State Space Search Algorithms

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8.11.2018.

Problem definition

- a set of states (state space)
- initial state
- transitions between states
- goal state test

Problem definition

```
class Problem:
  # Should return a State object
  def getInitialState(self):
    pass

  # Should check if given
  # state is goal state
  def isGoalState(self, state):
    pass

  # Should return a list
  # of triplets (state, action, cost)
  def getSuccessors(self, state):
    pass
```

Figure 1: 8-Puzzle initial state

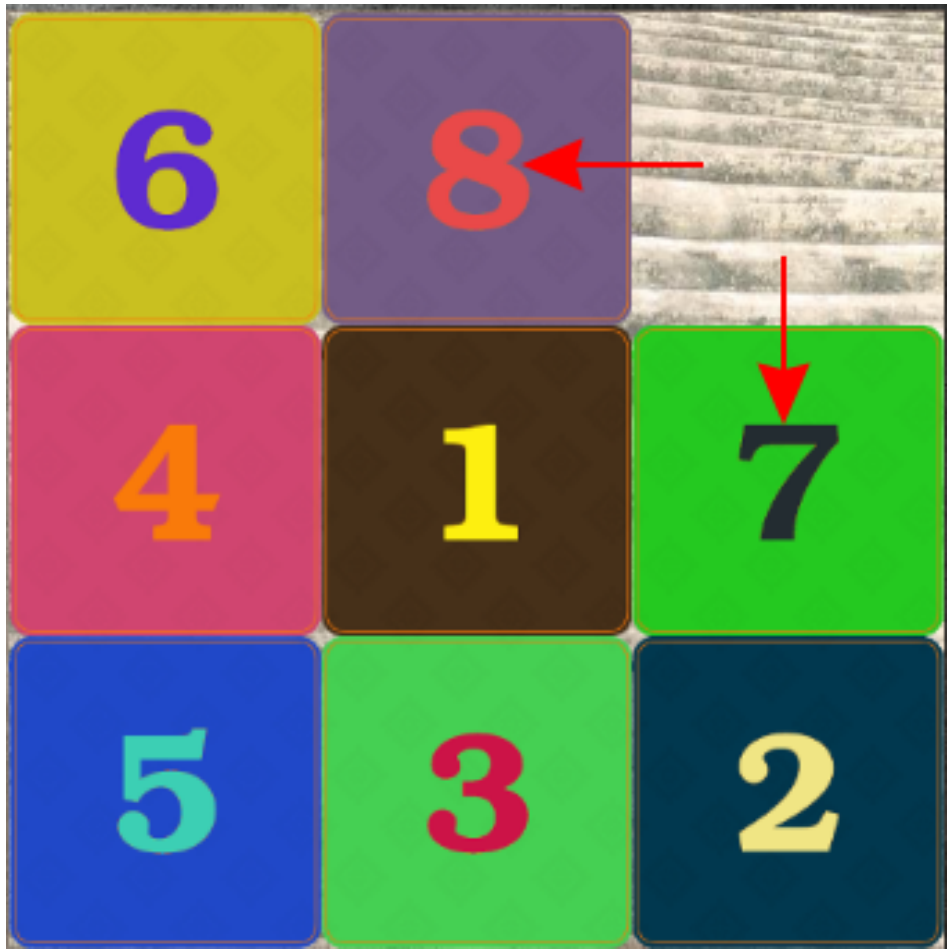


Figure 2: 8-Puzzle possible actions

MoveDown 1

MoveLeft 1

Figure 3: 8-Puzzle list of successor triplets

Figure 4: 8-Puzzle goal state

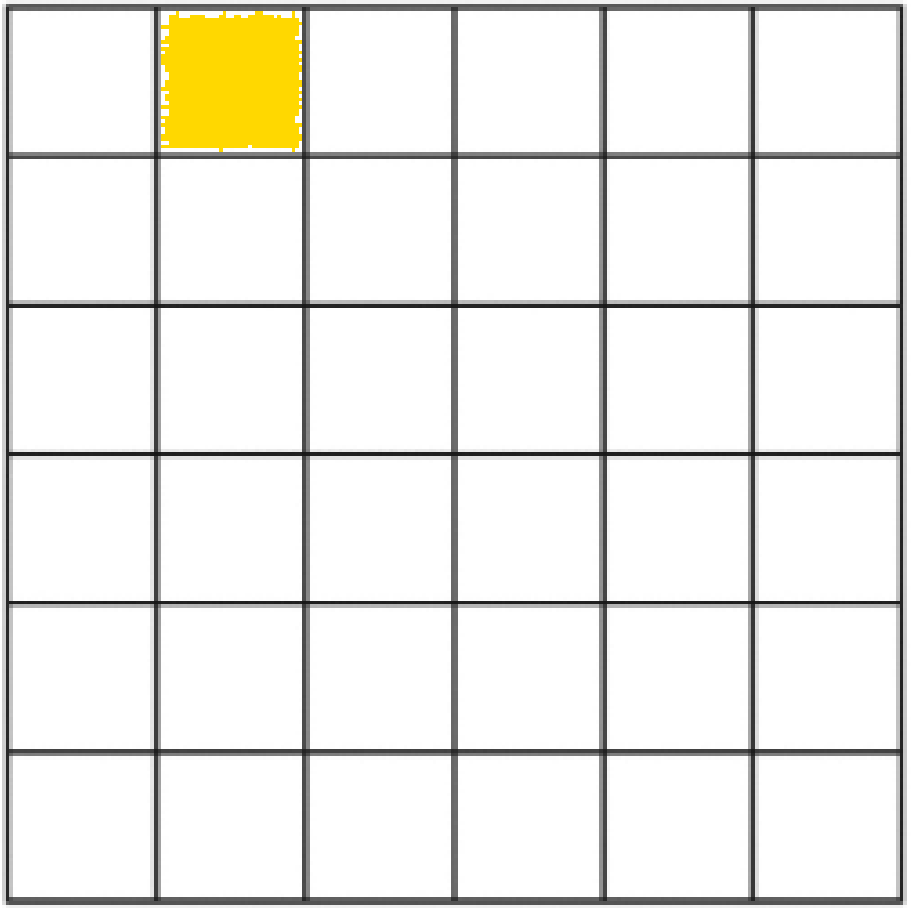


Figure 5: Pathfinding initial state

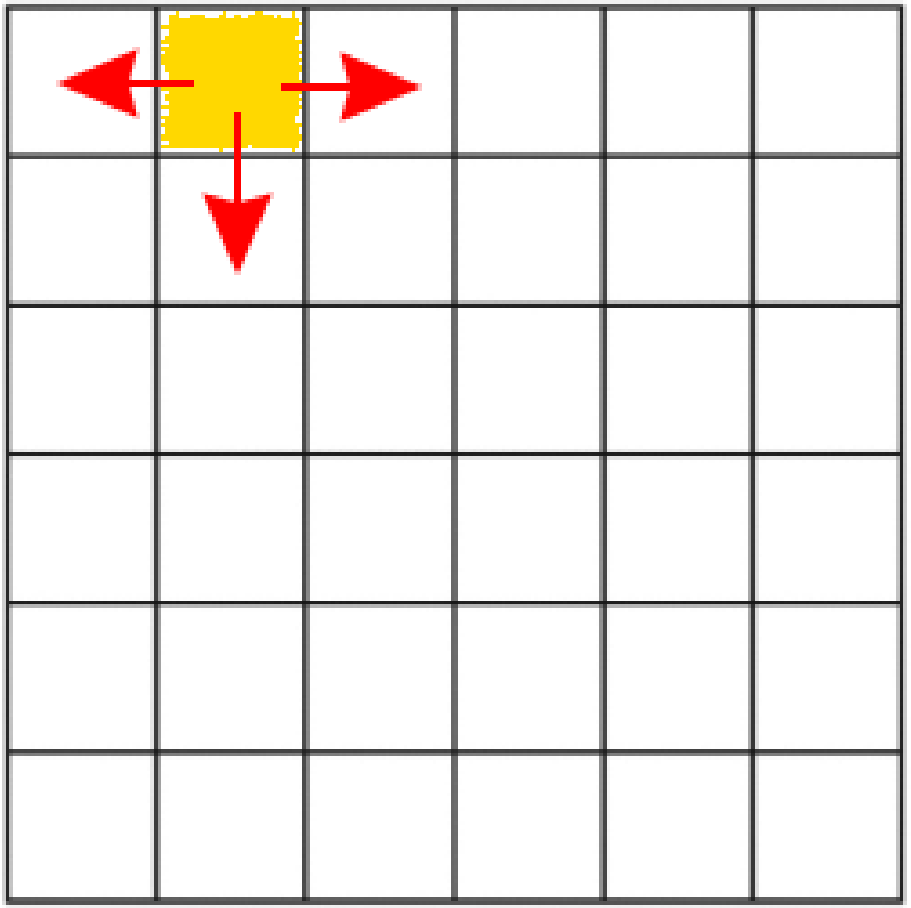


Figure 6: Pathfinding possible actions

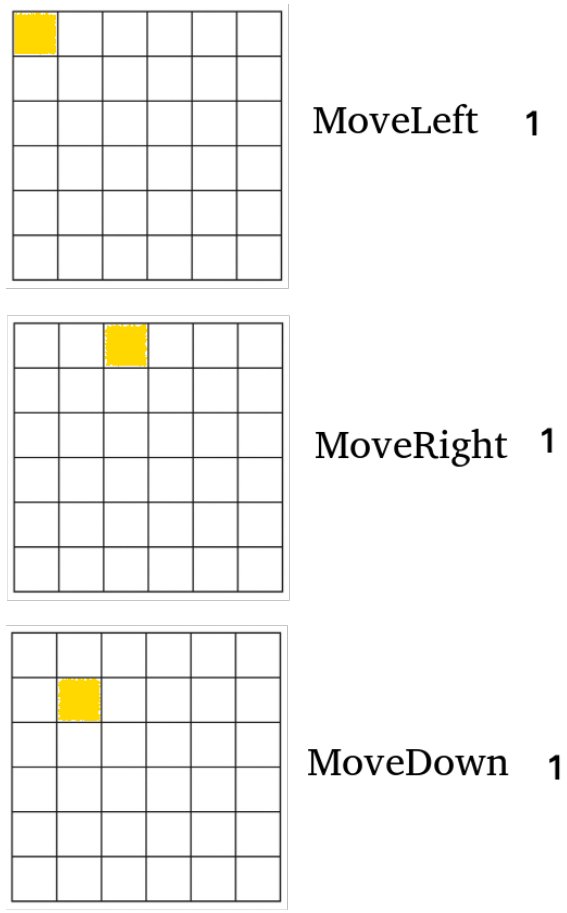


Figure 7: Pathfinding list of successor triplets

State space graph

State space graph

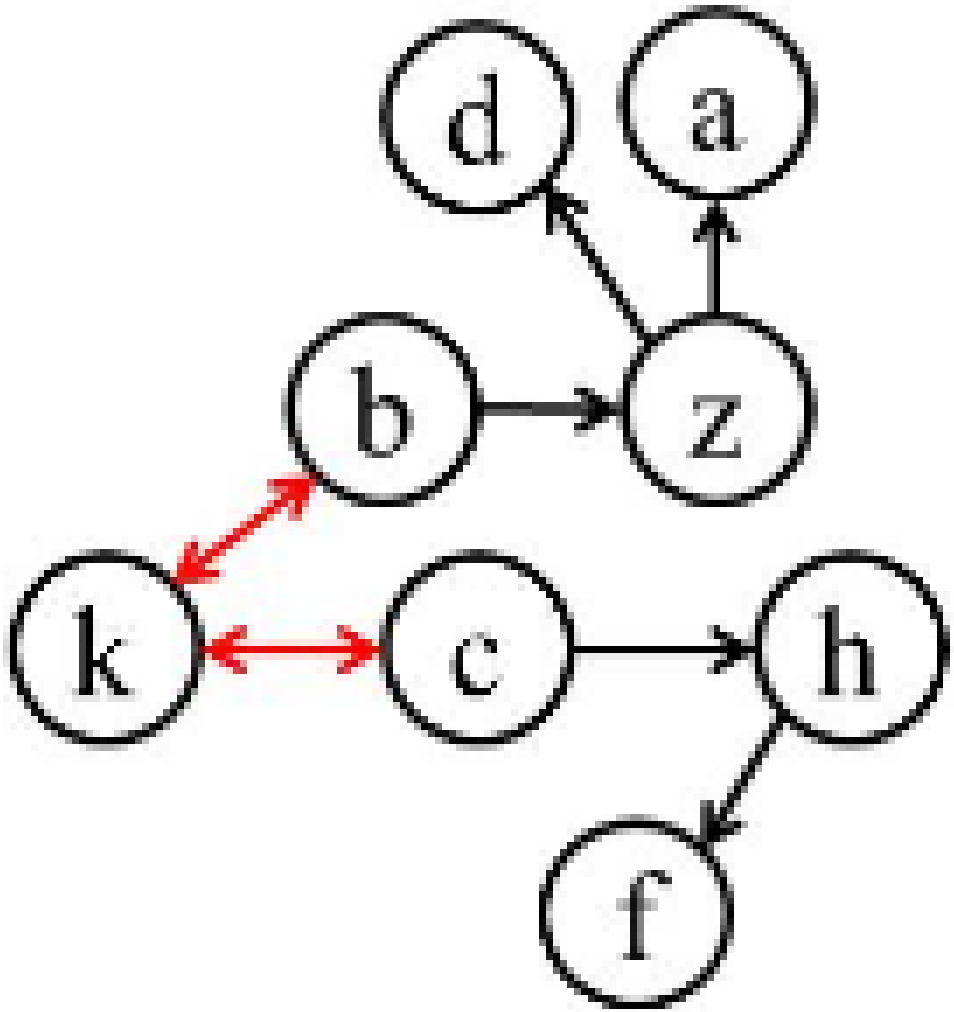


Figure 8: State space graph

Search tree

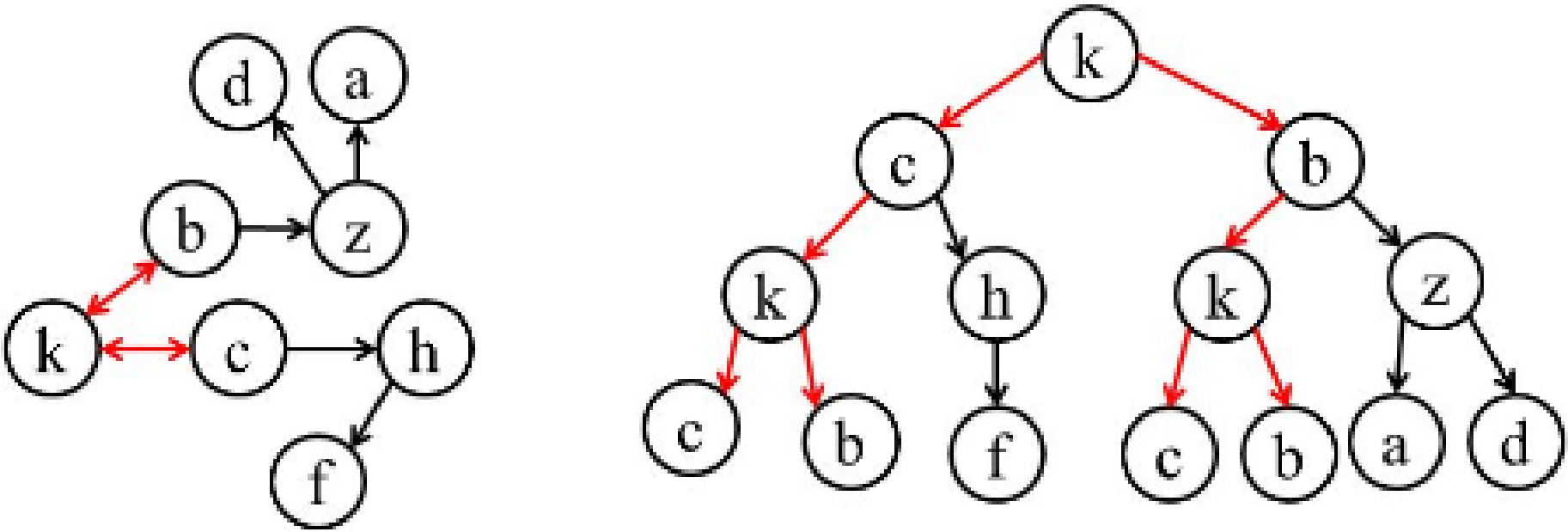


Figure 9: State space vs search tree

Nodes

- Open nodes - known but unexplored
- Closed nodes - explored i.e. checked against goal state and their successors were queried

General algorithm pseudocode

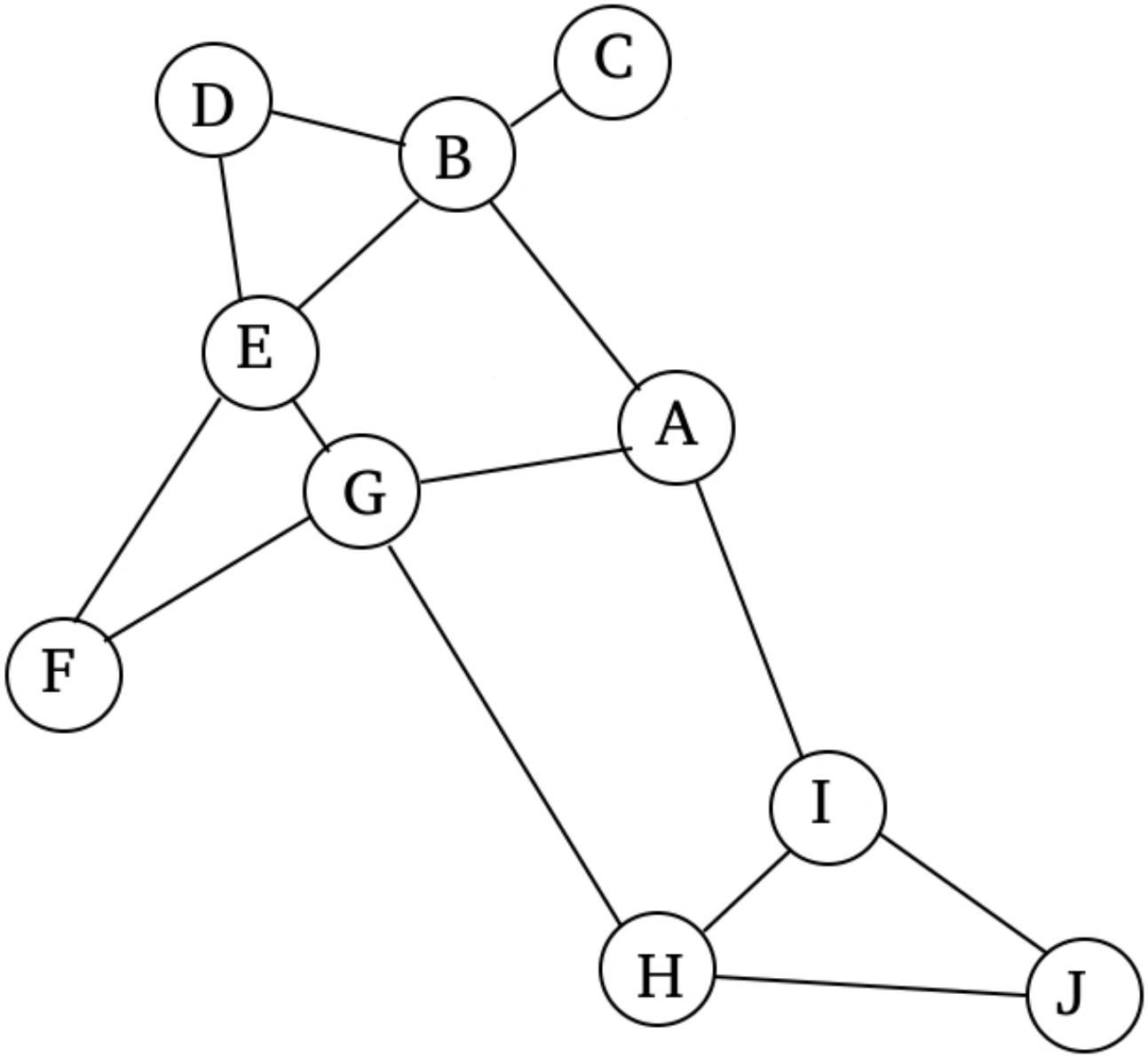
```
closedNodes = {}
openNodes = {}

openNodes.insert(getInitialState())
while openNodes not empty
  node = openNodes.get()
  if isGoalState(node)
    return node

  if node in closedNodes
    continue

  for childNode in getSuccessors(node)
    if childNode not in closedNodes
      openNodes.insert(childNode)
  closedNodes.insert(node)
```

Working example



Blind algorithms

- no additional information about the problem
- needs to figure everything out on it's own

Breadth First Search (BFS)

```
closedNodes = {}

# First In First Out
openNode = Queue()

openNodes.insert(getInitialState())
while openNodes not empty
  node = openNodes.get()
  if isGoalState(node)
    return node
  if node in closedNodes
    continue
  for childNode in getSuccessors(node)
    if childNode not in closedNodes
      openNodes.insert(childNode)
  closedNodes.insert(node)
```

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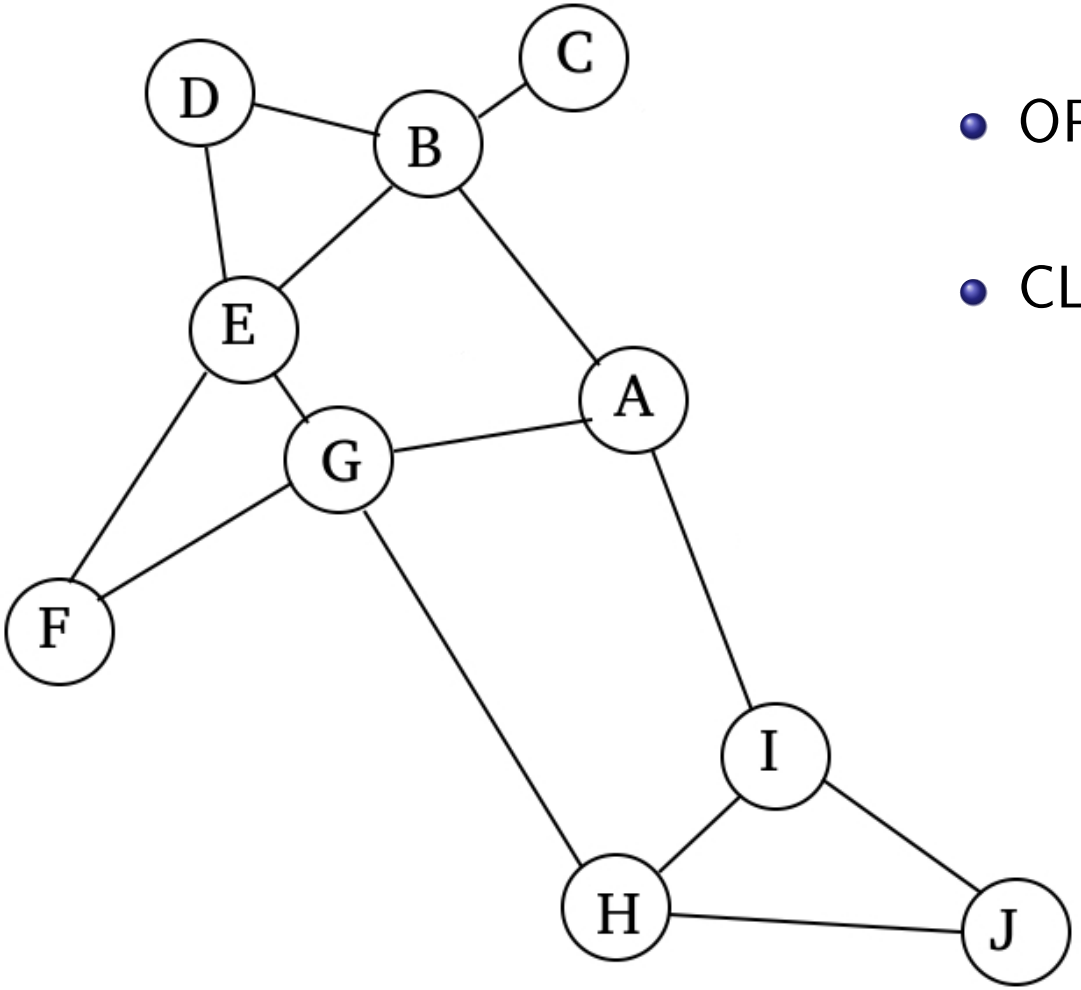
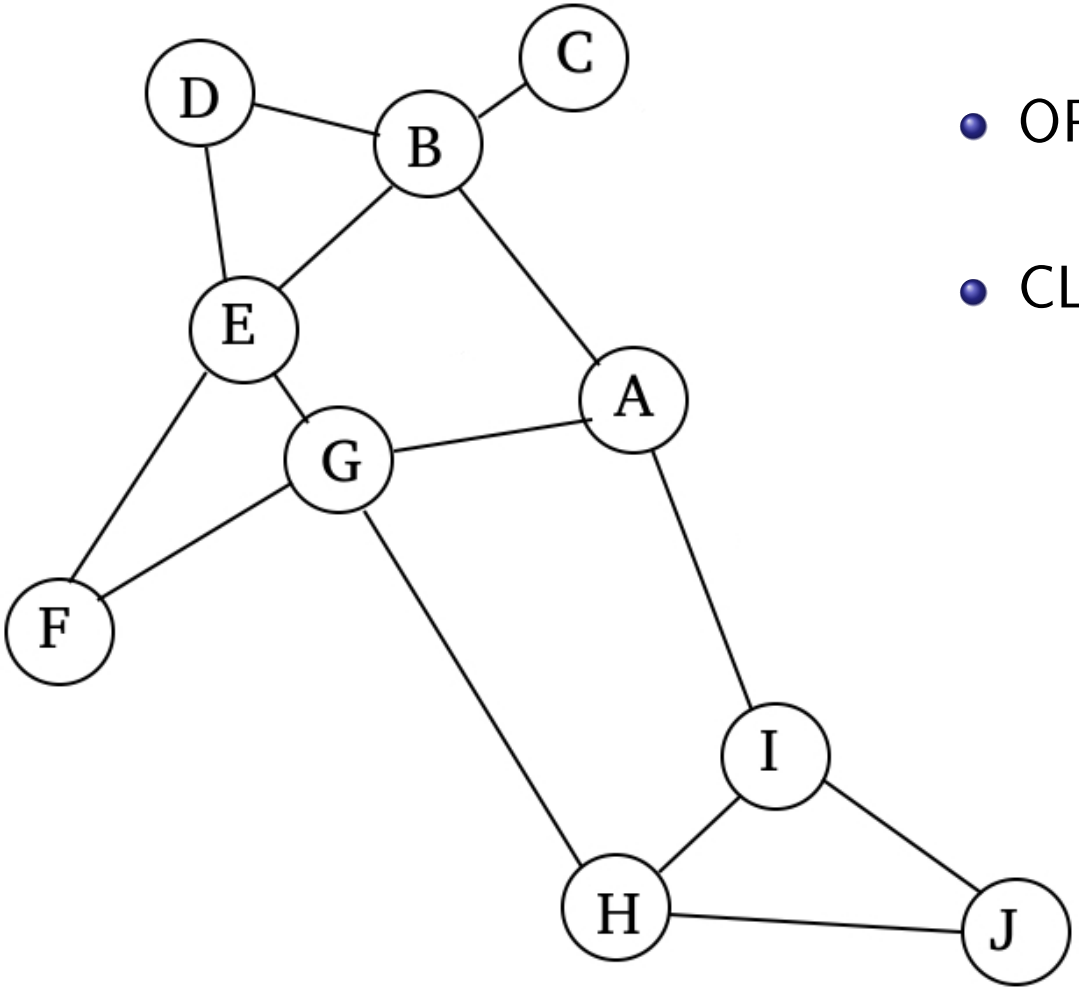


- Find a path from B to I
- OPEN: [B]
- CLOSED: {}

Breadth First Search (BFS)



