Performance measure: minimize number of moves to arrive at the goal

Find a ***solution***

- Algorithm that returns sequence of actions to get from the start sate to the goal.



Action Castle

Let's consider the full game.

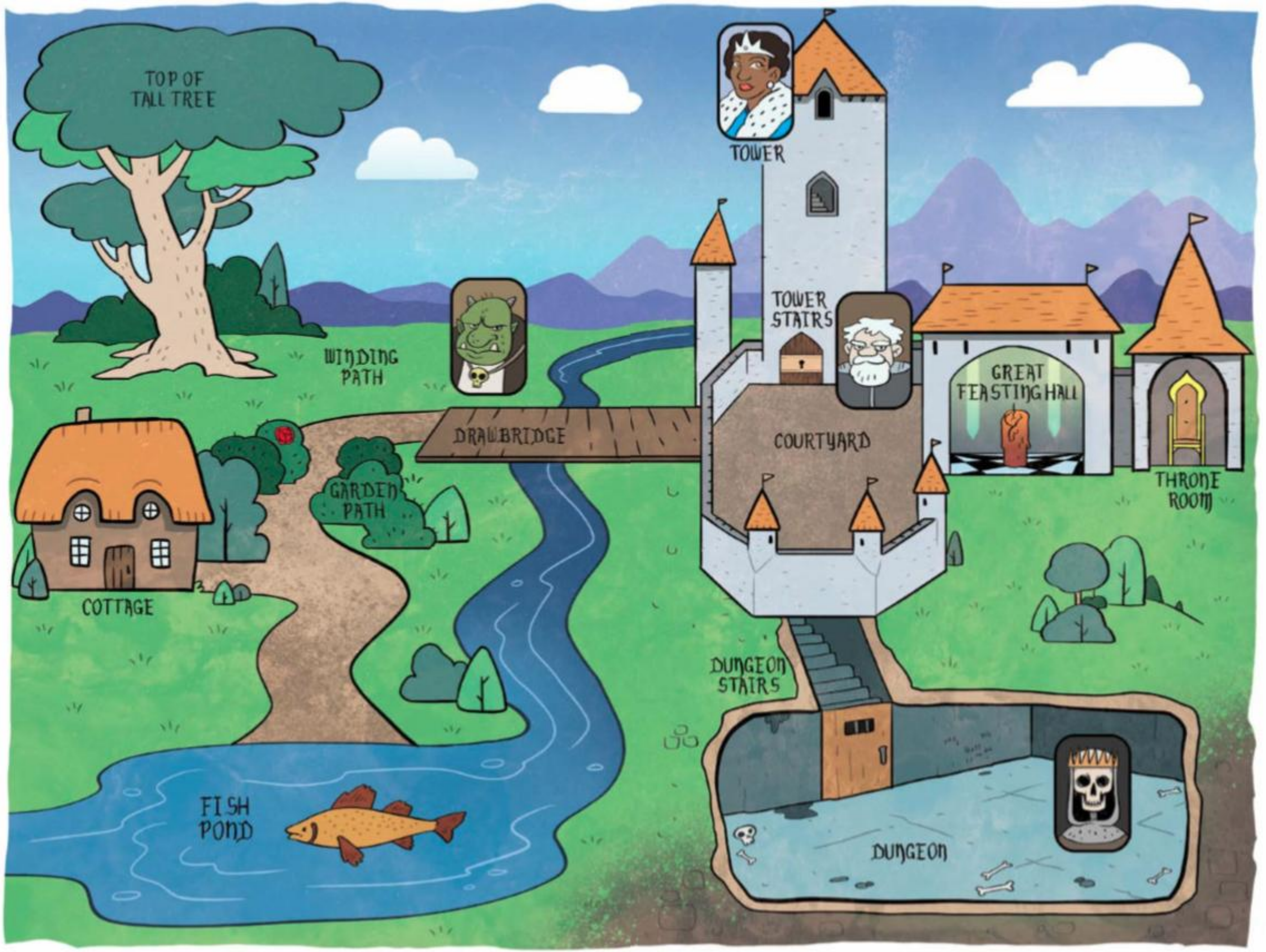
