BST Implementation

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Today's Plan

Recap

BST Implementation

Announcements

Teacher Evaluation:

- Smartphone: www.hunter.cuny.edu/mobilete
- Computer: www.hunter.cuny.edu/te
- Completely Anonymous

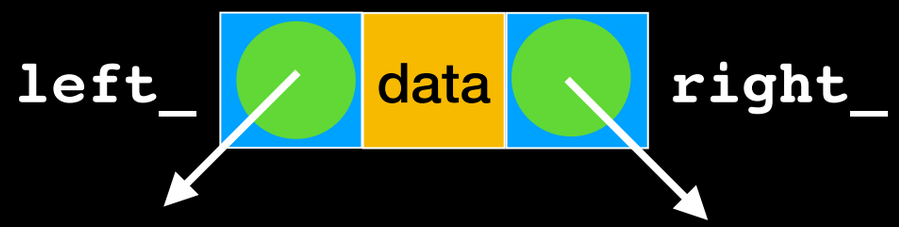
Recap

```
#ifndef BST_H_
#define BST_H_
#include <memory>

template<class T>
class BST
{

public:
     BST(); // constructor
     BST(const BST<T>& tree); // copy constructor
     ~ BST(); // destructor
     bool isEmpty() const;
     size_t getHeight() const;
     size_t getNumberOfNodes() const;
     void add(const T& new_item);
     void remove(const T& new_item);
     T find(const T& item) const;
     void clear();

     void preorderTraverse(Visitor<T>& visit) const;
     void inorderTraverse(Visitor<T>& visit) const;
     void postorderTraverse(Visitor<T>& visit) const;

     BST& operator= (const BST<T>& rhs);

private:
     std::shared_ptr<BinaryNode<T>> root_ptr_;
}; // end BST

#include "BST.cpp"
#endif // BST_H_
```

Let's try something new and use `shared_ptr`:
A bit of extra syntax at declaration but then you use them as regular pointers with less cleaning up

To implement this as a linked structure what do we need to change in our previous implementation of nodes???

BinaryNode



```cpp
#ifndef BinaryNode_H_
#define BinaryNode_H_
#include <memory>

template<class T>
class BinaryNode
{

public:
   BinaryNode();
   BinaryNode(const T& an_item, std::shared_ptr<BinaryNode<T>> left,
              std::shared_ptr<BinaryNode<T>> right);
   void setItem(const T& an_item);
   T getItem() const;

   bool isLeaf() const;

   auto getLeftChildPtr() const;
   auto getRightChildPtr() const;

   void setLeftChildPtr(std::shared_ptr<BinaryNode<T>> left_ptr);
   void setRightChildPtr(std::shared_ptr<BinaryNode<T>> right_ptr);

private:
   T item_;    // Data portion
   std::shared_ptr<BinaryNode<T>> left_;   // Pointer to left child
   std::shared_ptr<BinaryNode<T>> right_;  // Pointer to right child
}; // end BST


#include "BinaryNode.cpp"
#endif // BinaryNode_H_
```

Standard library for `shared_ptr`

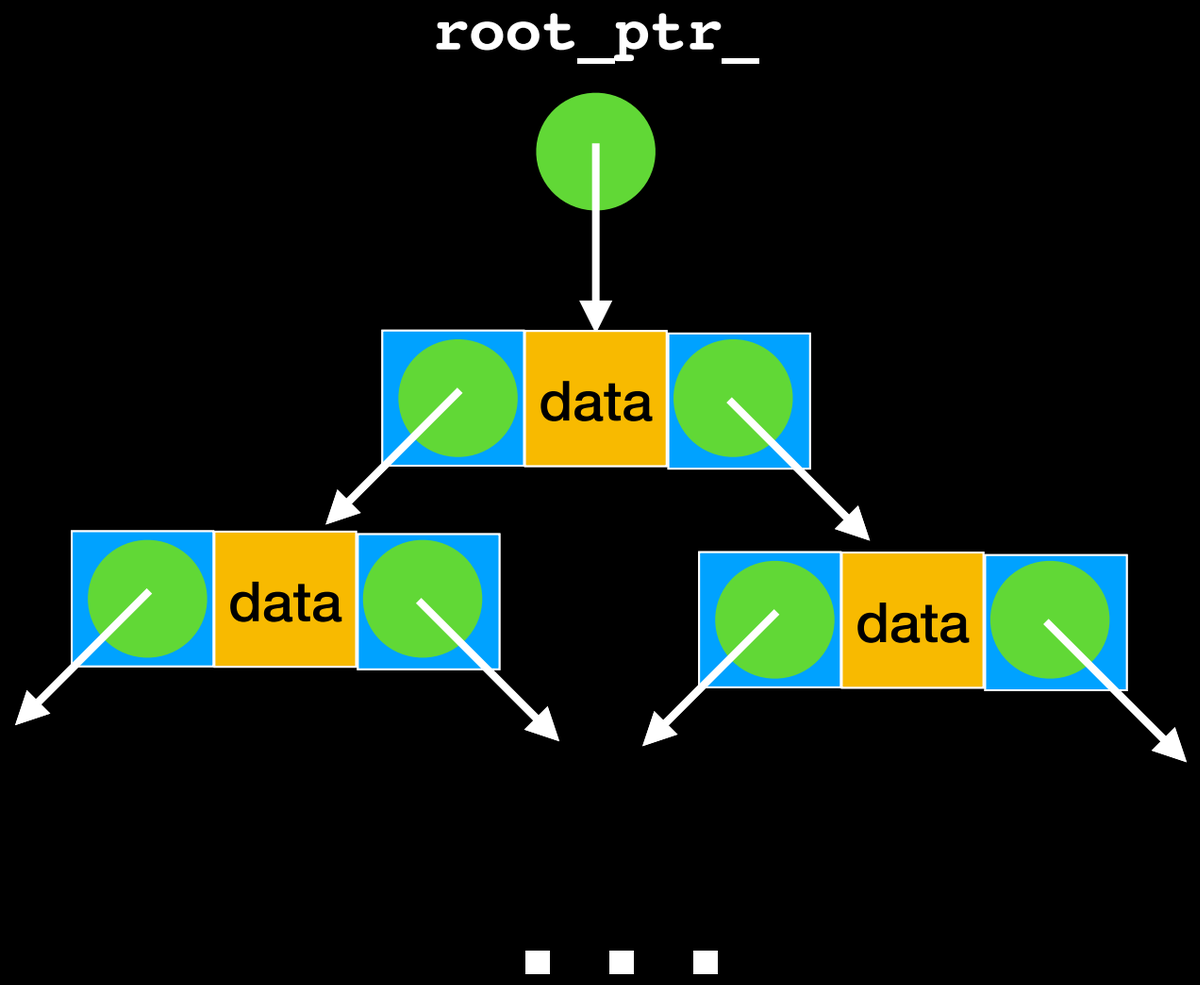
Lecture Activity

Implement:

```
BinaryNode(const T& an_item, std::shared_ptr<BinaryNode<T>> left,
           std::shared_ptr<BinaryNode<T>> right);

bool isLeaf() const;

void setLeftChildPtr(std::shared_ptr<BinaryNode<T>> left_ptr);
```

```cpp
template<class T>
BinaryNode(const T& an_item, std::shared_ptr<BinaryNode<T>> left,
           std::shared_ptr<BinaryNode<T>> right): item_{an_item},
           left_{left}, right_{right}{ }  // end constructor


template<class T>
bool BinaryNode<T>::isLeaf() const
{
   return ((left_ == nullptr) && (right_ == nullptr));
} // end isLeaf


template<class T>
void BinaryNode<T>::setLeftChildPtr(std::shared_ptr<BinaryNode<T>> left_ptr)
{
   left_ = left_ptr;
}  // end setLeftChildPtr
```

BST



```cpp
#ifndef BST_H_
#define BST_H_
#include <memory>

template<class T>
class BST
{

public:
     BST(); // constructor
     BST(const BST<T>& tree); // copy constructor
     ~ BST(); // destructor
     bool isEmpty() const;
     size_t getHeight() const;
     size_t getNumberOfNodes() const;
     void add(const T& new_item);
     void remove(const T& new_item);
     T find(const T& item) const;
     void clear();

     void preorderTraverse(Visitor<T>& visit) const;
     void inorderTraverse(Visitor<T>& visit) const;
     void postorderTraverse(Visitor<T>& visit) const;

     BST& operator= (const BST<T>& rhs);

private:
     std::shared_ptr<BinaryNode<T>> root_ptr_;
}; // end BST

#include "BST.cpp"
#endif // BST_H_
```

In the spirit of safe programming, our interface is generic and not tied to implementation. Many of these methods will use helper functions, which should be private (or protected if you envision inheritance). I do not include them here in the interface for lack of space.

Copy Constructor

`root_ptr` of this object

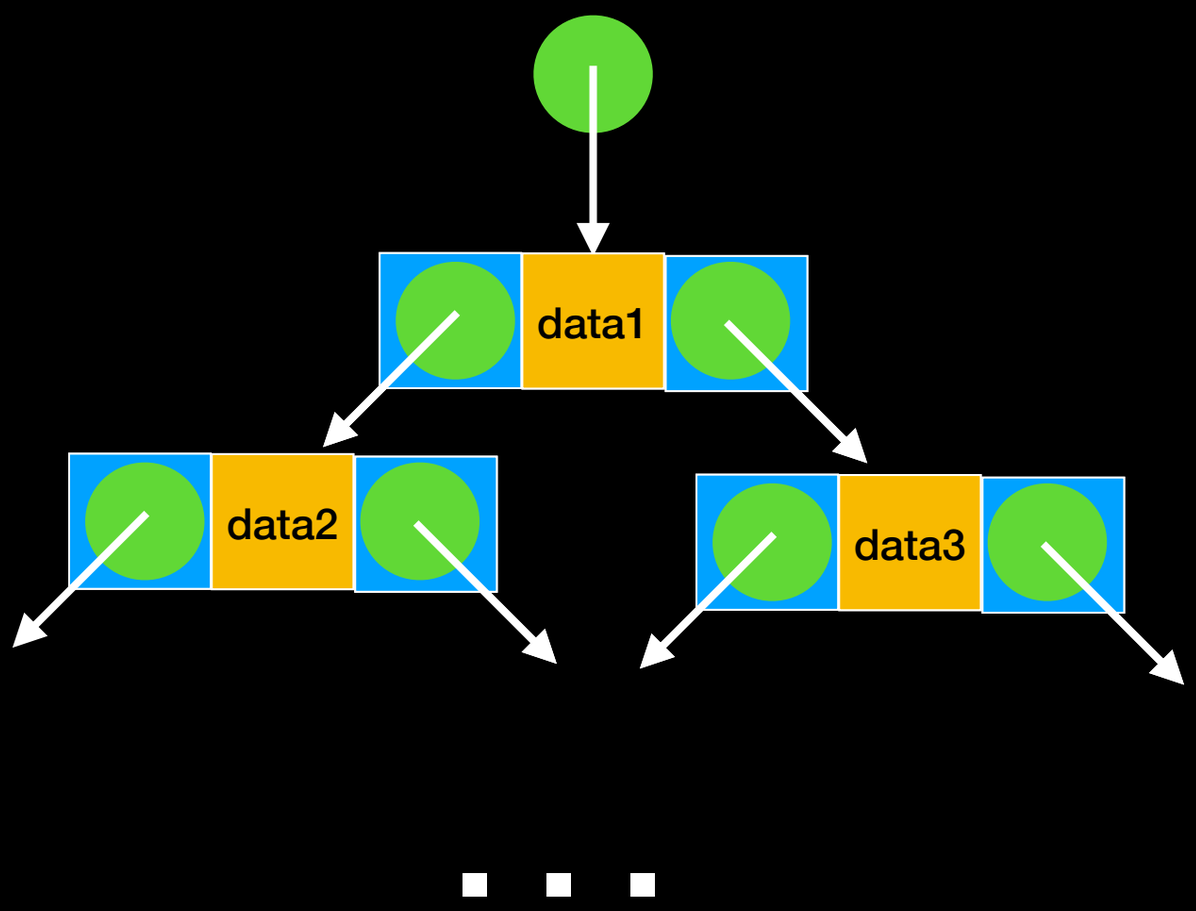
`root_ptr` of `tree`: the object I'm going to copy

```
template<class T>
BST<T>::BST(const BST<T>& tree)
{
   root_ptr_ = copyTree(tree.root_ptr_); // Call helper function
}  // end copy constructor
```

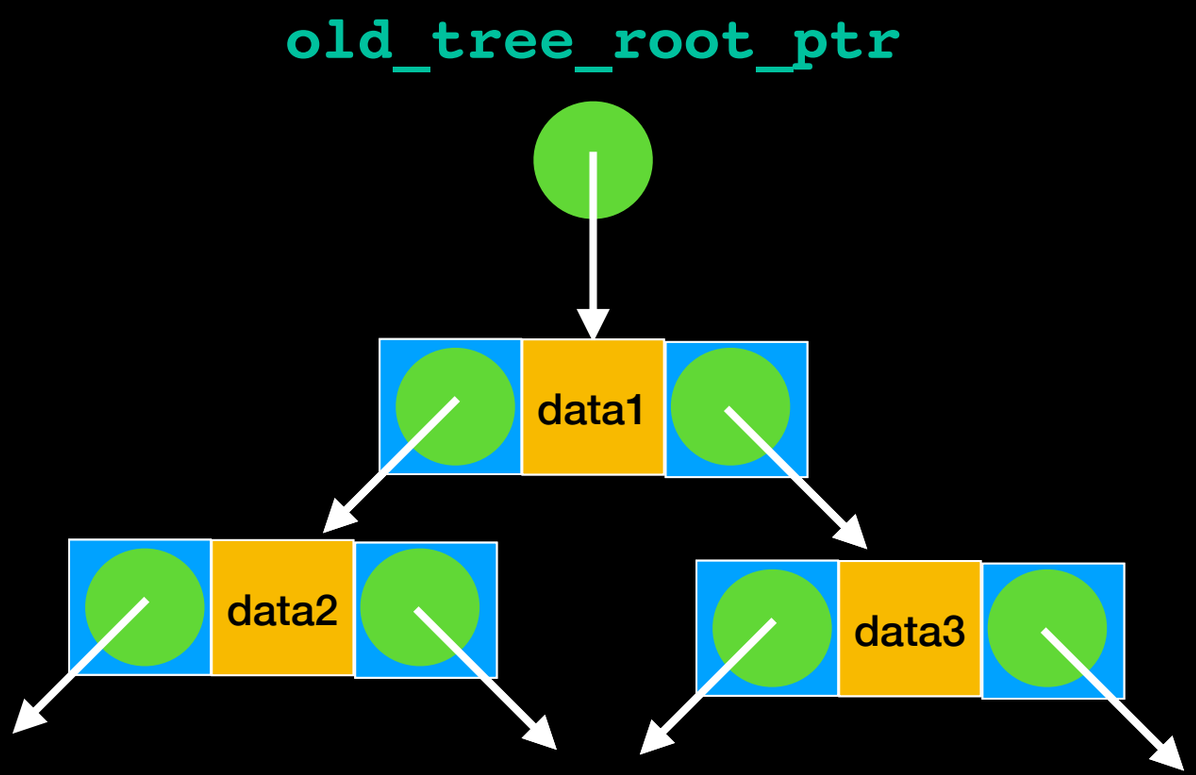
Safe programming: the public method does not take pointer parameter.
Only protected/private methods have access to pointers and may modify tree structure

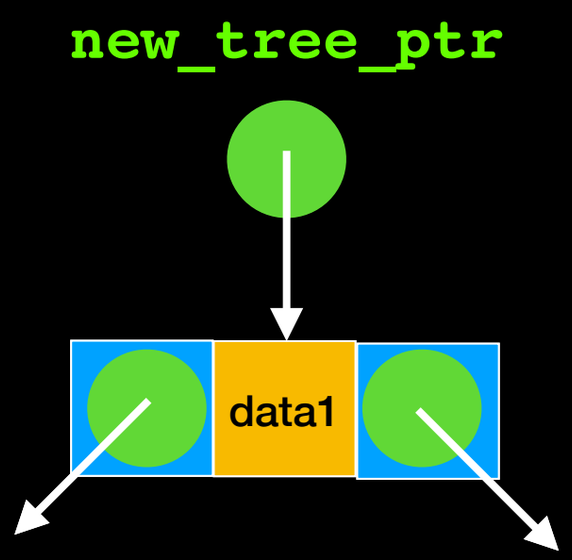
I can use the . operator to access a private member variable because it is s within the class definition.

copyTree(old_tree_root_ptr)

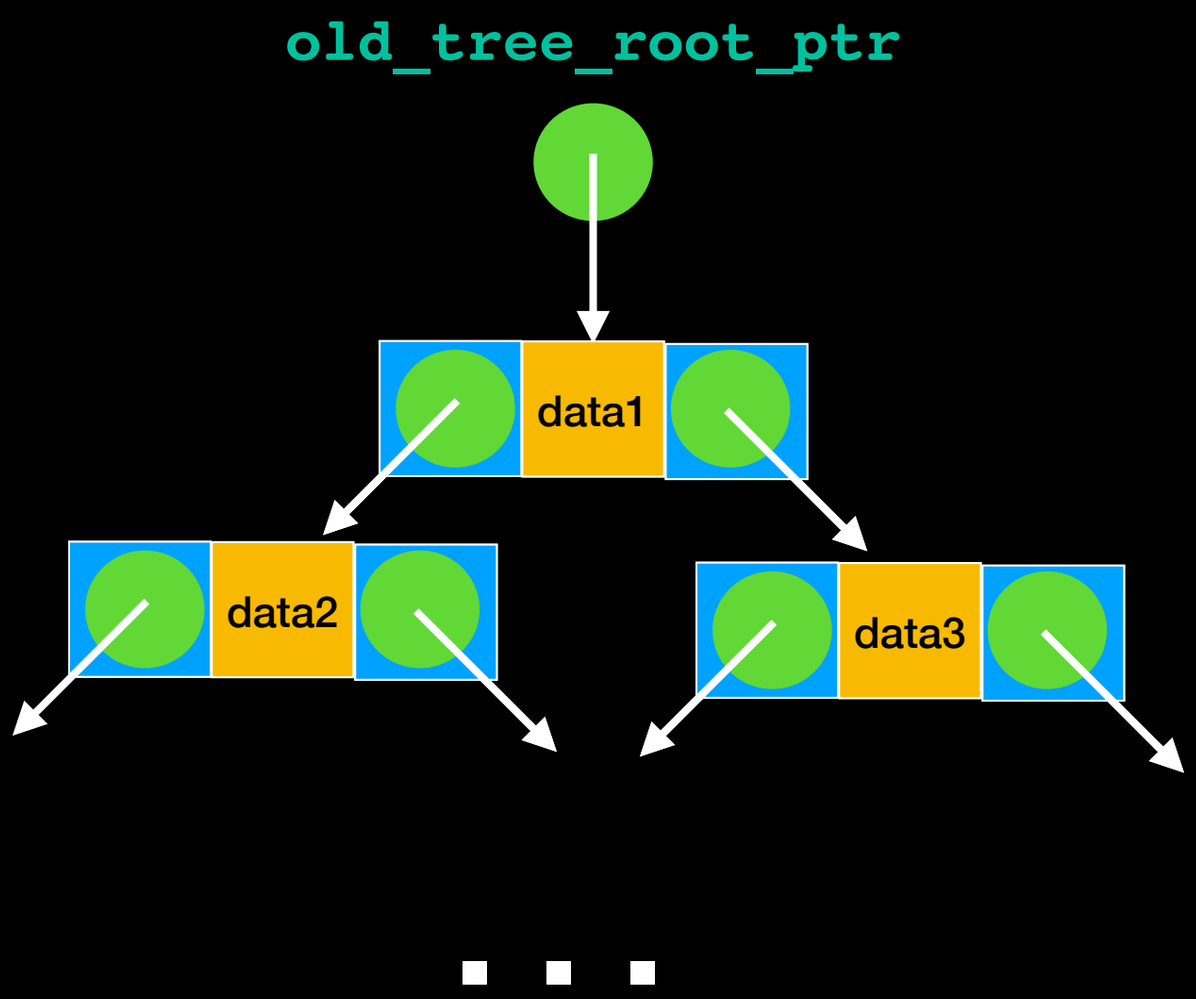


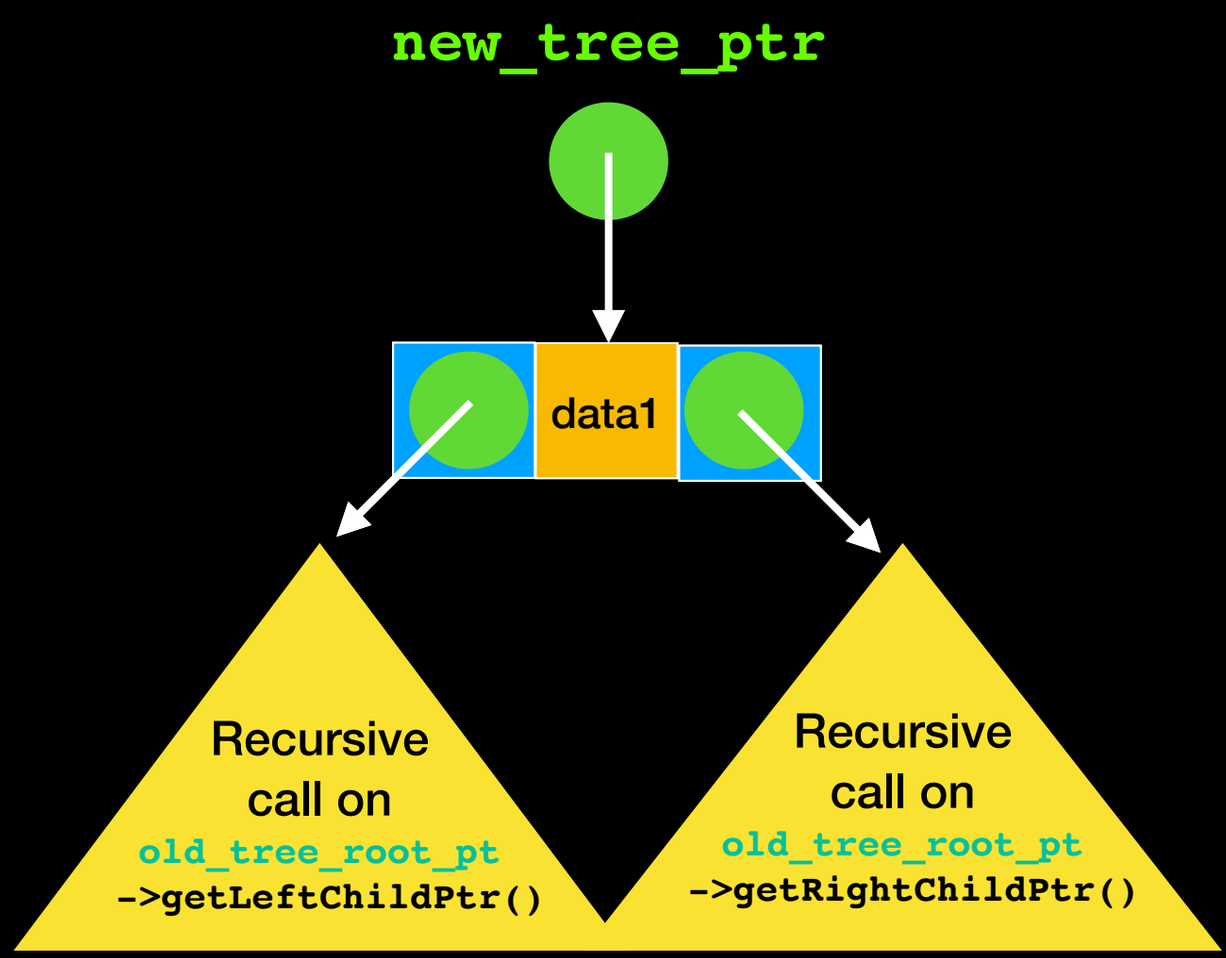
copyTree(old_tree_root_ptr)





copyTree(old_tree_root_ptr)





Copy Constructor Helper Function

Returning `shared_ptr`, cleaner to use auto return type: -std=c++14

```
template<class T>
auto BST<T>::copyTree(const std::shared_ptr<BinaryNode<T>> old_tree_root_ptr) const
{
   std::shared_ptr<BinaryNode<T>> new_tree_ptr;

   // Copy tree nodes during a preorder traversal
   if (old_tree_root_ptr != nullptr)
   {
      // Copy node
      new_tree_ptr = std::make_shared<BinaryNode<T>>(old_tree_root_ptr
                                                     ->getItem(), nullptr, nullptr);
     new_tree_ptr->setLeftChildPtr(copyTree(old_tree_root_ptr->getLeftChildPtr()));
      new_tree_ptr->setRightChildPtr(copyTree(old_tree_root_ptr
                                                       ->getRightChildPtr()));
   }  // end if

   return new_tree_ptr;
}  // end copyTree
```

Recall: this is the syntax for allocating a "**new**" object with `shared_ptr` pointing to it

Recursive Calls:
Don't want to tie interface to recursive implementation: Use helper function

Preorder Traversal Scheme: copy each node as soon as it is visited to make exact copy

Move Constructor

How would you implement it?

Move the root!

