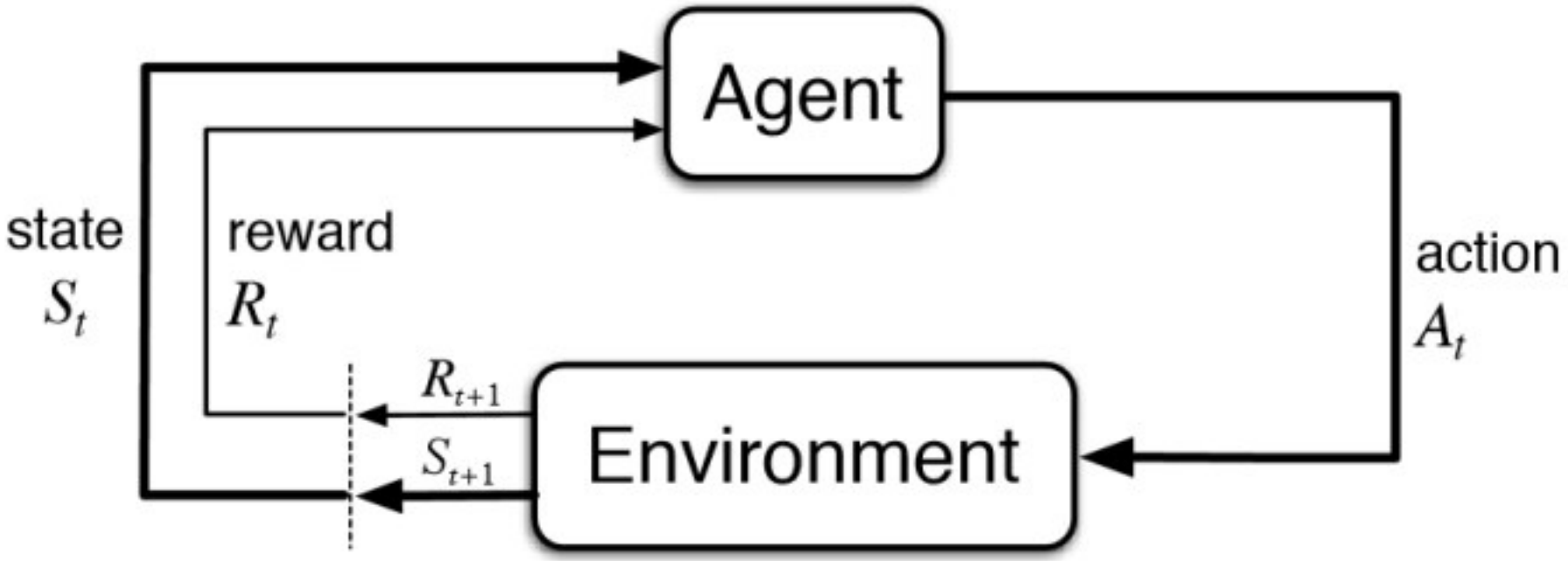
Tree Search

Week 3

Recap on Reinforcement Learning



Sutton, 2017. *Reinforcement Learning: An Introduction*

Formulating Problems as RL

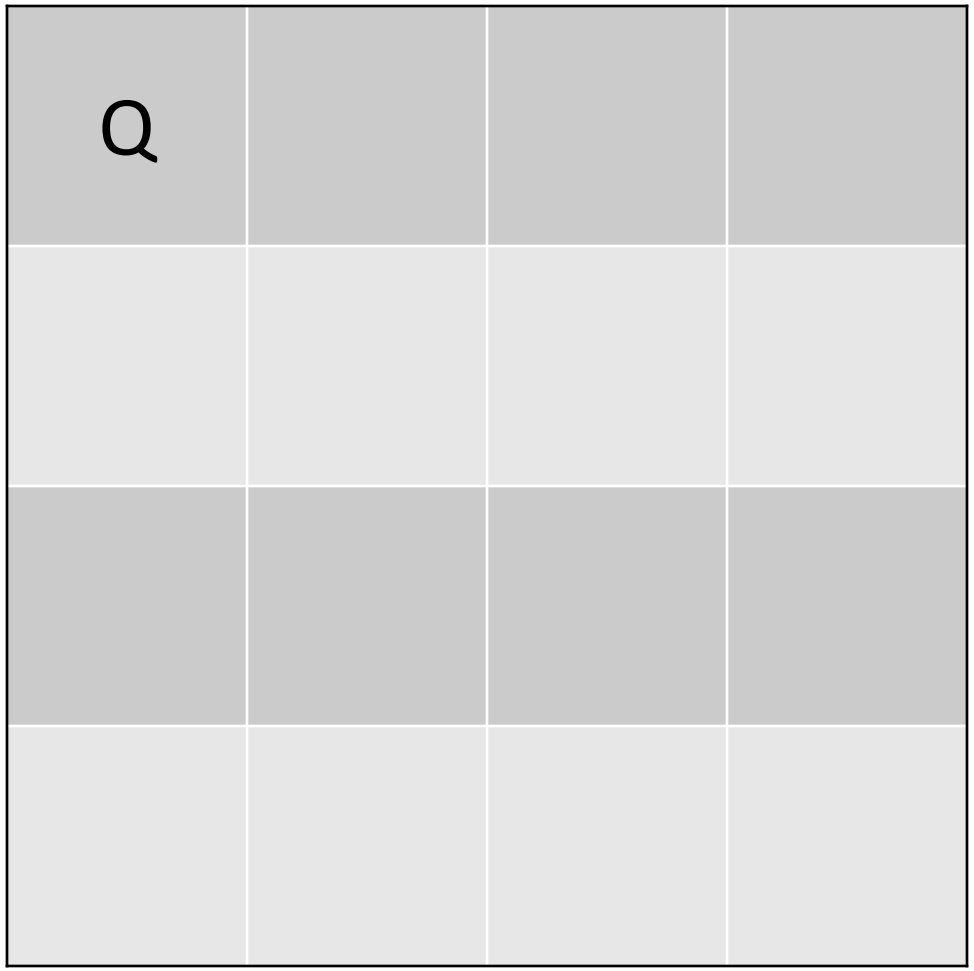
- State Space
  - Start State
  - Goal State
- Actions Space