- Find a path from B to I
- OPEN: [C, D, E, A]
- CLOSED: { B }

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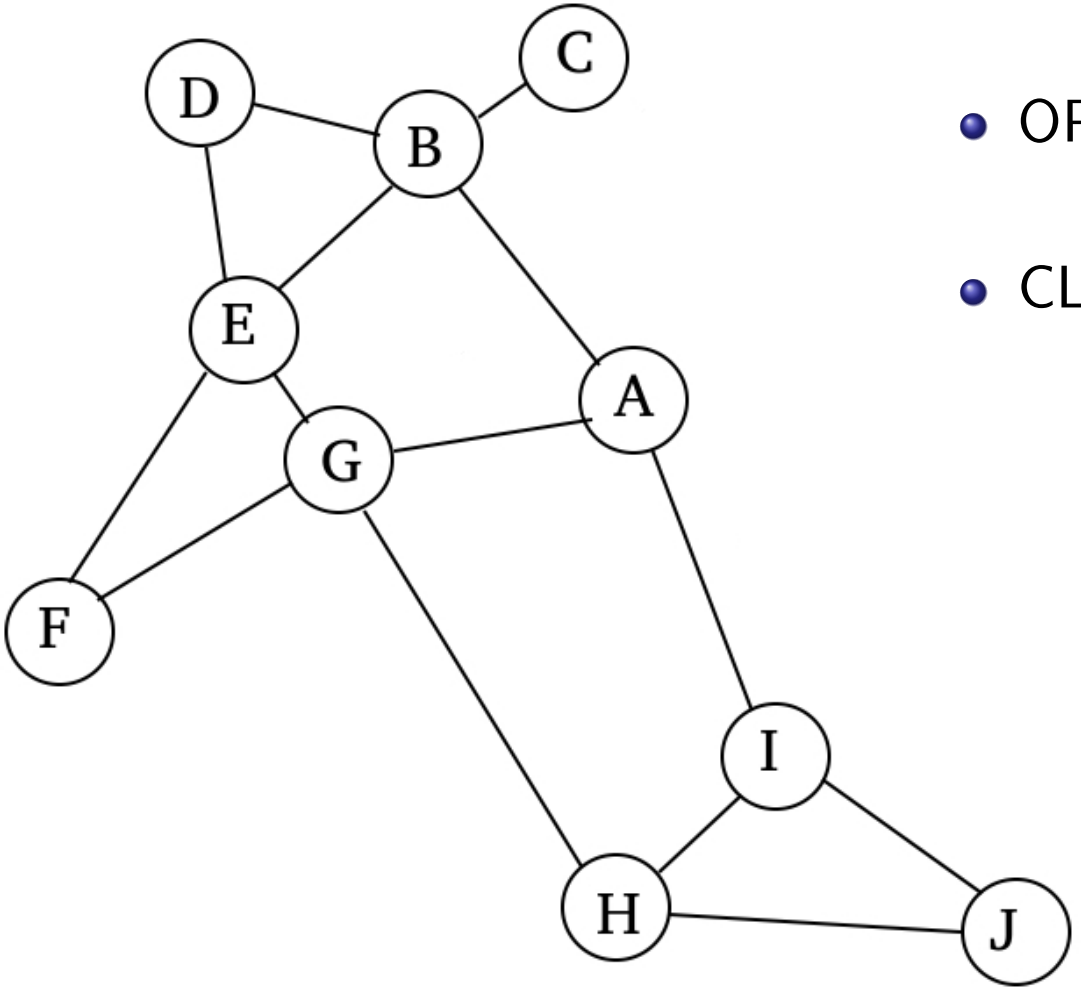

- Find a path from B to I
- OPEN: [D, E, A]
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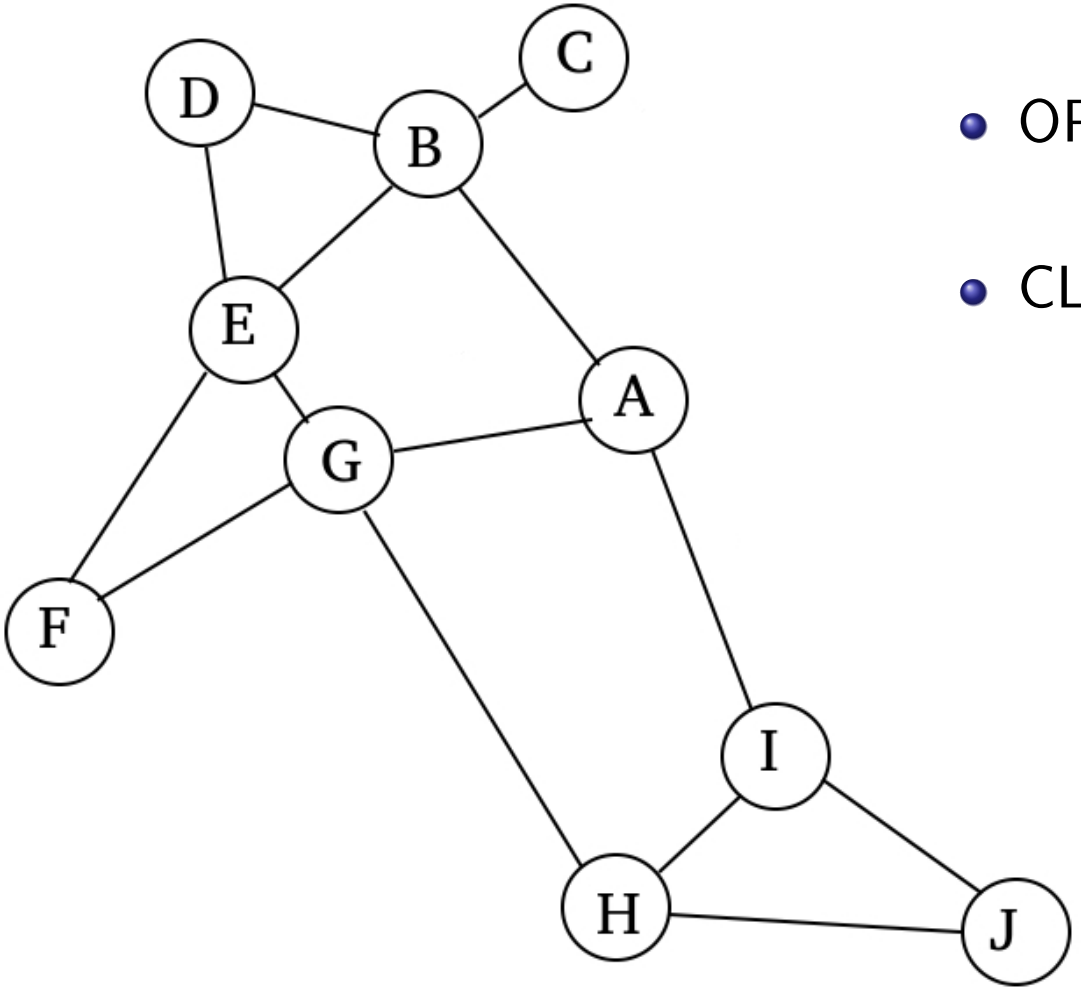
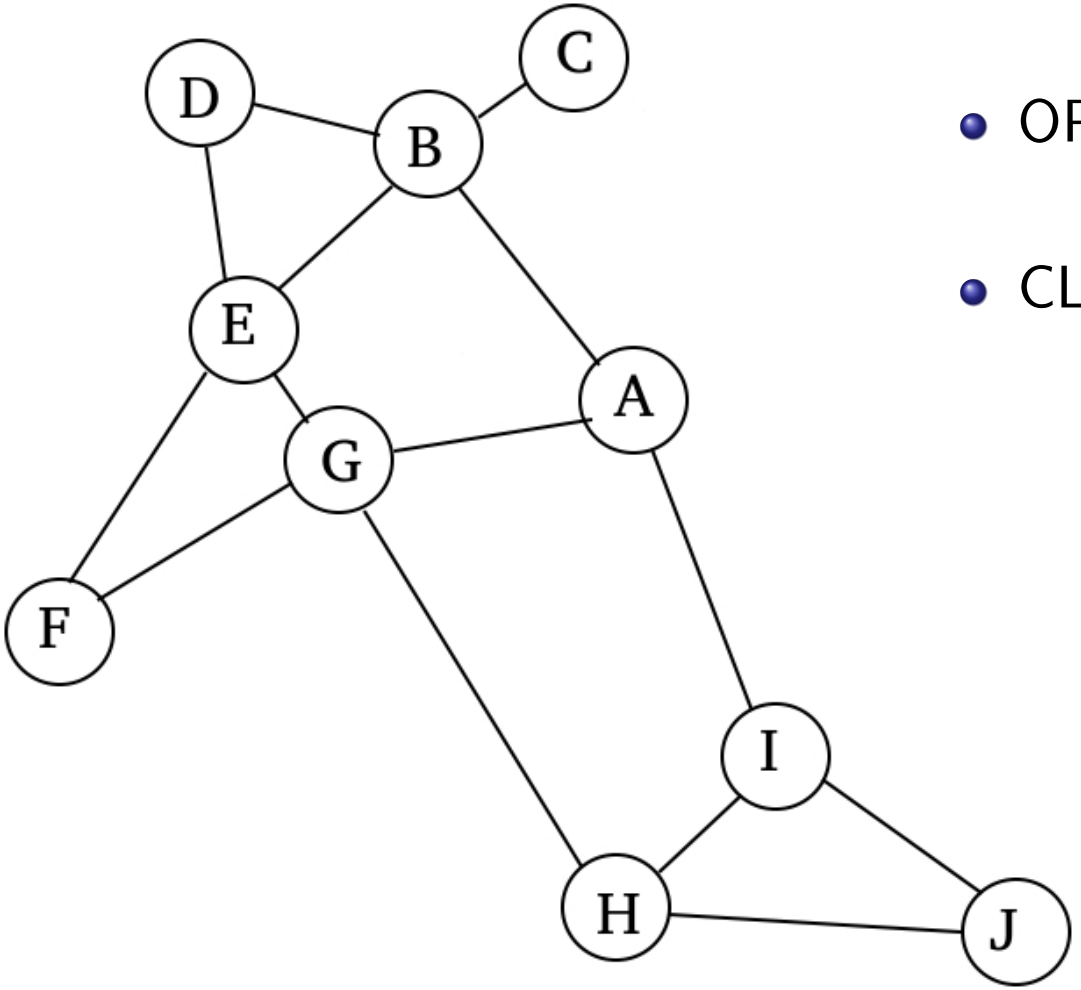
Breadth First Search (BFS)



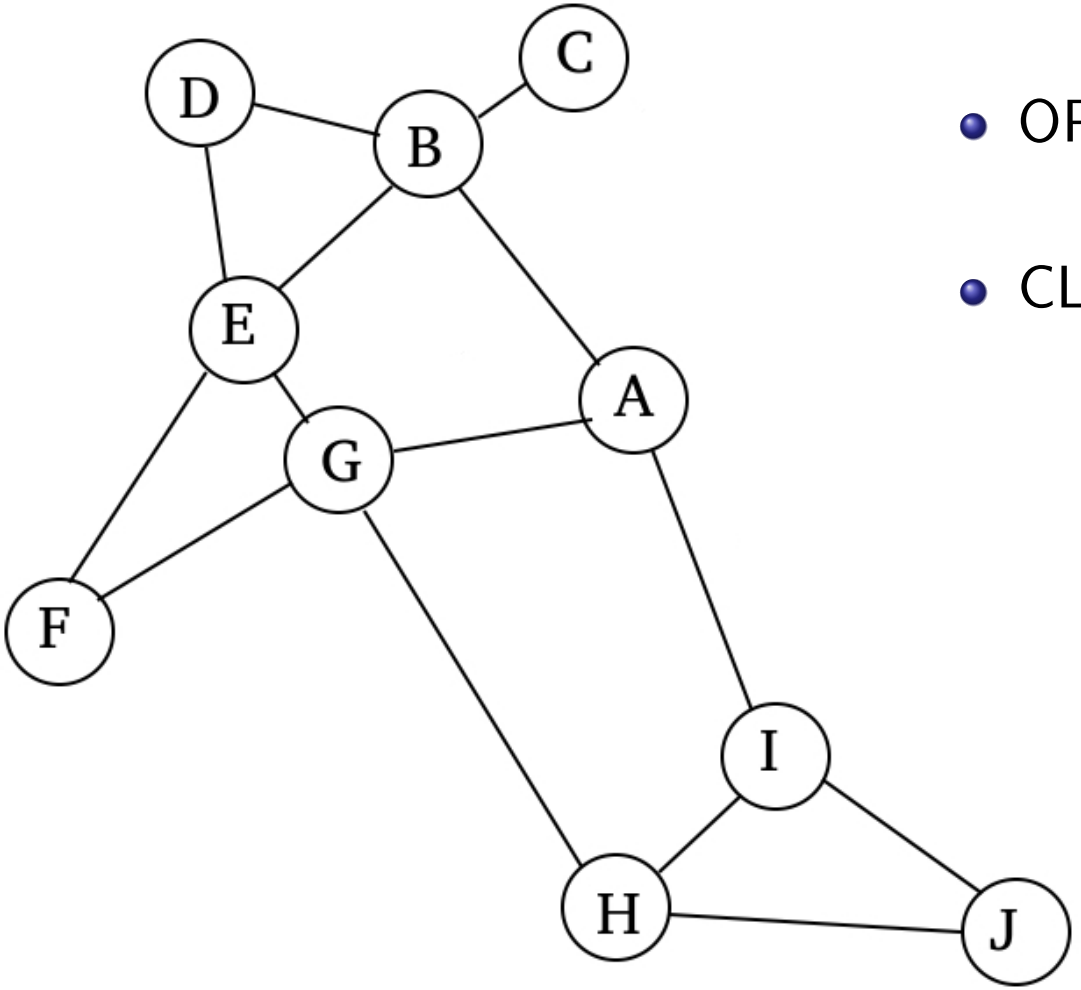
- Find a path from B to I
- OPEN: [E, A]
- CLOSED: { B, C, D }

Breadth First Search (BFS)



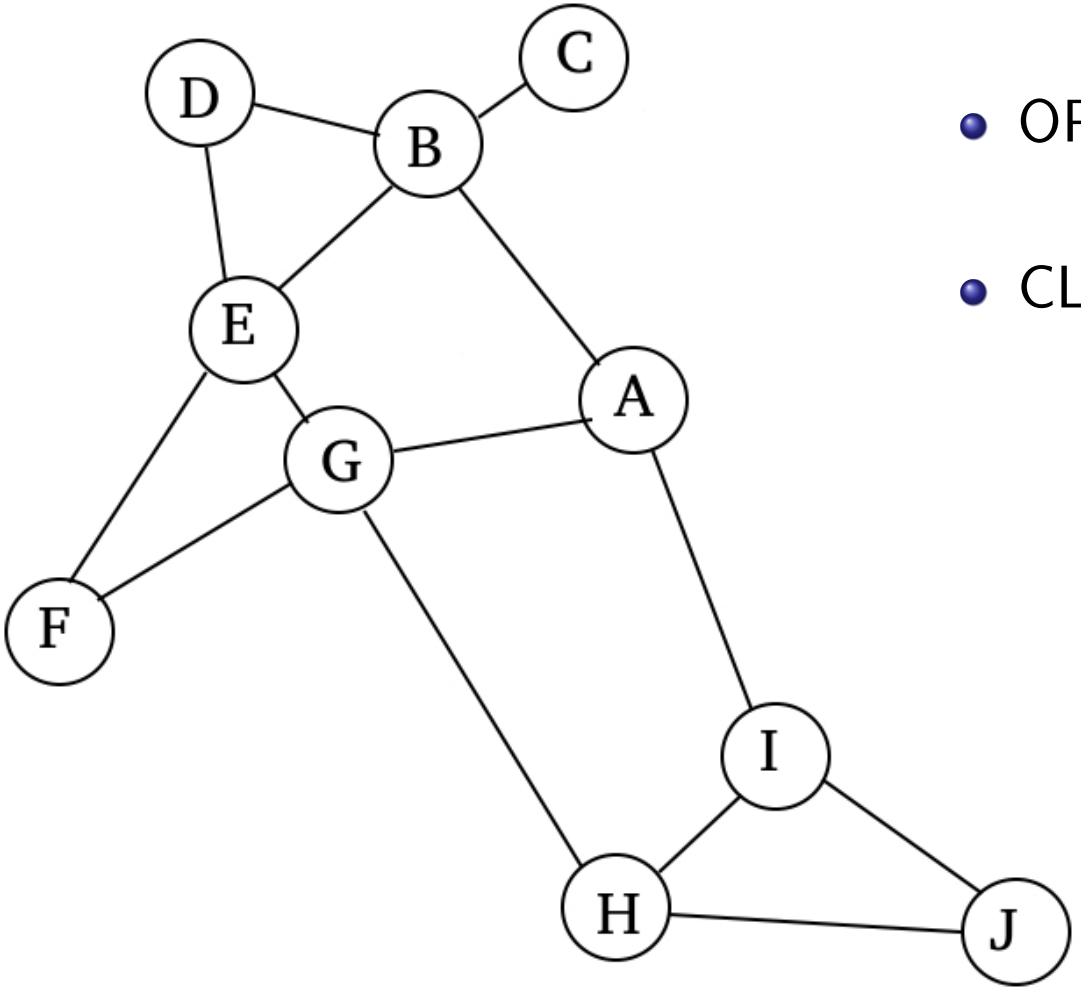
- Find a path from B to I
- OPEN: [A, F, G]
- CLOSED: { B, C, D, E }

Breadth First Search (BFS)



- Find a path from B to I
- OPEN: [F, G, I]
- CLOSED: { B, C, D, E, A }

Breadth First Search (BFS)



- Find a path from B to I
- OPEN: [G, I]
- CLOSED: { B, C, D, E, A, F }

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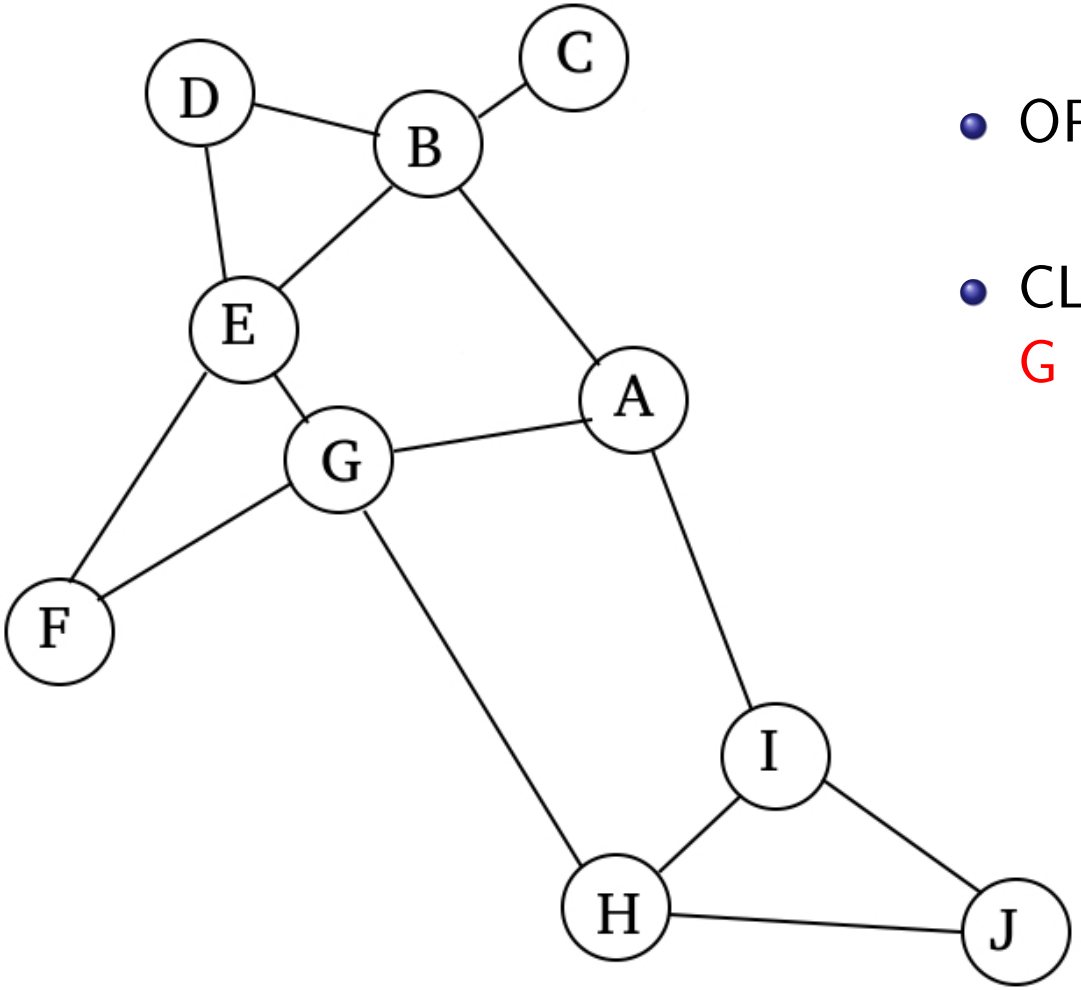

- Find a path from B to I
- OPEN: [I, H]
- CLOSED: { B, C, D, E, A, F, G }

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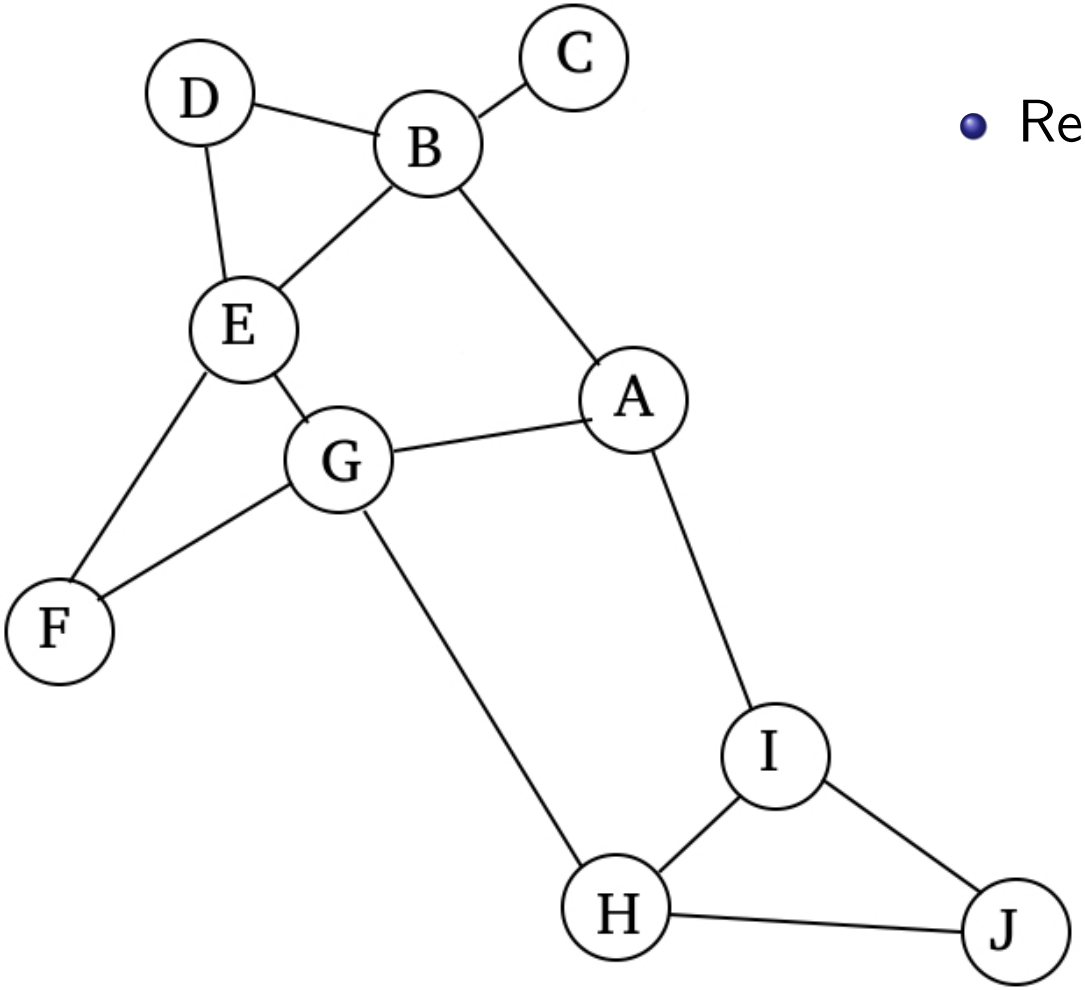

- Find a path from B to I
- Reached goal I

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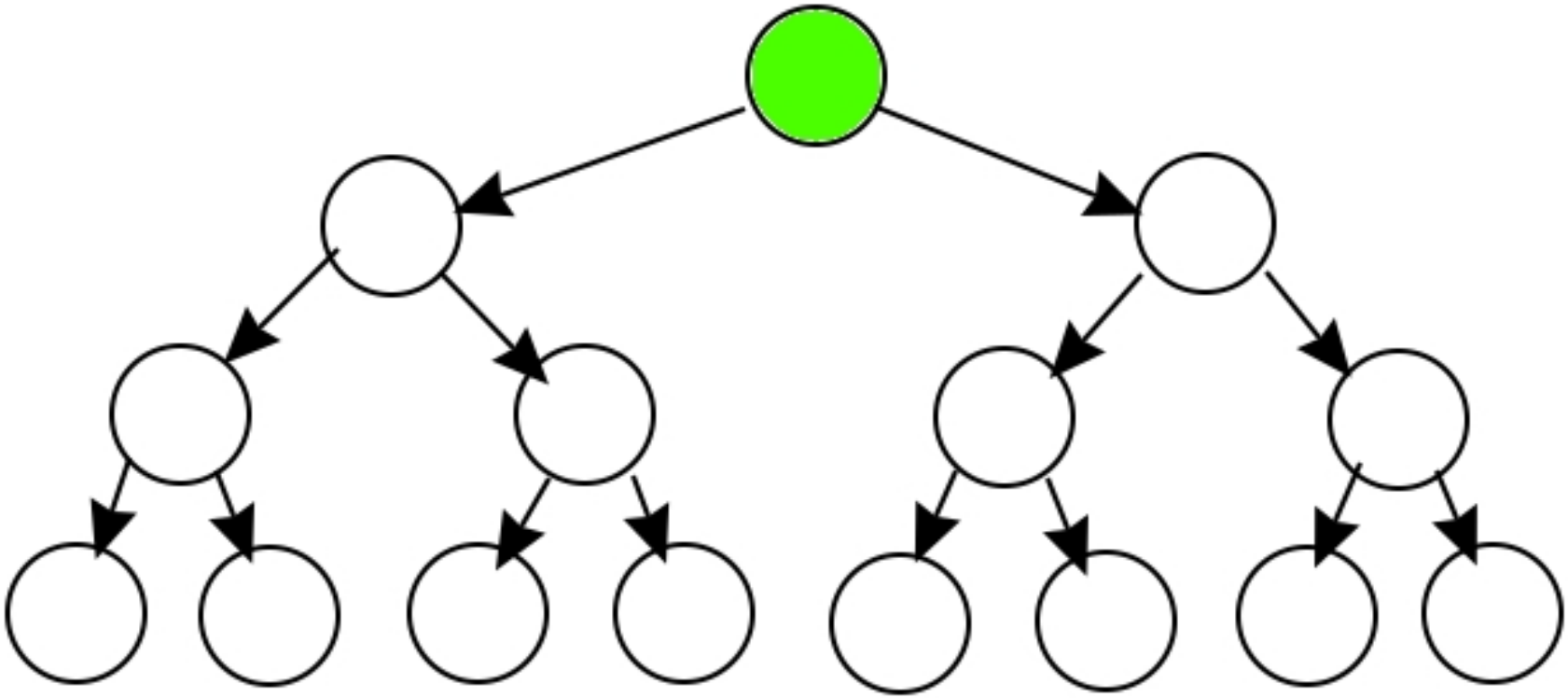

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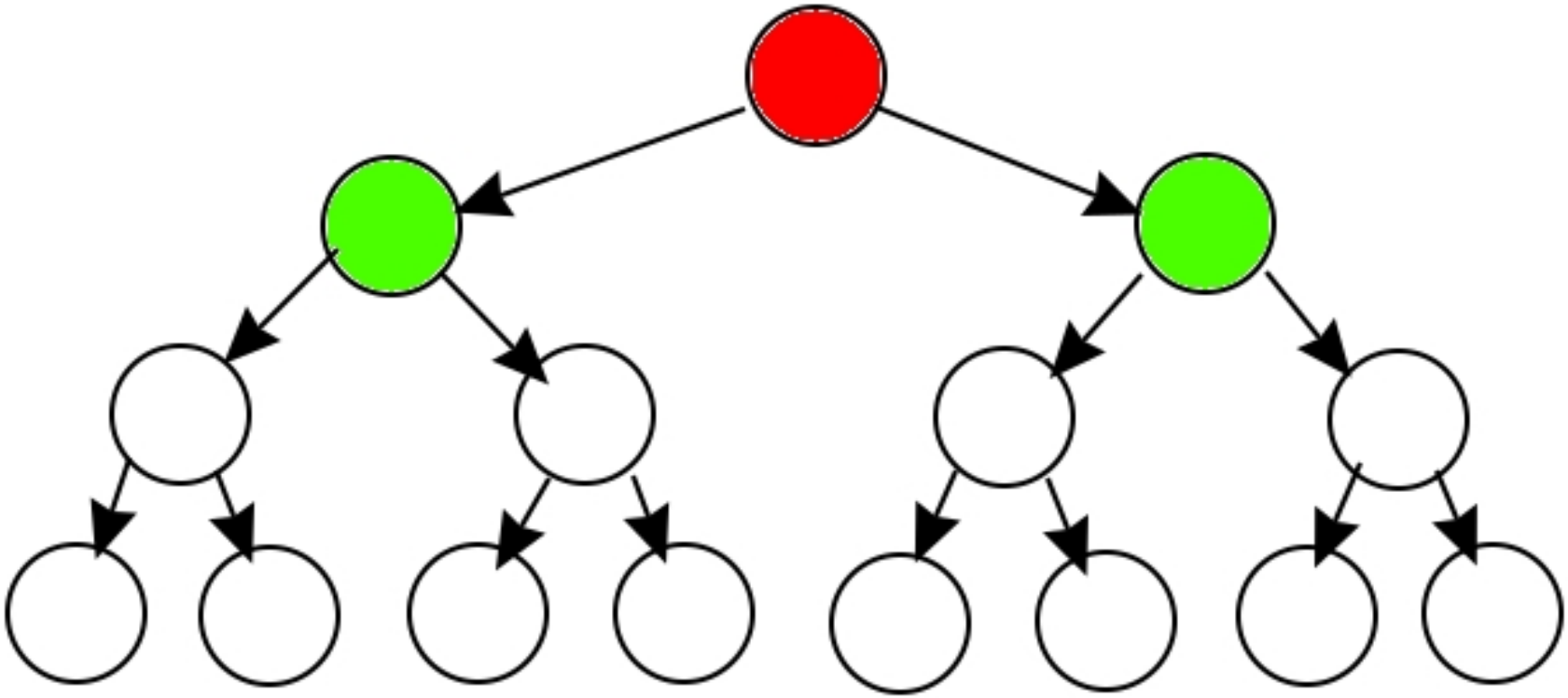