Move Constructor

rvalue reference

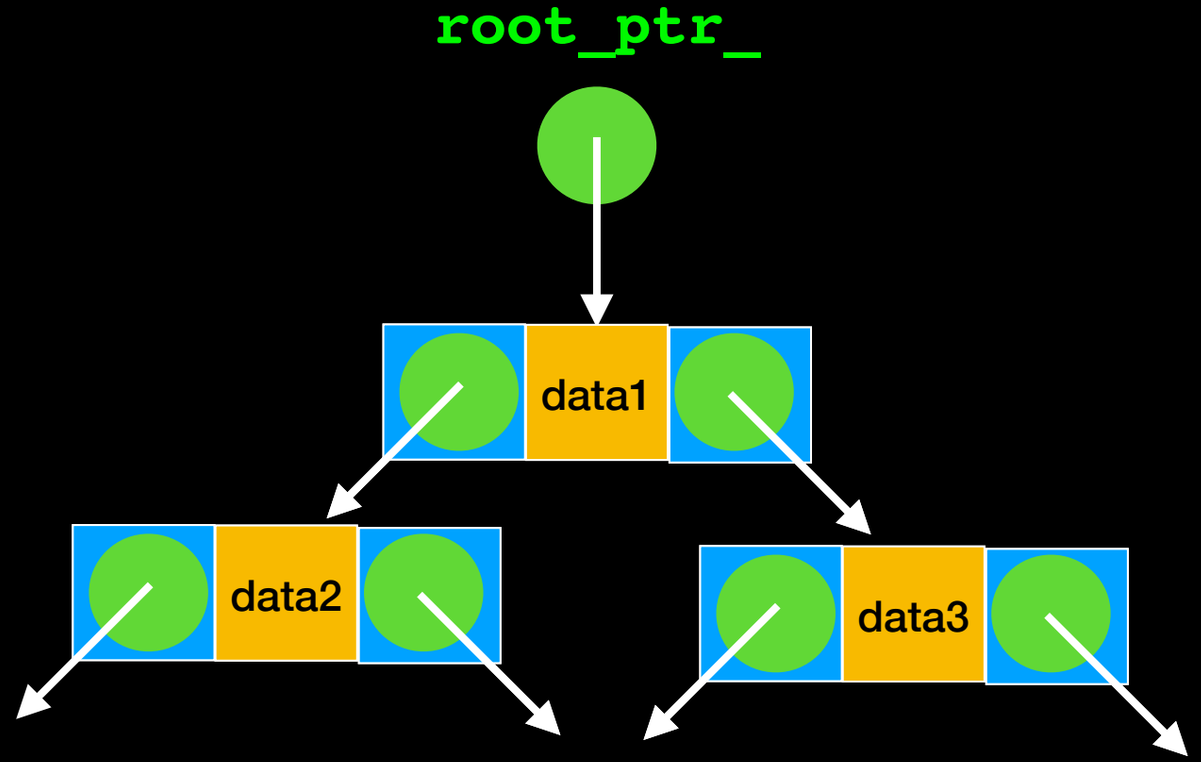
```
template<class T>
BST<T>::BST(const BST<T>&& tree)
{
   root_ptr_ = tree.root_ptr_;
   tree.root_ptr_.reset();

}  // end move constructor
```

Destructor

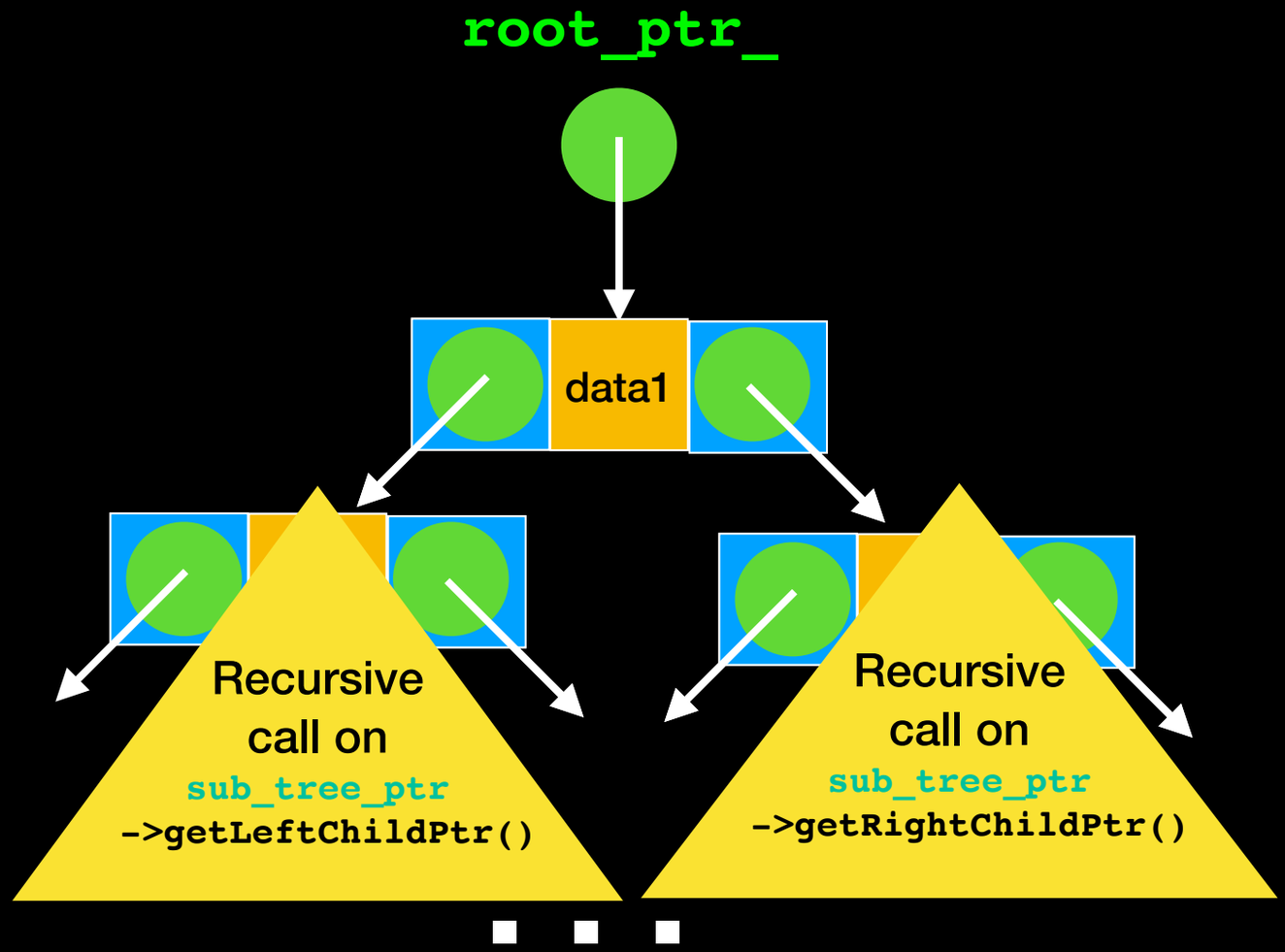
```
template<class T>
BST<T>::~BST()
{
    destroyTree(root_ptr_); // Call helper function
}  // end destructor
```

Safe programming: the public method does not take pointer parameter.
Only protected/private methods have access to pointers and may modify tree structure

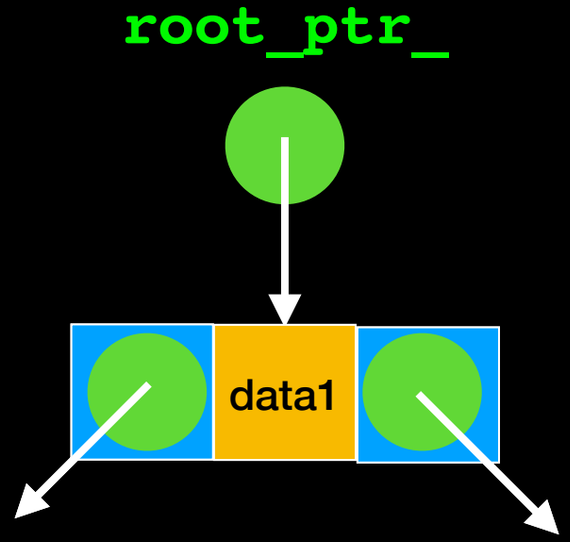
destroyTree(sub_tree_ptr)



destroyTree(sub_tree_ptr)



destroyTree(sub_tree_ptr)



`root_ptr_.reset()`

destroyTree(sub_tree_ptr)

Destructor Helper Function

```
template<class T>
void BST<T>::destroyTree(std::shared_ptr<BinaryNode<T>> sub_tree_ptr)
{
   if (sub_tree_ptr != nullptr)
   {
      destroyTree(sub_tree_ptr->getLeftChildPtr());
      destroyTree(sub_tree_ptr->getRightChildPtr());
      sub_tree_ptr.reset(); // same as sub_tree_ptr = nullptr for smart pointers
   }  // end if
}  // end destroyTree
```

Notice: all we have to do is set the `shared_ptr` to `nullptr` with `reset()` and it will take care of deleting the node.

PostOrder Traversal Scheme: Delete node only after deleting both of its subtrees

clear

```
template<class T>
void BST<T>::clear()
{
   destroyTree(root_ptr_); // Call helper method
}  // end clear
```

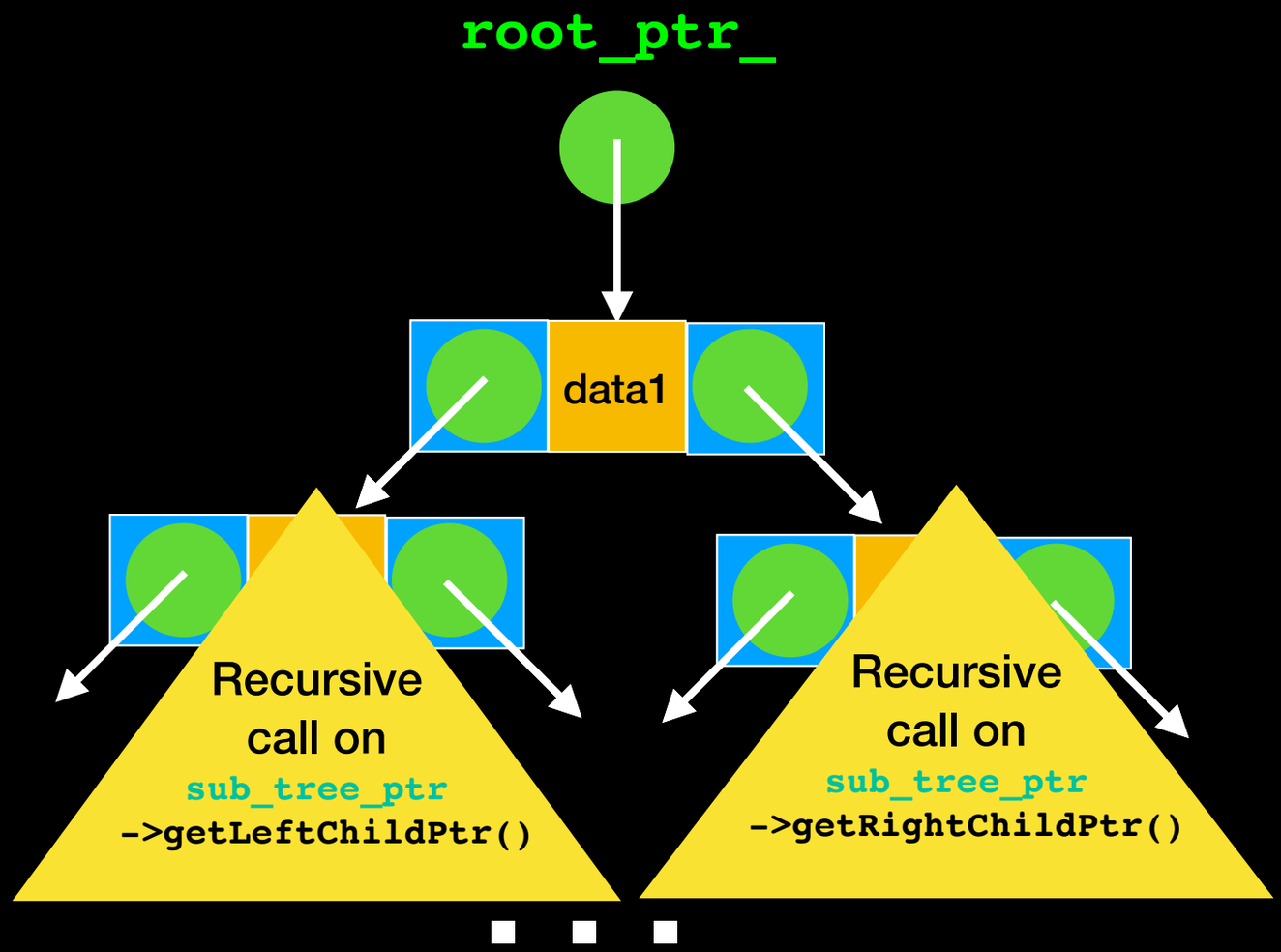
Safe programming: the public method does not take pointer parameter.
Only protected/private methods have access to pointers and may modify tree structure

getHeight

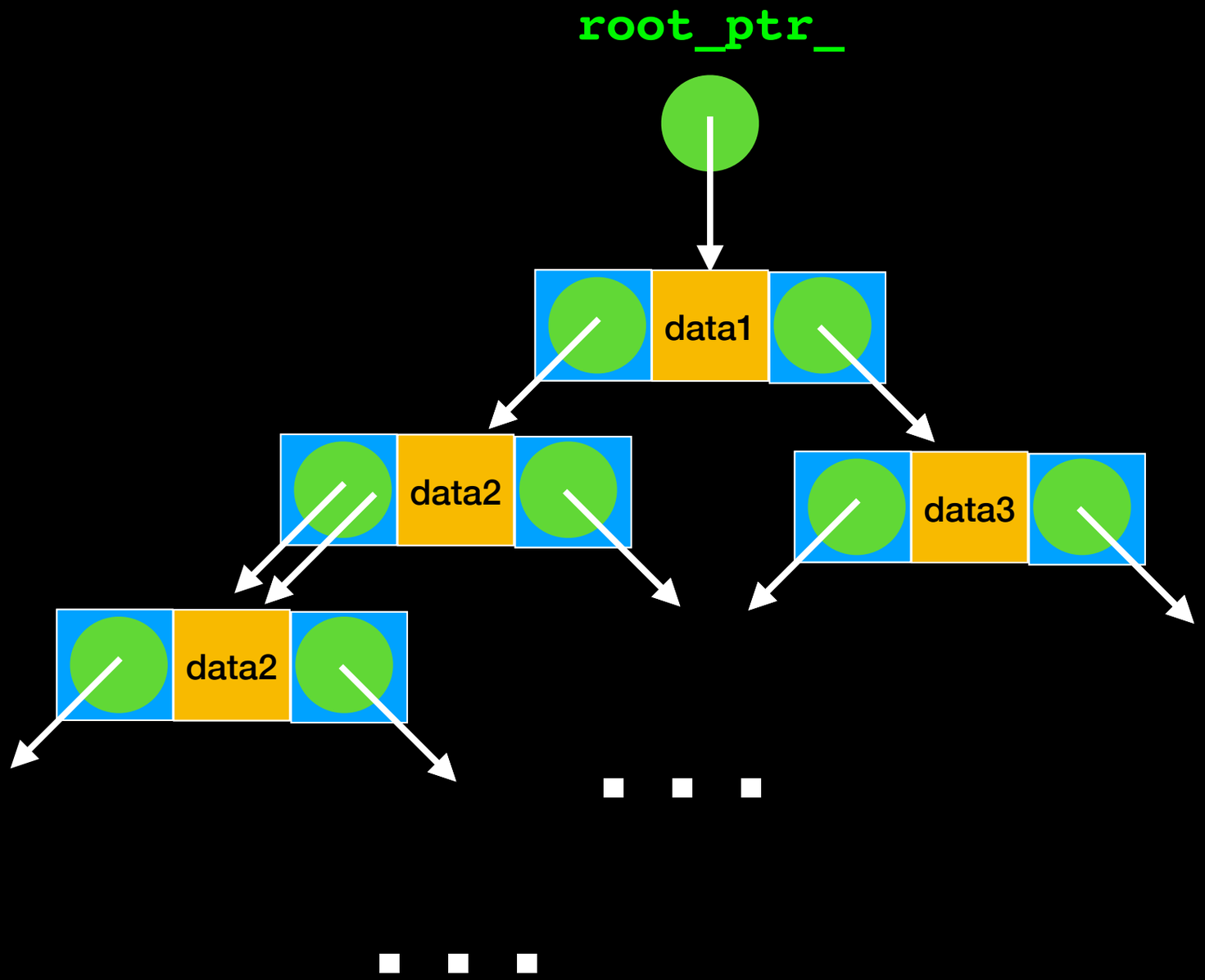
```
template<class T>
int BST<T>::getHeight() const
{
   return getHeightHelper(root_ptr_);
}  // end getHeight
```

Safe programming: the public method does not take pointer parameter.
Only protected/private methods have access to pointers and may modify tree structure

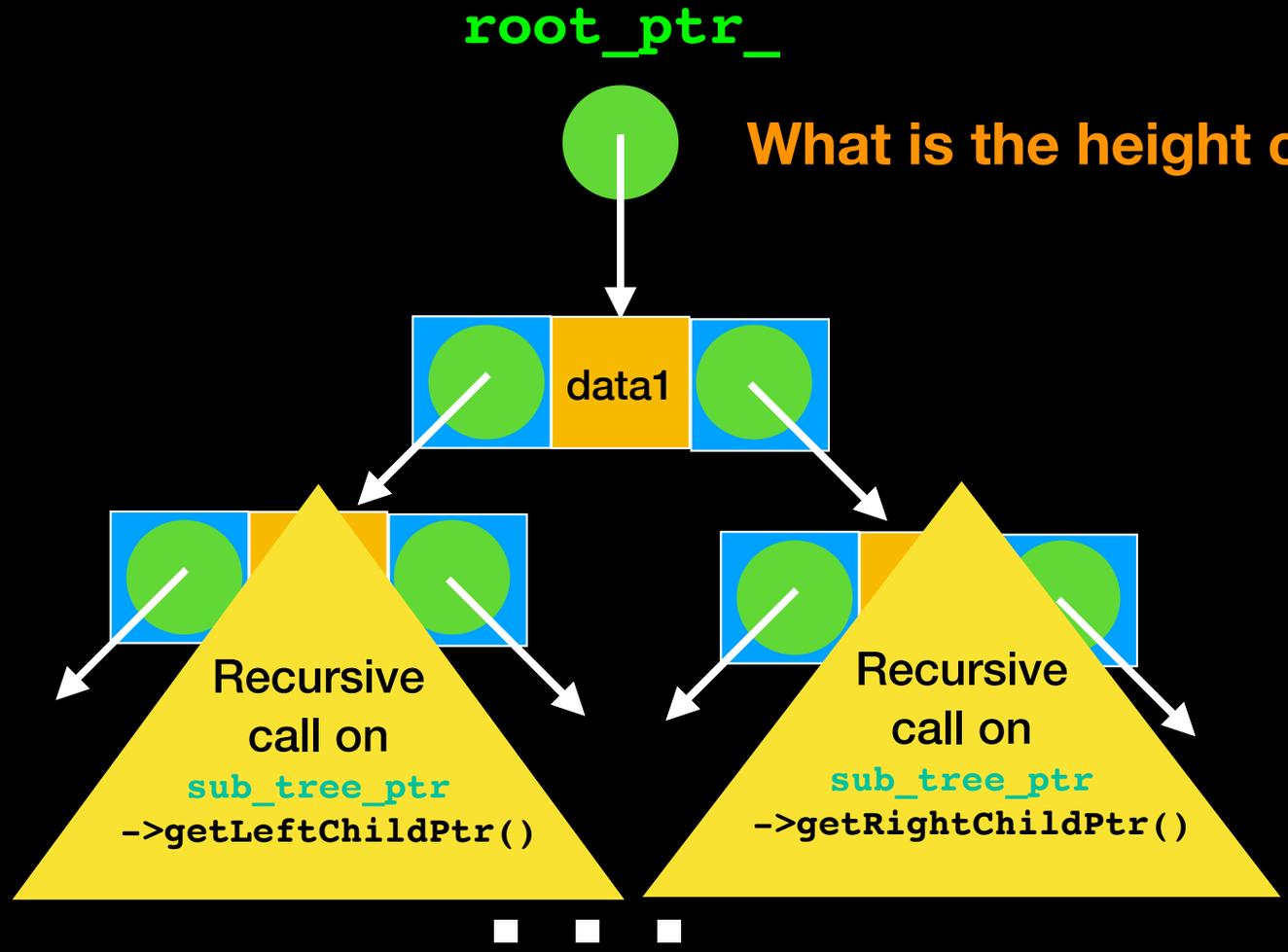
getHeightHelper(sub_tree_ptr)



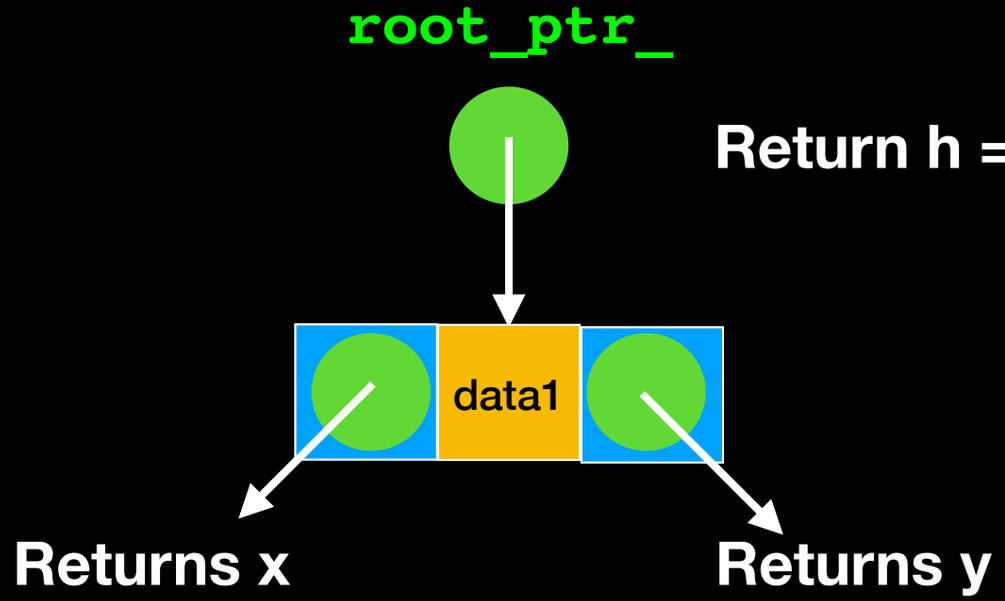
getHeightHelper(sub_tree_ptr)



getHeightHelper(sub_tree_ptr)

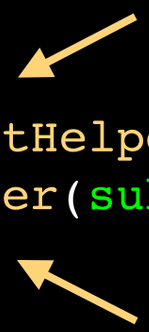


getHeightHelper(sub_tree_ptr)



getHeightHelper(sub_tree_ptr)

```
template<class T>
int BST<T>::getHeightHelper(std::shared_ptr<BinaryNode<T>> sub_tree_ptr) const
{
   if (sub_tree_ptr == nullptr)
      return 0;
   else
      return 1 + std::max(getHeightHelper(sub_tree_ptr->getLeftChildPtr()),
                          getHeightHelper(sub_tree_ptr->getRightChildPtr()));
}  // end getHeightHelper
```



Similarly: implement these at home!!!

```
int BST<T>::getNumberOfNodes() const
{ //try it at home!!!!}

int BST<T>::getNumberOfNodesHelper(std::shared_ptr
<BinaryNode<T>> sub_tree_ptr) {//try it at home!!!!}
```

