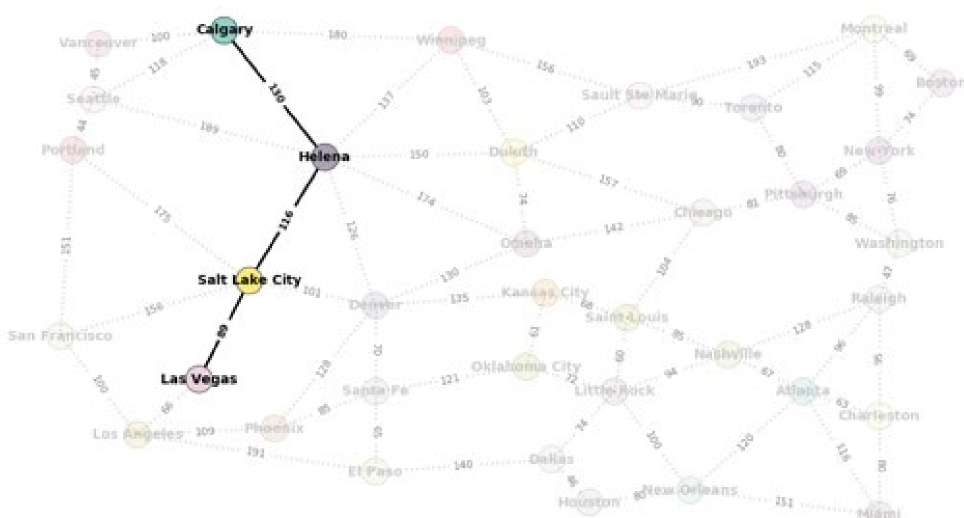
Artificial Intelligence

Search Agents
Informed search



Informed search

Use domain knowledge!

- Are we getting close to the goal?
- Use a heuristic function that estimates how close a state is to the goal
- A heuristic does NOT have to be perfect!

Informed search

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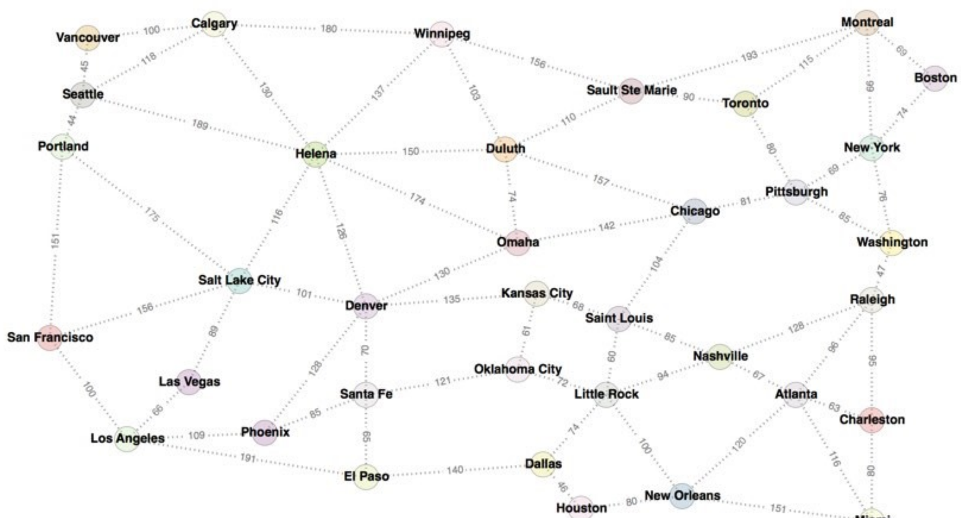
- Are we getting close to the goal?
- Use a heuristic function that estimates how close a state is to the goal
- A heuristic does NOT have to be perfect!
- Example of strategies:
  1. Greedy best-first search
  2. A* search
  3. IDA*

Informed search



Atlanta	272
Boston	240
Calgary	334
Charleston	322
Chicago	107
Dallas	303
Denver	270
Duluth	110
El Paso	370
Helena	254
Houston	332
Kansas City	176
Las Vegas	418
Little Rock	240
Los Angeles	484
Miami	389
Montreal	193
Nashville	221
New Orleans	322
New York	195
Oklahoma City	237
Omaha	150
Phoenix	396
Pittsburgh	152
Portland	452
Raleigh	251
Saint Louis	180
Salt Lake City	344
San Francisco	499
Santa Fe	318
Sault Ste Marie	0
Seattle	434
Toronto	90
Vancouver	432
Washington	238
Winnipeg	156

Heuristic!

The distance is the straight line distance. The goal is to get to Sault Ste Marie, so all the distances are from each city to Sault Ste Marie.

Greedy search

- Evaluation function $h(n)$ (*h*euristic)
- $h(n)$ estimates the cost from n to the closest goal
- Example: $h_{\text{SLD}}(n) =$ straight-line distance from n to Sault Ste Marie
- Greedy search expands the node that **appears** to be closest to goal

Greedy search

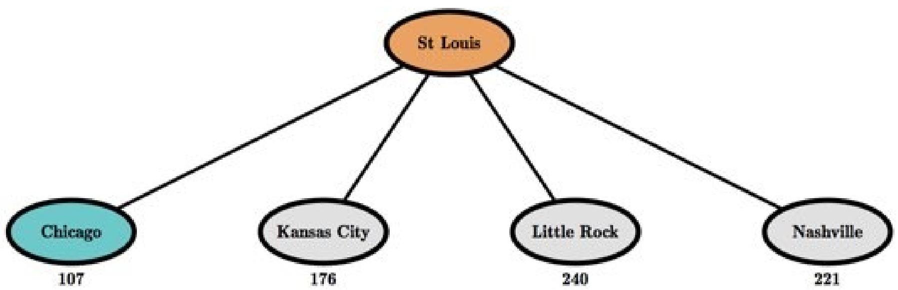
```
function GREEDY-BEST-FIRST-SEARCH(initialState, goalTest)
    returns SUCCESS or FAILURE :  /* Cost f(n) = h(n) */

    frontier = Heap.new(initialState)
    explored = Set.new()

    while not frontier.isEmpty():
        state = frontier.deleteMin()
        explored.add(state)

        if goalTest(state):
            return SUCCESS(state)

        for neighbor in state.neighbors():
            if neighbor not in frontier ∪ explored:
                frontier.insert(neighbor)
            else if neighbor in frontier:
                frontier.decreaseKey(neighbor)

    return FAILURE
```

Greedy search example

The initial state:

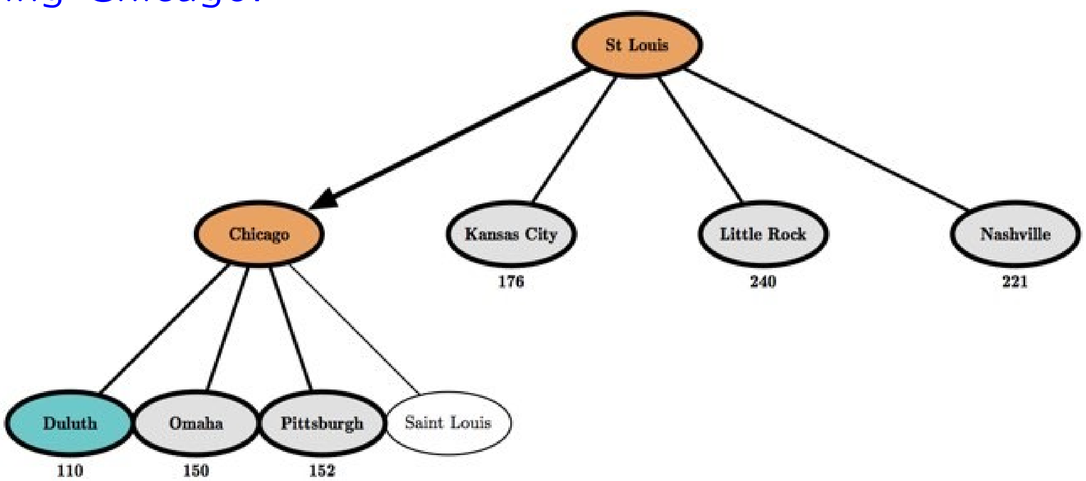
Greedy search example

After expanding St Louis:



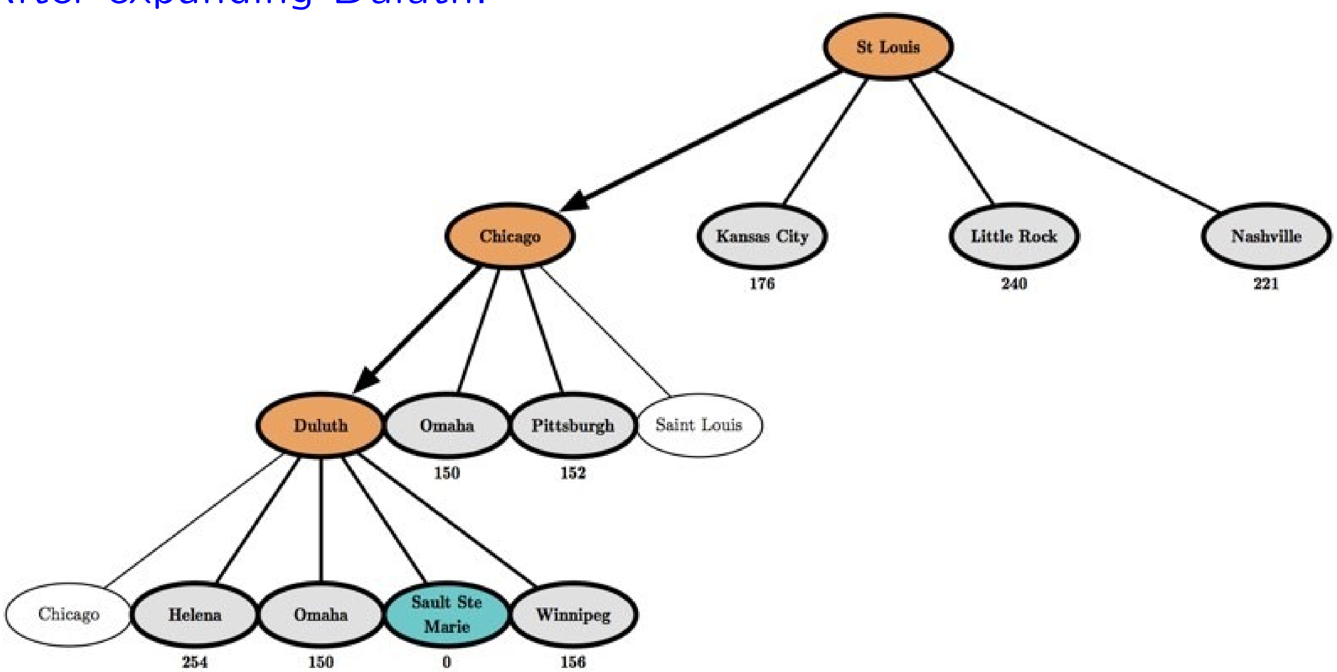
Greedy search example

After expanding Chicago:



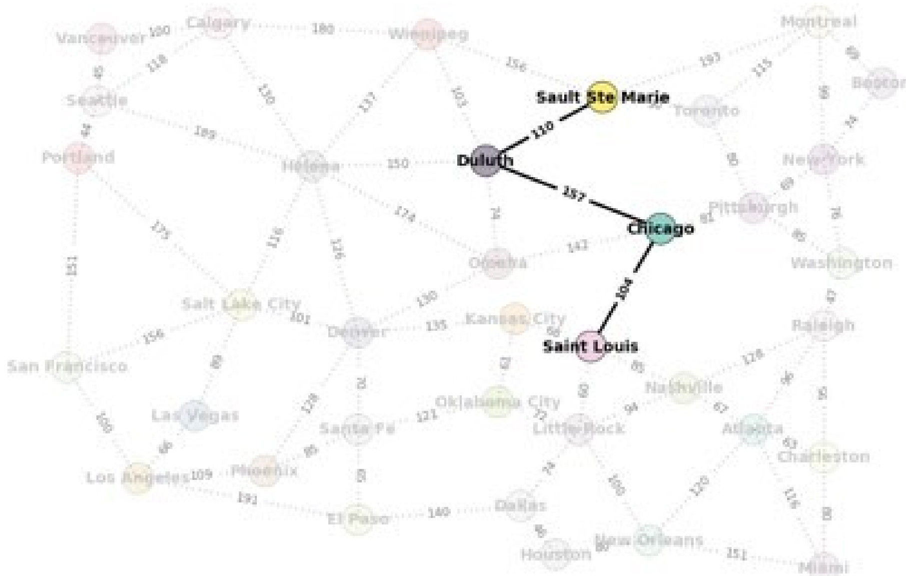
Greedy search example

After expanding Duluth:



Examples using the map

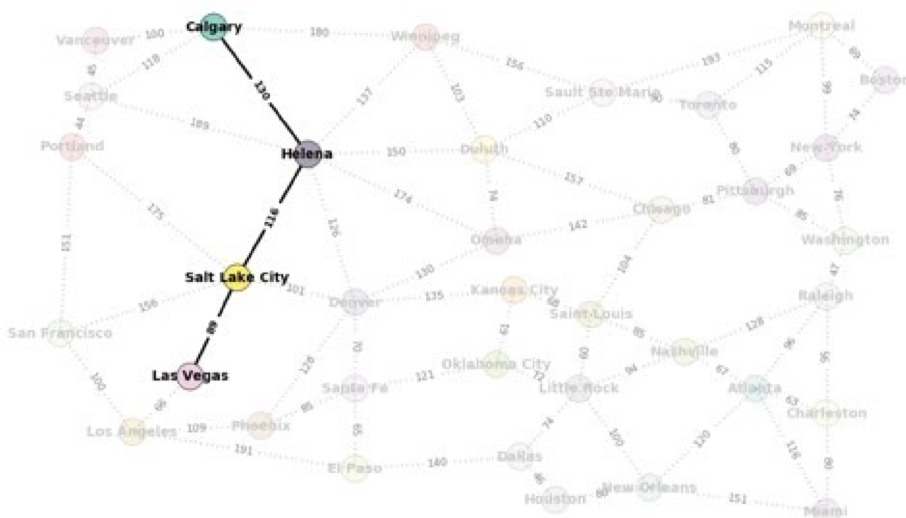
Start: Saint Louis
Goal: Sault Ste Marie



Greedy search

Examples using the map

Start: Las Vegas
Goal: Calgary



Greedy search

A* search

- Minimize the total estimated solution cost
- Combines:
  - $g(n)$: cost to reach node n
  - $h(n)$: cost to get from n to the goal
  - $f(n) = g(n) + h(n)$

$f(n)$ is the estimated cost of the cheapest solution through n

A* search

```
function A-STAR-SEARCH(initialState, goalTest)
    returns SUCCESS or FAILURE : /* Cost f(n) = g(n) + h(n) */

    frontier = Heap.new(initialState)
    explored = Set.new()

    while not frontier.isEmpty():
        state = frontier.deleteMin()
        explored.add(state)

        if goalTest(state):
            return SUCCESS(state)

        for neighbor in state.neighbors():
            if neighbor not in frontier ∪ explored:
                frontier.insert(neighbor)
            else if neighbor in frontier:
                frontier.decreaseKey(neighbor)

    return FAILURE
```

A* search example

The initial state:

A* search example

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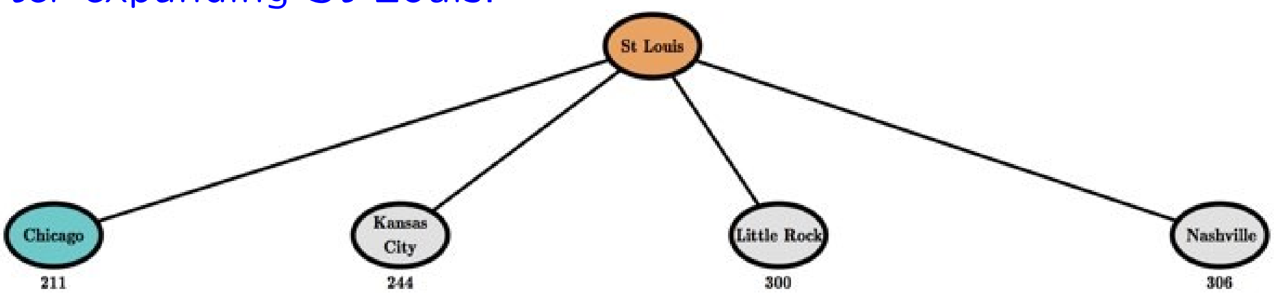

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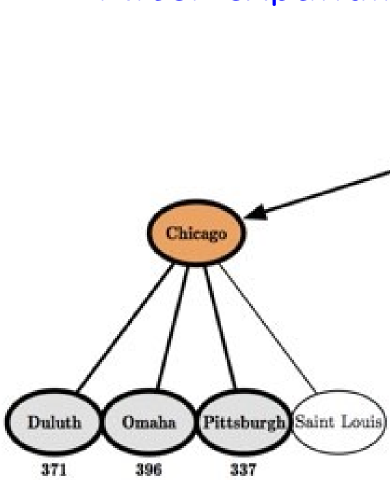
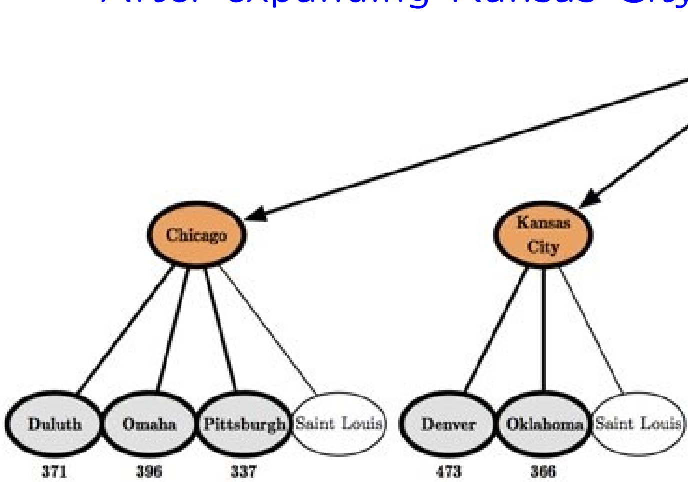


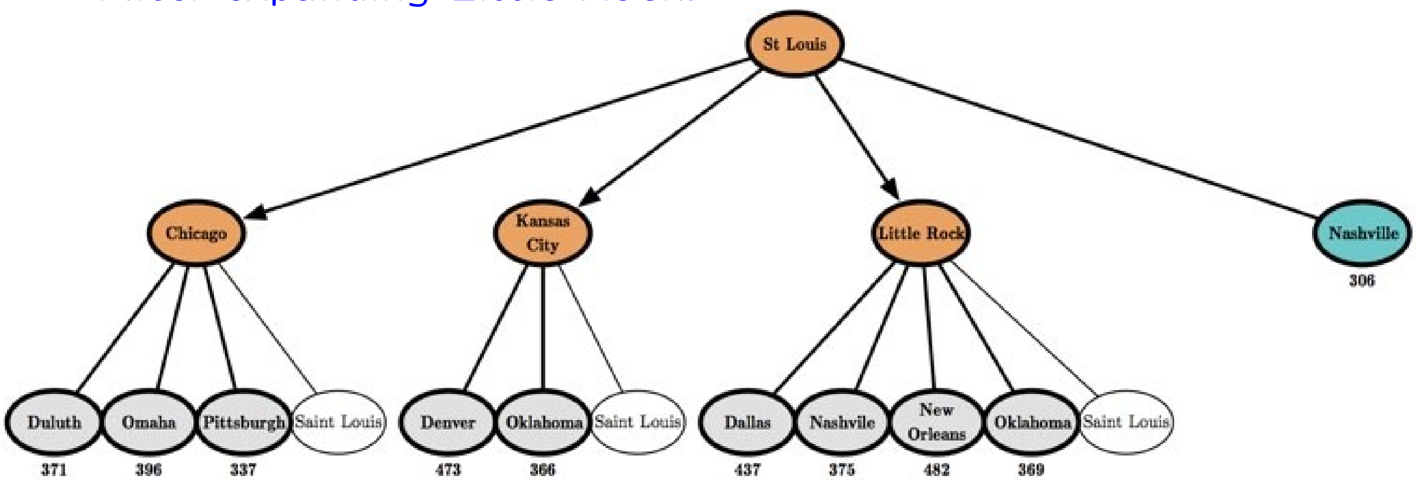
A* search example

After expanding Kansas City:



