南京大学
NANJING UNIVERSITY

人工智能导论

无信息搜索

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提纲

- 搜索问题
- 无信息搜索
  - 宽度优先搜索
  - 深度优先搜索
  - 迭代加深的深度优先搜索
  - 代价一致性搜索
- 本章小结

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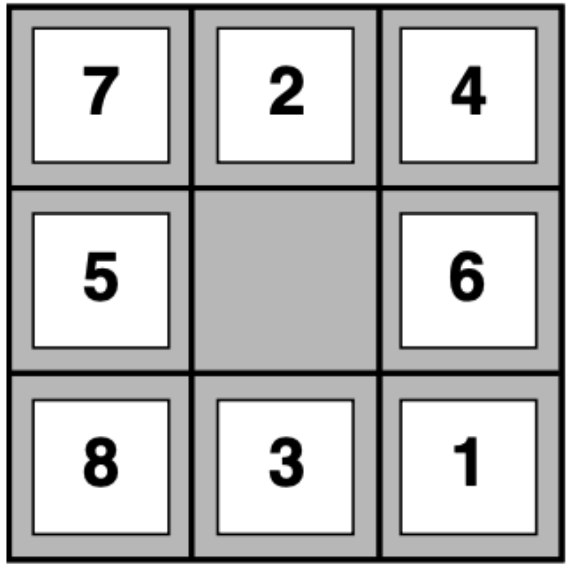
搜索问题

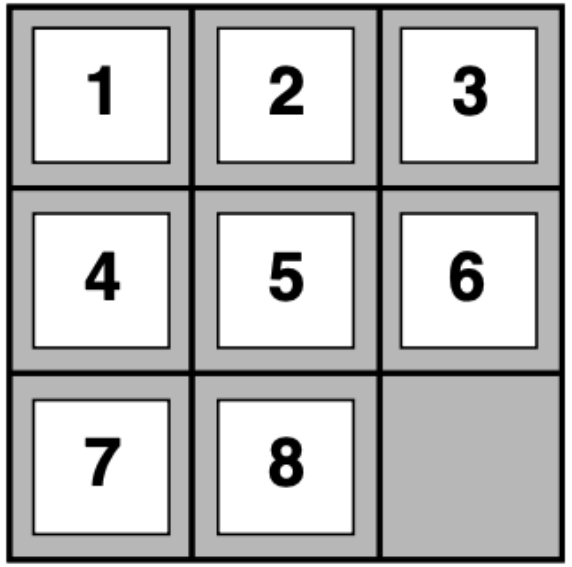
- 华容道

搜索问题

八数码



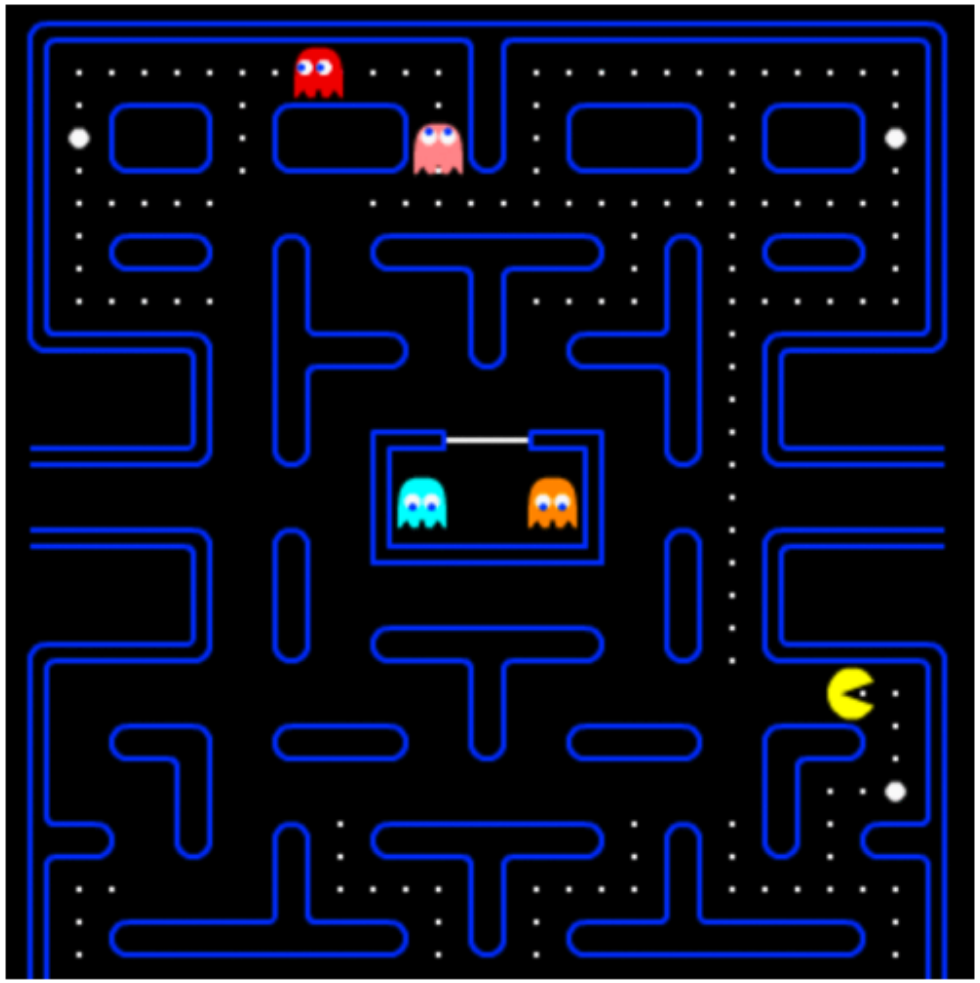
初始状态



目标状态

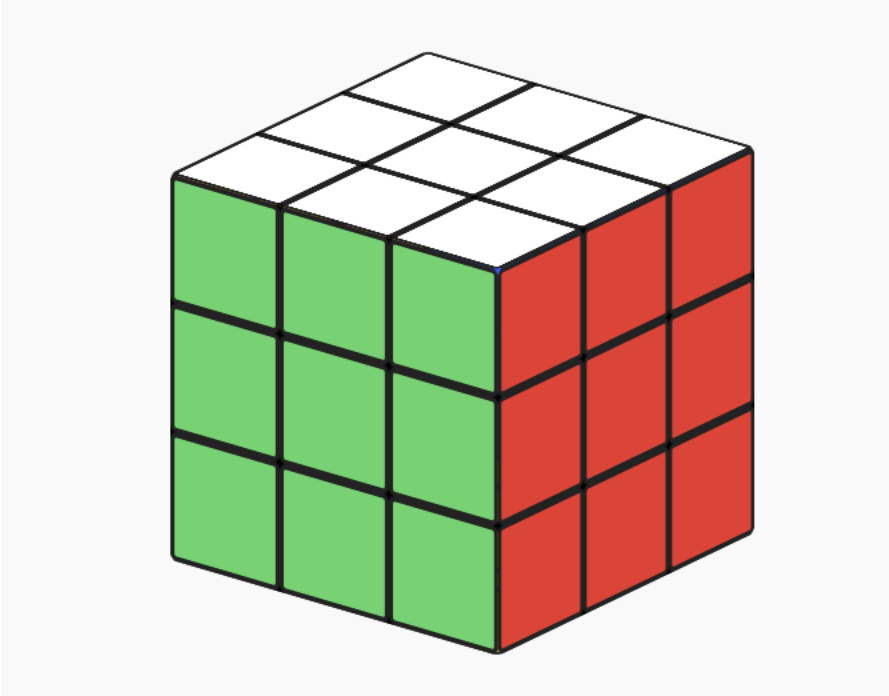
搜索问题

- 吃豆人



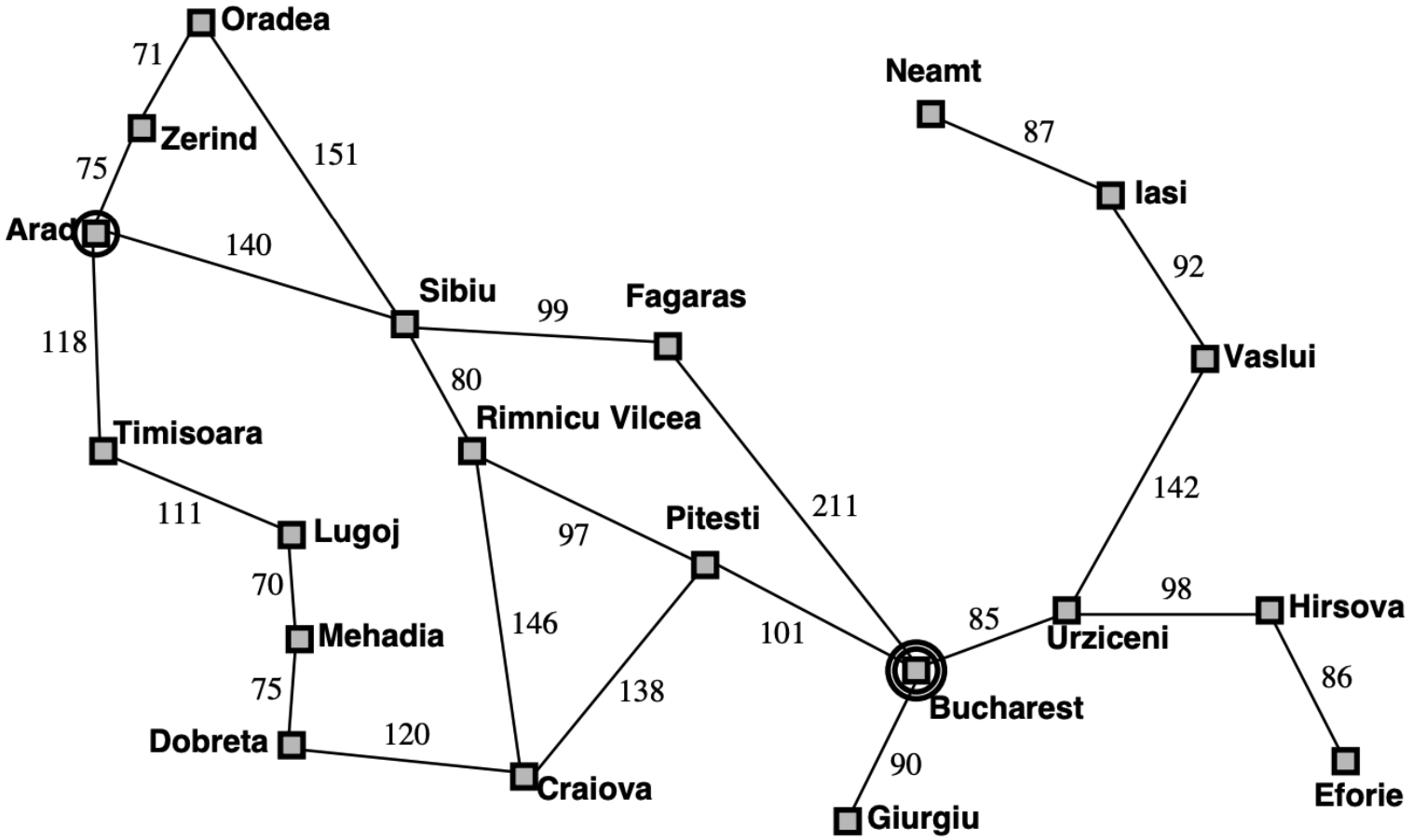
搜索问题

- 魔方



搜索问题

- 路径规划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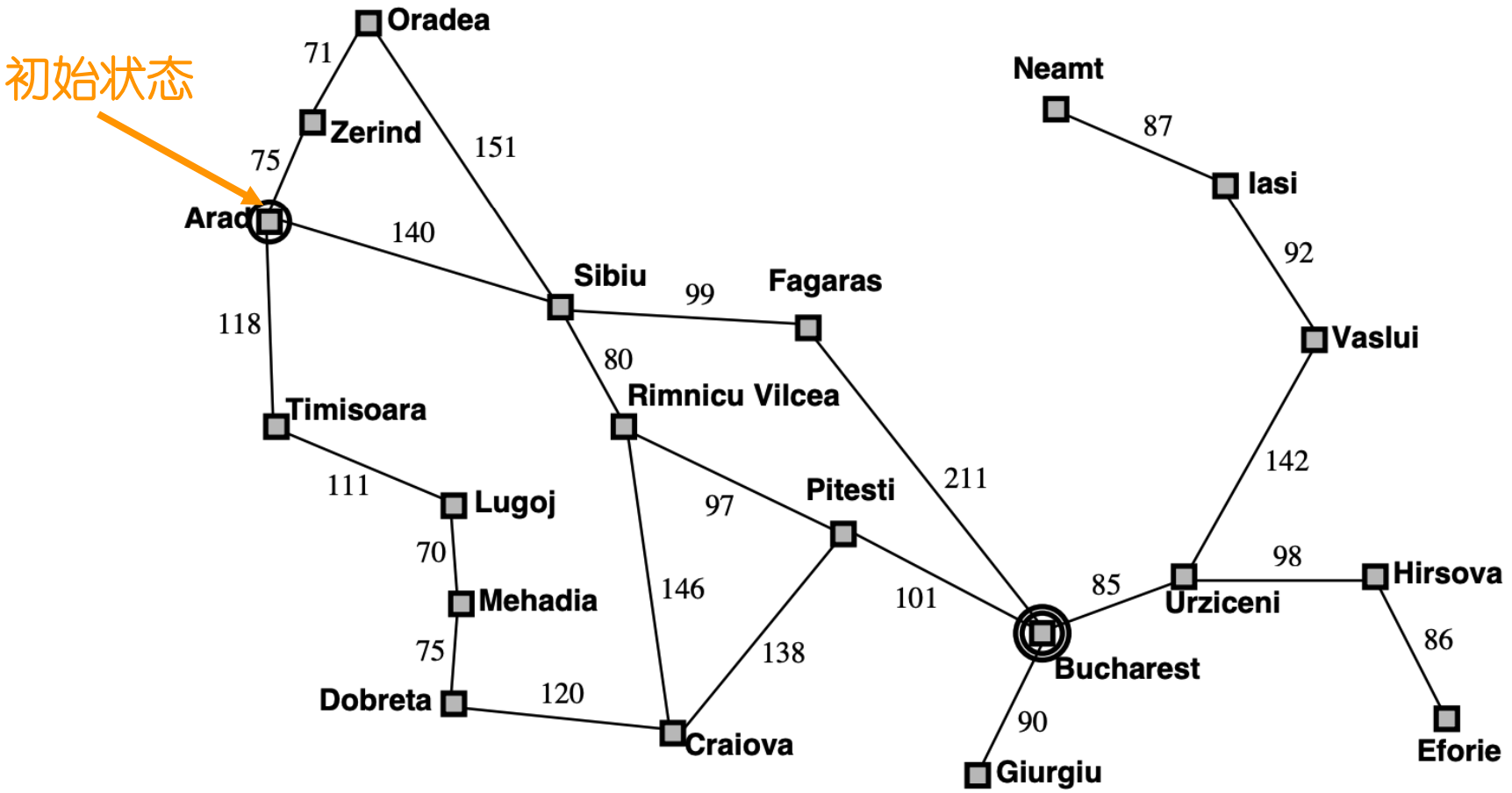
搜索问题

一个搜索问题可以用5个组成部分形式化描述

- 状态空间
- 初始状态
- 动作
- 状态转移
- 目标测试
- 路径/代价



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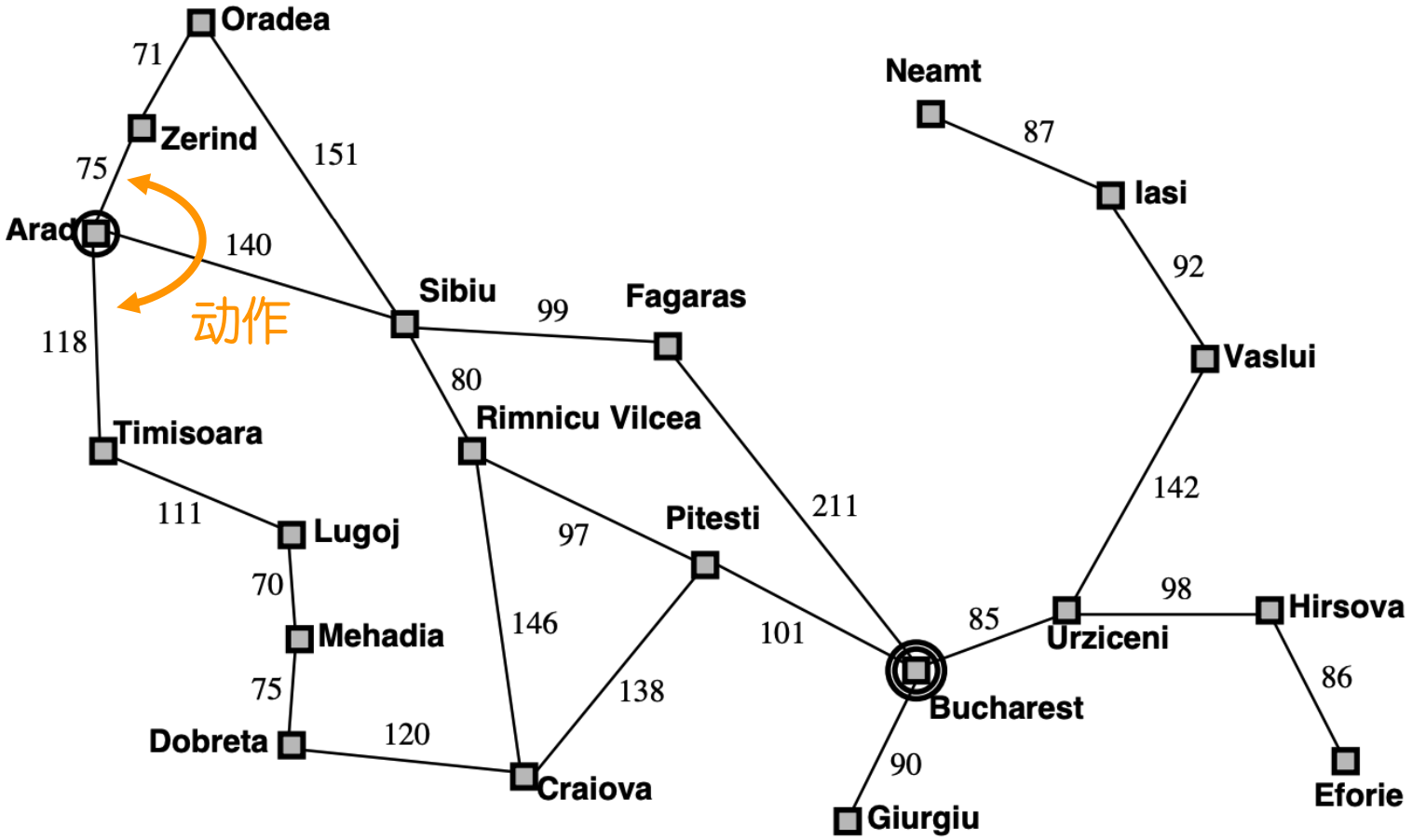

