Outline

Templates Allow Code For Different Types

Python doesn't associate types with variable names, so the same code might work for different types.
The function `Maximum` finds the larger of two numbers having the same type (as long as the operator `>` is defined for that type). For example, the types `int`, `float`, and even `Rational` will work here:

```
def Maximum(a, b):
   if a > b:
      return a
   else:
      return b
```

Dynamic typing is possible in Python because the interpretor waits until it is ready to execute a Python statement before converting it to machine language.

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C++: Different Versions For Different Types

In C++ we have learned that C++ variables must be defined with a fixed type, so that the compiler can generate the specific machine instructions needed to manipulate the variables.

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

C++: Different Versions For Different Types

```
double maximum_double(double a, double b)
{
   if (a > b){
      return a;
   }
   else {
      return b;
   }
}
```

There is a *template* mechanism in C++ that allows to write functions and classes with similar to Python's functionalities.

Template Function Example: C++

We used **typedef** statement in the previous chapter, however it doesn't allow the same code to be used for multiple types since the generated machine language code must be specific for the type.

```
template <typename Item> // or template <class Item>

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

Comment: you may use any legal identifier instead of `Item`, but commonly `Item` or `Type` are used.

Template Function Example: C++

C++ templates allow us to write one version of the code, and the compiler automatically generates different versions of the code to each data type as needed.

```
 int main()
{
   int a=3, b=4;
   double x=5.5, y=2.0;

   cout << maximum(a, b) << endl;
   cout << maximum(x, y) << endl;
   return 0;
}
```

Template Function Example: C++

- The C++ compiler doesn't generate any code if no template function is called
- Depending on compiler, it may or may not catch syntax errors in template functions that are not called, hence
- It is important to test all the template functions
- The term *instantiate* is used to indicate that the compiler generates the code for a specific type.
  In our previous example, the compiler instantiates an **int** and **double** versions of the **maximum** function.

C++ Template Classes: Container Classes

We can also write classes using templates.

Recall container classes which provide certain access to each item (Stack, Queue, ...) — all behave the same for different data types of the items contained.

Iterators should be provided to allow abstract traversal (without needing to know how the container is implemented).

C++ template classes are able to provide this.

Similarly to the function's template,

- As a container class is used for some datatype, the compiled template class for that type is instantiated.
- No code for a template class instance is compiled until it is needed.

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The Standard Template Library

- The *Standard Template Library* (*STL*) implements most of the common container classes as C++ template classes.
- It is now a standard part of the C++ library.
- It defines a wide variety of containers for classes which implement a few basic operations. (For example, < for binary search trees or priority queues.)
- It provides iterators for these classes.

The vector Template Class: Example 1

One of the simpler *STL* classes is the **Vector** class. It provides functionality similar to the dynamic array classes we developed.

```
#include<vector>

   ...
int main()
{
   vector<int> iv;
   vector<double> dv;
   int i;

   for (i=0; i<10; ++i) {
      iv.push_back(i);
      dv.push_back(i + 0.5); }

   for (i=0; i< 10; ++i) {
      cout << iv[i] << " " << dv[i] << endl; }
   return 0;
}
```

The vector Template Class; example 2

```
#include <iostream>
#include <vector>

using namespace std;

int main()
{
   //create a vector with 5 int elems, each set to 3
   vector<int> iv(5, 3);
   //create a vector with 5 double elems, set to 0.0
   vector<double> dv(5);
   int i;

   for (i=0; i<5; ++i) {
      cout << iv[i] << " " << dv[i] << endl; }
}
```

The vector Template Class: example 3

