COMP 3200
Artificial Intelligence

Lecture 3

Problem Solving and Search

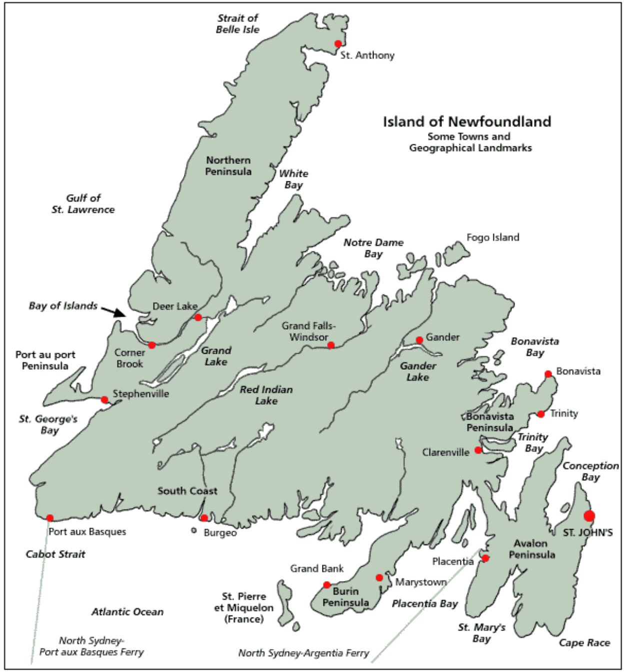
MEMORIAL UNIVERSITY

Problem Solving Agents

- Rational agents maximize performance
- Simplest Case: Satisfy a goal condition
  - Reach the end of a maze
  - Solve a puzzle
- Problem Solving Agent
  - Type of Goal-Based Agent
  - Find a sequence of actions that satisfies goal

Example Scenario

- Tourist comes to NL
  - Lands in St. John's
- Wants to go to one of:
  - St. Anthony
  - Port aux Basques
- Extra constraints?
  - Has X hours total
  - Has $$ total for gas



Goal Formulation

- Goal is a set of states in the environment
  - [St. Anthony, Port aux Basques]
- Goal is satisfied if one of them is reached
  - If a sequence of actions leads us to a goal state, the goal has been satisfied, and the problem is solved
- Goal can also be a function evaluation
  - If (enemy health <= 0)
  - If (enemy in checkmate)
  - If (player has all pieces of triforce AND Ganon dead)

Problem Formulation

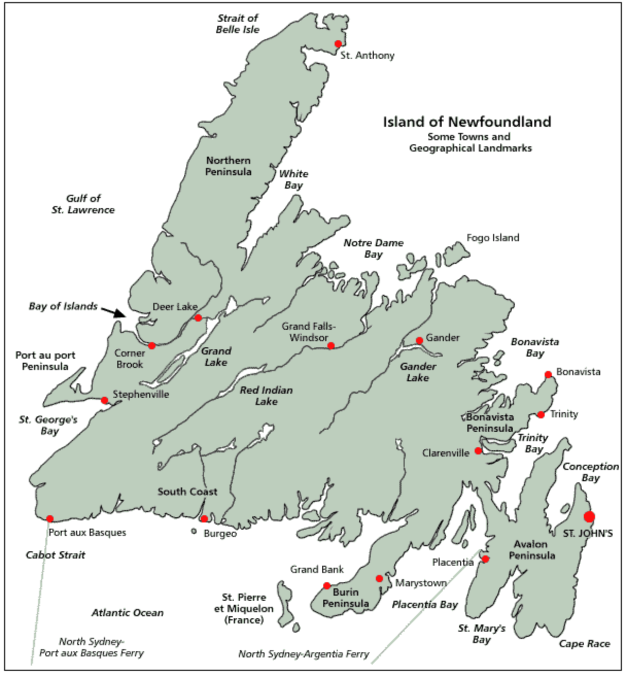
- What states to consider?
  - Every square meter in Newfoundland
  - Towns in Newfoundland
- What actions to consider?
  - Move left by a meter
  - Move from town X to town Y
- What information is stored in a node?
  - Current town location
  - Distance / time driven so far

Well-Defined Problem

1. Initial State that the agent starts in
2. Actions possible from each State
   - Transition / Successor Function
3. The set of goal states
   - Goal test function
4. Action cost function
   - Path cost = sum(cost(actions in path))

Example Problem Definition

1. Initial State
   - St. John’s
2. Actions
   - Towns connected by roads
3. Goal
   - [SA, PAB]
4. Action Cost Function
   - Travel distance or time

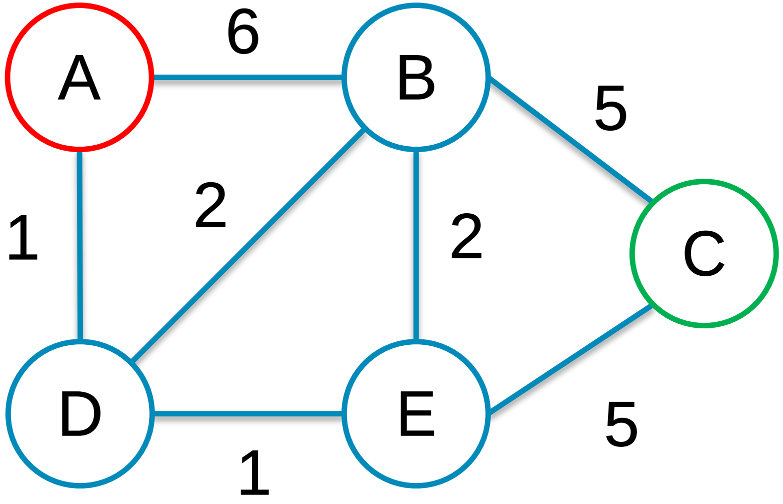


Problem Solution

- Path from start state to a goal state
  - Path = ordered sequence of actions
- Solution cost = path cost
  - Sum cost of actions (usually)
  - Most problems assume costs > 0
- Optimal solution has lowest path cost among all possible solutions

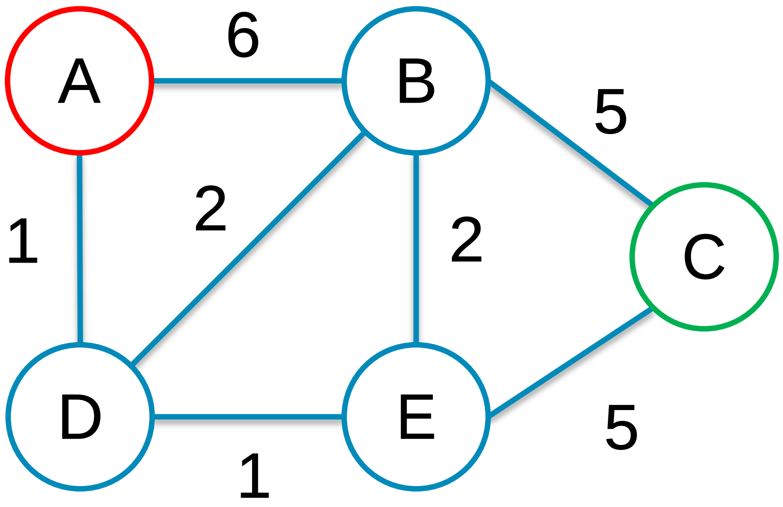
Example Graph Problem

- Initial State
  - State A
- Actions
  - (A,B) legal if edge
- Goal State
  - State C
- Action Cost Function
  - Edge label (A,B)=6