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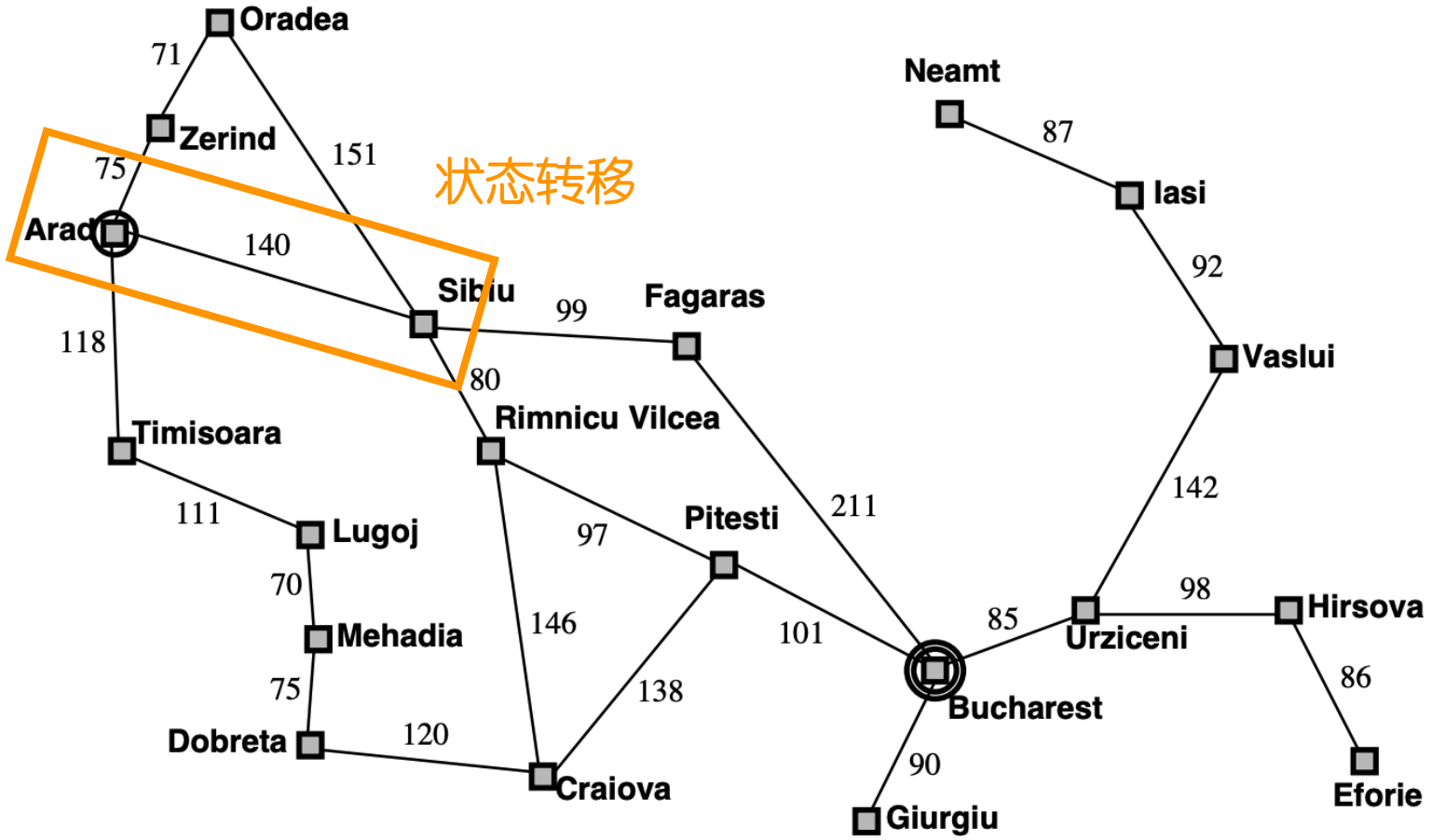

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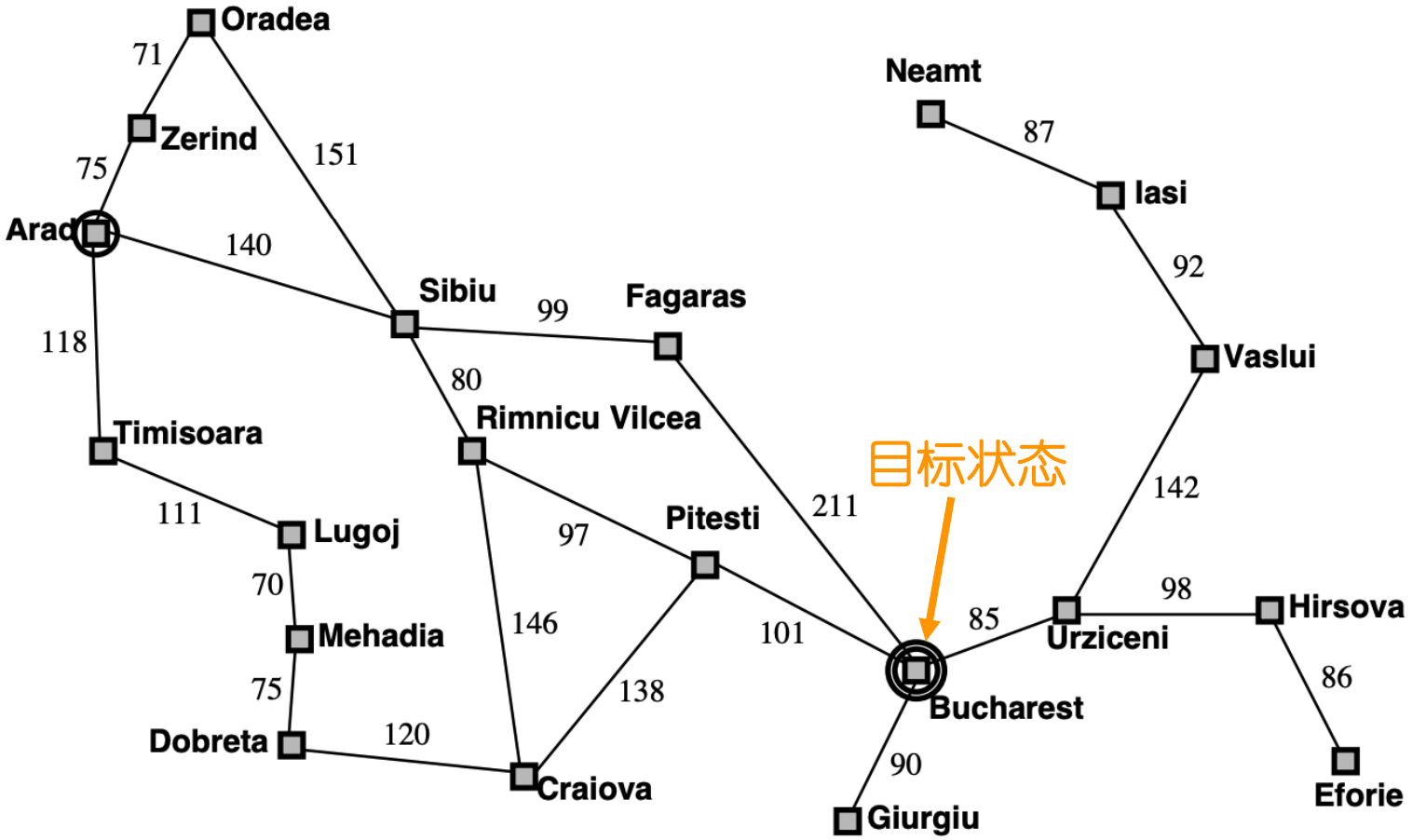

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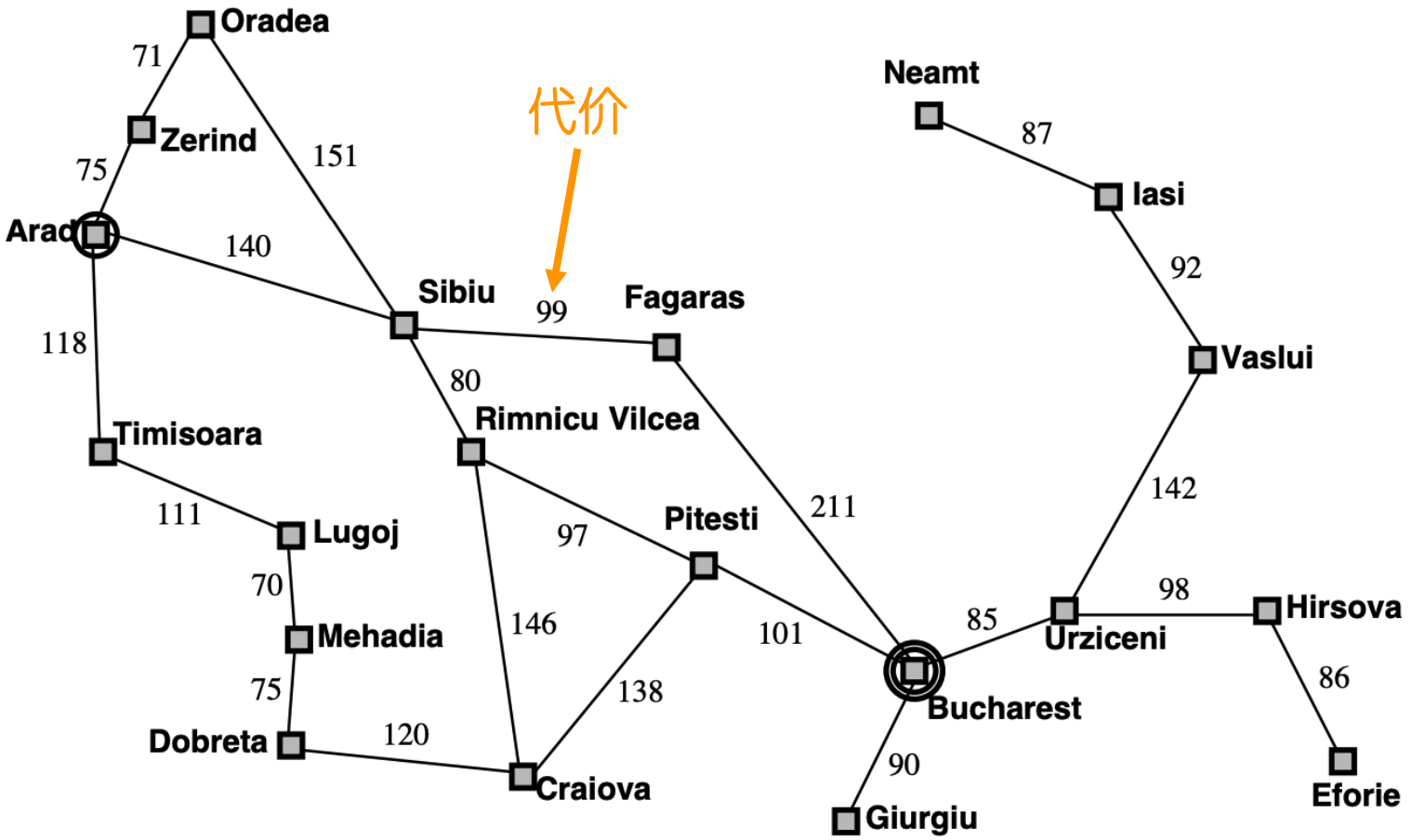

搜索问题

一个搜索问题可以用5个组成部分形式化描述

- 状态空间
- 初始状态
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- 状态转移
- 目标测试
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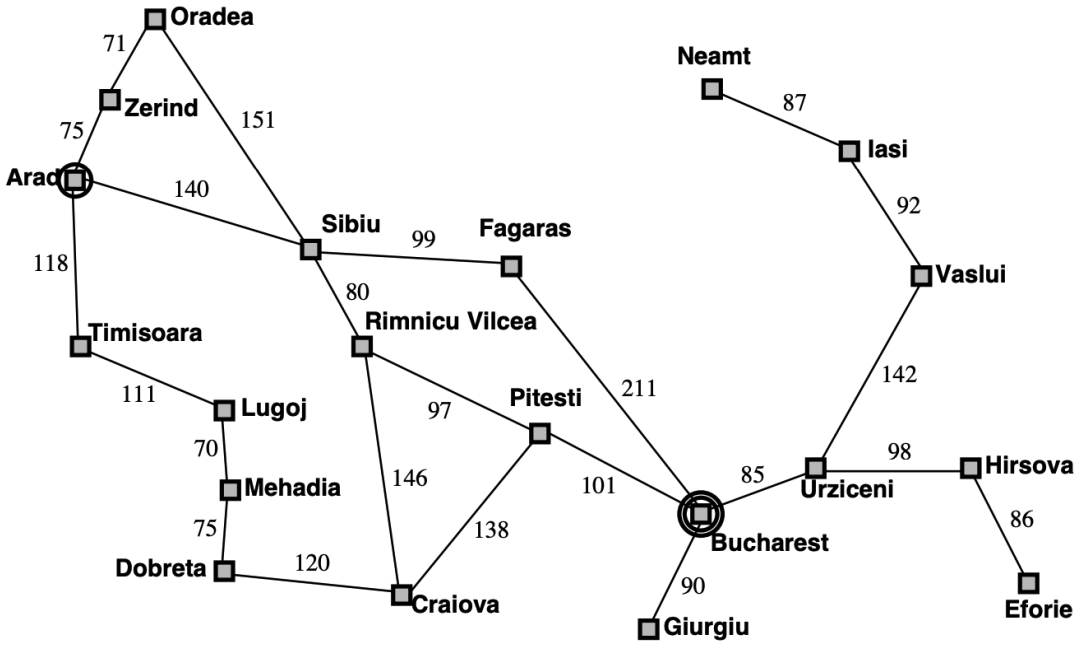
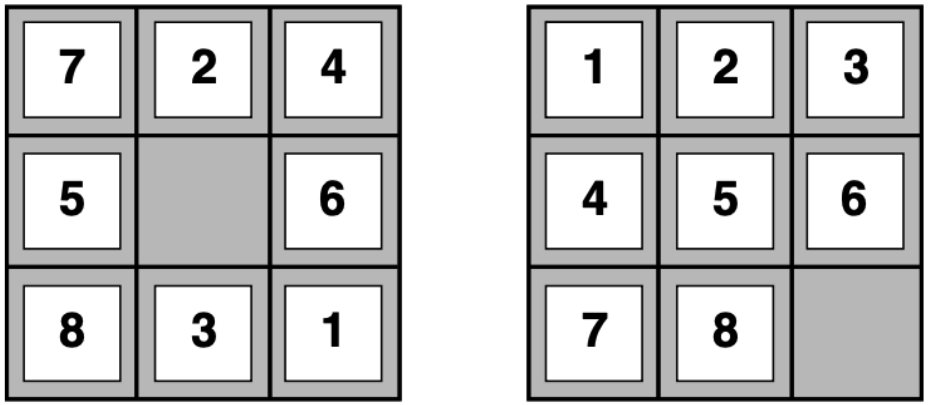
问题的解就是从初始状态到目标状态的一组行动序列

所有解里面代价最小的解即为最优解



搜索问题

八数码

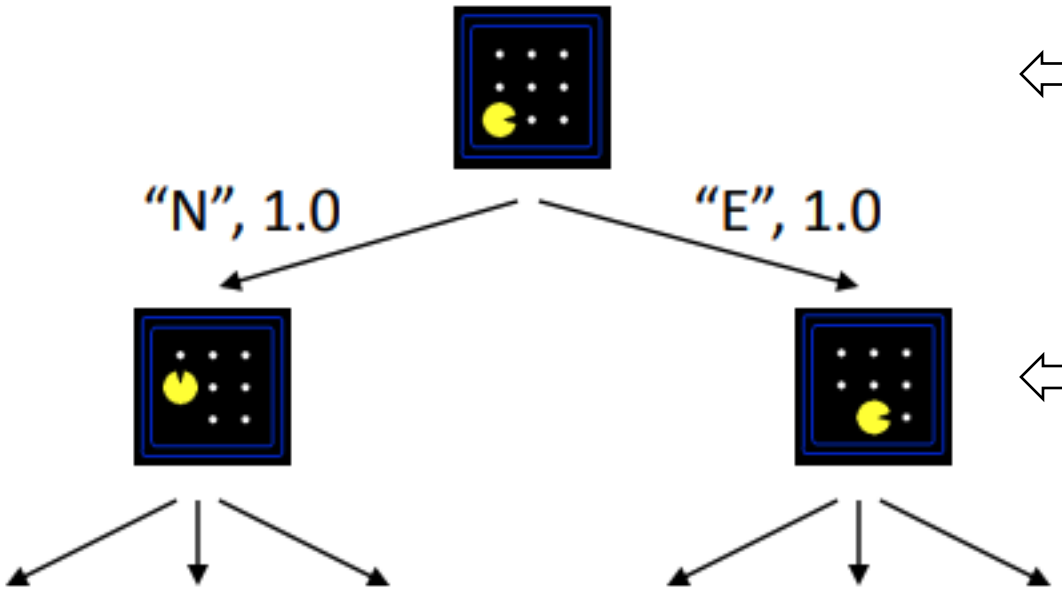


- 状态：8个数字方块和空格在棋盘上的分布
- 初始状态：任何状态都可能是初始状态
- 动作：移动空格
- 目标测试：检查是否到达目标状态
- 路径代价：每一步的代价为1

现实世界的搜索问题

- 游戏
- 旅行规划问题
- 旅行商问题
- 芯片布线问题
- 机器人导航问题
- 蛋白质设计问题
- ...

