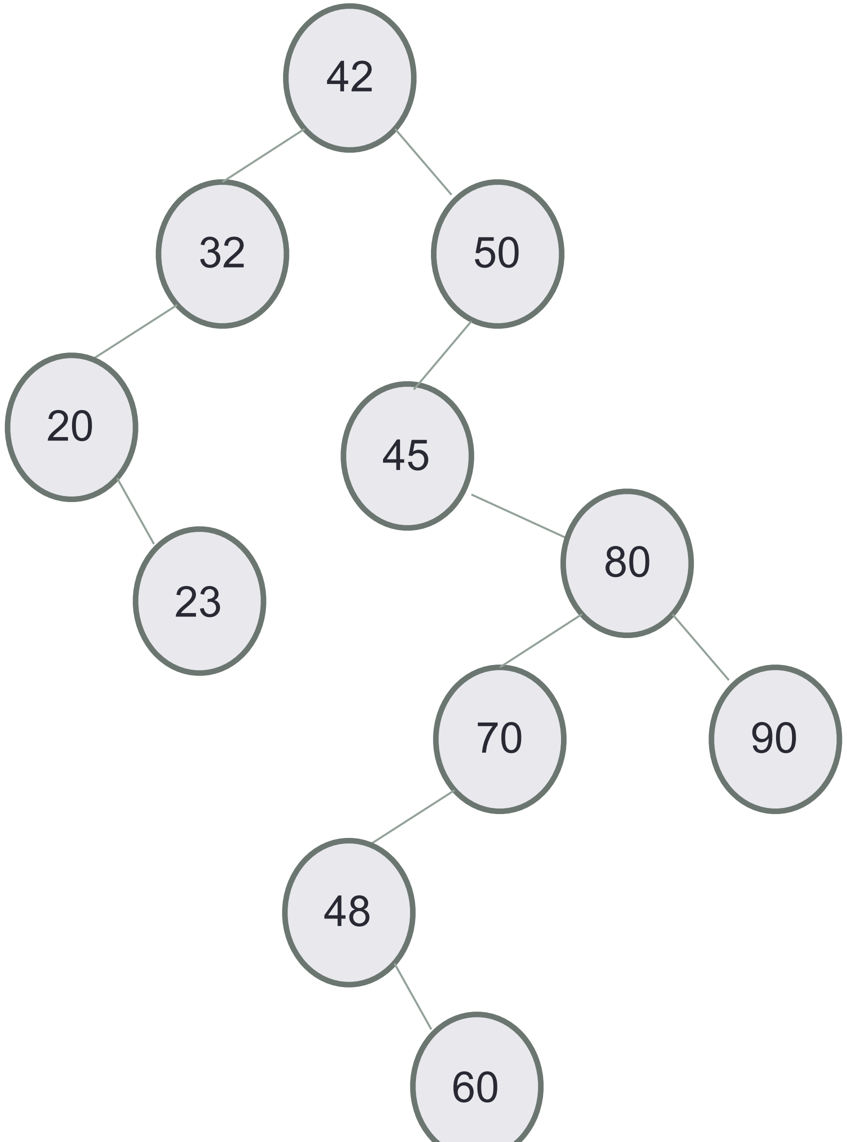
BINARY SEARCH TREES (CONTD)
C++ TEMPLATES

