CS 1571 Introduction to AI
Lecture 3

Problem solving by searching

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Solving problems by searching

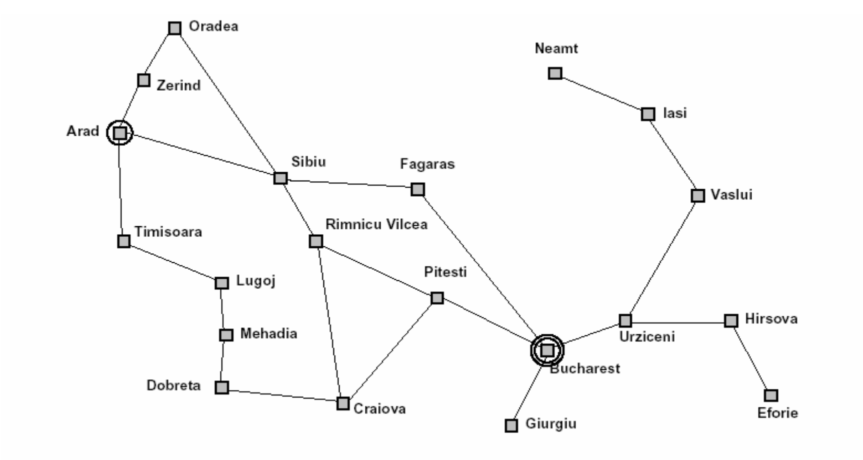
- Some problems have a straightforward solution
  - Just apply the formula, or follow a standardized procedure

    Example: solution of the quadratic equation
  - Hardly a sign of intelligence

- More interesting problems require **search**:
  - more than one possible alternative needs to be explored before the problem is solved
  - the number of alternatives to search among can be very large, even infinite.

Search example: Traveler problem

- Find a route from one city (**Arad**) to the other (**Bucharest**)



Example. Puzzle 8.

- Find the sequence of the empty tile moves from the initial game position to the designated target position

Initial position

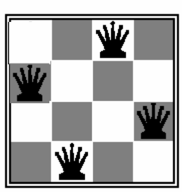
4	5	
6	1	8
7	3	2

Goal position

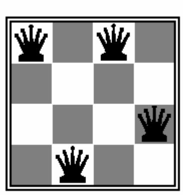
1	2	3
4	5	6
7	8	

Example. N-queens problem.

Find a configuration of n queens not attacking each other



A goal configuration



A bad configuration

A search problem

is defined by:

- **A search space:**
  - **What is it?**
- **A goal condition**

A search problem

is defined by:

- **A search space:**
  - What is it?
  - A set of objects among which we search for the solution.
  - **What is the search space for the puzzle 8 problem?**
- **A goal condition**

A search problem

is defined by:

- **A search space:**
  - What is it?
  - A set of objects among which we search for the solution.
  - What is the search space for the puzzle 8 problem?
  - A sequence of moves.
- **A goal condition**
  - **Give an example of a goal condition for the map problem.**

A search problem

is defined by:

- **A search space:**
  - What is it?
  - A set of objects among which we search for the solution.
  - What is the search space for the puzzle 8 problem?
  - A sequence of moves.
- **A goal condition**
  - **Give an example of a goal condition for the map problem.**
  - A path from A to B.
  - The shortest path from A to B.

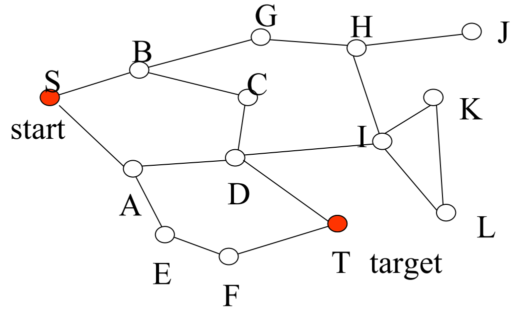
Search

- **Search (process)**
  – The process of exploration of the search space
- **The efficiency of the search depends on:**
  – The search space and its size
  – Method used to explore (traverse) the search space
  – Condition to test the satisfaction of the search objective (what it takes to determine I found the desired goal object)