```
#include <iostream>
#include <vector>

using namespace std;

int main()
{
   vector<int> iv;
   vector<int>::iterator iter;
   int i;

   for (i=0; i<10; ++i) {
      iv.push_back(i);
   }
   for (iter=iv.begin(); iter != iv.end(); ++iter) {
      cout << *iter << endl;
   }
   return 0;
}
```

Vector CLASS - CONCLUSION

Vector class is implemented as a dynamic array, so its use and efficiency are similar to the C++ dynamic array class we developed and the built-in Python list.

You can visit http://www.cplusplus.com/reference/vector/vector/ for the list of Vector class methods, as well as pages 433–444 in our book.

The *STL* - Conclusion

The *Standard Template Library* provides template class implementations of a queue, list, set, and hash tables along with algorithms and iterators to use with a number of classes.

User-Defined Template Classes

- The header file, `<classname>.h`, is the same as for ordinary classes, but class definition has a template data type, a "wild card" typename instead of a normal type like `int` or `double`.
- The class definition is preceded by `template <typename T>` where `T` can be any identifier not in use.
  (for example, `Item` in the `Stack` class.)
- Whenever the template data type is needed in a function declaration, it is used like an ordinary type name:
  `bool pop(Item &item);`
- The last line of the header file includes the implementation file:
  `#include "<classname>.template"`
  (which does **not** include the header file).

User-Defined Template Classes

```
 //Stack.h
...
#include<cstdlib> //for NULL
template <typename Item>
class Stack {
public:
   Stack();
   ~Stack();

   int size() const { return size_; }
   bool top(Item &item) const;

   bool push(const Item &item);
   bool pop(Item &item);
```

User-Defined Template Classes

```
 private:
// prevent these methods from being called
   Stack(const Stack &s);
   void operator=(const Stack &s);

   void resize();

   Item *s_;
   int size_;
   int capacity_;
};
#include "Stack.template"
```

User-Defined Template Classes

```
 // Stack.template
template <typename Item>
Stack<Item>::Stack() constructor
{
   s_ = NULL;          size_ = 0;          capacity_ = 0;
}

template <typename Item>
Stack<Item>::~Stack() destructor
{
   delete [] s_;
}
```

The rest see in Stack.template

Comment: we could put all the defs at the end of the header file Stack.h

User-Defined Template Classes

```
 // test_Stack.cpp
#include "Stack.h"
int main()
{
   Stack<int> int_stack;
   Stack<double> double_stack;
   int_stack.push(3);
   double_stack.push(4.5);
   return 0;
}
```

Outline

Priority Queues

- A Priority Queue is a container for items with different **priorities**.
- The interface of a Priority queue resembles that of a queue, since an item can be put into the priority queue (**enqueued**) at any time.
- The item with the highest priority is the first one to be removed from the priority queue (**dequeued**). (Rather than first-in-first-out, as a normal queue, a priority queue is **best-in-first-out**.)

Priority Queues

Applications:

- A hospital emergency room.
- An event handler in a computer's operating system. Different processes running at the same time share access to the CPU. Essential services have higher priority than user applications.
- Pattern-matching algorithms (voice or handwriting recognition) where input is compared with stored patterns. The best matches will get the highest scores and saved in a priority queue for further processing.

Priority Queue in Python

This would be the interface to a Python class implementing the Priority Queue ADT:

```
class PQueue(object):
   def enqueue(self, item, priority):
      '''post:  item is inserted with specified priority'''

   def first(self):
      ''''''post:  returns, but does not remove, highest priority
item'''

   def dequeue(self):
      ''''''post:  removes and returns the highest priority
item'''

