Uninformed search strategies
(Section 3.4)

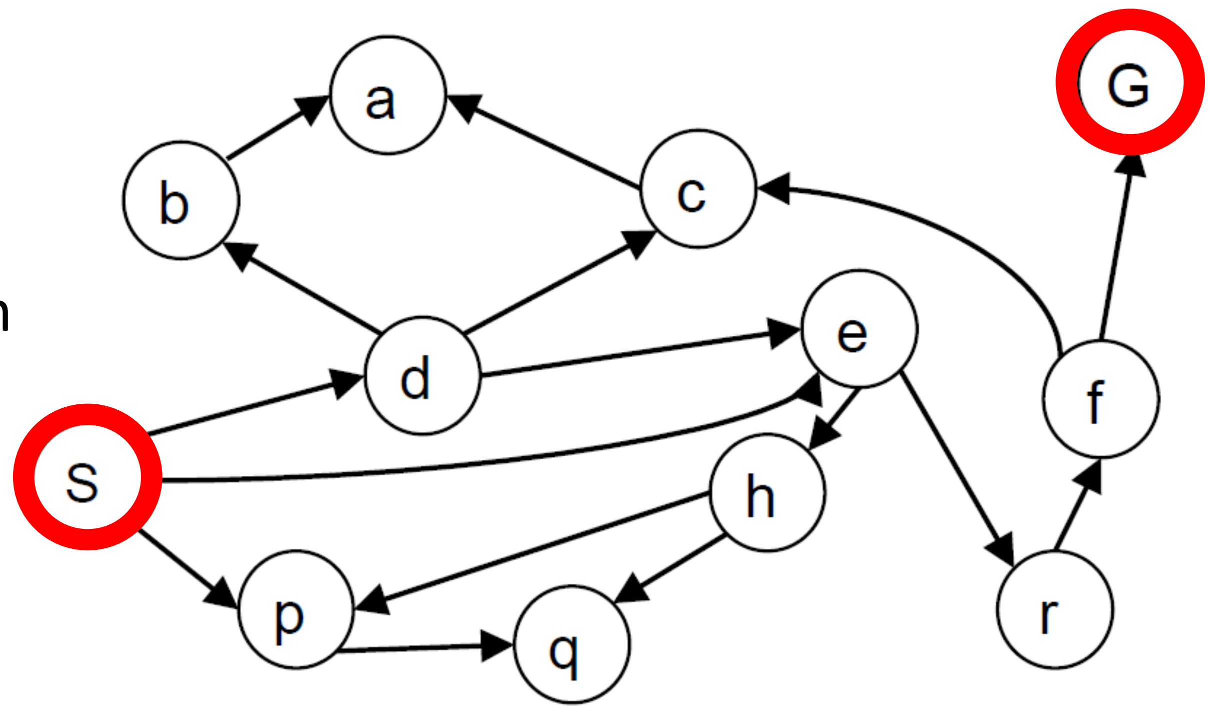
Uninformed search strategies

- A **search strategy** is defined by picking the order of node expansion
- **Uninformed** search strategies use only the information available in the problem definition
  - Breadth-first search
  - Depth-first search
  - Iterative deepening search
  - Uniform-cost search

Breadth-first search

- Expand shallowest unexpanded node
- Implementation: *frontier* is a FIFO queue

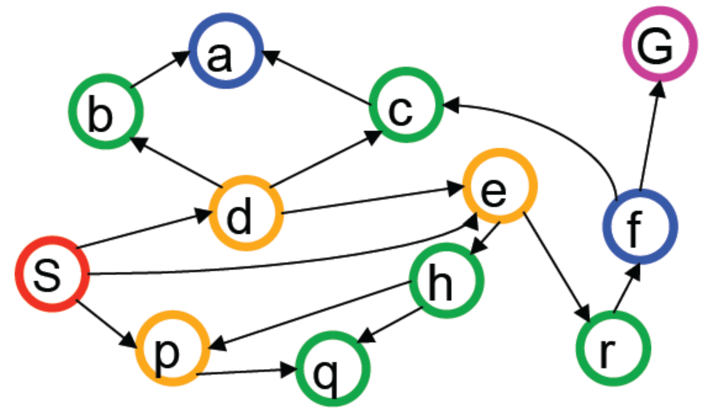
Example state space graph for a tiny search problem

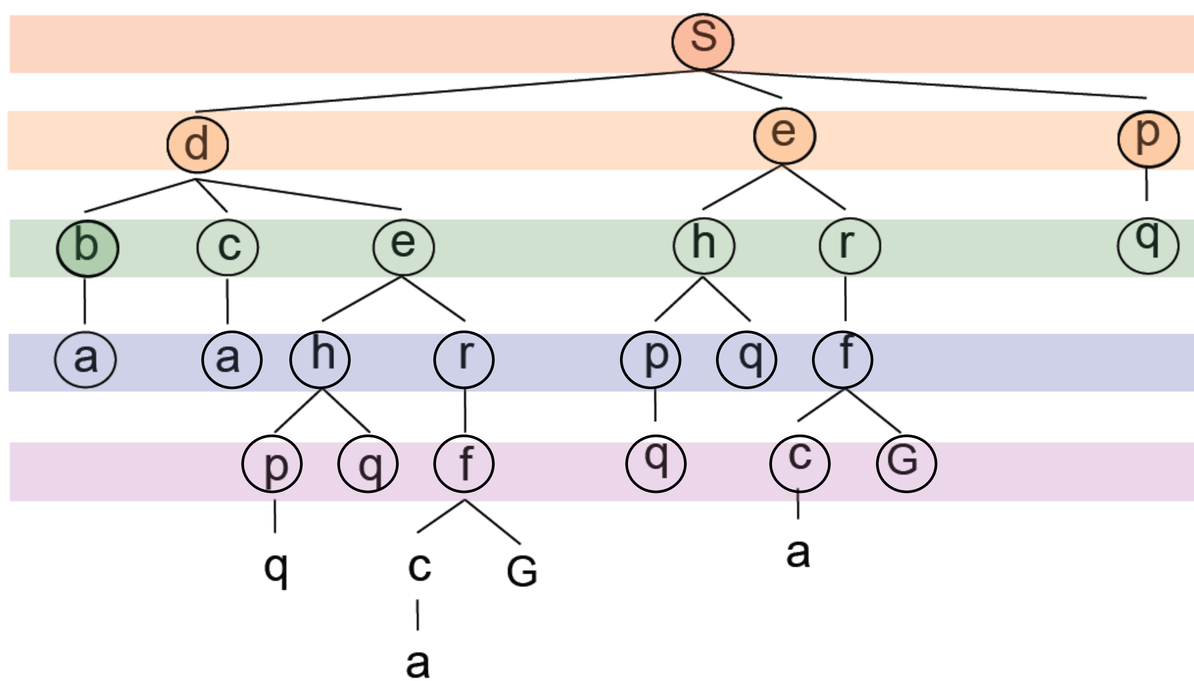


Example from P. Abbeel and D. Klein

Breadth-first search

- Expansion order: (S,d,e,p,b,c,e,h,r,q,a,a, h,r,p,q,f,p,q,f,q,c,G)