Four Queens Problem

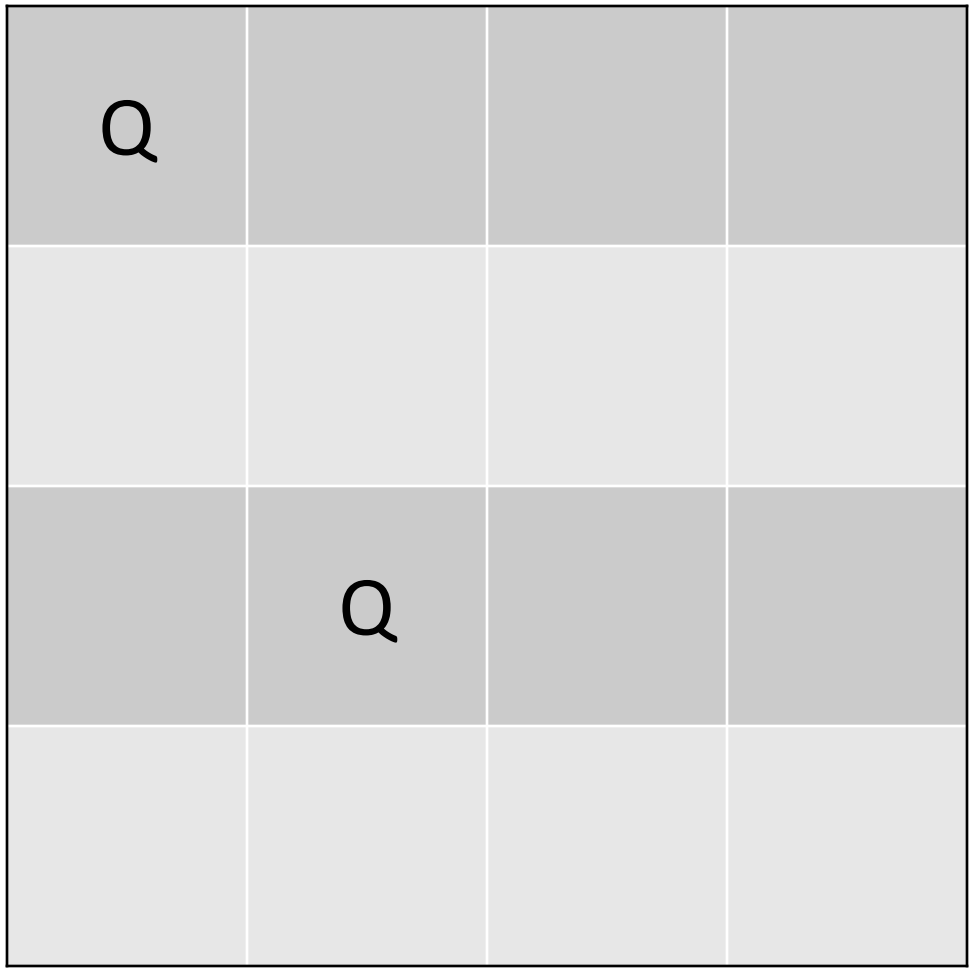
- Place four queens on a 4 x 4 board such that they do not attack each other.