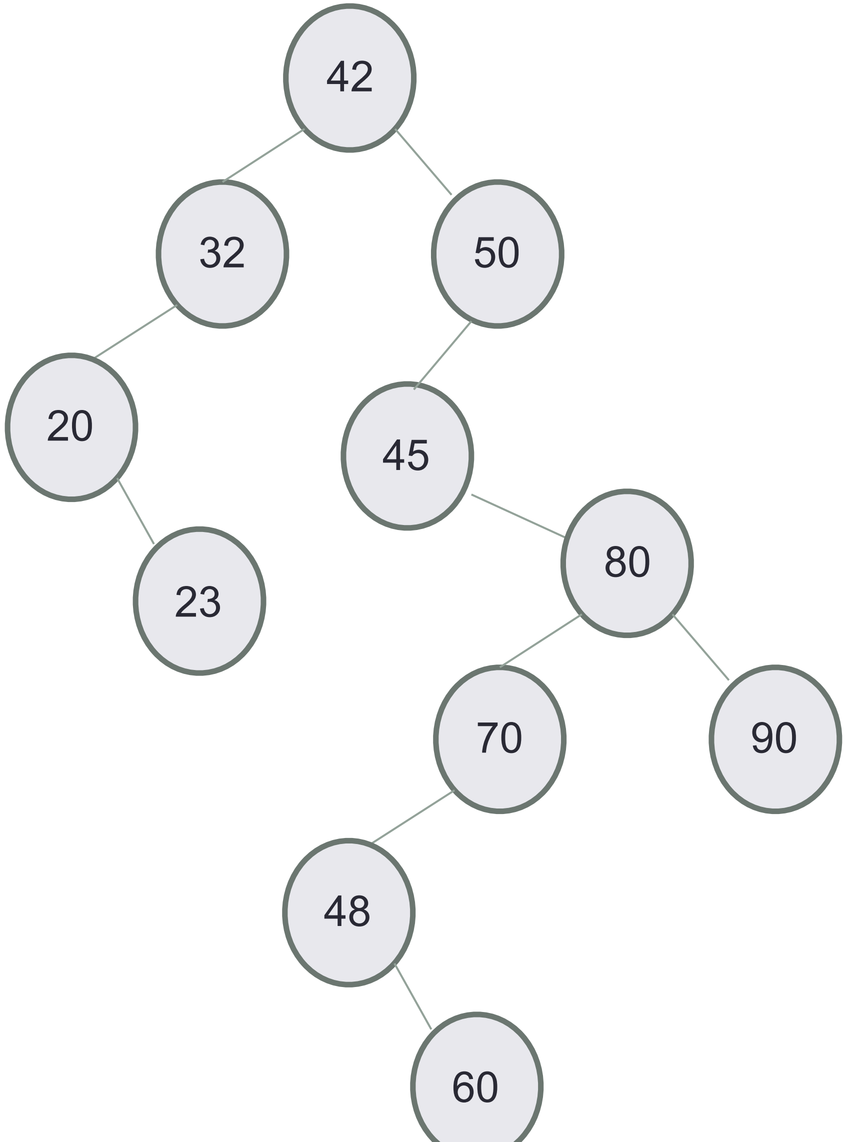
Problem Solving with Computers-II

Successor: Next largest element



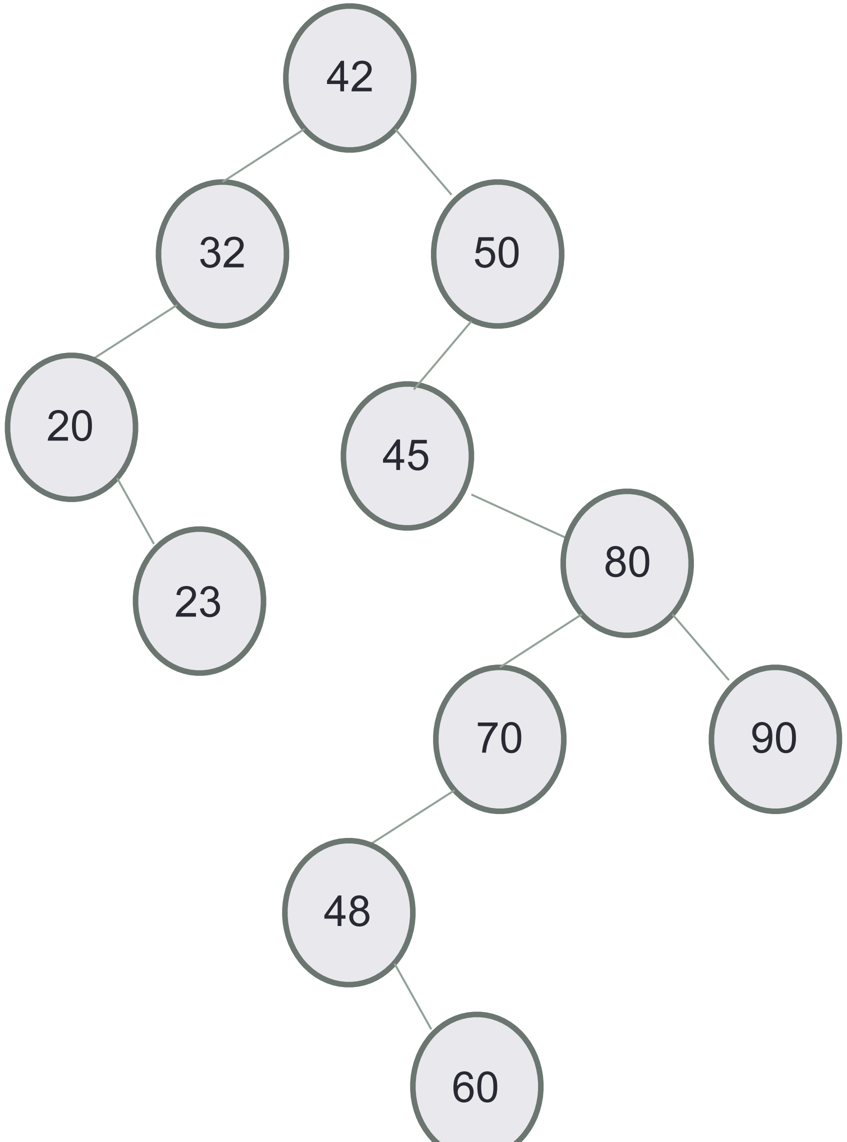
- What is the successor of 45?
