

COMP219: Artificial Intelligence

Lecture 11: Search in Complex Environments

Overview

- Last time
 - Uniform cost search
 - Heuristics and heuristic search (greedy, A^*)
- Today:
 - Search with partial observations
 - Belief states
- Learning outcome covered today:

Identify, contrast and apply to simple examples the major search techniques that have been developed for problem-solving in AI;

Problem Types

- Deterministic, fully observable **single-state problem**
 - Agent knows exactly which state it will be in; solution is a sequence
- Non-observable **sensorless problem (conformant problem)**
 - Agent may have no idea where it is; solution is a sequence
- Non-deterministic and/or partially observable **contingency problem**
 - percepts provide **new** information about current state
 - often **interleave** search, execution
- Unknown state space **exploration problem**



Search Without Full Observation

- Agent's percepts do not determine the exact state
- If agent in one of several possible states then an action may lead to one of several possible outcomes
- **Belief state:** agent's *current belief* about the possible *physical states* it might be in (given history – sequence of actions + percepts)

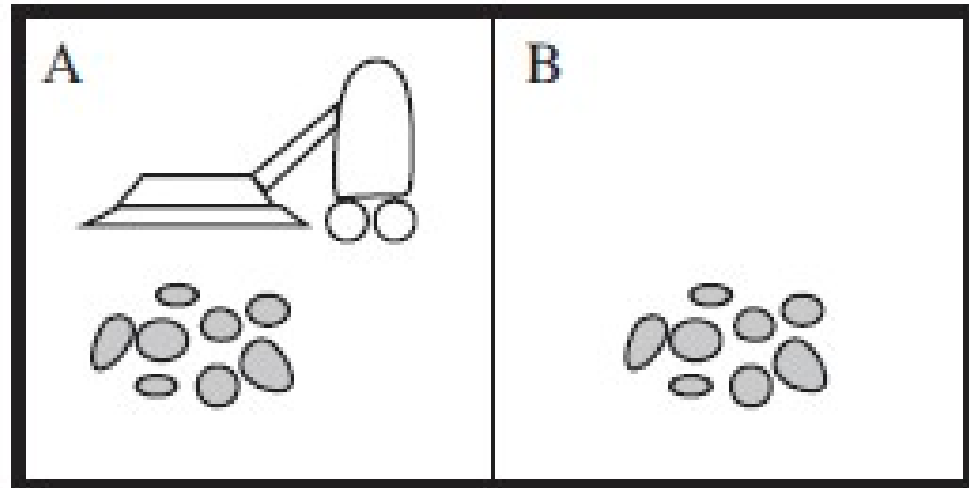
Search with No Observations

- Sensorless problem
- No need to rely on sensors working properly, e.g. manufacturing
- Less costly
- Search in belief states not physical states



Example: Robot Vacuum Cleaner World

- Actions:
 - Right
 - Left
 - Suck

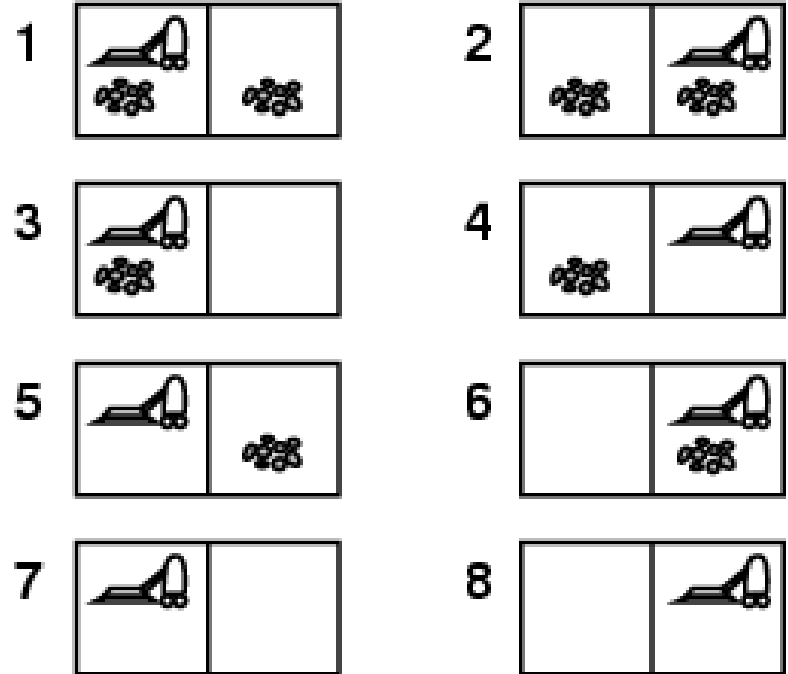


Example: vacuum world - 1

Single-state:

- Start in #5

Solution?