`add` and `remove`

Key methods: determine order of data

Distinguish between different types of Binary Trees

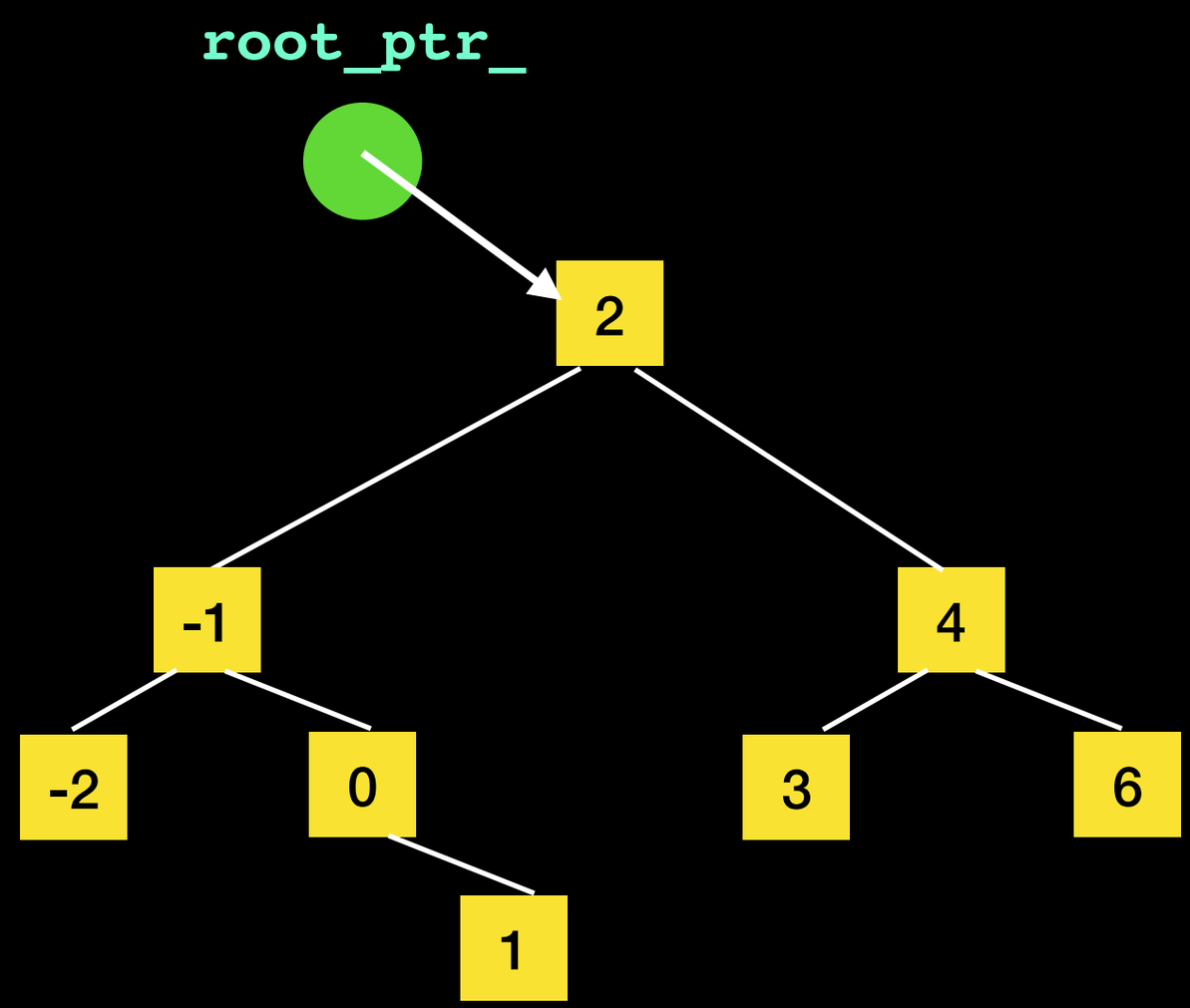
Implement the BST structural property

add

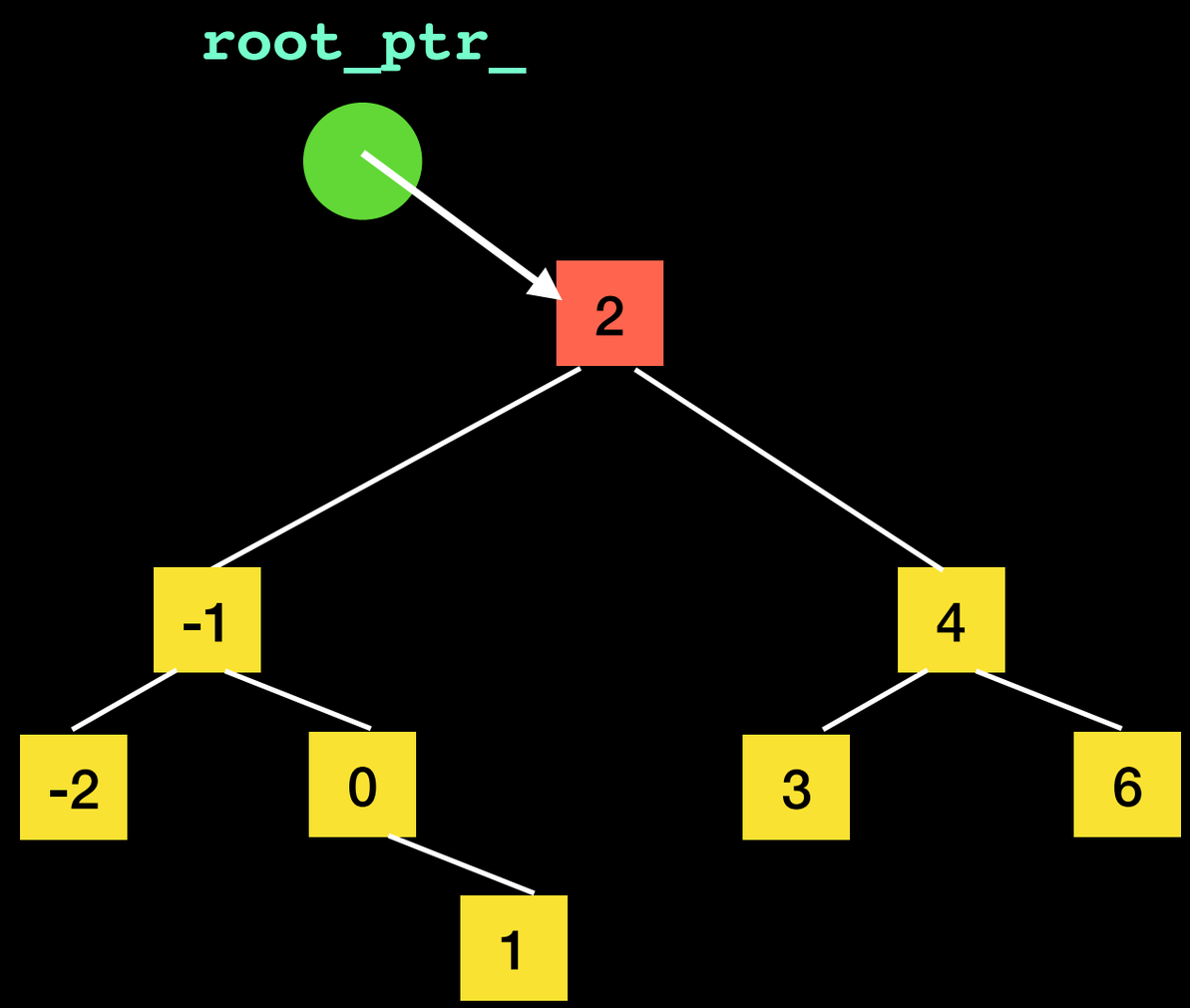
```
template<class T>
void BST<T>::add(const T& new_item)
{
   auto new_node_ptr =
                  std::make_shared<BinaryNode<T>>(new_item);
   root_ptr_ = placeNode(root_ptr_, new_node_ptr);

}  // end add
```

Safe programming: the public method does not take pointer parameter.
Only protected/private methods have access to pointers and may modify tree structure

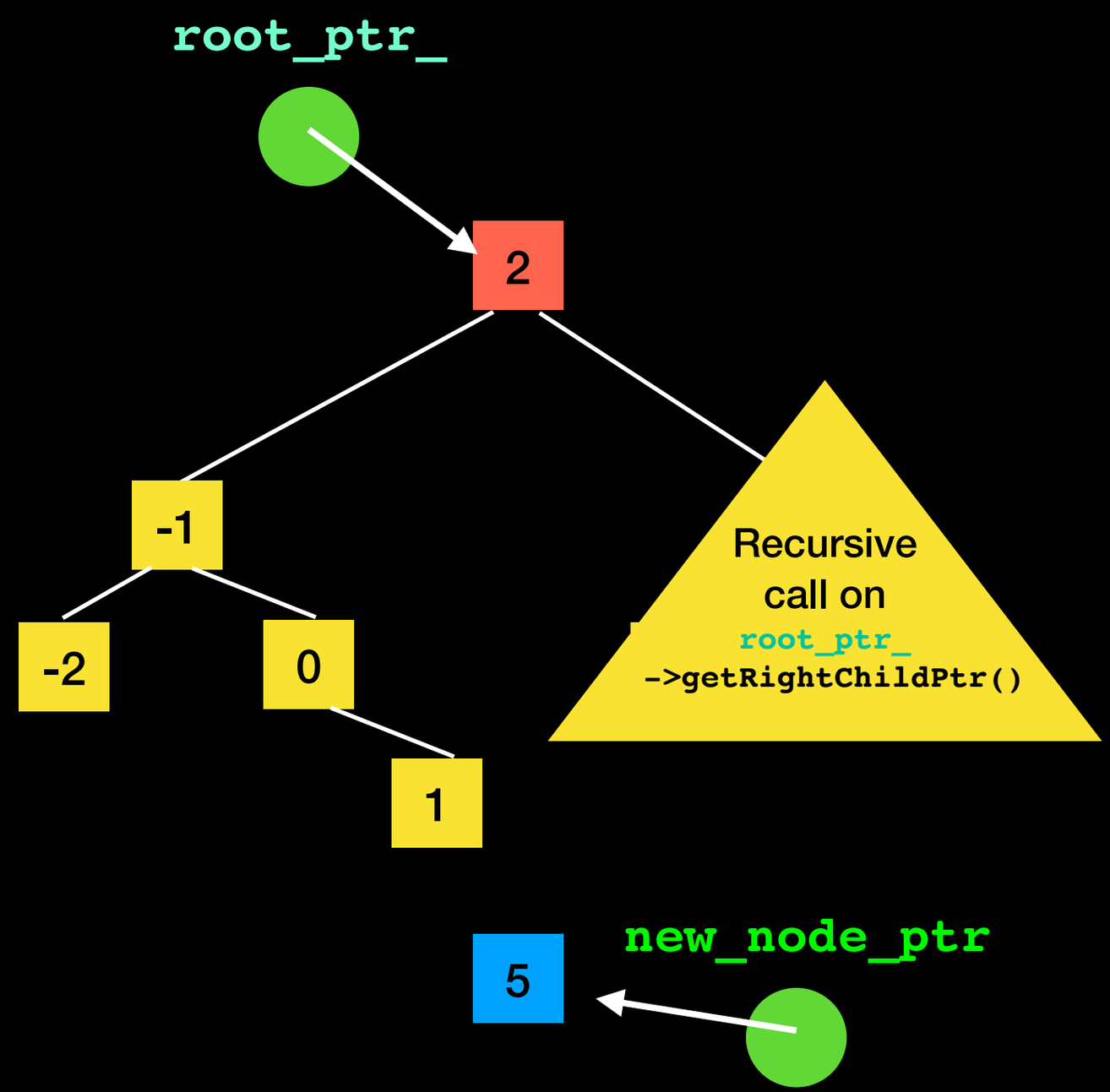
```
placeNode(root_ptr_, new_node_ptr);
```



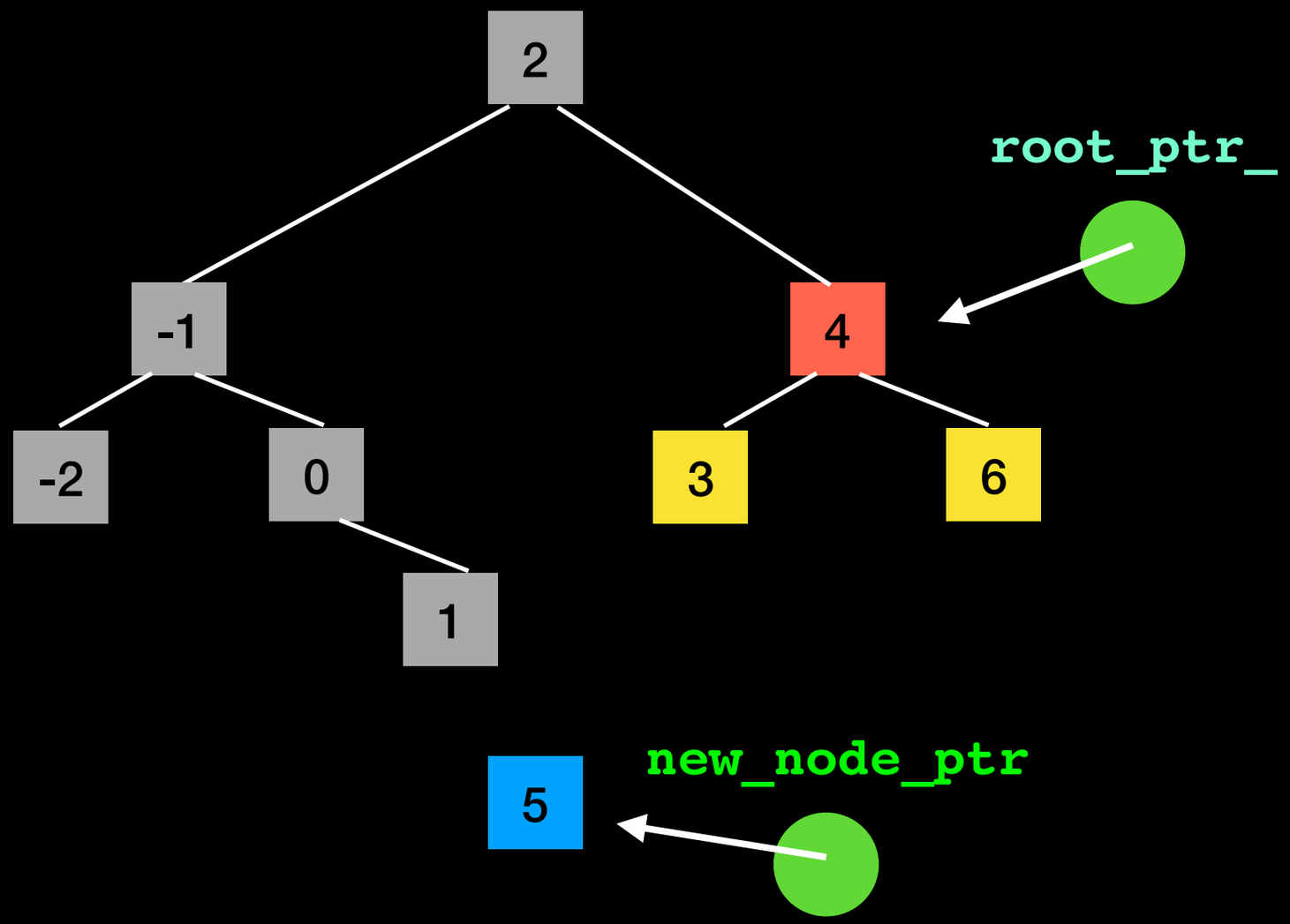
```
placeNode(root_ptr_, new_node_ptr);
```



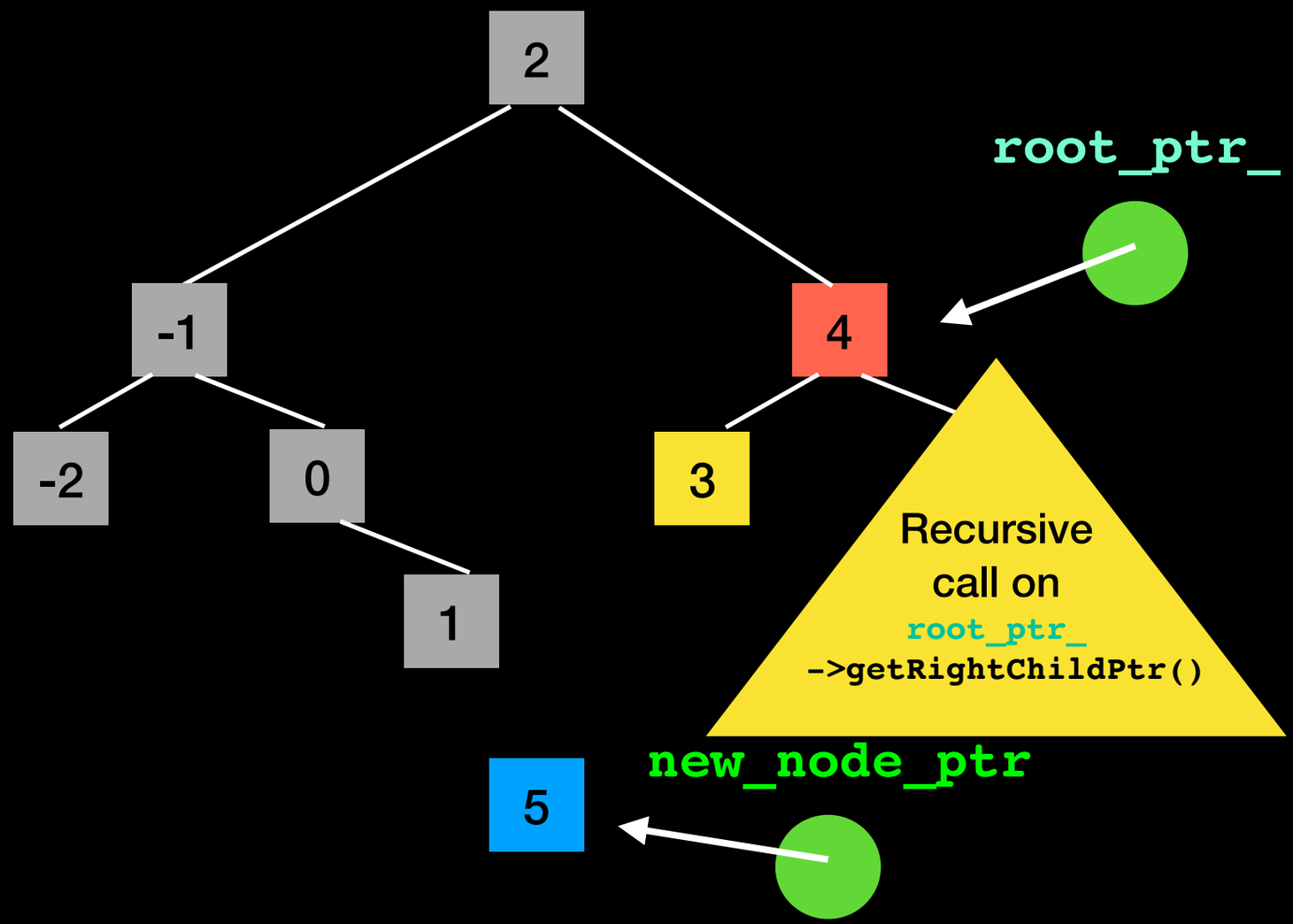
```
placeNode(root_ptr_, new_node_ptr);
```



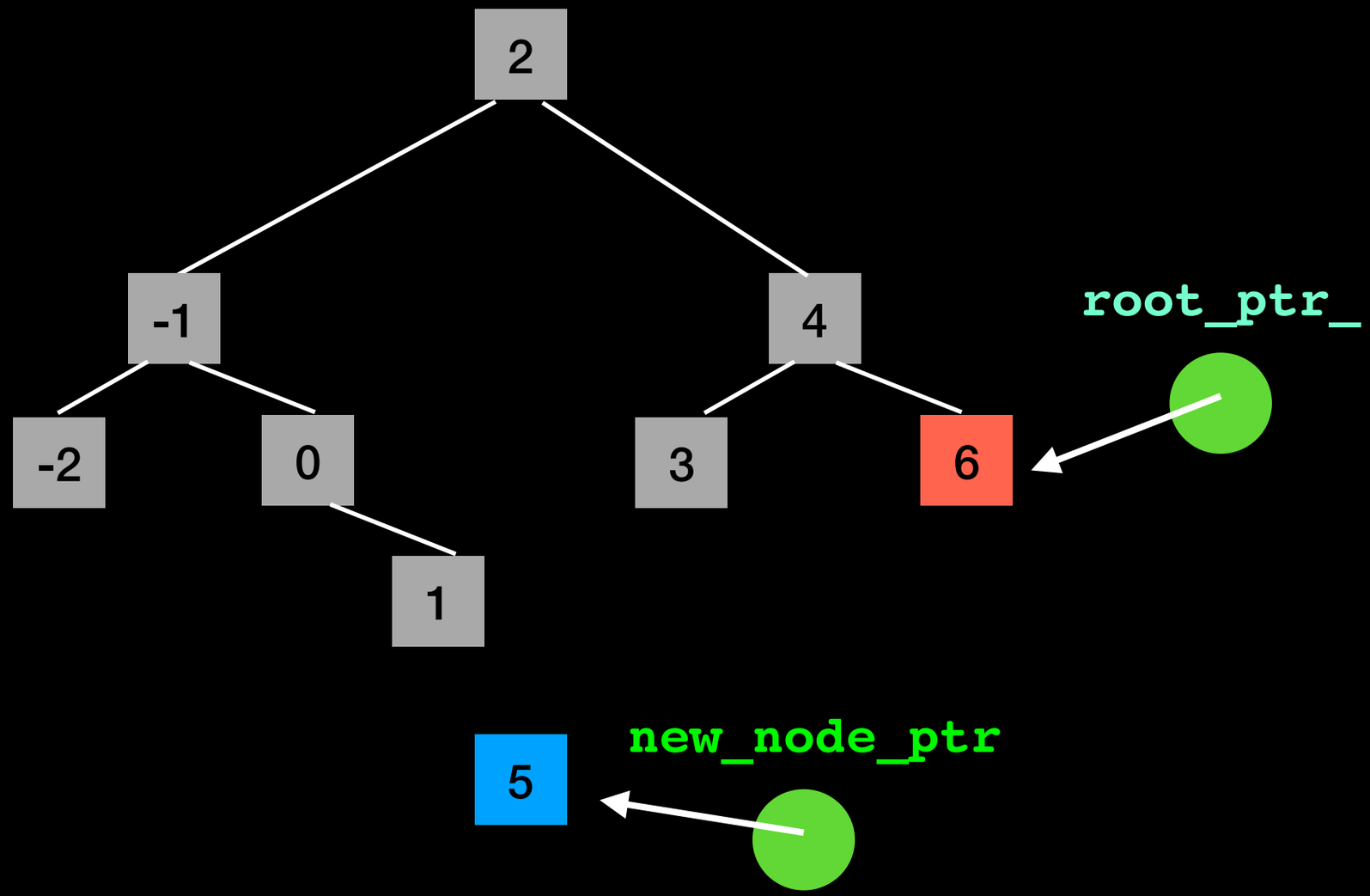
```
placeNode(root_ptr_, new_node_ptr);
```



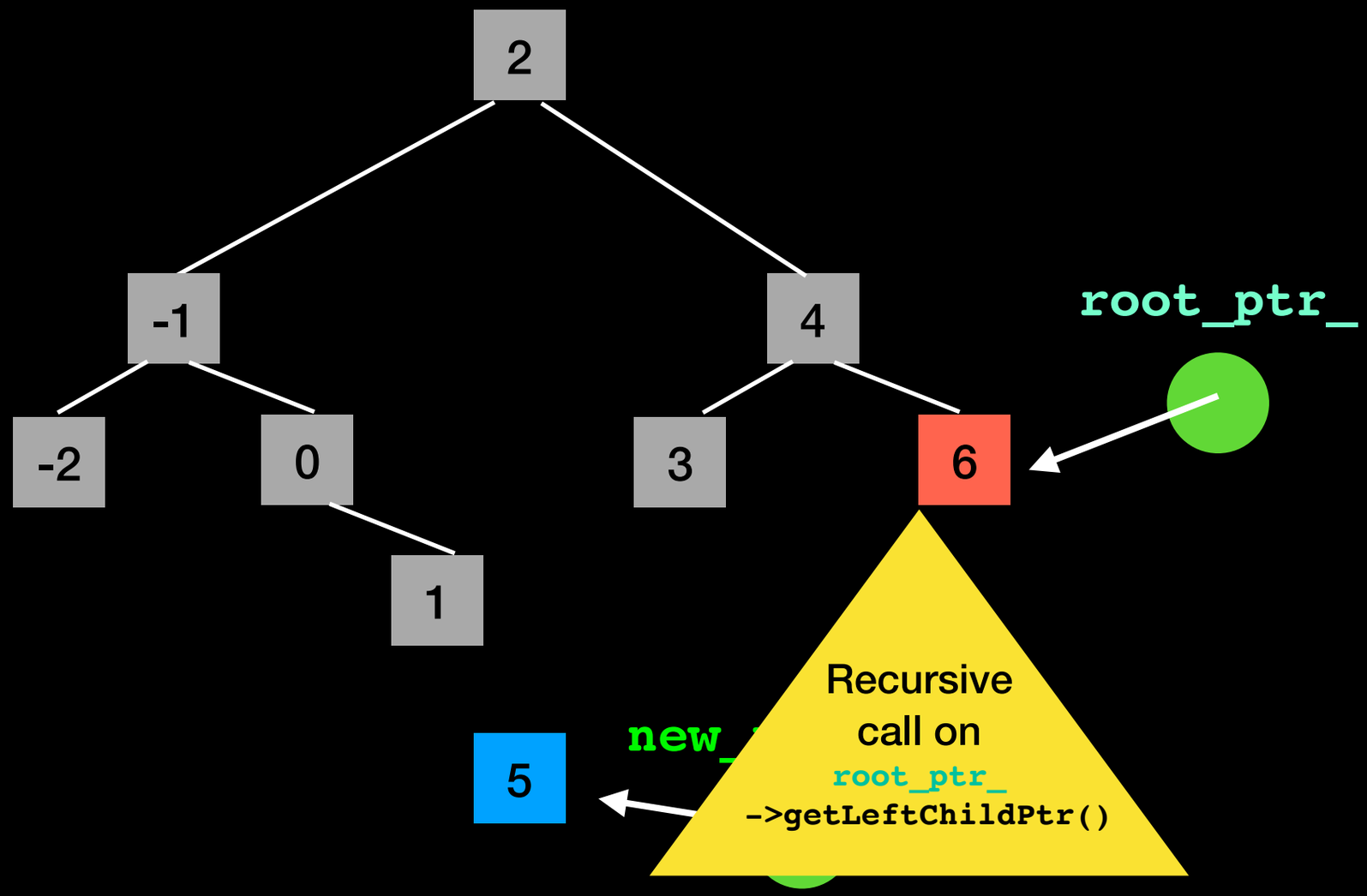
```
placeNode(root_ptr_, new_node_ptr);
```