- What is the successor of 48?
- What is the successor of 60?

Delete: Case 1: Node is a leaf node



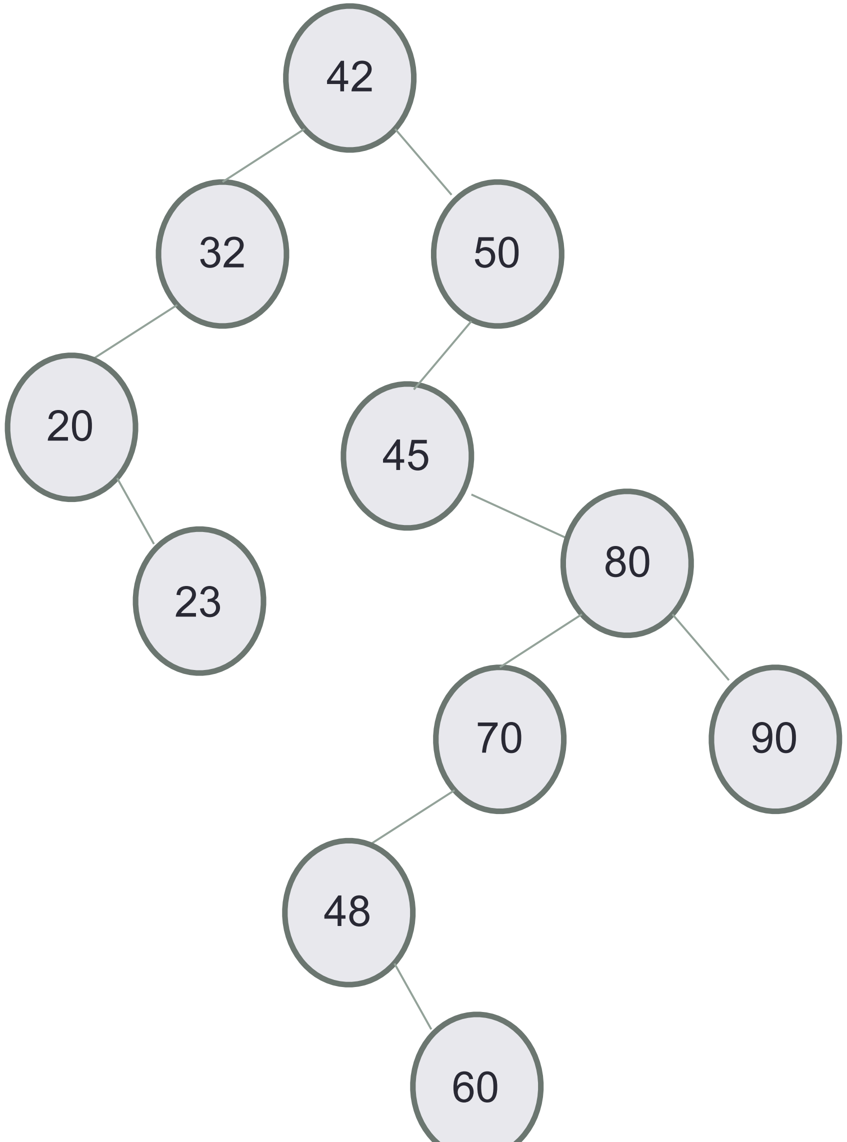
- Set parent's appropriate child pointer to null
- Delete the node