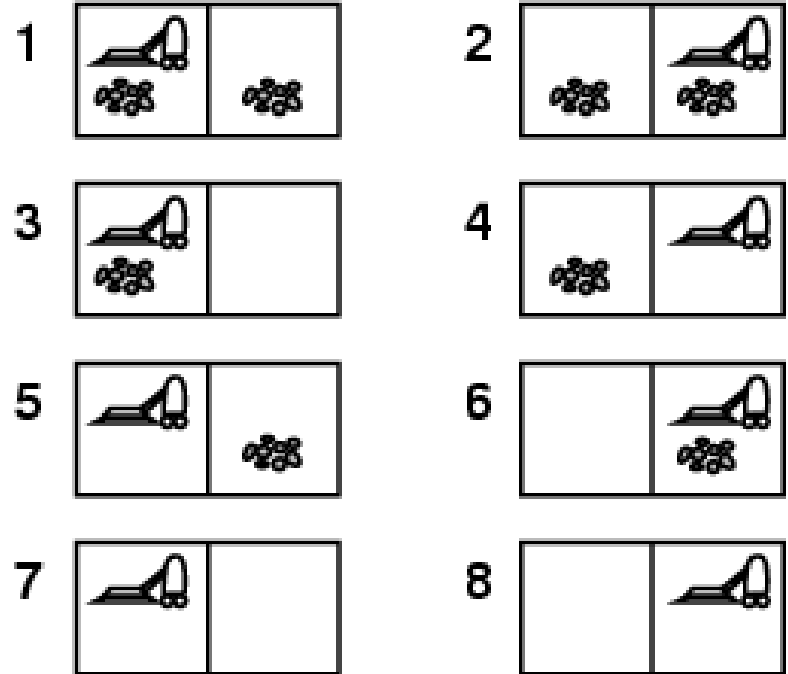
Answer: vacuum world - 1

Single-state:

- Start in #5

Solution?

- *[Right, Suck]*

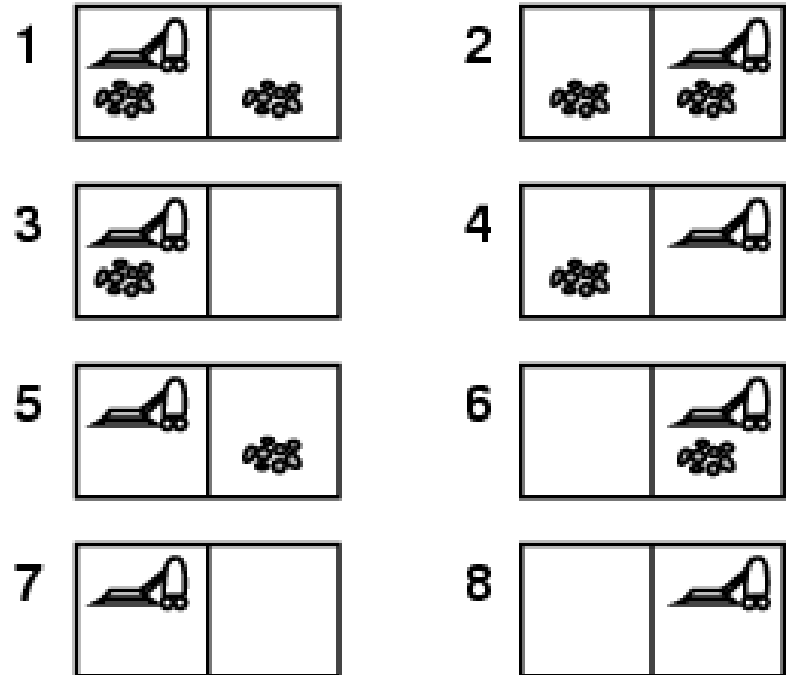


Example: vacuum world - 2

Sensorless:

- Start in $\{1,2,3,4,5,6,7,8\}$
- e.g. *Right* goes to $\{2,4,6,8\}$

Solution?