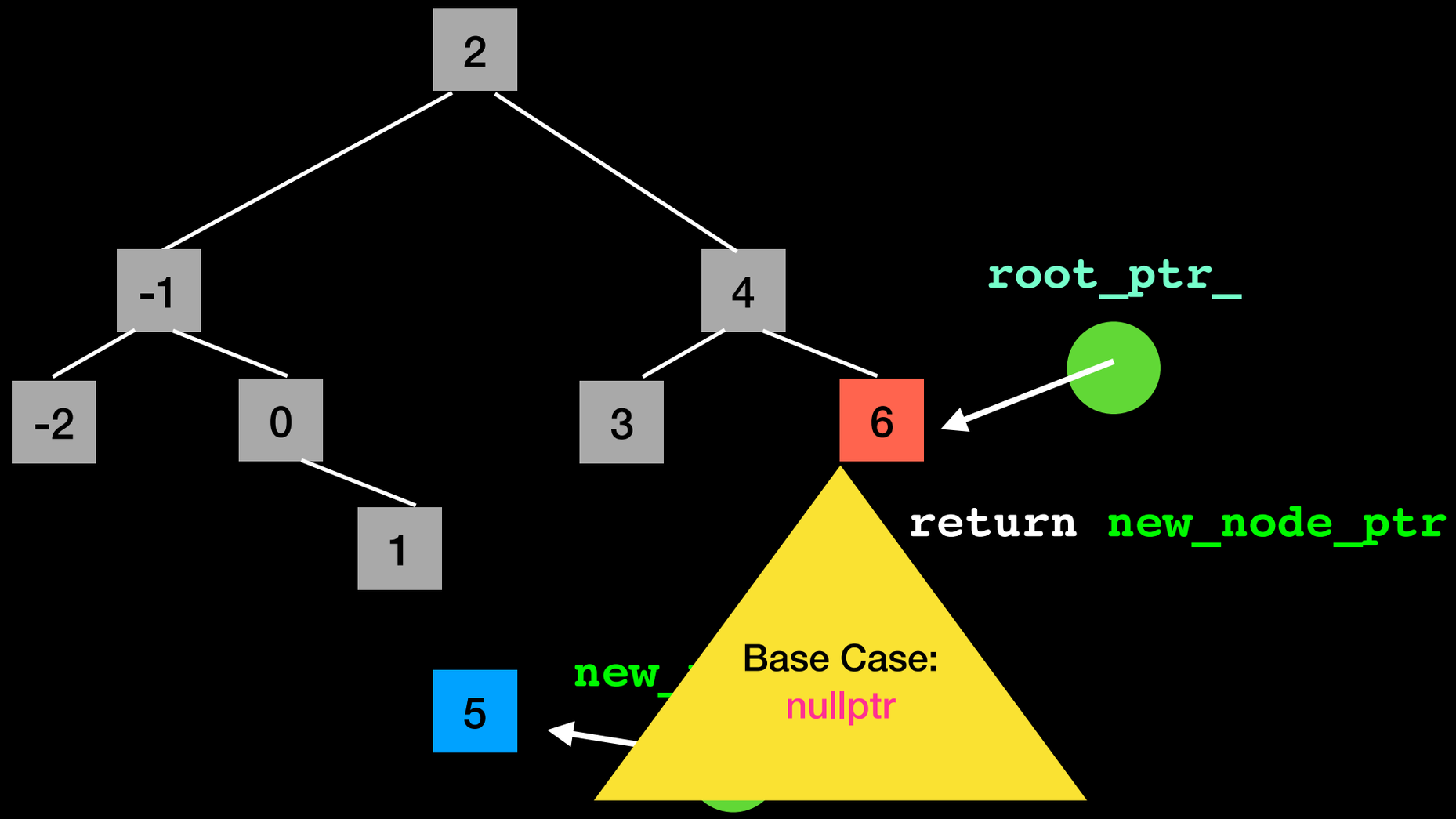
```
placeNode(root_ptr_, new_node_ptr);
```



```
placeNode(root_ptr_, new_node_ptr);
```



```
placeNode(root_ptr_, new_node_ptr);
```



```
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```
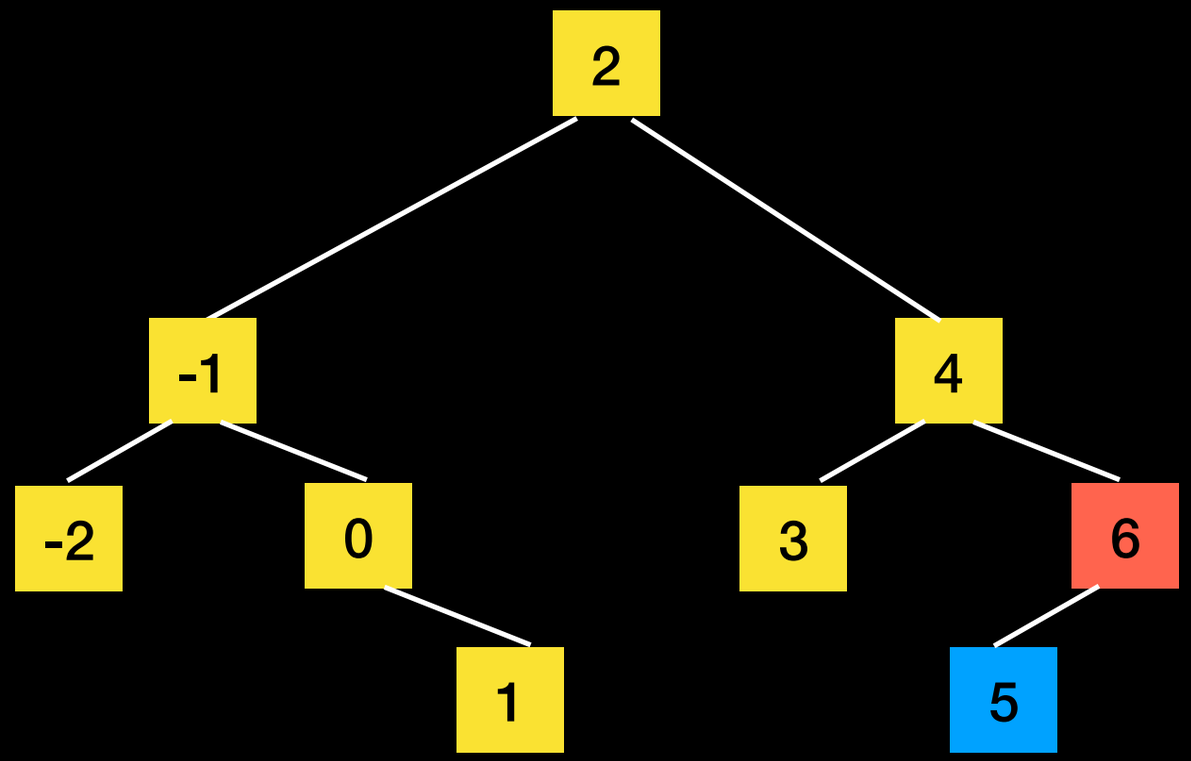
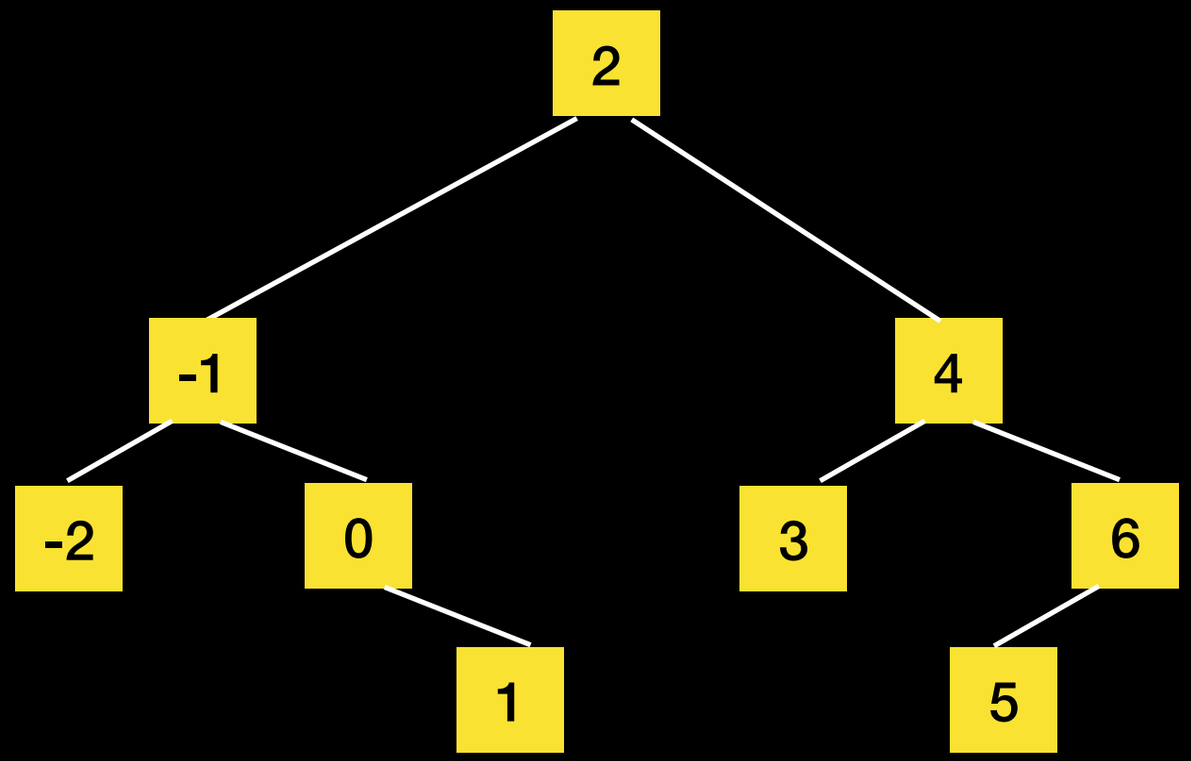



```
placeNode(root_ptr_, new_node_ptr);
```



add helper function

```
template<class T>
auto BST<T>::placeNode(std::shared_ptr<BinaryNode<T>> subtree_ptr,

                       std::shared_ptr<BinaryNode<T>> new_node_ptr)
{
   if (subtree_ptr == nullptr)
      return new_node_ptr;  //base case
   else
   {
      if (subtree_ptr->getItem() > new_node_ptr->getItem())
         subtree_ptr->setLeftChildPtr(placeNode(subtree_ptr->getLeftChildPtr(),
                                                new_node_ptr));
      else
         subtree_ptr->setRightChildPtr(placeNode(subtree_ptr->getRightChildPtr(),
                                                 new_node_ptr));

      return subtree_ptr;

   }  // end if
}  // end placeNode
```

remove

```
template<class T>
bool BST<T>::remove(const T& target)
{
   bool is_successful = false;
   // call may change is_successful
   root_ptr_ = removeValue(root_ptr_, target, is_successful);
   return is_successful;
}  // end remove
```

Safe programming: the public method does not take pointer parameter.
Only protected/private methods have access to pointers and may modify tree structure

`remove` helper function

Looks for the value to remove

```
template<class T>
auto BST<T>::removeValue(std::shared_ptr<BinaryNode<T>>
      subtree_ptr, const T target,  bool& success)
{
   if (subtree_ptr == nullptr)
   {
      // Not found here
      success = false;
      return subtree_ptr;
   }
   if (subtree_ptr->getItem() == target)
   {
      // Item is in the root of this subtree
      subtree_ptr = removeNode(subtree_ptr);
      success = true;
      return subtree_ptr;
   }
```

target not in tree

Found target now remove the node

`remove` helper function cont.ed

```
else
{
   if (subtree_ptr->getItem() > target)
   {
      // Search the left subtree
      subtree_ptr->setLeftChildPtr(removeValue(subtree_ptr
                                   ->getLeftChildPtr(), target, success));
   }
   else
   {
      // Search the right subtree
      subtree_ptr->setRightChildPtr(removeValue(subtree_ptr
                                    ->getRightChildPtr(), target, success));
   }
   return subtree_ptr;
  }  // end if
}  // end removeValue
```

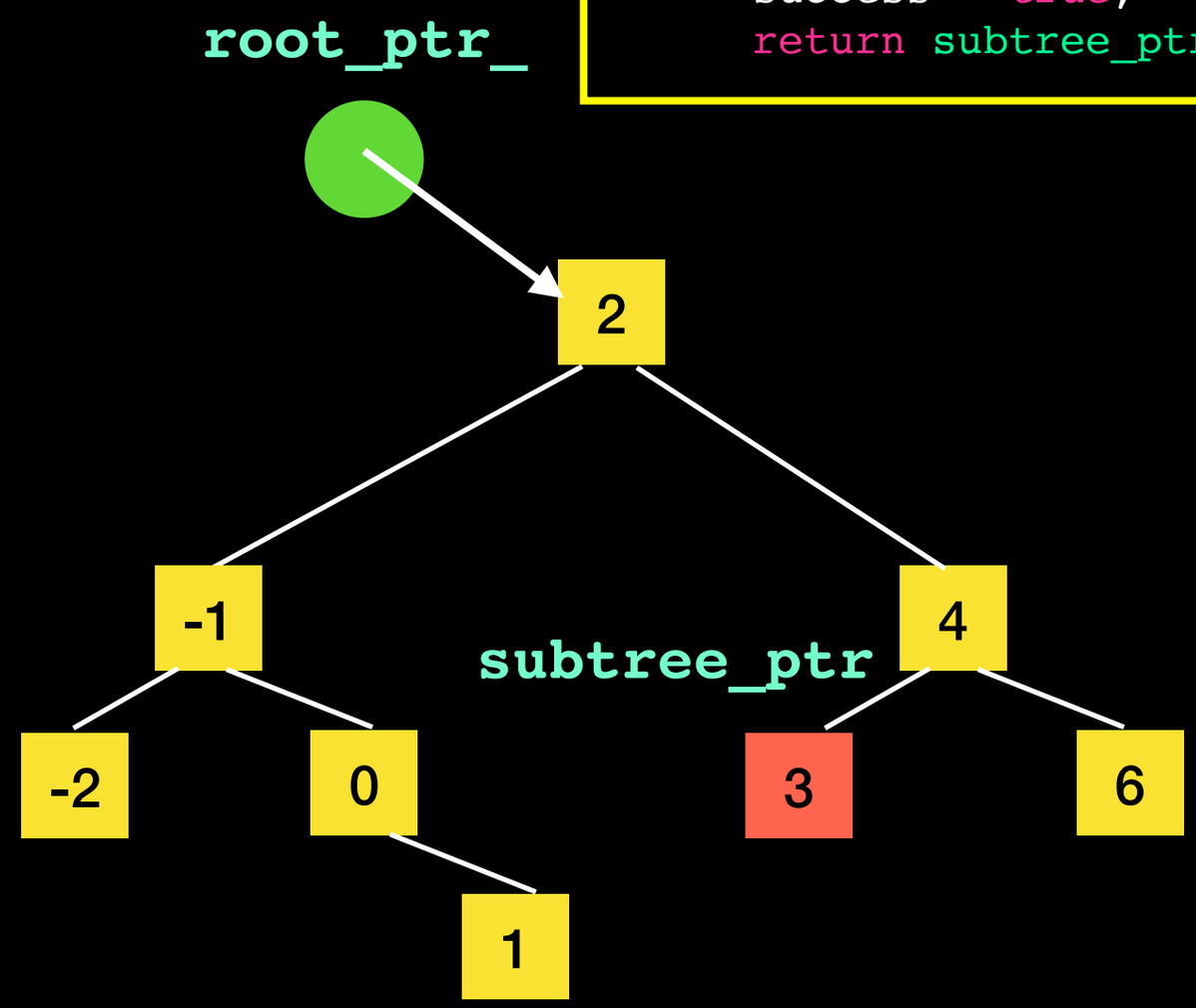
Search for target in left subtree

Search for target in right subtree

removeNode(subtree_ptr);

```
if (subtree_ptr->getItem() == target)
   {
      // Item is in the root of this subtree
      subtree_ptr = removeNode(subtree_ptr);
      success = true;
      return subtree_ptr;
```

Case 1: target is a leaf



removeNode(subtree_ptr);

```
if (subtree_ptr->getItem() == target)
   {
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      success = true;
      return subtree_ptr;
```
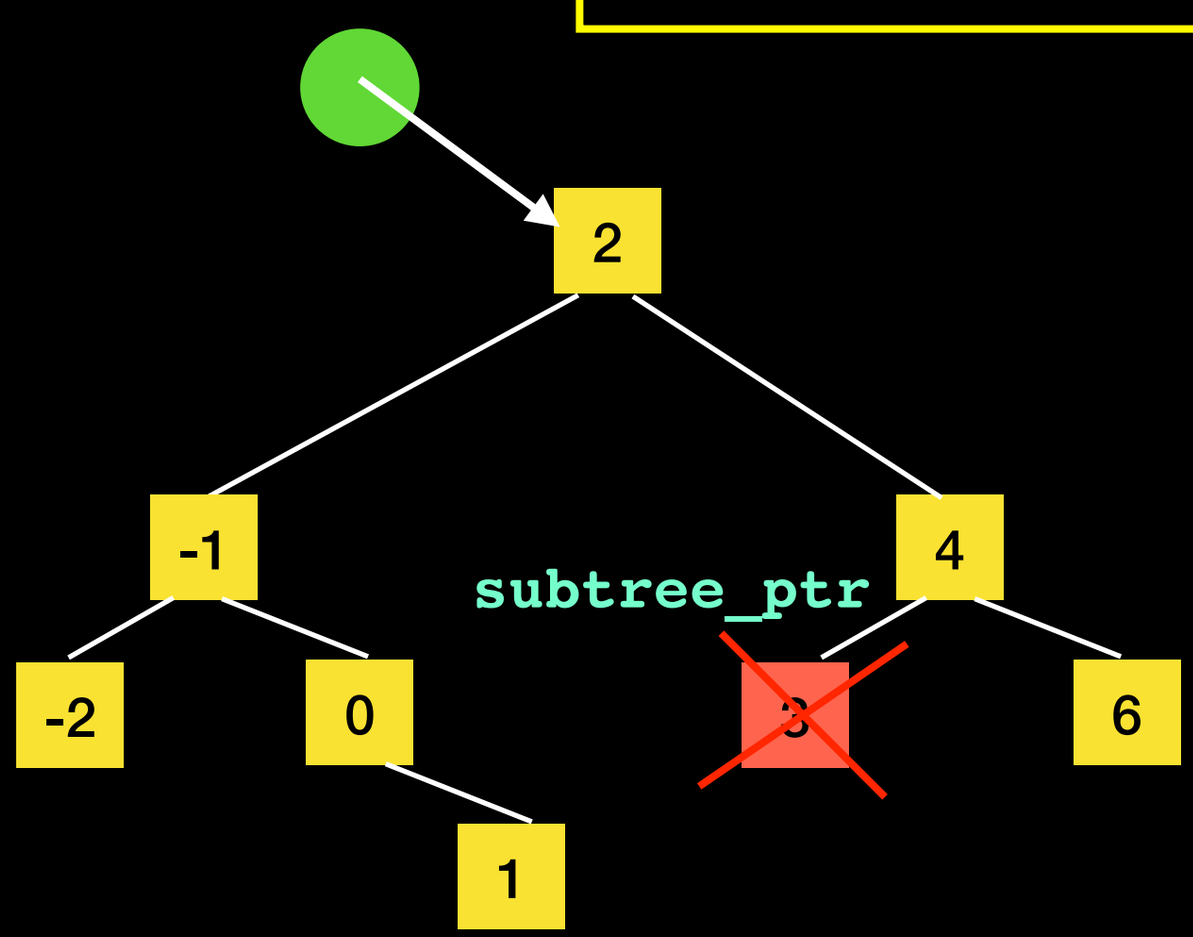

Case 1: target is a leaf



removeNode(subtree_ptr);