Delete: Case 2 Node has only one child



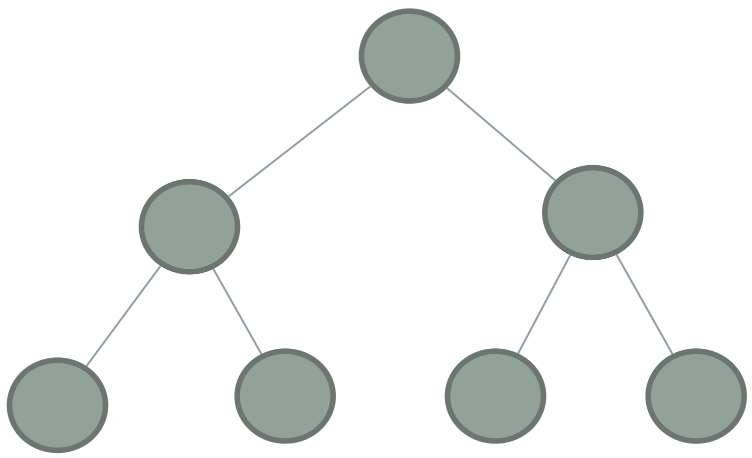
- Replace the node by its only child

Delete: Case 3 Node has two children

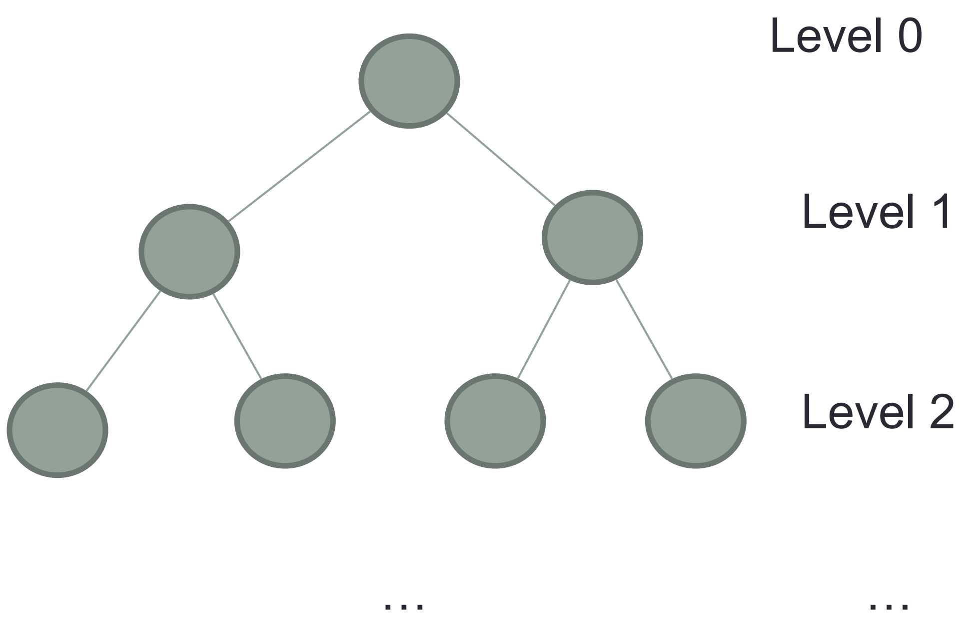


- Can we still replace the node with one of its children? Why or Why not?

