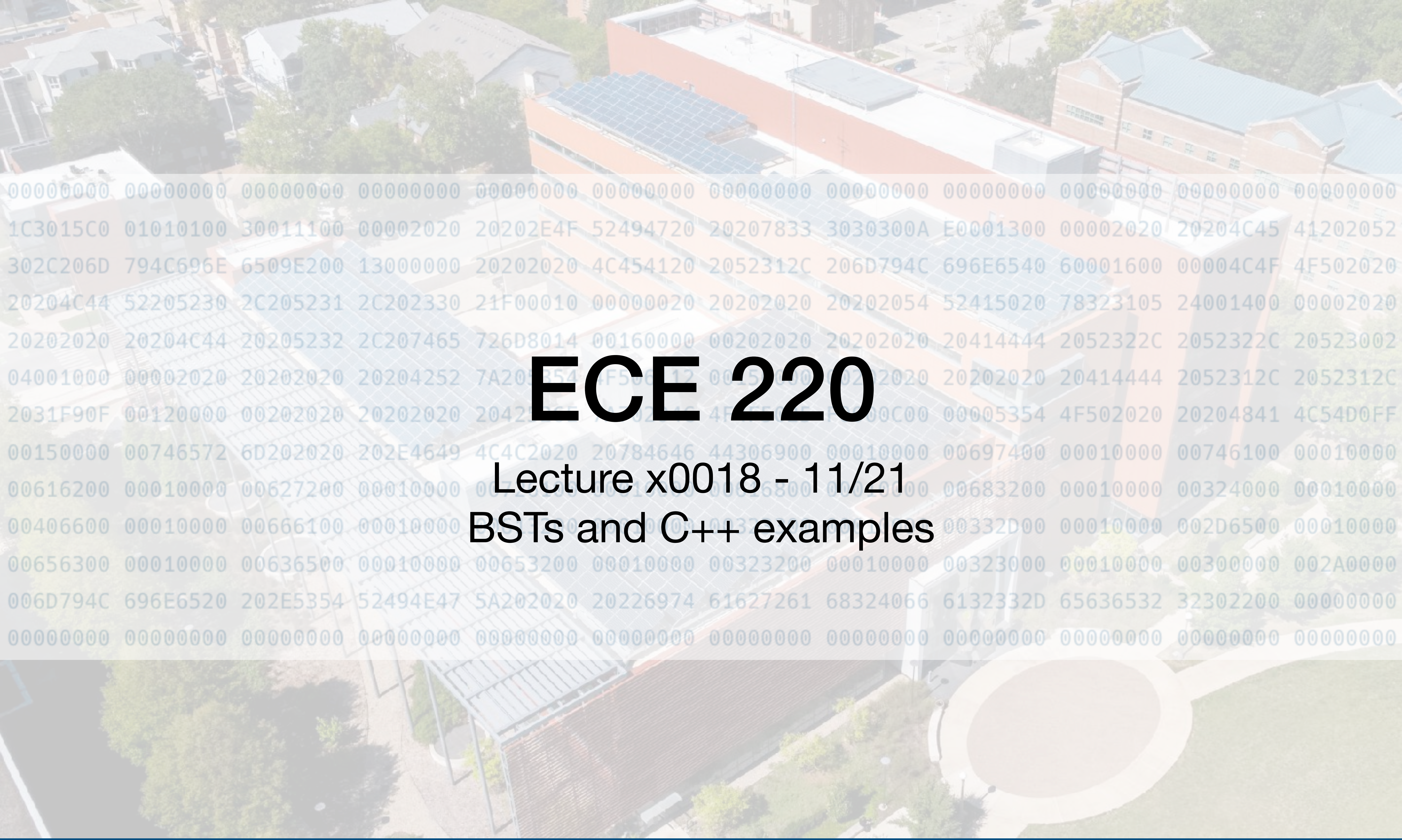


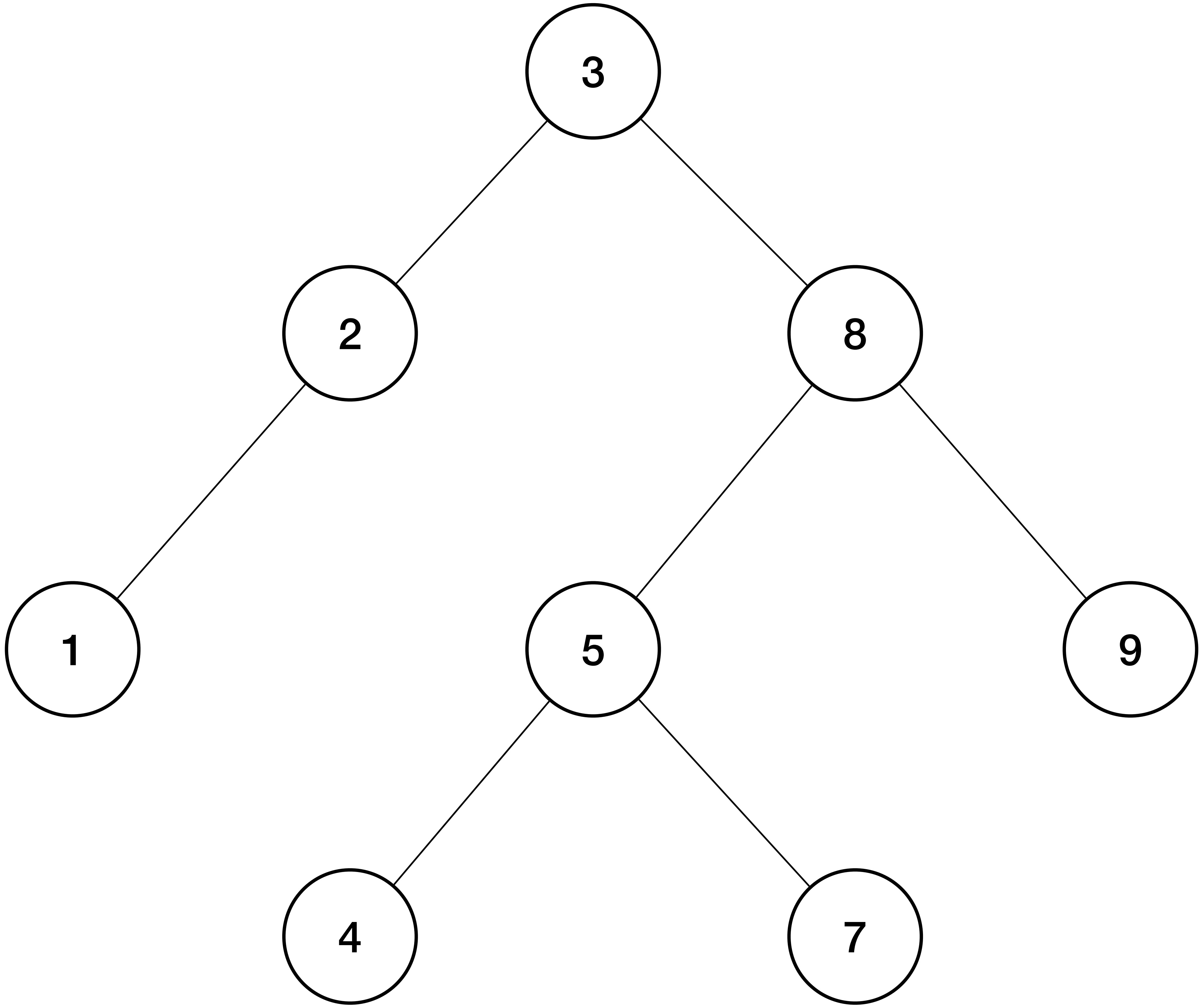
ECE 220

Lecture x0018 - 11/21

BSTs and C++ examples

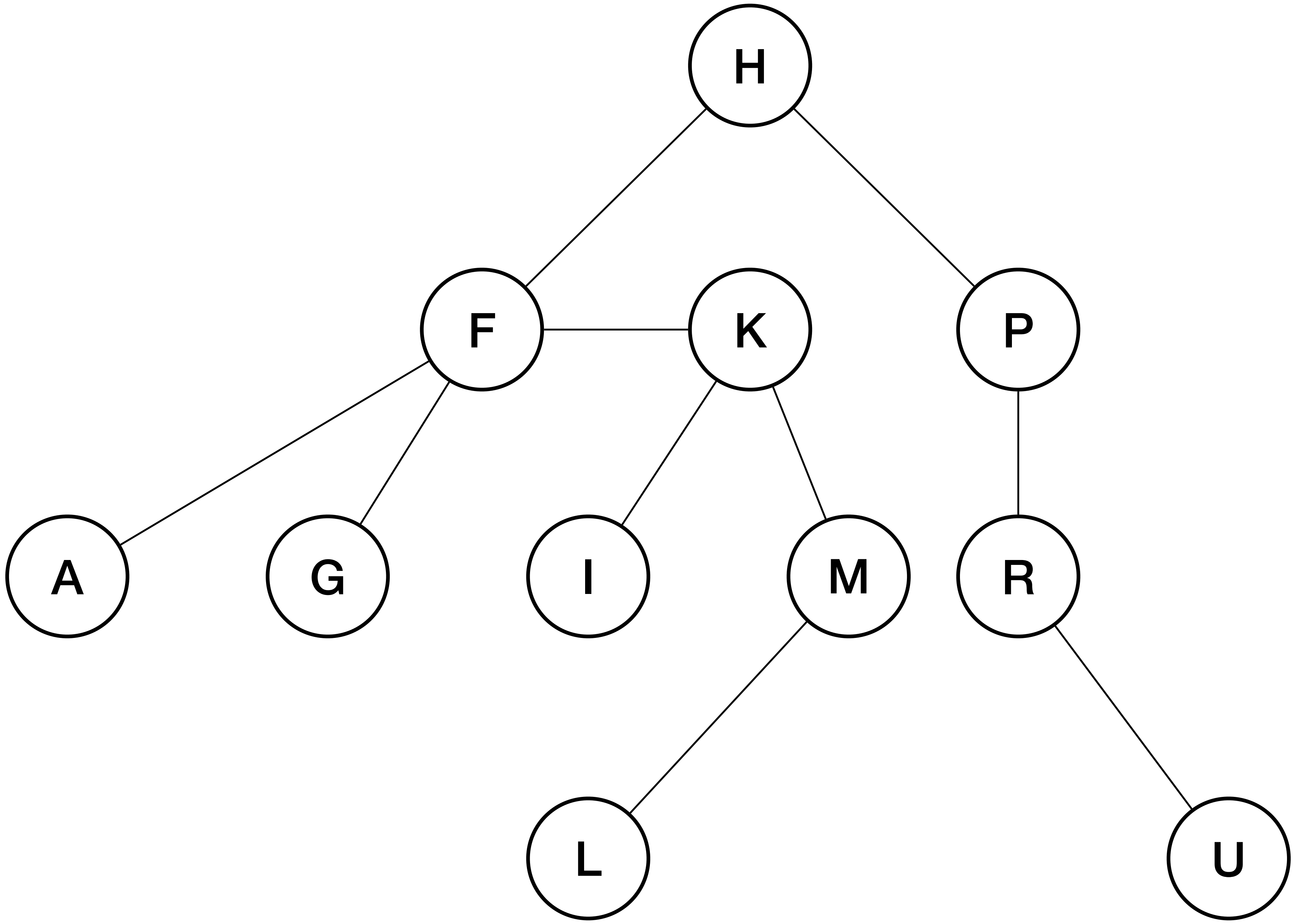
Binary Search Trees

- Binary trees that have a particular *sorted* property are called **binary search trees** (BST)
  - All nodes in the **left subtree** of a given node are <u>*lesser than or equal*</u> to the node
  - All nodes in the **right subtree** of a given node are <u>*greater*</u> than that node



Concept check

- Who are the siblings of R?
- What is the depth of node I?
- List the leaf nodes?
- What is the height of the tree?
- Is this a Binary Search Tree?