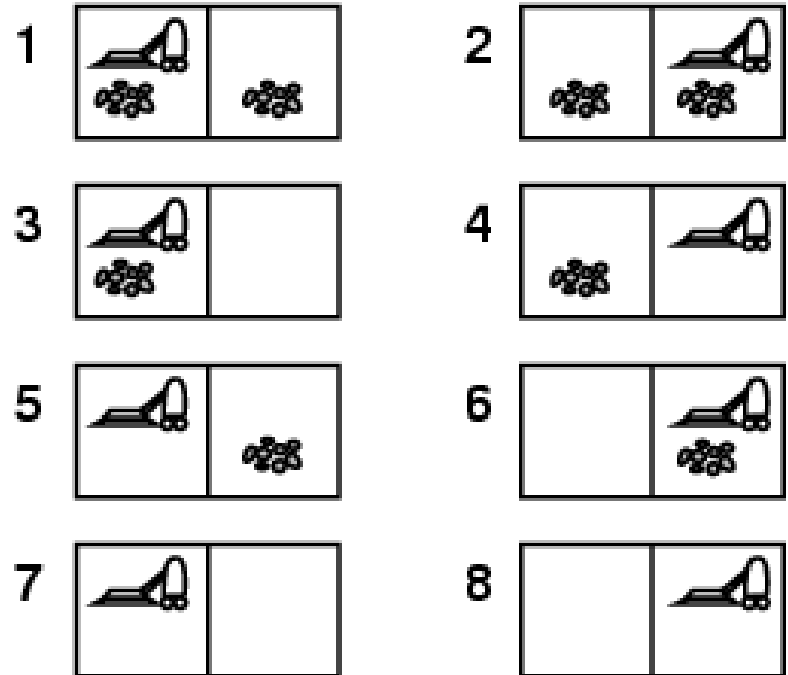
Answer: vacuum world - 2

Sensorless:

- Start in $\{1,2,3,4,5,6,7,8\}$
- e.g. *Right* goes to $\{2,4,6,8\}$

Solution?

- $[Right, Suck, Left, Suck]$

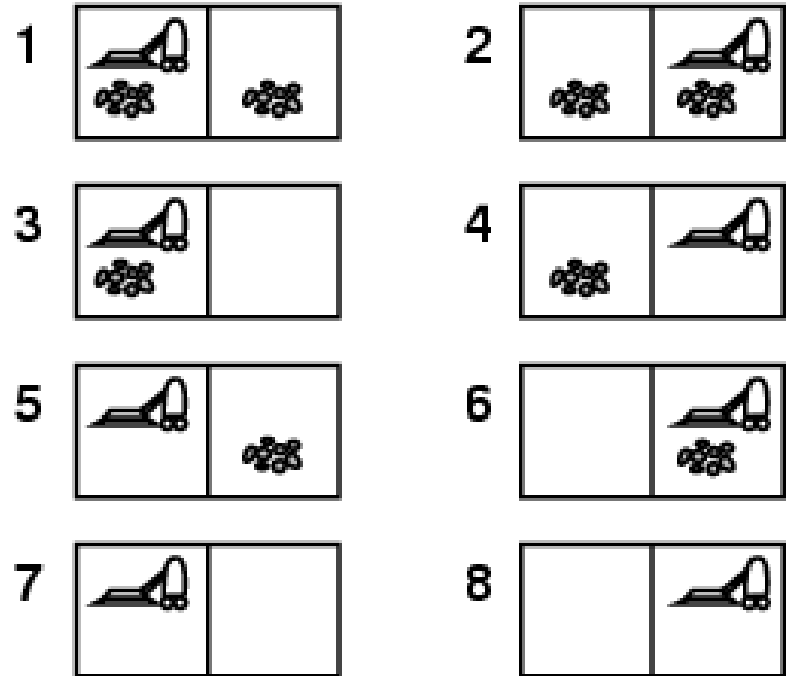


Example: vacuum world - 3

Contingency:

- *Non-deterministic*:
suck may dirty a clean carpet
- *Partially observable*:
location, dirt at current location
- Percept: [A, Clean]
i.e. start in #5 or #7

Solution?