Completely filled BSTs



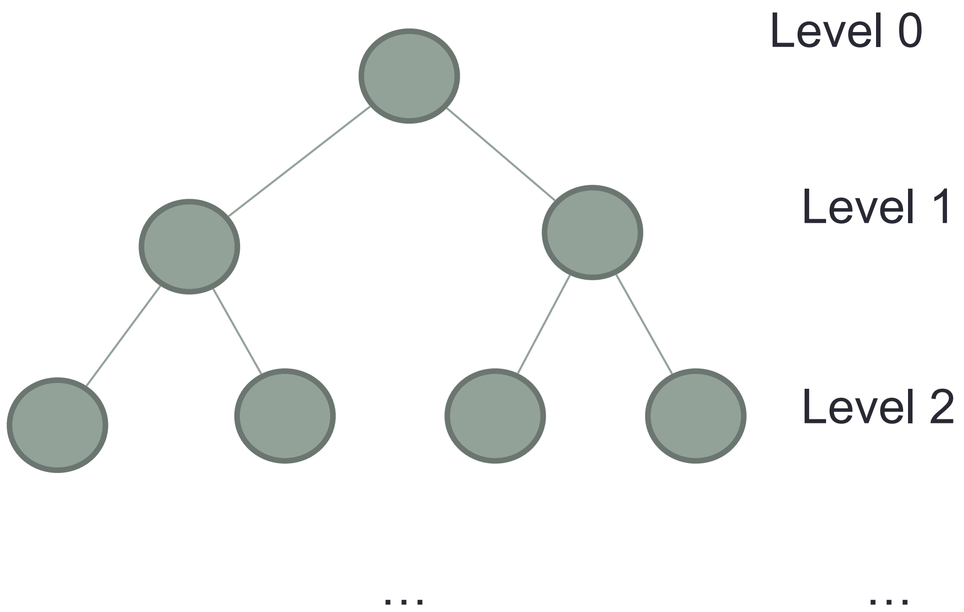
Relating H (height) and N (#nodes)
find is O(H), we want to find a f(N) = H



How many nodes are on level L in a completely filled binary search tree?

A. 2
B. L
C. 2*L
D. 2^L

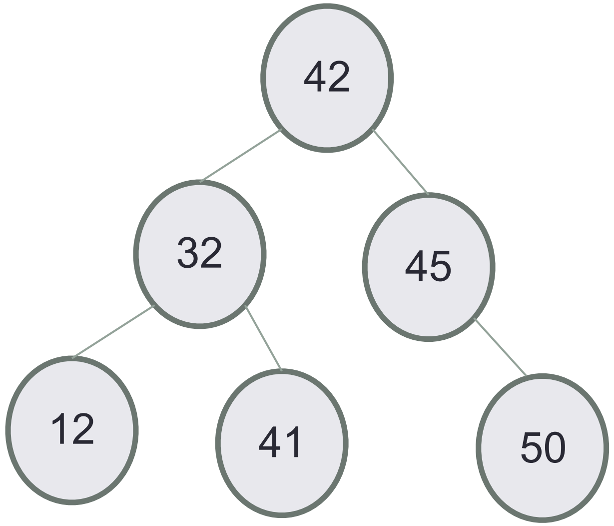
Relating H (height) and N (#nodes)
find is O(H), we want to find a f(N) = H