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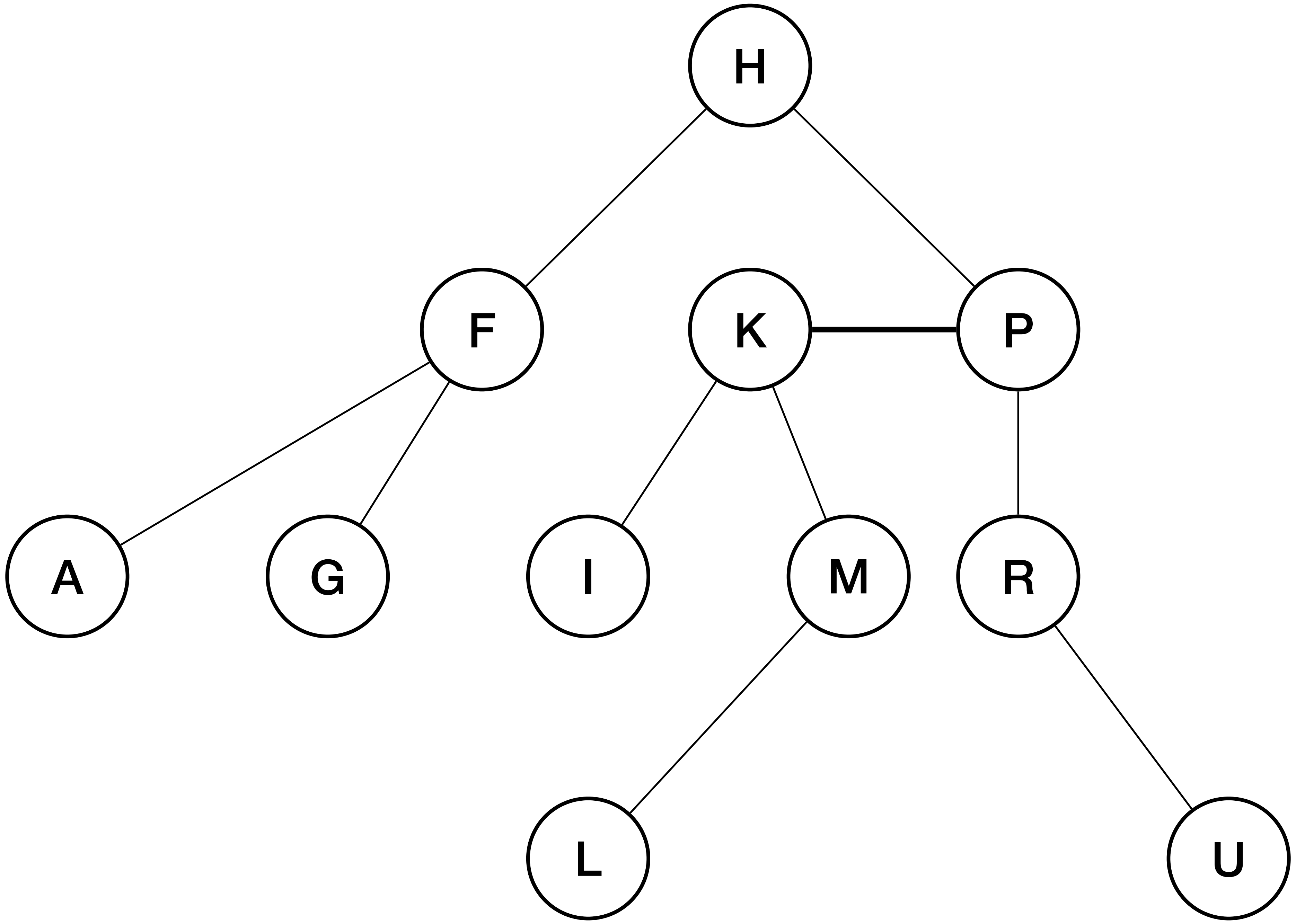


Exercises with BST

- How can you find the minimum or maximum element in a BST?
- How can we search a BST for a node?
- How should you insert a new node in a BST?
- How can you find the height of a *general* tree (can also be BST)?

```
typedef struct node{
    int data;
    struct node *left;
    struct node *right;
} node;
```

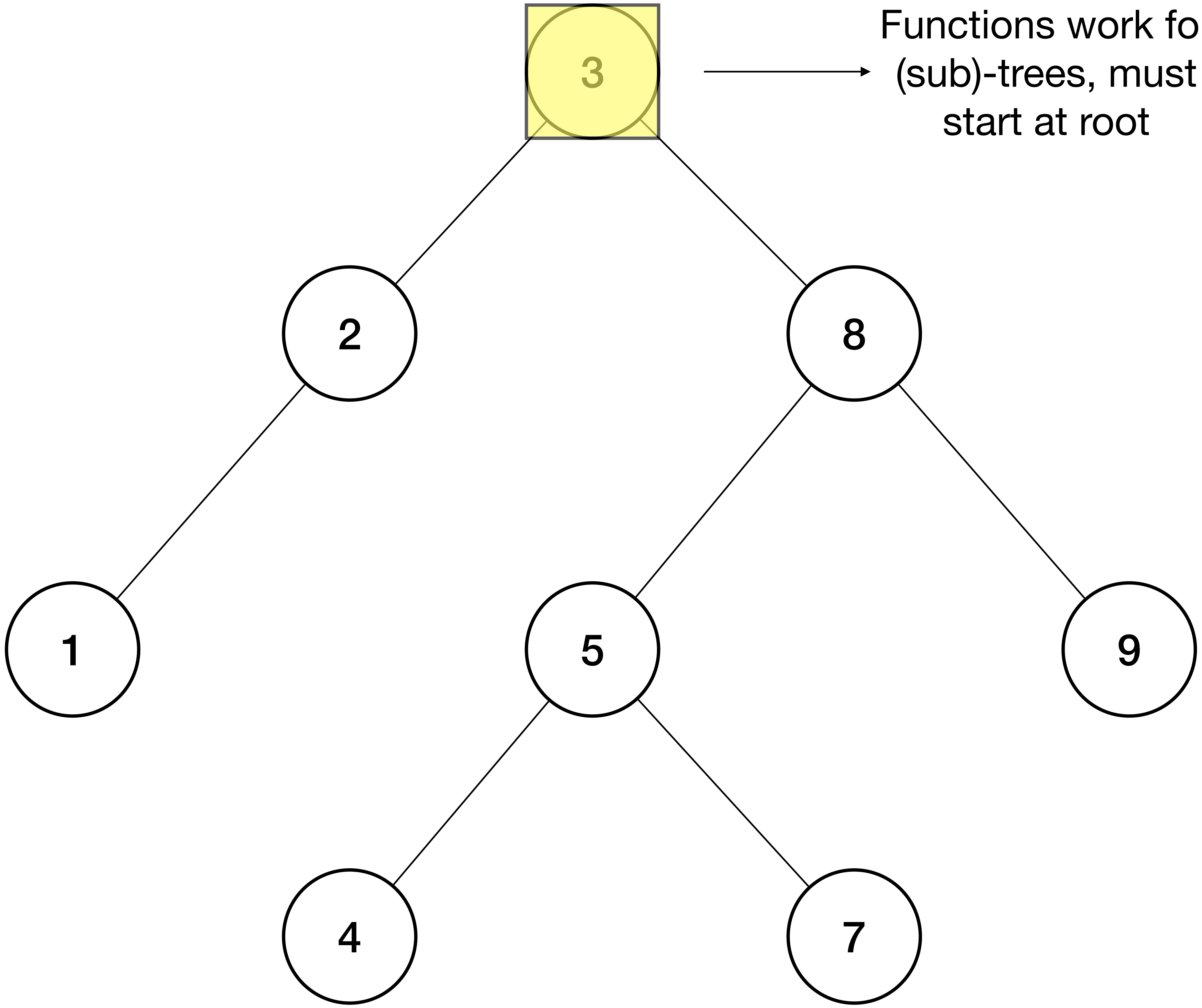
Finding extremals in a BST

Minimum - keep going left

```
node * findmin(node *cursor){
   if (cursor->left==NULL)
     return cursor;
   else
     return findmin(cursor->left);
}
```