```
if (subtree_ptr->getItem() == target)
   {
      // Item is in the root of this subtree
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      success = true;
      return subtree_ptr;
```
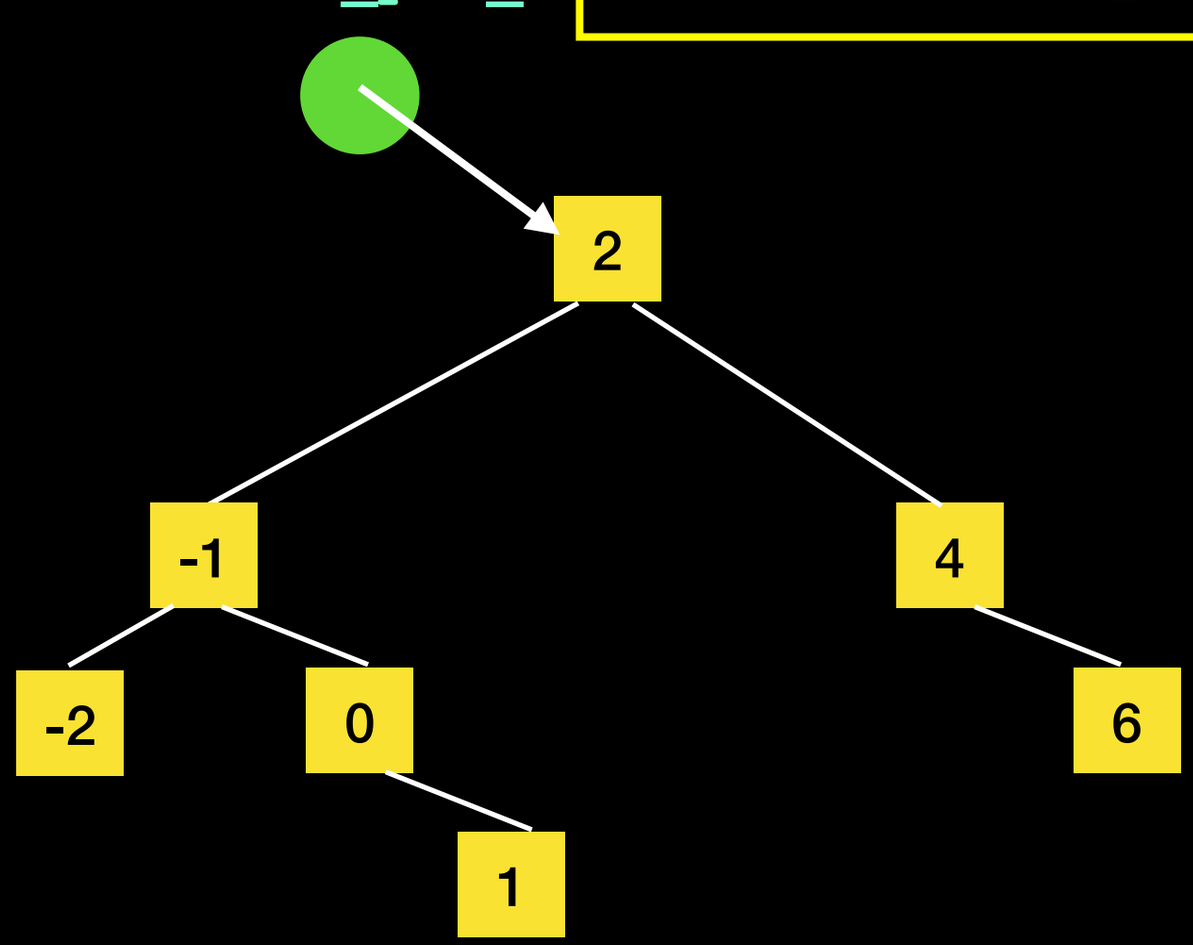
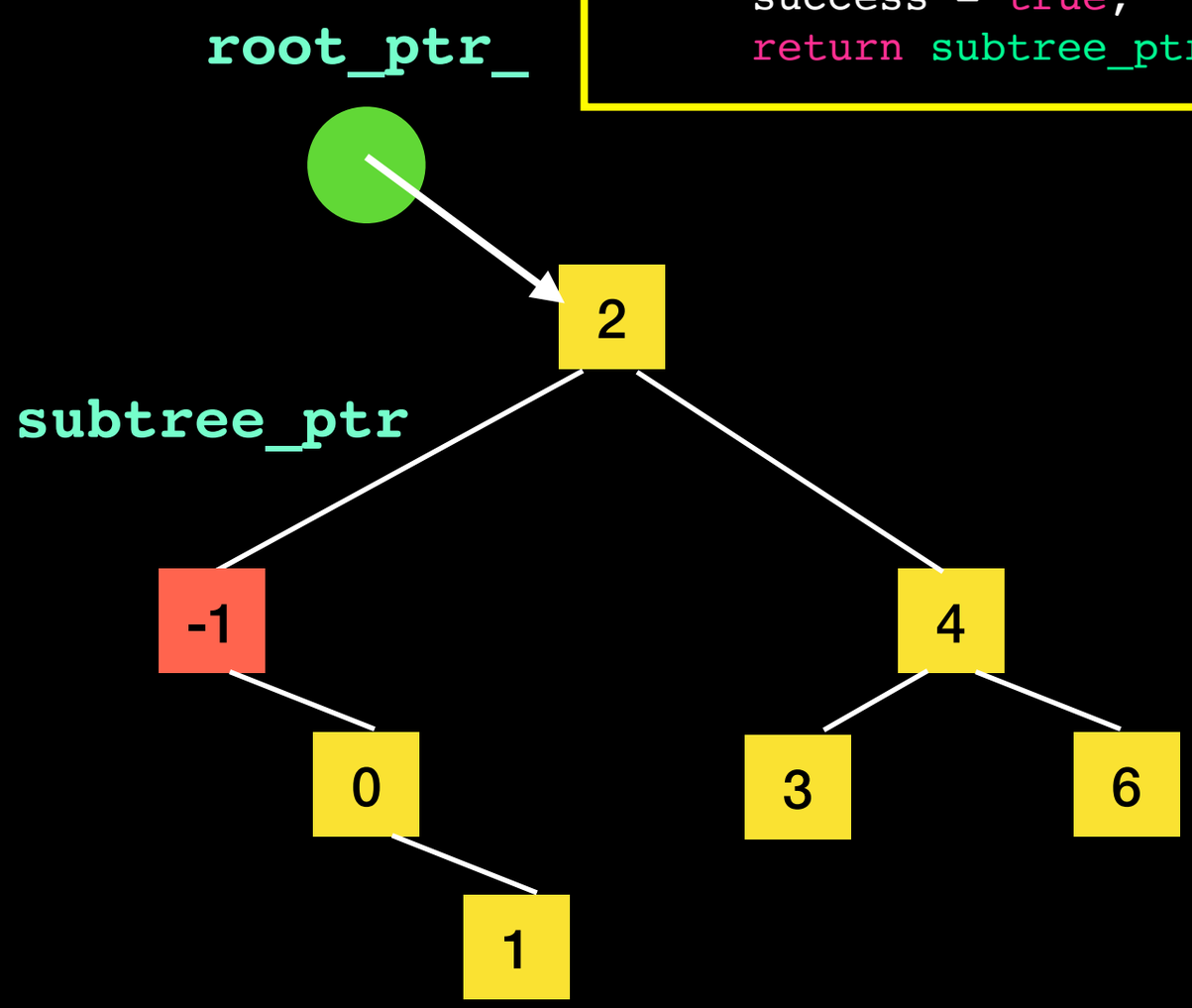

Case 1: target is a leaf



removeNode(subtree_ptr);

Case 2: target has 1 child
Left and right case are symmetric

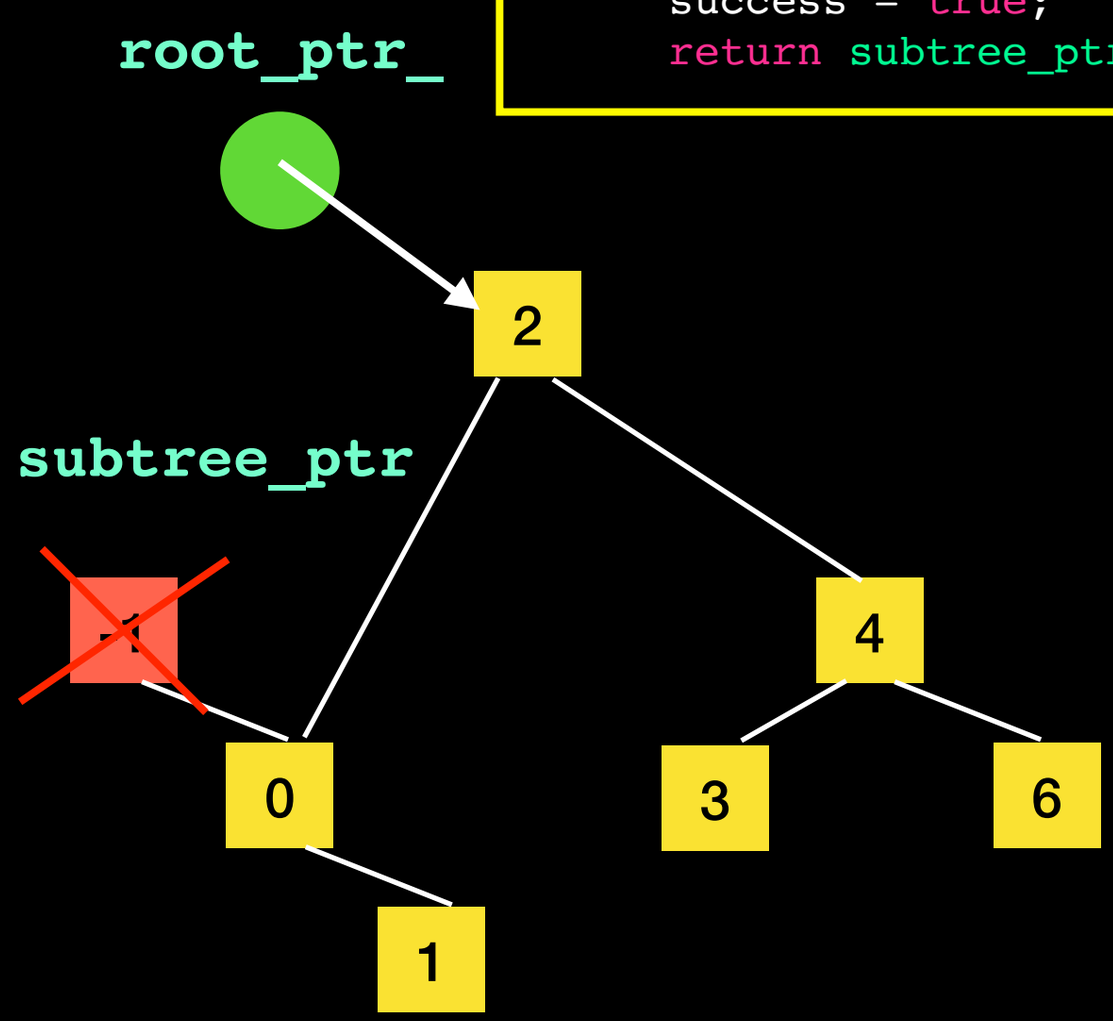
```
if (subtree_ptr->getItem() == target)
   {
      // Item is in the root of this subtree
      subtree_ptr = removeNode(subtree_ptr);
      success = true;
      return subtree_ptr;
```



removeNode(subtree_ptr);

Case 2: target has 1 child
Left and right case are symmetric

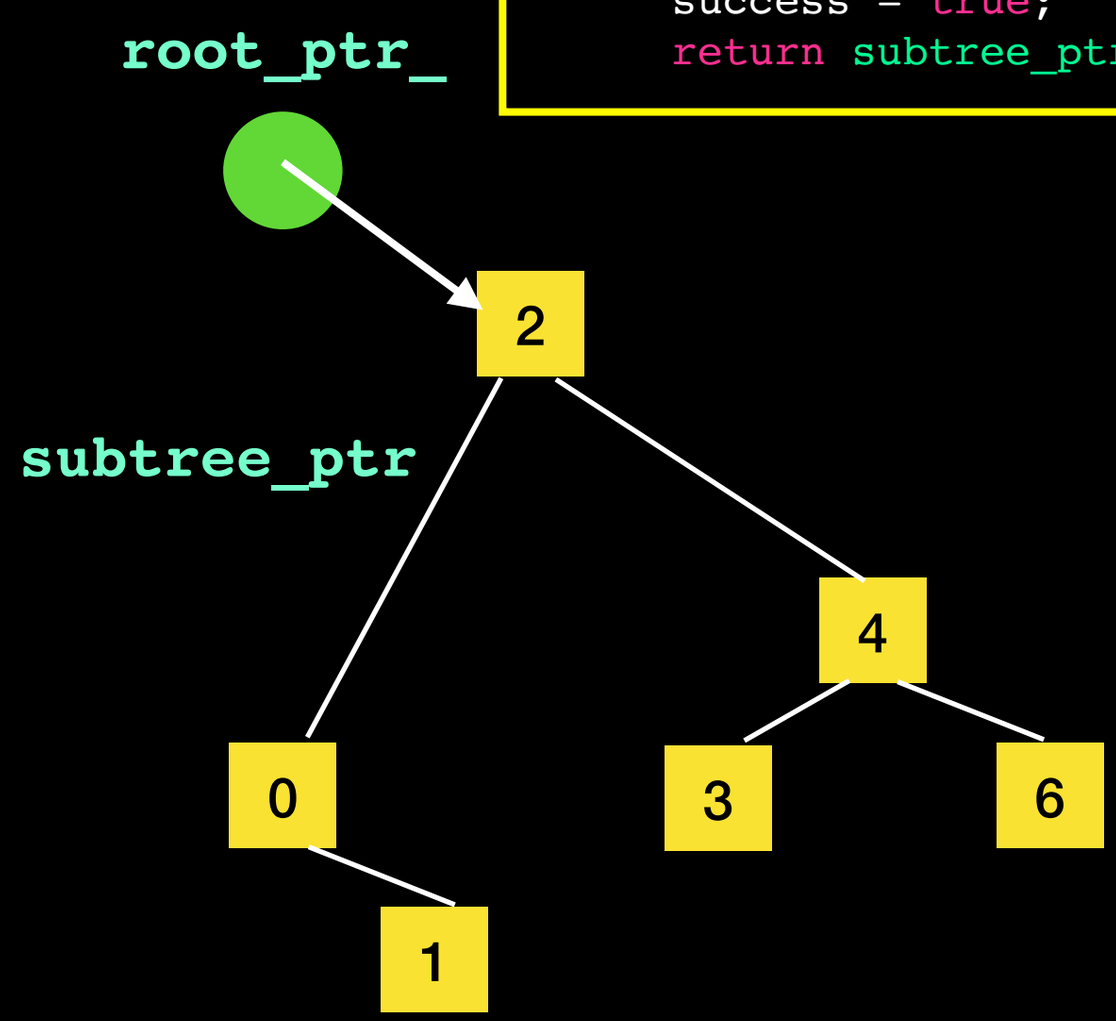
```
if (subtree_ptr->getItem() == target)
   {
      // Item is in the root of this subtree
      subtree_ptr = removeNode(subtree_ptr);
      success = true;
      return subtree_ptr;
```



removeNode(subtree_ptr);

Case 2: target has 1 child
Left and right case are symmetric

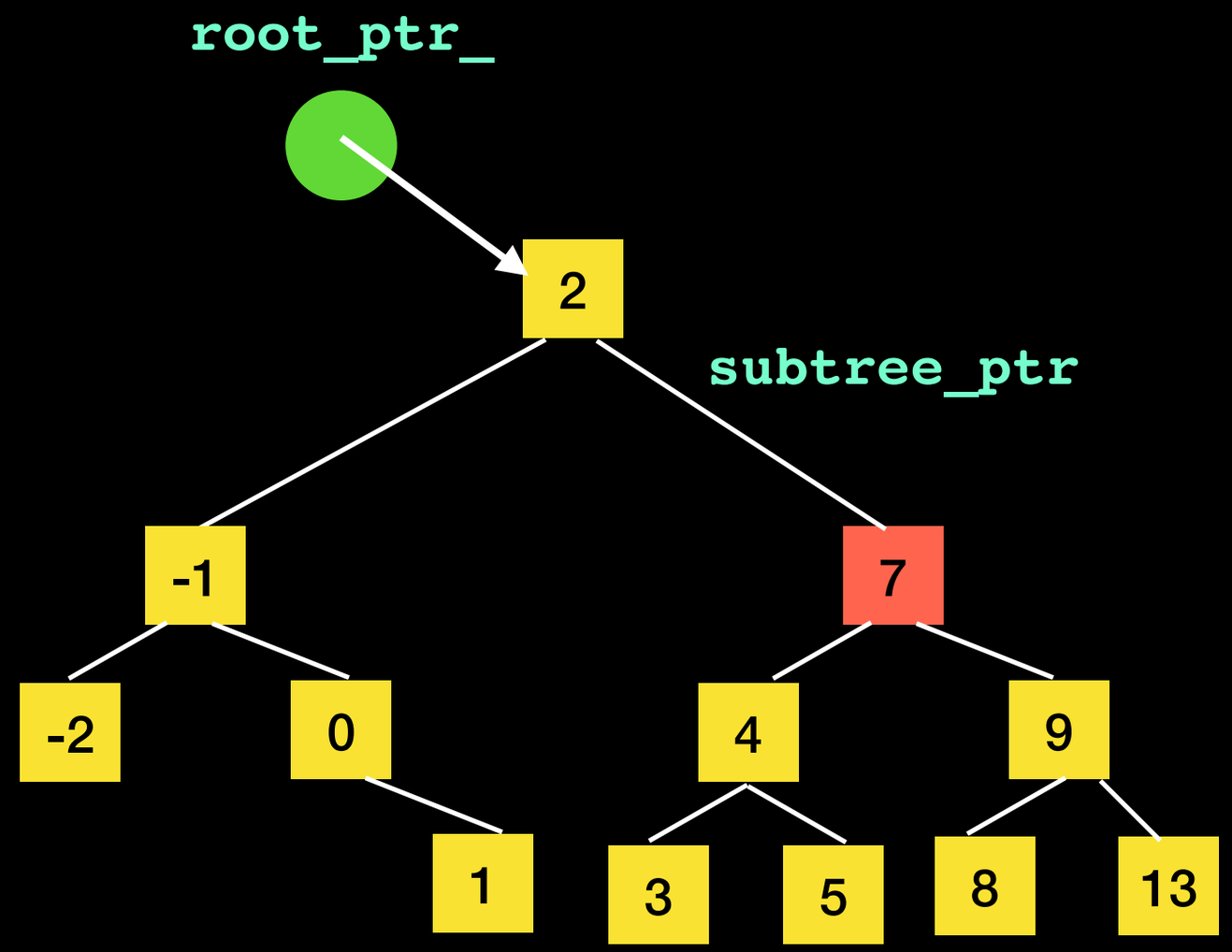
```
if (subtree_ptr->getItem() == target)
   {
      // Item is in the root of this subtree
      subtree_ptr = removeNode(subtree_ptr);
      success = true;
      return subtree_ptr;
```



Lecture Activity

How would you remove node 7?

Case 3: target has 2 children

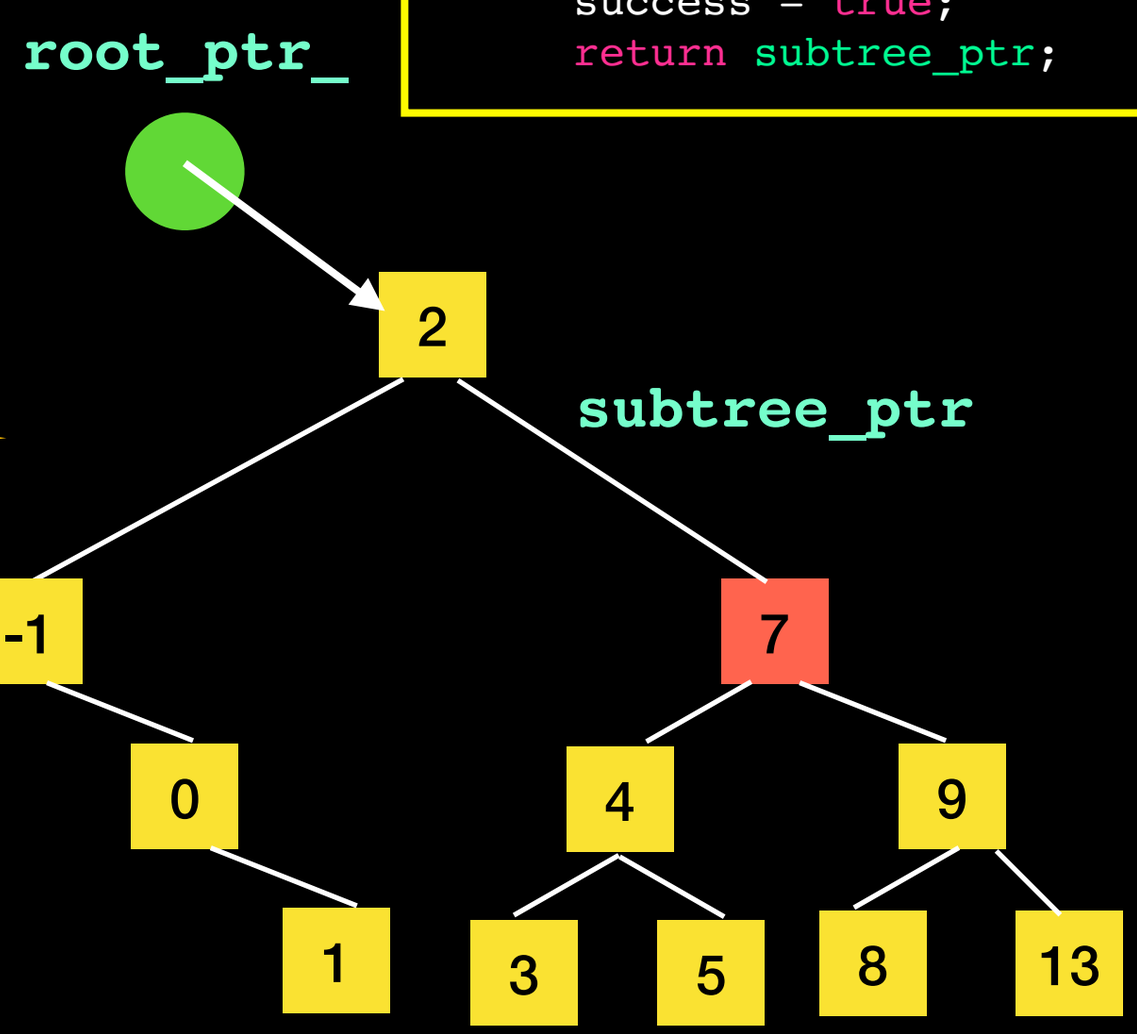


removeNode(subtree_ptr);

```
if (subtree_ptr->getItem() == target)
   {
      // Item is in the root of this subtree
      subtree_ptr = removeNode(subtree_ptr);
      success = true;
      return subtree_ptr;
```

Case 3: target has 2 children

Find a node that is easy to remove and remove that one instead.



removeNode(subtree_ptr);

```
if (subtree_ptr->getItem() == target)
   {
      // Item is in the root of this subtree
      subtree_ptr = removeNode(subtree_ptr);
      success = true;
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```
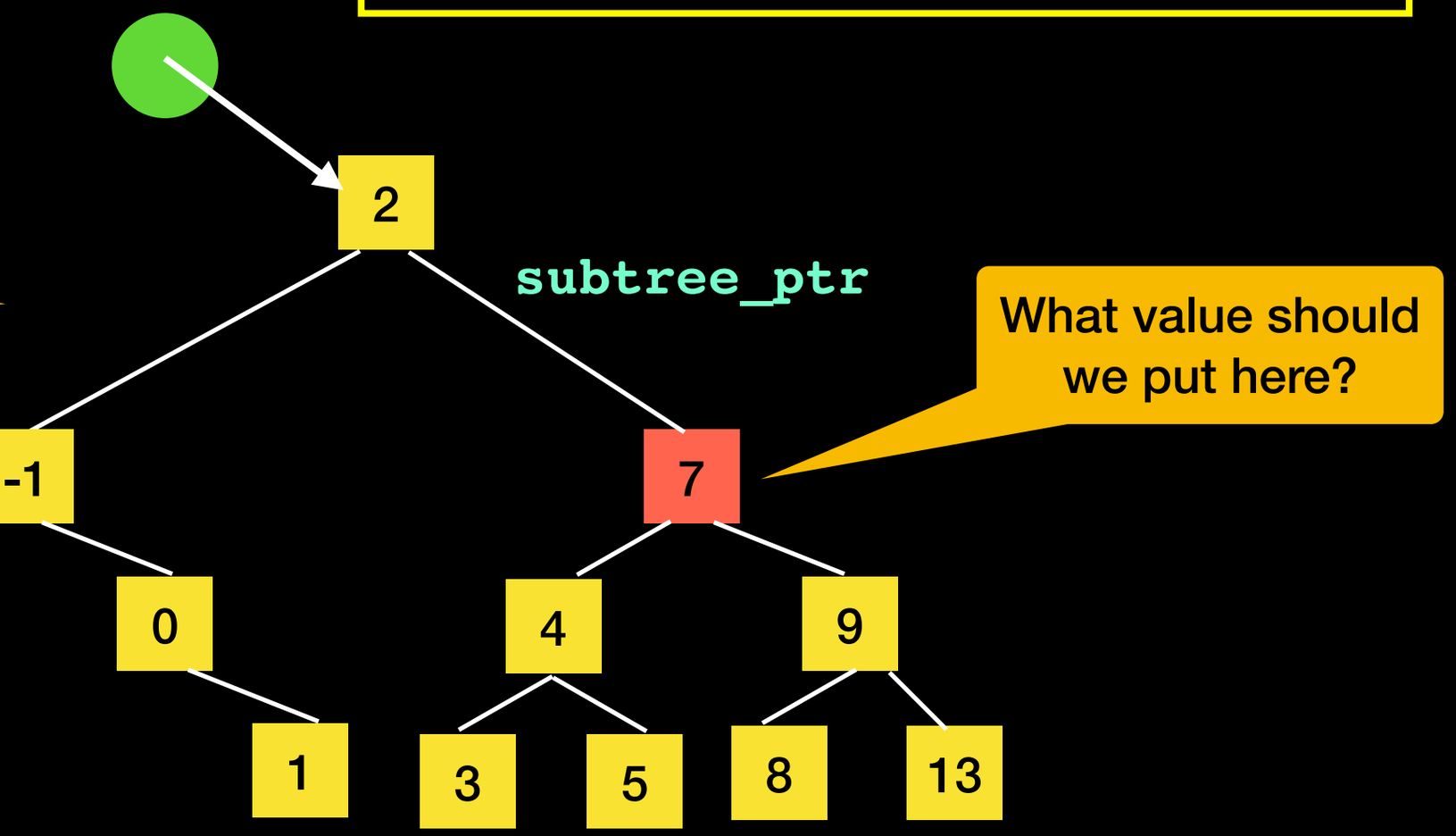

Case 3: target has 2 children

Find a node that is easy to remove and remove that one instead.

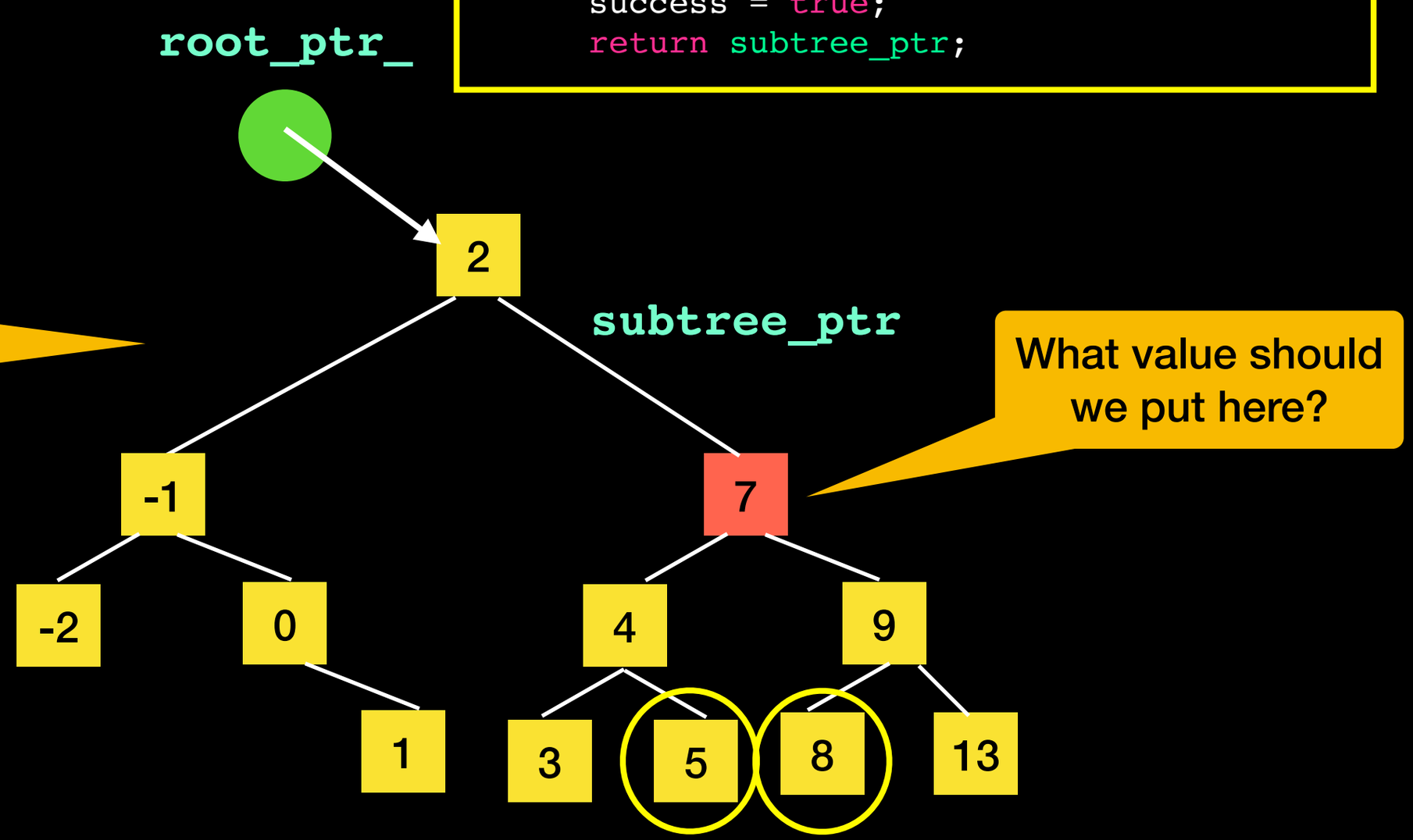


removeNode(subtree_ptr);

```
if (subtree_ptr->getItem() == target)
   {
      // Item is in the root of this subtree
      subtree_ptr = removeNode(subtree_ptr);
      success = true;
      return subtree_ptr;
```

Case 3: target has 2 children

Find a node that is easy to remove and remove that one instead.

