# COMP219: Artificial Intelligence

## Lecture 5: Search



# Overview

- Last time
  - Intelligent agents and environments
- Today:
  - introduce *problem solving* and *problem formulation*
  - show how problems can be stated as *state space search*
  - show the importance and role of *abstraction*
  - define main performance measures for search
- 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 Solving

- What is a problem?

  A *goal* and a means *for achieving the goal*
- The goal specifies the state of affairs we want to bring about
- The means specifies the operations we can perform in an attempt to bring about the goal
- The difficulty is deciding what *order* to carry out the operations
- Solution will be a sequence of operations leading from initial state to goal state (plan)



# Problem Formulation

More precisely, a problem can be defined by the following items:

States – a set;

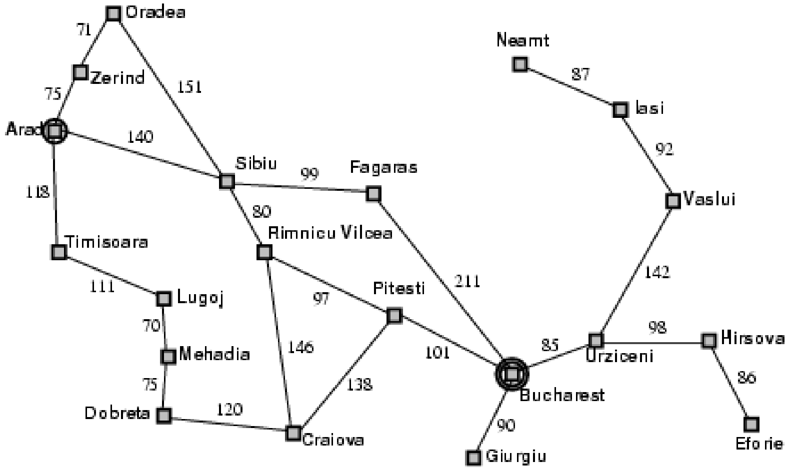
- Initial state – a particular state where the agent starts off;
- Actions – are applicable in states;
- Transition model – specified by a function that returns the state that results from performing action *a* in state *s;*

Goal test - determines whether a given state is a goal state (may be explicit or implicit);

- Path cost - a function that assigns a numeric cost to each path.
- A solution is a sequence of actions leading from the initial state to a goal state.