Minimum - keep going right

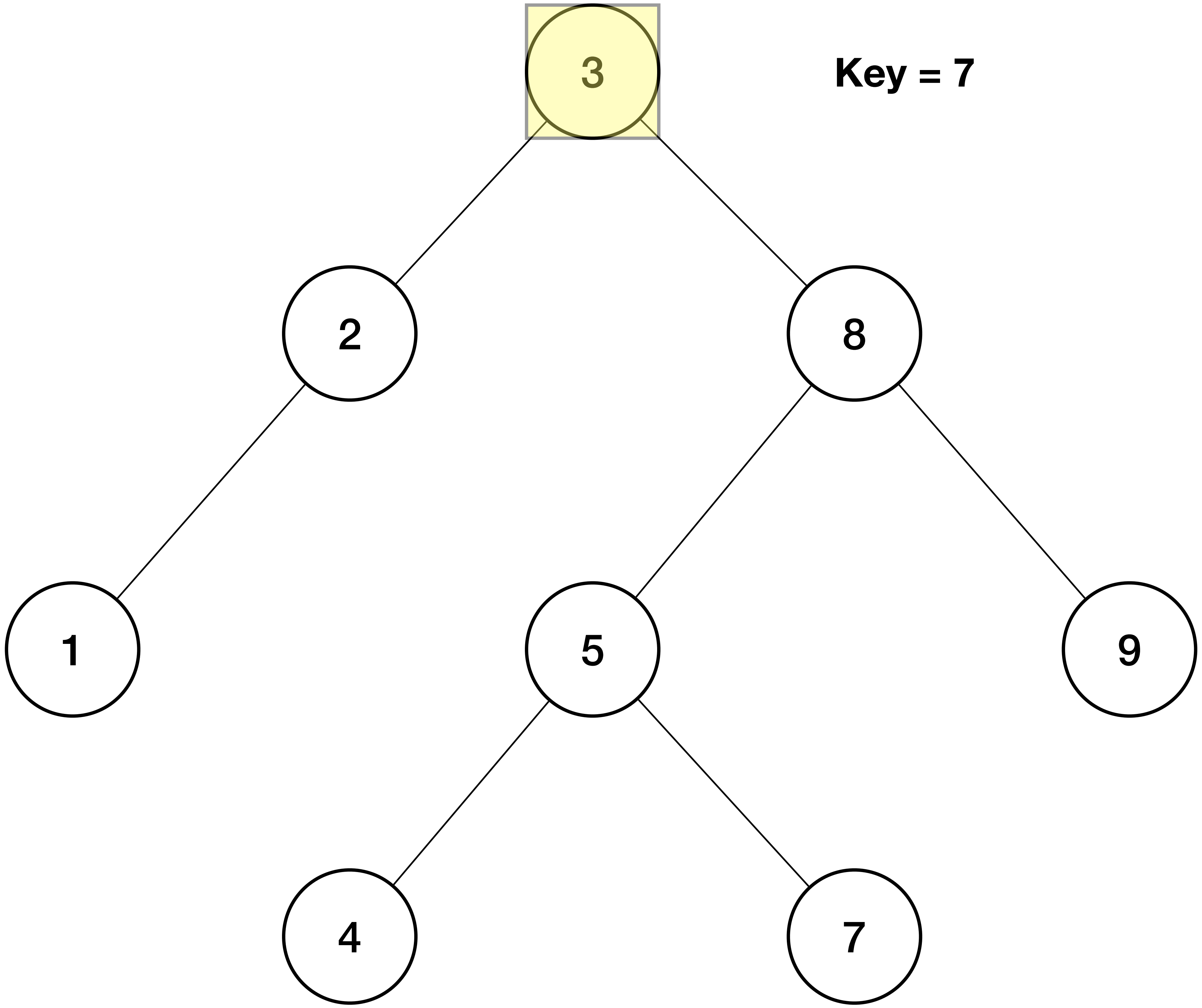
```
node * findmax(node *cursor){
   if (cursor->right==NULL)
     return cursor;
   else
     return findmax(cursor->right);
}
```



Functions work for (sub)-trees, must start at root

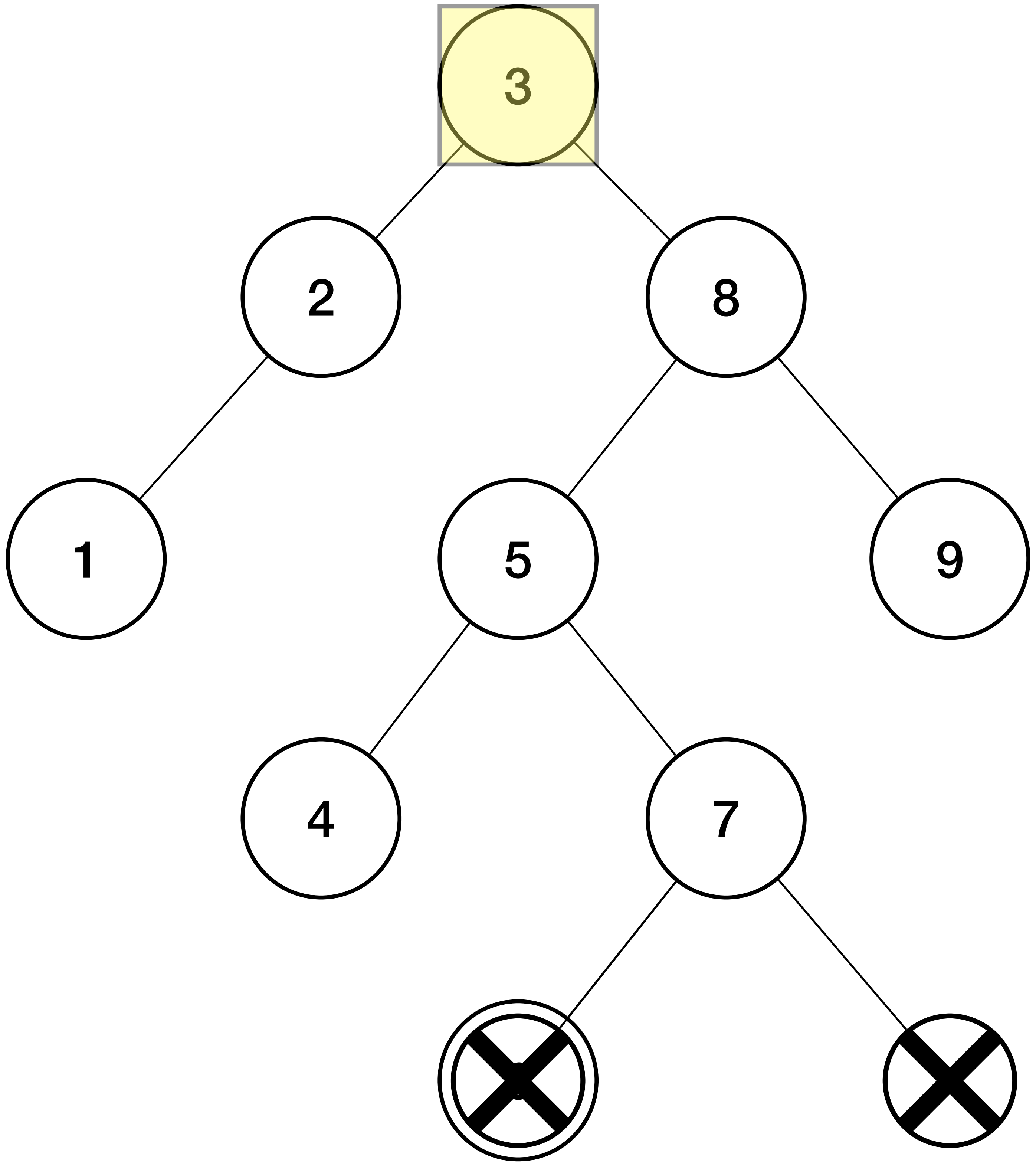
Searching in a BST

```
node * find_elem(node *cursor, int key){
  if (cursor==NULL) // Key not found

  if (cursor->data == key)
                    // Found key
  if (cursor->data < key)


  else


}
```



