Linear Search and Binary Search

DATA STRUCTURES AND ALGORITHMS IN PYTHON

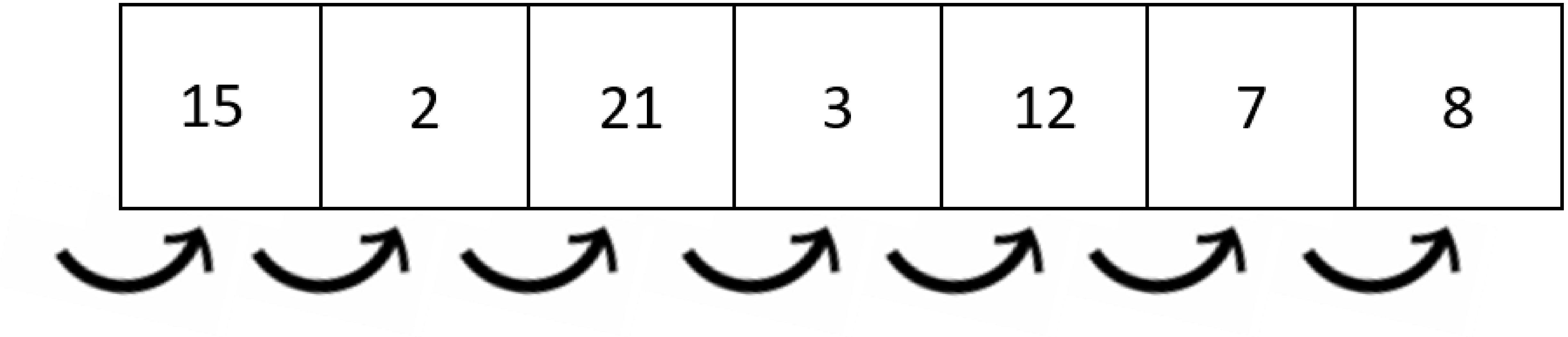
Miriam Antona
Software engineer

Searching algorithms

- **Searching** is an essential operation
  - Several ways
- Algorithms that search for an element within a collection:
  - **Linear search**
  - **Binary search**

Linear search

- Looping through each element



- Element found
  - algorithm stops
  - returns the result
- Element not found
  - algorithm continues

Linear search

```python
def linear_search(unordered_list, search_value):
  for index in range(len(unordered_list)):
    if unordered_list[index] == search_value:
      return True
  return False
```

```python
print(linear_search([15,2,21,3,12,7,8], 8))
```

```
True
```

```python
print(linear_search([15,2,21,3,12,7,8], 800))
```

```
False
```

Linear search - complexity

- Complexity: $O(n)$

Binary search

- Only applies to ordered lists

2	5	10	12	15	17	20

- 15 ???

Binary search

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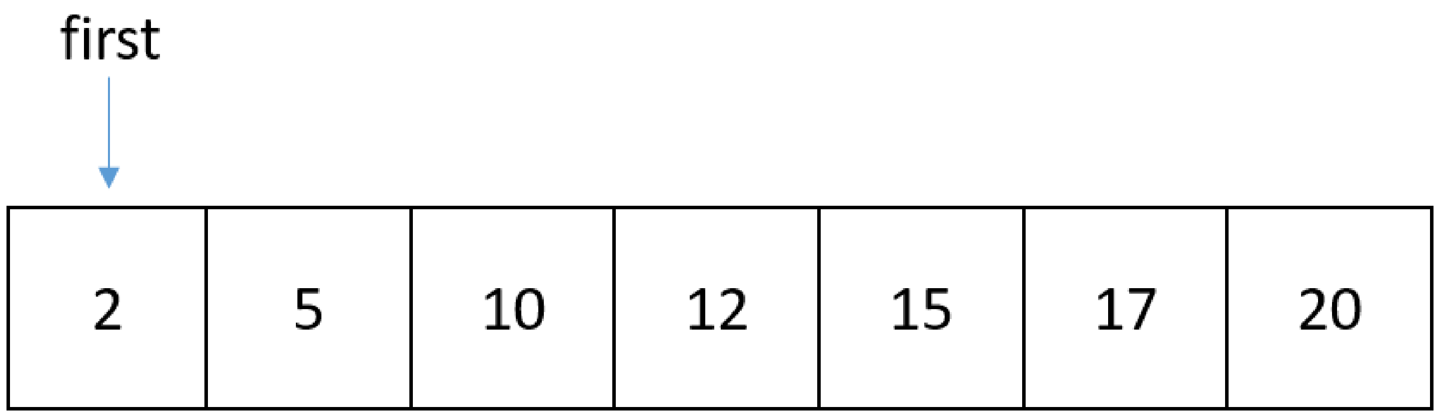
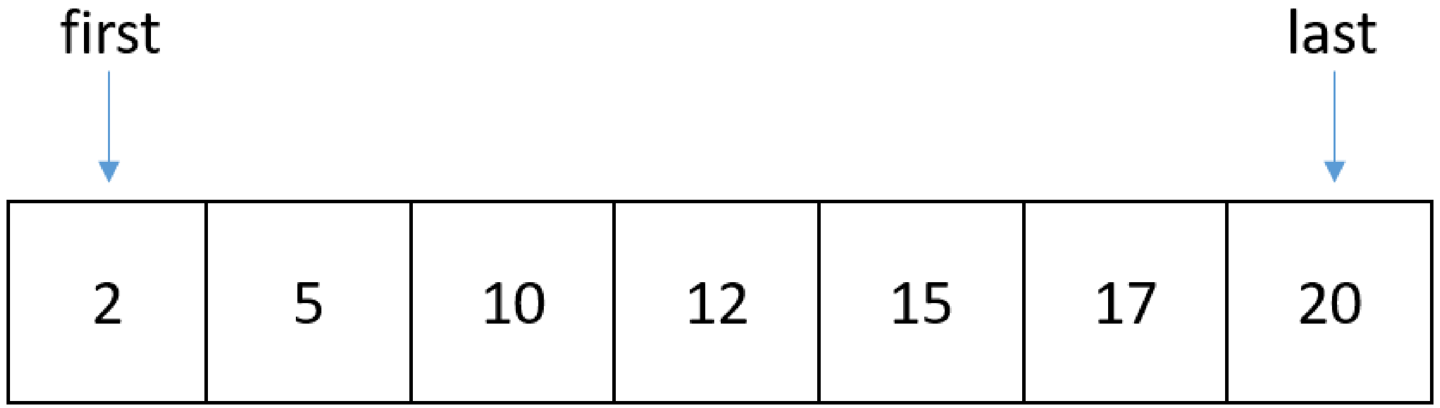


- 15 ???

```python
def binary_search(ordered_list, search_value):
  first = 0
```

Binary search

- Only applies to ordered lists



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```python
def binary_search(ordered_list, search_value):
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  last = len(ordered_list) - 1

  while first <= last:
```

Binary search

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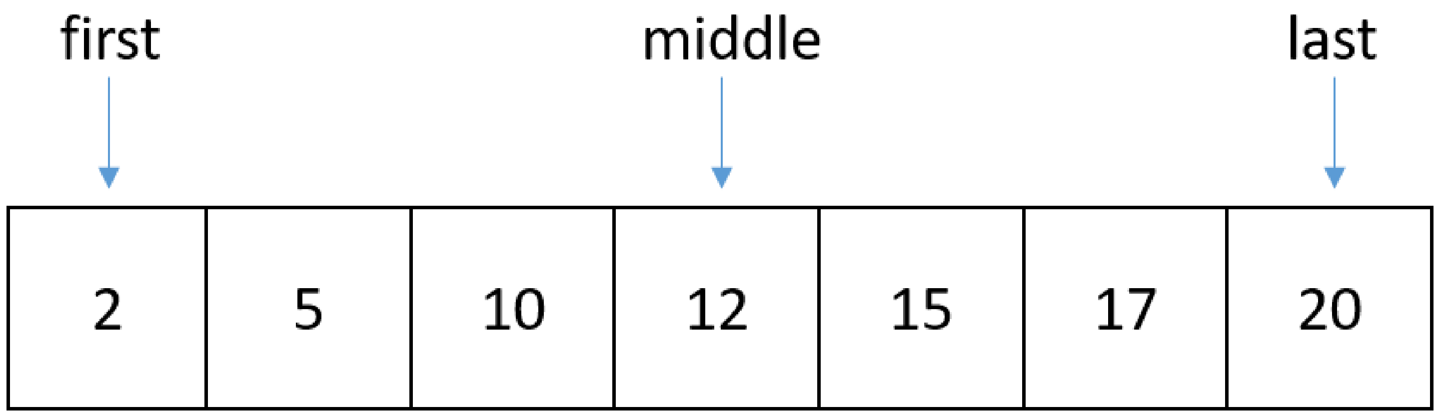

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```python
def binary_search(ordered_list, search_value):
  first = 0
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  while first <= last:
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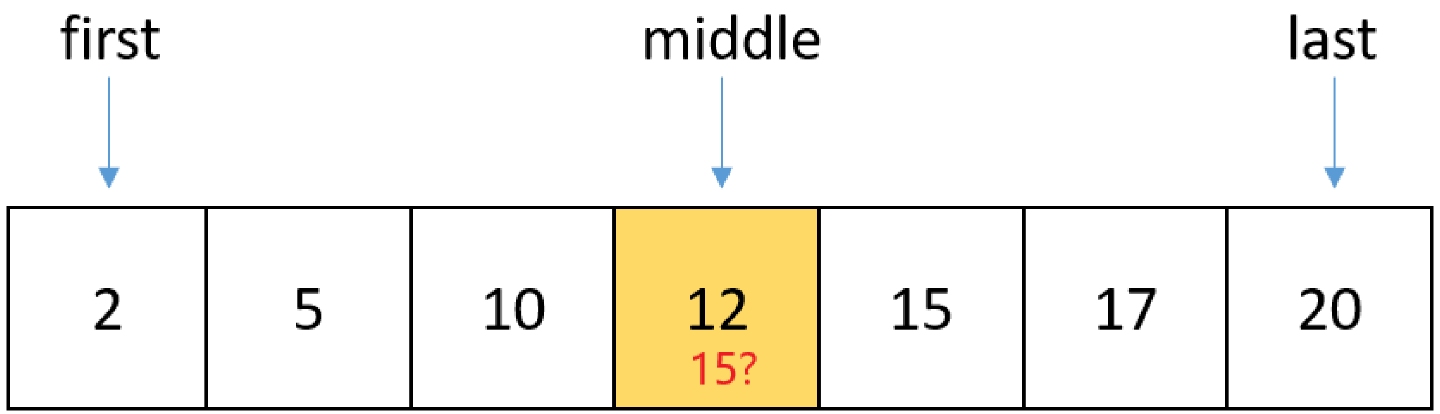

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- Compare `search_value` with the item in the **middle** of the list

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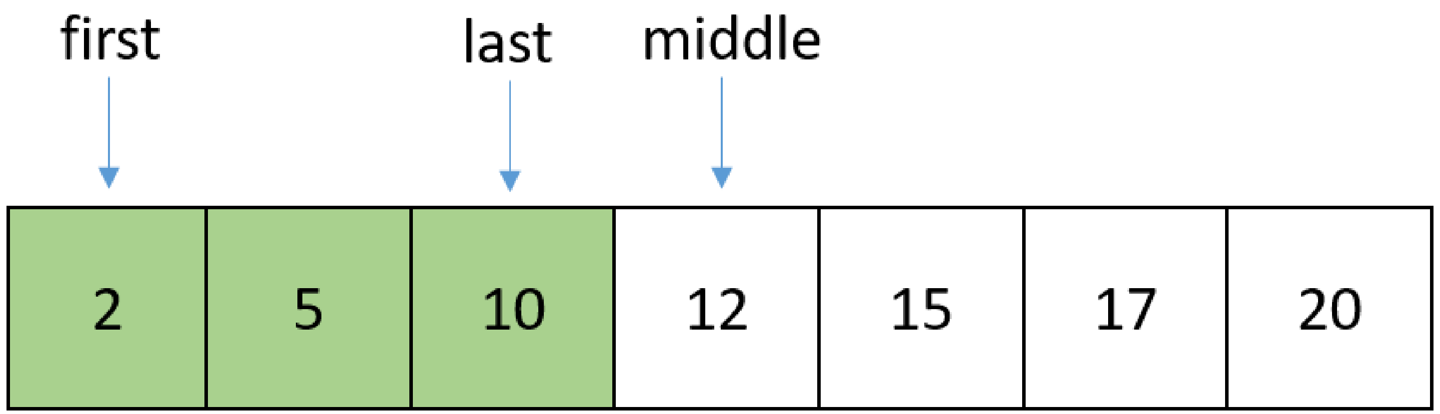

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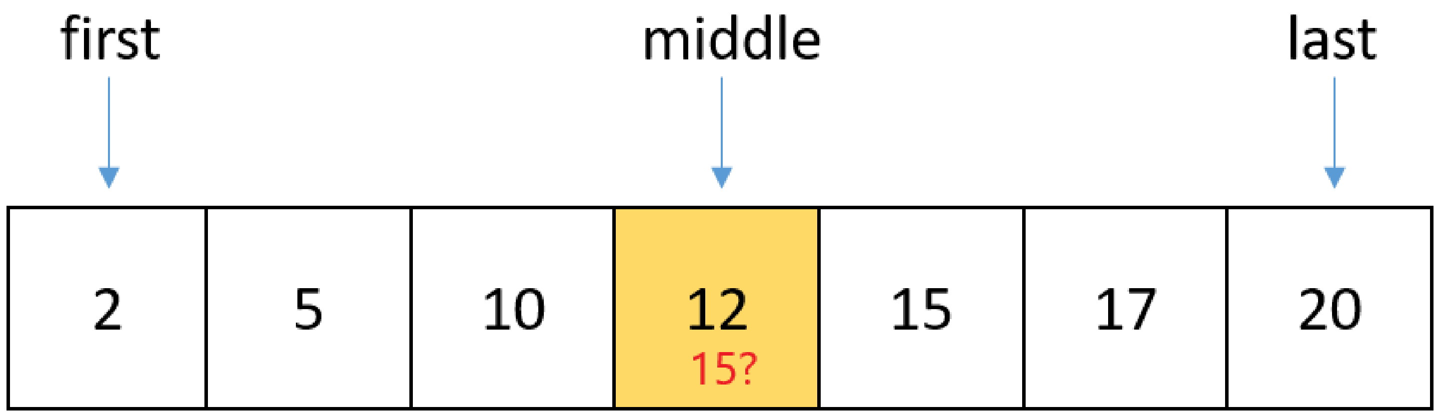

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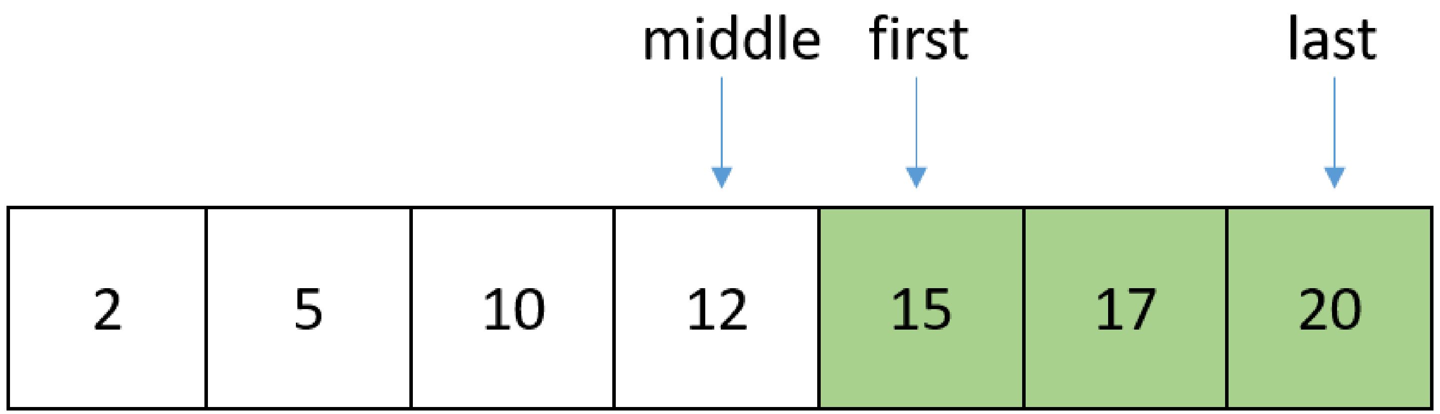

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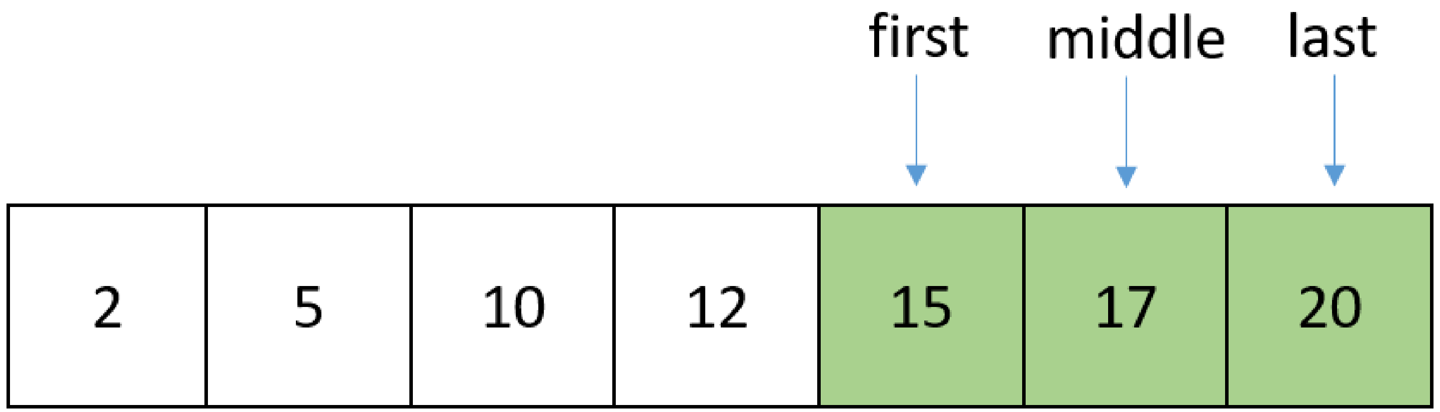

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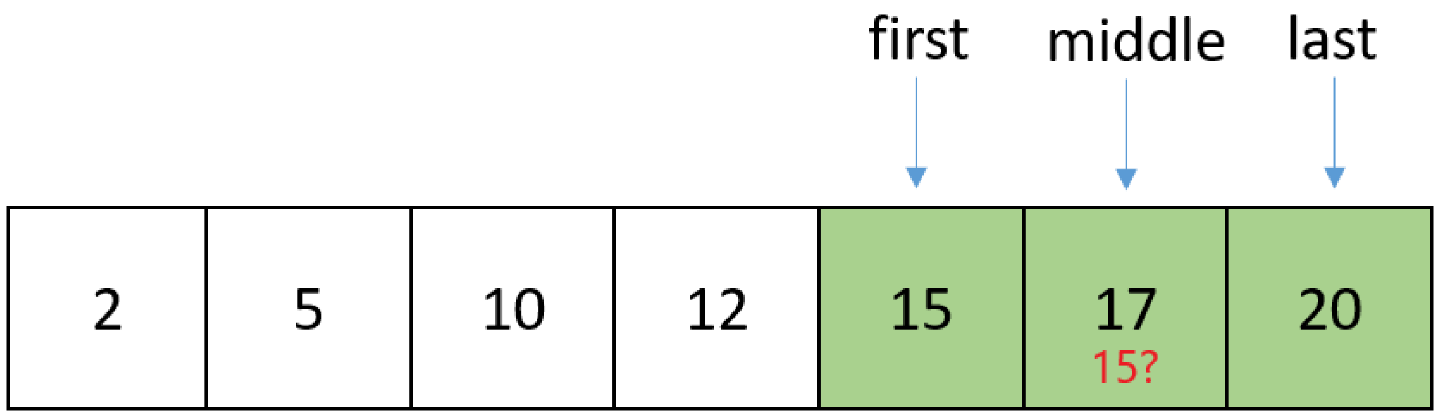

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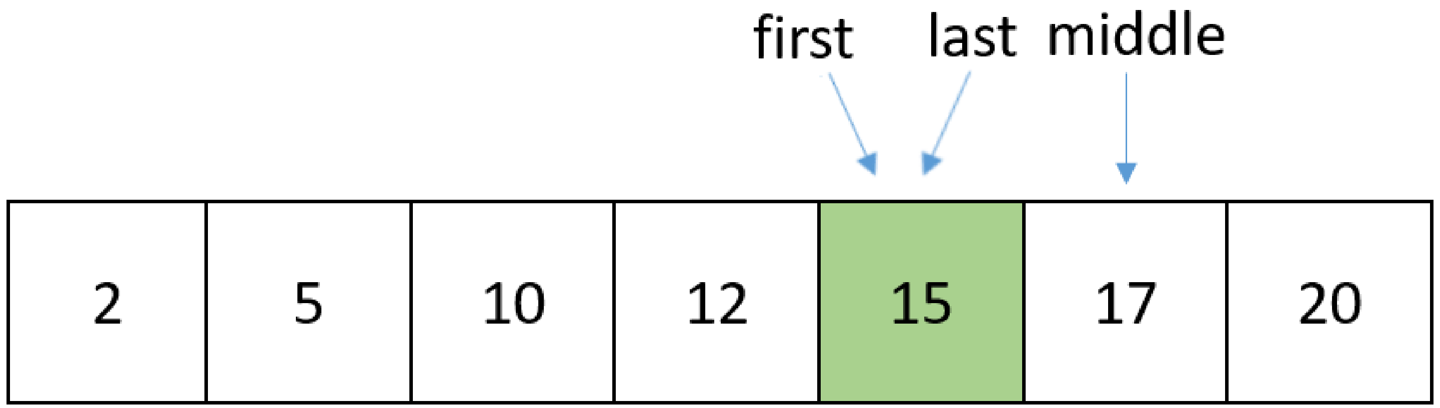

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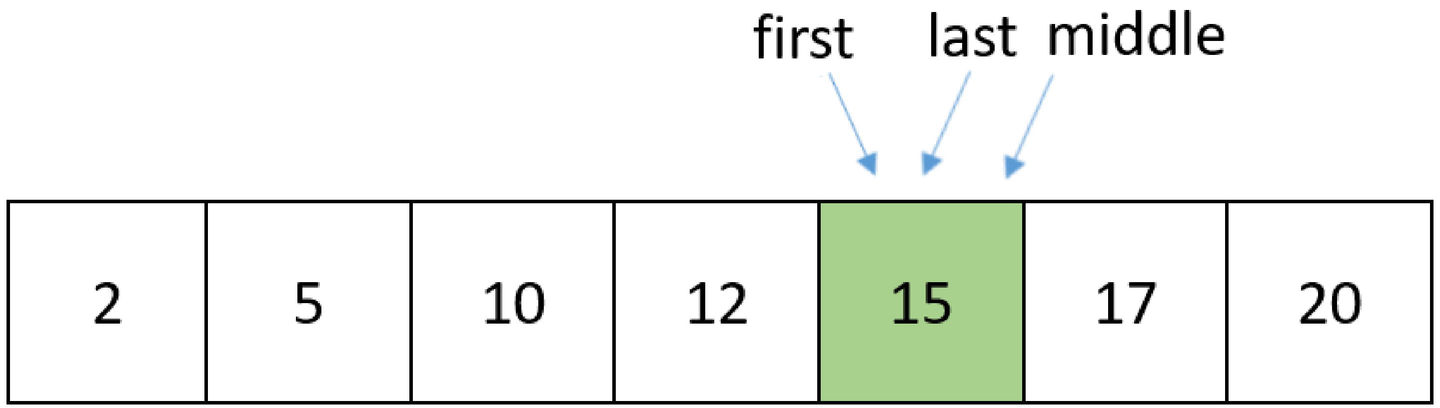

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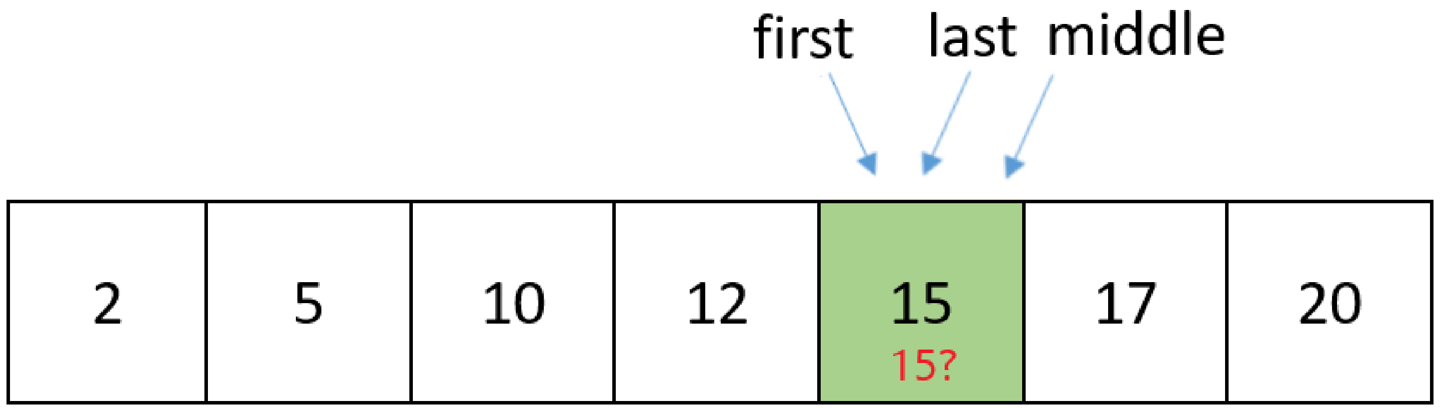

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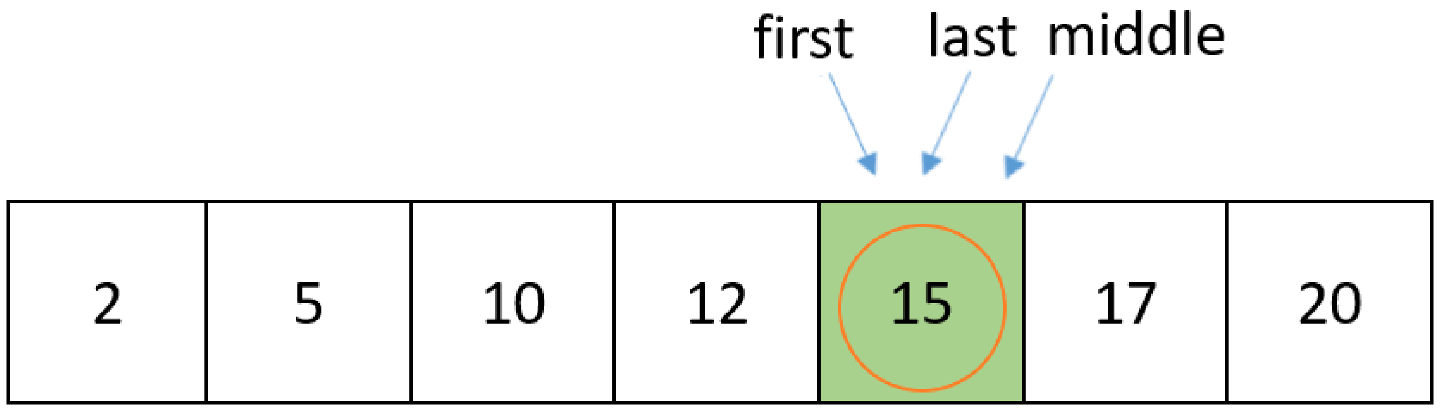

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```
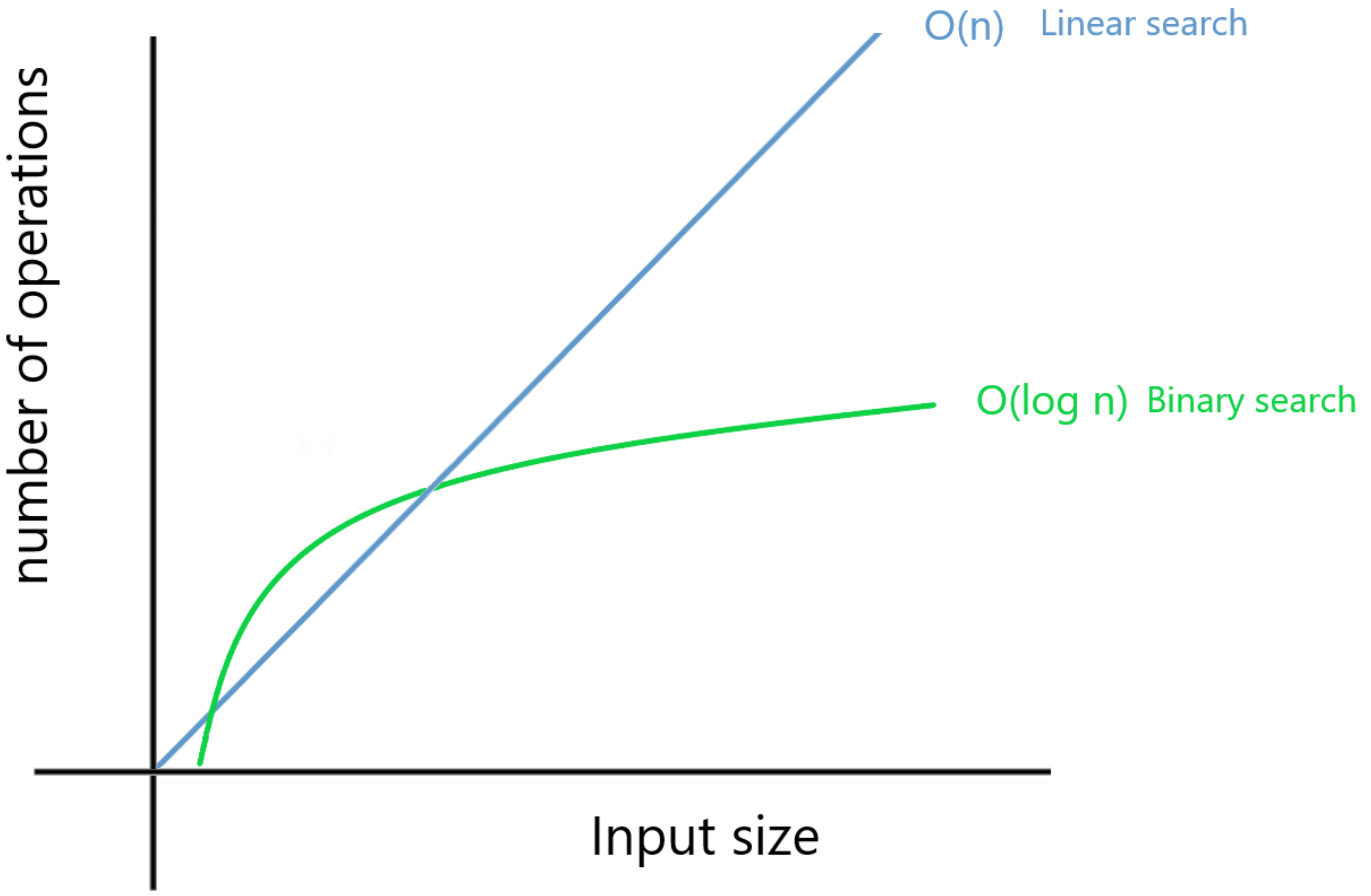

Binary search - complexity

- **Complexity:** $O(\log n)$



Let's practice!

Binary Search Tree (BST)

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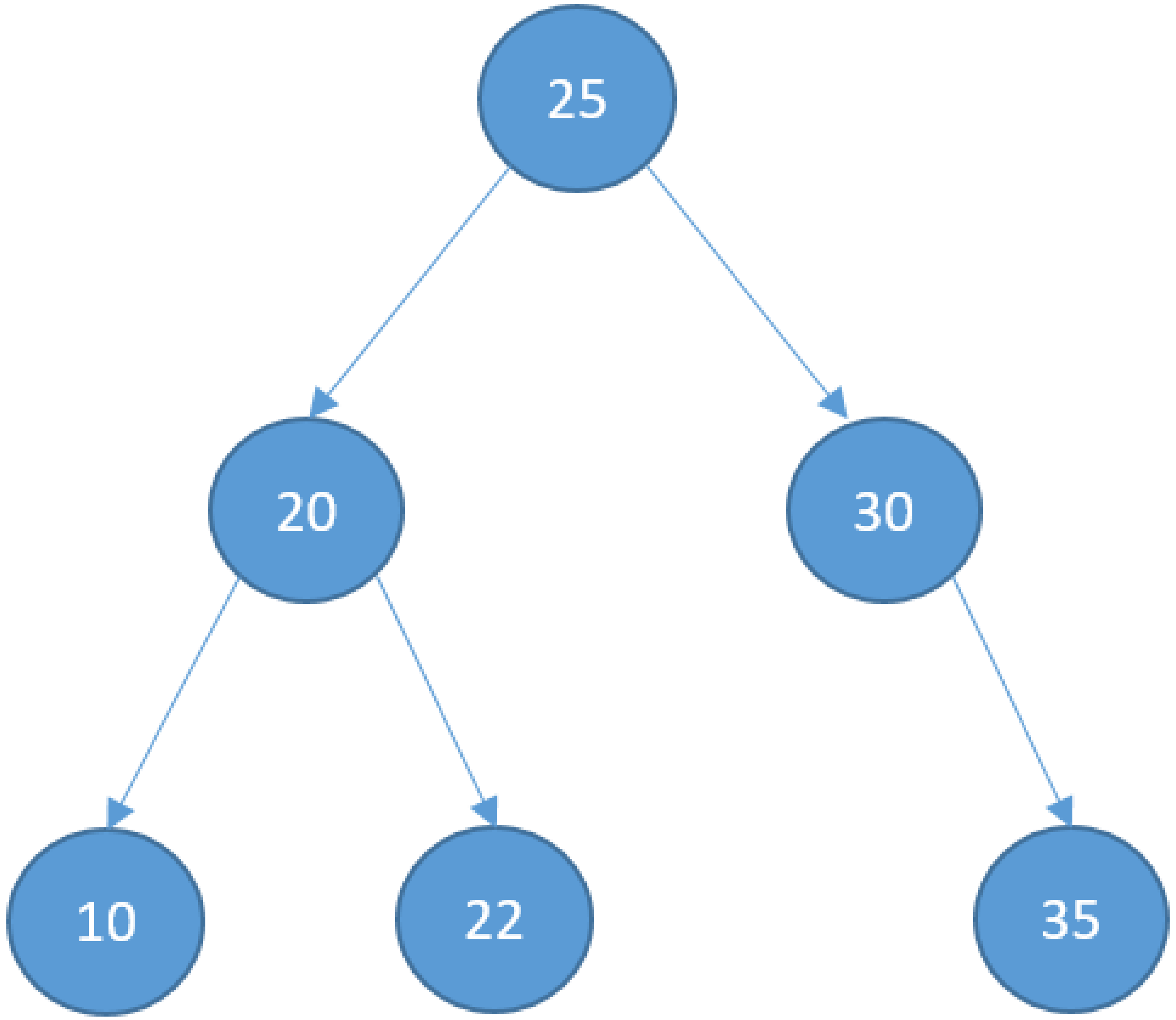
Definition

- **Left subtree** of a node:
  - values **less** than the node itself
- **Right subtree** of a node:
  - values **greater** than the node itself
- Left and right subtrees must be binary search trees



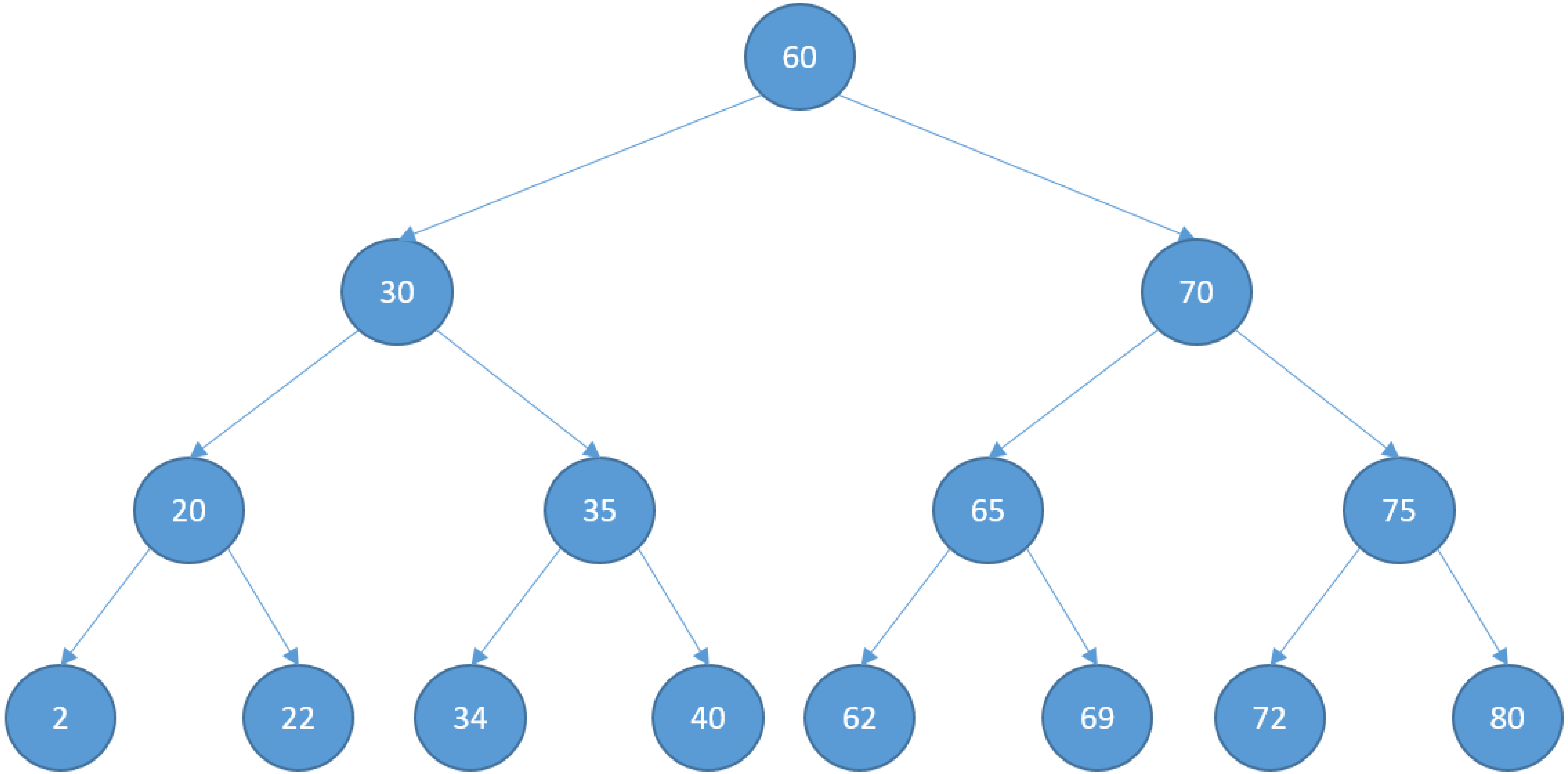
Implementation

```
class TreeNode:
  def __init__(self, data, left=None, right=None):
    self.data = data
    self.left_child = left
    self.right_child = right
```

```
class BinarySearchTree:
  def __init__(self):
    self.root = None
```

Searching

- Search for 72



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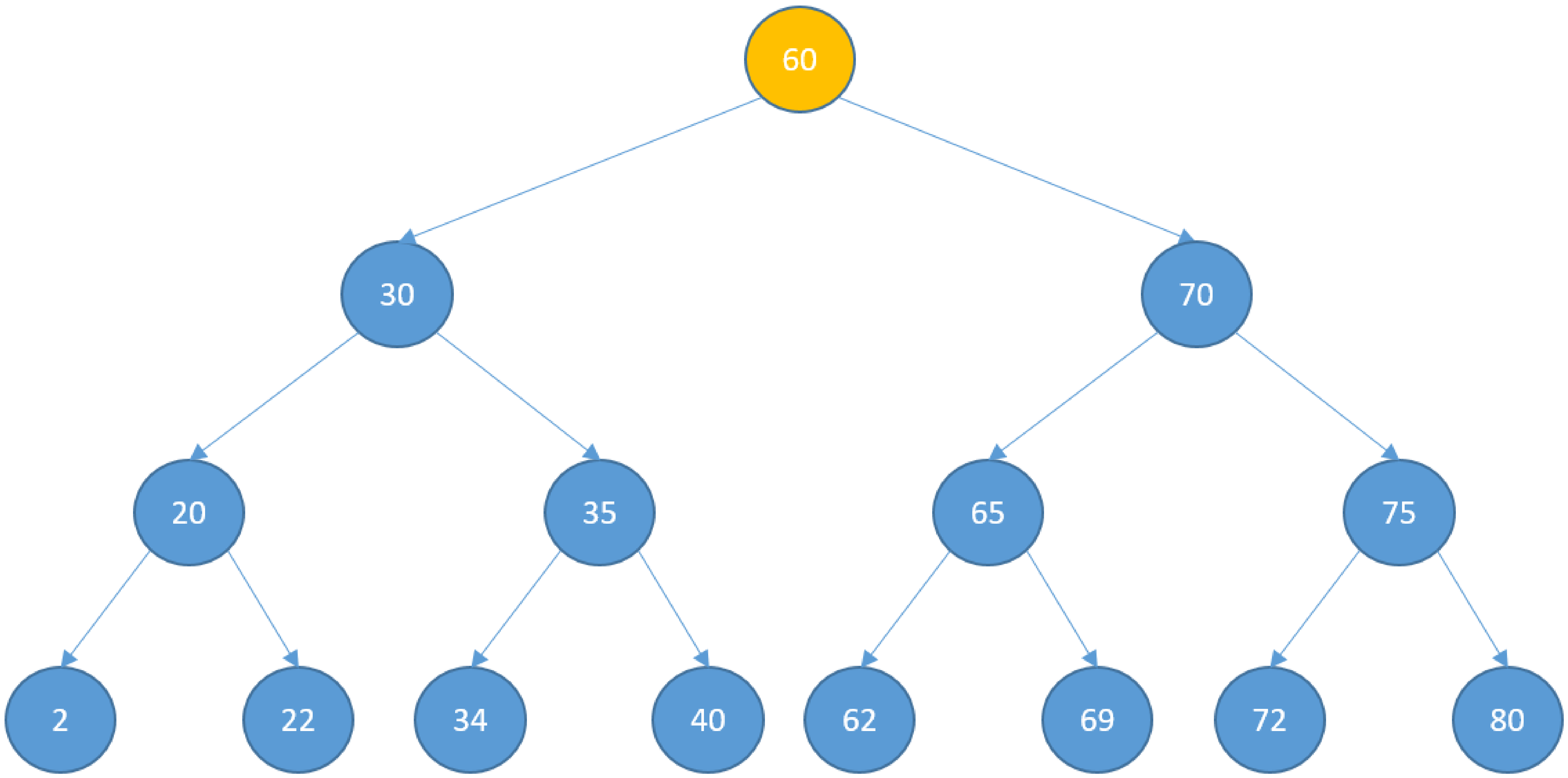

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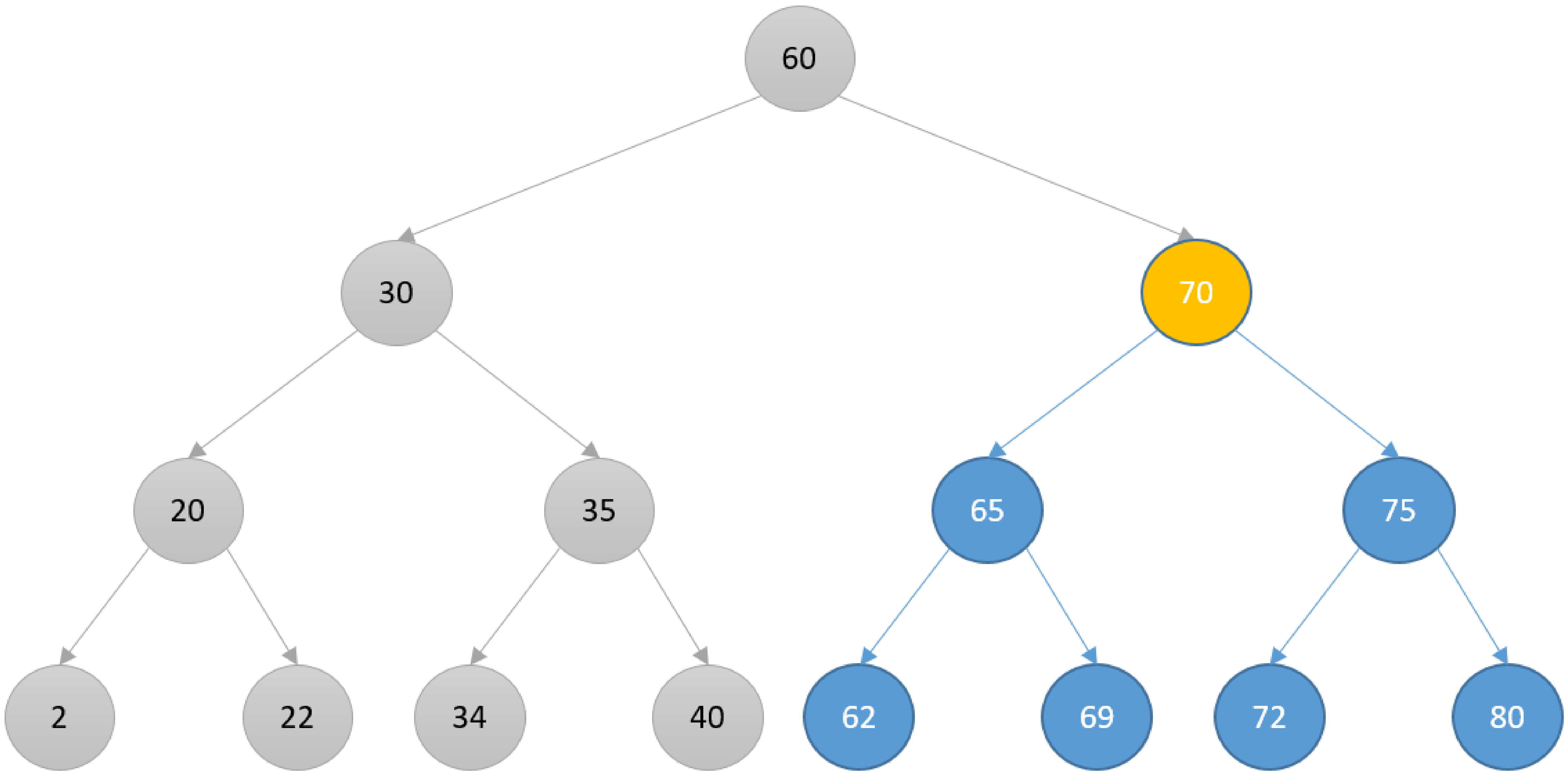

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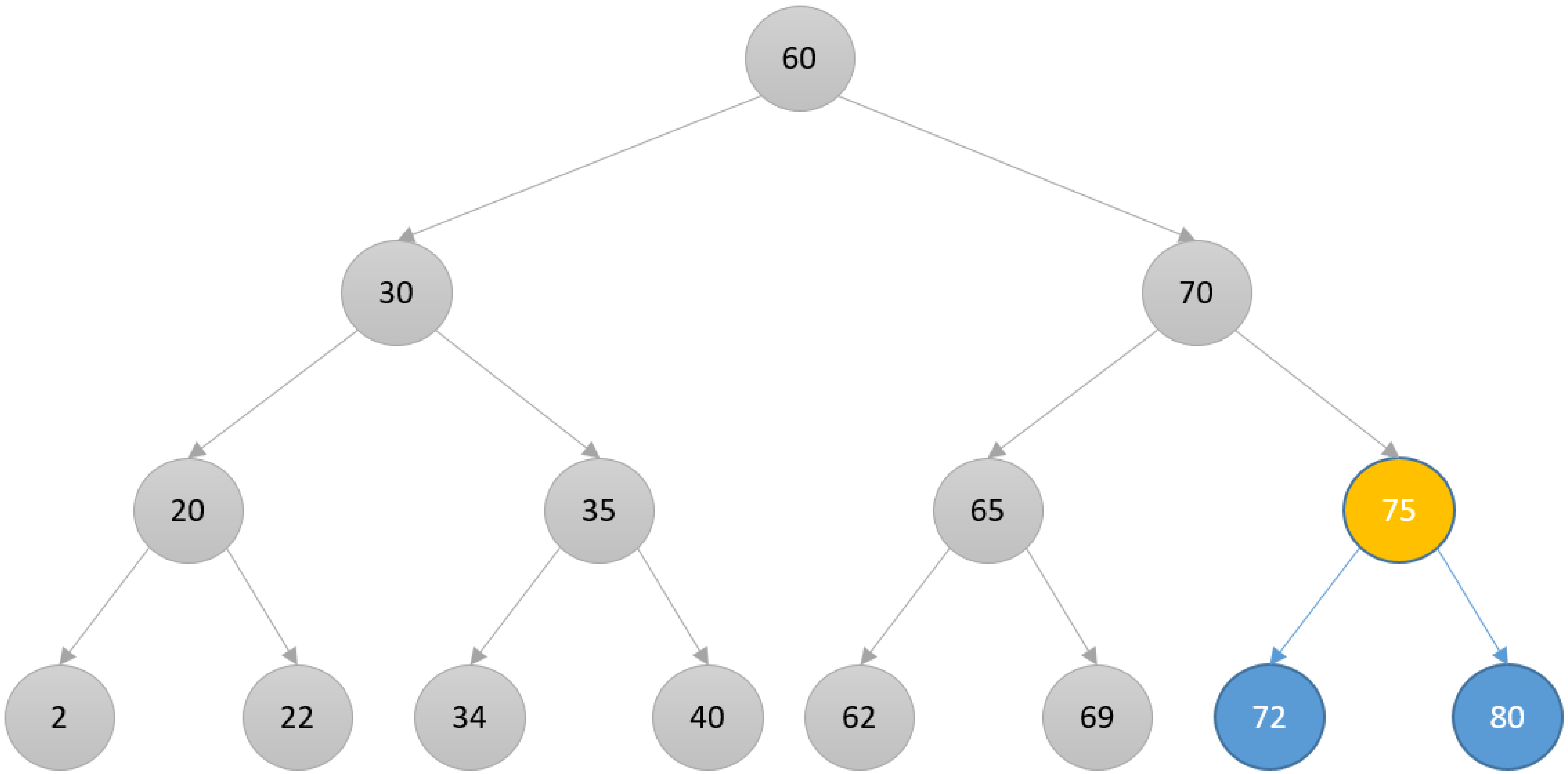

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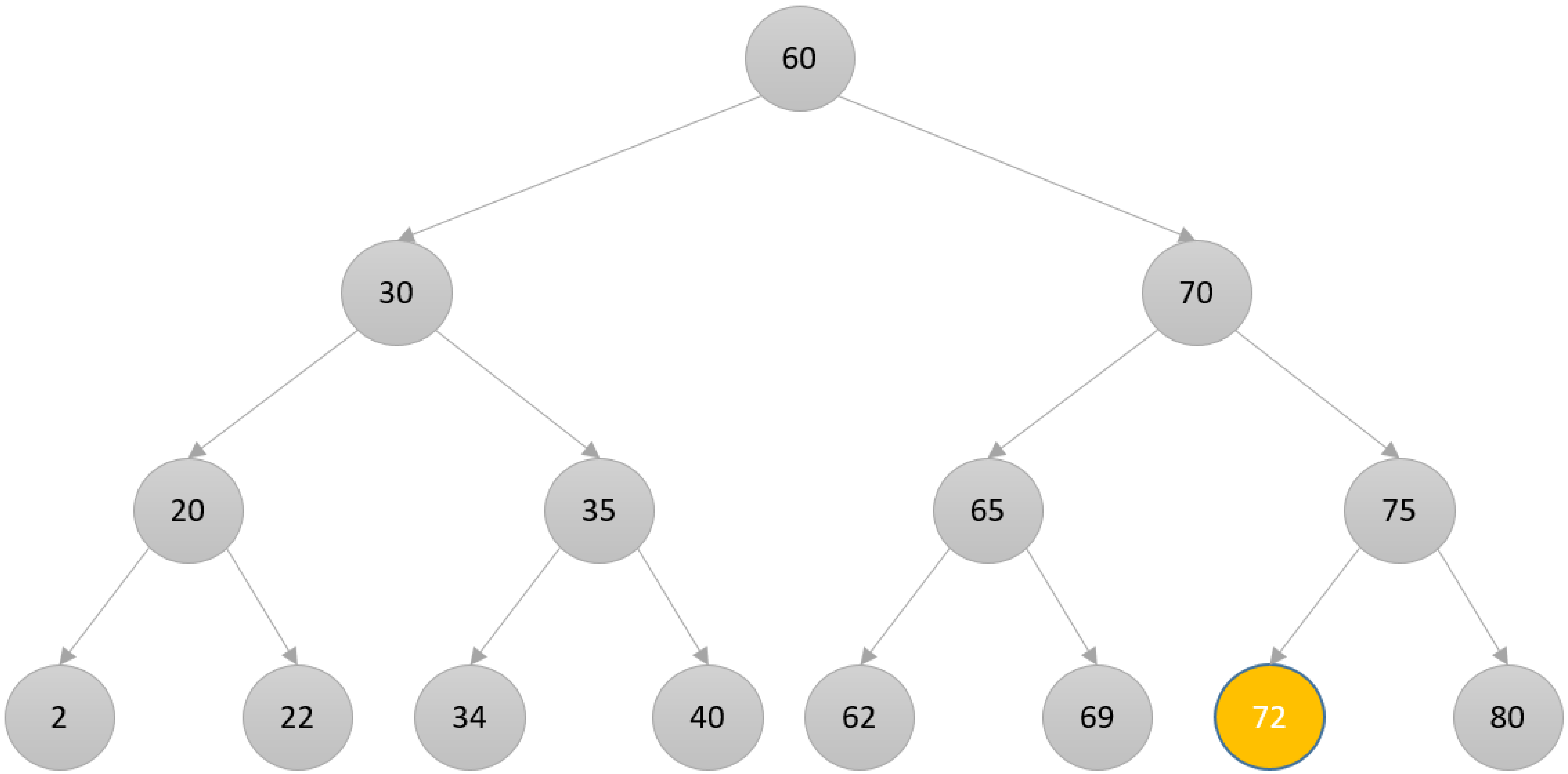

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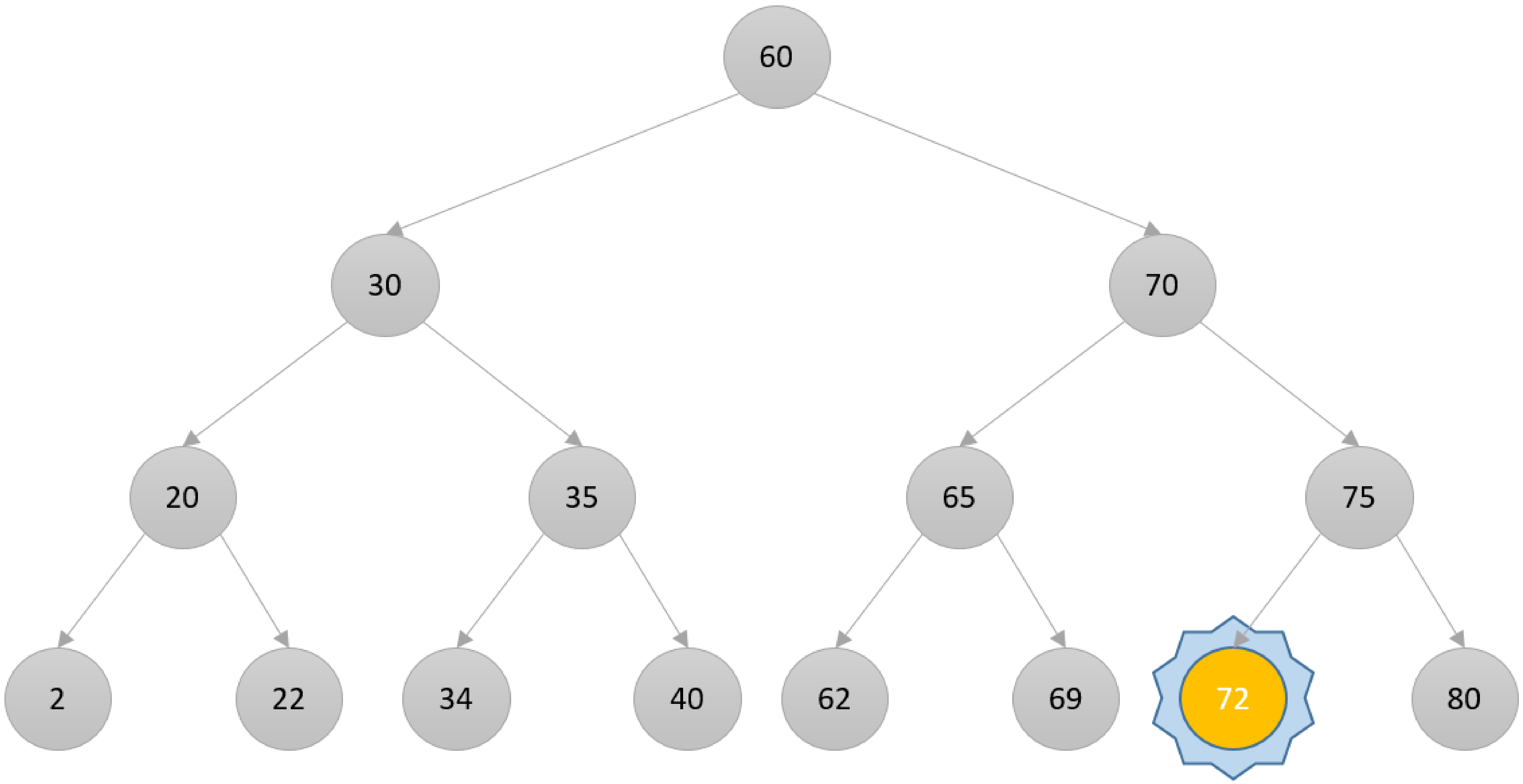

Searching

