Tree Implementation

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Today’s Plan

Recap

BST Implementation

Announcements

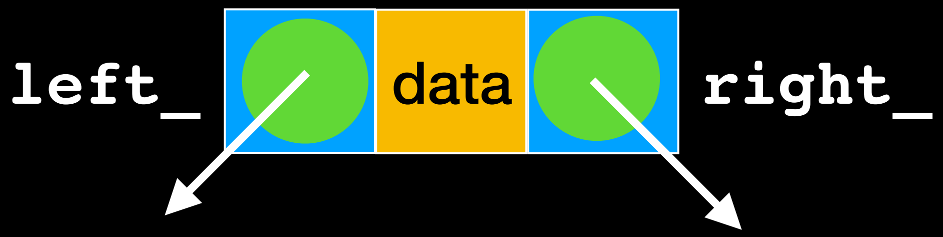
Tomorrow Mock Final Exam

```
#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 ???

BinaryNode



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

template<class T>
class BinaryNode
{

public:
   BinaryNode();
   BinaryNode(const T& an_item);
   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_
```

For shared_ptr

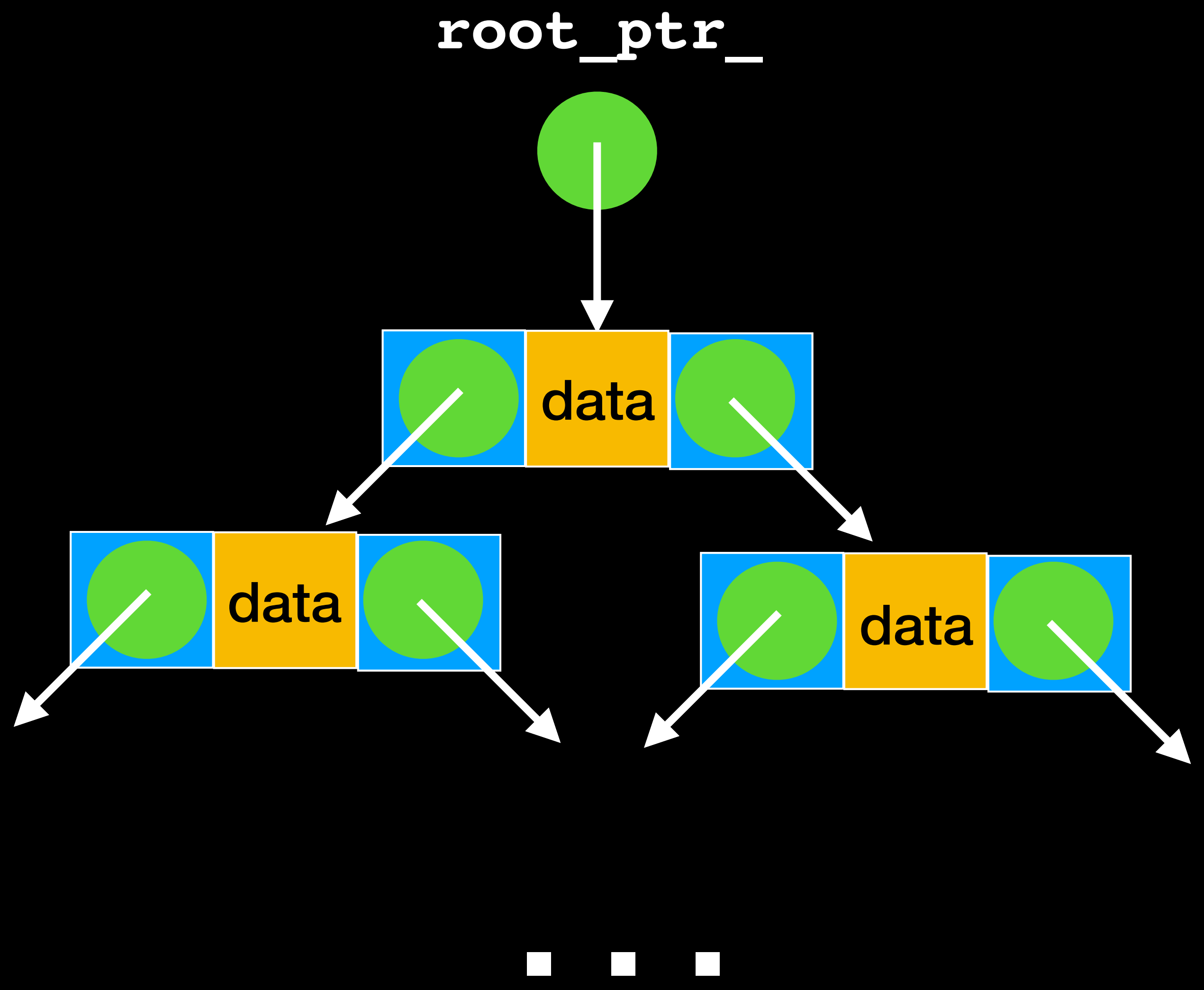
Lecture Activity

Implement:

```
BinaryNode(const T& an_item);


bool isLeaf() const;


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

```
template<class T>
BinaryNode<T>::BinaryNode(const T& an_item)
      : item_(an_item){ }  // 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



```
#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_
```

We want our interface to be generic and not tied to implementation. Many of these will therefore 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

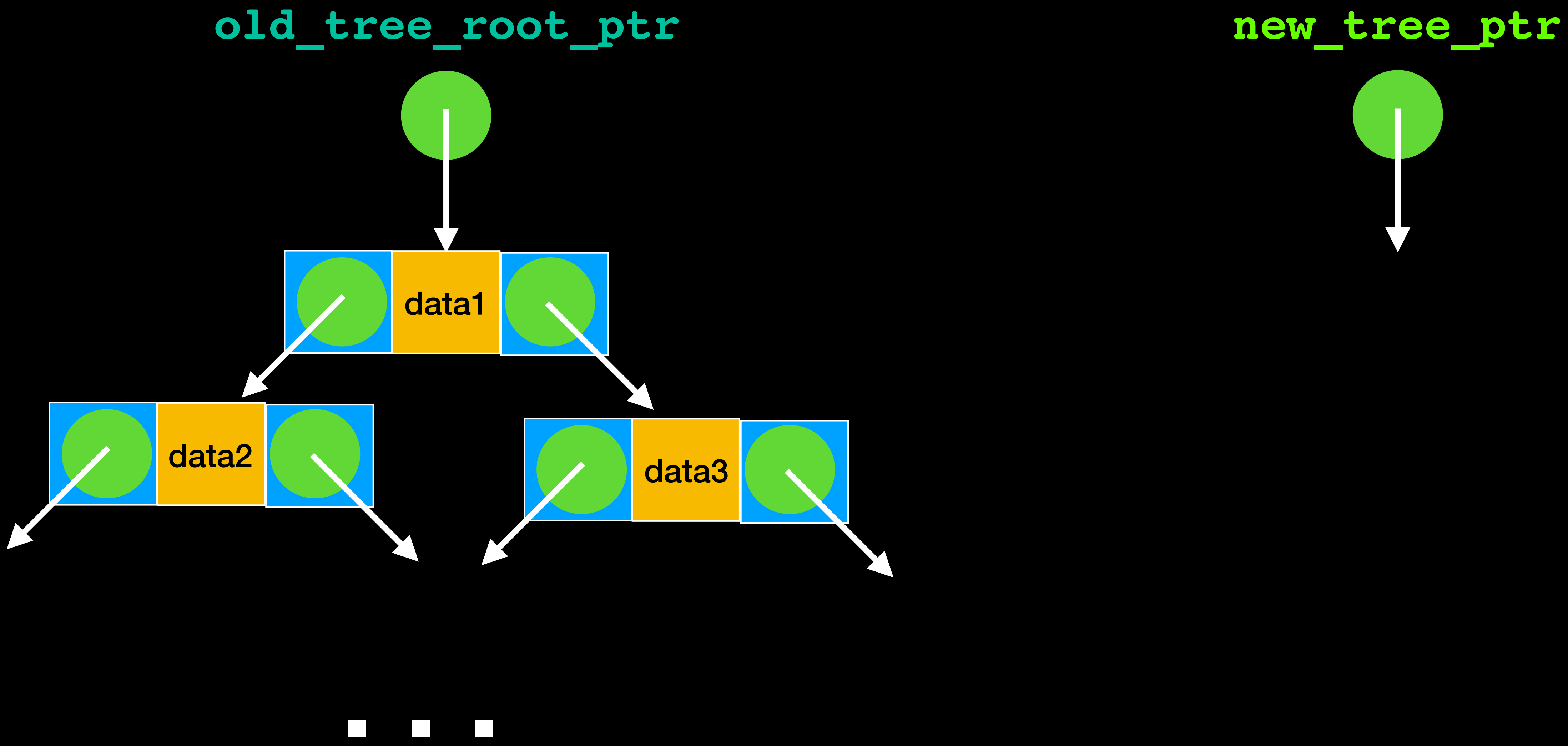
root_ptr of this object

root_ptr of tree: the object I’m going to copy

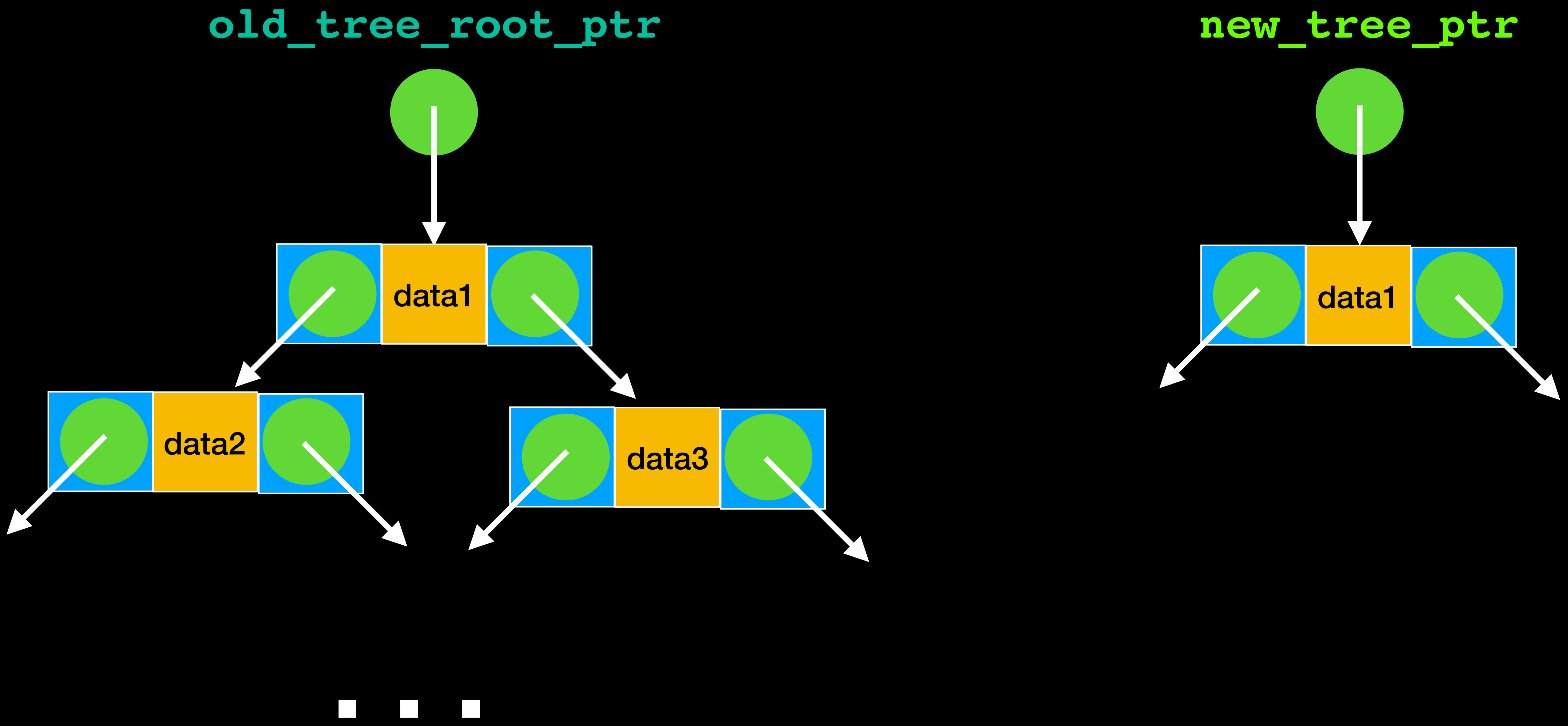
```
template<class T>
BST<T>::BST(const BST<T>& tree)
{
   root_ptr_ = copyTree(tree.root_ptr_); // Call helper function
}  // end copy constructor
```

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

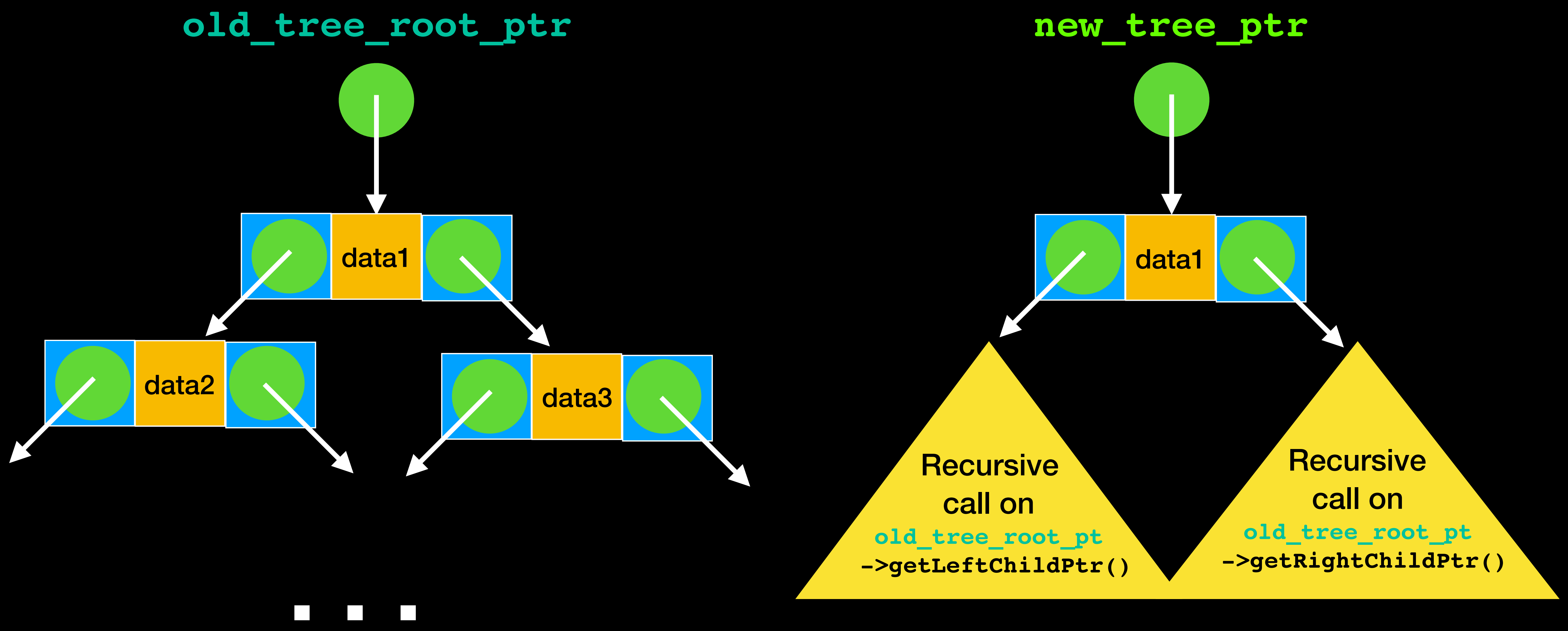
copyTree(old_tree_root_ptr)



copyTree(old_tree_root_ptr)



copyTree(old_tree_root_ptr)



old_tree_root_ptr

data1

data2

data3

...

new_tree_ptr

data1

Recursive call on old_tree_root_pt ->getLeftChildPtr()

Recursive call on old_tree_root_pt ->getRightChildPtr()

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

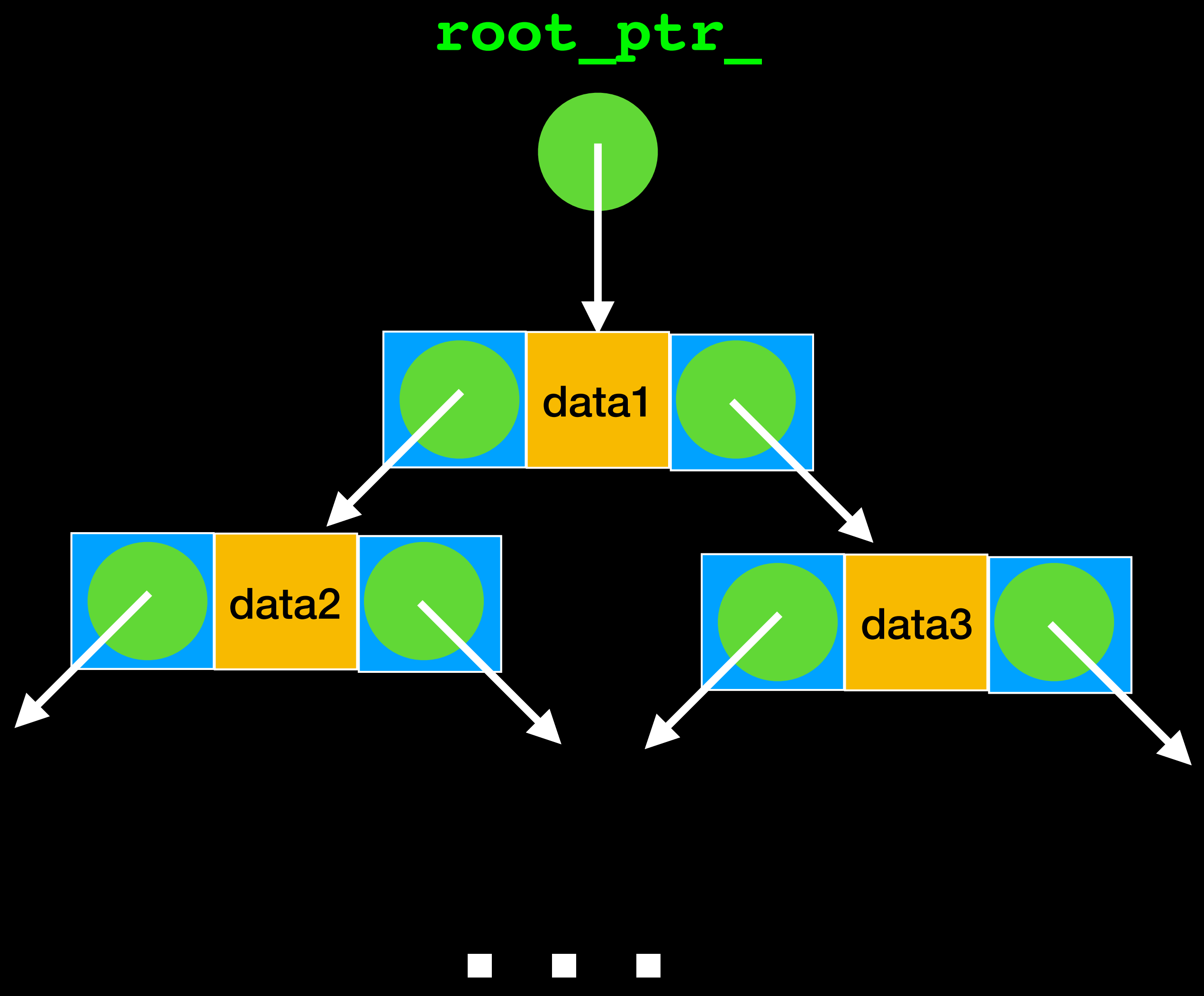
Recursive Calls:
Don't want to tie interface to recursive implementation: Use helper function