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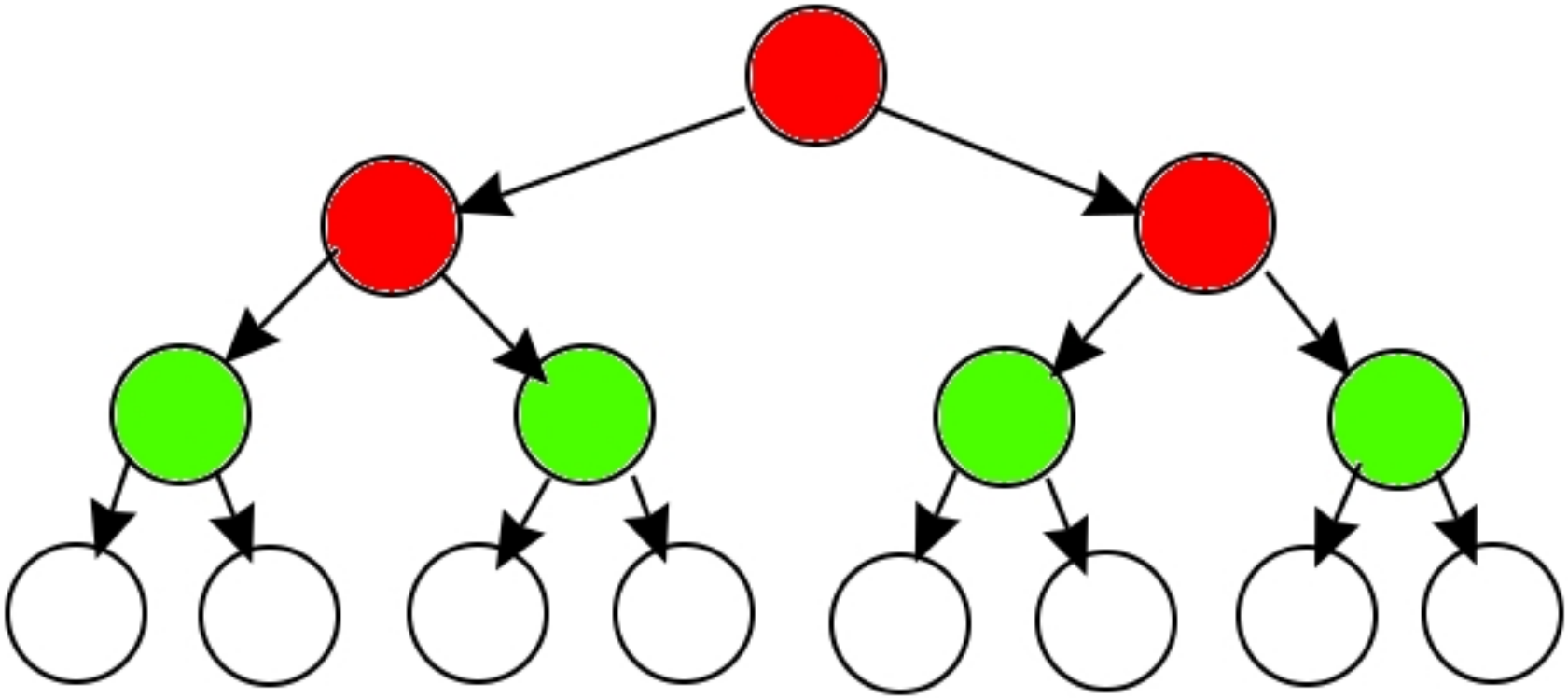

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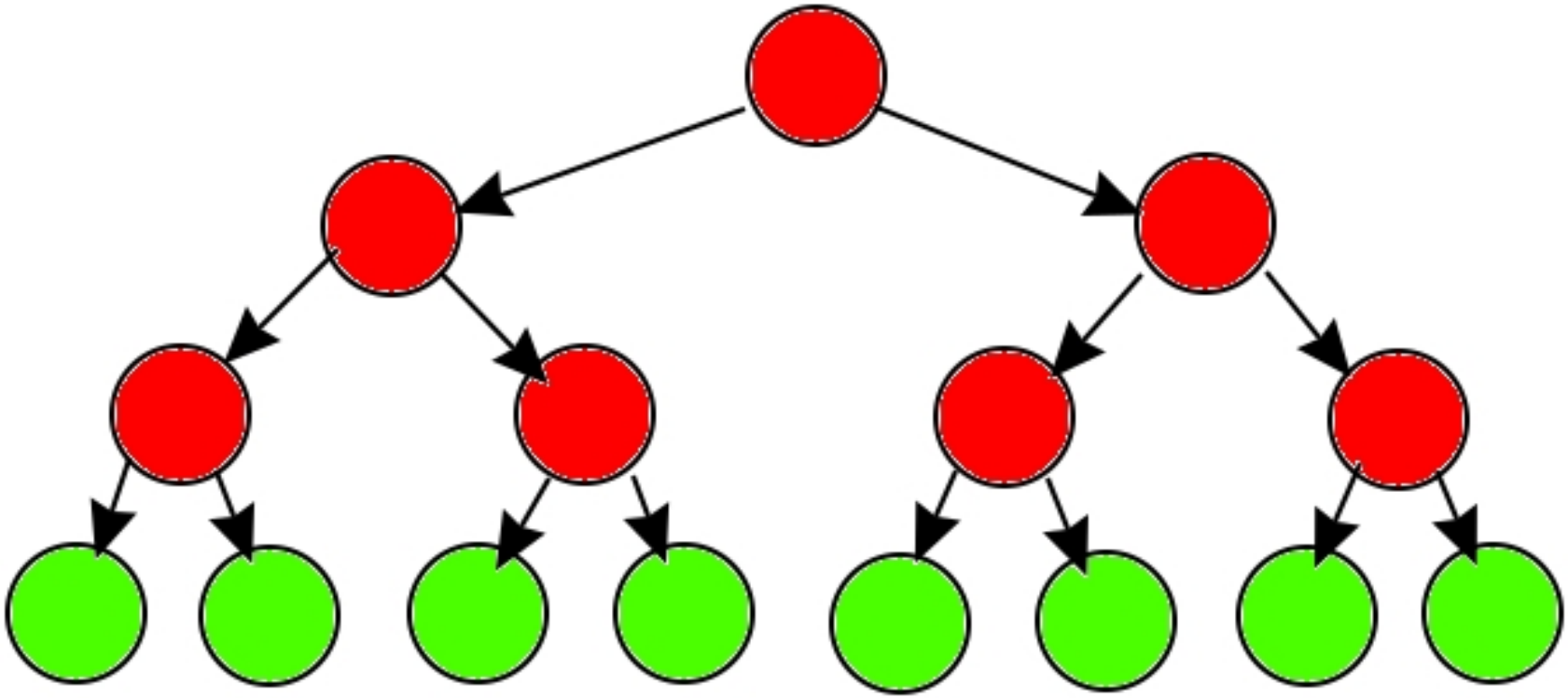

Breadth First Search (BFS)

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  - Always finds the solution
  - Optimal route to the solution

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Breadth First Search (BFS)

- The good:
  - Always finds the solution
  - Optimal route to the solution
- The bad:
  - Kinda dumb...
- The ugly:
  - Memory consumption on larger graphs

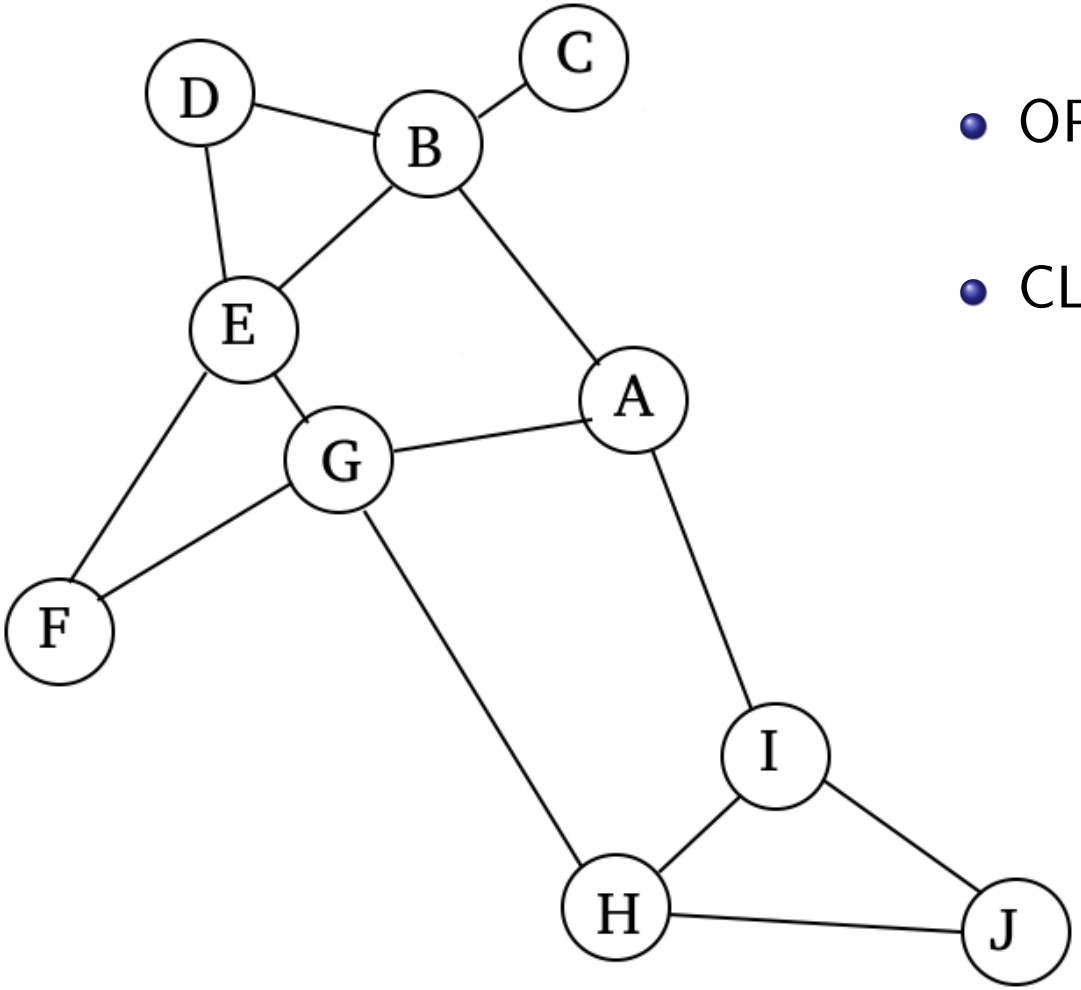
Depth First Search (DFS)

```
closedNodes = {}

 # Last In First Out
 openNode = Stack()

openNodes.insert(getInitialState())
while openNodes not empty
   node = openNodes.get()
   if isGoalState(node)
     return node
   if node in closedNodes
     continue
   for childNode in getSuccessors(node)
     if childNode not in closedNodes
       openNodes.insert(childNode)
   closedNodes.insert(node)
```

Depth First Search (DFS)



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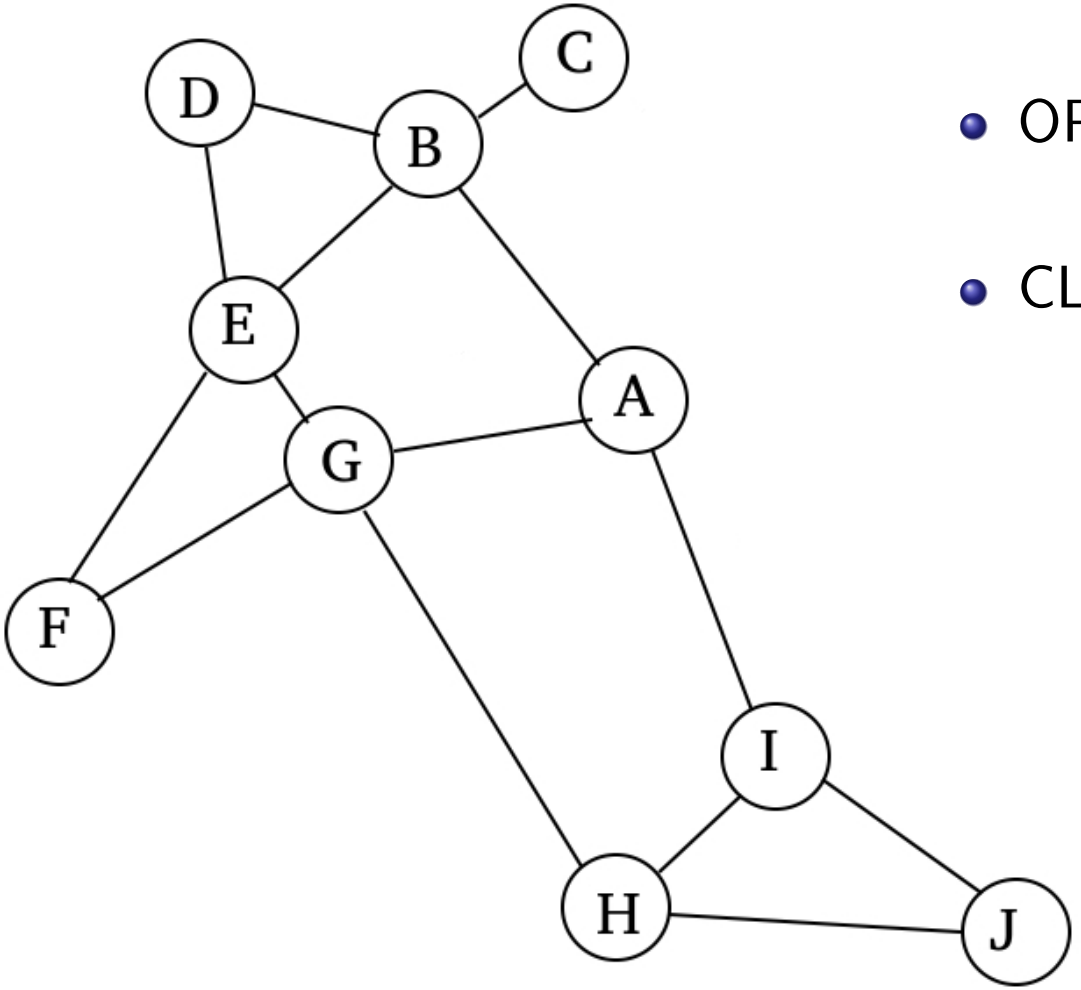
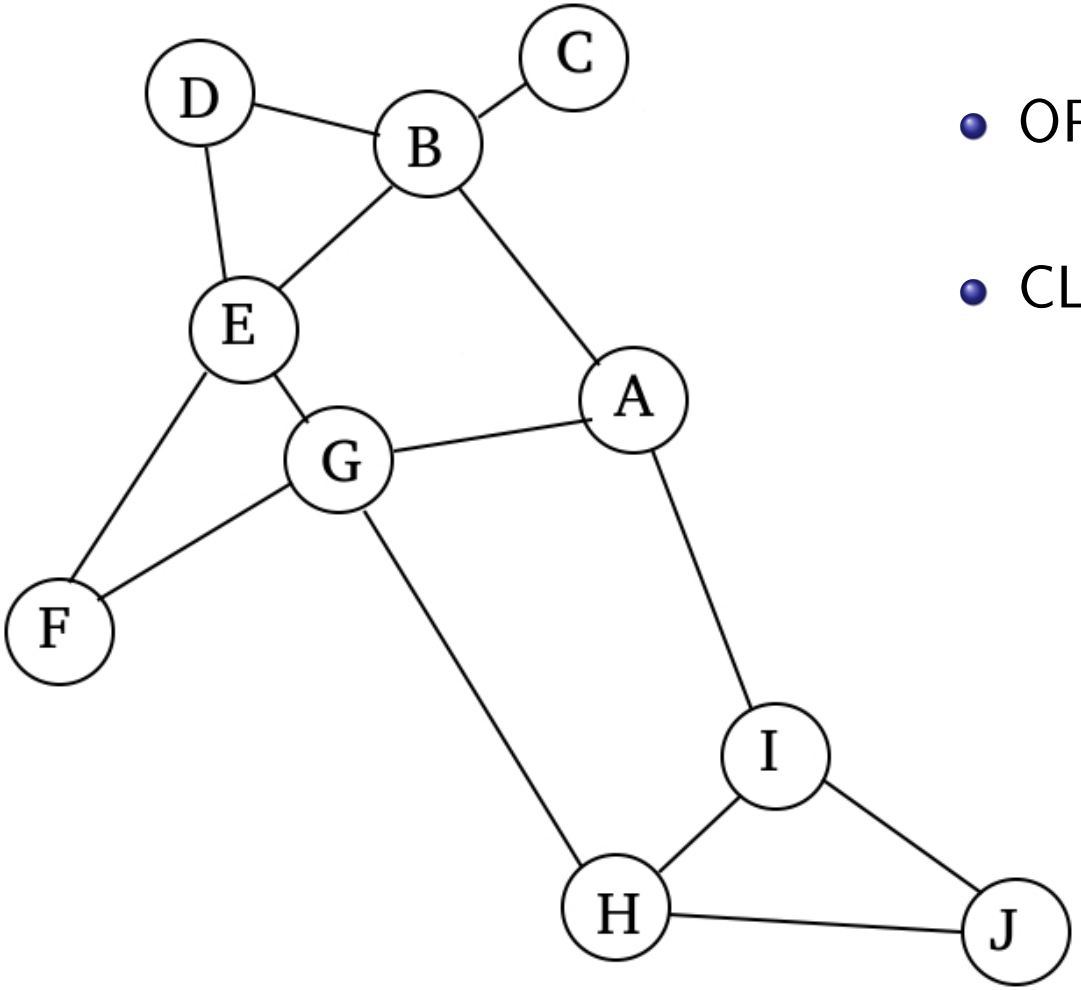


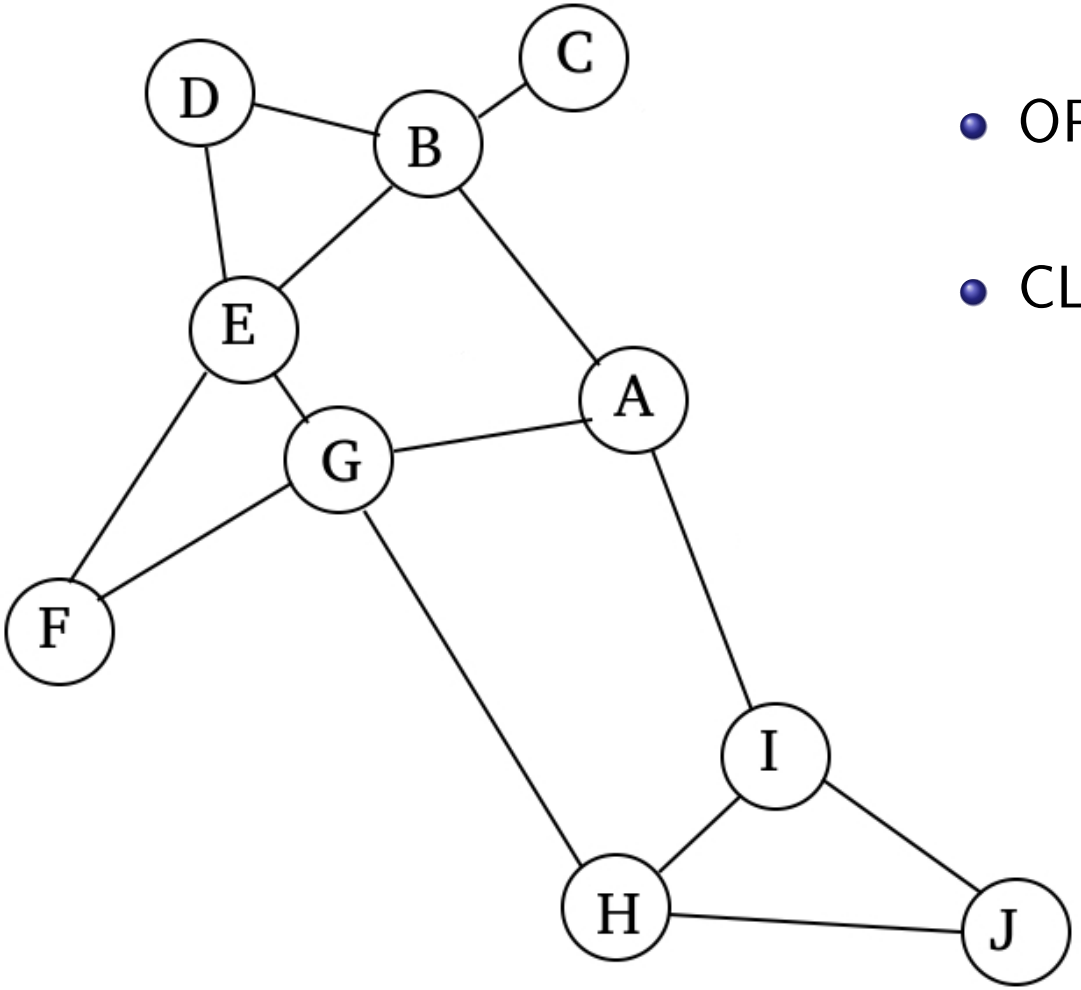
- Find a path from B to I
- OPEN: [C, D, E, A]
- CLOSED: { B }

Depth First Search (DFS)



- Find a path from B to I
- OPEN: [D, E, A]
- CLOSED: { B, C }

Depth First Search (DFS)



- Find a path from B to I
- OPEN: [E, A]
- CLOSED: { B, C, D }

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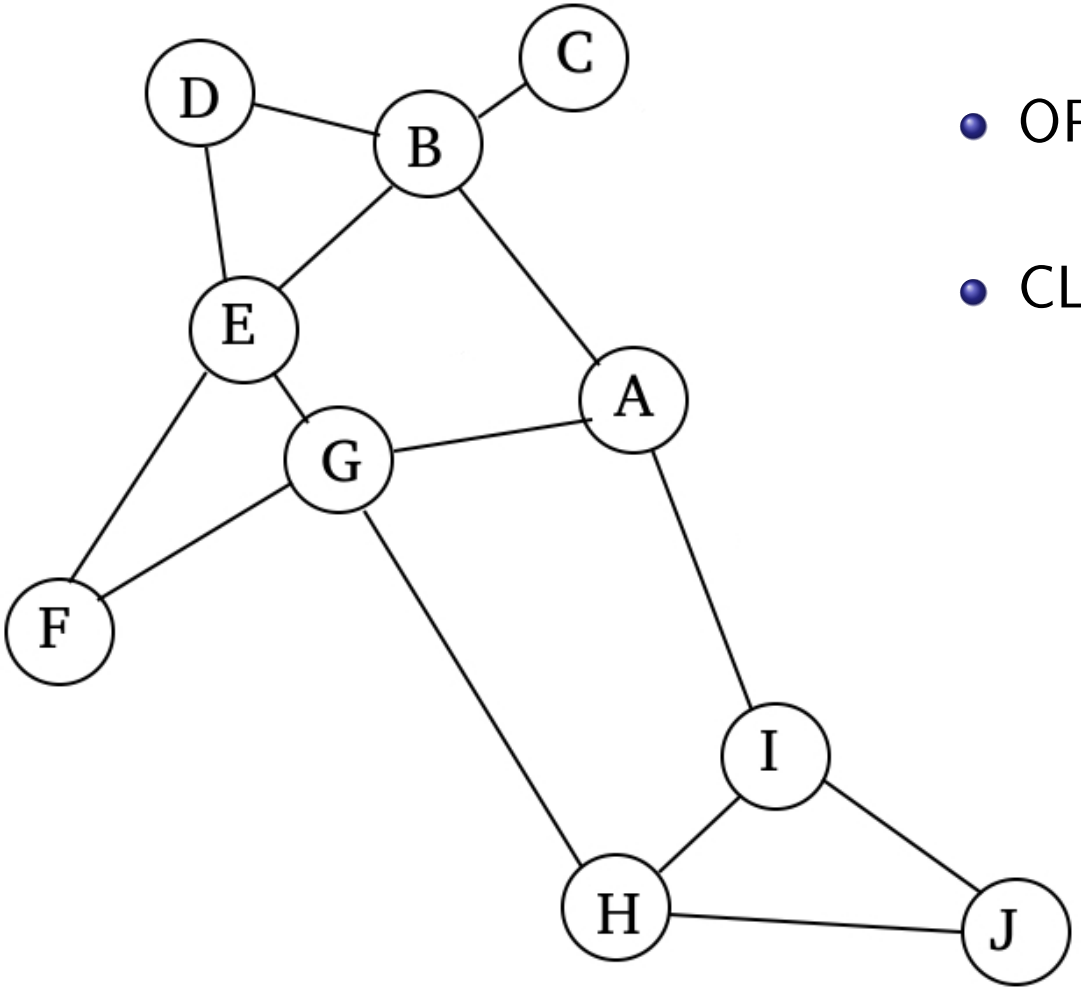
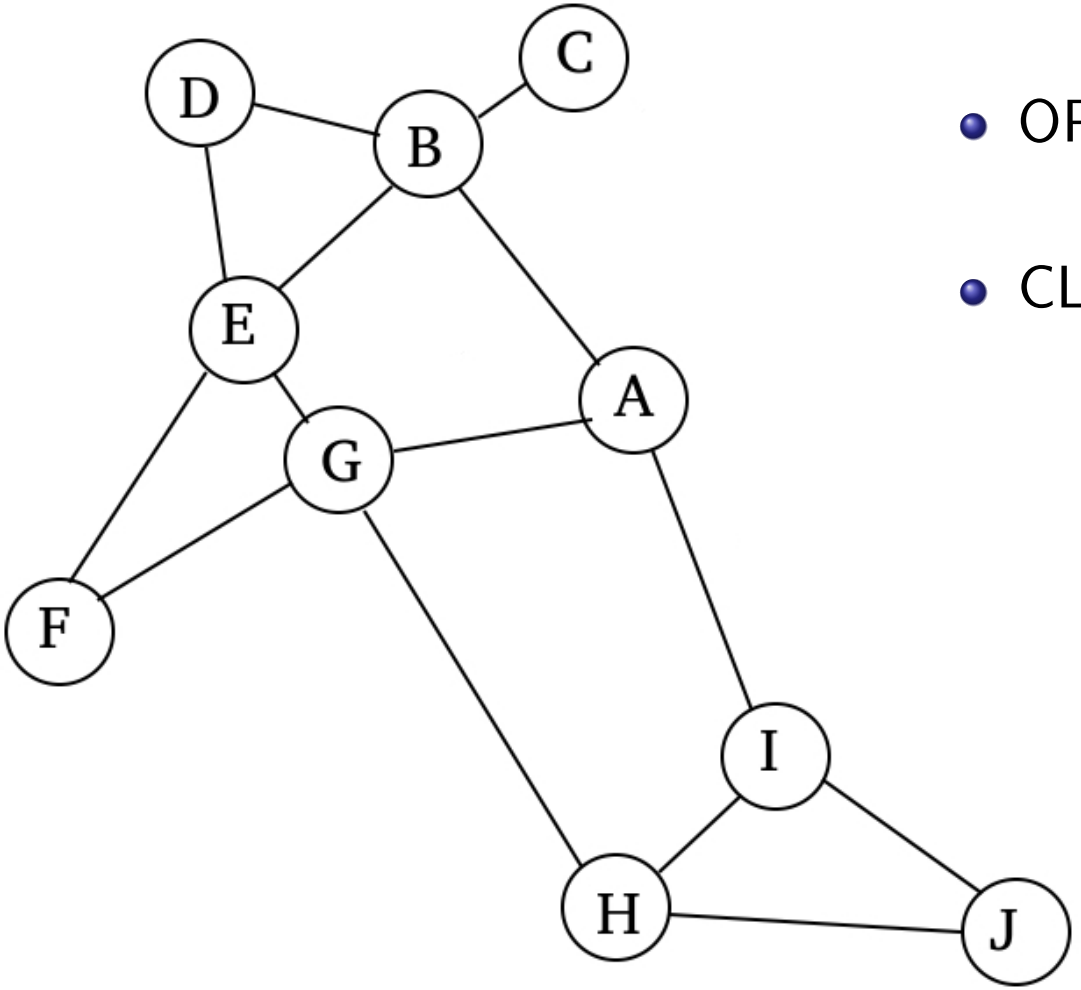