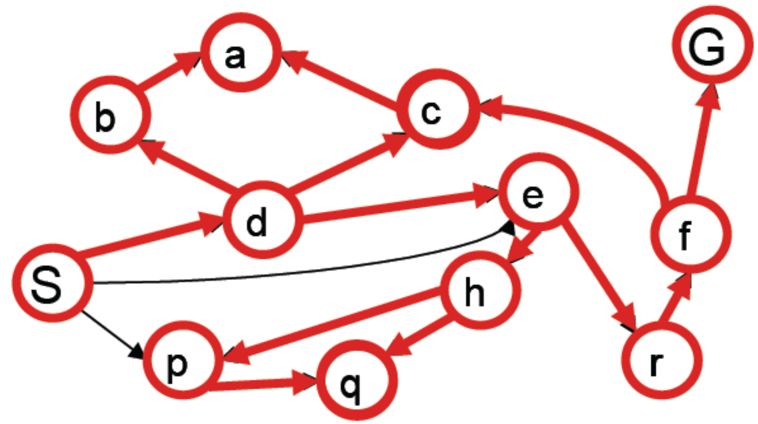


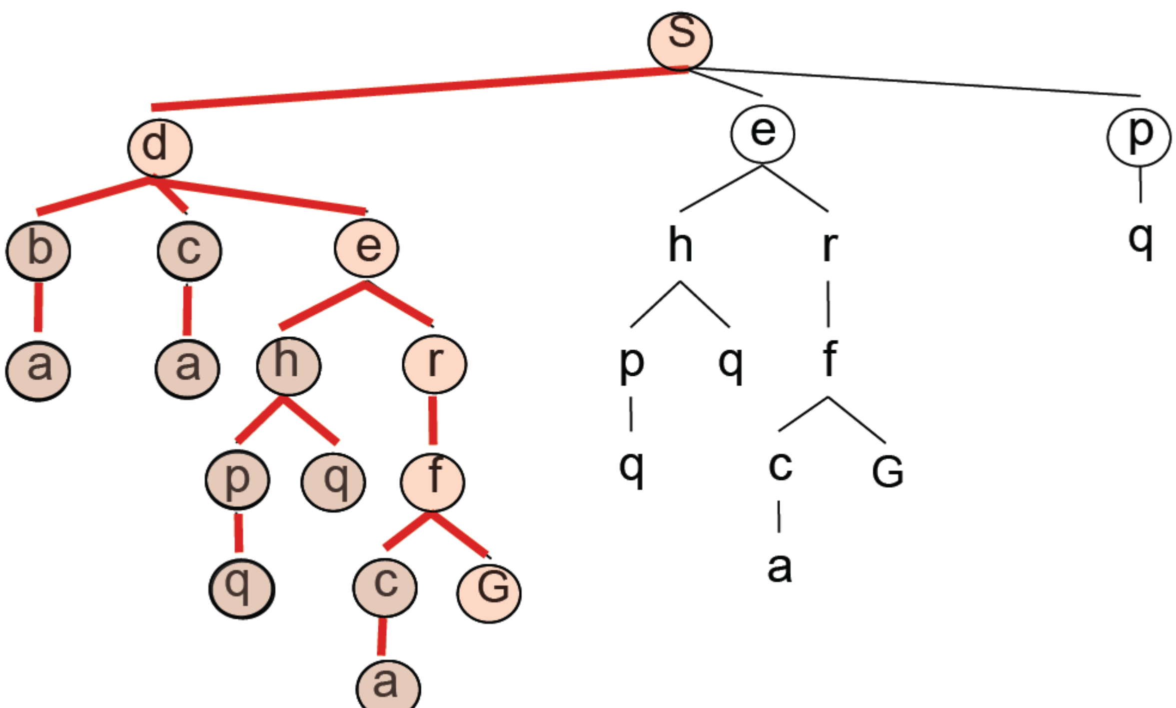
Depth-first search

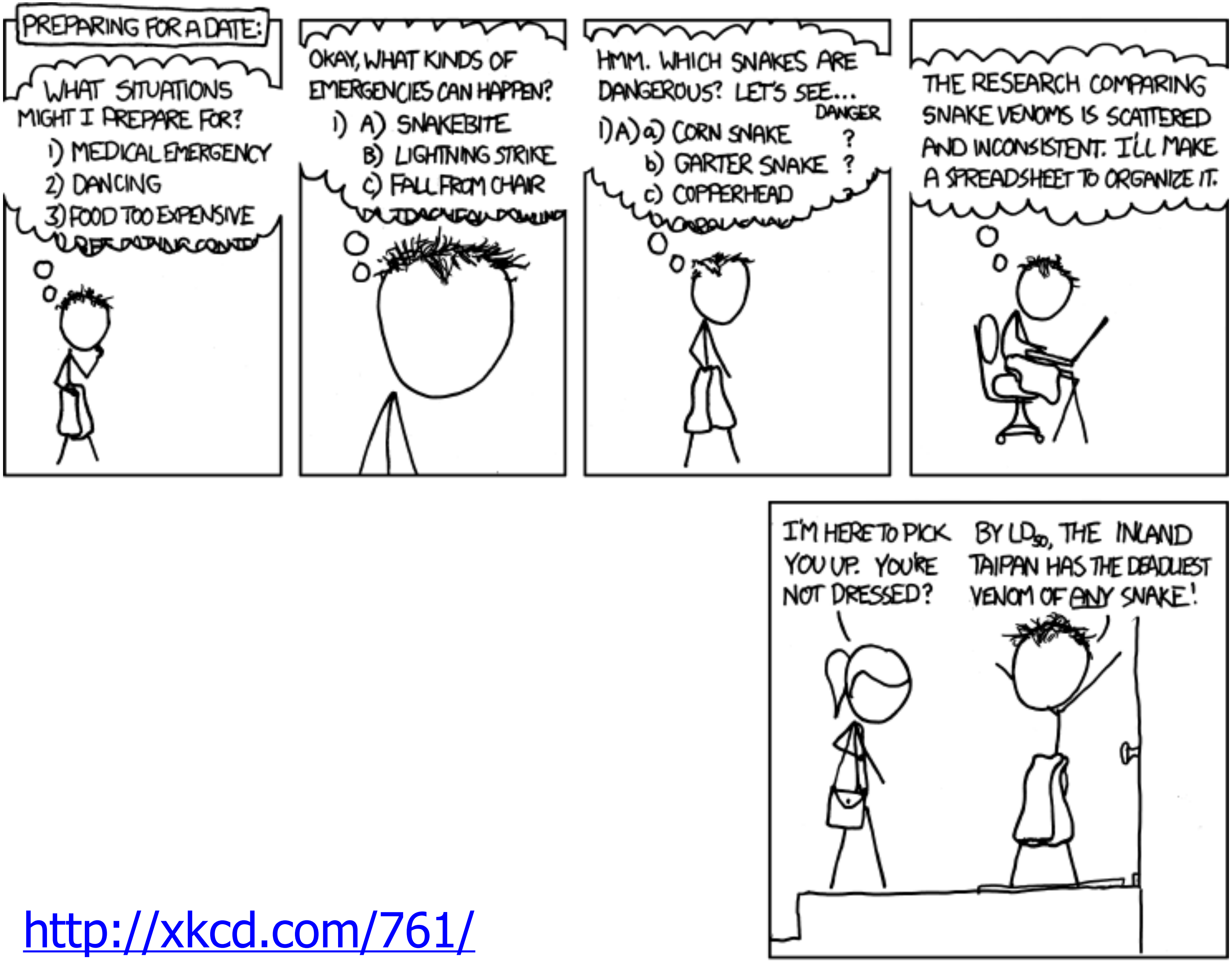
- Expand deepest unexpanded node
- Implementation: *frontier* is a LIFO queue

Depth-first search

- Expansion order: (d,b,a,c,a,e,h,p,q,q, r,f,c,a,G)



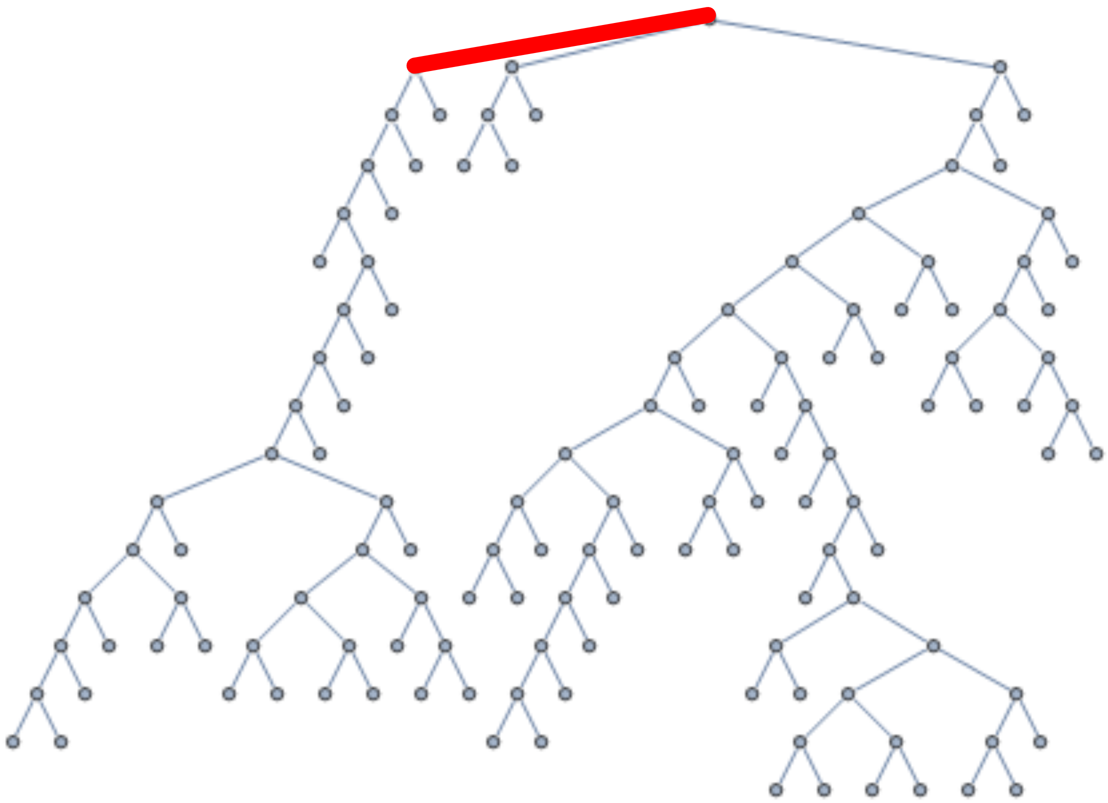




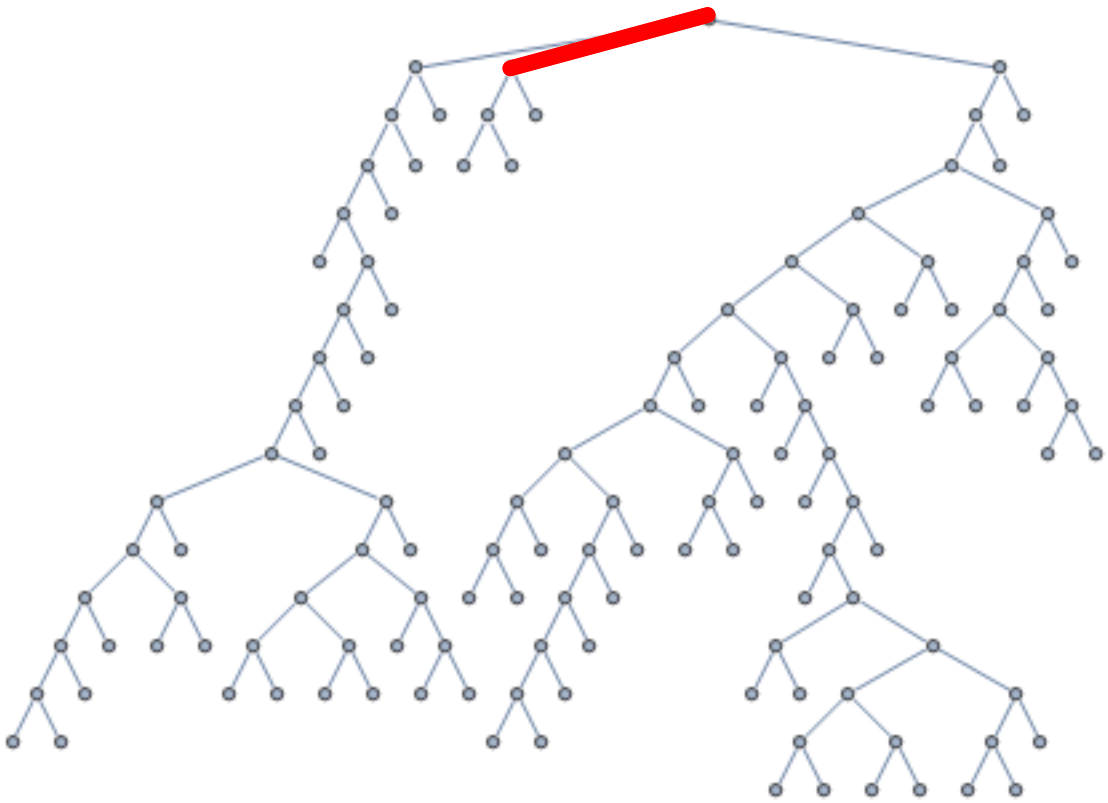
I REALLY NEED TO STOP USING DEPTH-FIRST SEARCHES.