- Initial State
- Action Space
- State Space
- Goal State

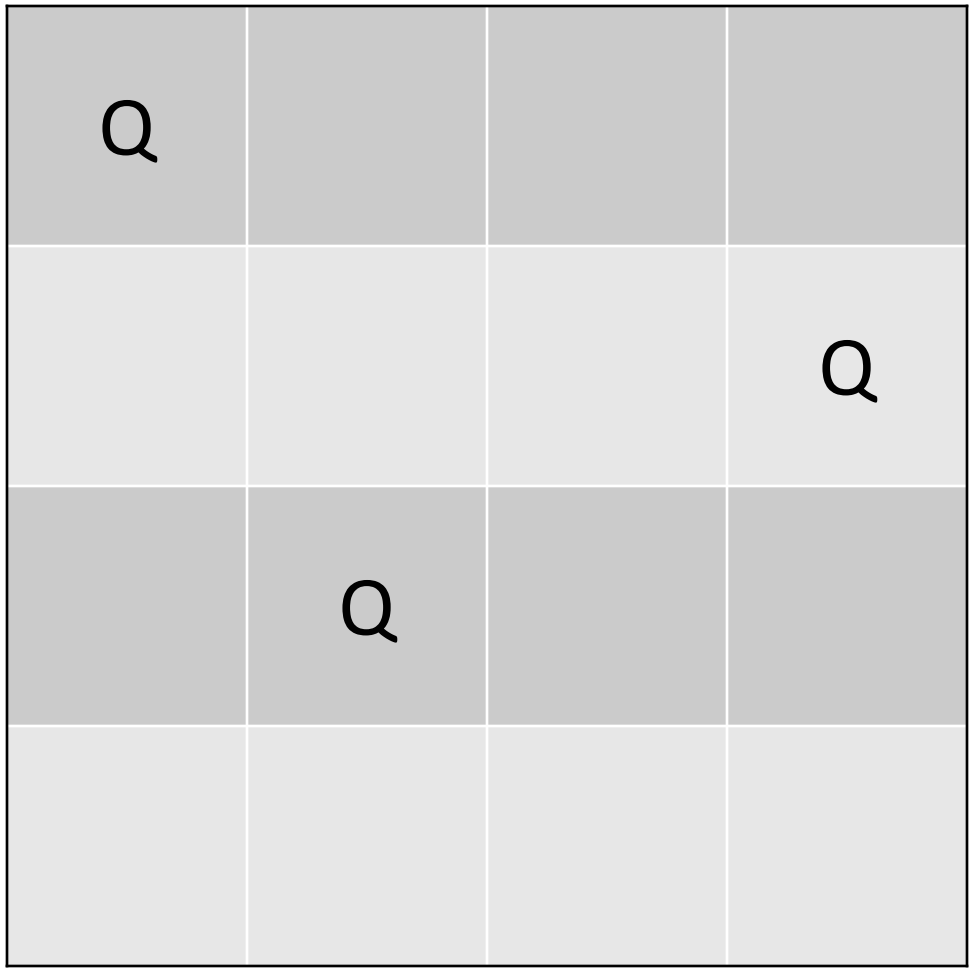
Four Queens Problem



Four Queens Problem



Four Queens Problem



Four Queens: Limiting Action Space

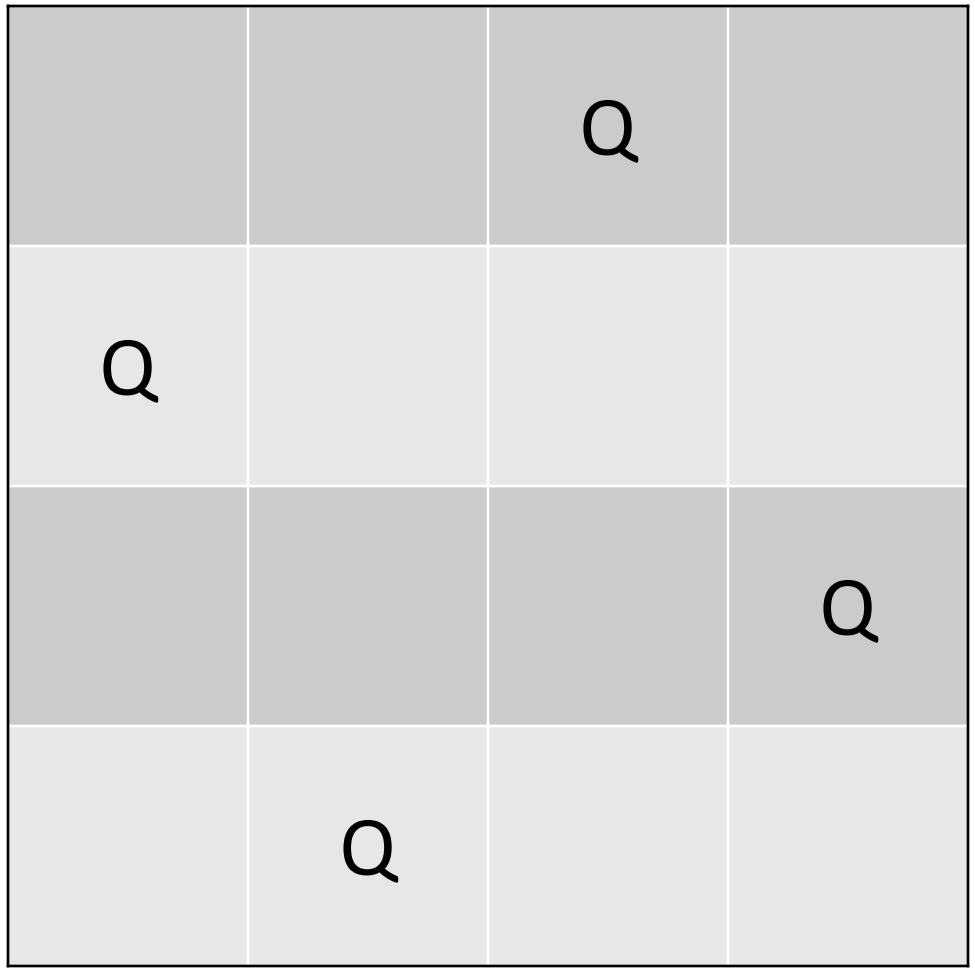
- State Space
  - 16 x 15 x 14 x 13 = 43,680
- Action Space
  - ~14 tiles

