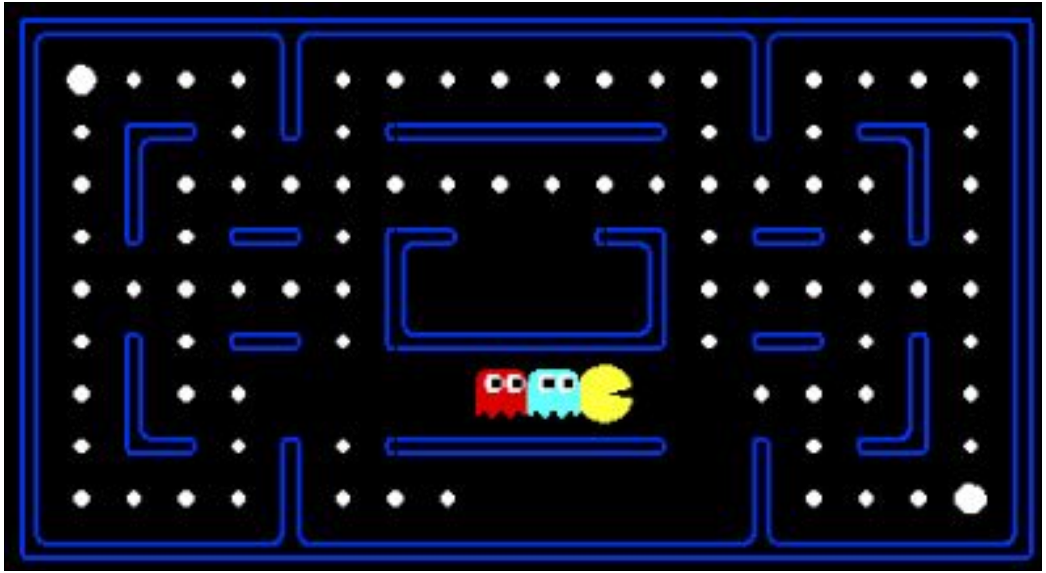
YS02 Artificial Intelligence Project 1: Search

Konstantinos Plas kplas@di.uoa.gr
Sergios-Anestis Kefalidis skefalidis@di.uoa.gr

Logistics

- Project: Homework 1
- Deadline: 29/10/2024
- Questions: On Piazza
- Grading:
  - Sergios-Anestis Kefalidis, skefalidis@di.uoa.gr
  - Giannis Papagiannoulis, giannispapagiannoulis95@gmail.com

The PacMan Project



Search Problems

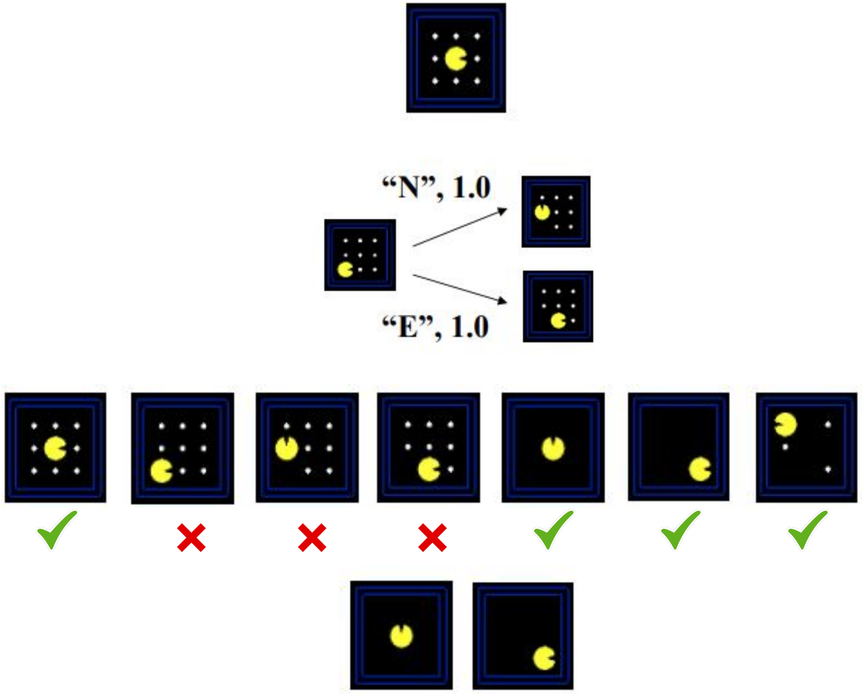
Consist of:

- Start State: the starting state of our problem
- Successor Function: function that takes as input a state and outputs the available actions
- State Space: all the possible states on the problem's world
- Goal State: the state of the problem the agent must reach

The solution is a sequence of actions from the Start State to the Goal State.

Search Problems: Pacman

- Start State
  - Pacman begins from the middle of the grid
- Successor Function
  - Pacman can move vertically or horizontally, but is blocked by walls
- State Space
  - All possible states of our "problem world" starting from the Start State and acting only as the Successor Function allows
- Goal State
  - Pacman has eaten all the food



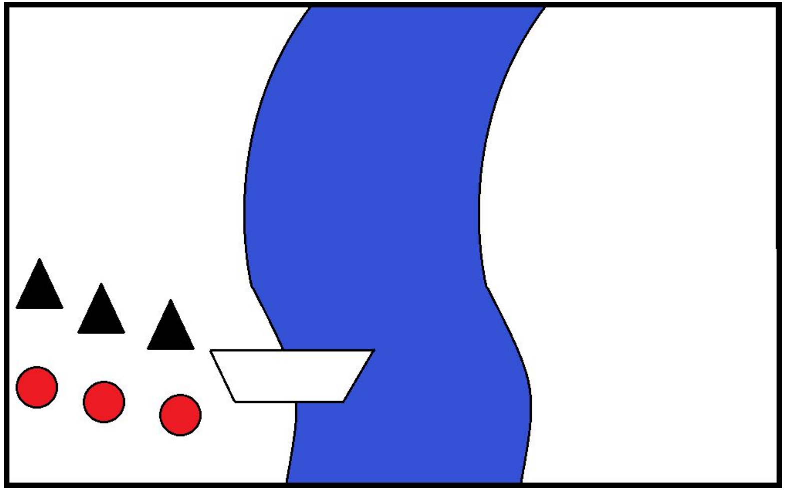
Modeling a Search Problem

- Given a real world problem, how can we formulate it into a search problem?