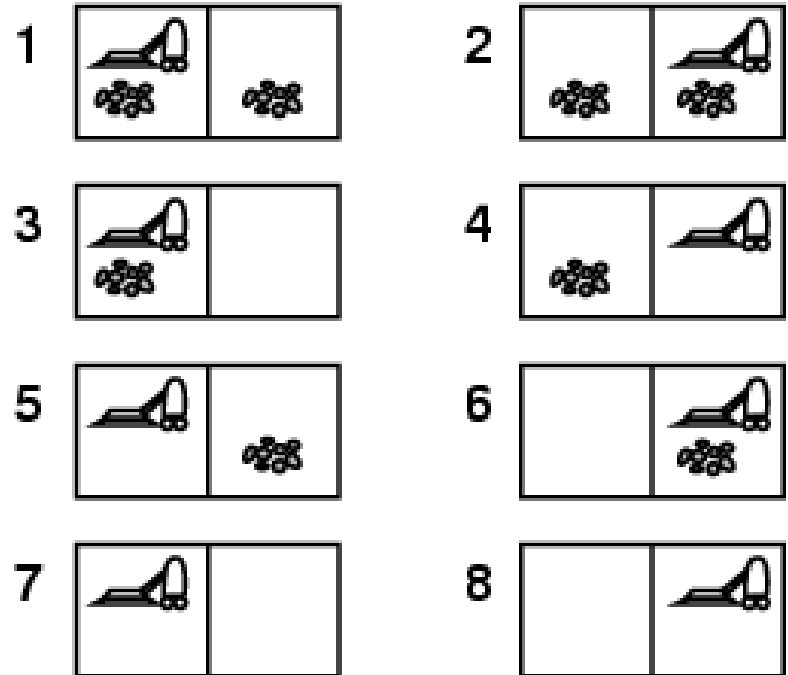
Answer: vacuum world - 3

Contingency:

- *Non-deterministic*:
suck may dirty a clean carpet
- *Partially observable*:
location, dirt at current location
- Percept: [A, Clean]
i.e. start in #5 or #7

Solution?

- [Right, **if dirt then Suck**]



No Observations: Constructing a Belief State Search Problem

- Physical problem P is defined by Actions_p , Result_p , Goal-Test_p , Step-Cost_p
- Sensorless problem is defined by:
 - **Belief States** – every possible set (B) of physical states
 - **Initial State** – set of all states in P
 - **Actions**
 - **Transition model**
 - **Goal test** – all states in belief state must satisfy goal
 - **Path cost**

Determining Possible Actions

- Depends on whether any illegal actions have an effect on the environment
- If not, **union** of all actions:

$$Actions(b) = \bigcup_{s \in b} Actions_p(s)$$

- If so, only allow the **intersection**, i.e. actions which are legal in ***all*** states

Transition Model

- For deterministic actions, the set of states that might be reached is:

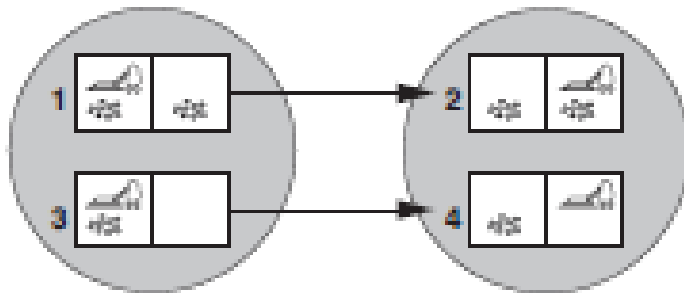
$$b' = \text{Result}(b, a) = \{s' : s' = \text{Result}_p(s, a) \text{ and } s \in b\}$$

- b' is never larger than b
 - Set of non-deterministic actions may be larger than b
- **Prediction step** is process of generating the new belief state after the action

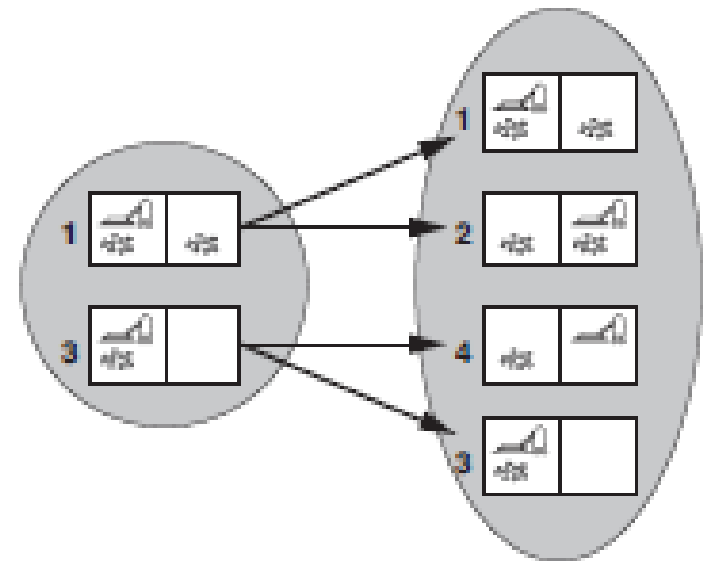
$$b' = \text{Predict}_p(b, a)$$

Prediction Step: Vacuum World

- Action: [Right]