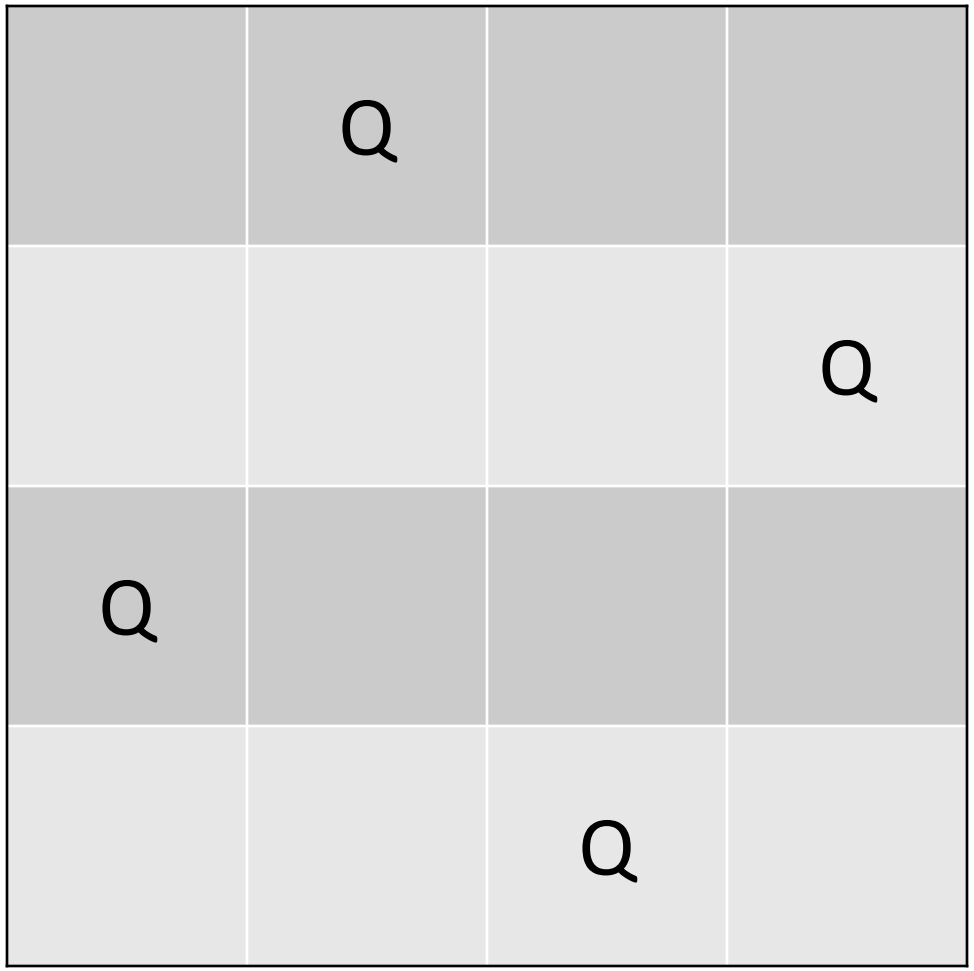
- Reformulate
  - One Queen per Column
- State Space
  - 4 x 4 x 4 x 4 = 16
- Action Space
  - 4 tiles

N-Queens Problem

- Eight Queens
  - Original, Published 1848
  - State Space ~ 10^{14} to 2,057
- Hundred Queens
  - State Space ~ 10^{400} to 10^{52}
- Million Queens
  - Literally Impossible (jk)
  - Solved in a few seconds with min-conflicts heuristics.

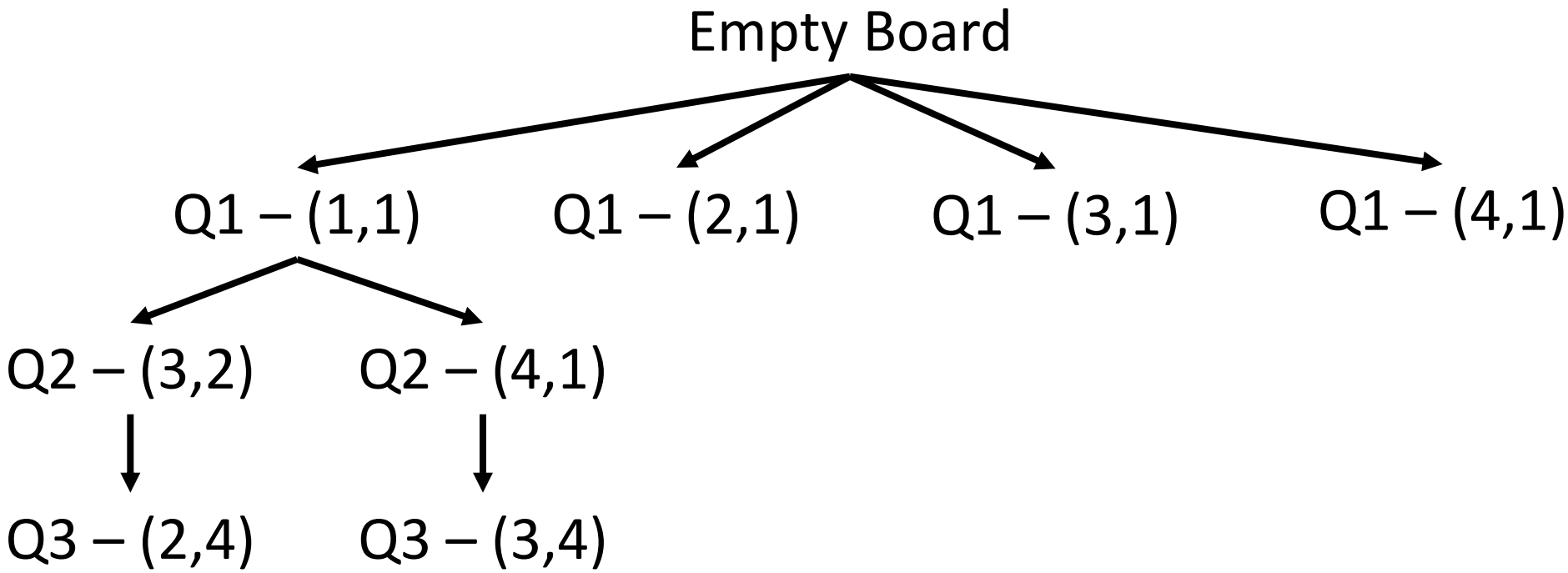
Four Queens Solution





Search Tree

- General strategy to search through possible plans.