- We will focus on two examples:
  - Missionaries and Cannibals
  - 8 puzzle problem

Modeling the Missionaries & Cannibals Problem

- **Problem:**
    - On one bank of a river are **3** missionaries and **3** cannibals.
    - There is **1** boat available that can carry at most **2** people and that they would like to use to cross the river.
    - If the cannibals ever outnumber the missionaries on either of the river's banks, the missionaries will get eaten.



Red circles represent cannibals
Black triangles missionaries

Modeling the Missionaries & Cannibals Problem

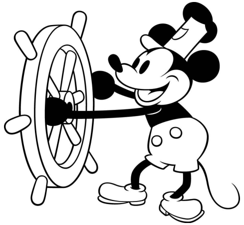
- **Goal:** Move all missionaries and cannibals to the other side of the river
  - Question**:** How can we formulate the given problem into a graph search problem?

- Remember what constitutes a search problem:
  - Start State: where do we start?
  - Successor Function: what actions can we take?
  - State Space: which are all the valid states of our world?
  - Goal State: what do we want to accomplish?

Modeling the Missionaries & Cannibals Problem

- **State:**
  - a tuple of 6 numbers
    - M_L, C_L, B_L the number of missionaries, cannibals and boats on the left side of the river
    - M_R, C_R, B_R the number of missionaries, cannibals and boats on the right side of the river
  - **State =** $(M_L, C_L, B_L, M_R, C_R, B_R)$
- StartState = $(3, 3, 1, 0, 0, 0)$, the boat and all missionaries and cannibals are on the left side of the river.
- GoalState = $(0, 0, 0, 3, 3, 1)$, all missionaries and cannibals crossed the river without any "*accidents*".

Modeling the Missionaries & Cannibals Problem



- **Actions:** move the boat across the river with 1 or 2 people.
  - if the boat is on the left side of the river the possible actions are:
    - *move 1 missionary to the right side* $(M_L\text{-}1, C_L, 0, M_R\text{+}1, C_R, 1)$
    - *move 2 missionaries to the right side* $(M_L\text{-}2, C_L, 0, M_R\text{+}2, C_R, 1)$
    - *move 1 cannibal to the right side* $(M_L, C_L\text{-}1, 0, M_R r, C_R\text{+}1, 1)$
    - *move 2 cannibals to the right side* $(M_L, C_L\text{-}2, 0, M_R, C_R\text{+}2, 1)$
    - *move 1 missionary and 1 cannibal to the right side* ***(Ml-1, Cl-1, 0, Mr+1, Cr+1, 1)***
  - likewise for the right side…
- Question: Are all these actions legal?
  - hint: if they are all legal, what do we need the Successor Function for?
  - reminder: the Successor Function takes as input a state and outputs the available actions.

Modeling the Missionaries & Cannibals Problem

- Question: Are all theoretically possible actions always legal?
  - **Answer:** not always we must check whether a state has more cannibals than missionaries in either side of the river.
  - When generating a successor the condition $(M_L >= C_L \text{ AND } M_R >= C_R)$ must be true, for it to be considered (responsibility of the Successor Function).
- For example if we consider the Start State *(3, 3, 1, 0, 0, 0)* and any possible action we get the following states:

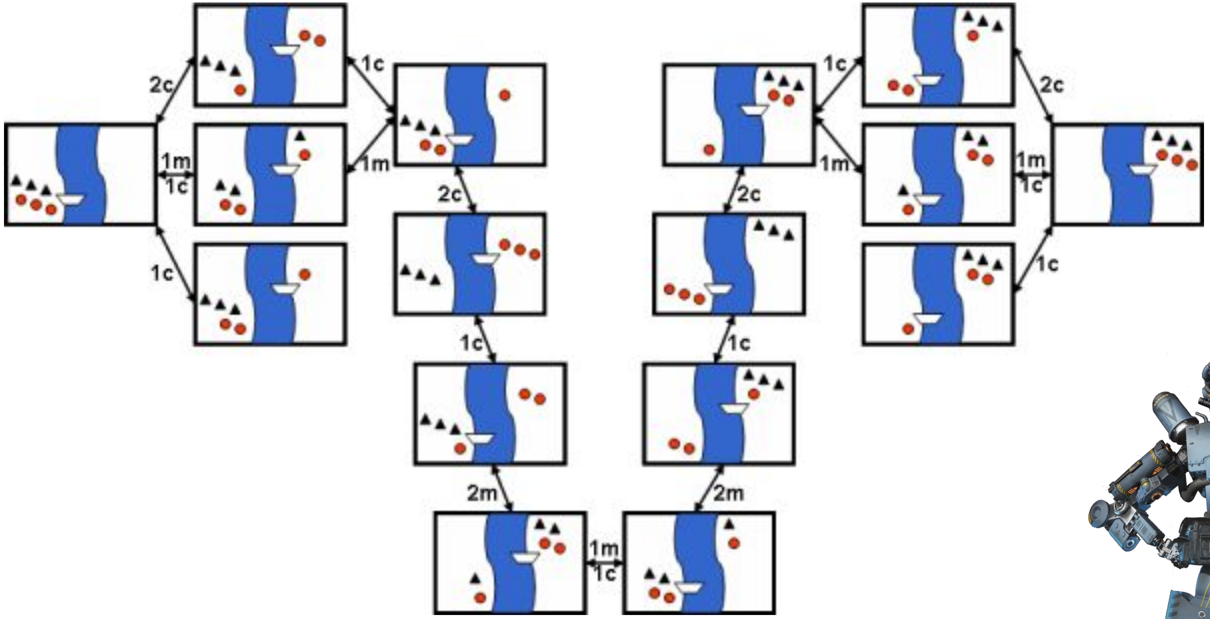
{(2, 3, 0, 1, 0, 1), (2, 2, 0, 1, 1, 1), (3, 2, 0, 0, 1, 1), (1,3,0,2,0,1), (3,1,0,0,2,1)}