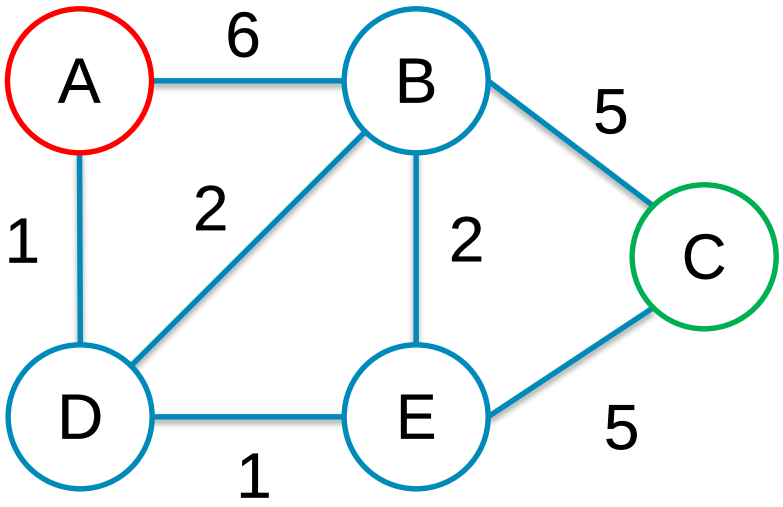
Example Graph Problem

- Fully Observable
- Static
- Discrete
- Deterministic
- Single Agent
- Sequential



Example Graph Problem

- Objective
  - Path to goal possible?
  - Shortest path to goal?
- Algorithm
  - Which to use?
- Let's try search



What is Search?

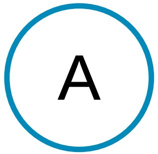
- Agent has several available actions
- Agent can explore various sequences of those actions
- Agent chooses the best sequence found

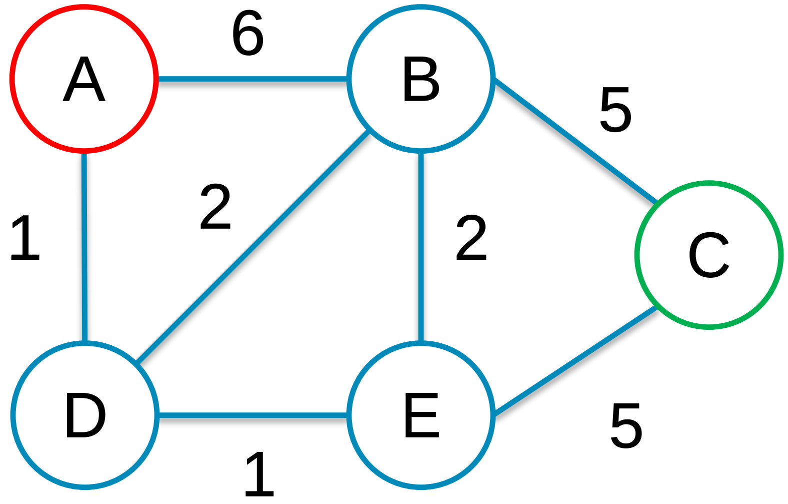
- This process in general is called search

Search

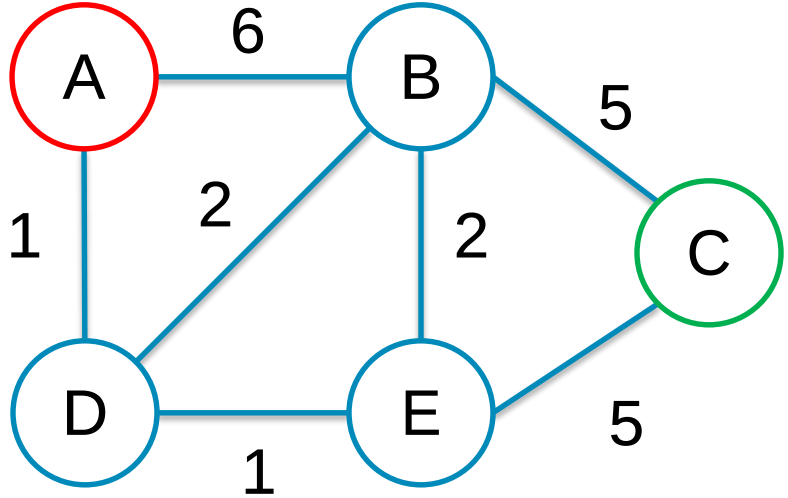
- Search will explore the problem state space
- Searching this space generates a search tree
- The search tree has nodes and edges