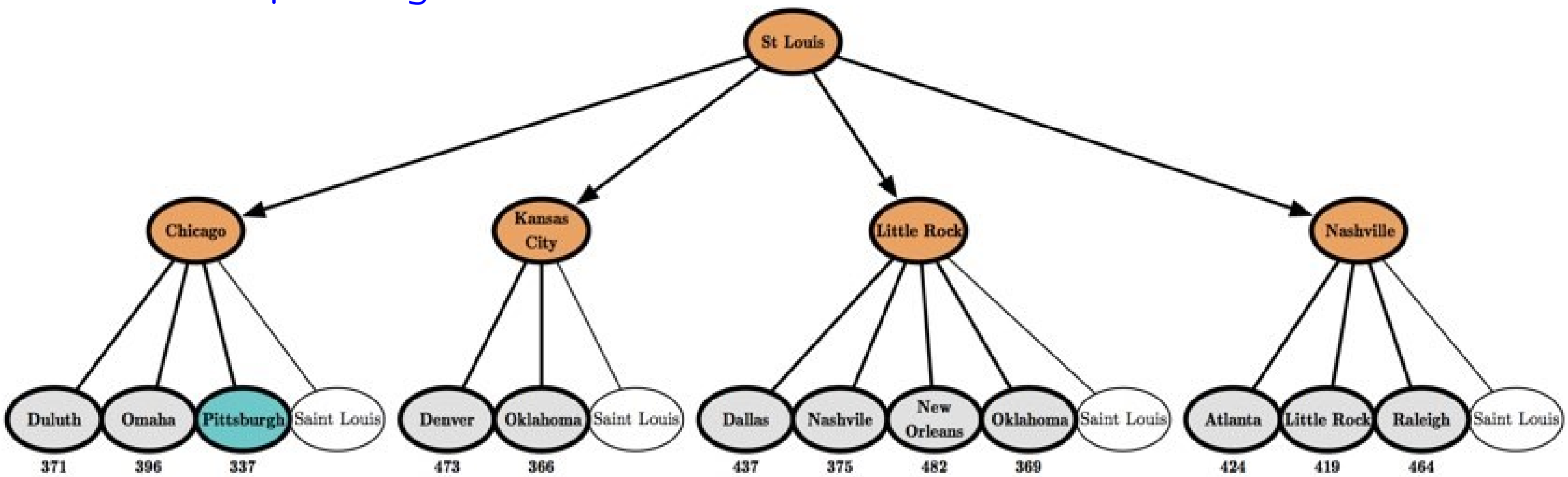
A* search example

After expanding Little Rock:



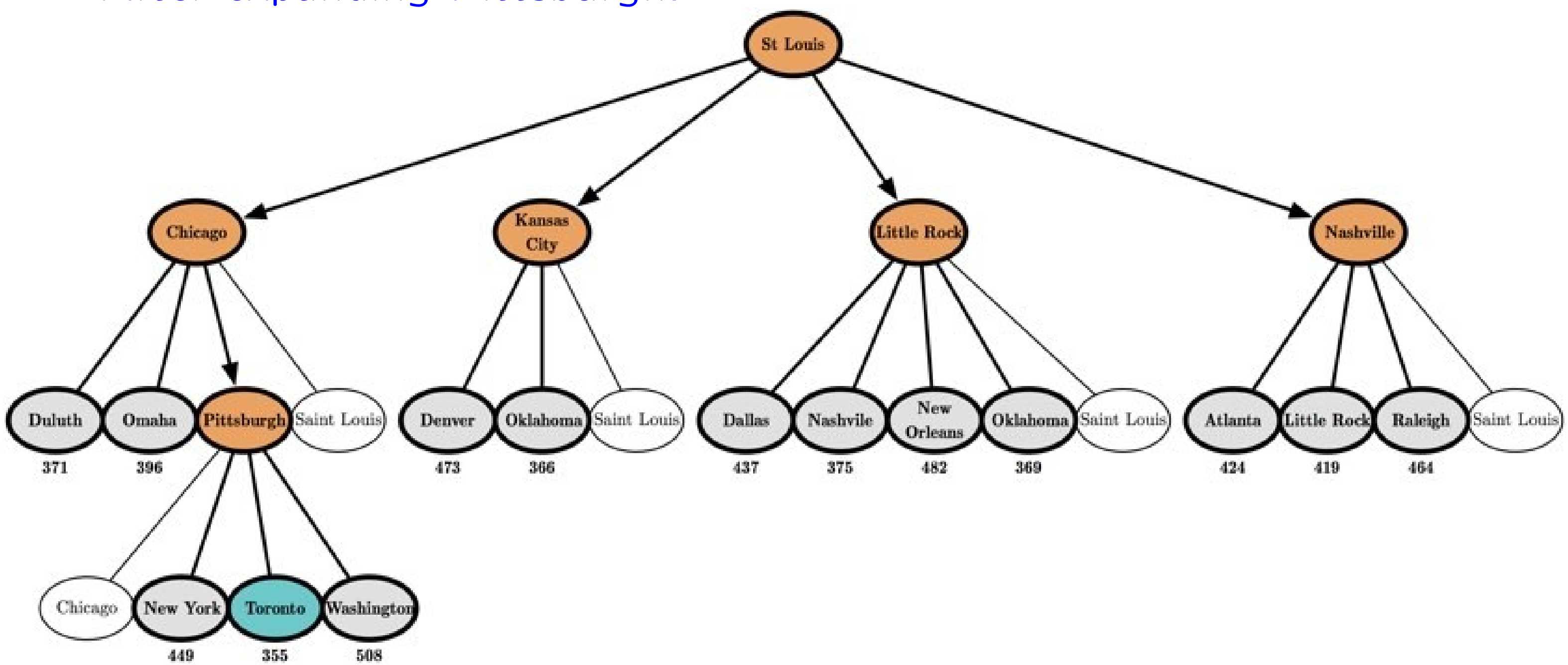
A* search example

After expanding Nashville:



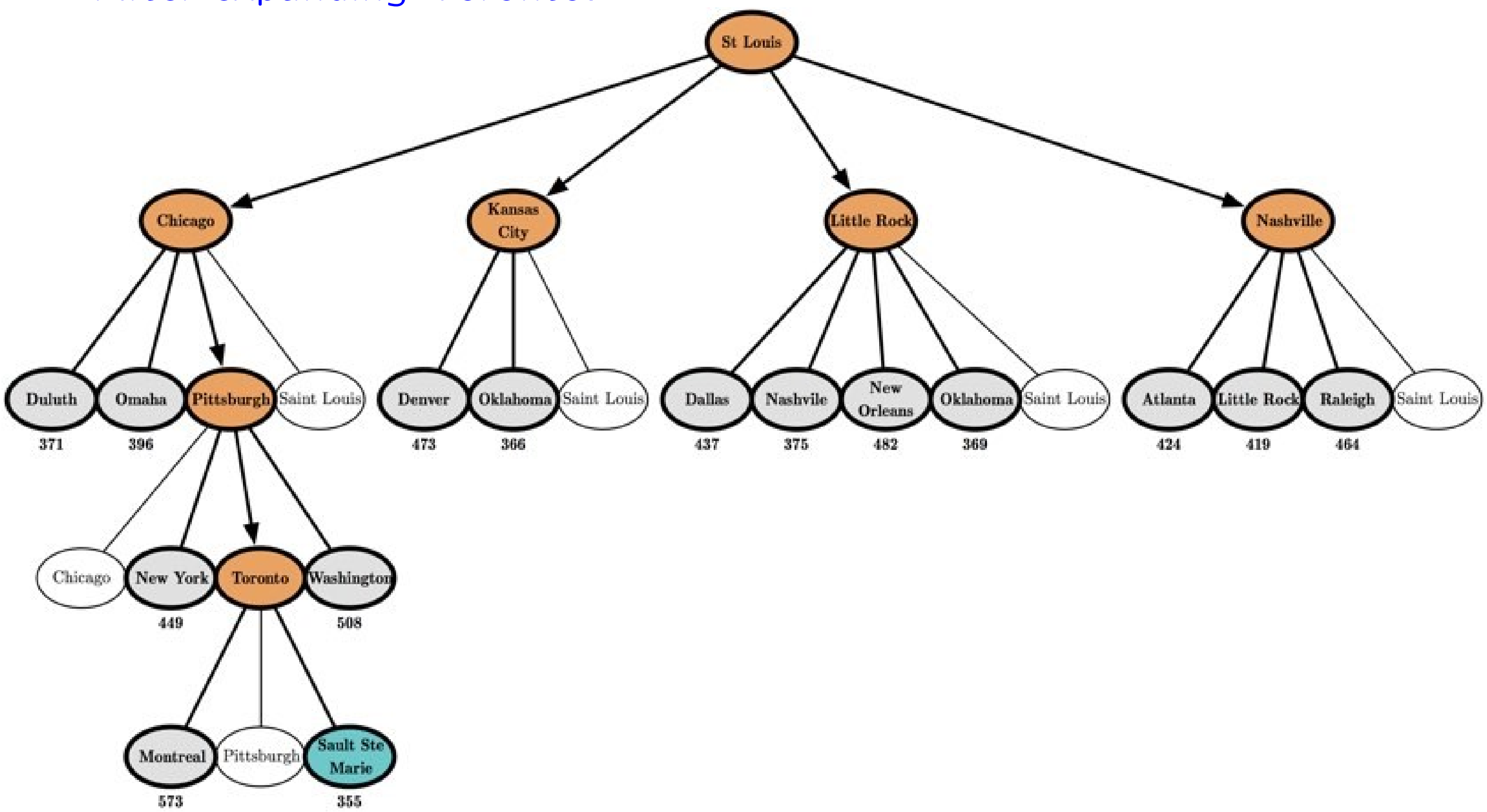
A* search example

After expanding Pittsburgh:



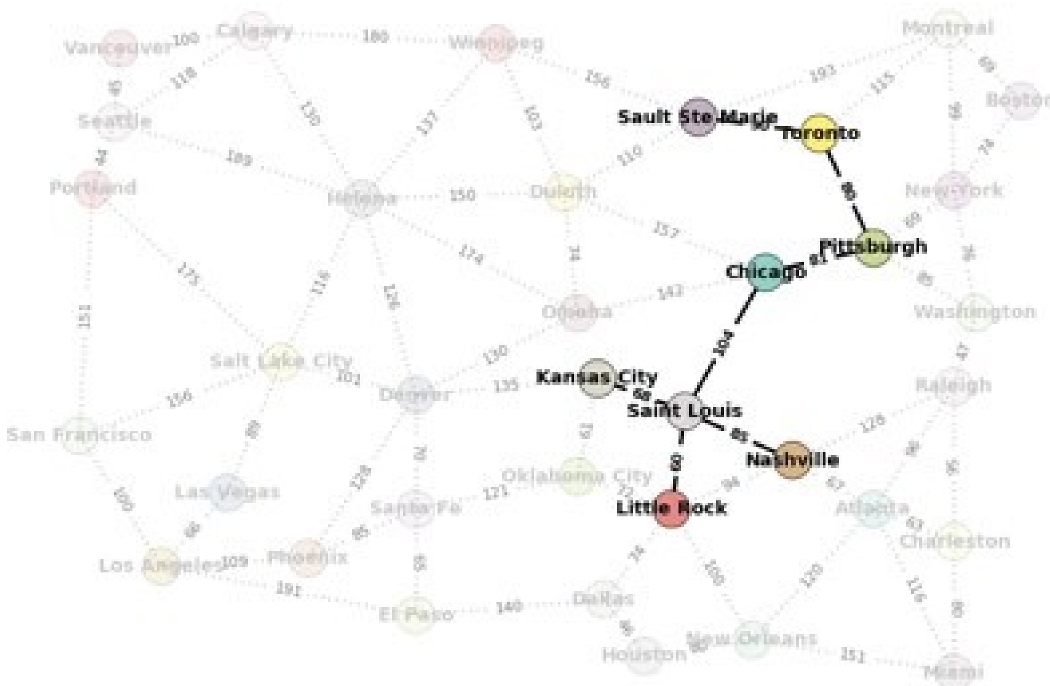
A* search example

After expanding Toronto:



Examples using the map

Start: Saint Louis
Goal: Sault Ste Marie



A*

Examples using the map

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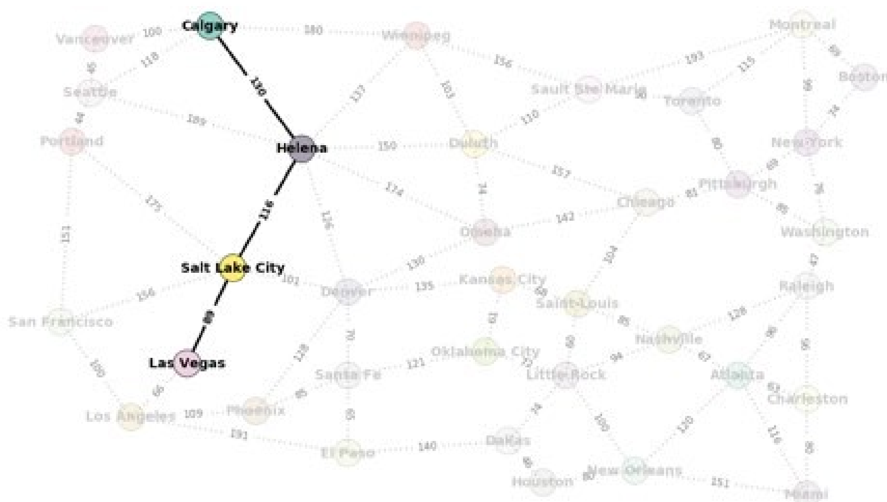
Goal: Calgary



A*

Admissible heuristics

A good heuristic can be powerful.

Only if it is of a “good quality”

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A good heuristic can be powerful.

Only if it is of a “good quality”

A good heuristic must be admissible.

Admissible heuristics

- An **admissible** heuristic never overestimates the cost to reach the goal, that is it is **optimistic**

- A heuristic h is admissible if

$$\forall\ node\ n, h(n) \leq h^*(n)$$

  where h^* is true cost to reach the goal from n.

- h_{SLD} (used as a heuristic in the map example) is admissible because it is by definition the shortest distance between two points.

A* Optimality

If $h(n)$ is admissible, A* using tree search is optimal.

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If $h(n)$ is admissible, A* using tree search is optimal.

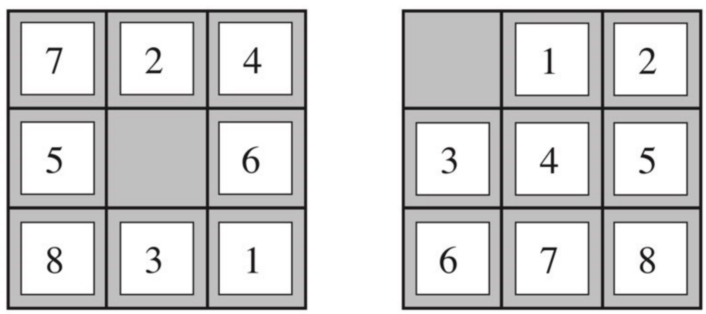
Rationale:

- Suppose G_o is the optimal goal.
- Suppose G_s is some suboptimal goal.
- Suppose n is an unexpanded node in the fringe such that n is on the shortest path to G_o.
- $f(G_s) = g(G_s)$ since $h(G_s) = 0$
  $f(G_o) = g(G_o)$ since $h(G_o) = 0$
  $f(G_s) > g(G_o)$ since G_s is suboptimal
  Then $f(G_s) > f(G_o)$ ... (1)
- $h(n) \leq h^*(n)$ since h is admissible
  $g(n) + h(n) \leq g(n) + h^*(n) = g(G_o) = f(G_o)$
  Then, $f(n) \leq f(G_o) \ldots (2)$
  From (1) and (2) $f(G_s) > f(n)$
  so A* will never select G_s during the search and hence A* is optimal.

A* search criteria

- **Complete**: Yes
- **Time**: exponential
- **Space**: keeps every node in memory, the biggest problem
- **Optimal**: Yes!

Heuristics



Start State Goal State

- The solution is 26 steps long.
- $h_1(n) =$ number of misplaced tiles
- $h_2(n) =$total Manhattan distance (sum of the horizontal and vertical distances).
- $h_1(n) = 8$
- Tiles 1 to 8 in the start state gives: $h_2 = 3 + 1 + 2 + 2 + 2 + 3 + 3 + 2 = 18$ which does not overestimate the true solution.

Search Algorithms: Recap

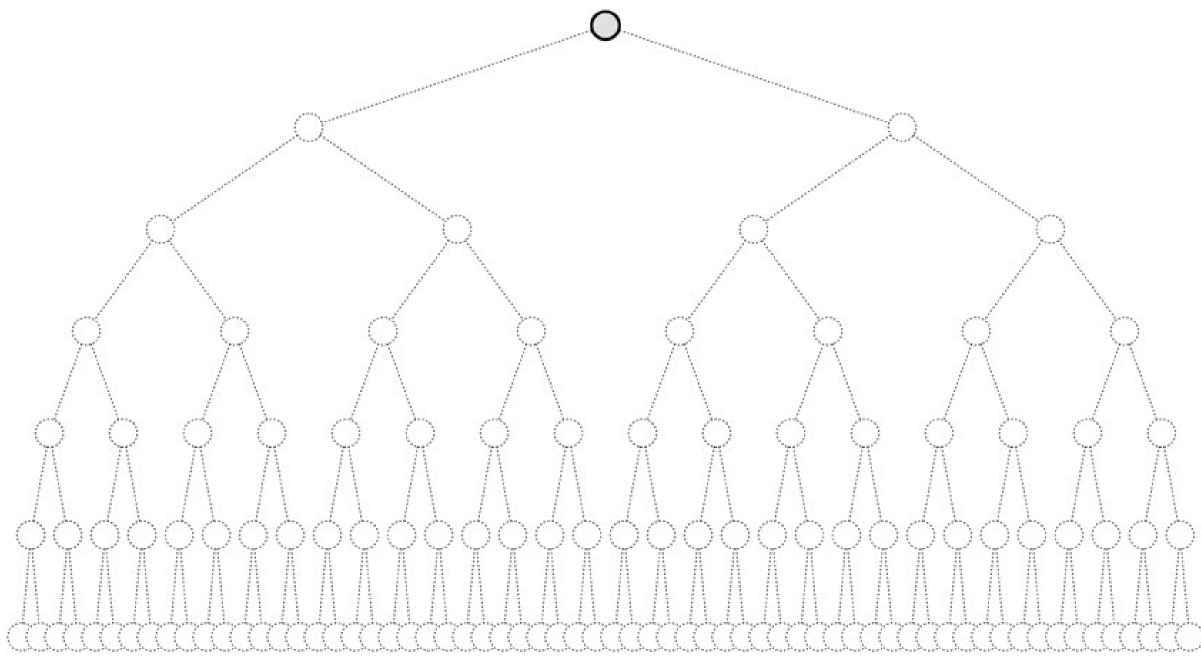
- **Uninformed Search**: Use no domain knowledge.

  BFS, DFS, DLS, IDS, UCS.

- **Informed Search**: Use a heuristic function that estimates how close a state is to the goal.

  Greedy search, A*, IDA*.

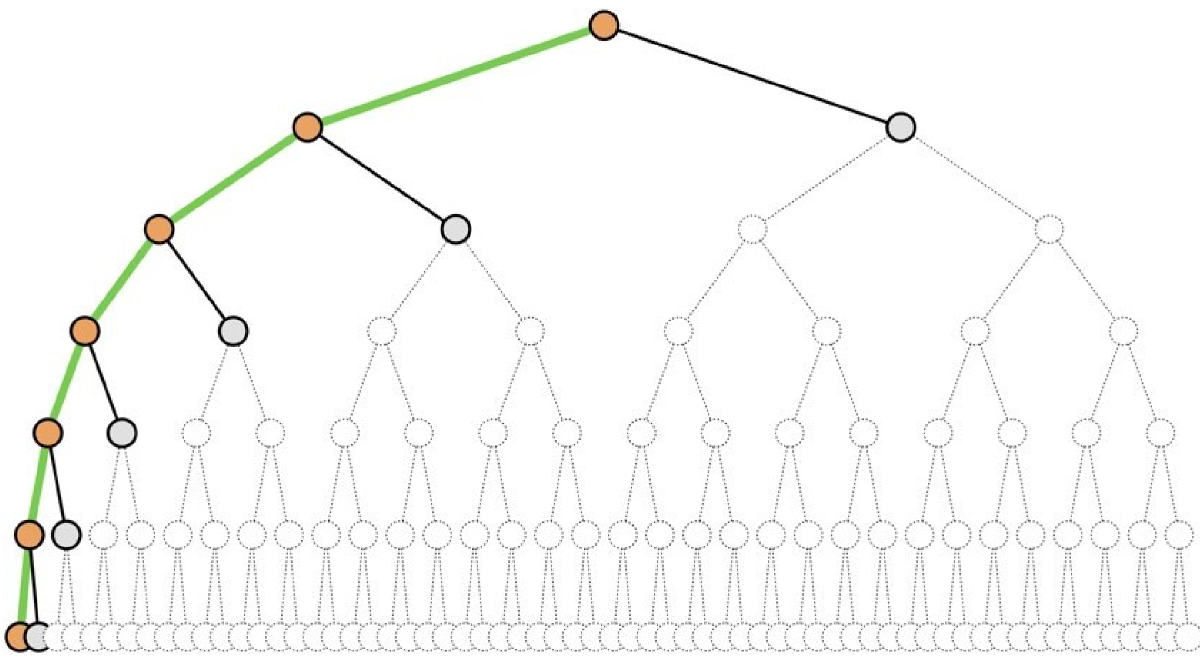
DFS



Searches branch by branch ...