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

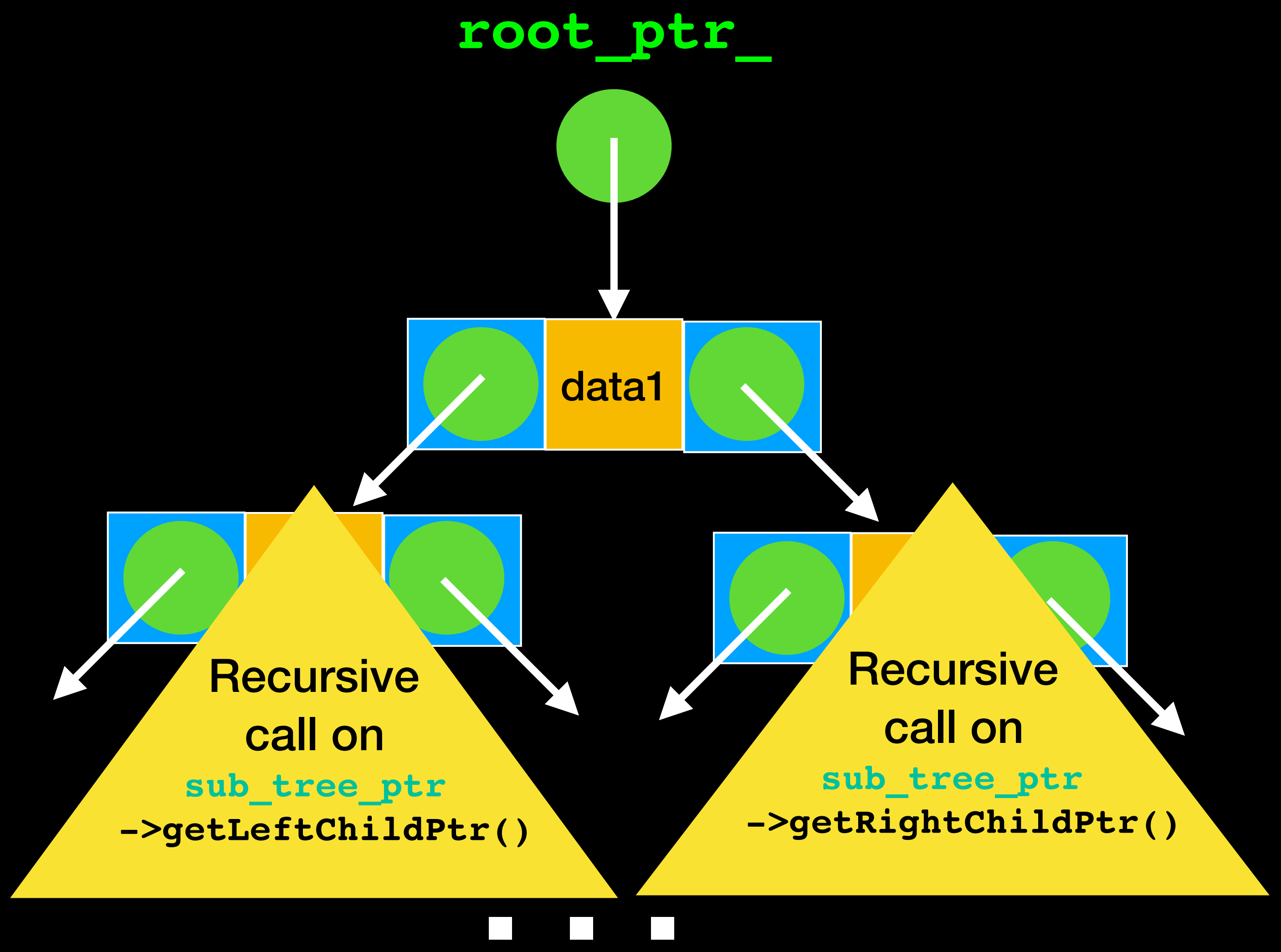
Destructor

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

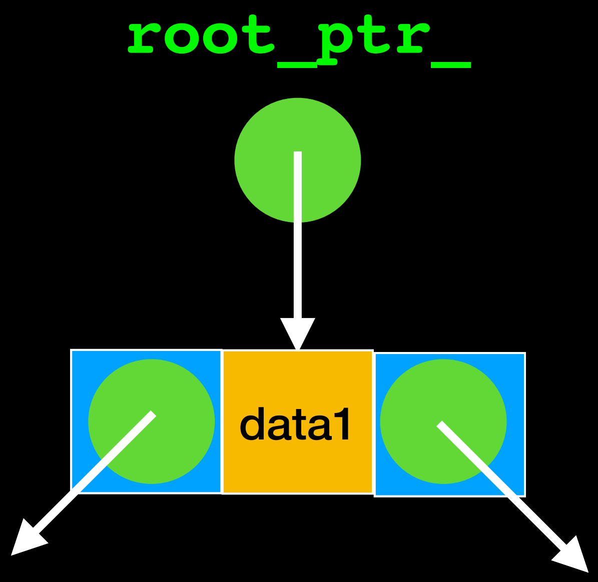
destroyTree(sub_tree_ptr)



destroyTree(sub_tree_ptr)

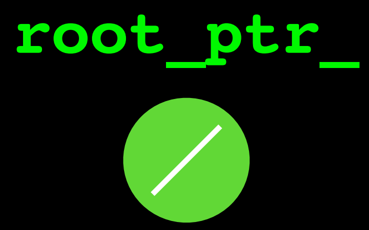

root_ptr_
data1
Recursive call on sub_tree_ptr ->getLeftChildPtr()
Recursive call on sub_tree_ptr ->getRightChildPtr()
. . .

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

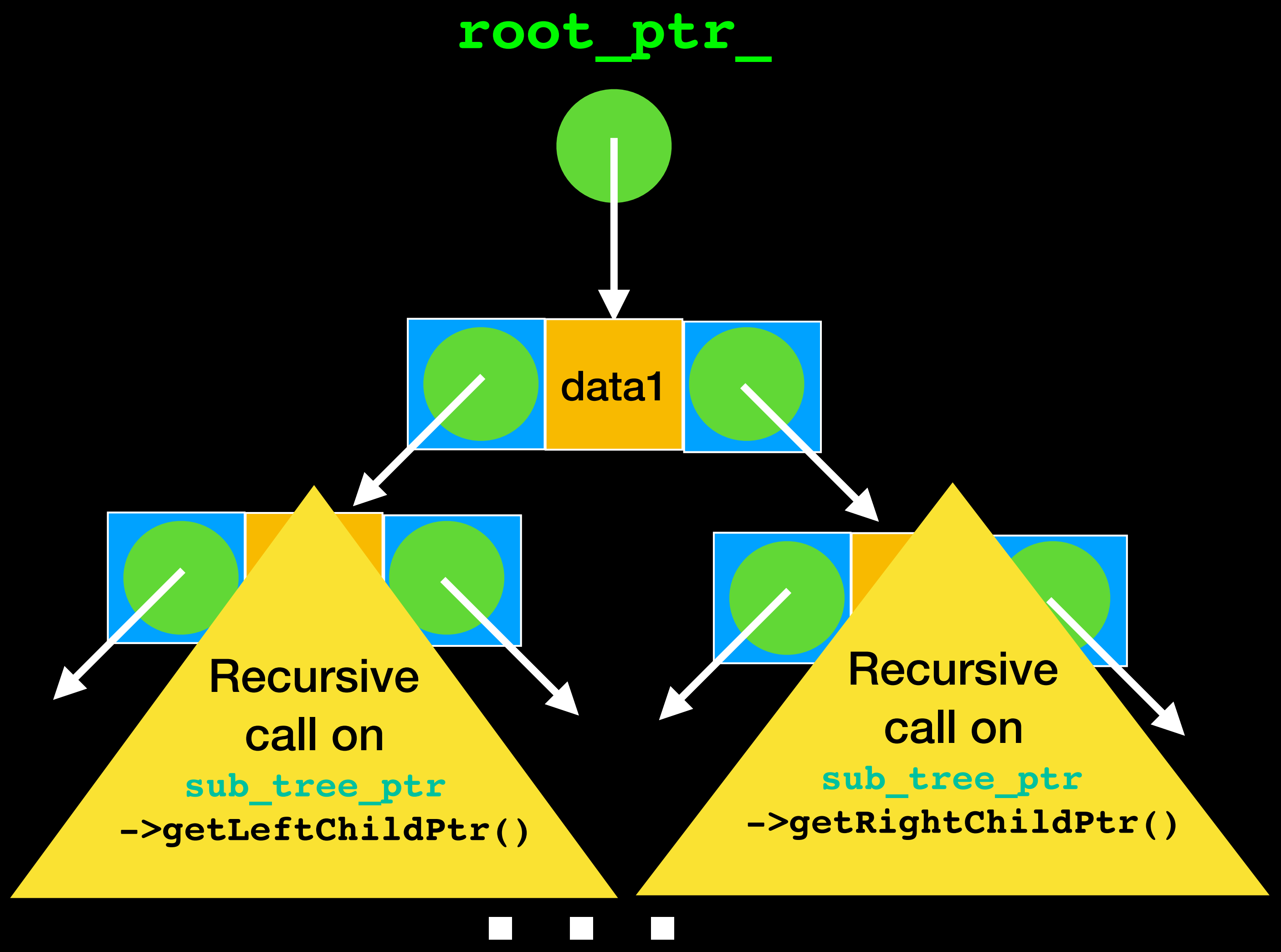
clear

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

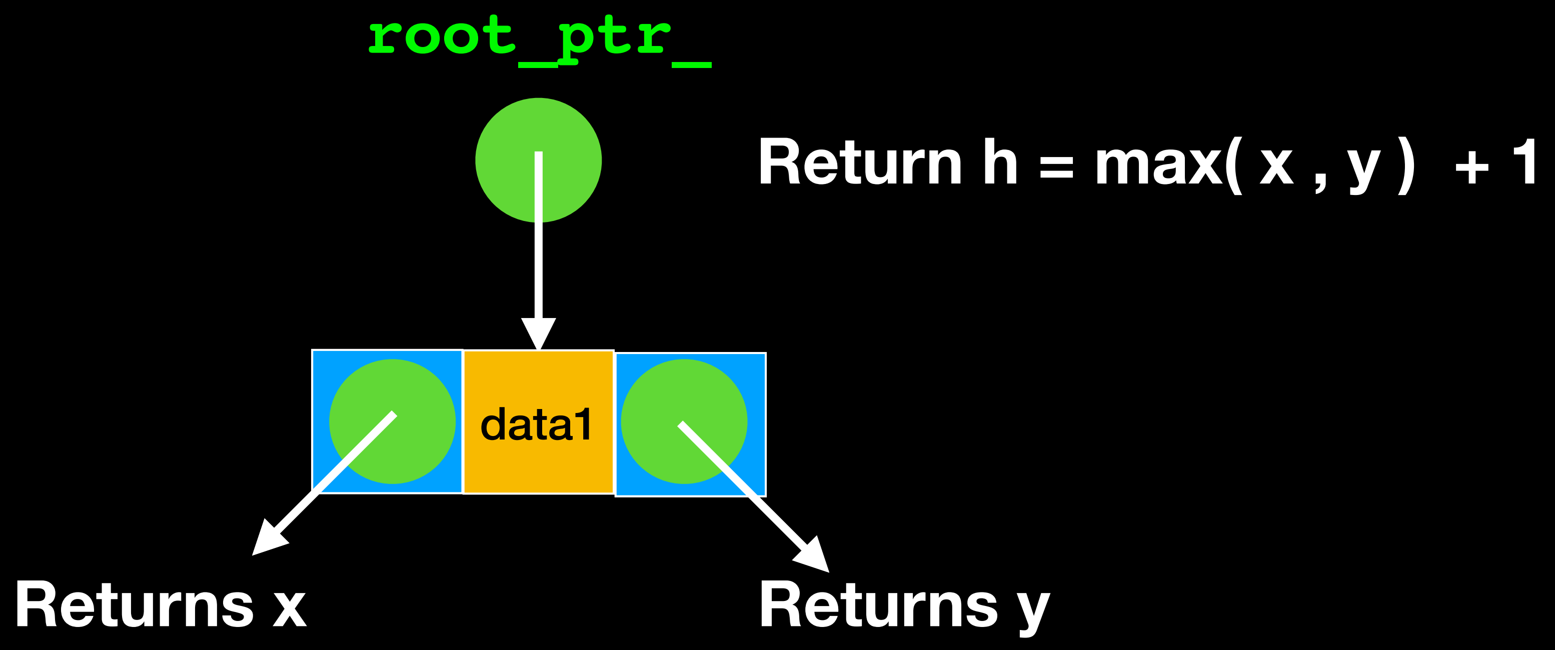
getHeight

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

getHeightHelper(sub_tree_ptr)


root_ptr_
data1
Recursive call on sub_tree_ptr ->getLeftChildPtr()
Recursive call on sub_tree_ptr ->getRightChildPtr()
...

getHeightHelper(sub_tree_ptr)



getHeightHelper(sub_tree_ptr)

```cpp
template<class T>
int BinaryNodeTree<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 BinaryNodeTree<T>::getNumberOfNodes() const
{ //try it at home!!!!}

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

`add` and `remove`

Key methods: determine order of data

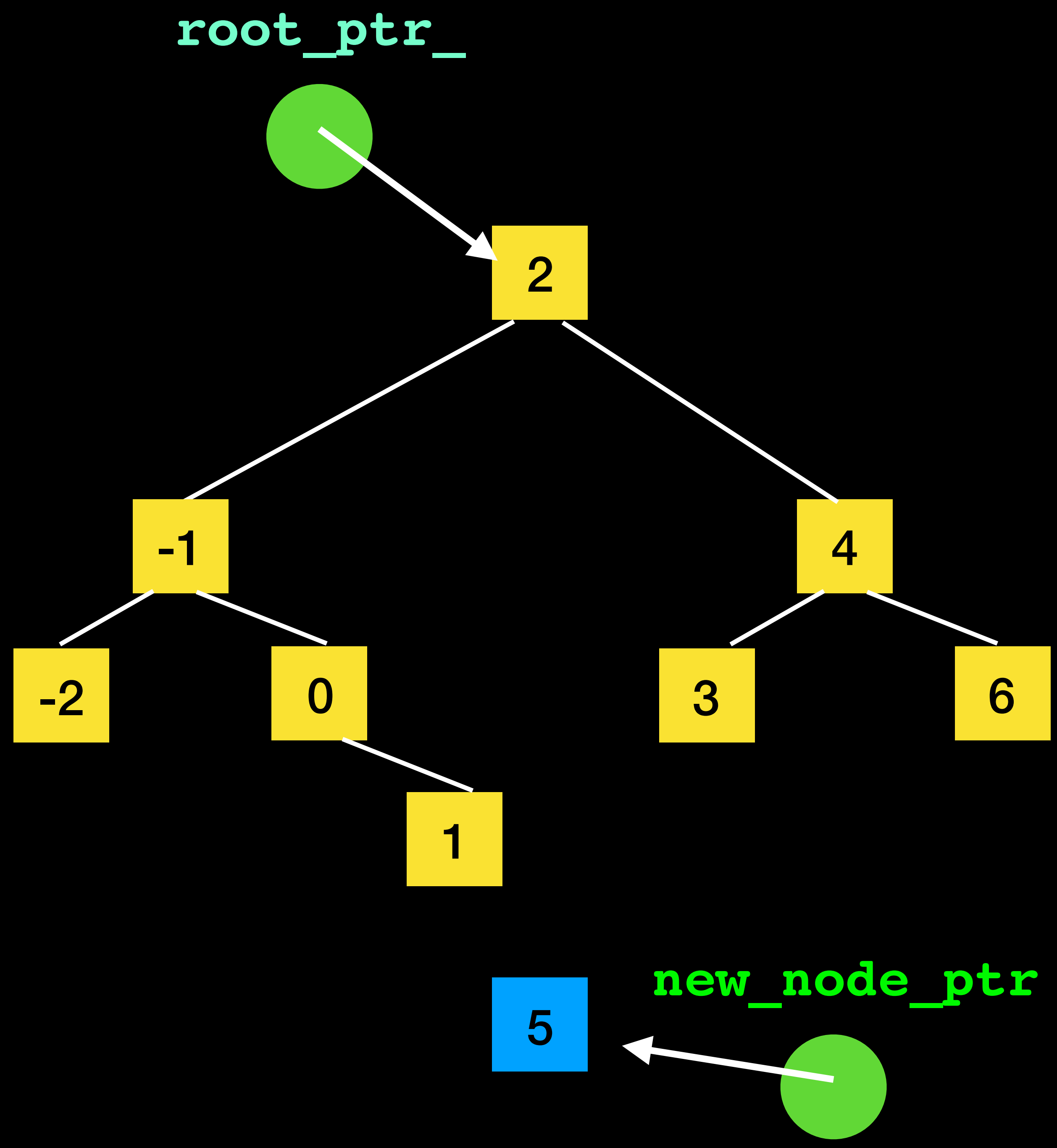
Distinguish between different types of Binary Trees

Implement the BST structural property

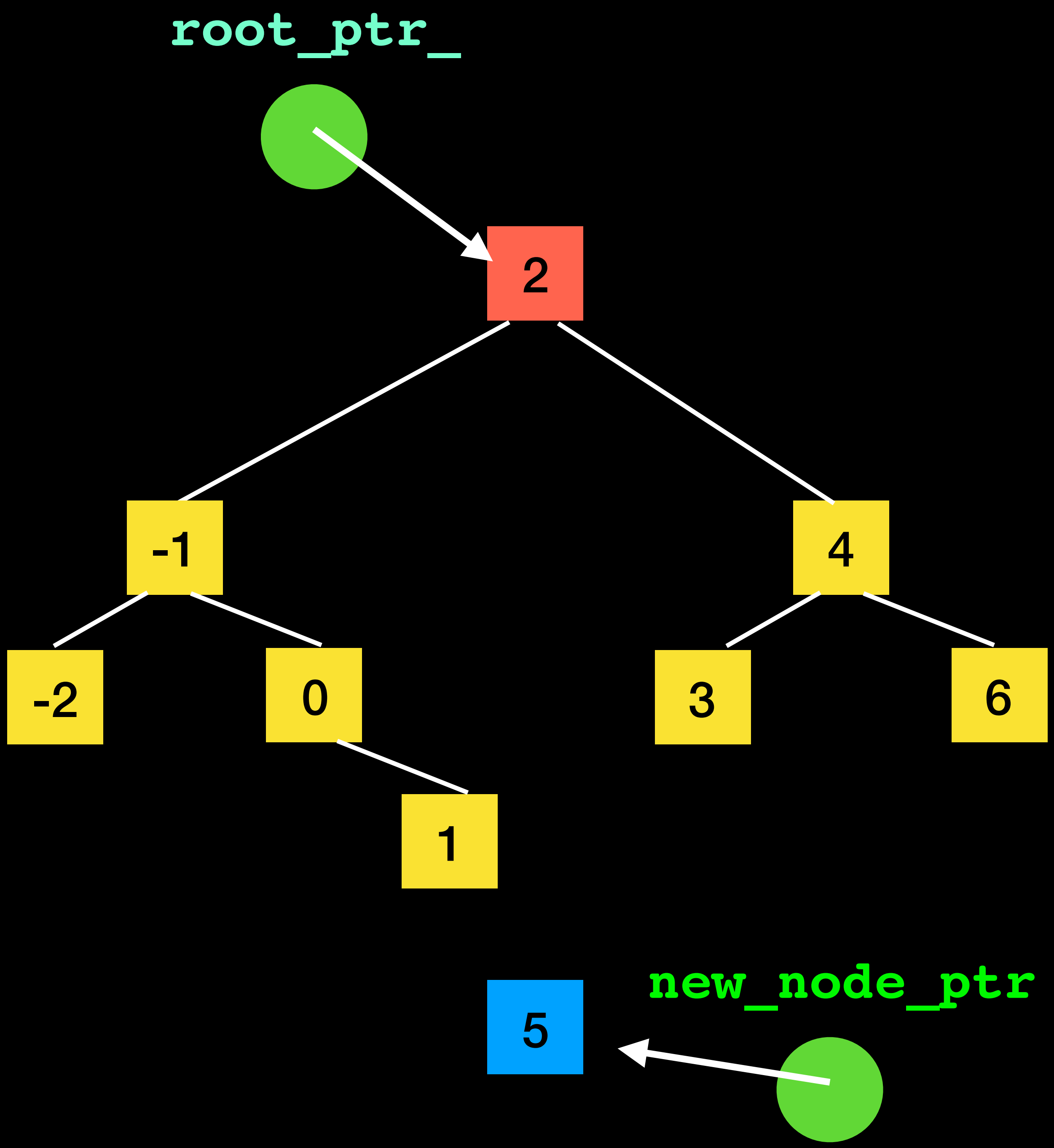
add

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

}  // end add
```