# Example: Romania

**On holiday in Romania; currently in Arad.**
**Flight leaves tomorrow from Bucharest.**



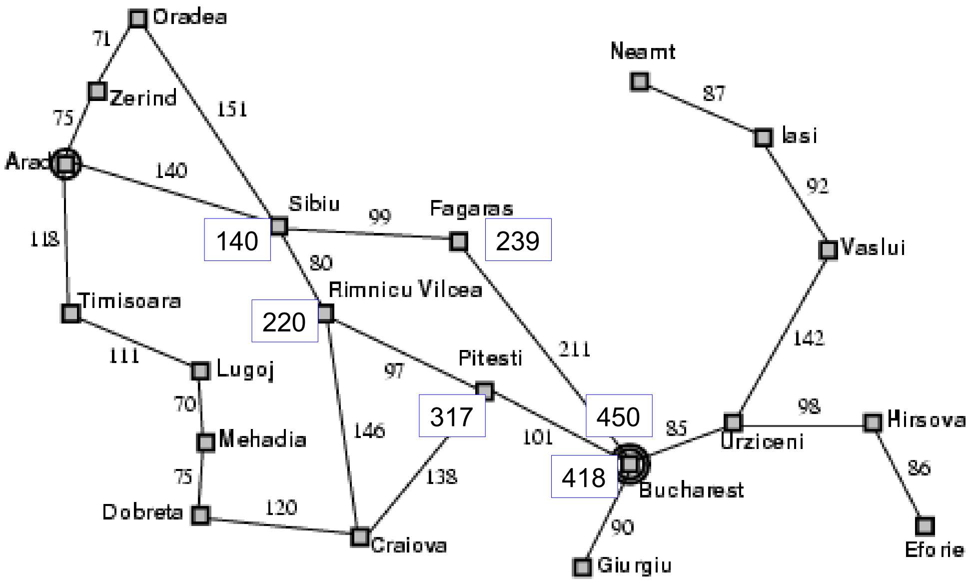



# Romania: Problem Formulation

- States: various cities
- Initial state: in Arad
- Actions: drive between cities
  - e.g. In Arad: drive to Sibiu, drive to Zerind, drive to Timisoara, etc.
- Transitions: cities lead to
  - e.g. When in Arad, driving to Zerind results in being in Zerind, etc.
- Goal: be in Bucharest (- an explicit goal state)
- Path cost: Sum of step costs, i.e. distances between cities, in kilometres

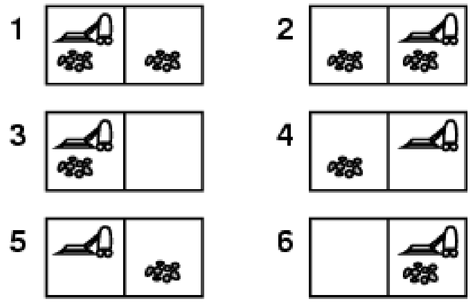


# Example: Romania

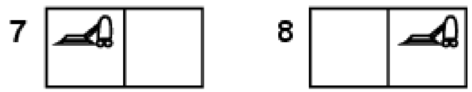





# Example: Vacuum World




- Consider an agent designed to vacuum clean.
- The world it inhabits has just two locations, squares A and B.
- The agent can perceive its location (which square it is in) and whether there is dirt in the square.




- The agent can choose to move left, move right, suck up the dirt, or do nothing.

# Vacuum World Problem Formulation

- States: integer dirt and robot location
- Initial state: any can be designated
- Actions: *Left*, *Right*, *Suck*
- Transition model: actions have expected effects, though some result in no effect, e.g. sucking in a clean square
- Goal test: no dirt at all locations
- Path cost: step costs 1 per action, so path is number of steps

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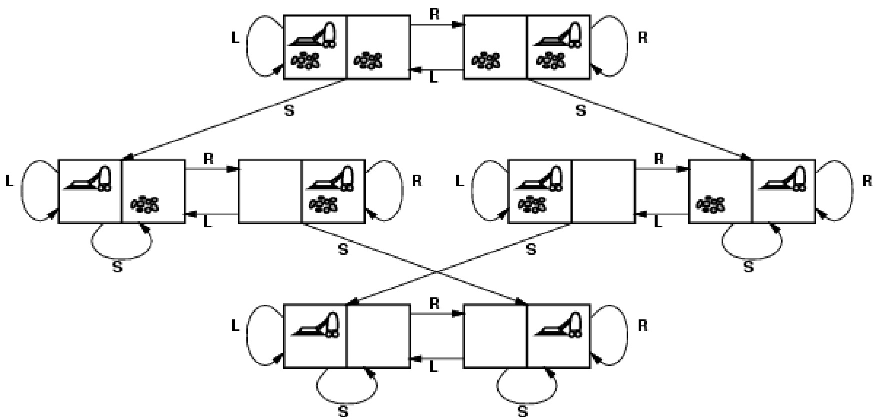
# State Space Graph

- When taken together, the initial state, actions and transition model implicitly define the state space of the problem
  - This is the set of all states reachable from the initial state by any sequence of actions.
- The state space forms a directed network or graph in which the nodes are states and the links between nodes are actions.
- For the Romania example: the previous map can be interpreted as a state space graph if each road is viewed as standing for two driving actions, one in each direction.
- For the vacuum world, the state space graph is as follows…



# Vacuum World State Space Graph






# More Examples of Real World Problems

- Game playing
- Route finding - routing in computer networks, rail travel, air travel
- Touring and travelling - find a route between Aberdeen and Glasgow; travelling salesperson problem
- Assembly sequencing
- VLSI layout
- Robot navigation
- . . . .