- The first and fourth generated states have more cannibals than missionaries on the left side of the river.
- These states are generated from illegal actions and are not considered.
- Thus the actual successors generated by the Successor Function are:

{ (2, 2, 0, 1, 1, 1), (3, 2, 0, 0, 1, 1), (3,1,0,0,2,1) }

Modeling the Missionaries & Cannibals Problem

The search space of missionaries and cannibals problem:



Modeling the 8 puzzle problem

1	3	2
5		6
8	7	4

Start State I

1	2	3
4	5	6
7	8	

Goal State G

Modeling the 8 puzzle problem

- **State Space (*S*):** All possible solvable combinations for the puzzle → 9!/2 = 181, 440 states

- **State = (*(x,y)* , *P*)** where:
    - $P \in S$, ***P*** is the current image of the puzzle
        - $P = \{ p_{11}, p_{12}, p_{13}, p_{21}, \ldots, p_{33} \}$, where p_{i}□ is the value of the tile in (i,j)
    - *(x,y)*, is the coordinates of the empty space in ***P***

- StartState = (*(2,2)* , *I*)

- GoalState = (*(3,3)*, *G*)

Modeling the 8 puzzle problem

- **Actions =** swap the empty space with one of its neighbors (up, down, left, right)

- Successor Function : For a given state $s_i = ((x_i , y_i), P_i)$ outputs $succ(s_i) = \{ ((x_i - 1 , y_i), P_1), ((x_i +1 , y_i), P_2), ((x_i , y_i - 1), P_3), ((x_i , y_i + 1), P_4) \}$, where $(x_i - 1 , y_i)$ indicates that the empty space was swapped with the tile above it, $(x_i +1 , y_i)$ with the tile below it etc. P_1, is the puzzle image produced if the empty tile was swapped with the tile above it etc.

- **isGoalState :** function that for a given state s_i outputs:

$$isGoalState(s_i) = isGoalState((x_i, y_i), P_i) = \begin{cases} 1, & \text{if } P_i = G \\ 0, & \text{otherwise} \end{cases}$$

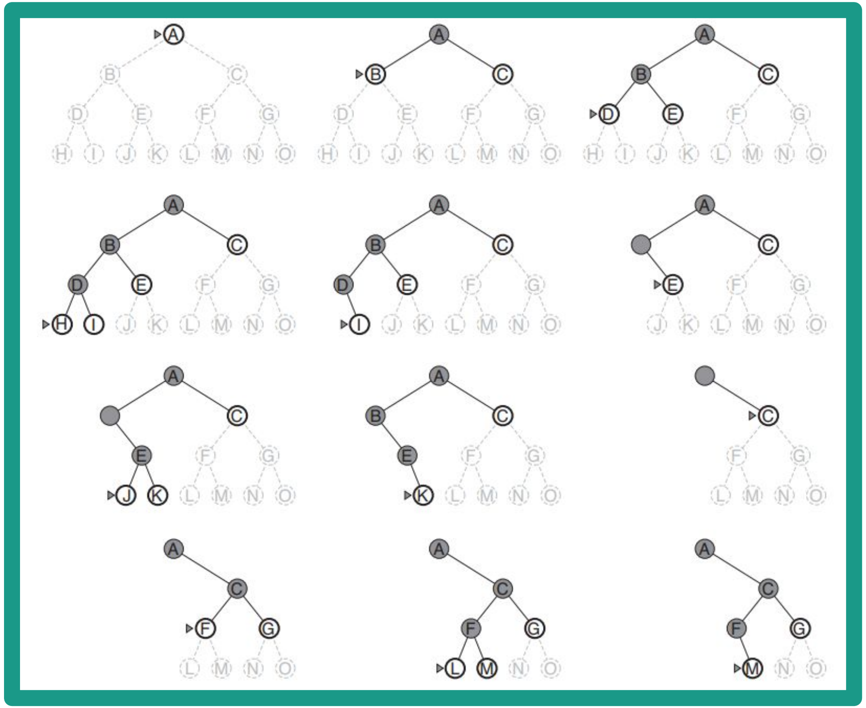
Graph Search Algorithms

- After we formulate a real world problem into a search problem we can utilize graph search algorithms to solve it:
    - DFS
    - BFS
    - UCS
    - A*


dreamstime.

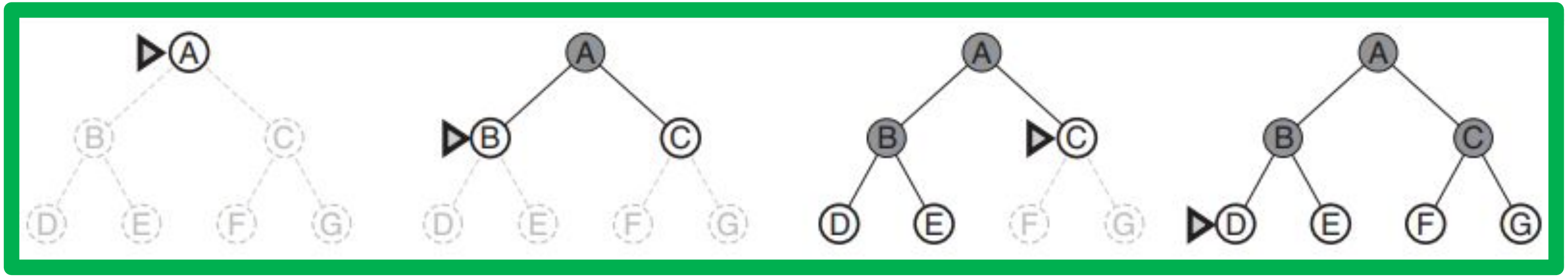
Depth First Search (DFS)