搜索树

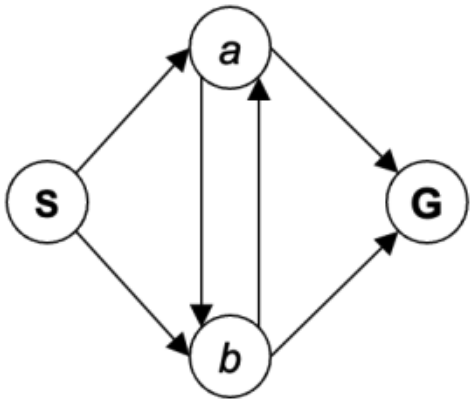


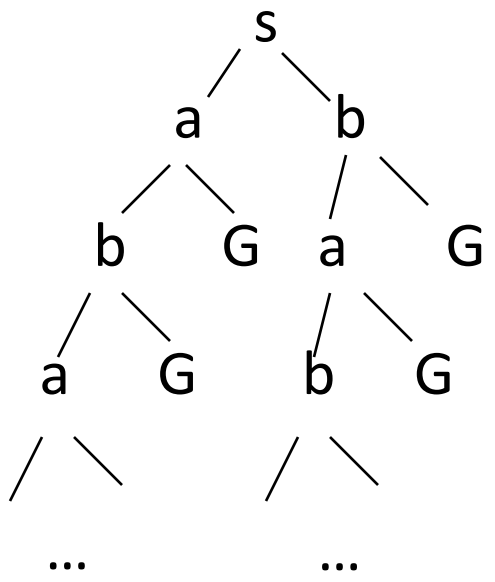
当前状态

可能的后继状态

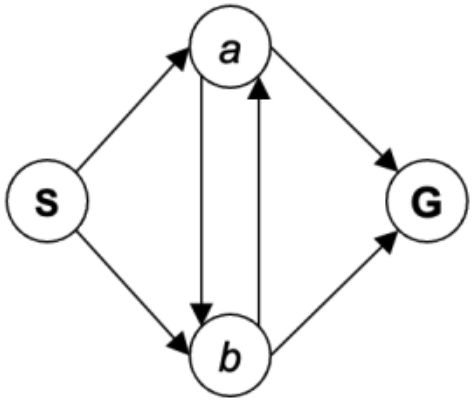
对于大多数问题，很难构建完整的搜索树

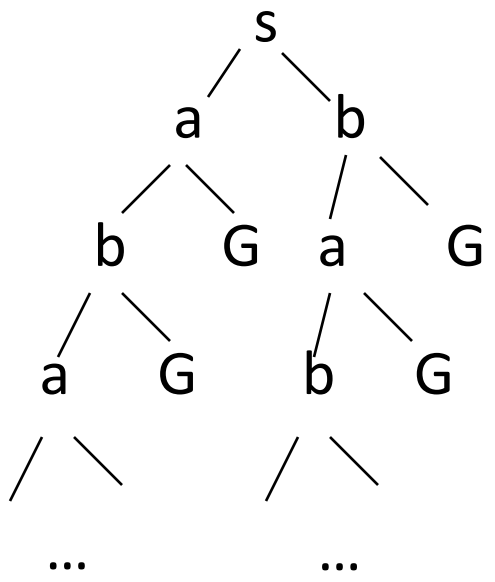
搜索树的深度



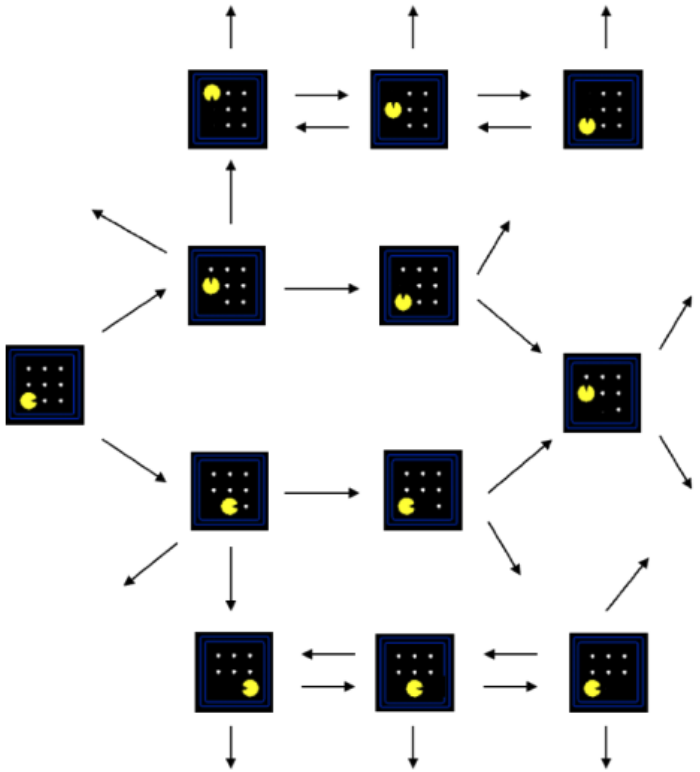


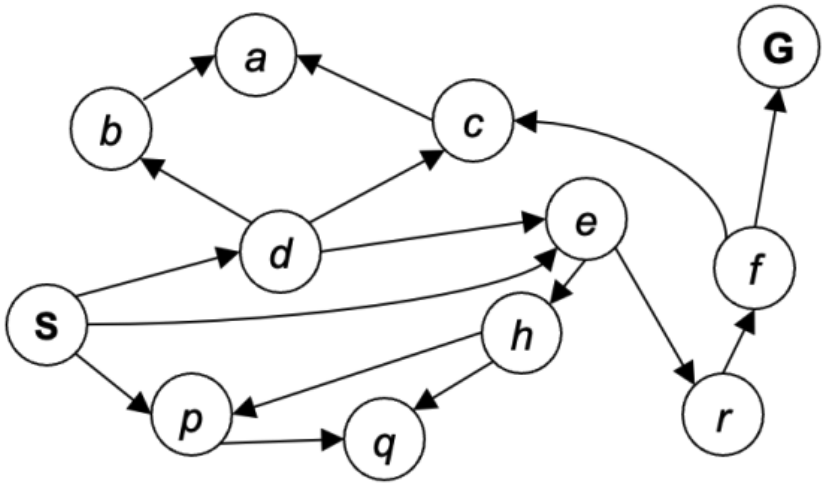
搜索树的深度





搜索图

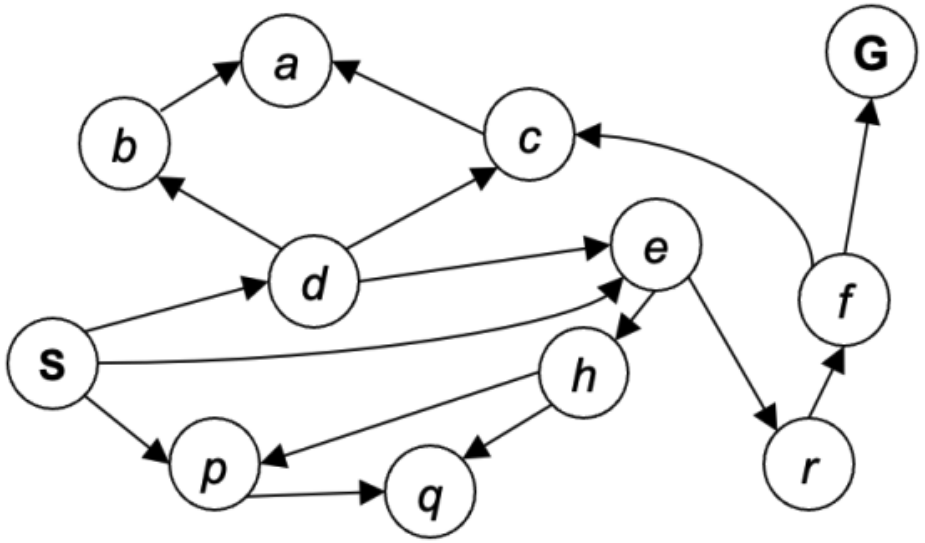


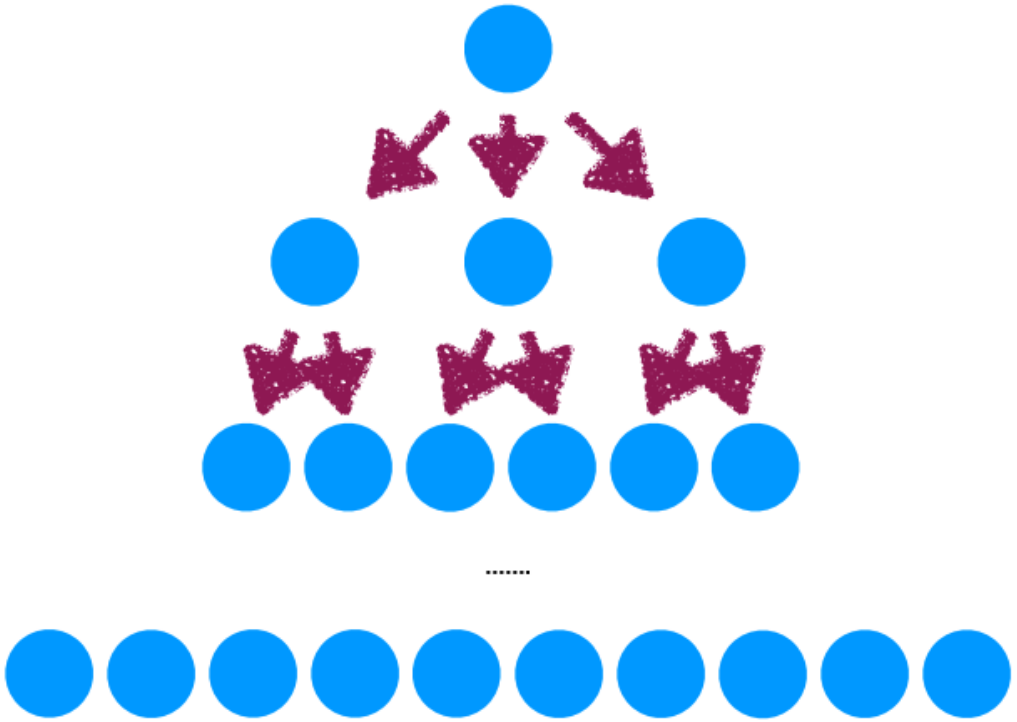


每个节点都是一个状态，图中的边体现了状态的转移

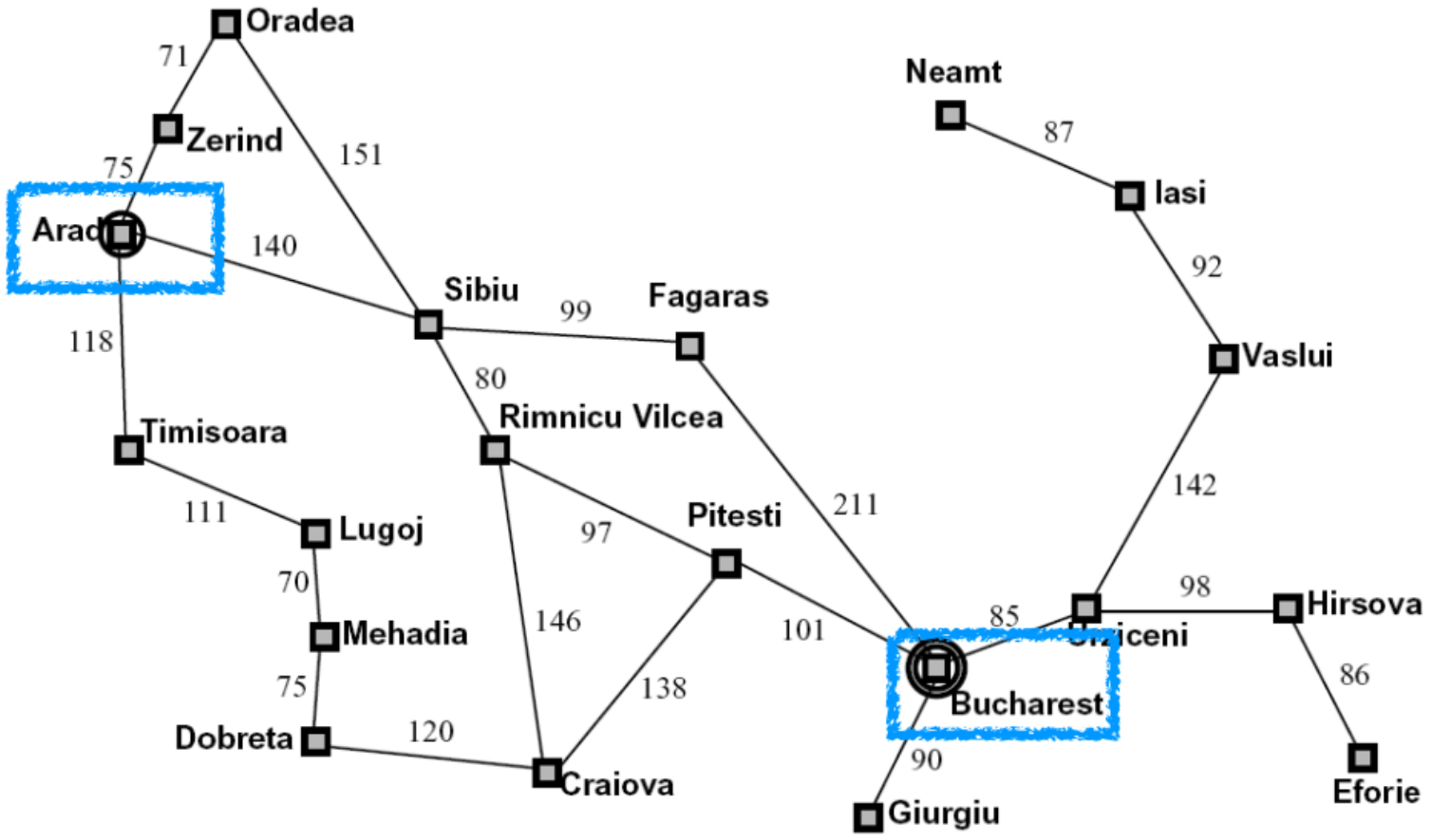
搜索图和搜索树

一个解是一个行动序列，搜索算法的工作就是考虑各种可能的行动序列





搜索问题求解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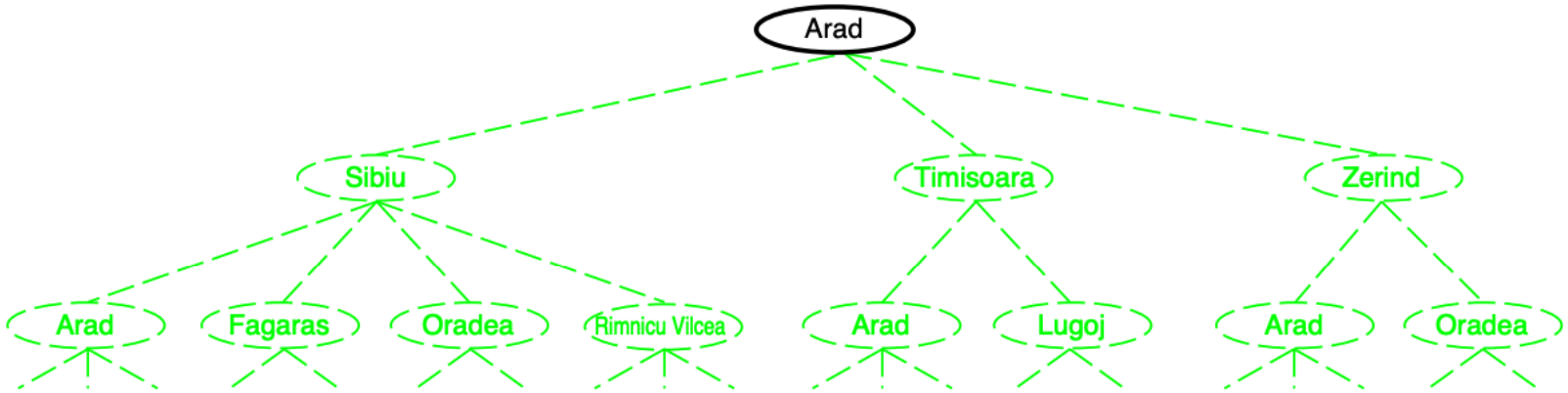
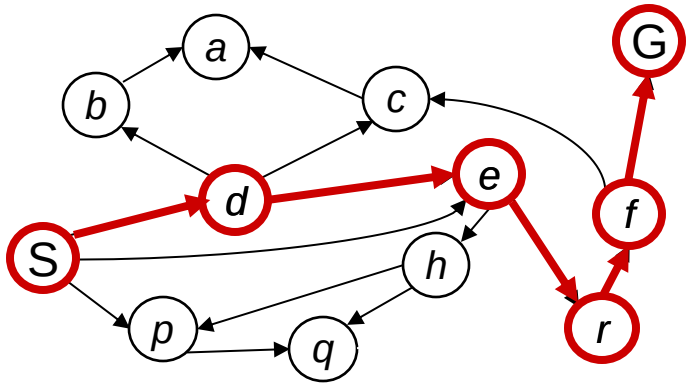
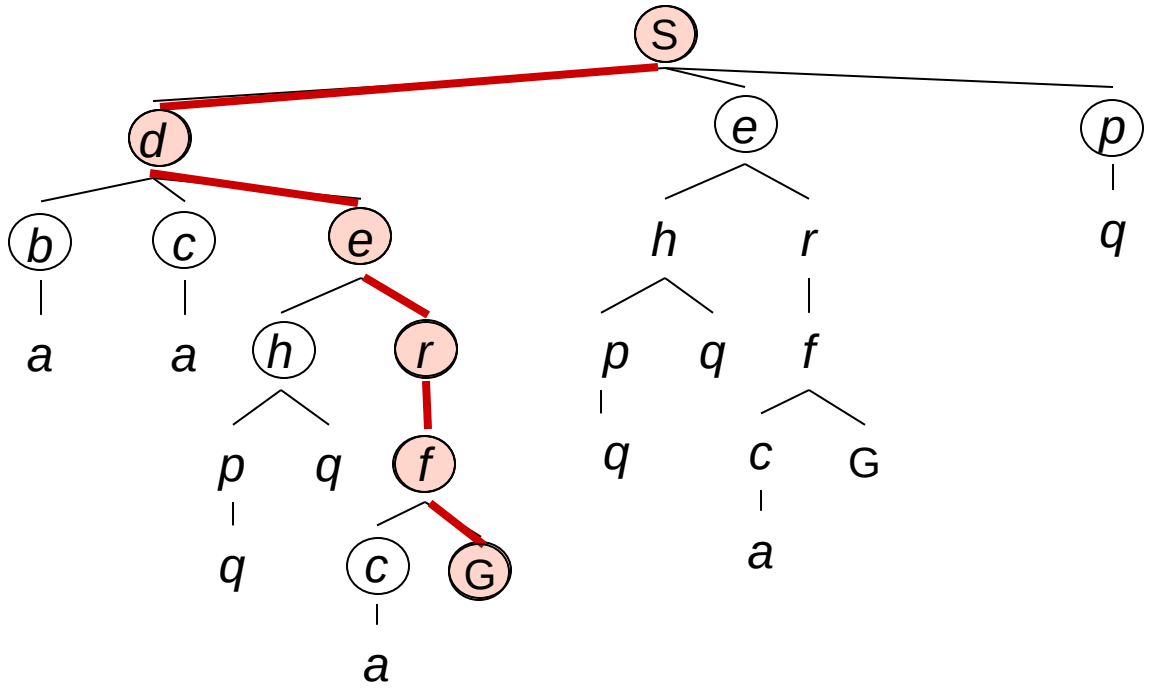
搜索问题求解



- 扩展当前的状态，在当前状态下采用各种行动，生成新的状态
- 所有待扩展的节点称为**边缘节点**
- 不断从边缘节点中选择节点并扩展，直到到达目标状态，或者没有状态可以扩展