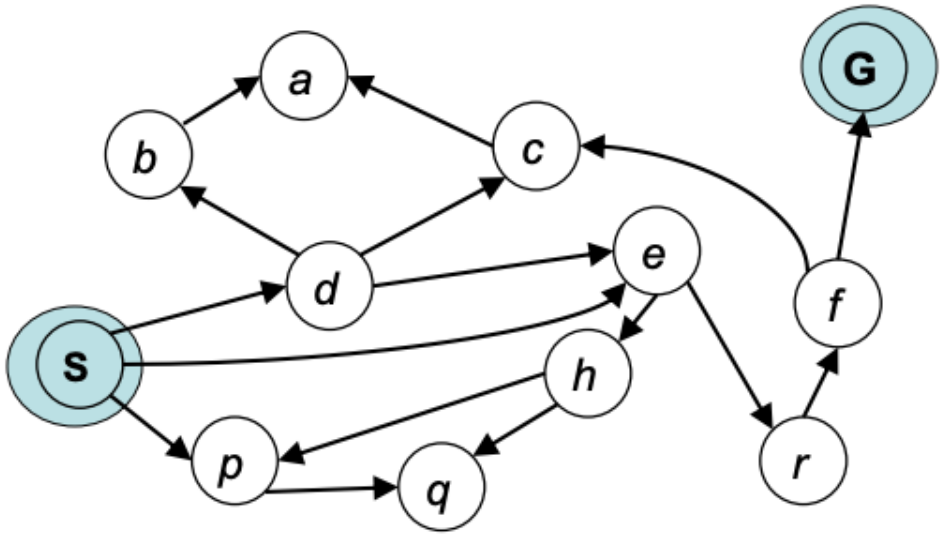


Tree Search

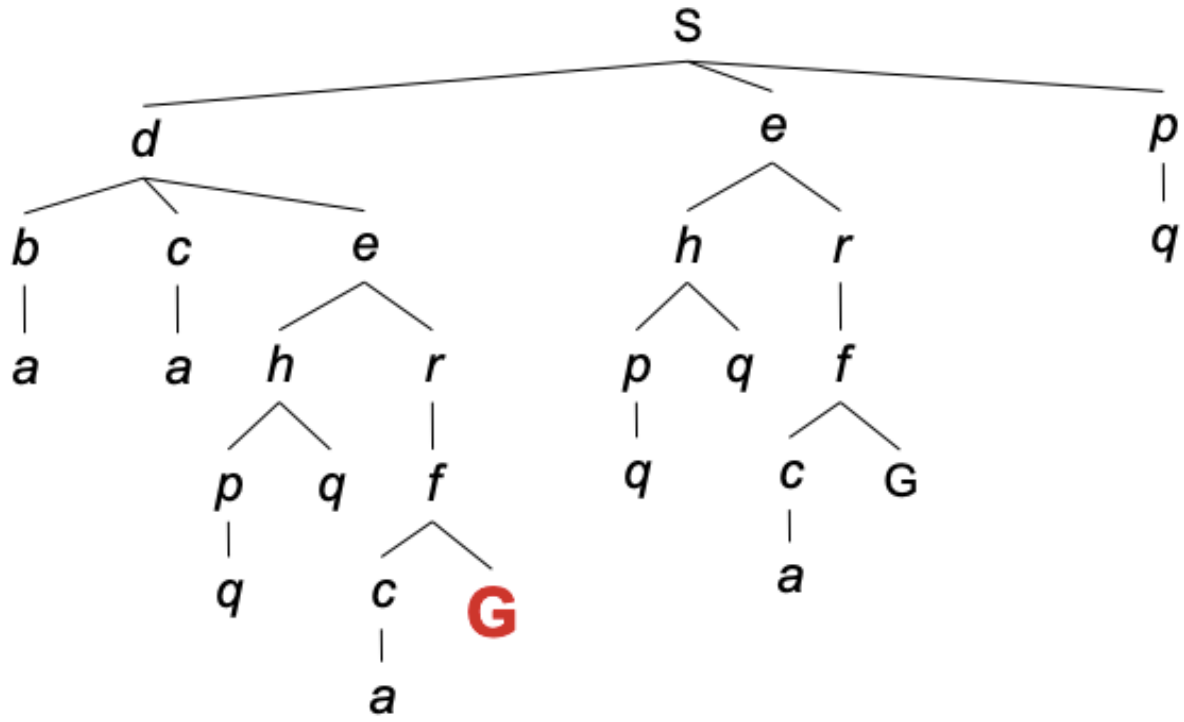
- Generalized Method of Searching State Space
  - Useful for Most Action Based Problems
  - Useful for NP-Hard Problems

- Breadth First Search
- Depth First Search
- Advanced
  - Uniform Cost Search
  - A* Search