   def size(self):
      '''post:  returns the number of items'''
```

Implementing a Priority Queue As A Heap

Worst-case running times for structures we have seen:

- Sorted (by priority) list: `enqueue` is $\Theta(n)$.
  An array would allow $\Theta(\log n)$ to find the position (Binary search), but $\Theta(n)$ is needed to insert by moving the higher items out of the way.
- Linked list: `enqueue` or `dequeue` is $\Theta(n)$.
  If the linked list is sorted by priority, it takes $\Theta(n)$ to find the position at which to insert the item, and $\Theta(1)$ to insert it.
  Otherwise (if we will append items at the end of the list and search by highest priority), `dequeue` takes $\Theta(n)$ to go through all items in an unsorted list to find the highest priority item.

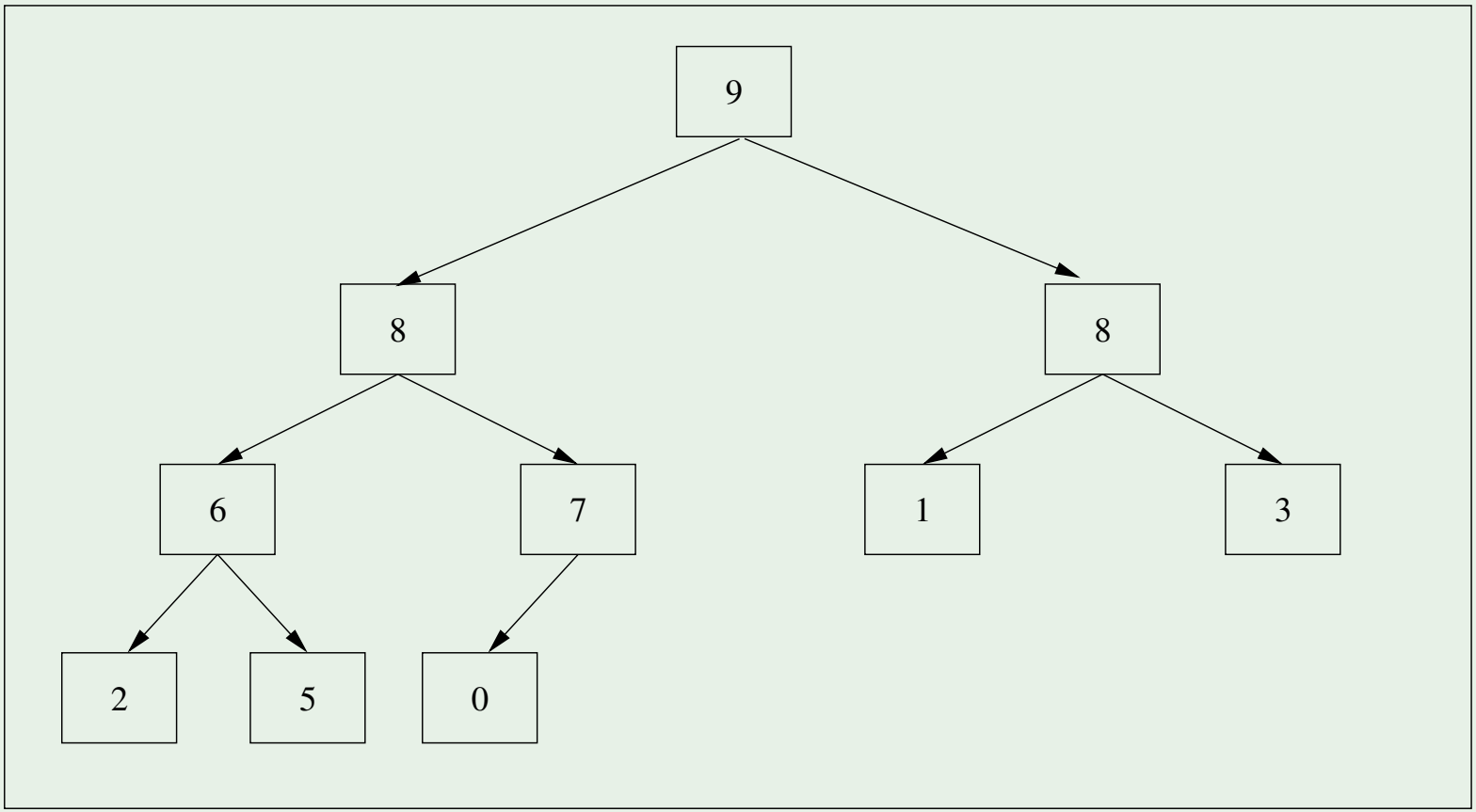