```python
def search(self, search_value):
    current_node = self.root
    while current_node:
      if search_value == current_node.data:
        return True
      elif search_value < current_node.data:
        current_node = current_node.left_child
      else:
        current_node = current_node.right_child
    return False
```

Inserting

```
def insert(self, data):
  new_node = TreeNode(data)
  if self.root == None:
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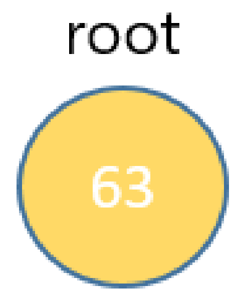

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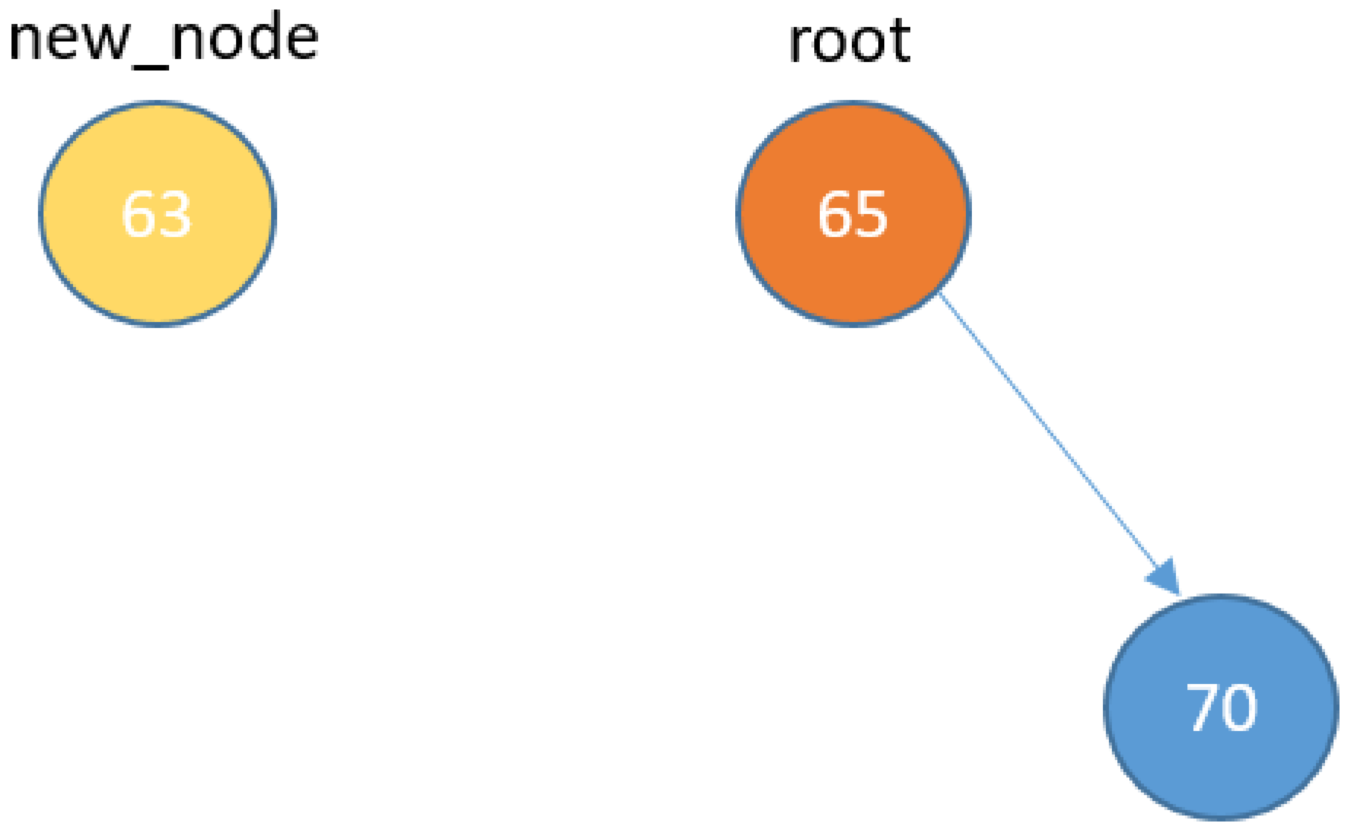

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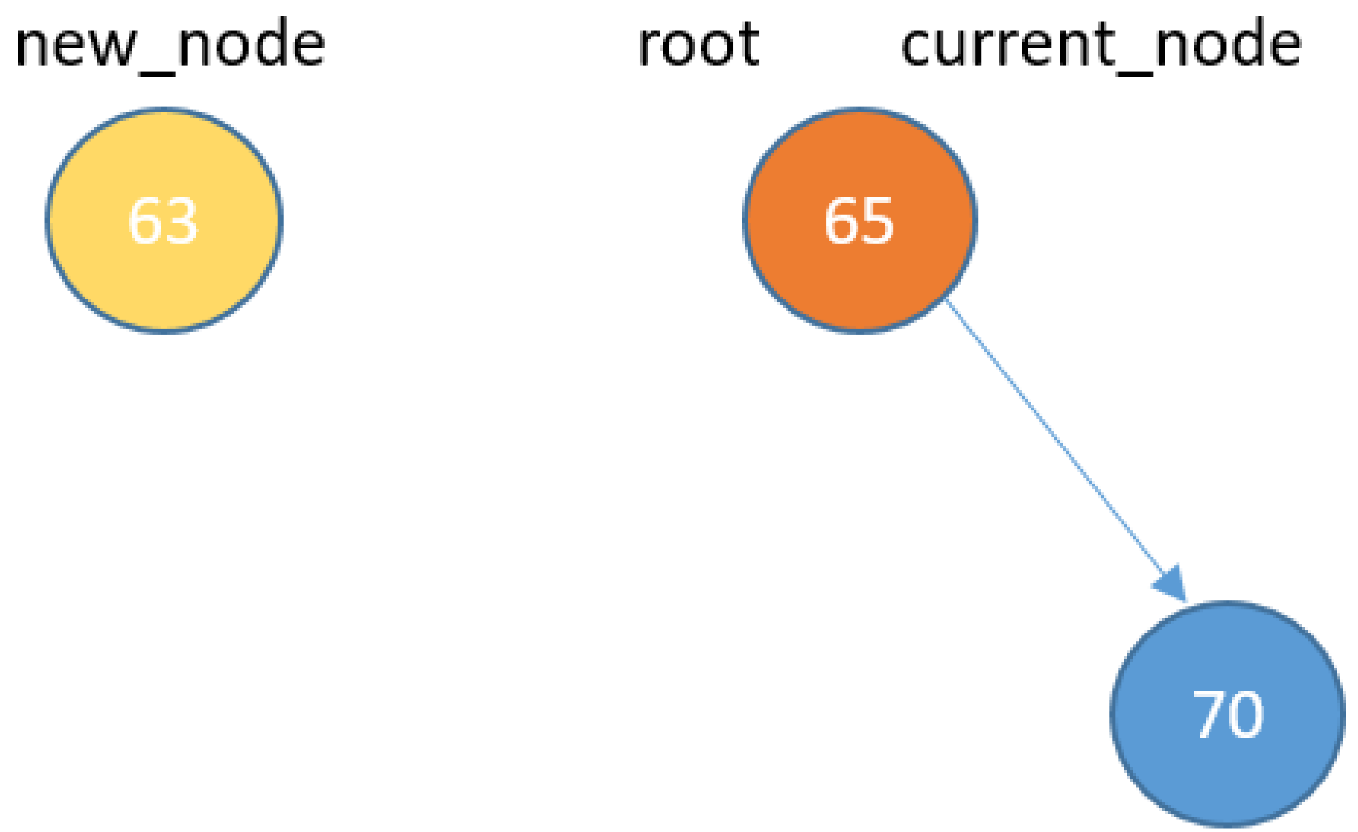

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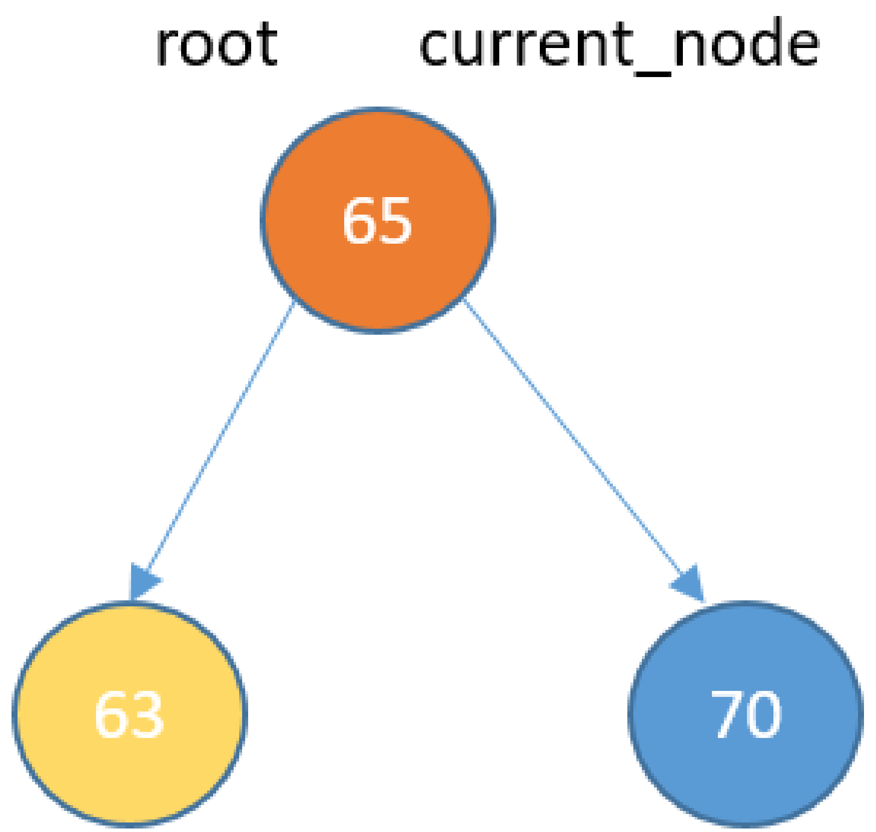

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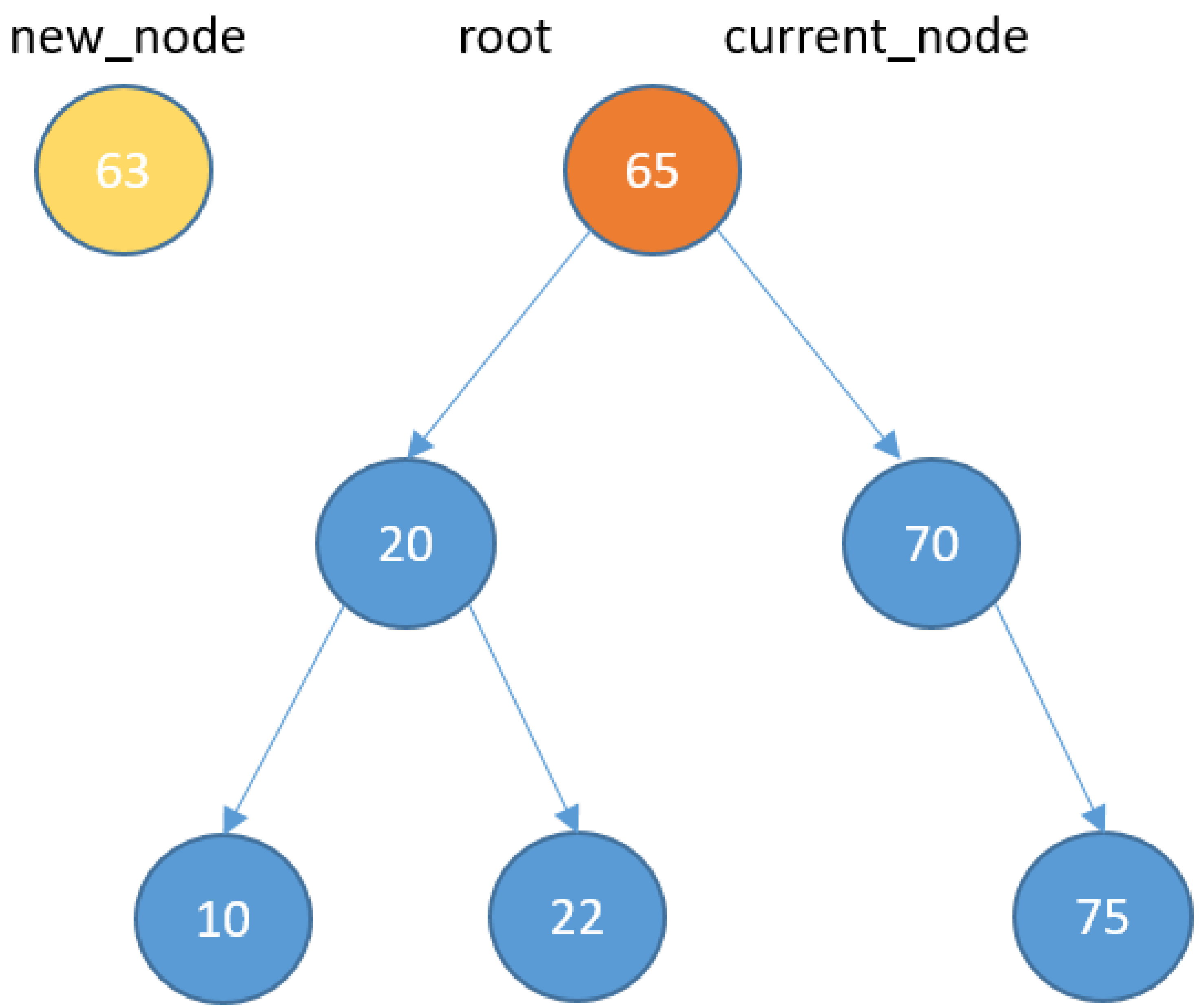

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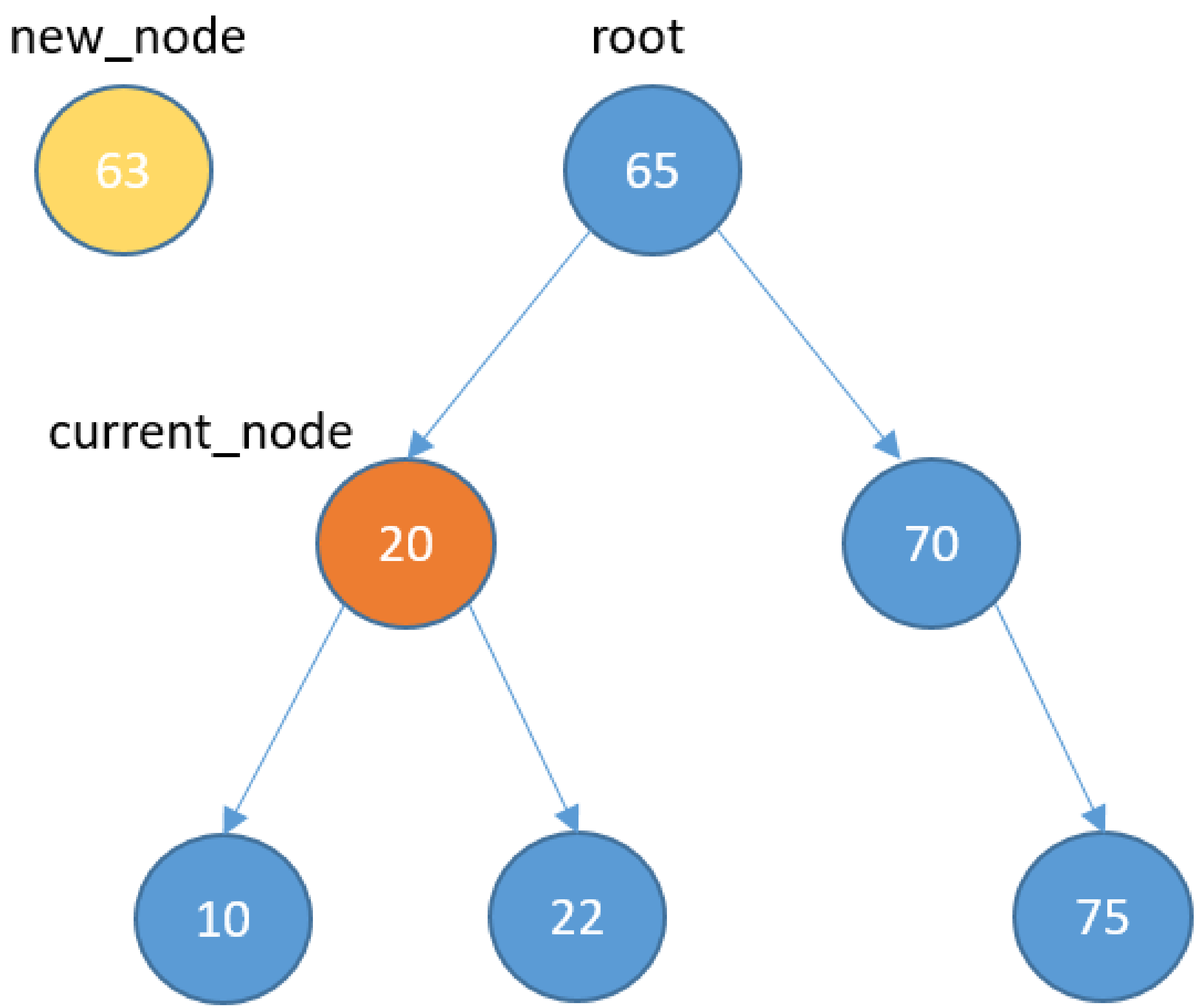

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      elif data > current_node.data:
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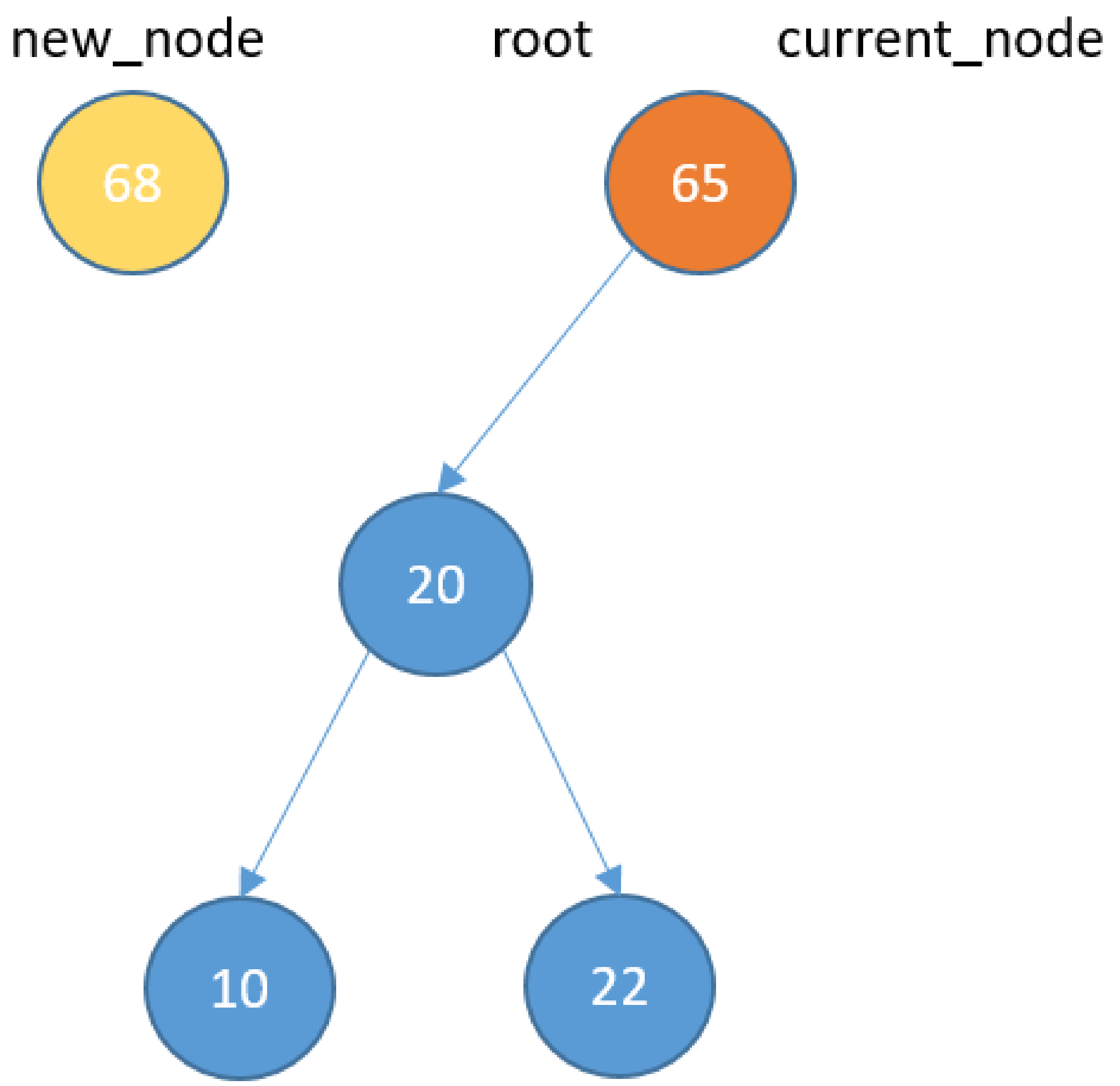

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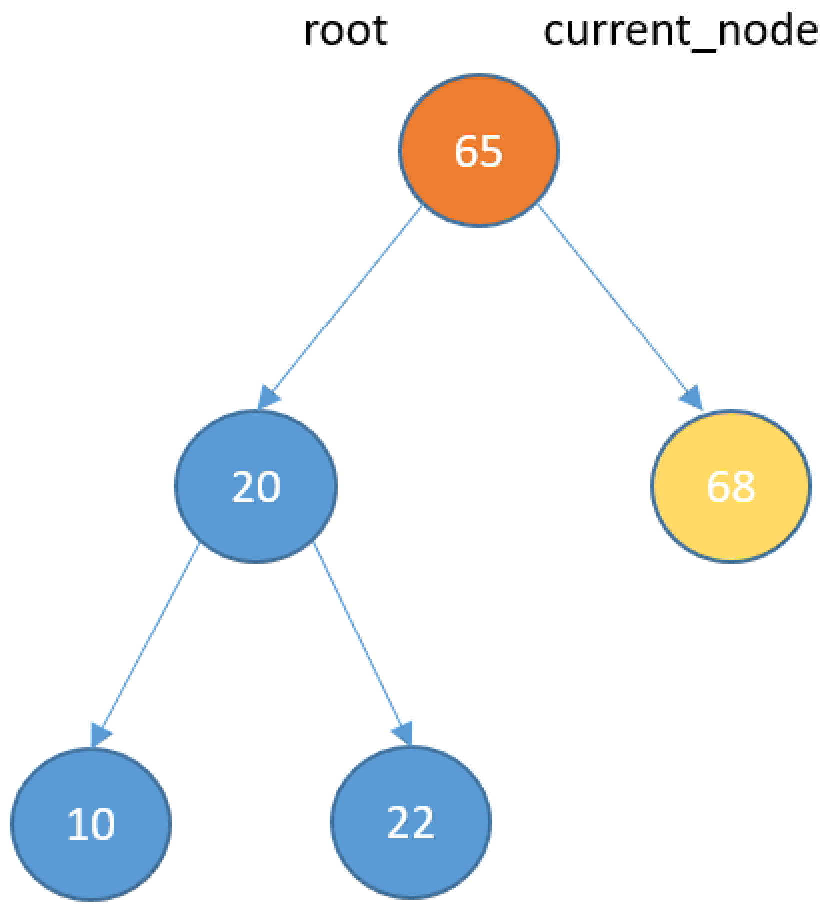

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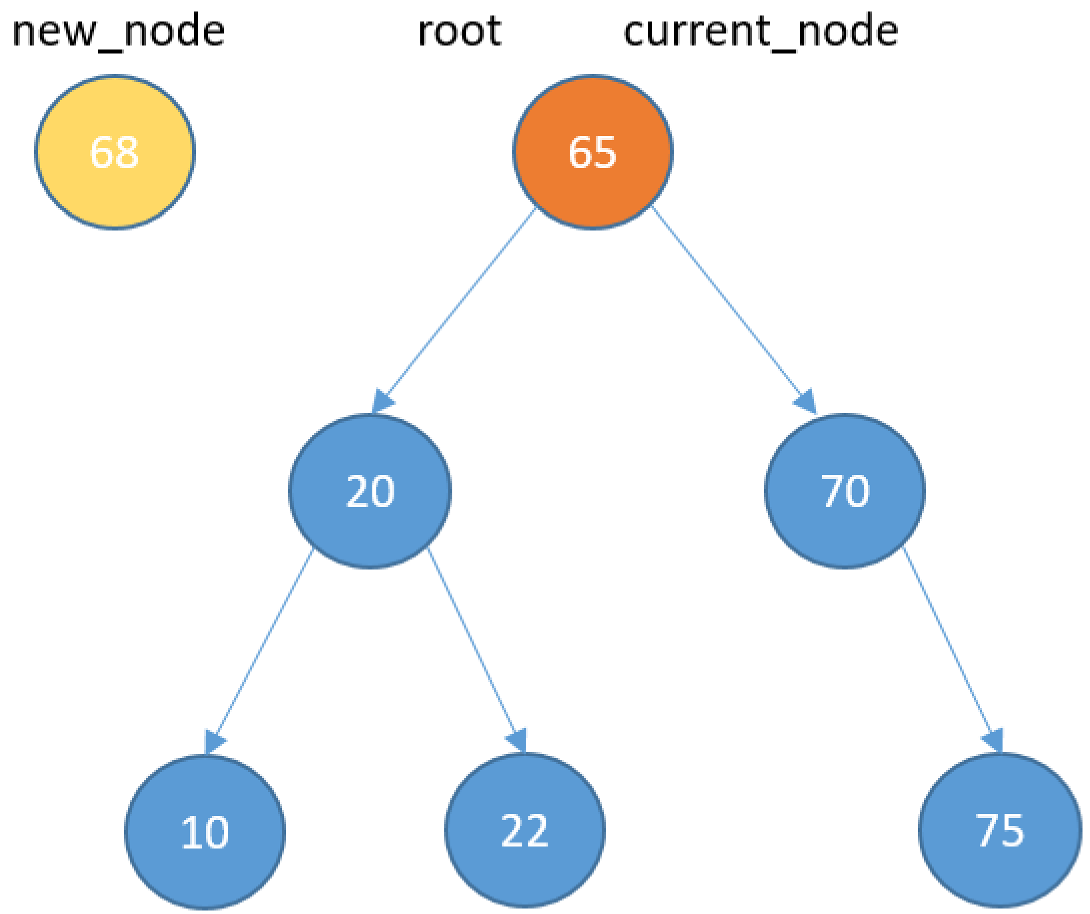

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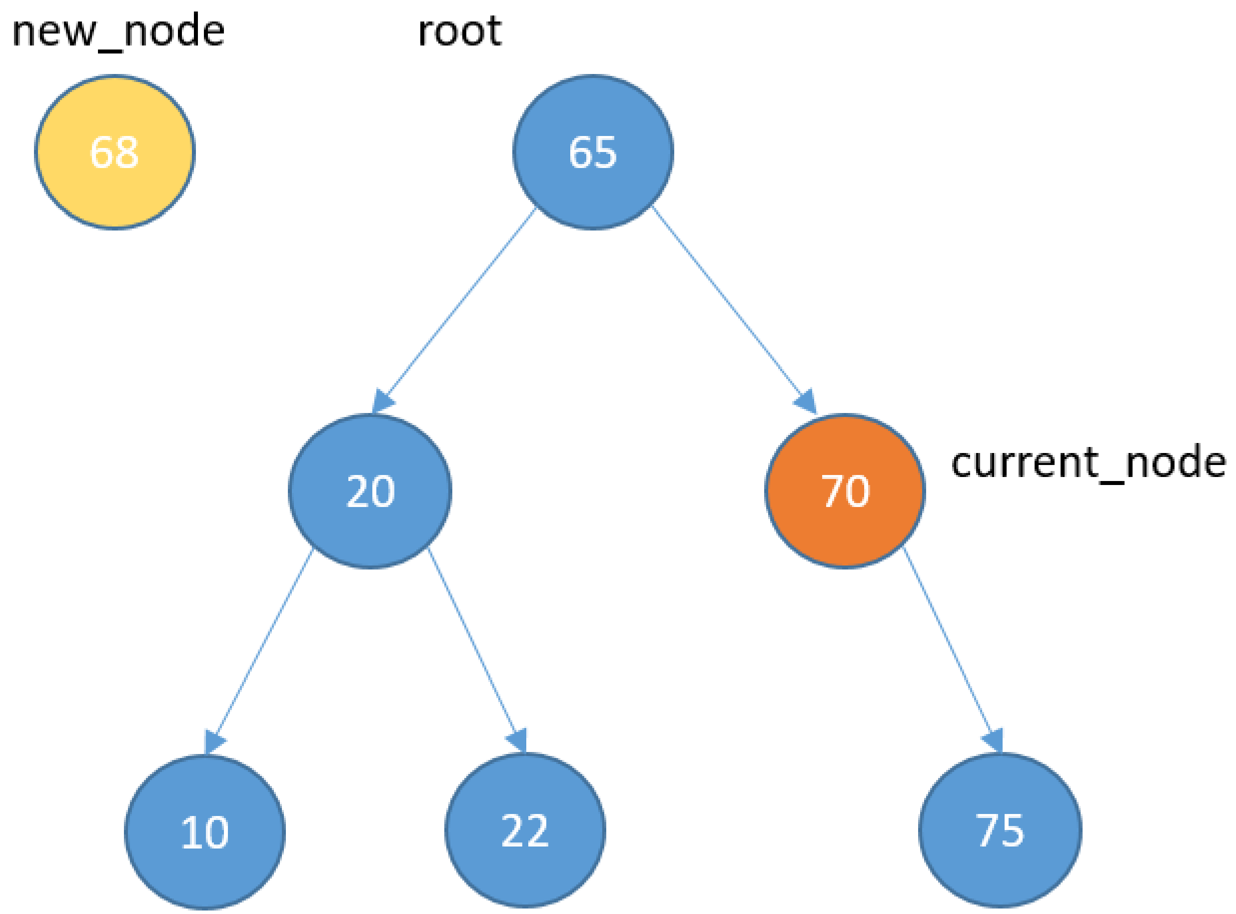

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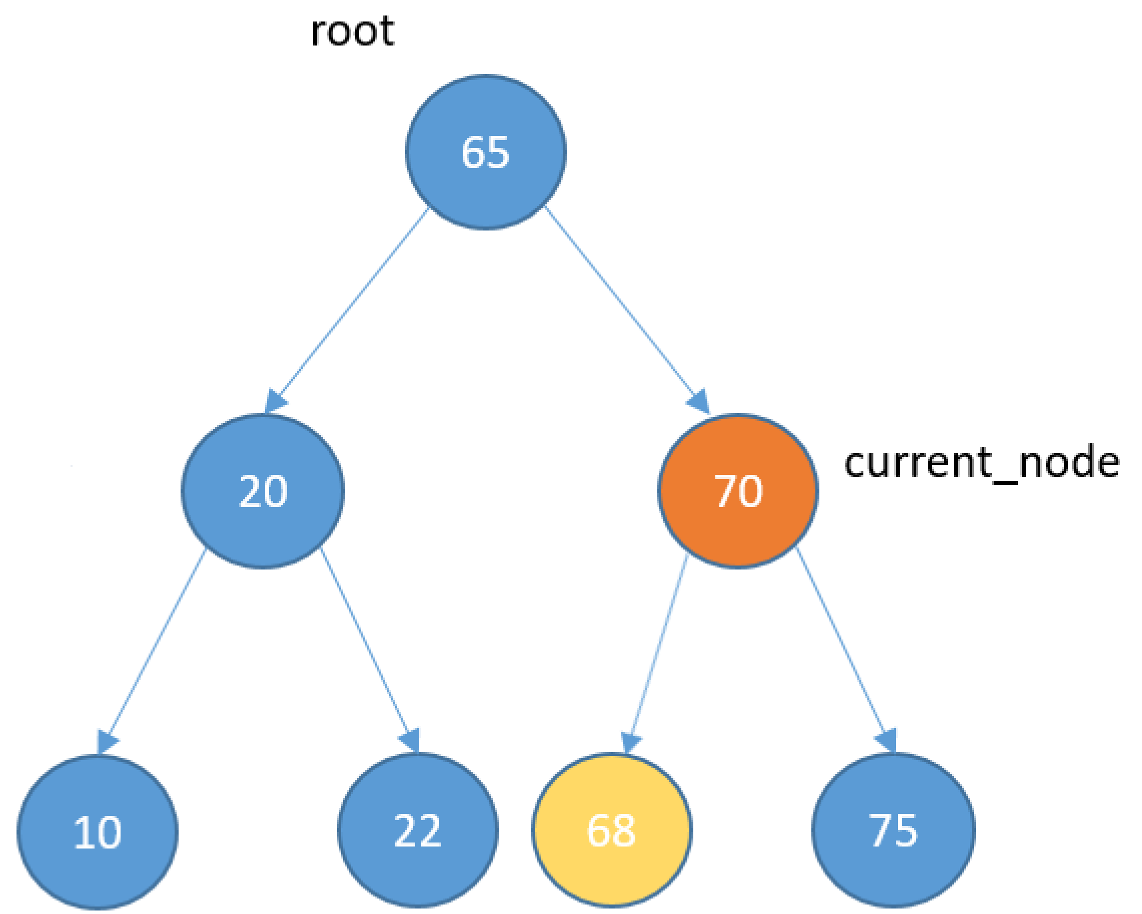
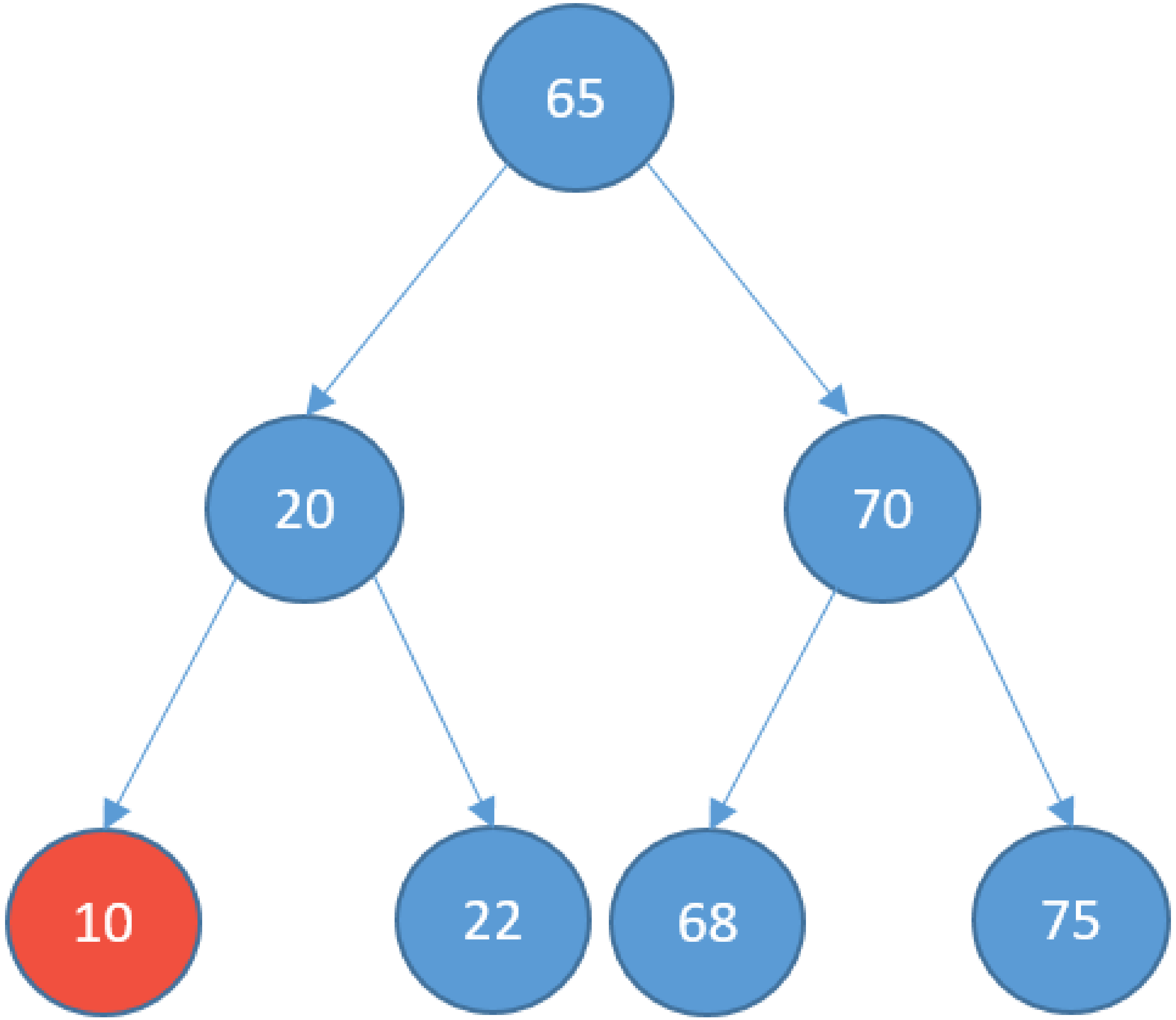


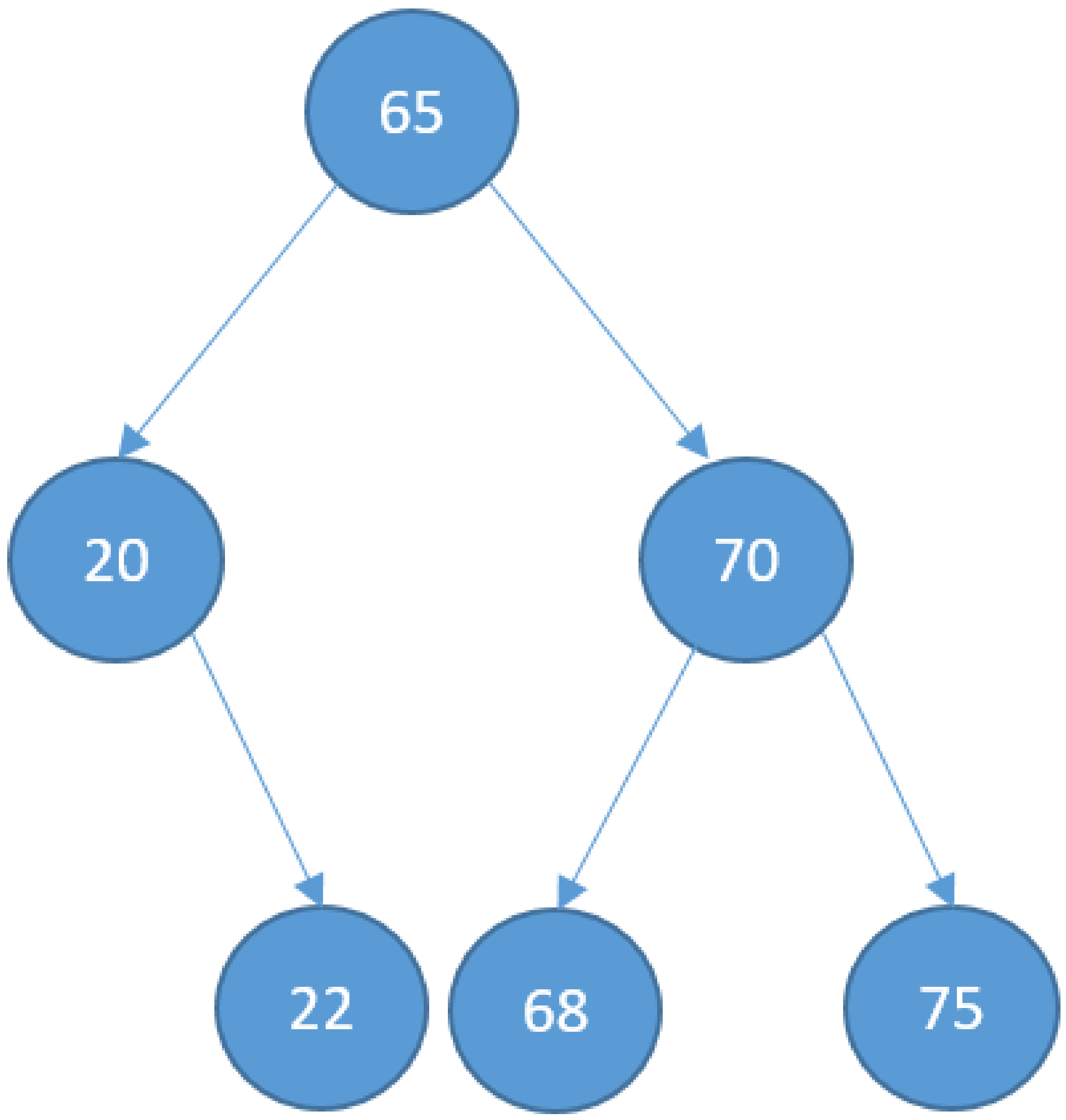
Deleting

- No children



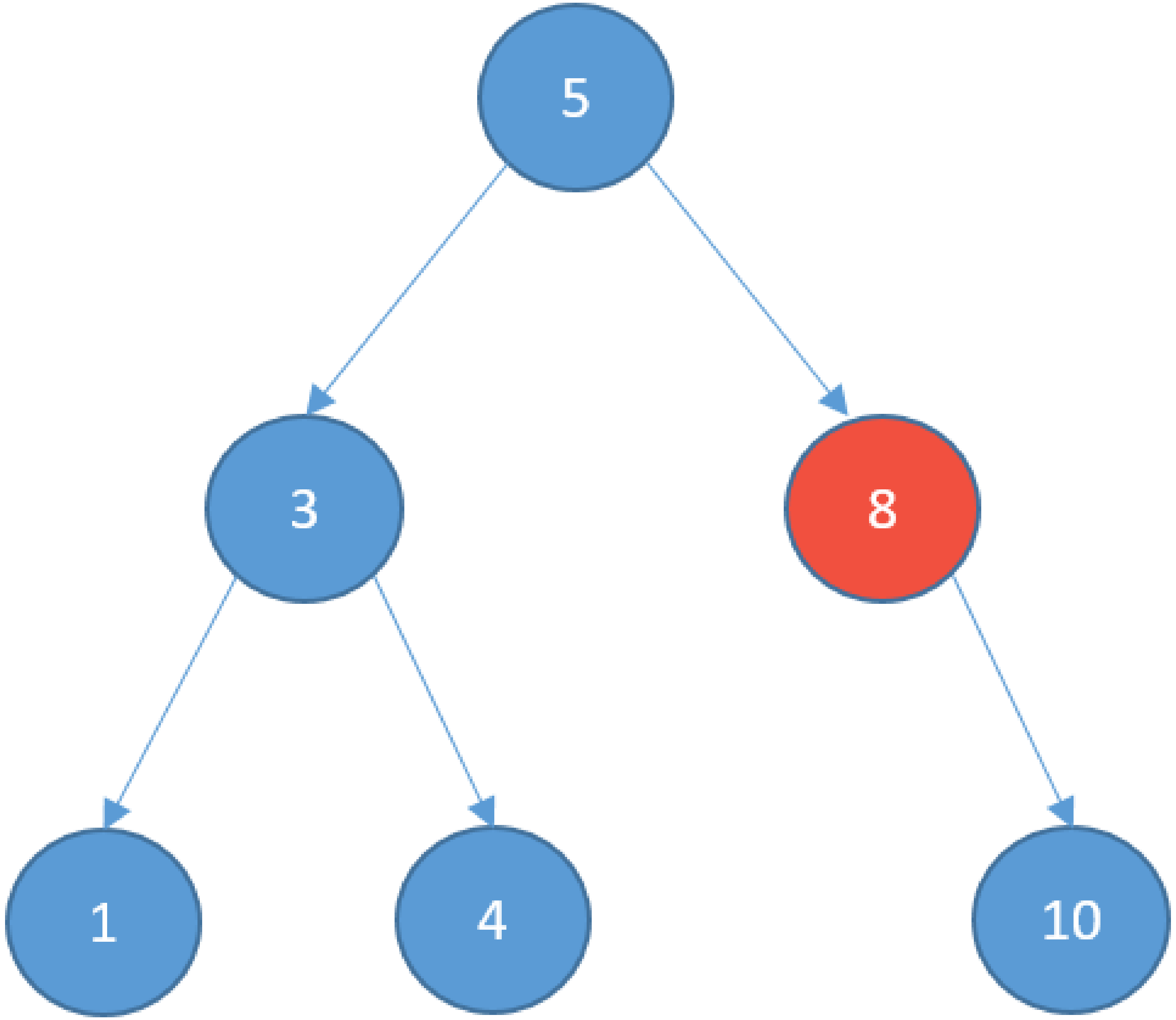
Deleting

- No children
  - delete it



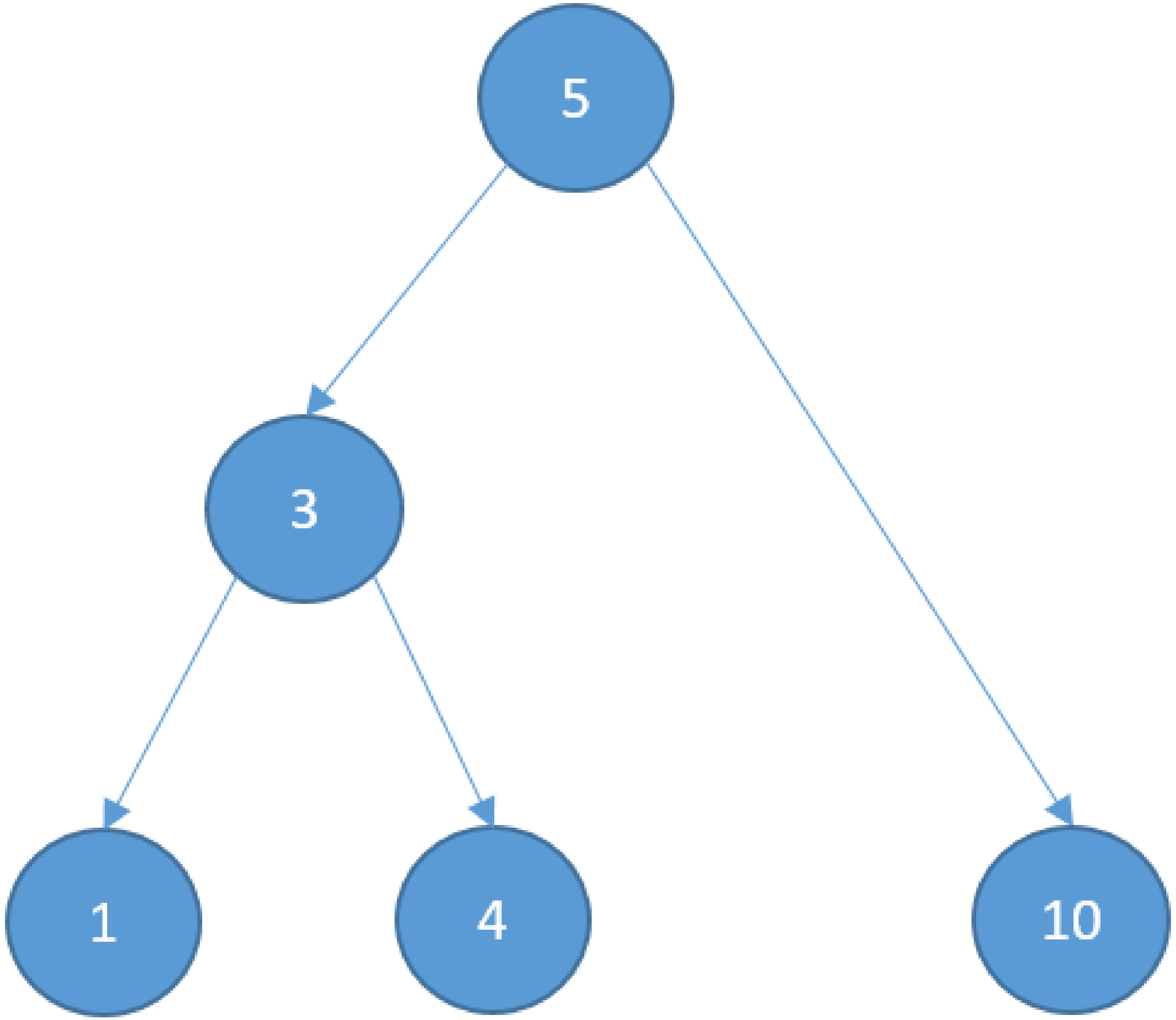
Deleting

- One child



Deleting

- **One child**
  - delete it
  - connect the child with node's parent



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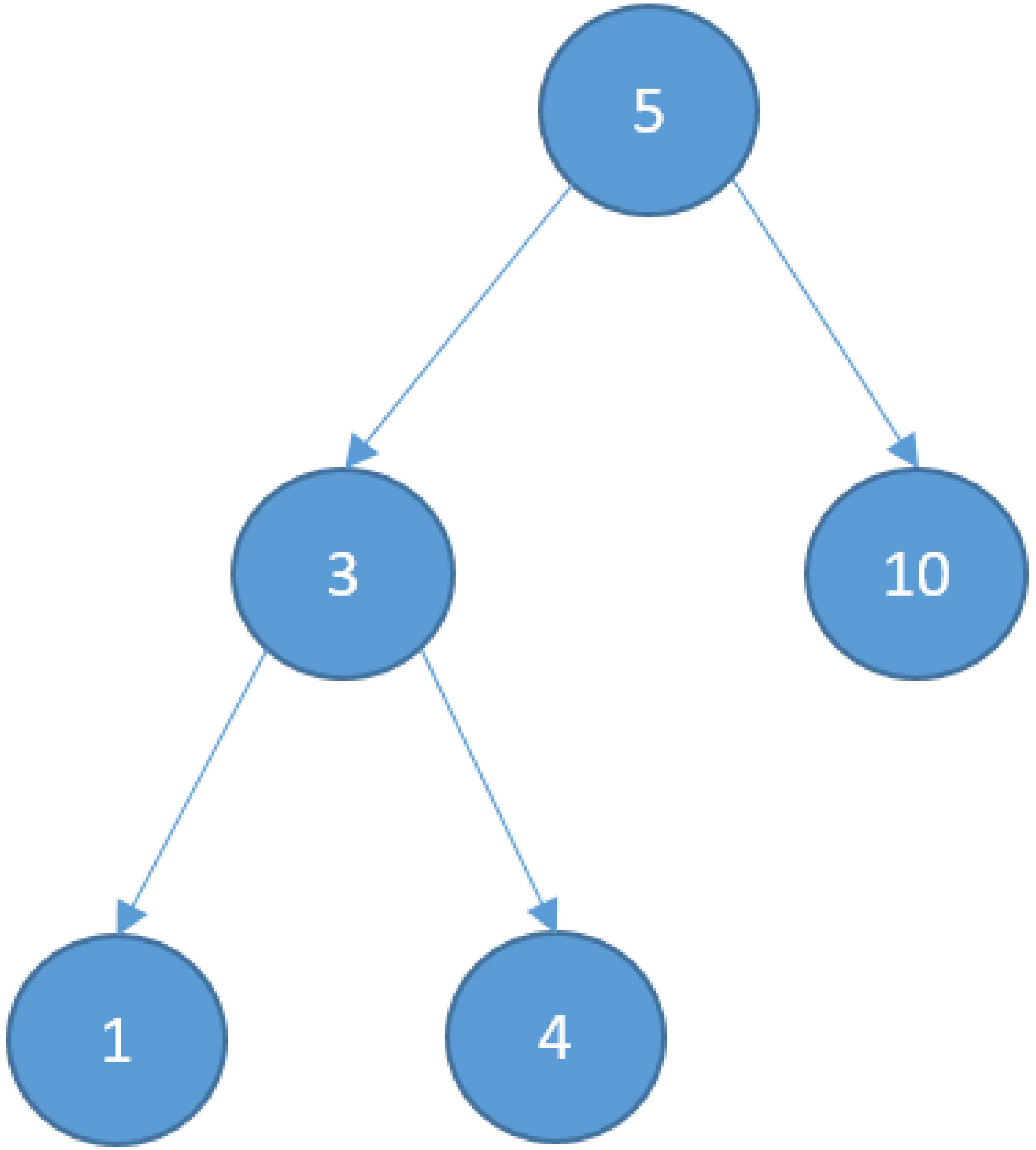
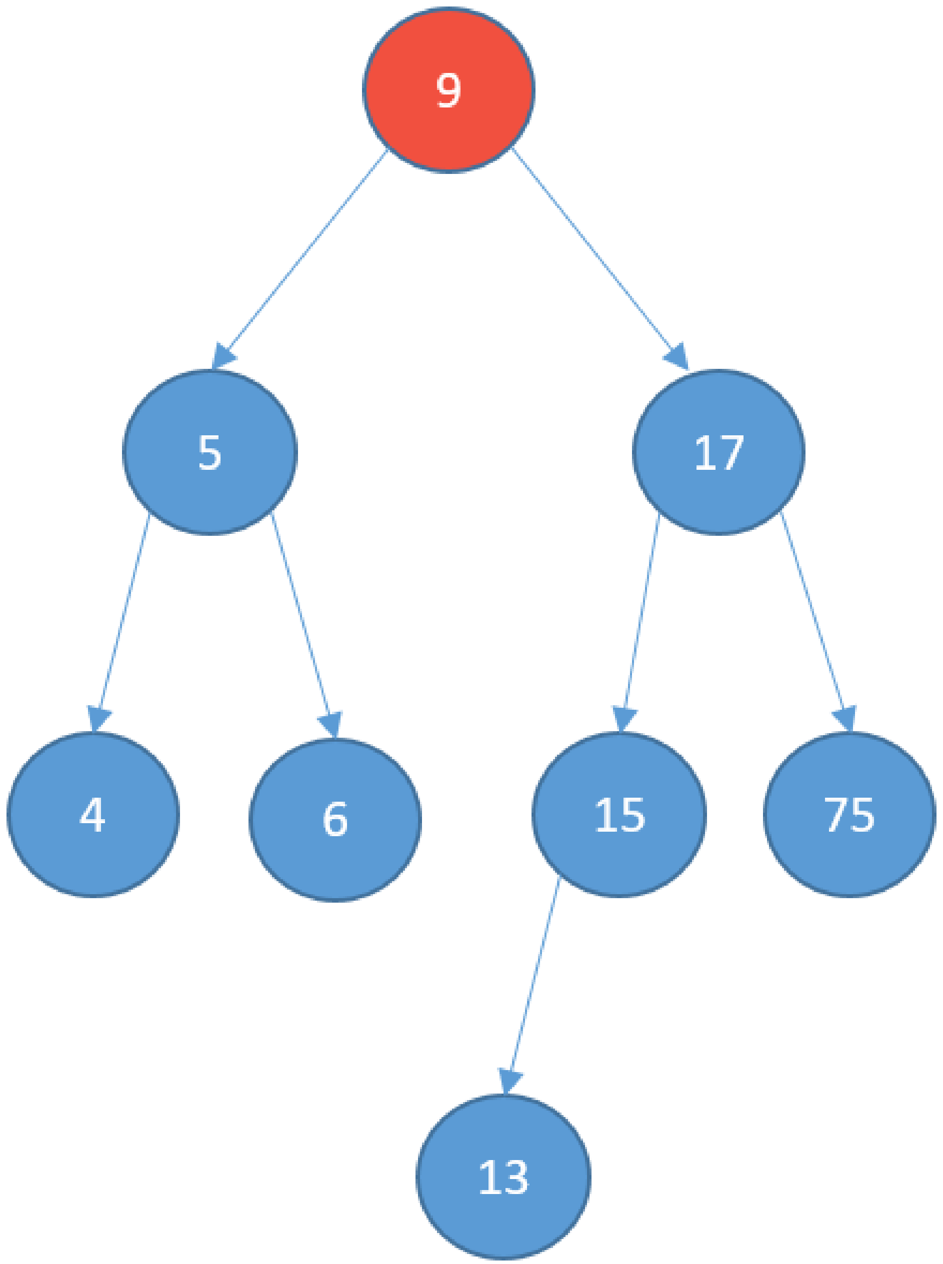