- Find a path from B to I
- OPEN: [F, G, A]
- CLOSED: { B, C, D, E }

Depth First Search (DFS)



- Find a path from B to I
- OPEN: [G, A]
- CLOSED: { B, C, D, E, F }

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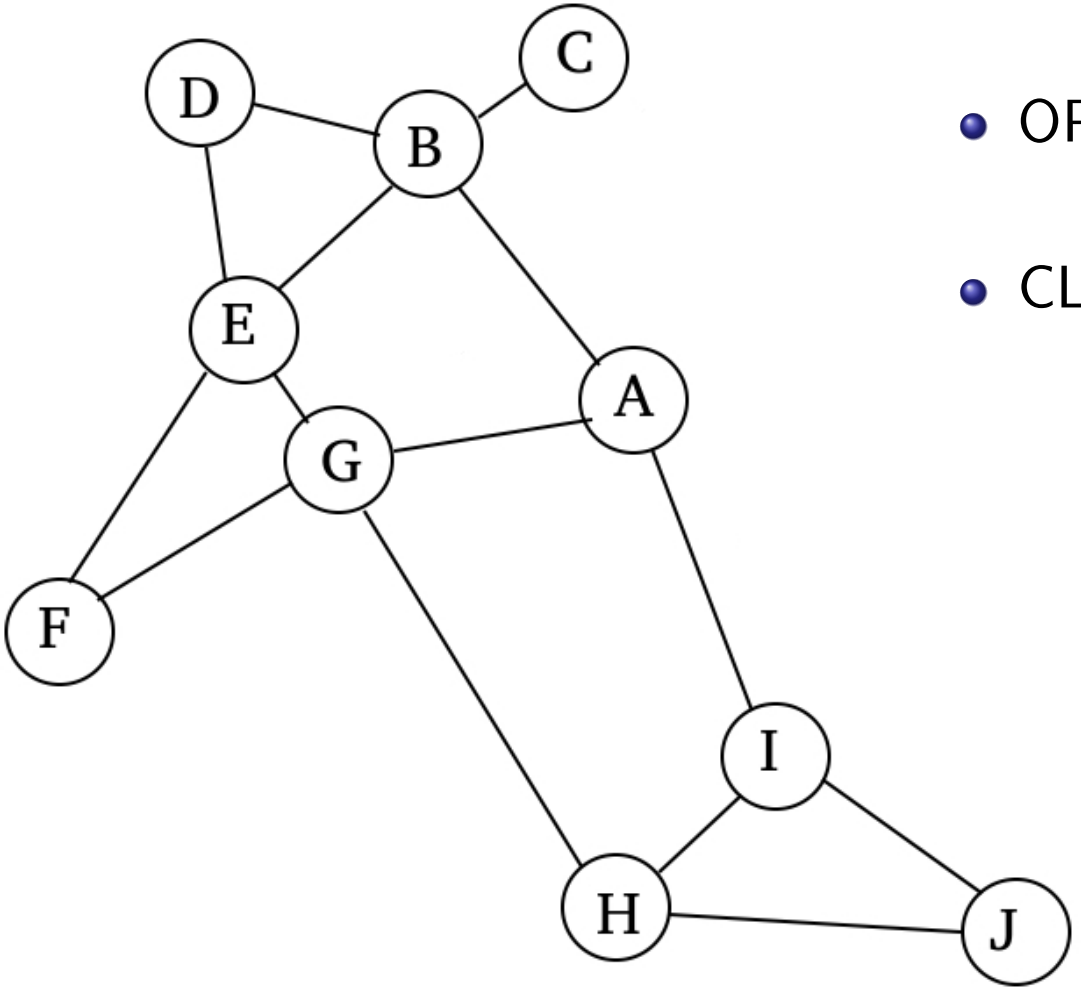

- Find a path from B to I
- OPEN: [H, A]
- CLOSED: { B, C, D, E, F, G }

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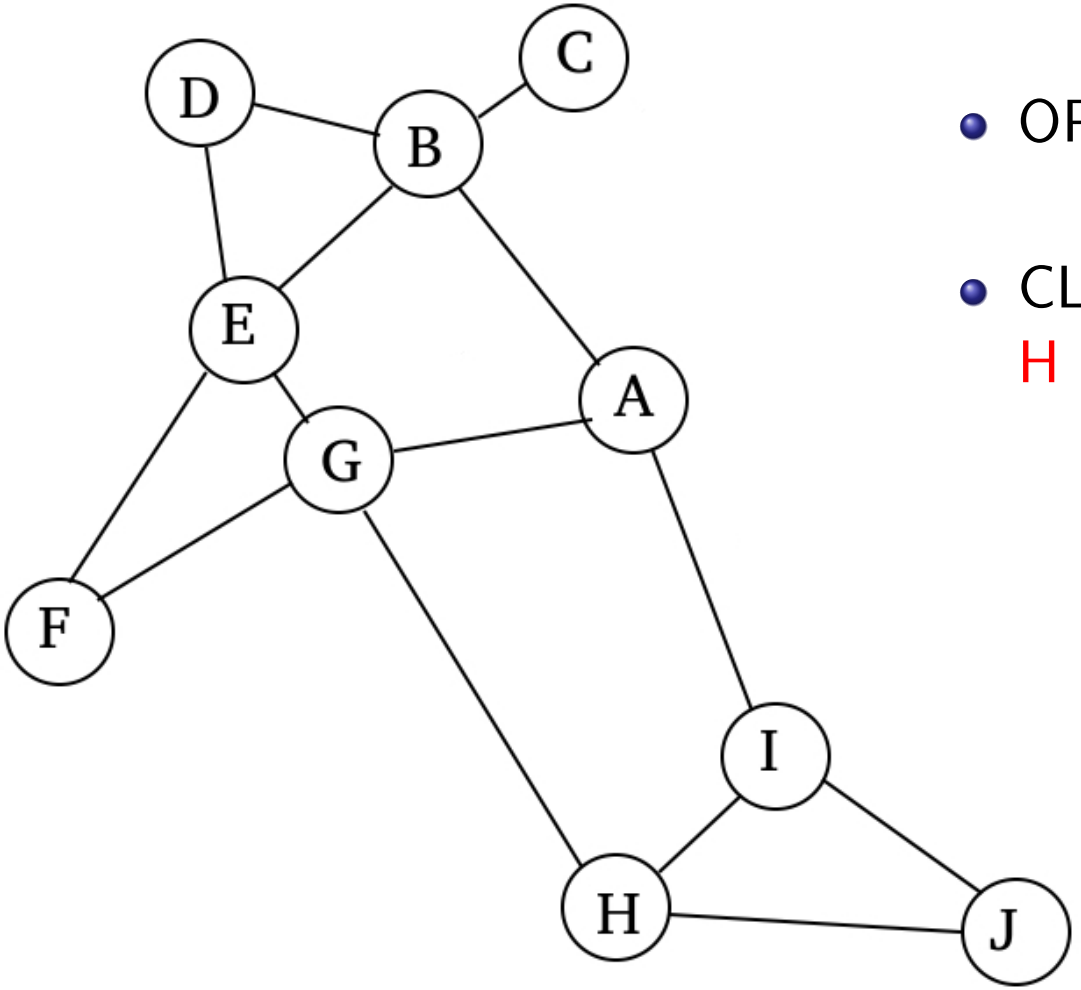

- Find a path from B to I
- OPEN: [I, J, A]
- CLOSED: { B, C, D, E, F, G, H }

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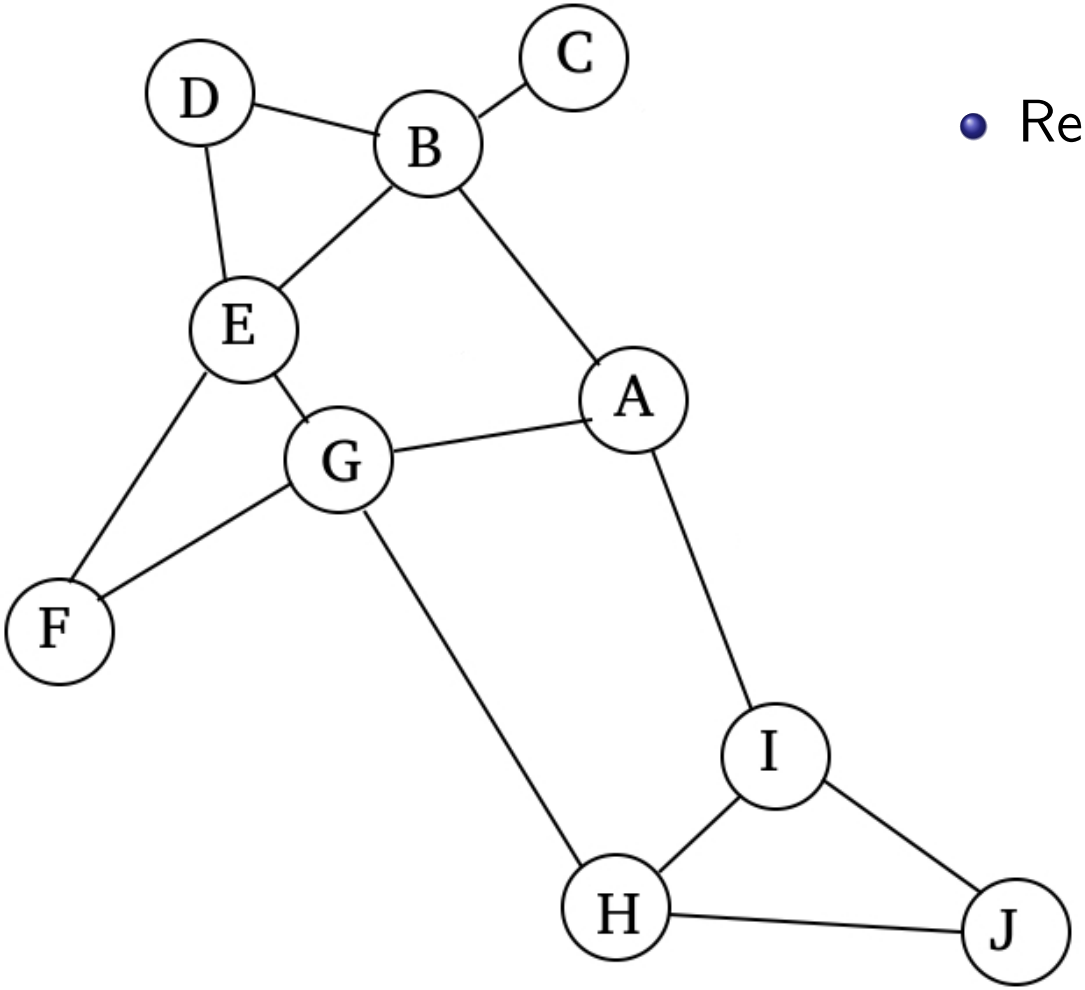

- Find a path from B to I
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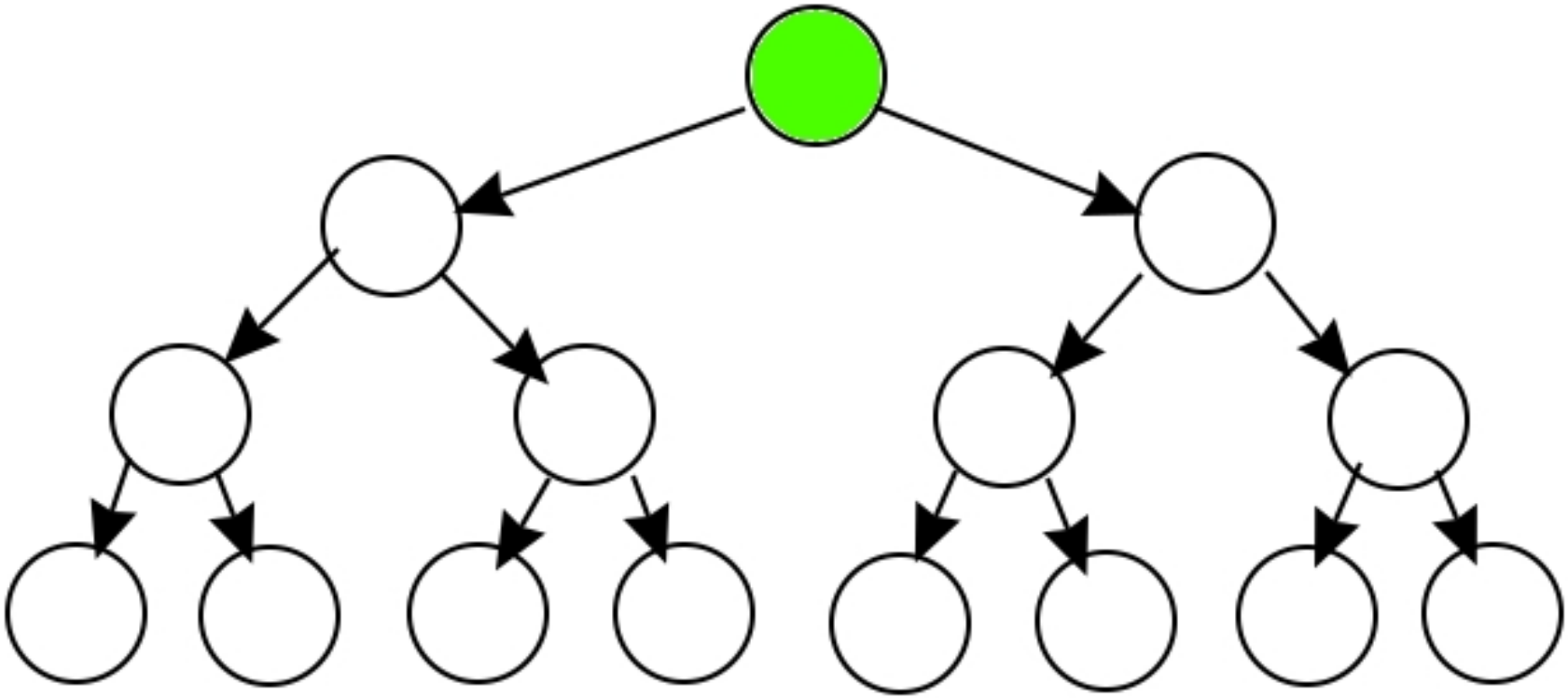

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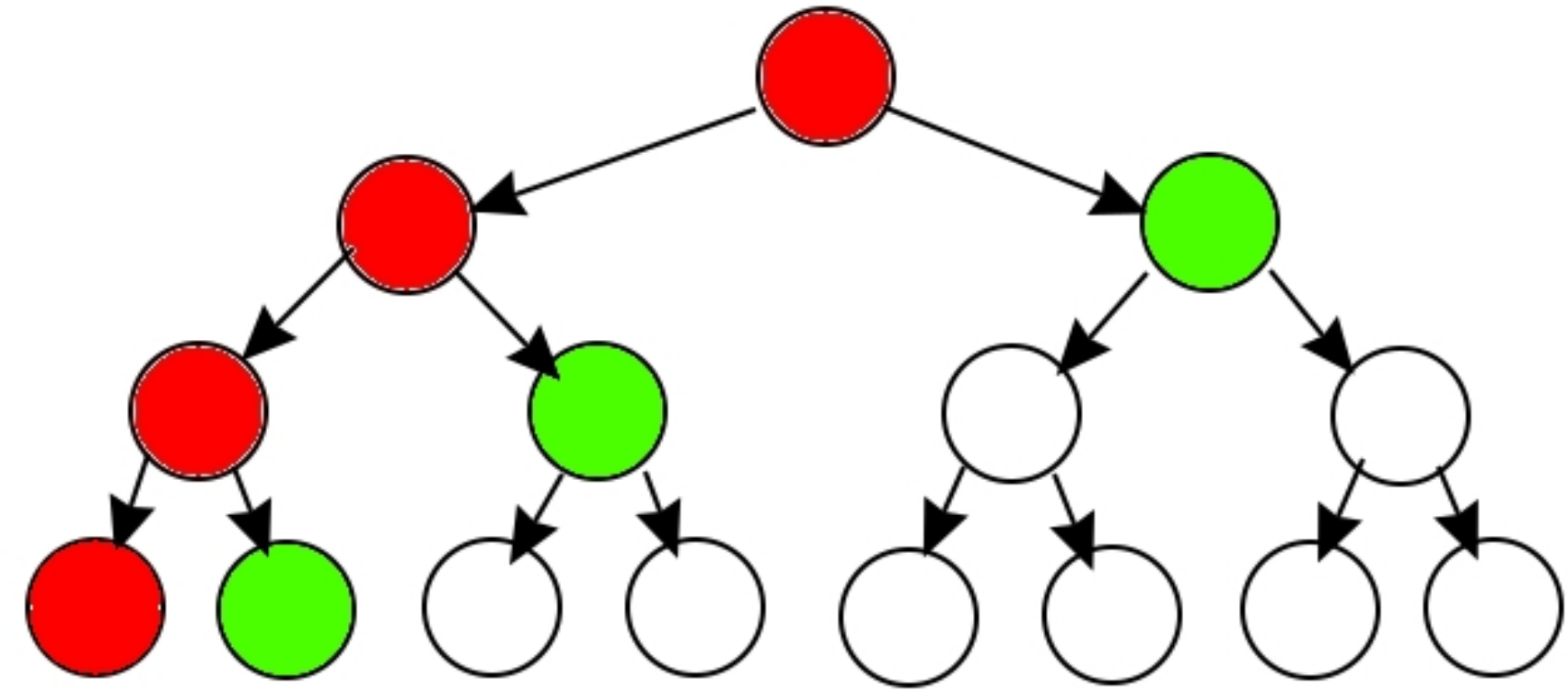

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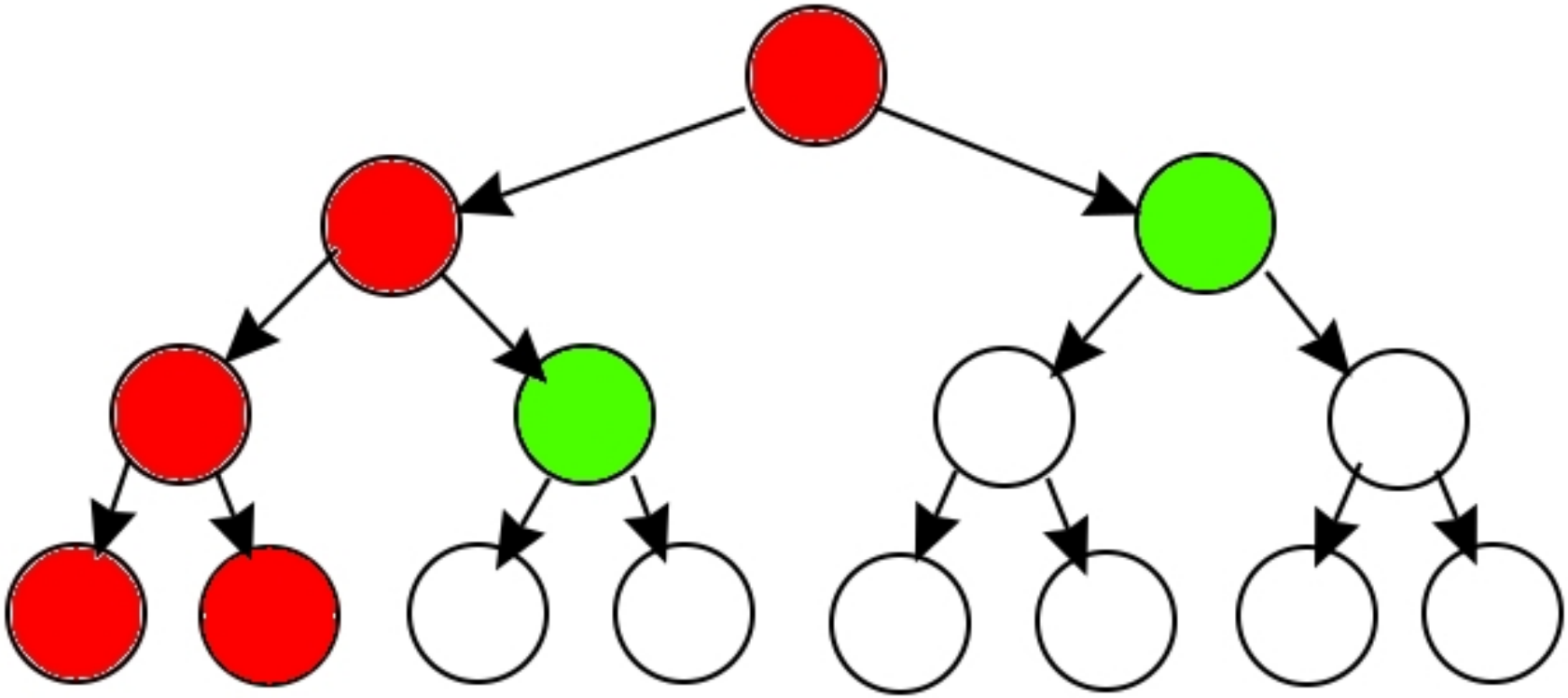

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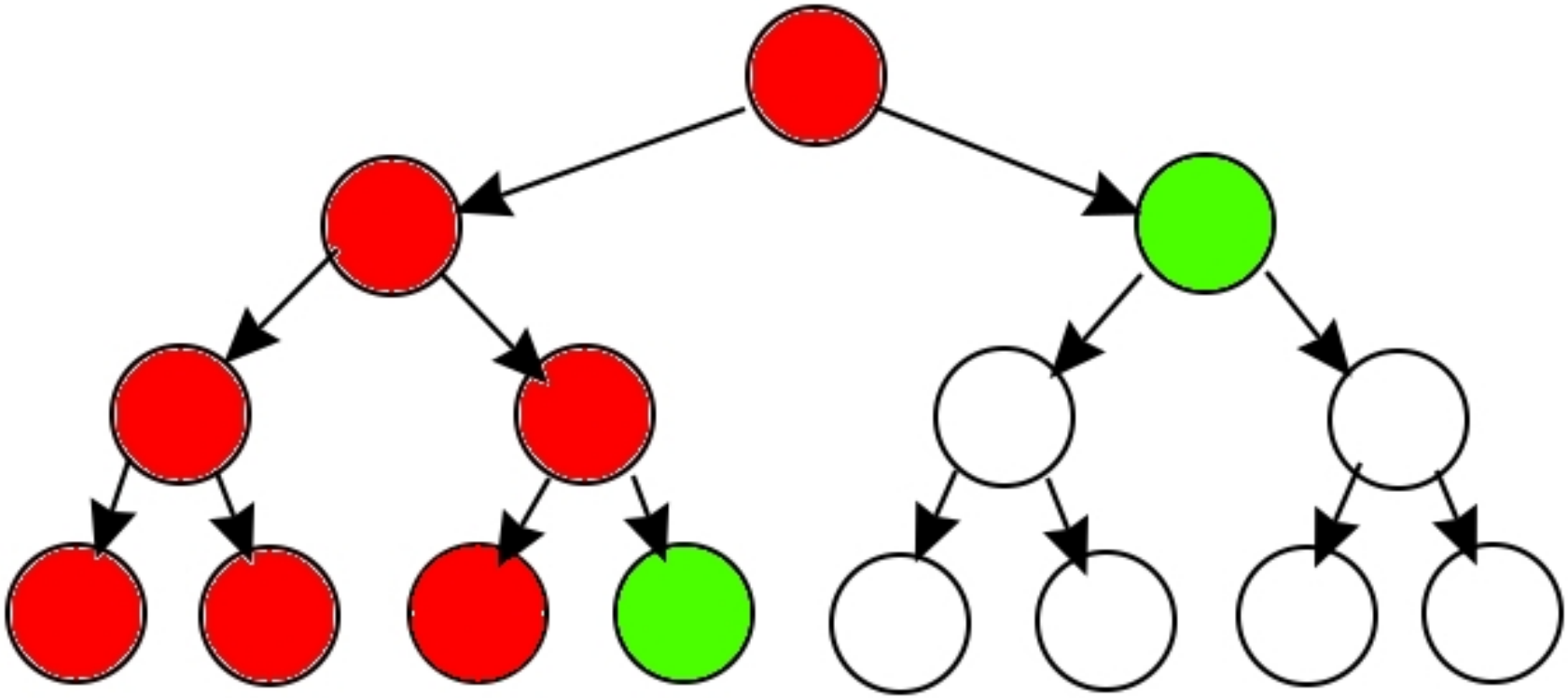

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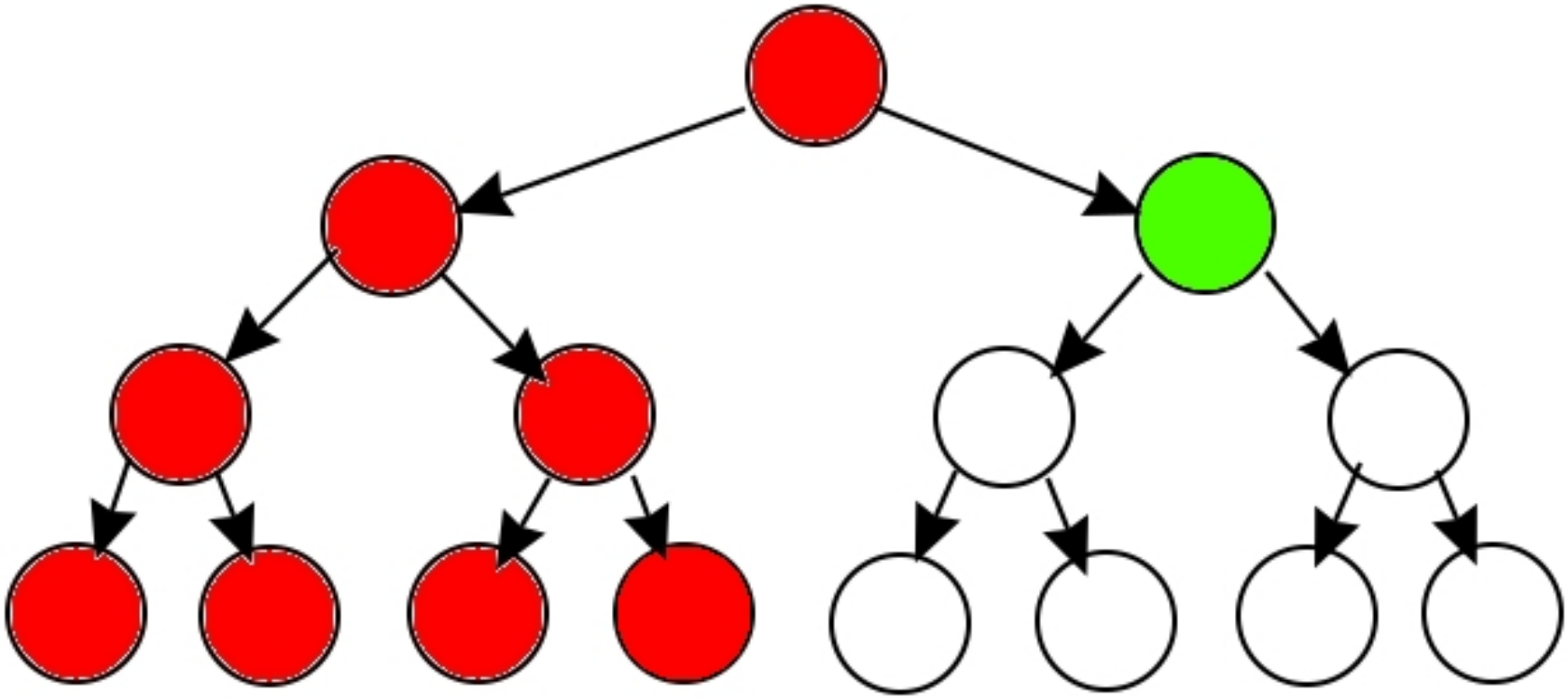