Search Problem



State Graph

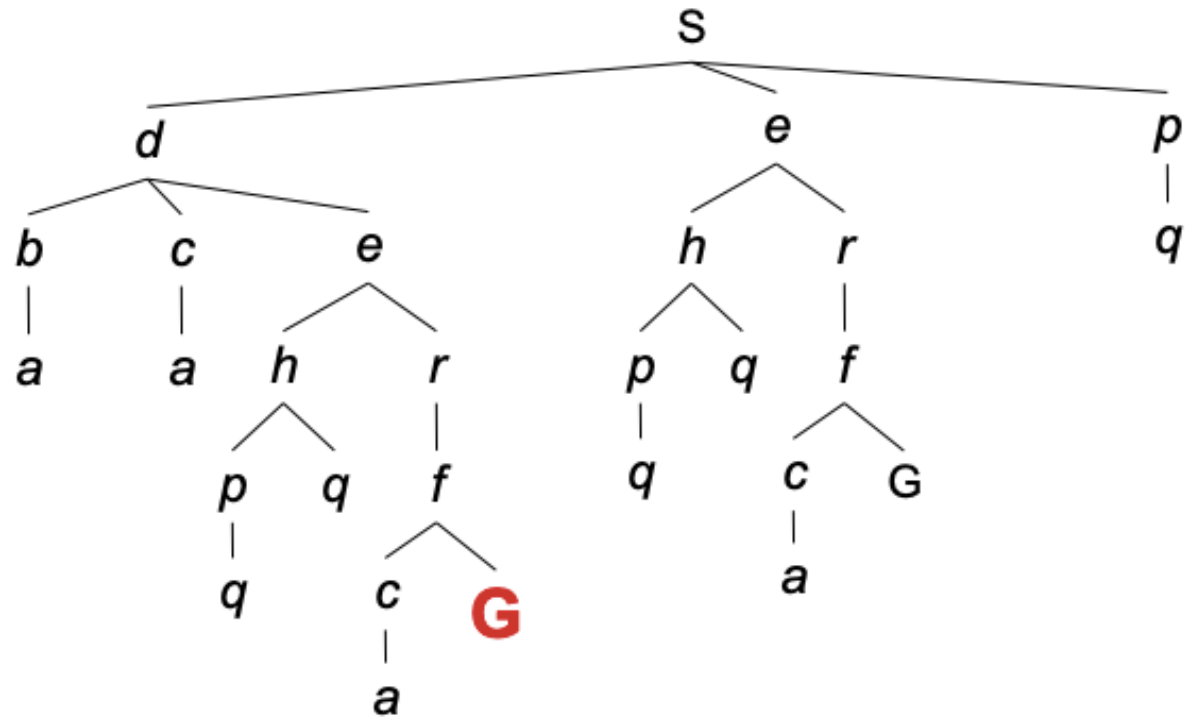


Search Tree

Depth First Search

- Strategy
  - Search the first unexplored path.
- Implementation
  - Stack – Last in First Out
  - Recursive

Depth First Search



- Order – S,p,q,e,r,f,G

Depth First Search

push first node to stack

while the stack is not empty:

    pop the stack

    if goal:

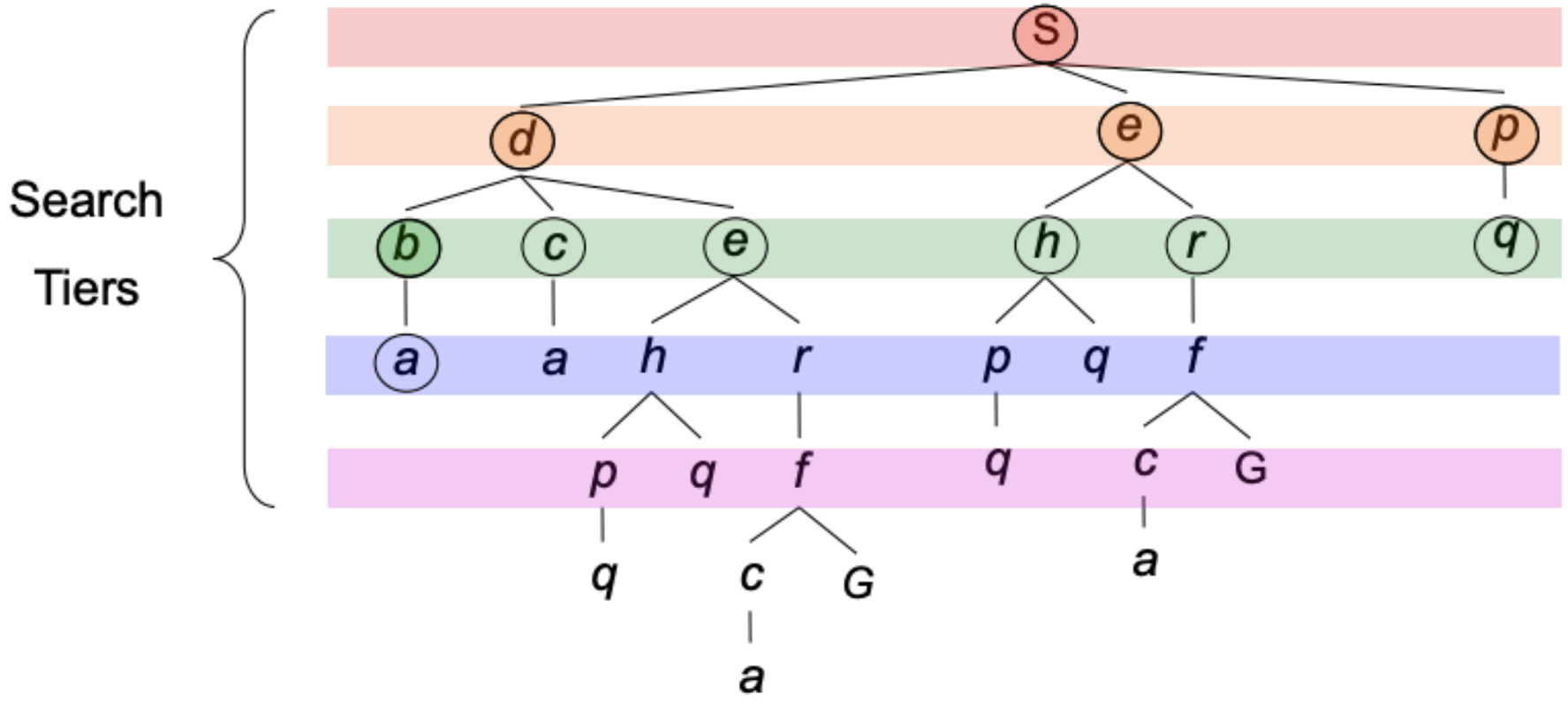
        end

    push children to stack

Breadth First Search

- Strategy
  - Search each layer at a time.
- Implementation
  - Queue – First in First Out

Breadth First Search



- Order – S,d,e,p,b,c,e,h,r,q,a,a,h,r,p,q,f,p,q,f,q,c,G

Breadth First Search

push first node to queue

while the queue is not empty:

    pop the queue

    if goal:

        end

    push children to queue

Search Algorithm Properties

- n – number of states
- b – max branching factor
- d – min depth of solution
- m – max depth of search tree

Search Algorithm Properties - DFS

- Complete
  - Yes
- Optimal
  - No
- Time Complexity
  - $O(b^m)$
- Space Complexity
  - O(bm)

n – number of states
b – max branching factor
d – min depth of solution
m – max depth of search tree