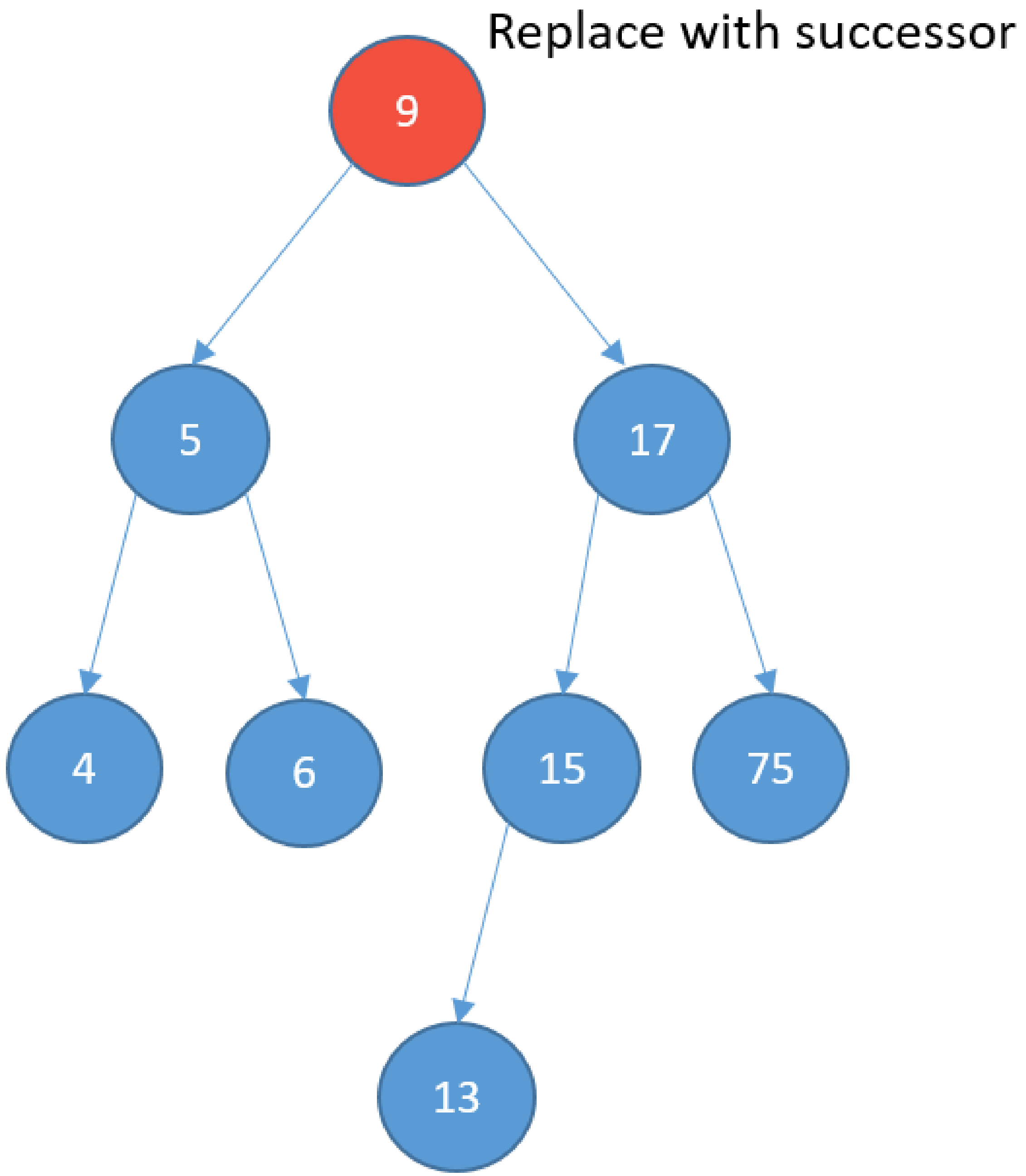
Deleting

- Two children



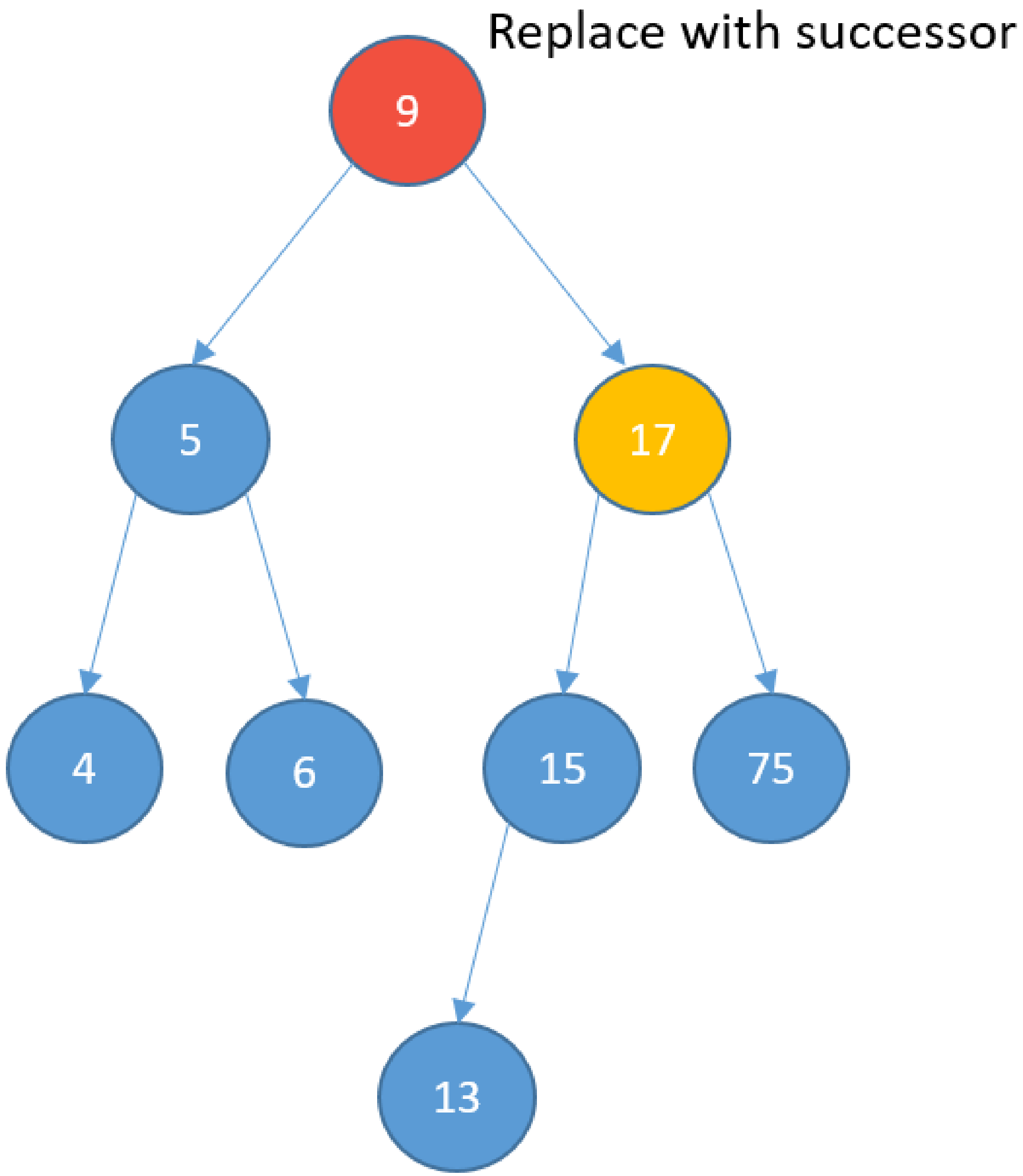
Deleting

- **Two children**
  - replace it with its successor
    - the node with the smallest value greater than the value of the node
  - find the successor:



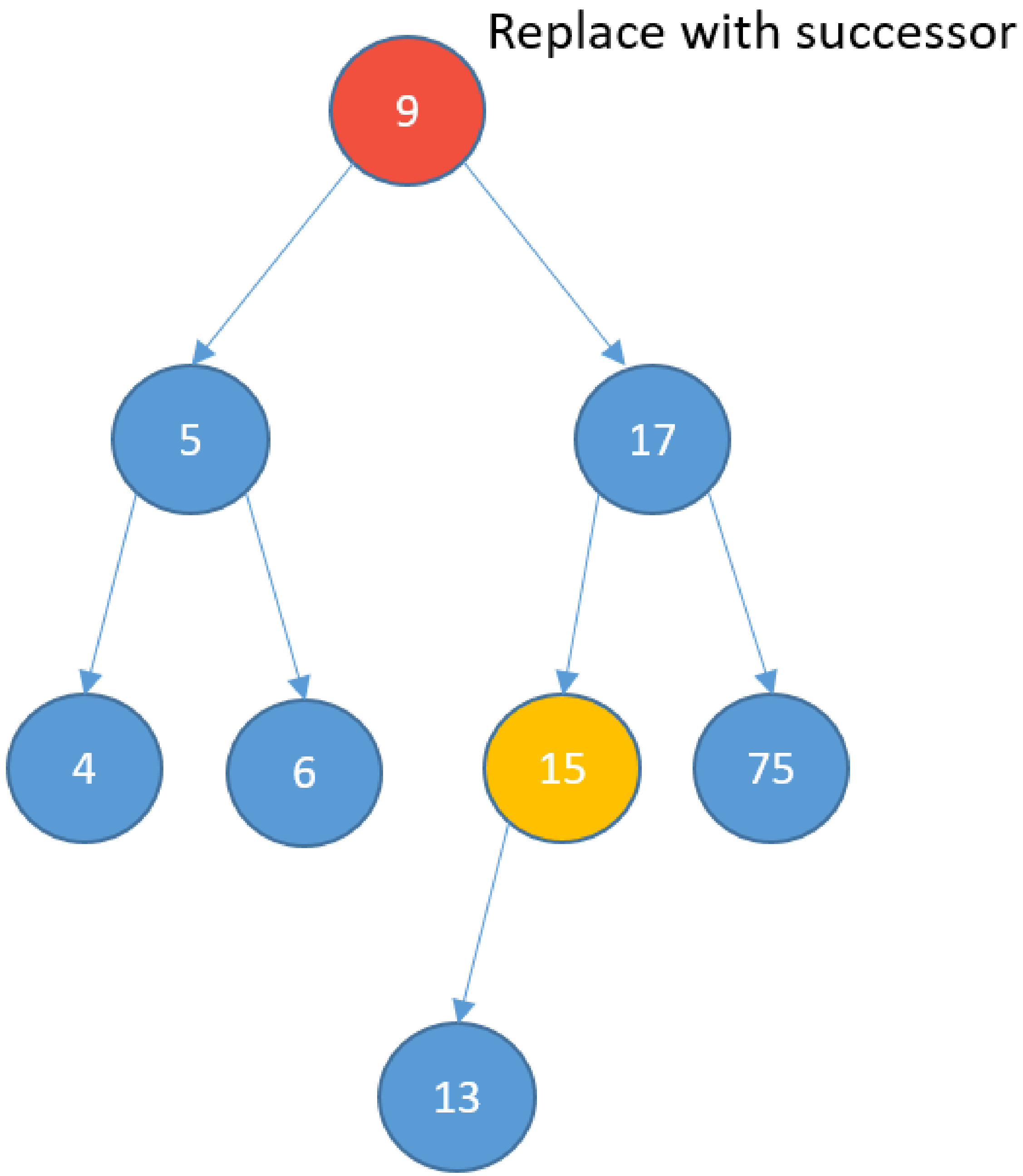
Deleting

- **Two children**
  - replace it with its successor
    - the node with the least value greater than the value of the node
  - find the successor:
    - visit the right child



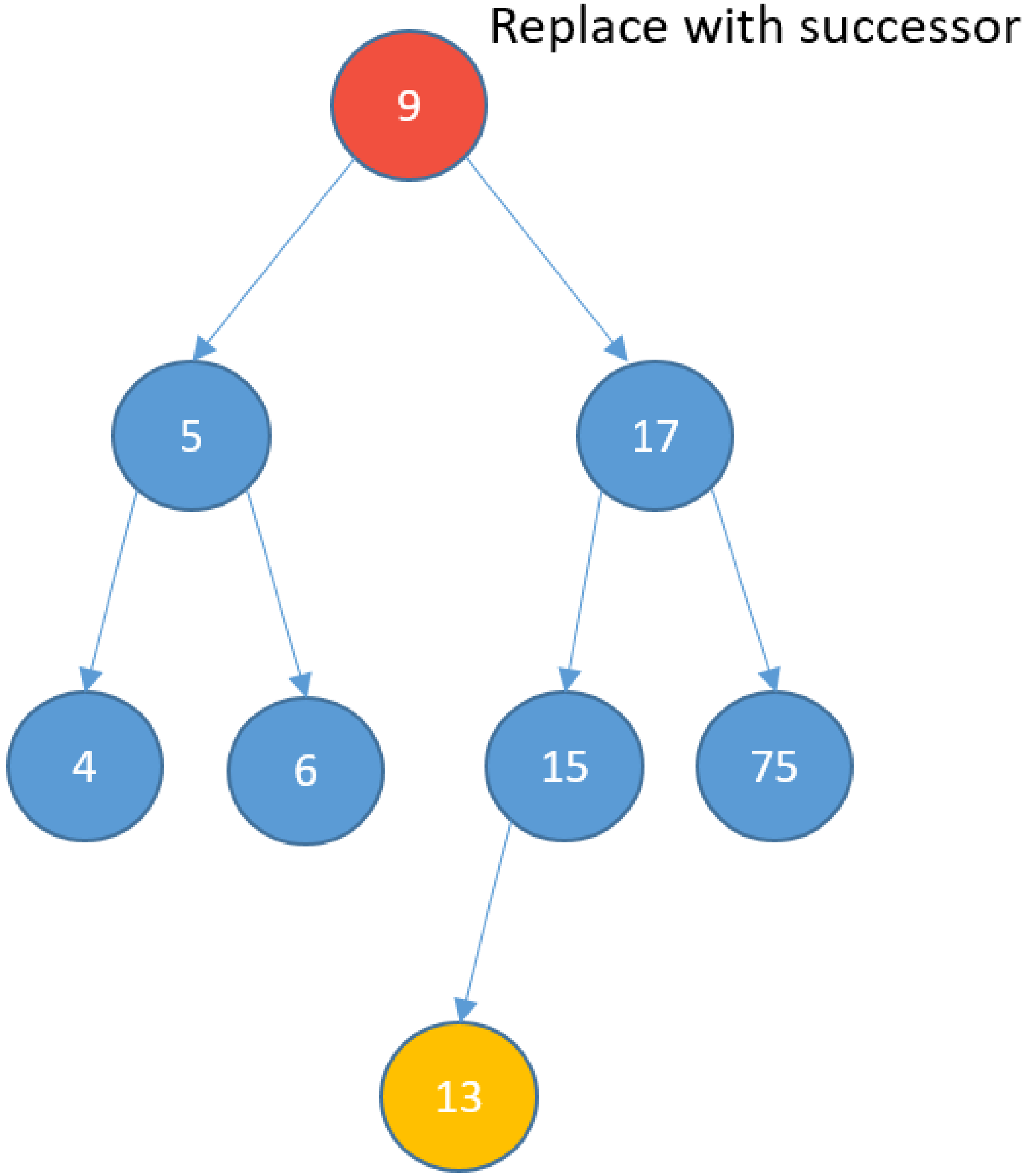
Deleting

- **Two children**
  - replace it with its successor
    - the node with the least value greater than the value of the node
  - find the successor:
    - visit the right child
    - keep visiting the left nodes until the end



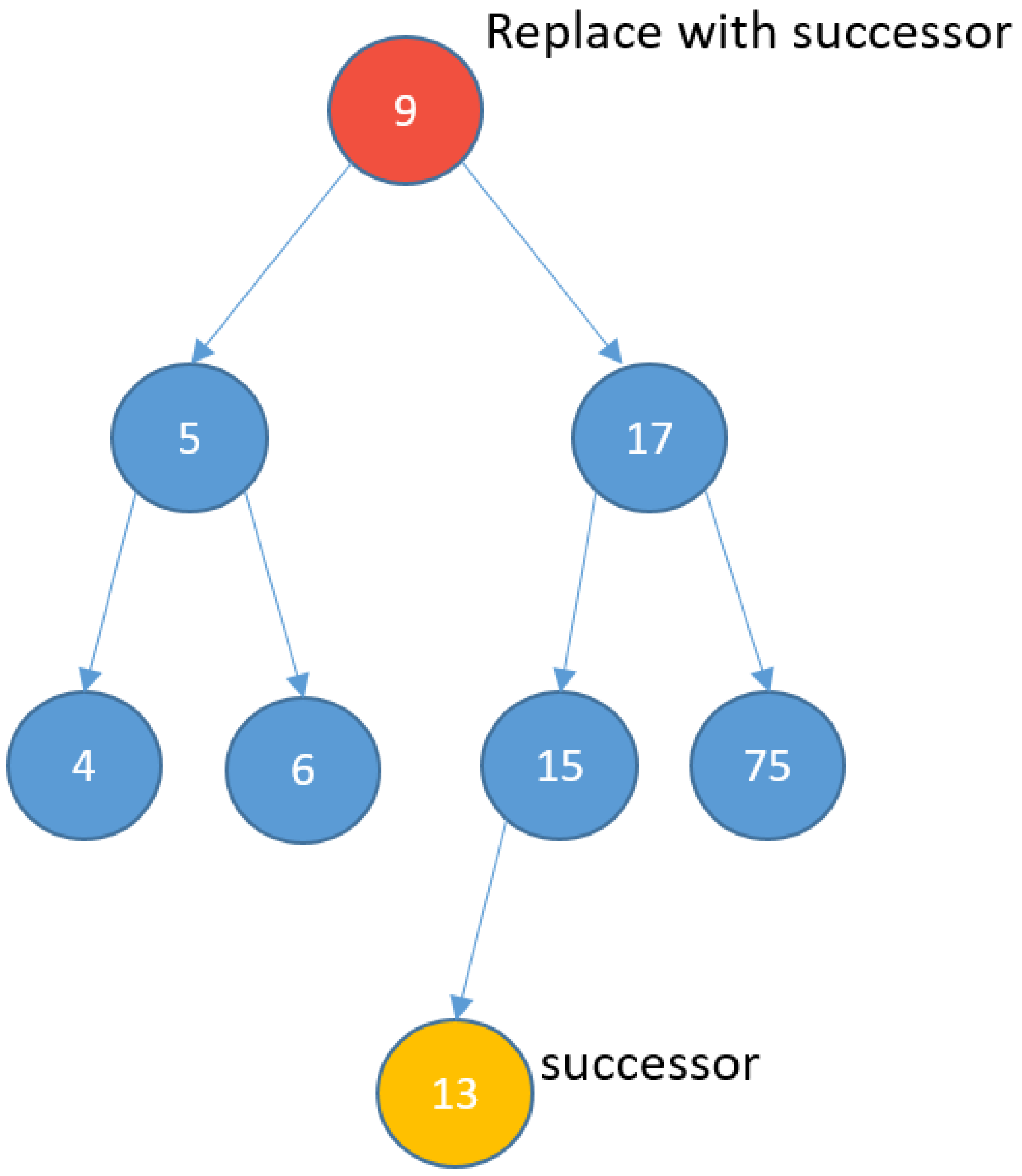
Deleting

- **Two children**
  - replace it with its successor
    - the node with the least value greater than the value of the node
  - find the successor:
    - visit the right child
    - keep visiting the left nodes until the end



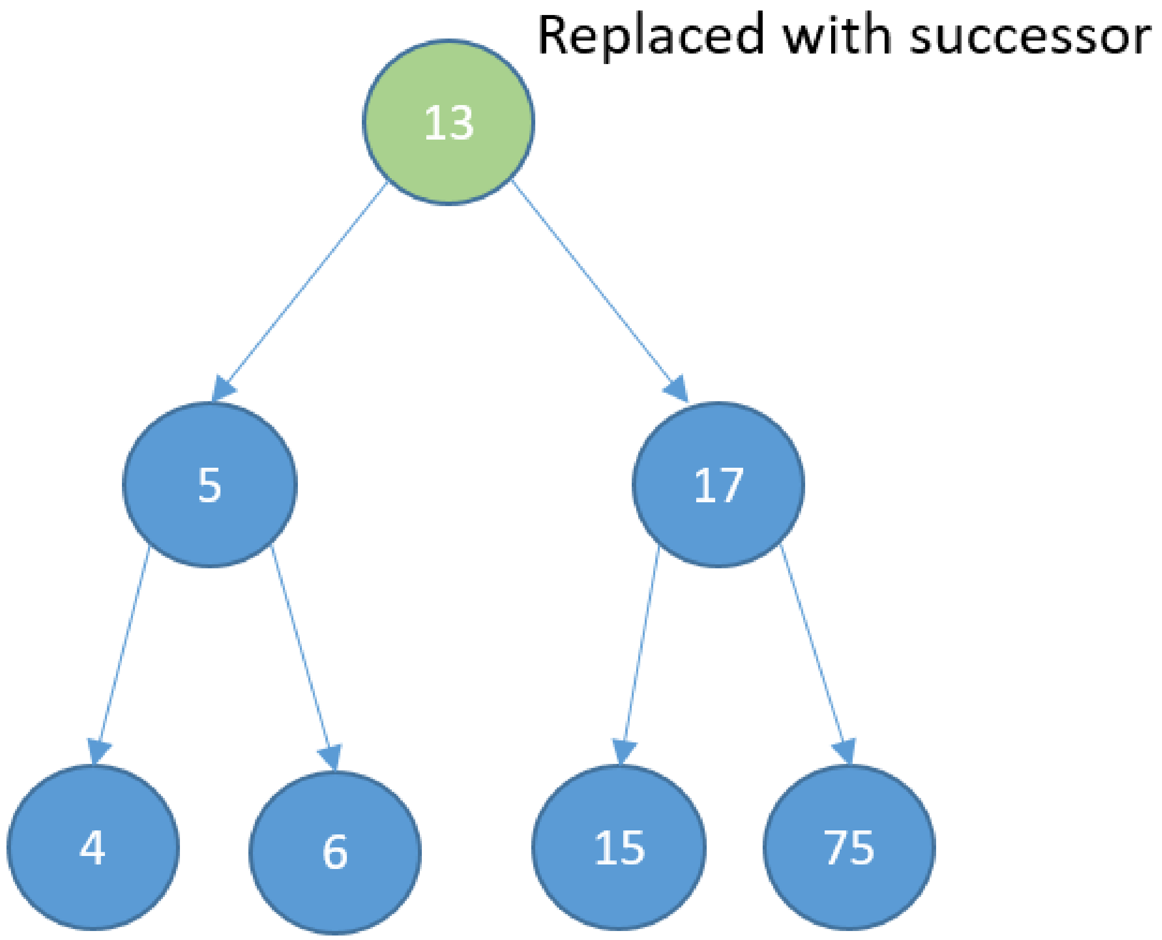
Deleting

- **Two children**
  - replace it with its successor
    - the node with the least value greater than the value of the node
  - find the successor:
    - visit the right child
    - keep visiting the left nodes until the end



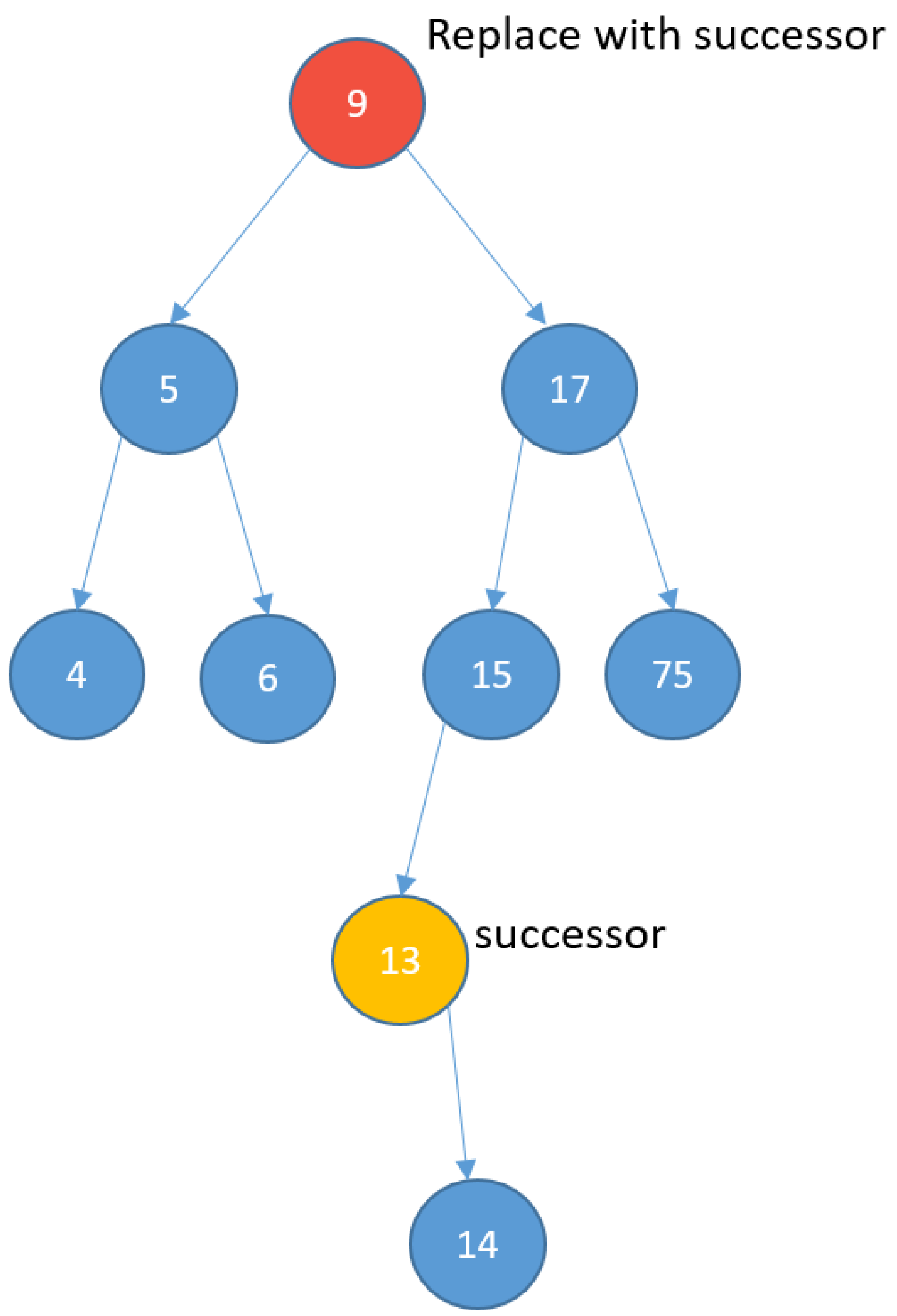
Deleting

- **Two children**
  - replace it with its successor
    - the node with the least value greater than the value of the node
  - find the successor:
    - visit the right child
    - keep visiting the left nodes until the end



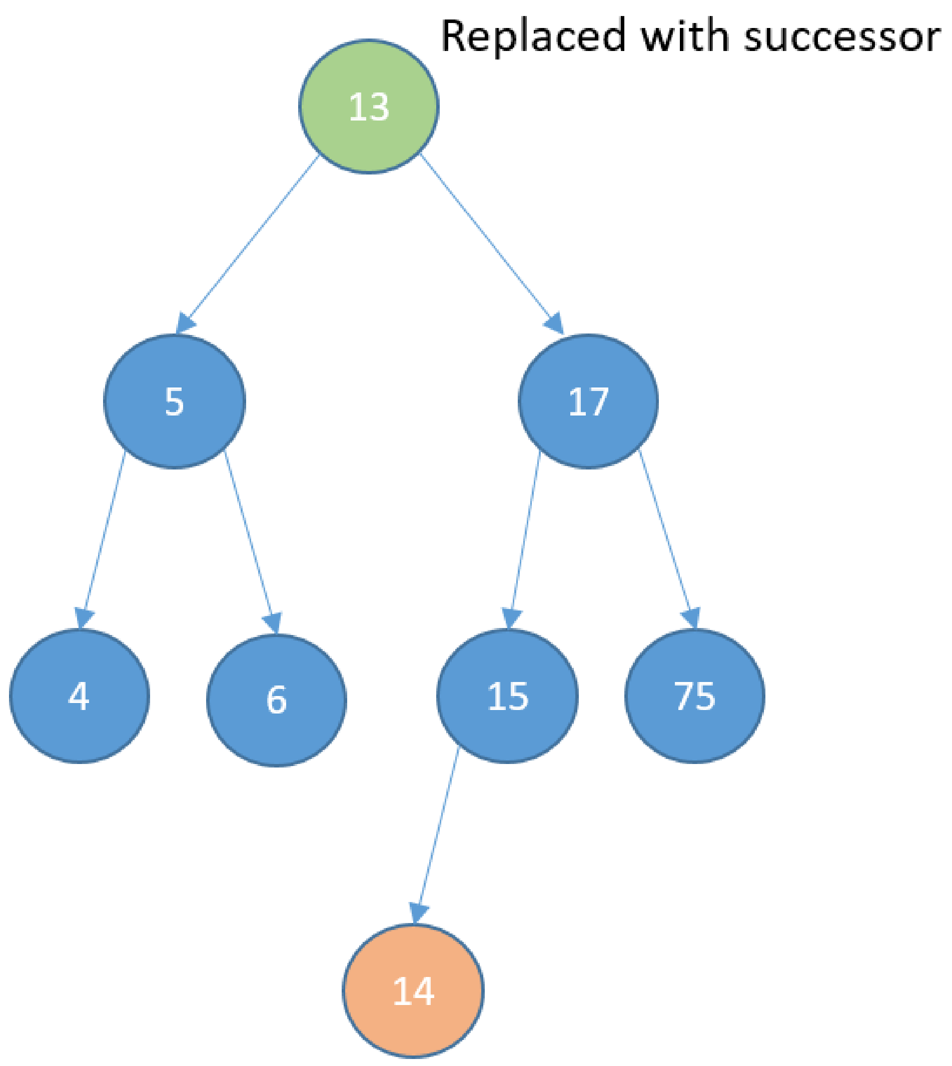
Deleting

- **Two children**
  - replace it with its successor
    - the node with the least value greater than the value of the node
  - find the successor:
    - visit the right child
    - keep visiting the left nodes until the end
    - if the successor has a right child:



Deleting

- **Two children**
  - replace it with its successor
    - the node with the least value greater than the value of the node
  - find the successor:
    - visit the right child
    - keep visiting the left nodes until the end
    - if the successor has a right child:
      - child becomes the left child of successor's parent.



Uses

- Order lists efficiently
- Much faster at searching than arrays and linked lists
- Much faster at inserting and deleting than arrays
- Used to implement more advanced data structures:
  - dynamic sets
  - lookup tables
  - priority queues

Let's practice!

DATA STRUCTURES AND ALGORITHMS IN PYTHON

Depth First Search (DFS)

DATA STRUCTURES AND ALGORITHMS IN PYTHON

Miriam Antona
Software engineer

Tree/graph traversal

- Process of visiting **all nodes**
- Depth first search (DFS)
- Breadth first search (BFS)

Depth first search - binary trees

- In-order
- Pre-order
- Post-order

In-order traversal

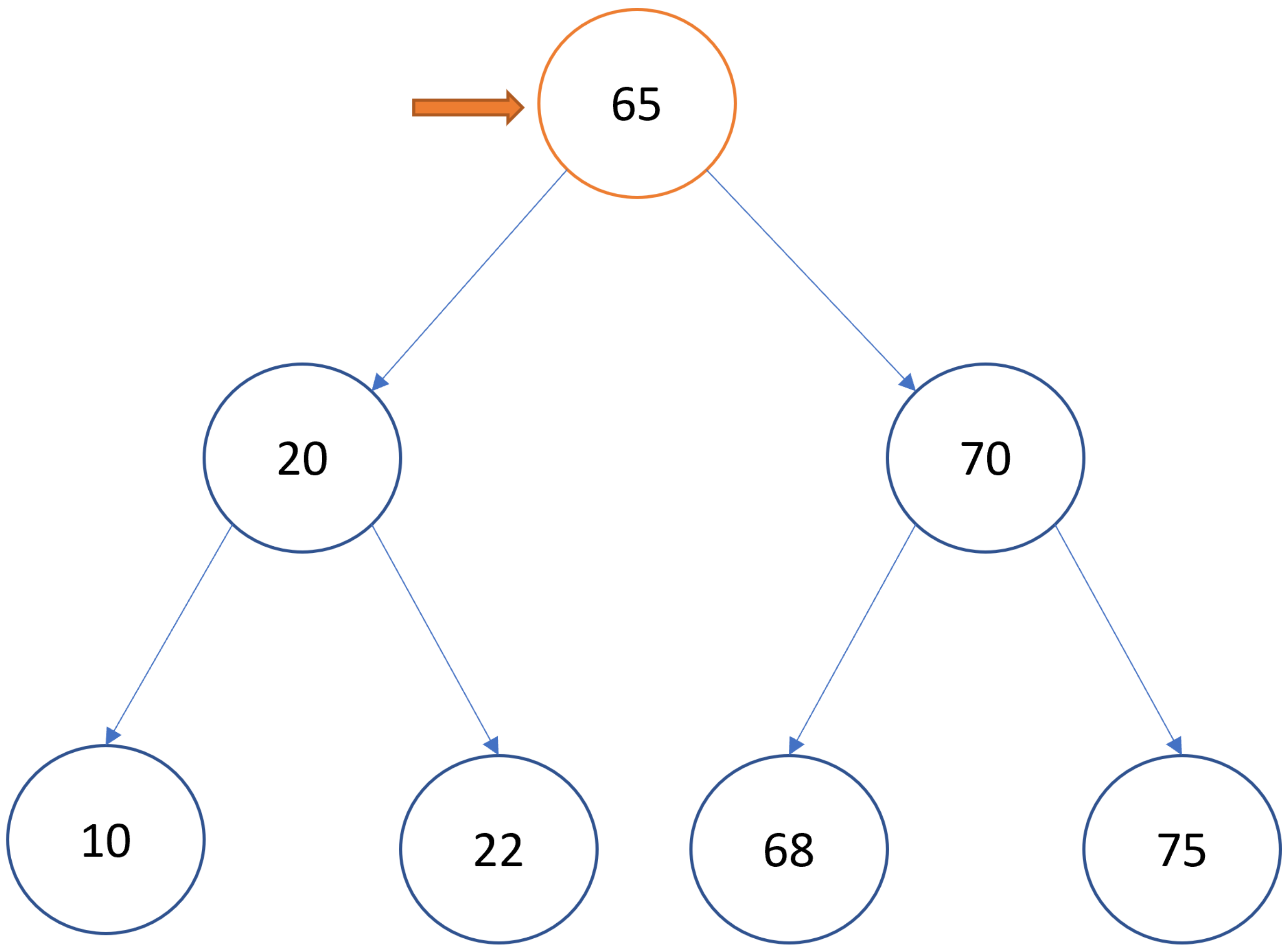
- **Order:** Left

In-order traversal

- **Order:** Left -> Current

In-order traversal

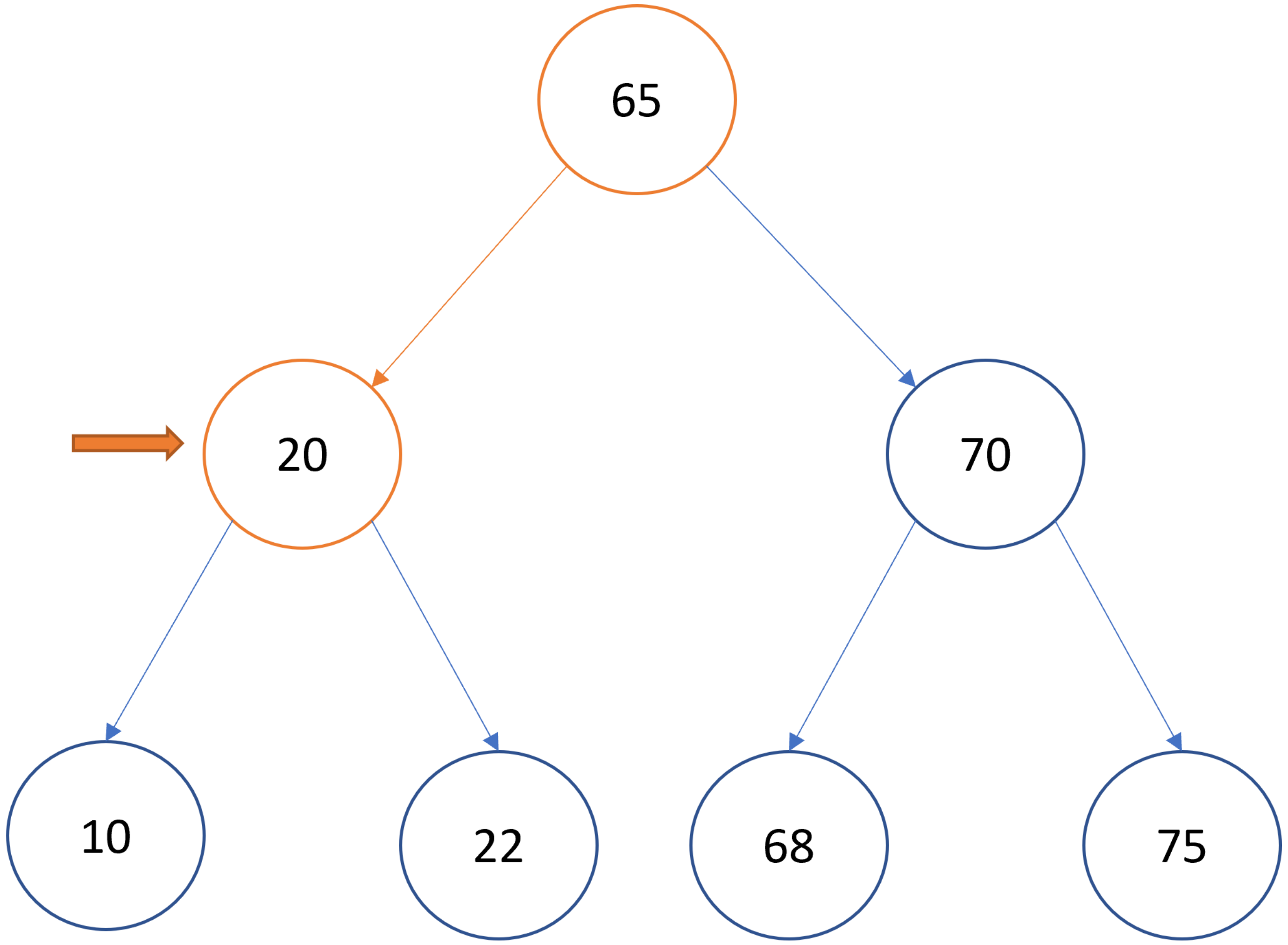
- **Order:** Left -> Current -> Right



Visited nodes:

In-order traversal

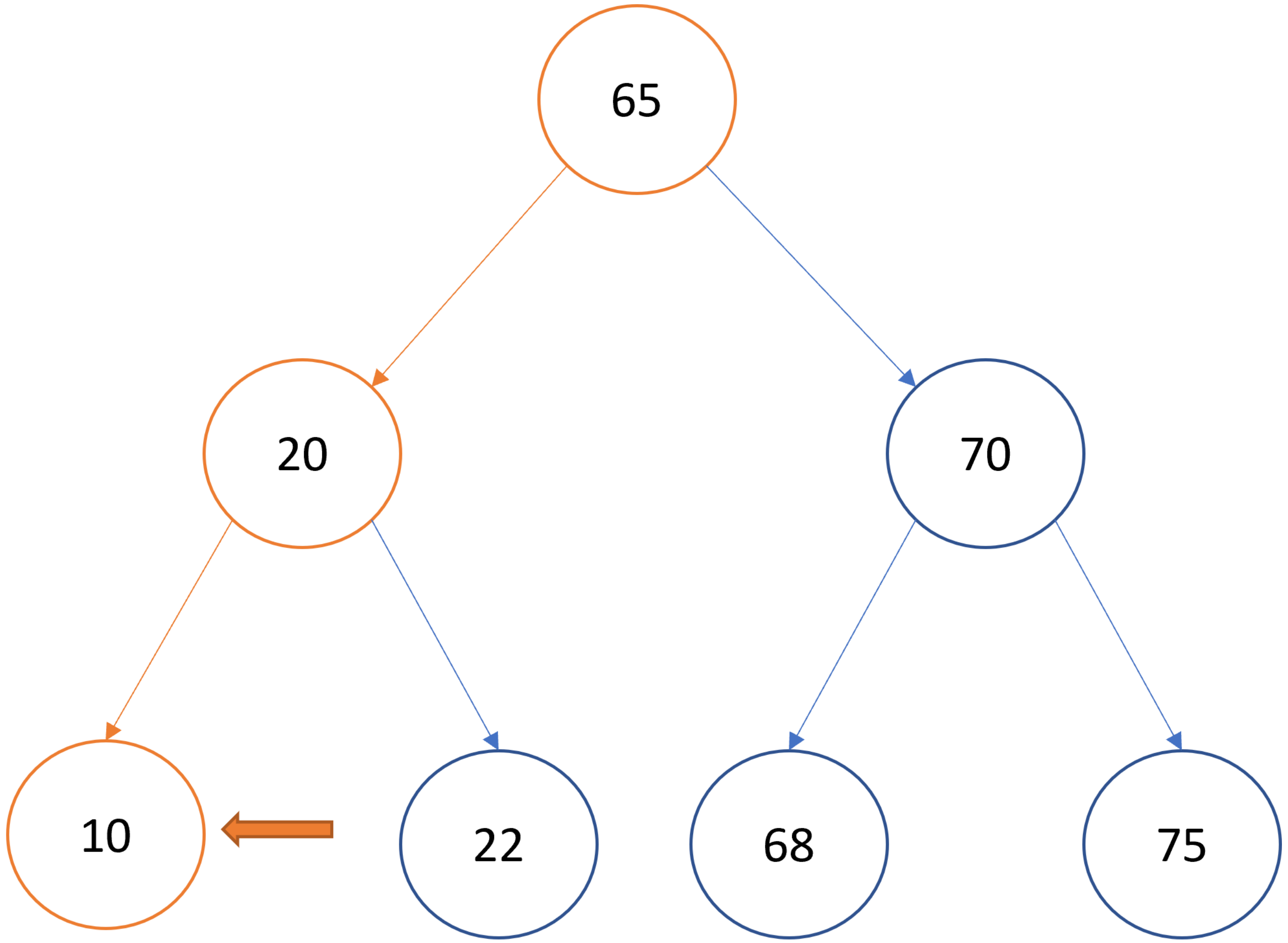
- **Order:** Left -> Current -> Right



Visited nodes:

In-order traversal

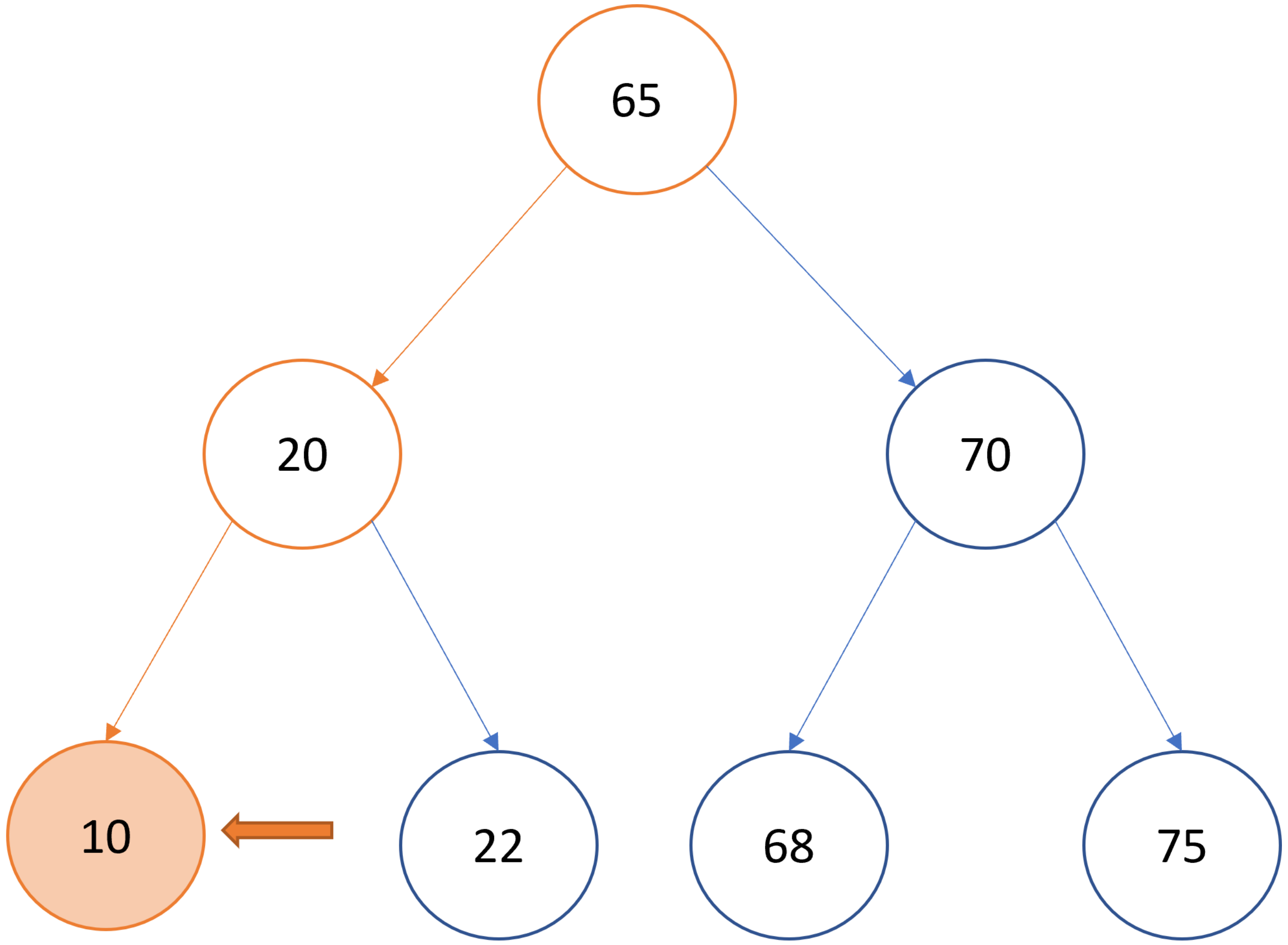
- **Order:** Left -> Current -> Right



Visited nodes:

In-order traversal

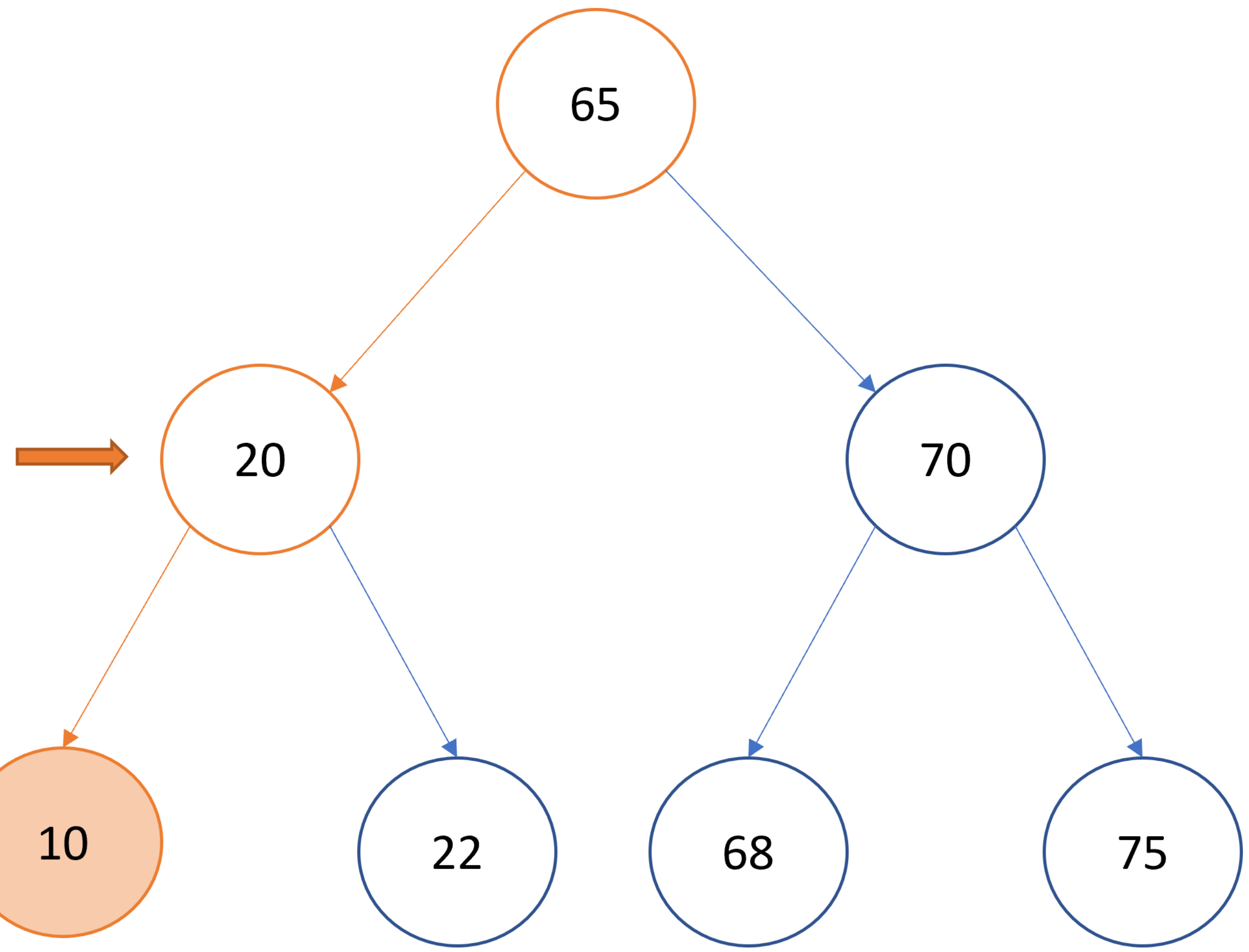
- **Order:** Left -> Current -> Right



Visited nodes: 10

In-order traversal

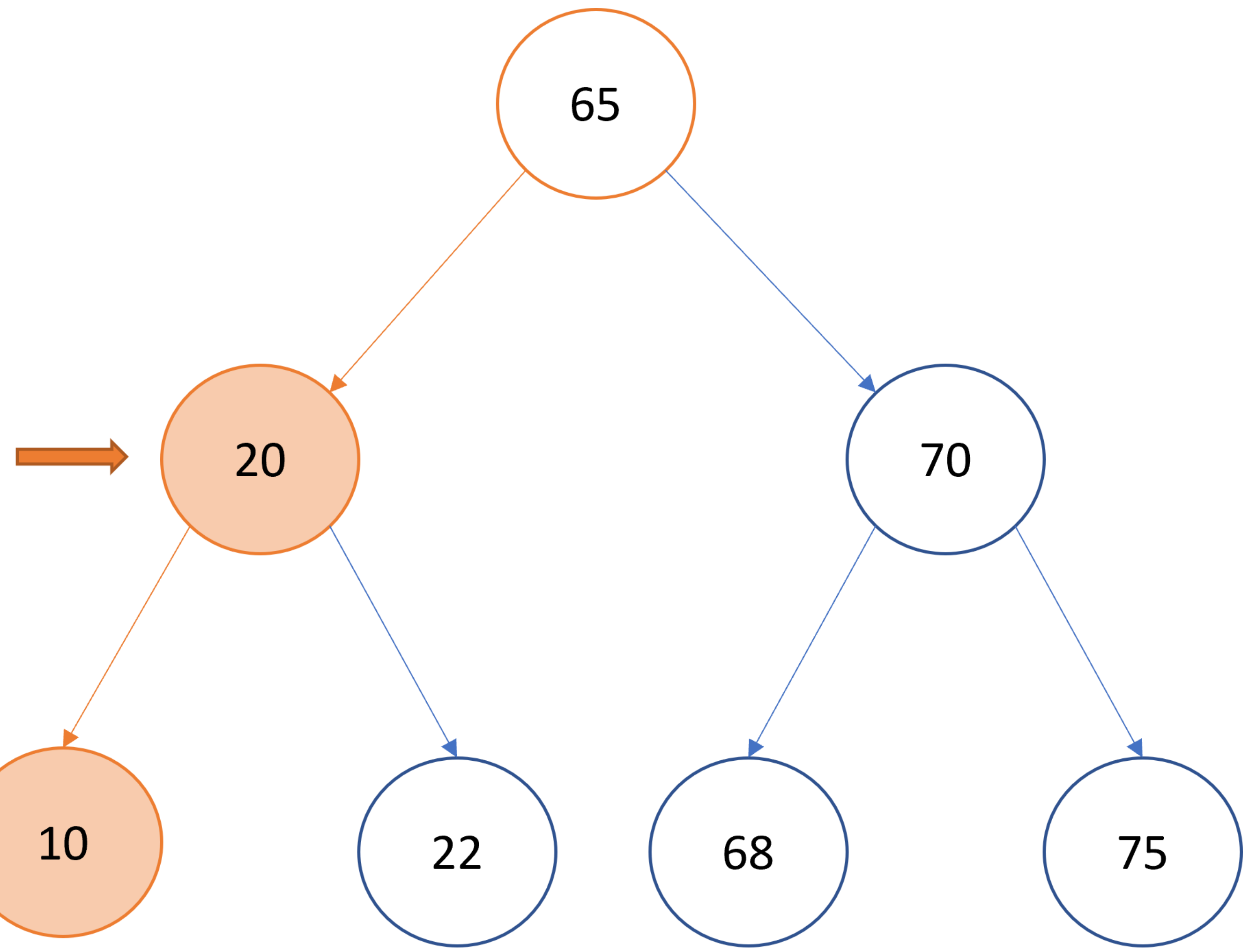
- **Order:** Left -> Current -> Right



Visited nodes: 10

In-order traversal

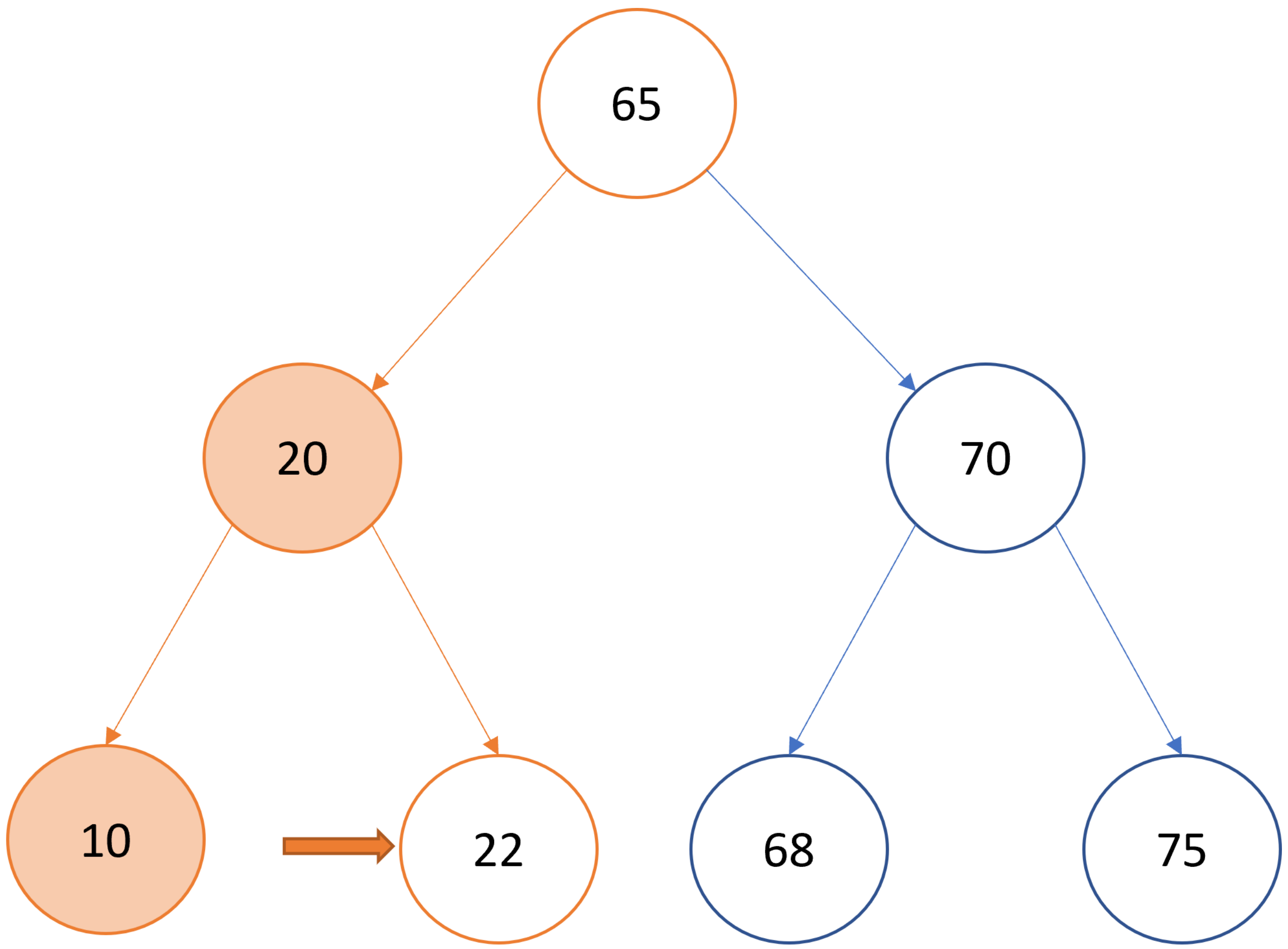
- **Order:** Left -> Current -> Right



Visited nodes: 10, 20

In-order traversal

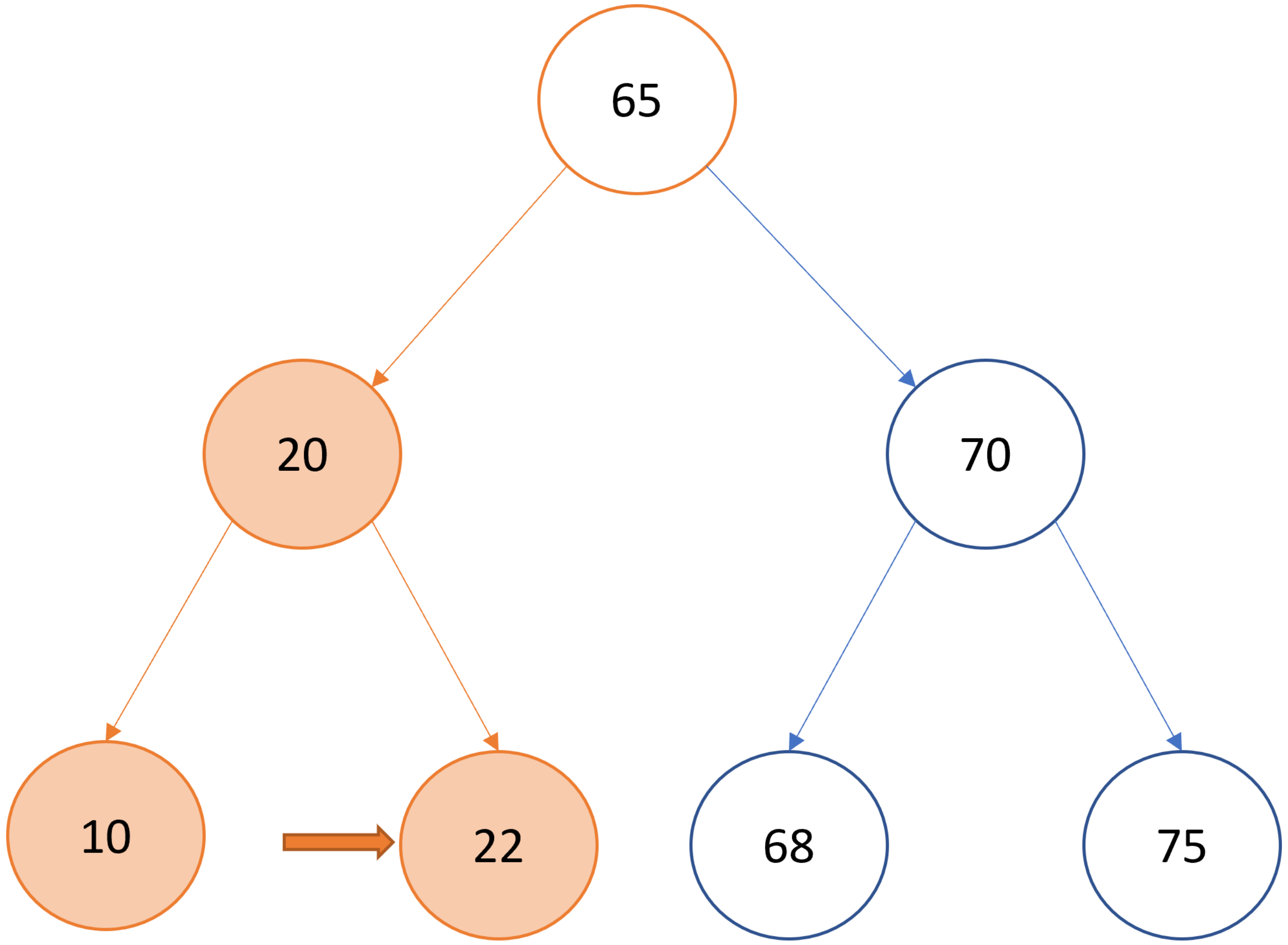
- **Order:** Left -> Current -> Right



Visited nodes: 10, 20

In-order traversal

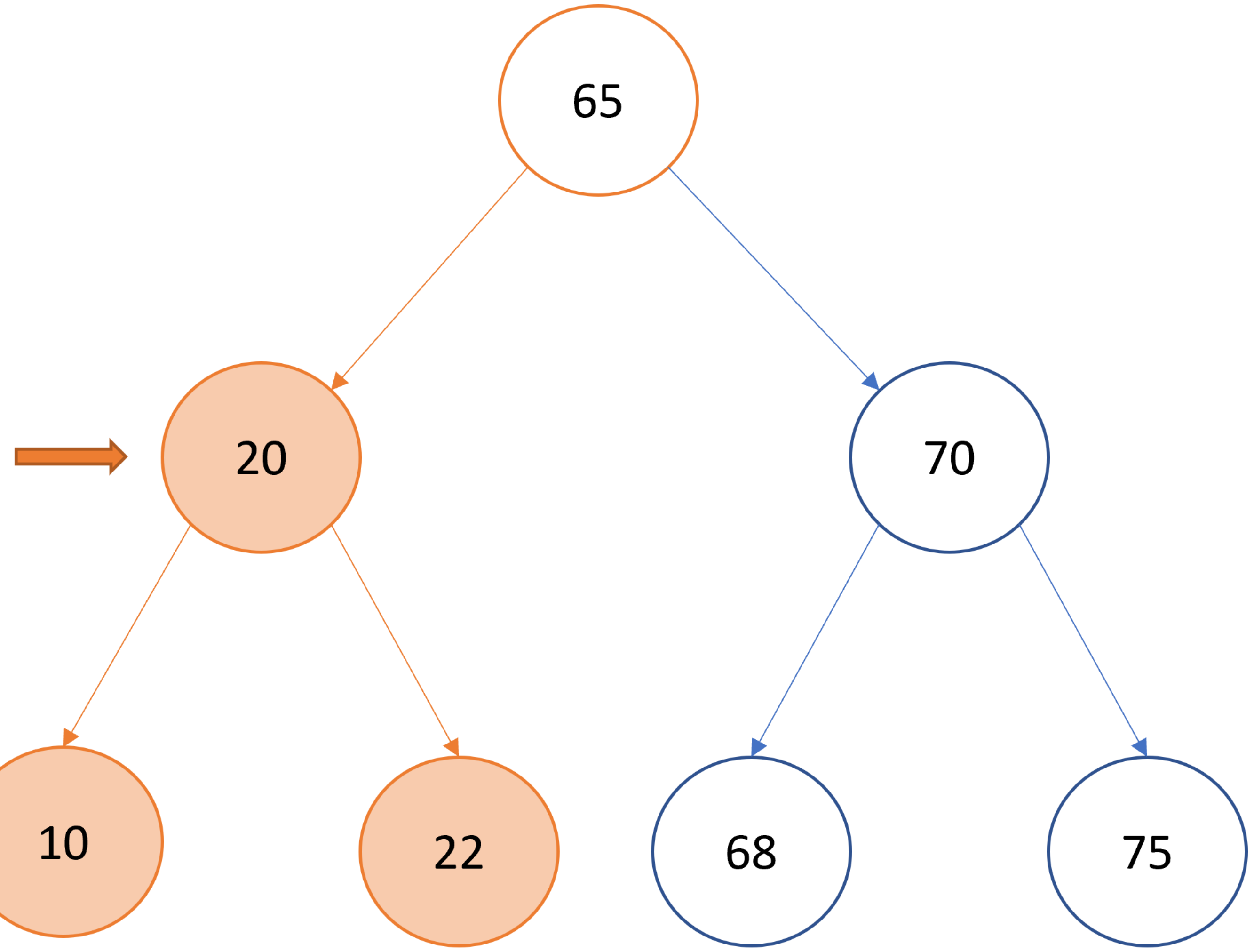
- **Order:** Left -> Current -> Right



Visited nodes: 10, 20, 22

In-order traversal

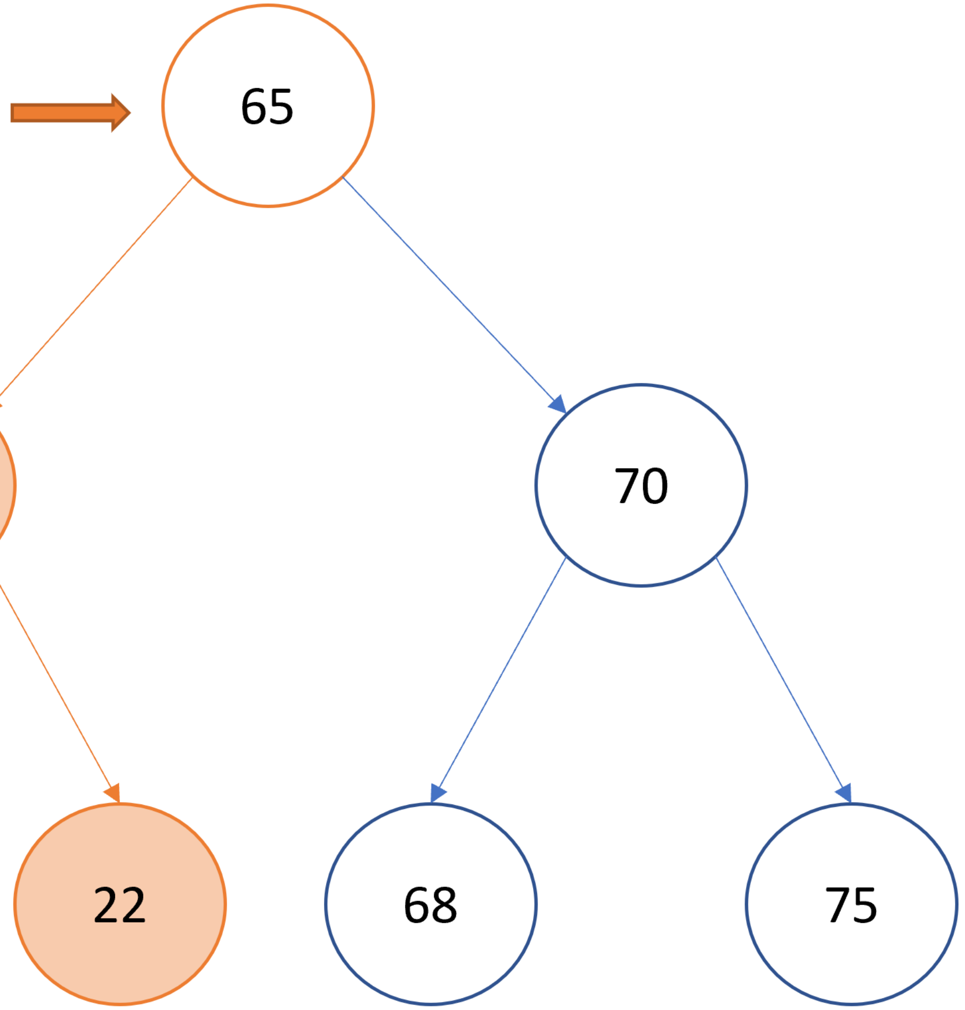
- **Order:** Left -> Current -> Right



Visited nodes: 10, 20, 22

In-order traversal

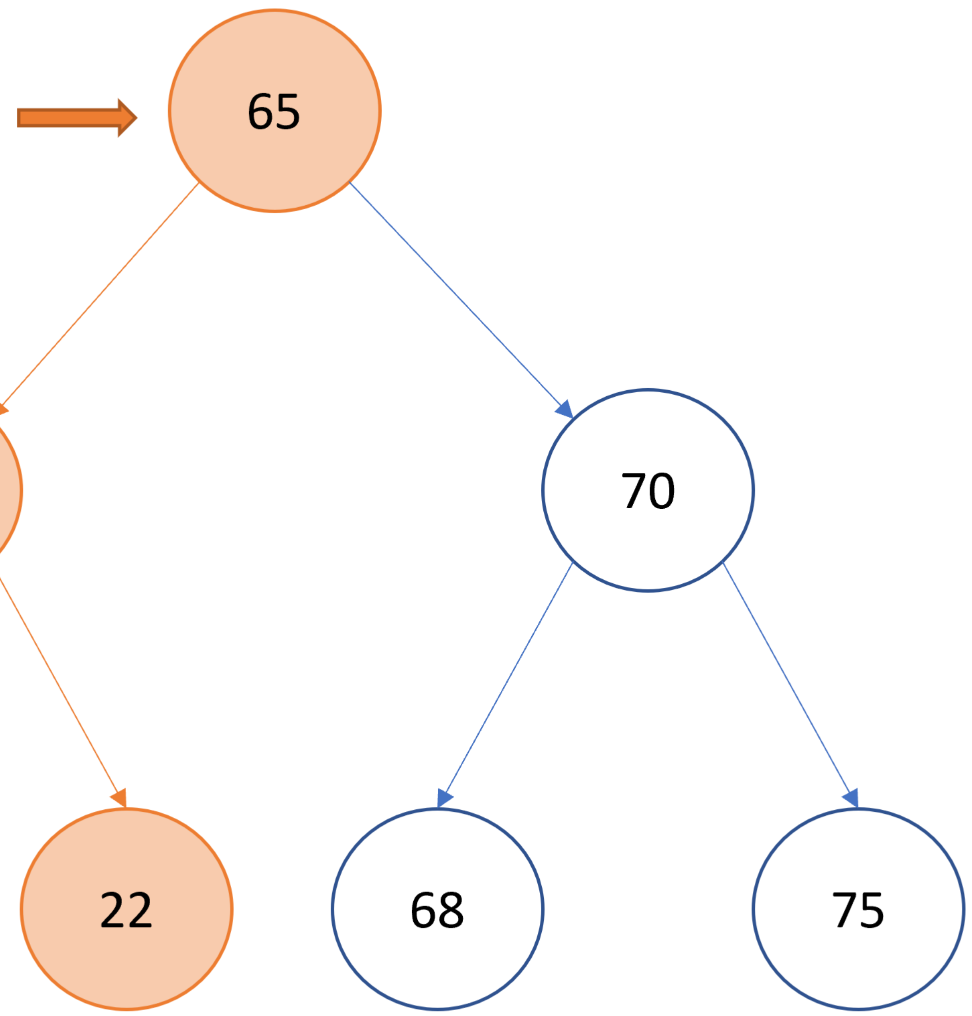
- **Order:** Left -> Current -> Right



Visited nodes: 10, 20, 22

In-order traversal

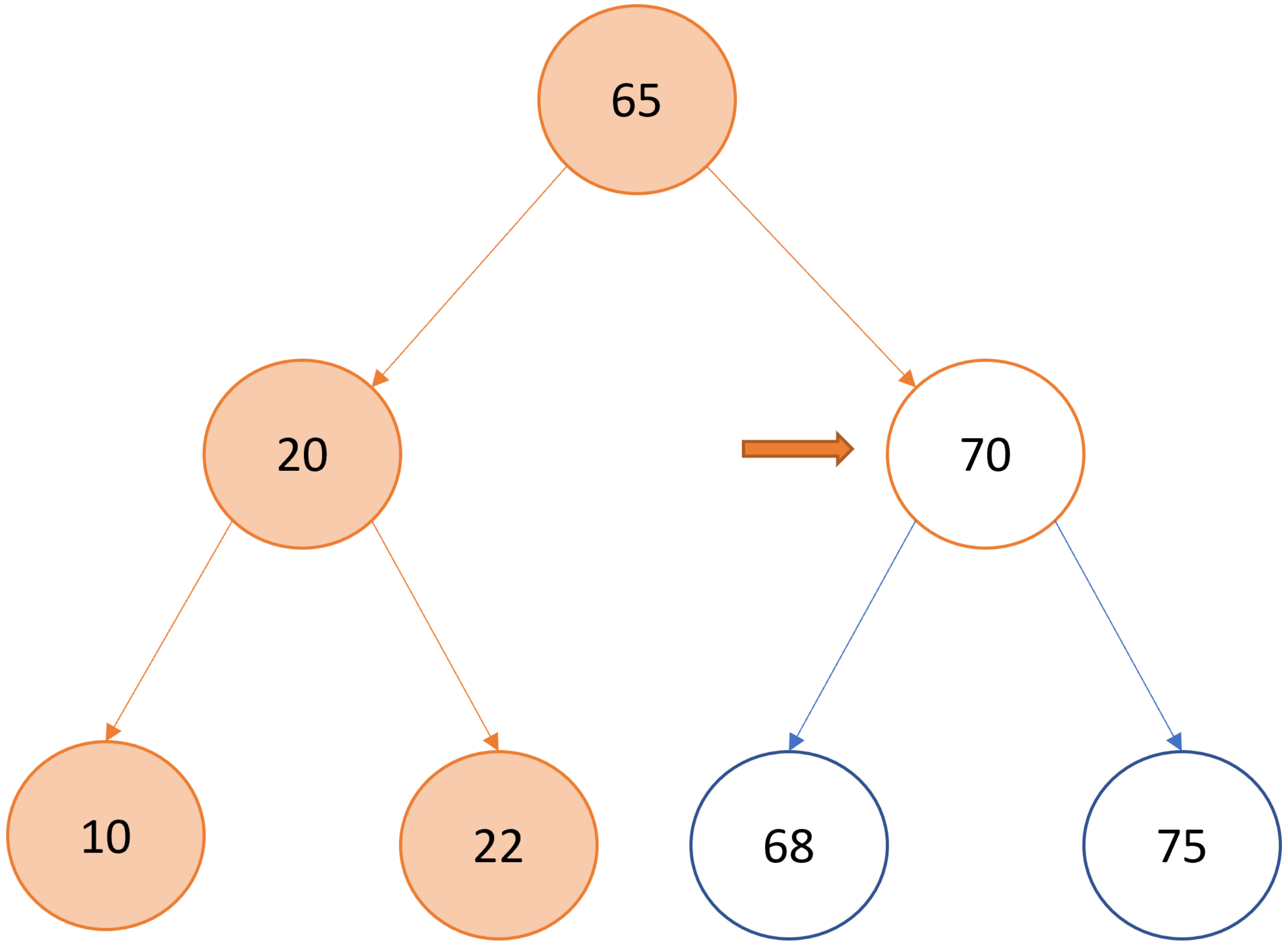
- **Order:** Left -> Current -> Right



Visited nodes: 10, 20, 22, 65

In-order traversal

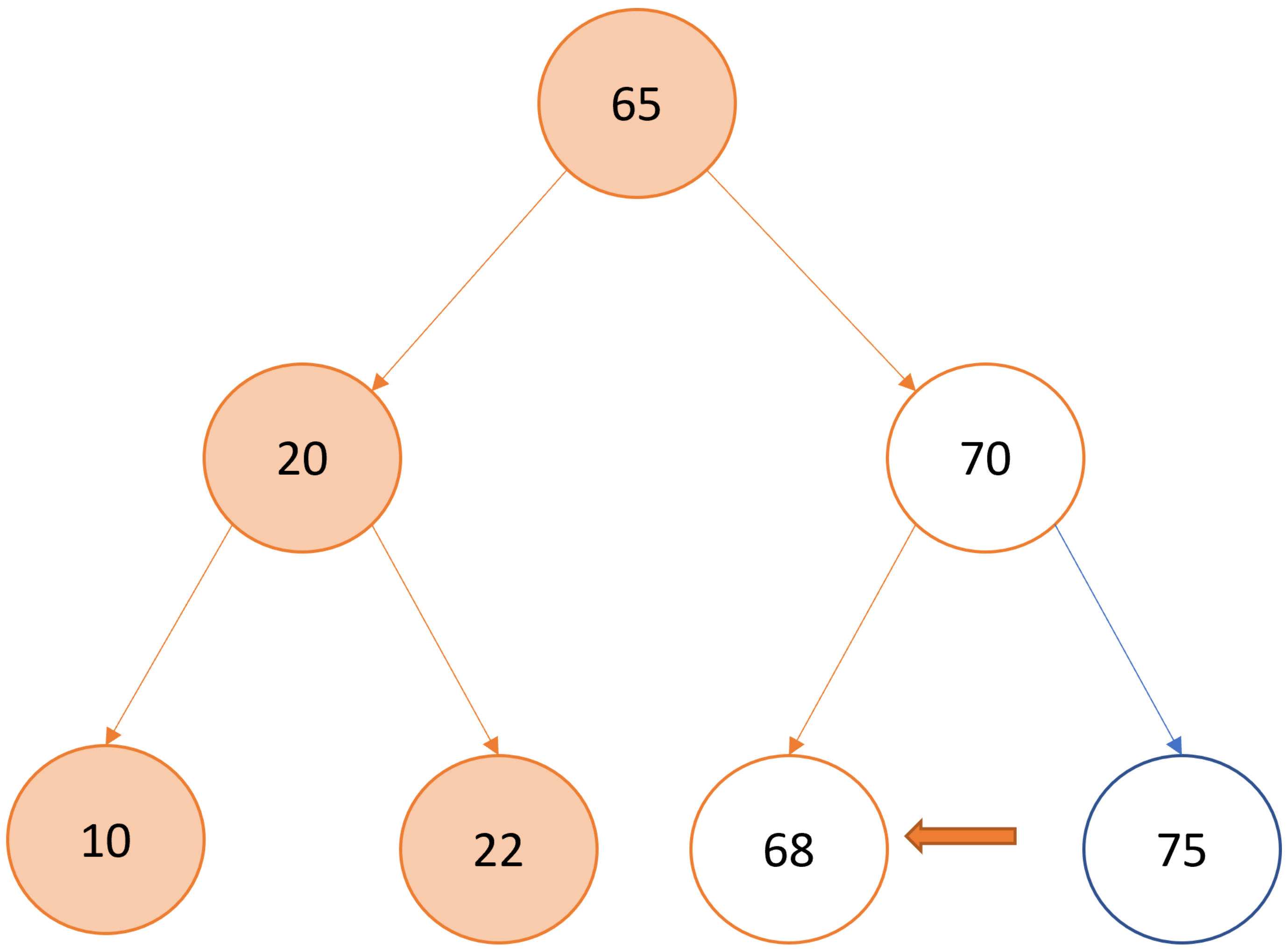
- **Order:** Left -> Current -> Right



Visited nodes: 10, 20, 22, 65

In-order traversal

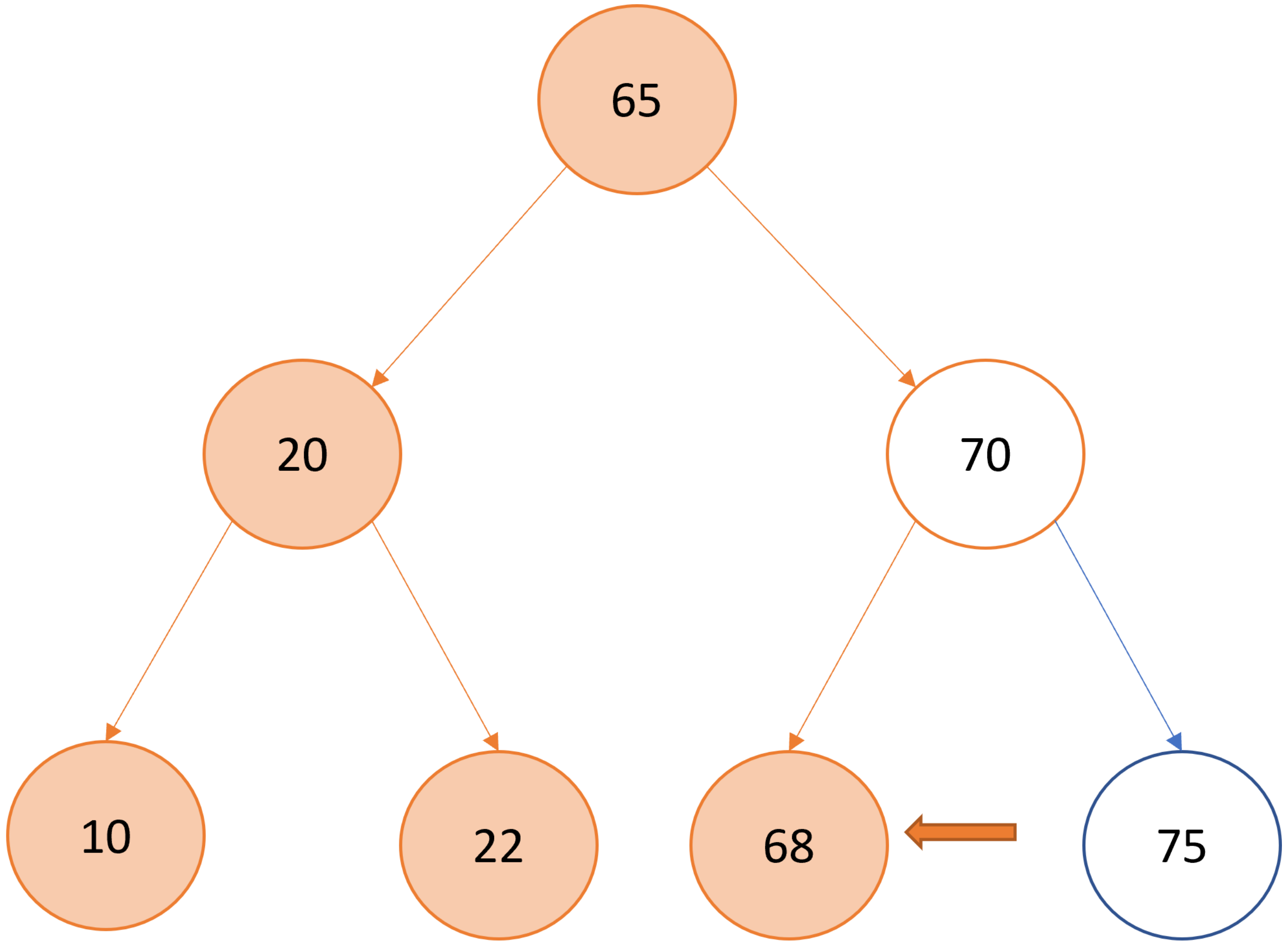
- **Order:** Left -> Current -> Right



Visited nodes: 10, 20, 22, 65

In-order traversal

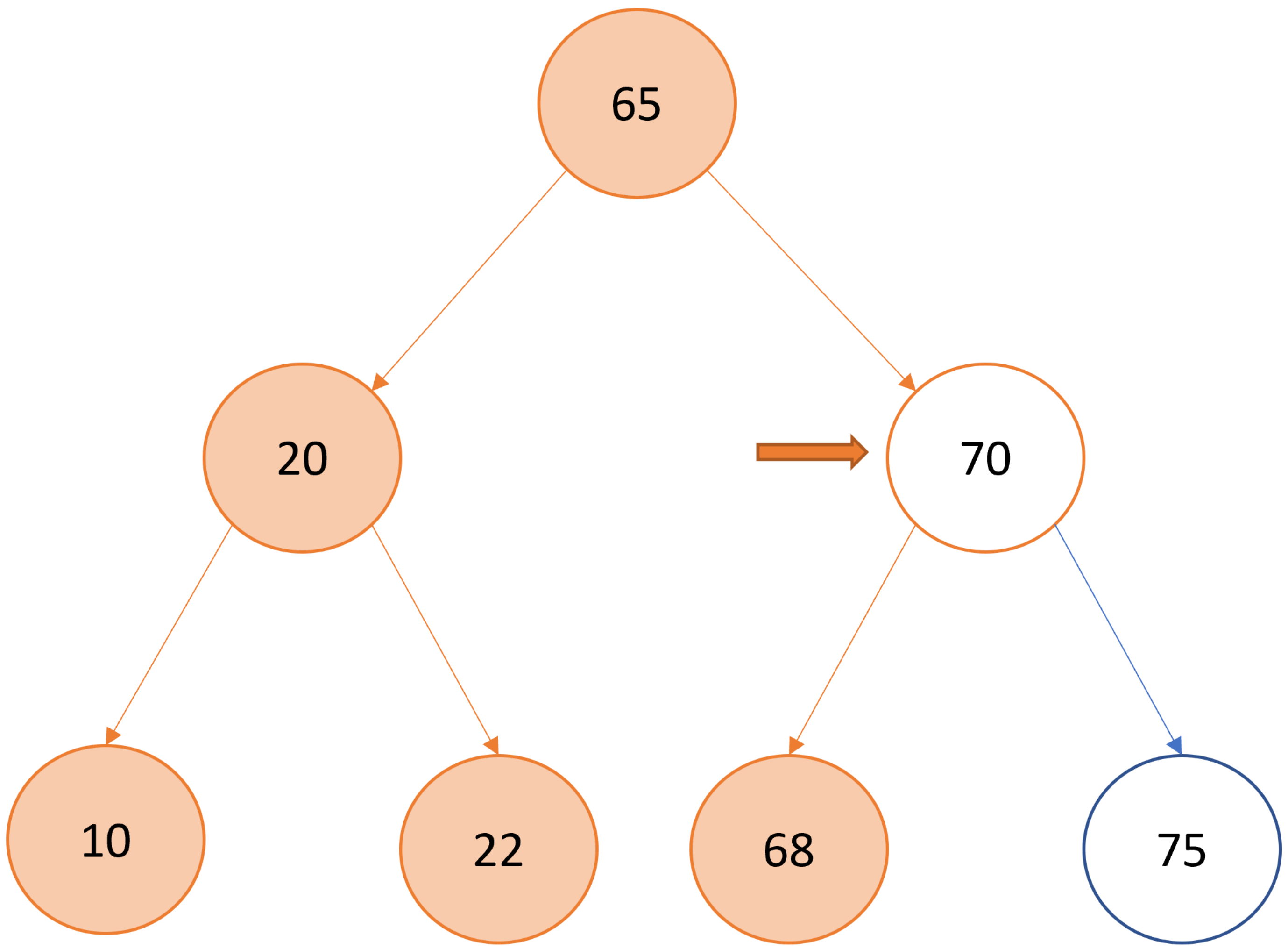
- **Order:** Left -> Current -> Right



Visited nodes: 10, 20, 22, 65, 68

In-order traversal

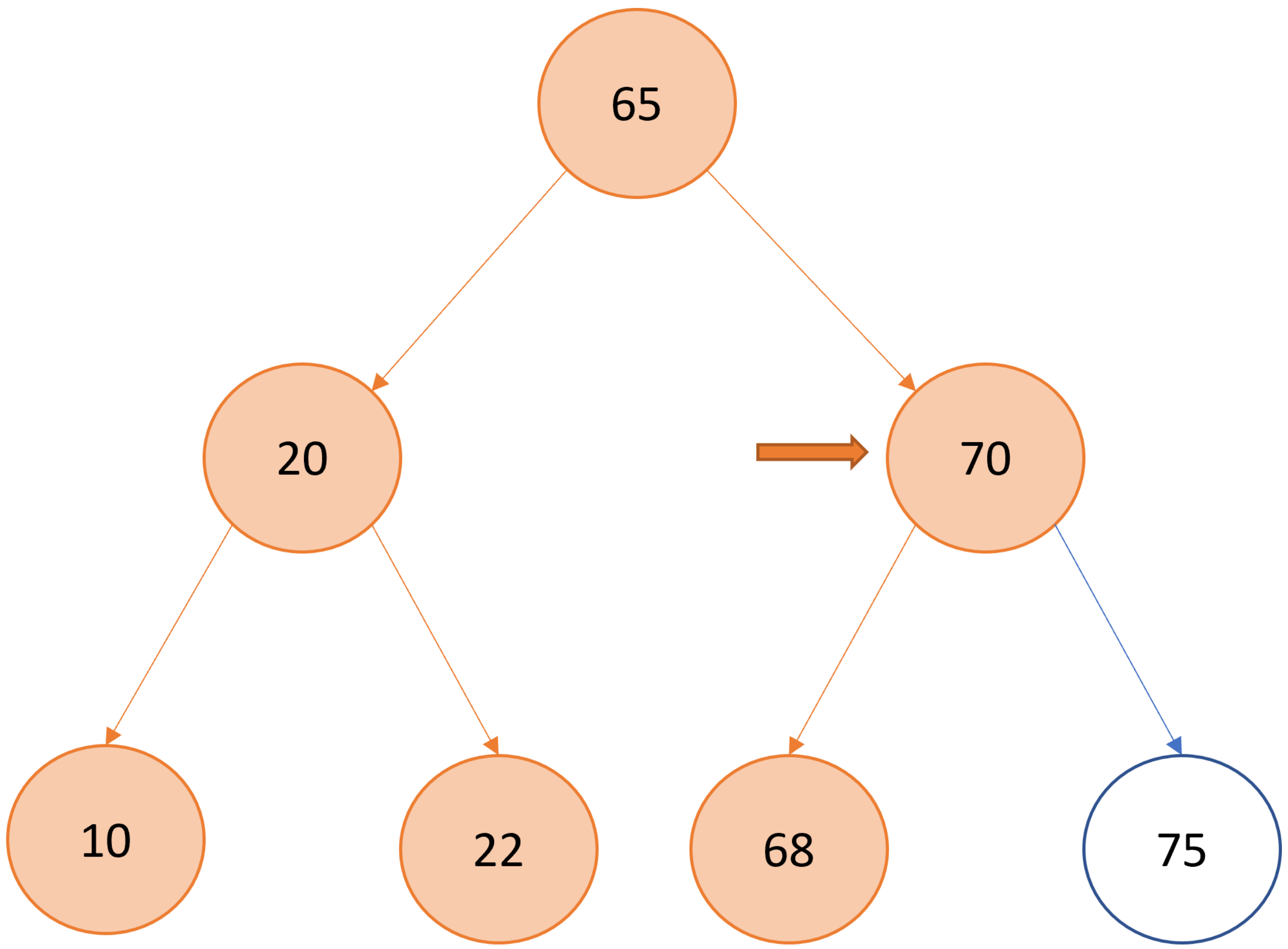
- **Order:** Left -> Current -> Right



Visited nodes: 10, 20, 22, 65, 68

In-order traversal

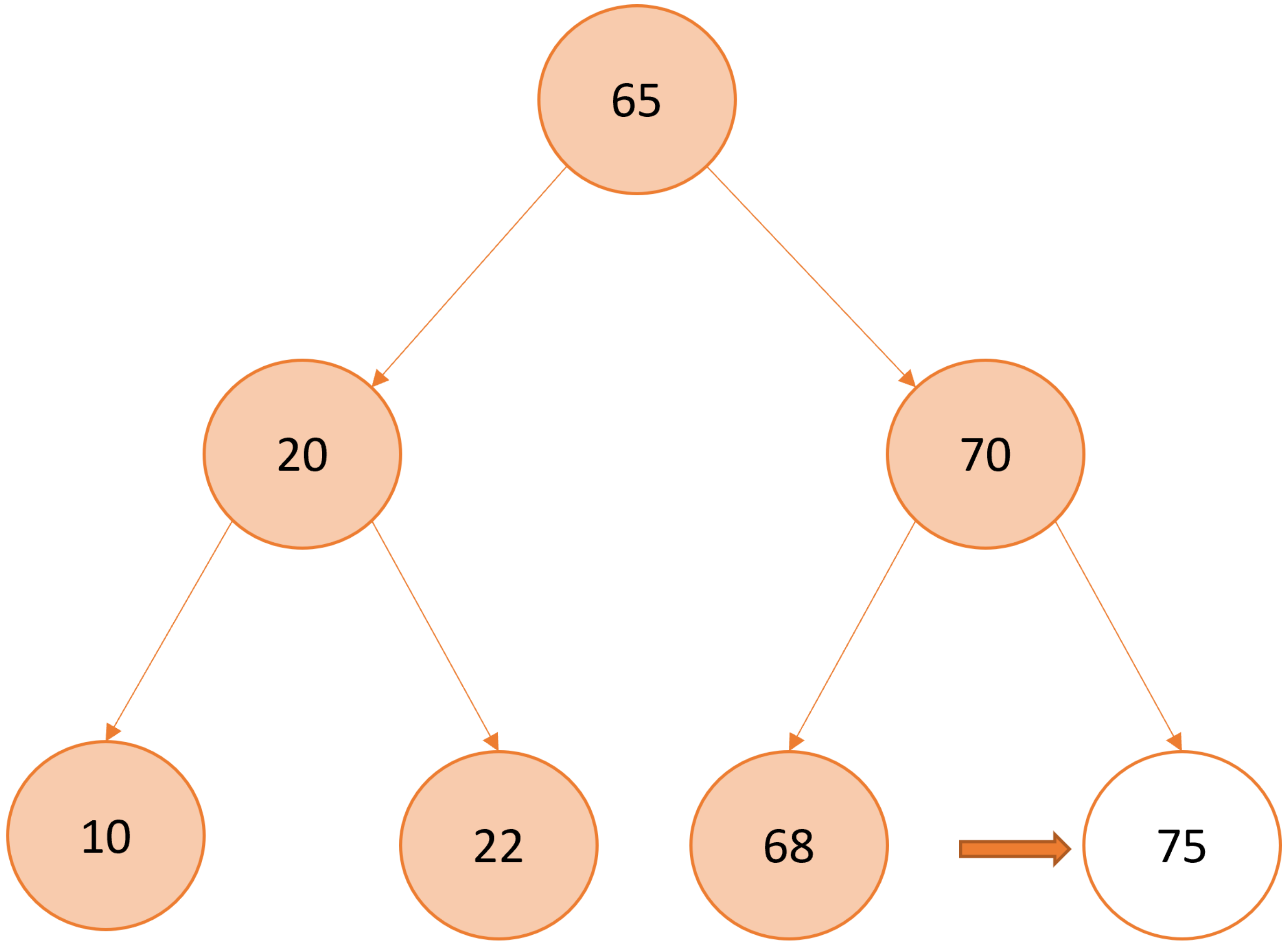
- **Order:** Left -> Current -> Right



Visited nodes: 10, 20, 22, 65, 68, 70

In-order traversal

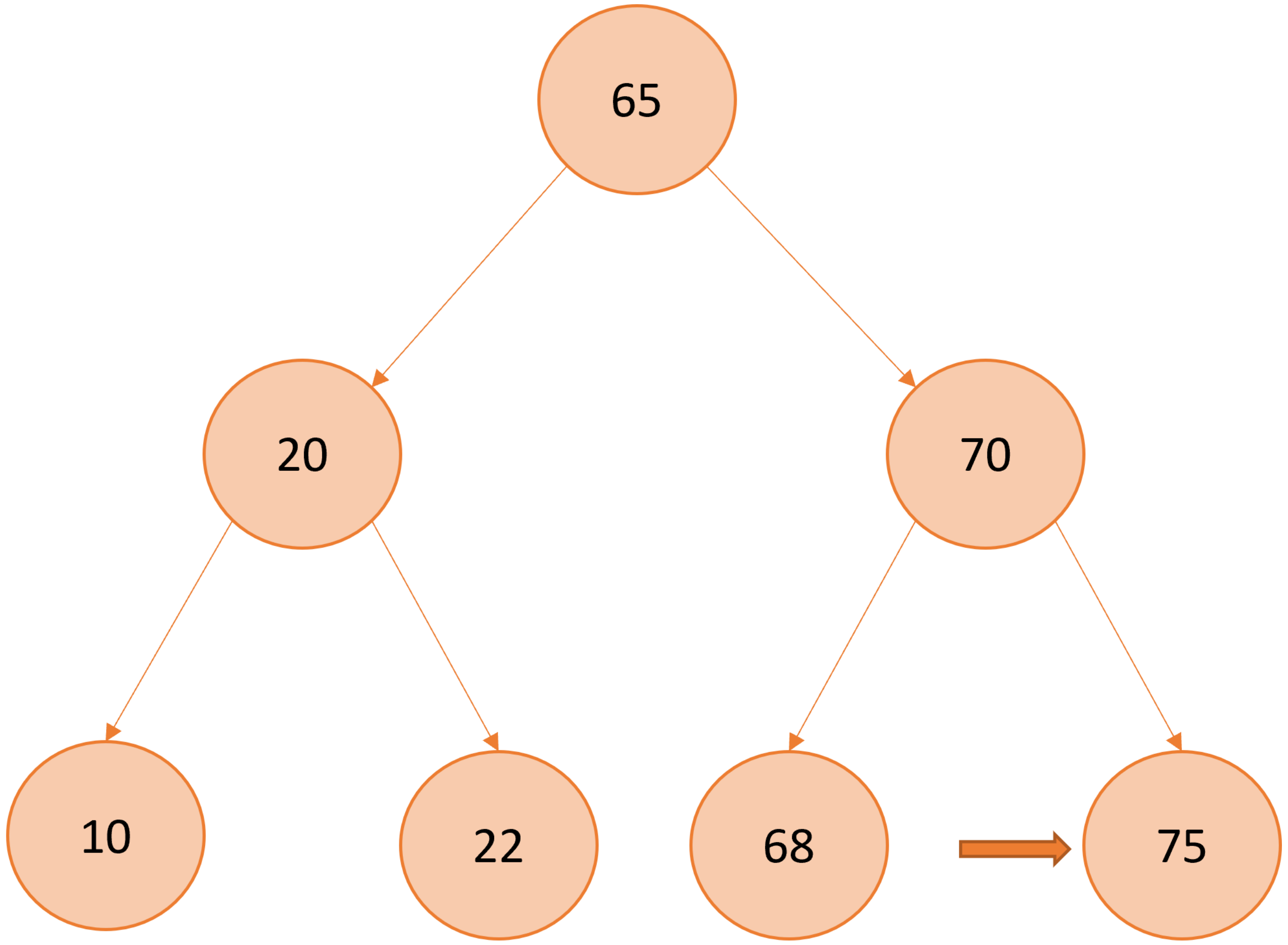
- **Order:** Left -> Current -> Right



Visited nodes: 10, 20, 22, 65, 68, 70

In-order traversal

- **Order:** Left -> Current -> Right



Visited nodes: 10, 20, 22, 65, 68, 70, 75

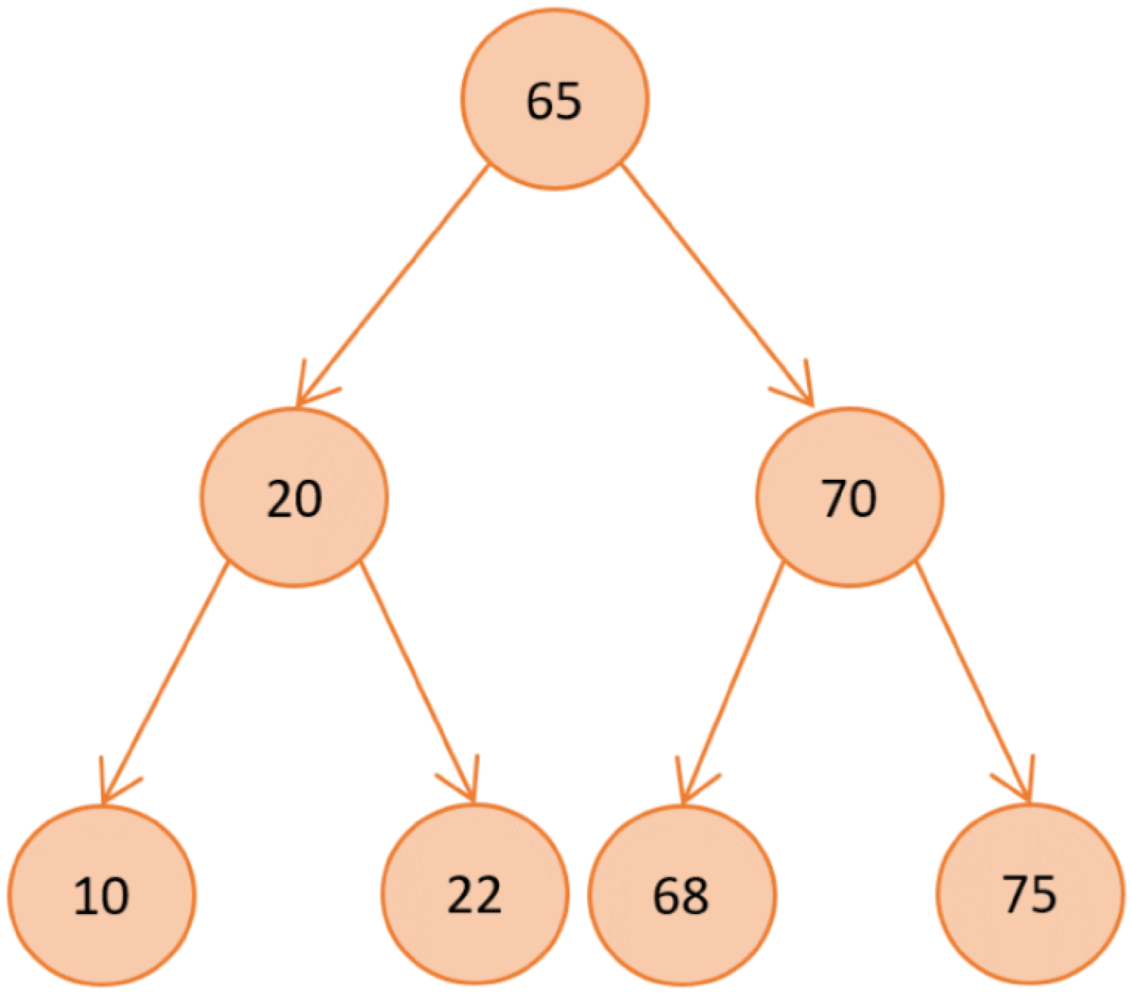
In-order traversal - implementation

- **Order:** Left -> Current -> Right

```
def in_order(self, current_node):
  if current_node:
    self.in_order(current_node.left_child)
    print(current_node.data)
    self.in_order(current_node.right_child)

my_tree.in_order(my_tree.root)
```

```
10
20
22
65
68
70
75
```



- Complexity: $O(n)$
  - n -> number of nodes

Pre-order traversal

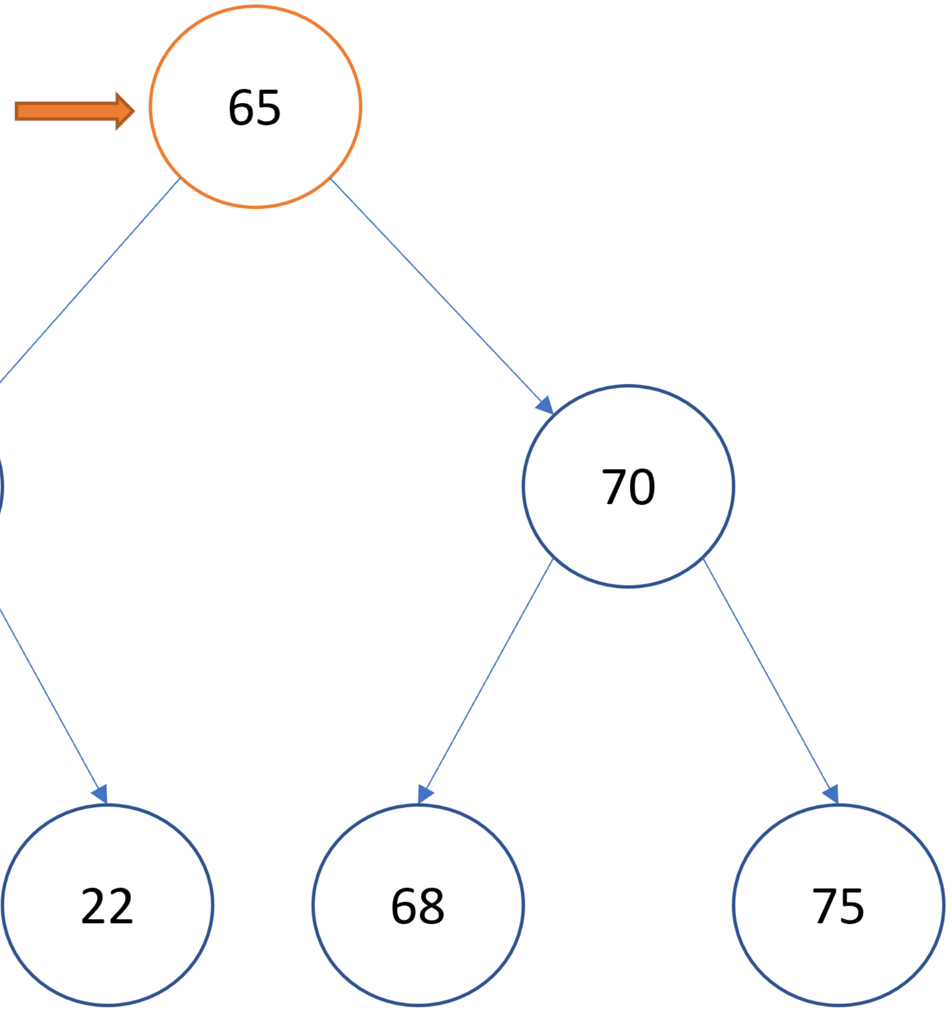
- **Order:** Current

Pre-order traversal

- **Order:** Current -> Left

Pre-order traversal

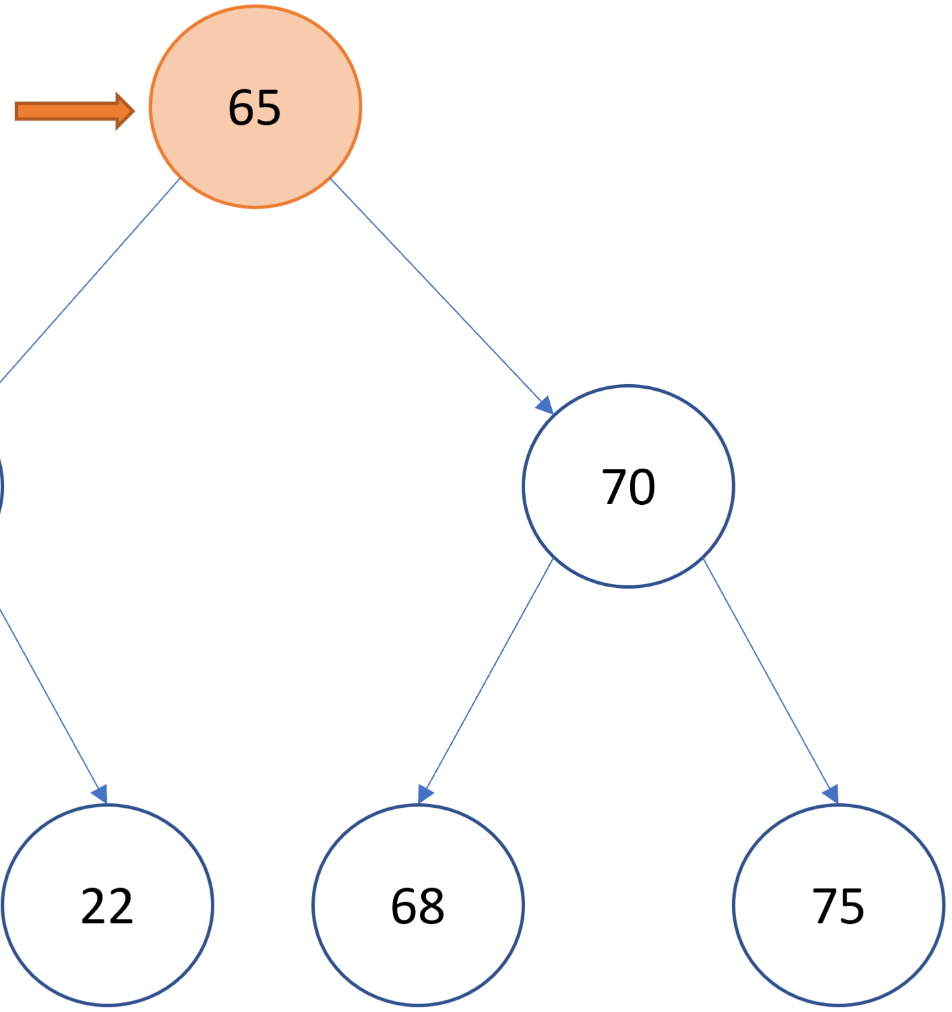
- **Order:** Current -> Left -> Right



Visited nodes:

Pre-order traversal

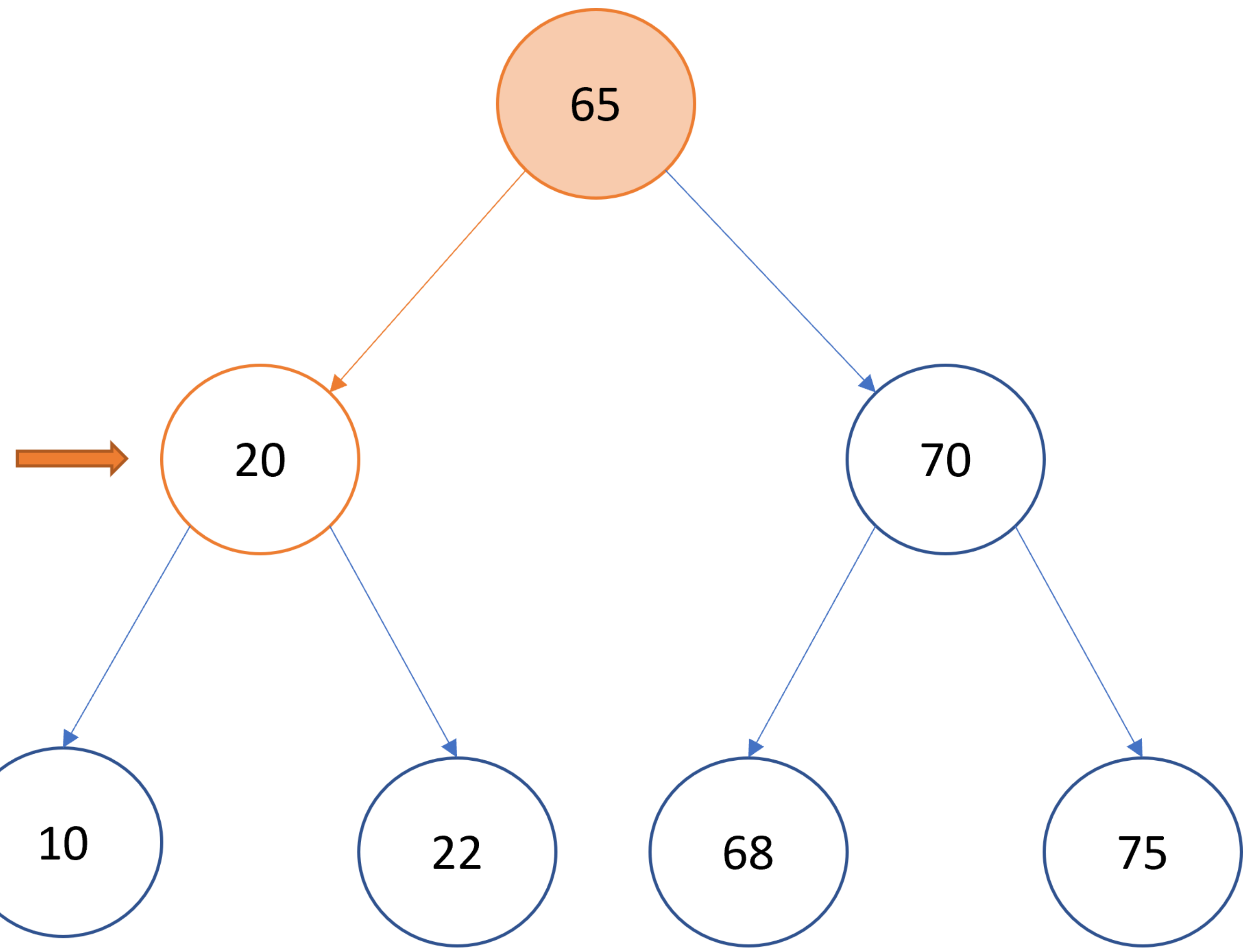
- **Order:** Current -> Left -> Right



Visited nodes: 65

Pre-order traversal

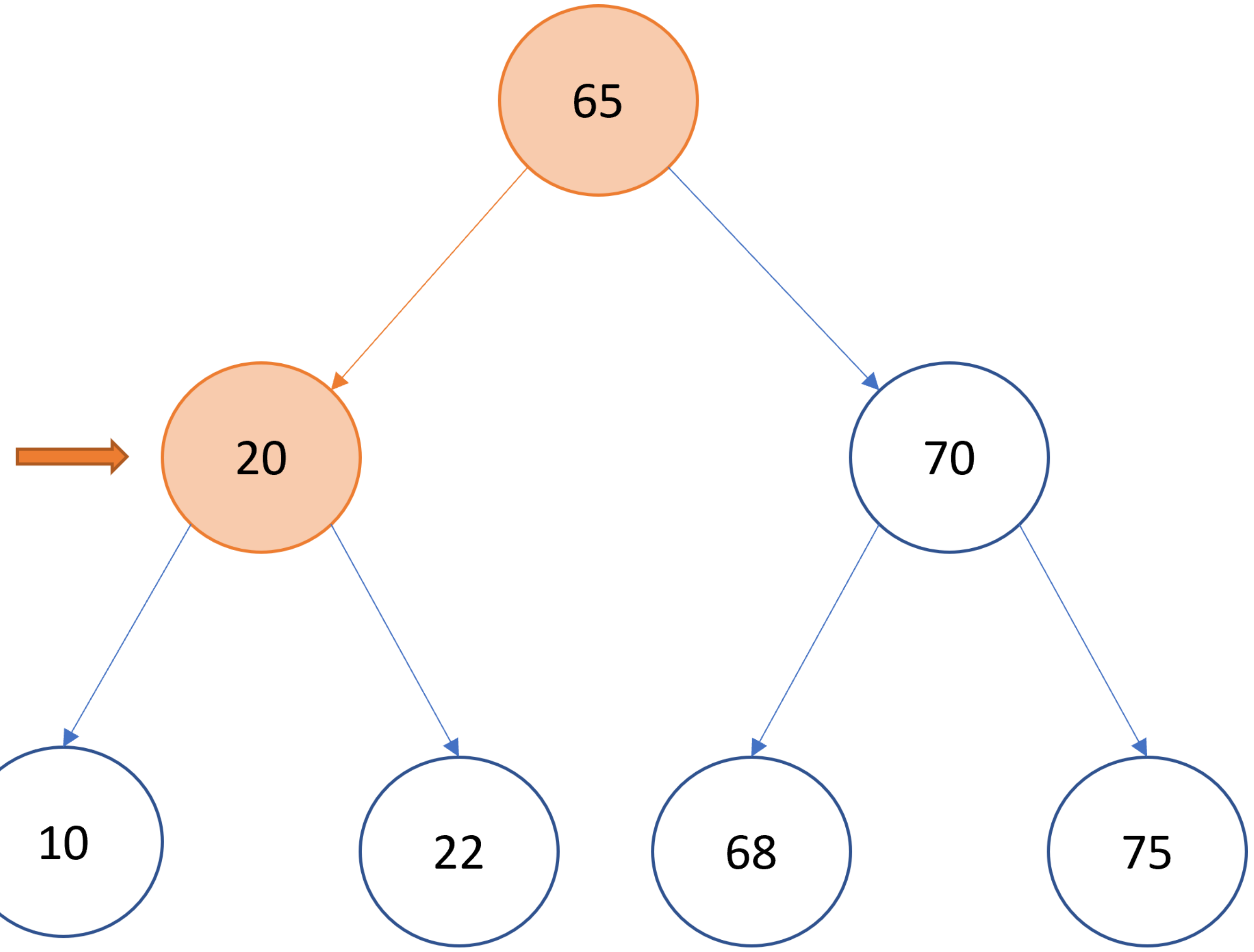
- **Order:** Current -> Left -> Right



Visited nodes: 65

Pre-order traversal

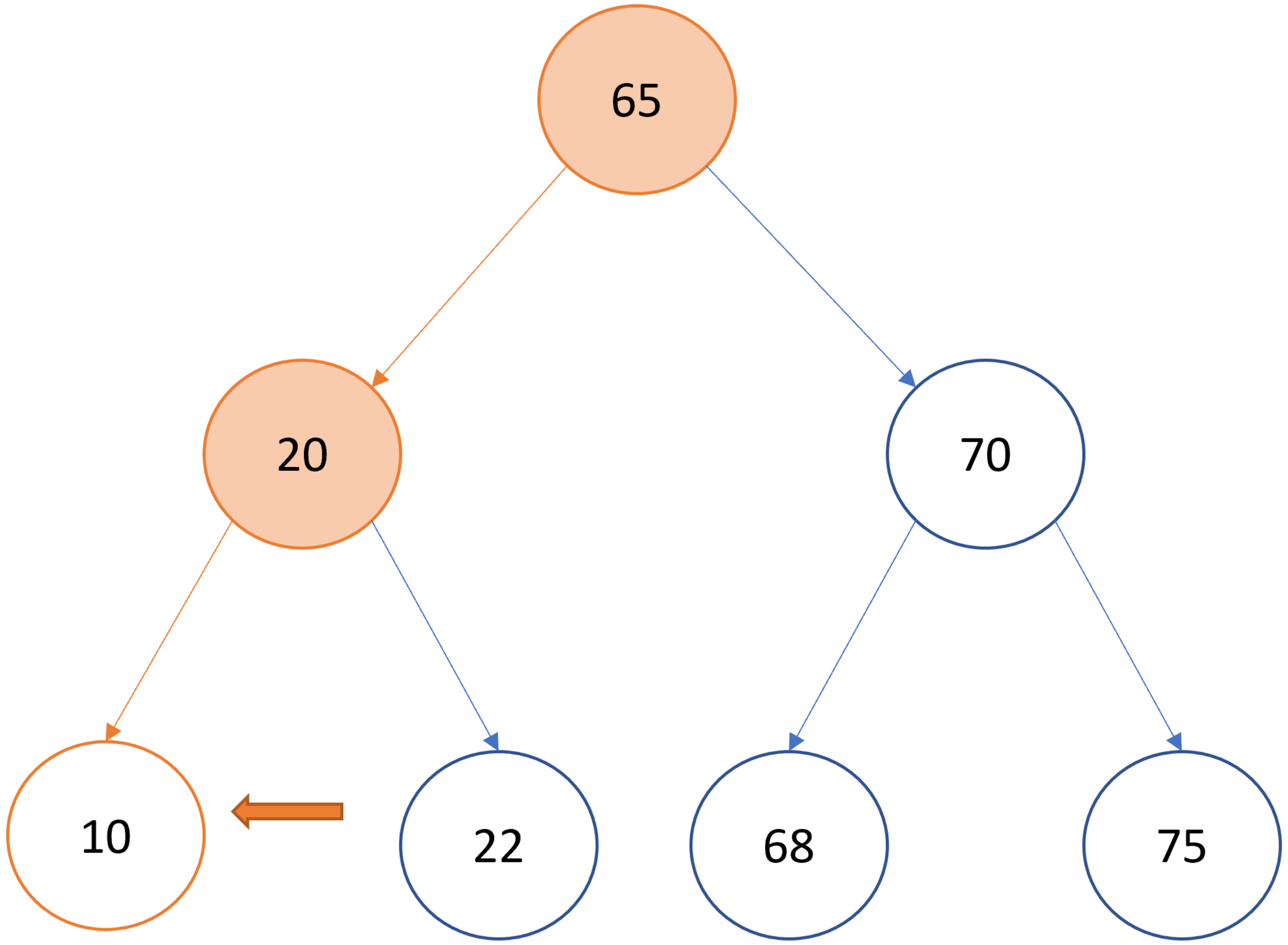
- **Order:** Current -> Left -> Right



Visited nodes: 65, 20

Pre-order traversal

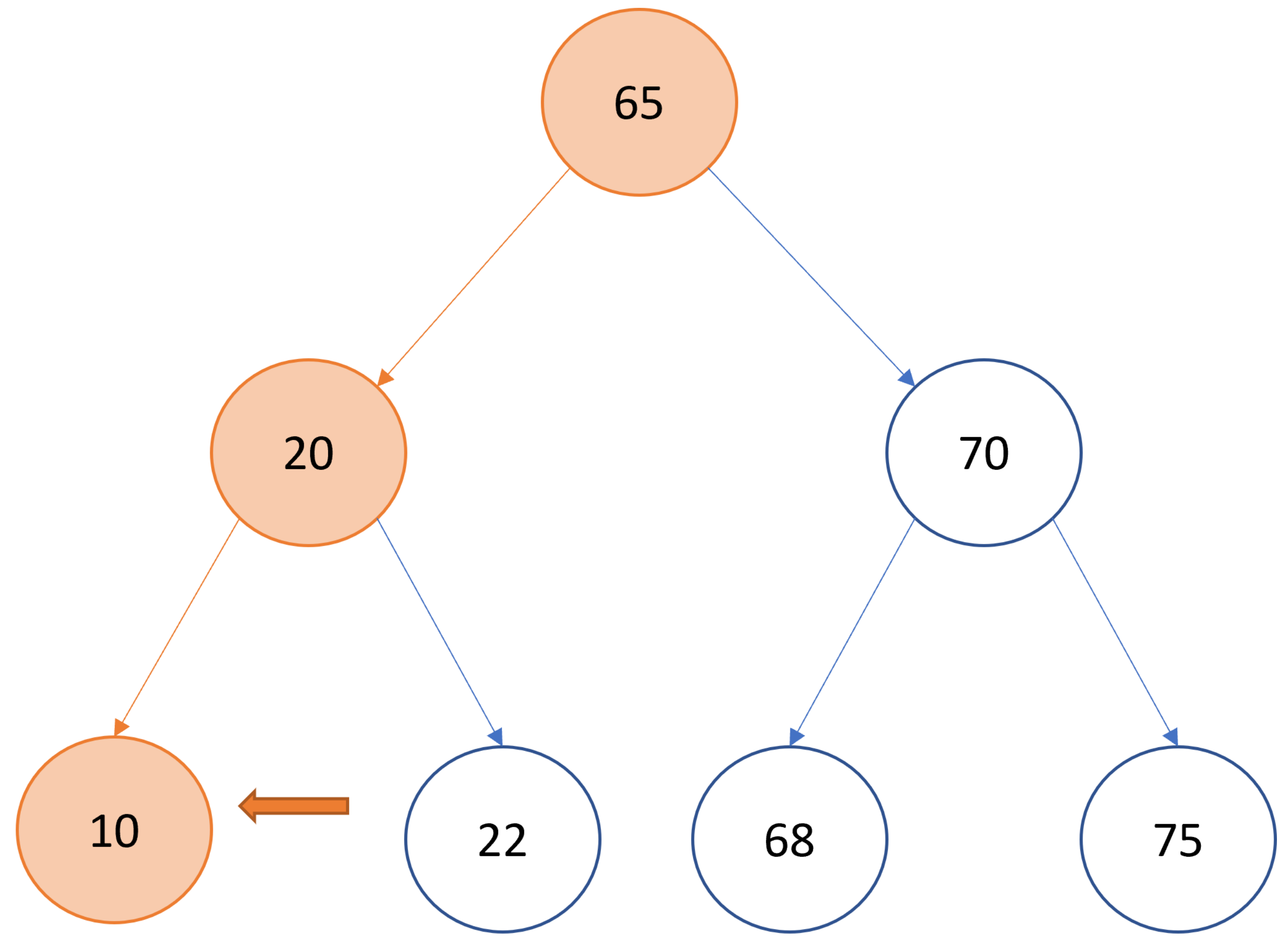
- **Order:** Current -> Left -> Right



Visited nodes: 65, 20

Pre-order traversal

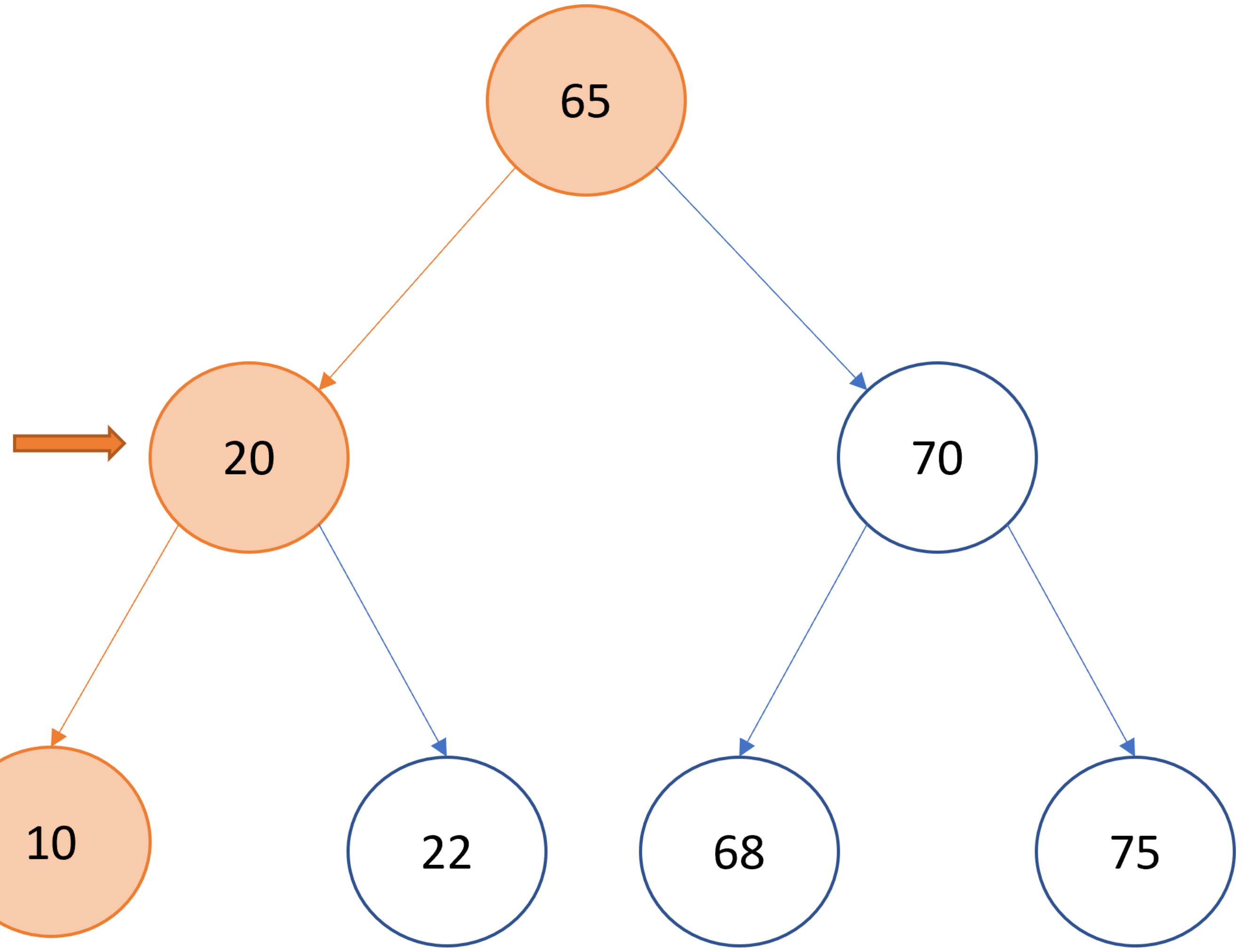
- **Order:** Current -> Left -> Right



Visited nodes: 65, 20, 10

Pre-order traversal

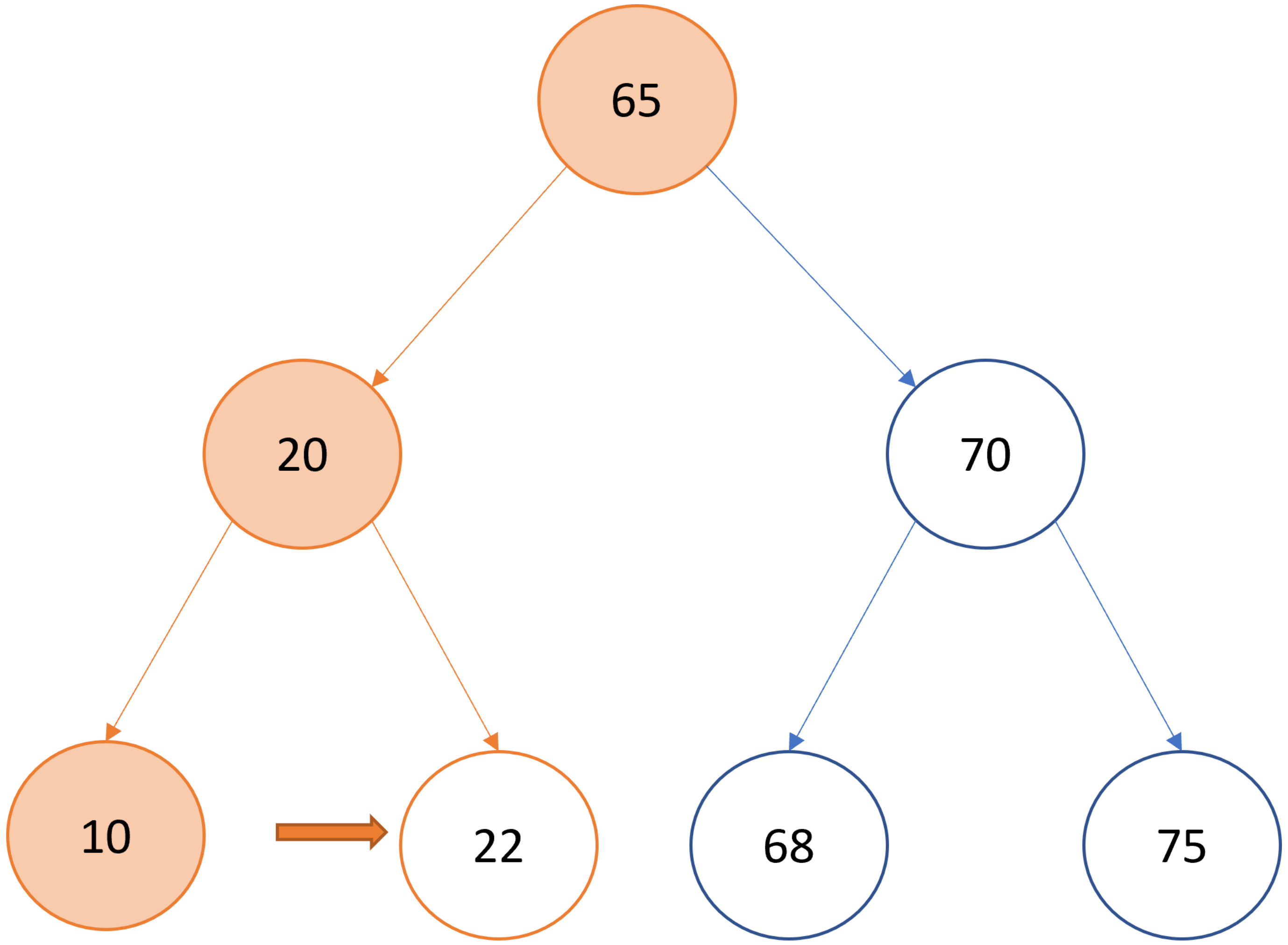
- **Order:** Current -> Left -> Right



Visited nodes: 65, 20, 10

Pre-order traversal

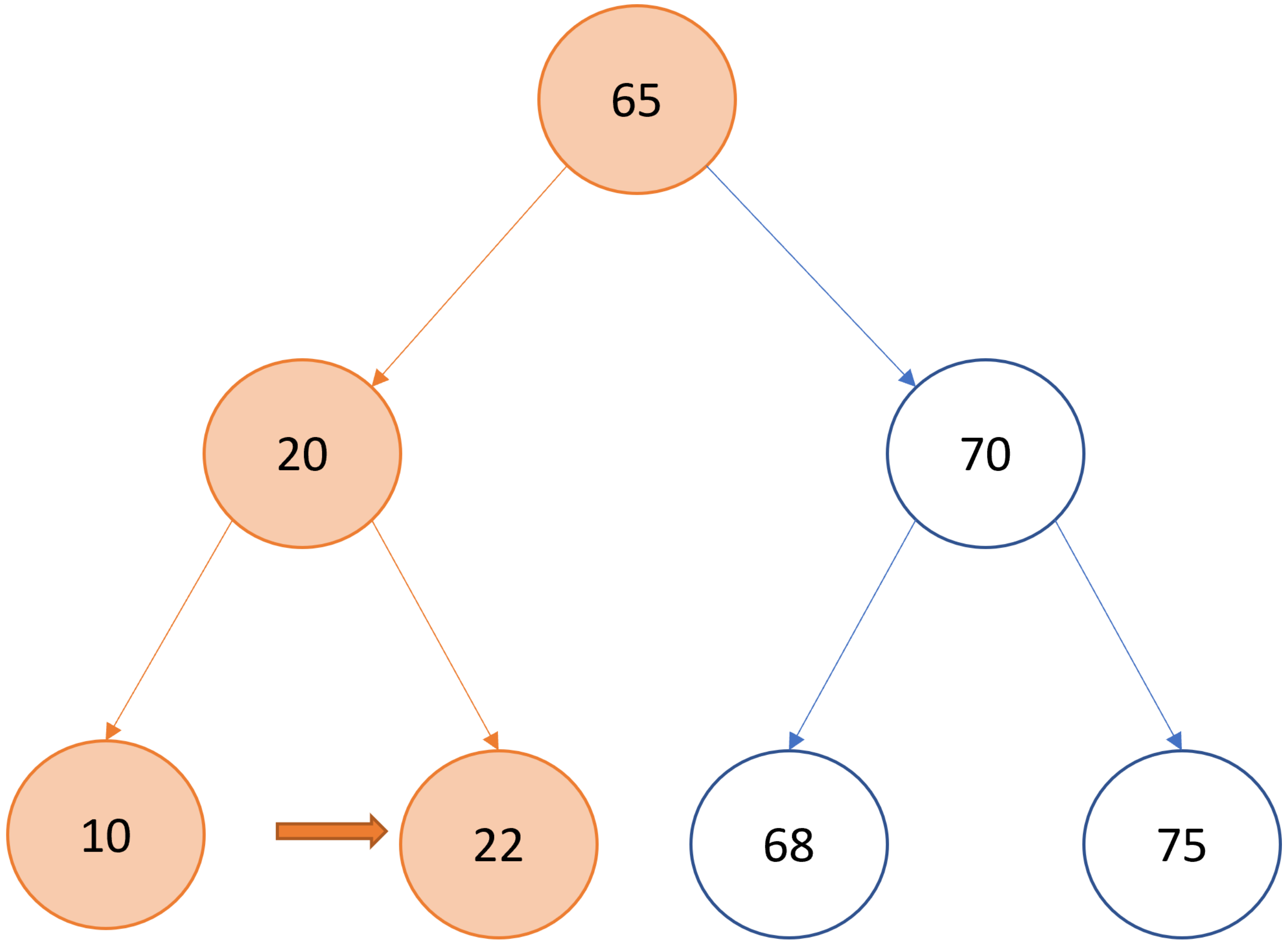
- **Order:** Current -> Left -> Right



Visited nodes: 65, 20, 10

Pre-order traversal

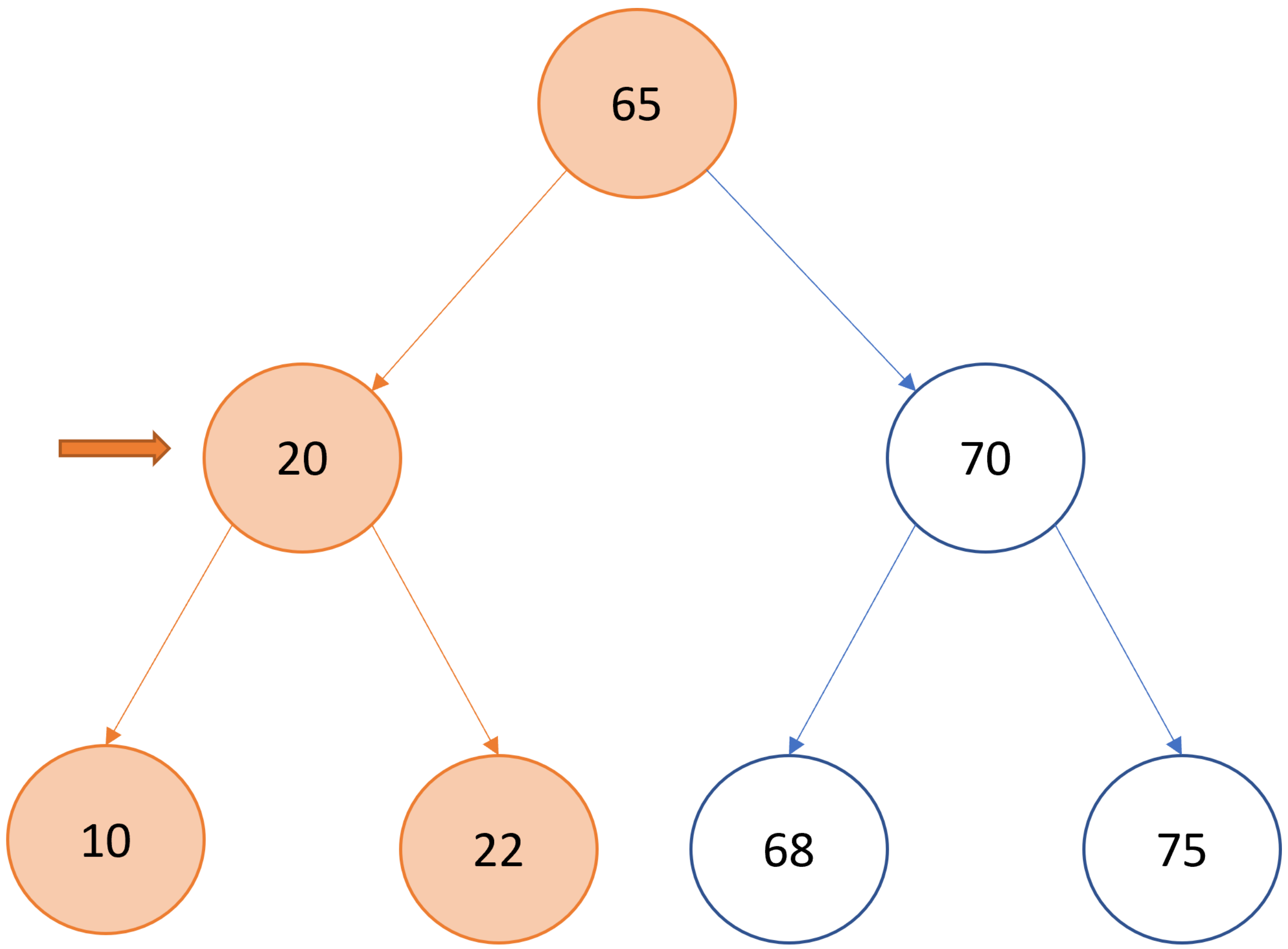
- **Order:** Current -> Left -> Right



Visited nodes: 65, 20, 10, 22

Pre-order traversal

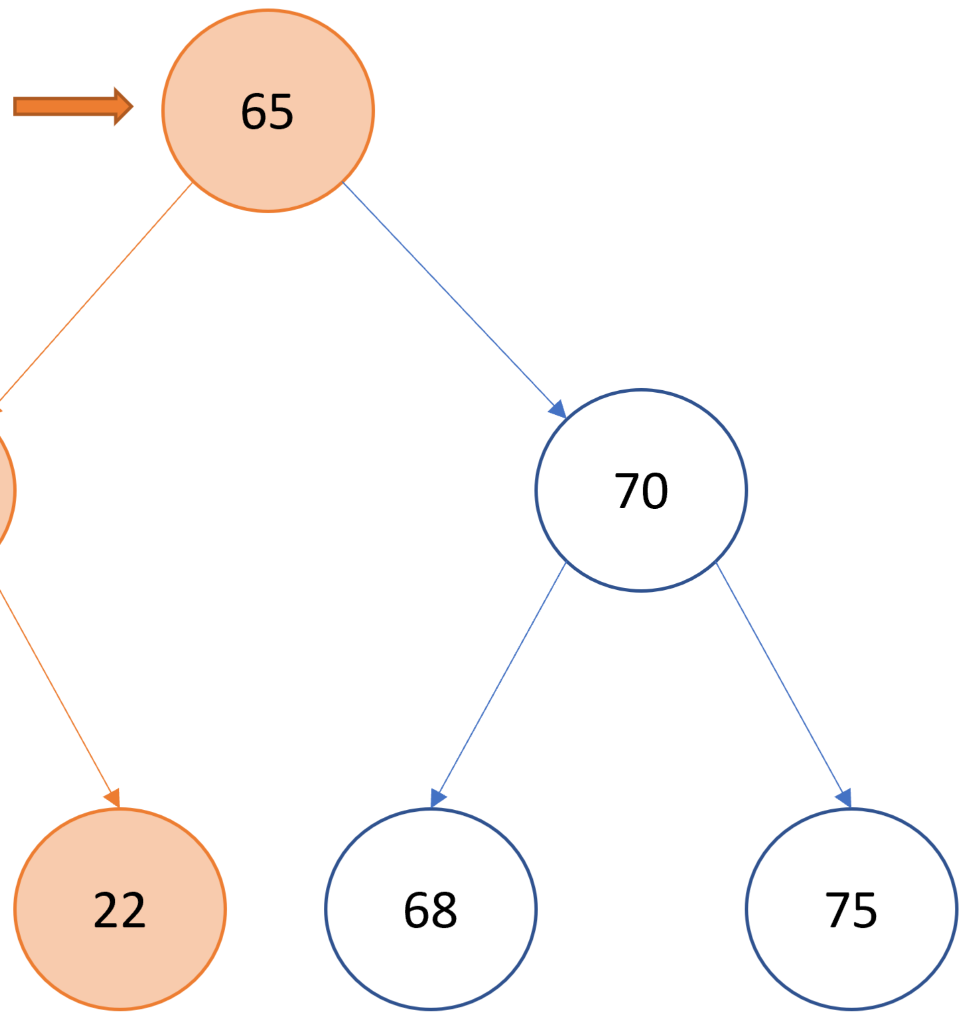
- **Order:** Current -> Left -> Right



Visited nodes: 65, 20, 10, 22

Pre-order traversal

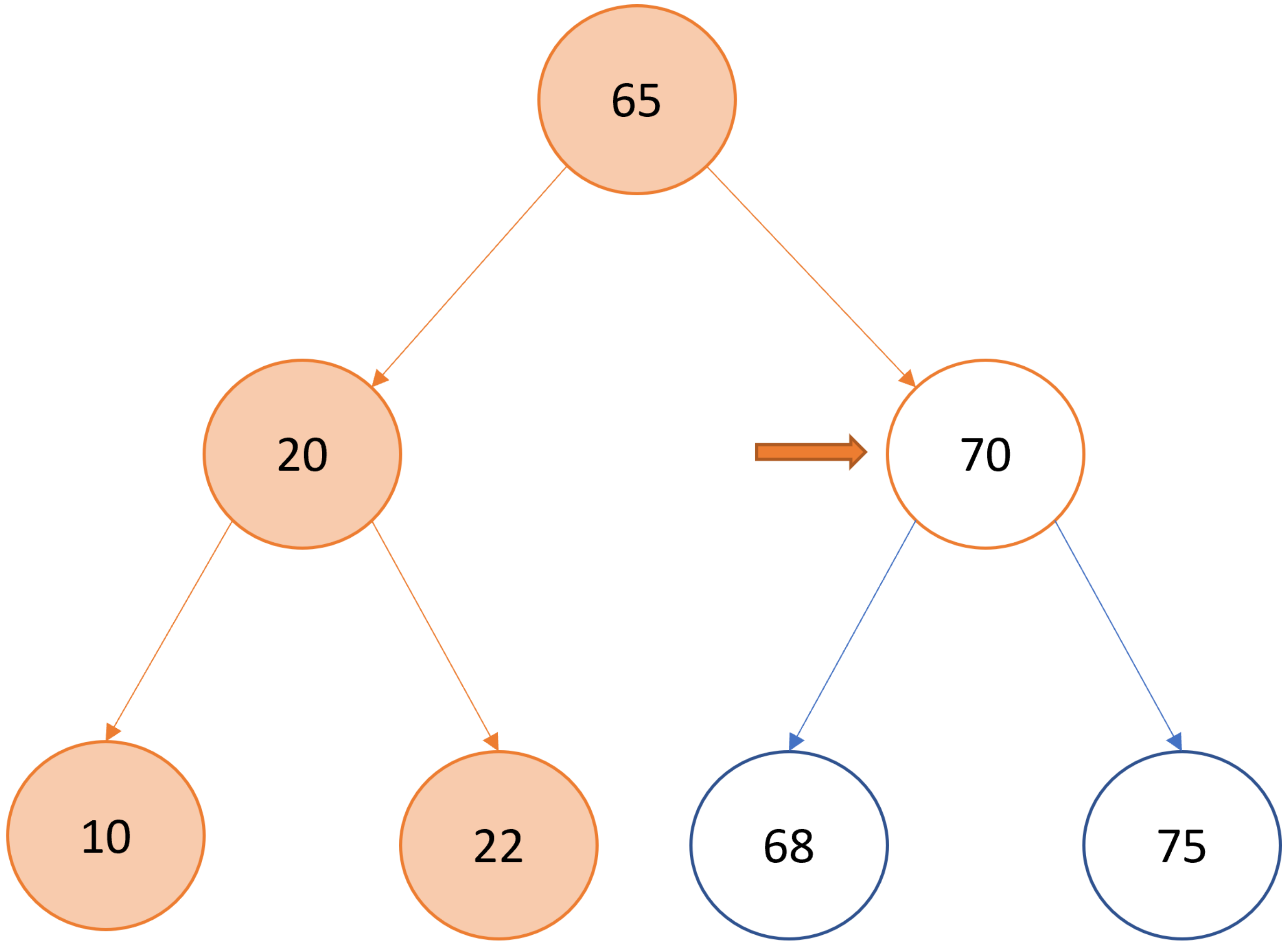
- **Order:** Current -> Left -> Right



Visited nodes: 65, 20, 10, 22

Pre-order traversal

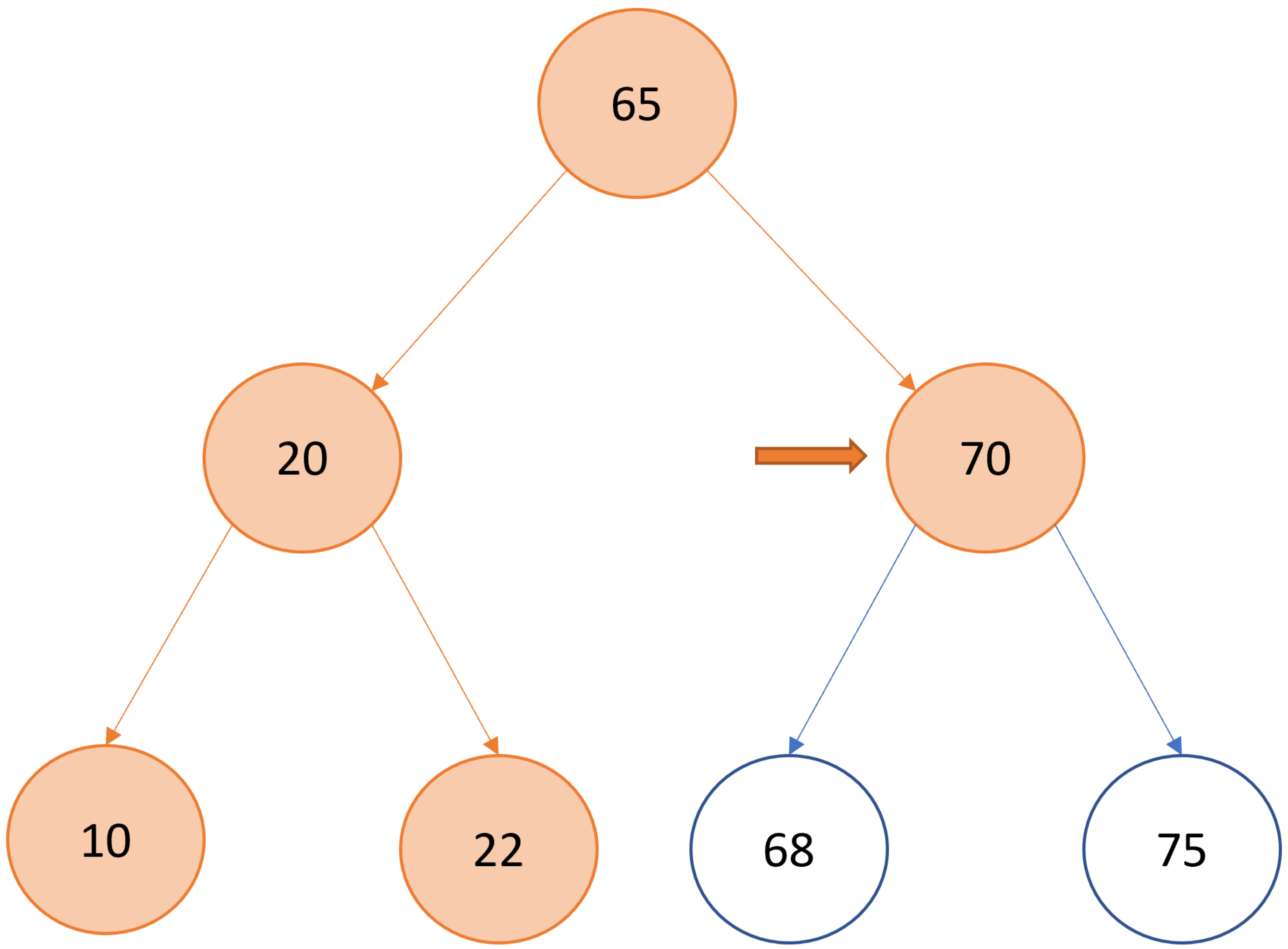
- **Order:** Current -> Left -> Right



Visited nodes: 65, 20, 10, 22

Pre-order traversal

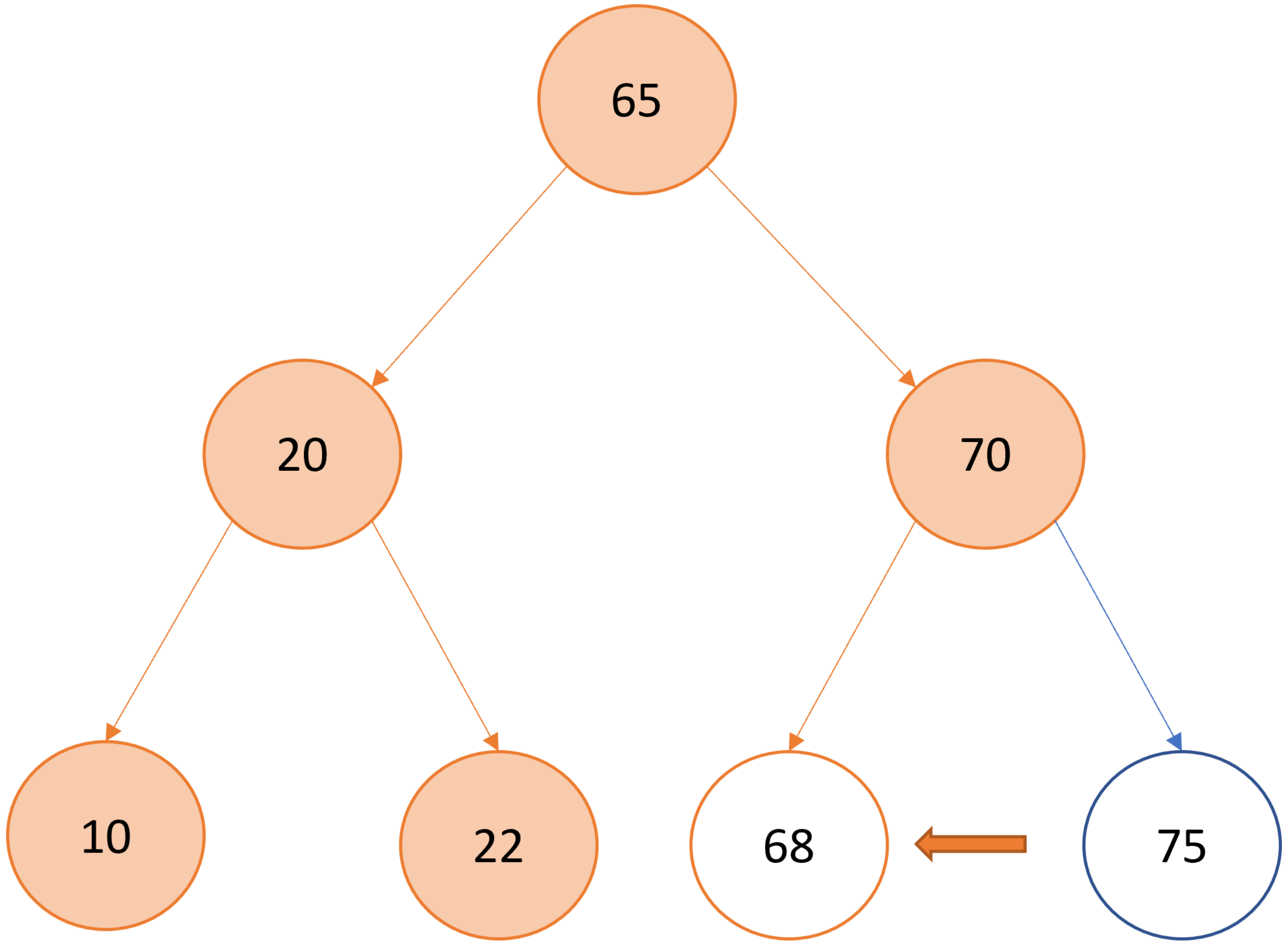
- **Order:** Current -> Left -> Right



Visited nodes: 65, 20, 10, 22, 70

Pre-order traversal

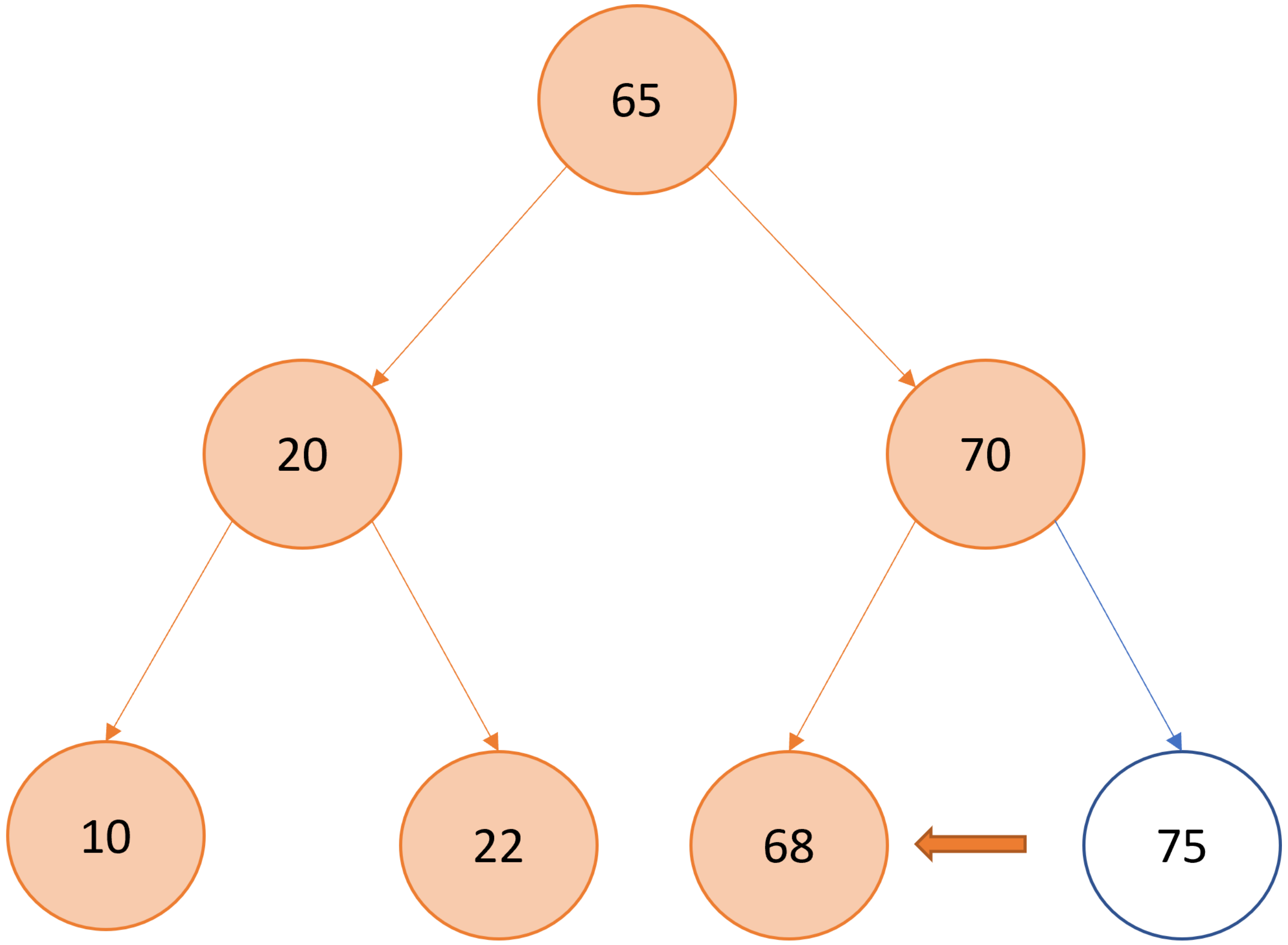
- **Order:** Current -> Left -> Right



Visited nodes: 65, 20, 10, 22, 70

Pre-order traversal

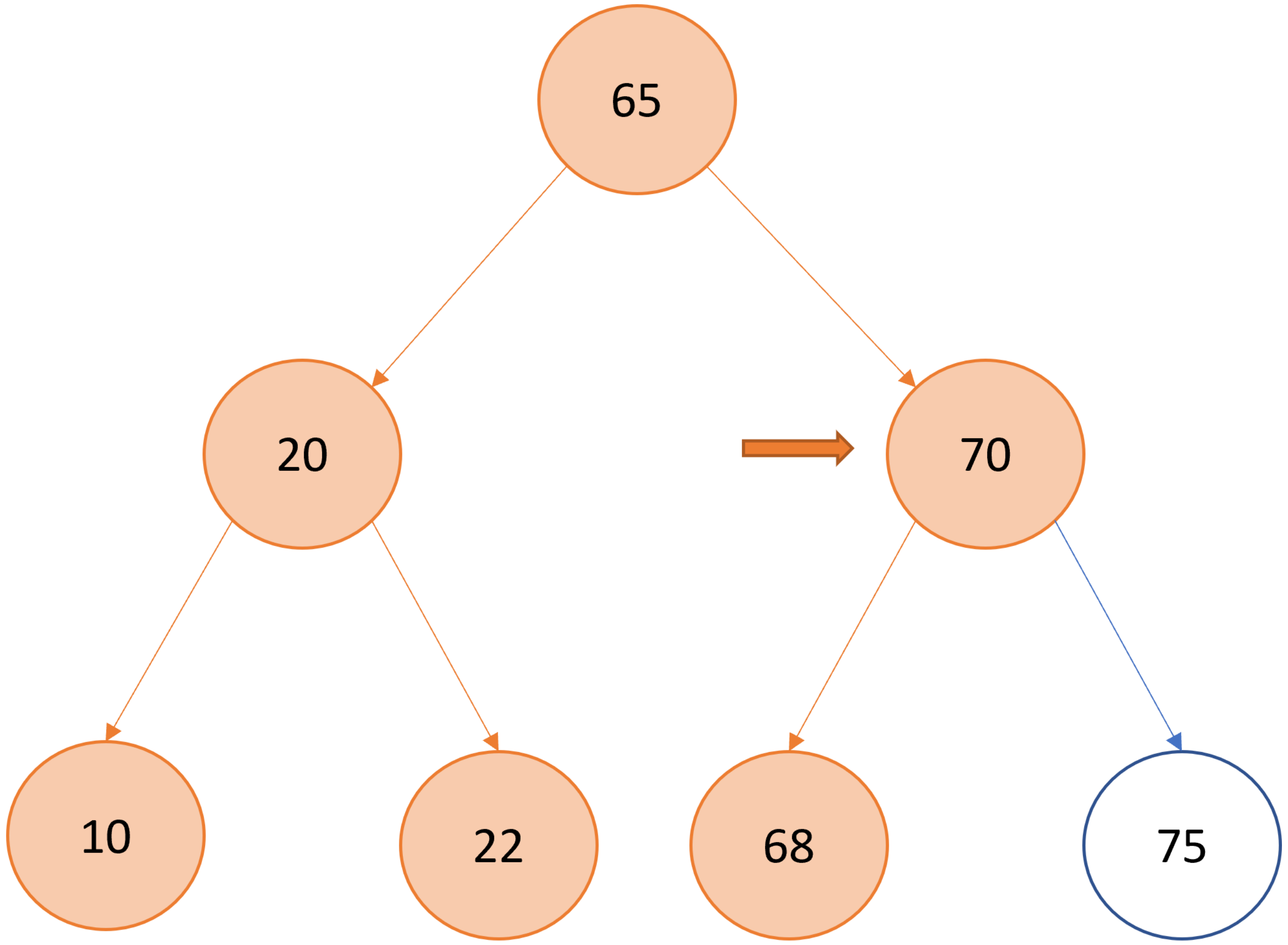
- **Order:** Current -> Left -> Right



Visited nodes: 65, 20, 10, 22, 70, 68

Pre-order traversal

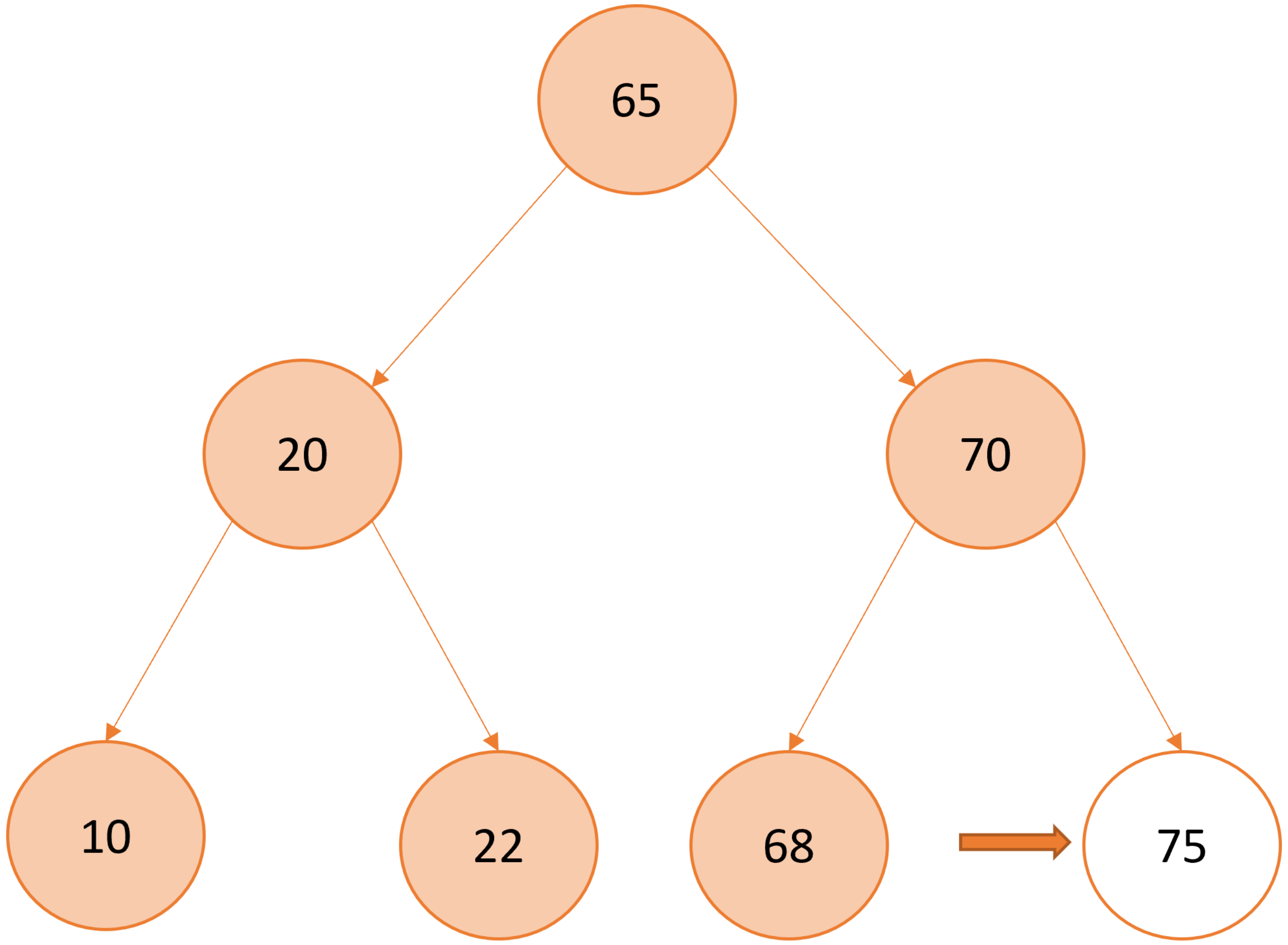
- **Order:** Current -> Left -> Right



Visited nodes: 65, 20, 10, 22, 70, 68

Pre-order traversal

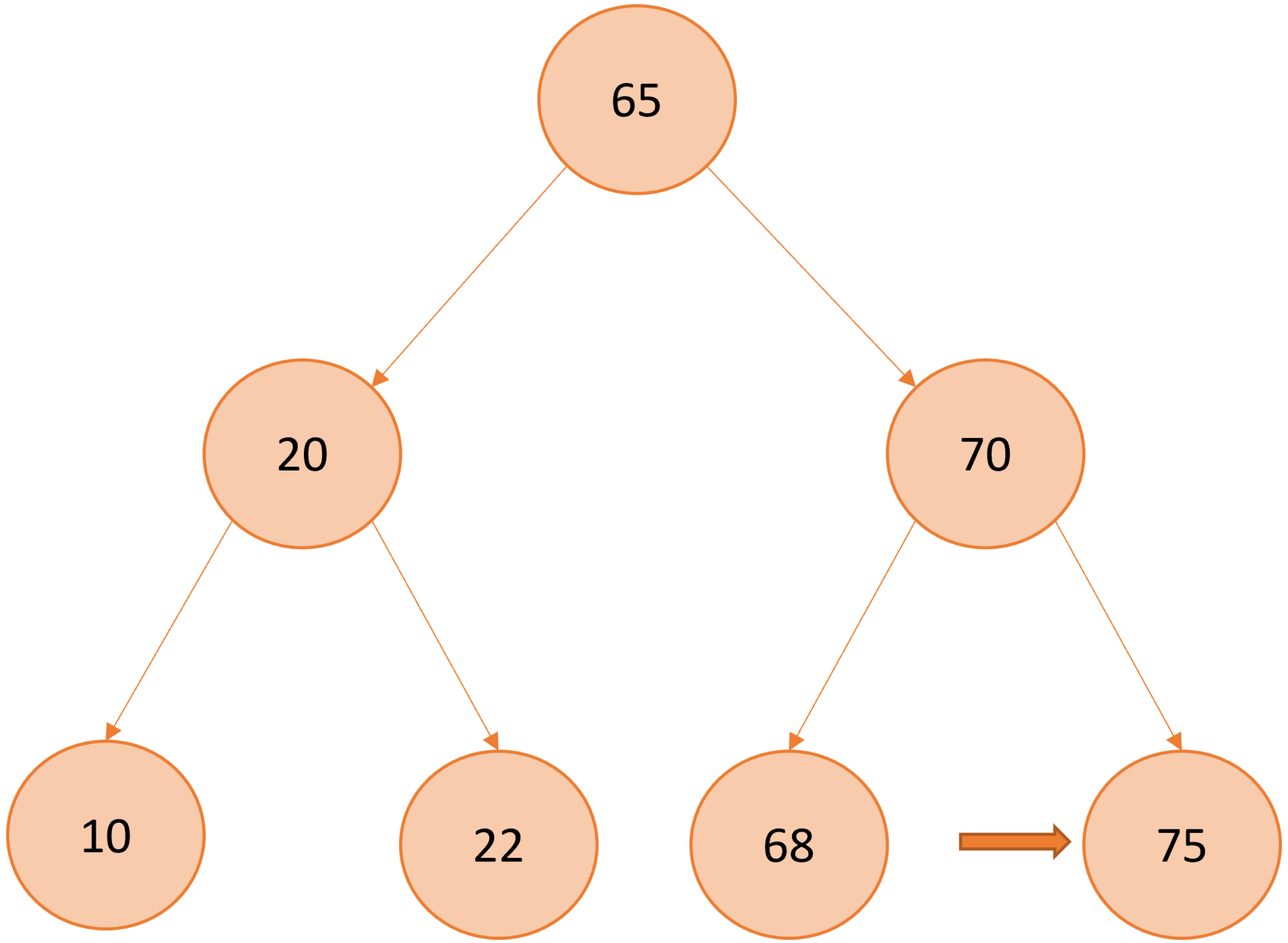
- **Order:** Current -> Left -> Right



Visited nodes: 65, 20, 10, 22, 70, 68

Pre-order traversal

- **Order:** Current -> Left -> Right



Visited nodes: 65, 20, 10, 22, 70, 68, 75

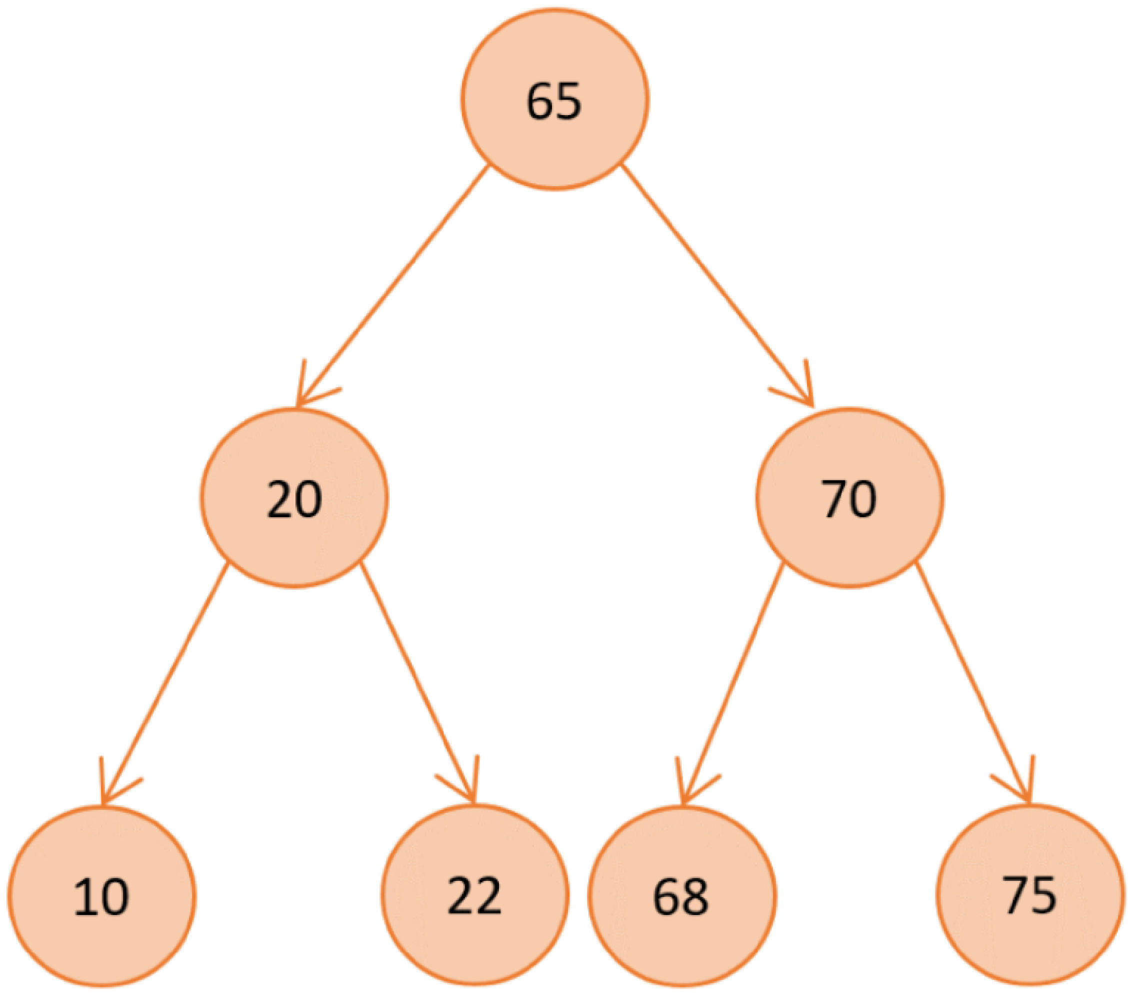
Pre-order traversal - implementation

- **Order:** Root -> Left -> Right

```
def pre_order(self, current_node):
  if current_node:
    print(current_node.data)
    self.pre_order(current_node.left_child)
    self.pre_order(current_node.right_child)
```

```
my_tree.pre_order(my_tree.root)
```

```
65
20
10
22
70
68
75
```