Search Tree

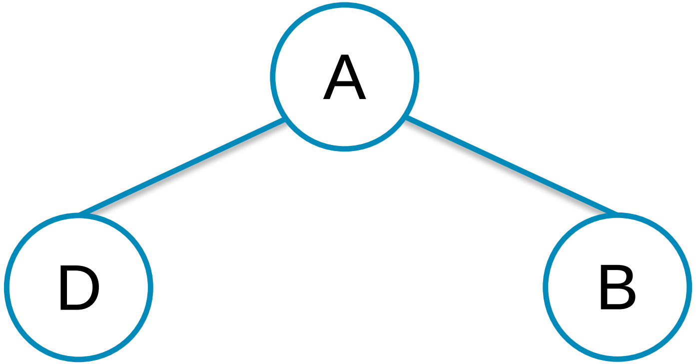


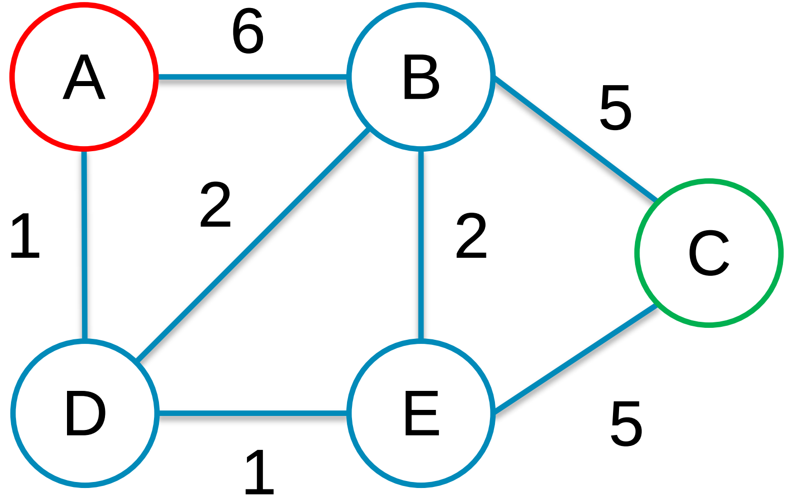


Search Tree

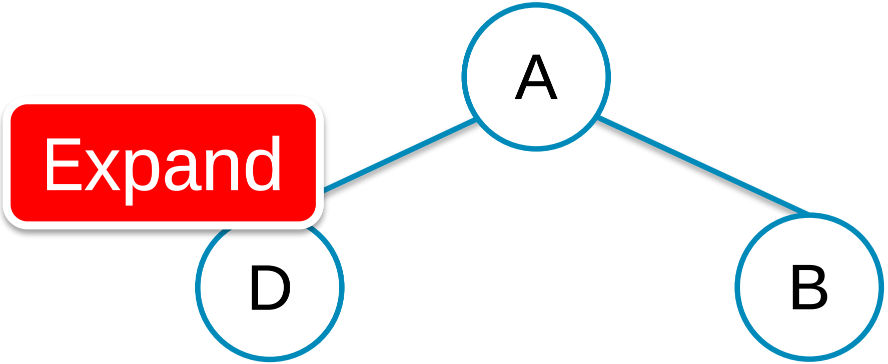


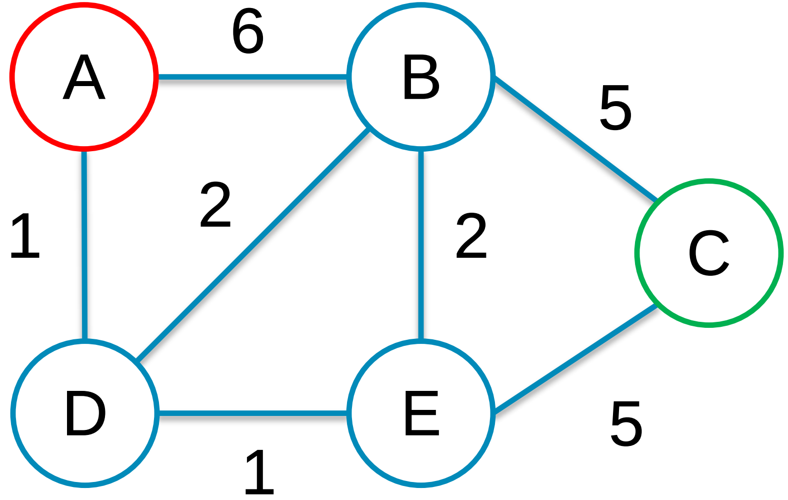
Search Tree





Search Tree





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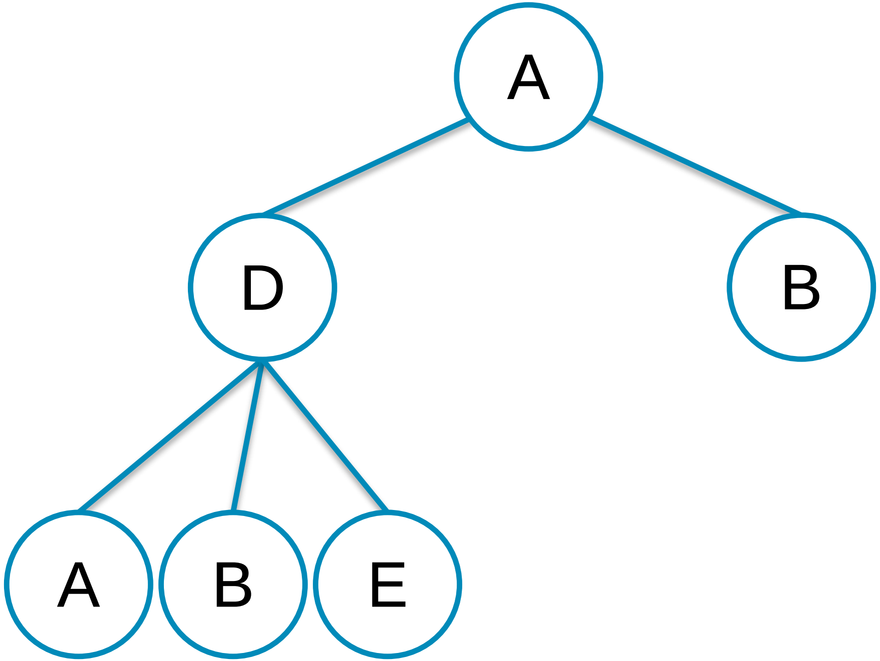
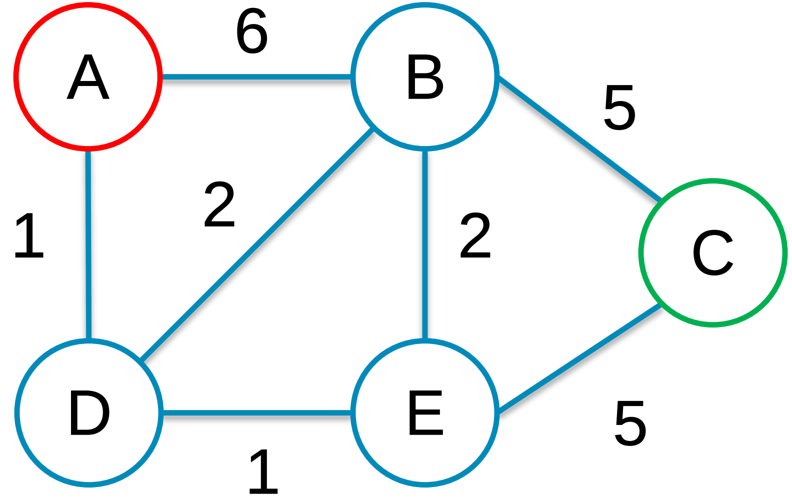
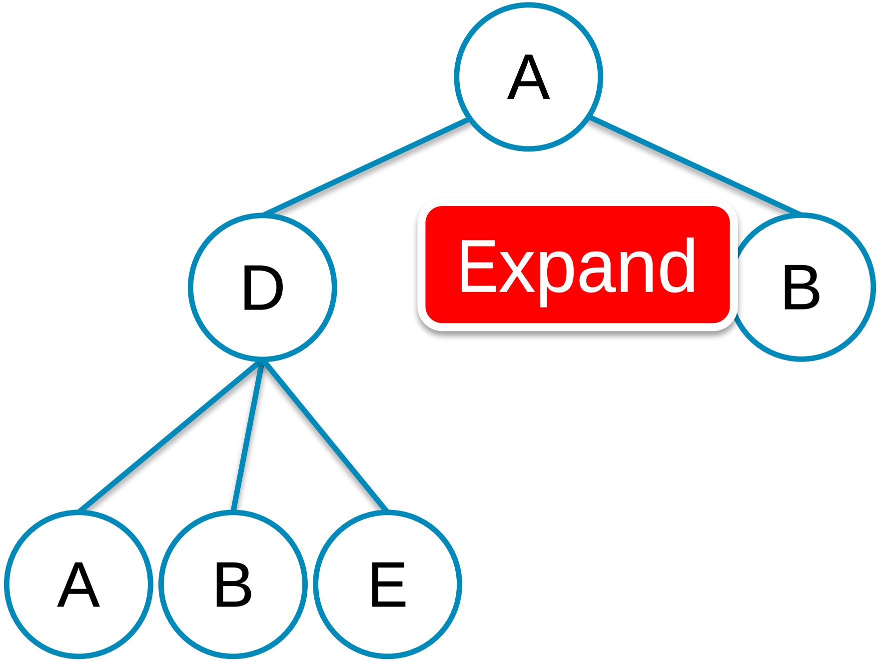
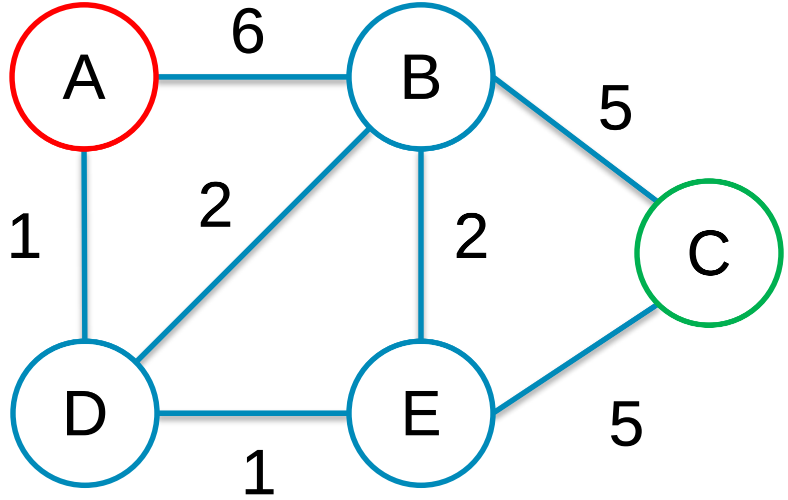