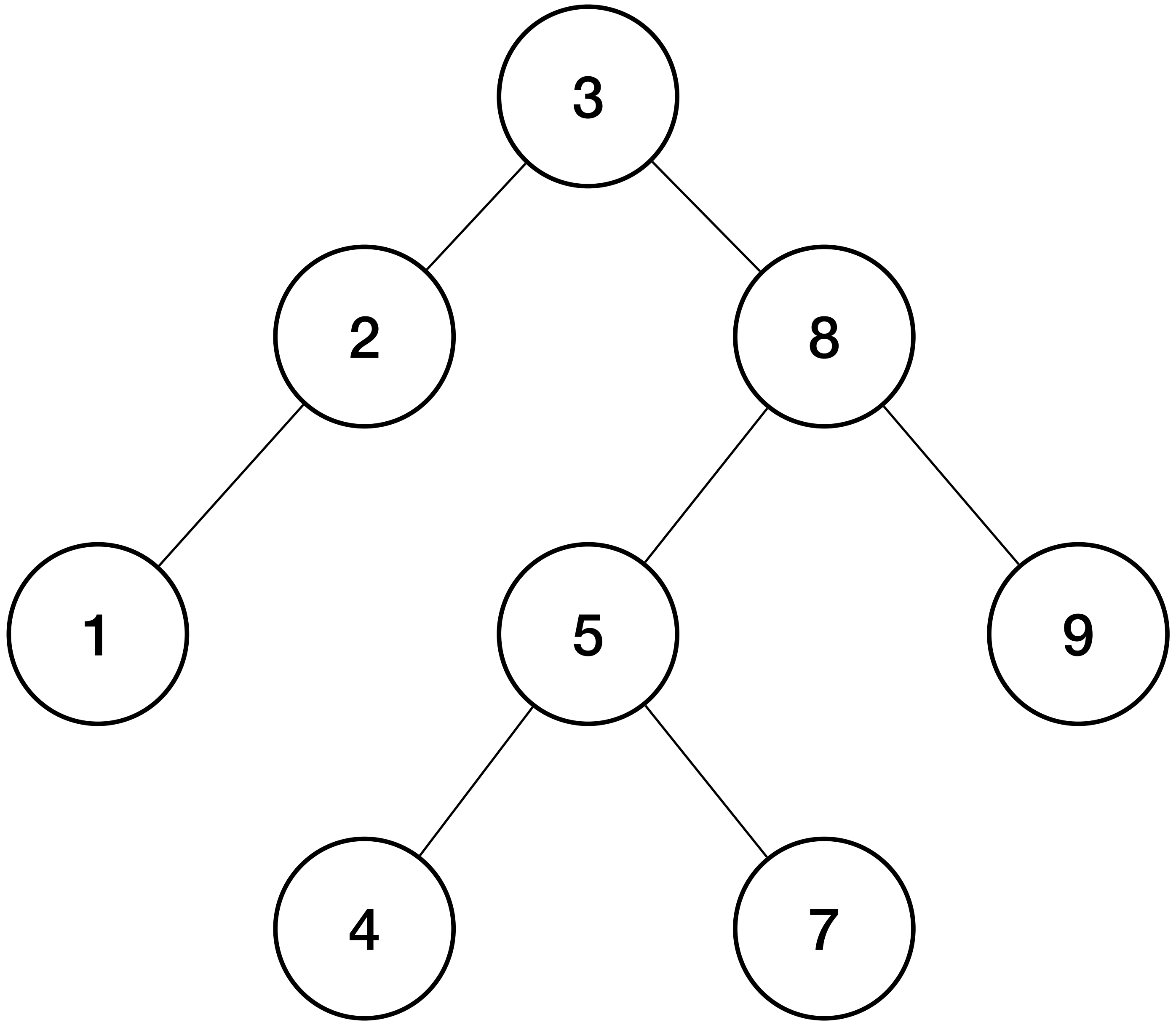
Insertion in a BST

- Insertions need to preserve the BST property
- Add new nodes only as leaf nodes
- Consider inserting 6 in the BST on the right …



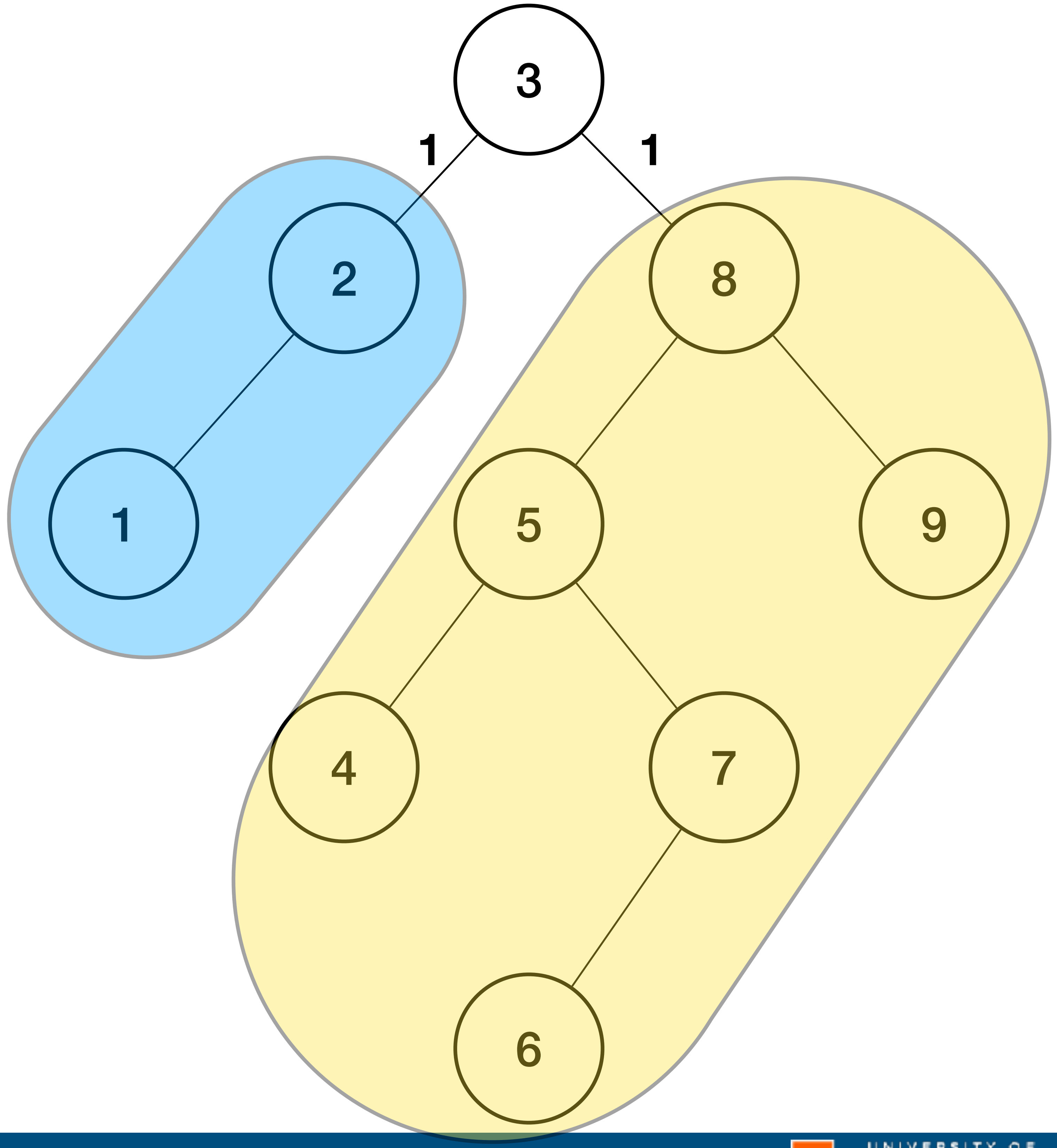
Insertion in a BST

```
node * insert(node *cursor, int data){
if (cursor==NULL)
  return newNode(data);
else{
    if (data < cursor->data)
      cursor->left =
    else
      cursor->right =
    return cursor;
  }
}
```



Finding height of a tree

- Height is length of *longest* path from root to leaf(s)
  - Recursively calculate: 1 + height of L/R subtree(s)
  - Take maximum at each step