... with each branch pursued to maximum depth.

DFS



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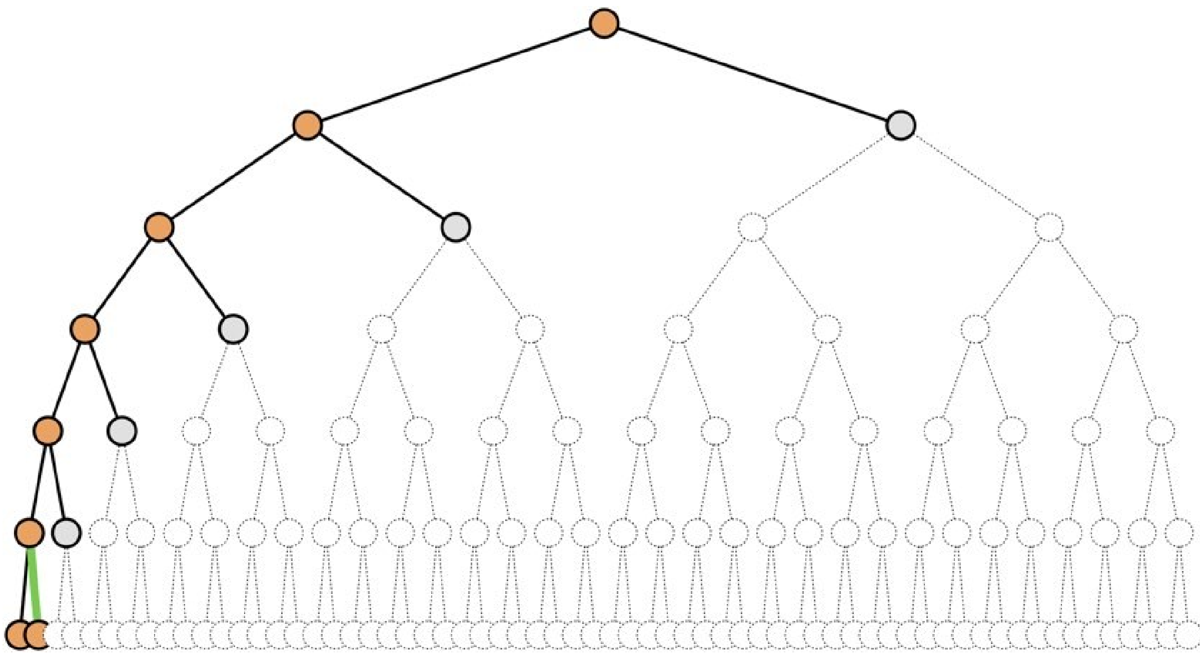

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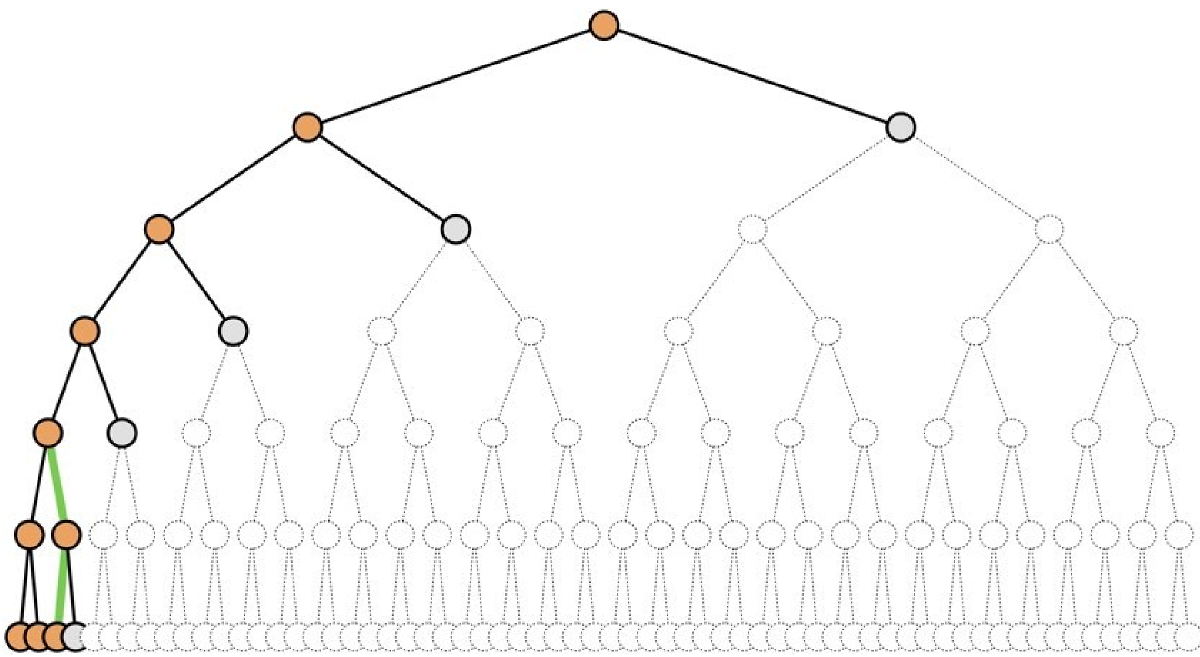

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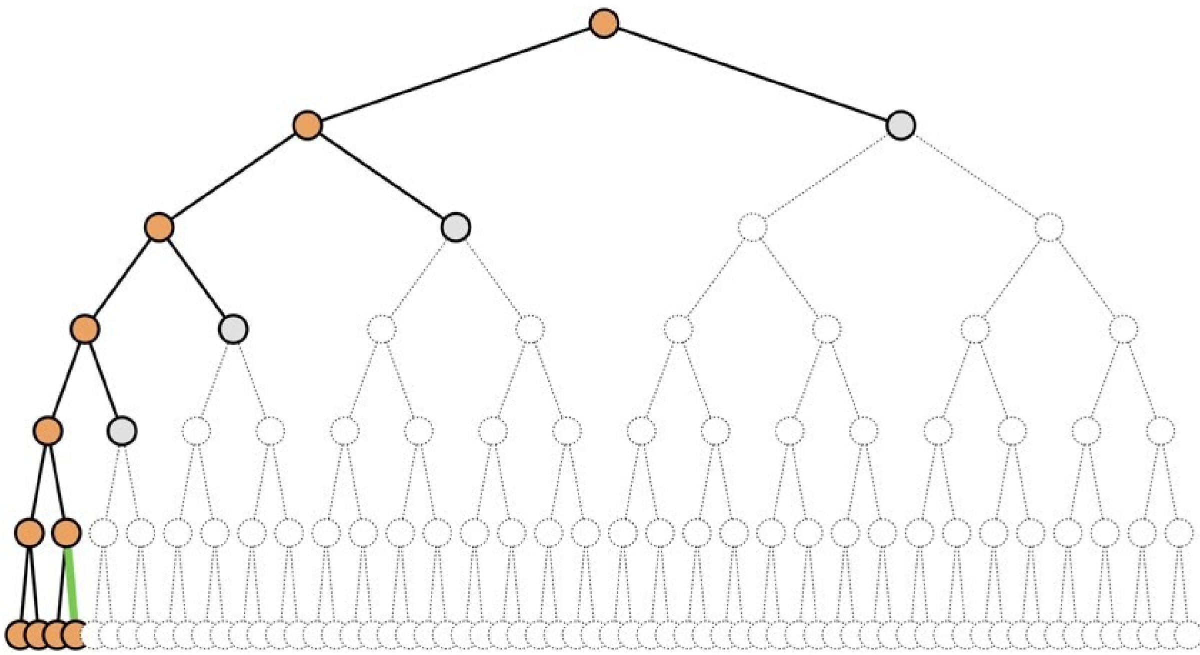

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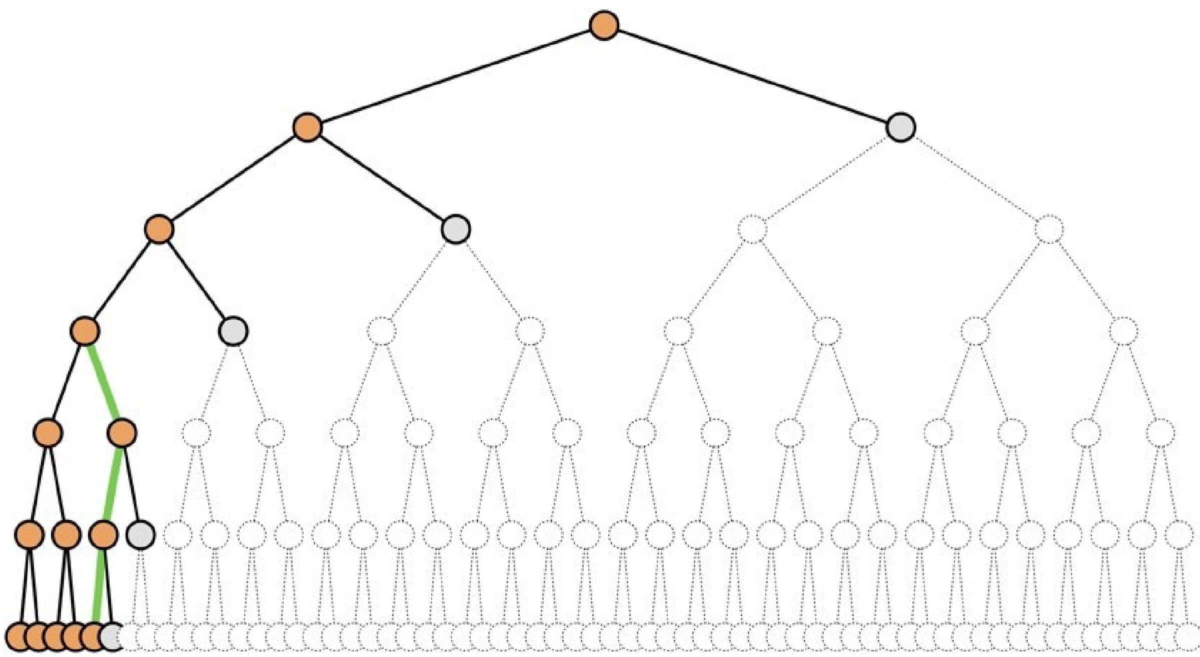

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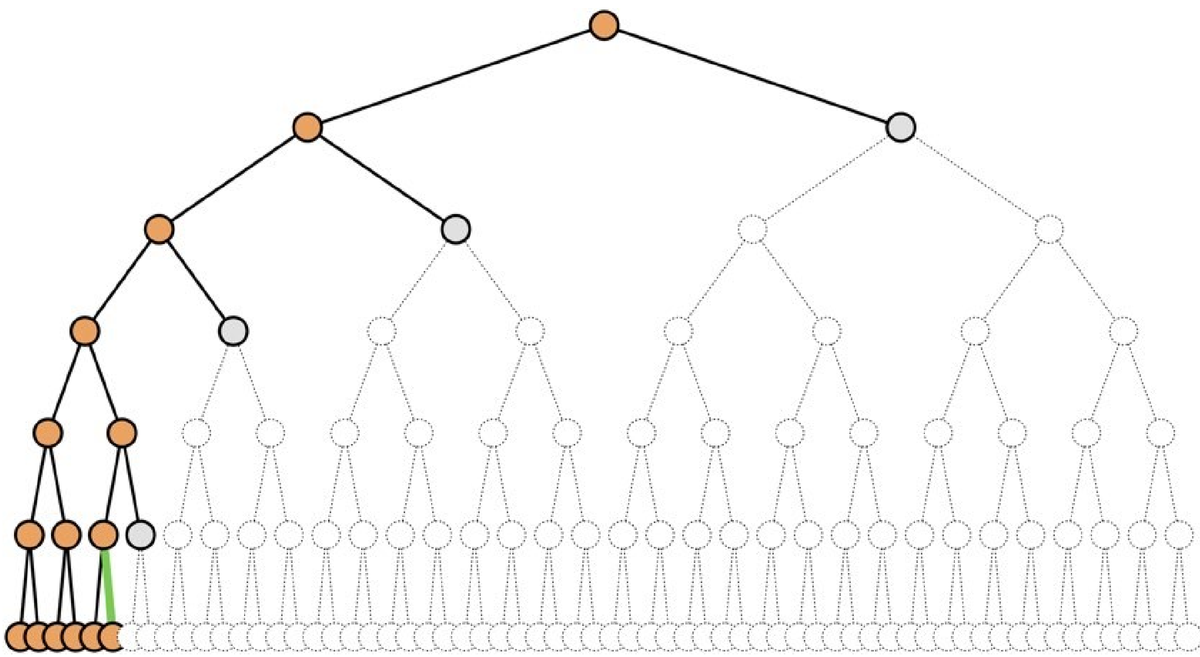

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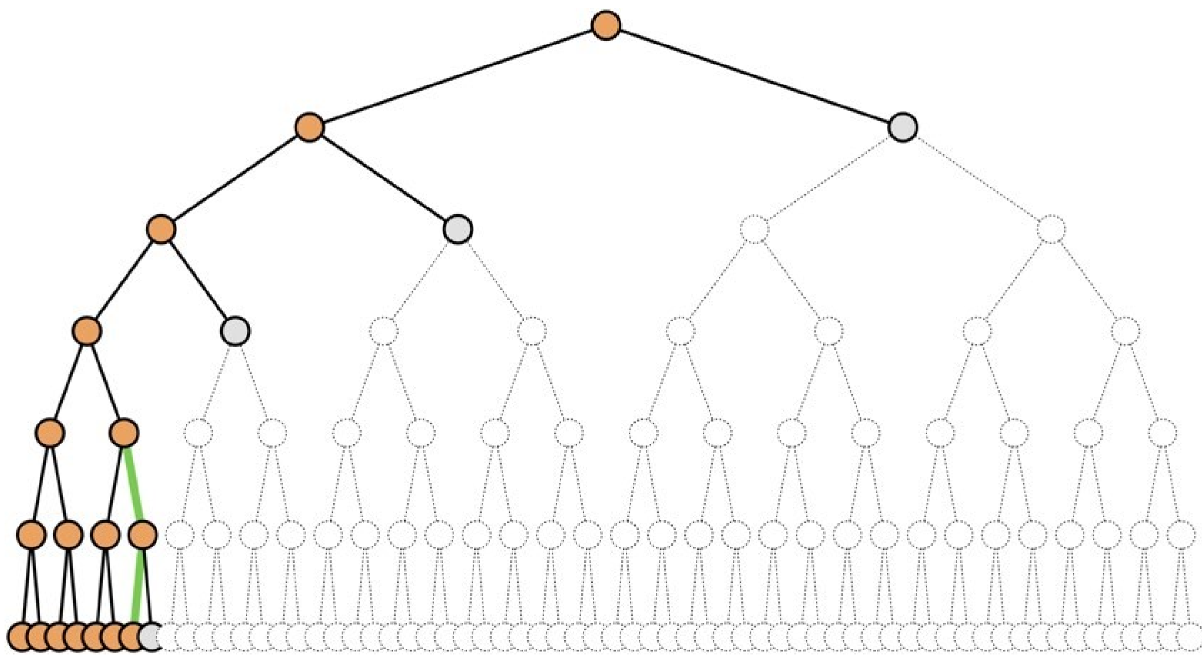

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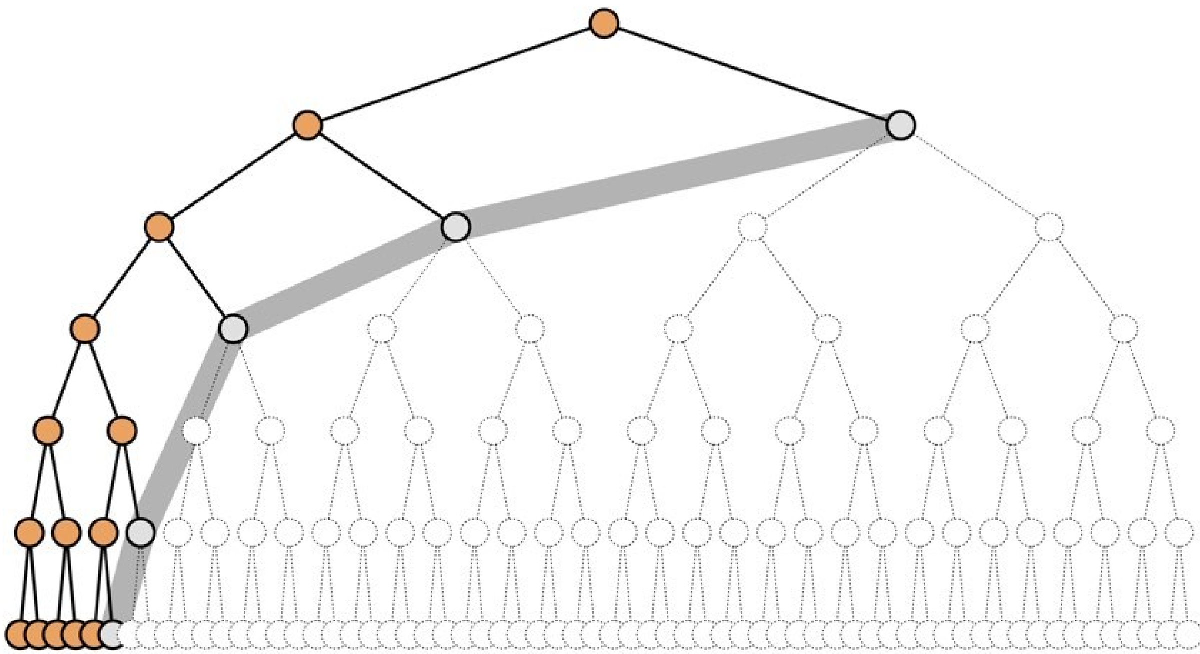
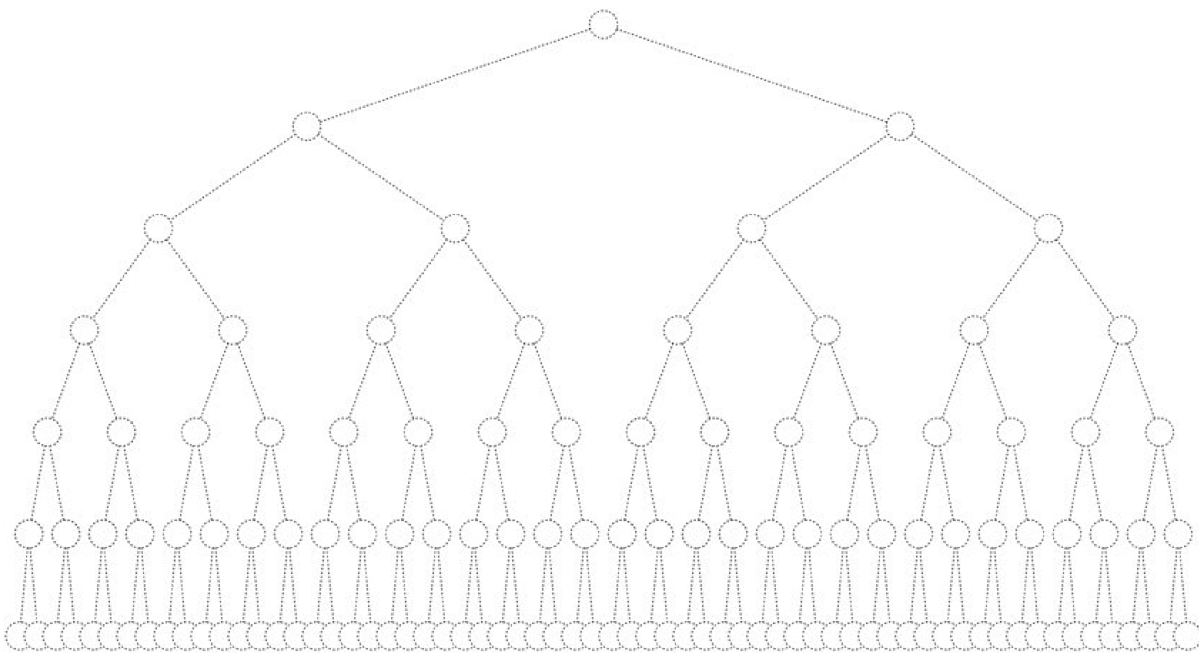


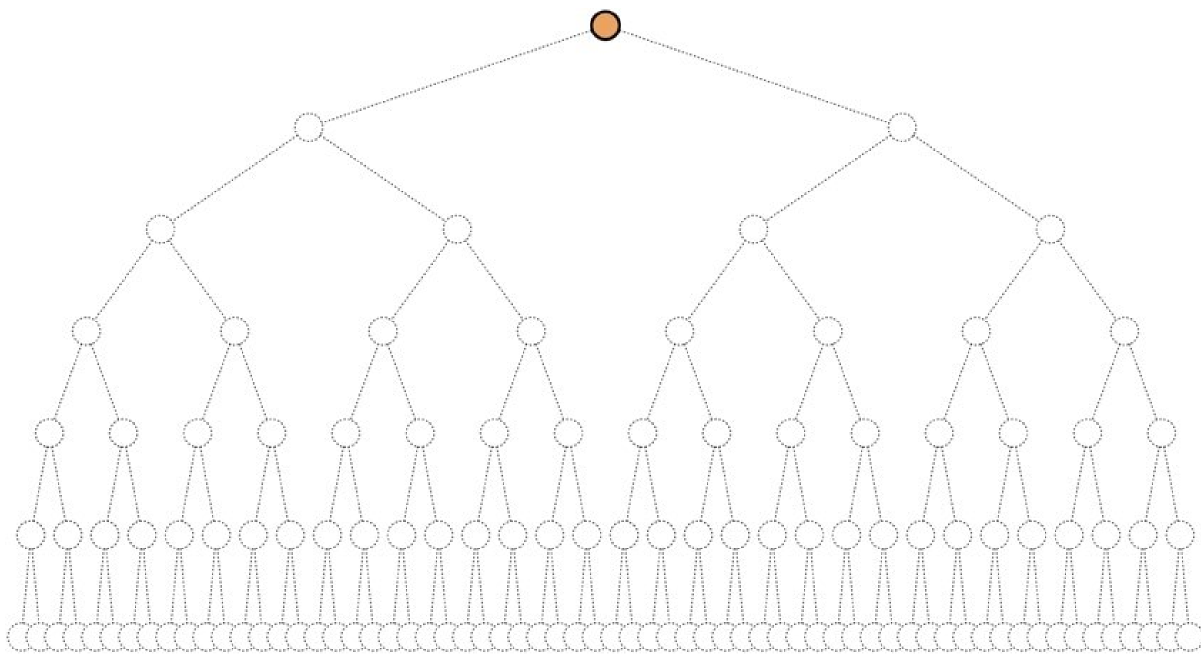
The frontier consists of unexplored siblings of all ancestors.
Search proceeds by exhausting one branch at a time.