Actions

Start State

Transitions

State Space

Goal test



Actions

Go

- Move to a location

Get

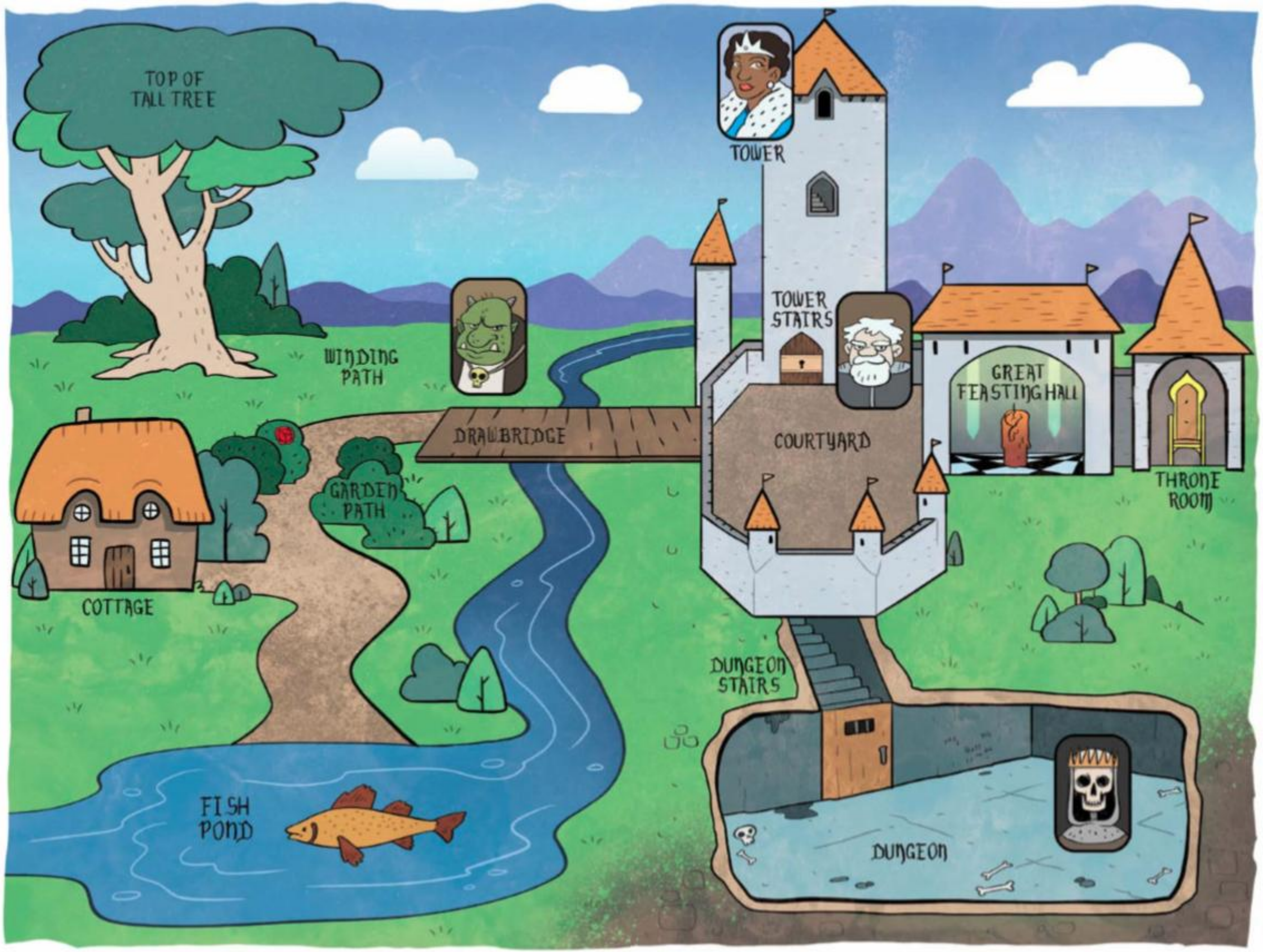
- Add an item to inventory

Special

- Perform a special action with an item like “Catch fish with pole”