- Strategy: expand nodes depth-wise until a node has no successors
- Implementation: frontier is a stack



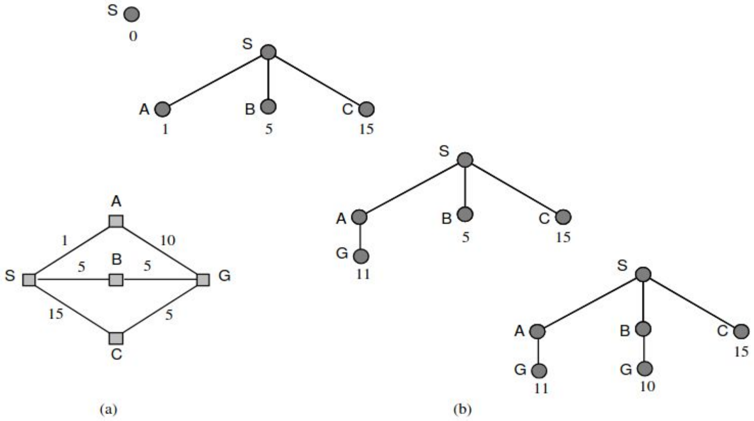
Breadth First Search (BFS)

- Strategy: expand nodes layerwise
- Implementation: frontier is a queue



Uniform Cost Search (UCS)

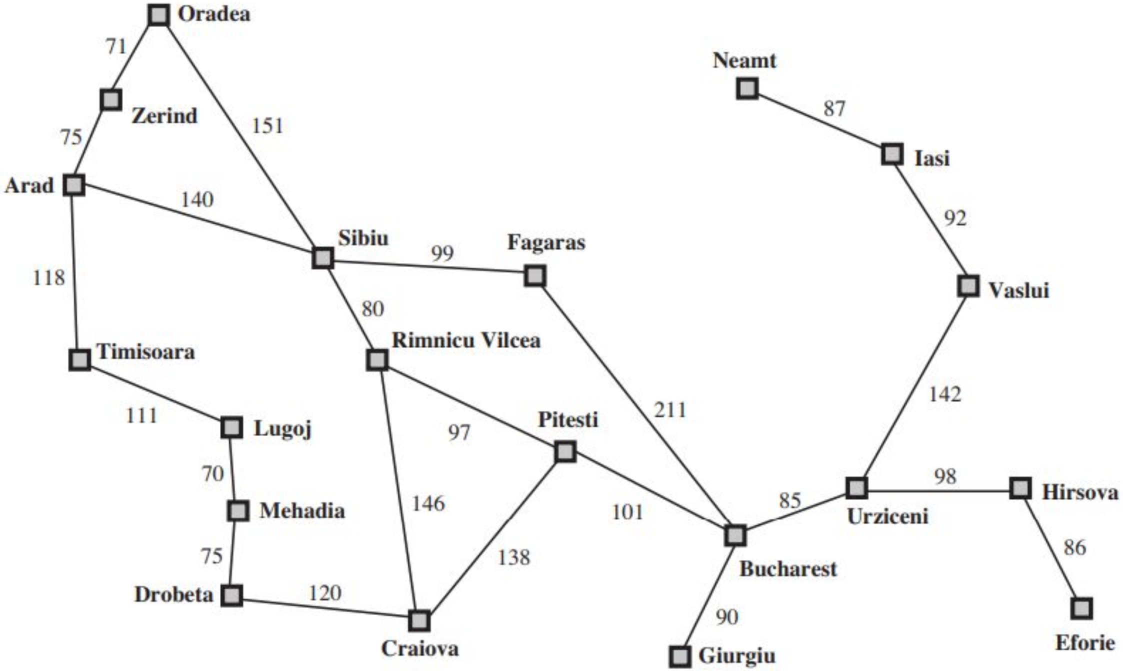
- UCS : sorts nodes according to cost g(n)
    - Like BFS (*min-depth*) but for Graphs with different path costs (*min-cost*)