IDS



Searches subtree by subtree ...
... with each subtree increasing by depth limit.

IDS



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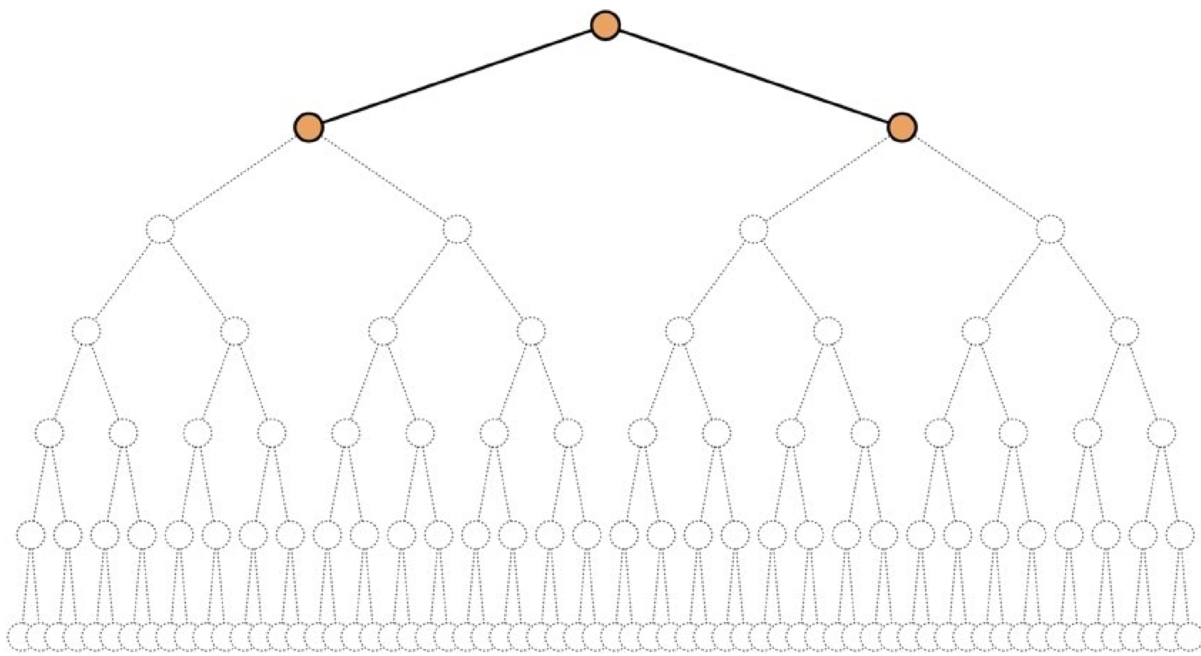

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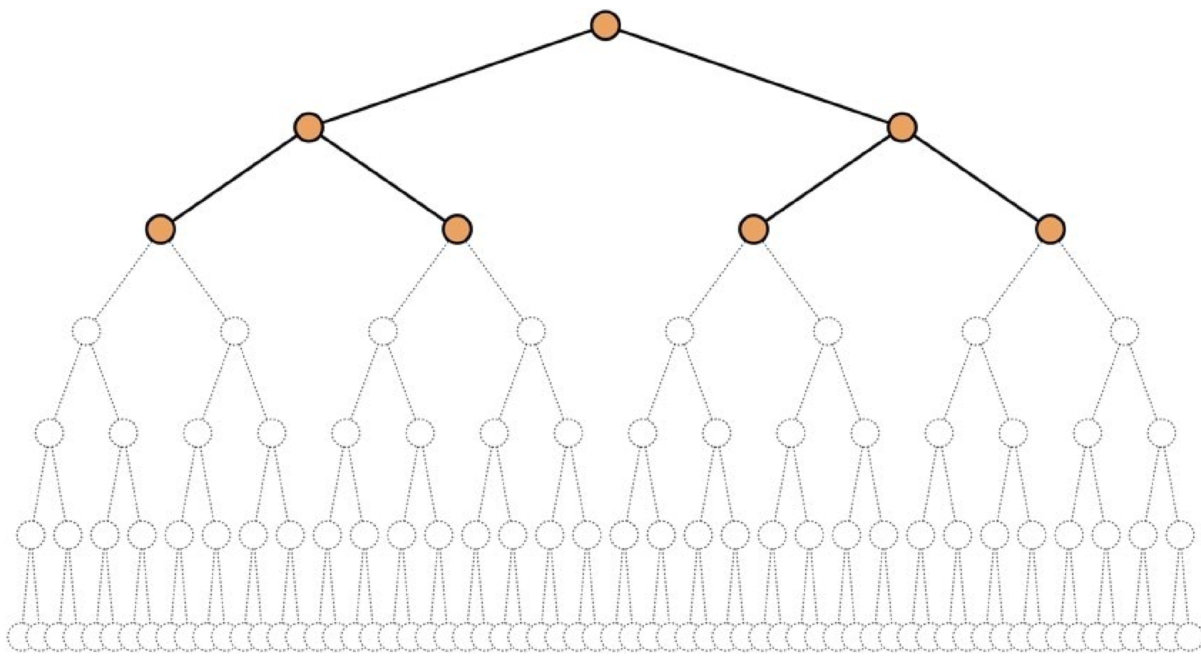

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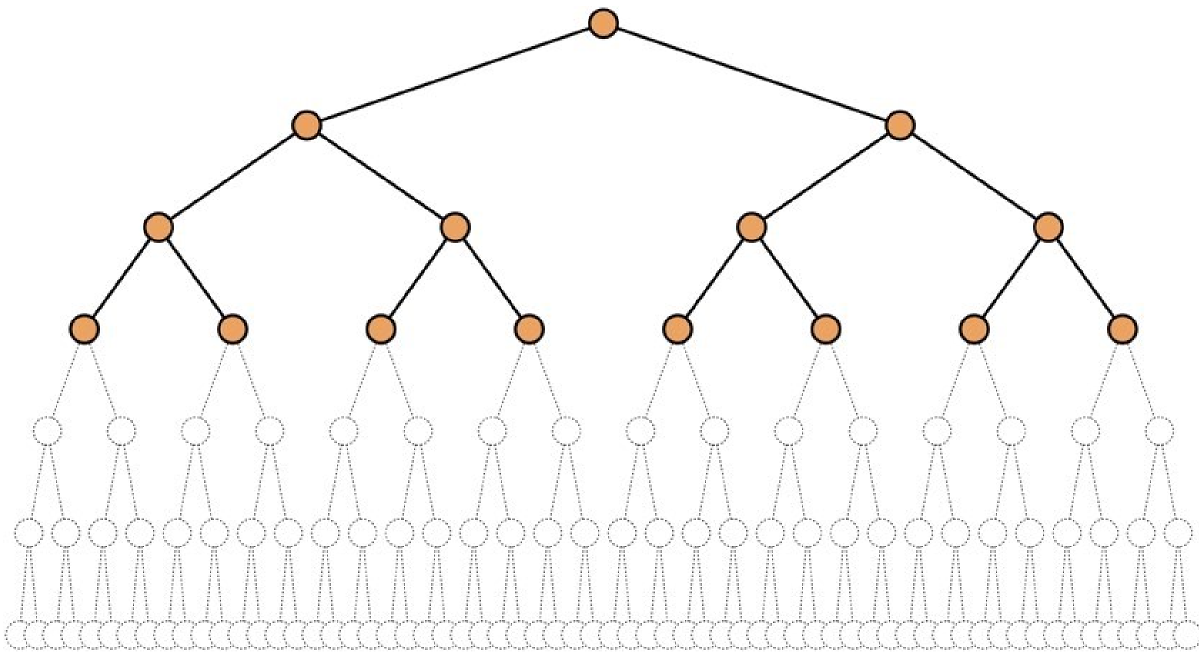

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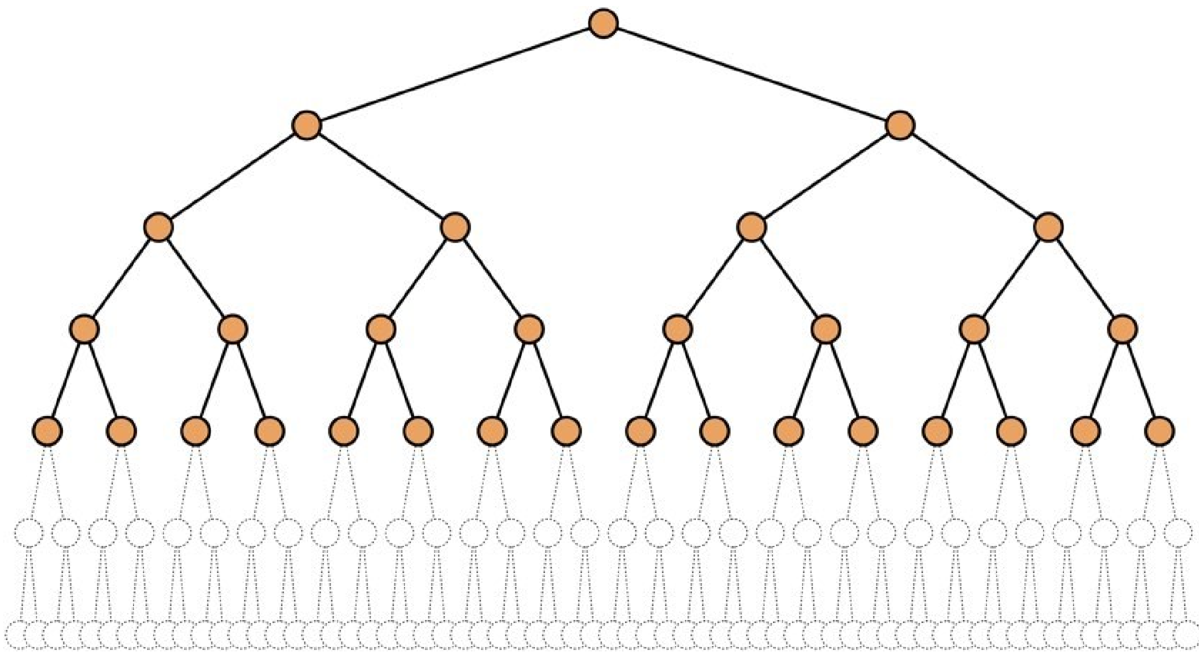

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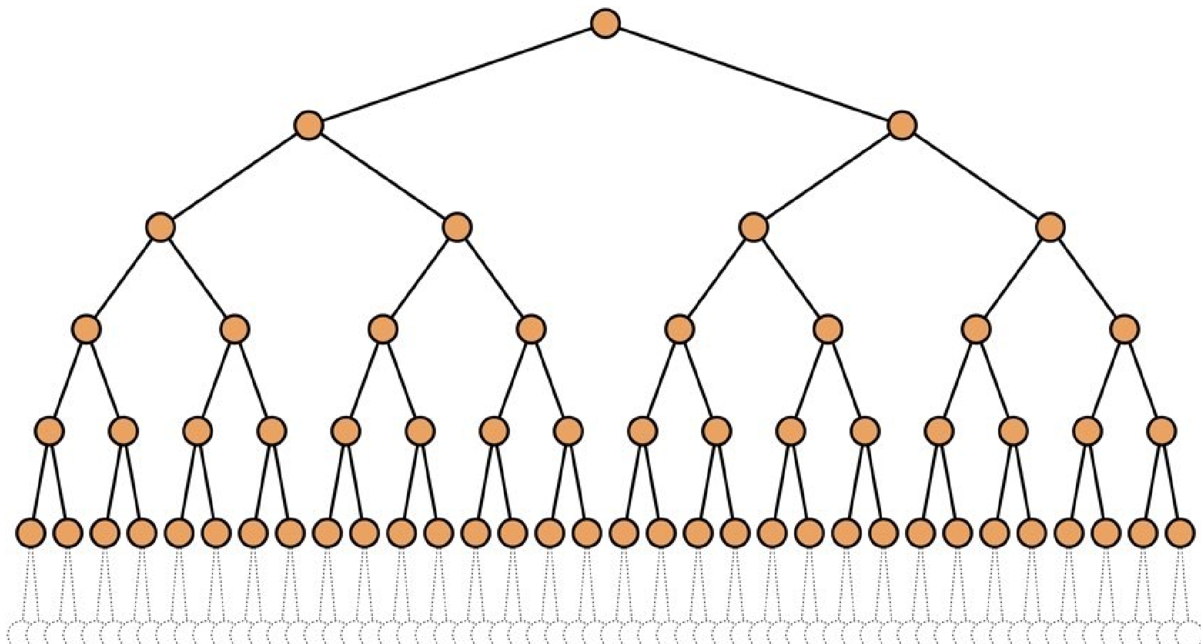

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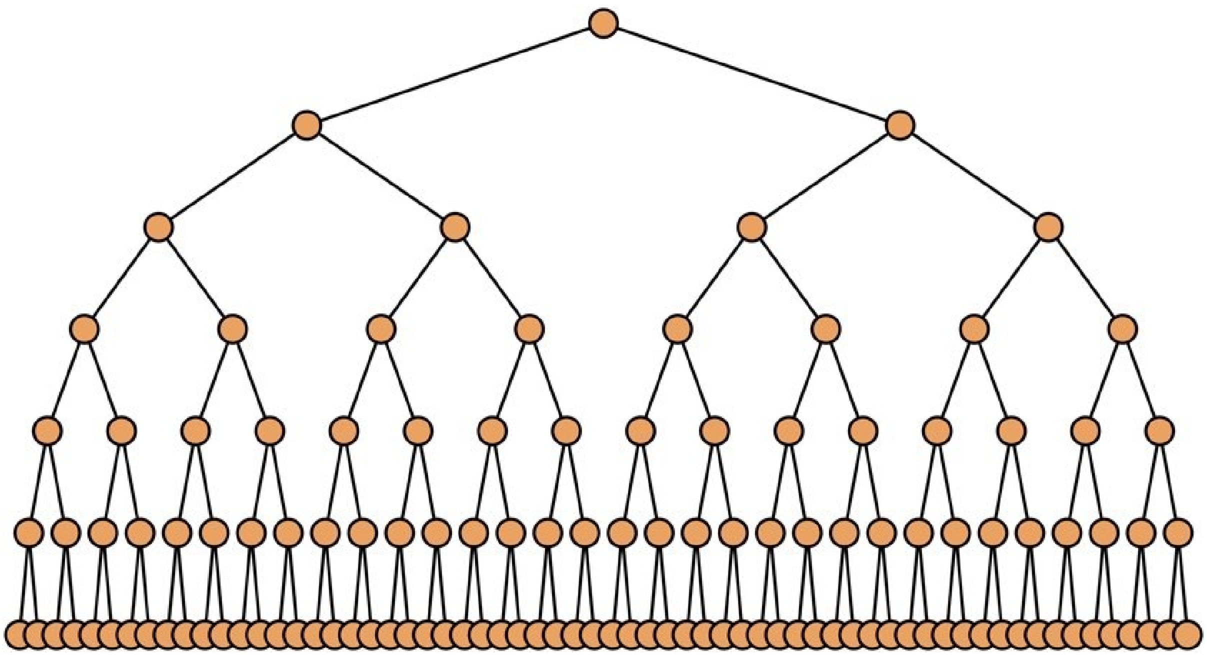

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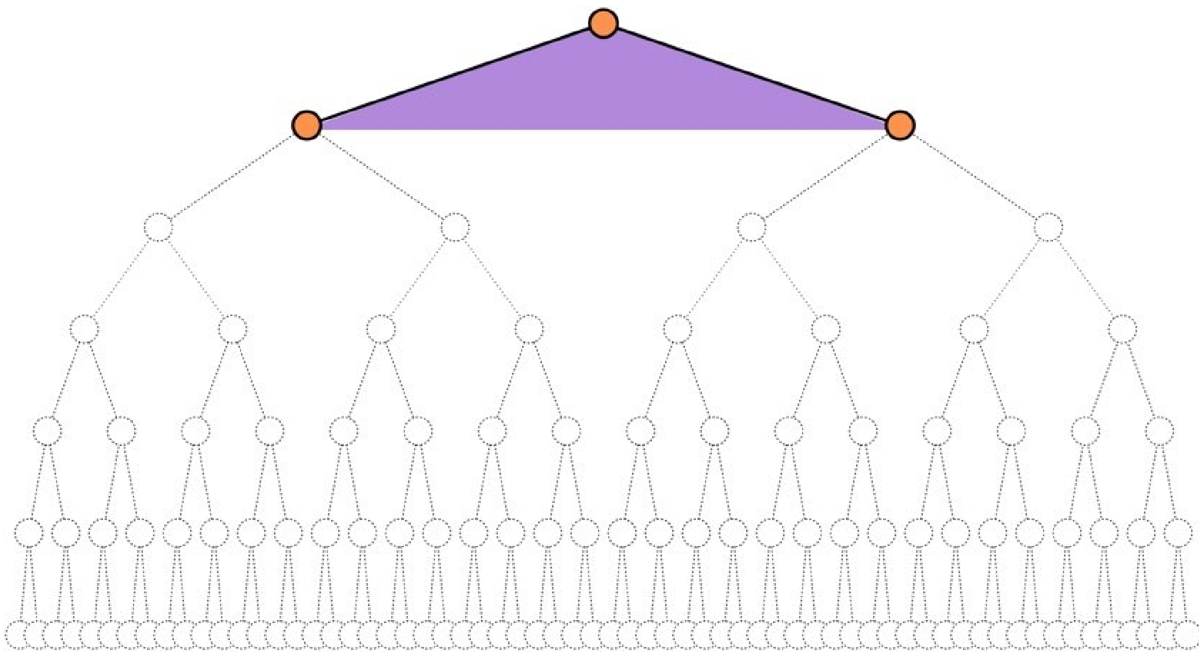

Each iteration is simply an instance of depth-limited search.
Search proceeds by exhausting larger and larger subtrees.