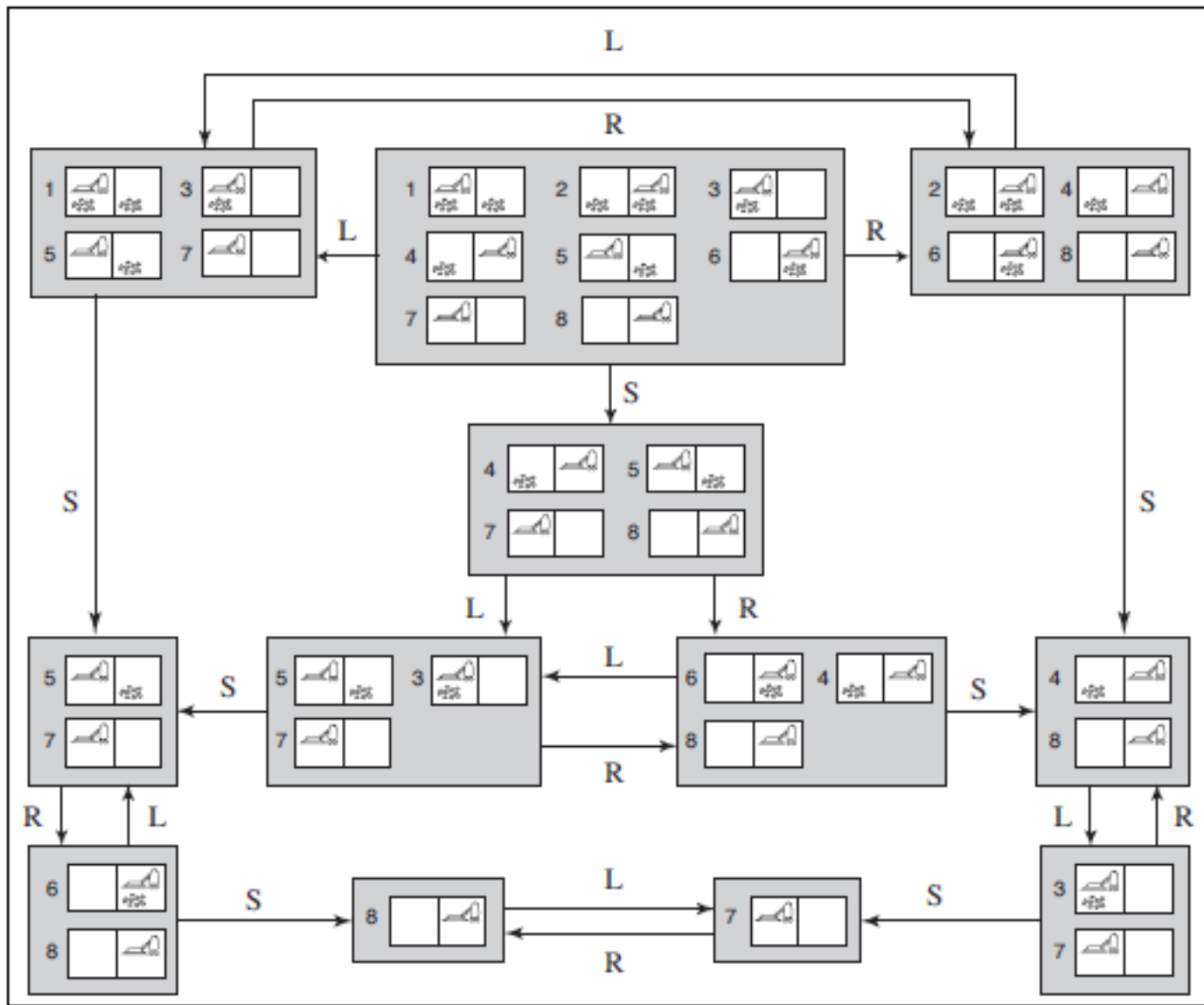


Deterministic



Non-deterministic
'slippery'