树搜索算法





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~~s → d → e → r → f~~

s → d → e → r → f → c

~~s → d → e → r → f → G~~

树搜索算法

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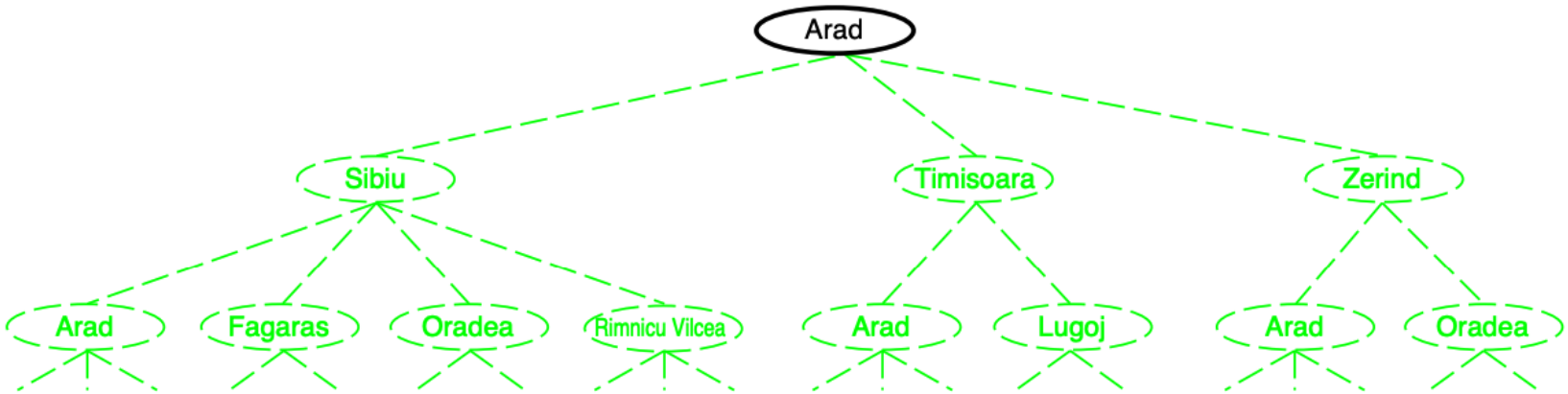
function TREE-SEARCH( problem, strategy) returns a solution, or failure
    initialize the search tree using the initial state of problem
    loop do
        if there are no candidates for expansion then return failure
        choose a leaf node for expansion according to strategy
        if the node contains a goal state then return the corresponding solution
        else expand the node and add the resulting nodes to the search tree
    end
```

不同搜索策略的核心区别在于如何选择要扩展的边缘节点

树搜索算法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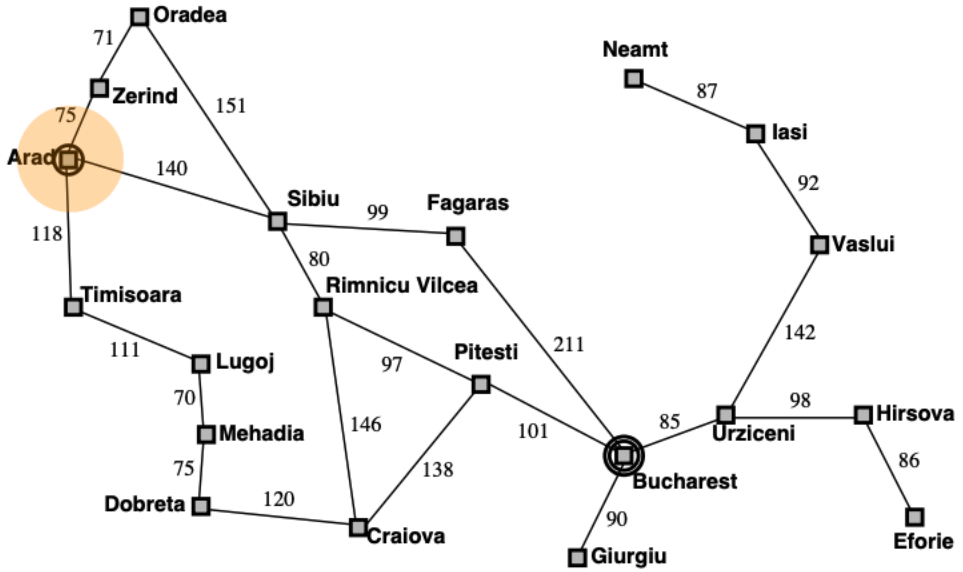
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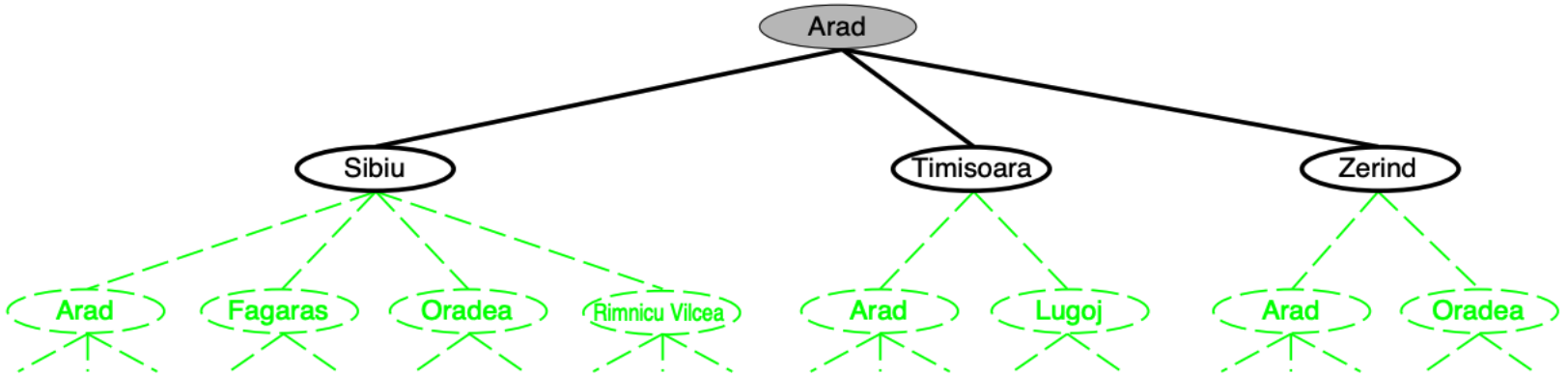
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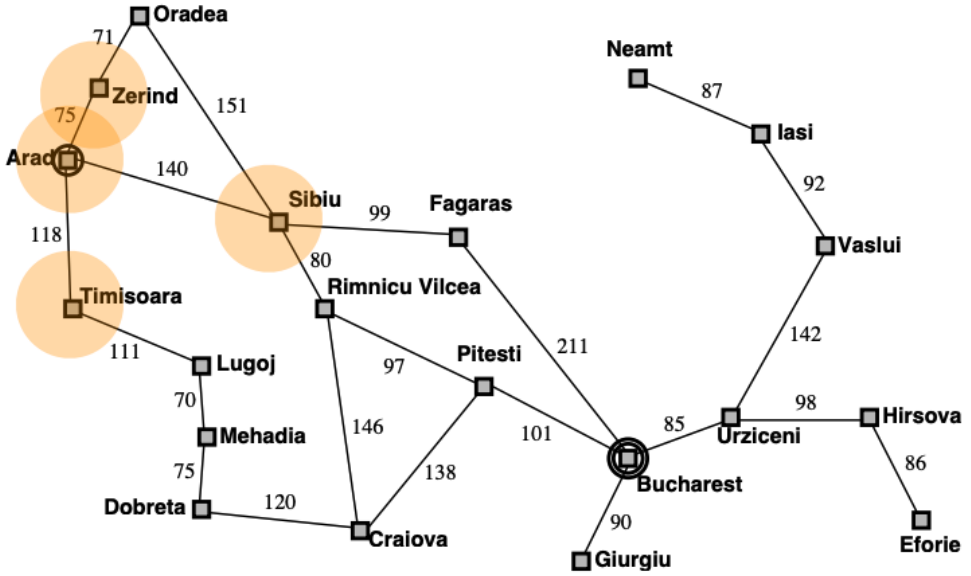
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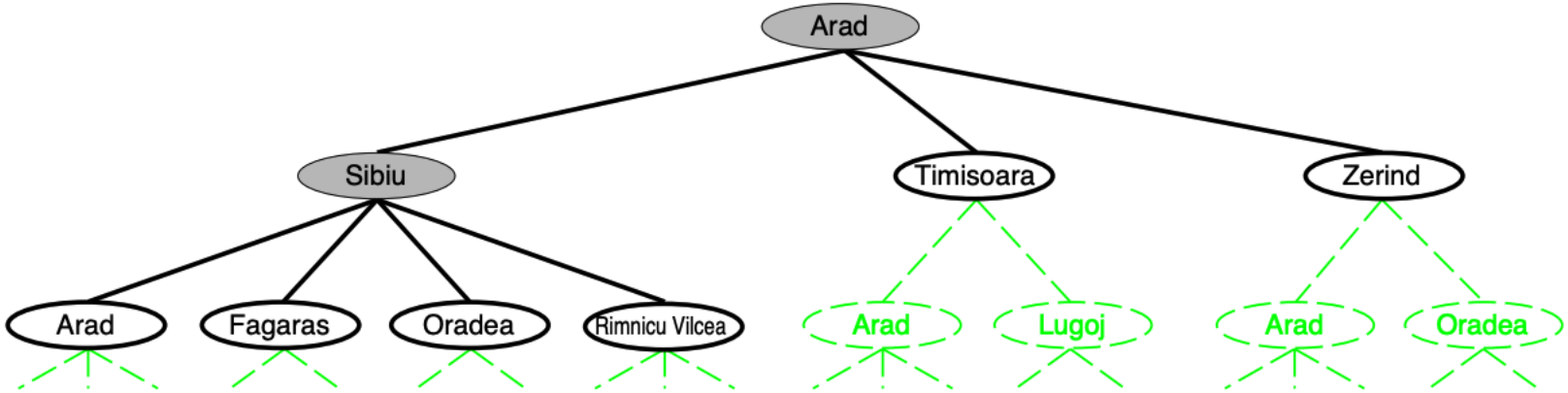
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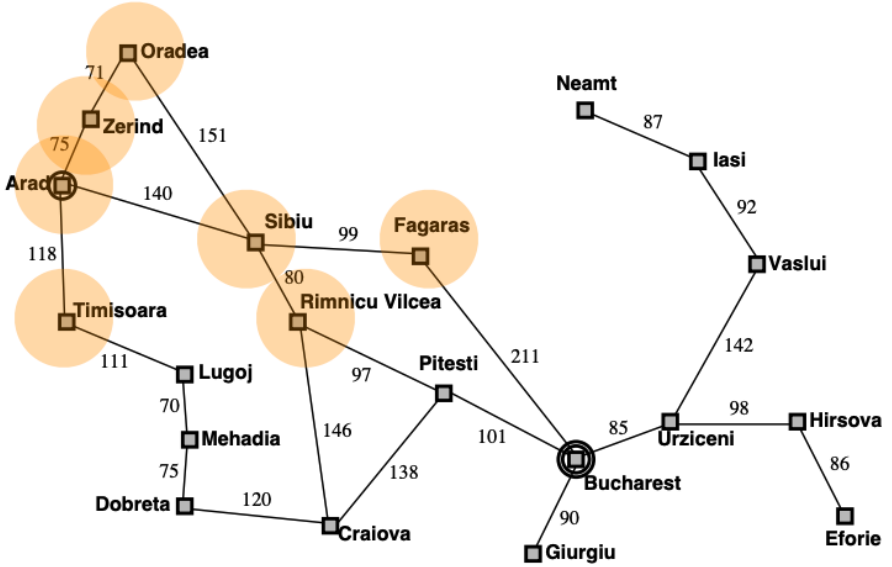
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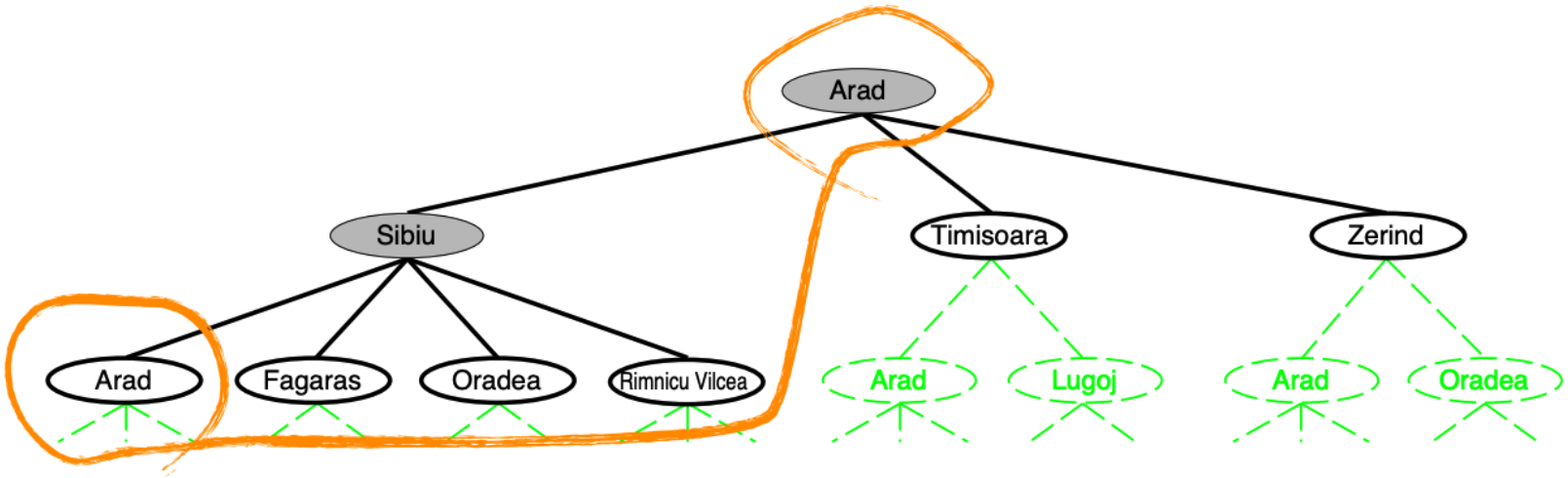
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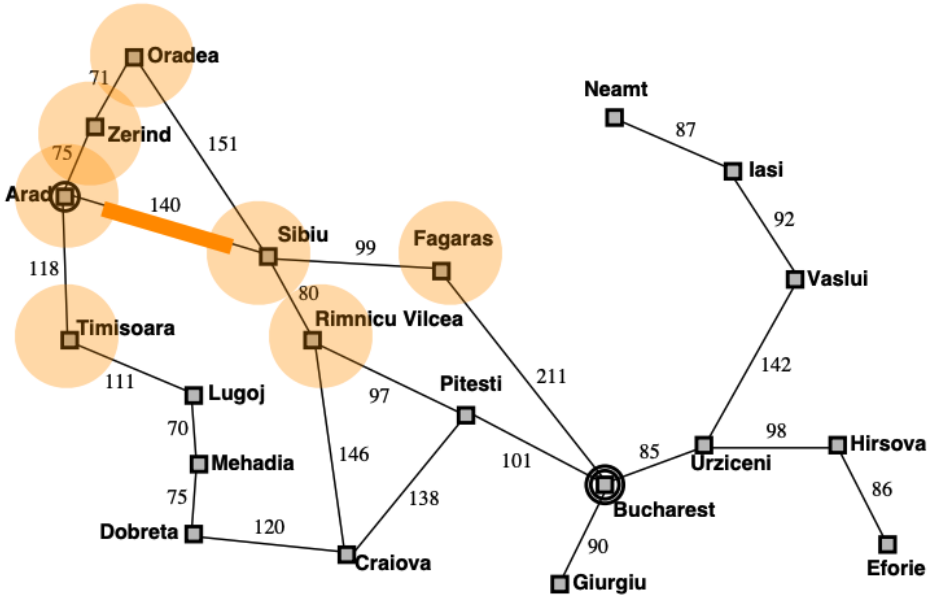
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图搜索算法

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    loop do
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        choose a leaf node for expansion according to strategy
        if the node contains a goal state then return the corresponding solution
        else expand the node and add the resulting nodes to the search tree
    end
```

```
function GRAPH-SEARCH( problem, fringe) returns a solution, or failure
    closed ← an empty set
    fringe ← INSERT(MAKE-NODE(INITIAL-STATE[problem]), fringe)
    loop do
        if fringe is empty then return failure
        node ← REMOVE-FRONT(fringe)
        if GOAL-TEST(problem, STATE[node]) then return node
        if STATE[node] is not in closed then
            add STATE[node] to closed
            fringe ← INSERTALL(EXPAND(node, problem), fringe)
    end
```

搜索策略

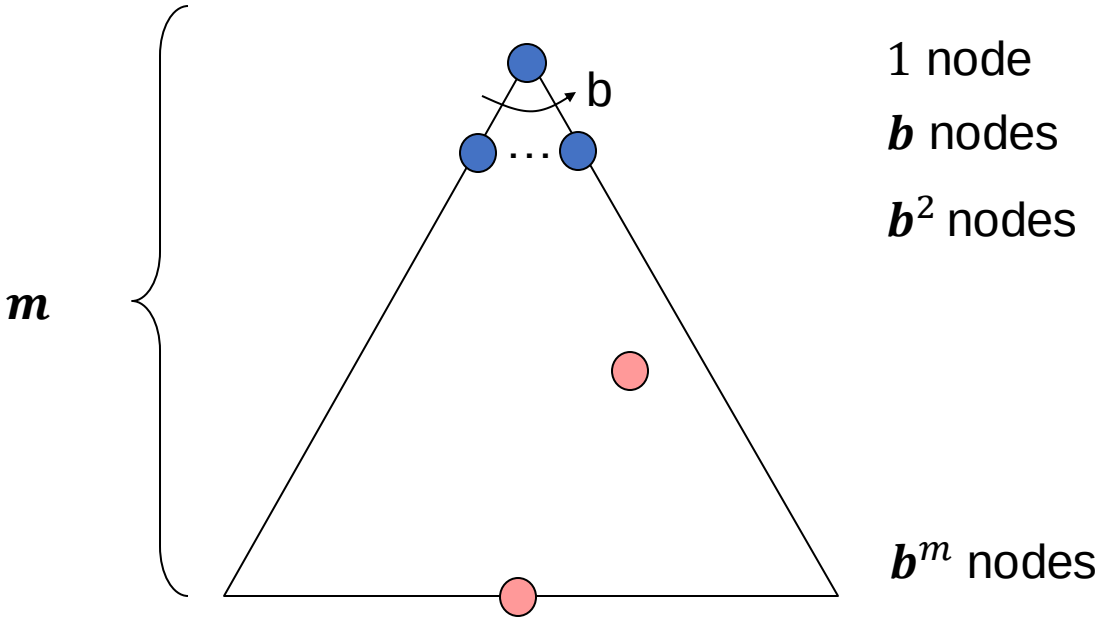
搜索策略的主要区别在于**如何选择要扩展的状态**

如何评估搜索算法的性能？

- ✓ **完备性**：当问题有解时，这个算法是否能保证找到解？
- ✓ **最优性**：搜索策略是否能找到最优解？
- ✓ **时间复杂度**：找到解需要花费多长时间？
- ✓ **空间复杂度**：在执行搜索的过程总需要多少内存？

搜索策略性能分析

符号	含义
b	分支因子，即搜索树中每个节点最大的分支数目
d	根节点到最浅的目标结点的路径长度
m	搜索树中路径的最大可能长度
n	状态空间中状态的数量



$$1 + b + b^2 + \cdots + b^m = O(b^m)$$

提纲

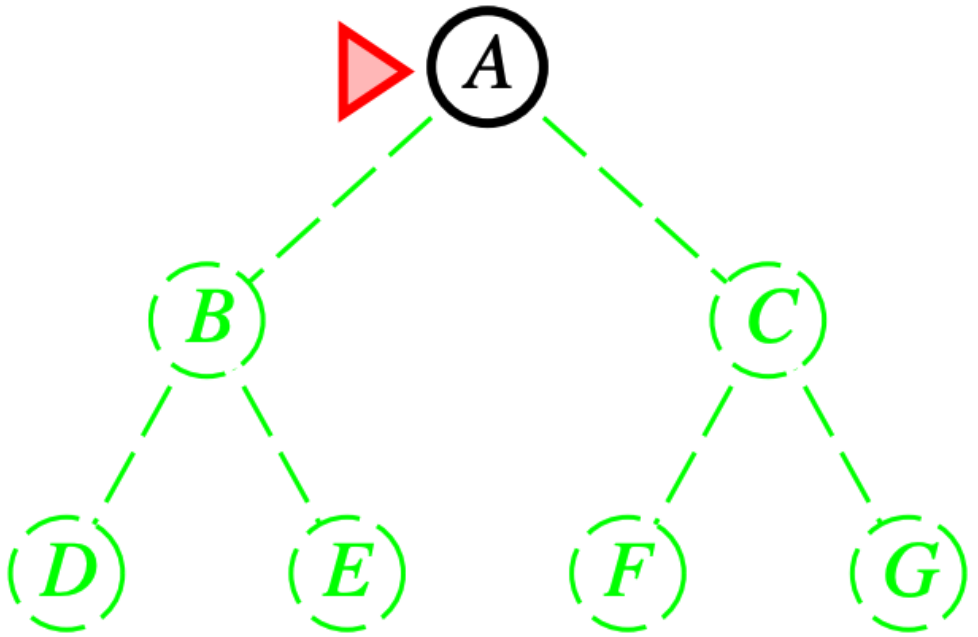
- 搜索问题
- 无信息搜索
  - 宽度优先搜索
  - 深度优先搜索
  - 迭代加深的深度优先搜索
  - 代价一致性搜索
- 本章小结

除了问题定义中给定的状态信息外没有任何附加信息

宽度优先搜索（breadth-first search, BFS）

先扩展根节点，接着扩展根节点的所有后继节点，然后再扩展它们的后继，以此类推。

一般地，在下一层的任何节点扩展之前，搜索树本层深度的搜有节点应该都已经扩展过



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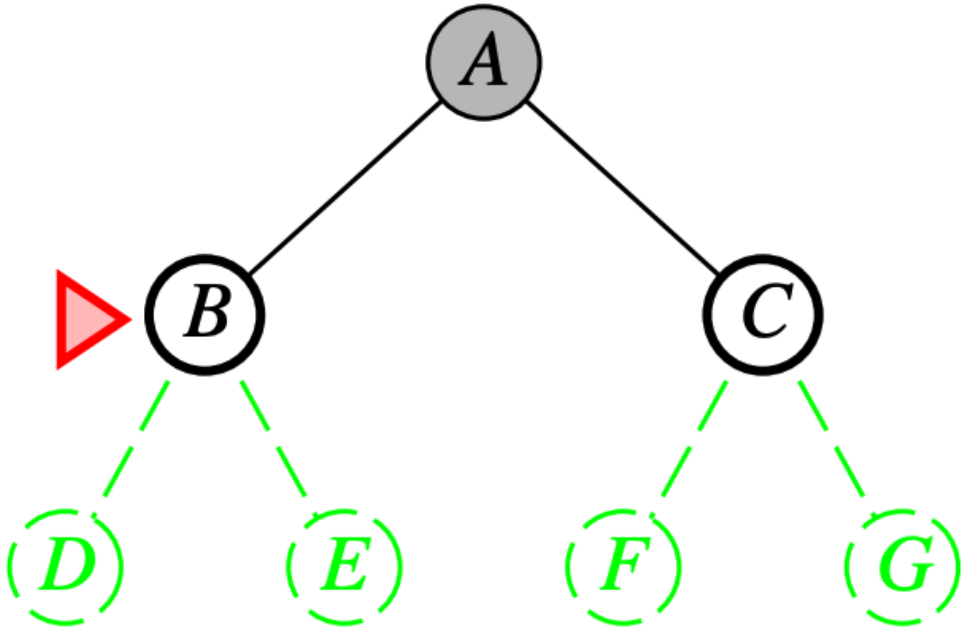