Search Algorithm Properties - BFS

- Complete
  - Yes
- Optimal
  - Yes
- Time Complexity
  - $O(b^d)$
- Space Complexity
  - $O(b^d)$

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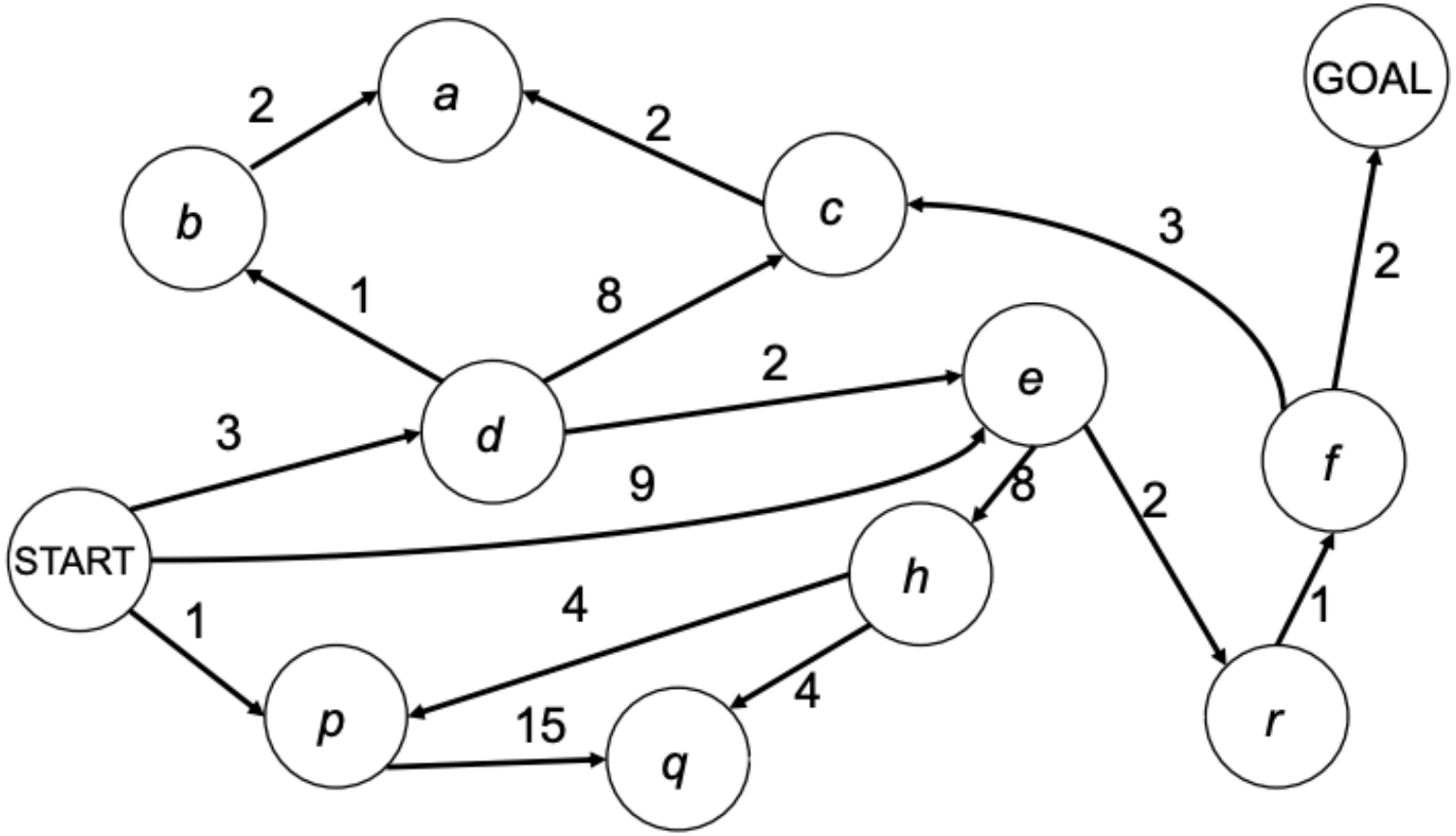
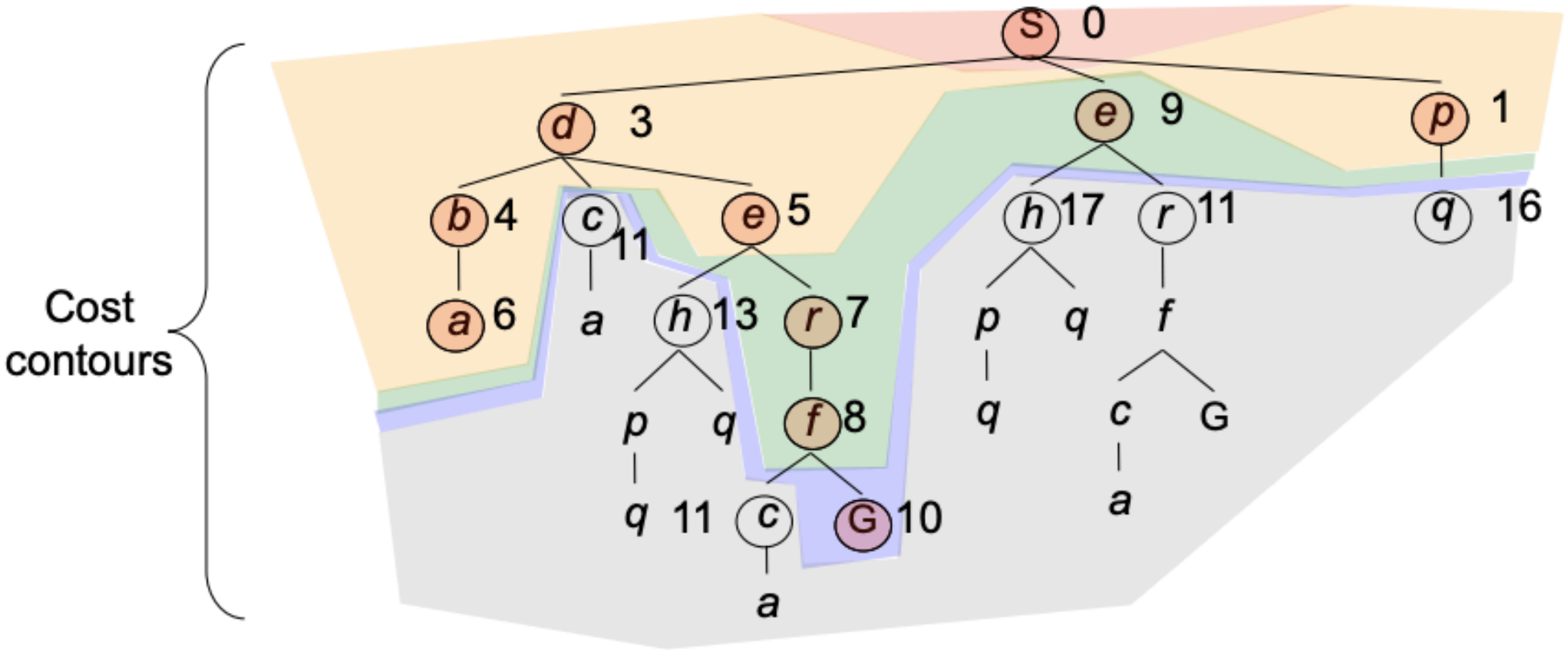
Actions can have Cost