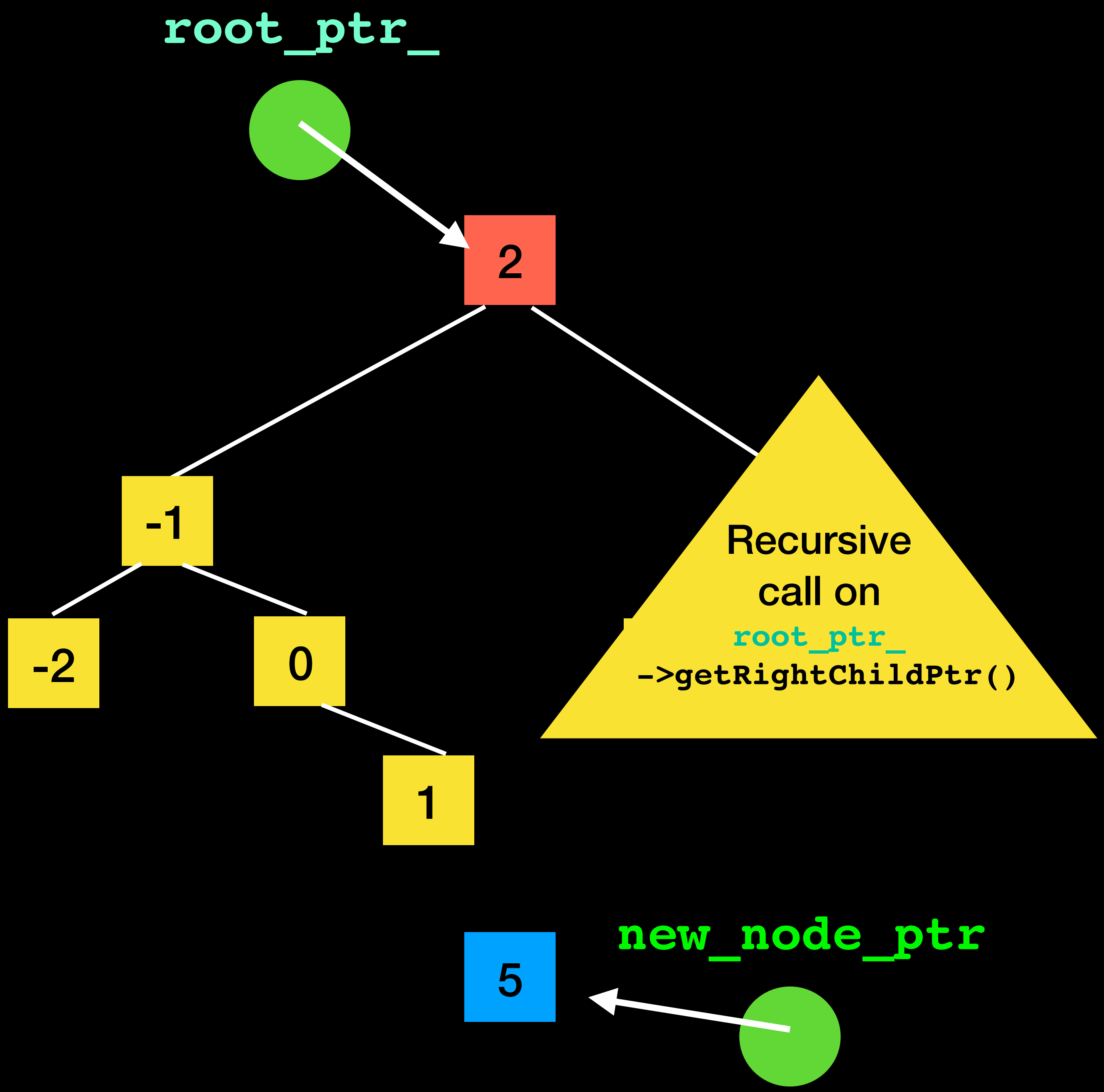
```
placeNode(root_ptr_, new_node_ptr);
```



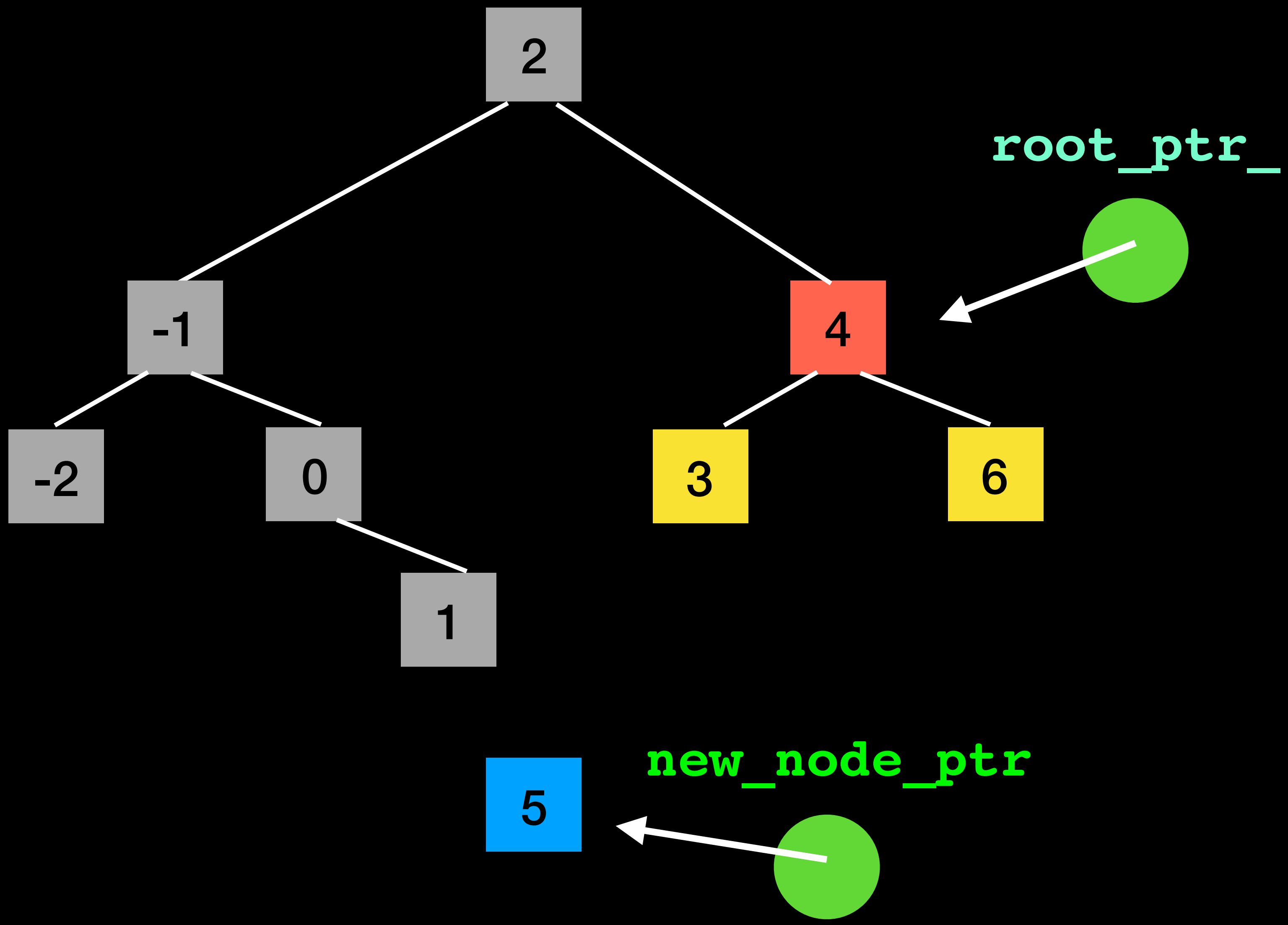
```
placeNode(root_ptr_, new_node_ptr);
```



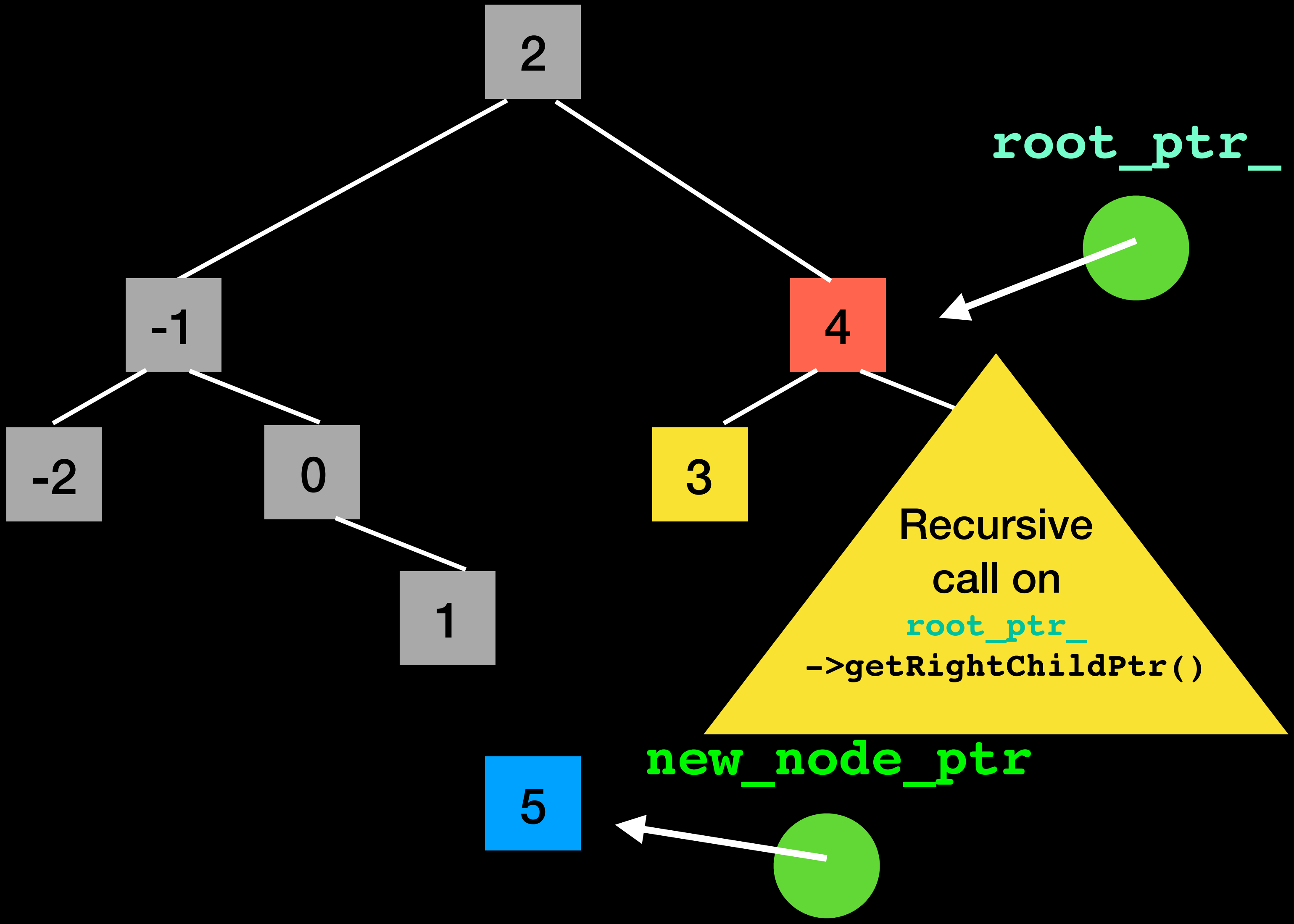
```
placeNode(root_ptr_, new_node_ptr);
```



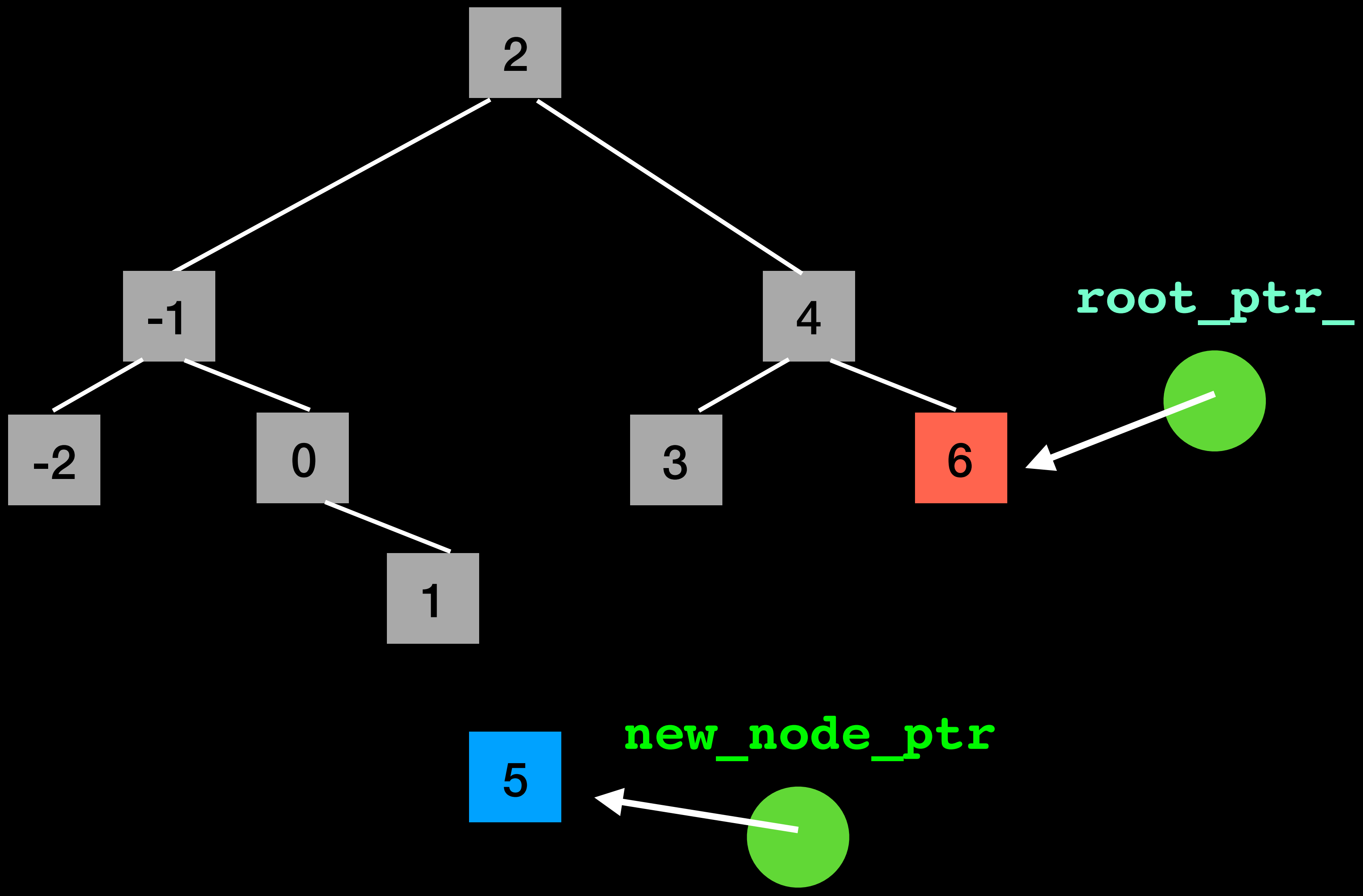
```
placeNode(root_ptr_, new_node_ptr);
```