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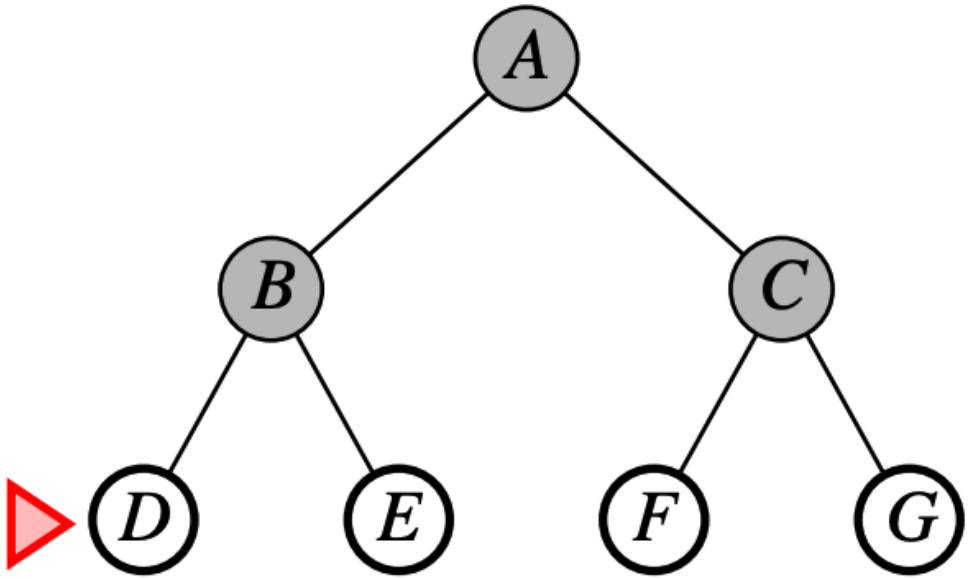

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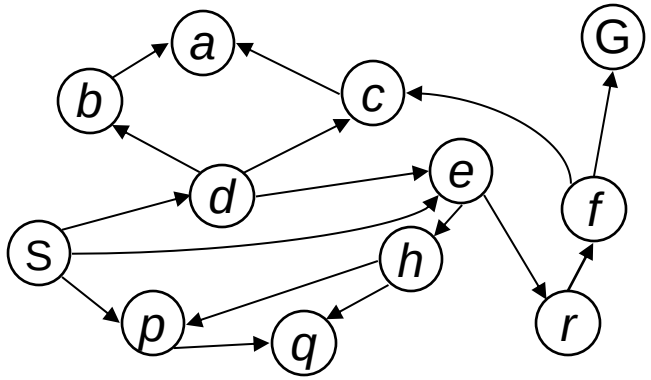
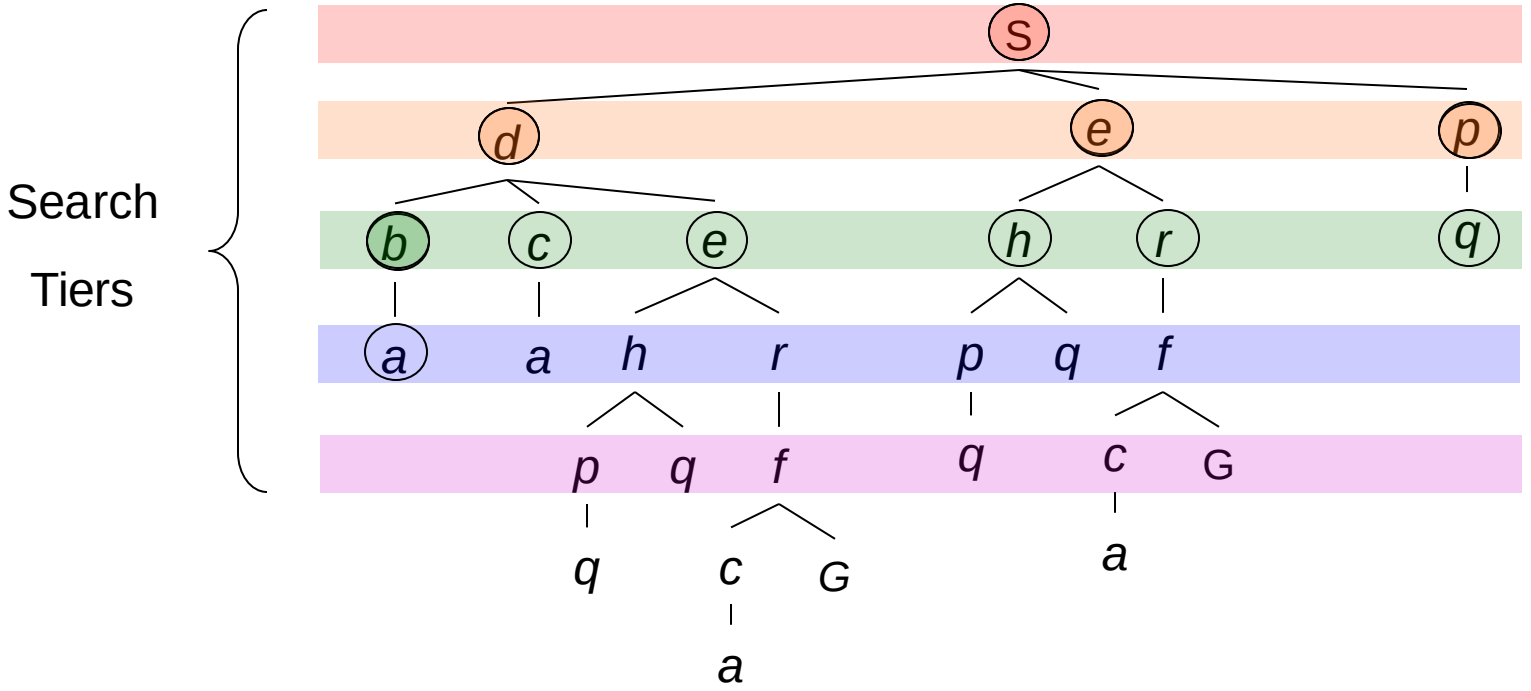
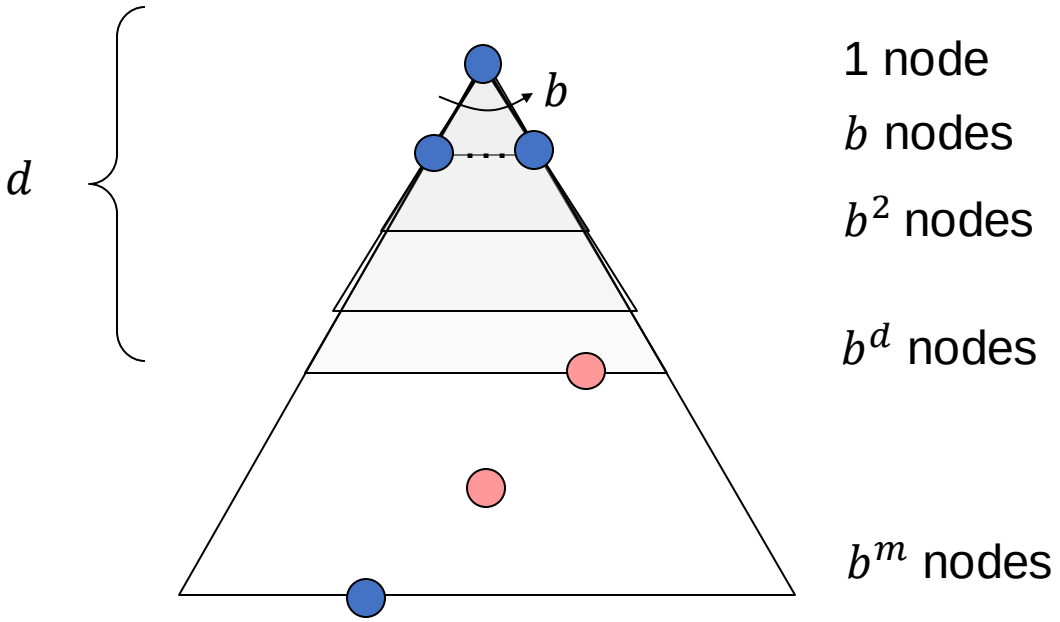




性能分析

- 时间复杂度?
  - $1 + b + b^2 + b^3 + \cdots + b^d = O(b^d)$
- 空间复杂度?
  - $O(b^d)$
- 完备性?
  - Yes
- 最优性?
  - Yes， 如果所有行动代价相同



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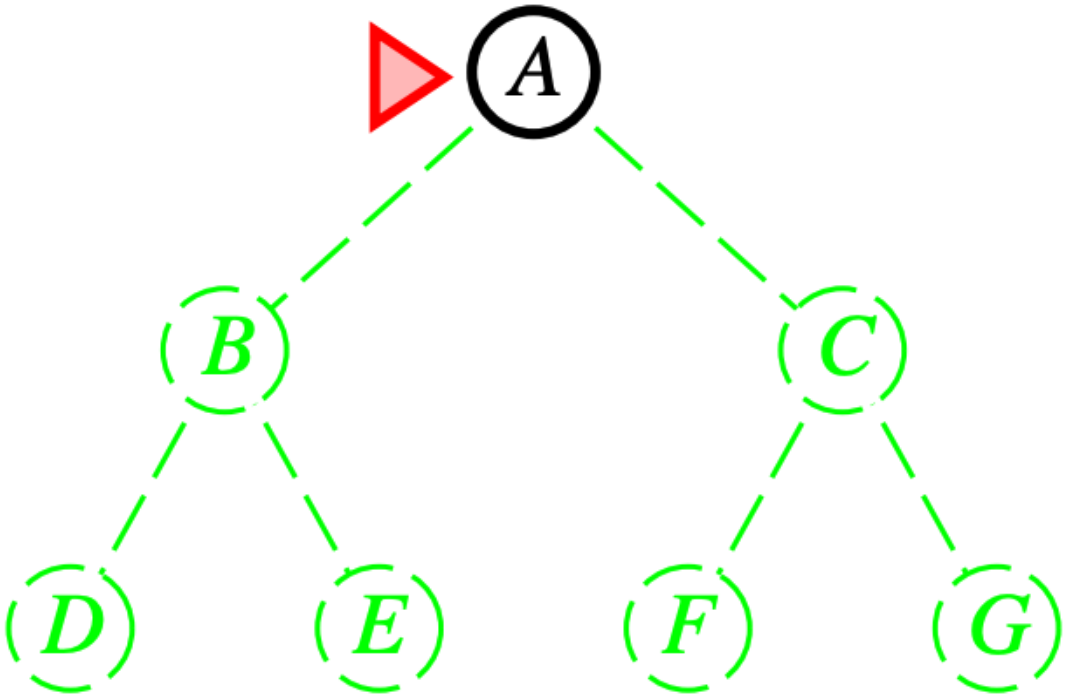
深度优先搜索（depth-first search, DFS）

总是扩展当前边缘节点集中最深的节点



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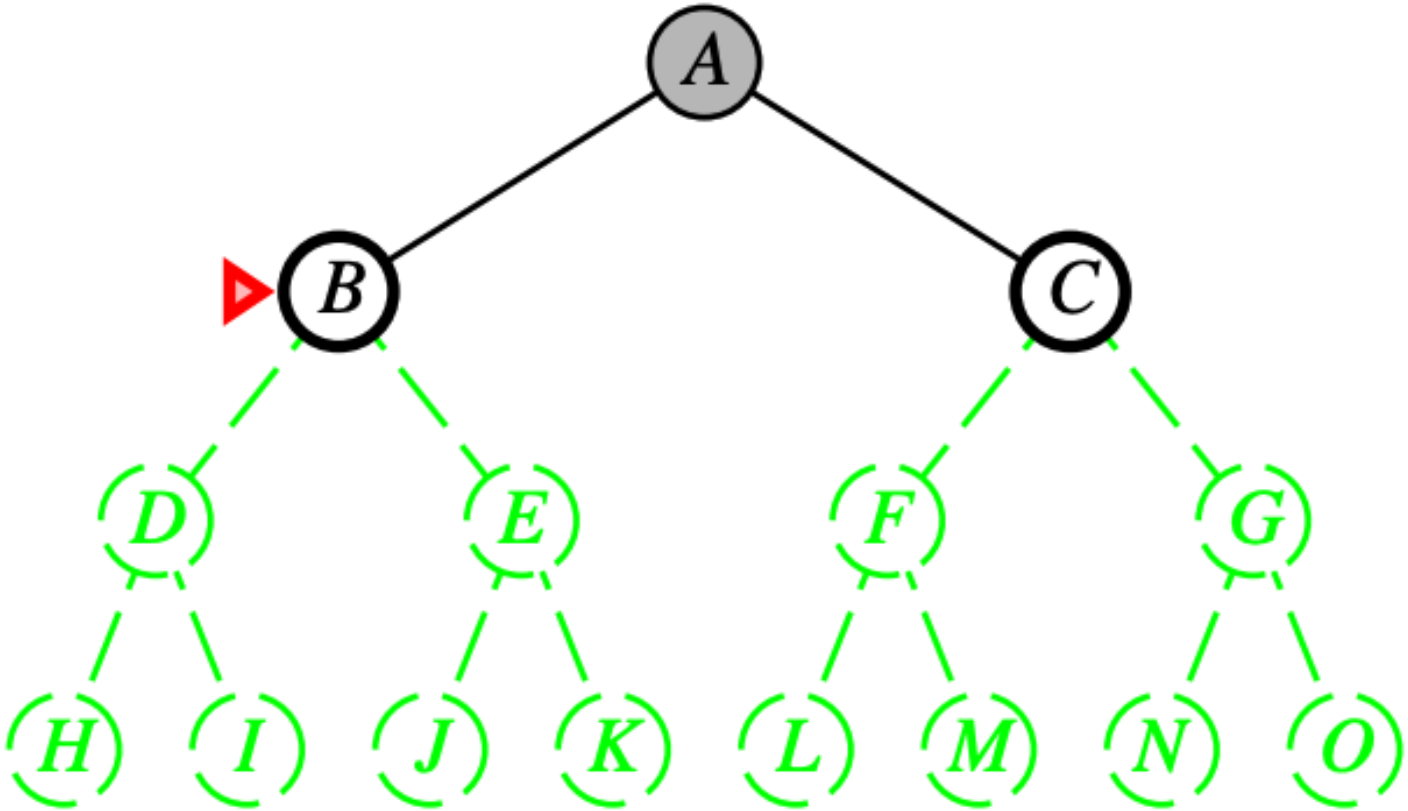

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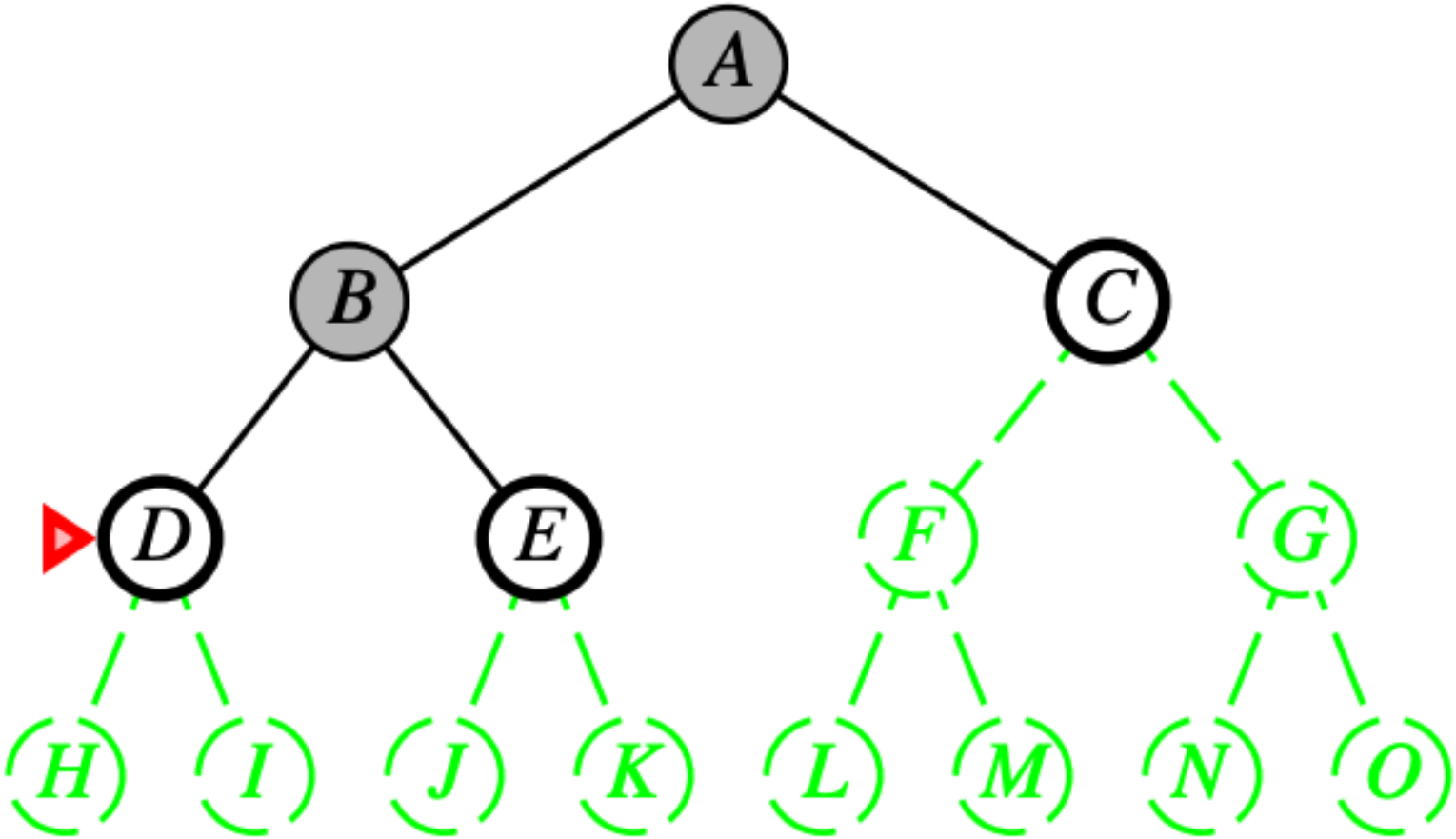