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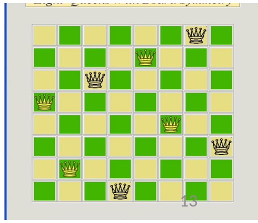
# Toy Problems: The n-Queens Problem

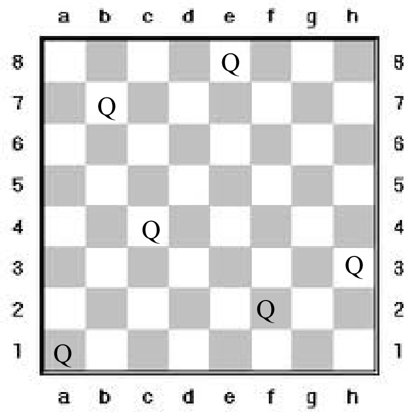
- This is a problem from chess.
- In the 8-queens version, place 8 queens on chess board so that no queen can be taken by another.
- A queen attacks any piece in the same row, column or diagonal.
- Has served as a useful test scenario for search algorithms.





# Exercise

Add two more queens to this board to provide a solution to the 8-queens problem.



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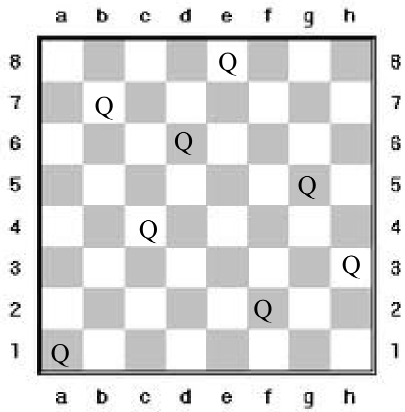



A program that solves the problem.

And another one.

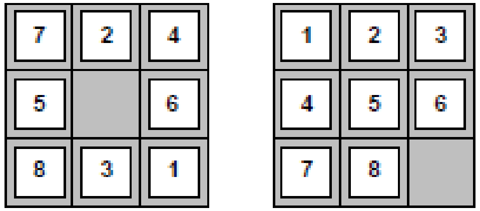


# n-Queens as a Search Problem

- States: Any arrangement of 0-8 queens on the board.
- Initial state: empty chess board.
- Actions: place queen in empty square.
  - Place queens anywhere
    - For the 8-queens problem $64^8$ possibilities.
  - Place queens only where they are not attacked already.
    - Around 2,000 possible sequences to check.
- Transition model: returns the board with a queen added to the specified square.
- Goal test: n queens on chess board so that none can take any other.

# Toy Problems: The 8 Puzzle

States: 3 × 3 grid filled with numbers 1–8 and a blank.
Initial state: as shown on the left.
Goal test: as shown on the right.
Actions: $a_1$ - move any tile to left of empty square to right; ….
Transition model: the states resulting from actions in a given state.
Path cost: number of steps, with each step cost = 1.

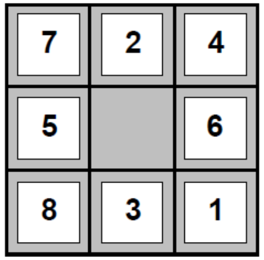


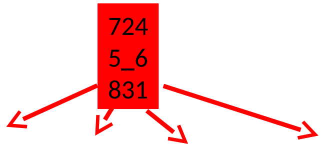

Start State Goal State



# 8 Puzzle Search Space

Again we can map out all possible states reachable from the initial state to give the full search space.





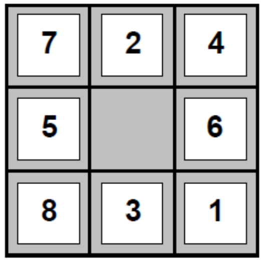

# Exercise

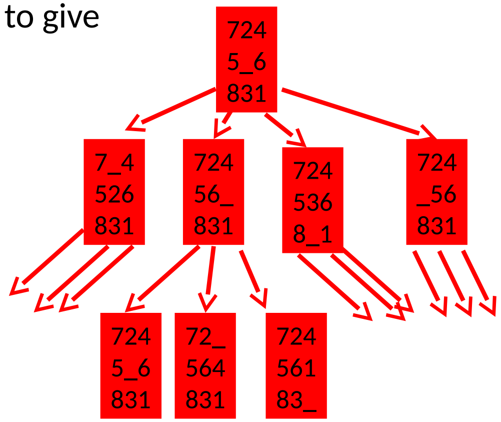
For the 8 puzzle, add the next level to the search space showing all possible states reachable from the initial state.