http://xkcd.com/761/

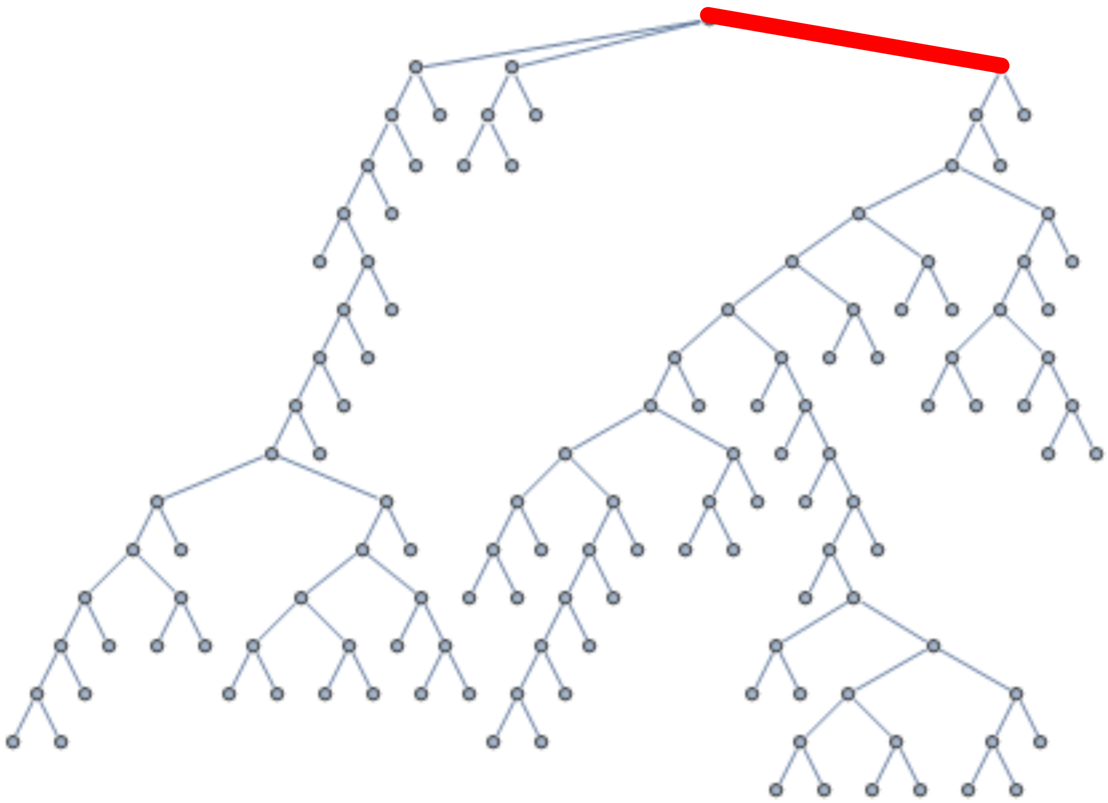
BFS vs. DFS



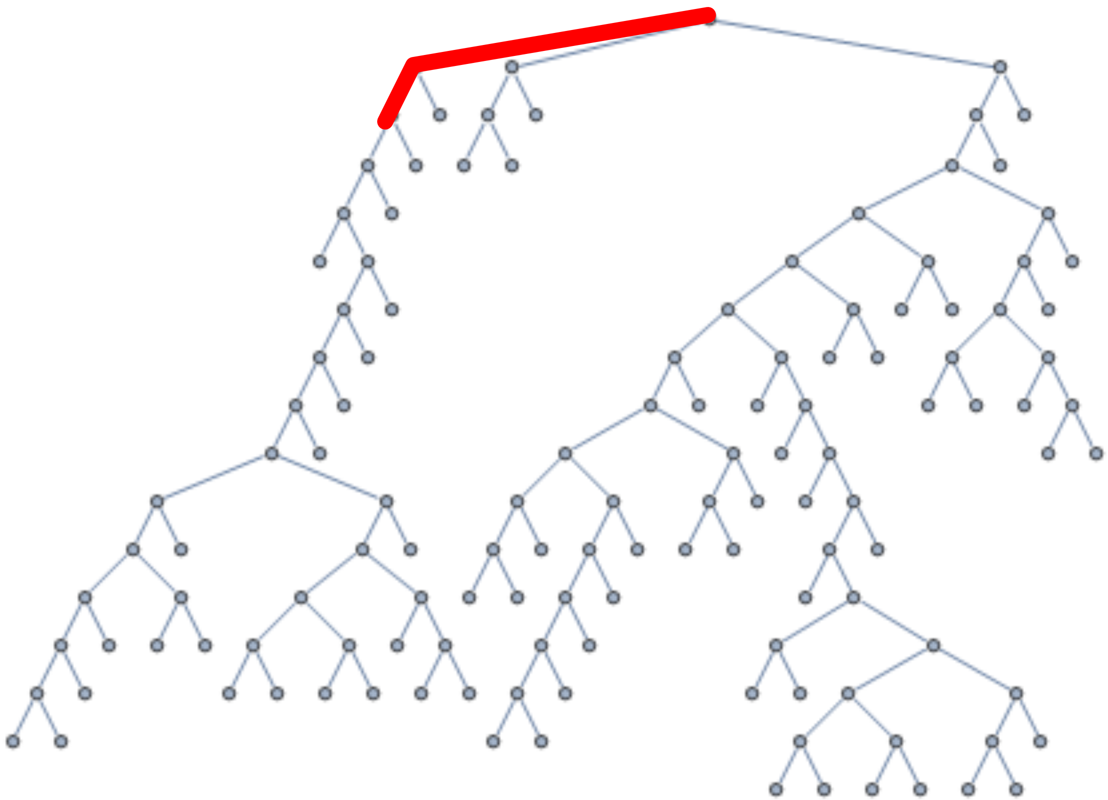
BFS vs. DFS



BFS vs. DFS



BFS vs. DFS



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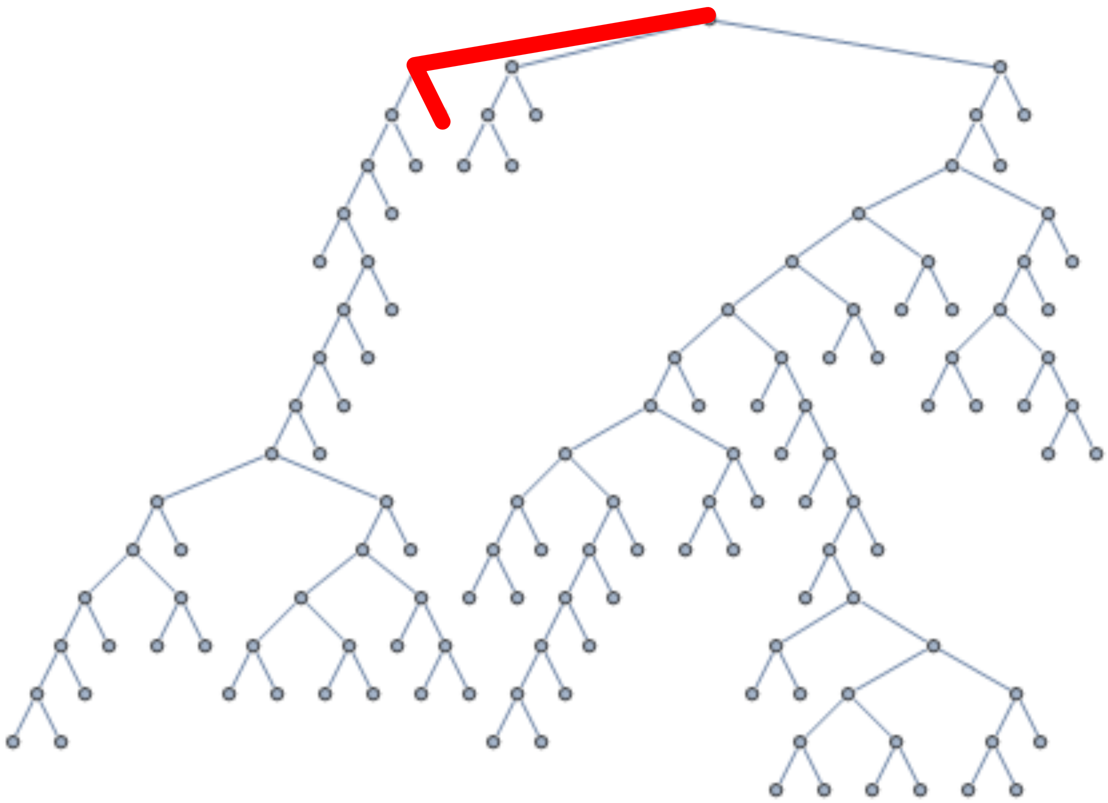

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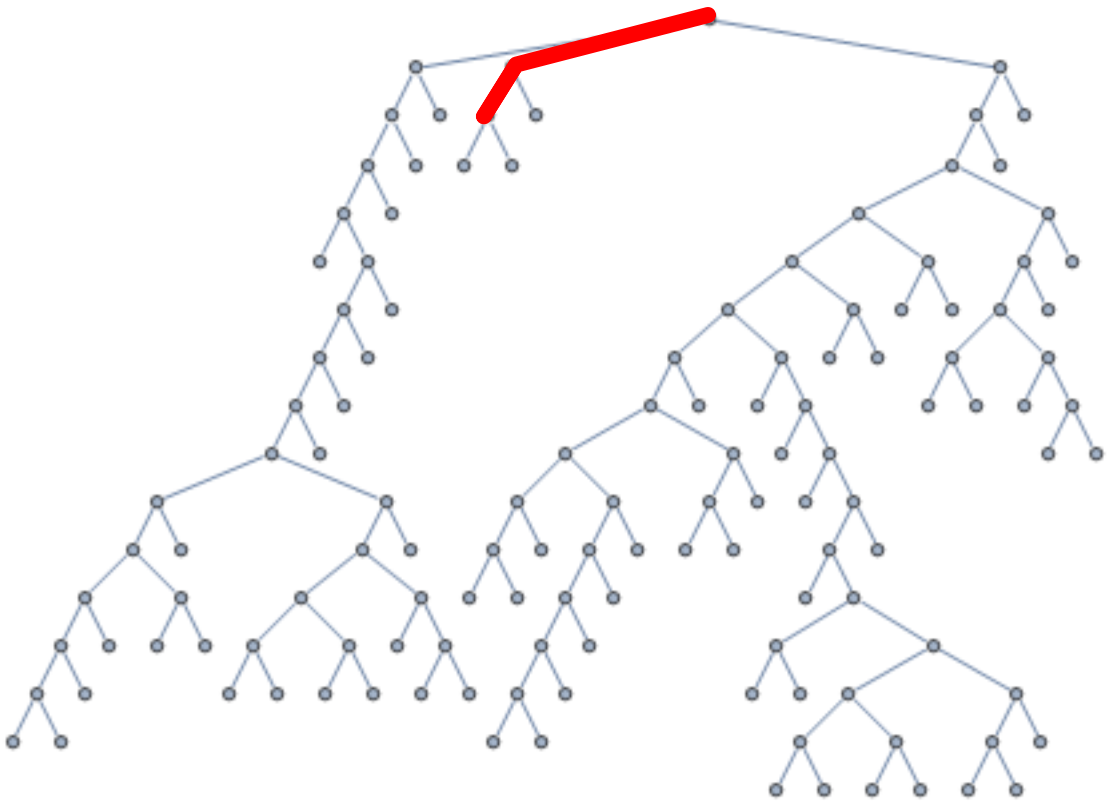

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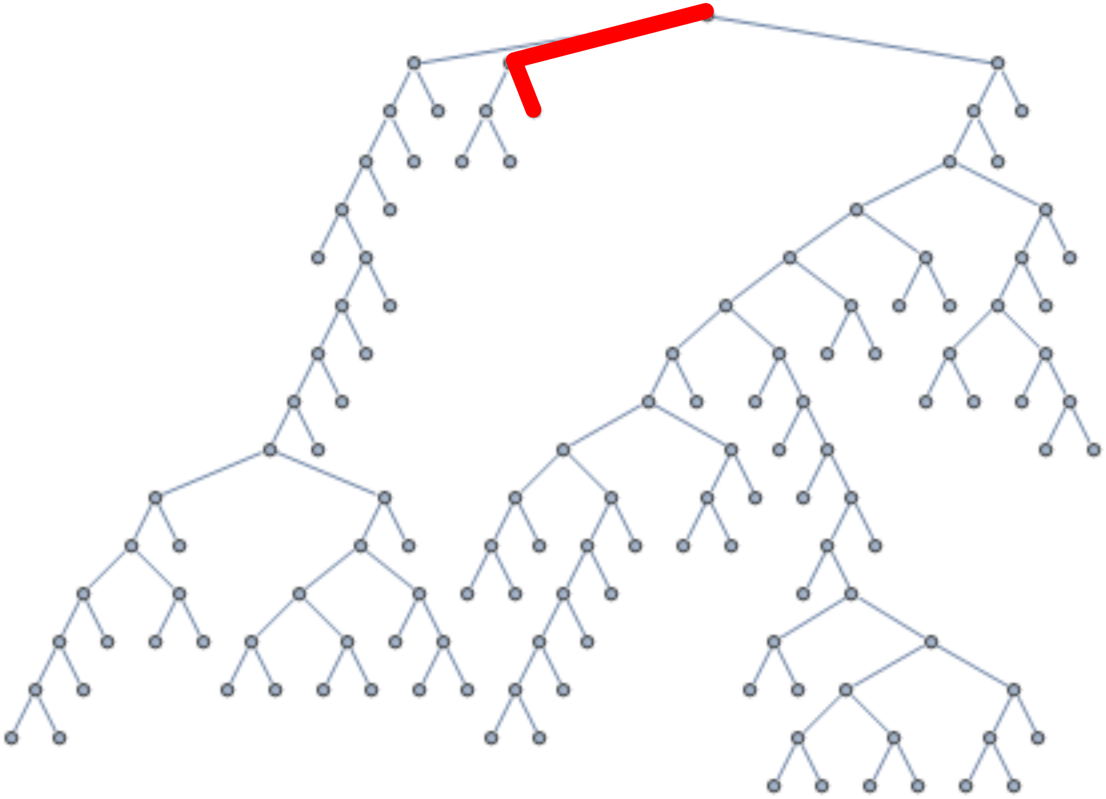