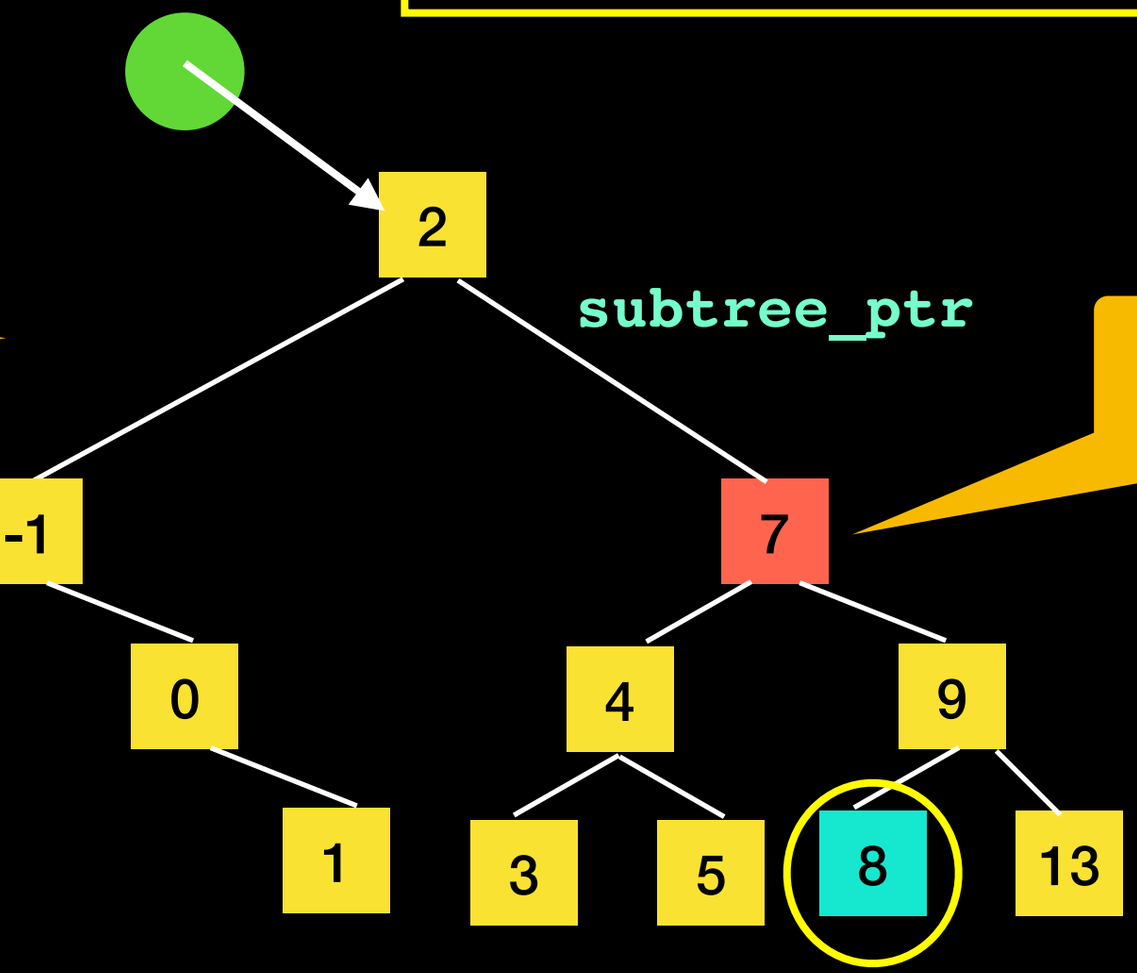


removeNode(subtree_ptr);

```
if (subtree_ptr->getItem() == target)
   {
      // Item is in the root of this subtree
      subtree_ptr = removeNode(subtree_ptr);
      success = true;
      return subtree_ptr;
```

Case 3: target has 2 children

Find a node that is easy to remove and remove that one instead.



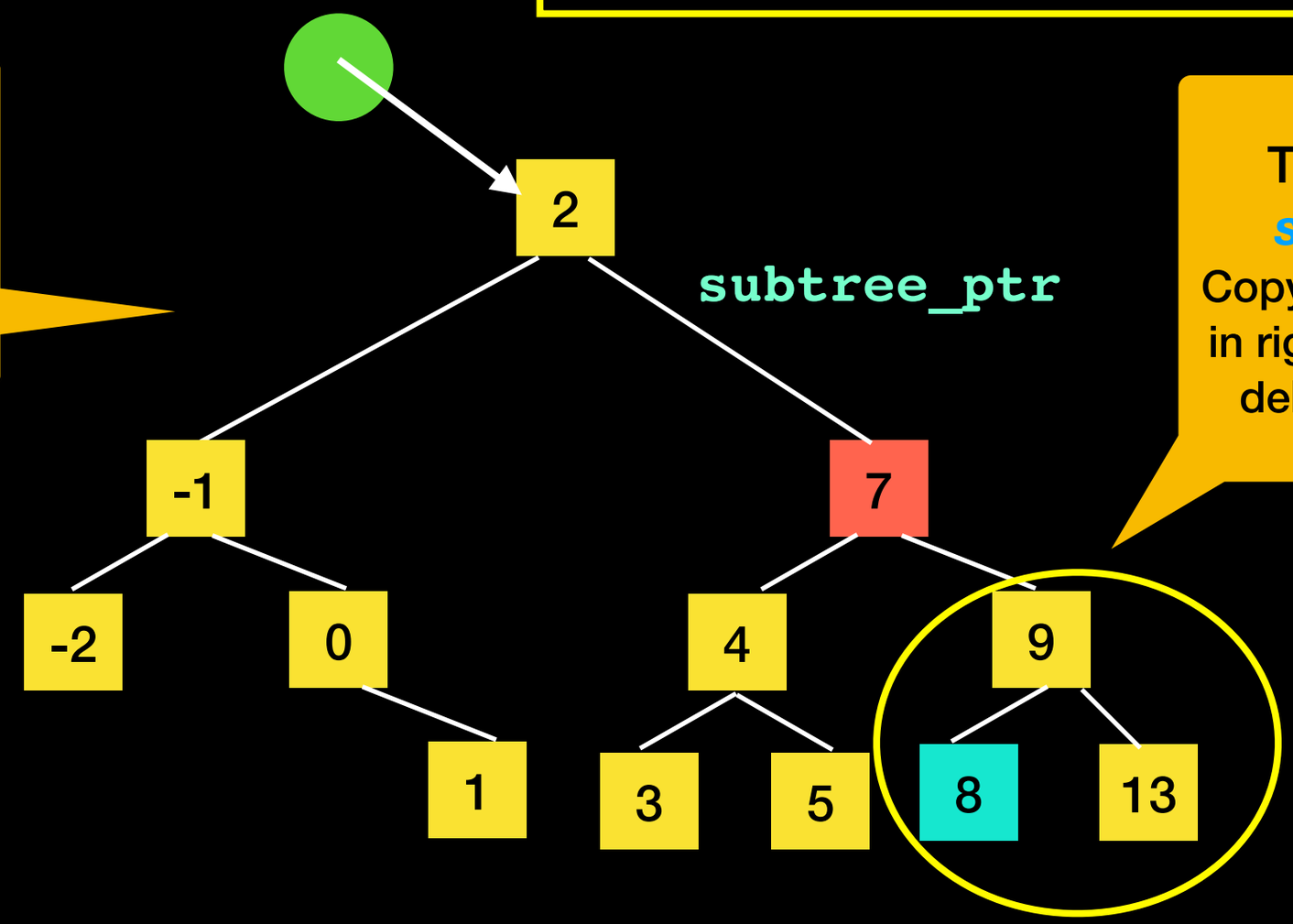
The *inorder successor*

removeNode(subtree_ptr);

```
if (subtree_ptr->getItem() == target)
   {
      // Item is in the root of this subtree
      subtree_ptr = removeNode(subtree_ptr);
      success = true;
      return subtree_ptr;
```

Case 3: target has 2 children

Find a node that is easy to remove and remove that one instead.



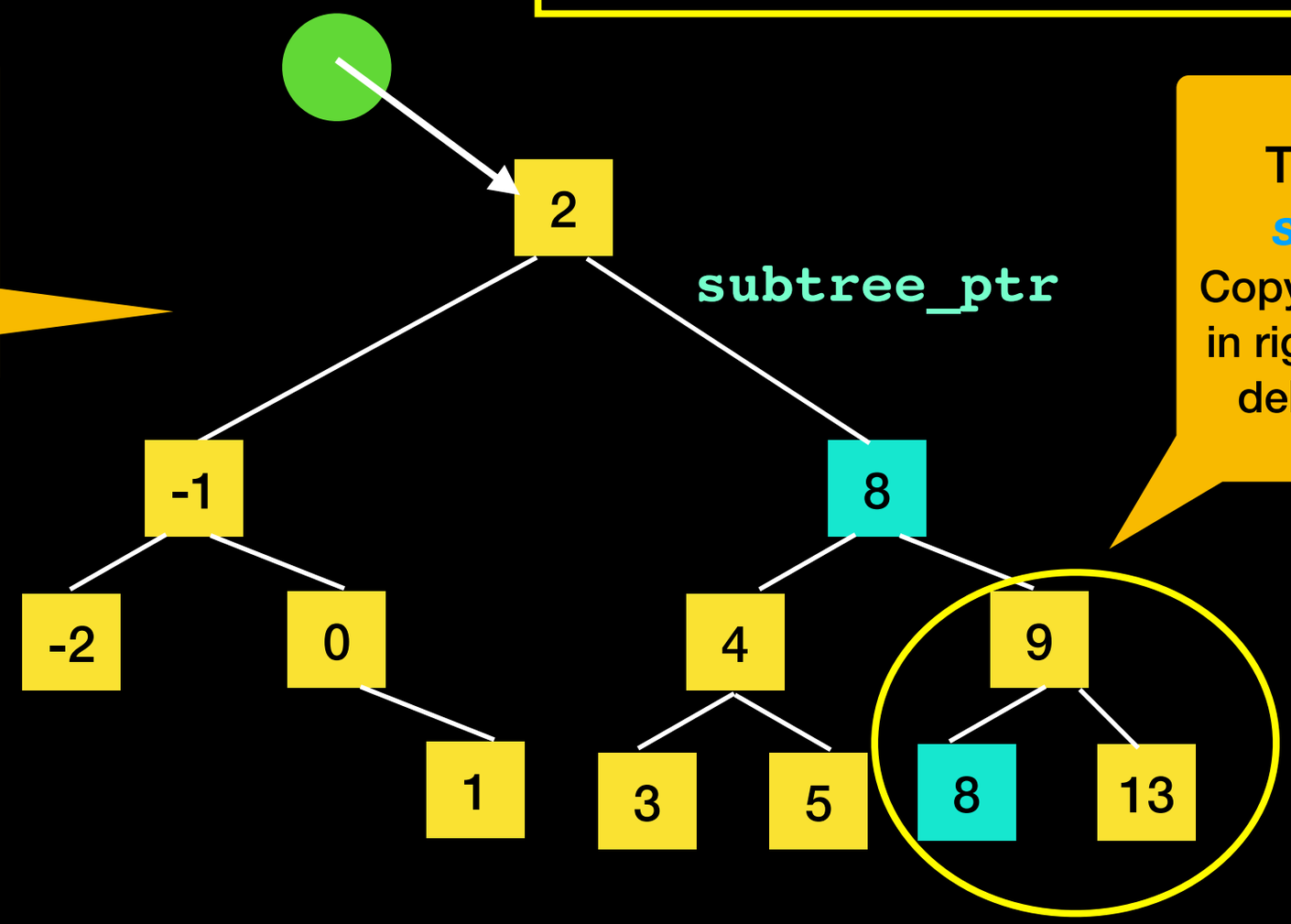
The *inorder successor:*
Copy smallest value in right subtree and delete that node

removeNode(subtree_ptr);

```
if (subtree_ptr->getItem() == target)
   {
      // Item is in the root of this subtree
      subtree_ptr = removeNode(subtree_ptr);
      success = true;
      return subtree_ptr;
```

Case 3: target has 2 children

Find a node that is easy to remove and remove that one instead.



The *inorder successor:*
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```
if (subtree_ptr->getItem() == target)
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      // Item is in the root of this subtree
      subtree_ptr = removeNode(subtree_ptr);
      success = true;
      return subtree_ptr;
```
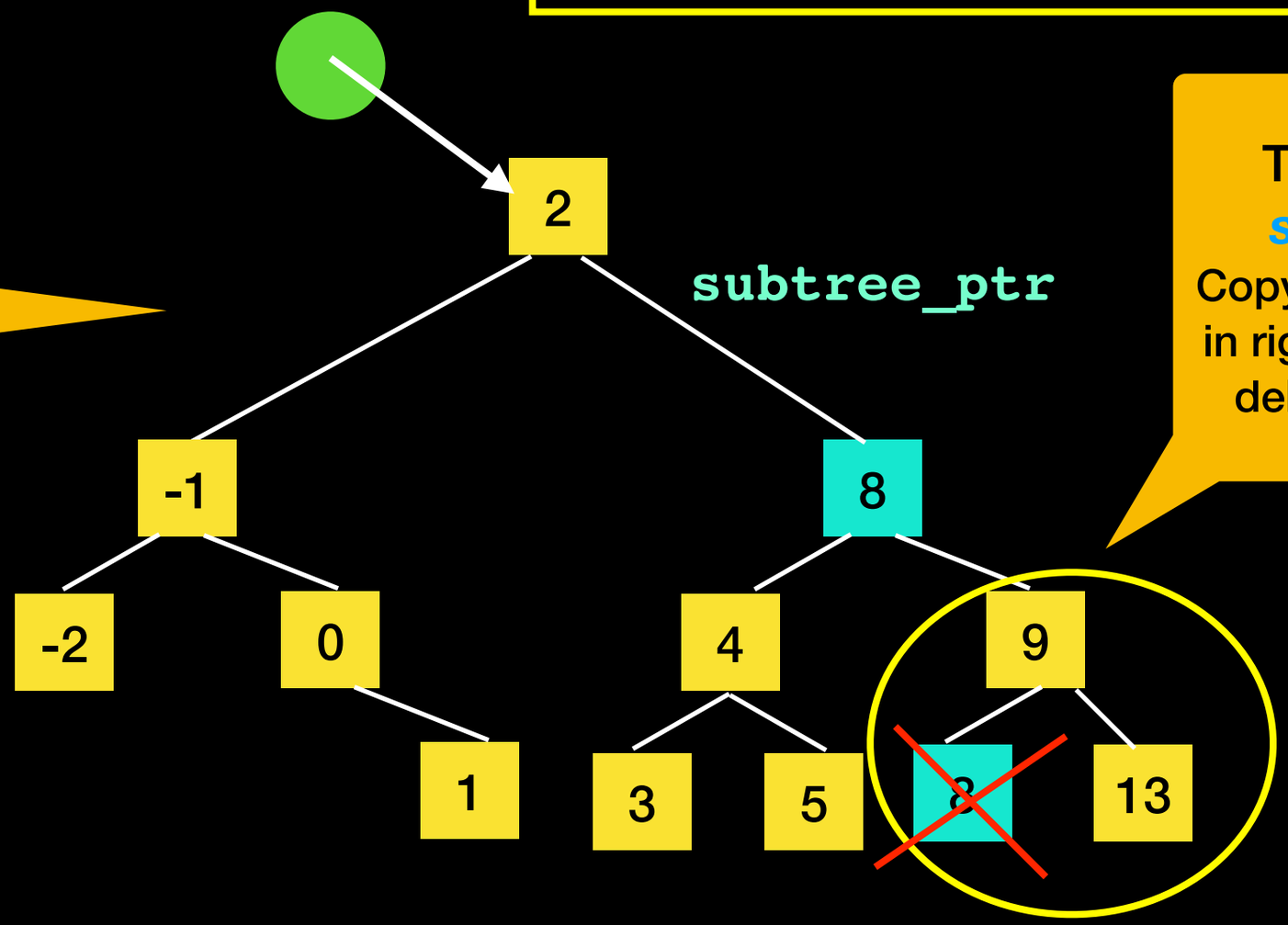

Case 3: target has 2 children

Find a node that is easy to remove and remove that one instead.



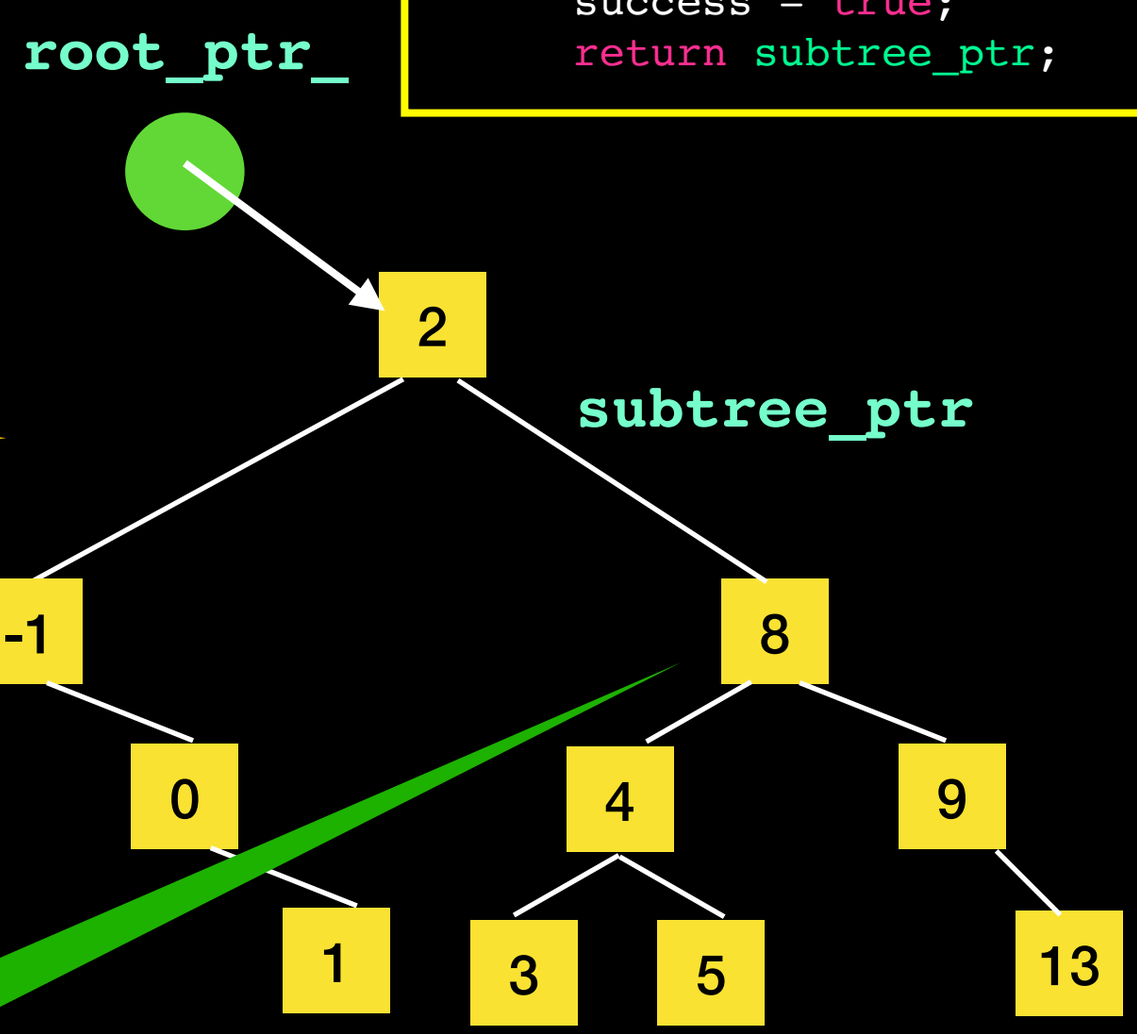
The *inorder successor:*
Copy smallest value in right subtree and delete that node

removeNode(subtree_ptr);

```
if (subtree_ptr->getItem() == target)
   {
      // Item is in the root of this subtree
      subtree_ptr = removeNode(subtree_ptr);
      success = true;
      return subtree_ptr;
```

Case 3: target has 2 children

Find a node that is easy to remove and remove that one instead.



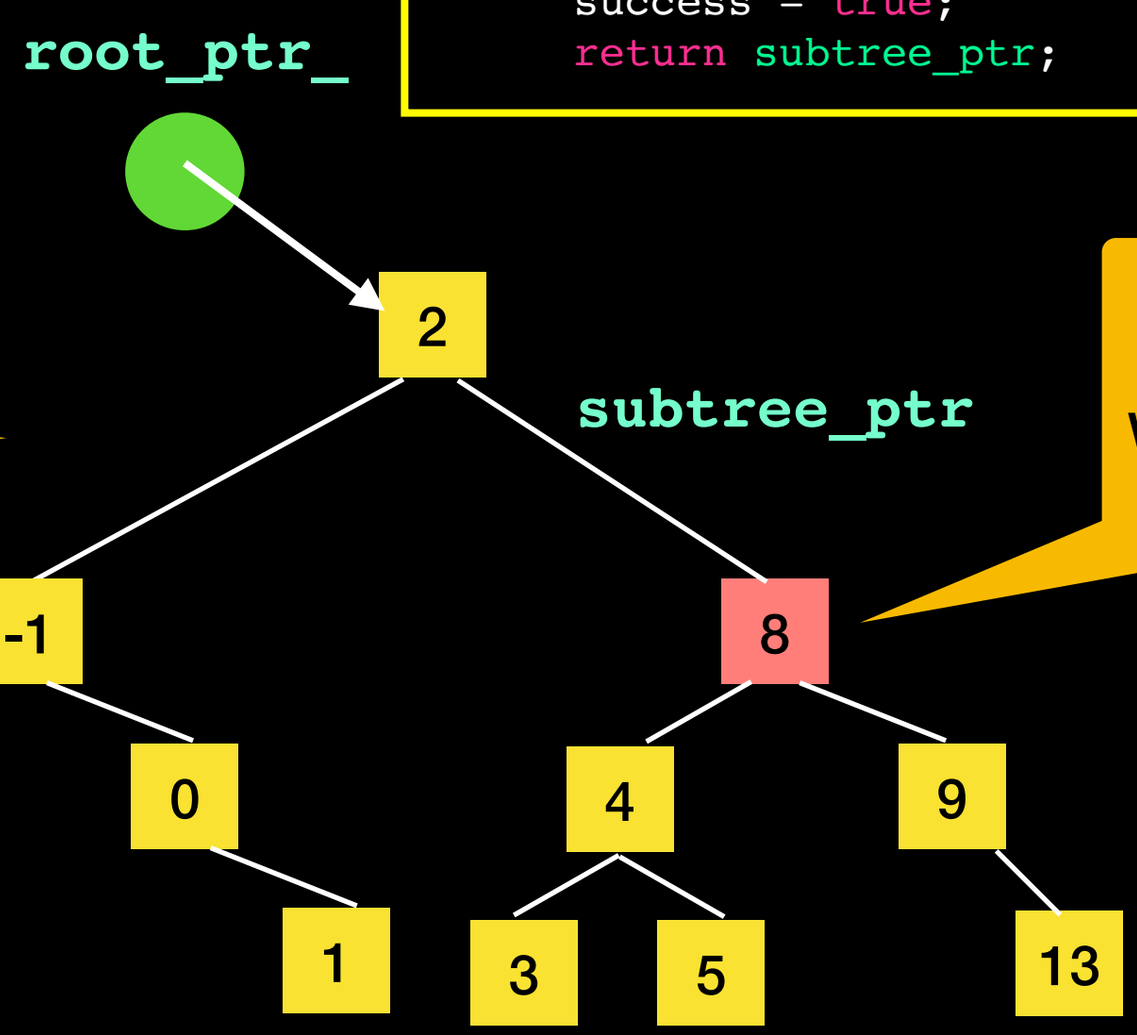
This operation will actually "reorganize" the tree

removeNode(subtree_ptr);