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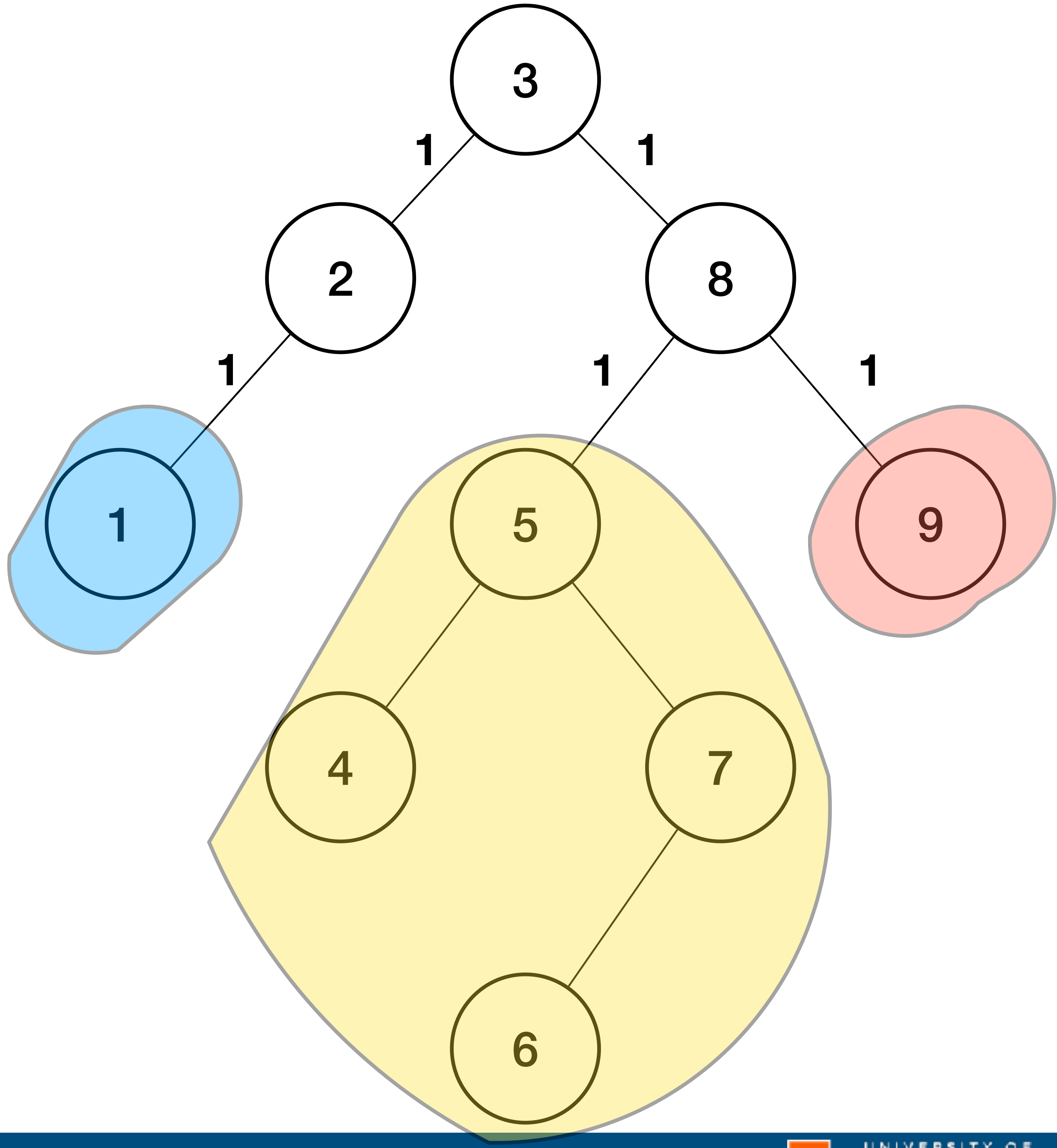

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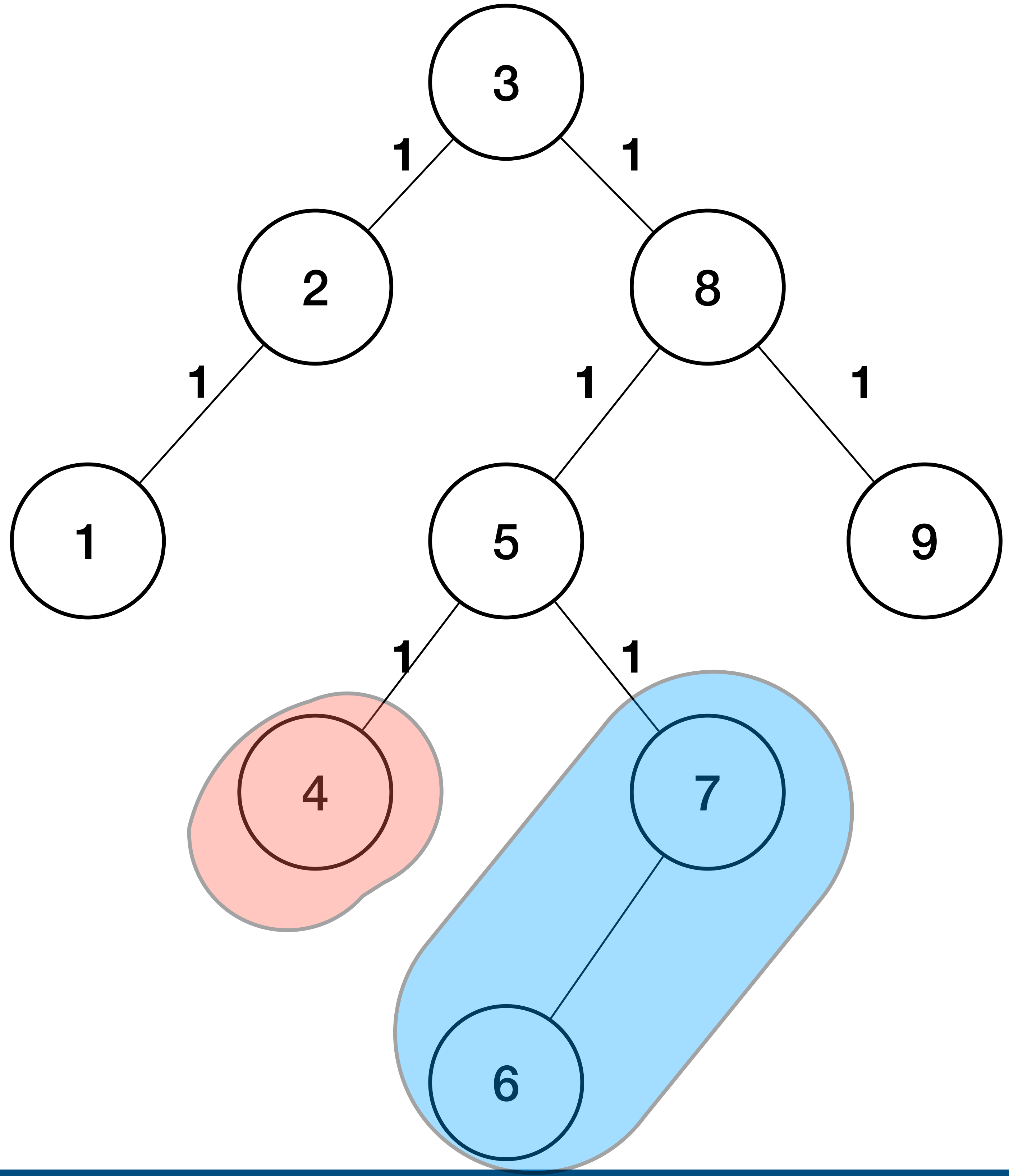

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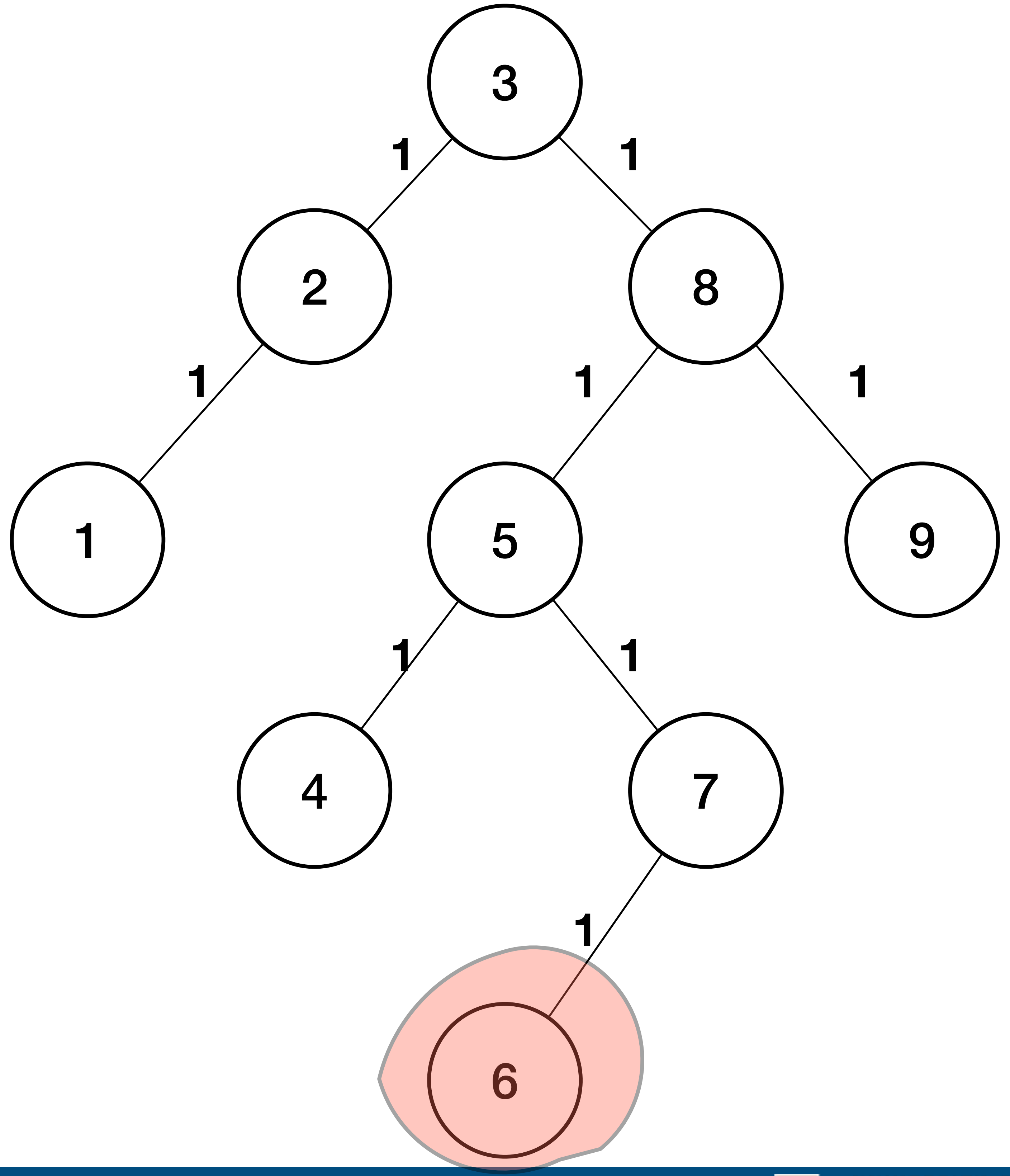