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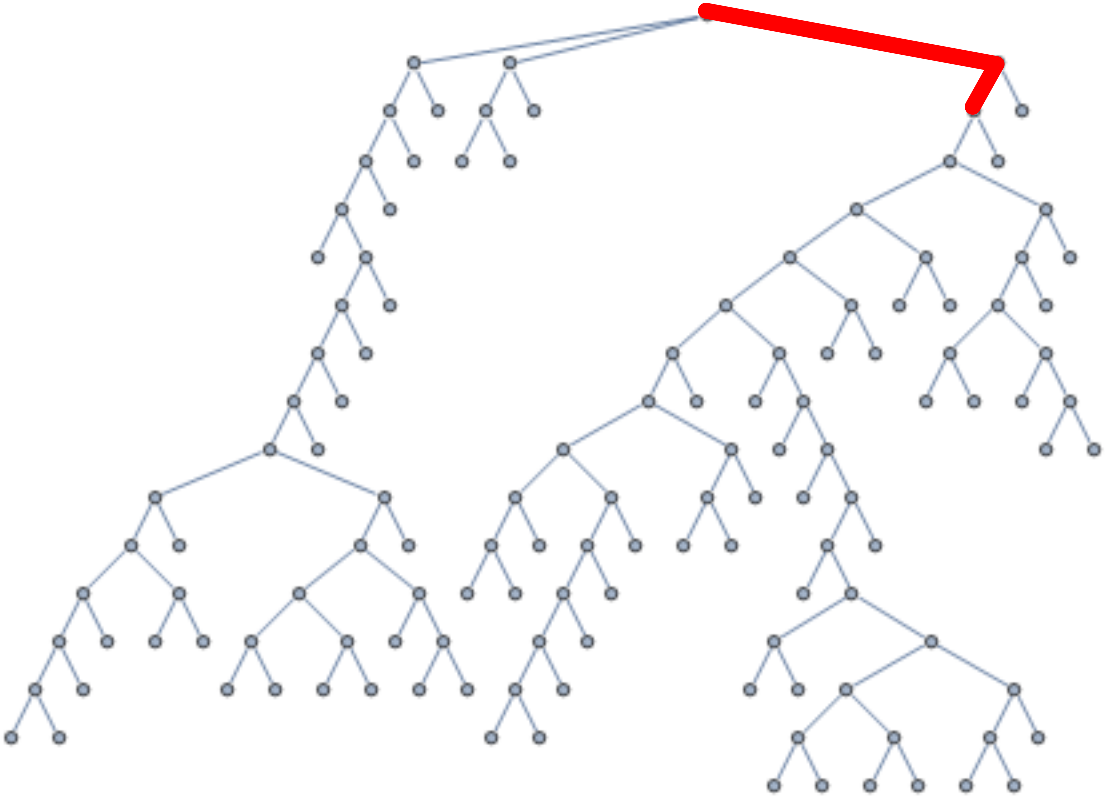
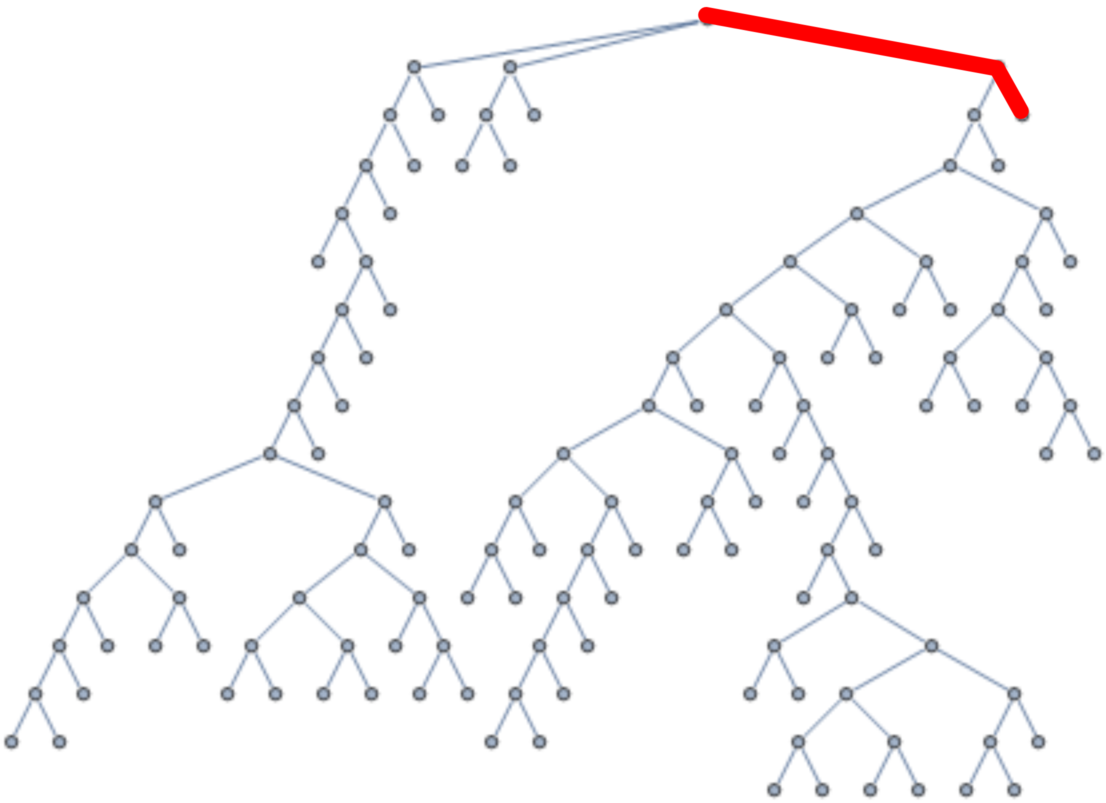
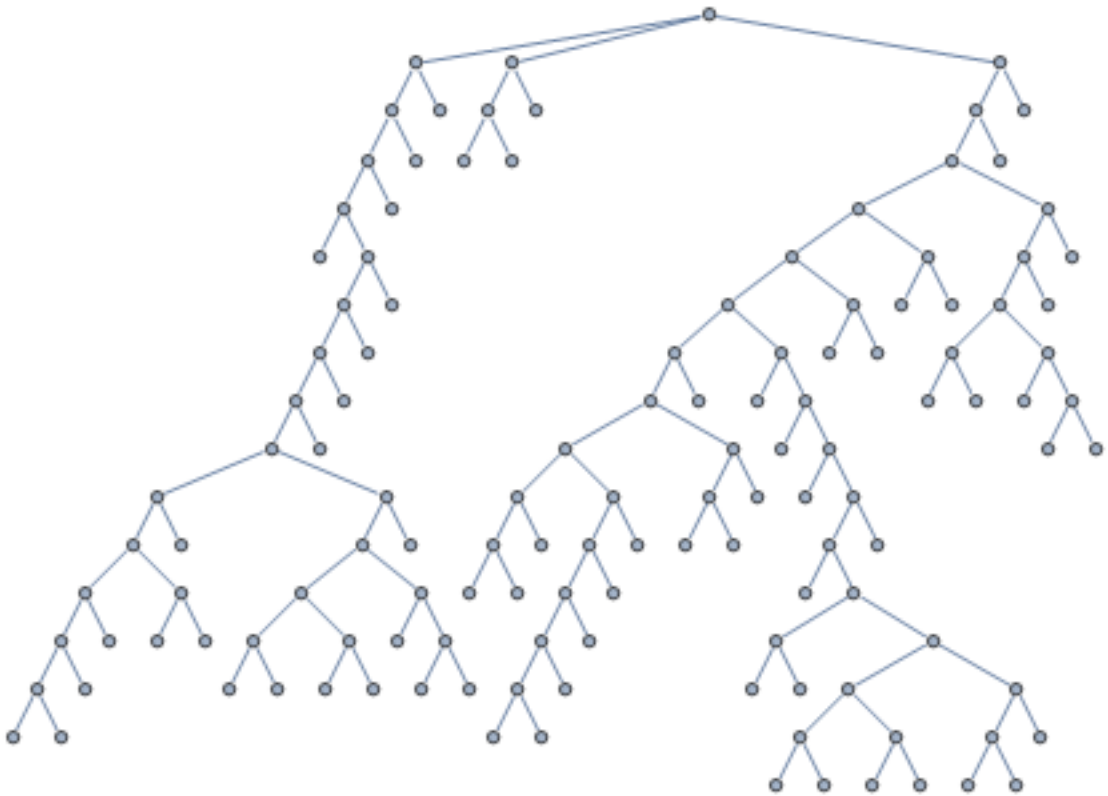


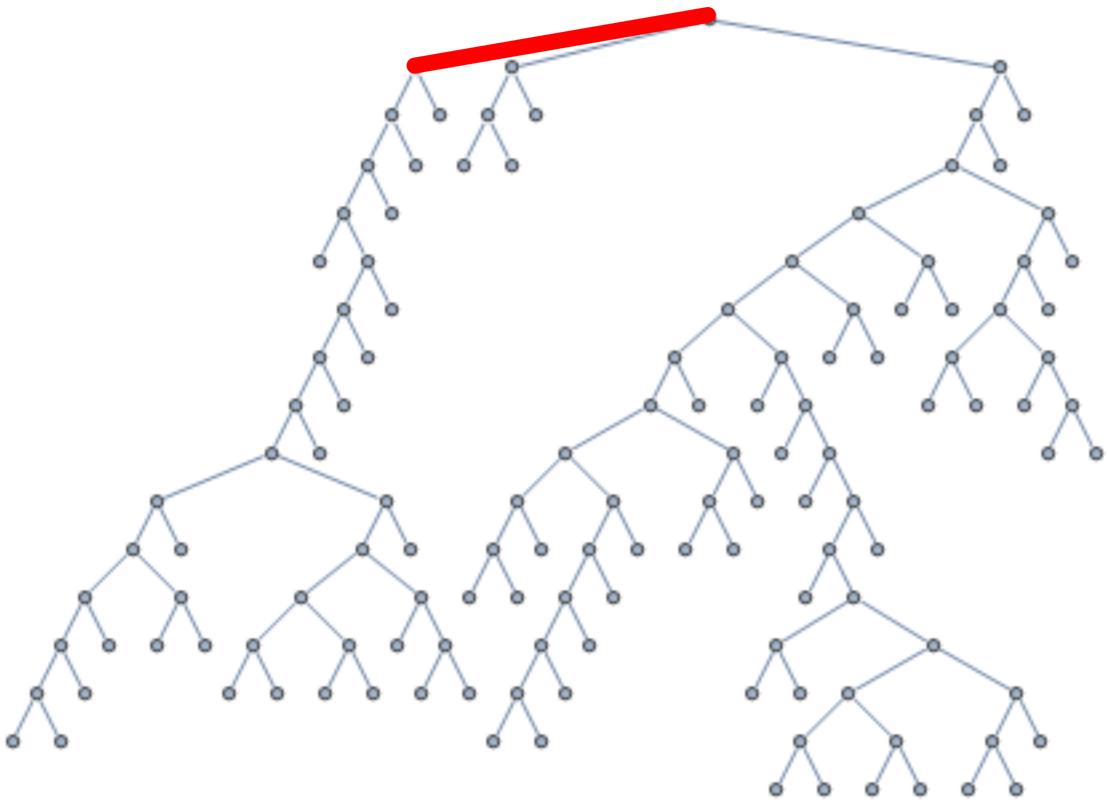
BFS vs. DFS



BFS vs. **DFS**



BFS vs. **DFS**



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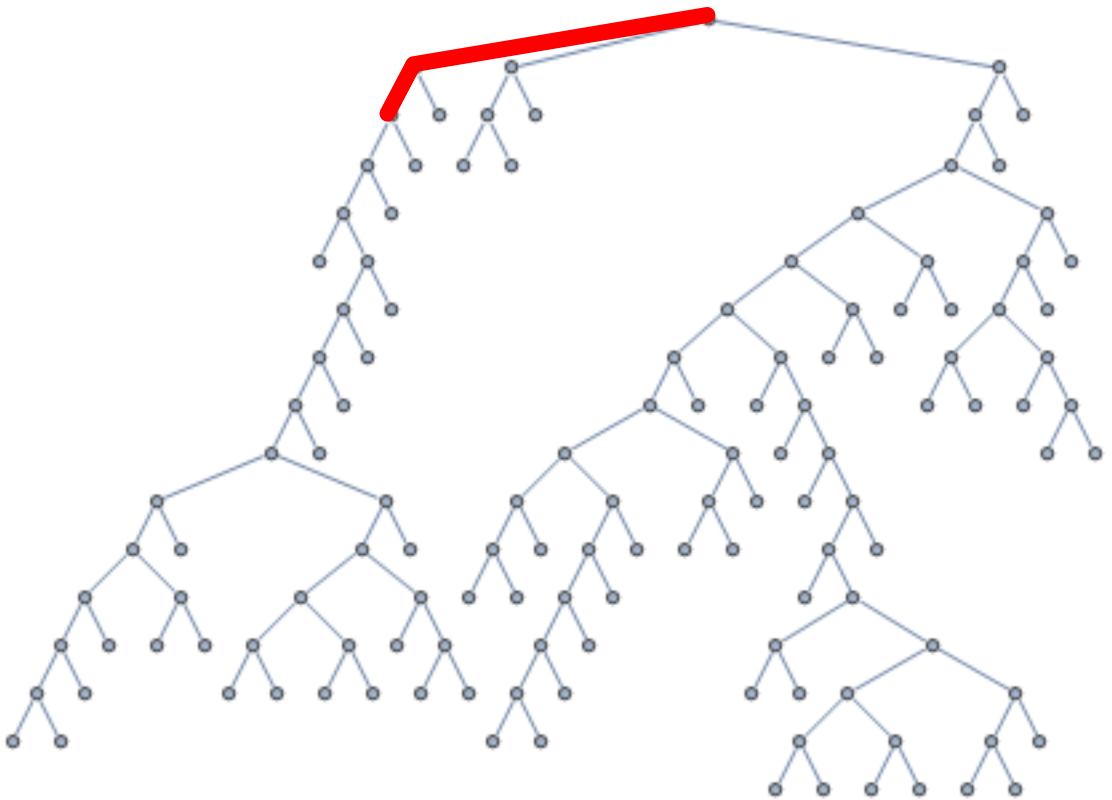