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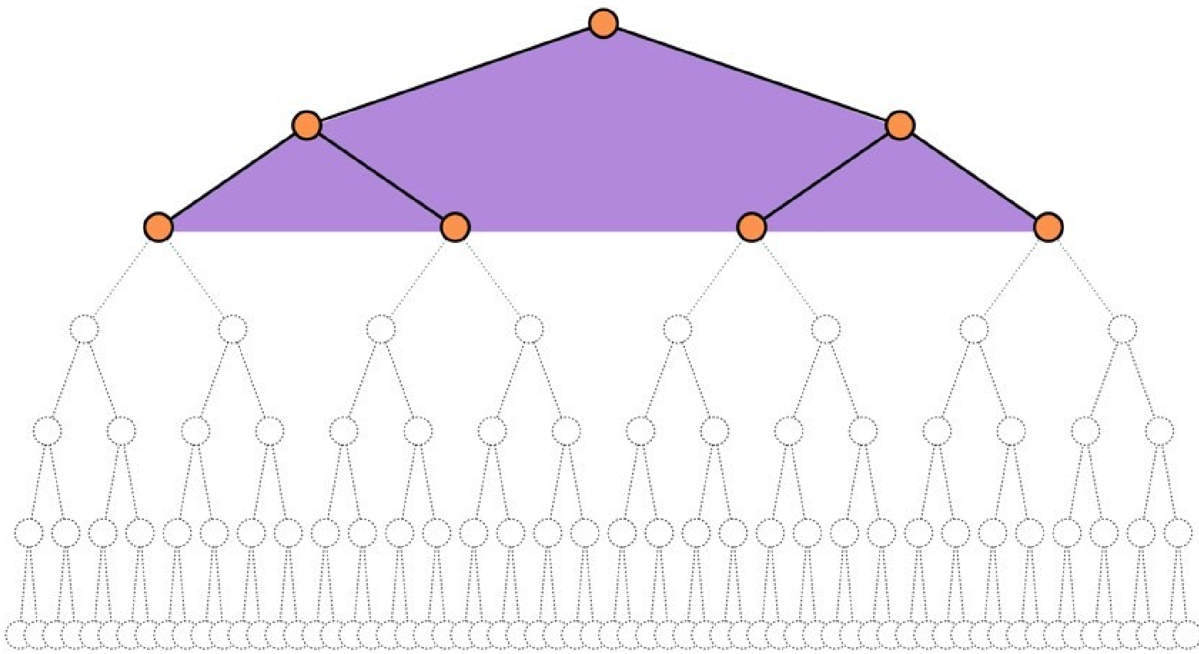

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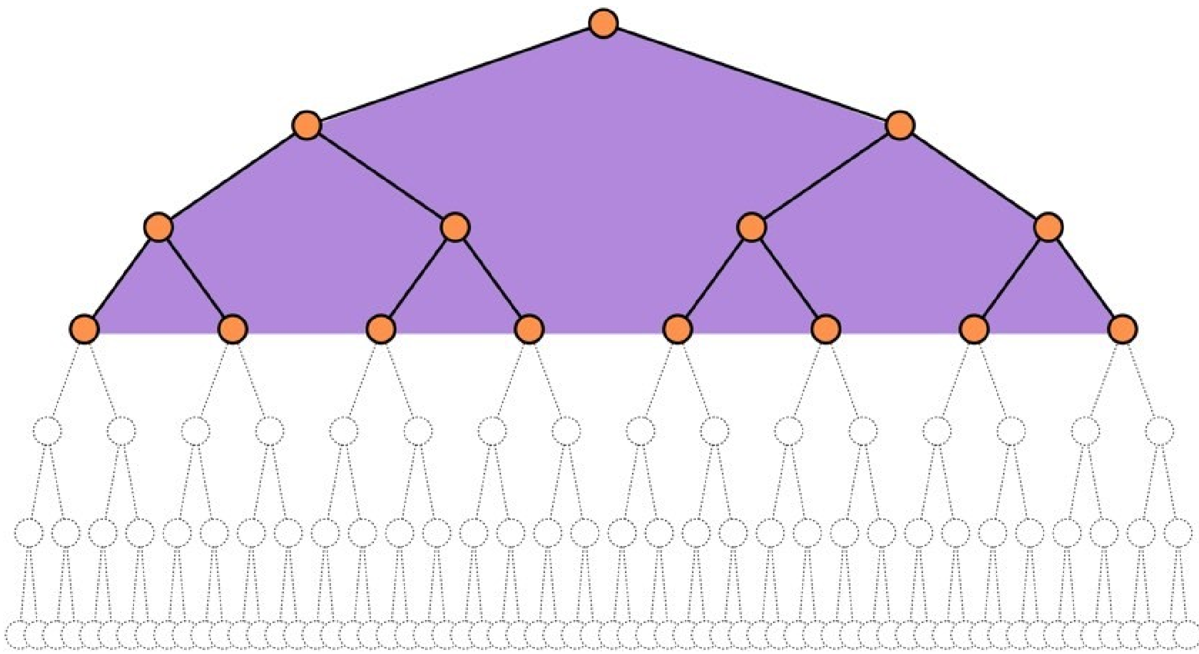

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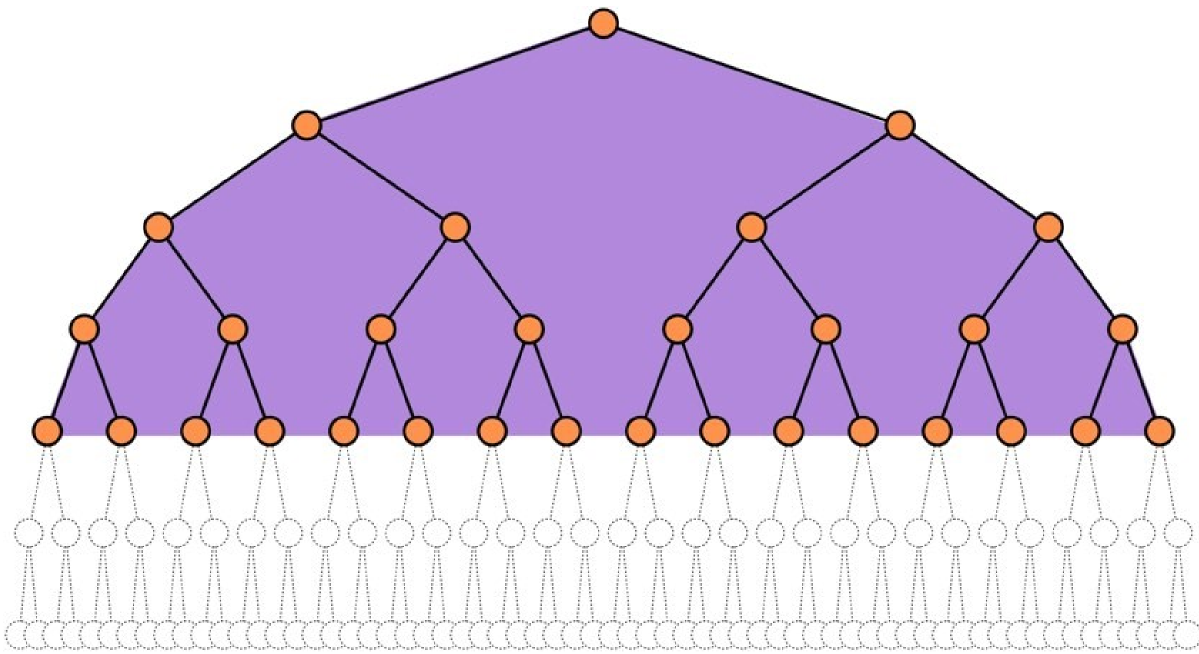

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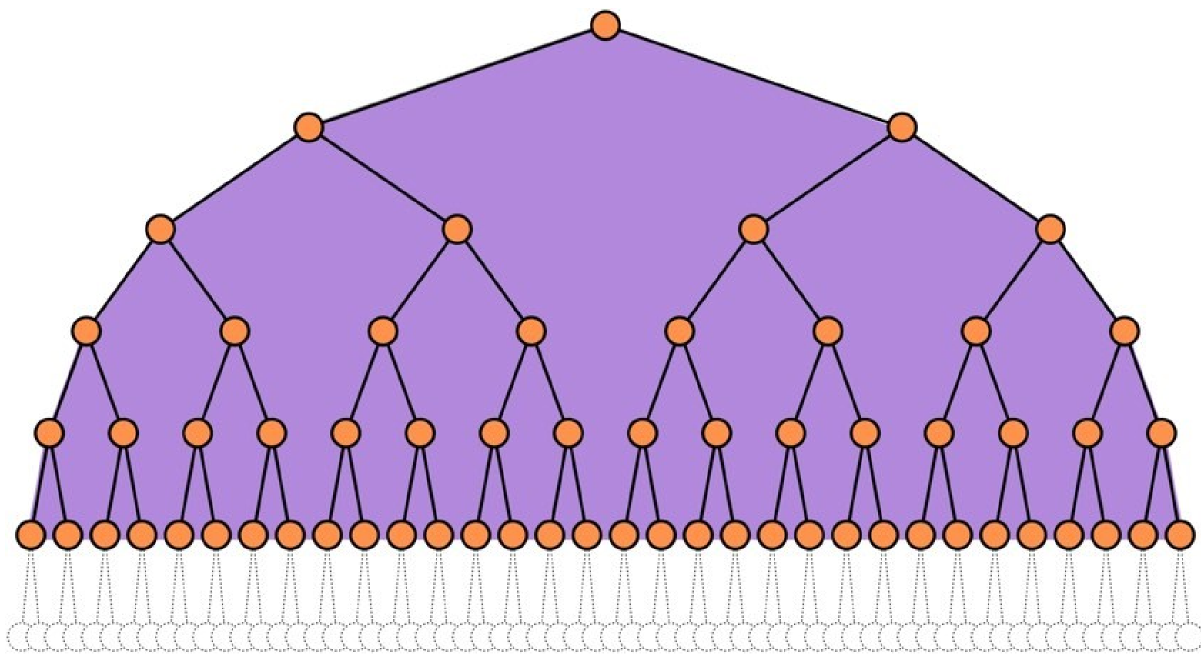

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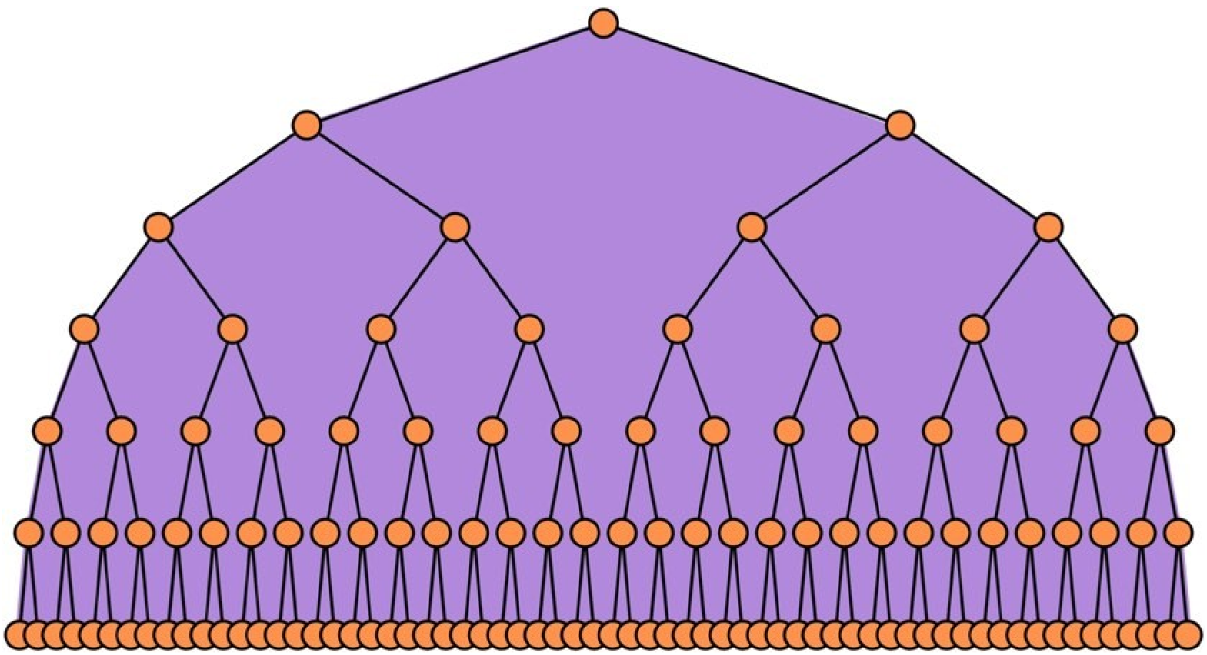

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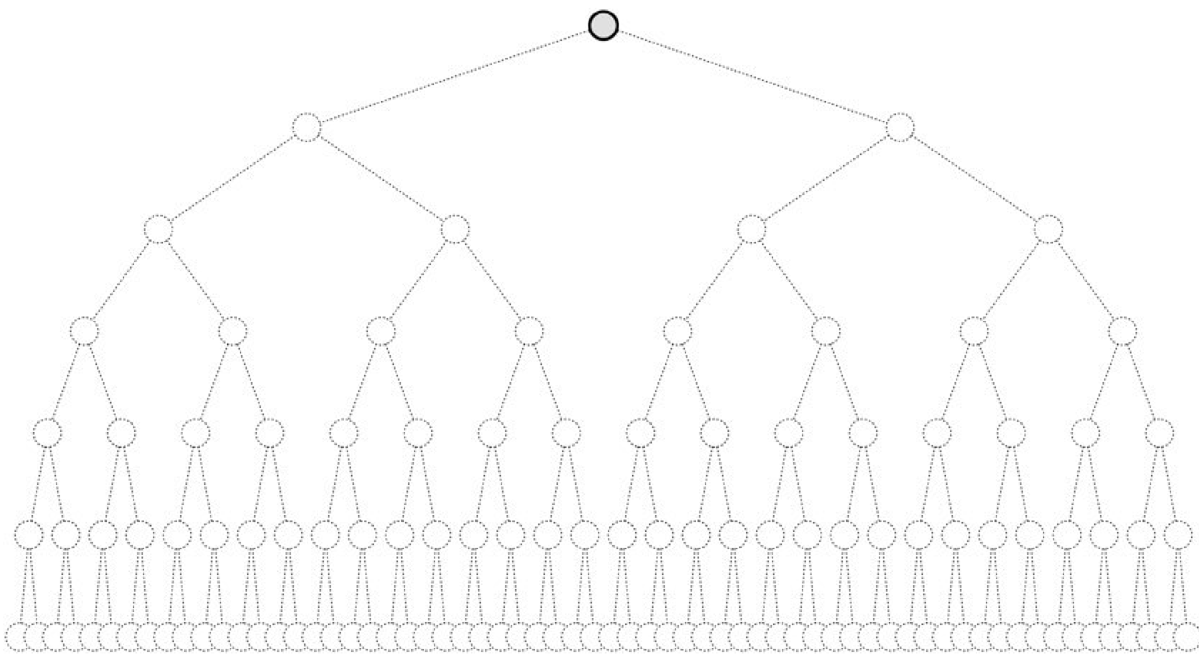
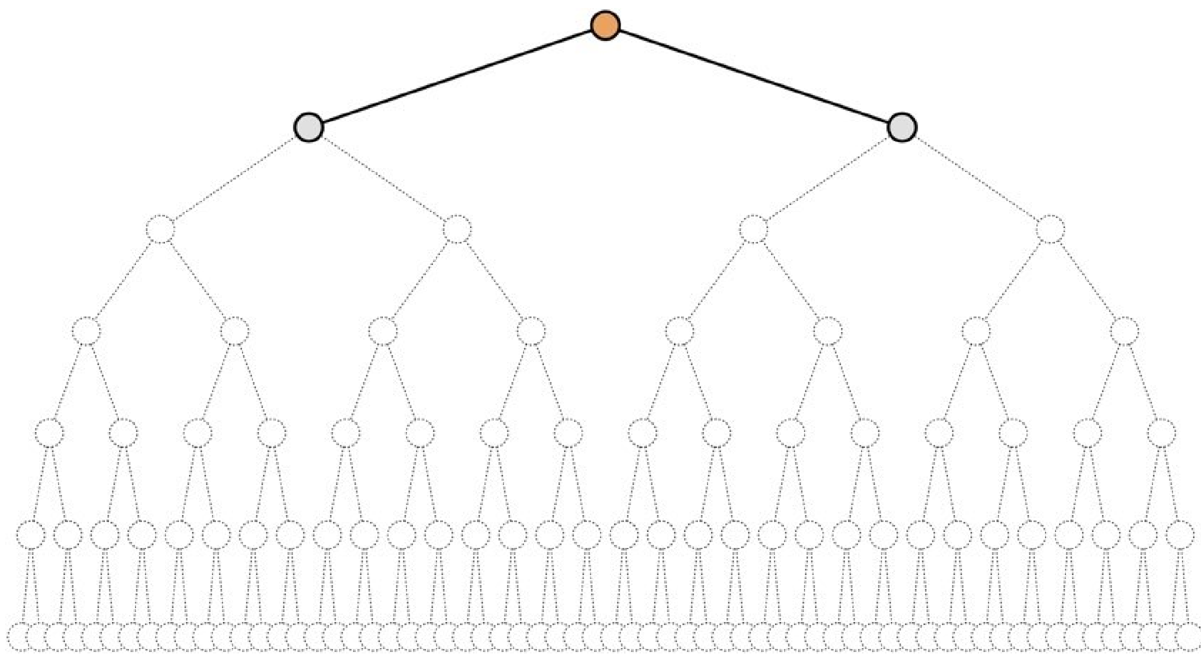
BFS



Searches layer by layer ...

... with each layer organized by node depth.

BFS



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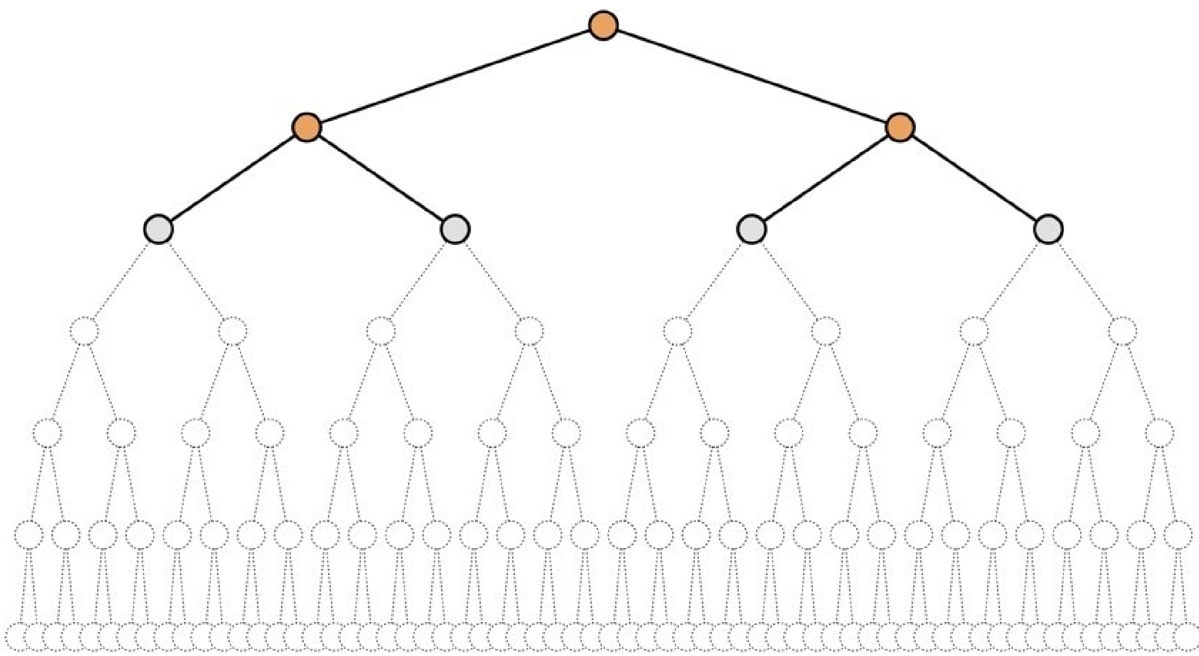

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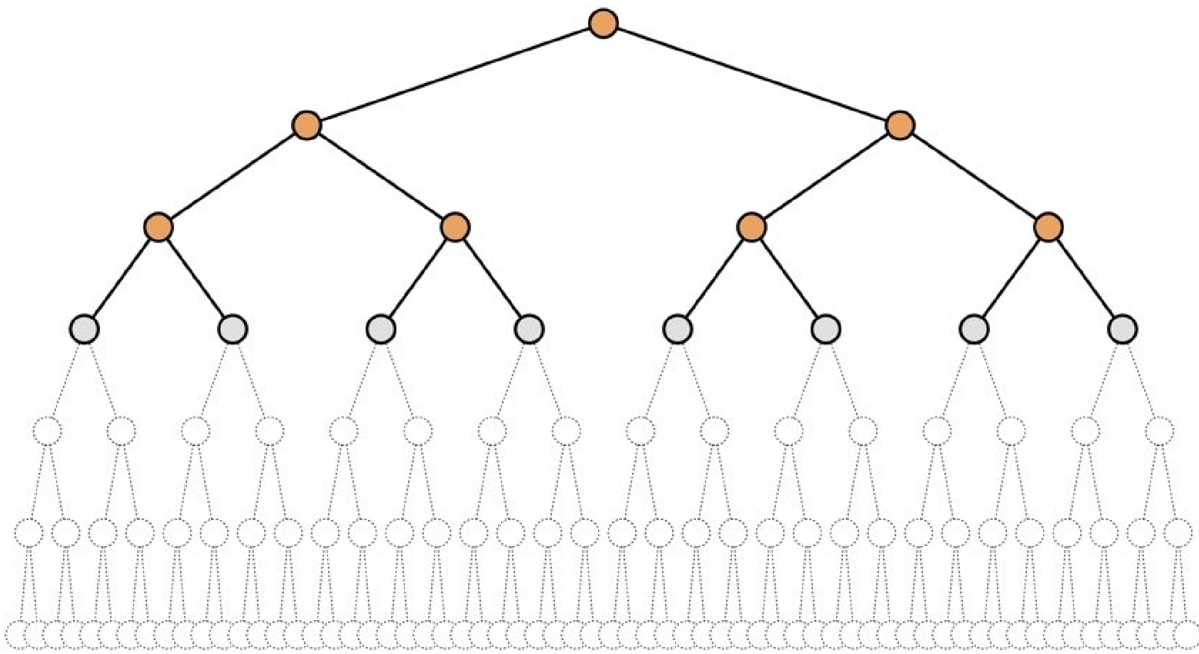