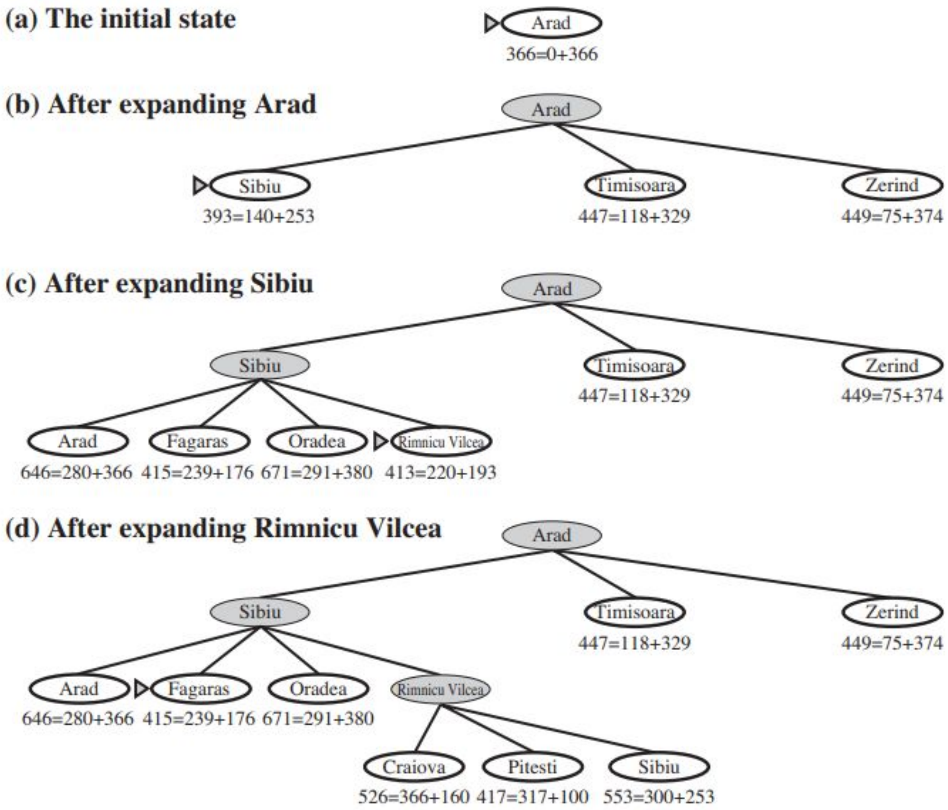


A* (A star)

- UCS : sorts nodes according to cost g(n)
- A* : expansion of UCS, nodes are sorted based on the sum g(n) + h(n)
  - g(n): cost to reach a node n from the root node
  - h(n): heuristic function to approximate the solution

A* : Execution Example





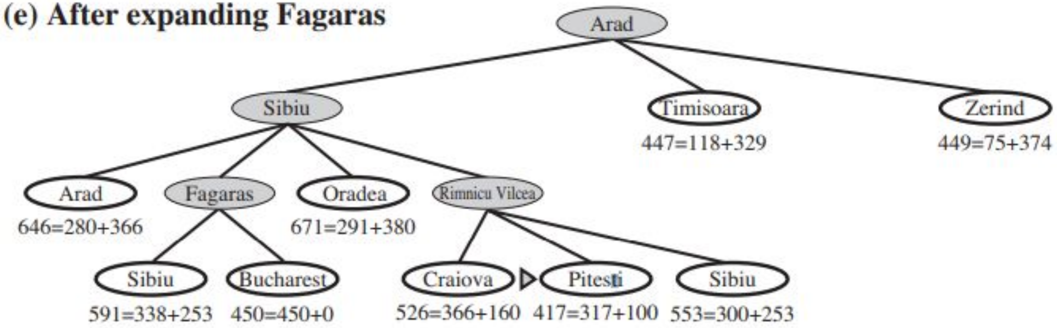
(a) The initial state

(b) After expanding Arad

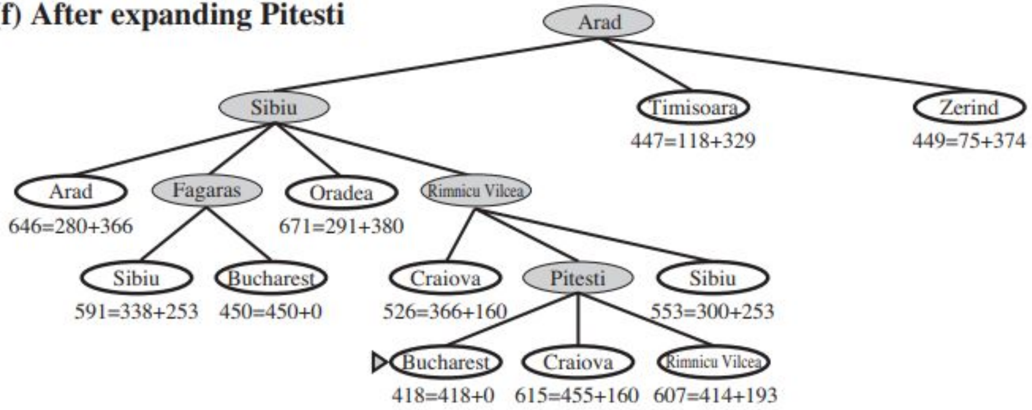
(c) After expanding Sibiu

(d) After expanding Rimnicu Vilcea

(e) After expanding Fagaras



(f) After expanding Pitesti



Heuristic Function

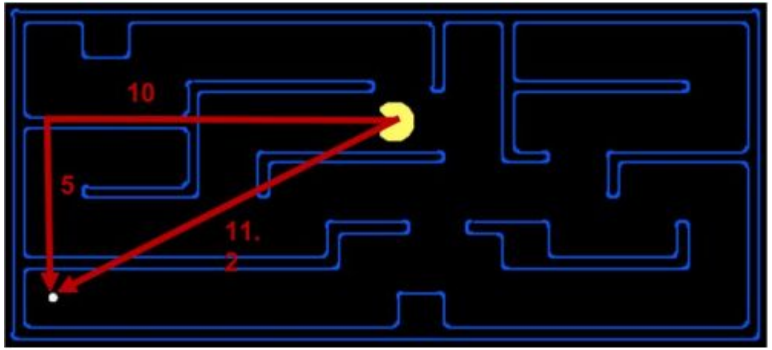
- For a given state, estimates the cost from that state to the Goal State
- **Trivial:** Always returns 0 (same as UCS) or always returns the true cost
- **Admissible:** It does not overestimate the cost to reach the goal state
    - 0 ≤ heuristic_cost(s) ≤ true_cost(s)
- **Consistent:** The estimation is less than or equal to the estimation of a neighboring state plus the cost to reach that state
    - $h(s) \leq c(s, a, s') + h(s')$
    - intuition: That is, you don't think that it costs 5 from B to the goal, 2 from A to B, and yet 20 from A to the goal.
- All consistent heuristics are admissible. The opposite is necessarily not true.
- Consistent heuristics make our algorithm faster, because we don’t need to revisit nodes (in Graph Search).