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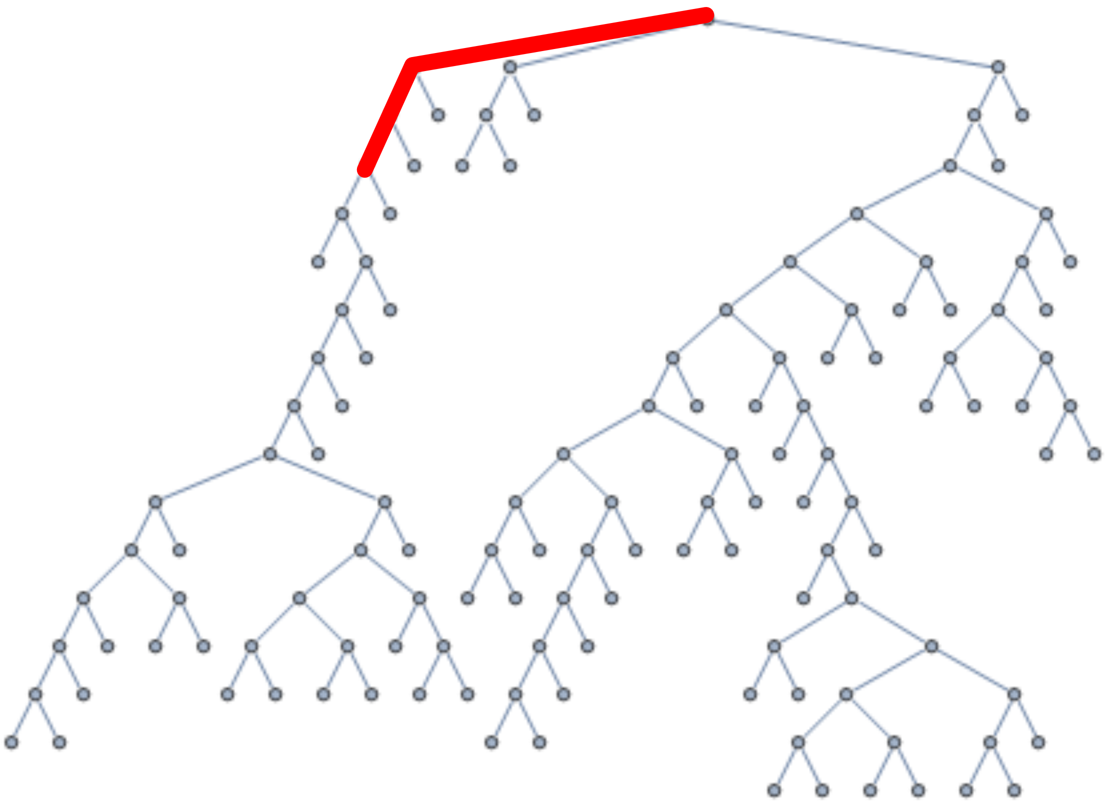

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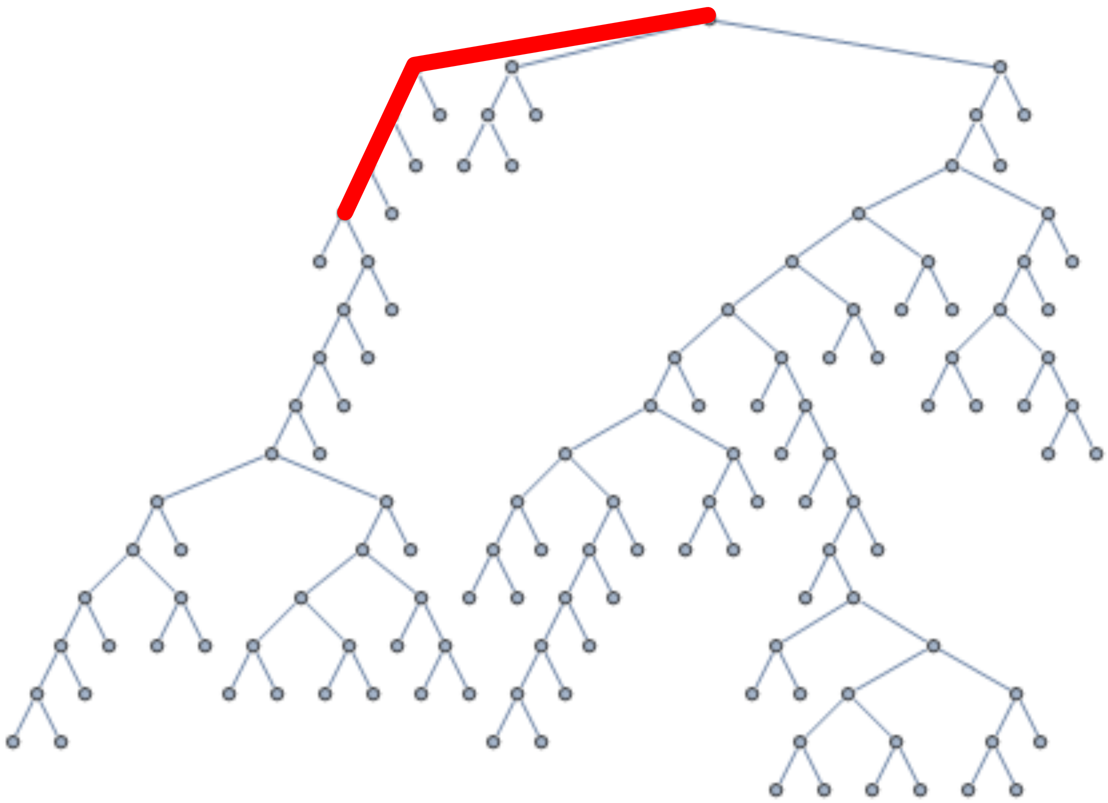

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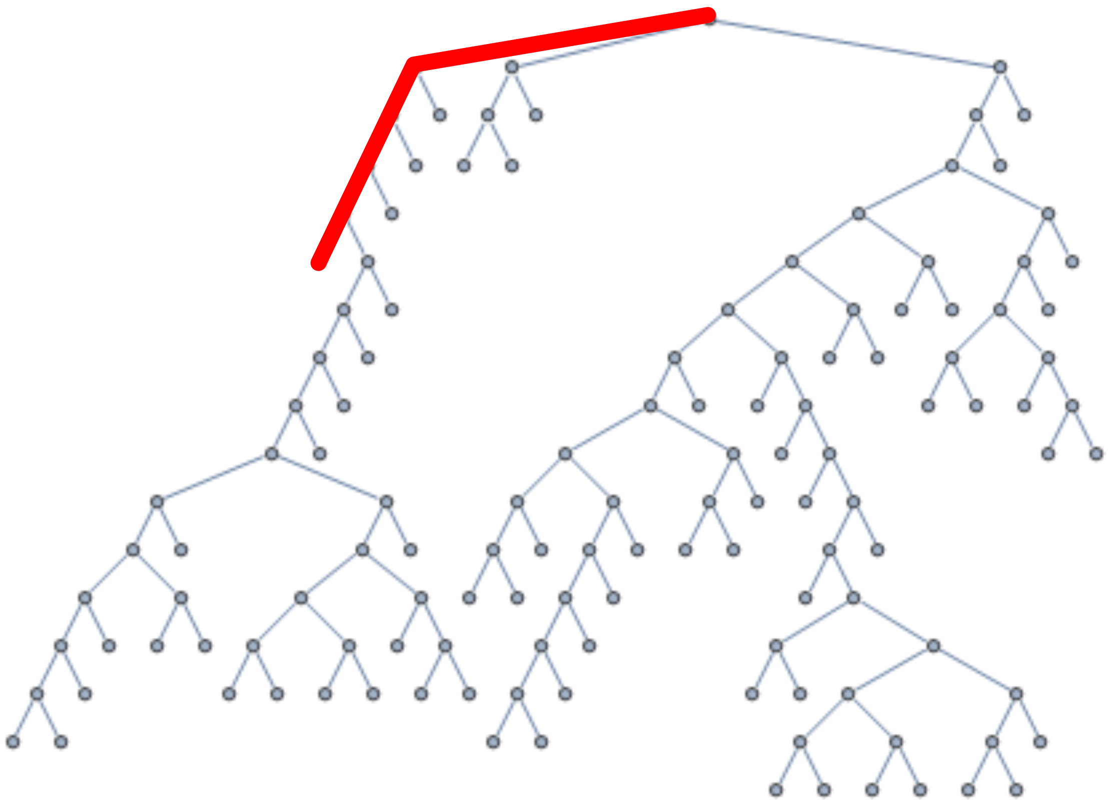

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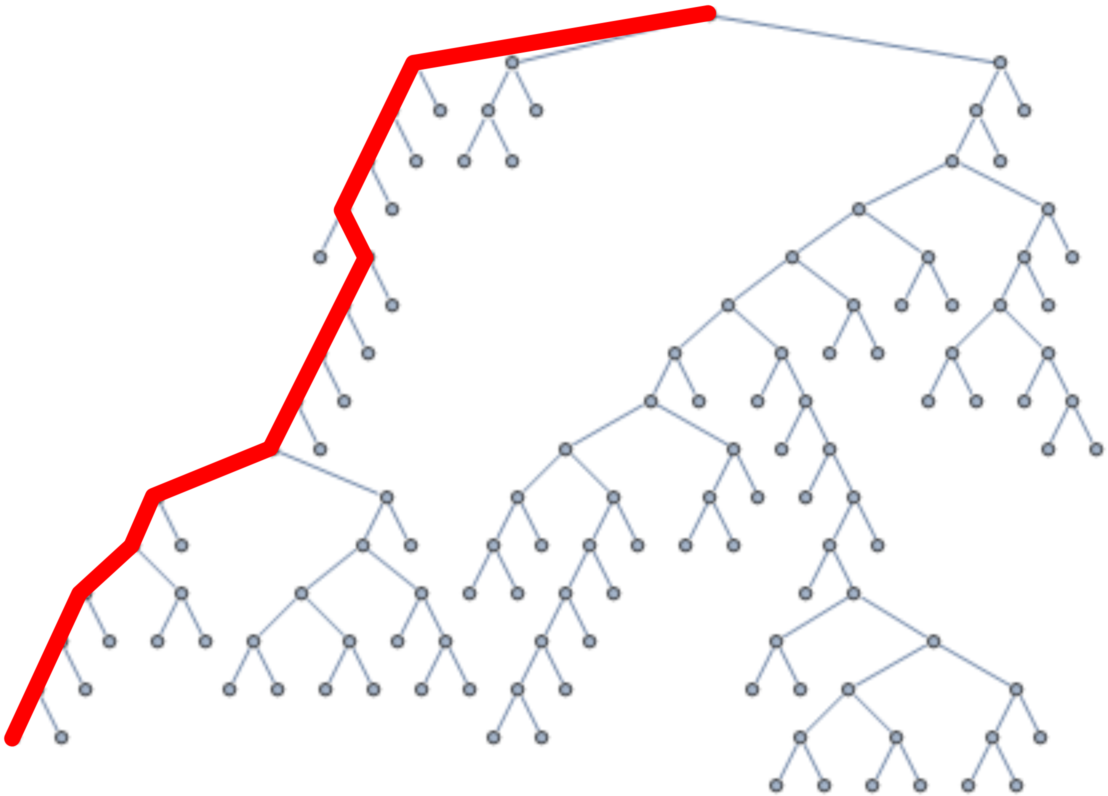