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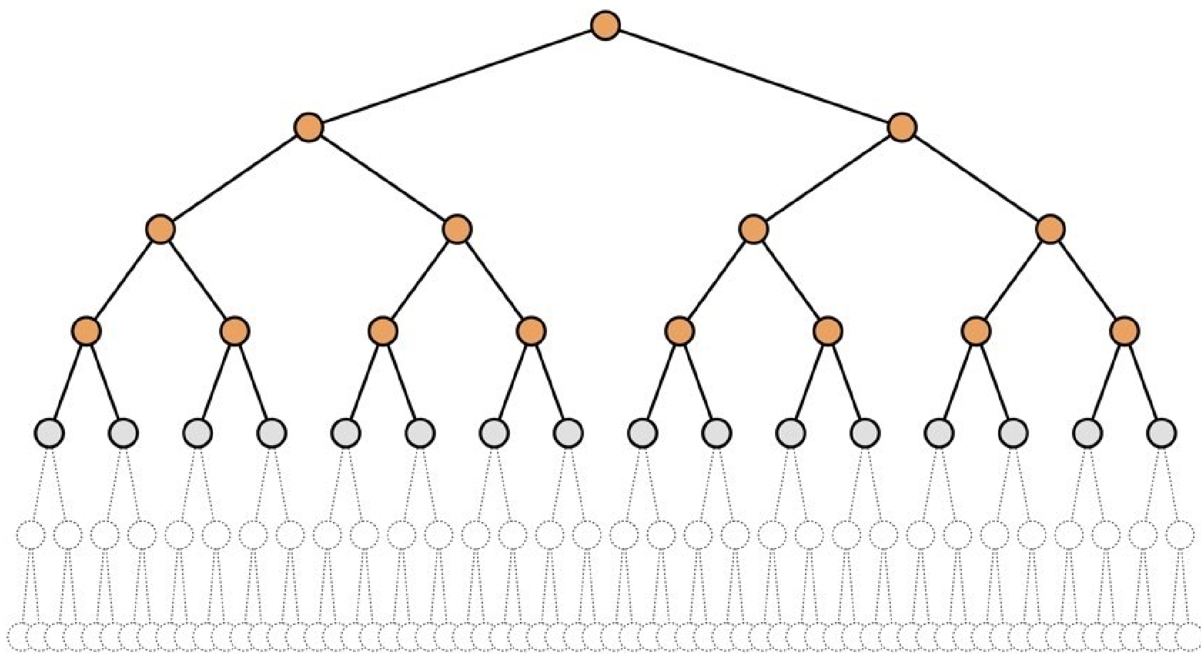

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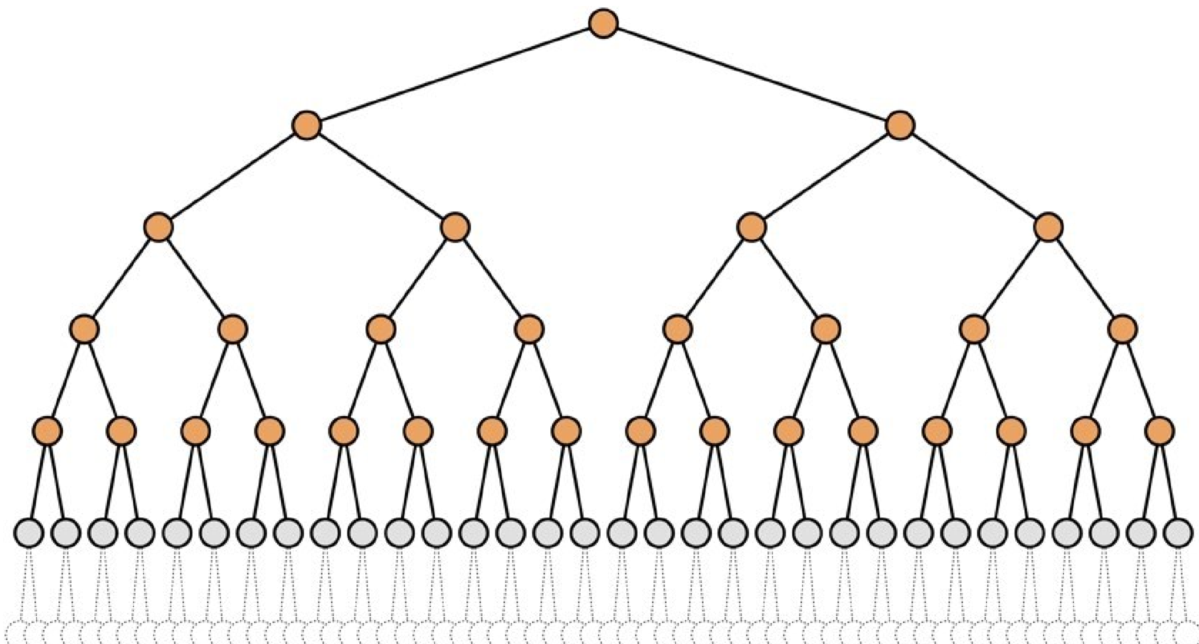

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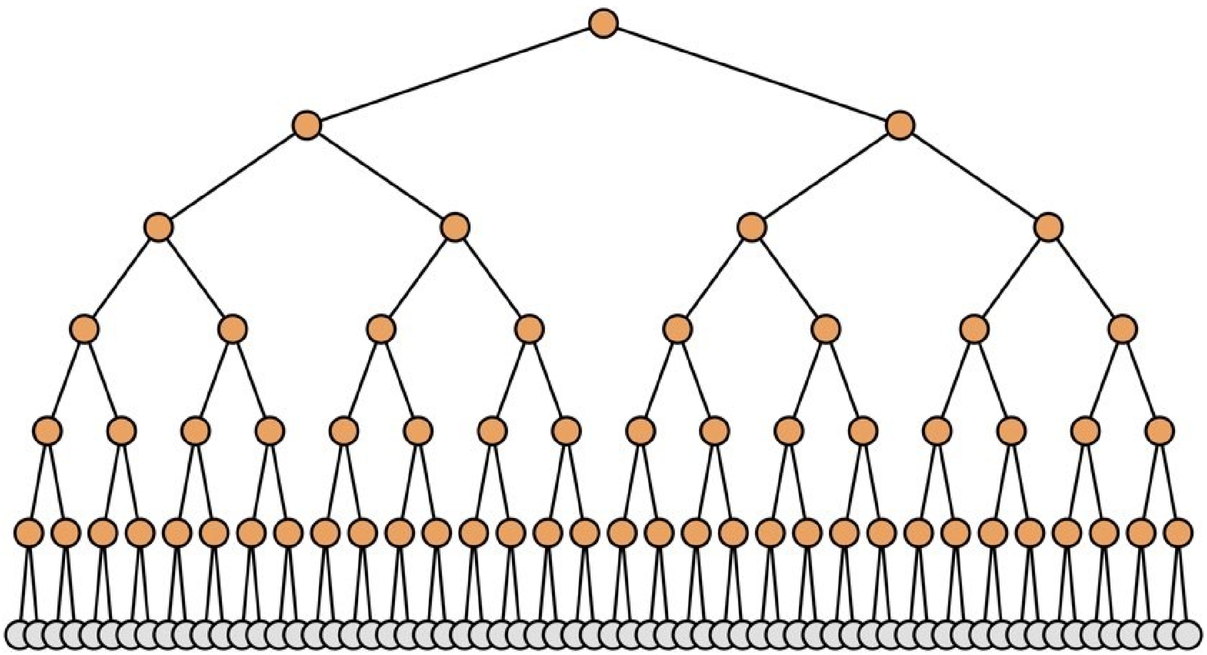

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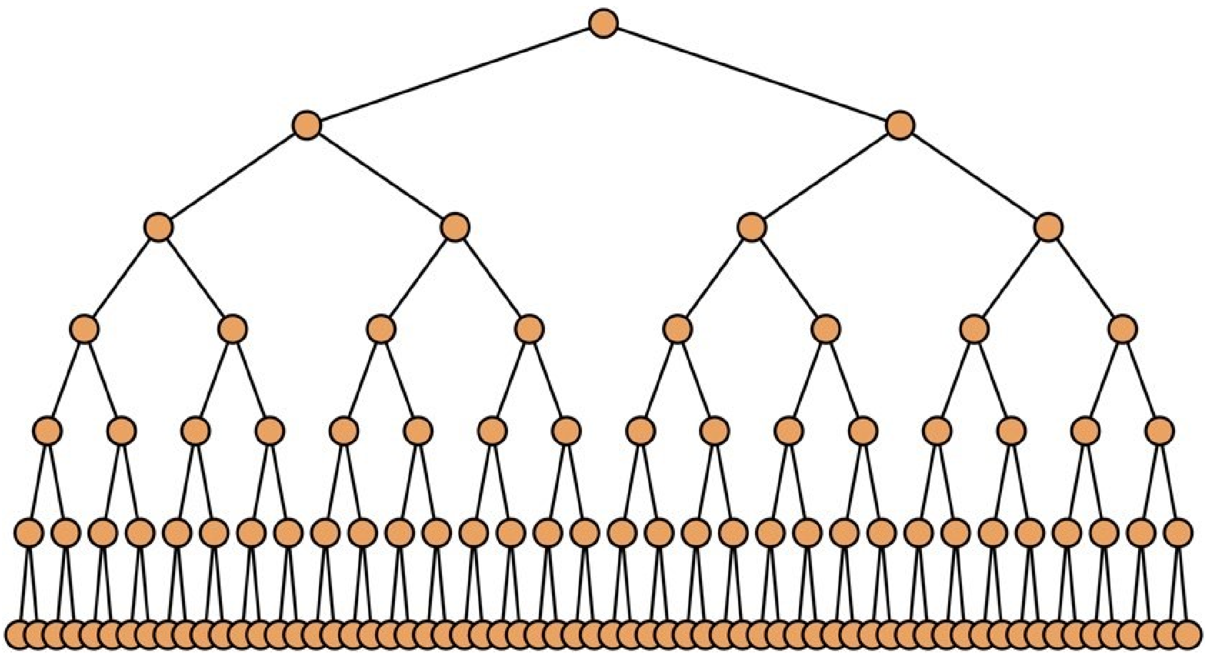

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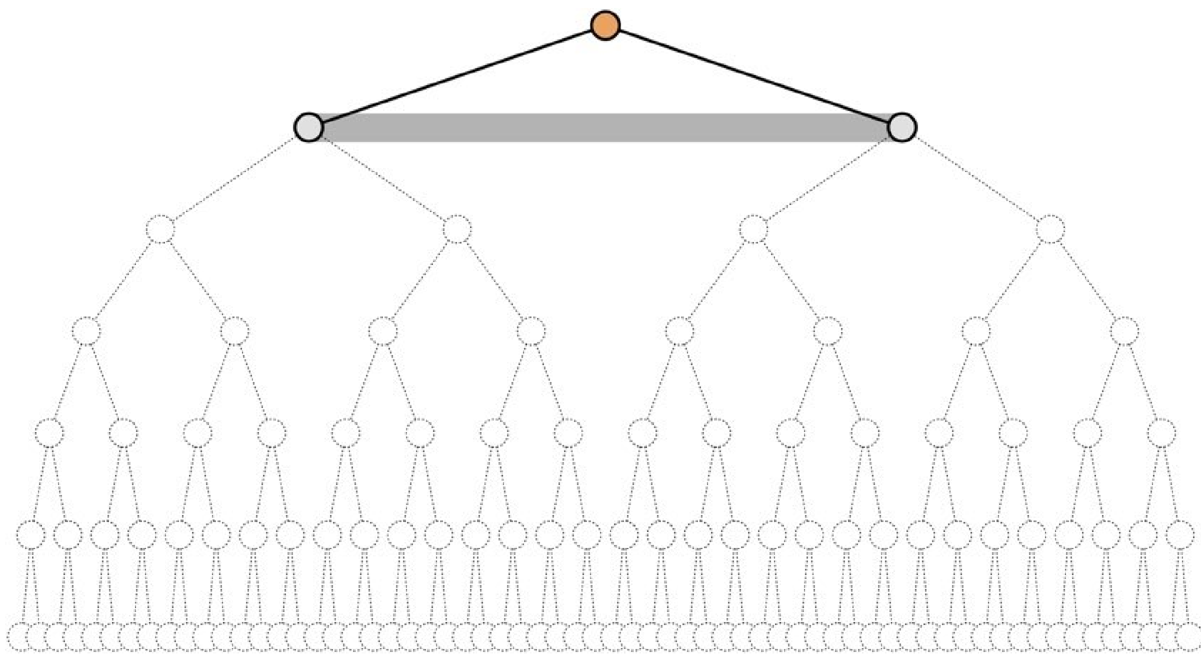

The frontier consists of nodes of similar depth (horizontal).
Search proceeds by exhausting one layer at a time.

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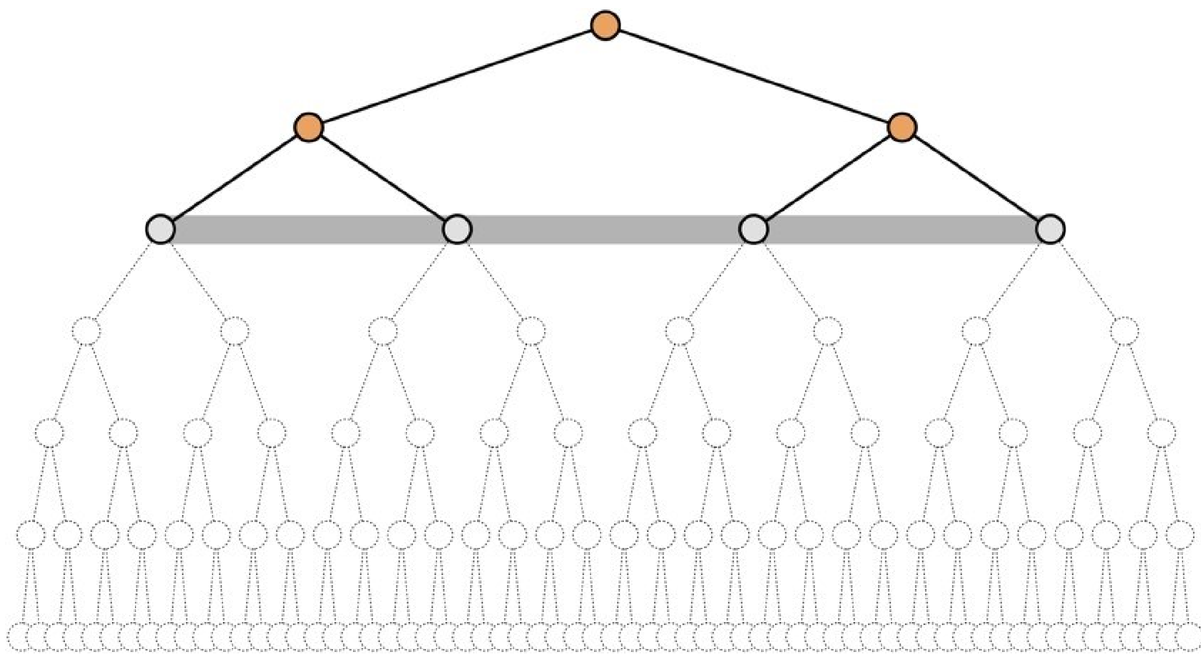

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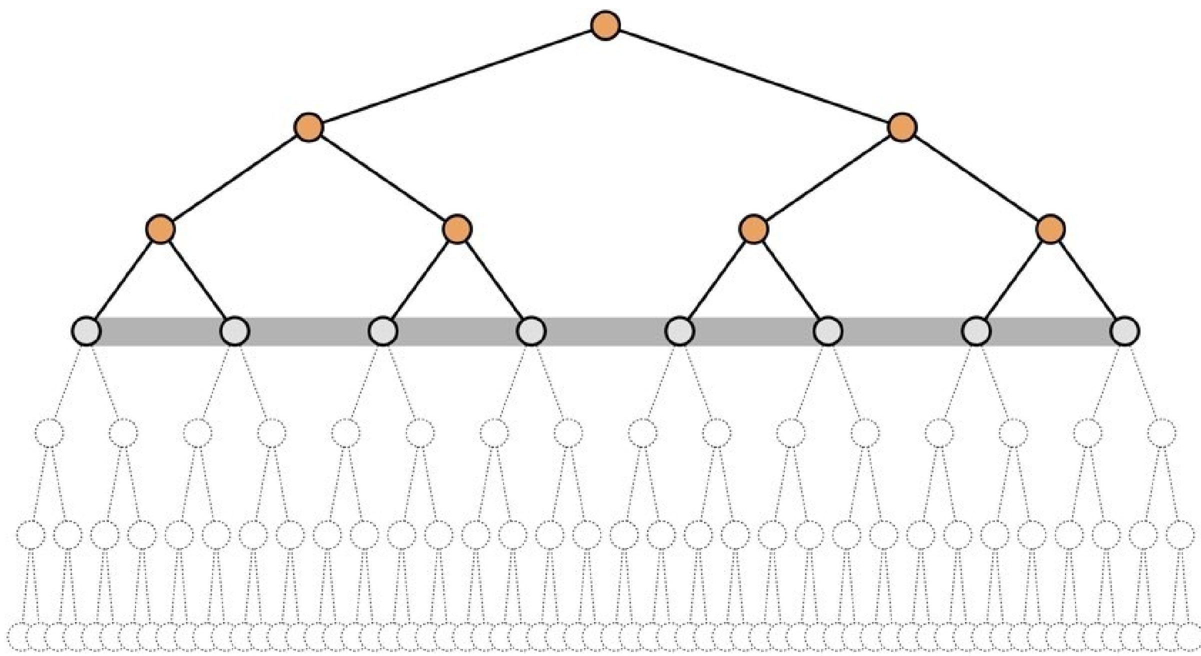

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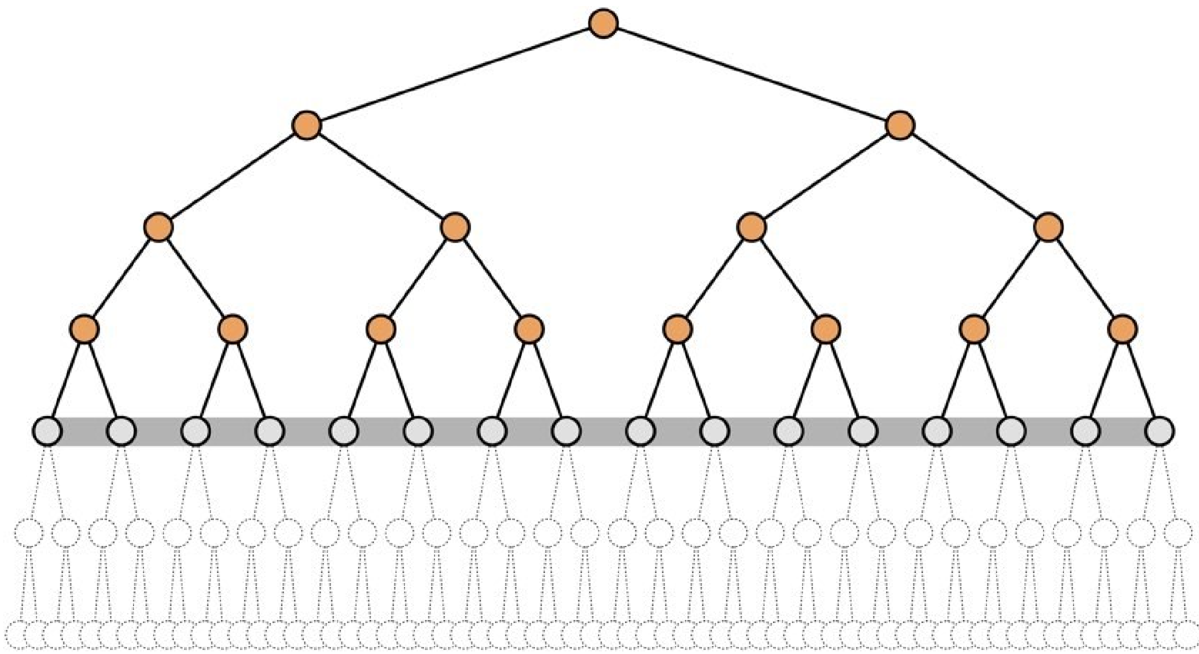
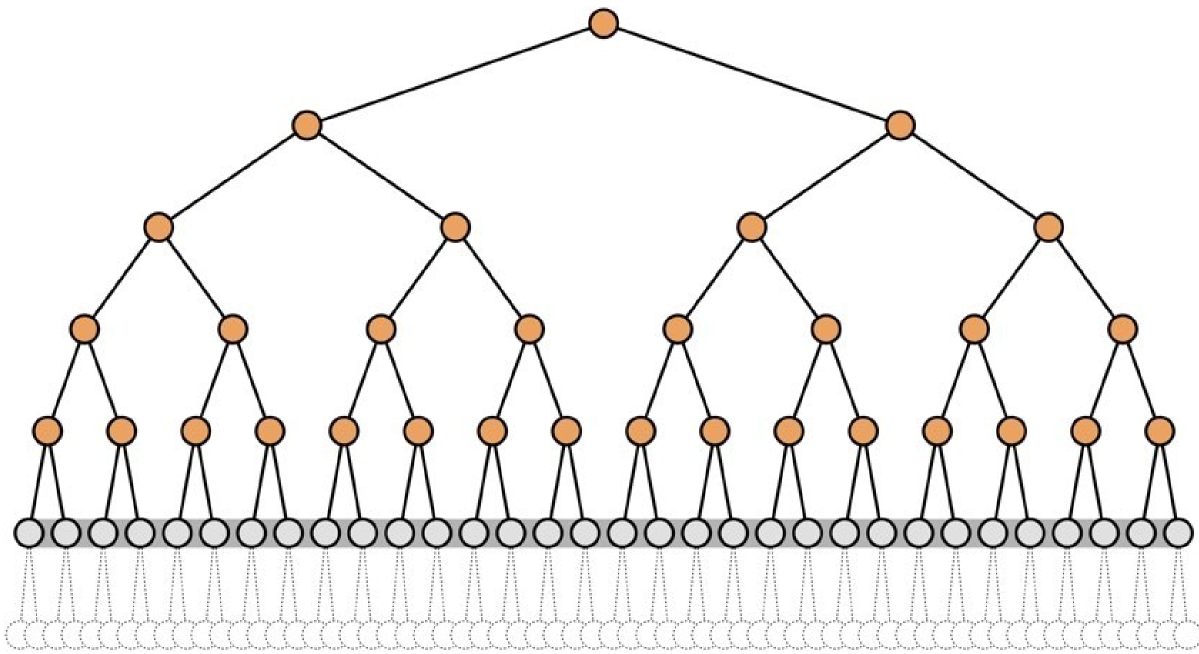


The frontier consists of nodes of similar depth (horizontal).
Search proceeds by exhausting one layer at a time.