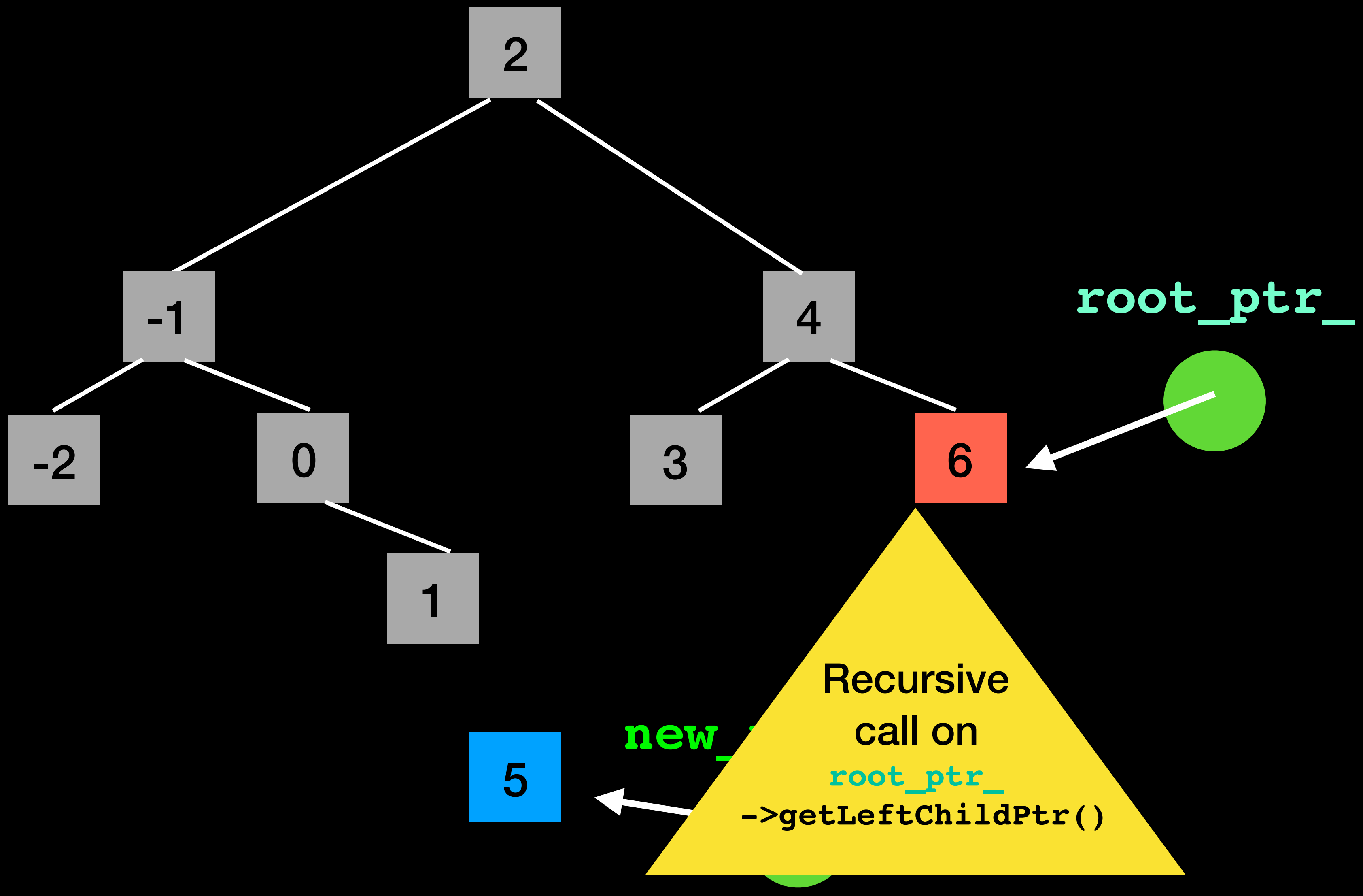
```
placeNode(root_ptr_, new_node_ptr);
```



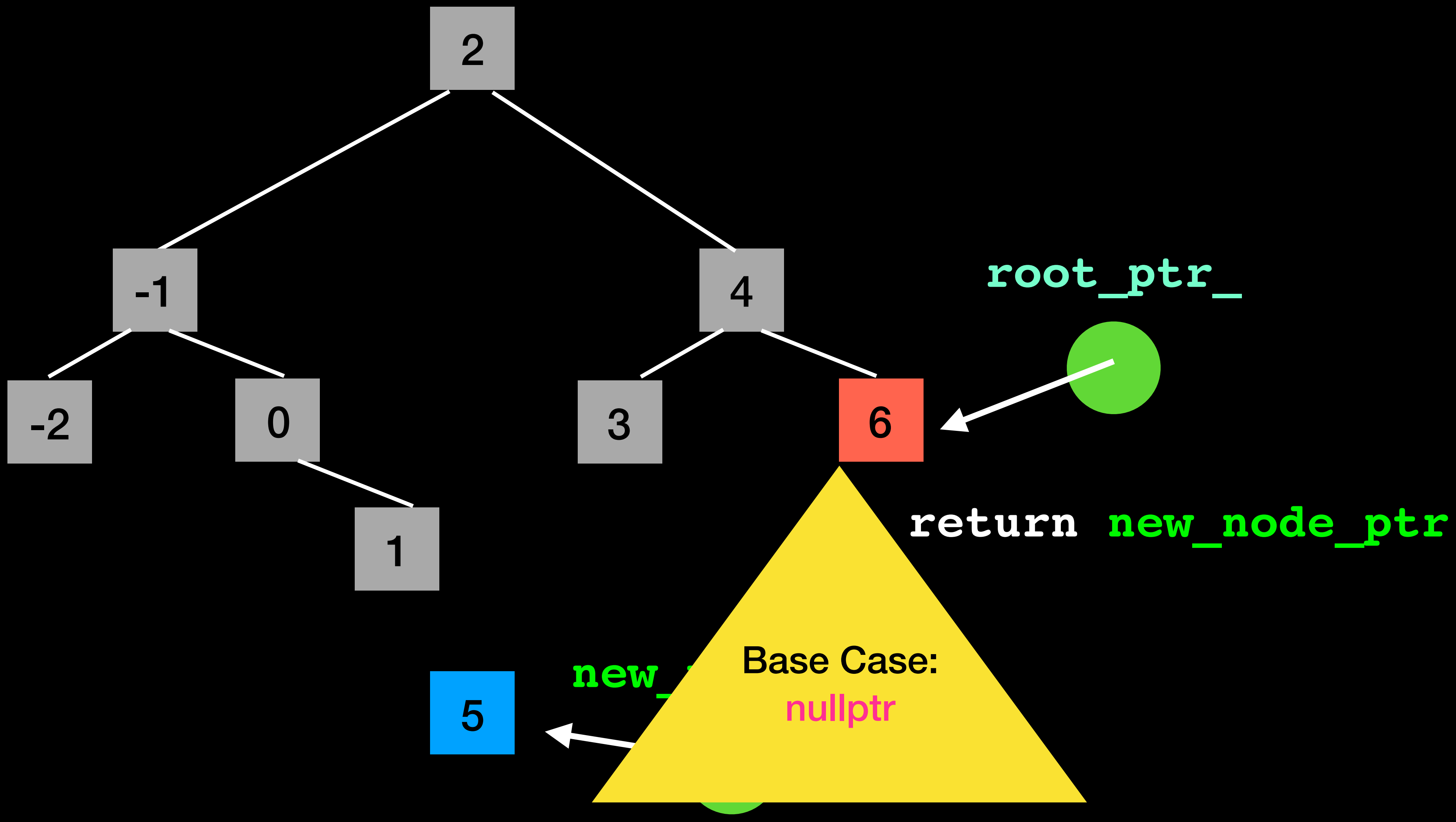
```
placeNode(root_ptr_, new_node_ptr);
```



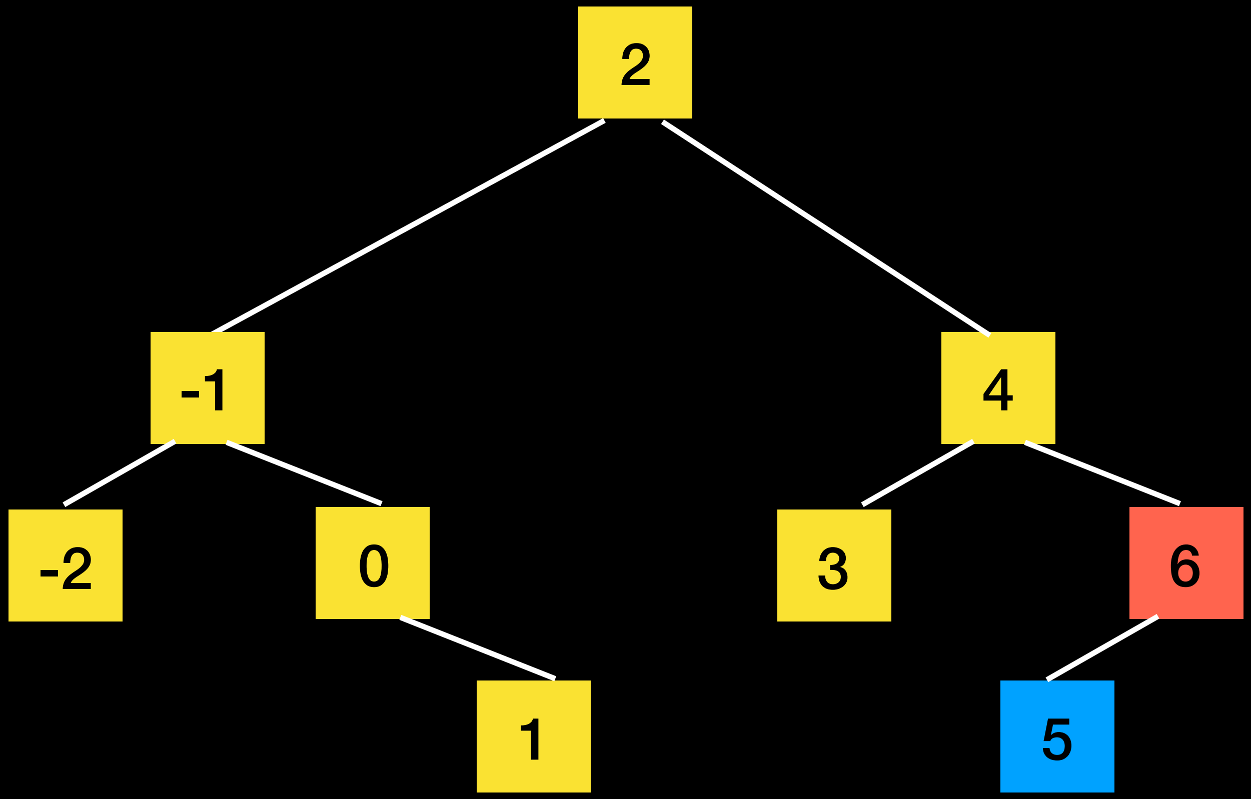
```
placeNode(root_ptr_, new_node_ptr);
```



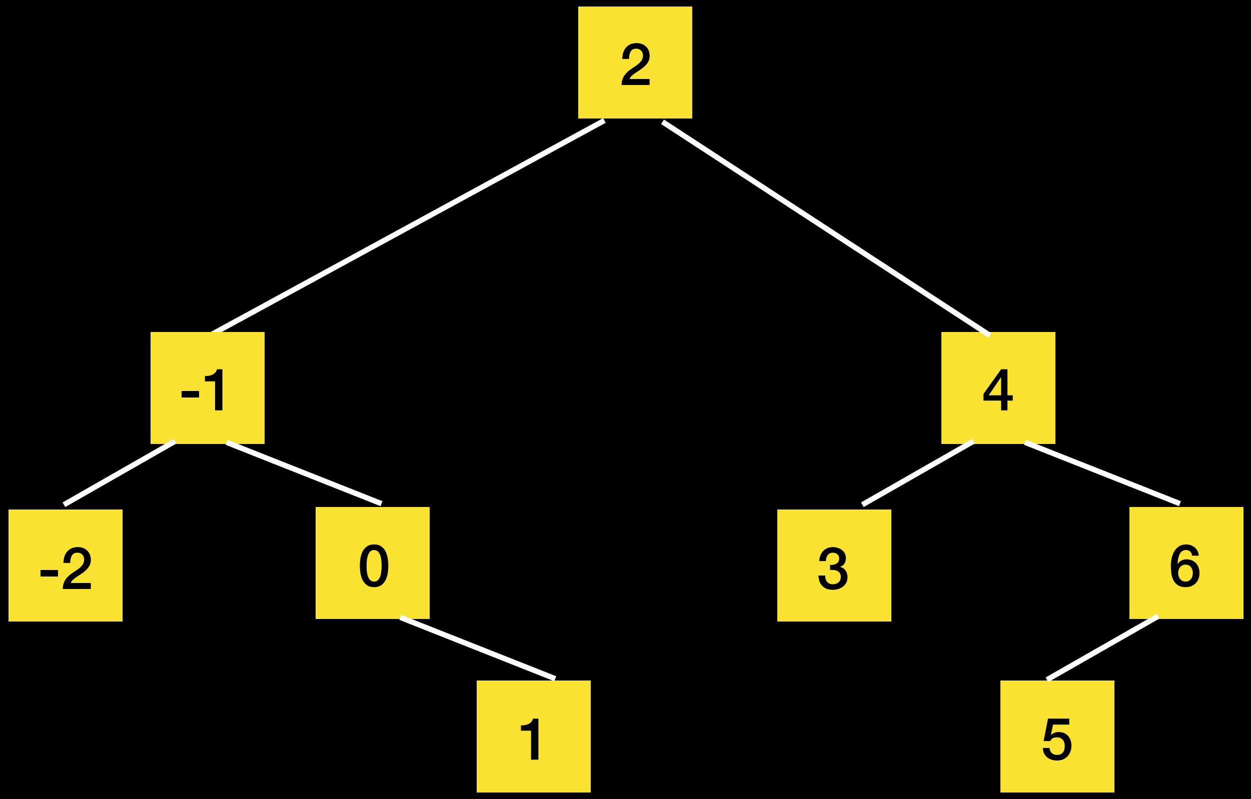
```
placeNode(root_ptr_, new_node_ptr);
```



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



```
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
```

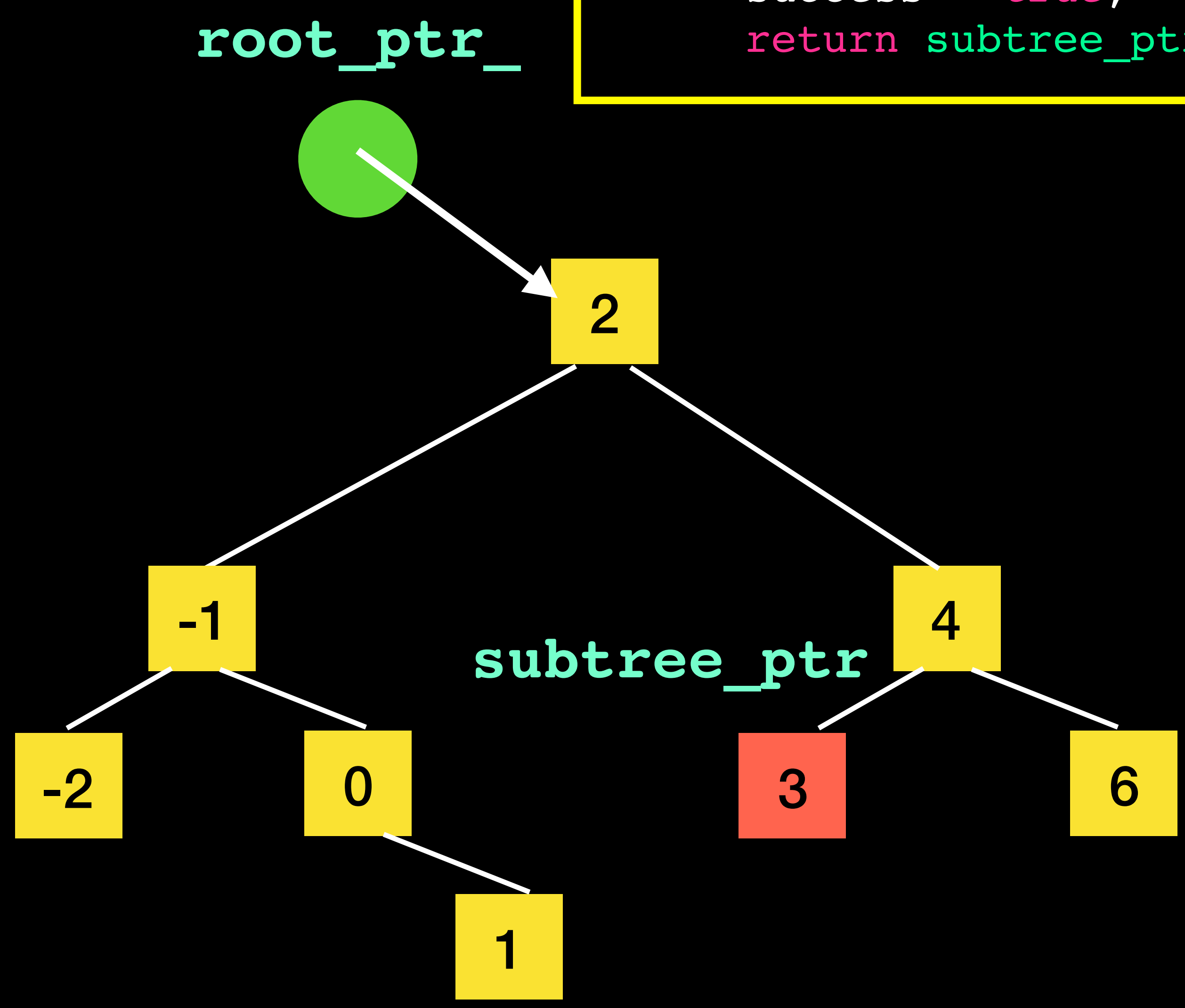
Search for target in left subtree

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

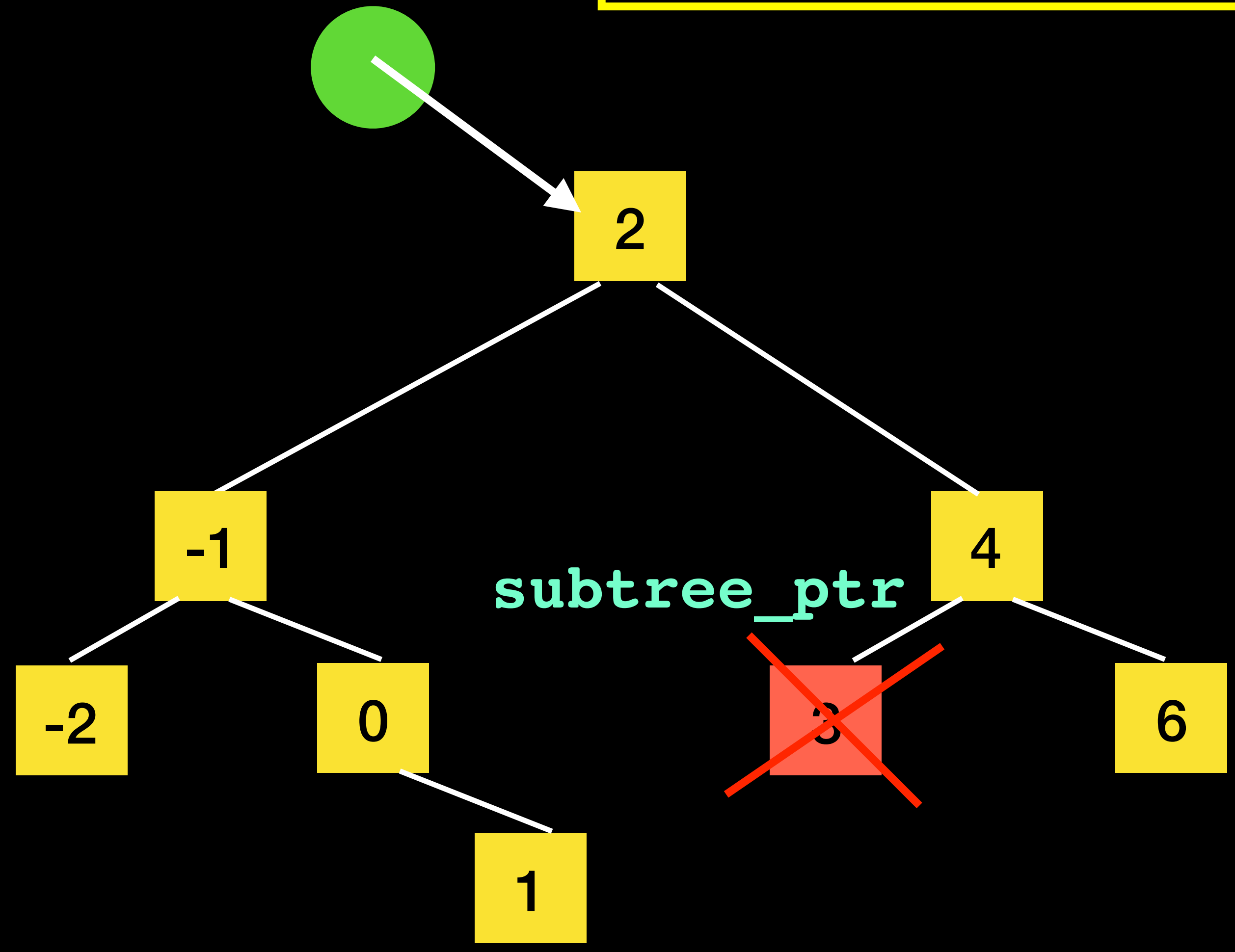


removeNode(subtree_ptr);