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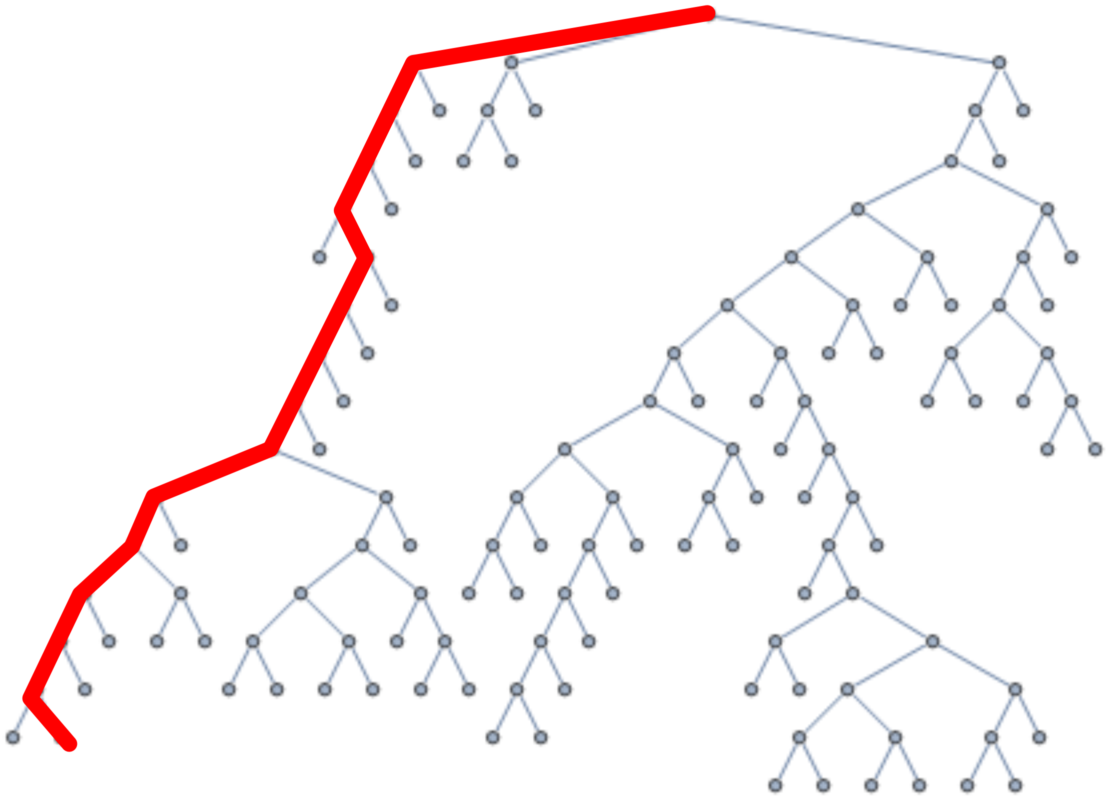

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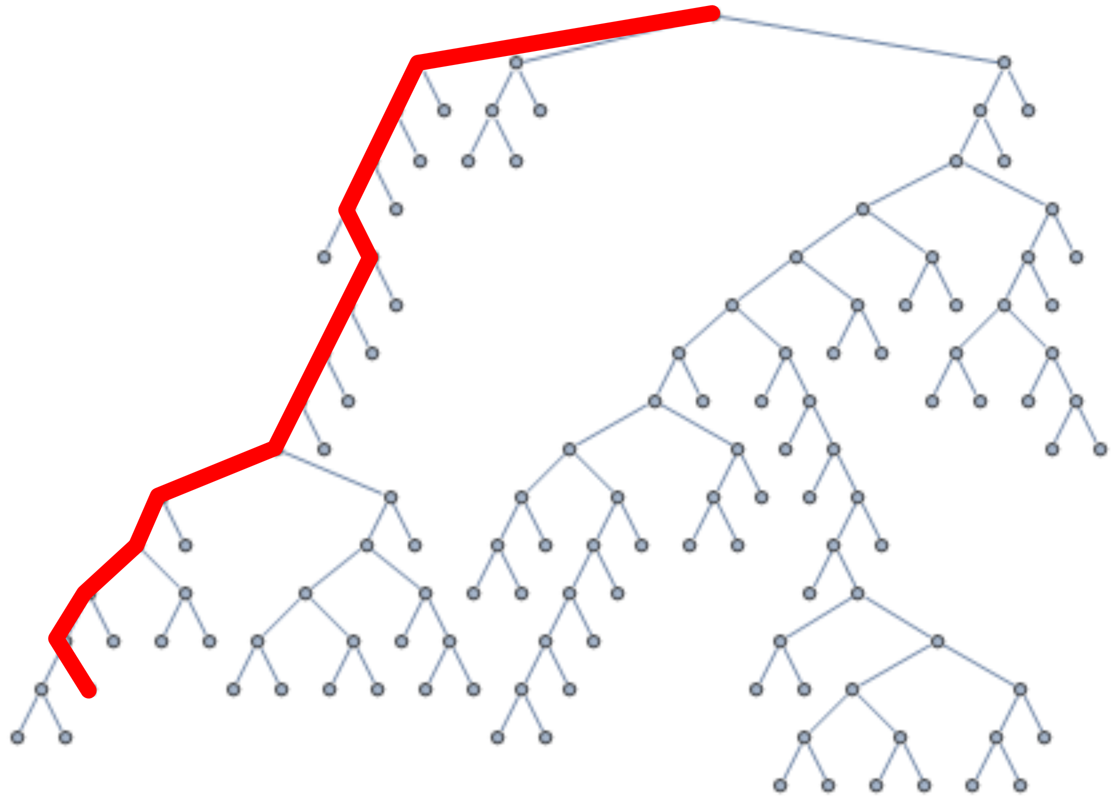

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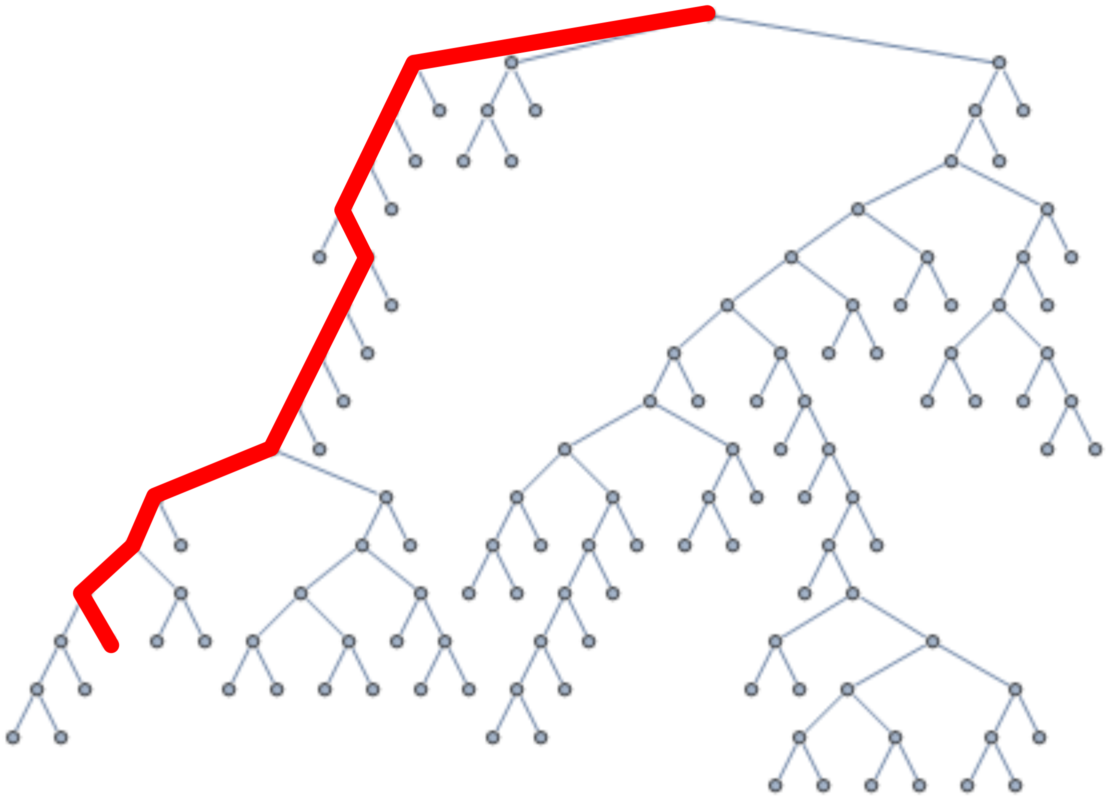

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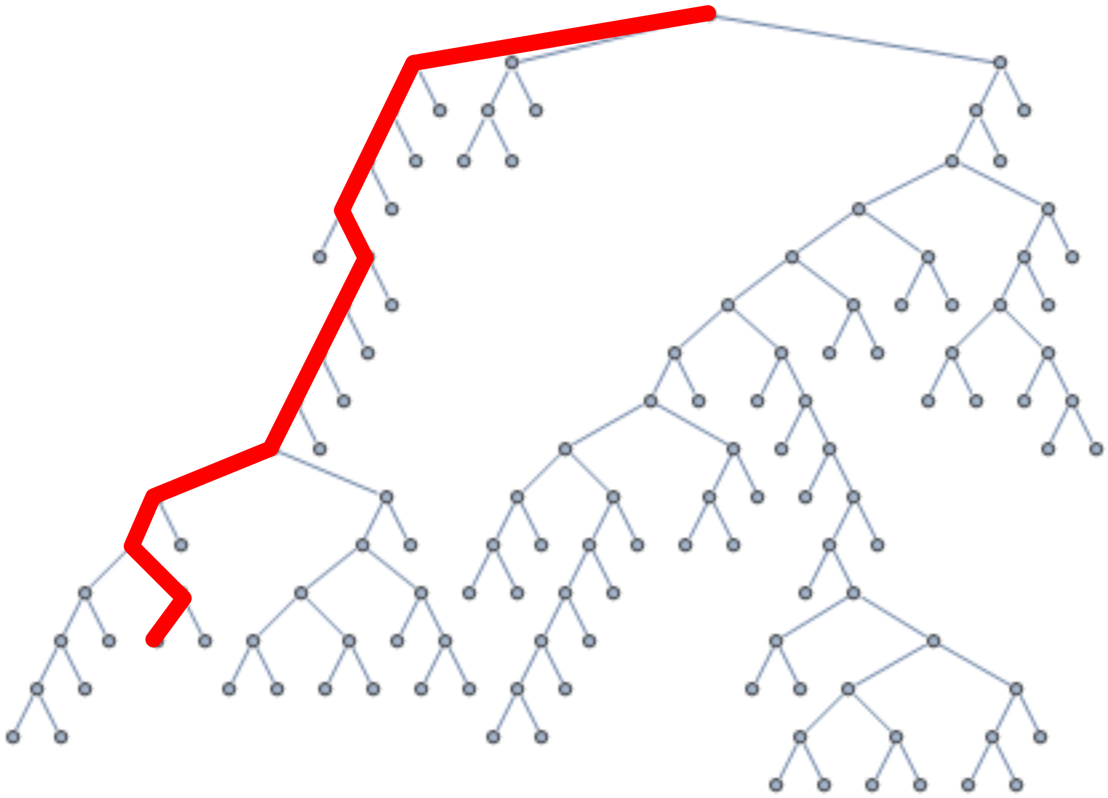