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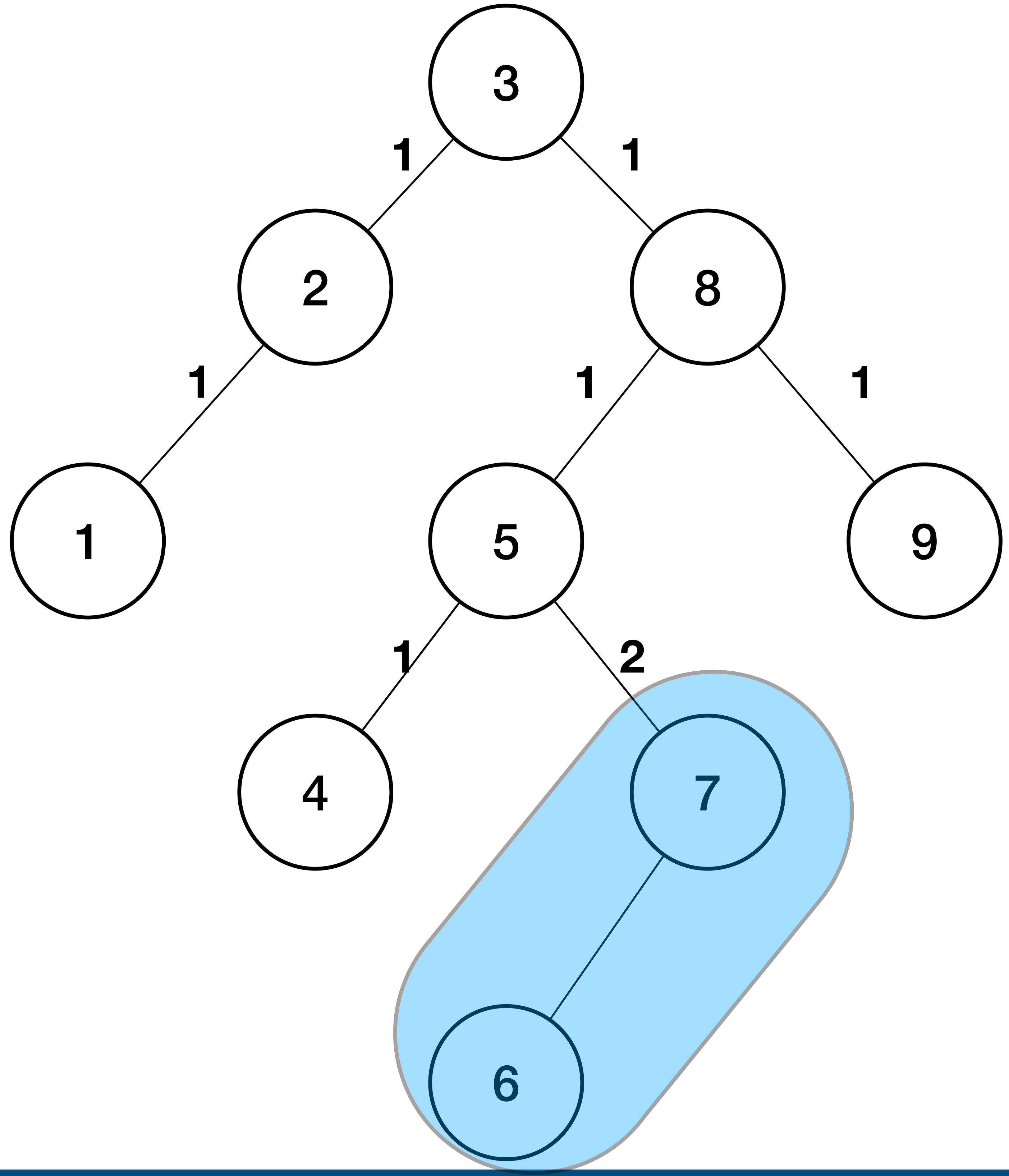

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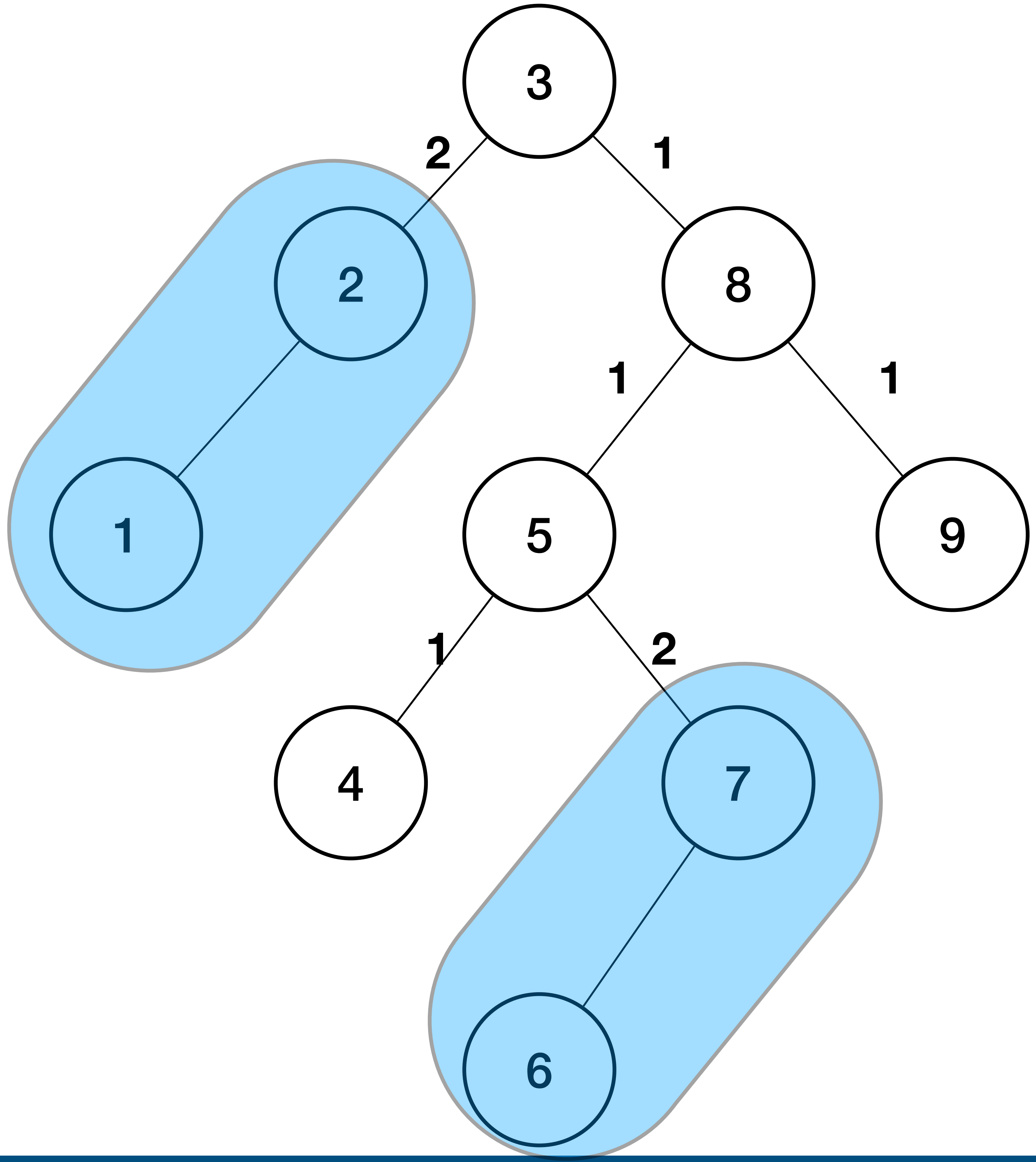