- **Important to remember !!!**
  – Conveniently chosen **search space** and the **exploration policy** can have a profound effect on the efficiency of the solution

Graph search

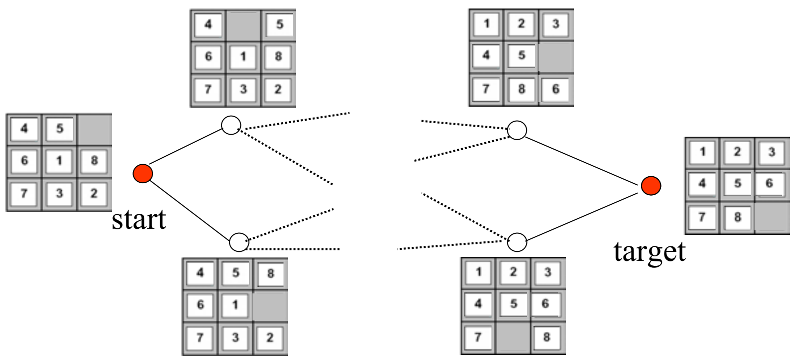
- **Many search problems can be naturally represented as graph search problems**
- **Typical example: Route finding**
  – Map corresponds to the graph, nodes to cities, links to available connections between cities
  – **Goal:** find a route (path) in the graph from S to T



Graph search

- **Less obvious conversion:**

  Puzzle 8. Find a sequence of moves from the initial configuration to the goal configuration.
  - nodes corresponds to states of the game,
  - links to valid moves made by the player



Search problem

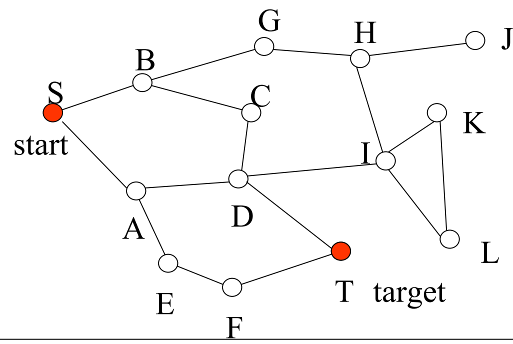
Search problems that can be represented or converted into a graph search problems can be defined in terms of:

- **Initial state**
  - State (configuration) we start to search from (e.g. start city, initial game position)
- **Operators**:
  - Transform one state to another (e.g. valid connections between cities, valid moves in Puzzle 8)
- **Goal condition:**
  - Defines the target state (destination, winning position)
- **Search space (**the set of objects we search for the solution) **:**
  - is now defined indirectly through**:**

    the initial state + operators

Graph search problem

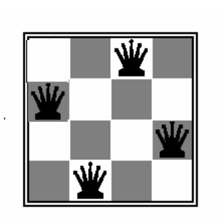
- **States** - game positions, or locations in the map that are represented by nodes in the graph
- **Operators -** connections between cities, valid moves
- **Initial state** – start position, start city
- **Goal state** – target position (positions), target city (cities)



N-queens

Some problems can be converted to the graph search problems

- **But some problems are harder and less intuitive**
  - Take e.g. N-queens problem.



Goal configuration

- **Problem:**
  - **We look for a configuration, not a sequence of moves**
  - **No distinguished initial state, no operators (moves)**

N-queens

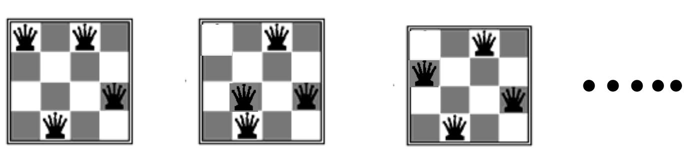
How to choose the search space for N-queens?

- Ideas?

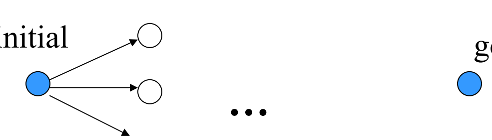
N-queens

How to choose the search space for N-queens?