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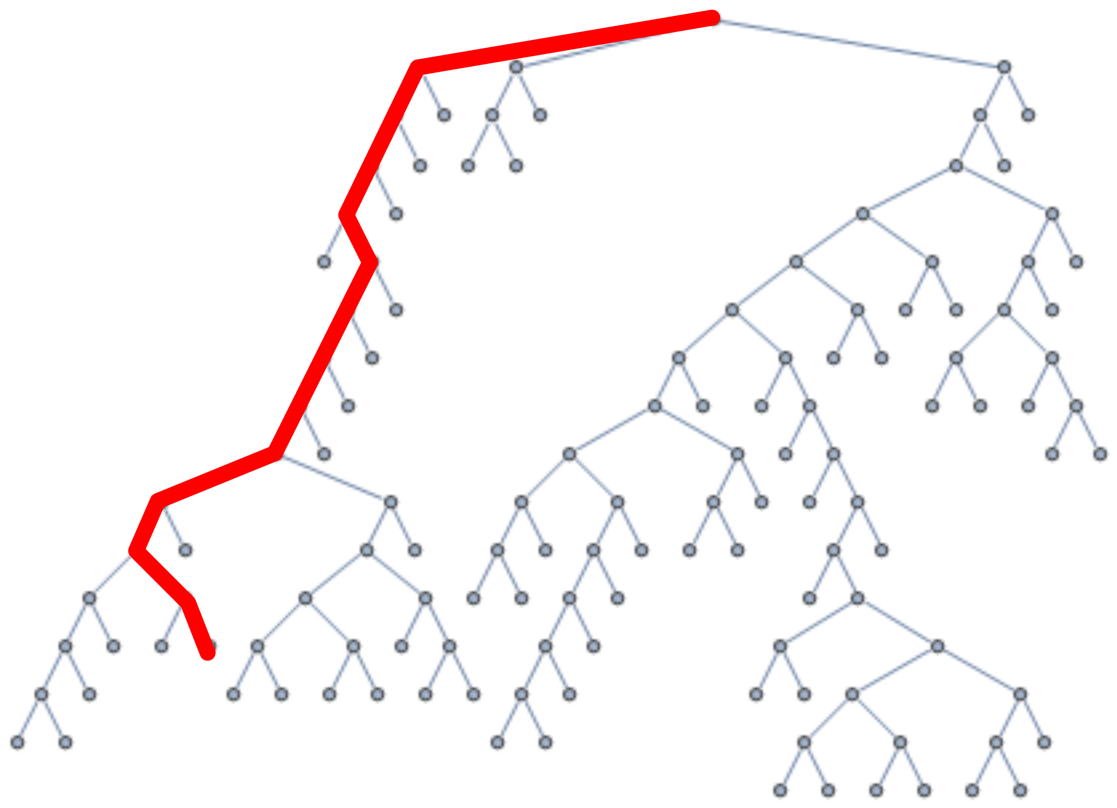

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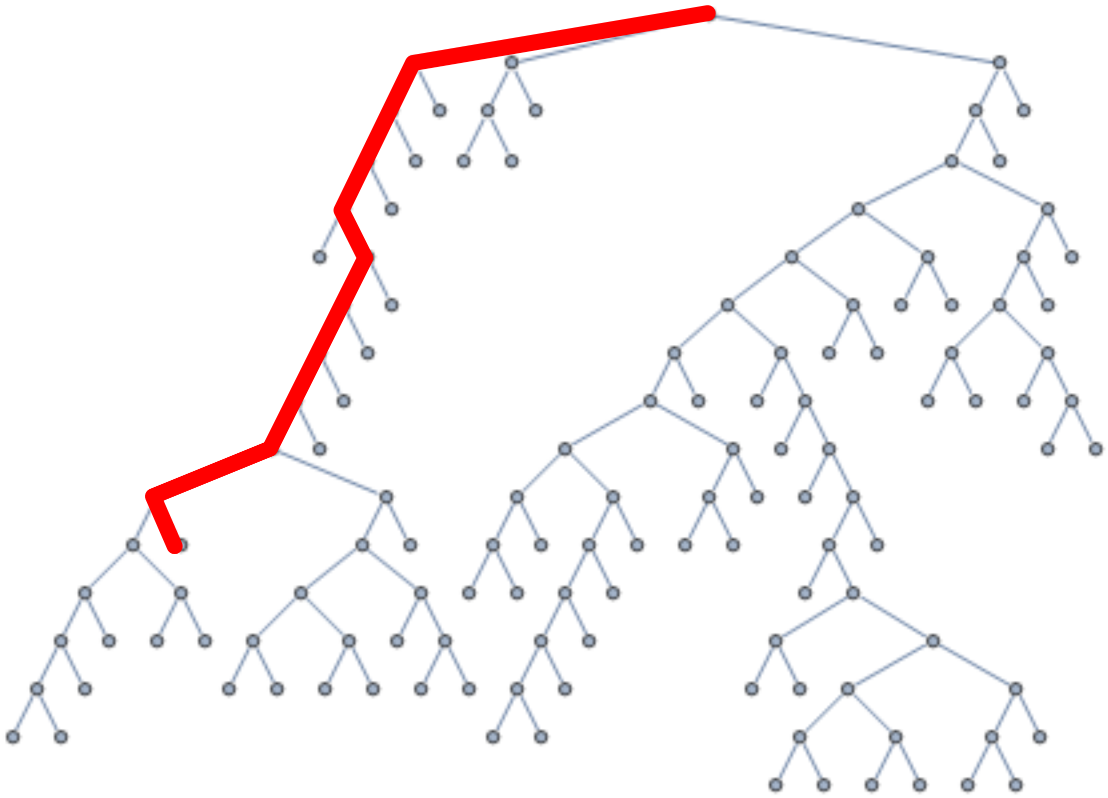


Analysis of search strategies

- Strategies are evaluated along the following criteria:
  - **Completeness:** does it always find a solution if one exists?
  - **Optimality:** does it always find a least-cost solution?
  - **Time complexity:** number of nodes generated
  - **Space complexity:** maximum number of nodes in memory
- Time and space complexity are measured in terms of
  - ***b**:* maximum branching factor of the search tree
  - ***d**:* depth of the optimal solution
  - ***m***: maximum length of any path in the state space (may be infinite)

Properties of breadth-first search

- **Complete?**
  Yes (if branching factor b is finite)
- **Optimal?**
  Yes – if cost = 1 per step
- **Time?**
  Number of nodes in a b-ary tree of depth d: $O(b^d)$
  (d is the depth of the optimal solution)
- **Space?**
  $O(b^d)$

- Space is the bigger problem (more than time)

Properties of depth-first search

- **Complete?**

  Fails in infinite-depth spaces, spaces with loops

  Modify to avoid repeated states along path

  → complete in finite spaces

- **Optimal?**

  No – returns the first solution it finds

- **Time?**

  Could be the time to reach a solution at maximum depth m: $O(b^m)$

  Terrible if m is much larger than d

  But if there are lots of solutions, may be much faster than BFS

- **Space?**

  $O(bm)$, i.e., linear space!

Iterative deepening search

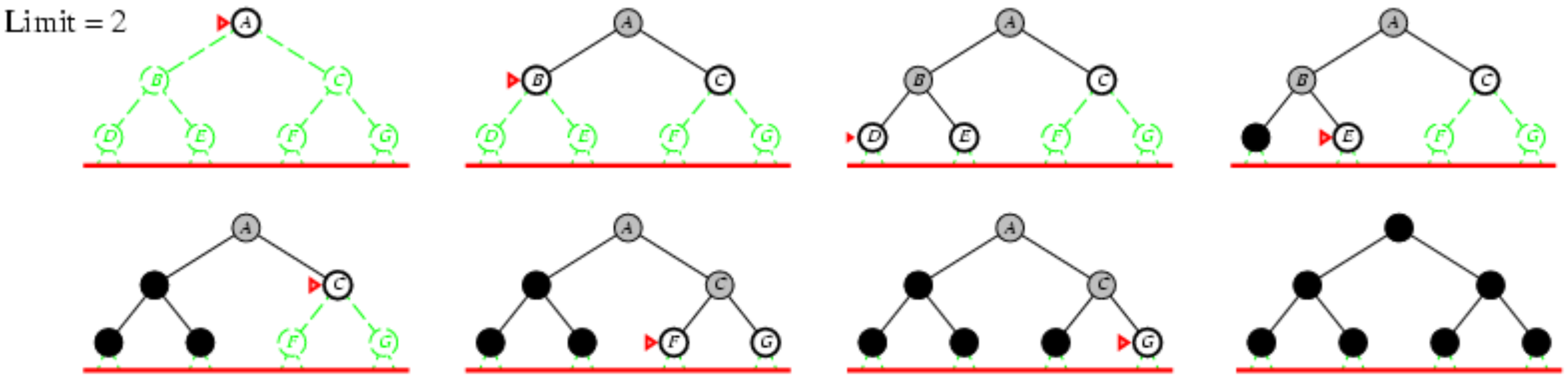
- Use DFS as a subroutine
  1. Check the root
  2. Do a DFS searching for a path of length 1
  3. If there is no path of length 1, do a DFS searching for a path of length 2
  4. If there is no path of length 2, do a DFS searching for a path of length 3…