BFS



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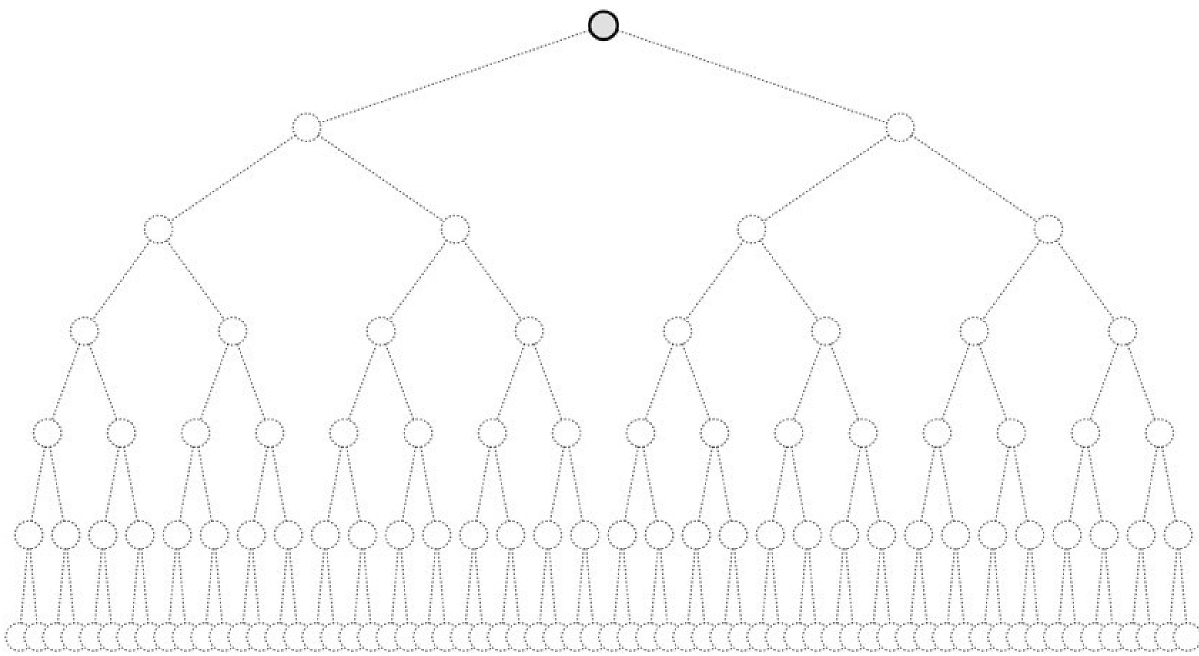
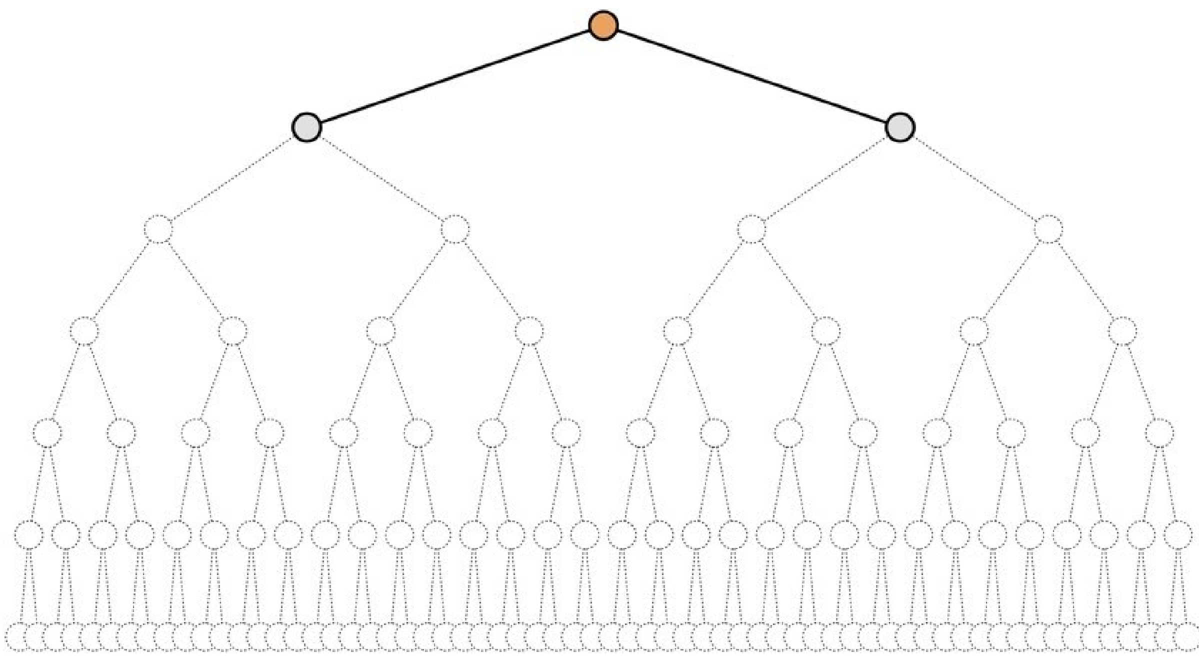
UCS



Searches layer by layer ...
... with each layer organized by path cost.

UCS



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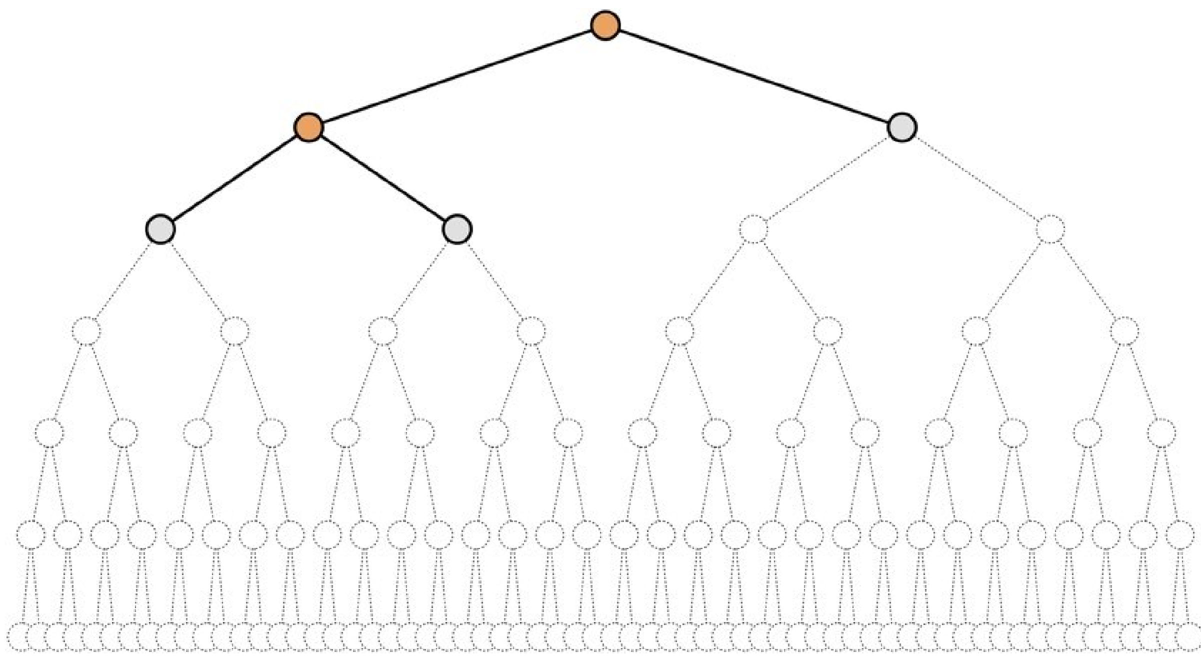

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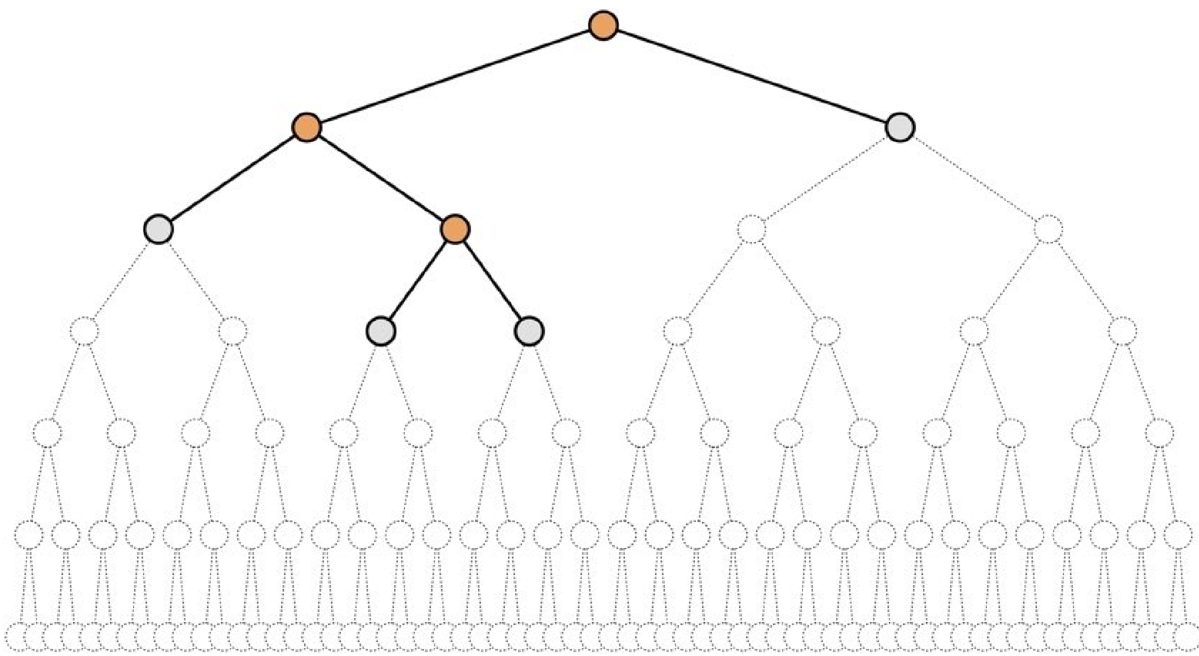

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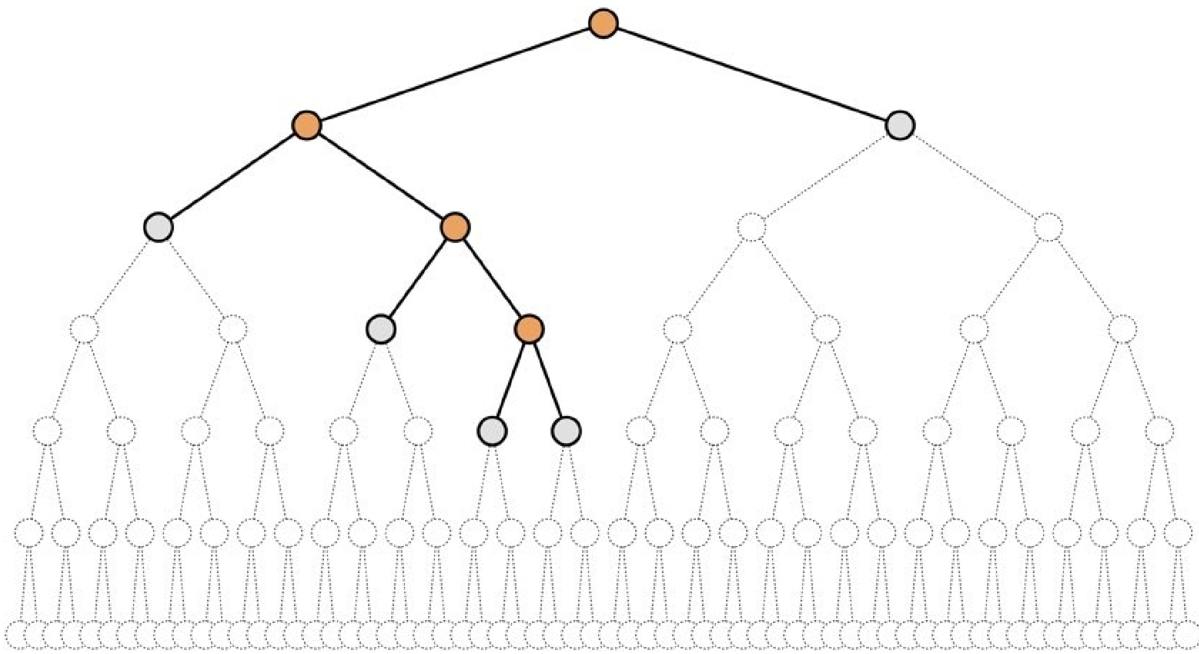

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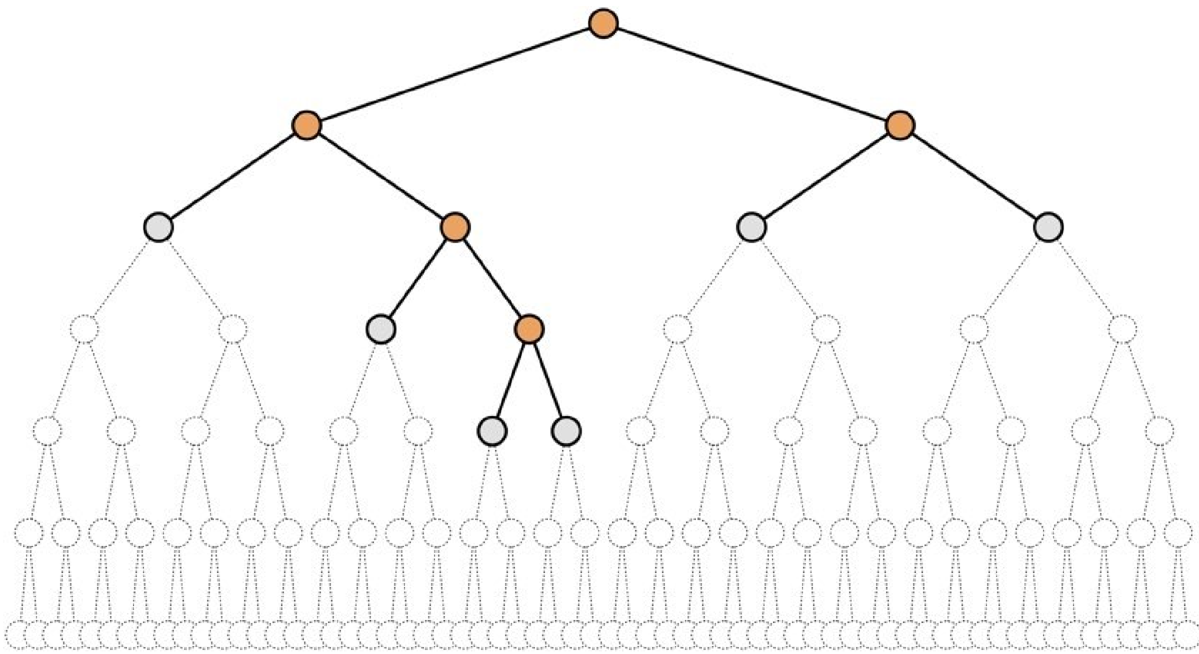

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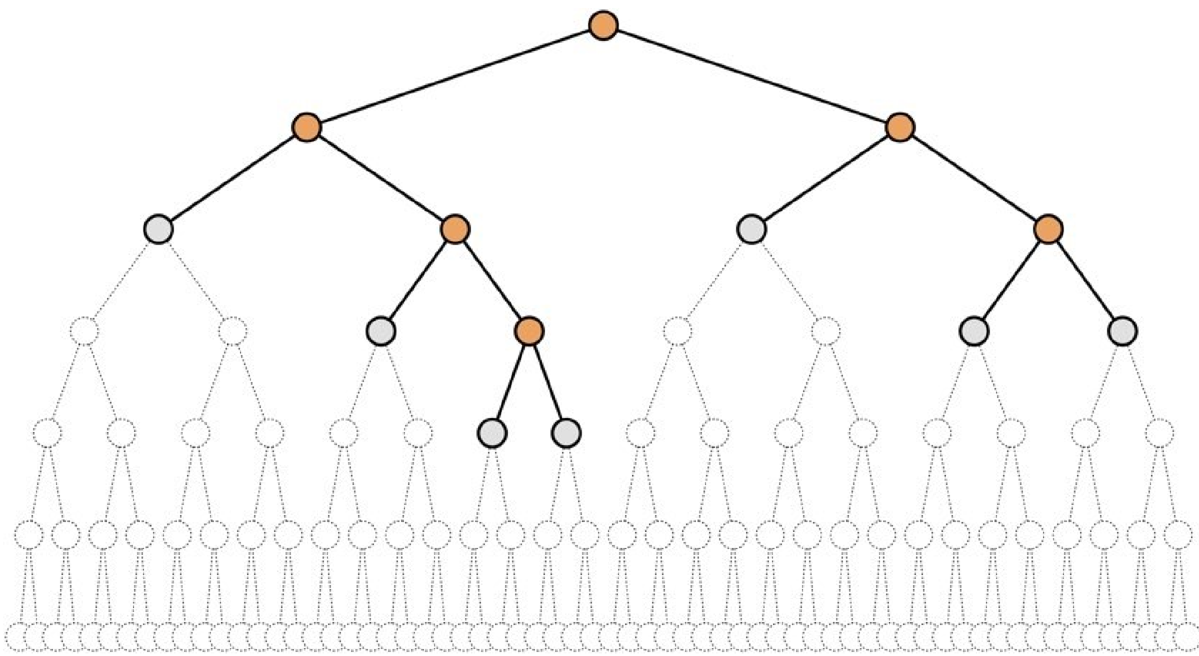