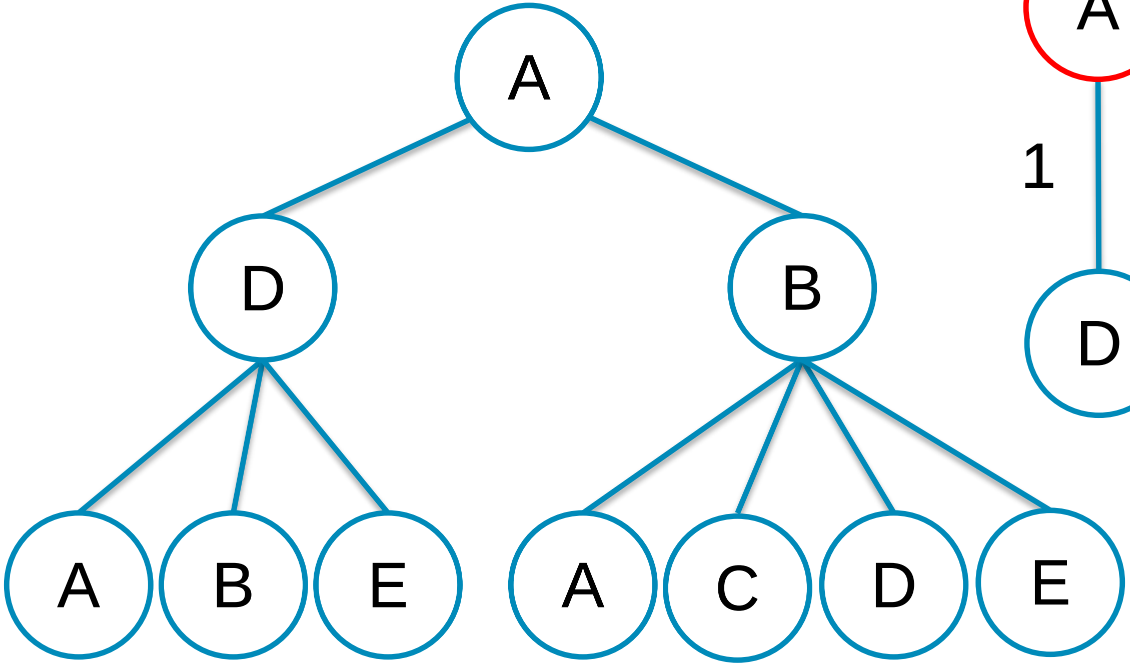


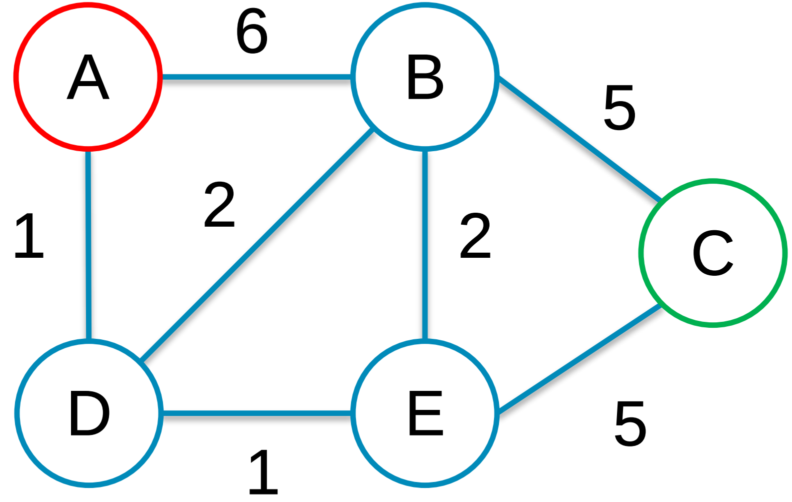
Search Tree



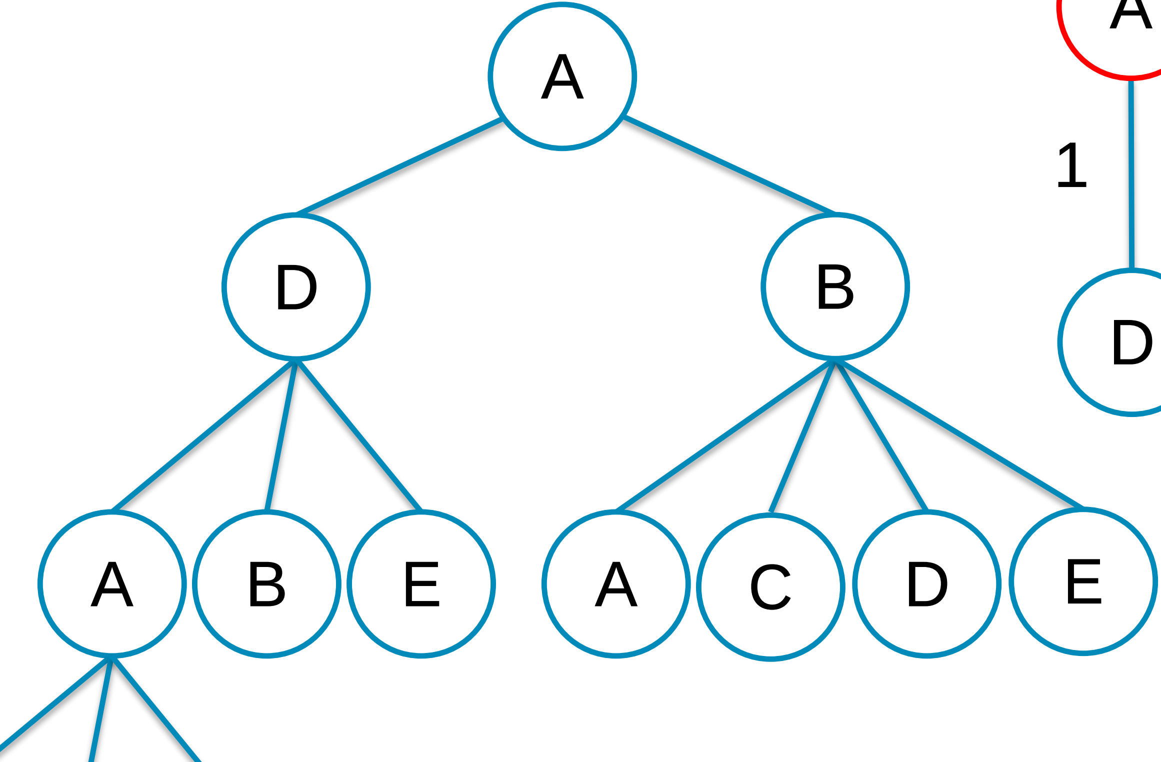


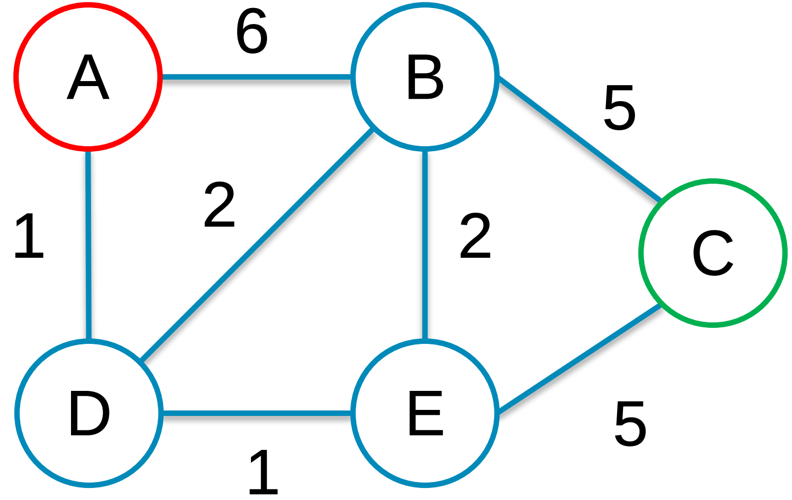
Search Tree



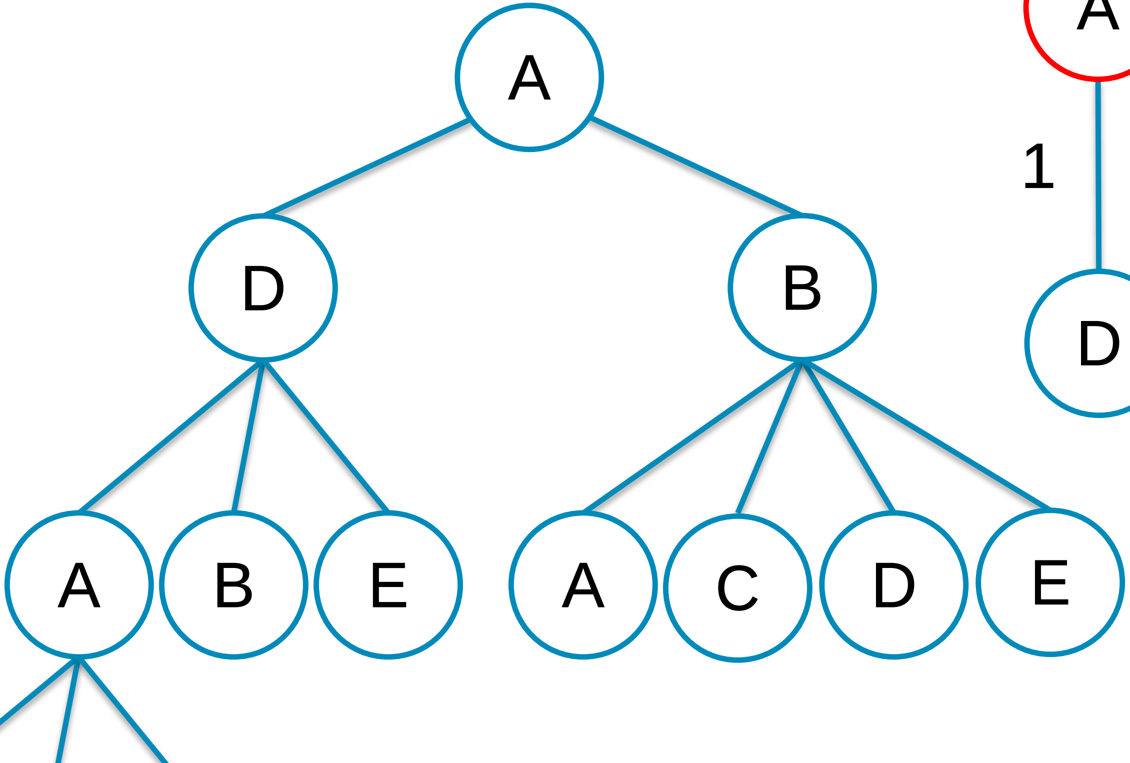