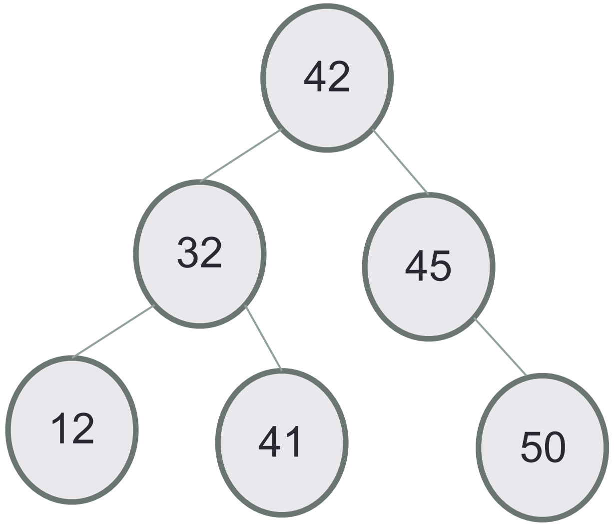
Finally, what is the height (exactly) of the tree in terms of N?

And since we knew finding a node was O(H), we now know it is $O(\log_2 N)$

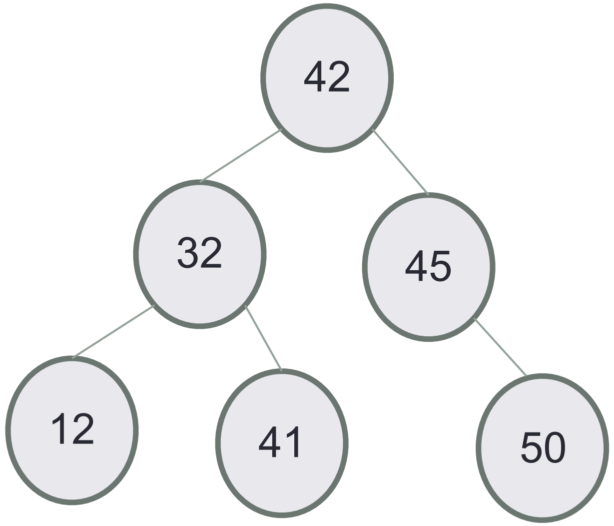
In order traversal: print elements in sorted order



Pre-order traversal: nice way to linearize your tree!



Post-order traversal: use in recursive destructors!



Sorted arrays, linked-lists, Balanced Binary Search Trees

Operations	Sorted Array	Balanced BST	Linked list
Min			
Max			
Successor			
Predecessor			
Search			
Insert			
Delete			
Print elements in order			

Finding the Maximum of Two Integers

- Here's a small function that you might write to find the maximum of two integers.