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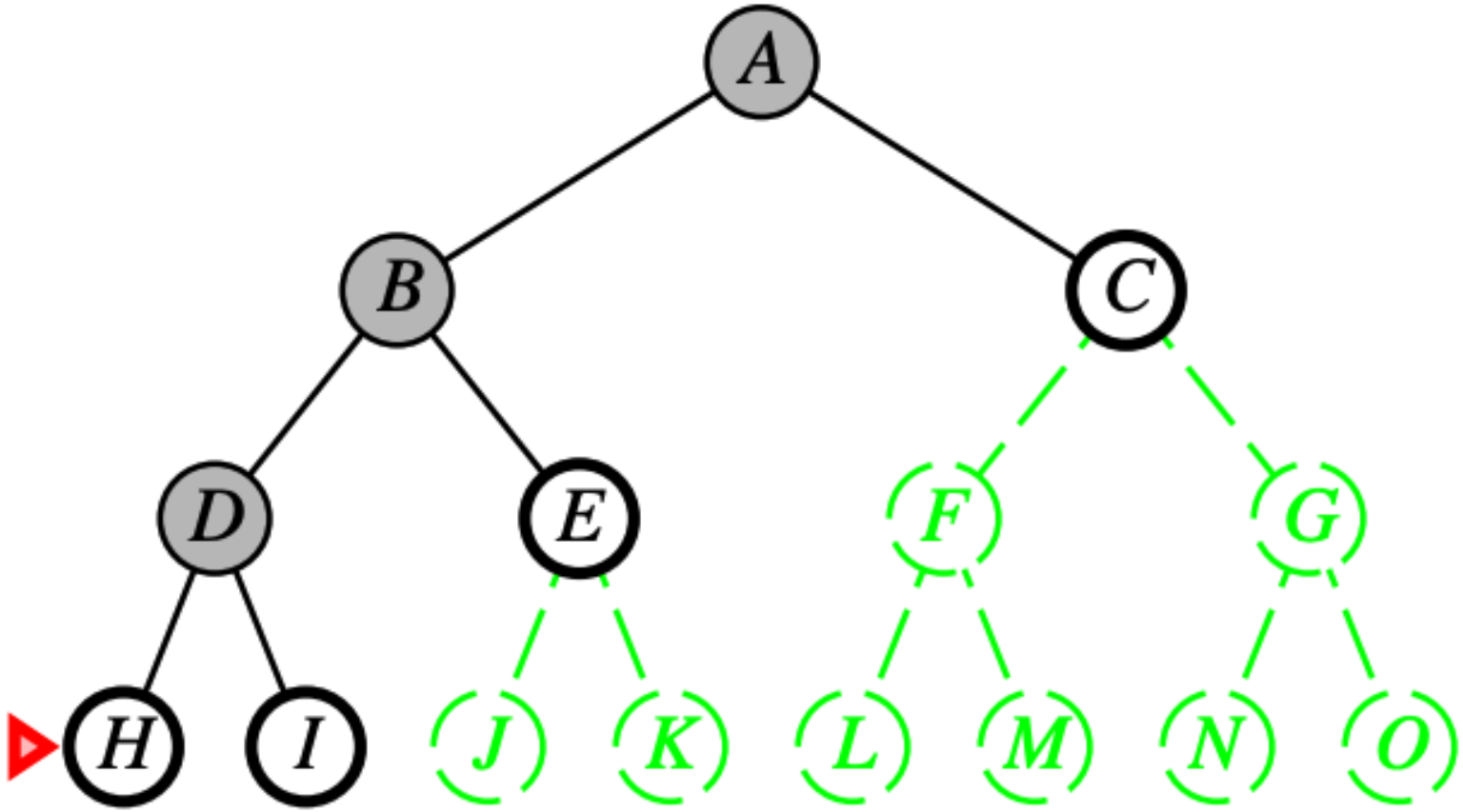

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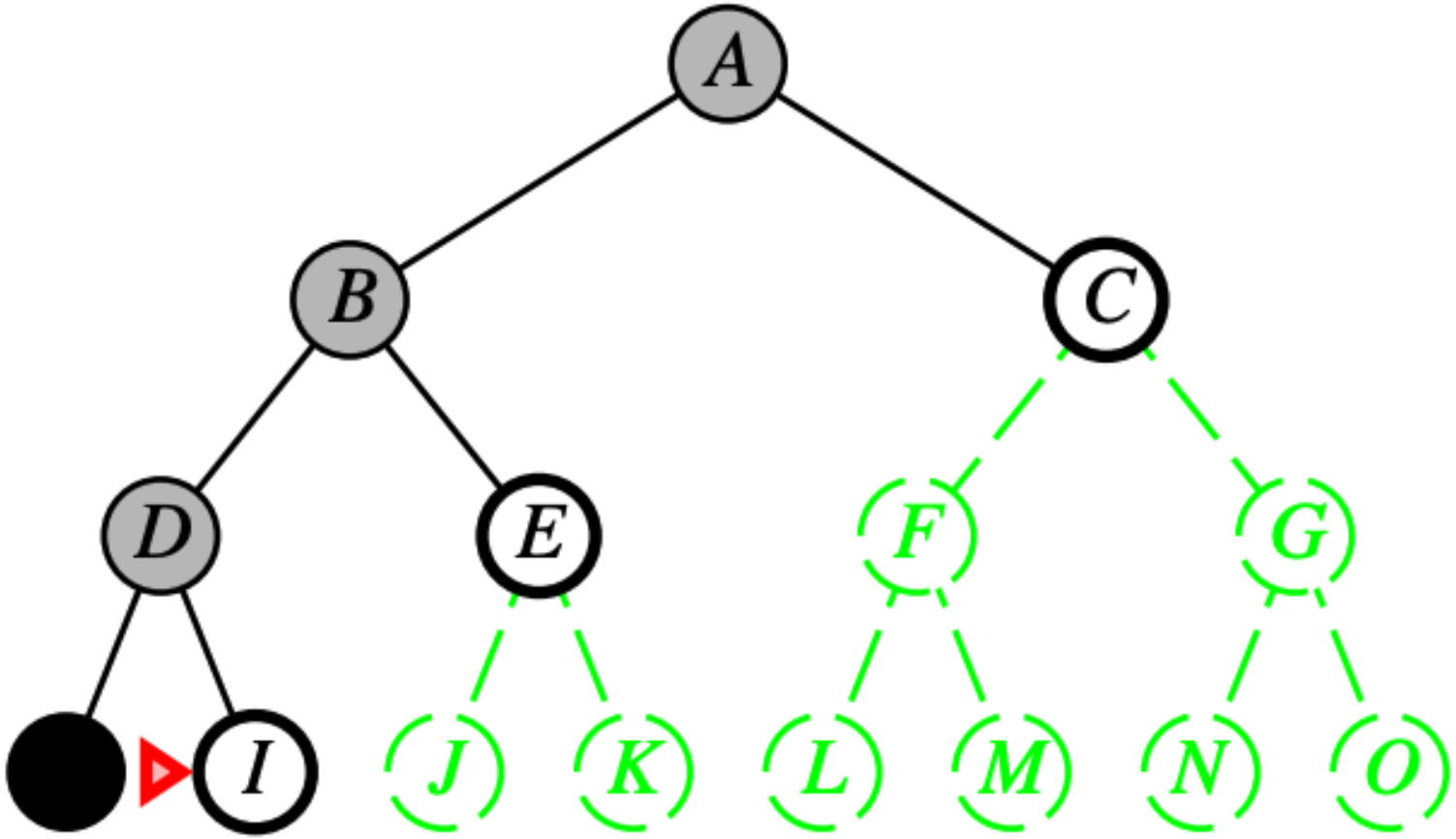

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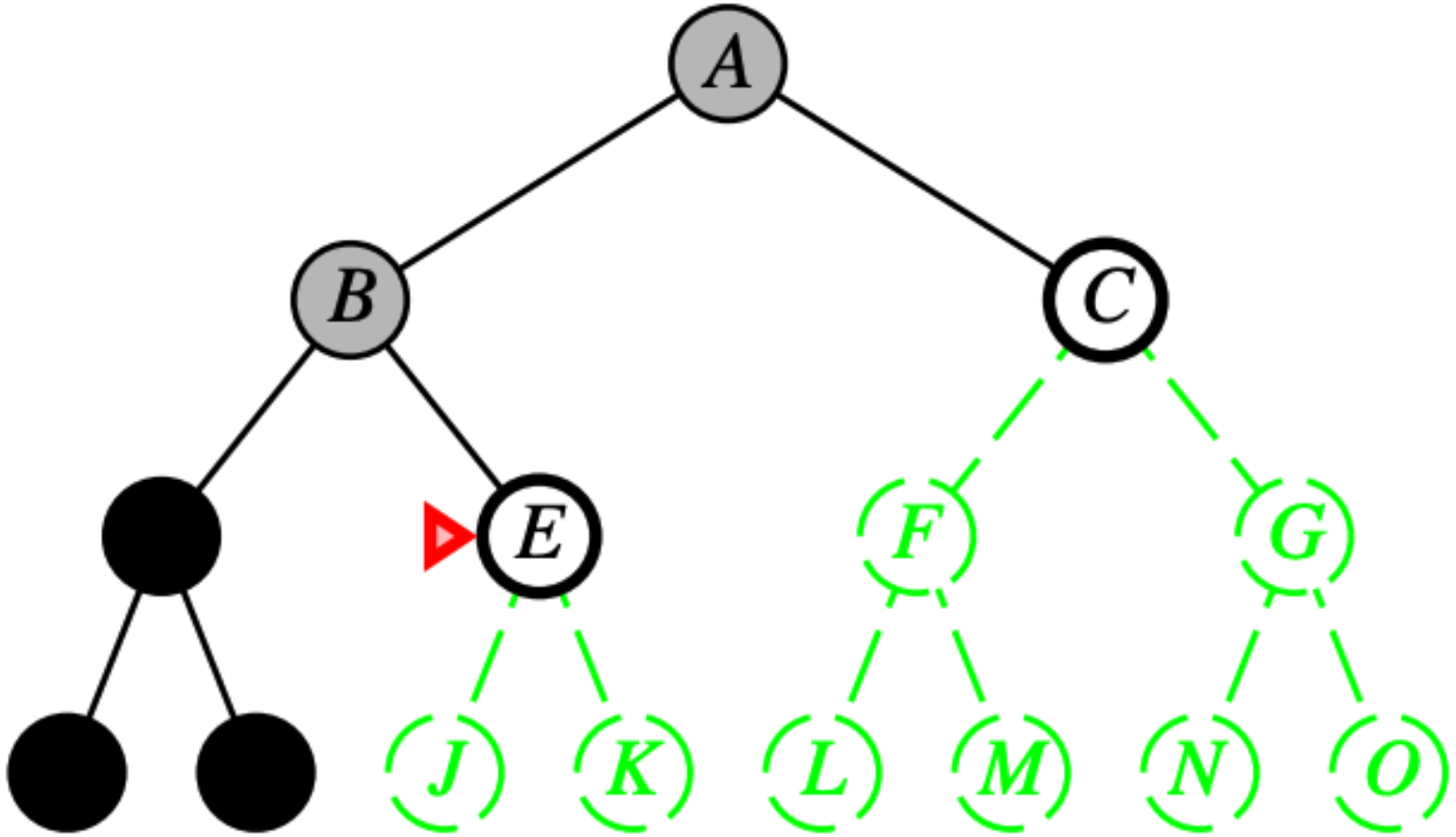

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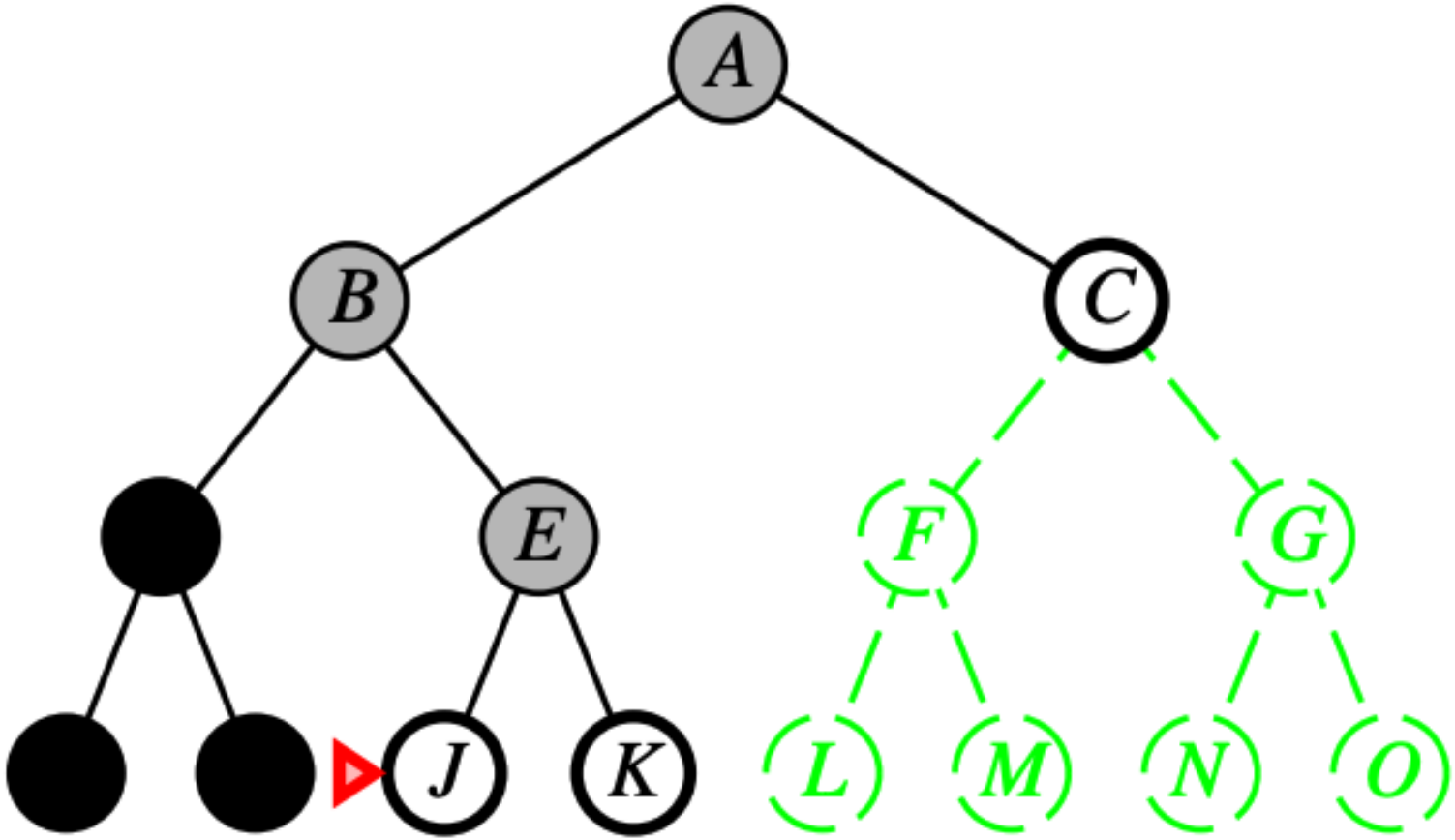

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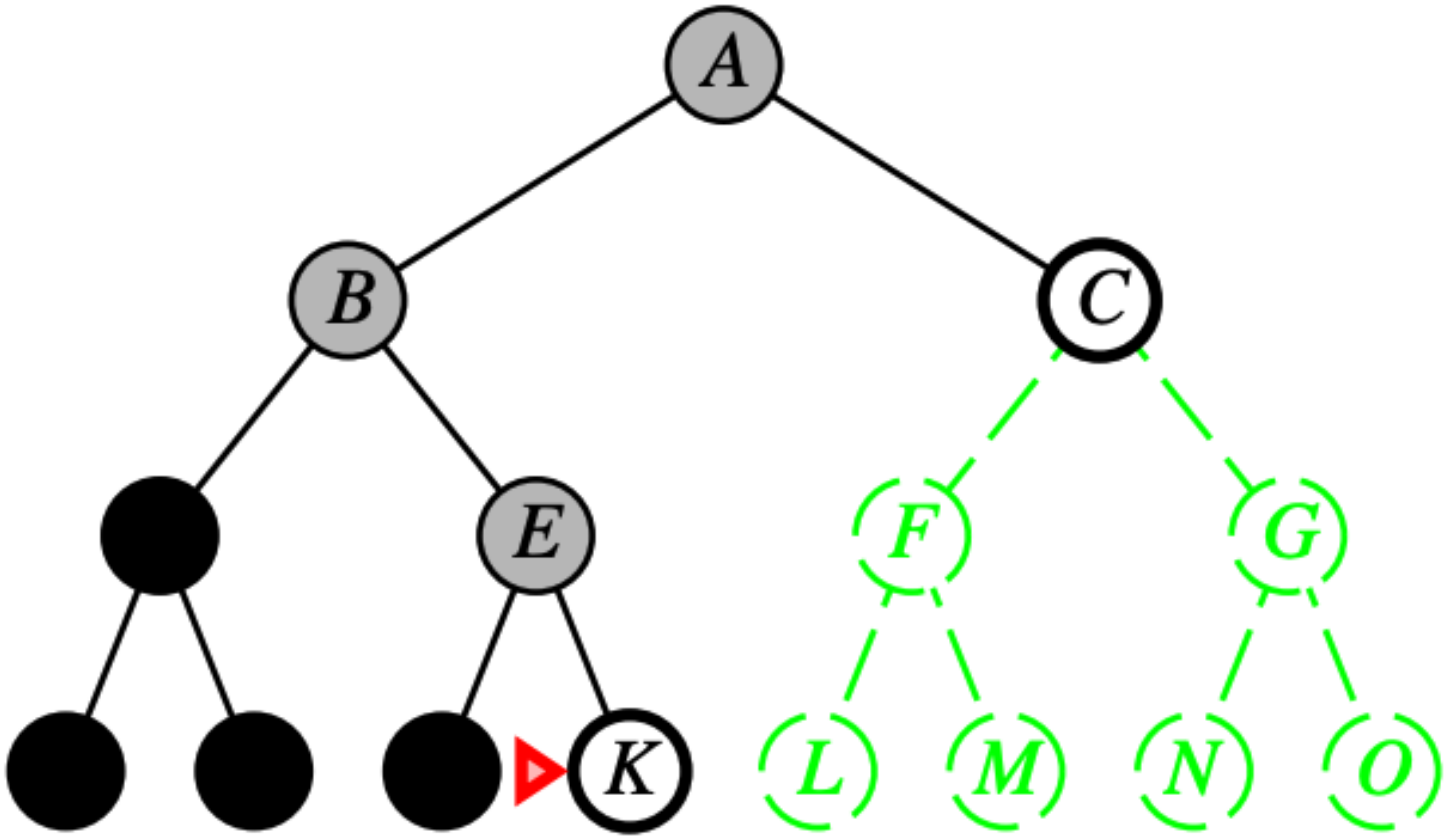

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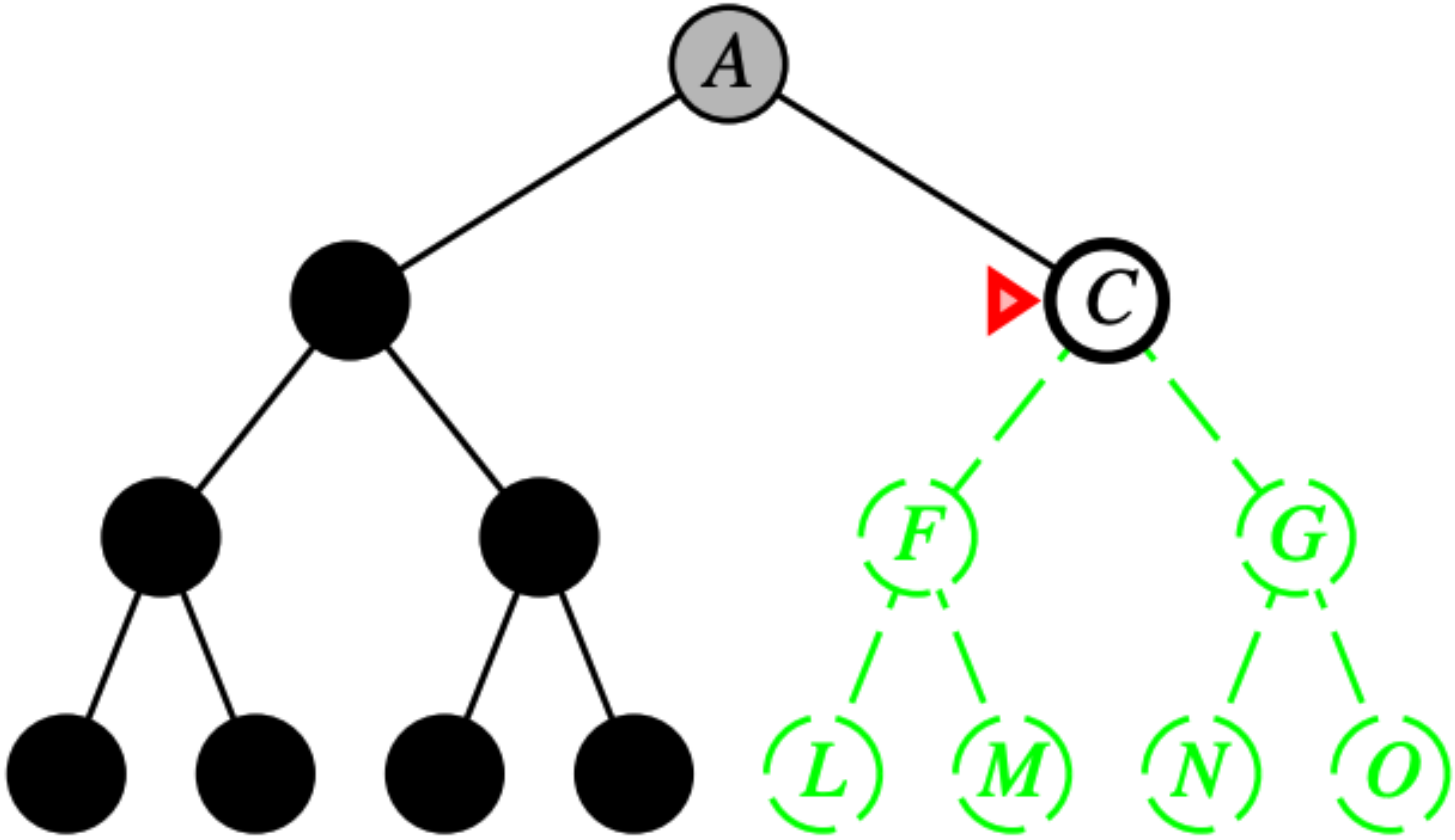