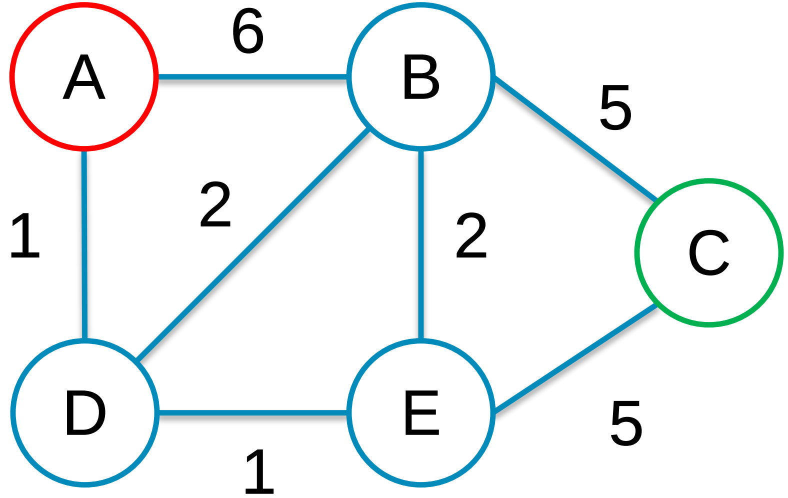
Search Tree





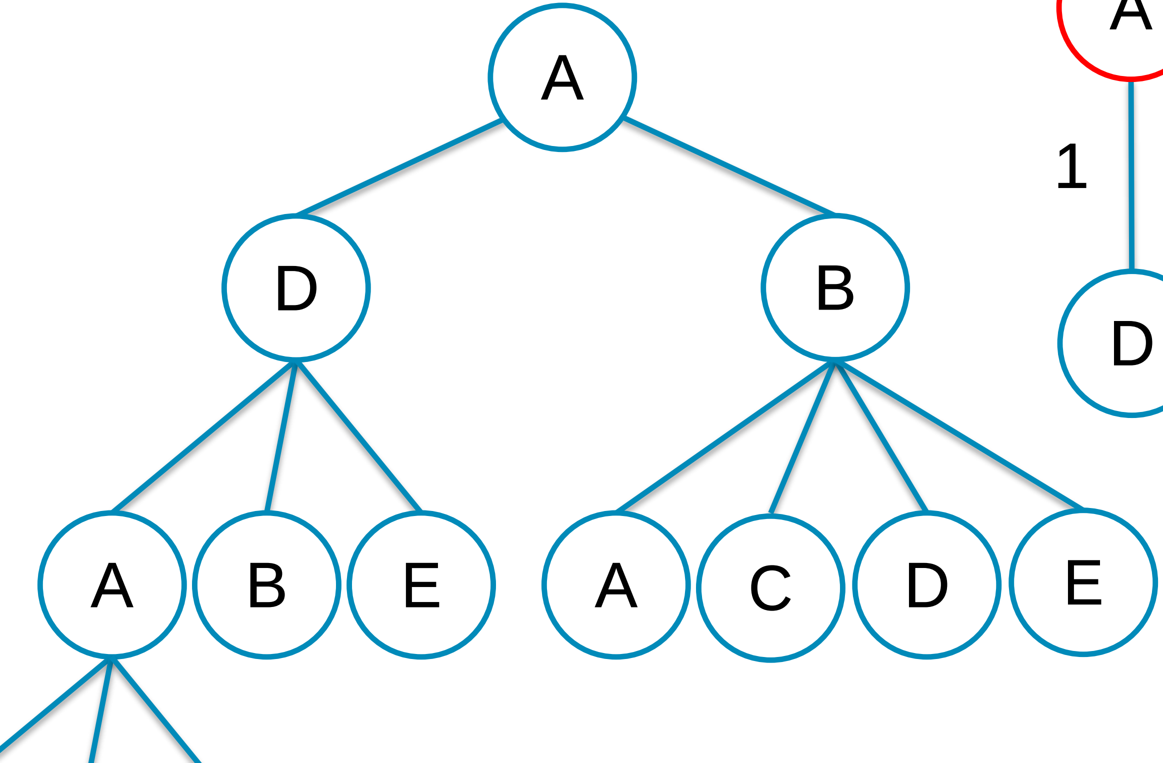
Search Tree

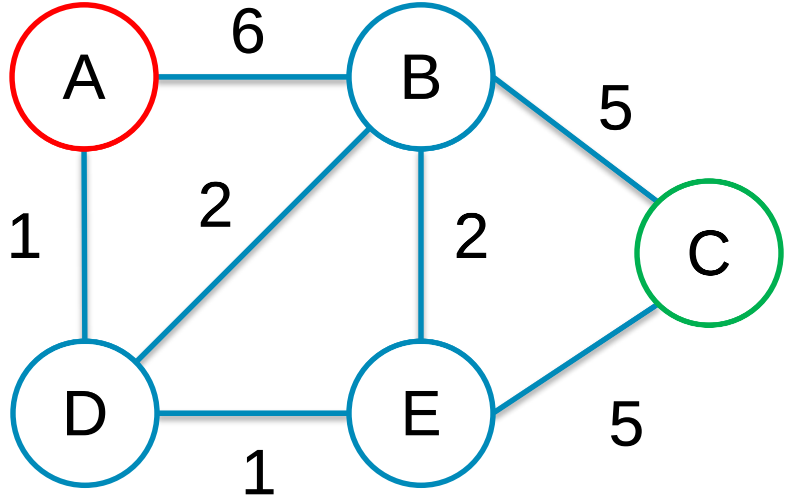




Continue Until Goal Found

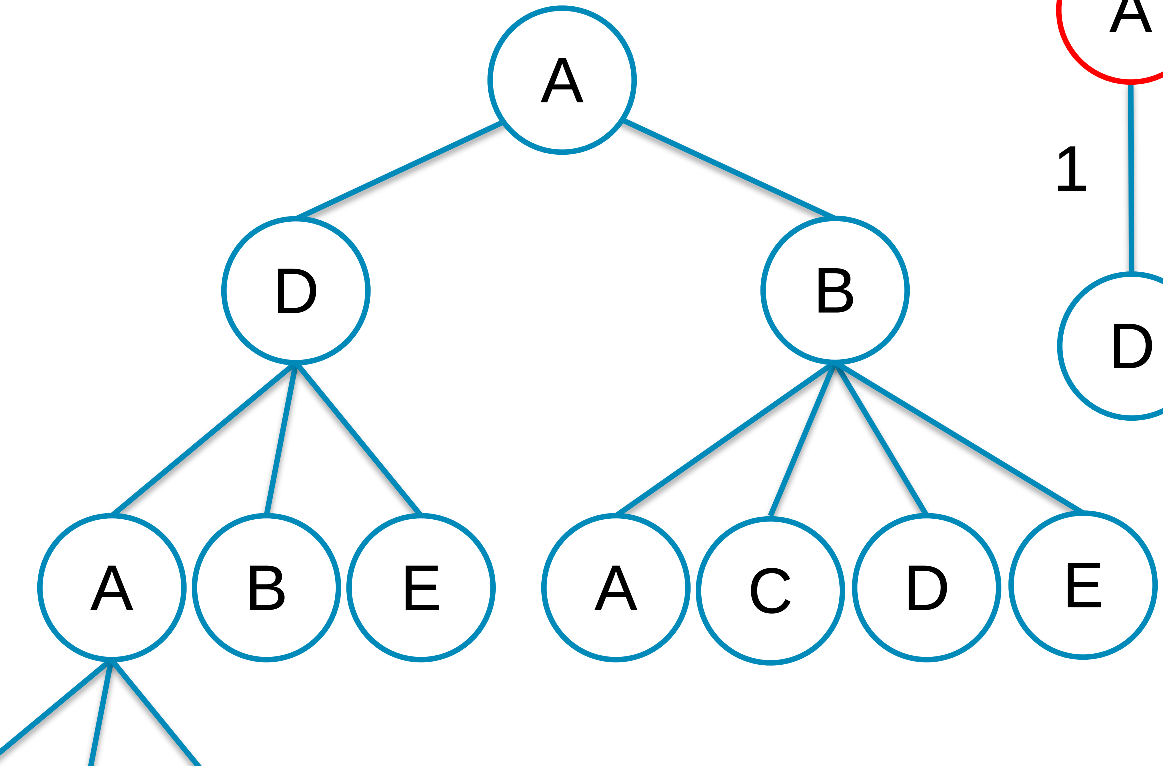
Search Tree