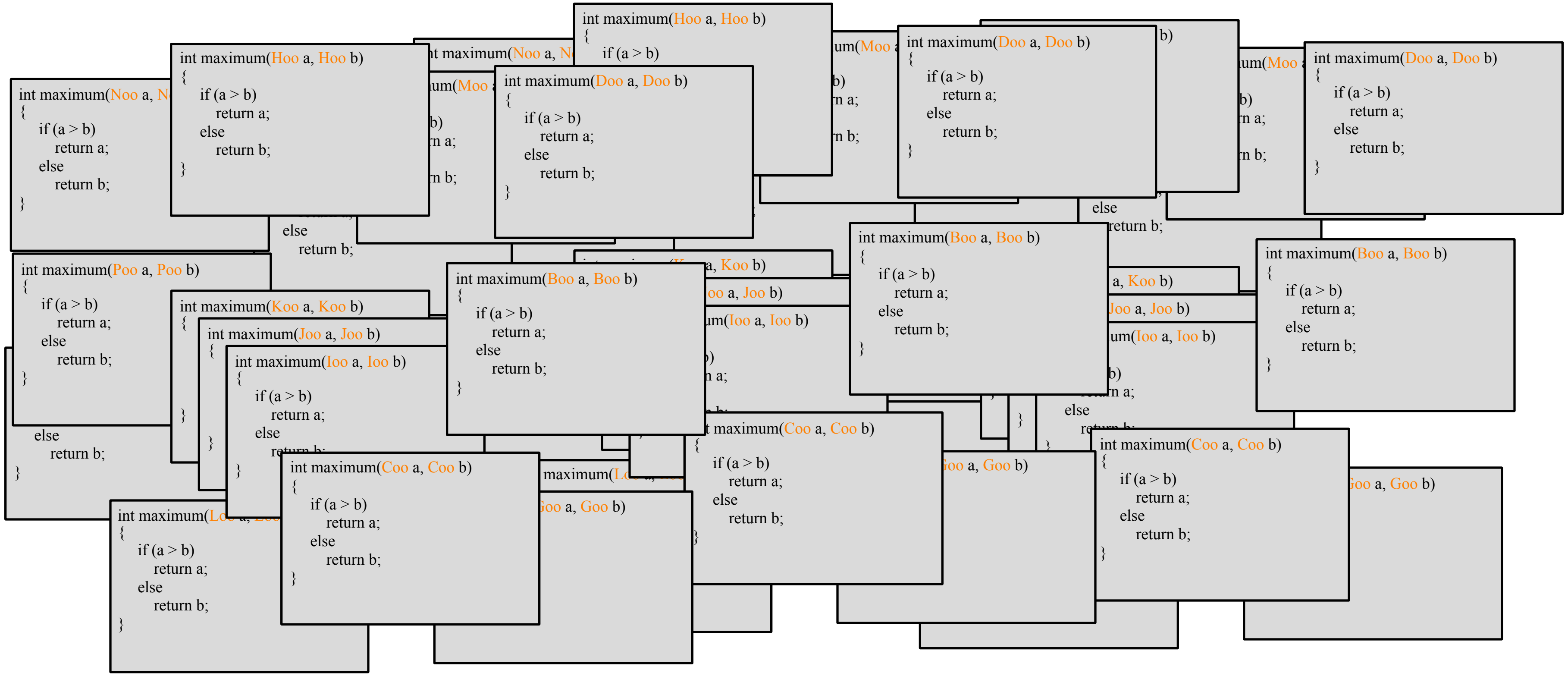
```
int maximum(int a, int b)
{
    if (a > b)
        return a;
    else
        return b;
}
```

Finding the Maximum of Two Points

```
point maximum(Point a, Point b)
{
    if (a > b)
        return a;
    else
        return b;
}
```

One Hundred Million Functions...

- Suppose your program uses 100,000,000 different data types, and you need a maximum function for each...



A Template Function for Maximum

- When you write a template function, you choose a data type for the function to depend upon...

```
template <class Item>
Item maximum(Item a, Item b)
{
    if (a > b)
        return a;
    else
        return b;
}
```

What are the advantages over typedef?

```
template <class Item>
Item maximum(Item a, Item b)
{
    if (a > b)
        return a;
    else
        return b;
}
```

```
typedef int item;
item maximum(item a, item b)
{
    if (a > b)
        return a;
    else
        return b;
}
```

Demo maximum.cpp

BST, with templates:

```
template<typename Data>

class BSTNode {
public:
  BSTNode<Data>* left;
  BSTNode<Data>* right;
  BSTNode<Data>* parent;
  Data const data;

  BSTNode( const Data & d ) :
     data(d) {
    left = right = parent = 0;
  }

};
```

BST, with templates:

```
template<typename Data>

class BSTNode {
public:
  BSTNode<Data>* left;
  BSTNode<Data>* right;
  BSTNode<Data>* parent;
  Data const data;

  BSTNode( const Data & d ) :
     data(d) {
    left = right = parent = 0;
  }

};
```

How would you create **a BSTNode object** on the runtime stack?

A. BSTNode n(10);
B. BSTNode<int> n;
C. BSTNode<int> n(10);
D. BSTNode<int> n = new BSTNode<int>(10);
E. More than one of these will work

{ } syntax OK too

BST, with templates:

```
template<typename Data>

class BSTNode {
public:
  BSTNode<Data>* left;
  BSTNode<Data>* right;
  BSTNode<Data>* parent;
  Data const data;

  BSTNode( const Data & d ) :
     data(d) {
    left = right = parent = 0;
  }

};
```

How would you create a **pointer** to BSTNode with integer data?