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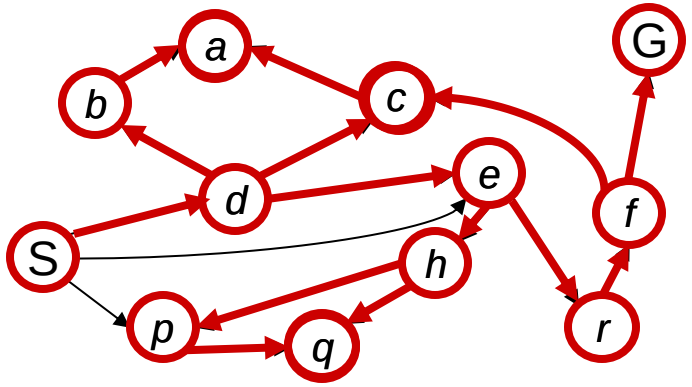

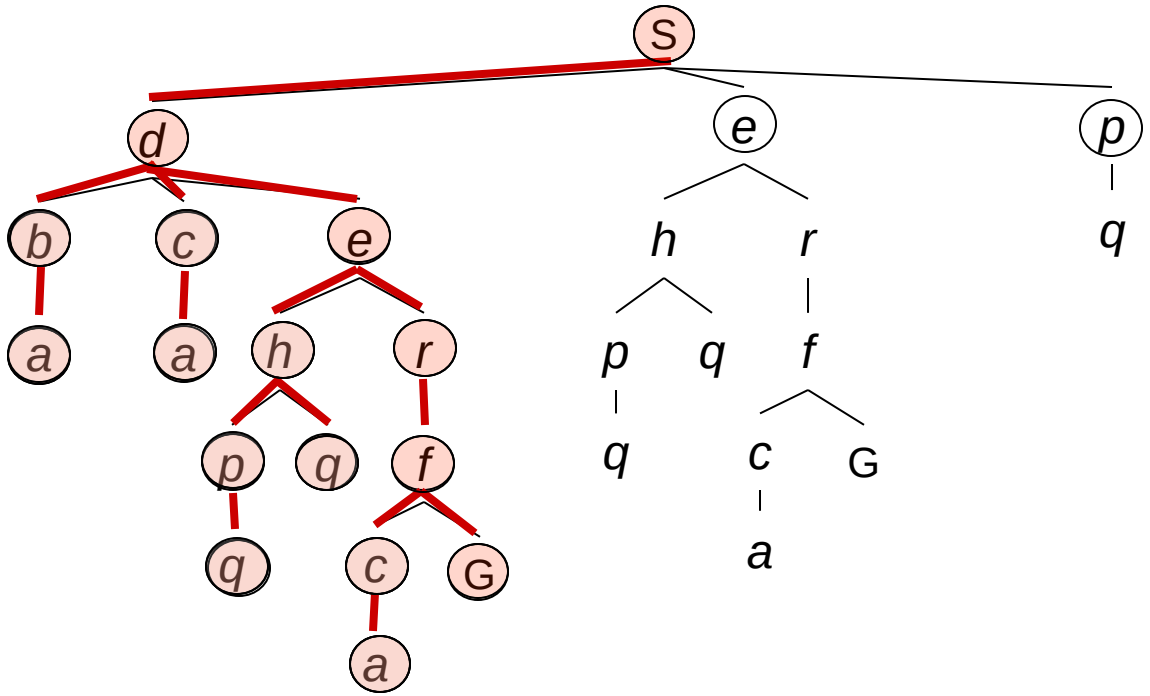

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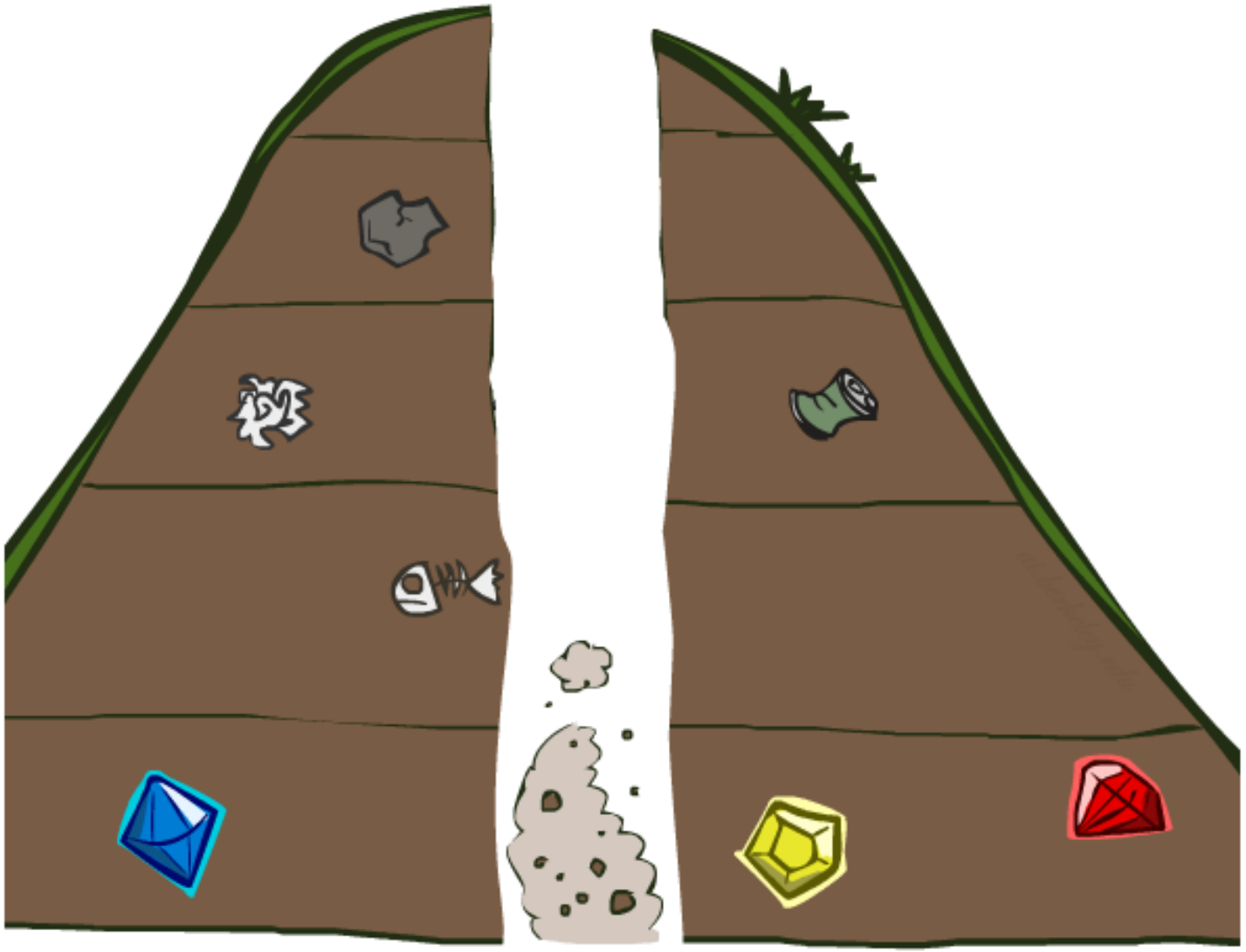
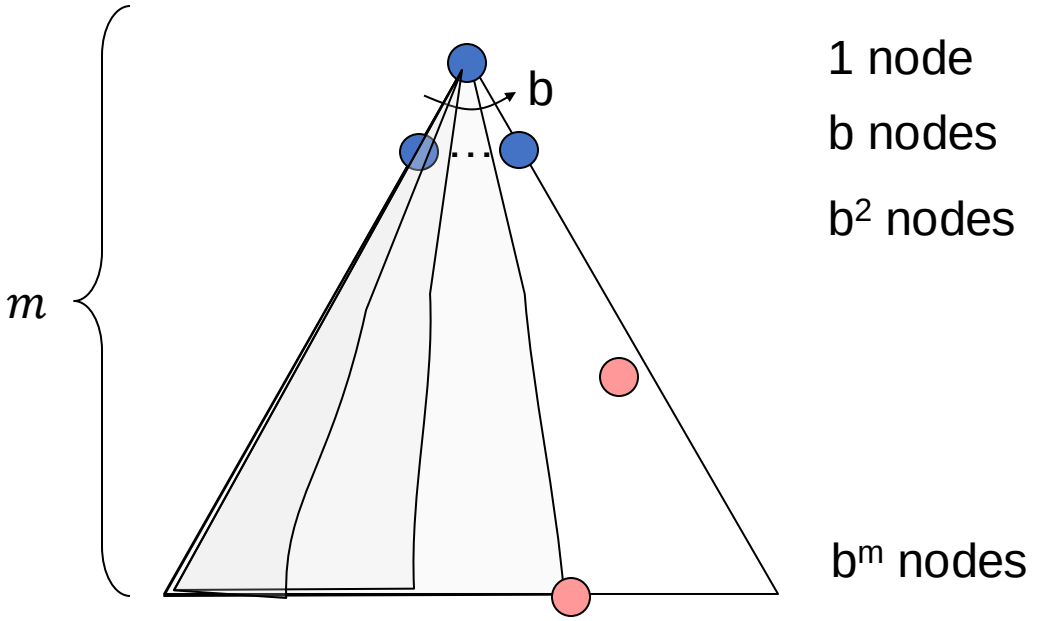
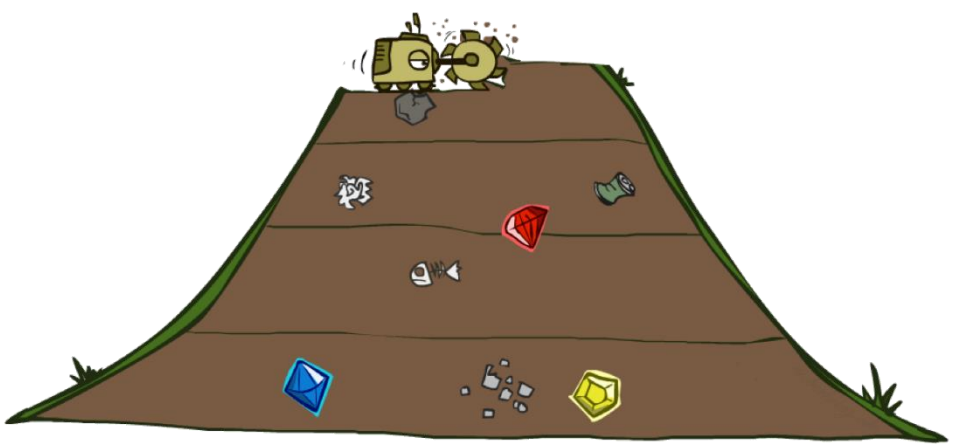


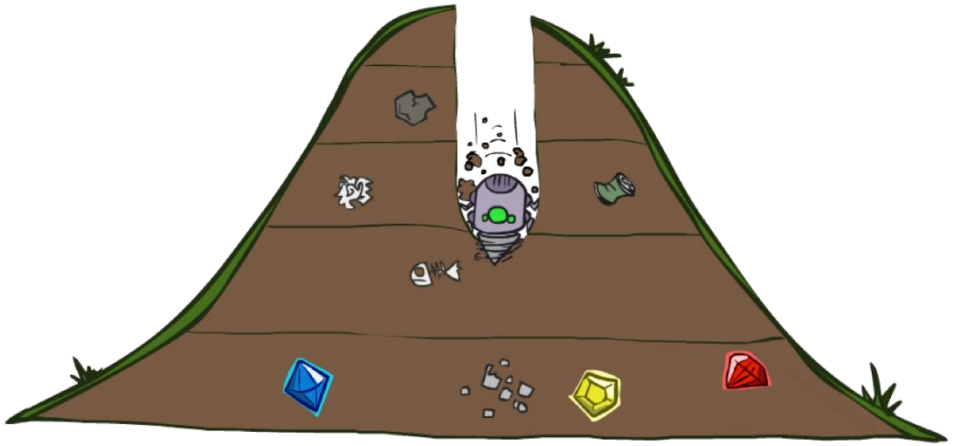
性能分析

- 时间复杂度?
  - $O(b^m)$
- 空间复杂度?
  - 只需要存储一条从根节点到叶节点的路径，以及该路径上每个节点的所有未被扩展的兄弟节点$O(bm)$
- 完备性?
  - No
- 最优性?
  - NO



BFS v.s. DFS





- 什么情况下，DFS比BFS更好
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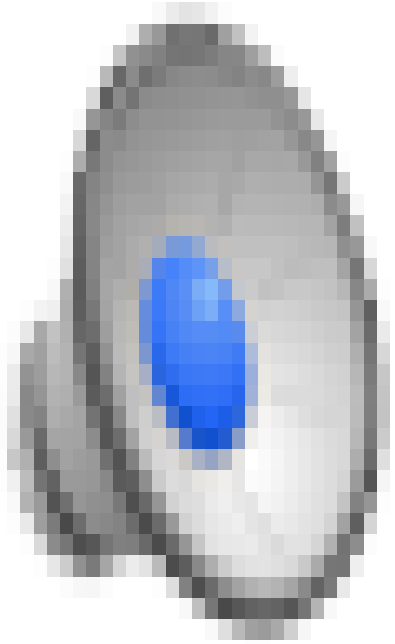
Video of Demo Maze Water DFS/BFS



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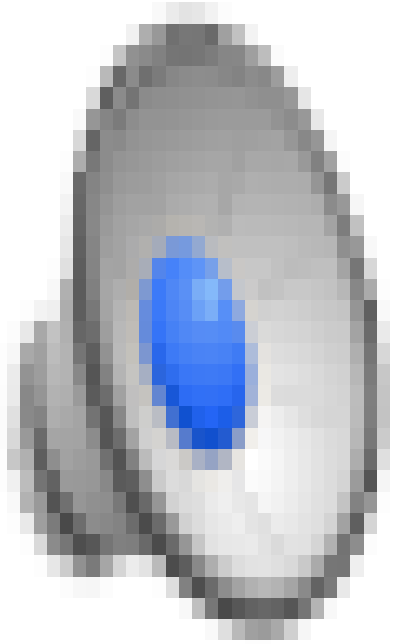

提纲

- 搜索问题
- 无信息搜索
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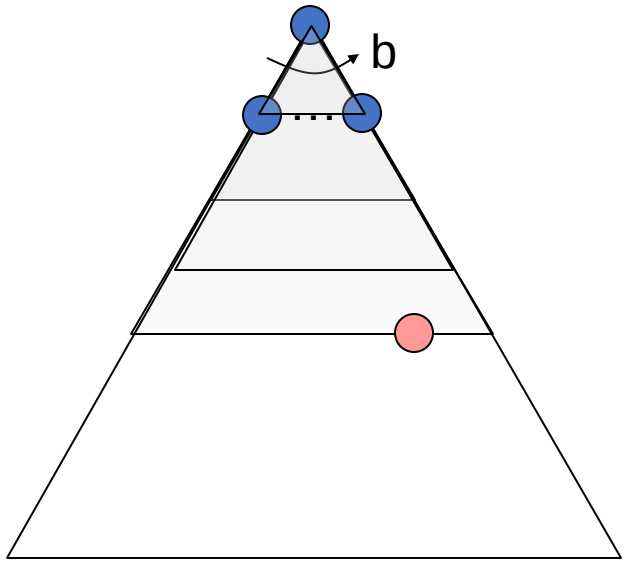
  - 深度优先搜索
  - 迭代加深的深度优先搜索
  - 代价一致性搜索
- 本章小结

迭代加深的深度优先搜索 (iterative deepening search)

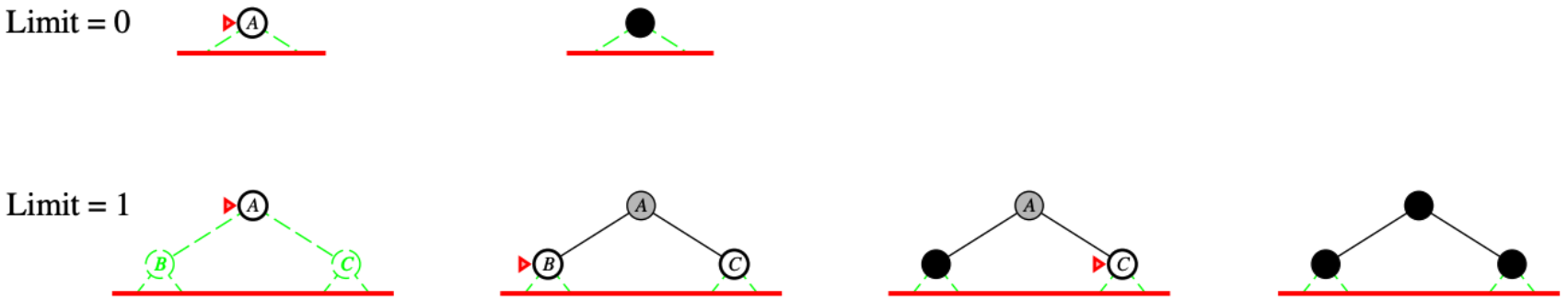
- 能否兼顾DFS和BFS的优势？
  - Run a DFS with depth limit 1. If no solution…
  - Run a DFS with depth limit 2. If no solution…
  - Run a DFS with depth limit 3. …..