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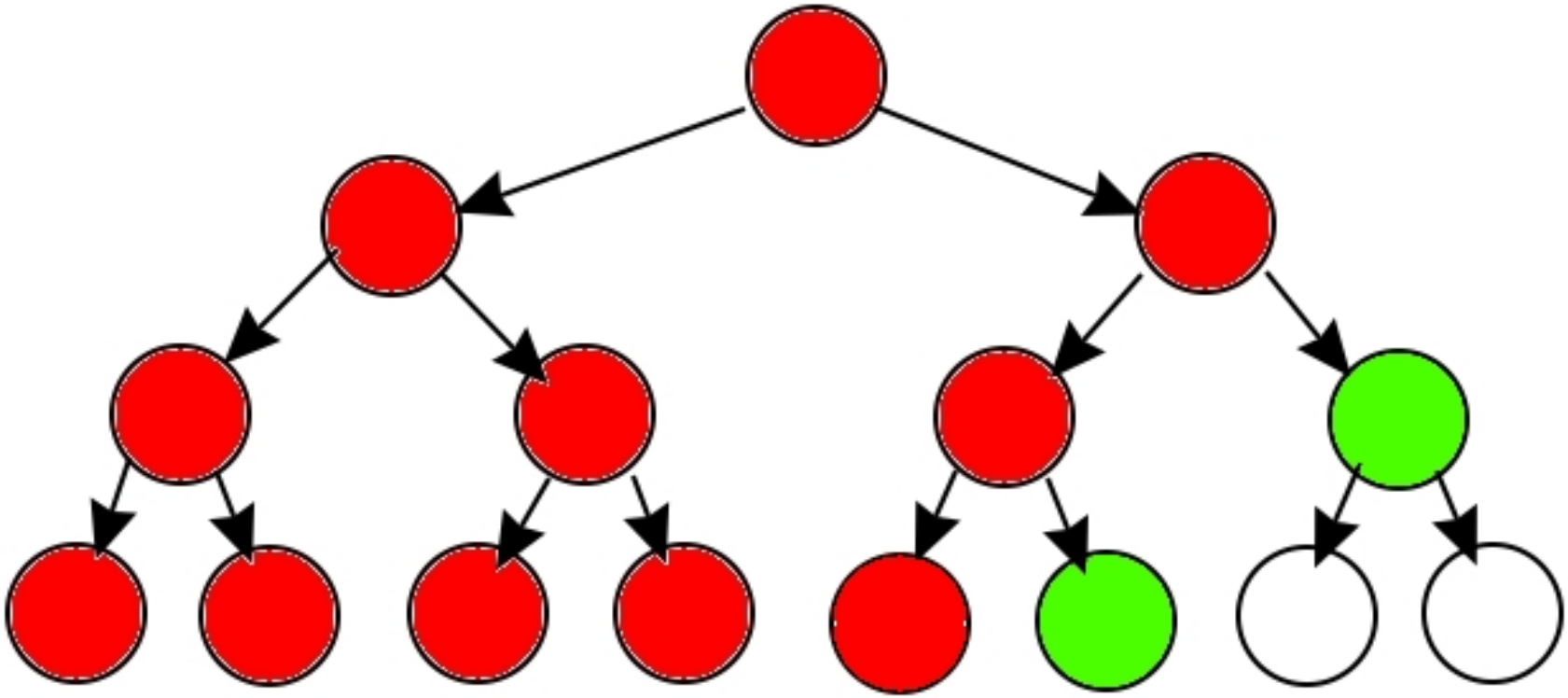

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  - Always finds the solution (when taking care not to revisit states multiple times)

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  - Always finds the solution (when taking care not to revisit states multiple times)
- The bad:
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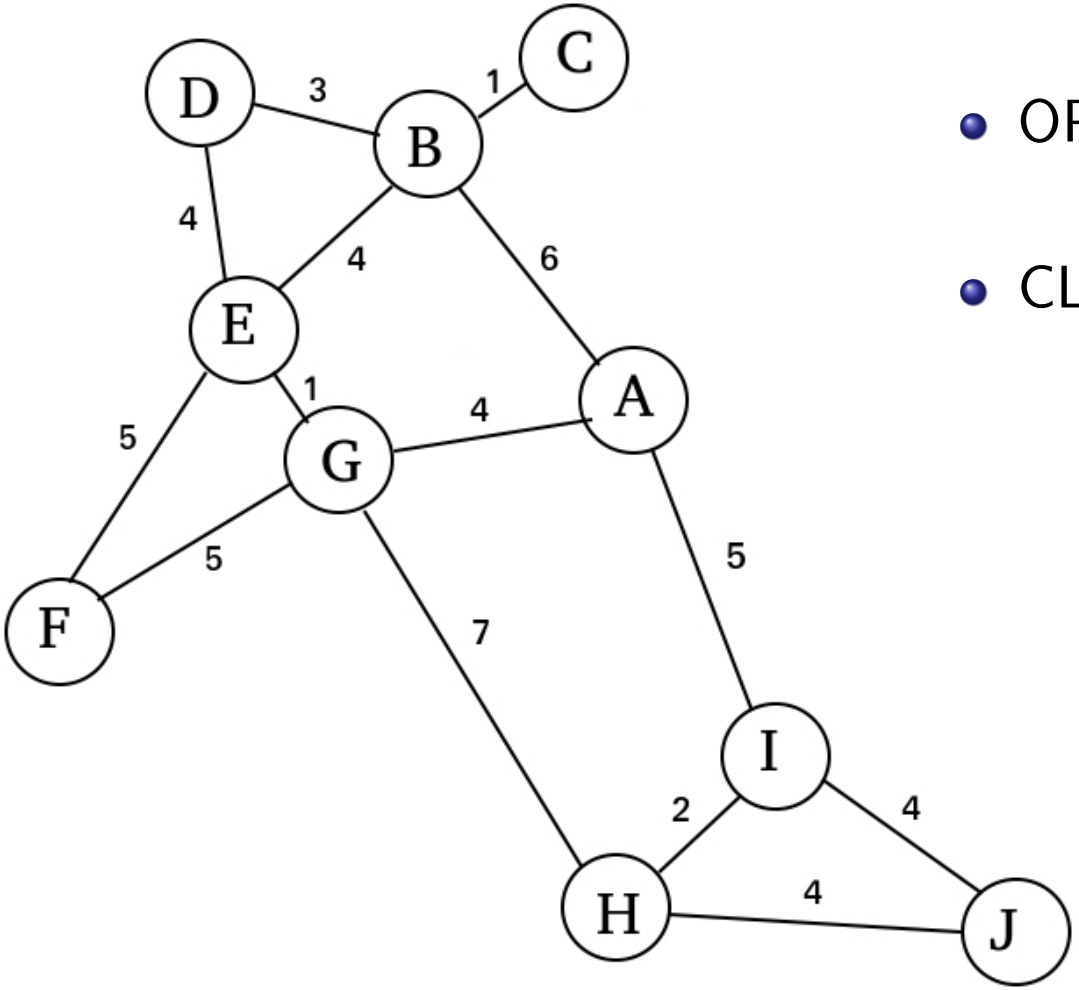
- The ugly:
  - Kinda dumb...er

Uniform Cost Search (UCS)

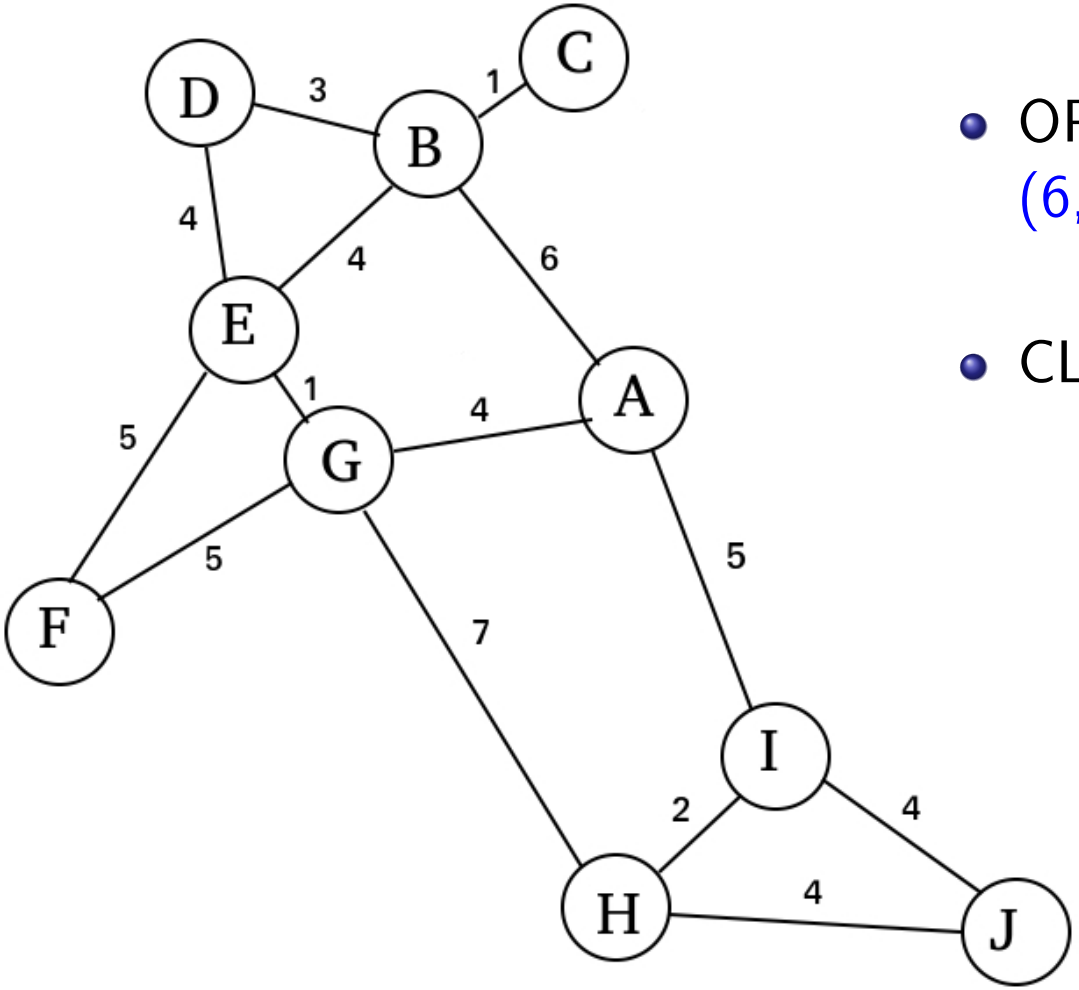
```
closedNodes = {}

# Elements sorted by priority
openNode = PriorityQueue()

openNodes.insert((0, getInitialState()))
while openNodes not empty
    cost, node = openNodes.get()
    if isGoalState(node)
        return node
    if node in closedNodes
        continue
    for childNode, actionCost in getSuccessors(node)
        if childNode not in closedNodes
            openNodes.insert((cost + actionCost, childNode))
    closedNodes.insert(node)
```

Uniform Cost Search (UCS)



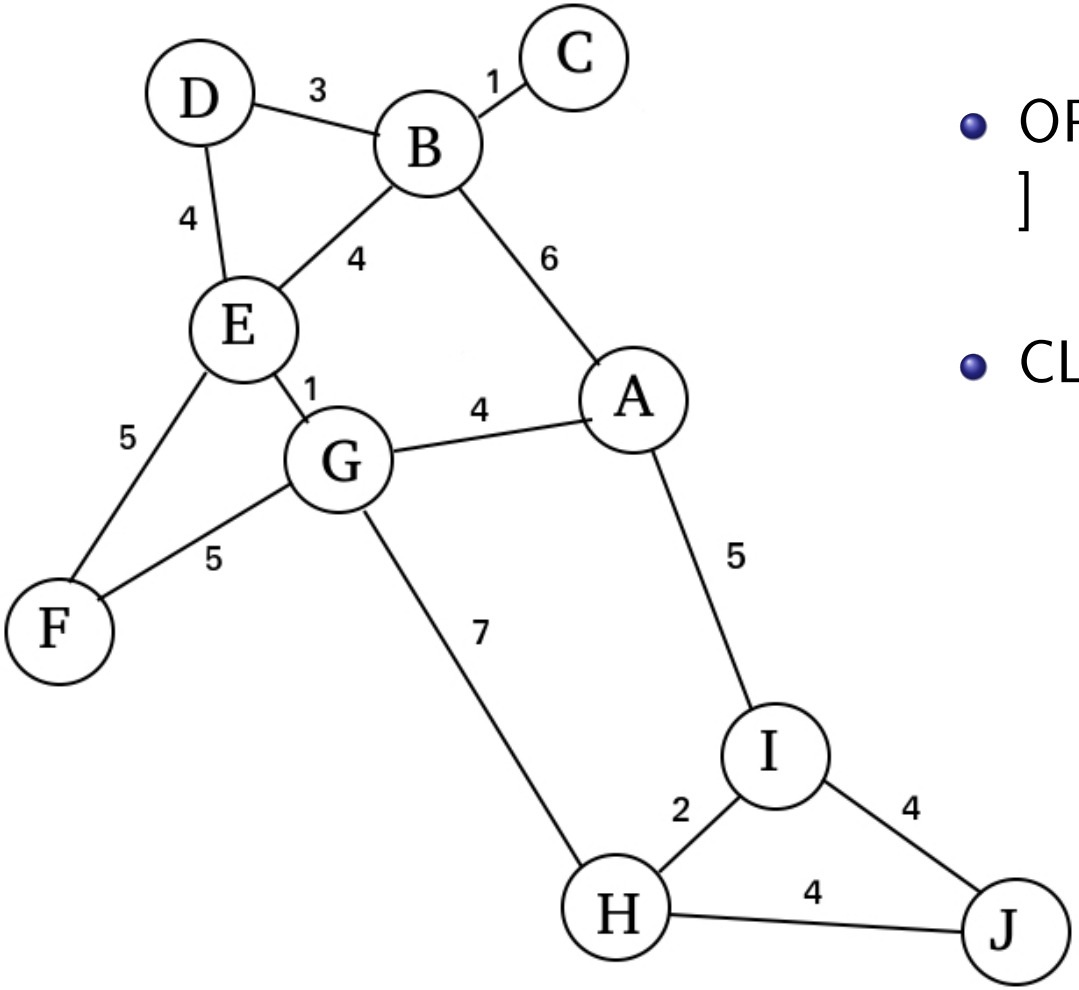
- Find a path from B to I
- OPEN: [(0, B)]
- CLOSED: {}

Uniform Cost Search (UCS)



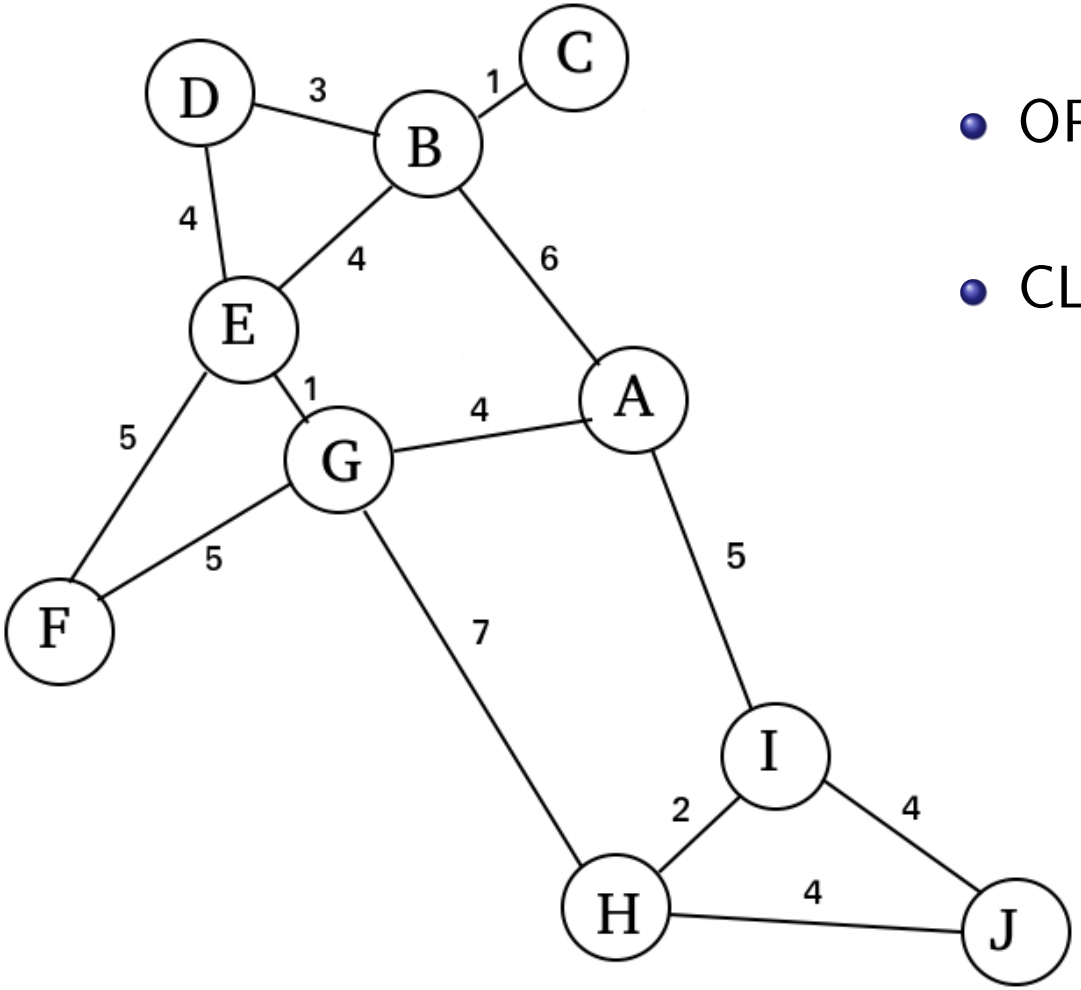
- Find a path from B to I
- OPEN: [(1, C), (3, D), (4, E), (6, A)]
- CLOSED: { B }

Uniform Cost Search (UCS)



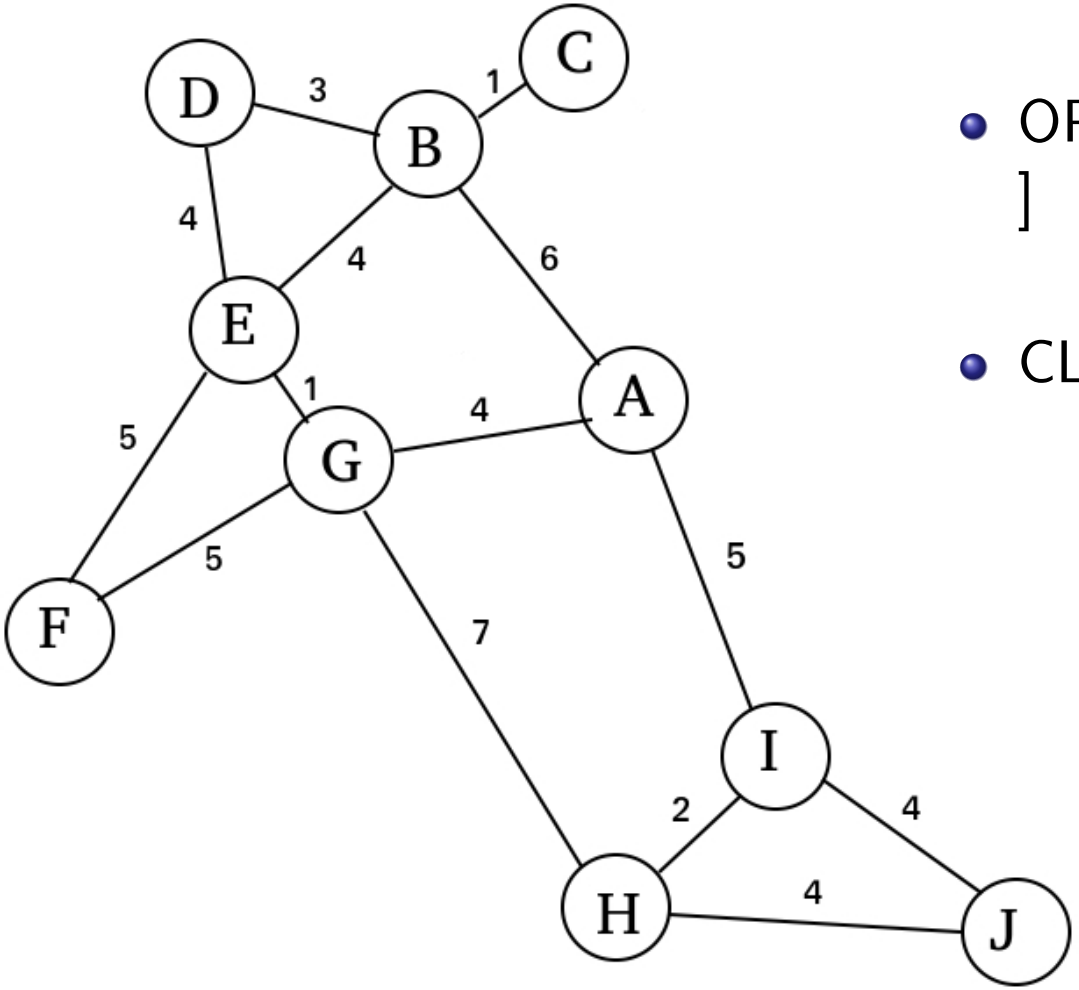
- Find a path from B to I
- OPEN: [(3, D), (4, E), (6, A)]
- CLOSED: { B, C }

Uniform Cost Search (UCS)



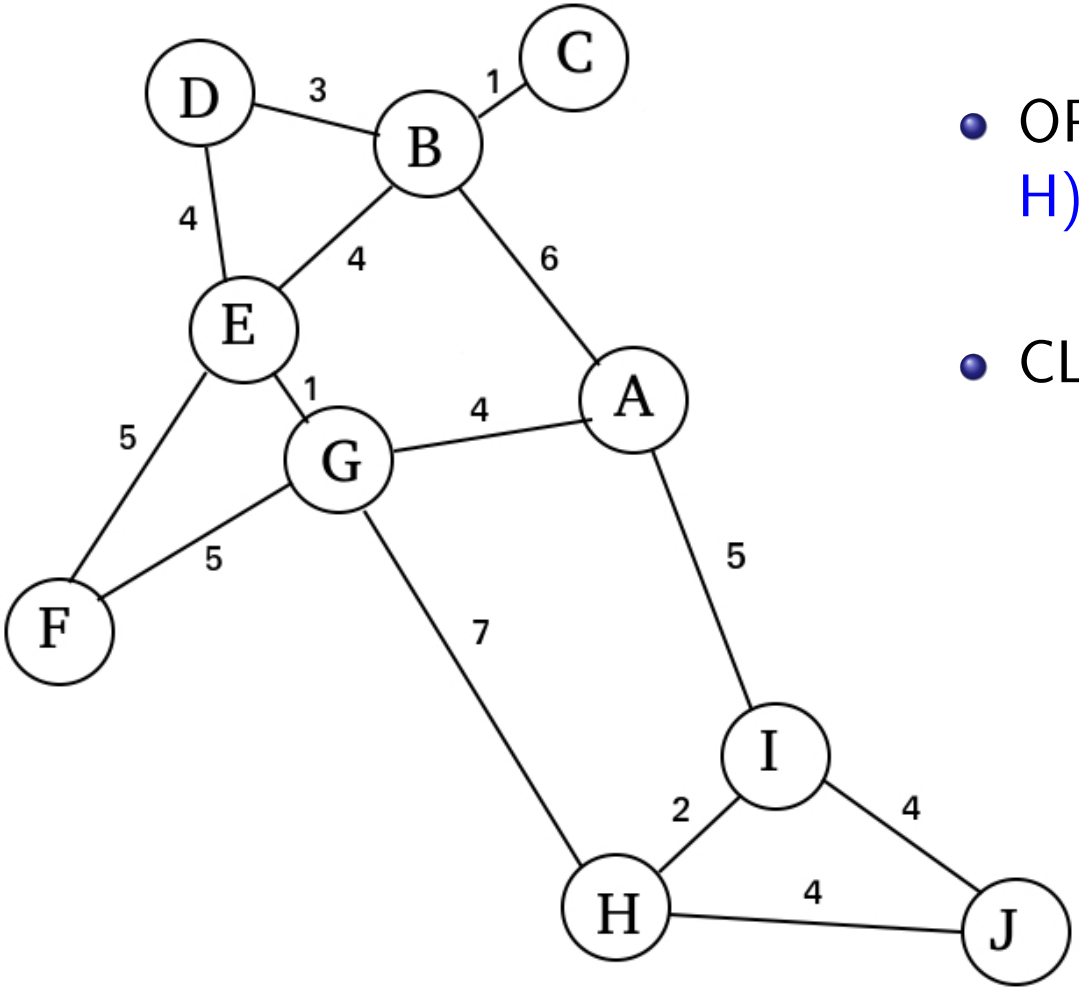
- Find a path from B to I
- OPEN: [(4, E), (6, A)]
- CLOSED: { B, C, D }

Uniform Cost Search (UCS)



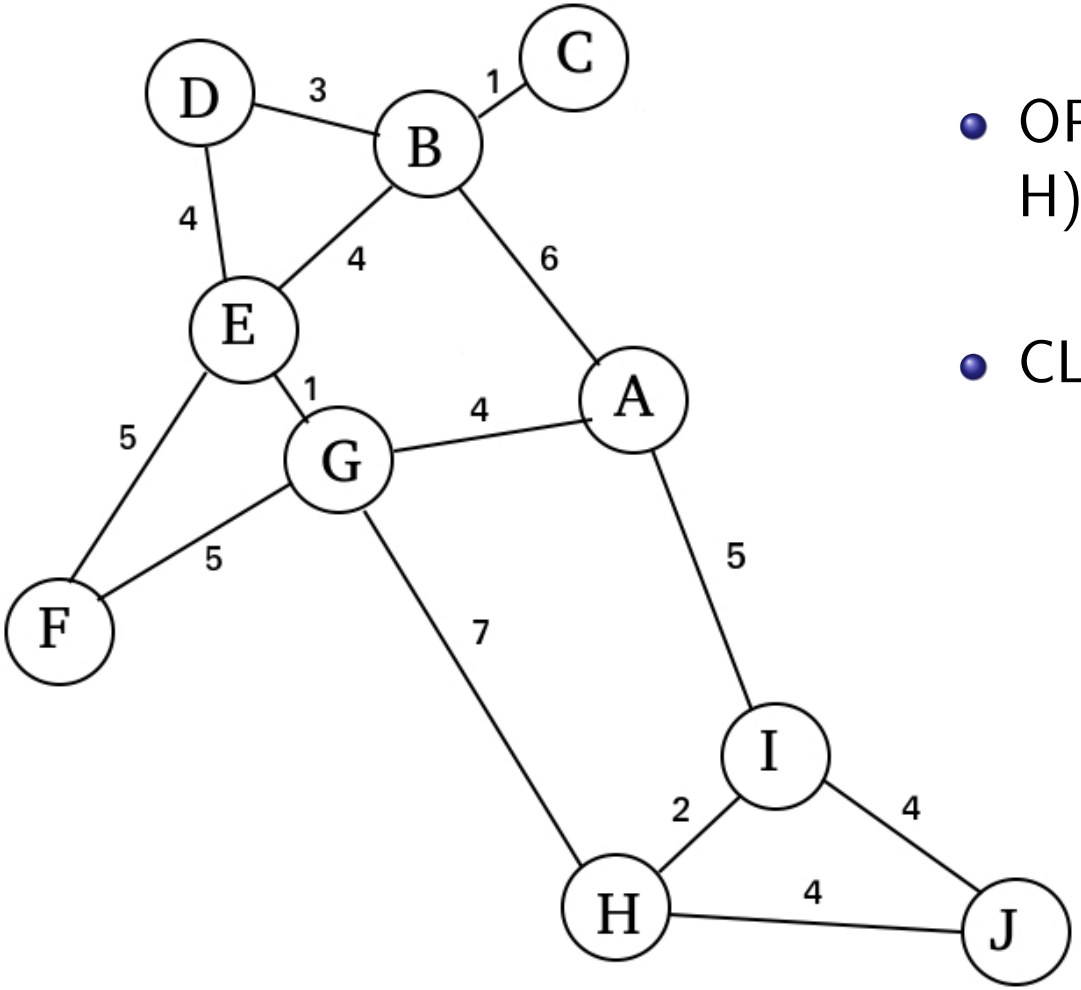
- Find a path from B to I
- OPEN: [(5, G), (6, A), (9, F)]
- CLOSED: { B, C, D, E }

Uniform Cost Search (UCS)