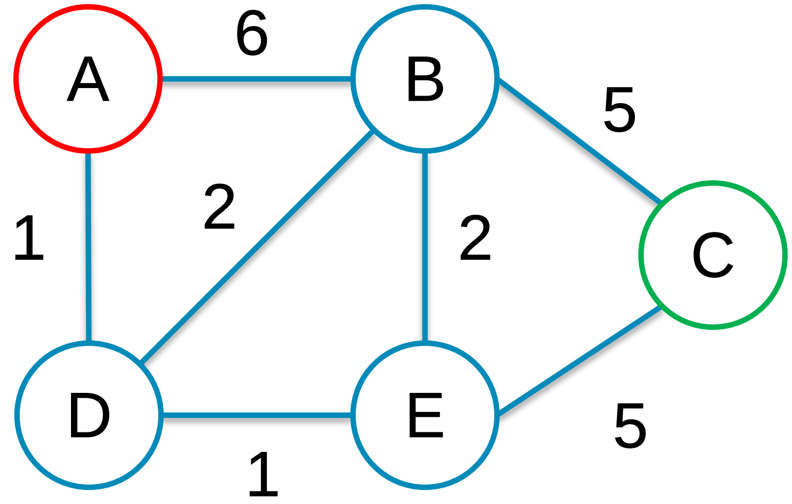




State Space: Finite

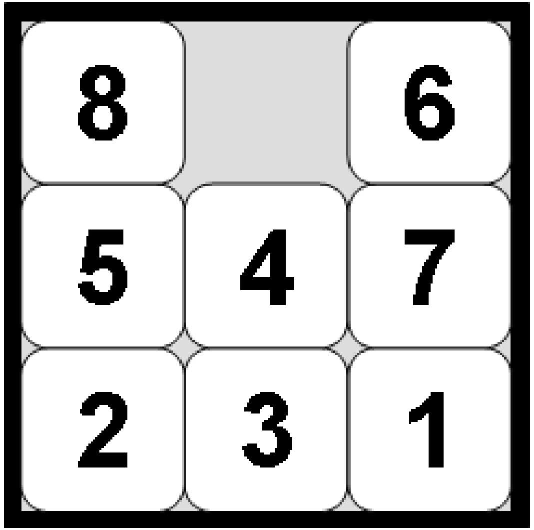
Search Tree

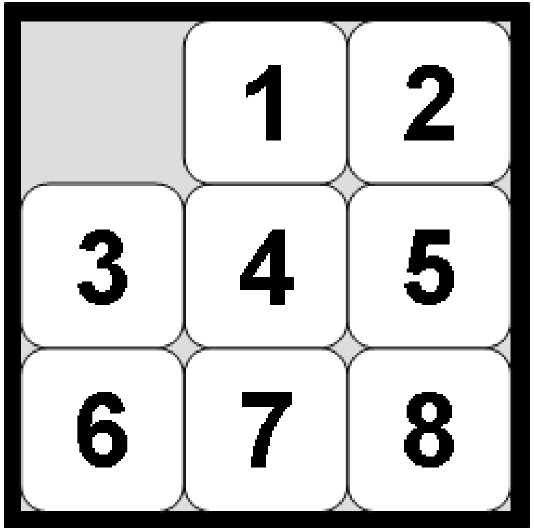




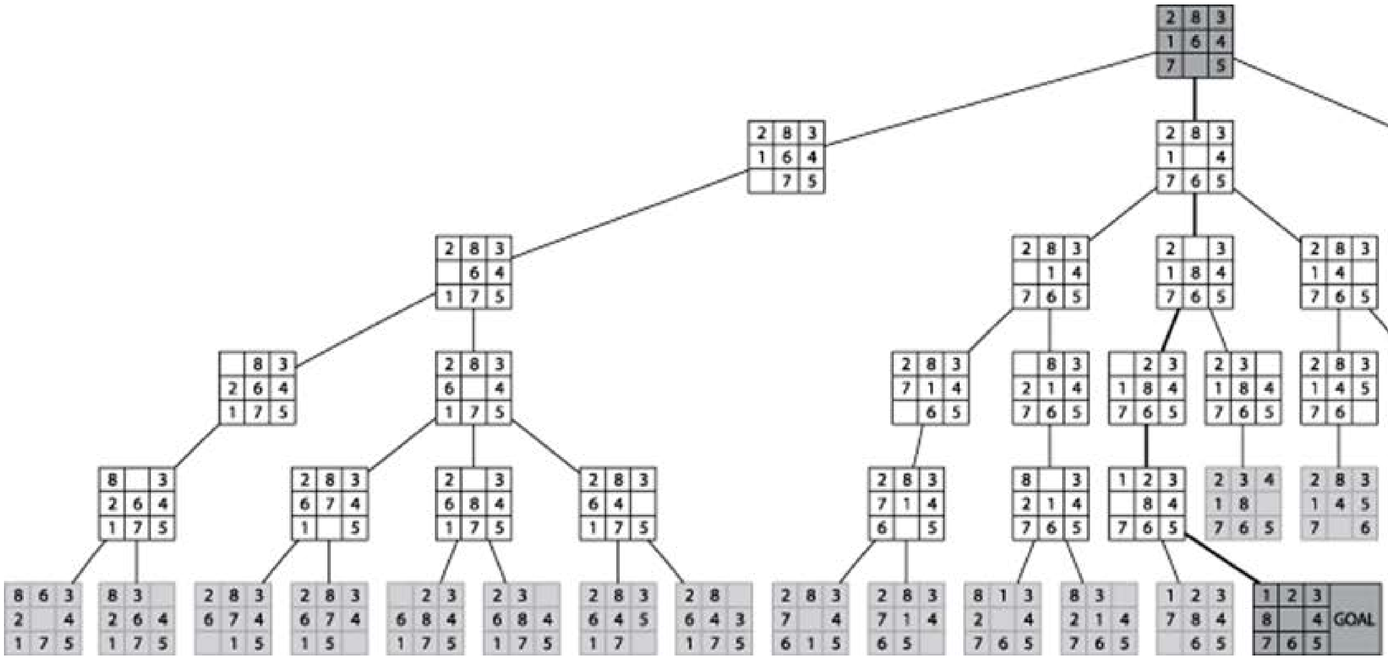
State Space: Finite
Search Tree: Infinite