~~Drop~~

- ~~Leave an item in current location~~



State Info

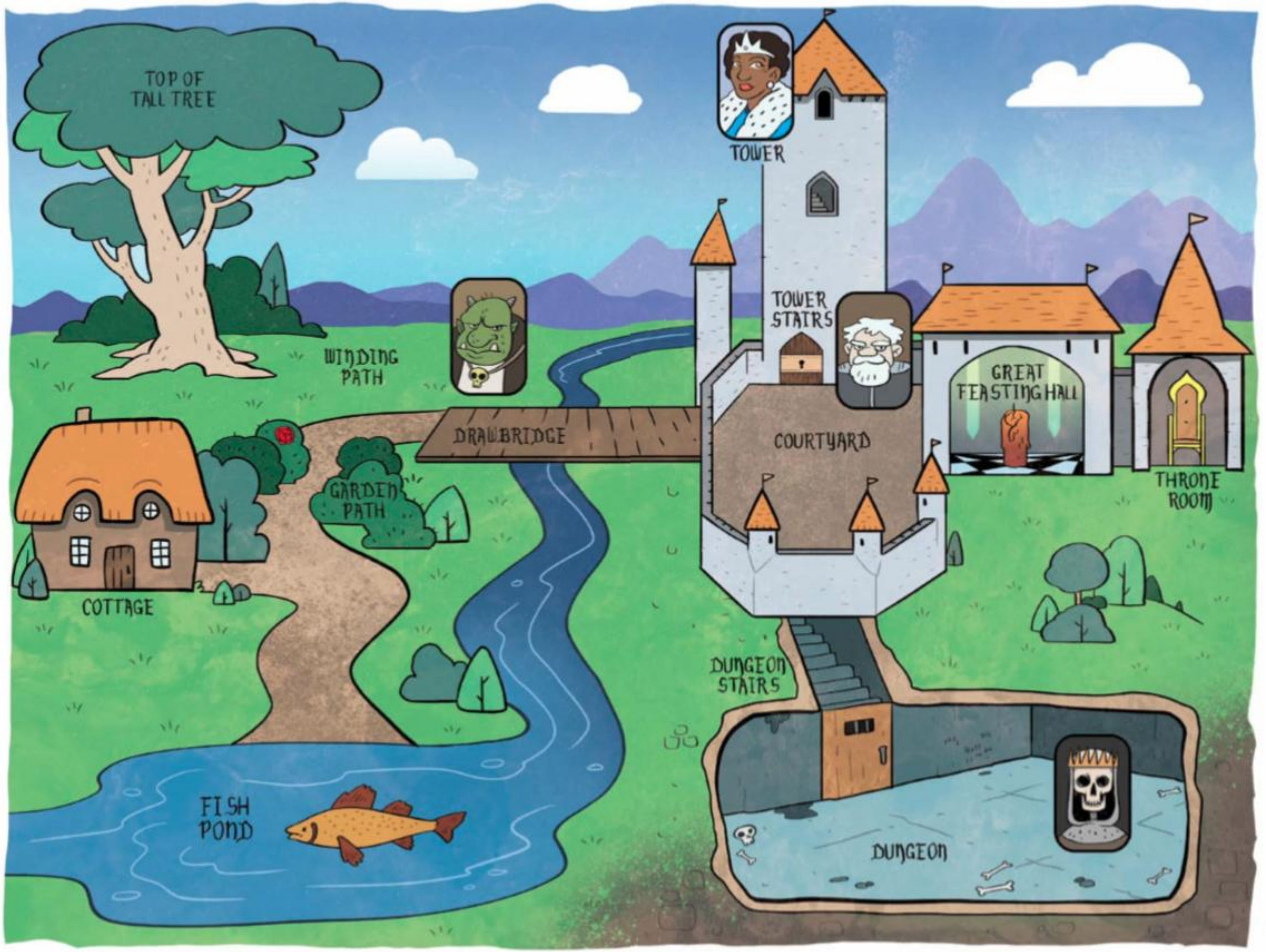
Location of Player

Items in their inventory

Location of all items / NPCs

Blocks like

- Troll guarding bridge,
- Locked door to tower,
- Guard barring entry to castle



In-Class Activity

https://laramartin.net/interactive-fiction-class/in_class_activities/search/action-castle-search.html

BFS has been implemented for you. You will be defining the action space, the state space, and the goal test.