```
if (subtree_ptr->getItem() == target)
   {
      // Item is in the root of this subtree
      subtree_ptr = removeNode(subtree_ptr);
      success = true;
      return subtree_ptr;
```

Case 3: target has 2 children

Find a node that is easy to remove and remove that one instead.



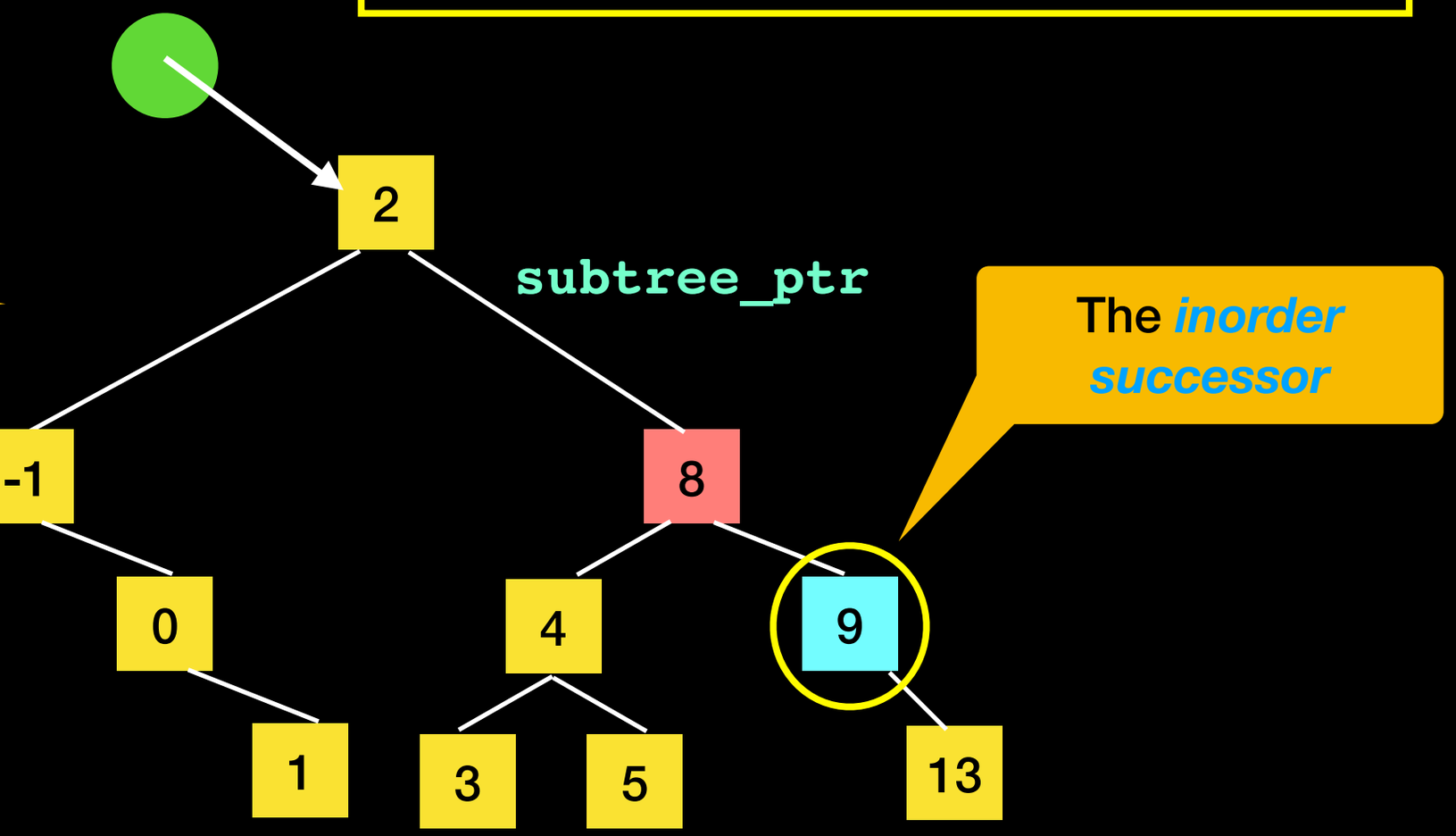
What about removing 8 now? What value should we put here?

removeNode(subtree_ptr);

```
if (subtree_ptr->getItem() == target)
   {
      // Item is in the root of this subtree
      subtree_ptr = removeNode(subtree_ptr);
      success = true;
      return subtree_ptr;
```

Case 3: target has 2 children

Find a node that is easy to remove and remove that one instead.

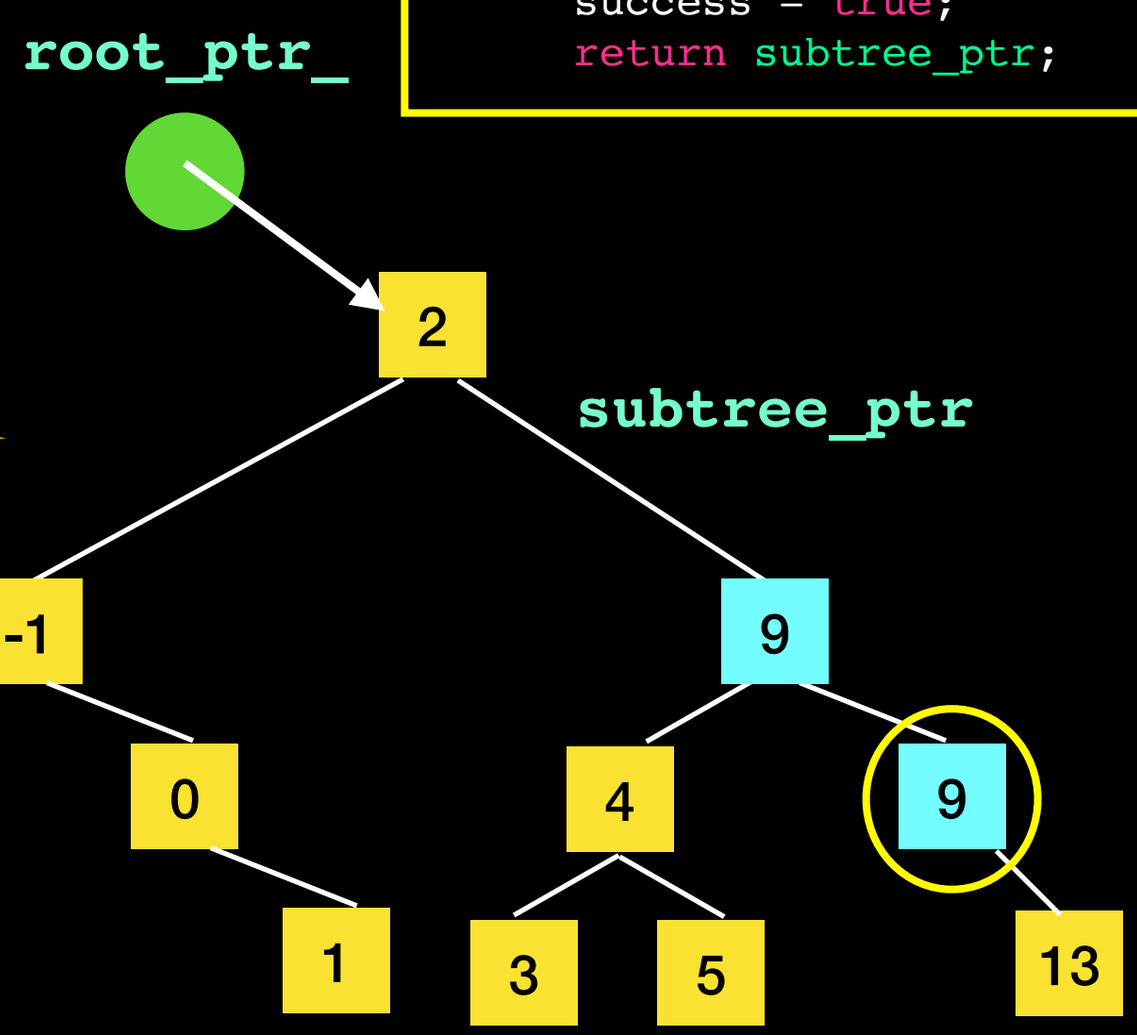


removeNode(subtree_ptr);

```
if (subtree_ptr->getItem() == target)
   {
      // Item is in the root of this subtree
      subtree_ptr = removeNode(subtree_ptr);
      success = true;
      return subtree_ptr;
```

Case 3: target has 2 children

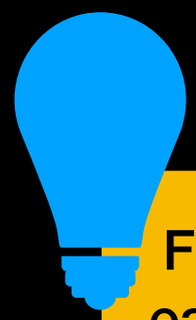
Find a node that is easy to remove and remove that one instead.



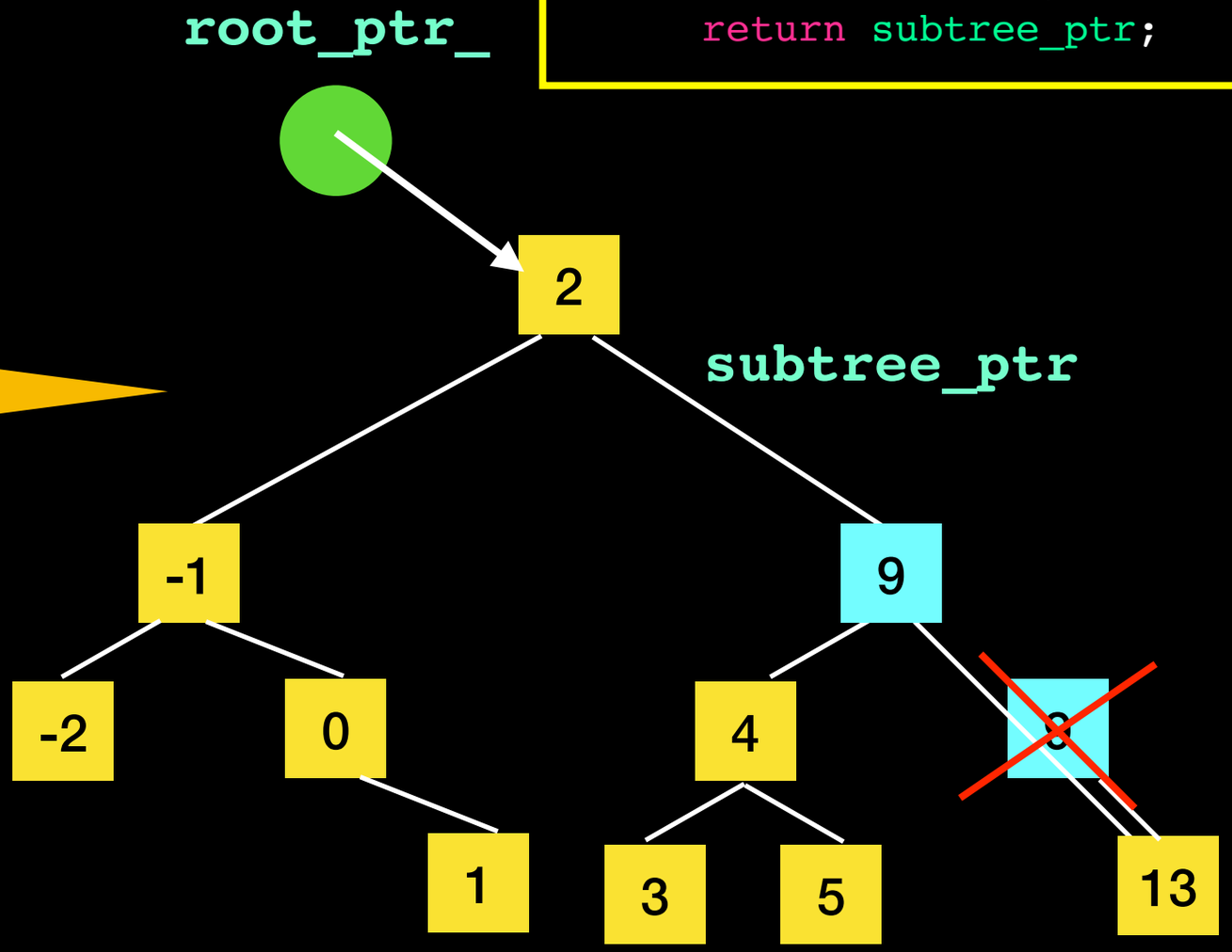
removeNode(subtree_ptr);

```
if (subtree_ptr->getItem() == target)
   {
      // Item is in the root of this subtree
      subtree_ptr = removeNode(subtree_ptr);
      success = true;
      return subtree_ptr;
```

Case 3: target has 2 children



Find a node that is easy to remove and remove that one instead.

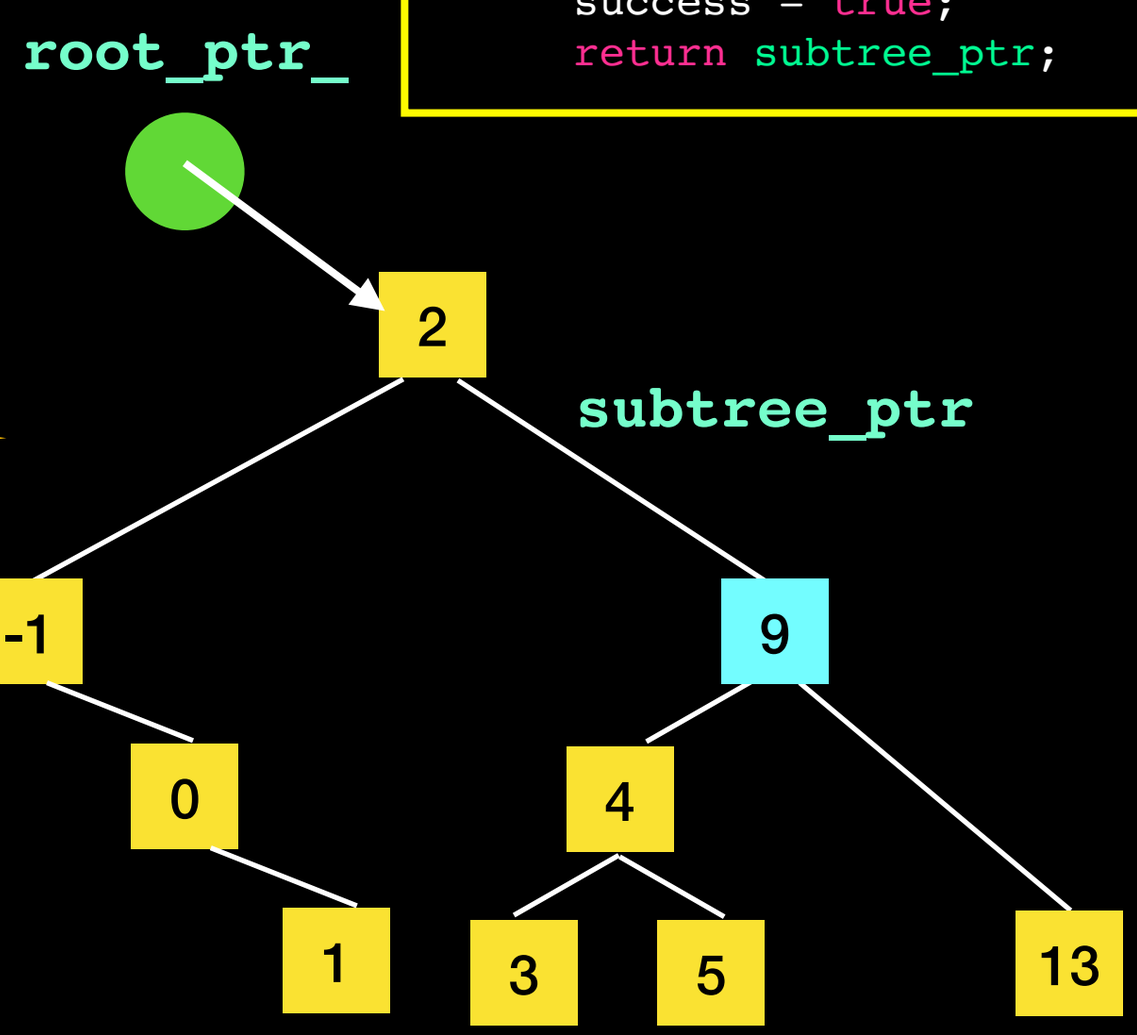


removeNode(subtree_ptr);

```
if (subtree_ptr->getItem() == target)
   {
      // Item is in the root of this subtree
      subtree_ptr = removeNode(subtree_ptr);
      success = true;
      return subtree_ptr;
```

Case 3: target has 2 children

Find a node that is easy to remove and remove that one instead.



removeNode(node_ptr);

```
template<class T>
auto BST<T>::removeNode(std::shared_ptr<BinaryNode<T>> node_ptr)
{
   // Case 1) Node is a leaf - it is deleted
   if (node_ptr->isLeaf())
   {
      node_ptr.reset();
      return node_ptr; // delete and return nullptr
   }
   // Case 2) Node has one child - parent adopts child
   else if (node_ptr->getLeftChildPtr() == nullptr)  // Has rightChild only
   {
      return node_ptr->getRightChildPtr();
   }
   else if (node_ptr->getRightChildPtr() == nullptr) // Has left child only
   {
      return node_ptr->getLeftChildPtr();
   }
   // Case 3) Node has two children:
   else
   {
      T new_node_value;
      node_ptr->setRightChildPtr(removeLeftmostNode(node_ptr->getRightChildPtr(),
                                                    new_node_value));

      node_ptr->setItem(new_node_value);
      return node_ptr;

   }  // end if
}  // end removeNode
```

Node is leaf

Node has 1 child

Node has 2 children

Will find leftmost leaf in right subtree, save value in `new_node_value` and delete

Safe Programming:
reference parameter is local to the private calling function

removeLeftmostNode

```
template<class T>
auto BST<T>::removeLeftmostNode(std::shared_ptr<BinaryNode<T>>
                                                nodePtr, T& inorderSuccessor)
{
   if (nodePtr->getLeftChildPtr() == nullptr)
   {
      inorderSuccessor = nodePtr->getItem();
      return removeNode(nodePtr);
   }
   else
   {
      nodePtr->setLeftChildPtr(removeLeftmostNode(nodePtr->getLeftChildPtr(),
                                                            inorderSuccessor));
      return nodePtr;
   }  // end if
}  // end removeLeftmostNode
```

Traversals

Let's focus on the traversal for now, we will find out what Visitor does next

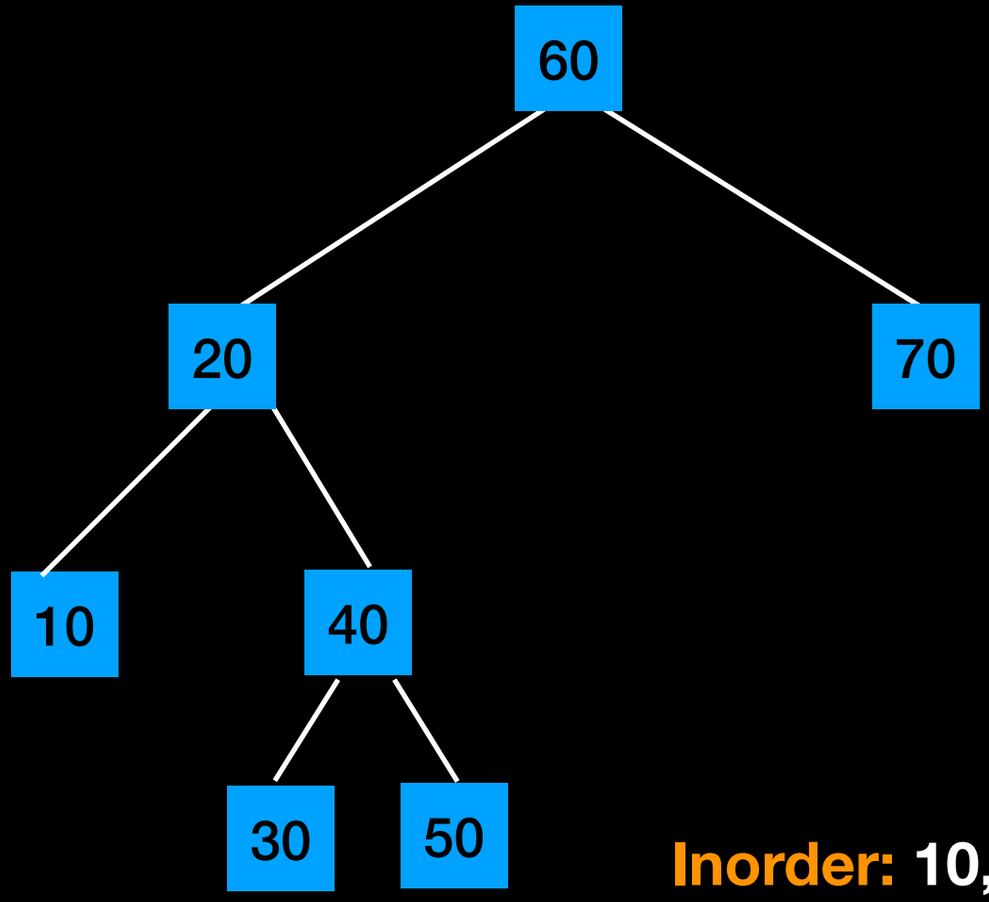
```
template<class T>
void BST<T>::preorderTraverse(Visitor<T>& visit) const
{
   preorder(visit, root_ptr_);
}  // end preorderTraverse
```

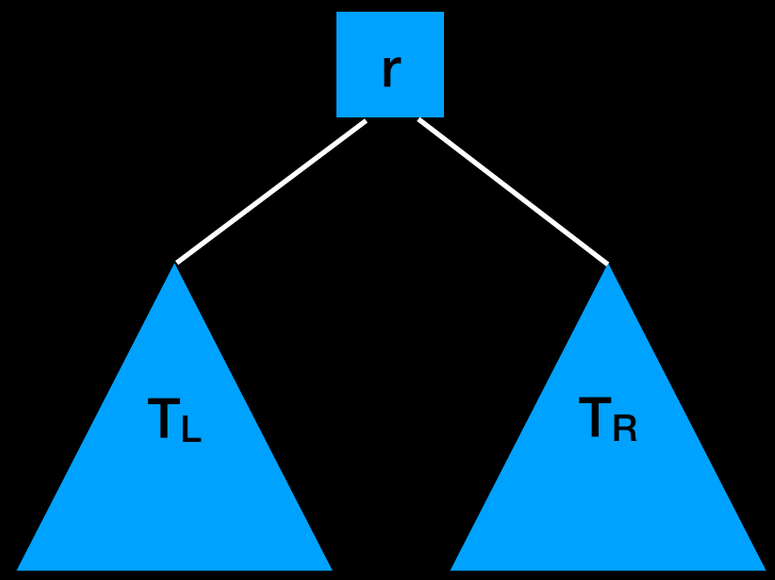
```
template<class T>
void BST<T>::inorderTraverse(Visitor<T>& visit) const
{
   inorder(visit, root_ptr_);
}  // end inorderTraverse

template<class T>
void BST<T>::postorderTraverse(Visitor<T>& visit) const
{
   postorder(visit, root_ptr_);
}  // end postorderTraverse
```

Visit (retrieve, print, modify …) every node in the tree

Inorder Traversal:

```
if (T is not empty) //implicit base case
{
    traverse T_L
    visit the root r
    traverse T_R
}
```





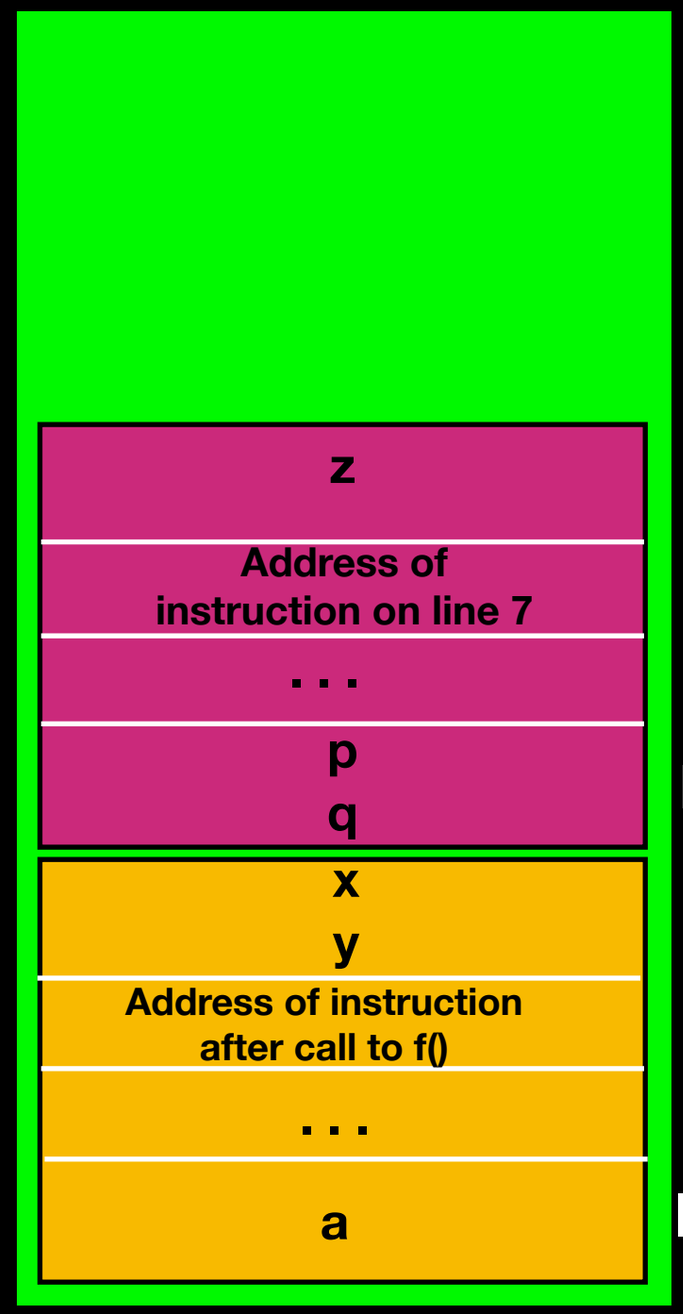
Inorder: 10, 20, 30, 40, 50, 60, 70

`inorderTraverse` Helper Function