Finding height of a tree

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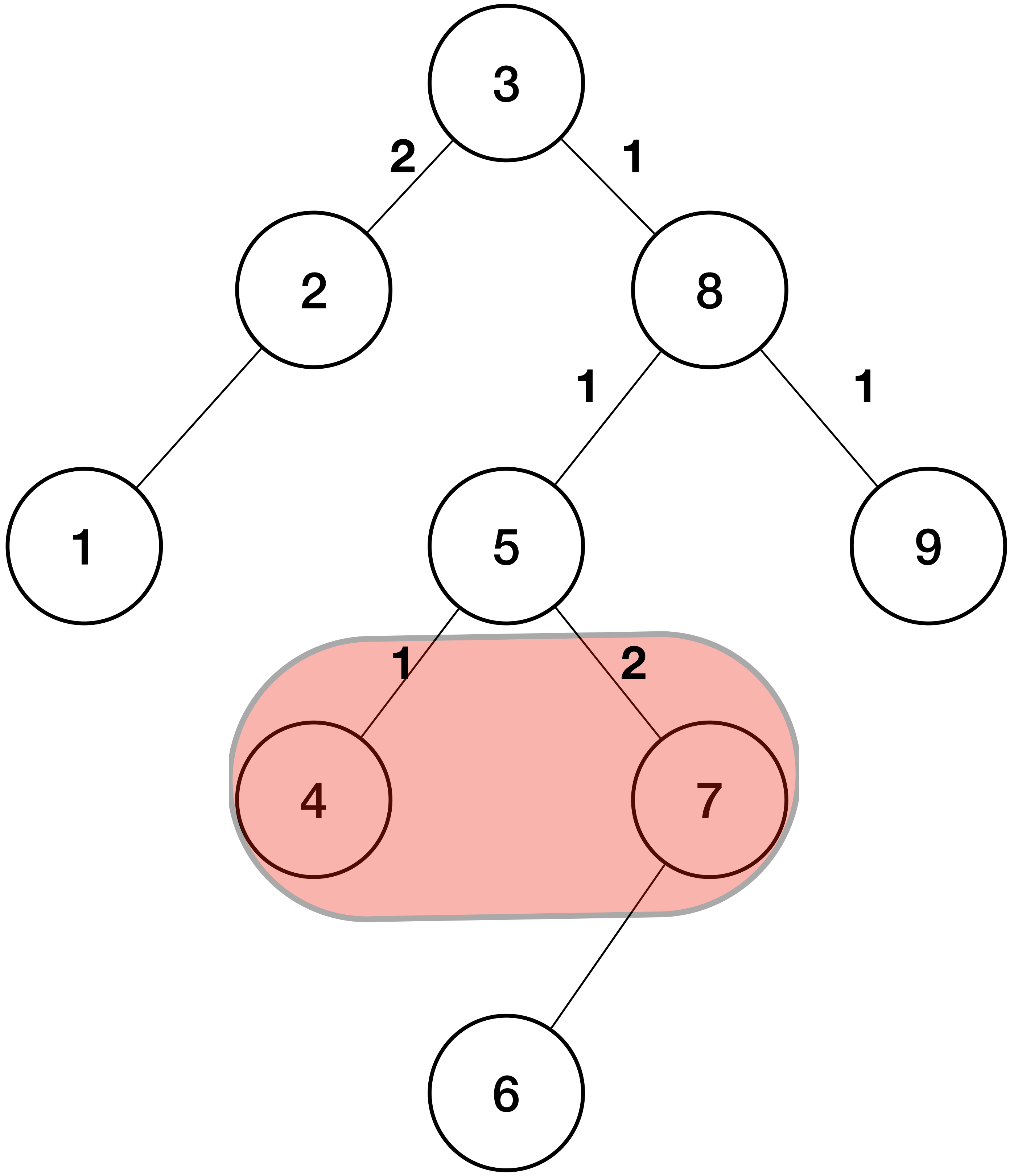

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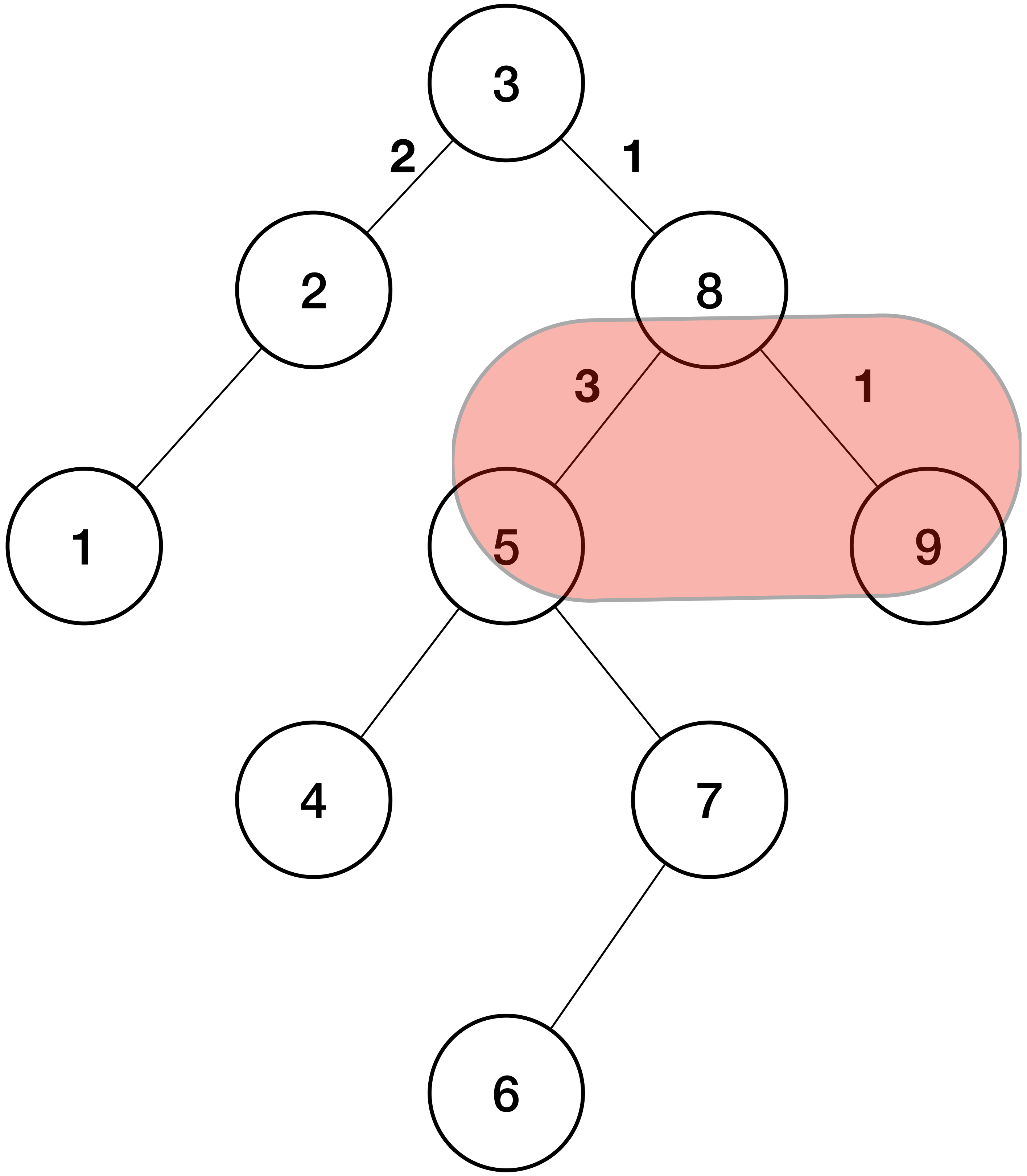