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

Case 1: target is a leaf

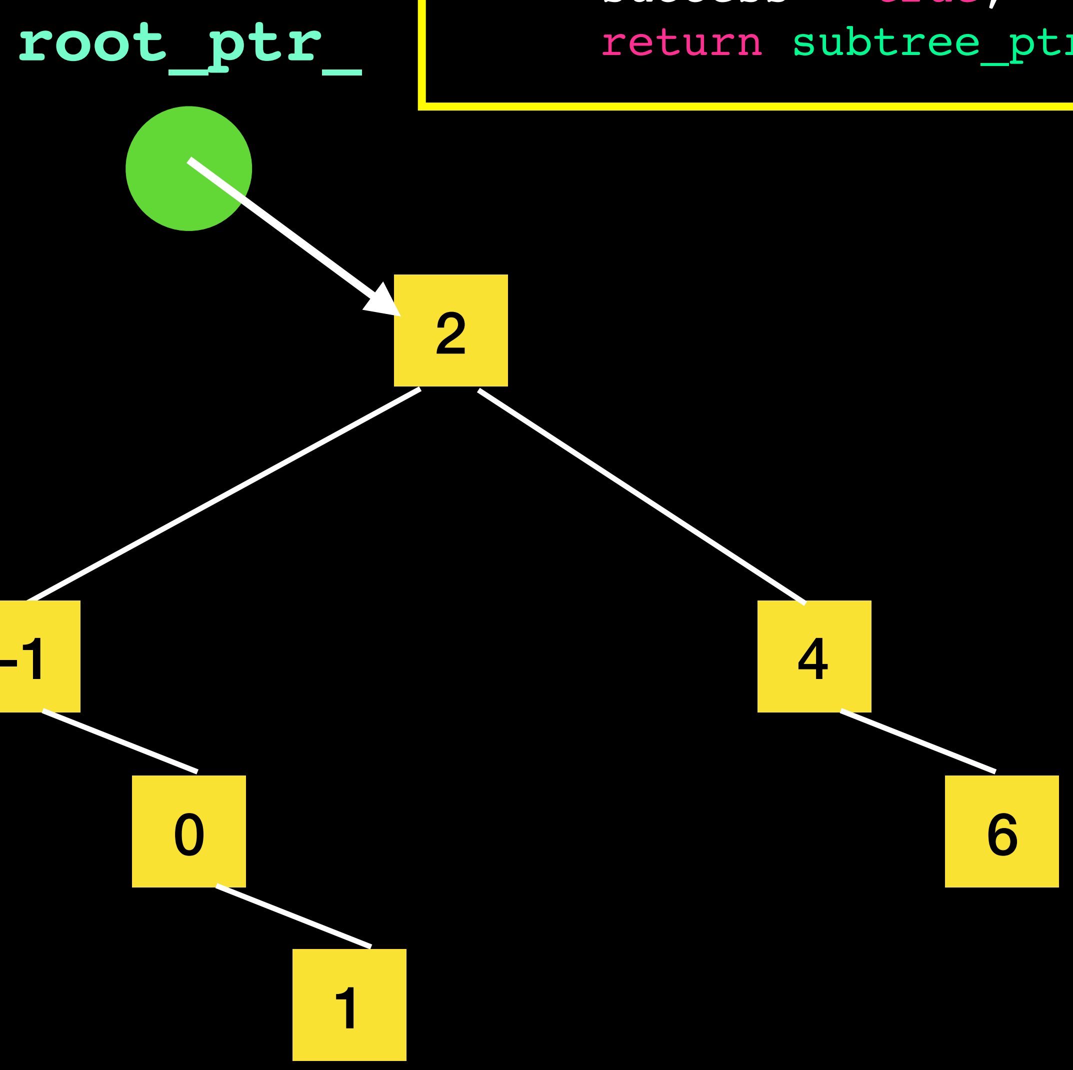
root_ptr_



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;
```

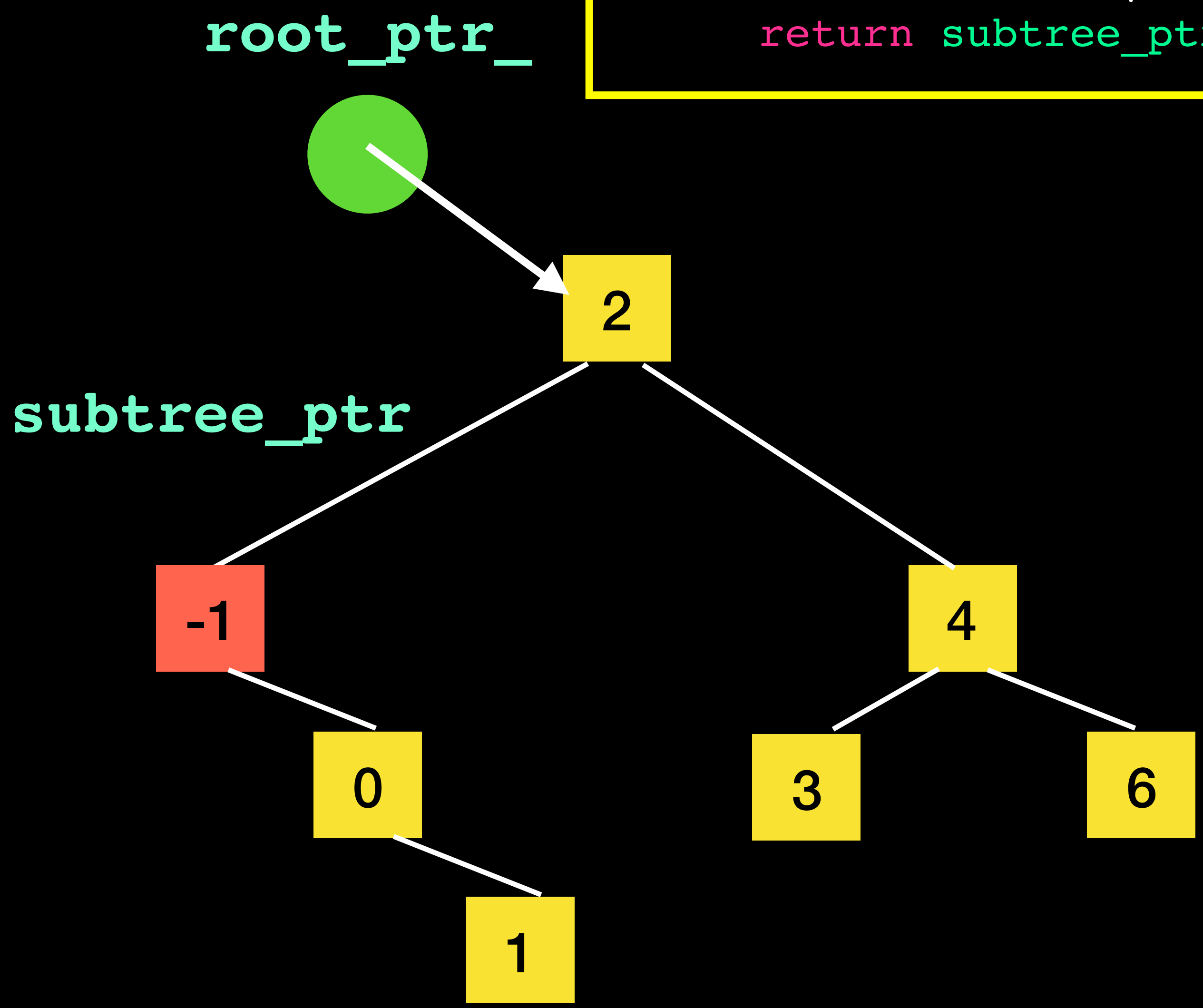
Case 1: target is a leaf



removeNode(subtree_ptr);

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);

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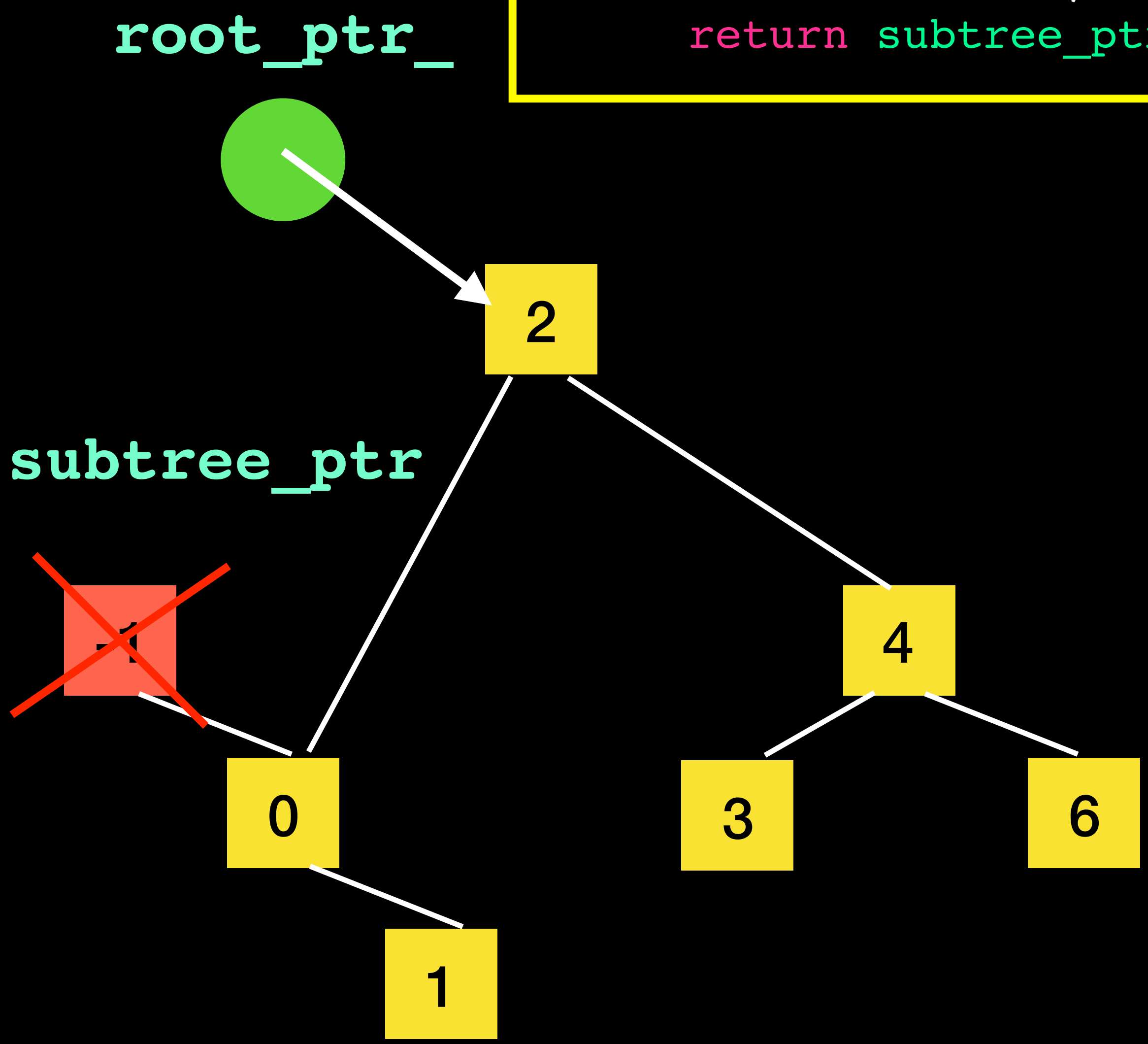
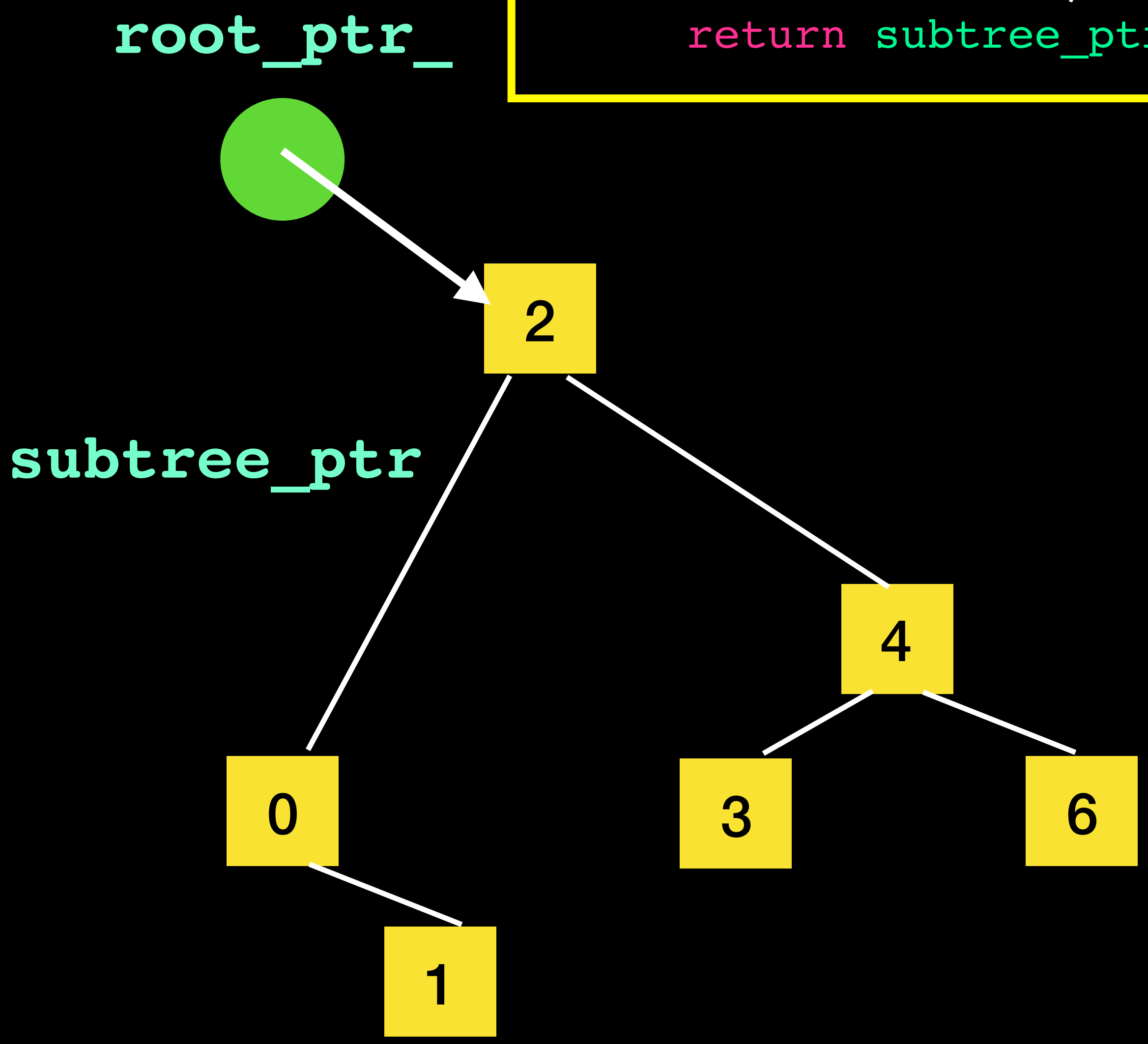

Case 2: target has 1 child
Left and right case are symmetric



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;
```

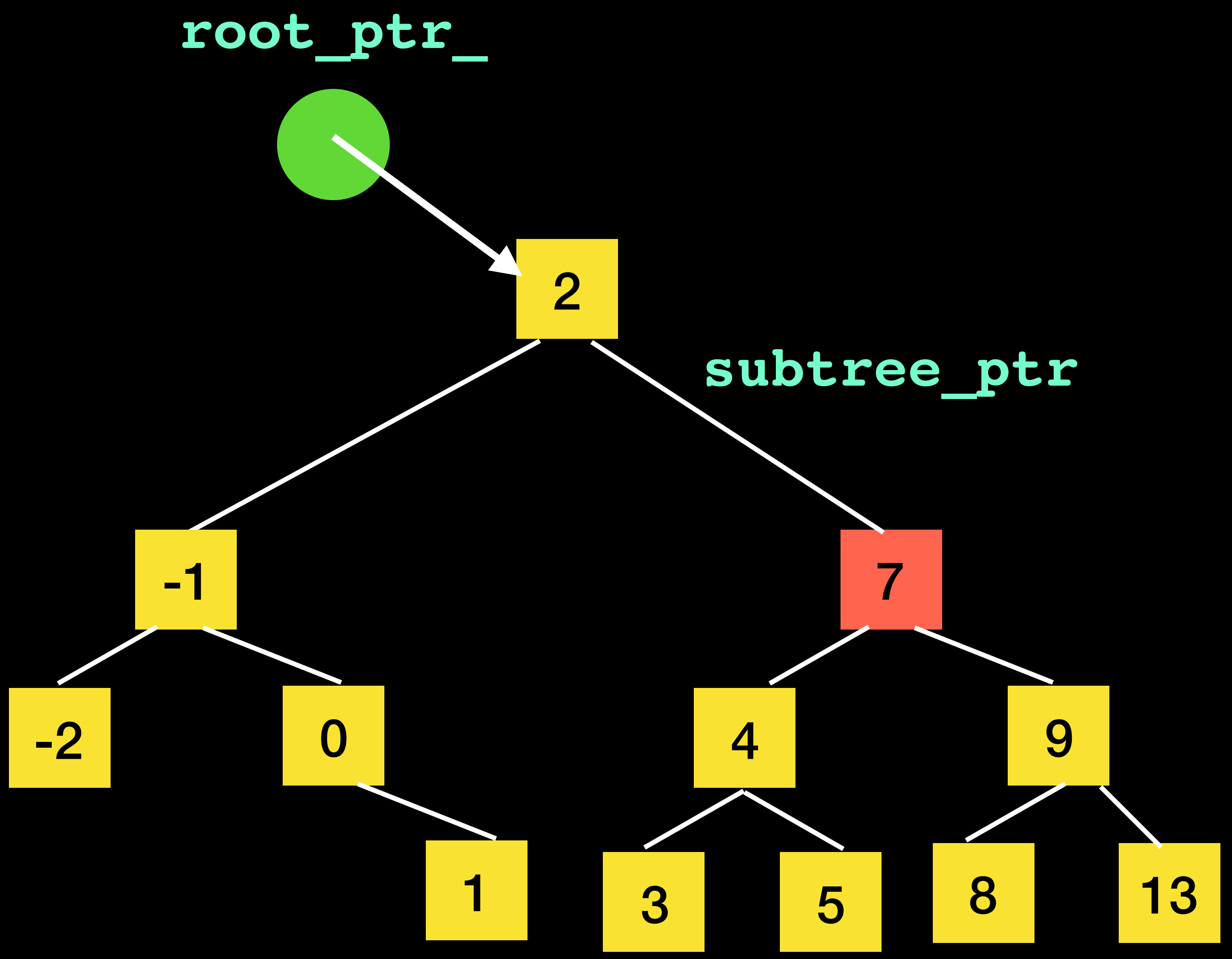
Case 2: target has 1 child
Left and right case are symmetric



Lecture Activity

How would you remove node 7?