Example: 15 Puzzle

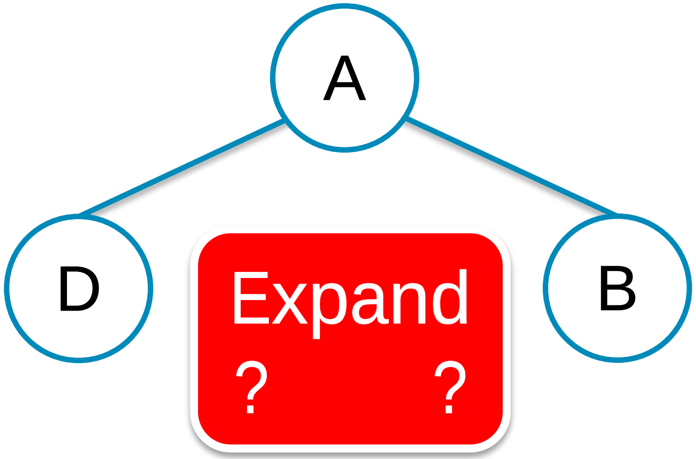


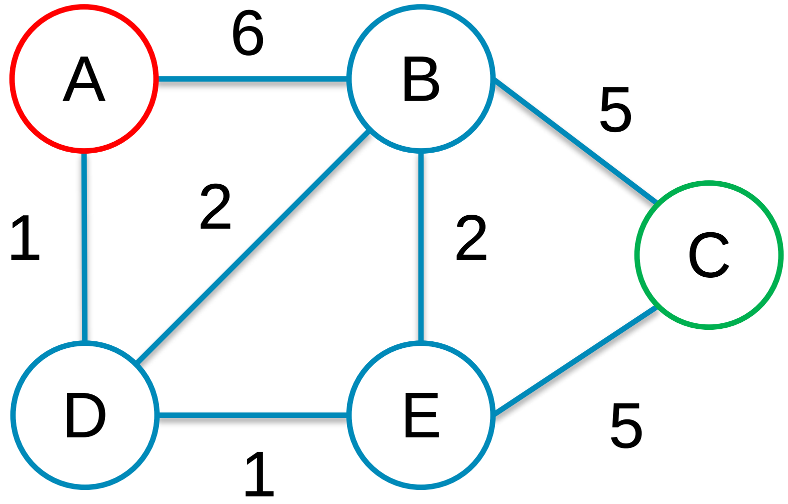


Example: 15 Puzzle



Search Strategy





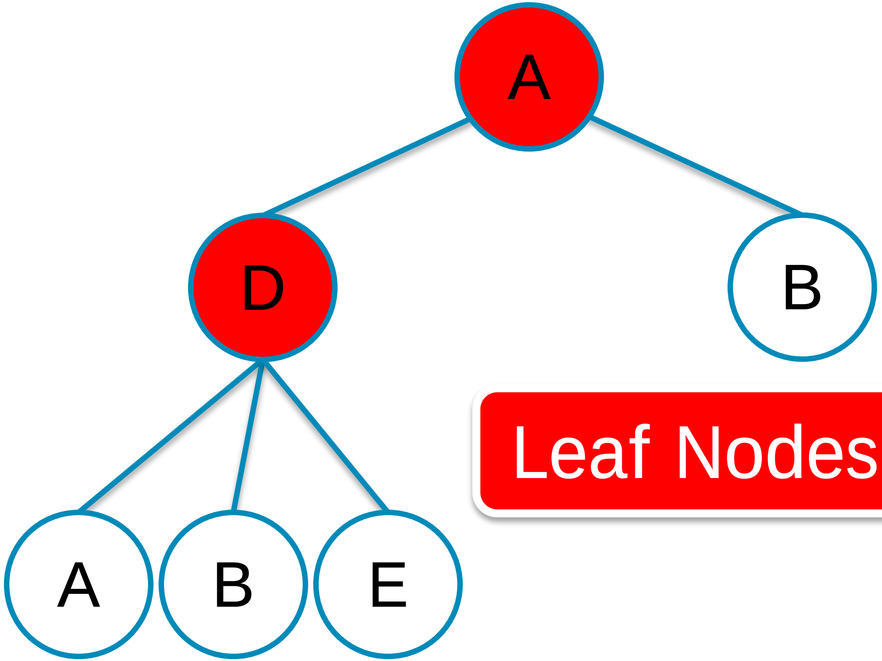
Search Tree Node Data

- State: The state in the graph
- Parent Node: Tree node that generated this node
- Action: Action that produced this node
- Path Cost: Cost of path so far from start
  - Traditionally denoted by g(n)
- Depth: Number of actions to this node
- Other: Can contain precomputed data (optimization)
  - Legal actions, heuristics, etc

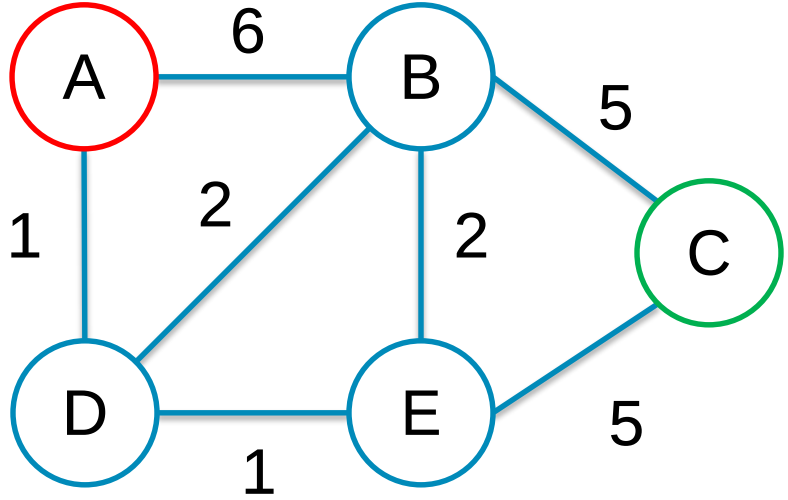
Node vs. State

- Important distinction
- State
  - Configuration of the environment
- Node
  - Bookkeeping data structure
  - Exists only within the search tree
  - Nodes are ‘on paths’ in the search tree

The Fringe



Leaf Nodes



Nodes that have been generated but not yet expanded

General Uninformed Tree Search

```
Function Tree-Search(problem, strategy)
    fringe = {Node(problem.initial_state)}
    while (true)
        if (fringe.empty) return fail
        node = strategy.select_node(fringe)
        if (node.state is goal) return solution
        else fringe.add(Expand(node, problem))
```

Node Expansion

```
Function Expand(node, problem)
    successors = { }
    for a : problem.actions(node)
        s = Node(node.state.do_action(a))
        s.parent = node
        s.g = node.g + s.action.cost
        s.action = a
        s.depth = node.depth + 1
        succesors.add(s)
    return successors
```

Problem Solving Performance

- Completeness
  - Is it guaranteed to find a solution if it exists?
- Optimality
  - Does it find the optimal solution?
- Time Complexity