Iterative deepening search

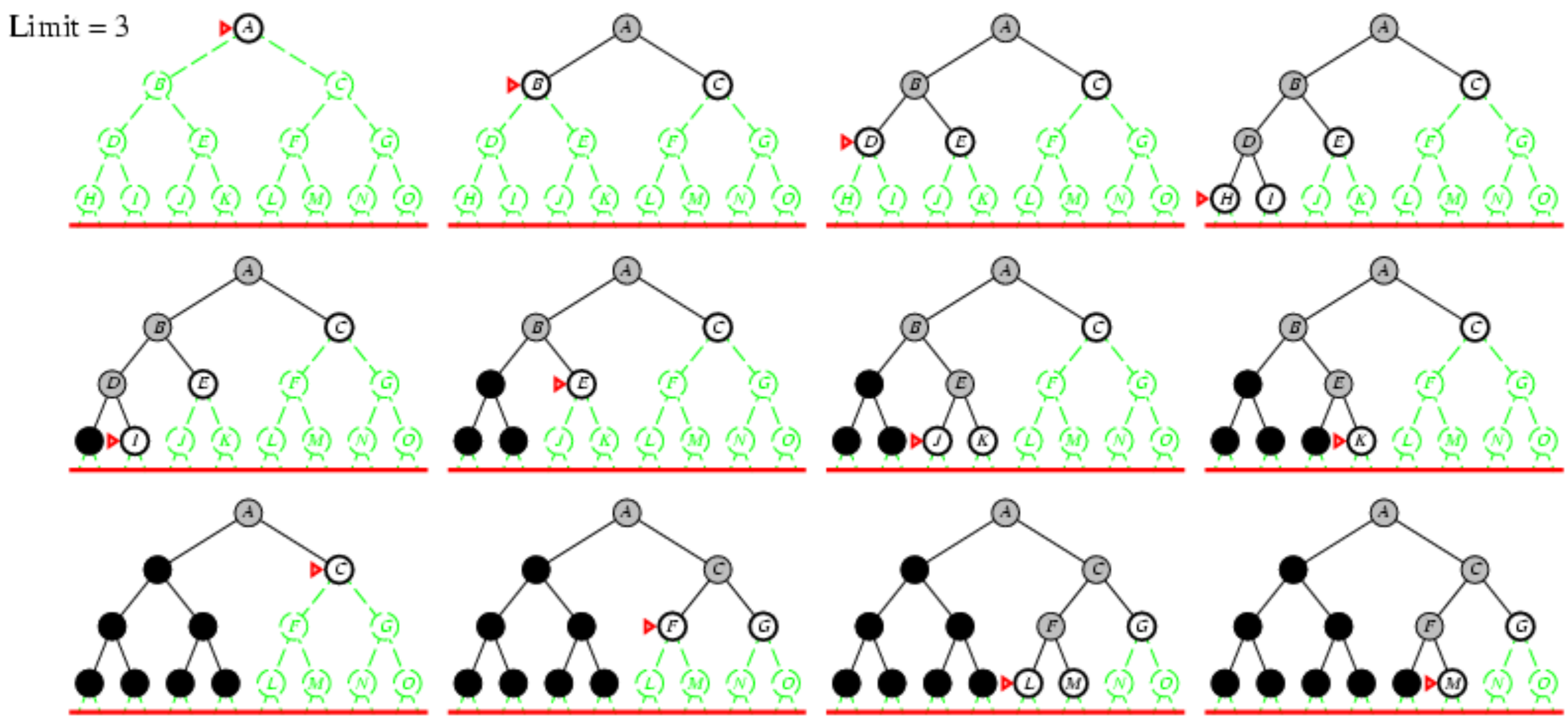
Limit = 0

Iterative deepening search

Iterative deepening search



Iterative deepening search



Properties of iterative deepening search

- **Complete?**

  Yes

- **Optimal?**

  Yes, if step cost = 1

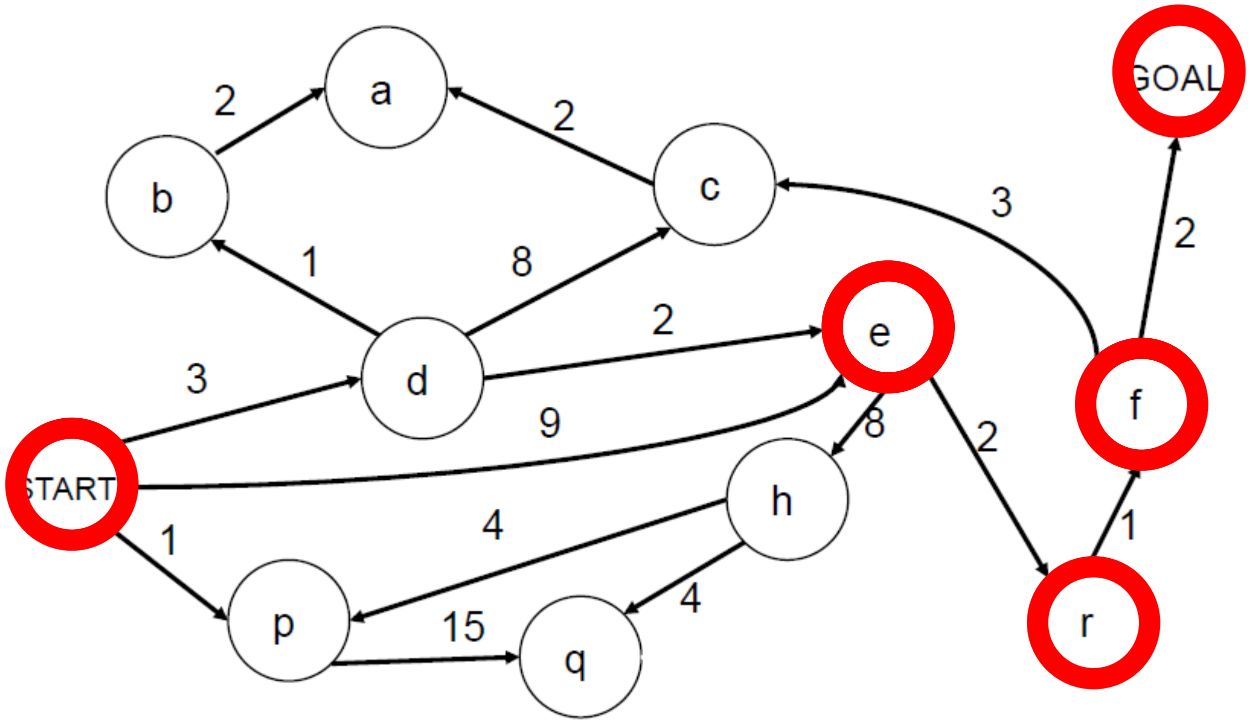
- **Time?**

  $(d+1)b^0 + d\,b^1 + (d-1)b^2 + \ldots + b^d$

- **Space?**

  $O(bd)$

Search with varying step costs



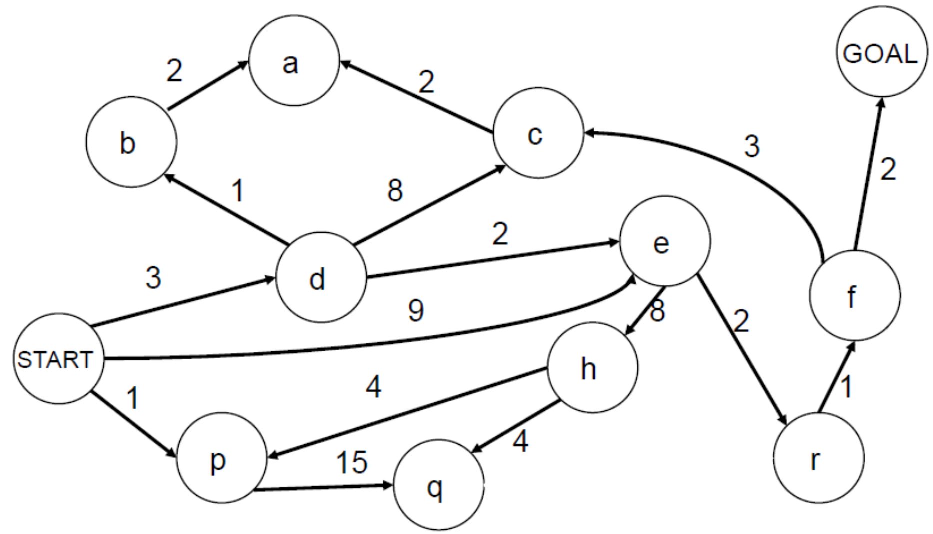
- BFS finds the path with the fewest steps, but does not always find the cheapest path

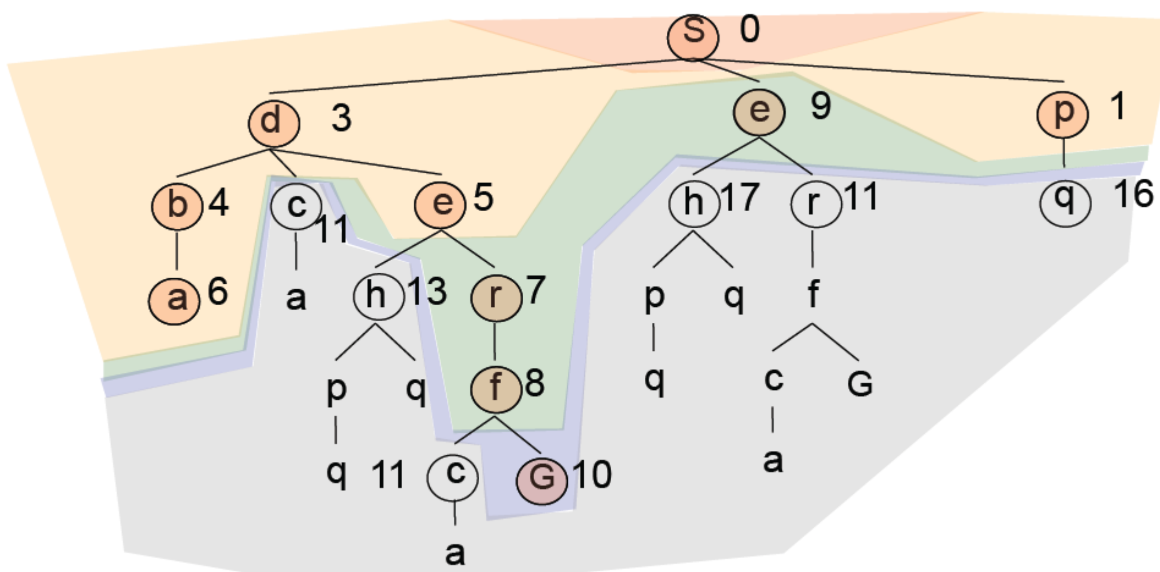
Uniform-cost search

- For each frontier node, save the total cost of the path from the initial state to that node
- Expand the frontier node with the lowest path cost
- Implementation: *frontier* is a priority queue ordered by path cost
- Equivalent to BFS if step costs all equal
- Equivalent to Dijkstra’s algorithm in general

Uniform-cost search example

- Expansion order:
  (S,p,d,b,e,a,r,f,e,G)





Properties of uniform-cost search

- **Complete?**

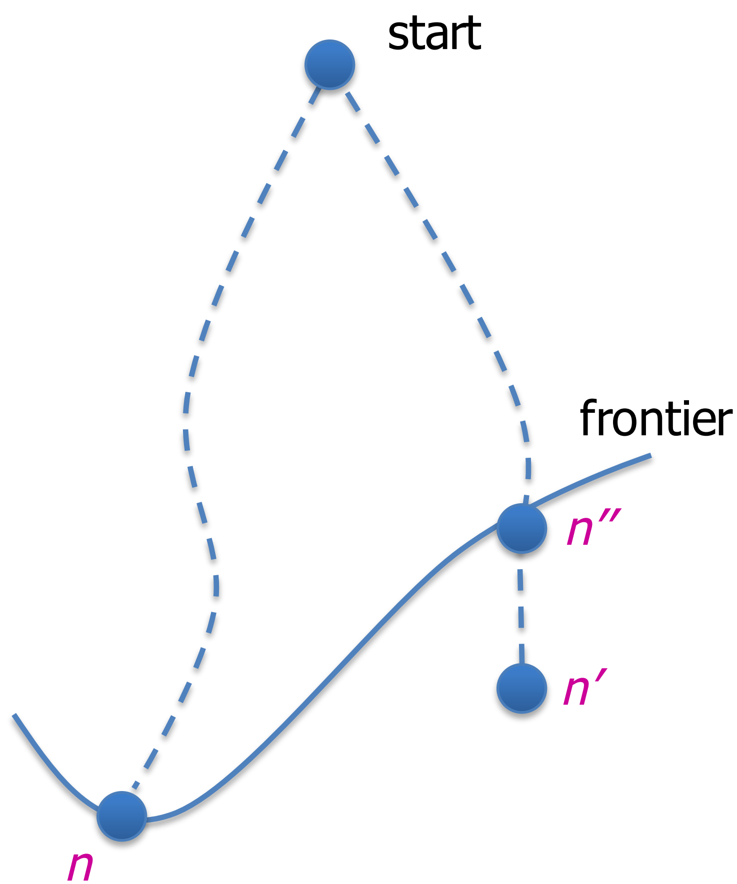
  Yes, if step cost is greater than some positive constant ε (we don't want infinite sequences of steps that have a finite total cost)
- **Optimal?**

  Yes

Optimality of uniform-cost search

- **Graph separation property**: every path from the initial state to an unexplored state has to pass through a state on the frontier
  - Proved inductively

- Optimality of UCS: proof by contradiction
  - Suppose UCS terminates at goal state n with path cost $g(n)$ but there exists another goal state n' with $g(n') < g(n)$
  - By the graph separation property, there must exist a node n'' on the frontier that is on the optimal path to n'
  - But because $g(n'') \leq g(n') < g(n)$, n'' should have been expanded first!



Properties of uniform-cost search

- **Complete?**

  Yes, if step cost is greater than some positive constant ε (we don't want infinite sequences of steps that have a finite total cost)
- **Optimal?**

  Yes – nodes expanded in increasing order of path cost
- **Time?**

  Number of nodes with path cost ≤ cost of optimal solution (C^*), $O(b^{C^*/\varepsilon})$

  This can be greater than $O(b^d)$: the search can explore long paths consisting of small steps before exploring shorter paths consisting of larger steps
- **Space?**

  $O(b^{C^*/\varepsilon})$

Review: Uninformed search strategies

Algorithm	Complete?	Optimal?	Time complexity	Space complexity
BFS	Yes	If all step costs are equal	$O(b^d)$	$O(b^d)$
DFS	No	No	$O(b^m)$	$O(bm)$
IDS	Yes	If all step costs are equal	$O(b^d)$	$O(bd)$
UCS	Yes	Yes	Number of nodes with $g(n) \le C^*$	

b: maximum branching factor of the search tree
d: depth of the optimal solution
m: maximum length of any path in the state space
C*: cost of optimal solution
g(n): cost of path from start state to node n

Attribution

Slides developed by Svetlana Lazebnik based on content from Stuart Russell and Peter Norvig, Artificial Intelligence: A Modern Approach, 3rd edition