Case 3: target has 2 children

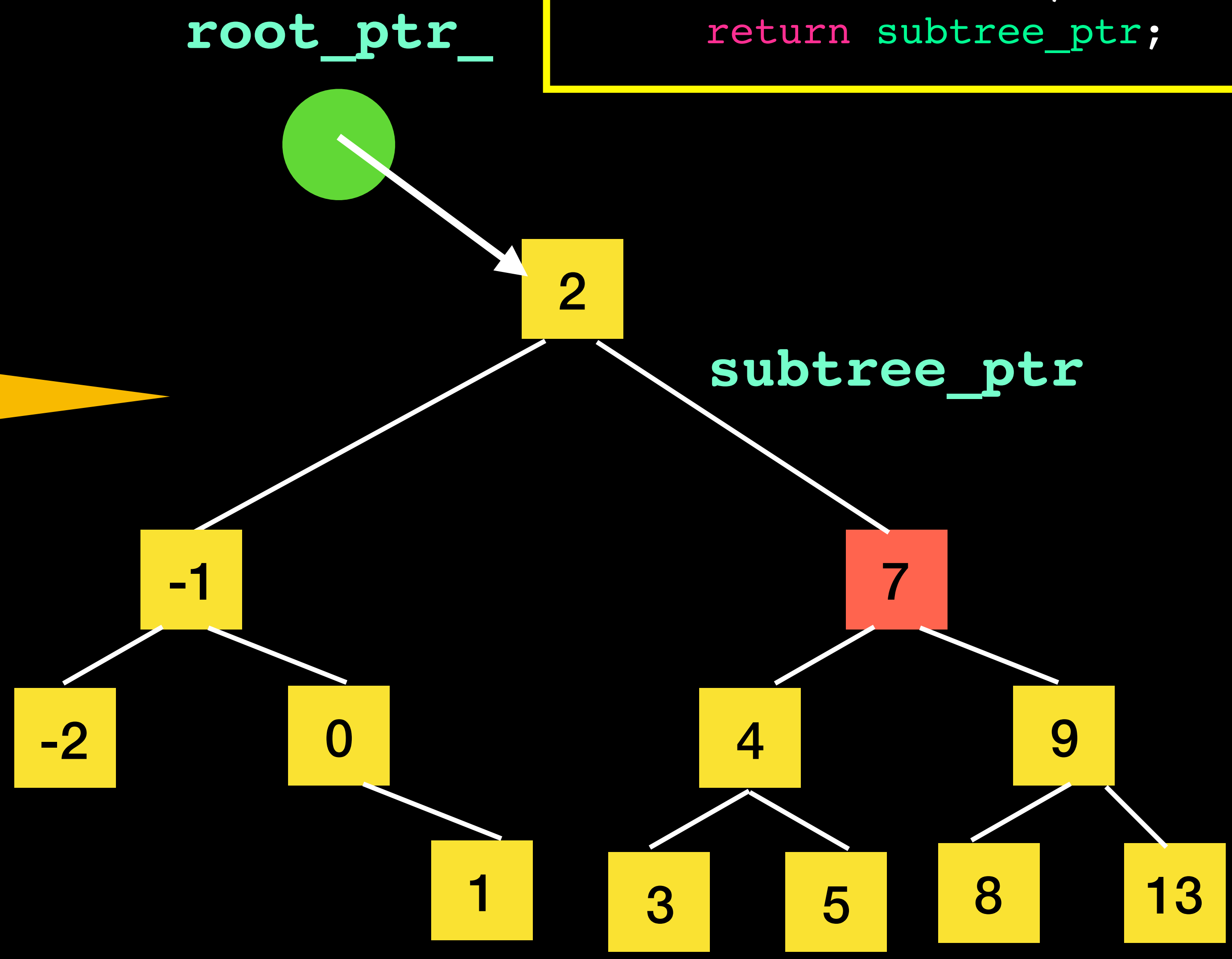


removeNode(subtree_ptr);

```
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

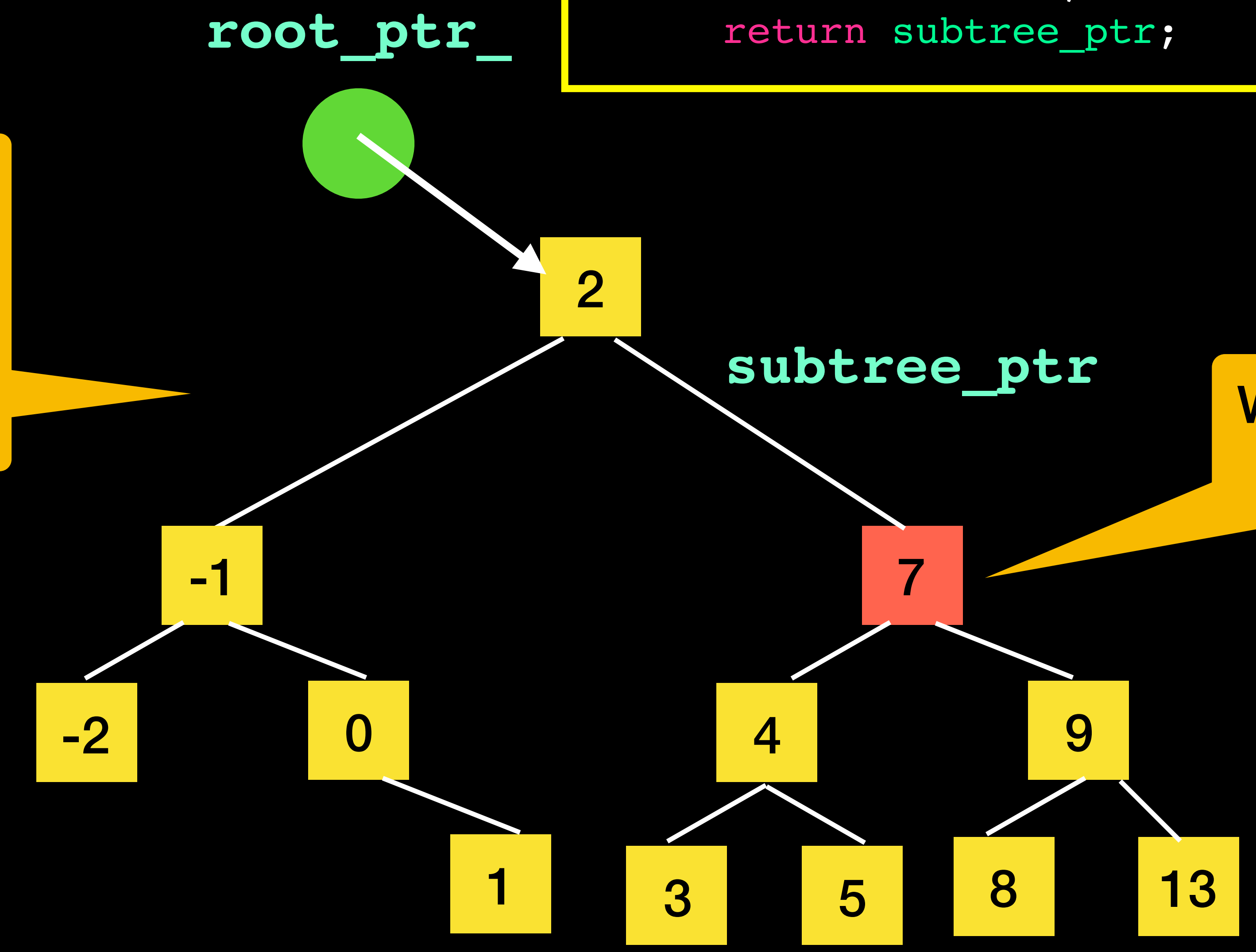
Find a node that is easy to remove and remove that one instead.



removeNode(subtree_ptr);

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

Case 3: target has 2 children



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

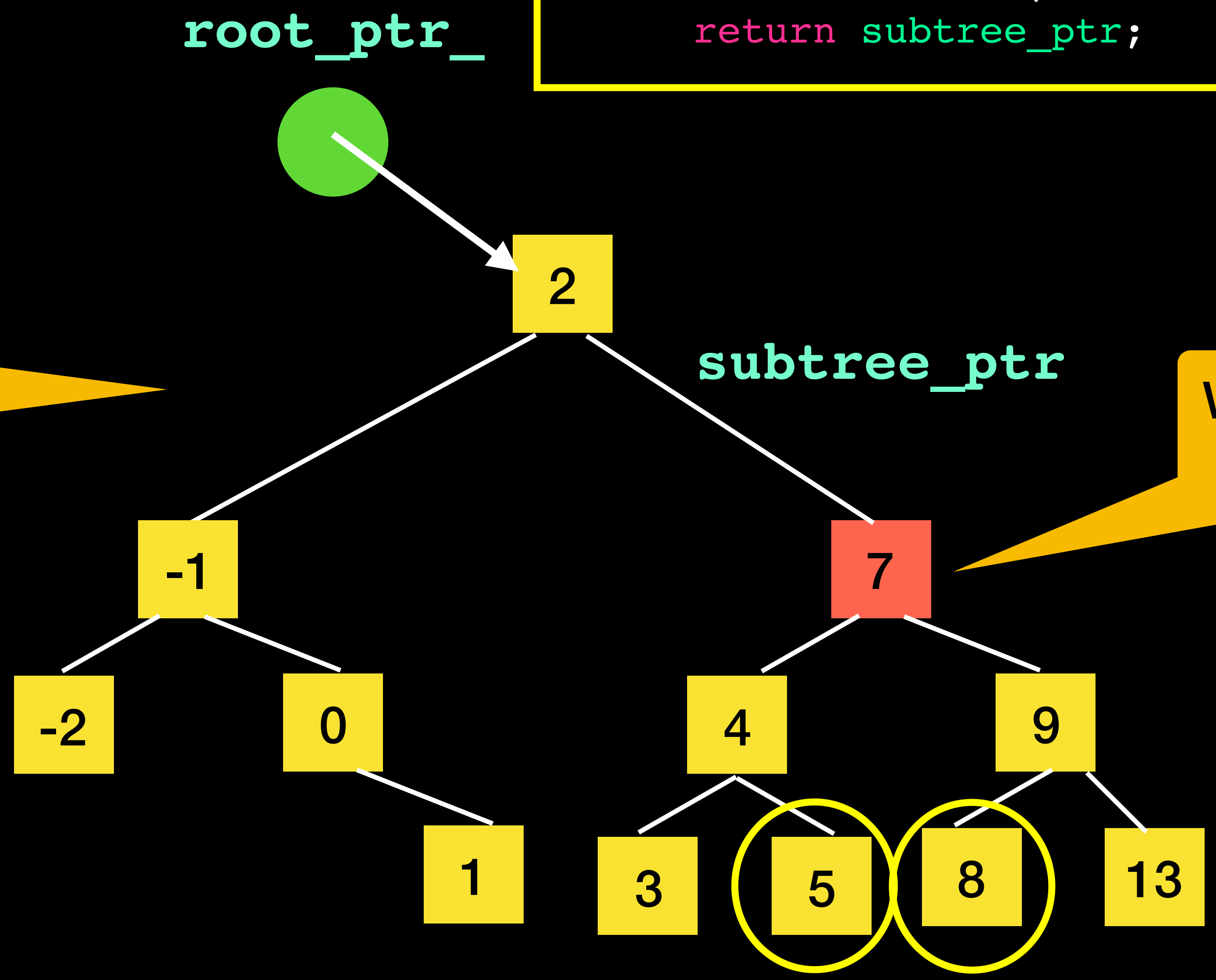
What value should we put here?

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.

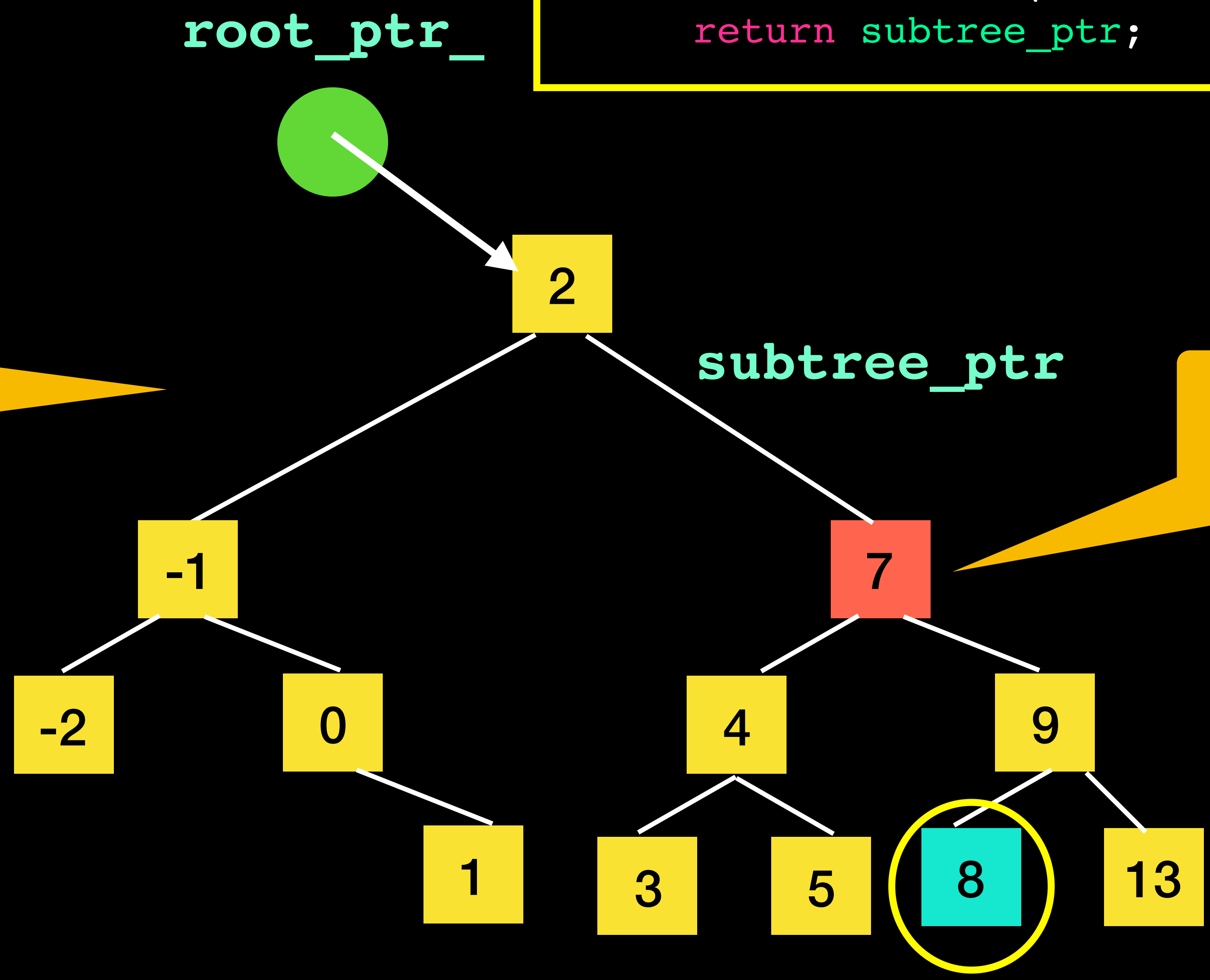


What value should we put here?

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.

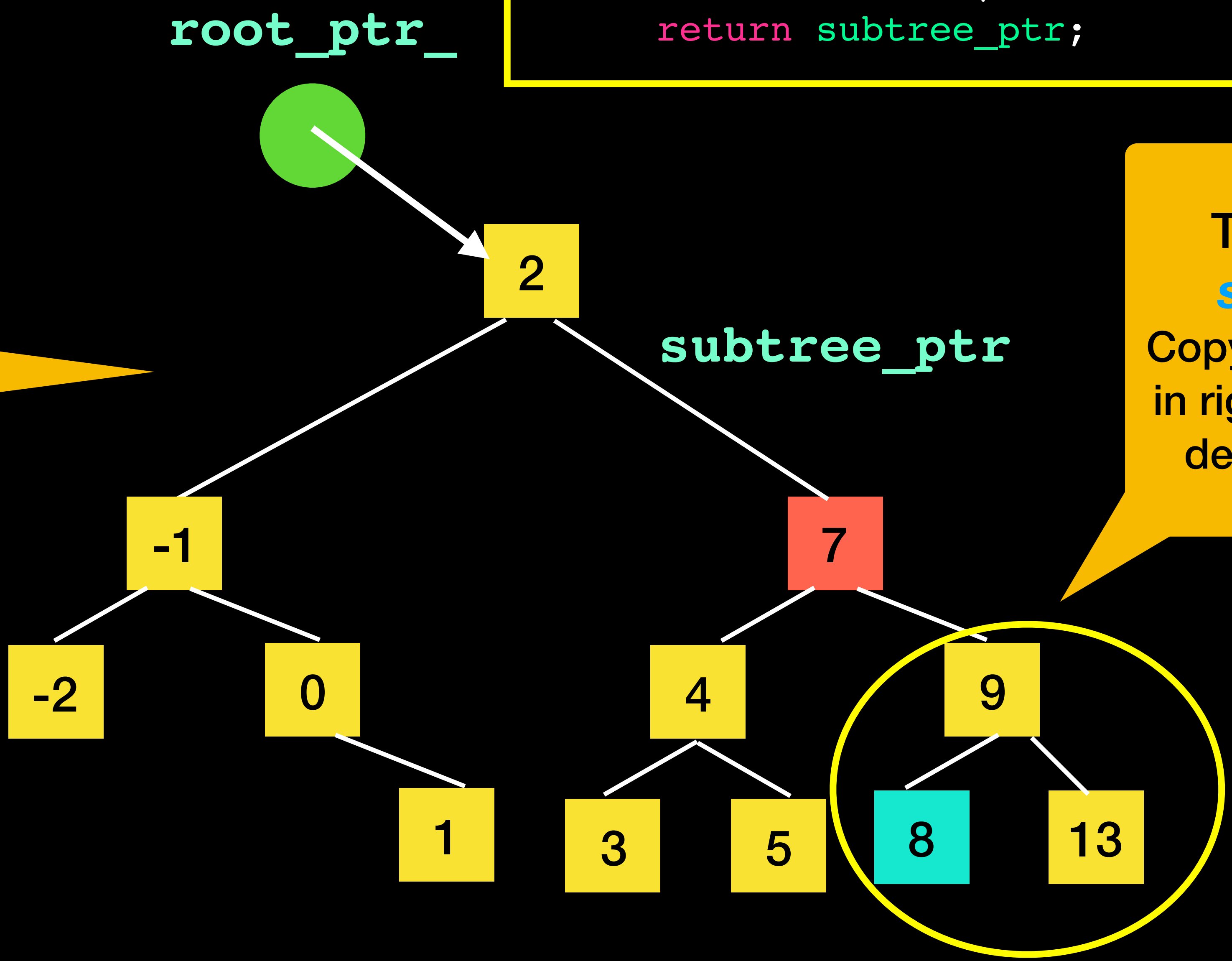
The *inorder successor*

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.



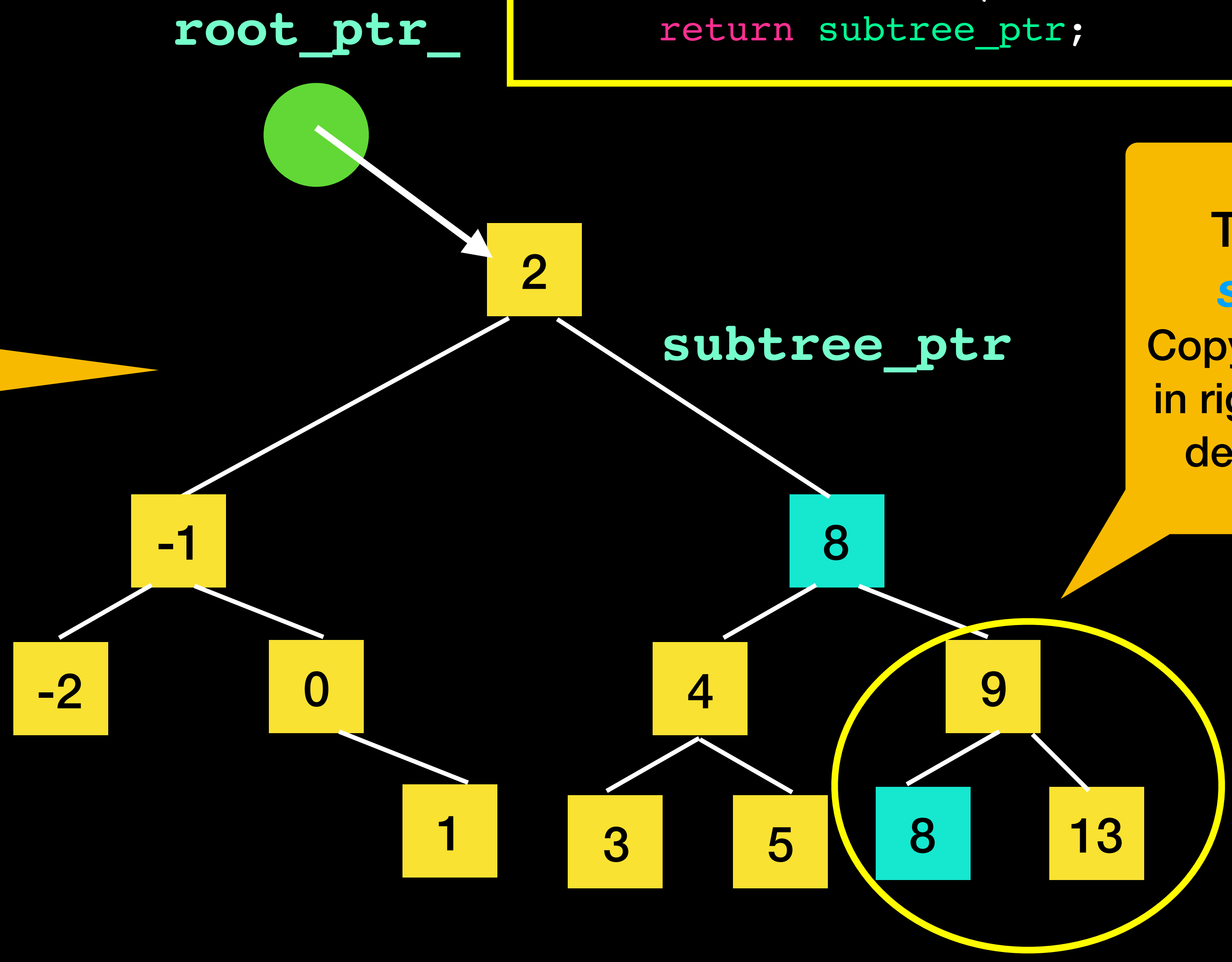
The *inorder successor:* Copy smallest value in right subtree and delete that node

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.