Belief State Problem: Vacuum World



Pruning the Belief State Graph

- If an action sequence is a solution for a belief state b , **it is also a solution for any subset of b**
 - $[Suck, Left, Suck]$ reaches the same b as $[Right, Left, Suck] = \{5, 7\}$
- Consider $[Left]$: $b = \{1, 3, 5, 7\}$
 - Can **discard** that path as its subset $\{5, 7\}$ has already been generated

Sensorless Problem Solving

- **Problem:** Size of each belief state
- e.g.
 - 10 x 10 vacuum world
 - $100 \times 2^{100} = 10^{32}$ physical states

Incremental Belief State Search

- Unlike standard search algorithms, look **inside** b
- Build up solution **one physical state at a time**
- One solution for all states
- Find action sequence that works for all states:
 - Find solution for state 1
 - Check if it works for state 2, then state 3, etc.
 - If not, find different solution for state 1, etc.
- Advantage: detects failure quickly
 - If b unsolvable, usually the small subset of first few states examined is also unsolvable

Searching with Partial Observations

- Specify how the environment generates percepts
 - e.g. vacuum agent has position and local dirt sensor but no dirt sensor for other squares
 - $\text{Percept}(\text{state } 1) = [\text{A,Dirty}]$
- Usually several states could have produced the same percept
 - e.g. $[\text{A,Dirty}] = \{1, 3\}$

Searching with Partial Observations – Transitions

- 3 stages:

- **Prediction** stage – same as sensorless problems

$$\hat{b} = \text{Predict}(b, a)$$

- **Observation prediction** stage determines set of percepts o that could be observed in predicted belief state

$$\text{Possible - Percepts}(\hat{b}) = \{o : o = \text{Percept}(s) \text{ and } s \in \hat{b}\}$$

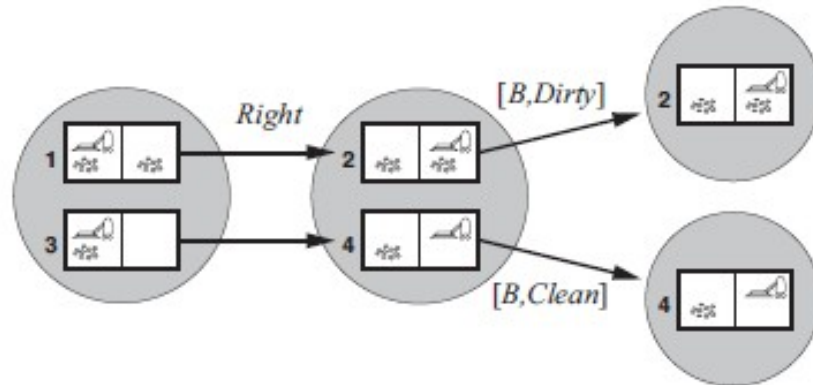
- **Update** stage – for each possible percept, determine which belief states could result from the percept

$$b_o = \text{Update}(\hat{b}, o) = \{s : o = \text{Percept}(s) \text{ and } s \in \hat{b}\}$$