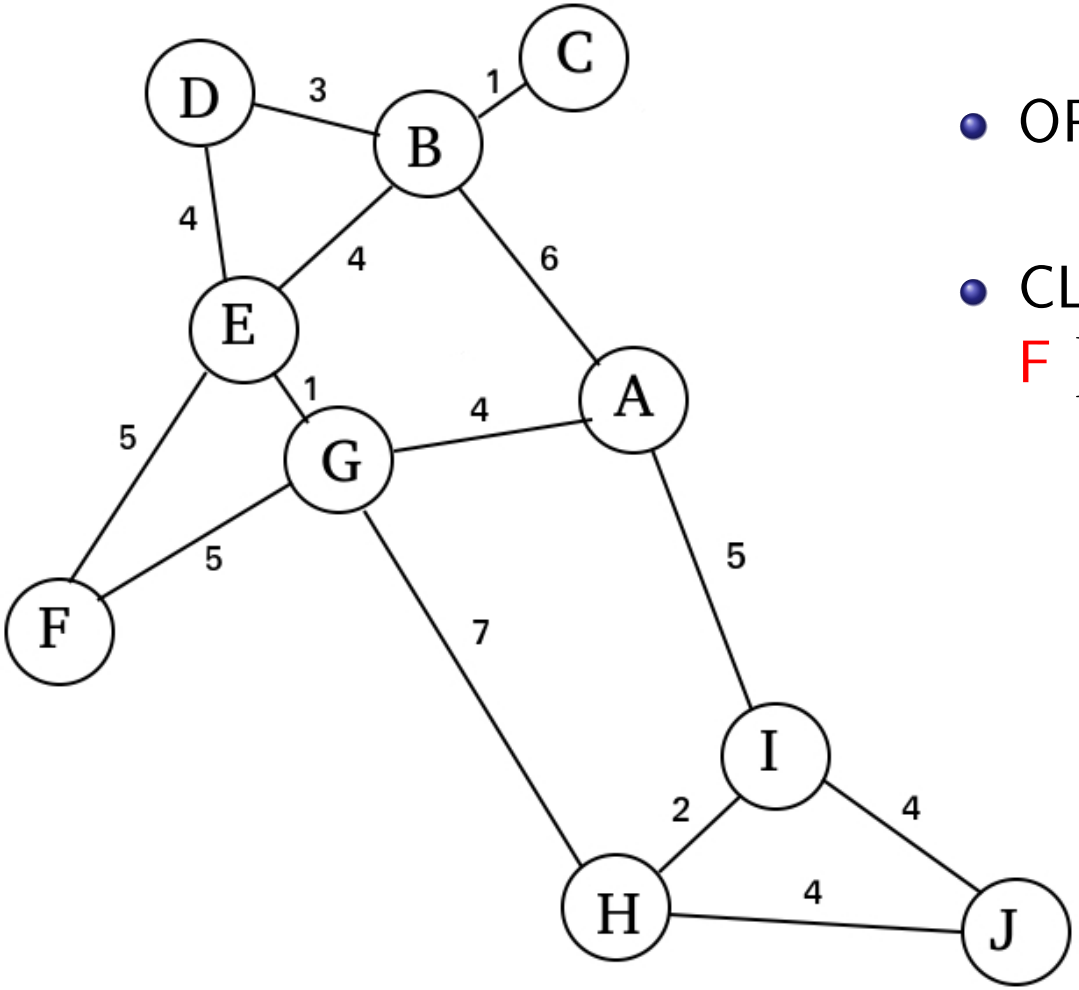
- Find a path from B to I
- OPEN: [(6, A), (9, F), (12, H)]
- CLOSED: { B, C, D, E, G }

Uniform Cost Search (UCS)



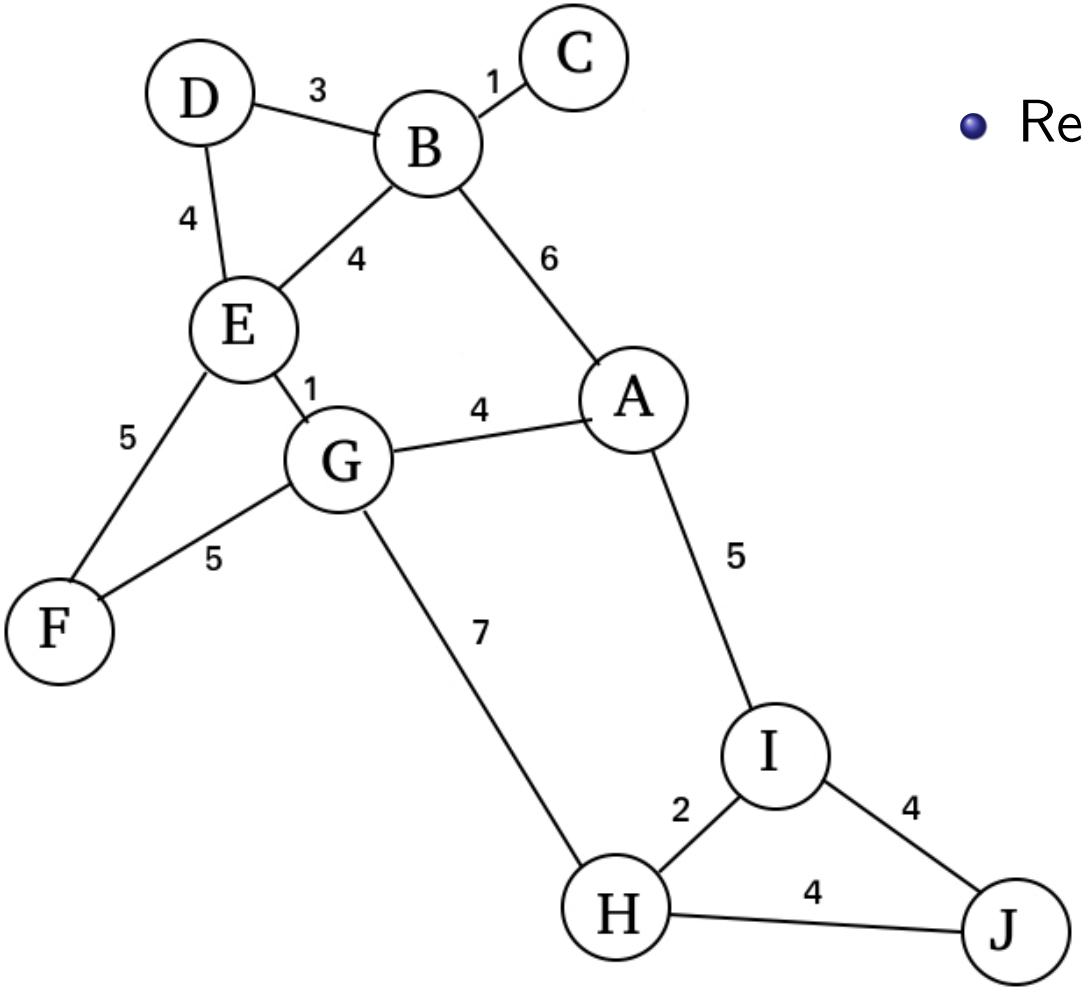
- Find a path from B to I
- OPEN: [(9, F), (11, I), (12, H)]
- CLOSED: { B, C, D, E, G, A }

Uniform Cost Search (UCS)



- Find a path from B to I
- OPEN: [(11, I), (12, H)]
- CLOSED: { B, C, D, E, G, A, F }

Uniform Cost Search (UCS)



- Find a path from B to I
- Reached goal I

Uniform Cost Search (UCS)

- Same as BFS but with variable cost transitions

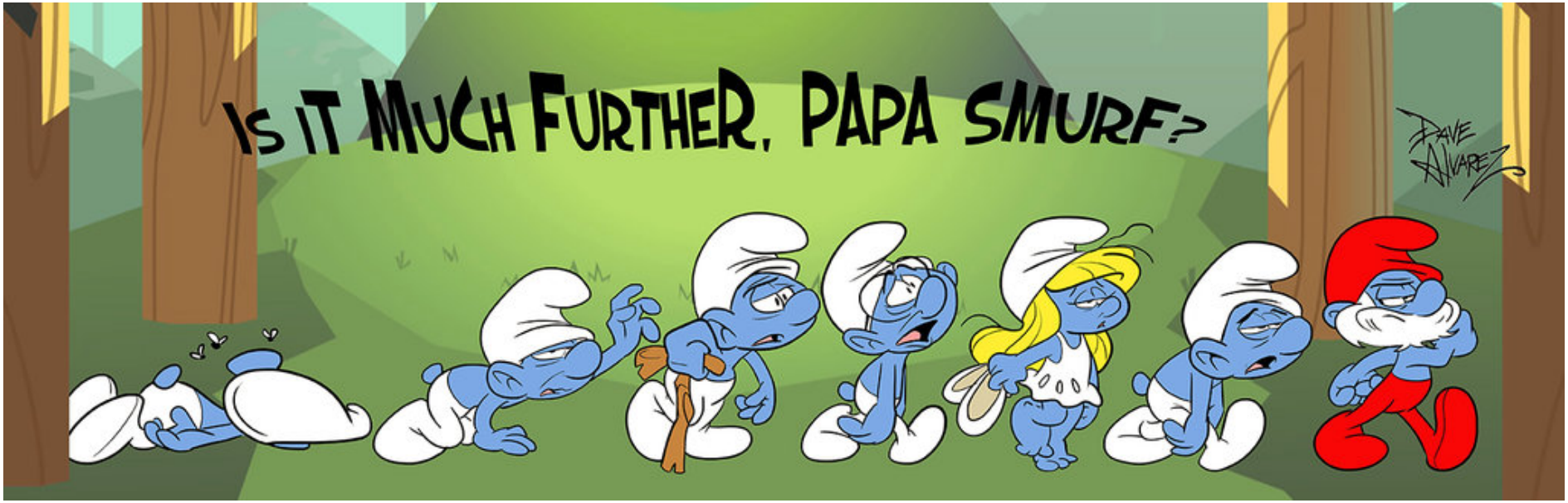
Heuristic algorithms

- You can give them some hints

Heuristic algorithms

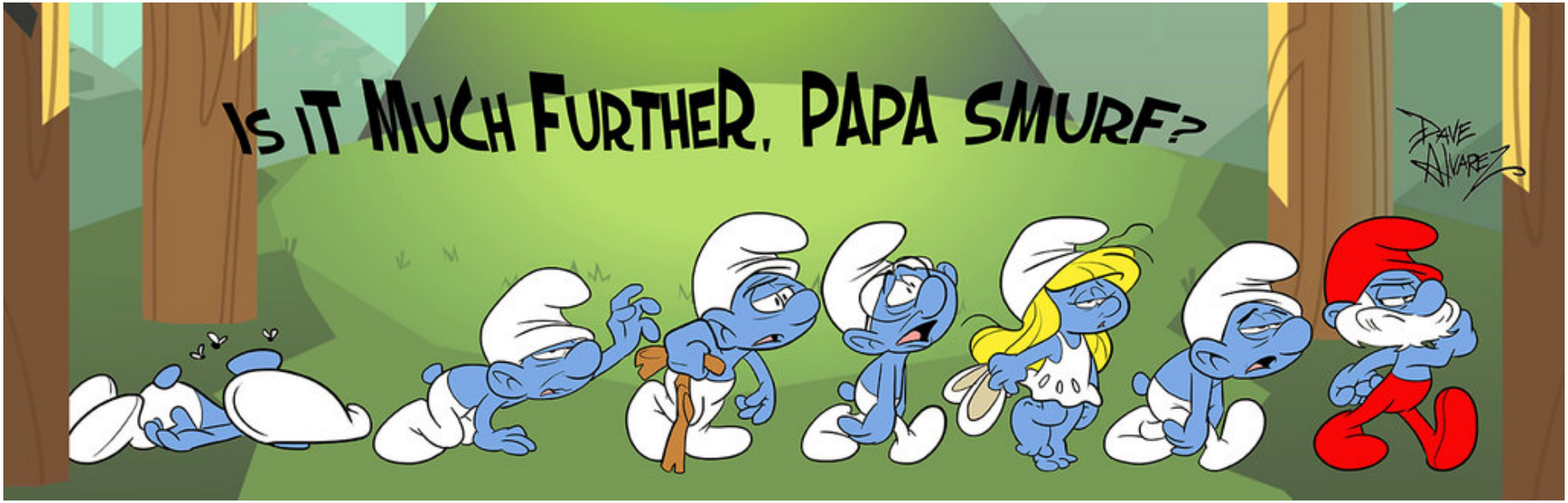
- You can give them some hints
- They may or may not listen to you though...

What is a heuristic?



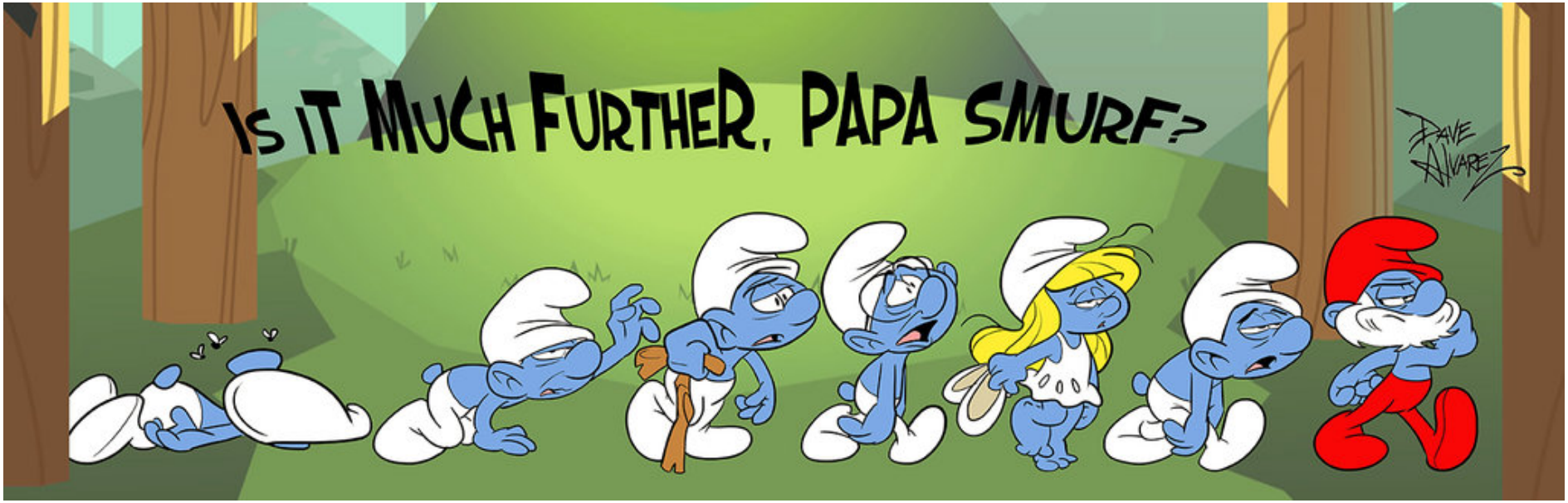
- Estimation of the distance to the goal
- Examples:

What is a heuristic?



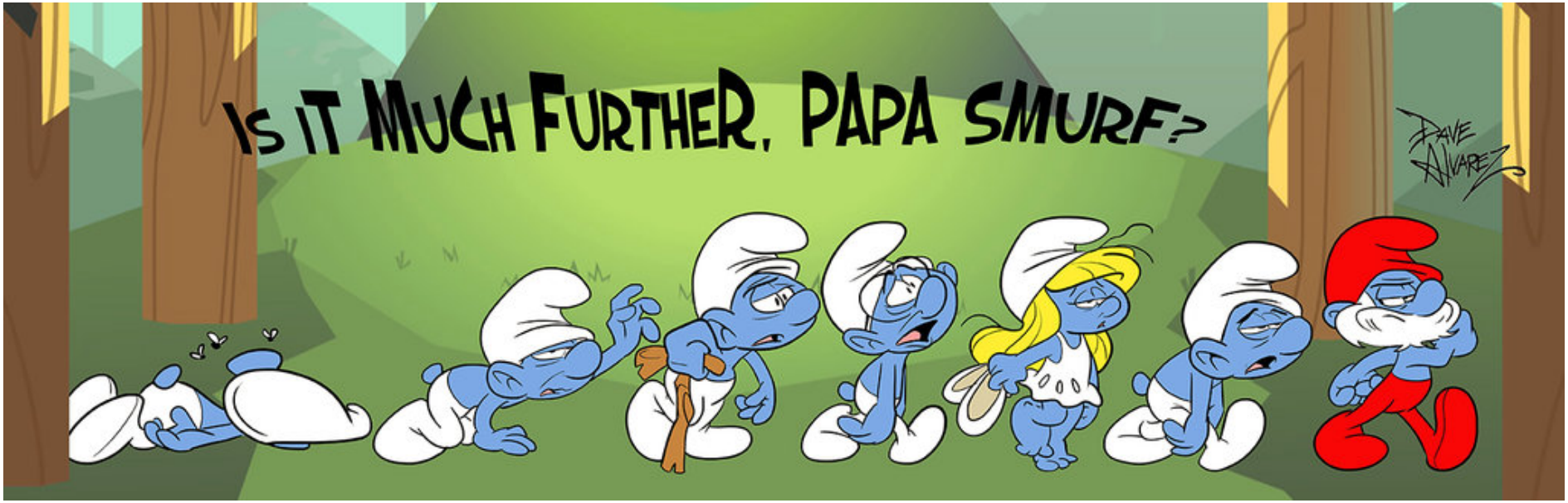
- Estimation of the distance to the goal
- Examples:
  - Manhattan distance on a grid

What is a heuristic?



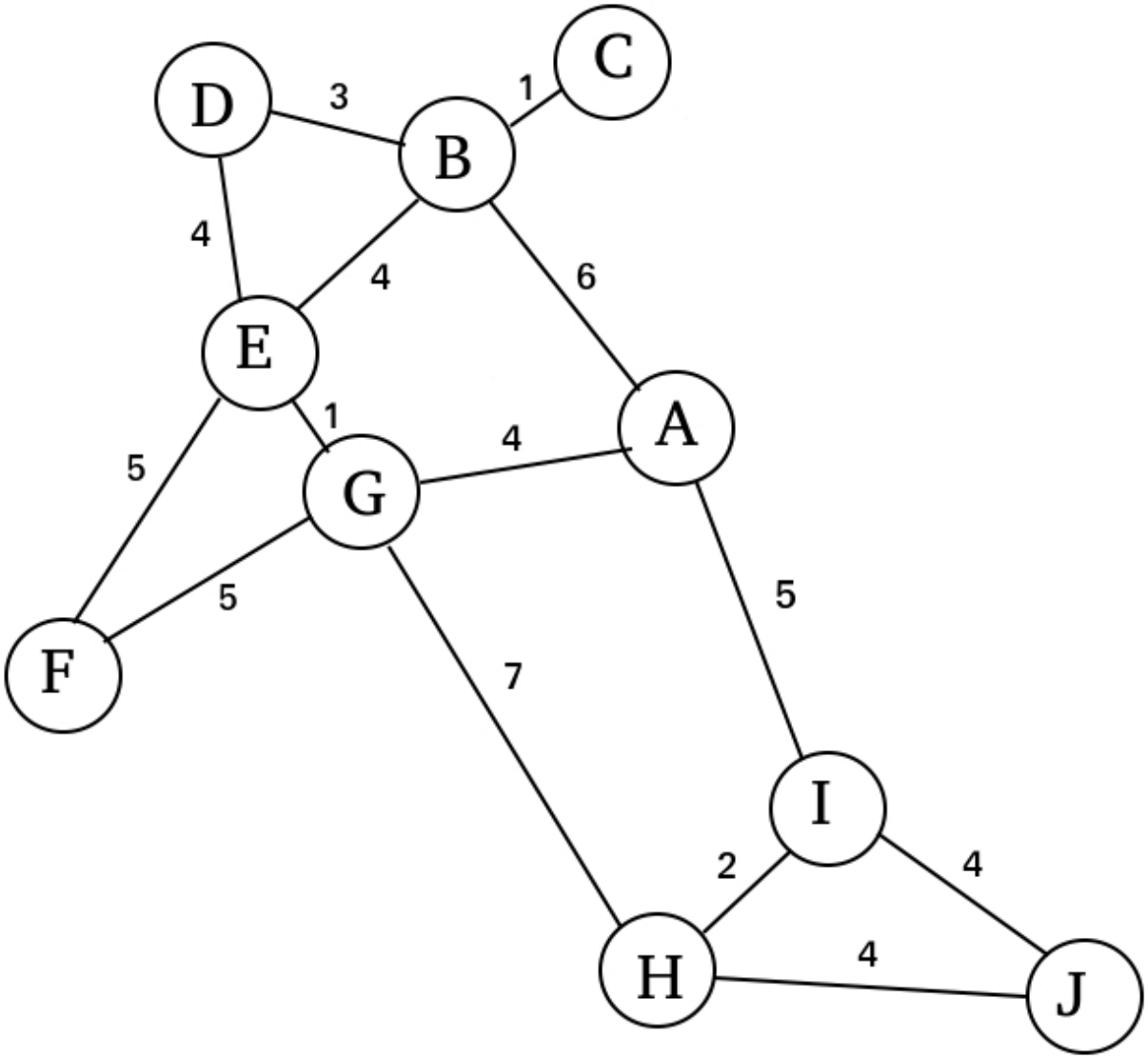
- Estimation of the distance to the goal
- Examples:
  - Manhattan distance on a grid
  - Euclidean distance (air distance) between cities

What is a heuristic?



- Estimation of the distance to the goal
- Examples:
  - Manhattan distance on a grid
  - Euclidean distance (air distance) between cities
  - In our example let's use minimal number of jumps needed to get to the goal

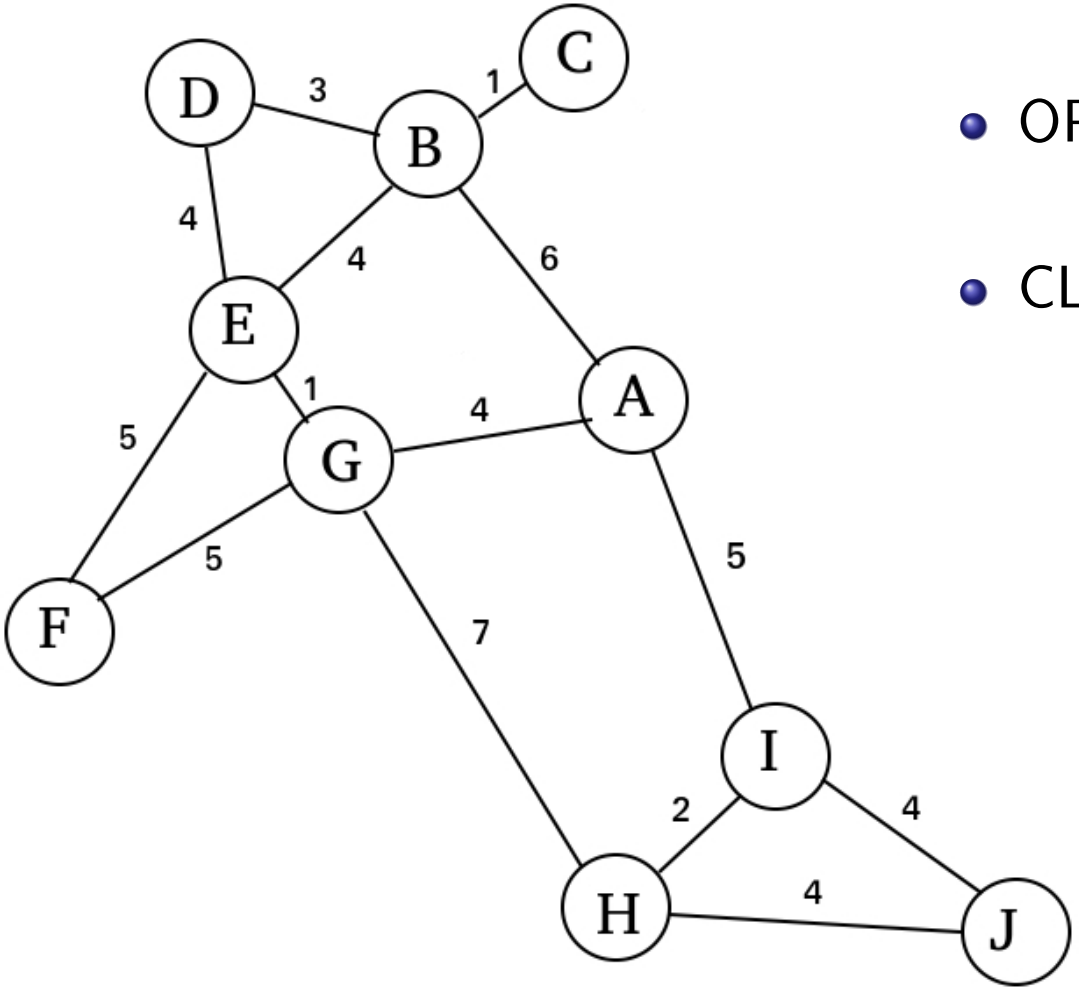
What is a heuristic?



Greedy Search

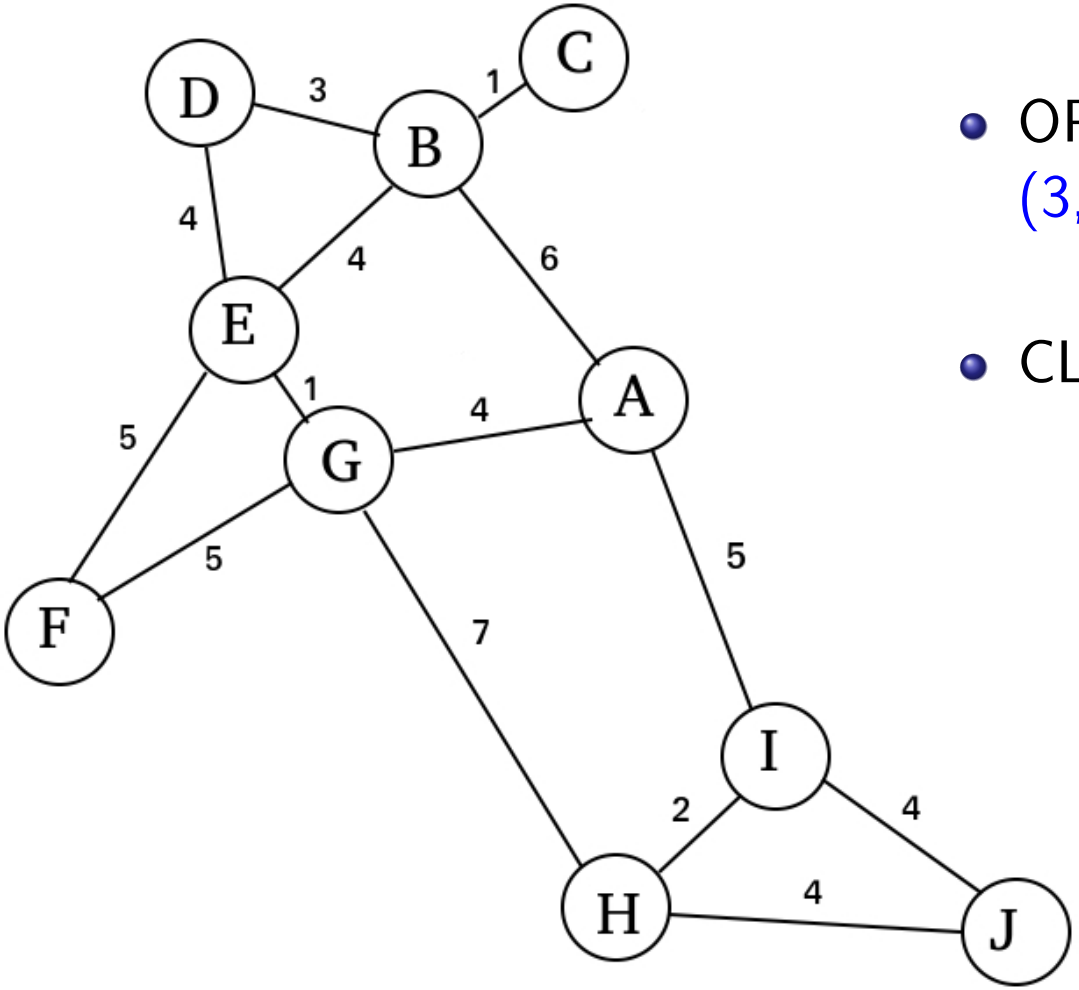
```
closedNodes = {}

# Elements sorted by priority
openNode = PriorityQueue()

openNodes.insert((0, getInitialState()))
while openNodes not empty
  cost, node = openNodes.get()
  if isGoalState(node)
    return node
  if node in closedNodes
    continue
  for childNode, actionCost in getSuccessors(node)
    if childNode not in closedNodes
      openNodes.insert((h(childNode), childNode))
  closedNodes.insert(node)
```