- Ideas? **Search space:**
  - all configurations of N queens on the board



- **Can we convert it to a graph search problem?**
- We need states, operators, initial state and goal condition.



N-queens

Search space:

– all configurations of N queens on the board

- **Can we convert it to a graph search problem?**
- We need states, operators, initial state and goal state.

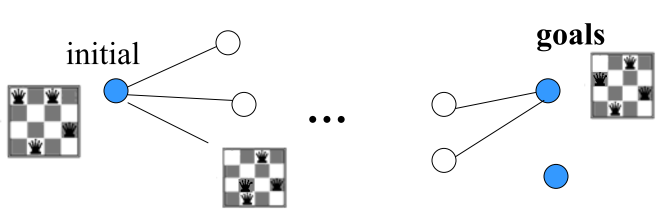
States are: N-queen configurations
Initial state: ?
Operators (moves)?

N-queens

Search space:

– all configurations of N queens on the board

- **Can we convert it to a graph search problem?**
- We need states, operators, initial state and goal condition.



Initial state: an arbitrary N-queen configuration
Operators (moves): change a position of one queen

N-queens

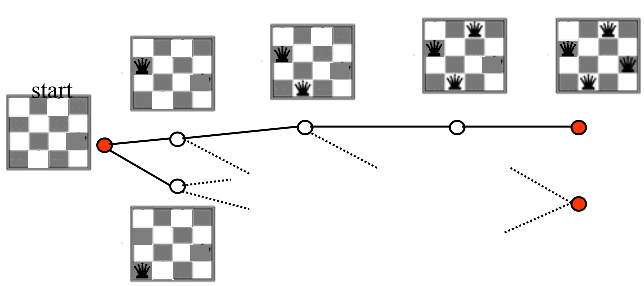
Is there an alternative way to formulate the N-queens problem as a search problem?

- Ideas?

N-queens

Is there an alternative way to formulate the N-queens problem as a search problem?

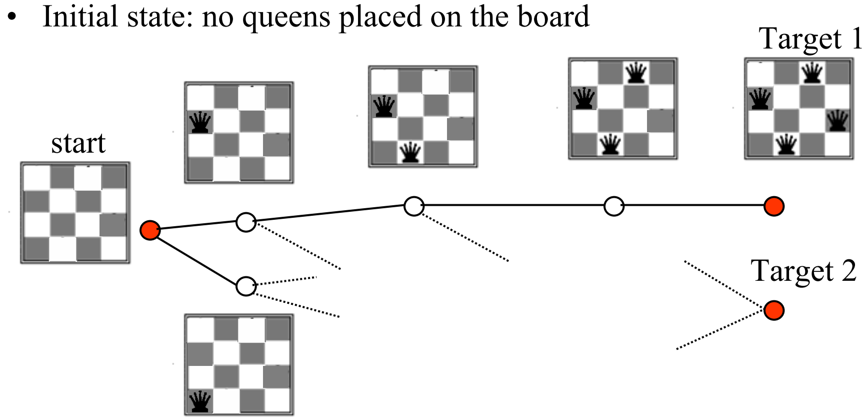
- **Search space:** configurations of 0,1,2, … N queens
- Graph search:
  - States configurations of 0,1,2,…N queens
  - Operators: additions of a queen to the board
  - Initial state: 0 queens on the board



Graph search

A trick: generate a configuration step by step (one queen per step)

- States (nodes) correspond to configurations of 0,1,2,3,4 queens
- Links (operators) correspond to the addition of a queen
- Initial state: no queens placed on the board

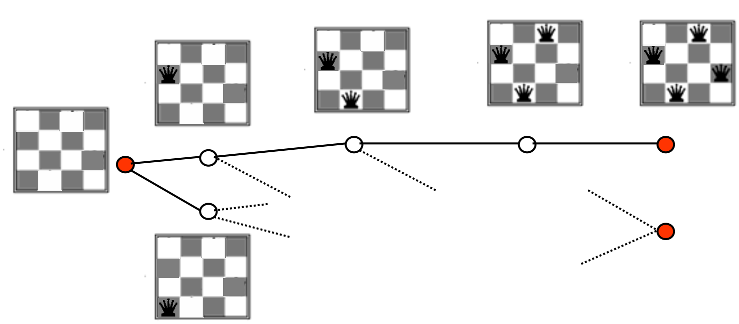


Graph search

N-queens problems

- This is a different graph search problem when compared to Puzzle 8 or Route planning:

  We want to find only the target configuration, not a path



Two types of graph search problems

- **Path search**
  - Find a path between states S and T
  - **Example:** traveler problem, Puzzle 8
  - **Additional goal criterion:** minimum length (cost) path
- **Configuration search (constraint satisfaction search)**
  - Find a state (configuration) satisfying the goal condition
  - **Example:** n-queens problem, design of a device with a predefined functionality
  - **Additional goal criterion:** "soft" preferences for configurations, e.g. minimum cost design

Search problem

Search problems that can be represented or converted into a graph search problems can be defined in terms of:

- **Initial state**
  - State (configuration) we start to search from (e.g. start city, initial game position)
- **Operators**:
  - Transform one state to another (e.g. valid connections between cities, valid moves in Puzzle 8)
- **Goal condition:**
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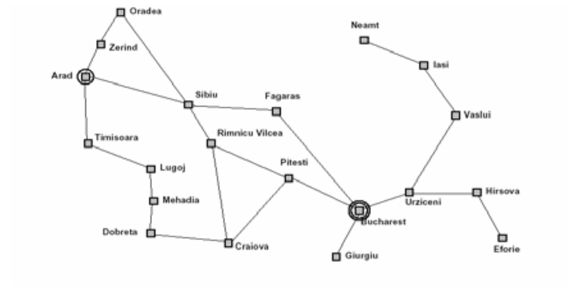
- **Search space (**the set of objects we search for the solution) **:**
  - is now defined indirectly through**:**

    the initial state + operators

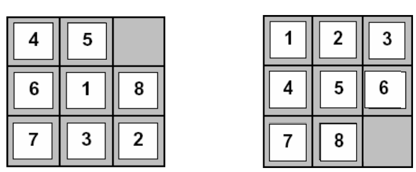
Traveler problem.



Traveler problem formulation:

- **States:** different cities
- **Initial state:** city Arad
- **Operators:** moves to cities in the neighborhood
- **Goal condition: city** Bucharest
- **Type of the problem:** path search
- **Possible solution cost:** path length

Puzzle 8 example

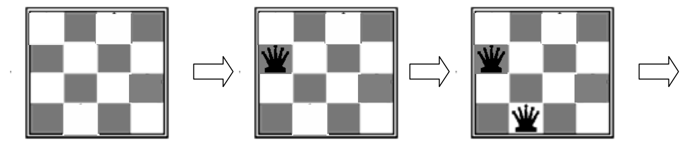


Initial state **Goal state**

Search problem formulation:

- **States:** tile configurations
- **Initial state:** initial configuration
- **Operators:** moves of the empty tile
- **Goal:** reach the winning configuration
- **Type of the problem: path search**
- **Possible solution cost:** a number of moves

N-queens problem



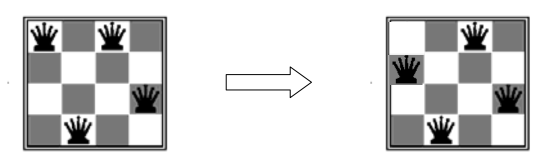
Initial configuration

Problem formulation:

- **States:** configurations of 0 to 4 queens on the board
- **Initial state:** no-queen configuration
- **Operators:** add a queen to the leftmost unoccupied column
- **Goal:** a configuration with 4 non-attacking queens
- **Type of the problem**: configuration search

N-queens problem

Alternative formulation of N-queens problem



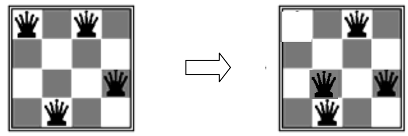
Bad goal configuration Valid goal configuration