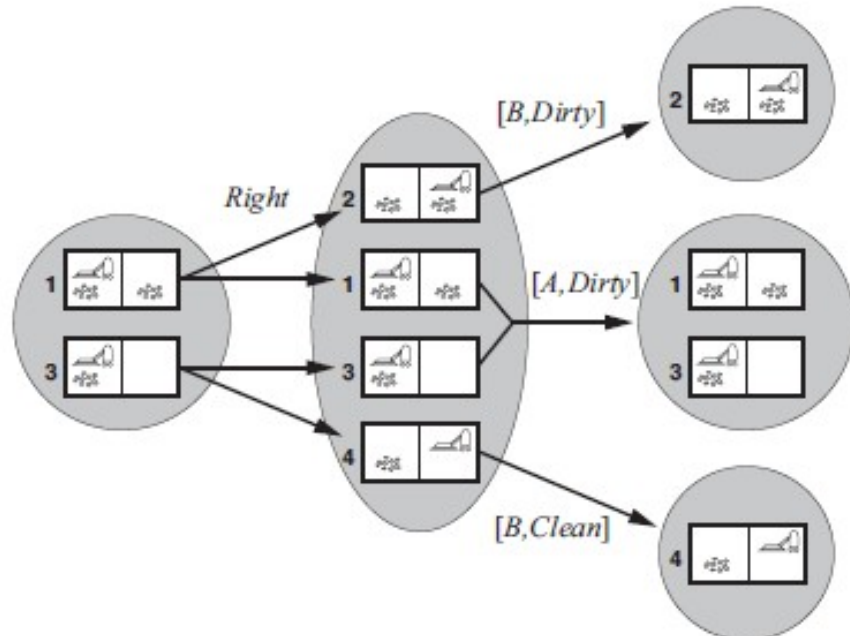
- Percepts reduce uncertainty

Transitions: Vacuum World

Deterministic



Non-deterministic
'slippery'

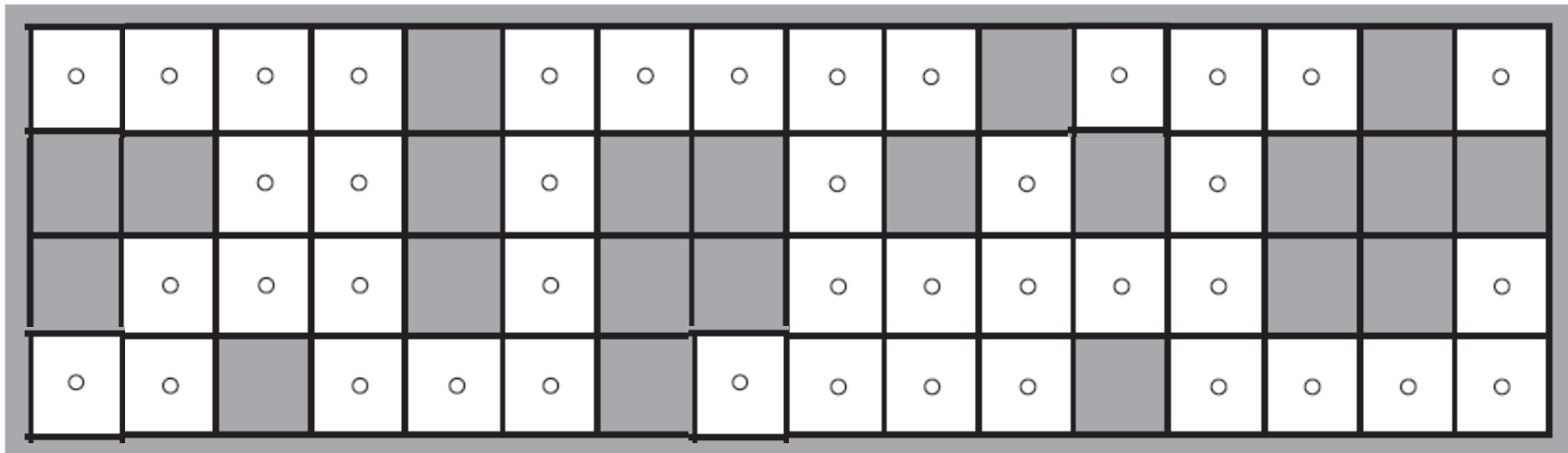


Exercise

- A robot has the task of localisation, i.e. working out where it is given a map of the world and a sequence of percepts and actions
- 4 sonar sensors tell the robot whether there is an obstacle in each compass direction (NESW)
- MOVE action moves randomly to an adjacent square