- Complexity: $O(n)$
  - n -> number of nodes

Post-order

- **Order:** Left

Post-order

- **Order:** Left -> Right

Post-order

- **Order:** Left -> Right -> Current
- Complexity: $O(n)$
  - n -> number of nodes

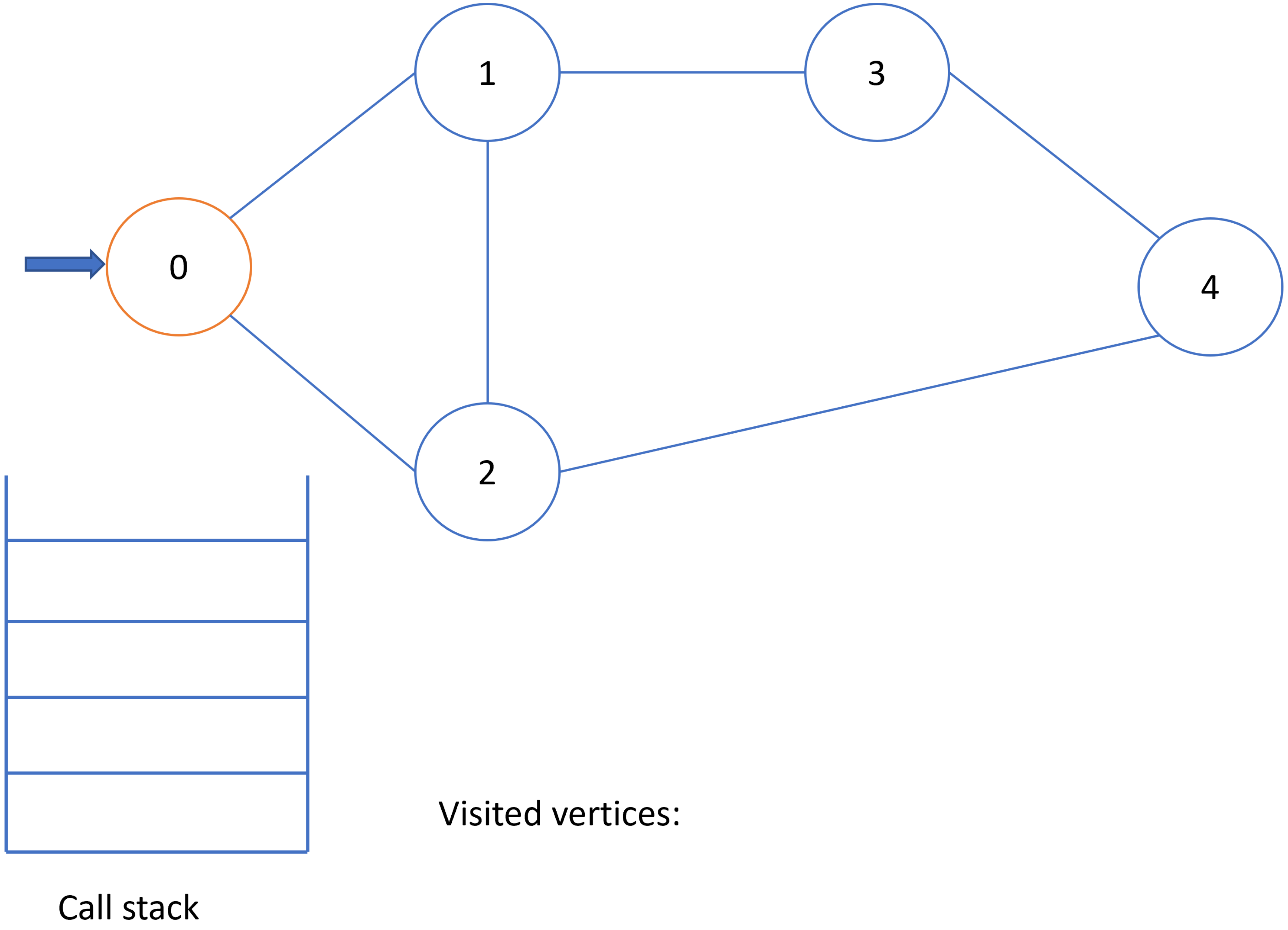
When to use in-order, pre-order, and post-order

- **in-order**
  - used BST to obtain the node's values in ascending order
- **pre-order**
  - create copies of a tree
  - get prefix expressions
- **post-order**
  - delete binary trees
  - get postfix expressions

Depth first search - graphs

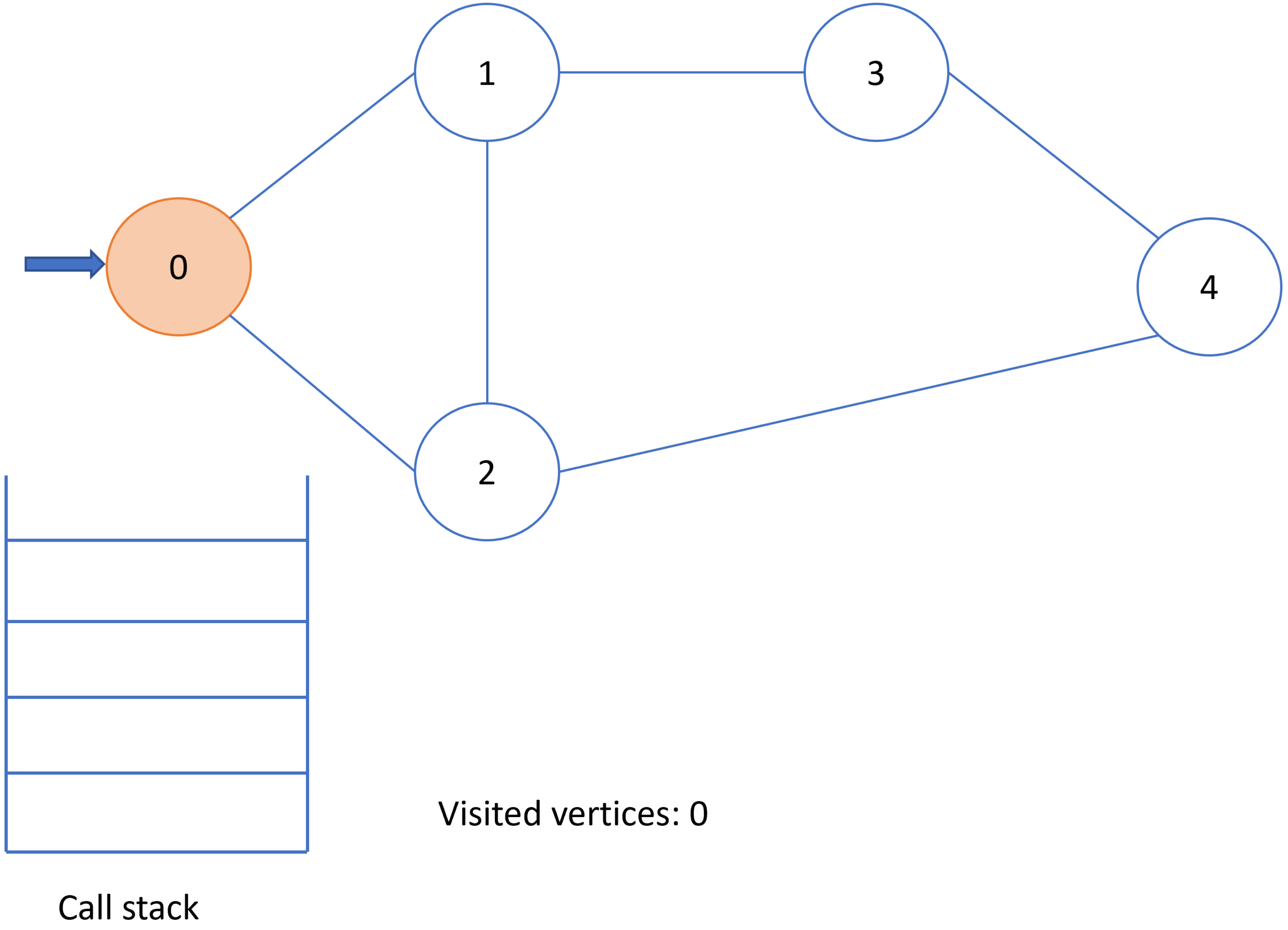
- Graphs can have cycles
  - need to keep track of visited vertices
- Steps:
  1. Start at any vertex
  2. Tracks current vertex to visited vertices list
  3. For each current node's adjacent vertex
     - If it has been visited -> ignore it
     - If it hasn't been visited -> recursively perform DFS

Depth first search - graphs



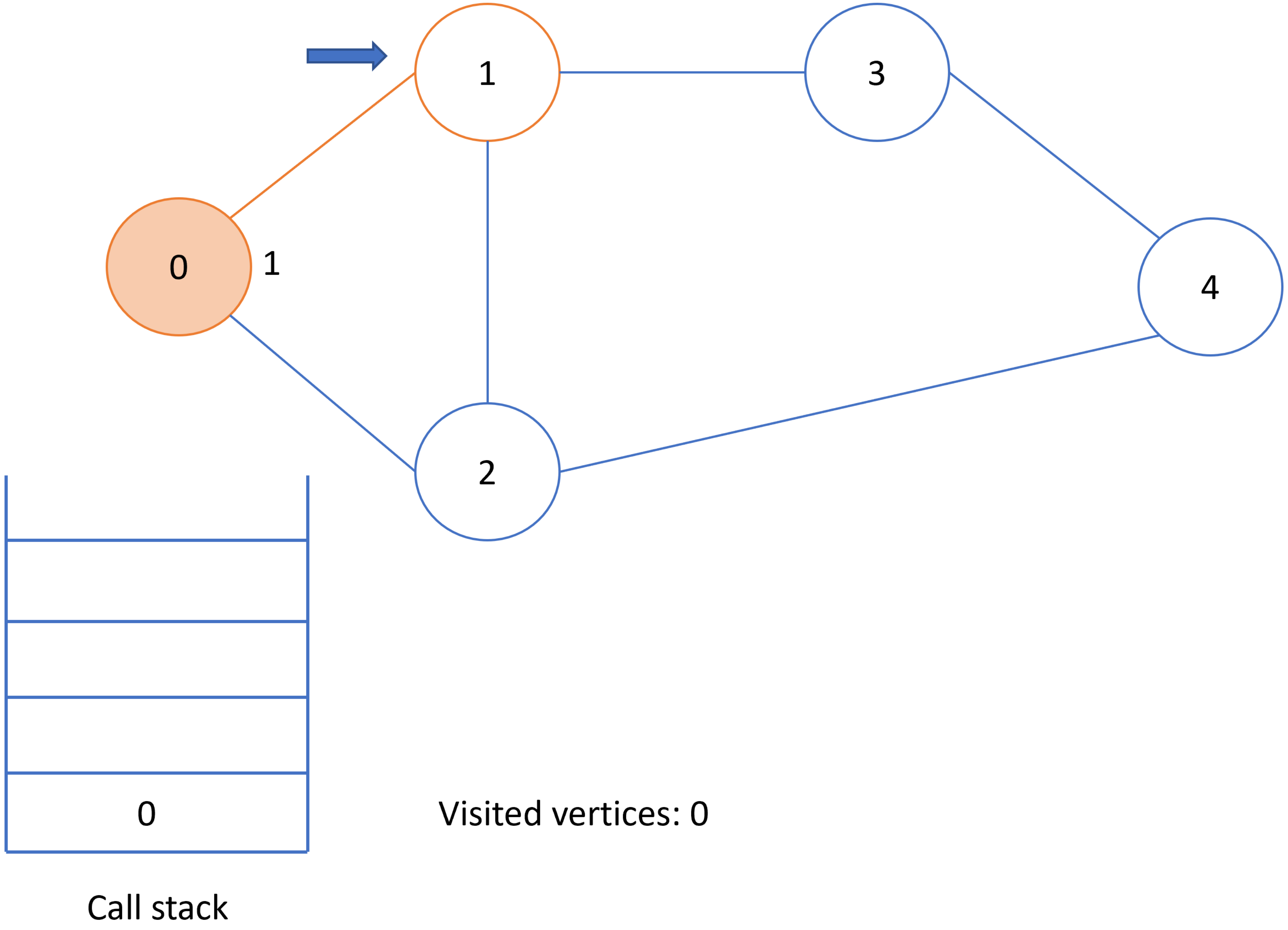
Visited vertices:

Depth first search - graphs

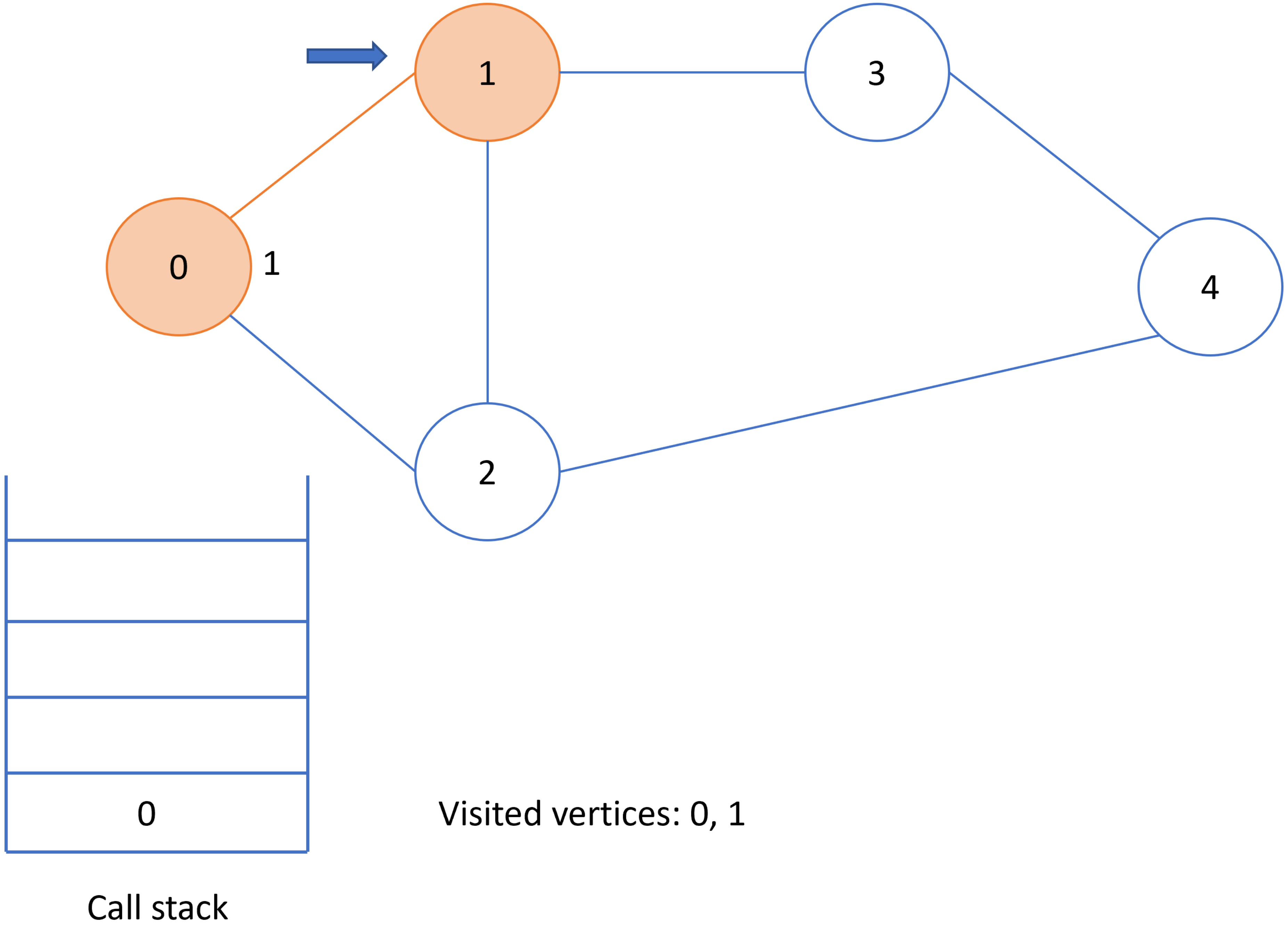


Visited vertices: 0

Depth first search - graphs

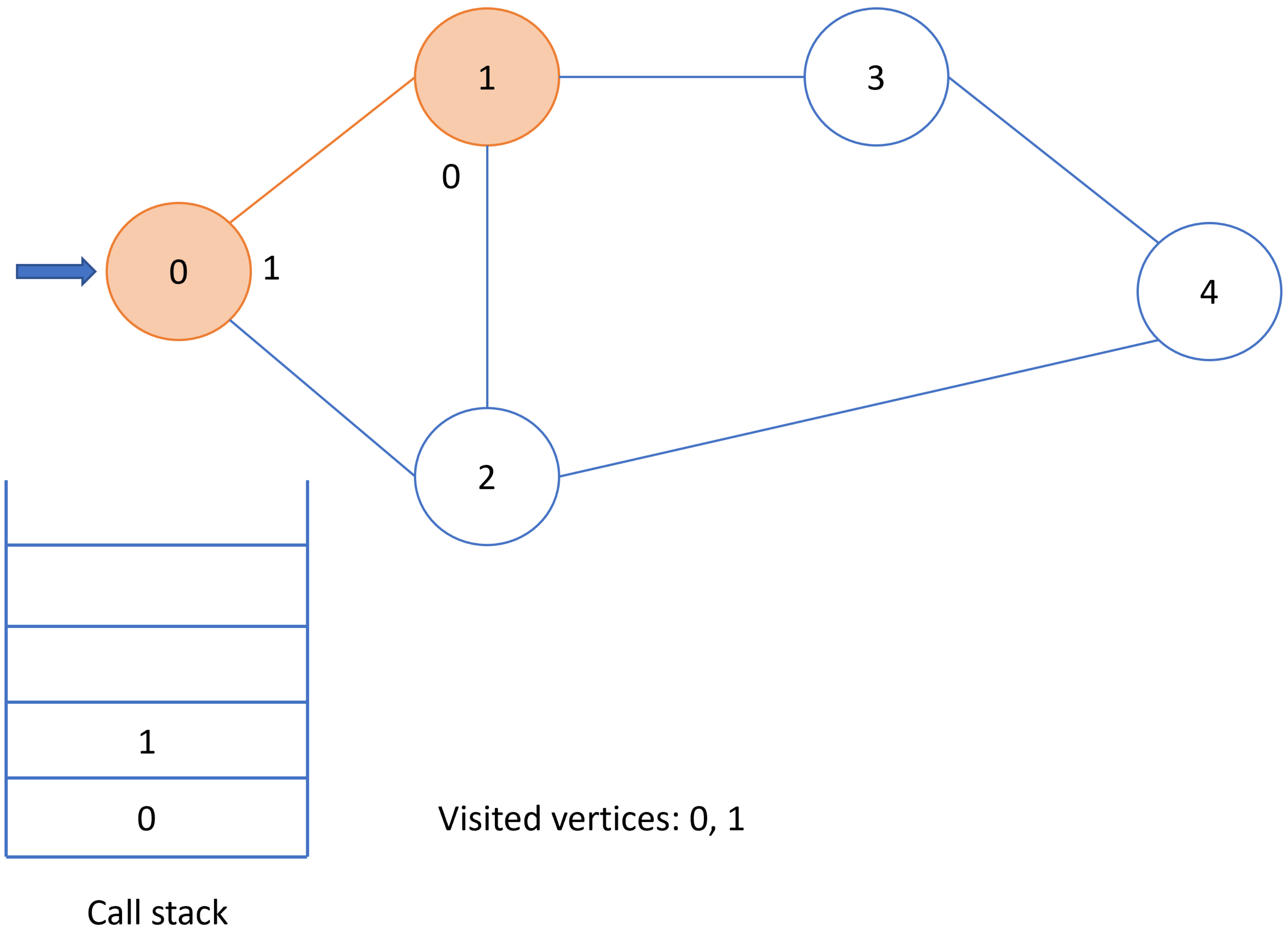


Depth first search - graphs

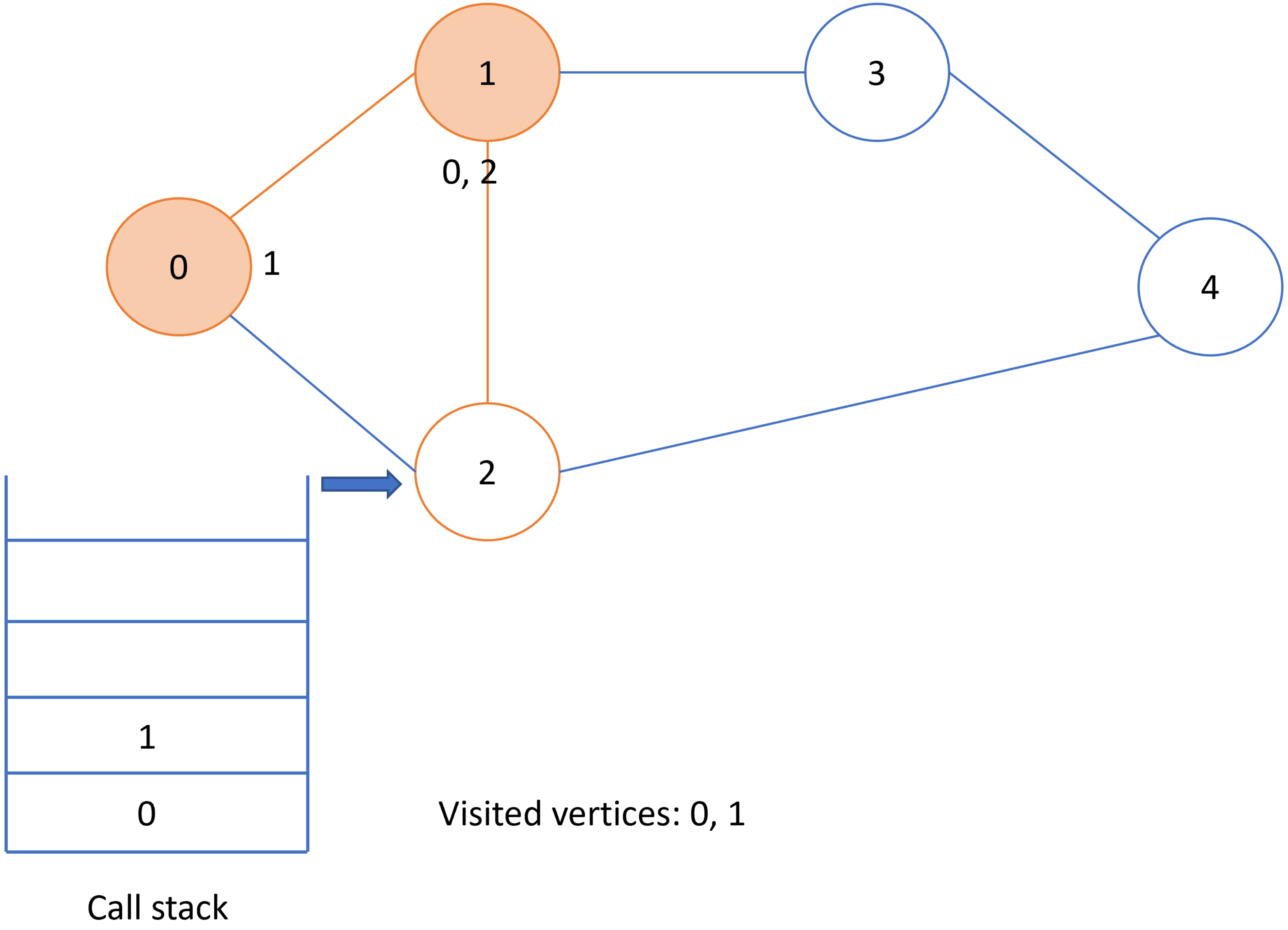


Visited vertices: 0, 1

Depth first search - graphs

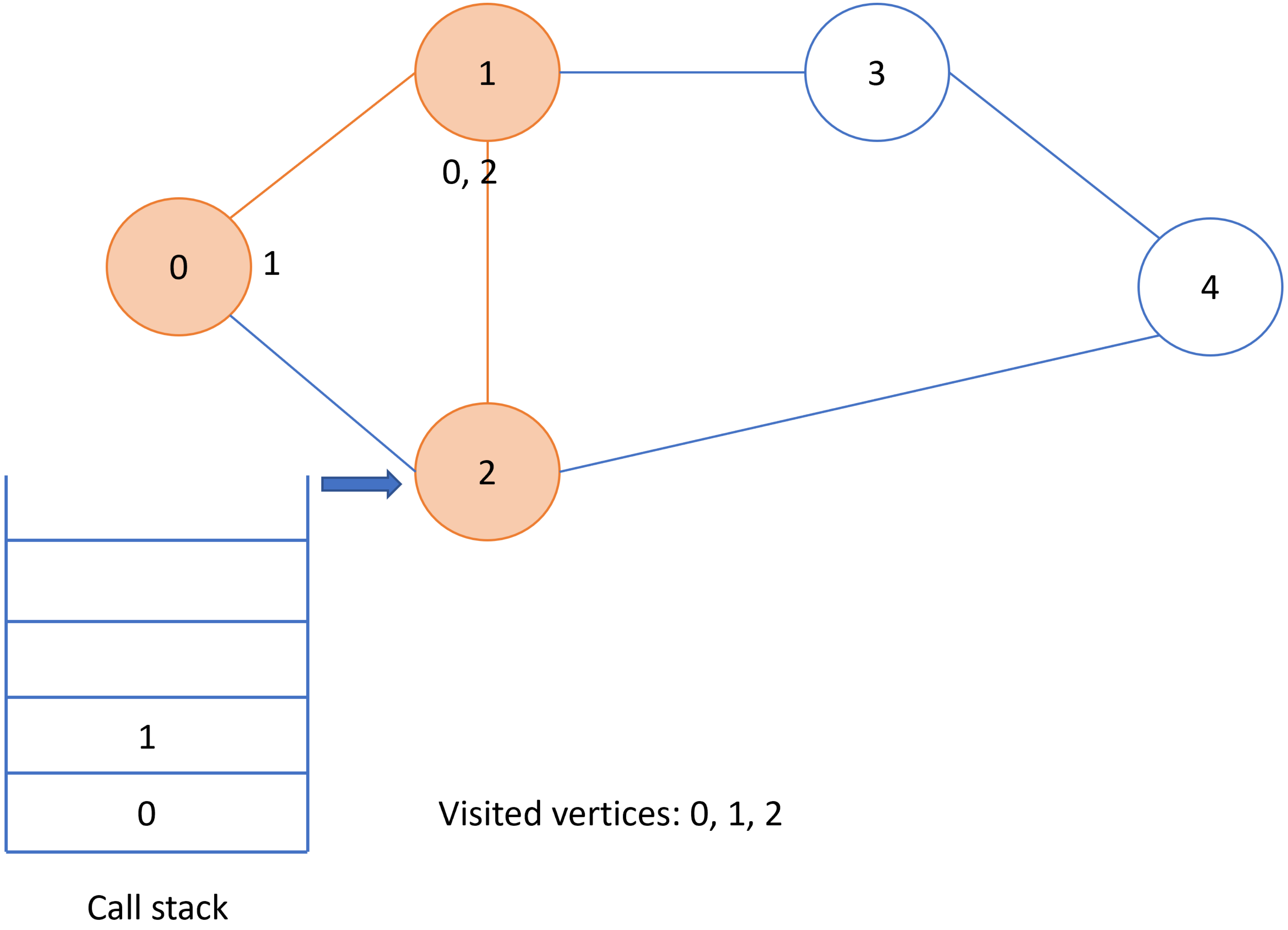


Depth first search - graphs

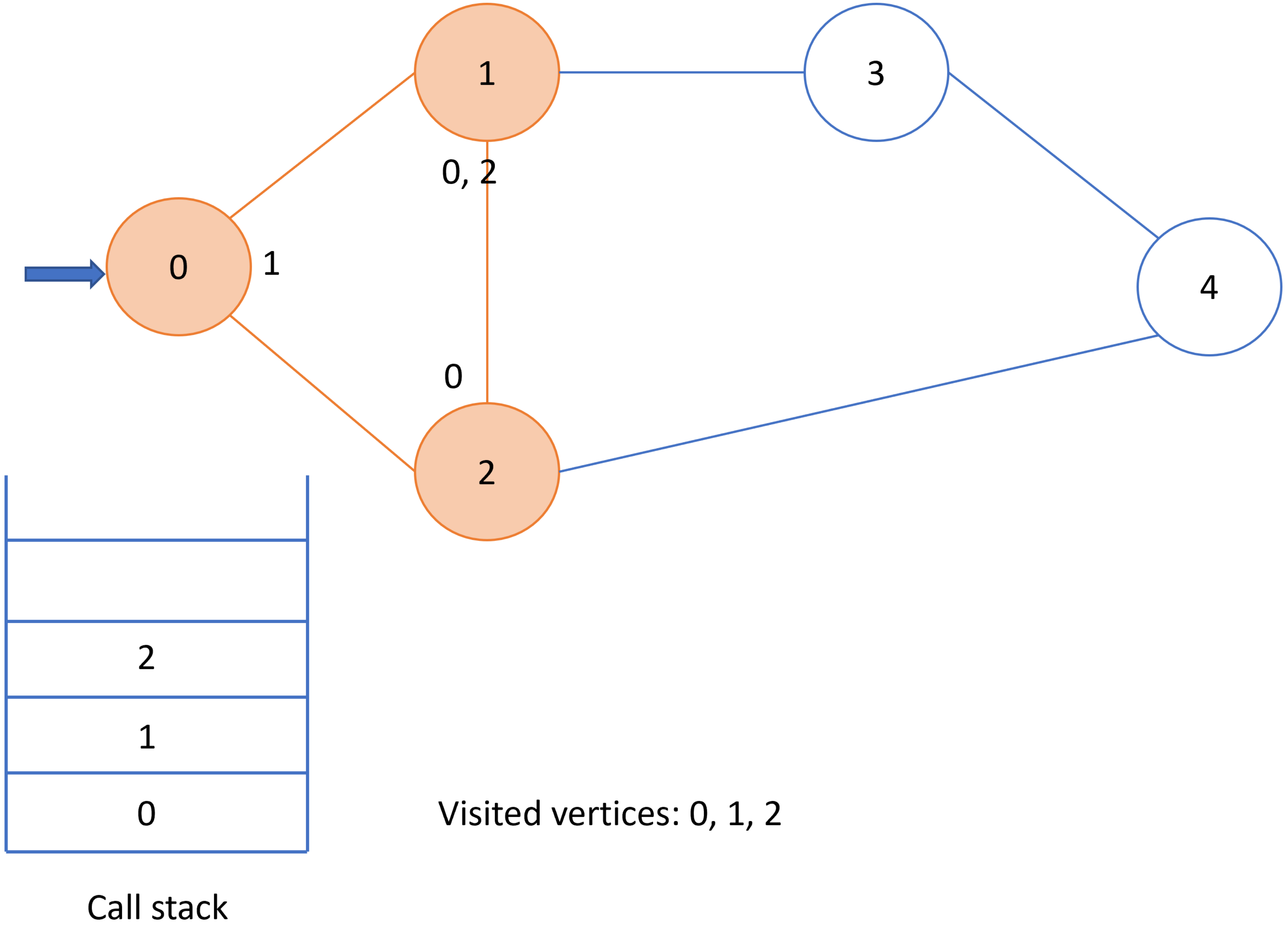


Visited vertices: 0, 1

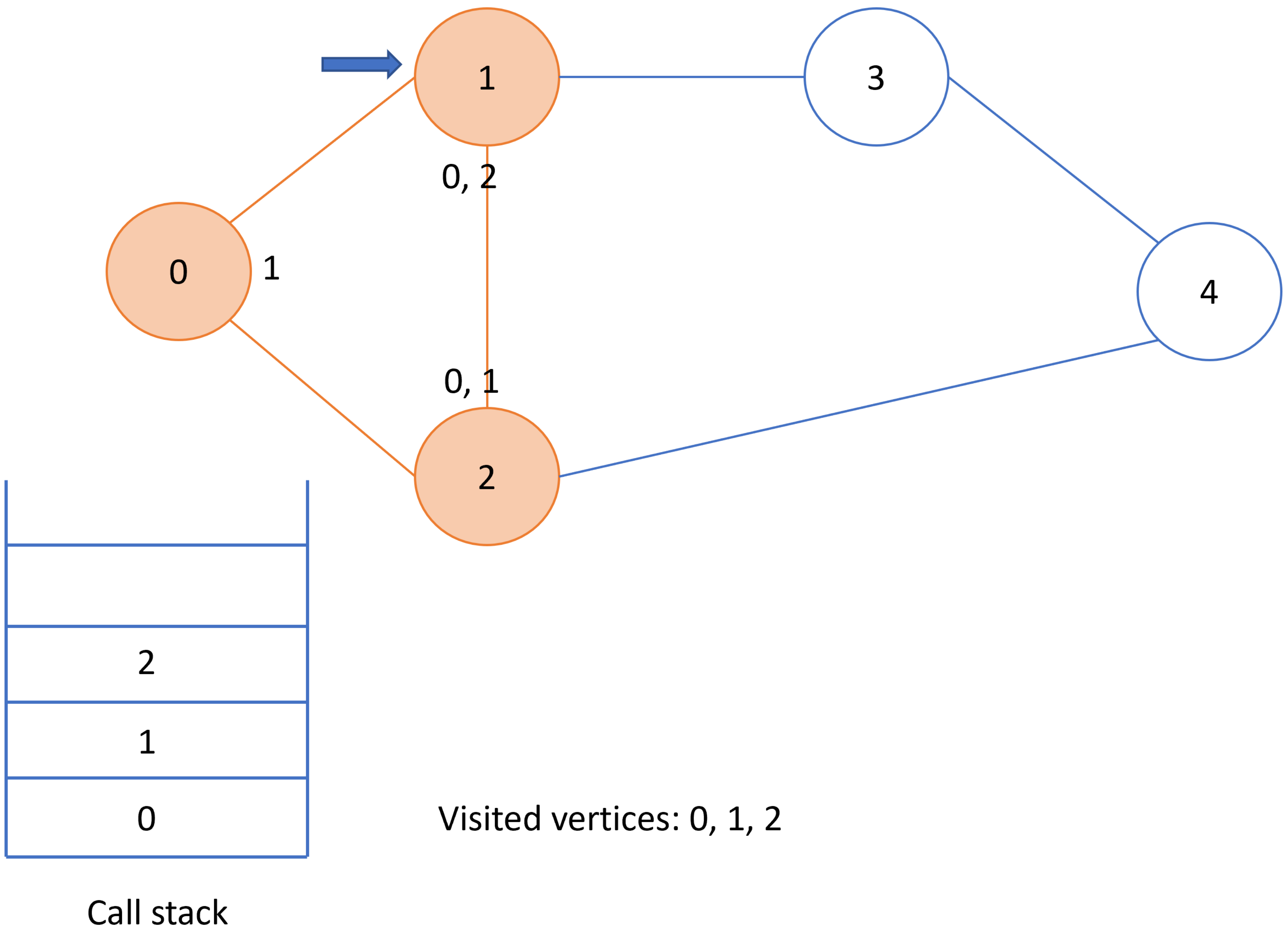
Depth first search - graphs



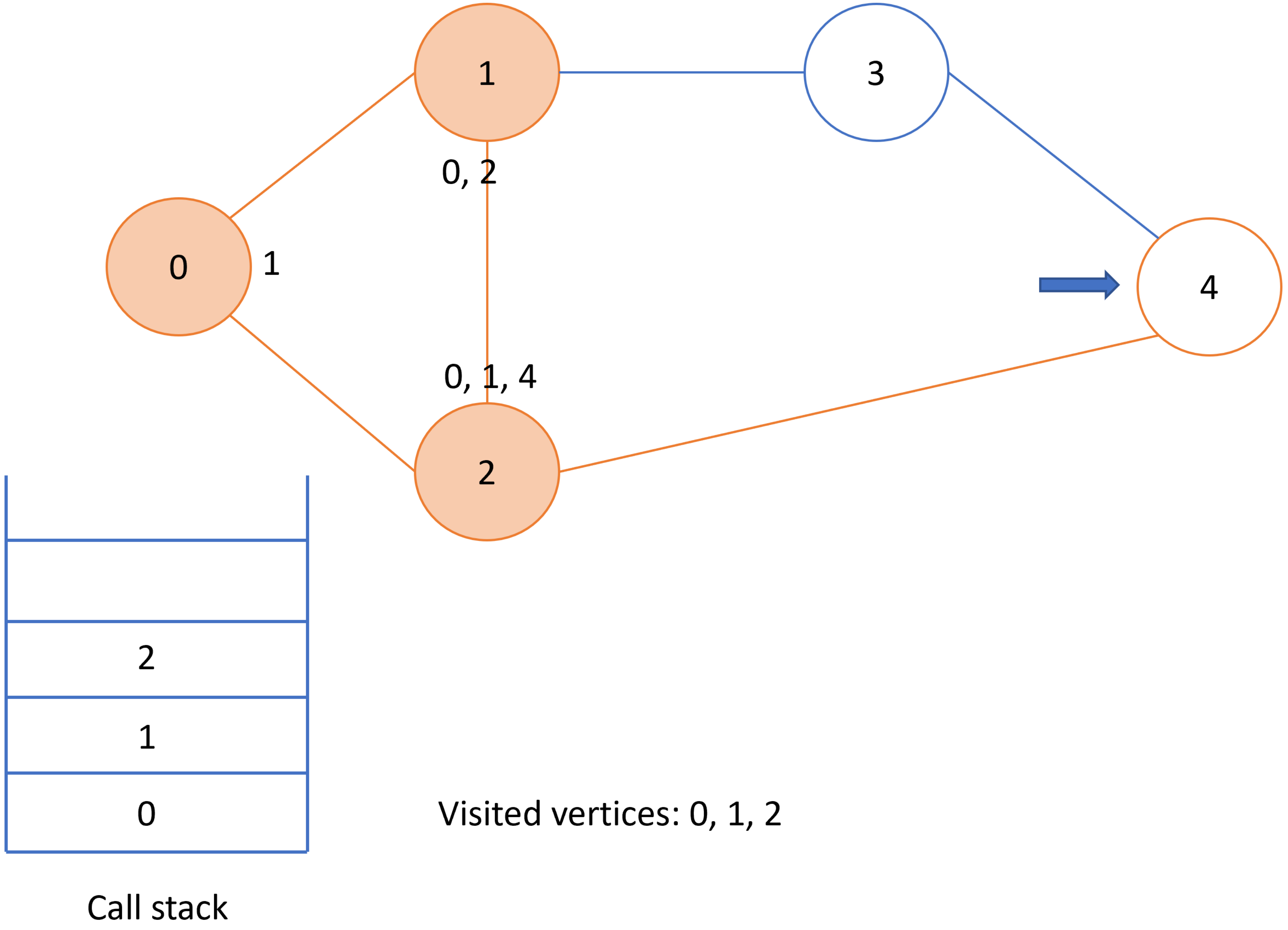
Depth first search - graphs



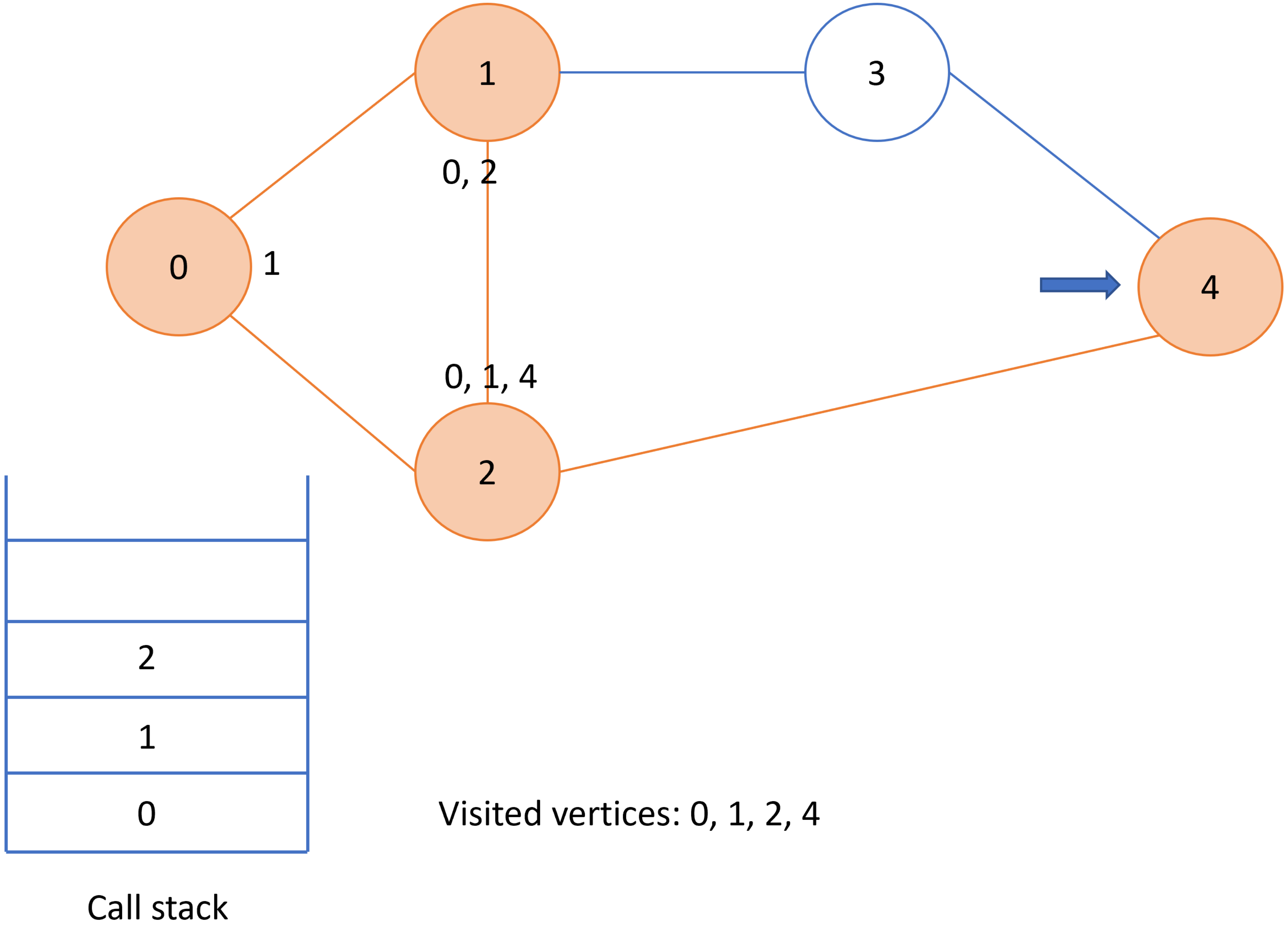
Depth first search - graphs



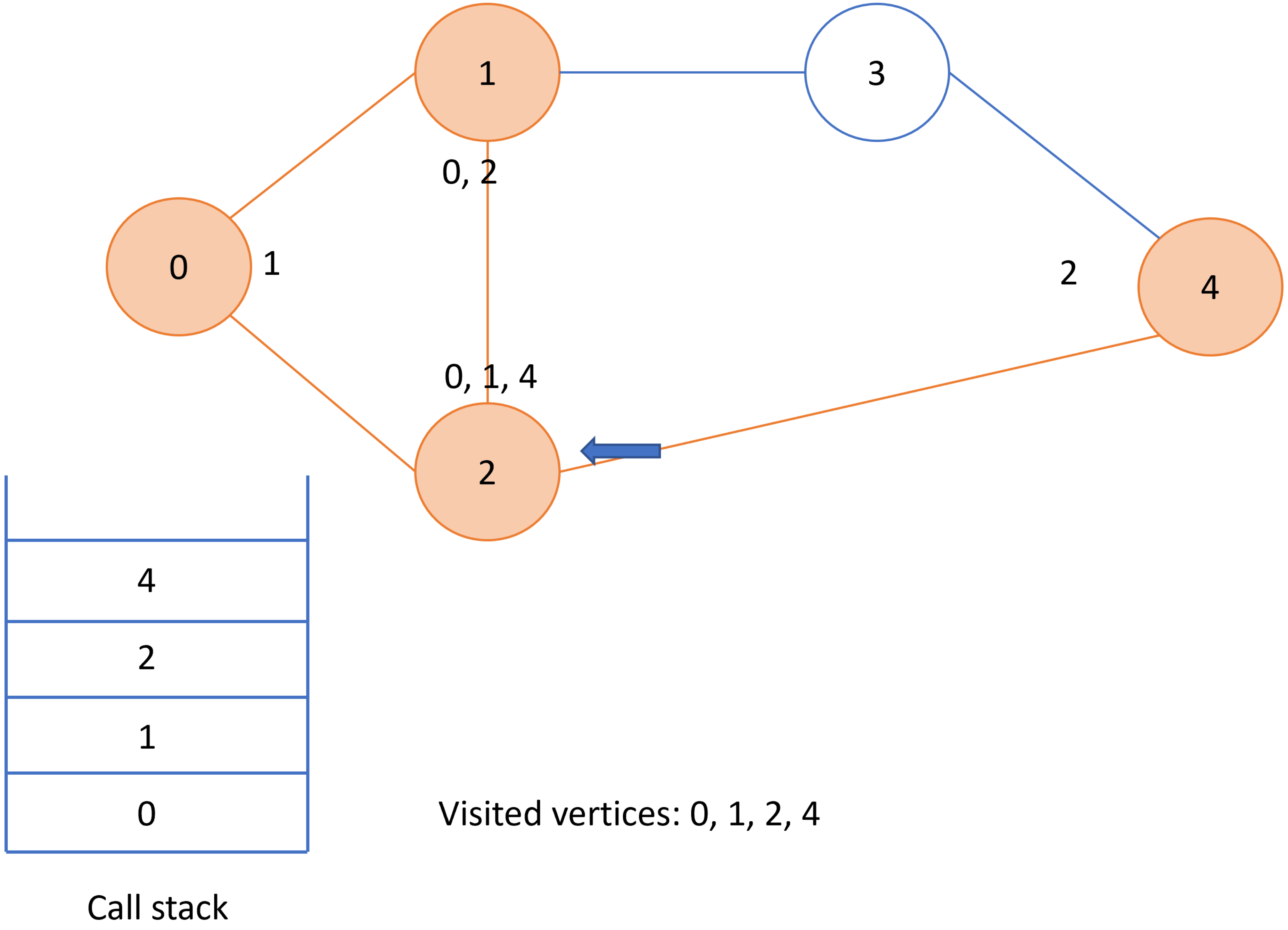
Depth first search - graphs



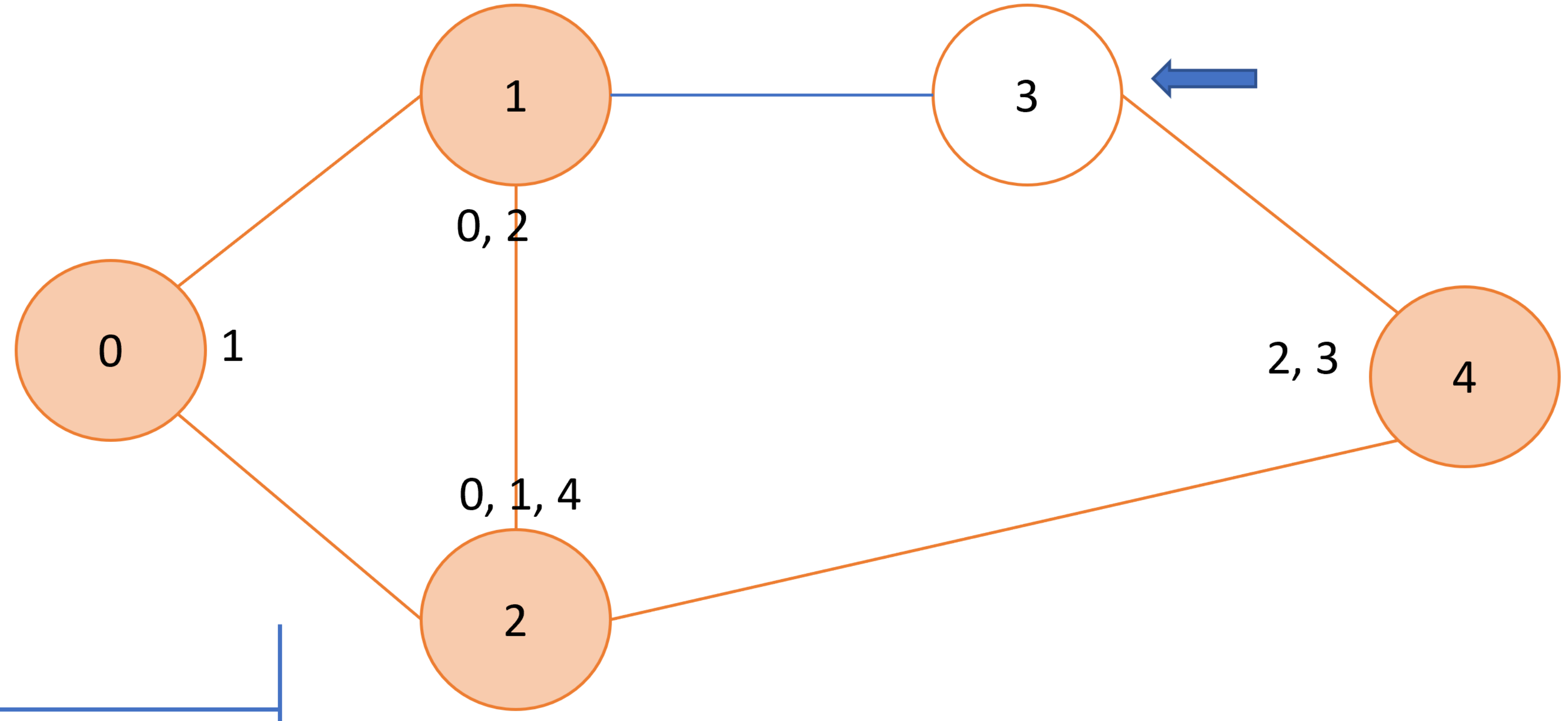
Depth first search - graphs

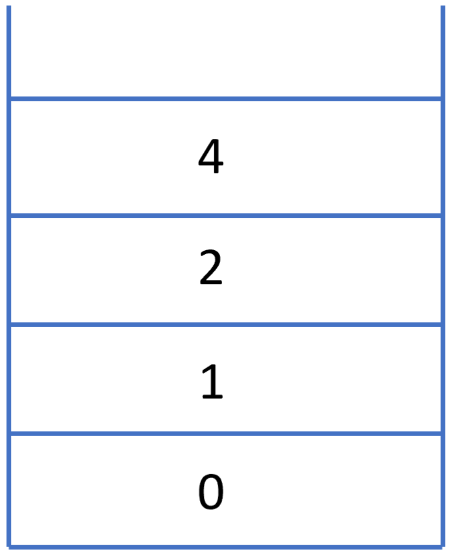


Depth first search - graphs



Depth first search - graphs

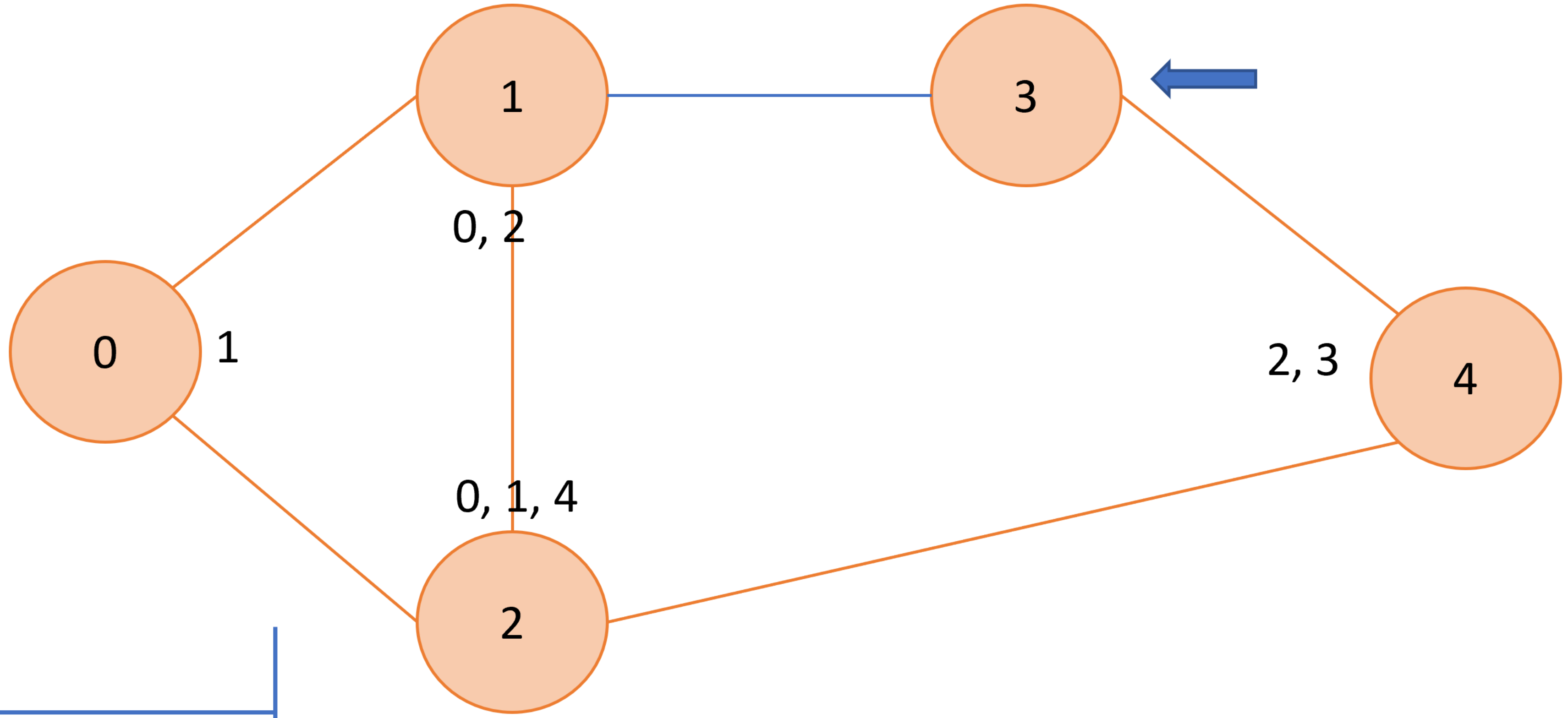


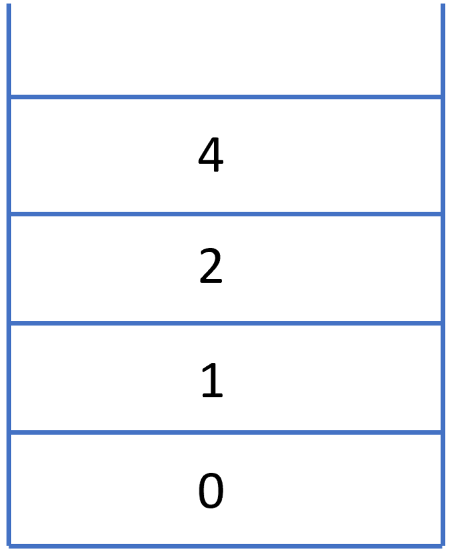


Call stack

Visited vertices: 0, 1, 2, 4

Depth first search - graphs

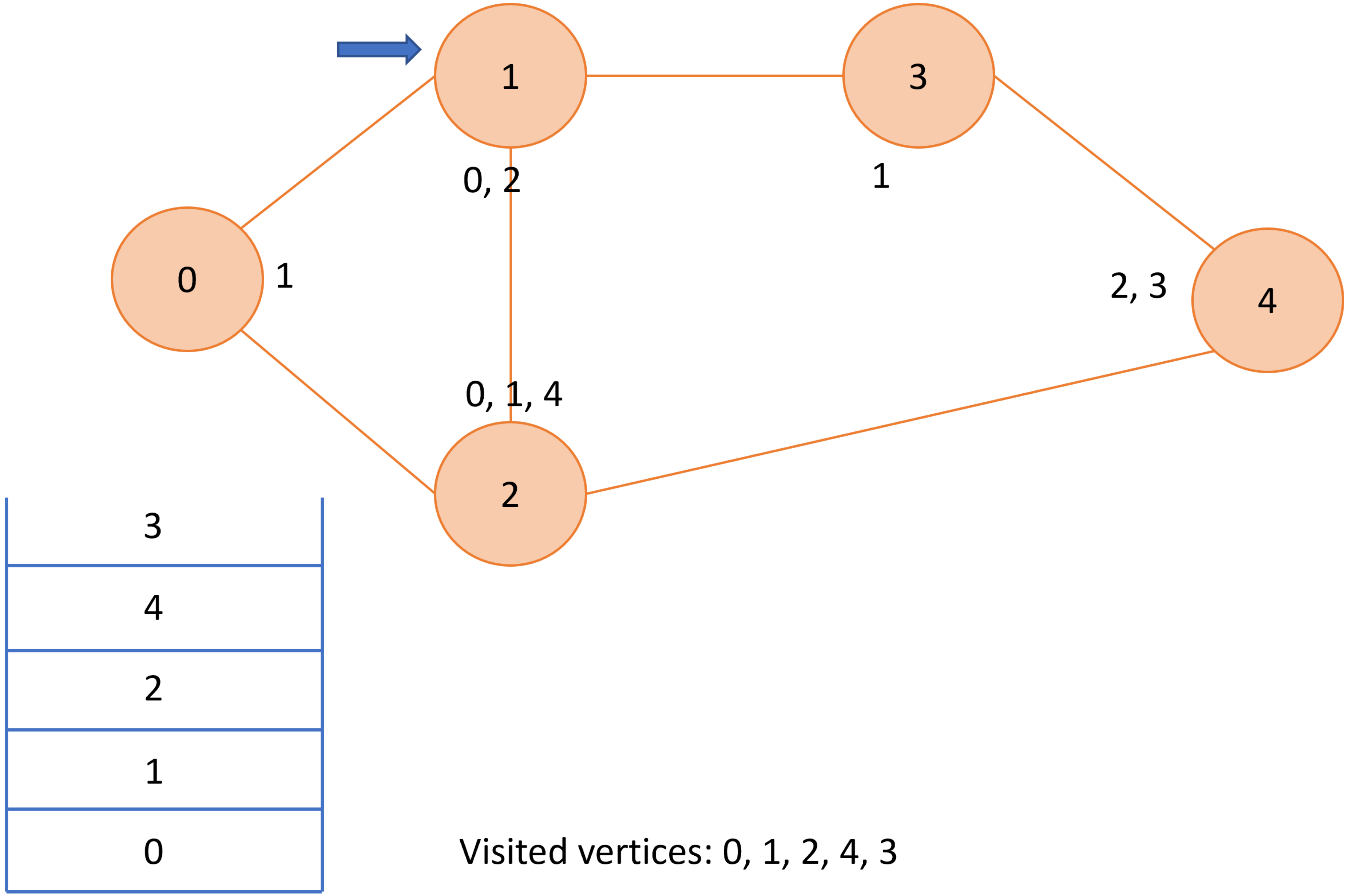




Call stack

Visited vertices: 0, 1, 2, 4, 3

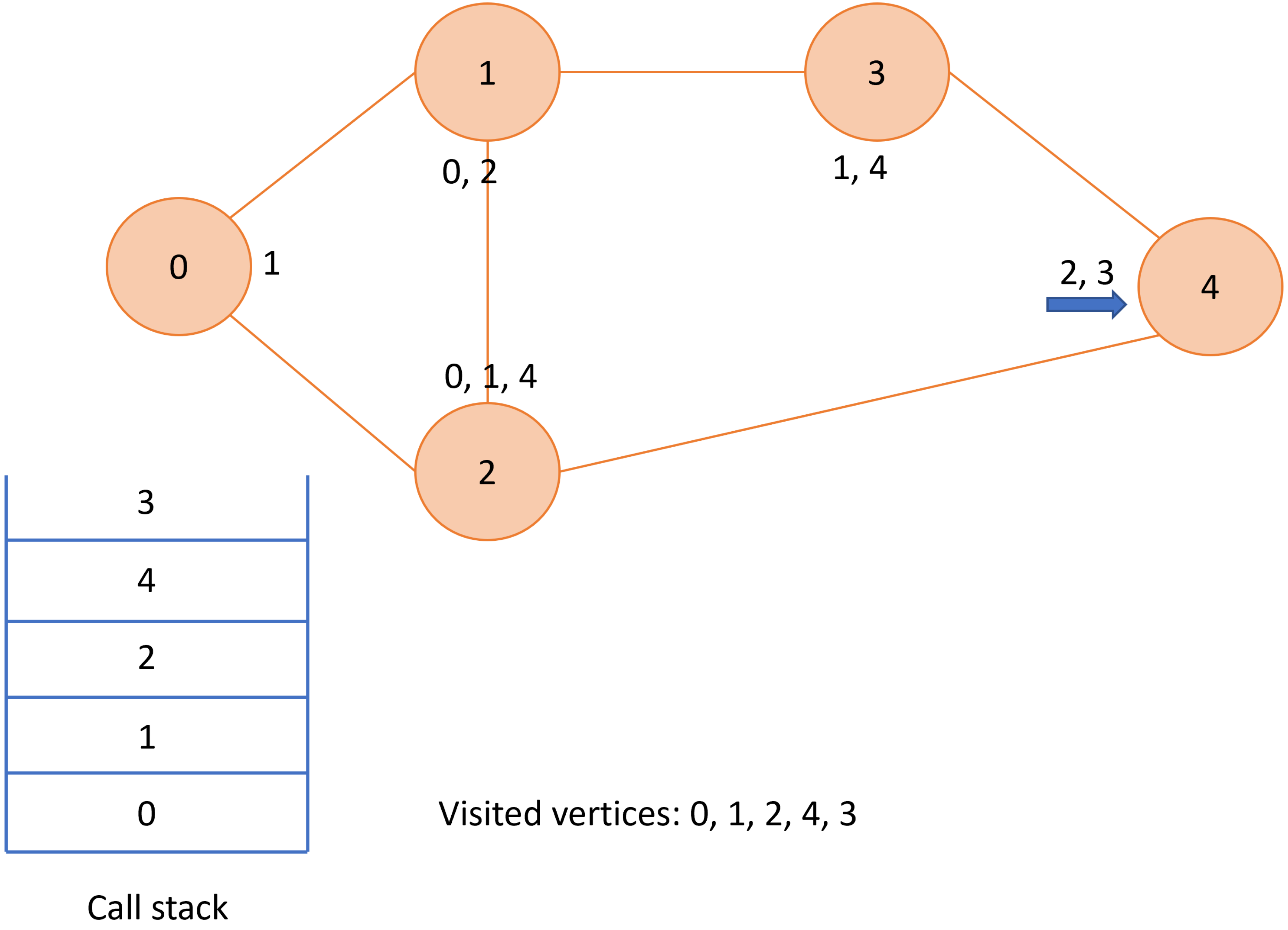
Depth first search - graphs



Call stack

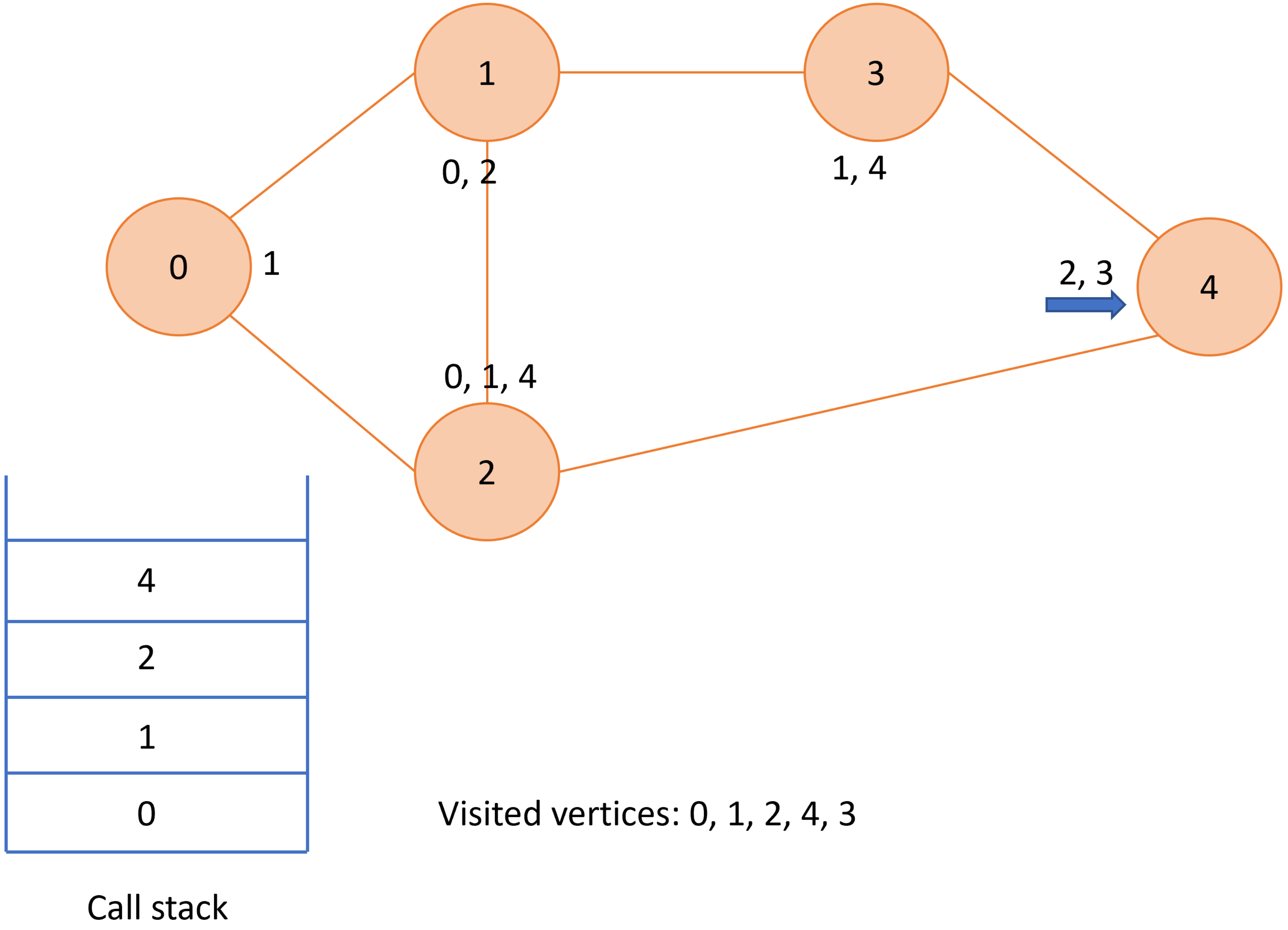
Visited vertices: 0, 1, 2, 4, 3

Depth first search - graphs

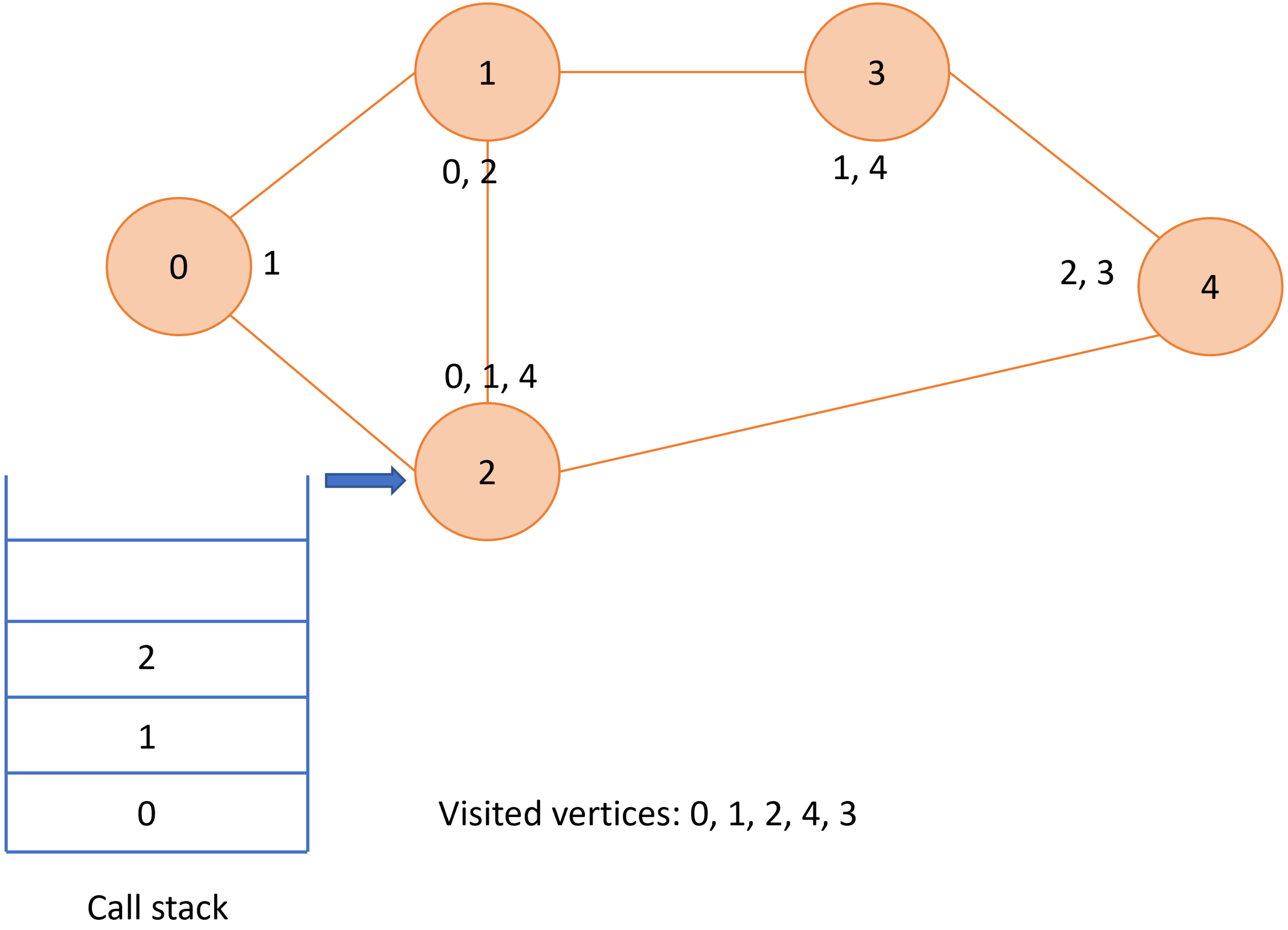


Visited vertices: 0, 1, 2, 4, 3

Depth first search - graphs

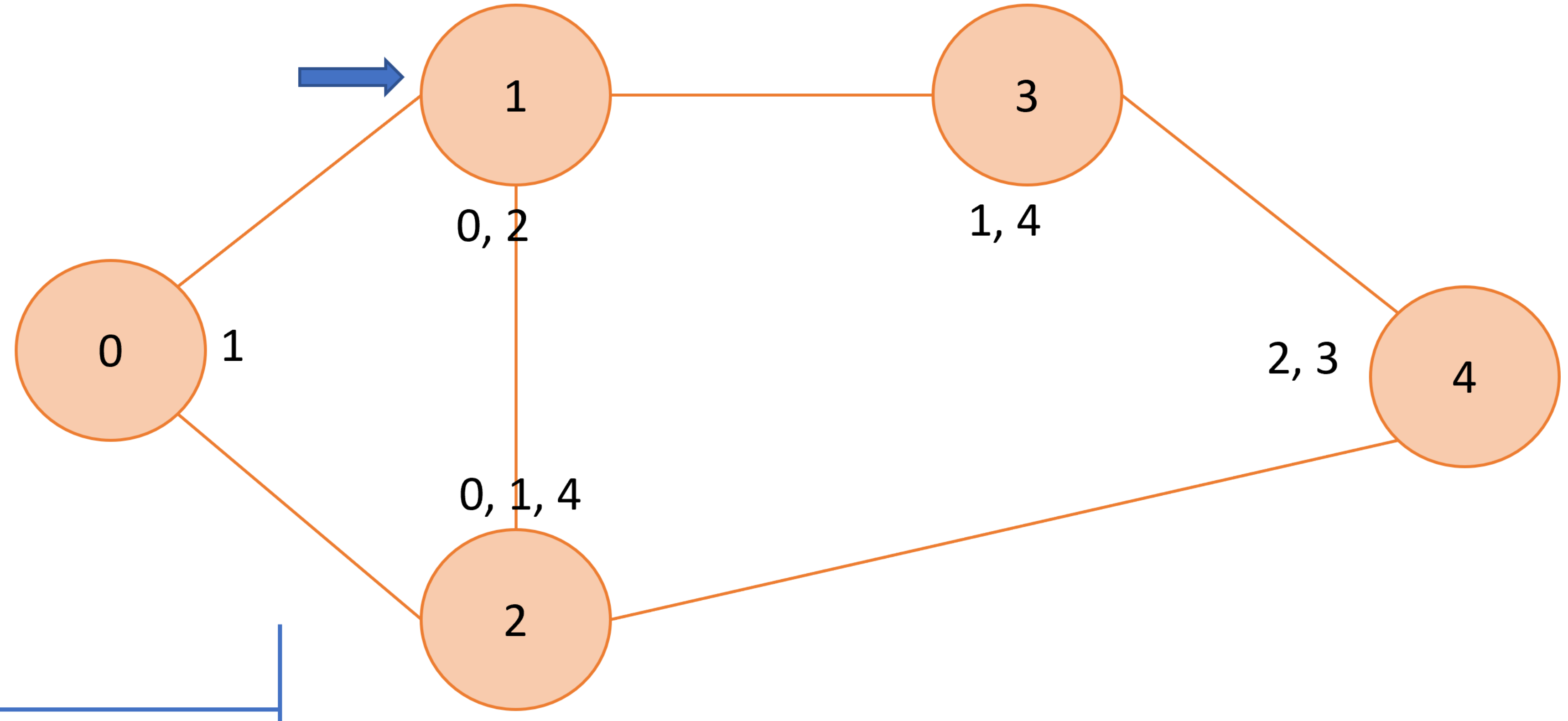


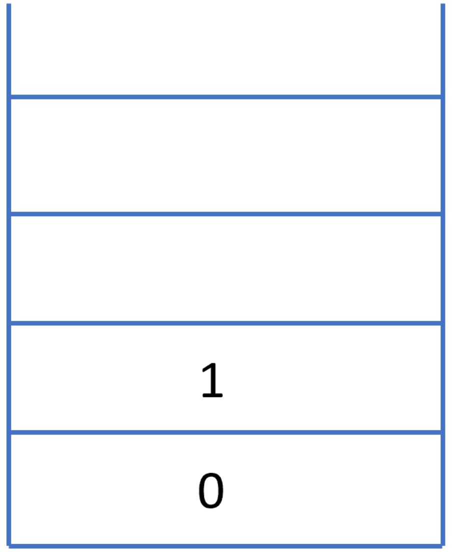
Depth first search - graphs



Visited vertices: 0, 1, 2, 4, 3

Depth first search - graphs

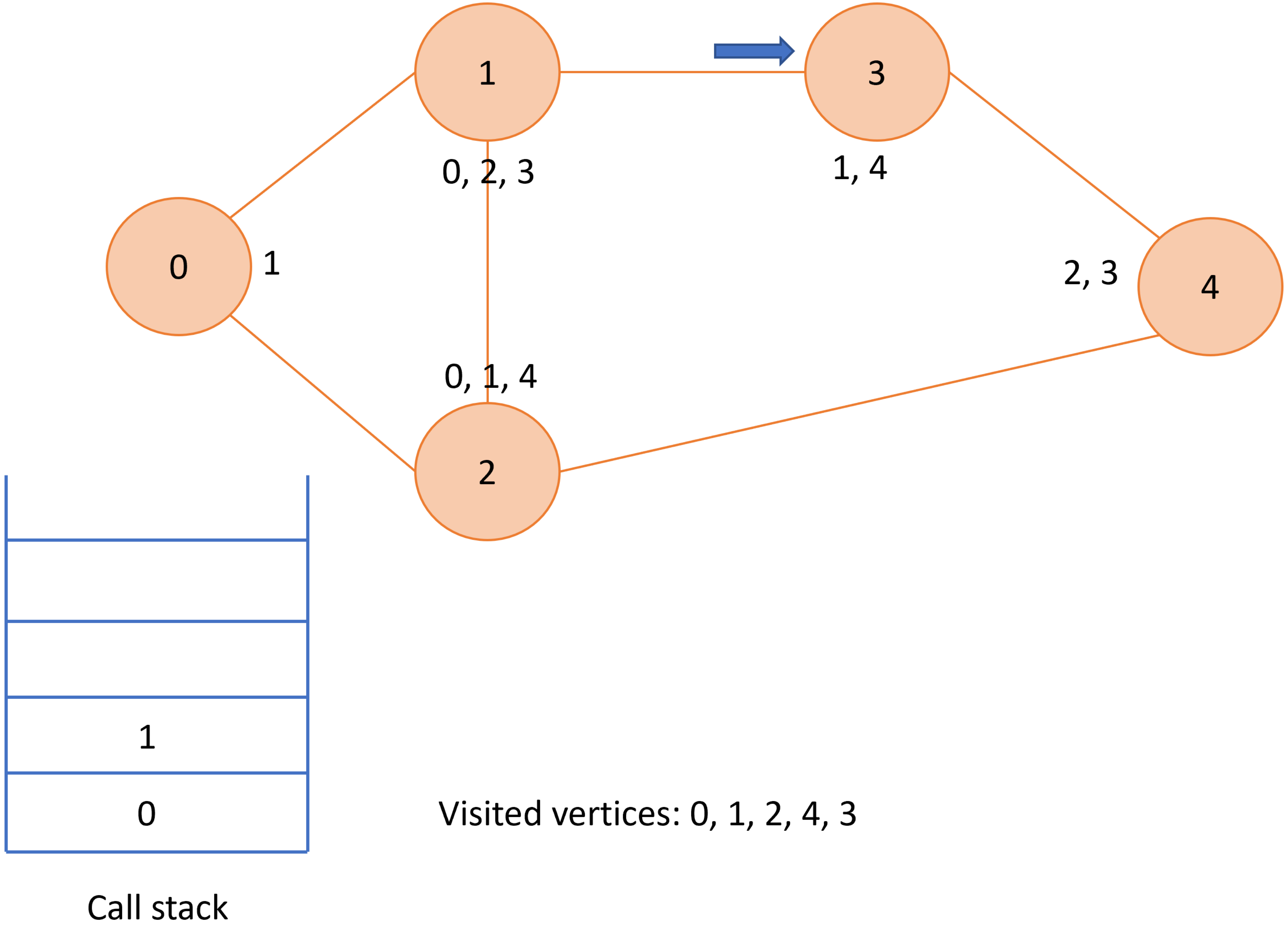




Call stack

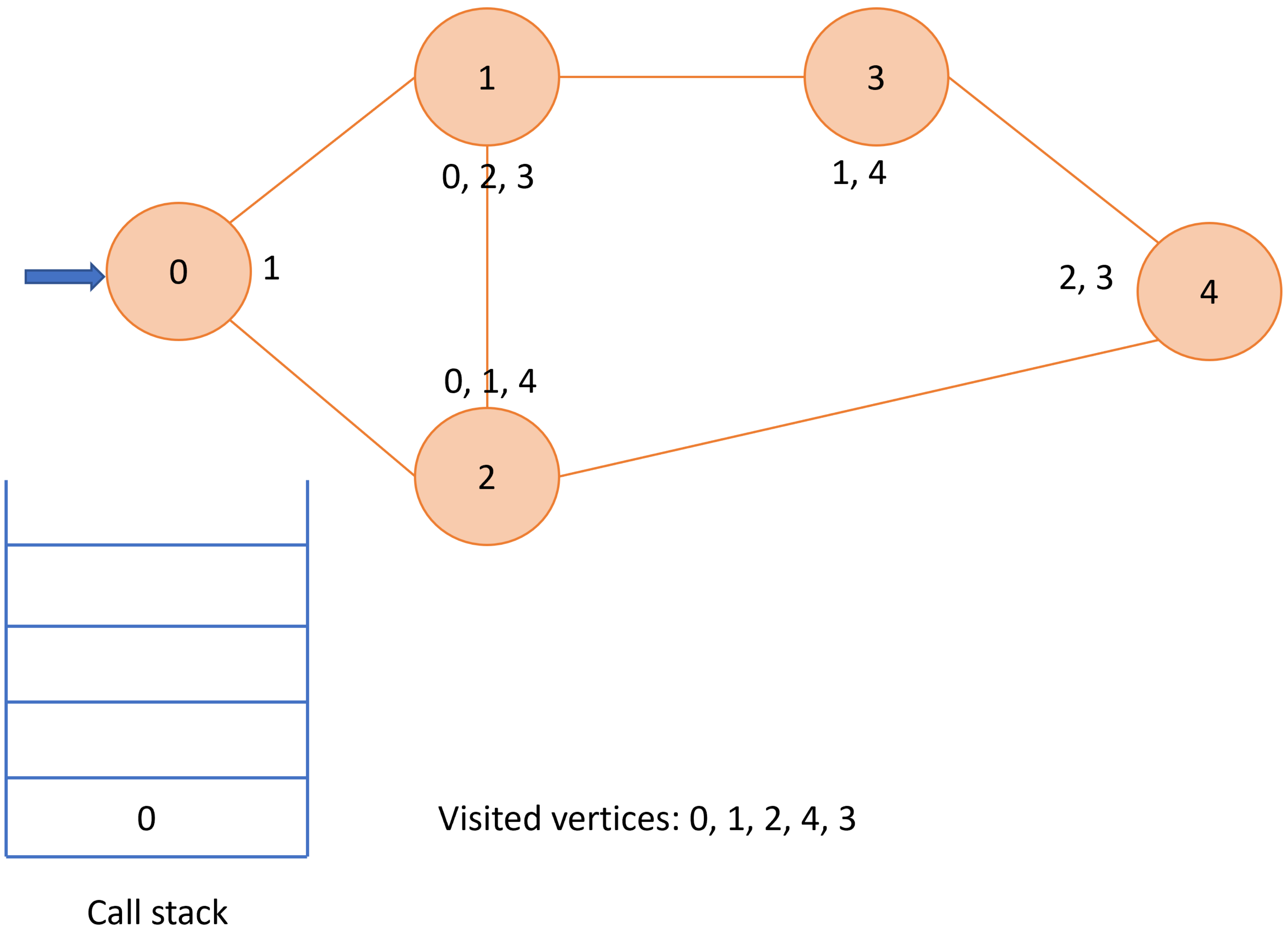
Visited vertices: 0, 1, 2, 4, 3

Depth first search - graphs

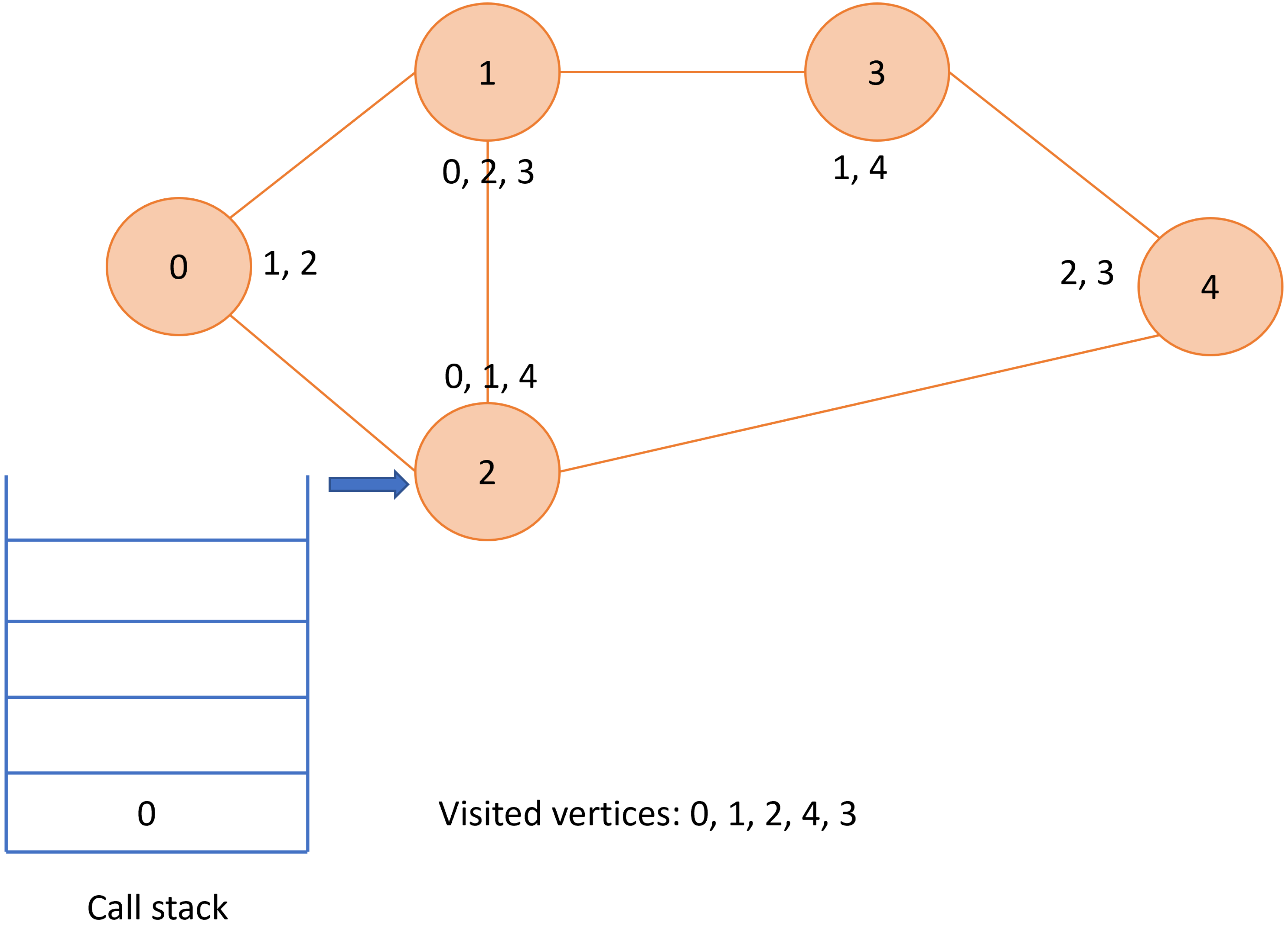


Visited vertices: 0, 1, 2, 4, 3

Depth first search - graphs

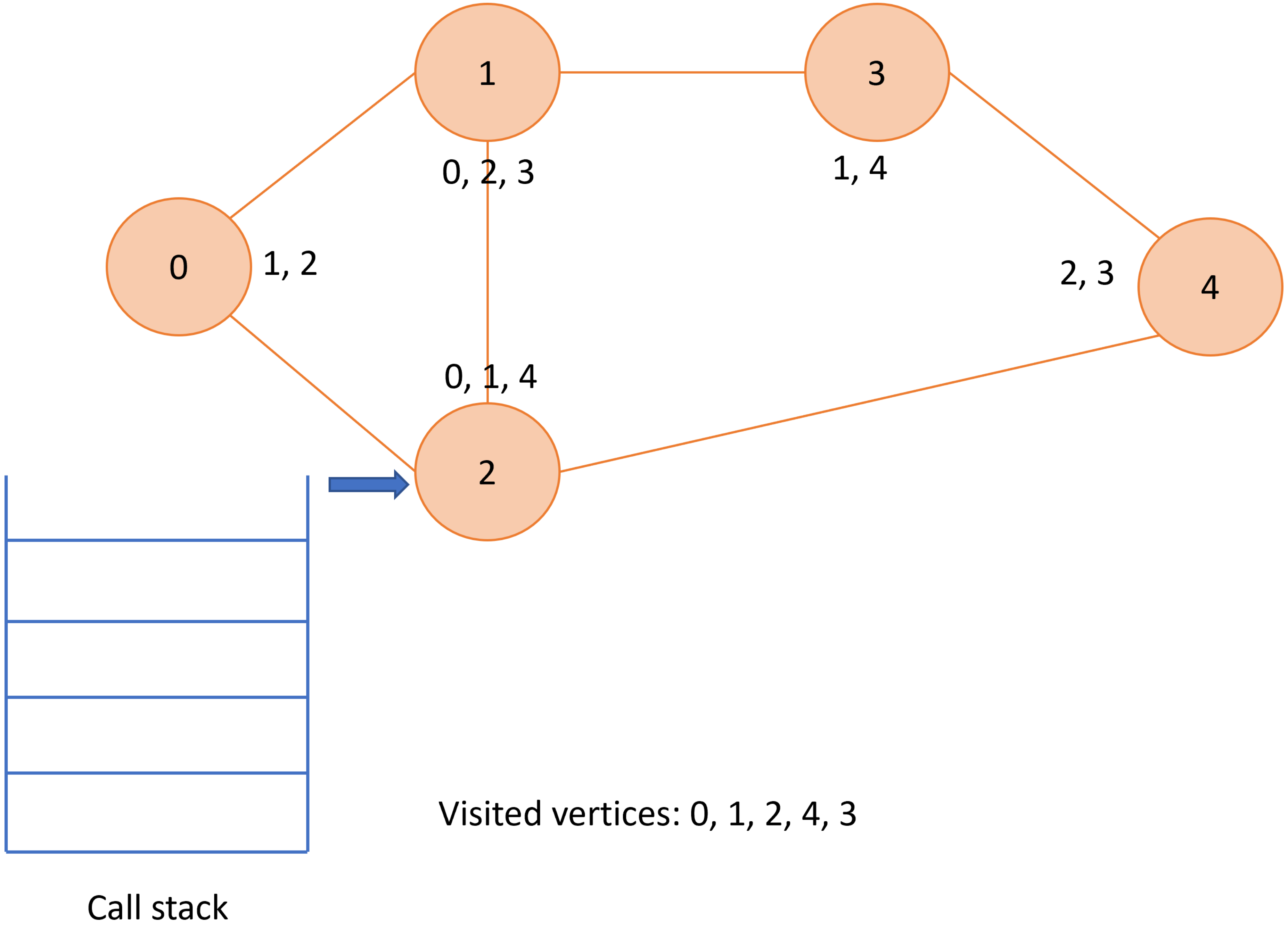


Depth first search - graphs



Visited vertices: 0, 1, 2, 4, 3

Depth first search - graphs



Visited vertices: 0, 1, 2, 4, 3

Depth first search - implementation

```
def dfs(visited_vertices, graph, current_vertex):
    if current_vertex not in visited_vertices:
        print(current_vertex)
        visited_vertices.add(current_vertex)
        for adjacent_vertex in graph[current_vertex]:
            dfs(visited_vertices, graph, adjacent_vertex)
```

- Complexity: $O(V + E)$
  - V -> number of vertices
  - E -> number of edges

Let's practice!

DATA STRUCTURES AND ALGORITHMS IN PYTHON

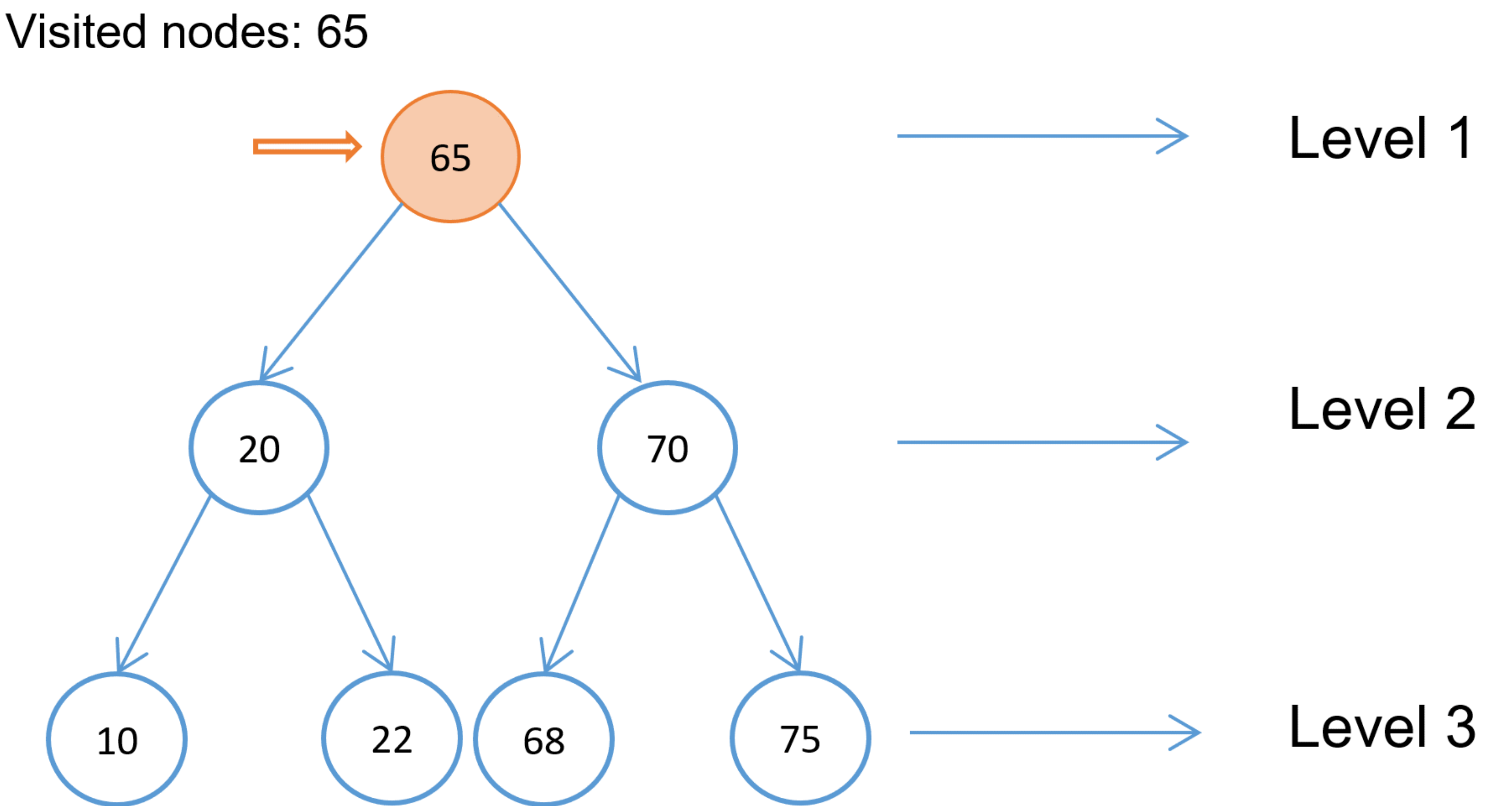
Breadth First Search (BFS)

DATA STRUCTURES AND ALGORITHMS IN PYTHON

Miriam Antona
Software engineer

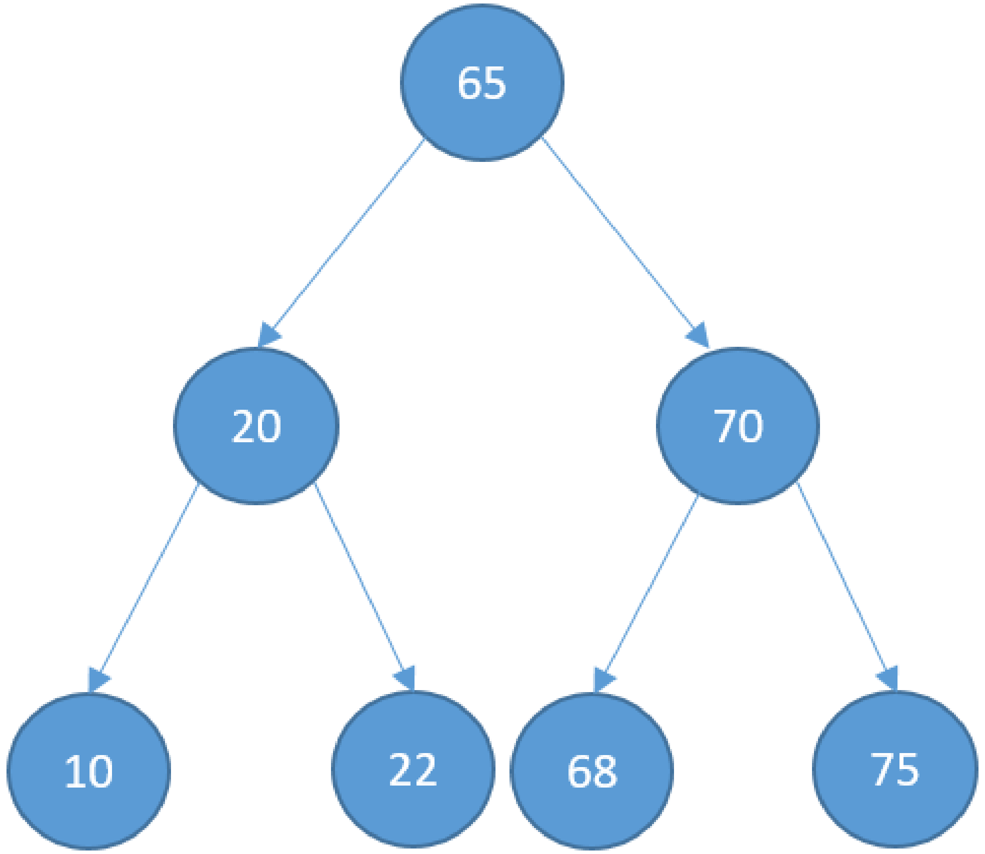
Breadth first search - binary trees

- Starts from the root
- Visits every node of every level



Breadth first search - binary trees

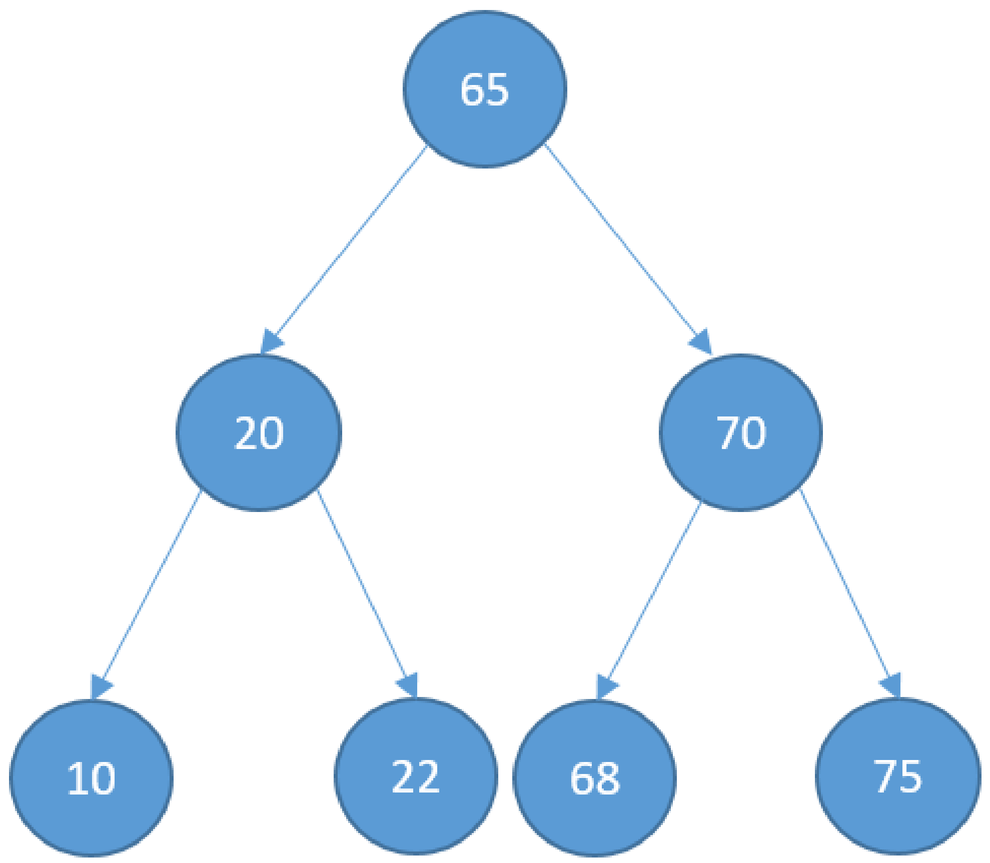
```
def bfs(self):
  if self.root:
    visited_nodes = []
    bfs_queue = queue.SimpleQueue()
```



- visited_nodes:
- bfs_queue:

Breadth first search - binary trees

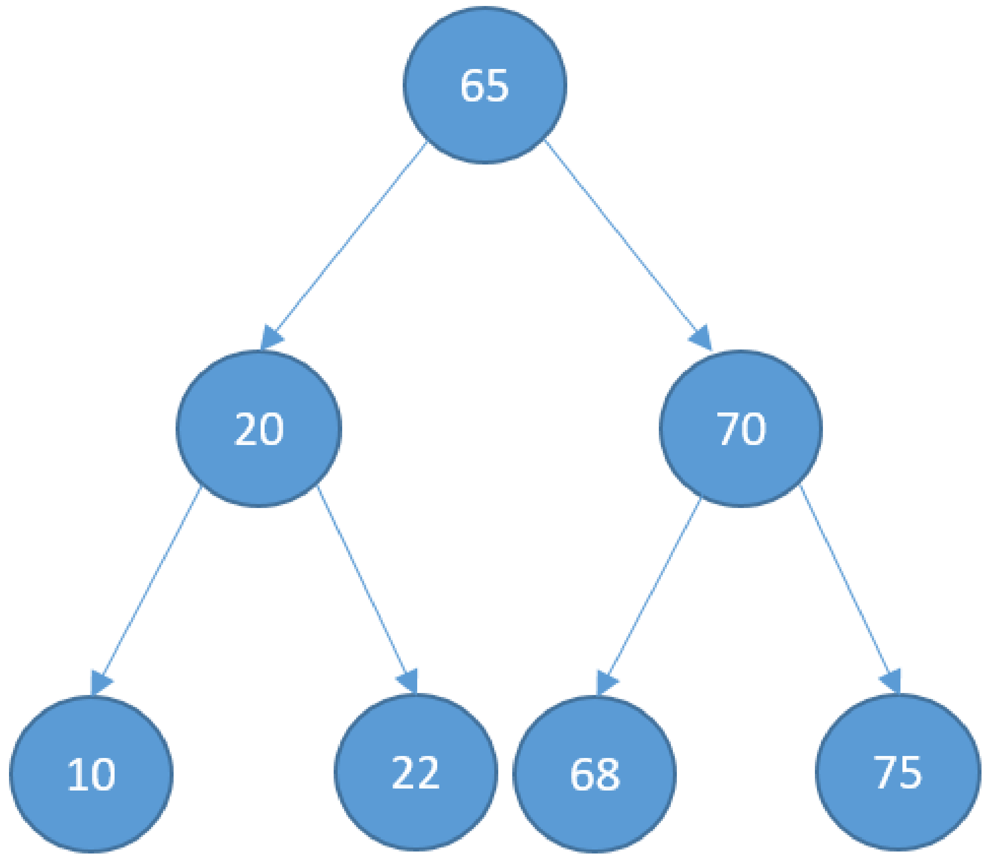
```
def bfs(self):
  if self.root:
    visited_nodes = []
    bfs_queue = queue.SimpleQueue()
    bfs_queue.put(self.root)
    while not bfs_queue.empty():
```



- visited_nodes:
- bfs_queue: 65

Breadth first search - binary trees

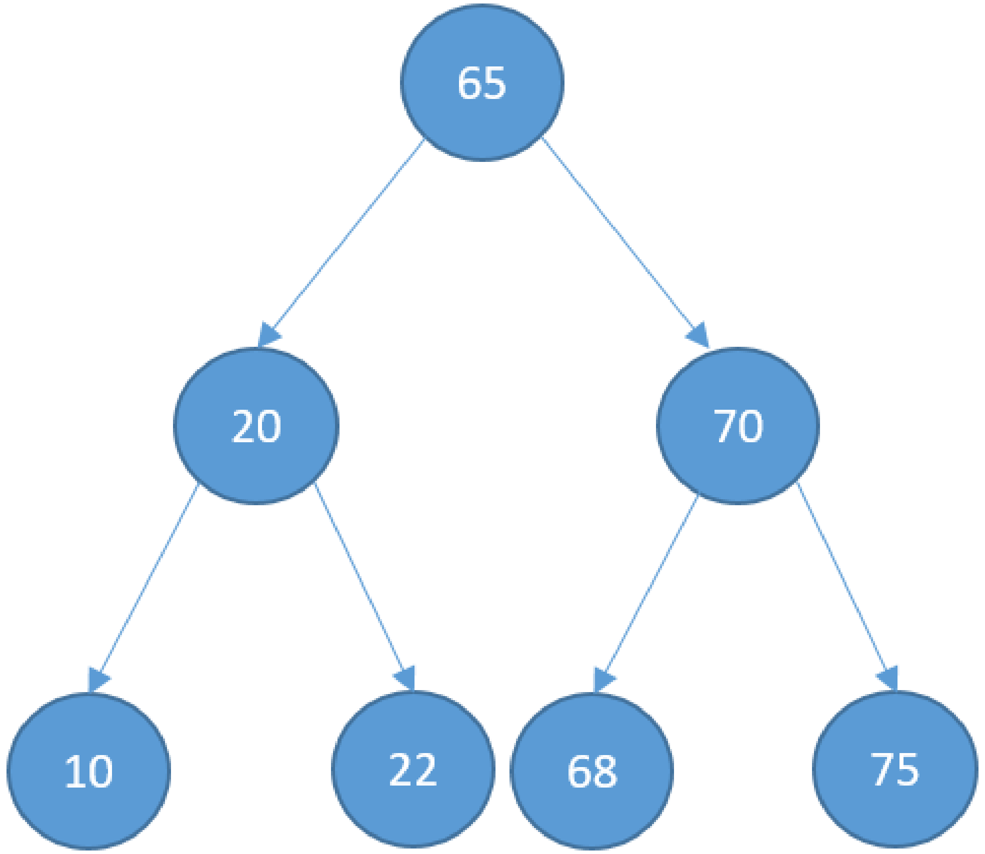
```python
def bfs(self):
  if self.root:
    visited_nodes = []
    bfs_queue = queue.SimpleQueue()
    bfs_queue.put(self.root)
    while not bfs_queue.empty():
      current_node = bfs_queue.get()
```



- visited_nodes:
- bfs_queue:
- current_node: 65

Breadth first search - binary trees

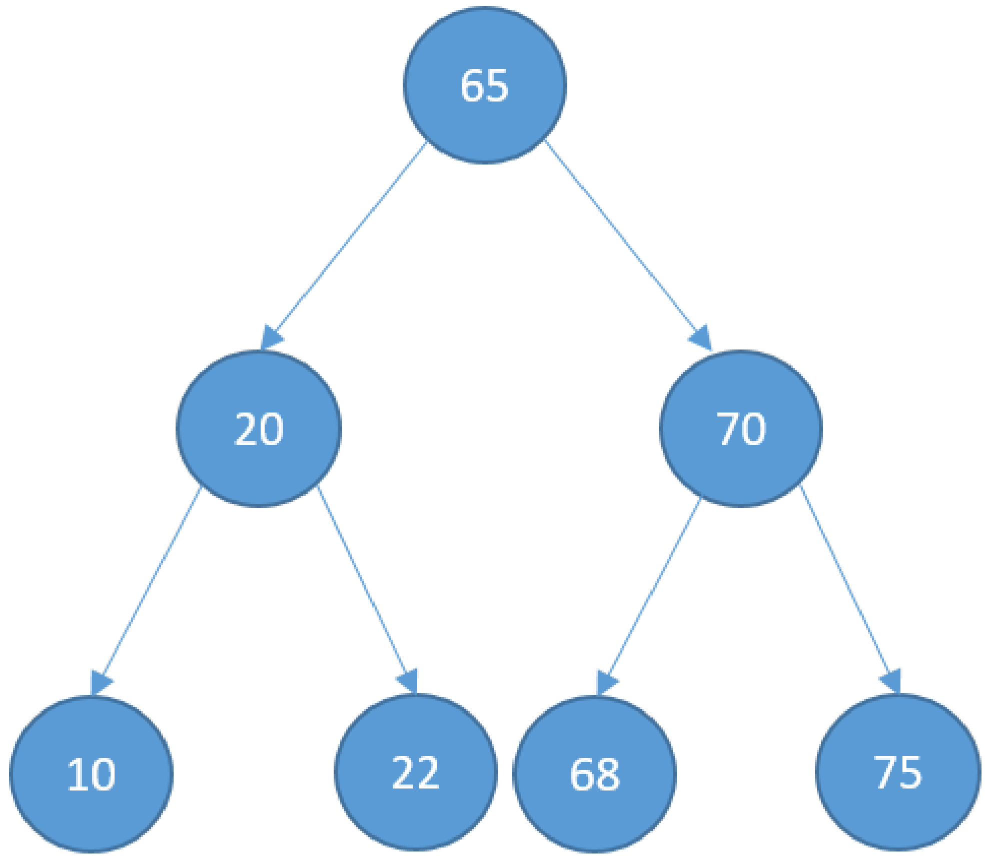
```
def bfs(self):
  if self.root:
    visited_nodes = []
    bfs_queue = queue.SimpleQueue()
    bfs_queue.put(self.root)
    while not bfs_queue.empty():
      current_node = bfs_queue.get()
      visited_nodes.append(current_node.data)
      if current_node.left:
```