迭代加深的深度优先搜索 (iterative deepening search)

Limit = 0

迭代加深的深度优先搜索 (iterative deepening search)



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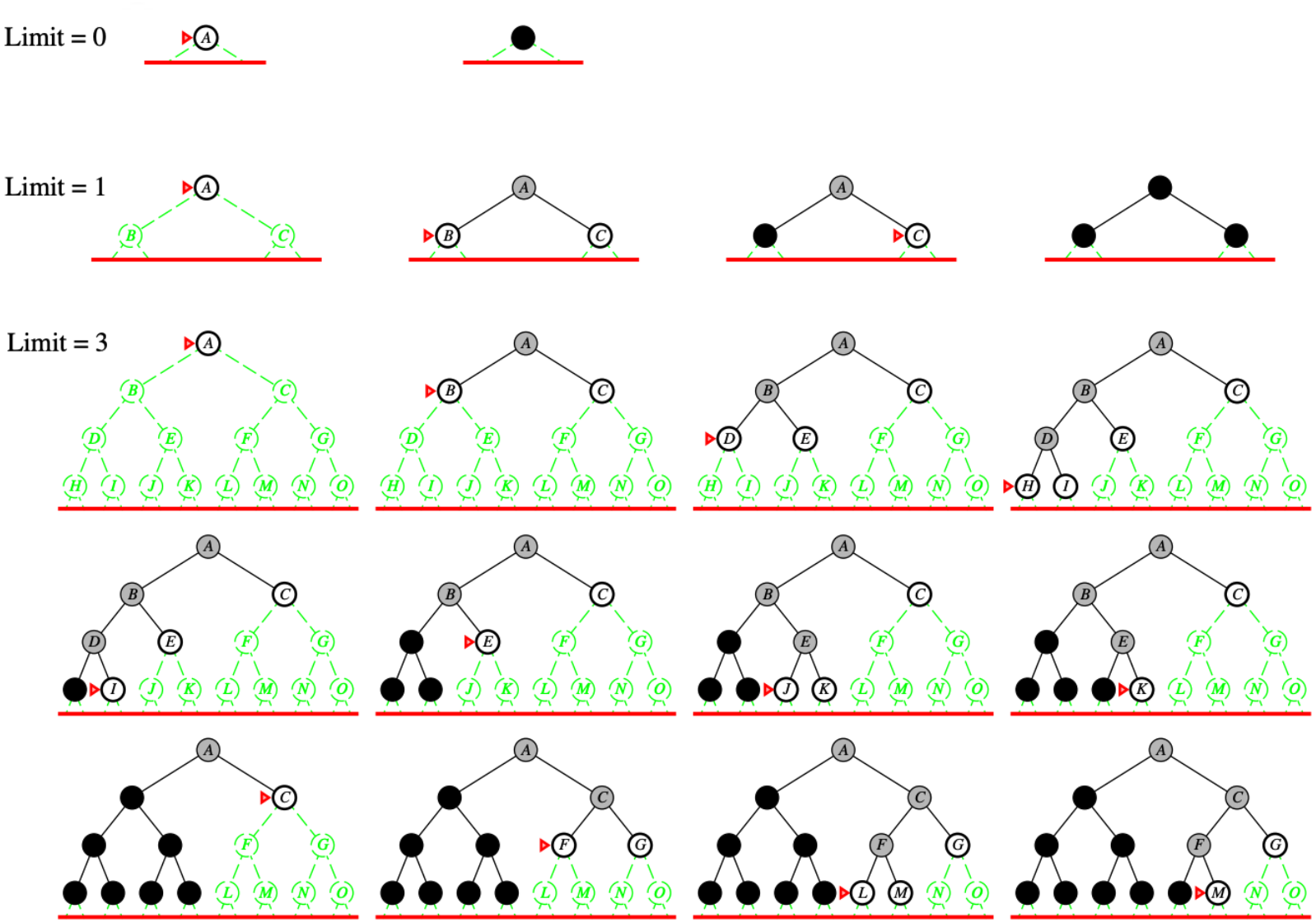


迭代加深的深度优先搜索 (iterative deepening search)

部分节点被多次生成，是否会造成浪费？

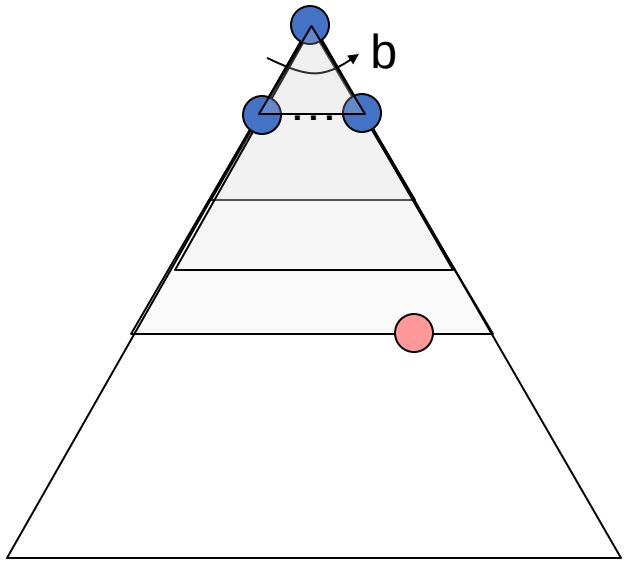
在迭代加深的深度优先搜索中，底层（深度d）节点只被生成一次，倒数第二层的节点被生成两次，以此类推，一直到根节点，被生成d次

$$d(b) + (d-1)b^2 + \cdots (1)b^d$$

绝大多数重复的节点都在上层，上层节点的重复生成影响不大

性能分析

- 时间复杂度?
  - $O(b^d)$
- 空间复杂度?
  - $O(bd)$
- 完备性?
  - Yes
- 最优性?
  - Yes，如果所有行动代价相同



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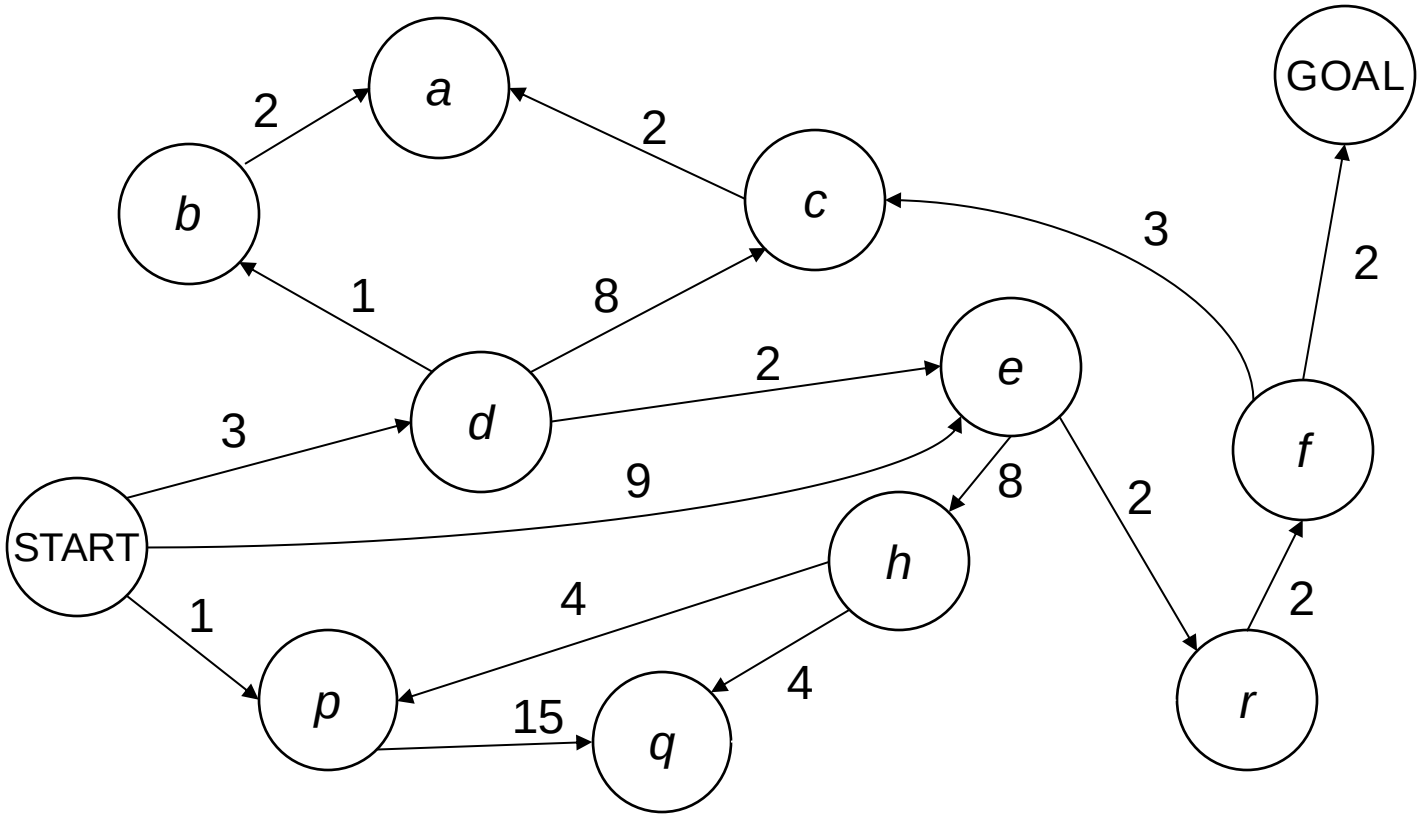
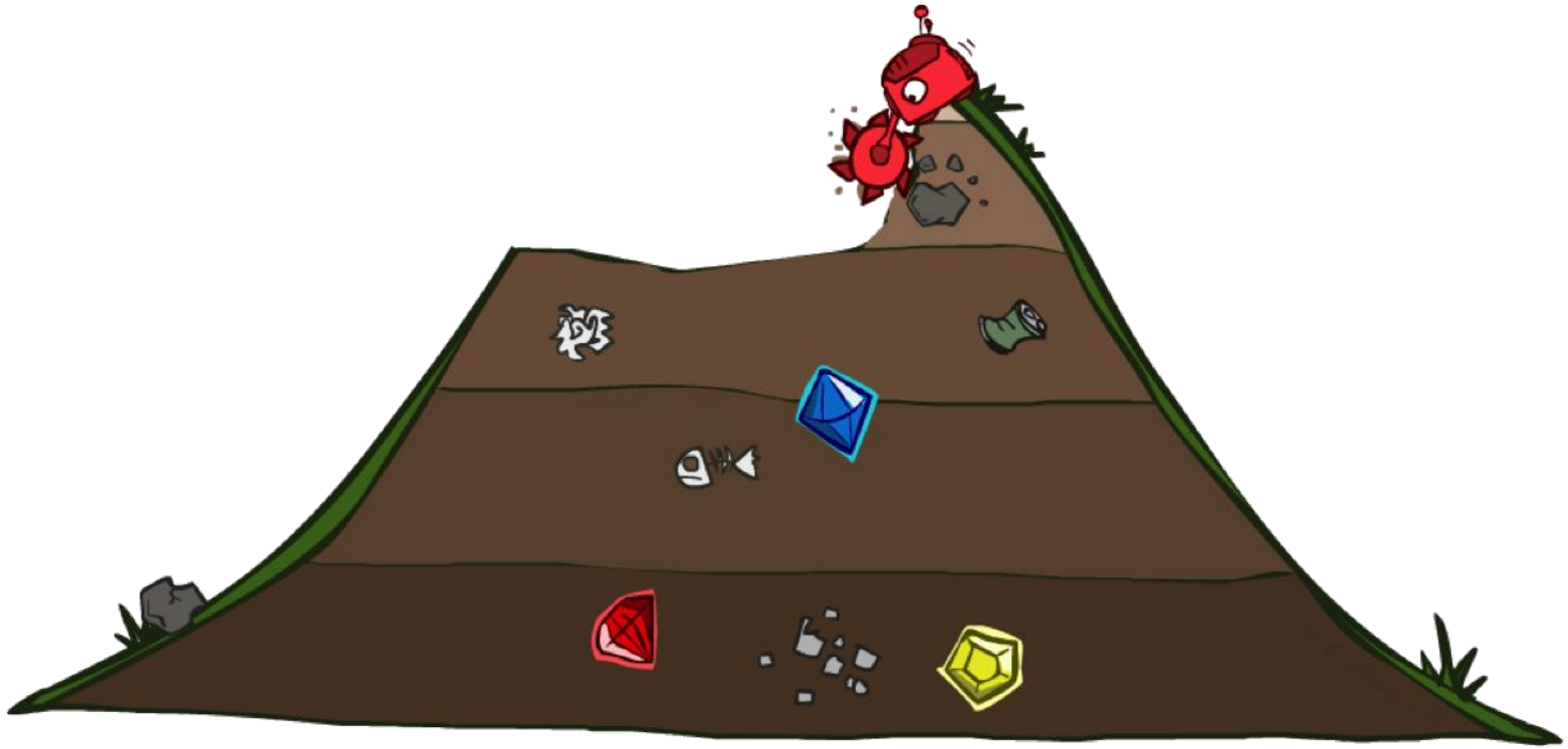
代价敏感搜索



如何寻找代价最小的路径？

一致代价搜索(uniform-cost search)

一致代价搜索扩展路径消耗最小的节点



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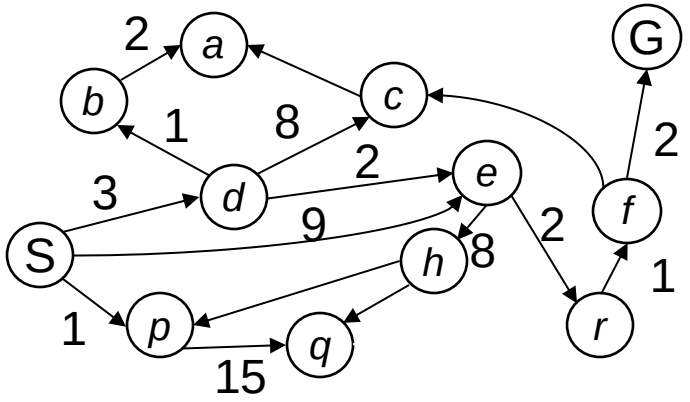
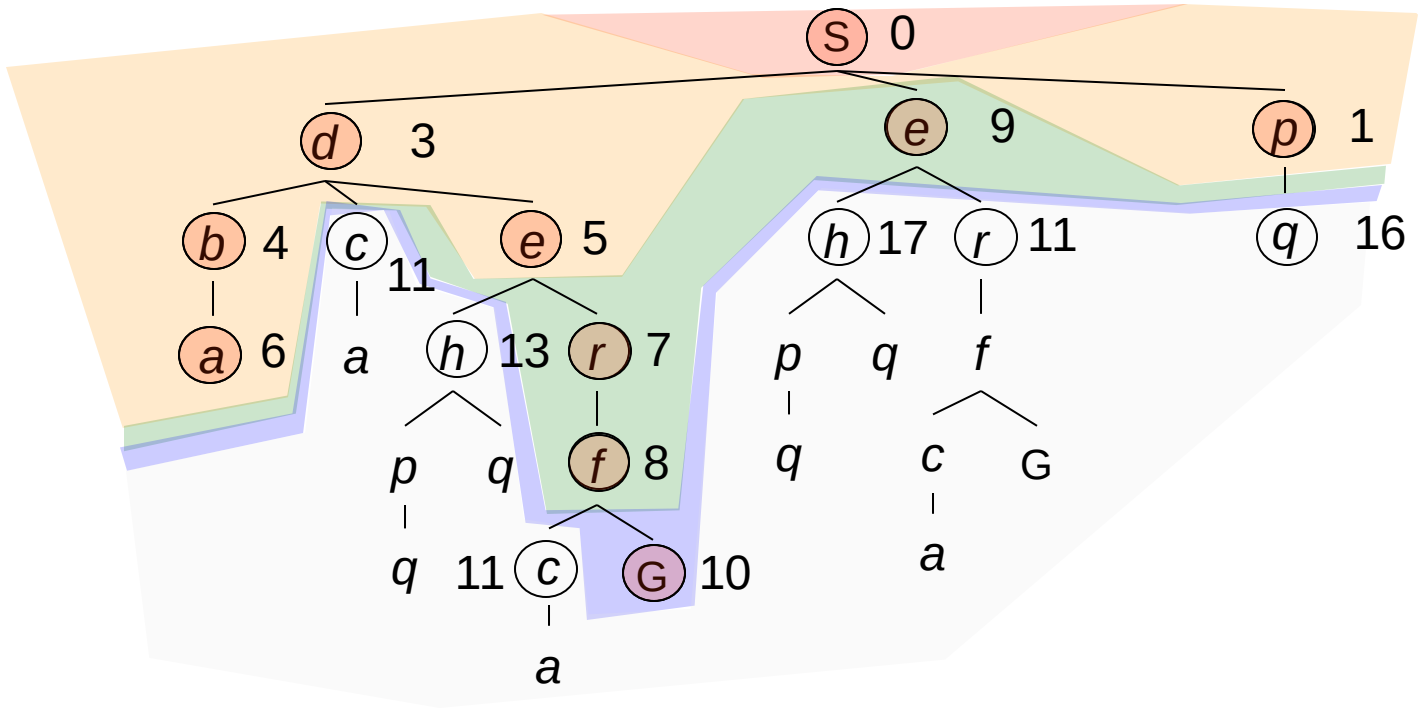
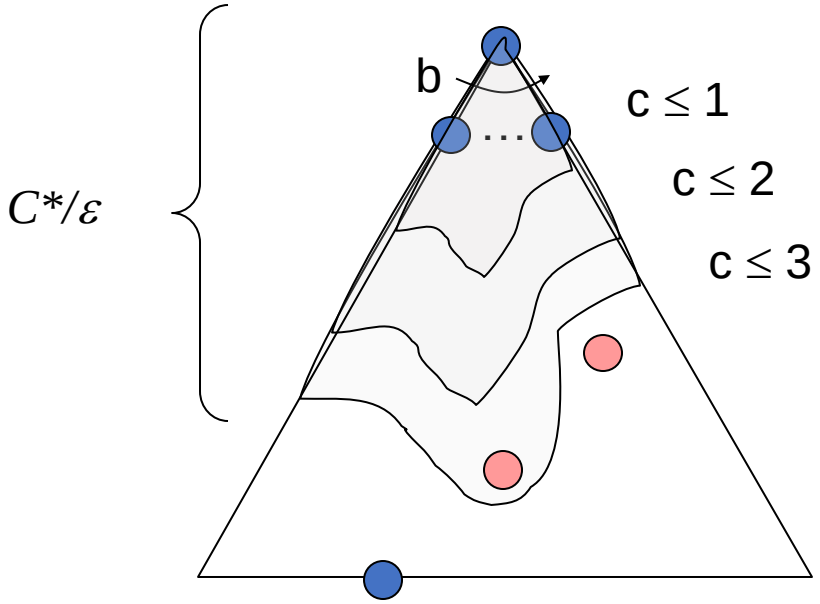




性能分析

假设最优解代价为C^*， ϵ为每个动作代价的下界

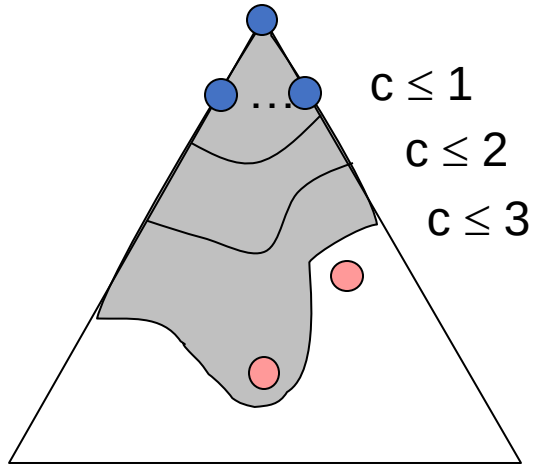
- 时间复杂度?
  - $O(b^{\frac{C^*}{\epsilon}})$
- 空间复杂度?
  - $O(b^{\frac{C^*}{\epsilon}})$
- 完备性?
  - Yes，如果每一步的代价≥ $\epsilon(\epsilon > 0)$
- 最优性?
  - Yes

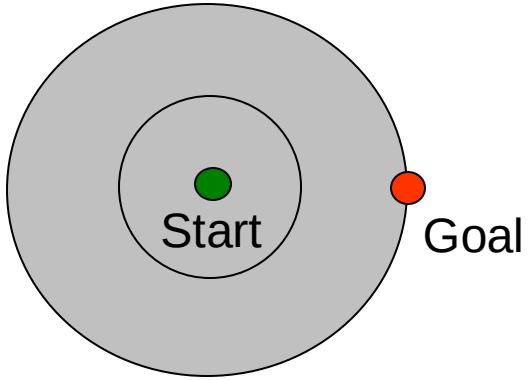


存在的问题

- UCS 按照路径代价进行探索

- 局限：
  - 需要在所有方向上进行探索
  - 没有利用关于目标状态的信息





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本章小结

- 搜索问题：初始状态、动作、状态转移、目标测试、路径代价
- 宽度优先搜索：逐层扩展节点
- 深度优先搜索：优先扩展最深的节点
- 迭代加深的深度优先搜索：限制深度的DFS
- 一致性代价搜索：优先扩展路径代价最小的节点