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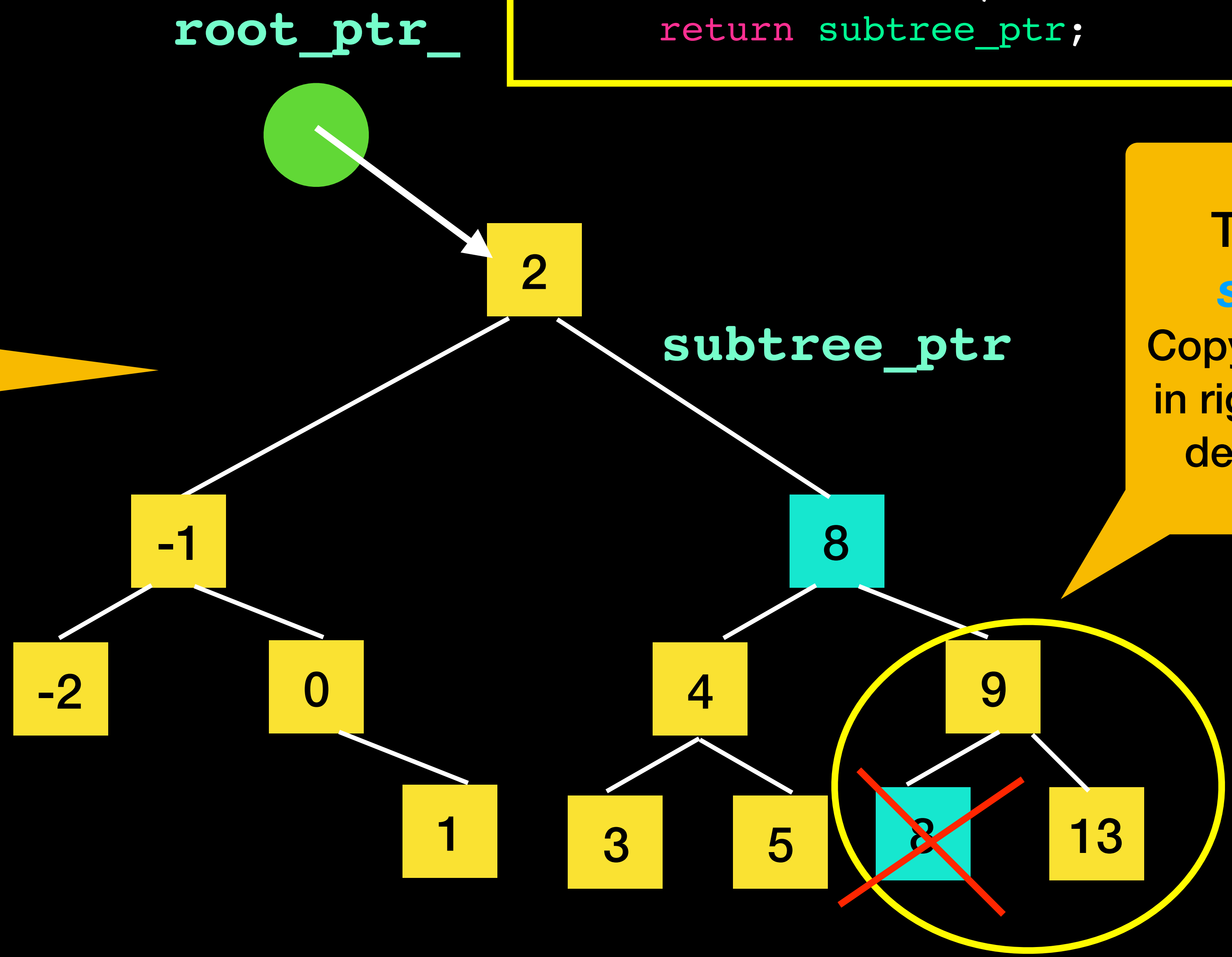

The *inorder successor:* Copy smallest value in right subtree and delete that node

removeNode(subtree_ptr);

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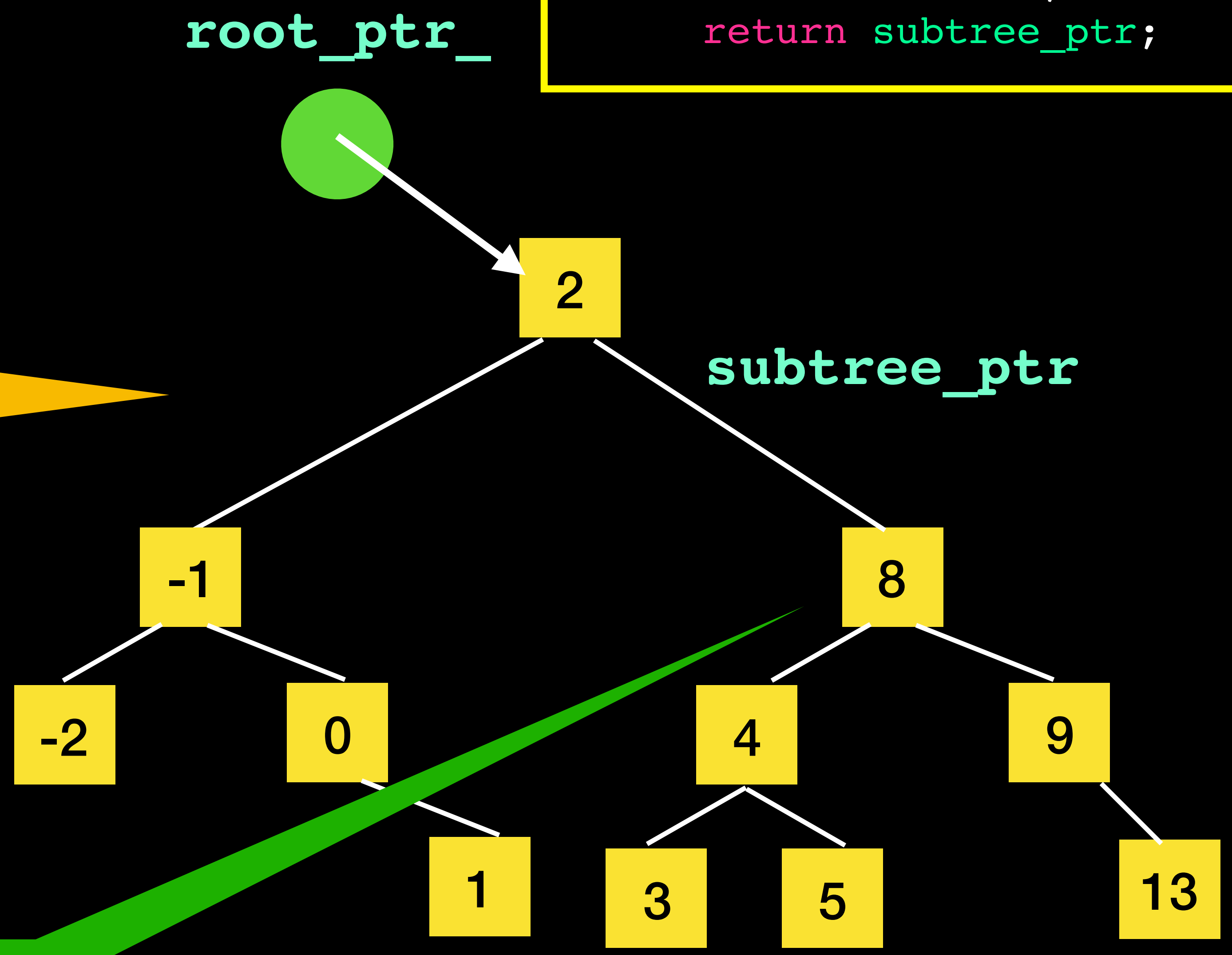


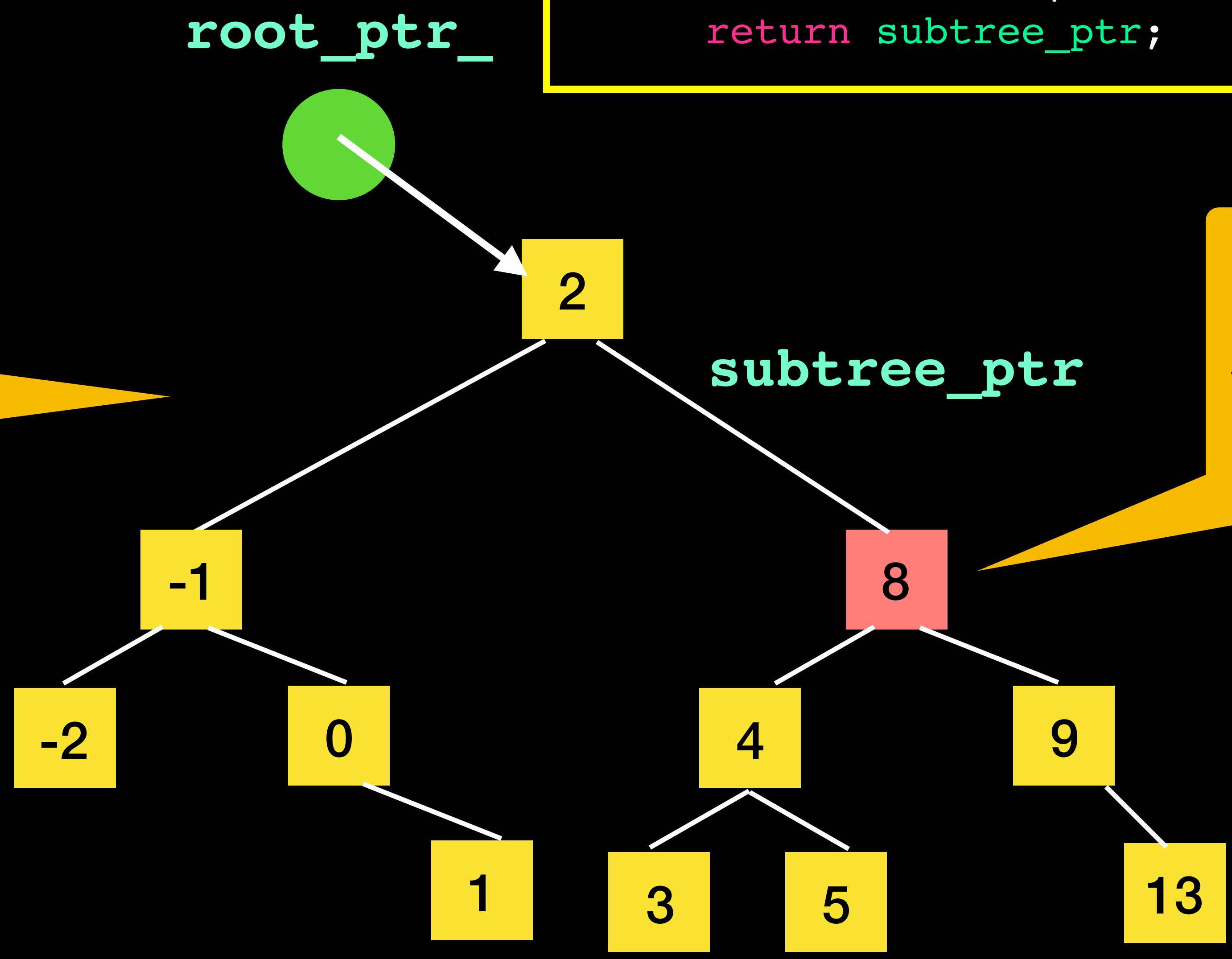
This operation will actually "reorganize" the tree

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.



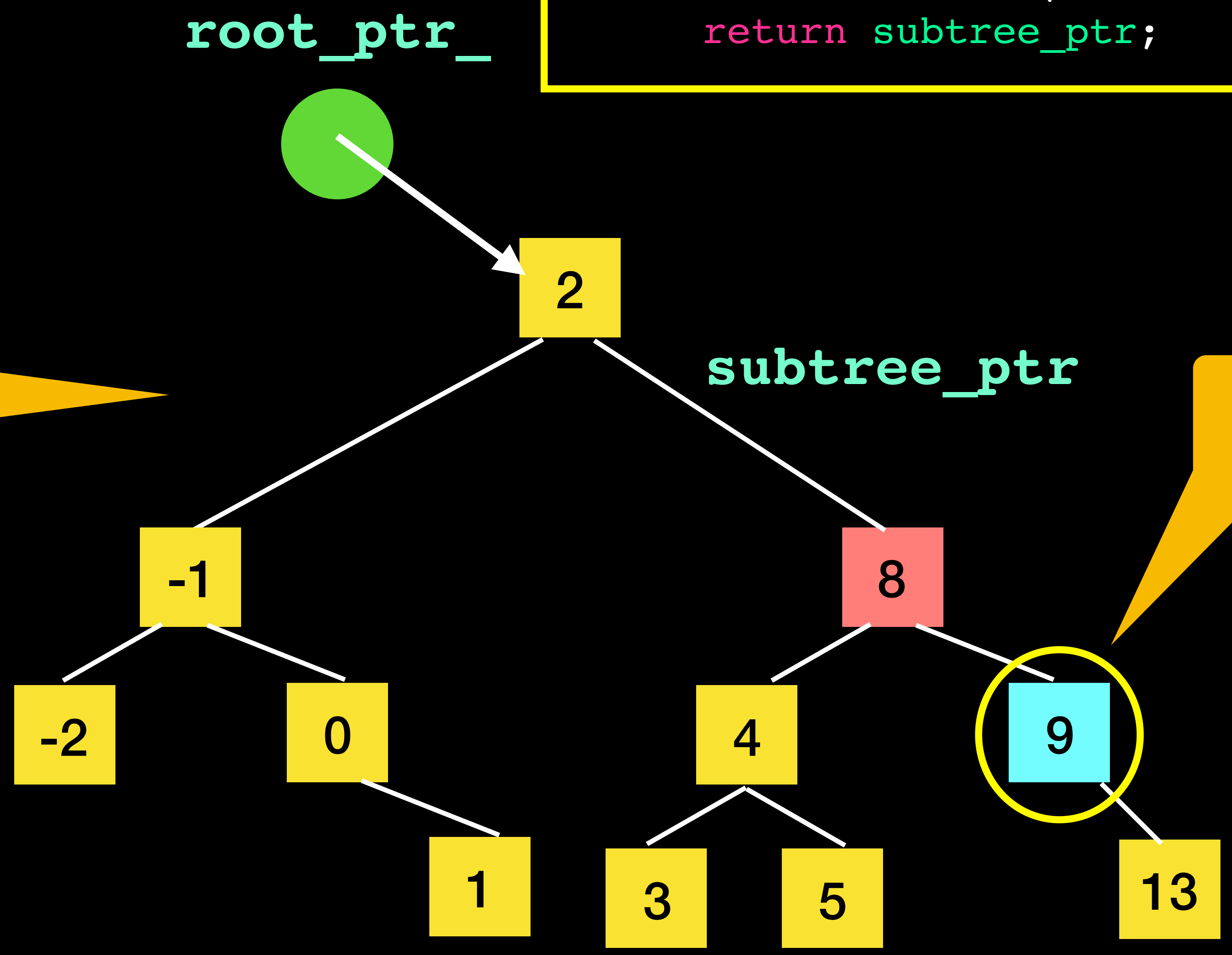
What about removing 8 now? What value should we put here?

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.



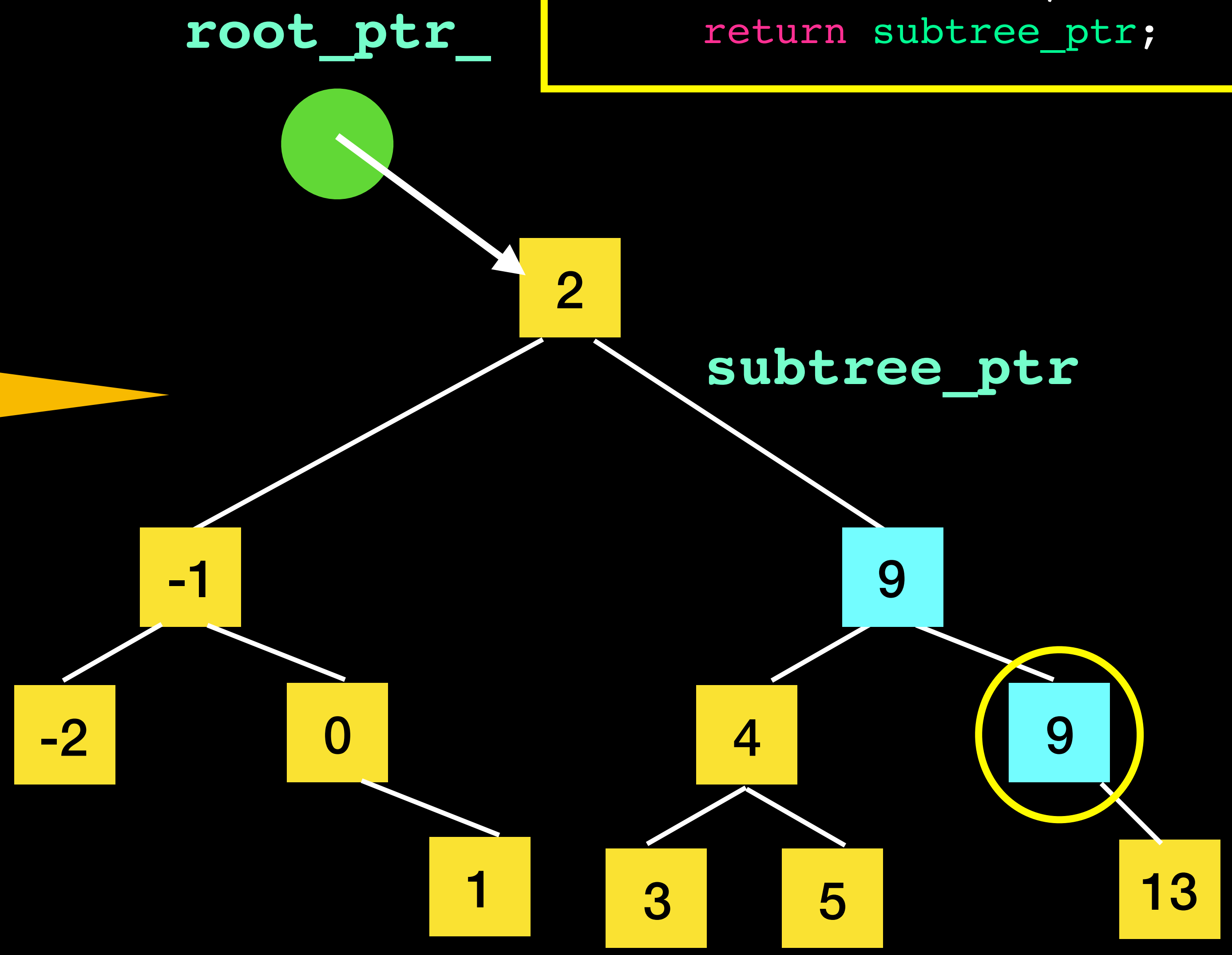
The *inorder successor*

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.



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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```
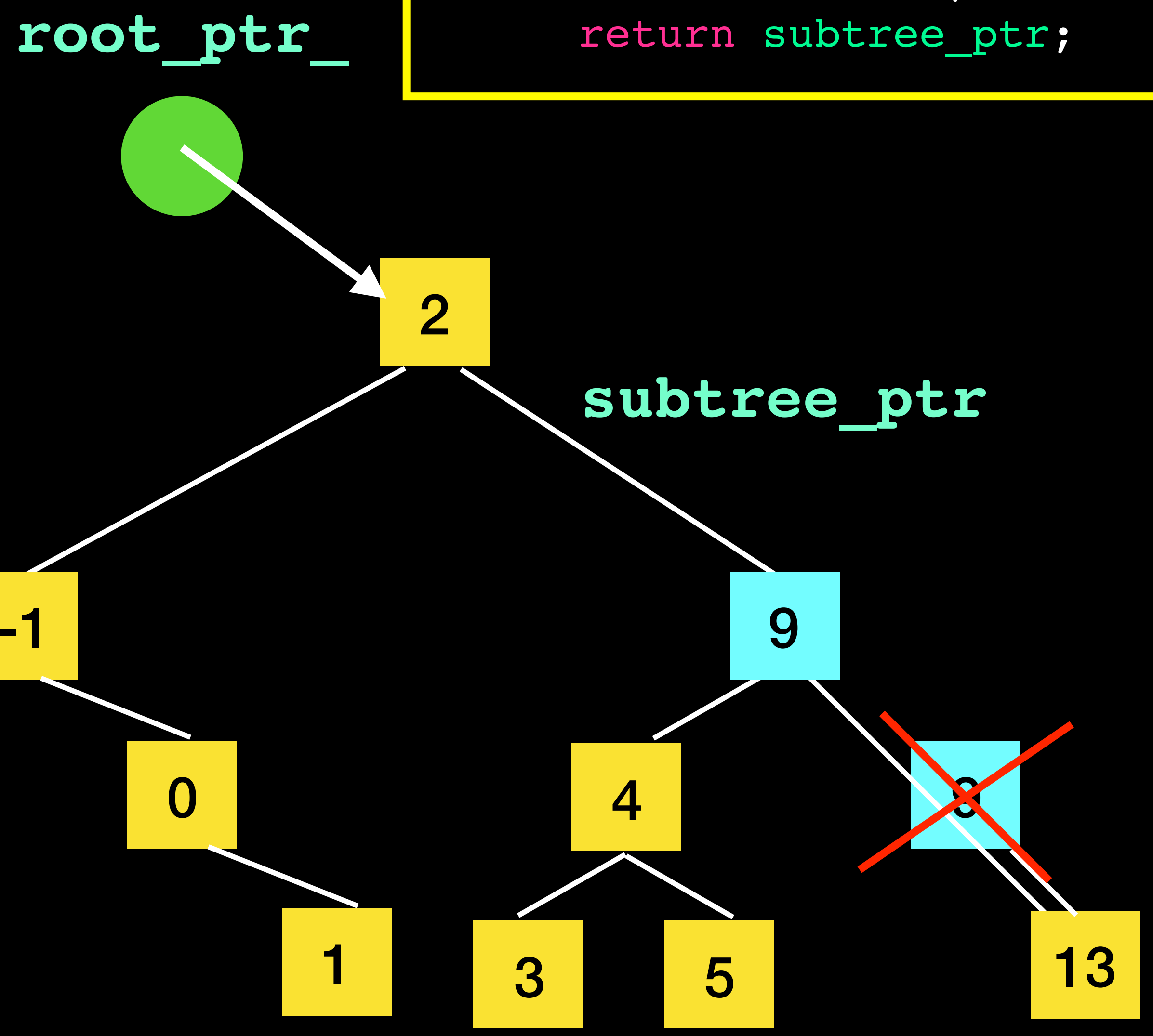

Case 3: target has 2 children

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

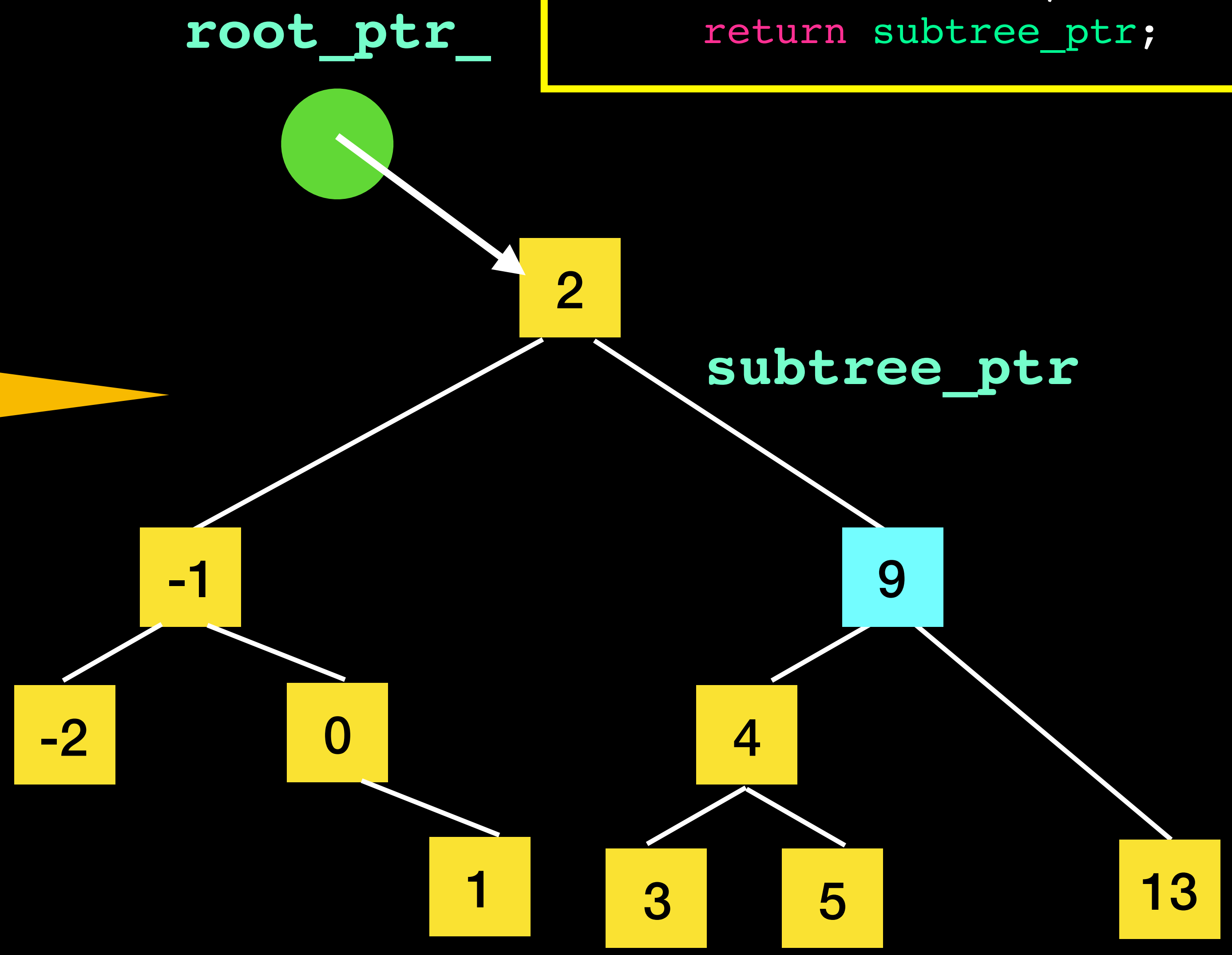


removeNode(subtree_ptr);