Greedy Search



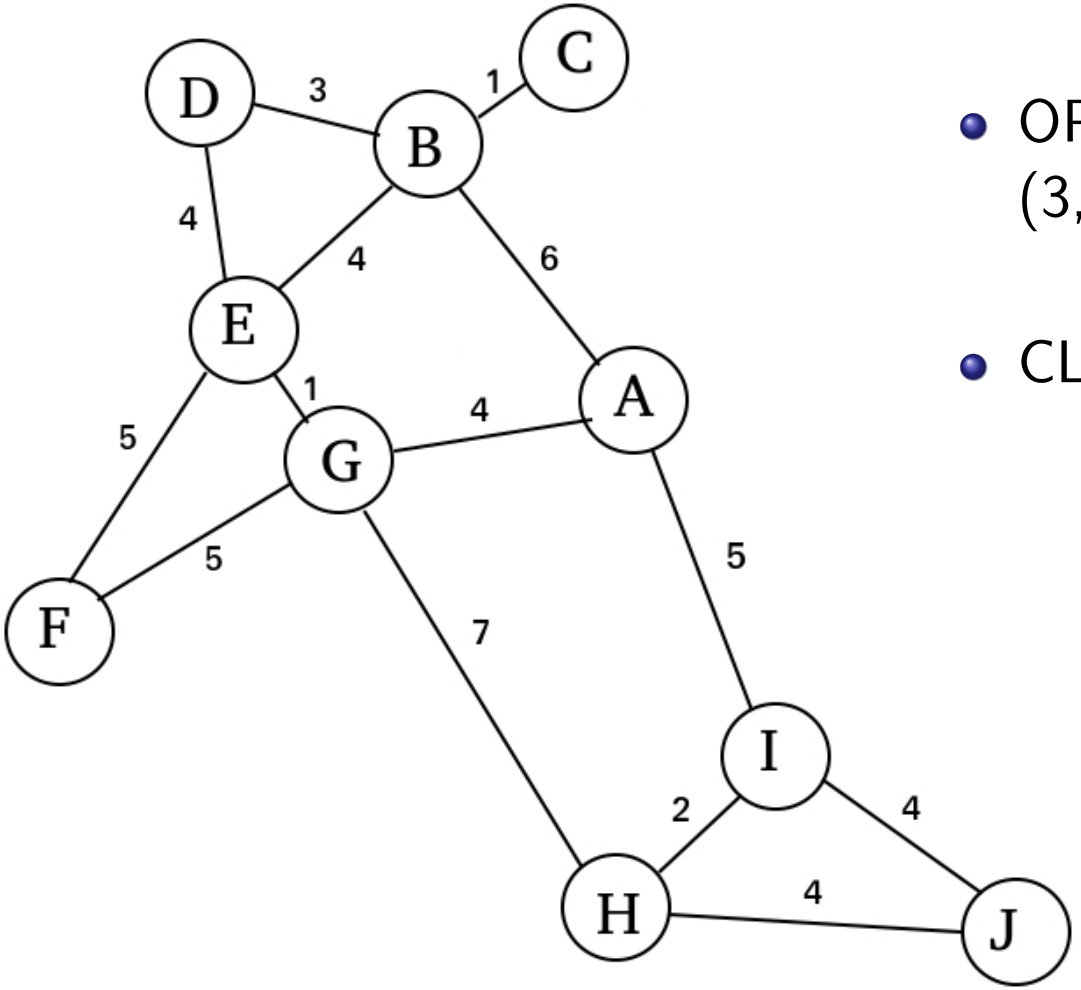
- Find a path from B to I
- OPEN: [(0, B)]
- CLOSED: {}

Greedy Search



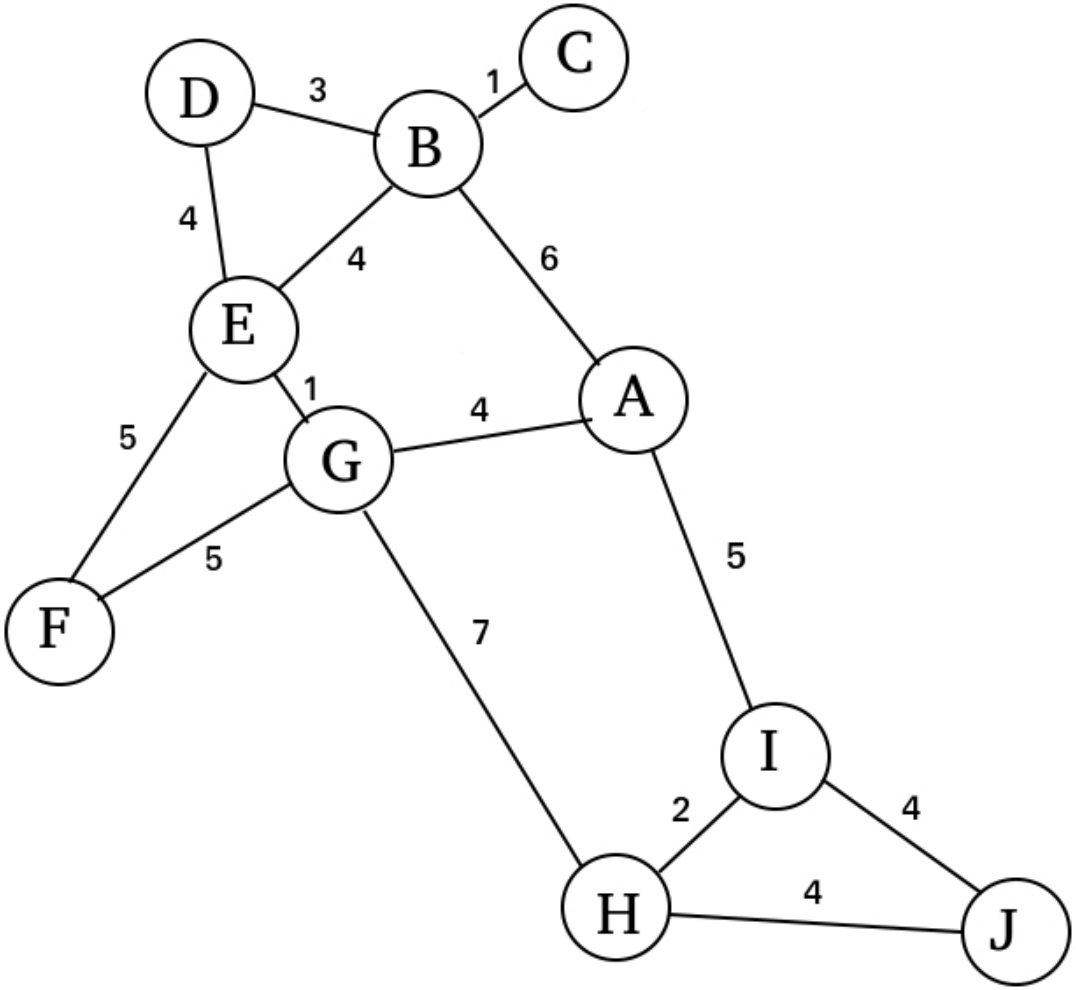
- Find a path from B to I
- OPEN: [(1, A), (3, D), (3, E), (3, C)]
- CLOSED: { B }

Greedy Search



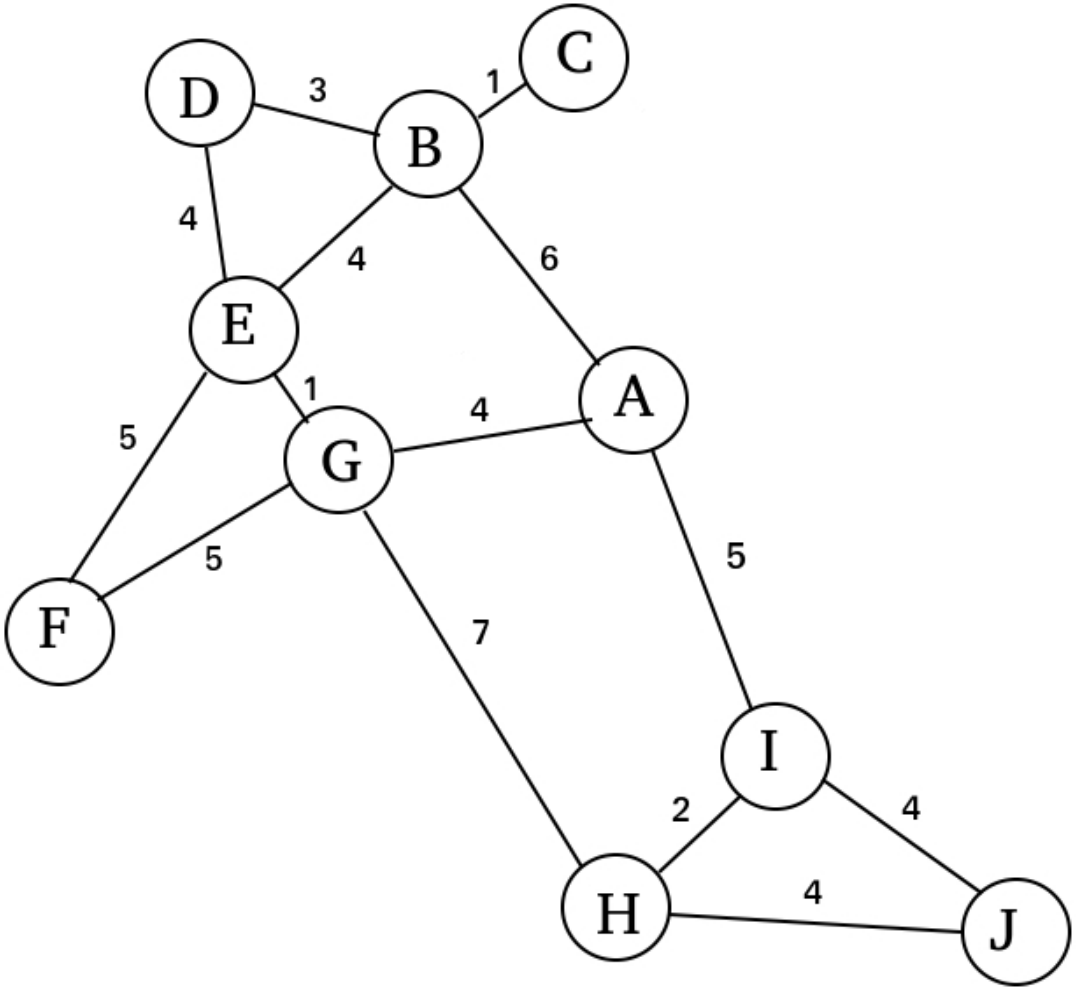
- Find a path from B to I
- OPEN: [(0, I), (3, D), (3, E), (3, C)]
- CLOSED: { B, A }

Greedy Search



- Find a path from B to I

Greedy Search



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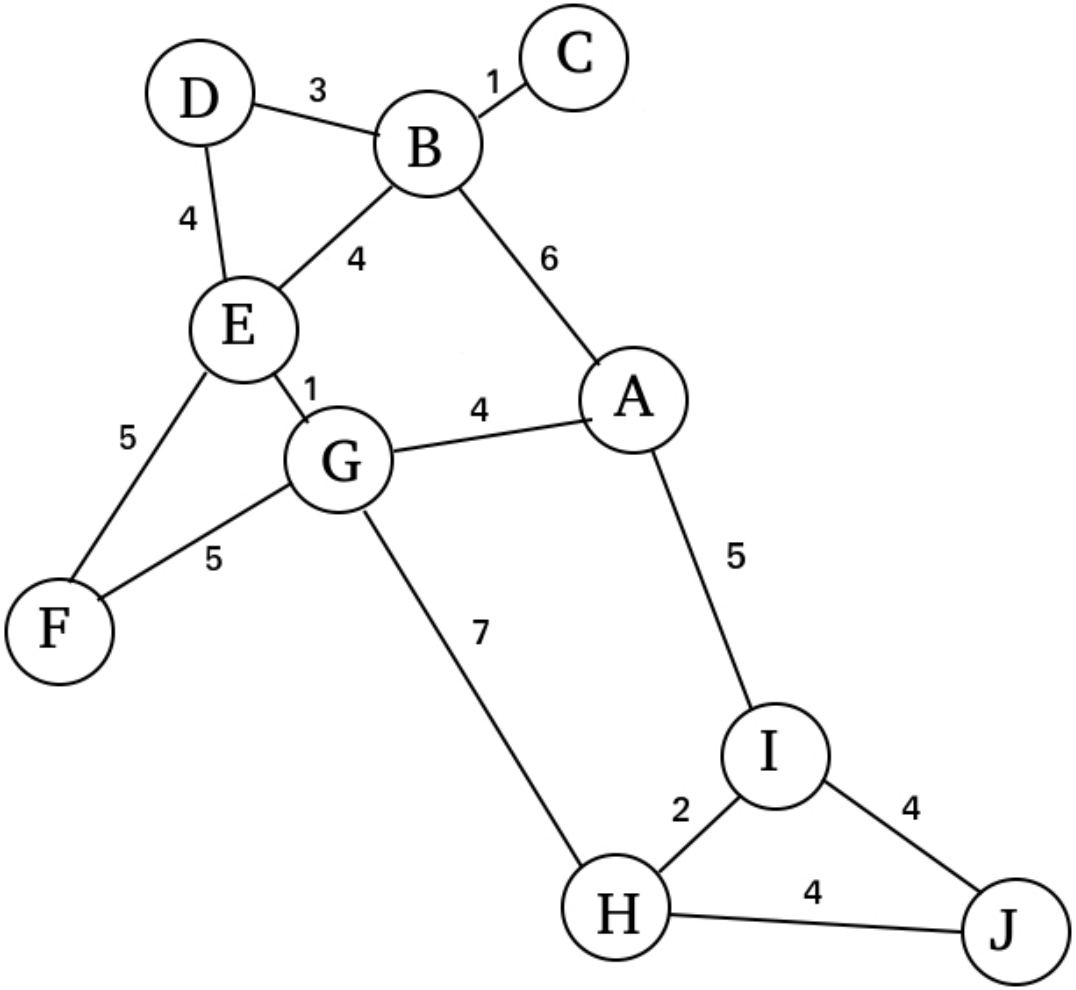

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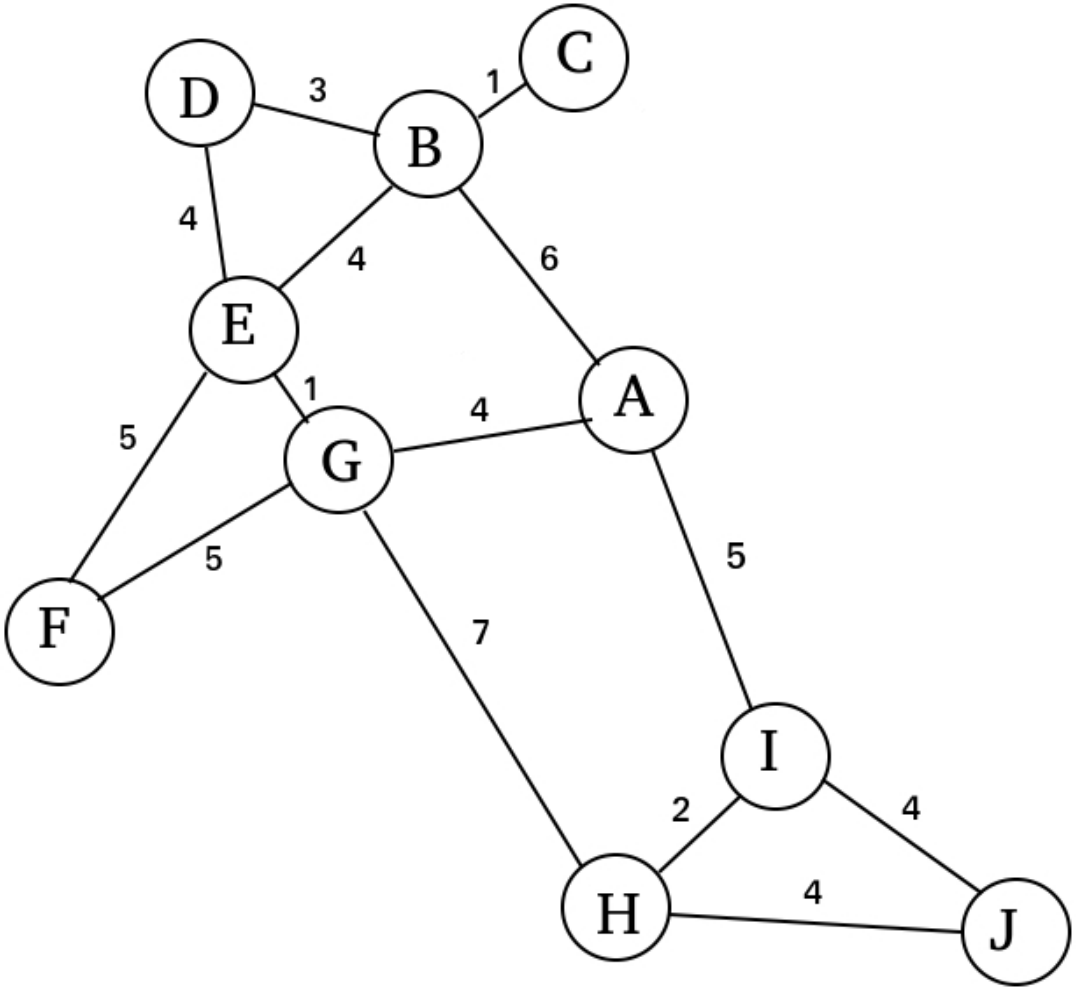
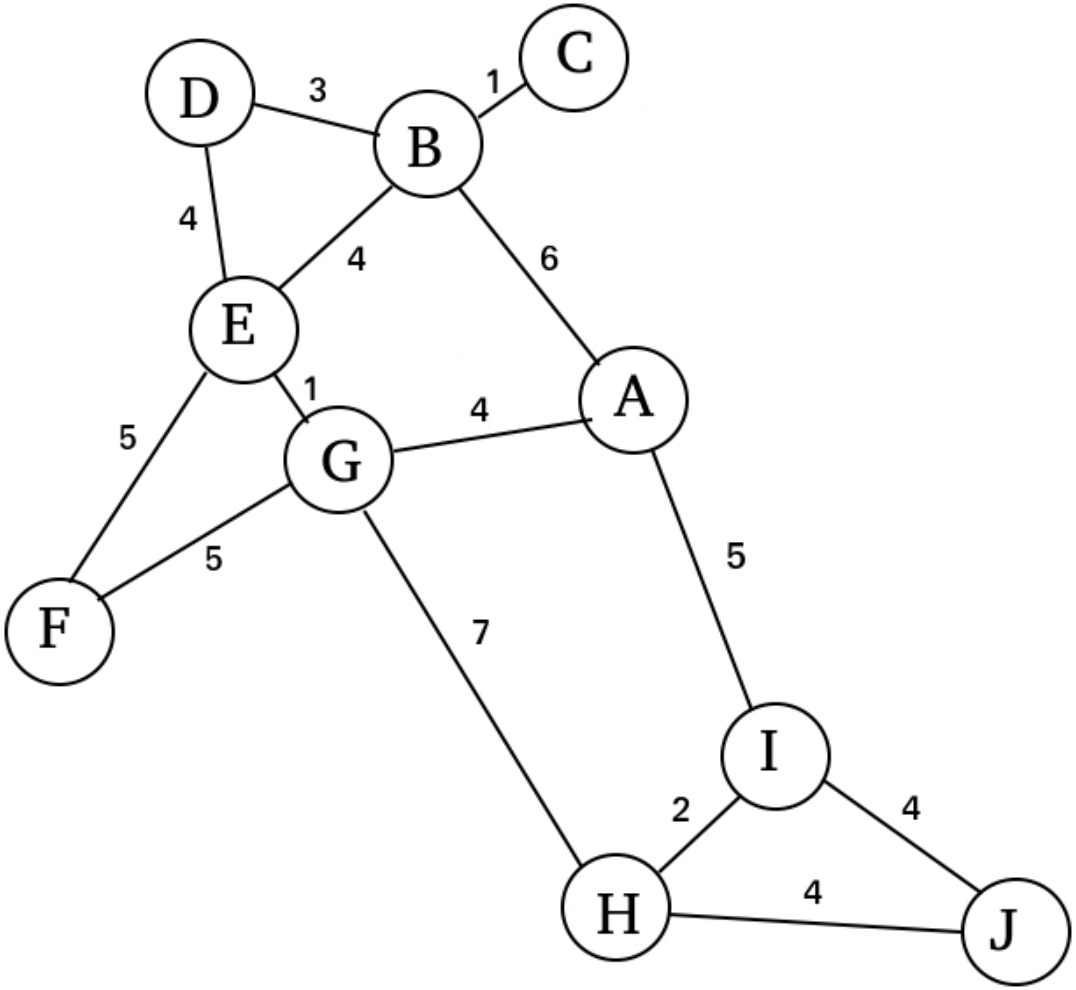
Greedy Search



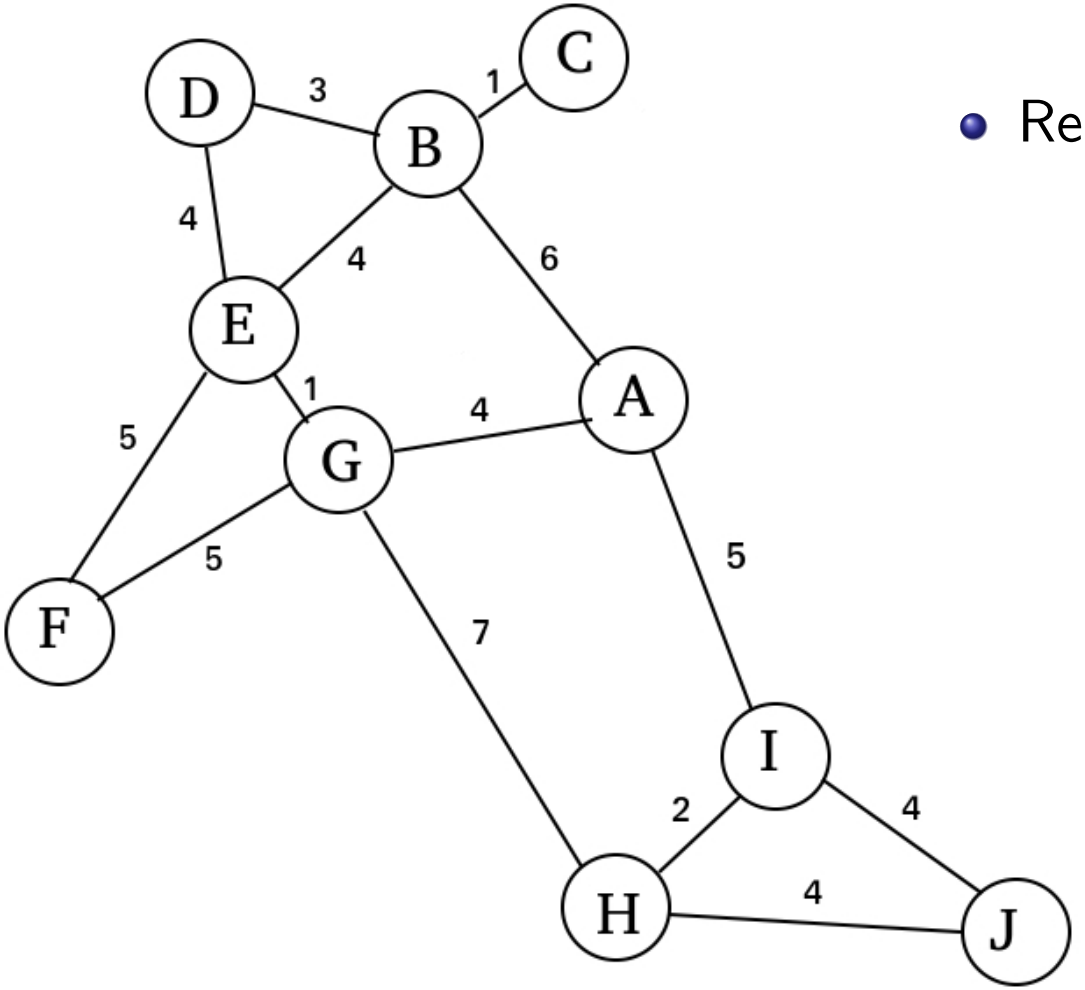
- Find a path from B to I

Greedy Search



- Find a path from B to I

Greedy Search



- Find a path from B to I
- Reached goal I

Greedy Search

- The good:

Greedy Search

- The good:
  - Always finds the solution (when taking care not to revisit states multiple times)
  - Quickly finds a solution

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- The good:
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- The bad:
  - Not the optimal solution though

Greedy Search

- The good:
  - Always finds the solution (when taking care not to revisit states multiple times)
  - Quickly finds a solution
- The bad:
  - Not the optimal solution though
- The ugly:

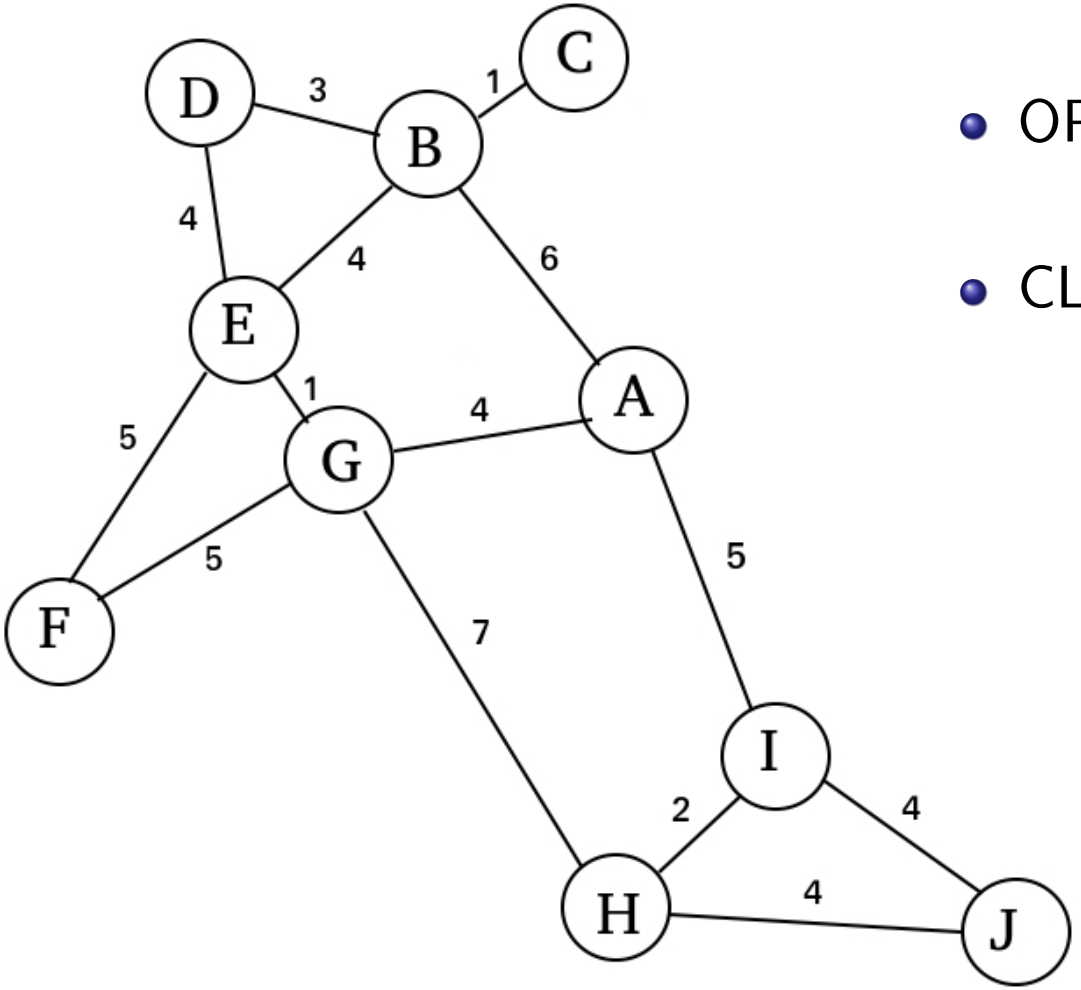
Greedy Search

- The good:
  - Always finds the solution (when taking care not to revisit states multiple times)
  - Quickly finds a solution
- The bad:
  - Not the optimal solution though
- The ugly:
  - Trusts you a bit too much...