- visited_nodes: 65
- bfs_queue:
- current_node: 65

Breadth first search - binary trees

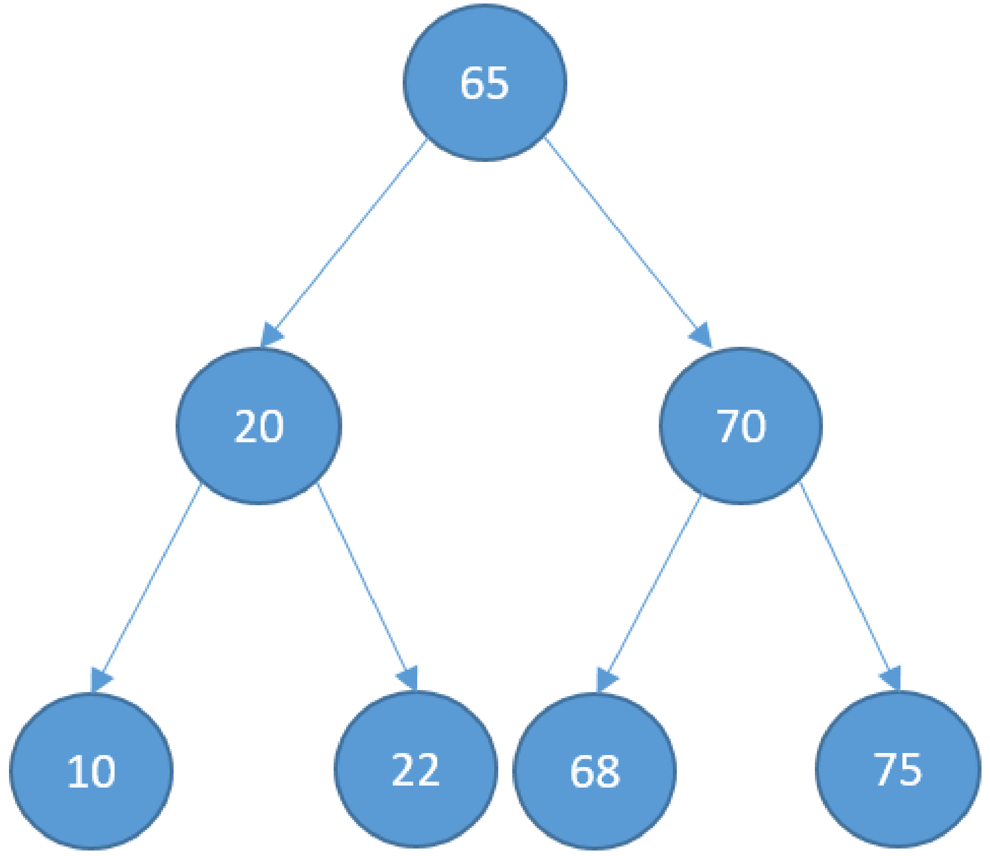
```
def bfs(self):
  if self.root:
    visited_nodes = []
    bfs_queue = queue.SimpleQueue()
    bfs_queue.put(self.root)
    while not bfs_queue.empty():
      current_node = bfs_queue.get()
      visited_nodes.append(current_node.data)
      if current_node.left:
        bfs_queue.put(current_node.left)
```



- visited_nodes: 65
- bfs_queue: 20
- current_node: 65

Breadth first search - binary trees

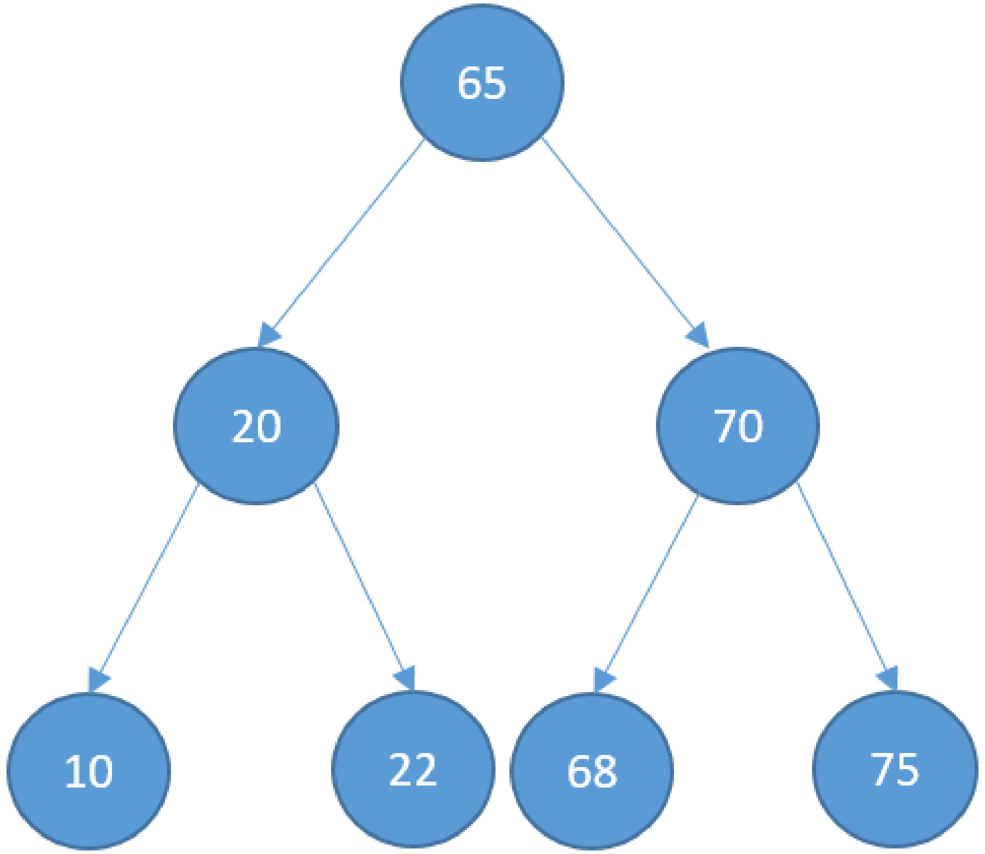
```
def bfs(self):
  if self.root:
    visited_nodes = []
    bfs_queue = queue.SimpleQueue()
    bfs_queue.put(self.root)
    while not bfs_queue.empty():
      current_node = bfs_queue.get()
      visited_nodes.append(current_node.data)
      if current_node.left:
        bfs_queue.put(current_node.left)
      if current_node.right:
        bfs_queue.put(current_node.right)
```



- visited_nodes: 65
- bfs_queue: 20, 70
- current_node: 65

Breadth first search - binary trees

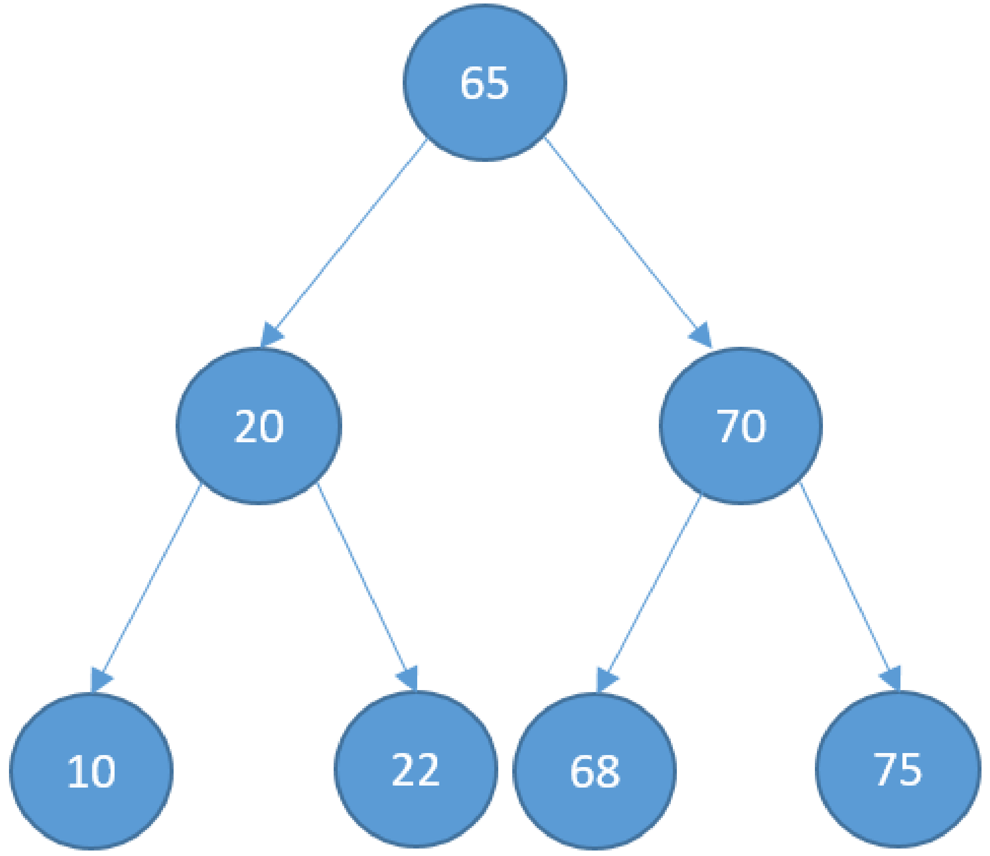
```python
def bfs(self):
  if self.root:
    visited_nodes = []
    bfs_queue = queue.SimpleQueue()
    bfs_queue.put(self.root)
    while not bfs_queue.empty():
      current_node = bfs_queue.get()
      visited_nodes.append(current_node.data)
      if current_node.left:
        bfs_queue.put(current_node.left)
      if current_node.right:
        bfs_queue.put(current_node.right)
```



- visited_nodes: 65
- bfs_queue: 70
- current_node: 20

Breadth first search - binary trees

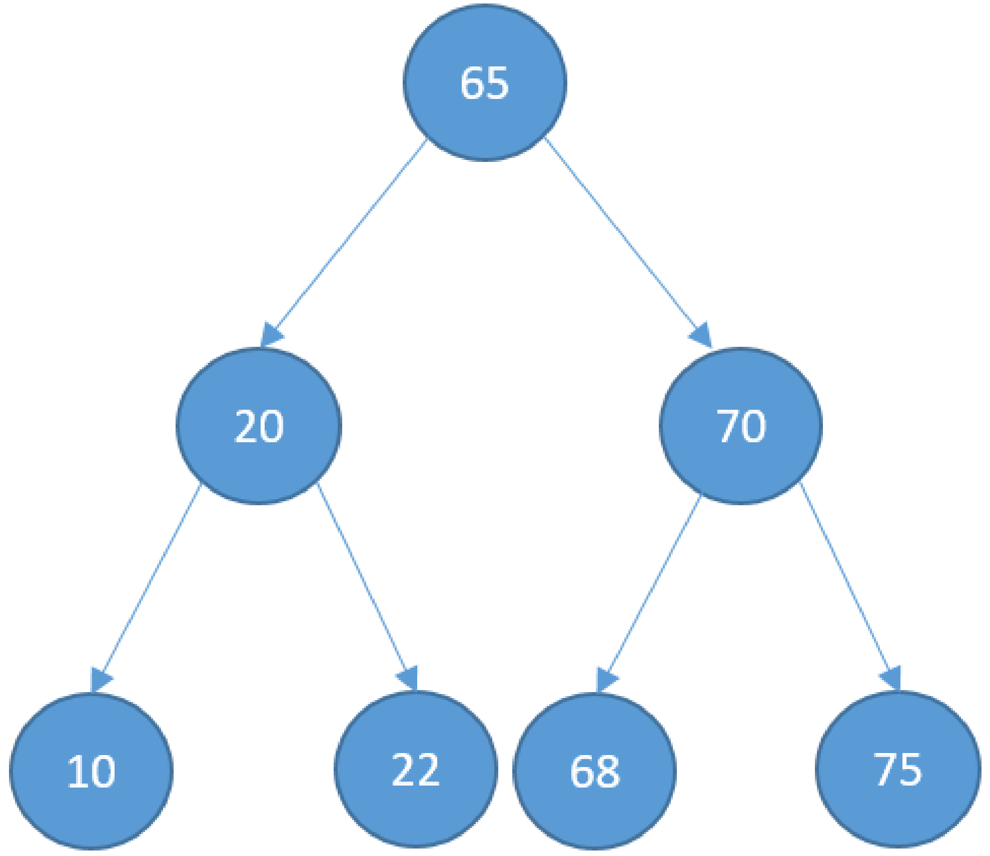
```
def bfs(self):
  if self.root:
    visited_nodes = []
    bfs_queue = queue.SimpleQueue()
    bfs_queue.put(self.root)
    while not bfs_queue.empty():
      current_node = bfs_queue.get()
      visited_nodes.append(current_node.data)
      if current_node.left:
        bfs_queue.put(current_node.left)
      if current_node.right:
        bfs_queue.put(current_node.right)
```



- visited_nodes: 65, 20
- bfs_queue: 70
- current_node: 20

Breadth first search - binary trees

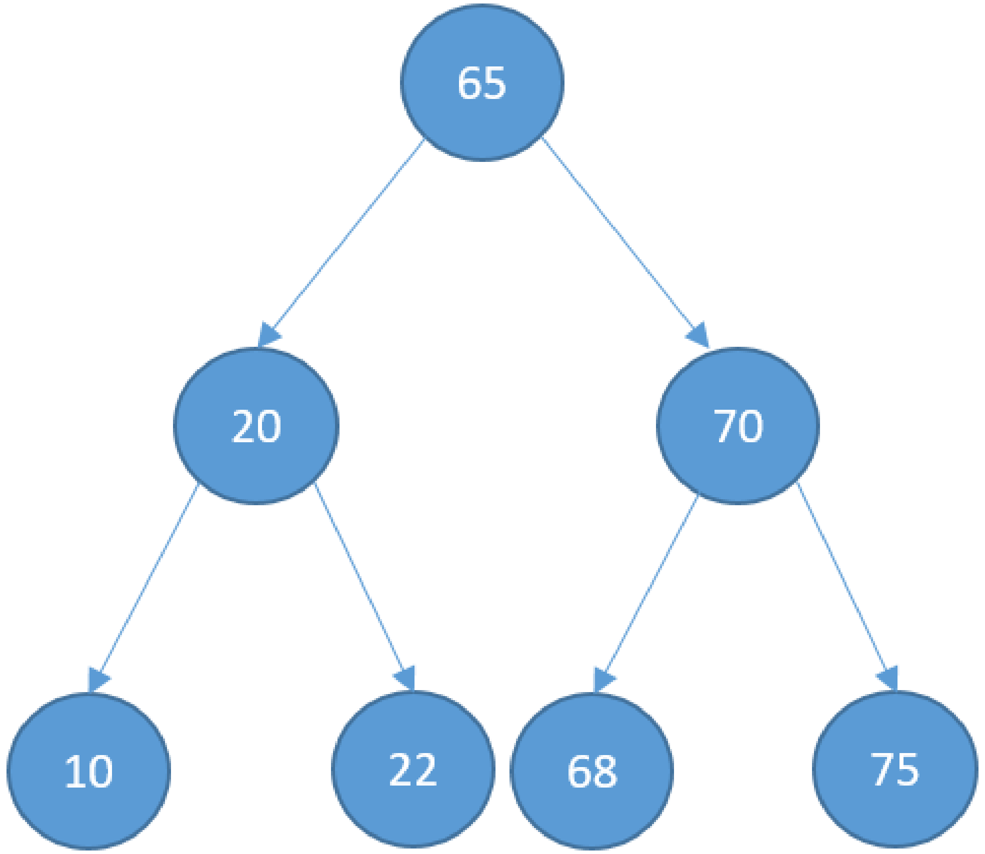
```python
def bfs(self):
  if self.root:
    visited_nodes = []
    bfs_queue = queue.SimpleQueue()
    bfs_queue.put(self.root)
    while not bfs_queue.empty():
      current_node = bfs_queue.get()
      visited_nodes.append(current_node.data)
      if current_node.left:
        bfs_queue.put(current_node.left)
      if current_node.right:
        bfs_queue.put(current_node.right)
```



- visited_nodes: 65, 20
- bfs_queue: 70, 10
- current_node: 20

Breadth first search - binary trees

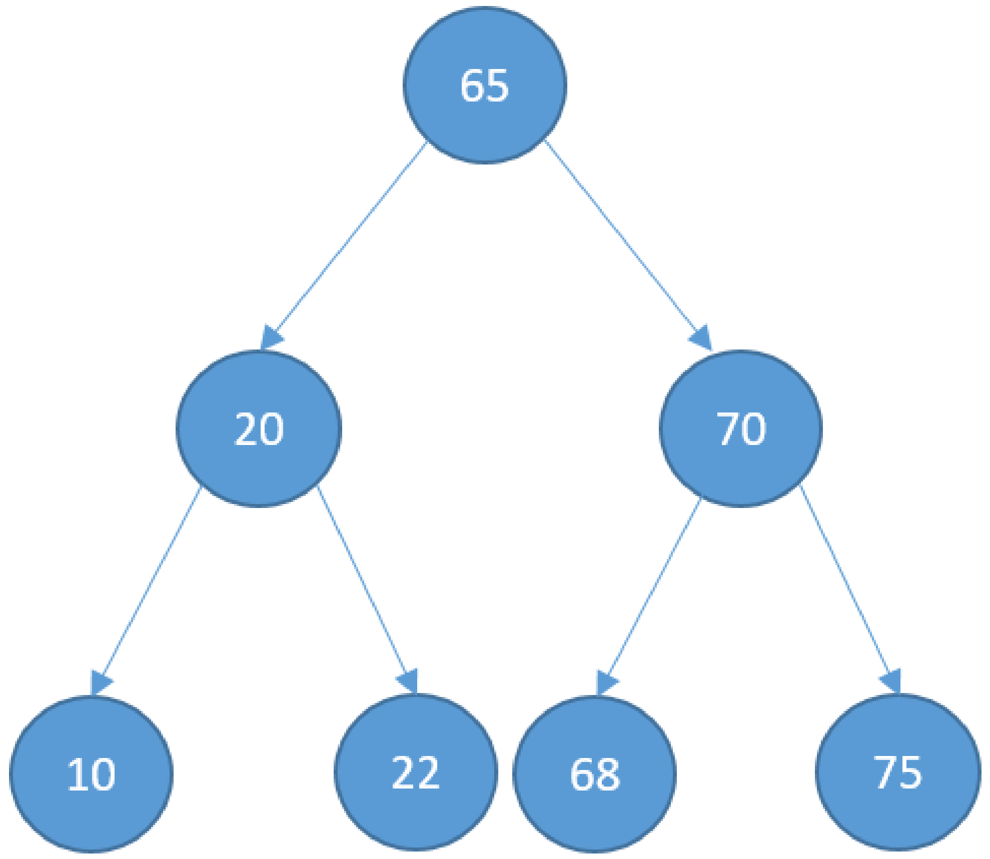
```
def bfs(self):
  if self.root:
    visited_nodes = []
    bfs_queue = queue.SimpleQueue()
    bfs_queue.put(self.root)
    while not bfs_queue.empty():
      current_node = bfs_queue.get()
      visited_nodes.append(current_node.data)
      if current_node.left:
        bfs_queue.put(current_node.left)
      if current_node.right:
        bfs_queue.put(current_node.right)
```



- visited_nodes: 65, 20
- bfs_queue: 70, 10, 22
- current_node: 20

Breadth first search - binary trees

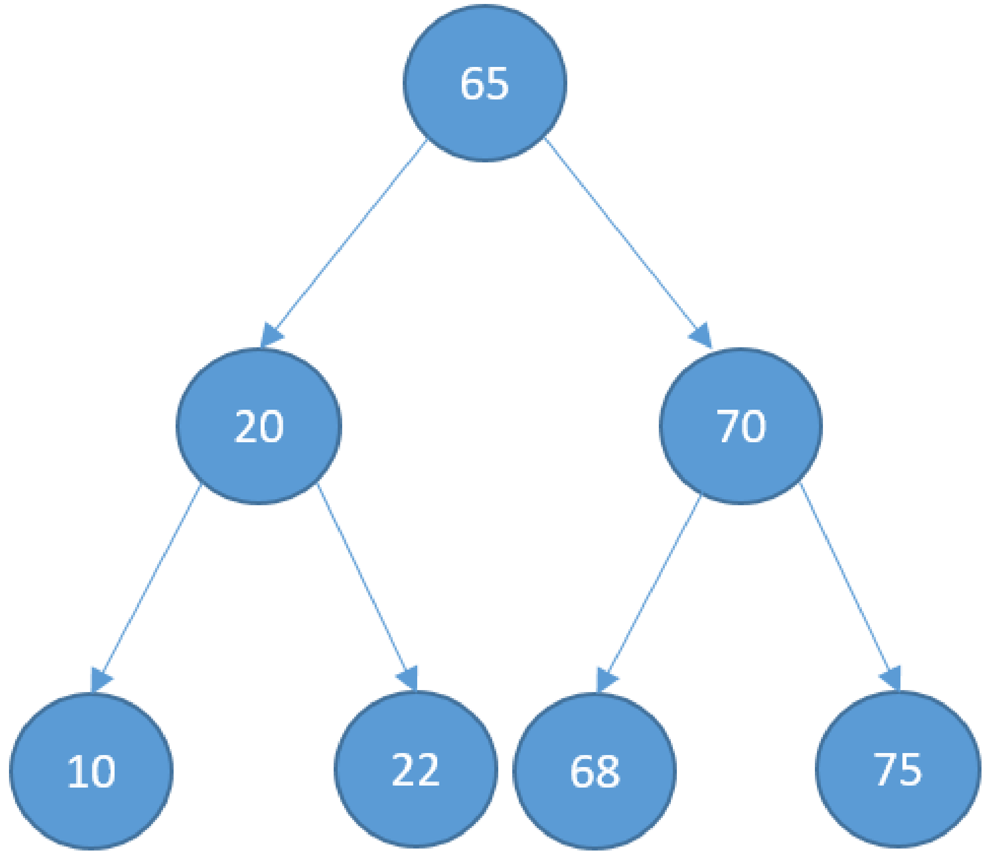
```
def bfs(self):
  if self.root:
    visited_nodes = []
    bfs_queue = queue.SimpleQueue()
    bfs_queue.put(self.root)
    while not bfs_queue.empty():
      current_node = bfs_queue.get()
      visited_nodes.append(current_node.data)
      if current_node.left:
        bfs_queue.put(current_node.left)
      if current_node.right:
        bfs_queue.put(current_node.right)
```



- visited_nodes: 65, 20
- bfs_queue: 10, 22
- current_node: 70

Breadth first search - binary trees

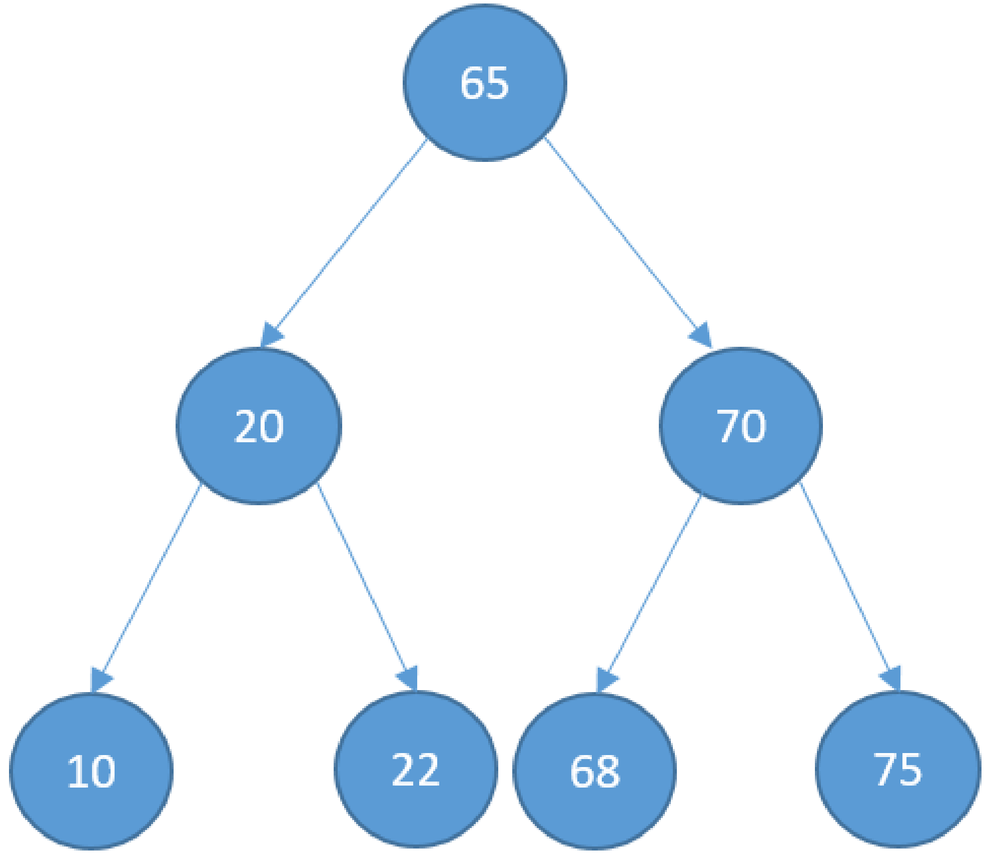
```
def bfs(self):
  if self.root:
    visited_nodes = []
    bfs_queue = queue.SimpleQueue()
    bfs_queue.put(self.root)
    while not bfs_queue.empty():
      current_node = bfs_queue.get()
      visited_nodes.append(current_node.data)
      if current_node.left:
        bfs_queue.put(current_node.left)
      if current_node.right:
        bfs_queue.put(current_node.right)
```



- visited_nodes: 65, 20, 70
- bfs_queue: 10, 22
- current_node: 70

Breadth first search - binary trees

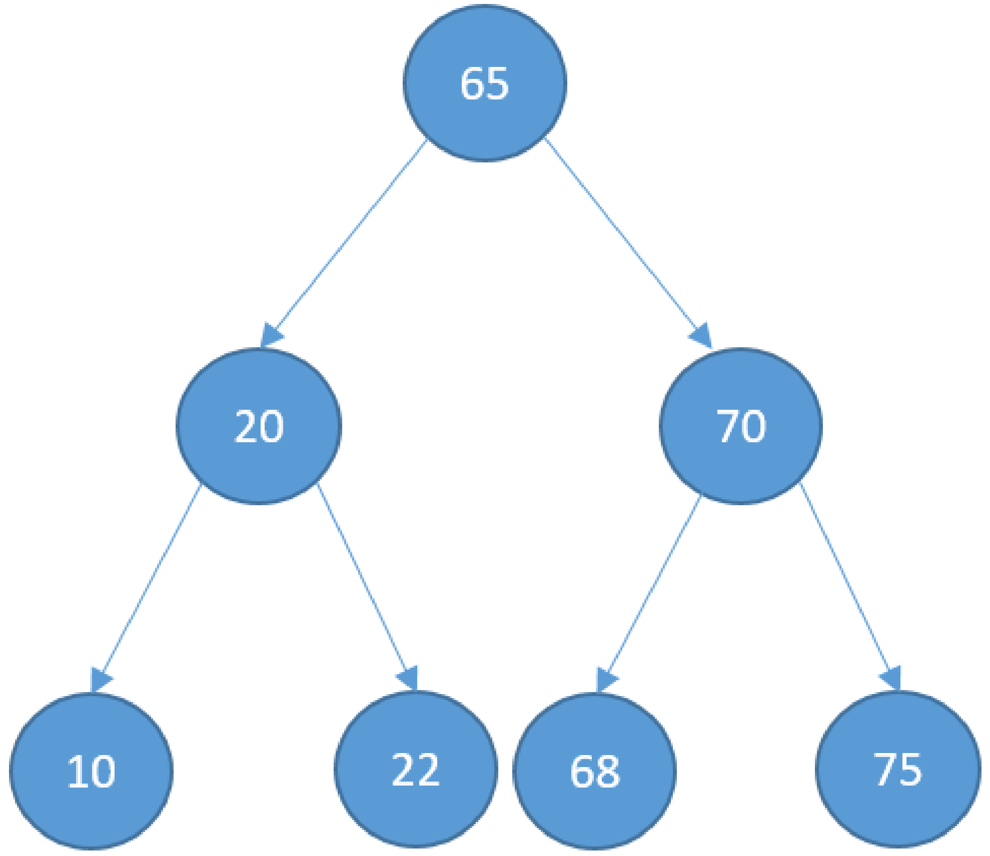
```
def bfs(self):
  if self.root:
    visited_nodes = []
    bfs_queue = queue.SimpleQueue()
    bfs_queue.put(self.root)
    while not bfs_queue.empty():
      current_node = bfs_queue.get()
      visited_nodes.append(current_node.data)
      if current_node.left:
        bfs_queue.put(current_node.left)
      if current_node.right:
        bfs_queue.put(current_node.right)
```



- visited_nodes: 65, 20, 70
- bfs_queue: 10, 22, 68
- current_node: 70

Breadth first search - binary trees

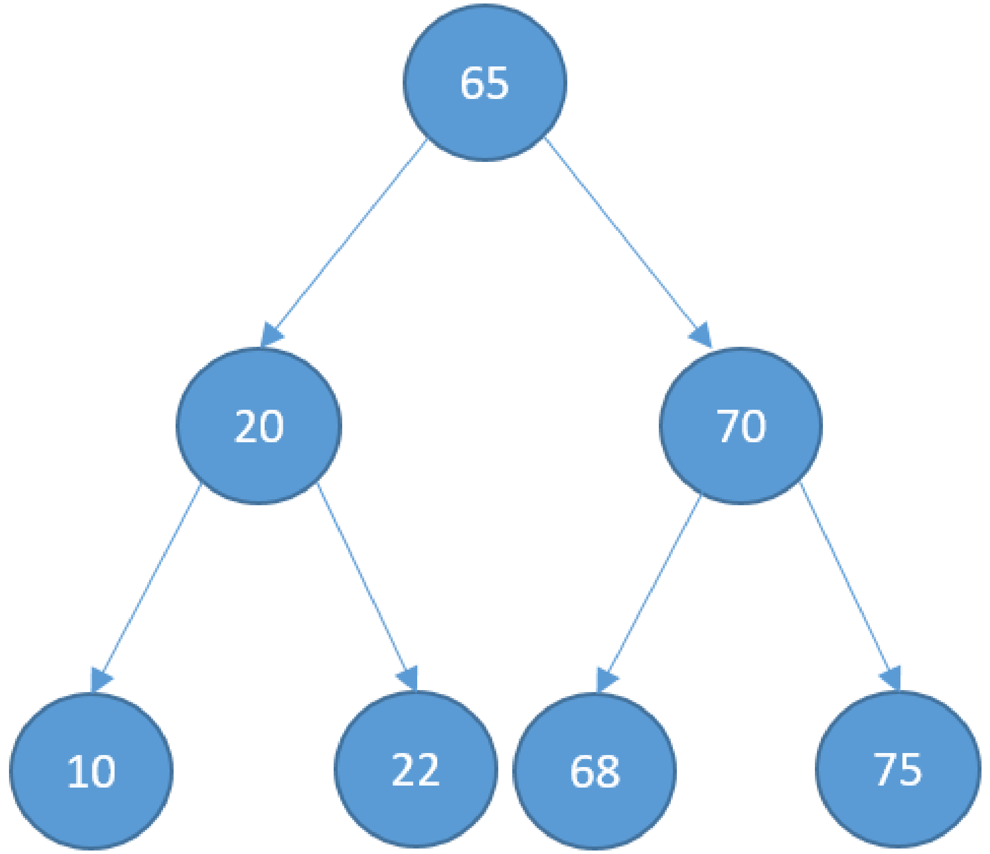
```python
def bfs(self):
  if self.root:
    visited_nodes = []
    bfs_queue = queue.SimpleQueue()
    bfs_queue.put(self.root)
    while not bfs_queue.empty():
      current_node = bfs_queue.get()
      visited_nodes.append(current_node.data)
      if current_node.left:
        bfs_queue.put(current_node.left)
      if current_node.right:
        bfs_queue.put(current_node.right)
```



- visited_nodes: 65, 20, 70
- bfs_queue: 10, 22, 68, 75
- current_node: 70

Breadth first search - binary trees

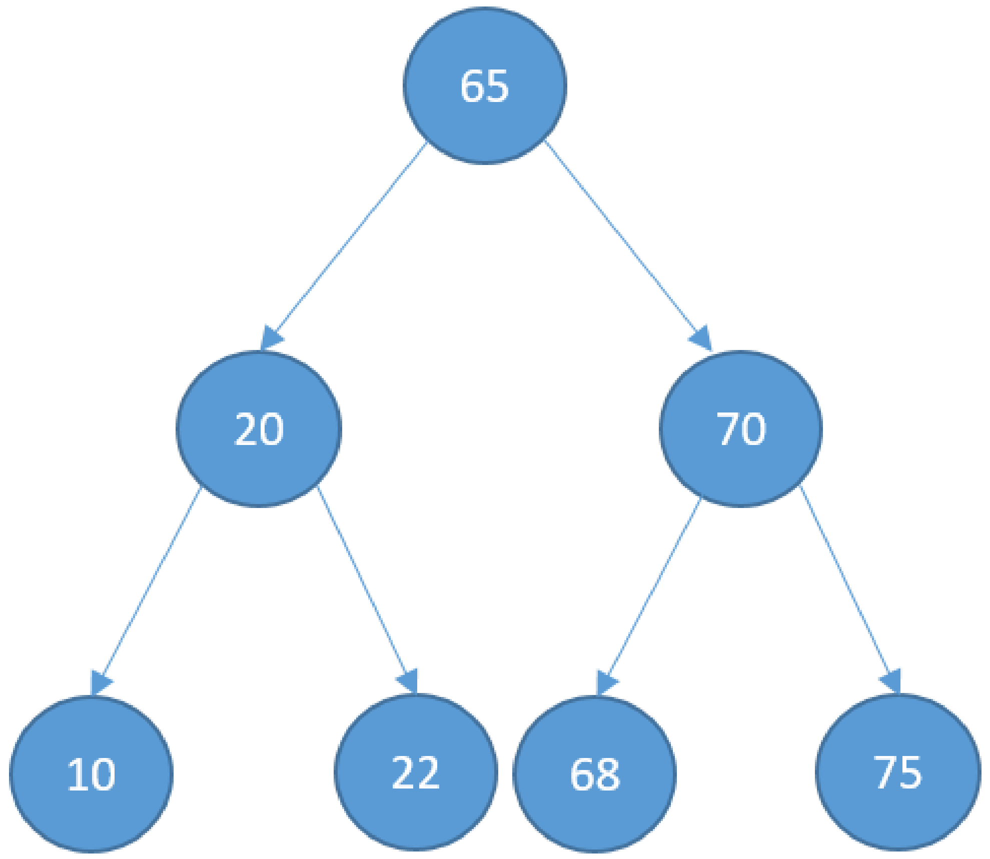
```
def bfs(self):
  if self.root:
    visited_nodes = []
    bfs_queue = queue.SimpleQueue()
    bfs_queue.put(self.root)
    while not bfs_queue.empty():
      current_node = bfs_queue.get()
      visited_nodes.append(current_node.data)
      if current_node.left:
        bfs_queue.put(current_node.left)
      if current_node.right:
        bfs_queue.put(current_node.right)
```



- visited_nodes: 65, 20, 70, 10
- bfs_queue: 22, 68, 75
- current_node: 10

Breadth first search - binary trees

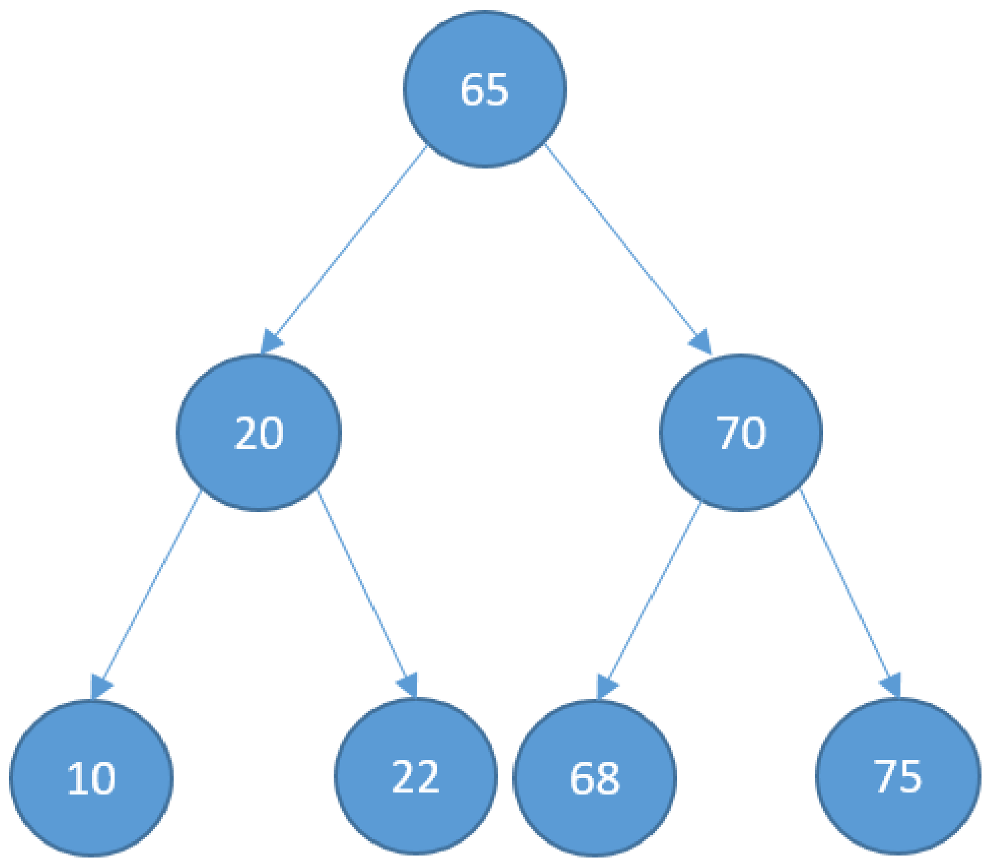
```python
def bfs(self):
  if self.root:
    visited_nodes = []
    bfs_queue = queue.SimpleQueue()
    bfs_queue.put(self.root)
    while not bfs_queue.empty():
      current_node = bfs_queue.get()
      visited_nodes.append(current_node.data)
      if current_node.left:
        bfs_queue.put(current_node.left)
      if current_node.right:
        bfs_queue.put(current_node.right)
```



- visited_nodes: 65, 20, 70, 10
- bfs_queue: 68, 75
- current_node: 22

Breadth first search - binary trees

```
def bfs(self):
  if self.root:
    visited_nodes = []
    bfs_queue = queue.SimpleQueue()
    bfs_queue.put(self.root)
    while not bfs_queue.empty():
      current_node = bfs_queue.get()
      visited_nodes.append(current_node.data)
      if current_node.left:
        bfs_queue.put(current_node.left)
      if current_node.right:
        bfs_queue.put(current_node.right)
```



- visited_nodes: 65, 20, 70, 10, 22
- bfs_queue: 68, 75
- current_node: 22

Breadth first search - binary trees

```python
def bfs(self):
  if self.root:
    visited_nodes = []
    bfs_queue = queue.SimpleQueue()
    bfs_queue.put(self.root)
    while not bfs_queue.empty():
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      visited_nodes.append(current_node.data)
      if current_node.left:
        bfs_queue.put(current_node.left)
      if current_node.right:
        bfs_queue.put(current_node.right)
```
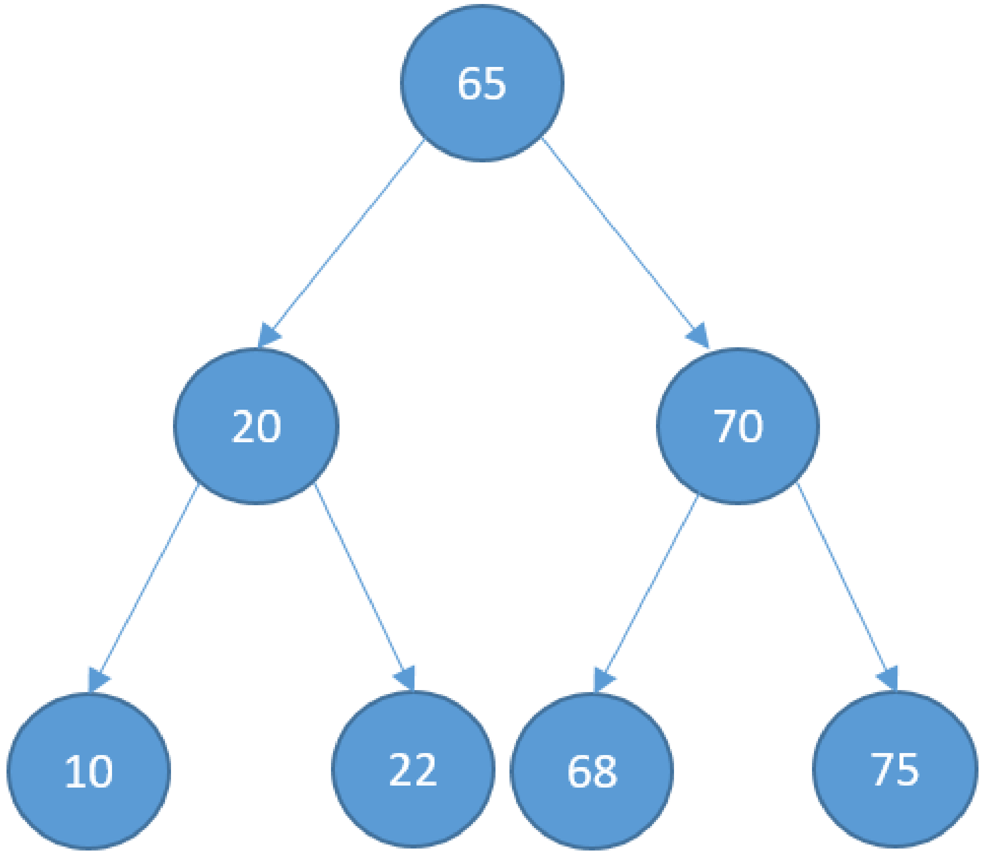
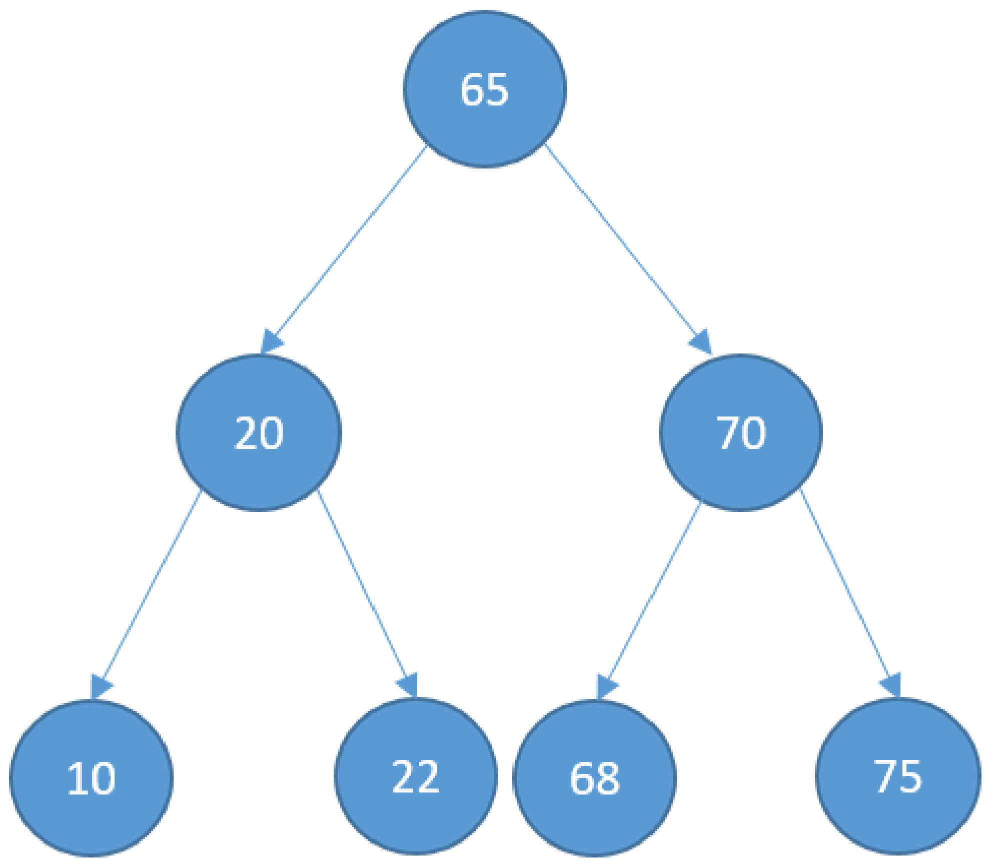



- visited_nodes: 65, 20, 70, 10, 22, 68
- bfs_queue: 75
- current_node: 68

Breadth first search - binary trees

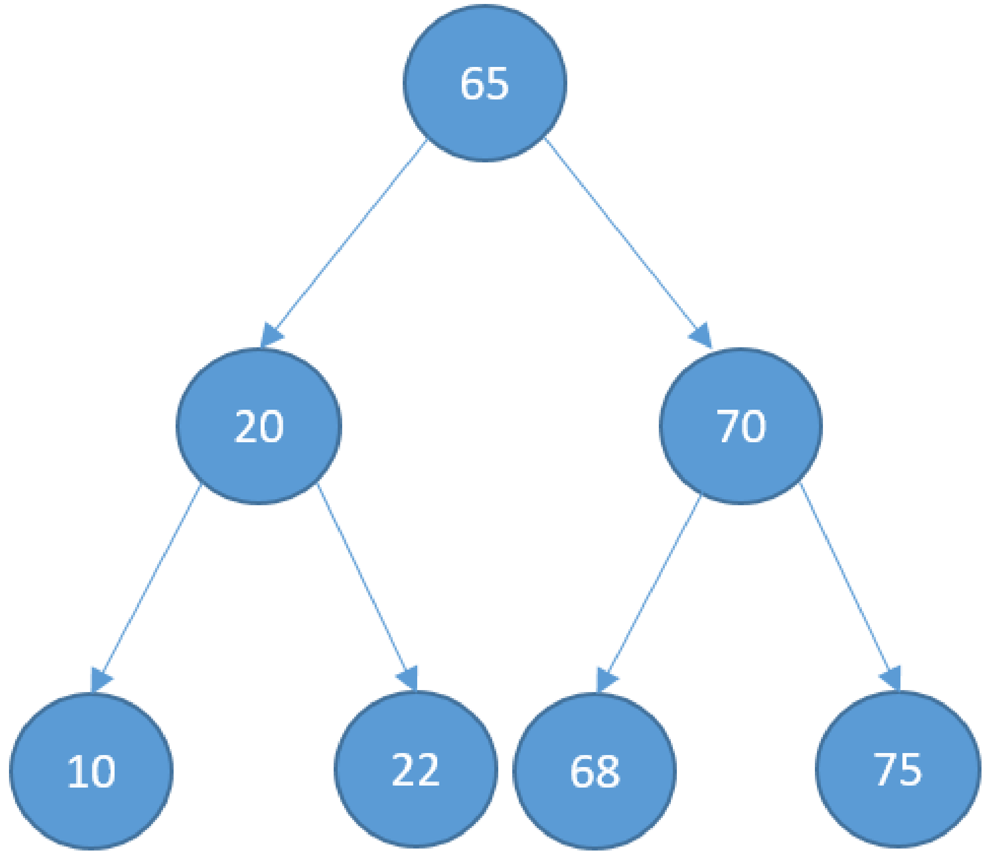
```
def bfs(self):
  if self.root:
    visited_nodes = []
    bfs_queue = queue.SimpleQueue()
    bfs_queue.put(self.root)
    while not bfs_queue.empty():
      current_node = bfs_queue.get()
      visited_nodes.append(current_node.data)
      if current_node.left:
        bfs_queue.put(current_node.left)
      if current_node.right:
        bfs_queue.put(current_node.right)
```



- visited_nodes: 65, 20, 70, 10, 22, 68
- bfs_queue:
- current_node: 75

Breadth first search - binary trees

```
def bfs(self):
  if self.root:
    visited_nodes = []
    bfs_queue = queue.SimpleQueue()
    bfs_queue.put(self.root)
    while not bfs_queue.empty():
      current_node = bfs_queue.get()
      visited_nodes.append(current_node.data)
      if current_node.left:
        bfs_queue.put(current_node.left)
      if current_node.right:
        bfs_queue.put(current_node.right)
```

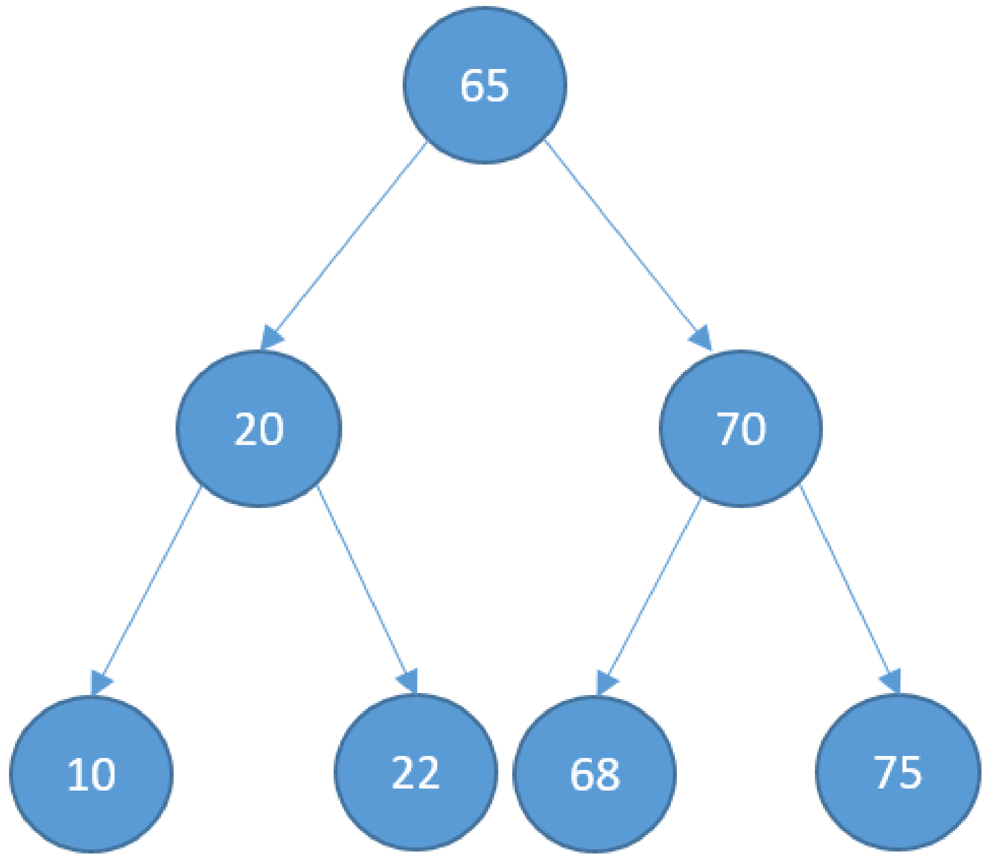


- visited_nodes: 65, 20, 70, 10, 22, 68, 75
- bfs_queue:
- current_node: 75

Breadth first search - binary trees

```python
def bfs(self):
  if self.root:
    visited_nodes = []
    bfs_queue = queue.SimpleQueue()
    bfs_queue.put(self.root)
    while not bfs_queue.empty():
      current_node = bfs_queue.get()
      visited_nodes.append(current_node.data)
      if current_node.left:
        bfs_queue.put(current_node.left)
      if current_node.right:
        bfs_queue.put(current_node.right)
  return visited_nodes
```

- Complexity: $O(n)$



- visited_nodes: 65, 20, 70, 10, 22, 68, 75
- bfs_queue:
- current_node: 75

Breadth first search - graphs

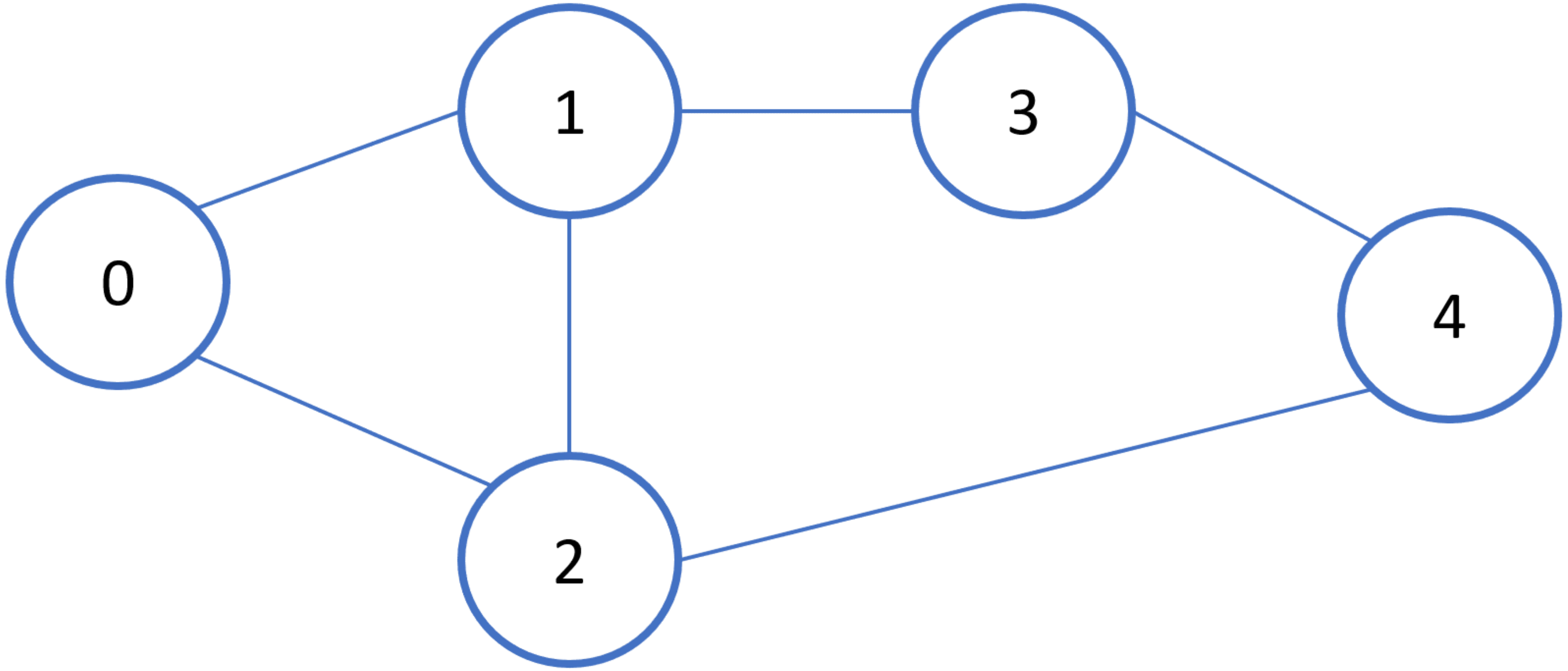
- Graphs can have cycles
  - Need to check if the vertices have already been visited

Breadth first search - graphs

```
def bfs(graph, initial_vertex):
  visited_vertices = []
  bfs_queue = queue.SimpleQueue()
  bfs_queue.put(initial_vertex)
  visited_vertices.append(initial_vertex)
  while not bfs_queue.empty():
    current_vertex = bfs_queue.get()
    for adjacent_vertex in graph[current_vertex]:
      if adjacent_vertex not in visited_vertices:
        visited_vertices.append(adjacent_vertex)
        bfs_queue.put(adjacent_vertex)
  return visited_vertices
```

- Complexity: $O(V + E)$
  - V -> number of vertices
  - E -> number of edges

Breadth first search - graphs



Visited vertices:

Queue:

Current vertex:

BFS vs DFS

BFS

- Target **close** to the **starting vertex**
- Applications:
  - Web crawling
  - Finding shortest path in unweighted graphs
  - Finding connected locations using GPS
  - Used as part of other more complex algorithms

DFS

- Target **far away** from the **starting vertex**
- Applications:
  - Solving puzzles with only one solution (e.g. mazes)
  - Detecting cycles in graphs
  - Finding shortest path in a weighted graph
  - Used as part of other more complex algorithms

Let's practice!

DATA STRUCTURES AND ALGORITHMS IN PYTHON