```
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(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 BinarySearchTree<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
```

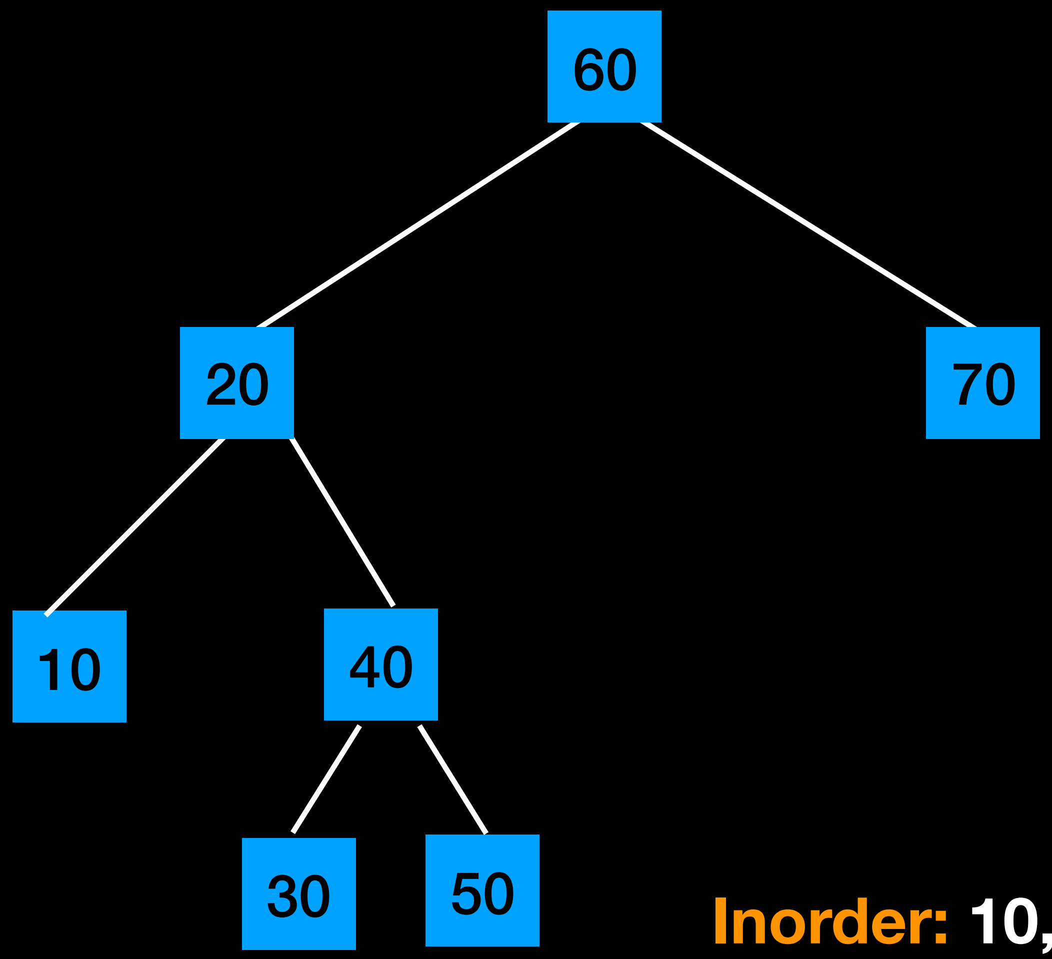
Traversals

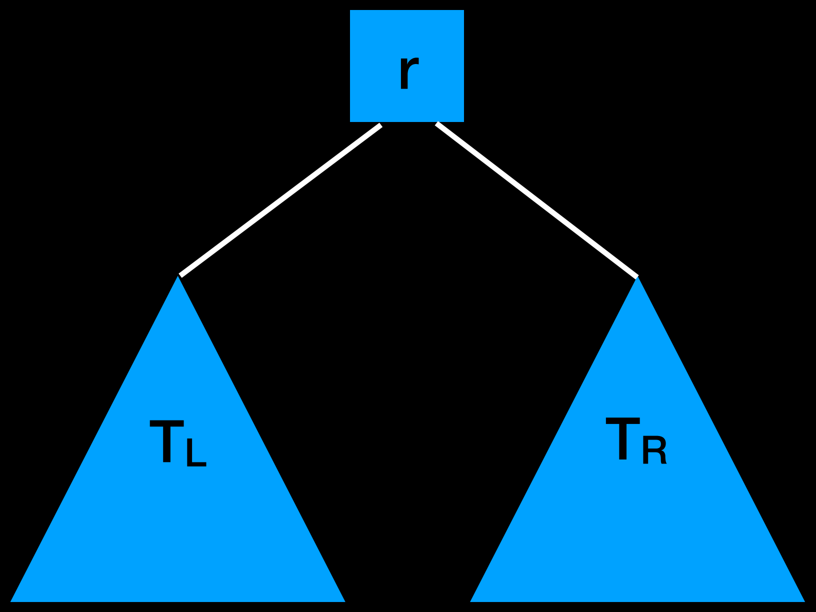
```
template<class T>
void BST<T>::preorderTraverse(Visitor<T>& visit) const
{
   preorder(visit, root_ptr_);
}  // end preorderTraverse

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**