Heuristic Function : How to choose a heuristic

- A heuristic is formulated based on the problem we try to solve
- Non consistent functions may prevent the search algorithms from exploring “good” paths.
- We can easily formulate a consistent heuristic if we consider a simpler problem (relaxation).

Heuristic Function : Pacman

- **Euclidean Distance**
  - Euclidean distance from the goal
  - For the given example ≈ 11.2
- **Manhattan Distance**
  - Manhattan distance from the goal
  - For the given example = 15
- The actual distance is greater because of obstacles
- By simplifying the problem it is easier to find “good” heuristics



Heuristic Function : 8 puzzle

- **Hamming Distance**
  - Tiles out of place
  - For the given example = 7
- **Manhattan Distance**
  - Manhattan distance of each tile for the goal position
  - For the given example = 10
    - h = 0+1+1+3+1+0+1+1+2

1	3	2
5		6
8	7	4

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7	8	

Project 1

- Important files:
  - pacman.py ⟶ Pacman main file (GameState classes)
  - game.py ⟶ The logic behind Pacman environment (Agent,Direction classes)
  - util.py ⟶ Useful structure classes (Stack, Queue, PriorityQueue classes)
- Files to edit:
  - search.py ⟶ Here you will implement the search algorithms (Q1-Q4)
  - searchAgents.py ⟶ Search based agents (Q5-Q8)

Project 1 : Questions 1-4

```
Algorithm: GRAPH_SEARCH:
  frontier = {startNode}
  expanded = {}
  while frontier is not empty:
      node = frontier.pop()
      if isGoal(node):
          return path_to_node
      if node not in expanded:
          expanded.add(node)
          for each child of node's children:
              frontier.push(child)
  return failure
```

- Generic algorithm:
    - DFS (Q1)
    - BFS (Q2)
    - UCS (Q3)
    - A* (Q4) (Pseudocode)
- Different frontiers for each algorithm:
    - Stack (DFS)
    - Queue (BFS)
    - PriorityQueue (UCS, A*)
- Expanded should be a **Set**
- **Keep in mind**: The autograder expects a specific number of nodes to be expanded.
    - Controlled by problem.getSuccessors, don't forget print statements

Project 1 : Questions 1-4 - DFS

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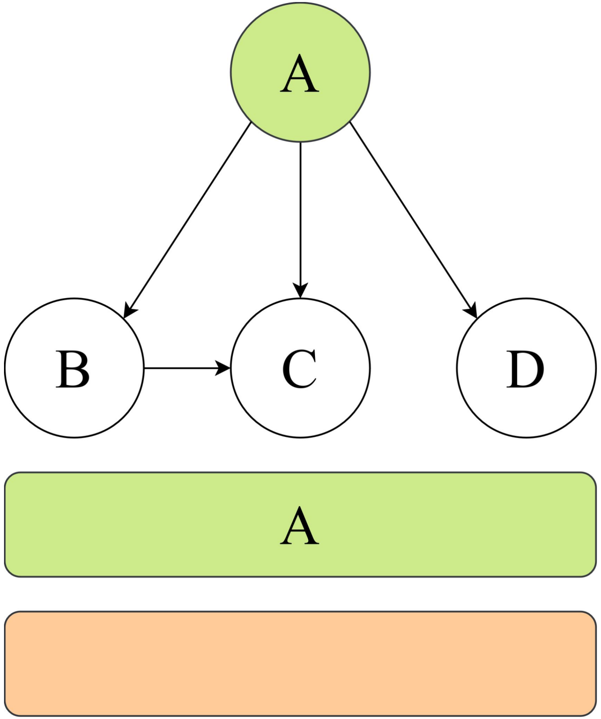

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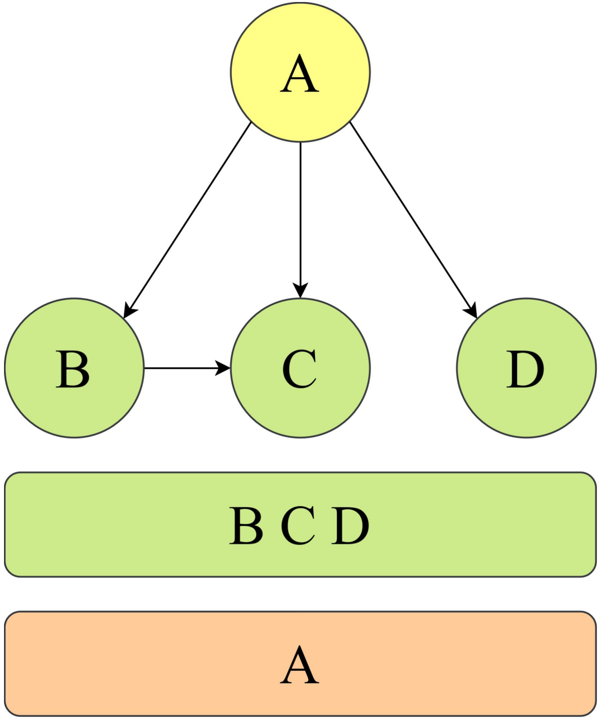

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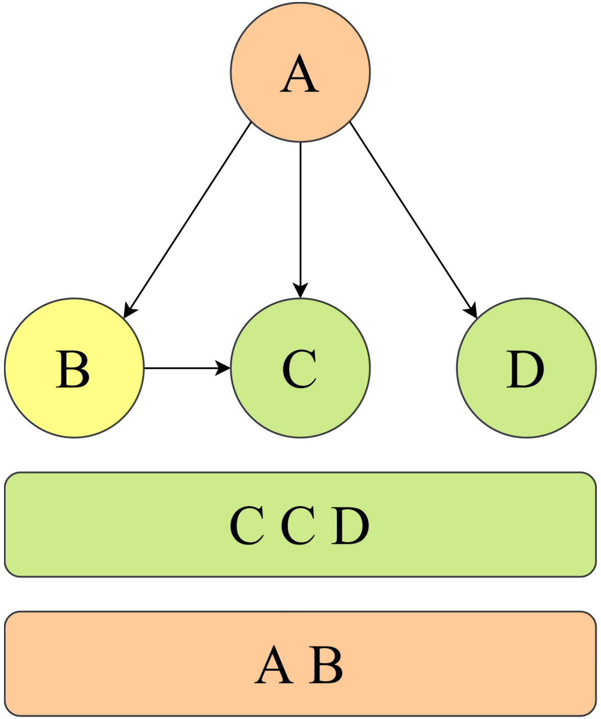