This knowledge check is worth 2 points since it's bigger.

```python
def BFS(game, goal_conditions):
  command_sequence = []
  if goal_test(game, goal_conditions): return co

  frontier = queue.Queue()
  frontier.put((game, command_sequence))

  visited = dict()
  visited[get_state(game)] = True

  while not frontier.empty():
    (current_game, command_sequence) = frontier.get()
    current_state = get_state(current_game)
    parser = Parser(current_game)
    available_actions = get_available_actions(current_game)

    for command in available_actions:
      # Clone the current game with its state
      new_game = copy.deepcopy(current_game)
      # Apply the command to it to get the resulting state
      parser = Parser(new_game)
      parser.parse_command(command)
      new_state = get_state(new_game)
      # Update the sequence of actions that we took to get to
      new_command_sequence = copy.copy(command_sequence)
      new_command_sequence.append(command)
      if not new_state in visited:
        visited[new_state] = True
        if goal_test(new_game, goal_conditions):
        frontier.put((new_game, new_command_sequence))
  # Return None to indicate there is no solution.
  return None
```

The frontier tracks order of unexpanded search nodes. Here we're using a FIFO queue

The visited dictionary prevents us from revising states.

TODO: implement get_state()

get_available_actions() to return all commands that could be used here.

TODO: implement get_available_actions()

The parser can execute this command to get the resulting state.

Check to see if this state satisfies the goal test, if so, return the command sequence that got us here.

TODO: implement goal_test()

```python
def BFS(game, goal_conditions):
    command_sequence = []
    if goal_test(game, goal_conditions): return command_sequence

    frontier = queue.Queue()
    frontier.put((game, command_sequence))

    visited = dict()
    visited[get_state(game)] = True

    while not frontier.empty():
        (current_game, command_sequence) = frontier.get
        current_state = get_state(current_game)
        parser = Parser(current_game)
        available_actions = get_available_actions(current_game)

        for command in available_actions:
            # Clone the current game with its state
            new_game = copy.deepcopy(current_game)
            # Apply the command to it to get the resulting state
            parser = Parser(new_game)
            parser.parse_command(command)
            new_state = get_state(new_game)
            # Update the sequence of actions that we took to get to the resulting state
            new_command_sequence = copy.copy(command_sequence)
            new_command_sequence.append(command)
            if not new_state in visited:
                visited[new_state] = True
                if goal_test(new_game, goal_conditions):
                frontier.put((new_game, new_command_sequence))
    # Return None to indicate there is no solution.
    return None
```

To be used, a key in the dictionary get_state() must return an immutable object

My Solution

```
goal_conditions = {"at_location" : "Throne Room",
                   "inventory_contains" : "crown (worn)"}

game = build_game()
solution = BFS(game, goal_conditions)
print("SOLUTION:", solution)
```

```
---
Found solution at depth 36.
Expanded 4138 nodes. Trimmed 18632 nodes.
There are 83 nodes on the frontier.
```

```
solution
```

```
['get pole',
 'go out',
 'go south',
 'catch fish with pole',
 'go north',
 'pick rose',
 'go north',
 'go up',
 'get branch',
 'go down',
 'go east',
 'give the troll the fish',
 'go east',
 'hit guard with branch',
 'go east',
 'get candle',
 'go west',
 'go down',
 'light lamp',
 'go down',
 'light candle',
 'read runes',
 'get crown',
 'go up',
 'go up',
 'get key',
 'go up',
 'unlock door',
 'go up',
 'give rose to princess',
 'propose to the princess',
 'wear crown',
 'go down',
 'go down',
 'go east',
 'go east']
```