A* Search

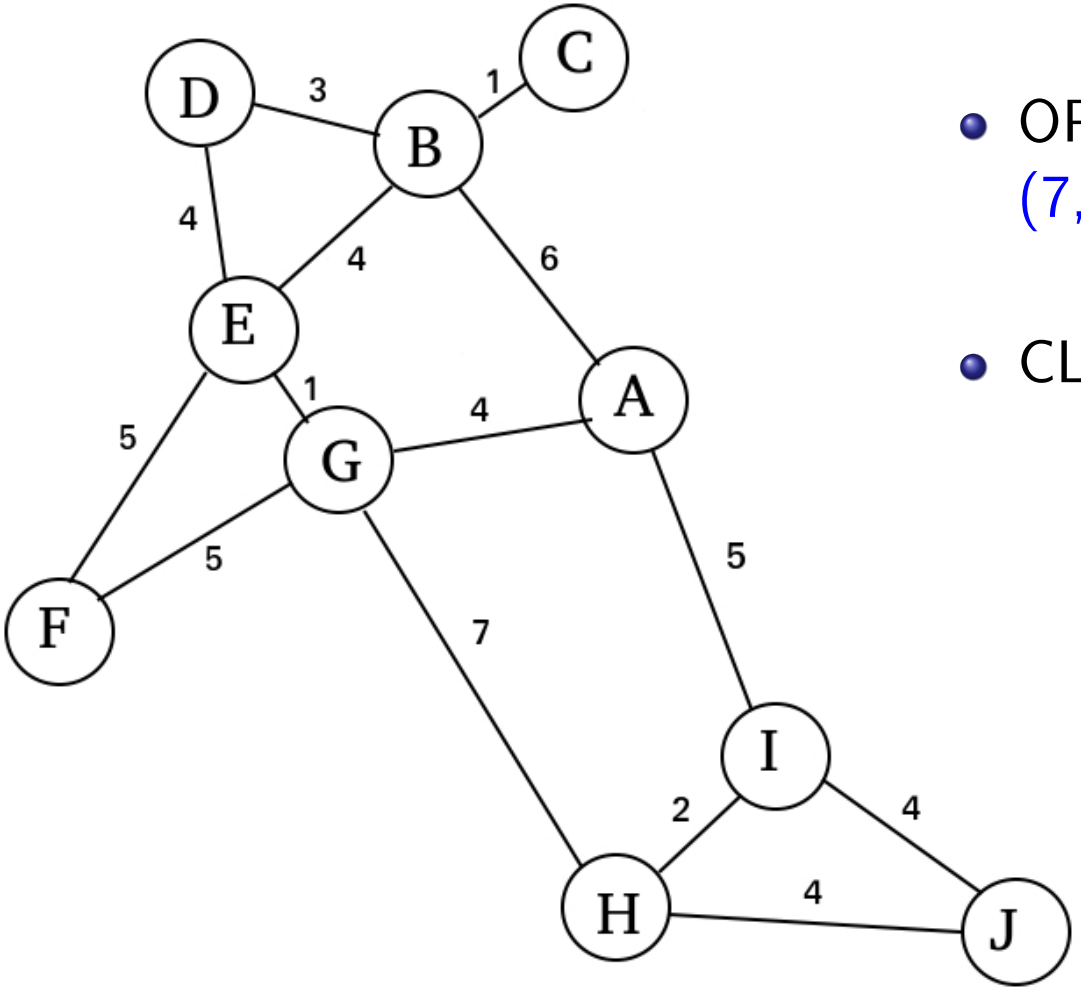
```
closedNodes = {}

# Elements sorted by priority
openNode = PriorityQueue()

openNodes.insert((0, 0, getInitialState()))
while openNodes not empty
   _, cost, node = openNodes.get()
   if isGoalState(node)
      return node
   if node in closedNodes
      continue
   for childNode, actionCost in getSuccessors(node)
      if childNode not in closedNodes
         totalCost = actionCost + cost
         openNodes.insert((totalCost + h(childNode), totalCost,
            childNode))
```

A* Search



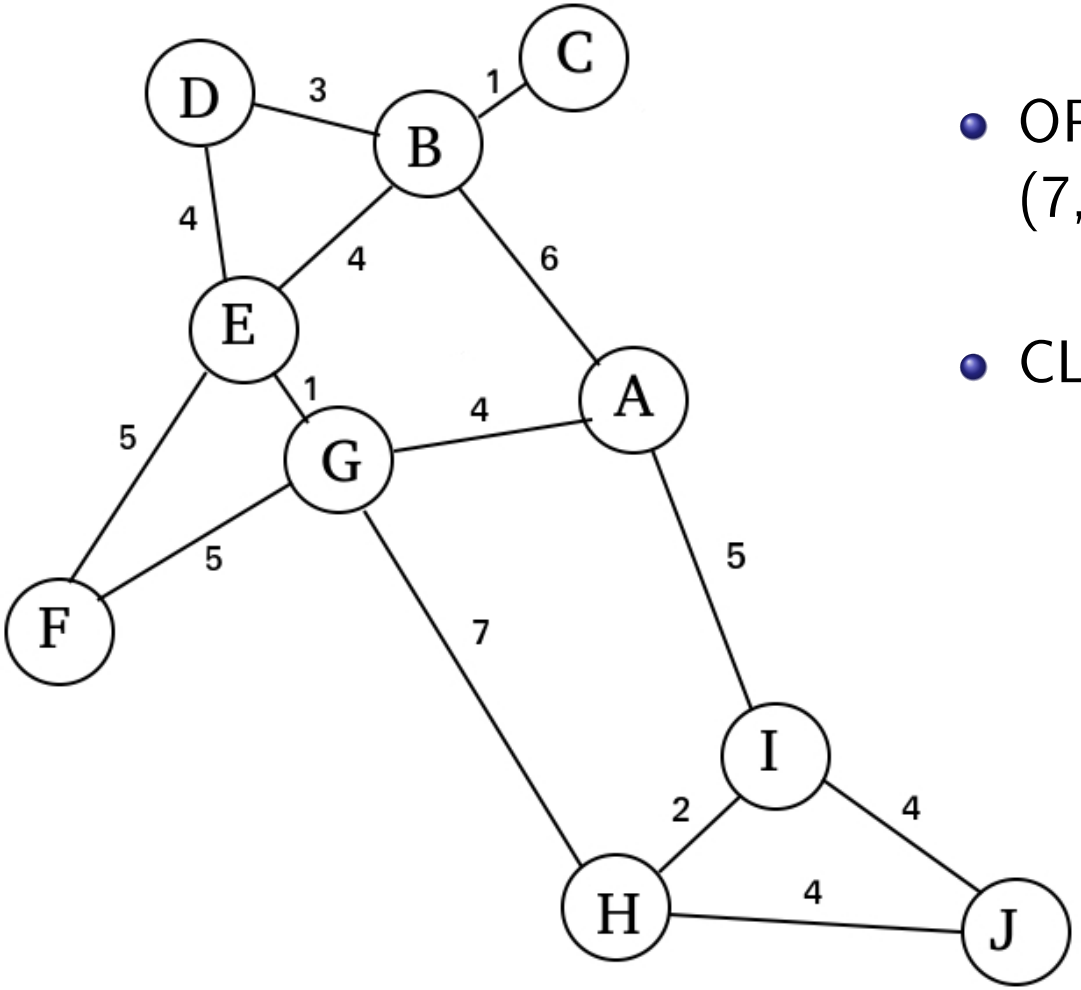
- Find a path from B to I
- OPEN: [(0, 0, B)]
- CLOSED: {}

A* Search



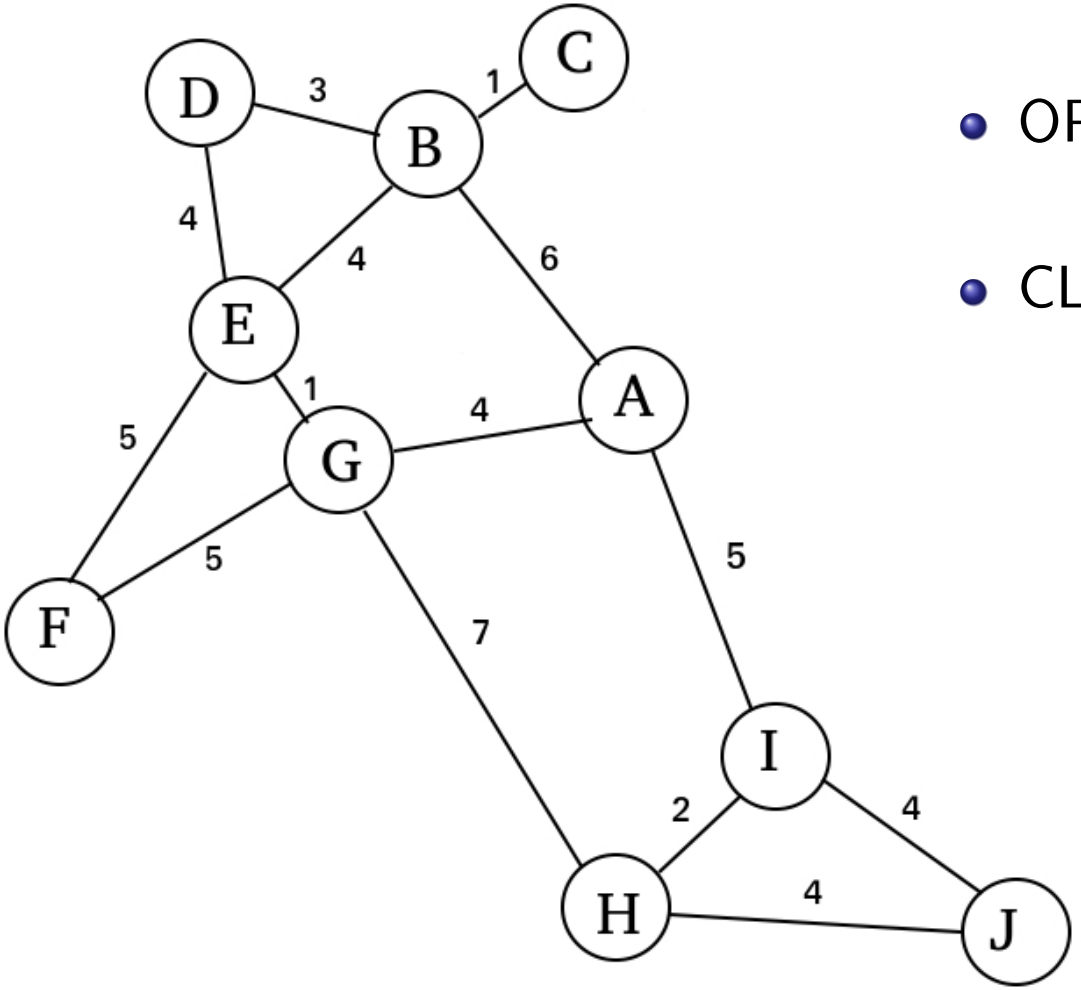
- Find a path from B to I
- OPEN: [(4, 1, C), (6, 3, D), (7, 4, E), (7, 6, A)]
- CLOSED: { B }

A* Search



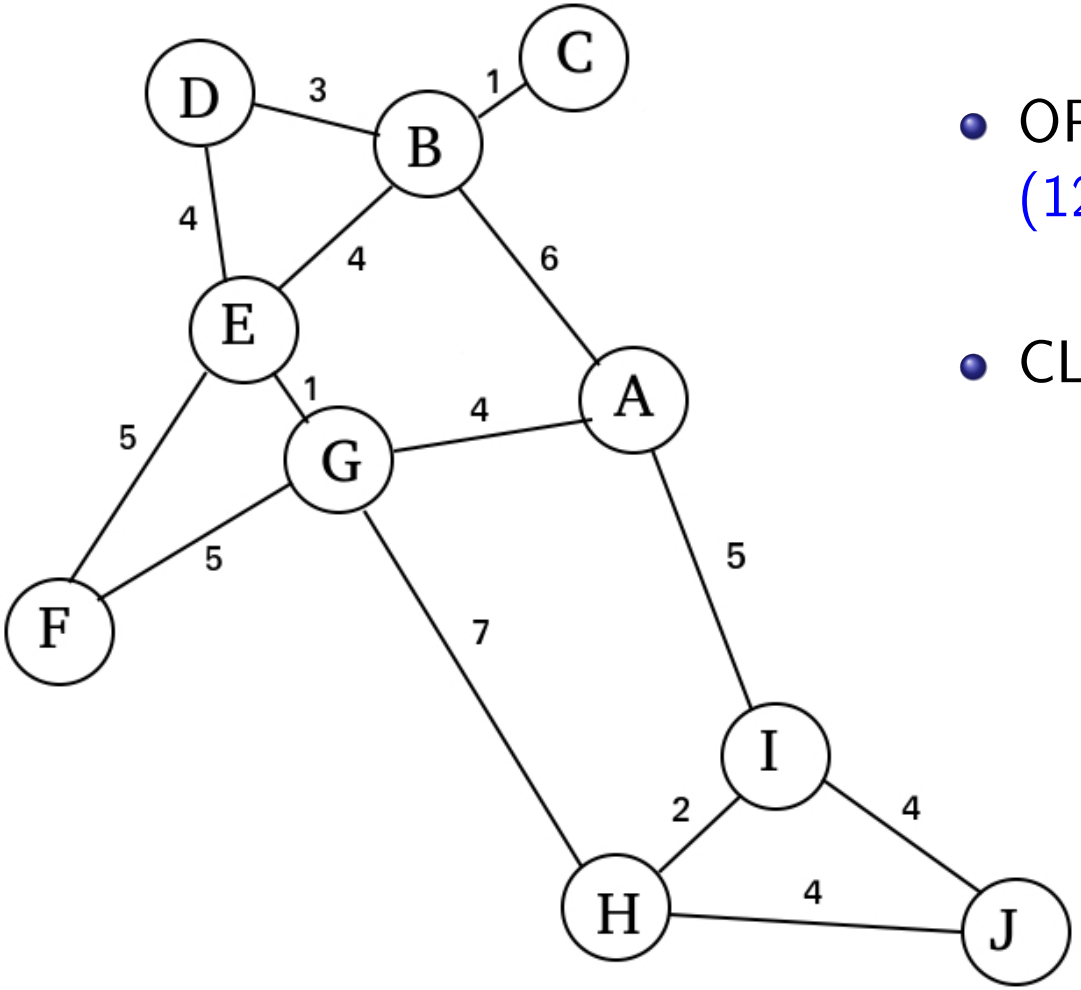
- Find a path from B to I
- OPEN: [(6, 3, D), (7, 4, E), (7, 6, A)]
- CLOSED: { B, C }

A* Search



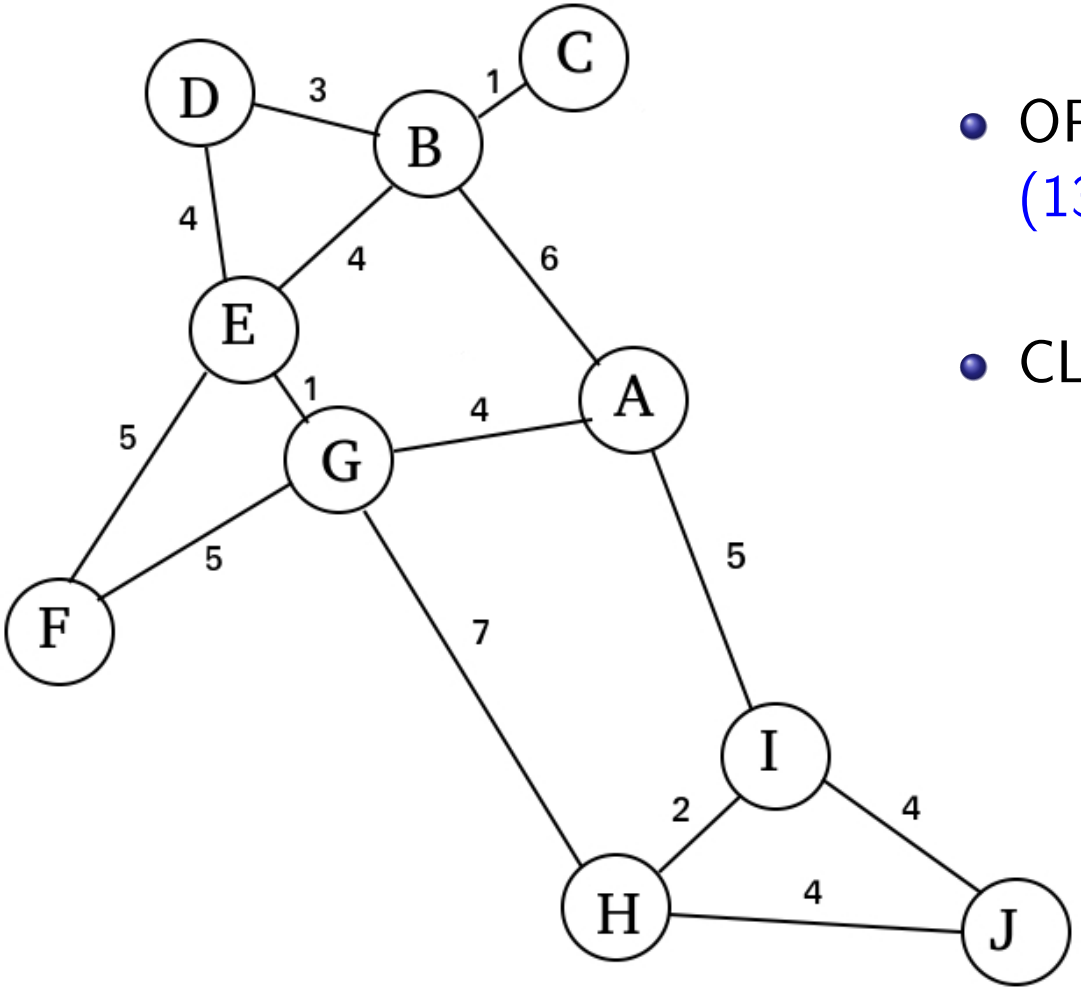
- Find a path from B to I
- OPEN: [(7, 4, E), (7, 6, A)]
- CLOSED: { B, C, D }

A* Search



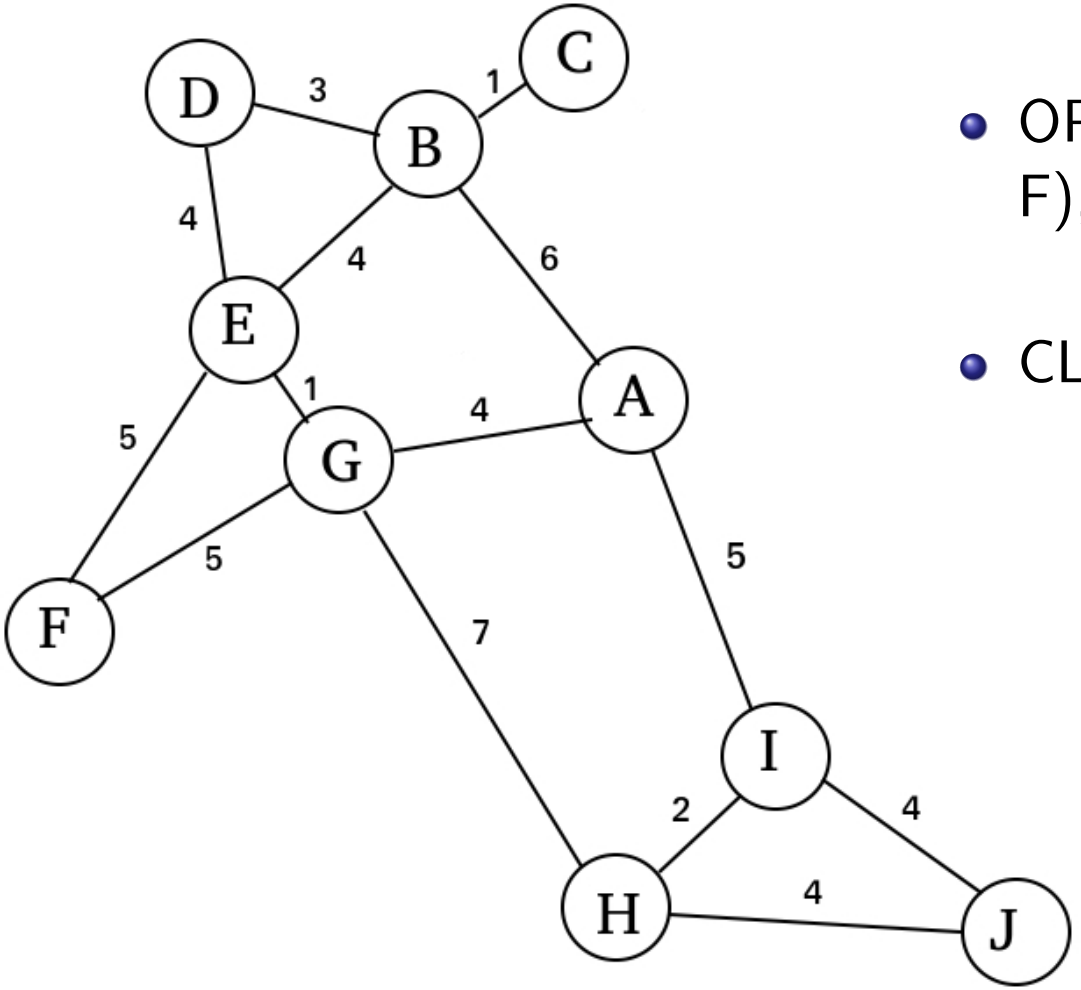
- Find a path from B to I
- OPEN: [(7, 5, G), (7, 6, A), (12, 9, F)]
- CLOSED: { B, C, D, E }

A* Search



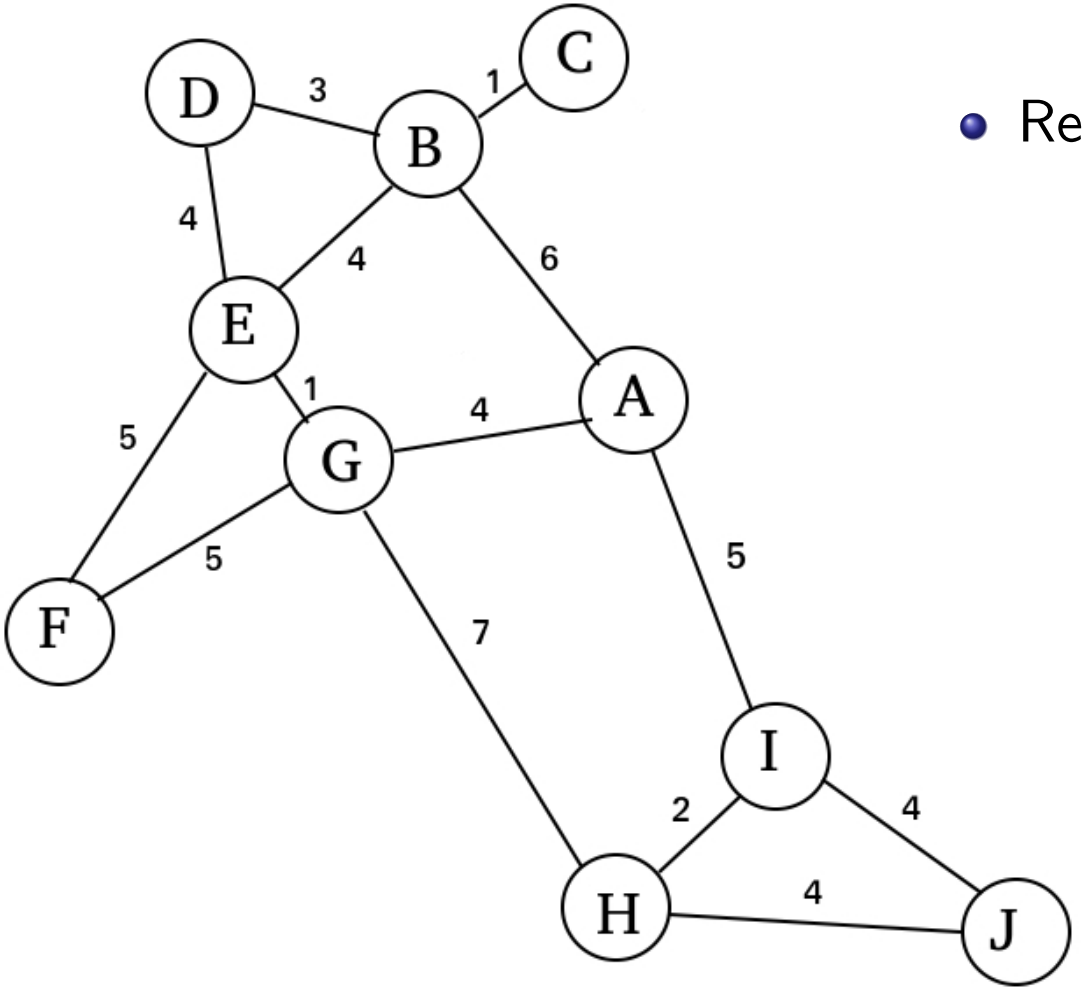
- Find a path from B to I
- OPEN: [(7, 6, A), (12, 9, F), (13, 12, H)]
- CLOSED: { B, C, D, E, G }

A* Search



- Find a path from B to I
- OPEN: [(11, 11, I), (12, 9, F), (13, 12, H)]
- CLOSED: { B, C, D, E, G, A }

A* Search



- Find a path from B to I
- Reached goal I

Greedy Search

- Always finds the solution
- If the given heuristic is **optimistic** the solution is optimal

Live demonstration

Is there anything better?

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Well...depends...

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- Dijkstra's algorithm (same as UCS but without an exact "goal") - mostly used in networking

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- D* search and variations - mostly used in robotics

Is there anything better?

Well...depends...

- Dijkstra's algorithm (same as UCS but without an exact "goal") - mostly used in networking
- D* search and variations - mostly used in robotics
- A* search and variations - most often the best solution for a video game pathfinding

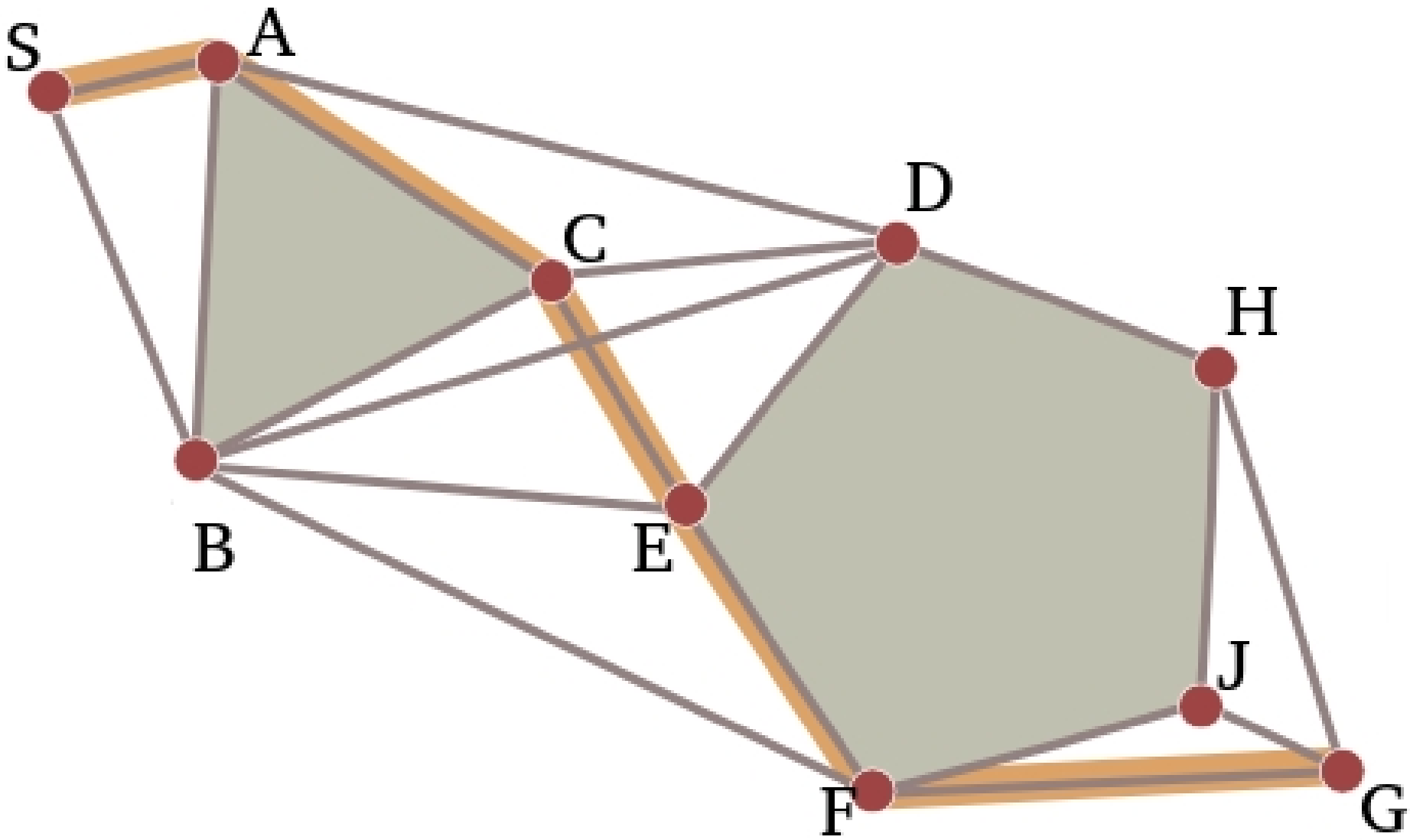
Pathfinding in video games

Alright there's an obvious grid...

Pathfinding in video games

...now what?

Visibility graph



Divide and conquer

- Divide the whole grid into several smaller pieces
- Agents don't need to find a path on the whole grid at once
- Easier to modify the graph in case of frequent smaller changes in the terrain

Any questions?

Plz no difficult ones