# Search Space

Again we can map out all possible states reachable from the initial state to give the full search space.



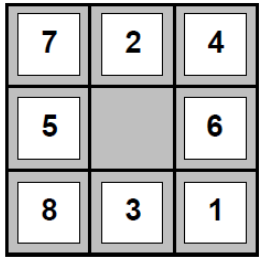



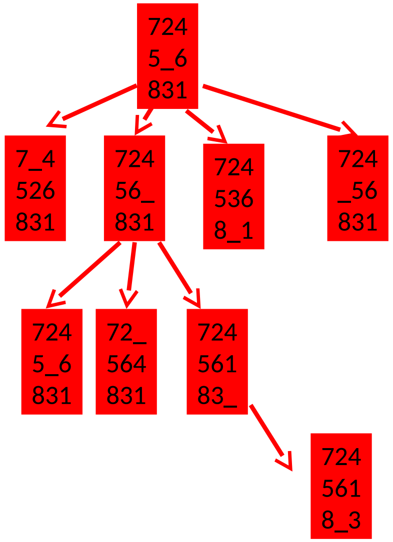
# Search Tree

The search tree shows nodes explored by a search algorithm to solve the problem.

Root is the initial state: successor nodes found by applying operations (expanding nodes).

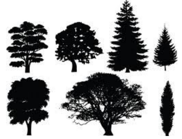
Stops when goal is reached.






# Tree Search Algorithms



- General description:

```
function TREE-SEARCH( problem, strategy) returns a solution, or failure
    initialize the search tree using the initial state of problem
    loop do
        if there are no candidates for expansion then return failure
        choose a leaf node for expansion according to strategy
        if the node contains a goal state then return the corresponding solution
        else expand the node and add the resulting nodes to the search tree
```



# Search Strategy Performance

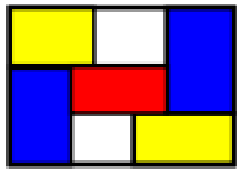
- A search strategy is defined by picking the order of node expansion

- Completeness: does it always find a solution if one exists?
- Time complexity: number of nodes generated/expanded.
- Space complexity: maximum number of nodes in memory.
- Optimality: does it always find a least-cost solution?

- Time and space complexity: are measured in terms of
  - *b*: maximum branching factor of the search tree
  - *d*: depth of the least-cost solution
  - *m*: maximum depth of the state space (may be infinite)

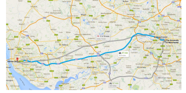


# Abstraction



- The real world is absurdly complex
  - therefore state space must be *abstracted* for problem solving.
- (Abstract) state = set of real states.
- (Abstract) action = complex combination of real actions
  - “Arad to Zerind” represents a complex set of possible routes, detours, rest stops, etc.
- For guaranteed realisability, any real state “in Arad” must get to some real state “in Zerind”.
- (Abstract) solution
  - a set of real paths that are solutions in the real world.
- Abstraction should be “easier” than the original problem.

# Right Level of Abstraction



- Example: driving from city A to city B.
  - Some possible actions. . .
    - depress clutch;
    - turn steering wheel right 10 degrees;
  - inappropriate level of abstraction; too much irrelevant detail.
- Better level of abstraction:
  - follow A143 to Colchester for 4 miles;
  - turn right onto M12;
  - . . . and so on.
- Getting abstraction level right lets you focus on the specifics of the problem and combats the combinatorial explosion.



# Solution Cost

- For most problems, some solutions are better than others:
  - 8 puzzle: number of moves to get to solution;
  - chess: number of moves to checkmate;
  - route planning: length of distance (or time) to travel.
- Mechanism for determining cost of solution is the path cost function.
- This is the length (cost) of the path through the state space from the initial state to the goal state.



# Summary

- Today
  - Some search problems
  - Representing a search problem
  - Search trees
  - Evaluating search strategy performance
- Next time
  - Recursion in Prolog