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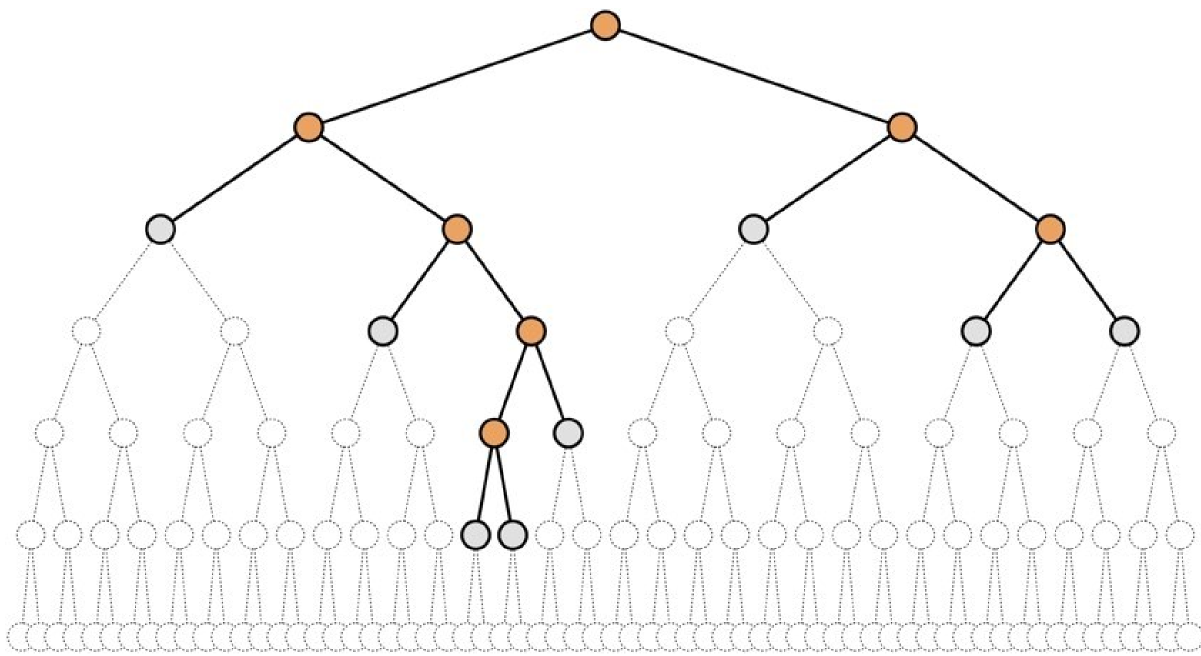

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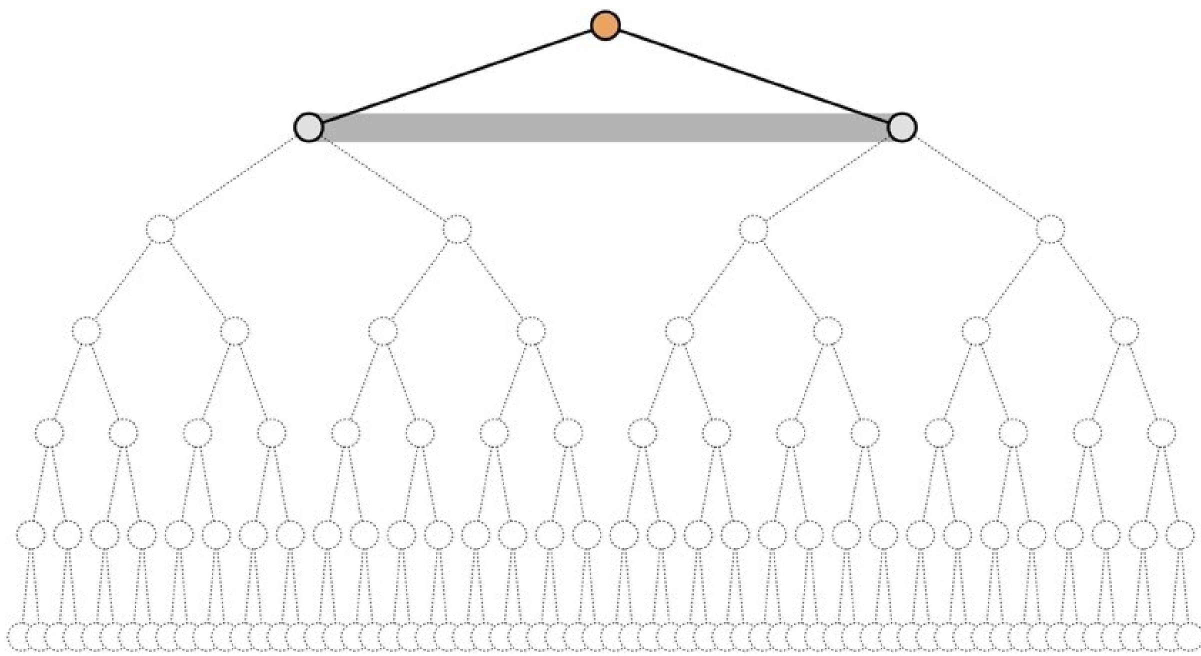
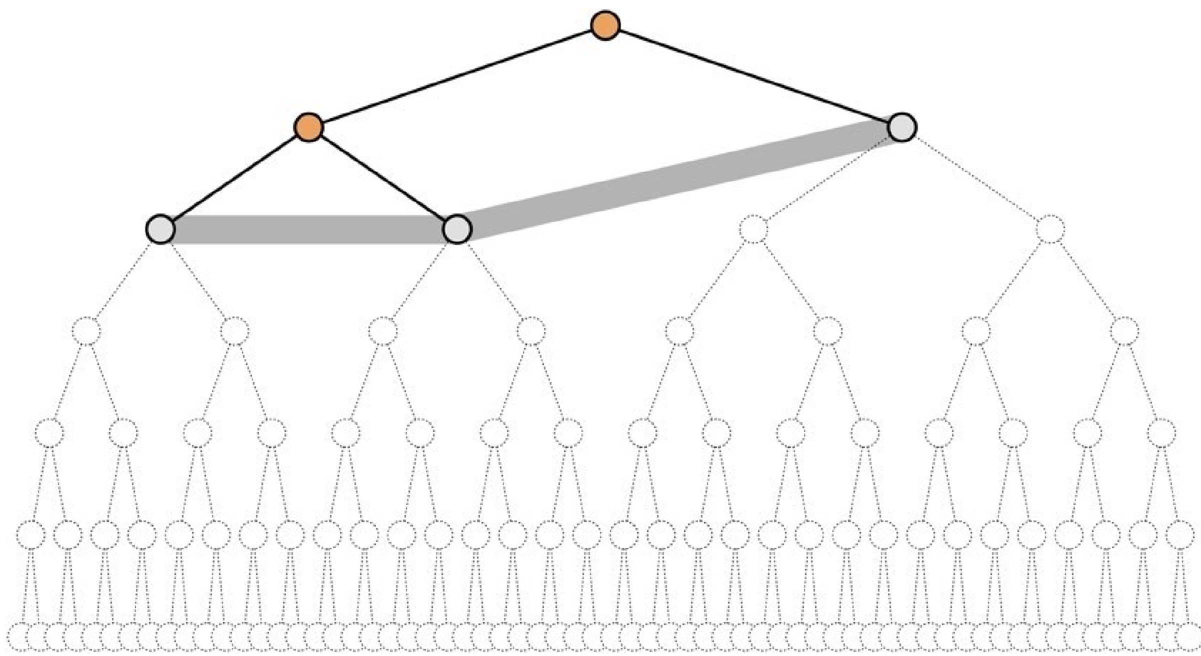


The frontier consists of nodes of various depths (jagged).
Search proceeds by expanding the lowest-cost nodes.

UCS



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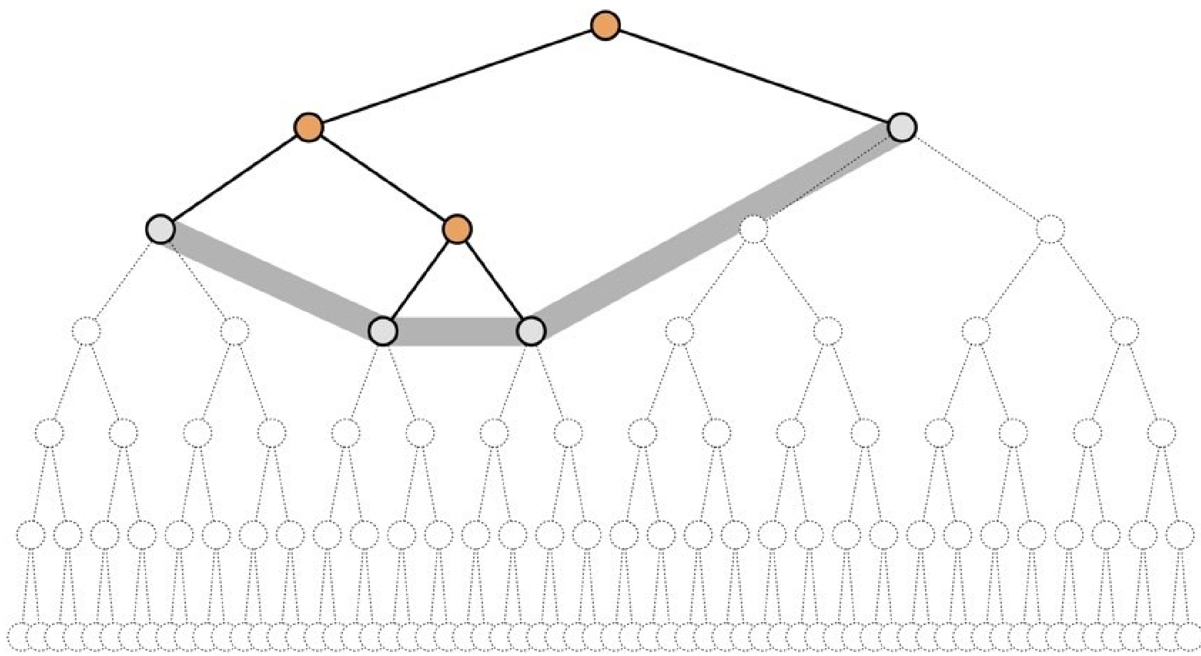

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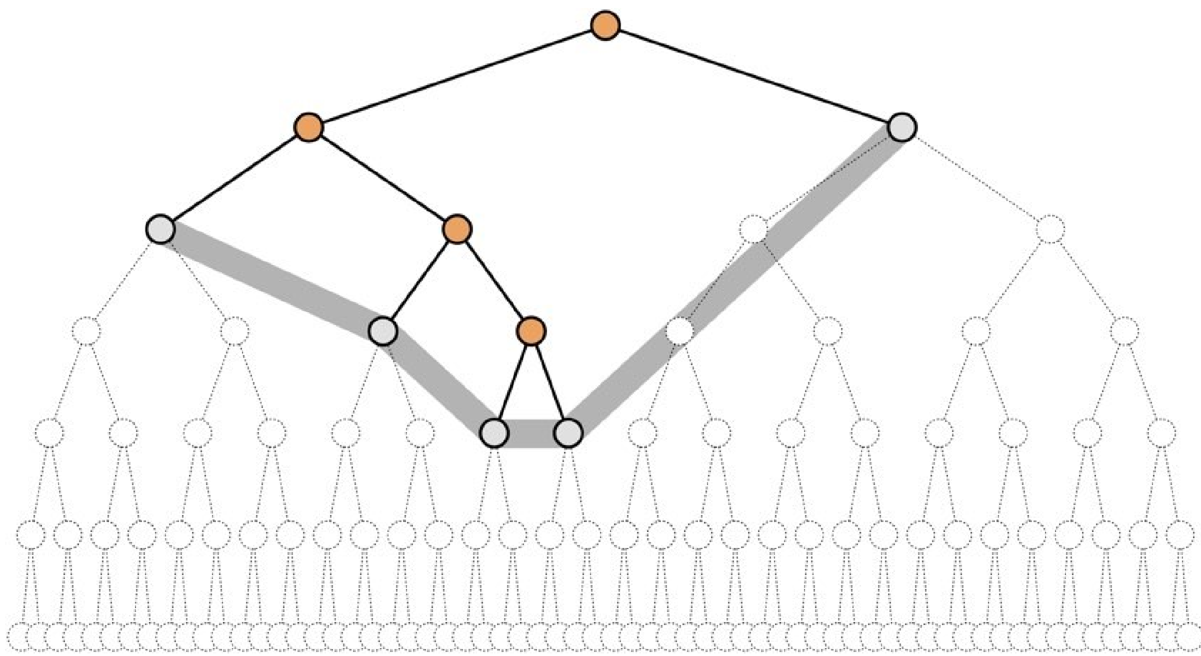

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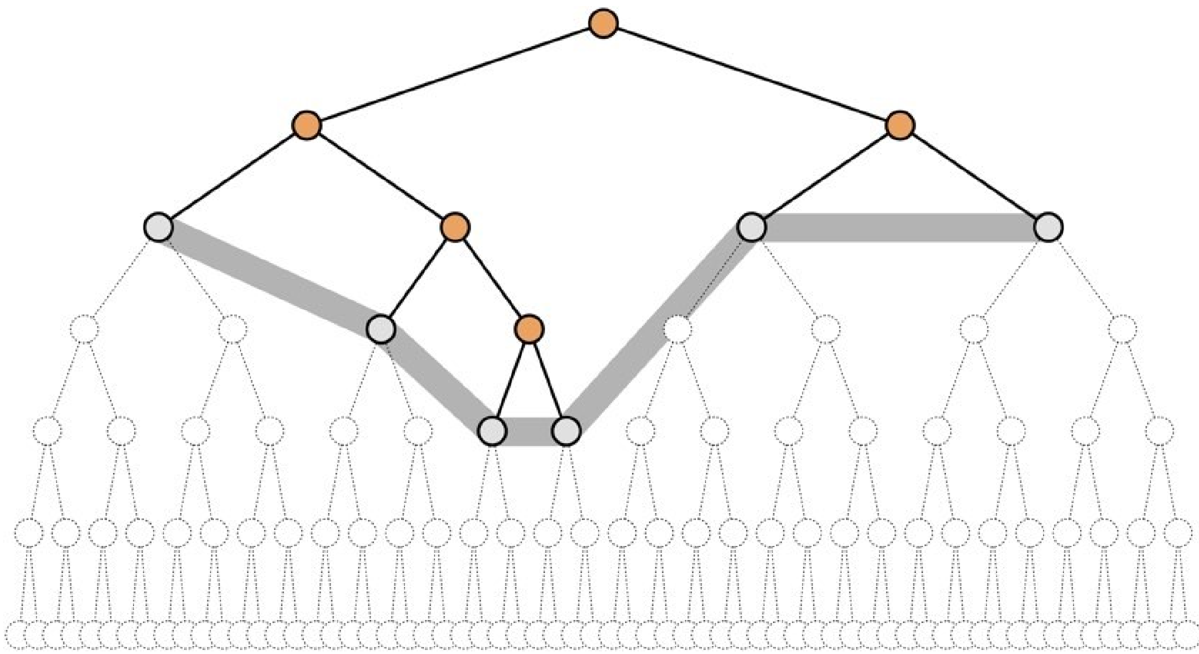

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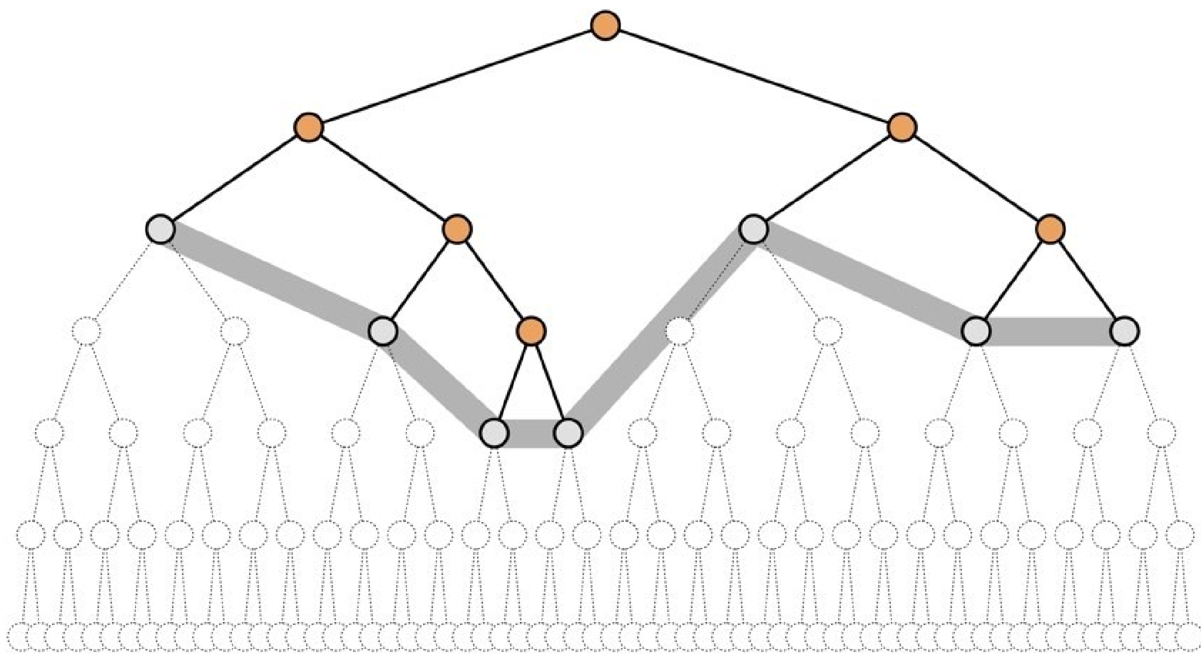

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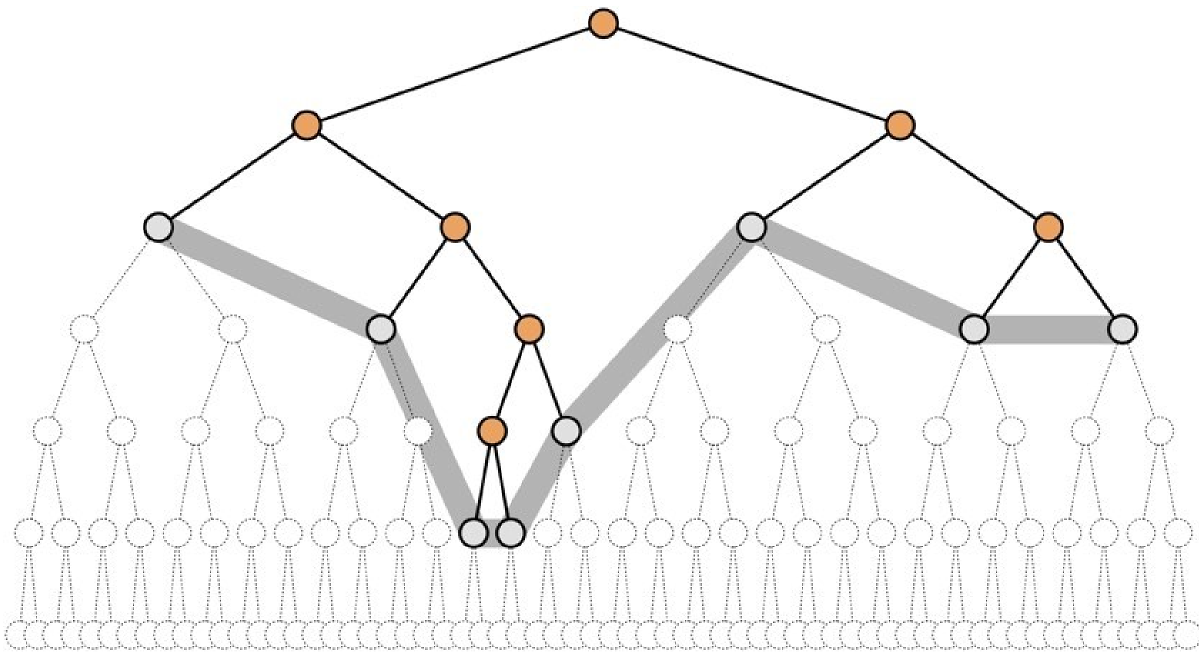

The frontier consists of nodes of various depths (jagged).
Search proceeds by expanding the lowest-cost nodes.

Recap

We can organize the algorithms into pairs where the first proceeds by layers, and the other proceeds by subtrees.

(1) Iterate on Node Depth:

- BFS searches layers of increasing node depth.
- IDS searches subtrees of increasing node depth.

Recap

We can organize the algorithms into pairs where the first proceeds by layers, and the other proceeds by subtrees.

(1) Iterate on Node Depth:

- BFS searches layers of increasing node depth.
- IDS searches subtrees of increasing node depth.

(2) Iterate on Path Cost + Heuristic Function:

- A* searches layers of increasing path cost + heuristic function.
- IDA* searches subtrees of increasing path cost + heuristic function.

Recap

Which cost function?

- UCS searches layers of increasing path cost.
- Greedy best first search searches layers of increasing heuristic function.
- A* search searches layers of increasing path cost + heuristic function.

Credit

- Artificial Intelligence, A Modern Approach. Stuart Russell and Peter Norvig. Third Edition. Pearson Education.

http://aima.cs.berkeley.edu/