Finding height of a tree

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  - Recursively calculate: 1 + height of L/R subtree(s)
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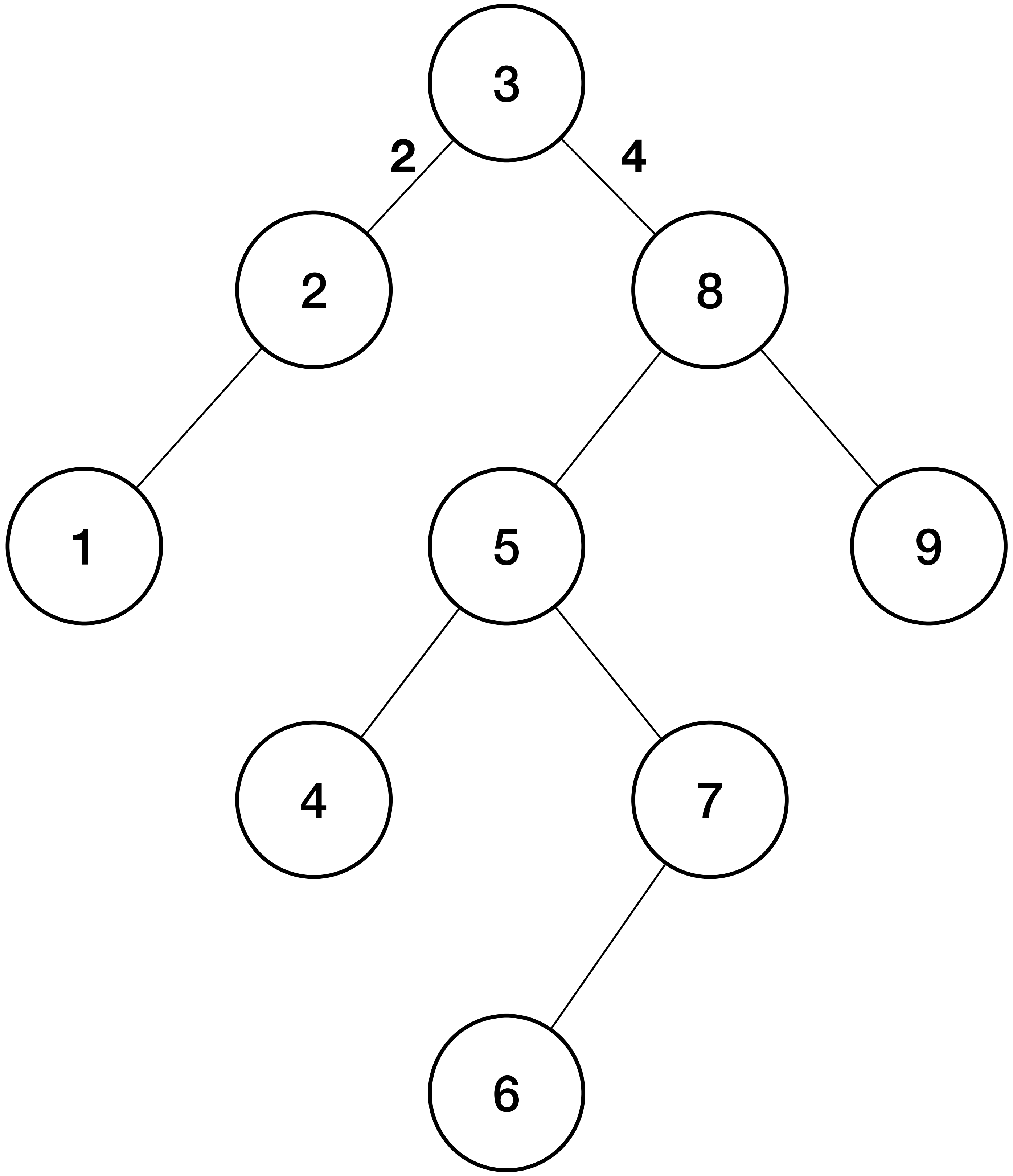
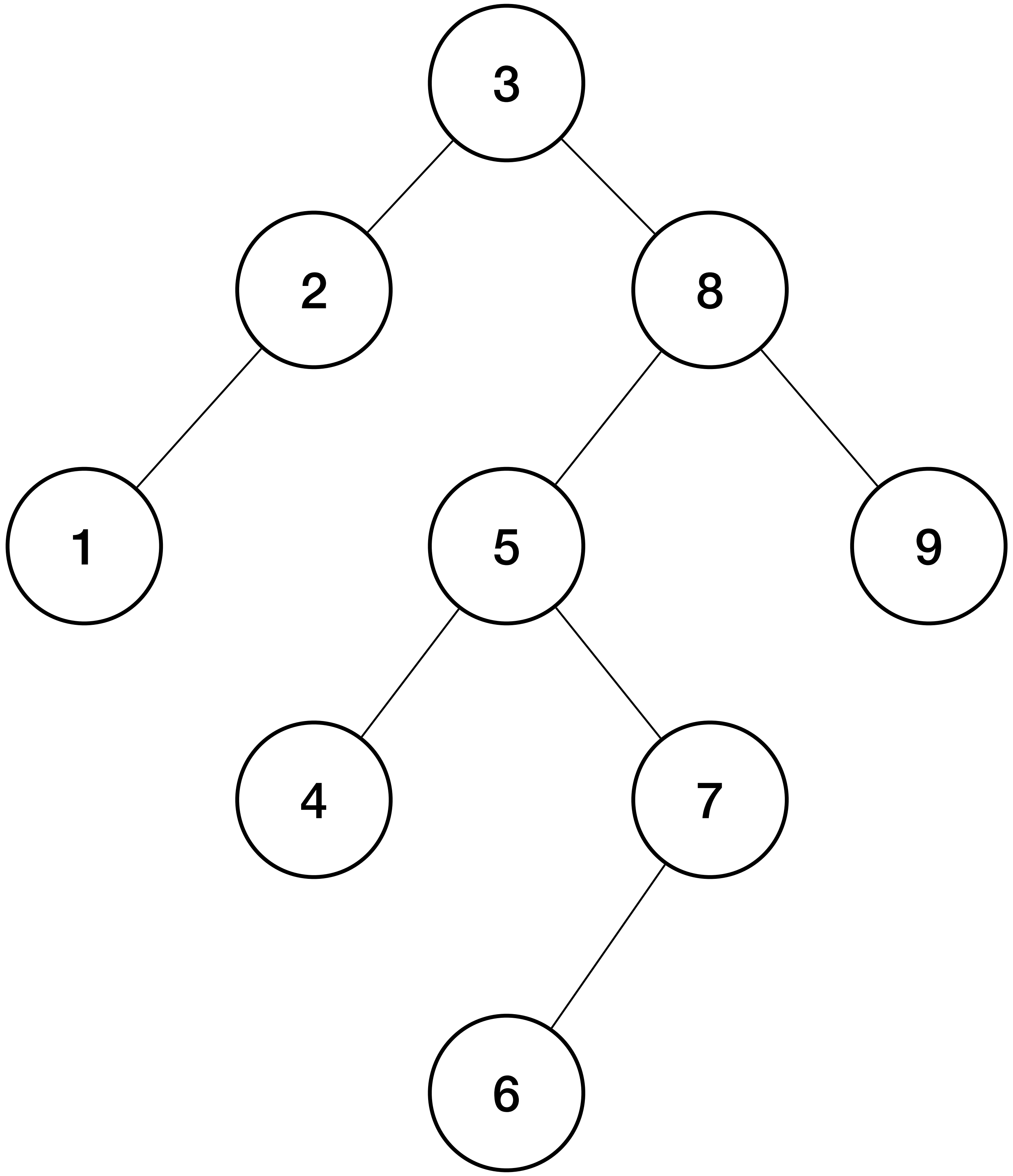


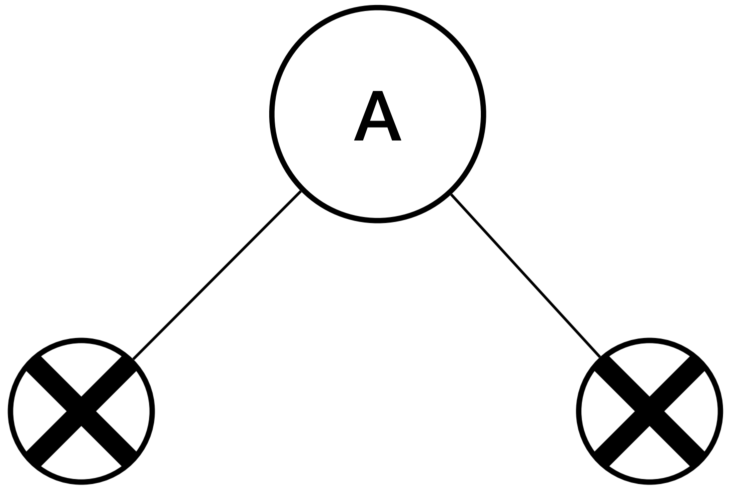
Find height of a tree

```
int tree_height(node *cursor){
  int lh, rh;
  if (cursor==NULL)

  else{
    lh =
    rh =
    return
  }
}
```



What should be height of single node?



```
template <typename T>
struct treenode{
  T data;
  treenode *left;
  treenode *right;
};
```

C++ Example

- Using classes in C++, create a BST class and perform or find:
  - Insertion
  - Searching
  - Traversal
  - Vectorization
  - Size of tree (# of nodes)
  - Find height of the tree
  - Deletion of tree

```
template <class N>
class bst{
private:
  …
  …
  …
public:
  bst();
  void insert(N data);
  treenode<N> *search(N data);
  void inorder();
  vector<N> vectorize();
  int node_count();
  int height();
  void print();
  ~bst();
};
```

```
template <typename T>
struct treenode{
  T data;
  treenode *left;
  treenode *right;
};
```

C++ Example

- Using classes in C++, create a BST class and perform or find:
  - Insertion
  - Searching
  - Traversal
  - Vectorization
  - Size of tree (# of nodes)
  - Find height of the tree
  - Deletion of tree

```
template <class N>
class bst{
private:
  typedef treenode<N> node;
  node *root;

  void insert(N data, node **cursor);
  node *search(N key, node *cursor);
  void inorder(node *cursor);
  vector<N> vectorize(node *cursor, vector<N> &v);
  int countnodes(node *cursor);
  void print(node *cursor, int depth);
  int height(node *cursor);
  void delete_tree(node *cursor);

public:
  …
  …
```

C++ Example

```
#include <iostream>
#include "bst.hpp"

using namespace std;

int main(){
  bst <int> tree1;
  cout<<"Building a Binary Search Tree"<<endl;

  tree1.insert(45);
  tree1.insert(50);
  tree1.insert(35);
  tree1.insert(30);
  tree1.insert(70);
  tree1.insert(20);
  tree1.insert(40);
  tree1.insert(80);
  tree1.insert(60);

  cout<<"Total number of nodes in this tree: ";
  cout<<tree1.node_count()<<endl;
  tree1.inorder();
```

```
cout<<endl;
tree1.print();
cout<<"The tree height is: "<<tree1.height();
cout<<endl;

vector <int> v = tree1.vectorize();
cout<<"Vectorized in order this is:"<<endl;
for (auto it= v.begin(); it != v.end(); ++it)
  cout<<*it<<", ";
return 0;
}
```

Happy Fall Break

- Take survey: https://surveys.illinois.edu/sec/1742038613
- Stay warm and travel safe!