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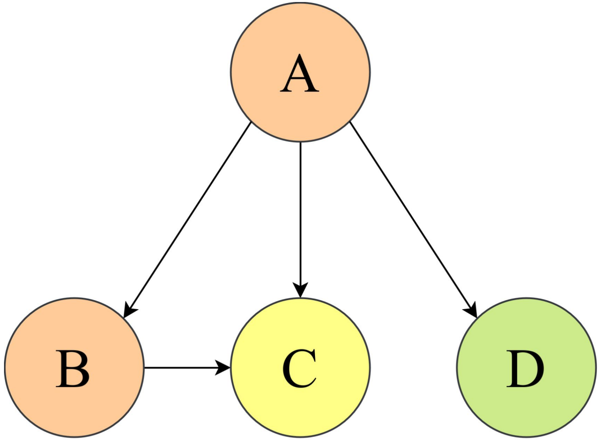

C D

A B C

Project 1 : Questions 1-4 - DFS

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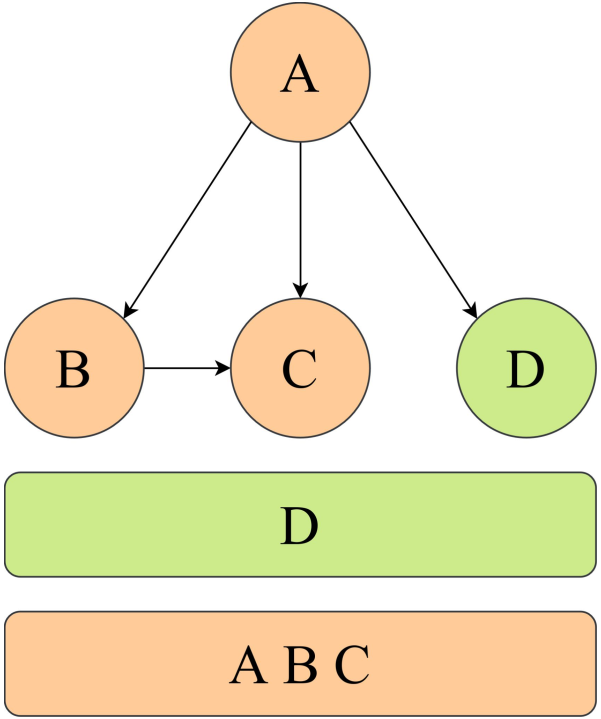

Project 1 : Questions 1-4 - DFS

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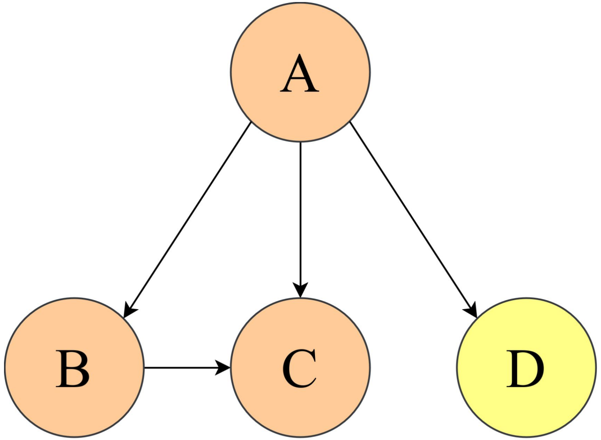


A B C D

Project 1: Question 5

- **Goal:** Define an abstract representation of the Corners Problem
  - How can we model this search problem?
  - Create a representation for start and goal state
  - Design the successor function [expand]
    - Return the next possible states, the actions required to reach them and their cost
    - Consider also the possibility that the next state is the goal state

Project 1: Question 6

- **Goal:** Write a non-trivial, non-decreasing **admissible** heuristic

➢ How to design a heuristic for the corners problem ?
  - Consider an intermediate state of the problem
  - Get the unvisited nodes
  - Think of ways to compute the distance to the nodes
  - Visit the corner that is closer

➢ Note: if you encounter problems, make sure that your solution to Question 5 does not have any subtle problems

Project 1: Question 7

- **Goal:** Write a non-trivial, non-decreasing **admissible** heuristic to eat all the food in as few steps as possible. In other words, you are asked to write a heuristic that estimates as closely as possible the number of steps that Pacman must take to eat all the food.

➢ You can get the full grade in around 10 lines of code.
➢ **Note:** The use of mazeDistance as a heuristic is forbidden! This is a trivial heuristic. You can use it as part of your solution, but not as your solution.