  - How long does it take to find a solution?
- Space Complexity
  - How much memory is needed to run the search?

Time + Space Complexity

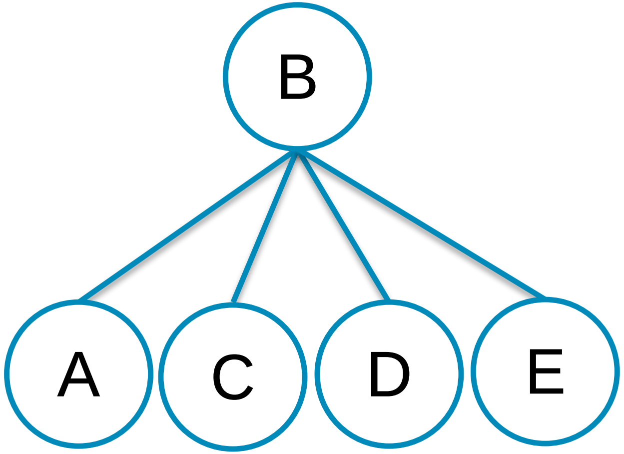
- Measured on size of input problem / graph
- Time measures number of nodes generated
- Space measured by how much memory is needed to store the maximum number of nodes (worst case) needed at any given time
- Search / AI traditionally measures:
  - Branching factor b (max successors at any node)
  - Depth d (of the shallowest goal node)
  - Tree size ~ b^d

Heuristic Search

- Improve upon uninformed tree search
- Incorporate knowledge (inform it)
- Large Search Trees
  - How to make the tree smaller?
  - How to choose a search strategy?
  - How to choose an action to perform?
- Data structures + other optimizations

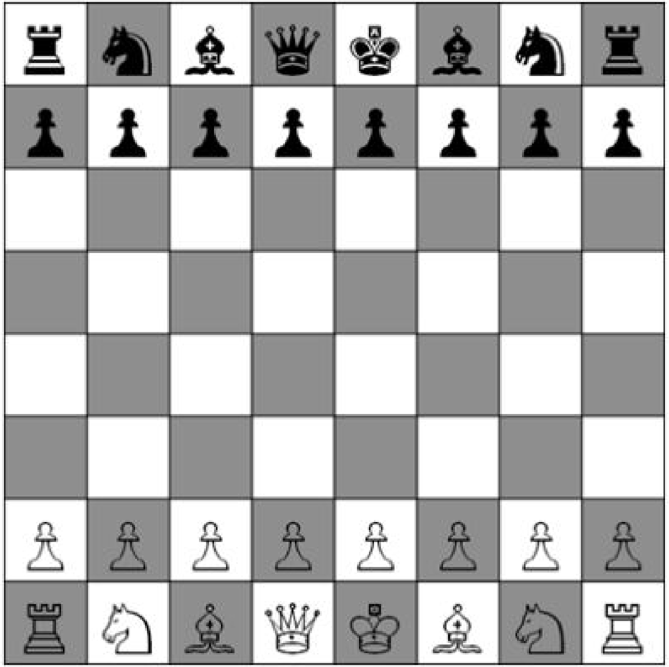
Heuristic Search

- Apply ‘heuristic’ guesses of value of nodes
- Node selection strategy
  - Move ordering
  - Iterative deepening
- “Pruning” nodes
- Bounding solutions



Heuristic Search Example

- Chess has ~40 moves at a state
- Most of them are bad
- Kasparov claimed to have only considered 2 moves per state
- Naïve search considers all 40
- Depth of search:
  - 40: 40, 1600, 64000, 2560000
  - 2: 2, 4, 8, 16, 32, ... depth 21
  - Pruning = Exponential gains



Recap

- Problems are defined by
  - Initial + Goal States, Actions, Cost Function
- Optimal solution
  - Has lowest cost function among all solutions
- Search
  - Finds solution by exploring the search tree
  - Search tree consists of Nodes, Edges
  - Nodes in search tree != states in problem
- Problem solving performance measured by
  - Completeness, Optimality, Space + Time Complexity