```
template<class T>
void BST<T>::inorder(Visitor<T>& visit,
    std::shared_ptr<BinaryNode<T>> tree_ptr) const
{
    if (tree_ptr != nullptr)
    {
        inorder(visit, tree_ptr->getLeftChildPtr());
        T the_item = tree_ptr->getItem();
        visit(the_item);
        inorder(visit, tree_ptr->getRightChildPtr());
    }  // end if
}  // end inorder
```

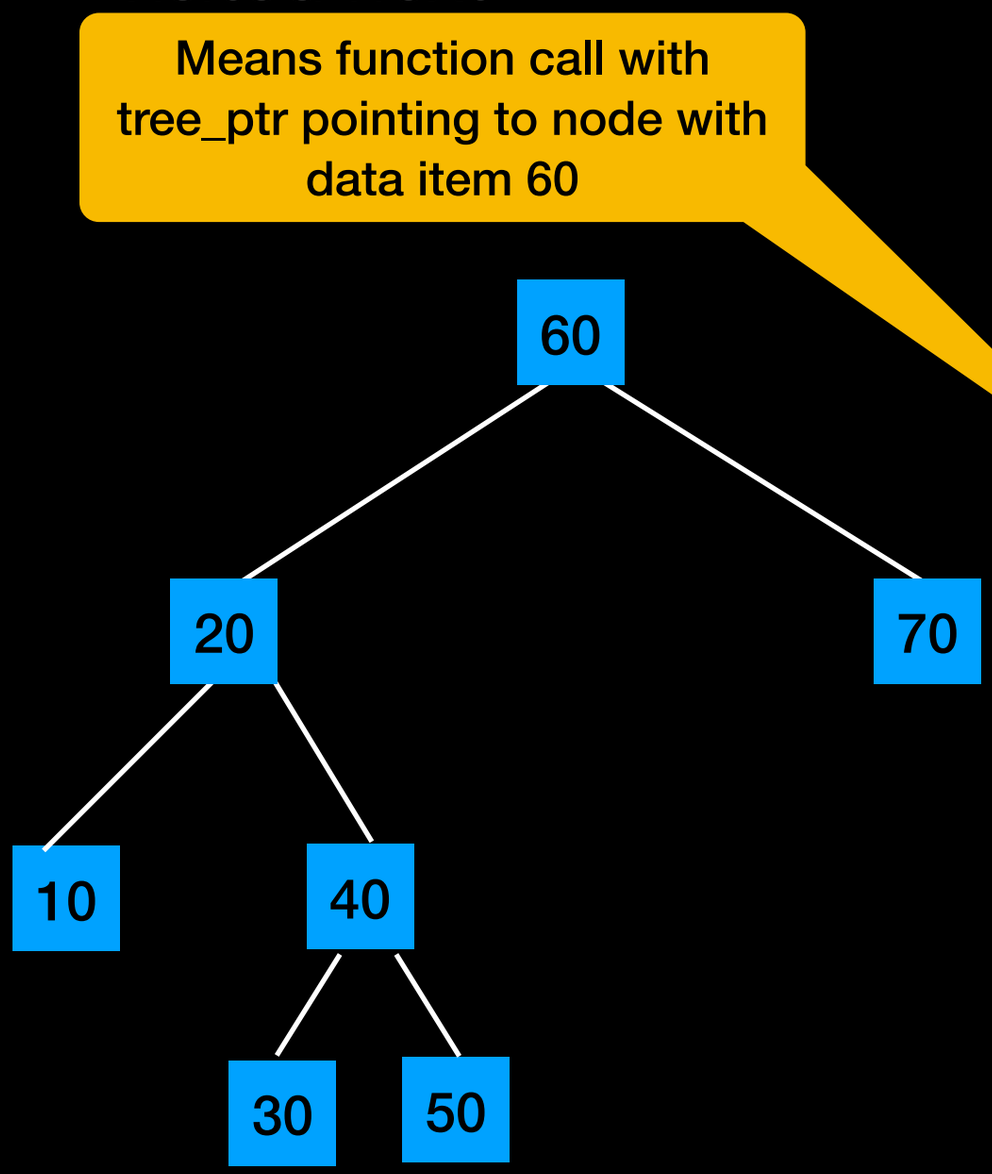
Recall: Program Stack

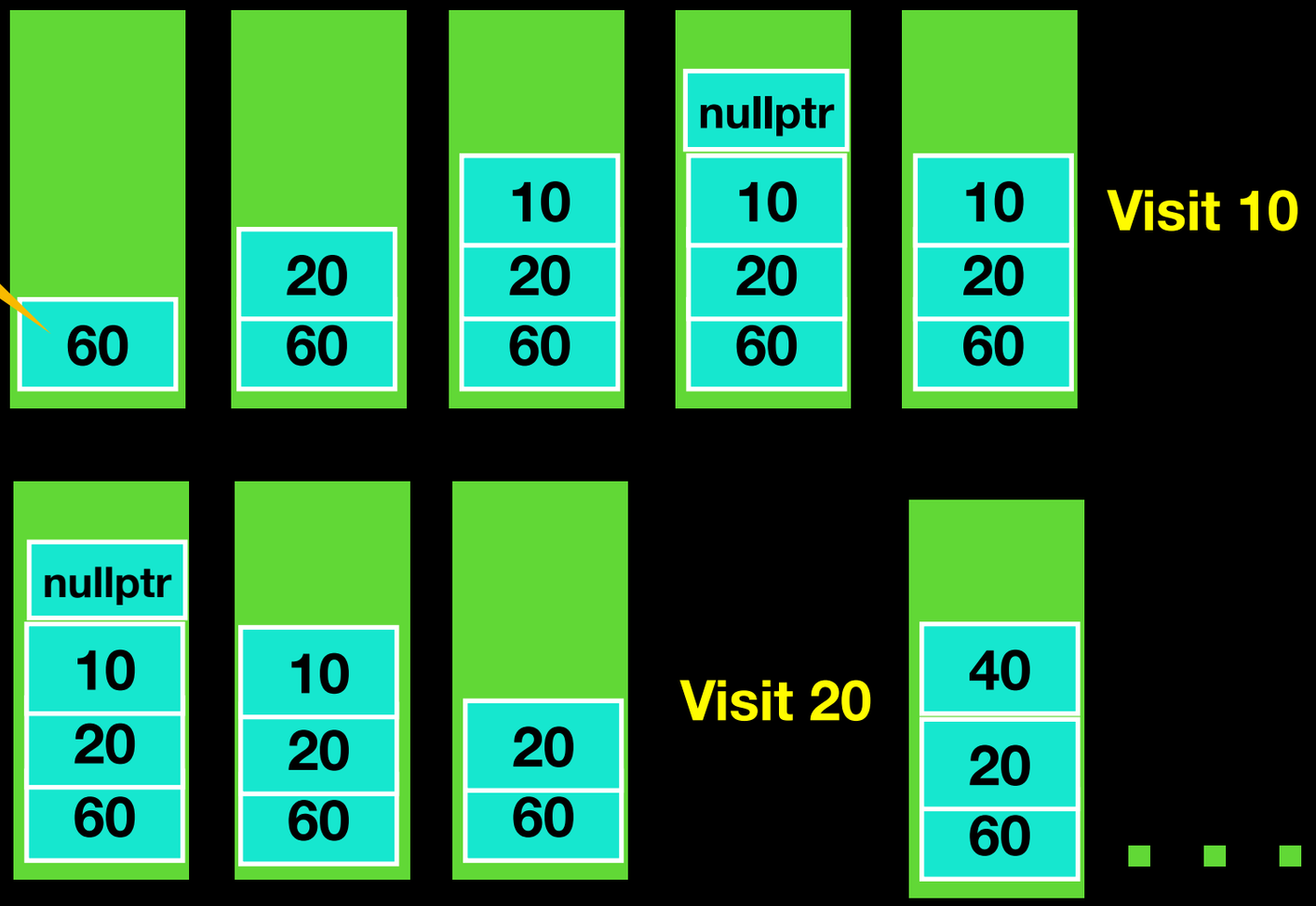
```
1   void f(int x, int y)
2   {
3      int a;
4      // stuff here
5      if(a<13)
6          a = g(a);
7      // stuff here
8   }

9   int g(int z)
10  {
11     int p ,q;
12     // stuff here
13     return q;
14  }
```



Recursive Traversal

In recursive solution program stack keeps track of what node must be visited next





Recursive Traversal

With recursion:

- program stack implicitly finds node traversal must visit next
- If traversal backs up to node *d* from right subtree it backs up further to *d*'s parent as a consequence of the recursive program execution

Non-recursive Traversal

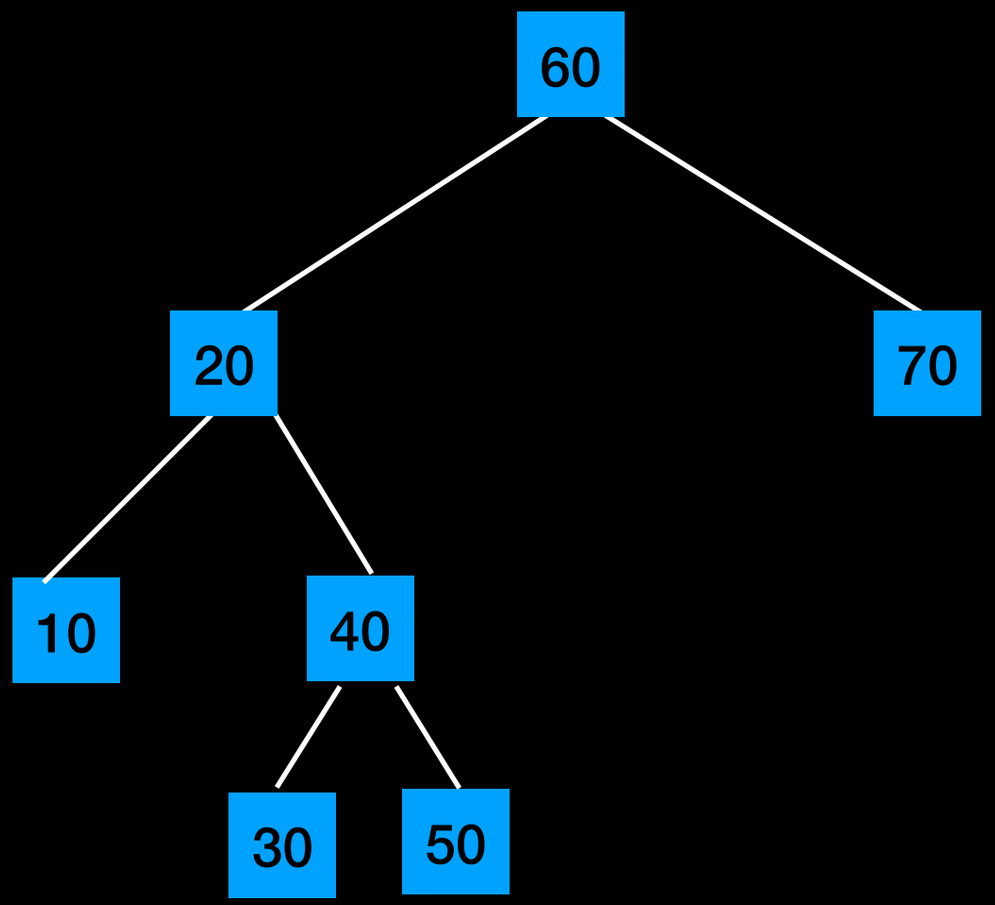
Optimize: Implement iterative approach that maintains an explicit stack to keep track of nodes that must be visited

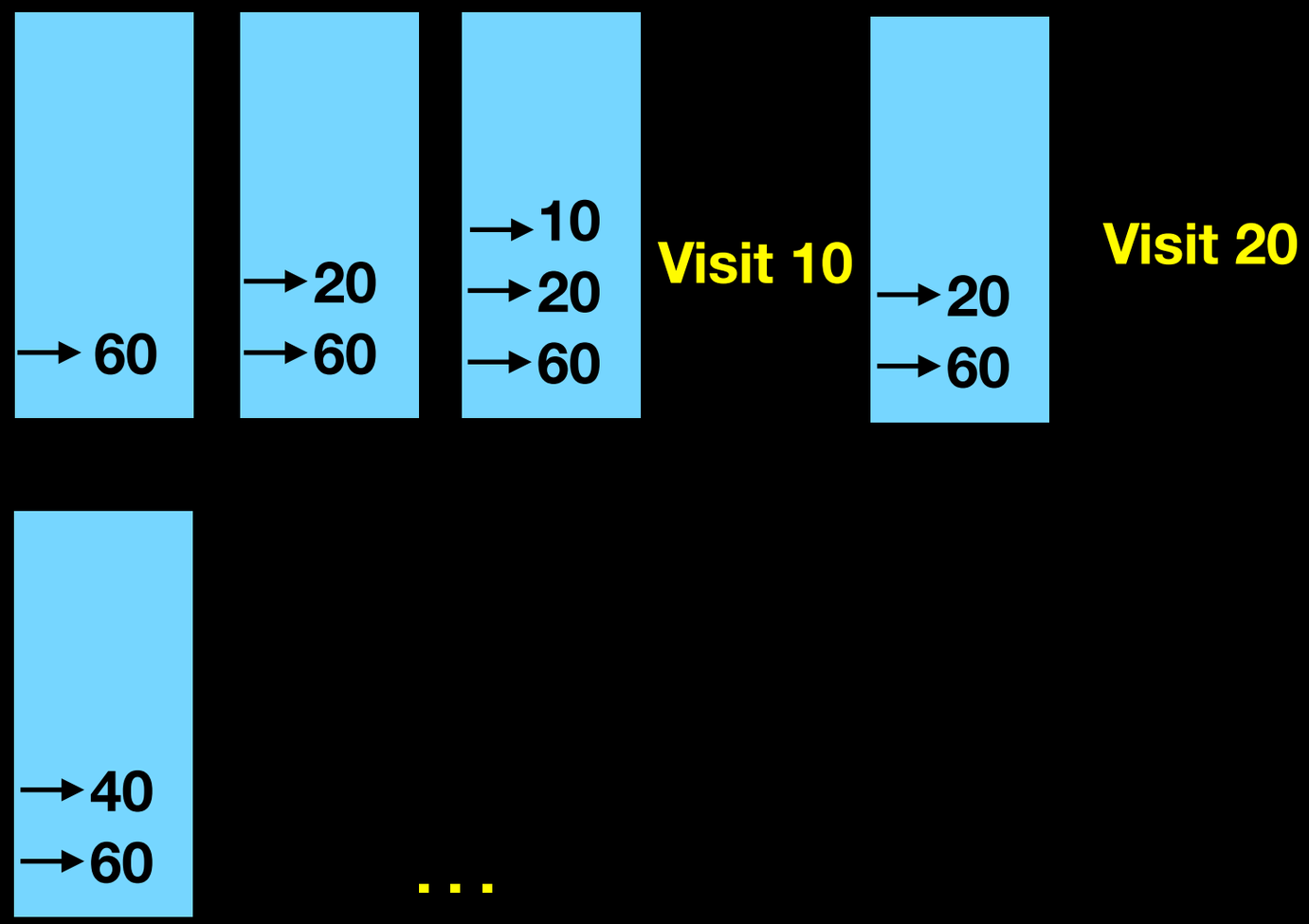
Place pointer to node on stack **only** before traversing it's left subtree but **NOT** before traversing right subtree

This will also save some "steps" that were unnecessary but implicit in recursive implementation

Non-recursive Traversal

Iterative solution explicitly maintains a stack of pointers to nodes to keep track of what node must be visited next





Non-recursive Traversal

```
template<class T>
void BST<T>::inorder(Visitor<T>& visit) const
{
    std::stack<T> node_stack;
    std::shared_ptr<BinaryNode<T>> current_ptr = root_ptr_;
    bool done = false;

    while(!done)
    {
        if(current_ptr != nullptr)
        {
            node_stack.push(current_ptr);

            //traverse left subtree
            current_ptr = current_ptr->getLeftChildPtr();
        }
```

Non-recursive Traversal cont.

```
        //backtrack from empt subtree and visit the node at top of
        //stack, but if stack is empty traversal is completed
        else{
            done = node_stack.isEmpty();
            if(!done)
                {
                    current_ptr = node_stack.top();
                    visit(current_ptr->getItem());
                    node_stack.pop();

                    //traverse right subtree of node just visited
                    current_ptr = current_ptr->getRightChildPtr();
                }
            }
        }
    }  // end inorder
```

Traversals

The last cool trick for you this semester

Looking for different behavior

```
template<class T>
void BST<T>::preorderTraverse(Visitor<T>& visit) const
{
   preorder(visit, root_ptr_);
}  // end preorderTraverse
```

```
template<class T>
void BST<T>::inorderTraverse(Visitor<T>& visit) const
{
   inorder(visit, root_ptr_);
}  // end inorderTraverse

template<class T>
void BST<T>::postorderTraverse(Visitor<T>& visit) const
{
   postorder(visit, root_ptr_);
}  // end postorderTraverse
```

Functors

Objects that by overloading `operator()` can be “called” like a function

POLYMORPHISM!
ABSTRACT CLASS!!!

```hpp
#ifndef Visitor_hpp
#define Visitor_hpp
#include <string>

template<class T>
class Visitor
{
public:

    virtual void operator()(T&) = 0;
    virtual void operator()(T&, T&) = 0;

};

#endif /* Visitor_hpp */
```

```hpp
#ifndef StringPrinter_hpp
#define StringPrinter_hpp

#include "Visitor.hpp"
#include <iostream>
#include <string>


class StringPrinter: public Visitor<std::string>
{
public:

    void operator()(std::string&) override;
    void operator()(std::string&, std::string&) override;

};


#endif /* StringPrinter_hpp */
```

```cpp
#include "StringPrinter.hpp"


void StringPrinter::operator()(std::string& x)
{
    std::cout << x << std::endl;
}

void StringPrinter::operator()(std::string& a, std::string& b)
{
    std::cout << a << b << std::endl;
}
```

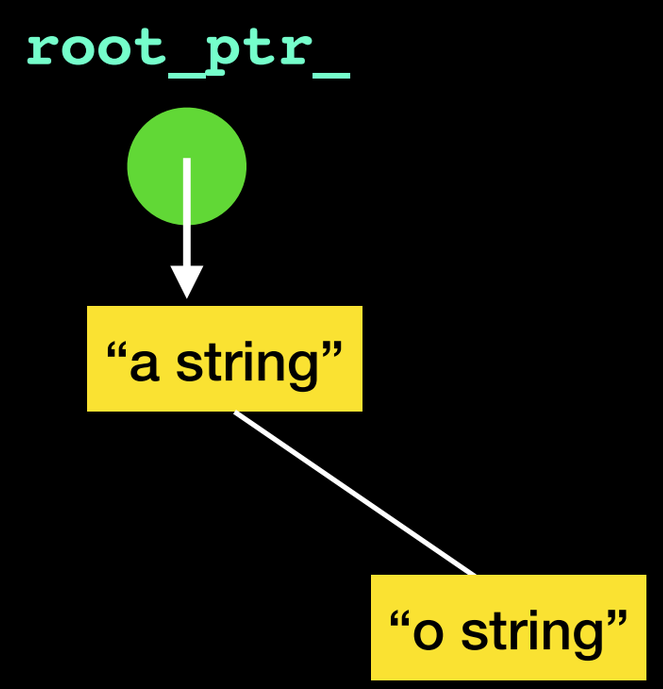
```hpp
#ifndef Inverter_hpp
#define Inverter_hpp

#include "Visitor.hpp"
#include <iostream>
#include <string>
#include <algorithm>


class Inverter: public Visitor<std::string>
{
public:

    void operator()(std::string&) override;
    void operator()(std::string&, std::string&) override;

};

#endif /* Inverter_hpp */
```

```cpp
#include "Inverter.hpp"

void Inverter::operator()(std::string& x)
{
    std::reverse(x.begin(), x.end());
    std::cout << x << std::endl;
}

void Inverter::operator()(std::string& a, std::string& b)
{
    a.swap(b);
    std::cout << a << b << std::endl;
}
```

Traversal with Functor parameter

```
template<class T>
void BST<T>::inorder(Visitor<T>& visit,
    std::shared_ptr<BinaryNode<T>> tree_ptr) const
{
     if (tree_ptr != nullptr)
     {
          inorder(visit, tree_ptr->getLeftChildPtr());
          T the_item = tree_ptr->getItem();

          visit(the_item);

          inorder(visit, tree_ptr->getRightChildPtr());
     }  // end if
}  // end inorder
```

```cpp
int main() {

    std::string a_string = "a string";
    std::string anoter_string = "o string";

    BST<std::string> a_tree(a_string);
    a_tree.add(anoter_string);

    StringPrinter p;
    Inverter i;


    a_tree.inorderTraverse(p);
    std::cout << std::endl;
    a_tree.inorderTraverse(i);


    return 0;
}
```




```
a string
o string

gnirts a
gnirts o
Program ended with exit code: 0
```

```cpp
int main() {

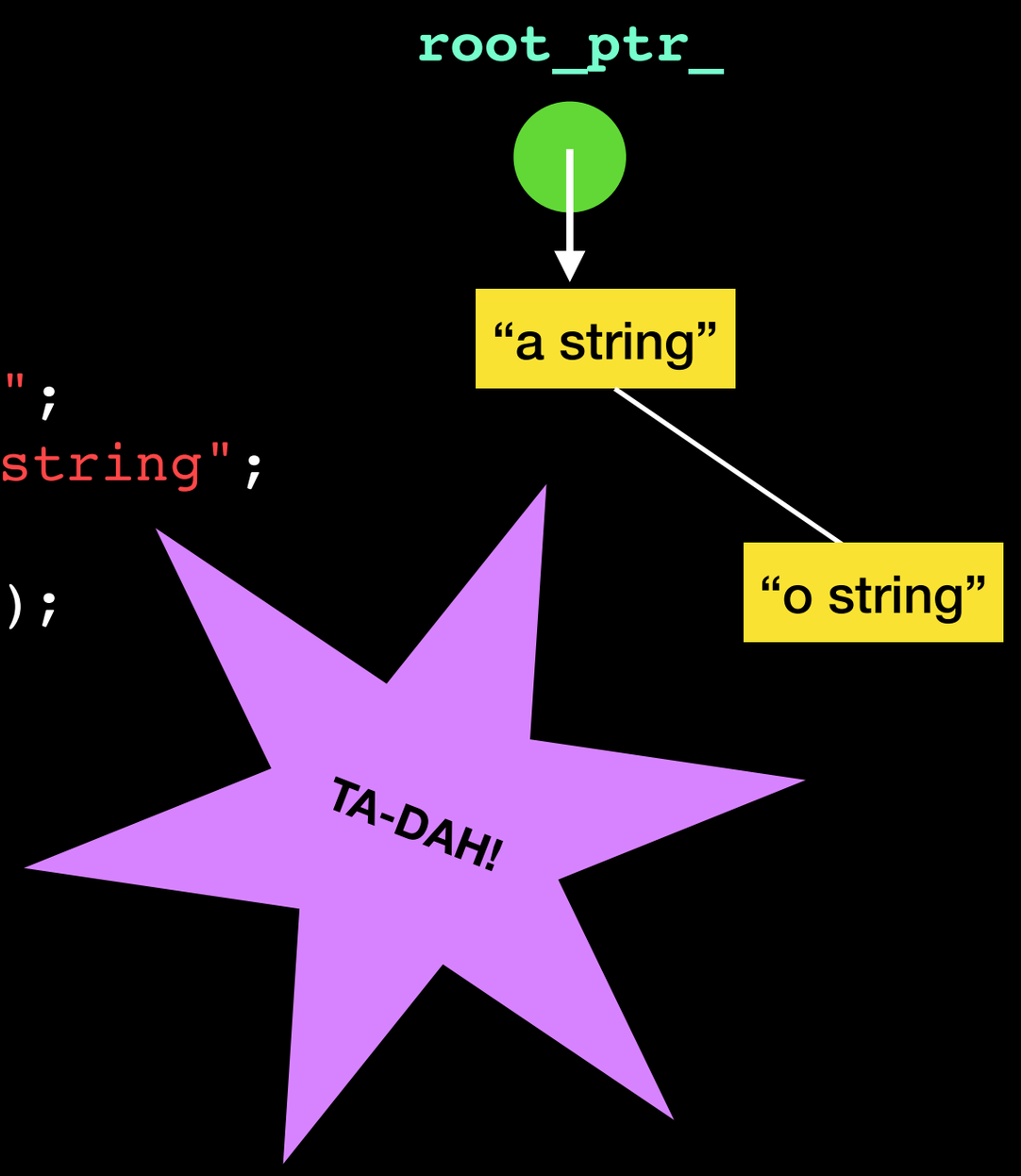
    std::string a_string = "a string";
    std::string another_string = "o string";

    BST<std::string> a_tree(a_string);
    a_tree.add(another_string);

    StringPrinter p;
    Inverter I;


    a_tree.inorderTraverse(p);
    std::cout << std::endl;
    a_tree.inorderTraverse(i);


    return 0;
}
```




```
a string
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