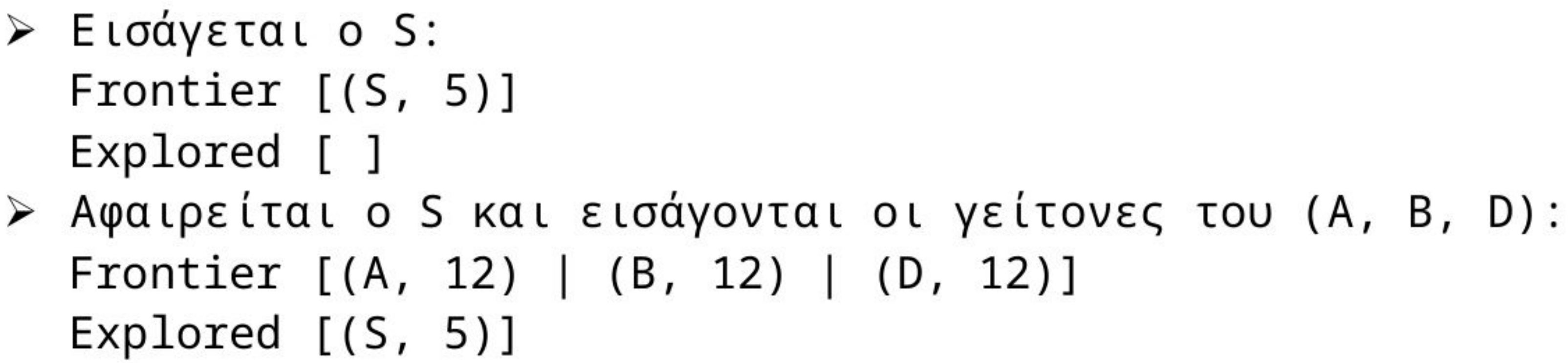
➢ Key items to use in foodHeuristic:
  - **foodGrid.asList:** Get a list of food coordinates
  - **problem.heuristicInfo:** A dictionary provided to store the information required to be reused in other calls of the heuristic

Project 1: Question 8

- **Goal:** Write an agent that always greedily eats the closest dot

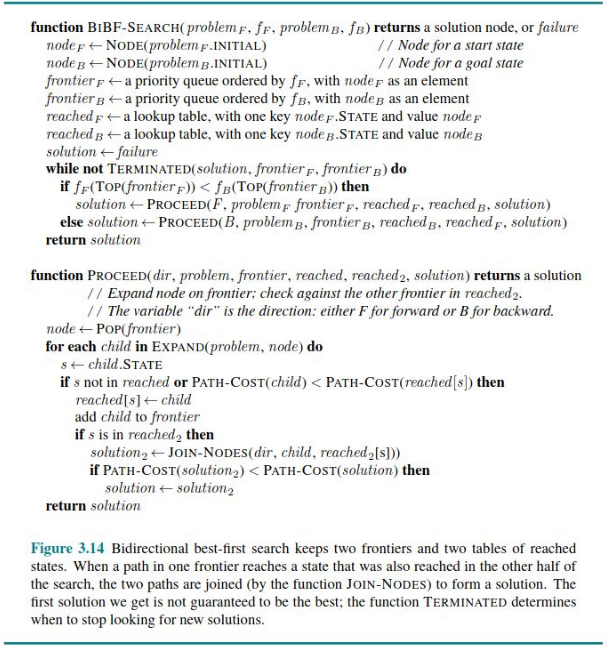
➢ Functions you will need to implement:
  - **ClosestDotSearchAgent.findPathToClosestDot :** Returns a path to the closest dot starting from gameState (Hint: You've already implemented that)
  - **AnyFoodSearchProblem.isGoalState:** Returns whether we have reached the goal state

Exercise 3: Inspiration



- Εισάγεται ο S:
  Frontier [(S, 5)]
  Explored [ ]
- Αφαιρείται ο S και εισάγονται οι γείτονες του (A, B, D):
  Frontier [(A, 12) | (B, 12) | (D, 12)]
  Explored [(S, 5)]

Exercise 4: Bidirectional Best-First Search



```
function BIBF-SEARCH($problem_F$, $f_F$, $problem_B$, $f_B$) returns a solution node, or failure
  $node_F \leftarrow$ NODE($problem_F$.INITIAL)                  // Node for a start state
  $node_B \leftarrow$ NODE($problem_B$.INITIAL)                  // Node for a goal state
  $frontier_F \leftarrow$ a priority queue ordered by $f_F$, with $node_F$ as an element
  $frontier_B \leftarrow$ a priority queue ordered by $f_B$, with $node_B$ as an element
  $reached_F \leftarrow$ a lookup table, with one key $node_F$.STATE and value $node_F$
  $reached_B \leftarrow$ a lookup table, with one key $node_B$.STATE and value $node_B$
  $solution \leftarrow failure$
  while not TERMINATED($solution$, $frontier_F$, $frontier_B$) do
    if $f_F$(TOP($frontier_F$)) $<$ $f_B$(TOP($frontier_B$)) then
      $solution \leftarrow$ PROCEED($F$, $problem_F$ $frontier_F$, $reached_F$, $reached_B$, $solution$)
    else $solution \leftarrow$ PROCEED($B$, $problem_B$, $frontier_B$, $reached_B$, $reached_F$, $solution$)
  return $solution$

function PROCEED($dir$, $problem$, $frontier$, $reached$, $reached_2$, $solution$) returns a solution
        // Expand node on frontier; check against the other frontier in $reached_2$.
        // The variable "dir" is the direction: either F for forward or B for backward.
  $node \leftarrow$ POP($frontier$)
  for each $child$ in EXPAND($problem$, $node$) do
    $s \leftarrow child$.STATE
    if $s$ not in $reached$ or PATH-COST($child$) $<$ PATH-COST($reached[s]$) then
      $reached[s] \leftarrow child$
      add $child$ to $frontier$
      if $s$ is in $reached_2$ then
        $solution_2 \leftarrow$ JOIN-NODES($dir$, $child$, $reached_2$[s]))
        if PATH-COST($solution_2$) $<$ PATH-COST($solution$) then
          $solution \leftarrow solution_2$
  return $solution$
```

Figure 3.14 Bidirectional best-first search keeps two frontiers and two tables of reached states. When a path in one frontier reaches a state that was also reached in the other half of the search, the two paths are joined (by the function JOIN-NODES) to form a solution. The first solution we get is not guaranteed to be the best; the function TERMINATED determines when to stop looking for new solutions.

Taken from: https://aima.cs.berkeley.edu/figures.pdf