Exercise: Localisation

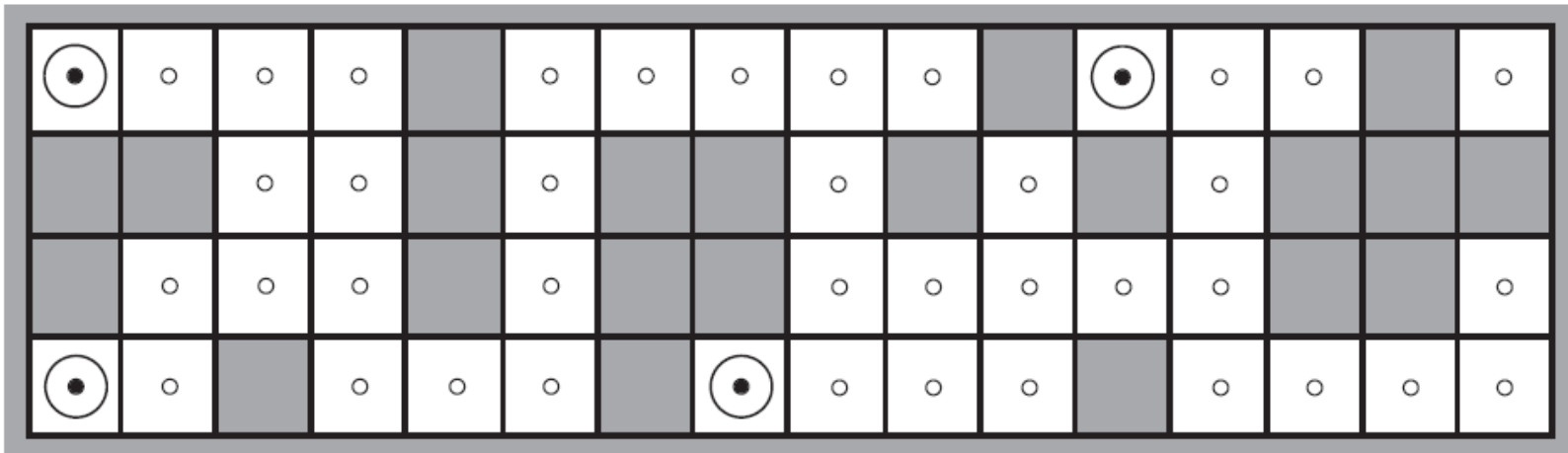
- Where is the robot?



- After one percept $P_1 = \text{NSW}$?

Exercise: Localisation

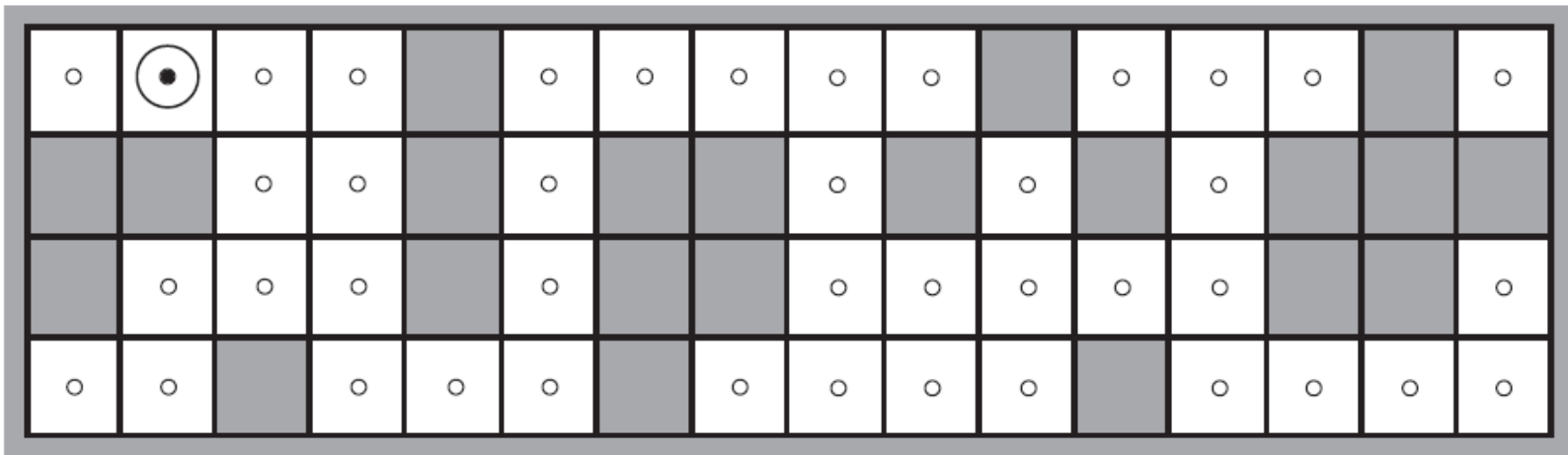
- Possible locations of the robot after one percept $P_1=NSW$



- After MOVE and next percept $P_2=NS$?

Exercise: Localisation

- After MOVE and next percept $P_2=NS$ we have a solution!



Summary

- Search with no observation
 - Belief states
 - Pruning the belief state graph
 - Incremental belief state search
- Search with partial observation
 - Transitions: prediction; observation prediction; update
- Next time
 - Applying search to games