Uniform Cost Search

- Generalization of Breadth First Search
- Strategy:
  - Search the next cheapest state.
- Implementation:
  - Priority Queue
  - Each state has a cost function f(n)

Uniform Cost Search



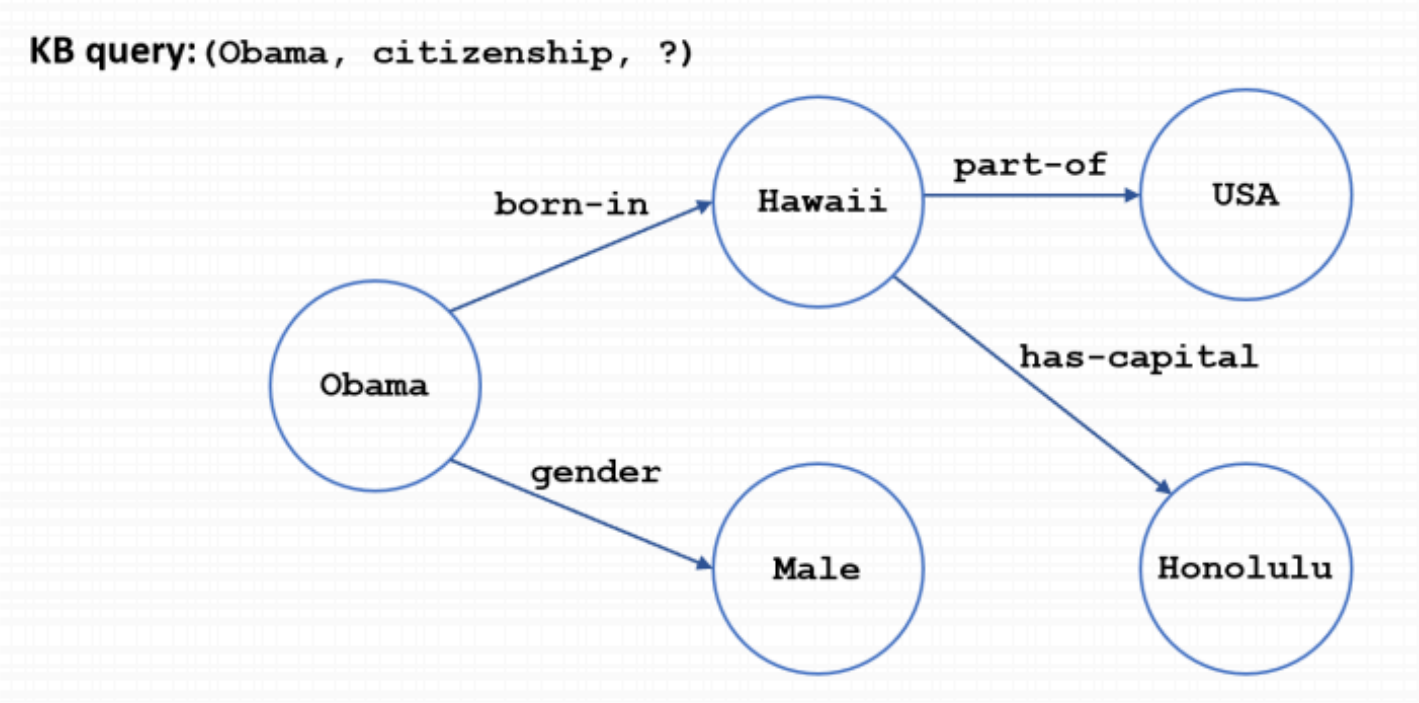
- Order – S,p,d,b,e,a,r,f,e,G

Trees and Conversational Question Answer

- How to query knowledge bases with natural language?
- Single-Step Reasoning
  - Semantic Parsing
  - Embedding Based
- Multi-Step Reasoning
  - Symbolic Methods
  - Embedding Based
  - Reinforcement Learning

Multi-Step Reasoning with RL

- What is the citizenship of Obama?



Multi-Step Reasoning with RL

- DeepPath (Xiong et al., 2017)
- MINERVA (Das et al., 2017)
- M-Walk (Shen et al., 2018)