Problem formulation:

- **States:** different configurations of 4 queens on the board
- **Initial state:** an arbitrary configuration of 4 queens
- **Operators:** move one queen to a different unoccupied position
- **Goal:** a configuration with non-attacking queens
- **Type of the problem:** configuration search

Comparison of two problem formulations

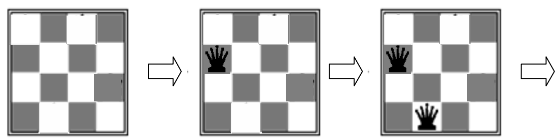
Solution 1:



Operators: switch one of the queens

$\binom{16}{4}$ - all configurations

Solution 2:

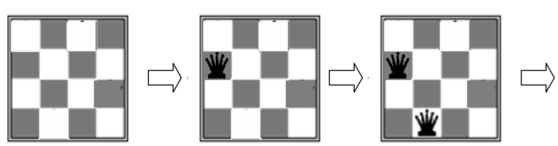


Operators: add a queen to the leftmost unoccupied column

$1 + 4 + 4^2 + 4^3 + 4^4 < 4^5$ - configurations altogether

Even better solution to the N-queens

Solution 2:



Operators: add a queen to the leftmost unoccupied column

$< 4^5$ - configurations altogether

Improved solution with a smaller search space

Operators: add a queen to the leftmost unoccupied column
such that it does not attack already placed queens

$$\leq 1 + 4 + 4*3 + 4*3*2 + 4*3*2*1 = 65$$

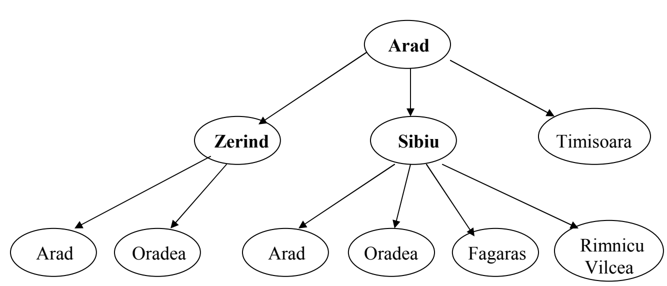
- configurations altogether

Formulating a search problem

- **Search (process)**
  - The process of exploration of the search space
- **The efficiency of the search depends on:**
  - The search space and its size
  - Method used to explore (traverse) the search space
  - Condition to test the satisfaction of the search objective (what it takes to determine I found the desired goal object)
- **Think twice before solving the problem by search:**
  - Choose the **search space** and the **exploration policy**

Search process

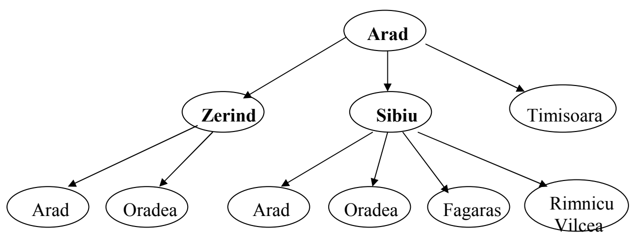
- Exploration of the state space through successive application of operators from the initial state
- A **search tree** = a kind of (search) exploration trace, with nodes corresponding to explored states



Search tree

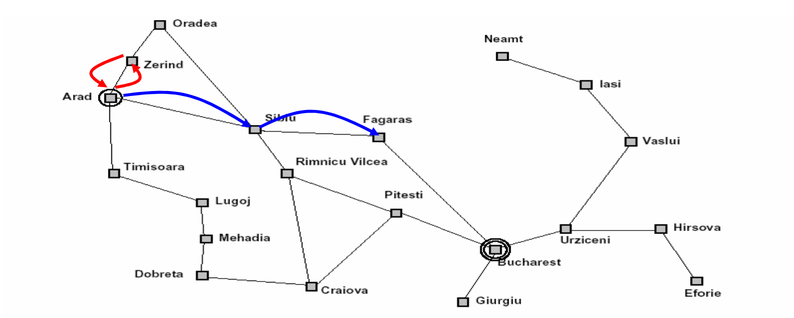
- A **search tree** = a (search) exploration trace
  - **It is different from the graph defining the problem**
  - States can repeat in the search tree