A. BSTNode* nodePtr;
B. BSTNode<int> nodePtr;
C. BSTNode<int>* nodePtr;

BST, with templates:

```
template<typename Data>

class BSTNode {
public:
  BSTNode<Data>* left;
  BSTNode<Data>* right;
  BSTNode<Data>* parent;
  Data const data;

  BSTNode( const Data & d ) :
     data(d) {
    left = right = parent = 0;
  }

};
```

Complete the line of code to create a new BSTNode object with int data on the heap and assign nodePtr to point to it.

```
BSTNode<int>* nodePtr
```

Working with a BST

```
template<typename Data>
class BST {

private:

  /** Pointer to the root of this BST, or 0 if the BST is
empty */
  BSTNode<Data>* root;

public:

  /** Default constructor. Initialize an empty BST. */
  BST() : root(nullptr){  }

  void insertAsLeftChild(BSTNode<Data>* parent, const Data &
item)
  {
     // Your code here
  }
```

Working with a BST: Insert

```
void insertAsLeftChild(BSTNode<Data>* parent, const Data &
item)
  {
     // Your code here
  }
```

Which line of code correctly inserts the data item into the BST as the left child of the parent parameter.

A. `parent.left = item;`
B. `parent->left = item;`
C. `parent->left = BSTNode(item);`
D. `parent->left = new BSTNode<Data>(item);`
E. `parent->left = new Data(item);`

Working with a BST: Insert

```
void insertAsLeftChild(BSTNode<Data>* parent, const Data &
item)
{
    parent->left = new BSTNode<Data>(item);
}
```

Is this function complete? (i.e. does it to everything it needs to correctly insert the node?)

A. Yes. The function correctly inserts the data
B. No. There is something missing.

Working with a BST: Insert

```
void insertAsLeftChild(BSTNode<Data>* parent, const Data &
item)
{

    parent->left = new BSTNode<Data>(item);


}
```

Template classes

Using a Typedef Statement:

```
class bag
{
public:
    typedef int value_type;
    . . .
```

Using a Template Class:

```
template <class Item>
class bag
{
public:
    typedef Item value_type;
    . . .
```

Template classes: Non-member functions

```
bag operator +(const bag& b1, const bag& b2)...
```

```
template <class Item>
bag<Item> operator +(const bag<Item>& b1, const bag<Item>& b2)...
```

Template classes: Member function prototype

- Rewrite the prototype of the member function "count" using templates

Before (without templates)

```
class bag{
        public:
                typedef std::size_t size_type;
                ….
                size_type count(const value_type& target) const;
                …..
};
```

Template classes: Member function definition

```
bag::size_type bag::count(const value_type& target) const ...
```

The function's return type is specified as bag::size_type. But this return type is specified before the compiler realizes that this is a bag member function. So we must put the keyword *typename* before bag<Item>::size_type. We also use Item instead of value_type:

```
template <class Item>
typename bag<Item>::size_type bag<Item>::count
    (const Item& target) const ...
```

Template classes: Including the implementation

```
#include "bag4.template"   // Include the implementation.
```

How to Convert a Container Class to a Template

1. The template prefix precedes each function prototype or implementation.
2. Outside the class definition, place the word `<Item>` with the class name, such as `bag<Item>`.
3. Use the name `Item` instead of `value_type`.
4. Outside of member functions and the class definition itself, add the keyword *typename* before any use of one of the class's type names. For example:

   `typename bag<Item>::size_type`

5. The implementation file name now ends with `.template` (instead of `.cxx`), and it is included in the header by an include directive.
6. Eliminate any using directives in the implementation file. Therefore, we must then write `std::` in front of any Standard Library function such as `std::copy`.
7. Some compilers require any default argument to be in both the prototype and the function implementation.

Review and demo bag4