Graph

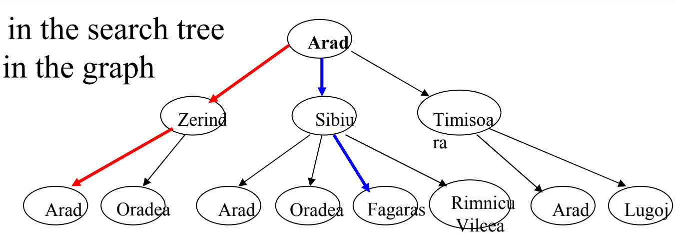


Search tree

Search tree



A branch in the search tree
= path in the graph



General search algorithm

General-search (*problem, strategy*)
initialize the search tree with the initial state of *problem*
loop
  if there are no candidate states to explore **return** failure
  choose a leaf node of the tree to expand next according to *strategy*
  if the node satisfies the goal condition **return** the solution
  expand the node and add all of its successors to the tree
end loop

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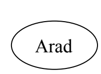

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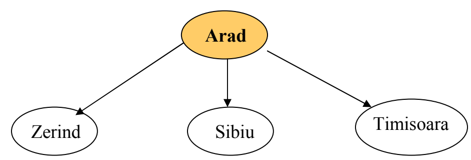

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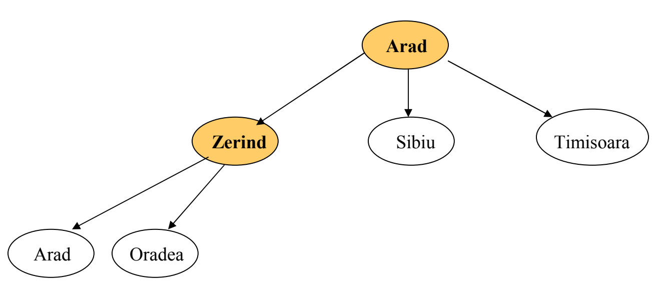

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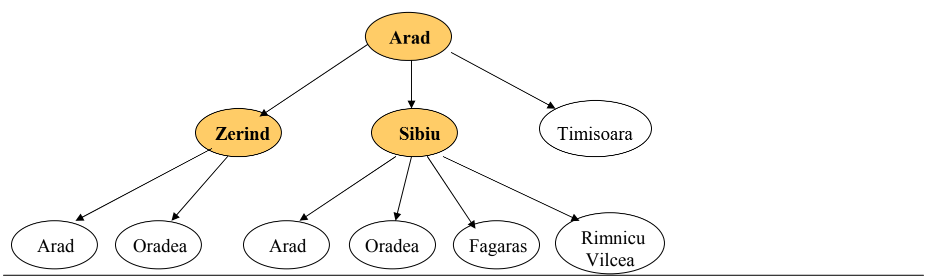

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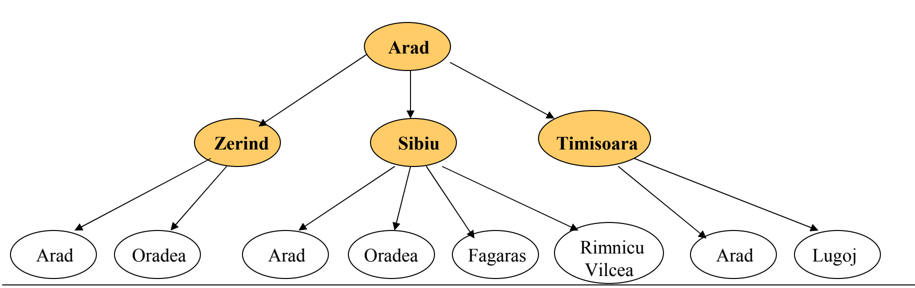

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end loop

- **Search methods differ in how they explore the space, that is how they choose the node to expand next !!!!!**