Implementing a Priority Queue As A Heap

For better performance, we use a new structure; a Binary Heap:

- A complete binary tree, whose nodes are labeled with integer values (**priorities**).
- Has the Heap property: *For any node, no node below it has a higher priority*.
- Notice how fast it is to find the node with the highest priority (it's at the top of the heap).
- The `enqueue` method is called the `insert` method for the `Heap` class.
- The `dequeue` method is called the `delete_max` method for the `Heap` class.

Implementing a Priority Queue As A Heap

A tree with the heap property



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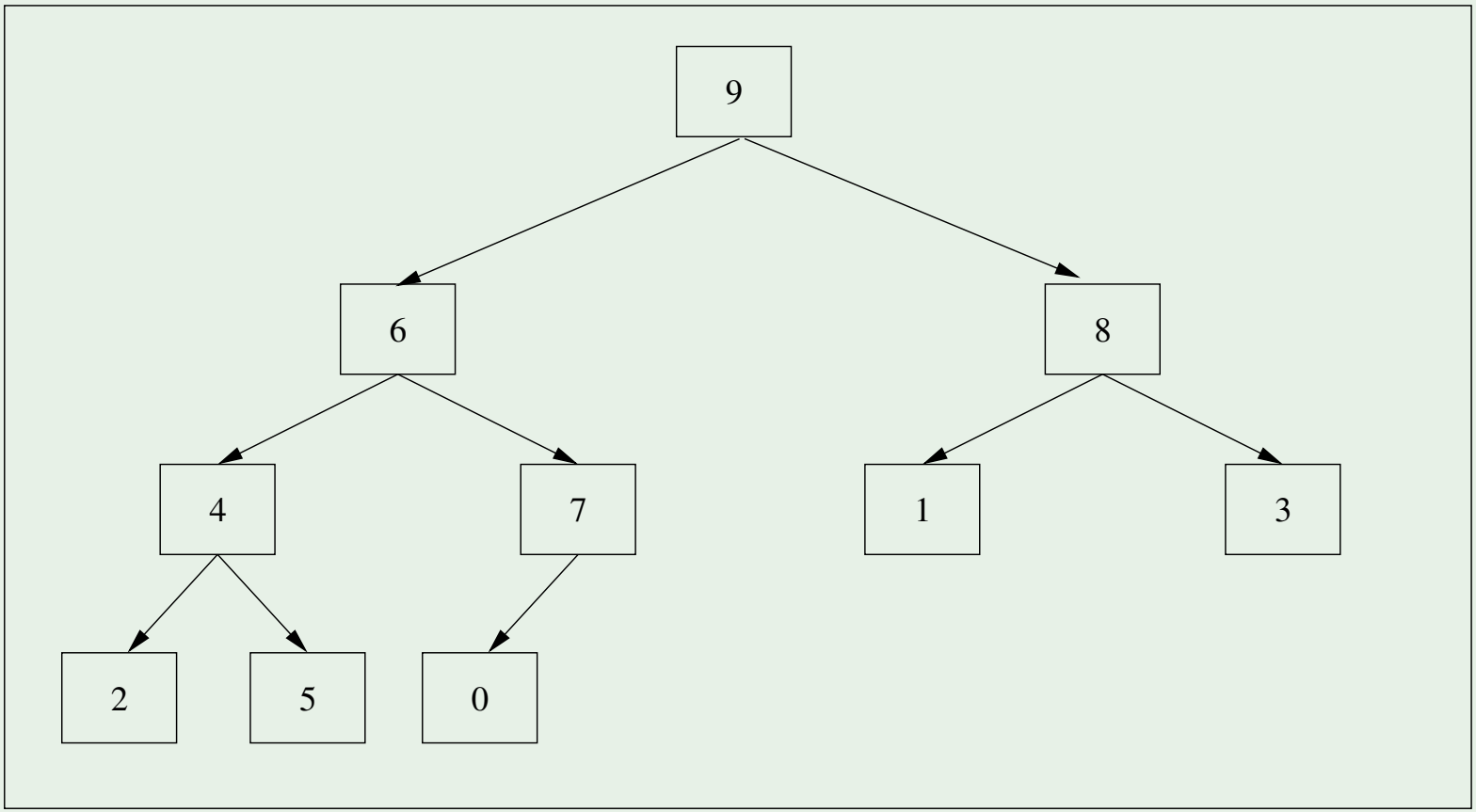
A tree without the heap property



Implementing a Priority Queue As A Heap

Implementation issues:

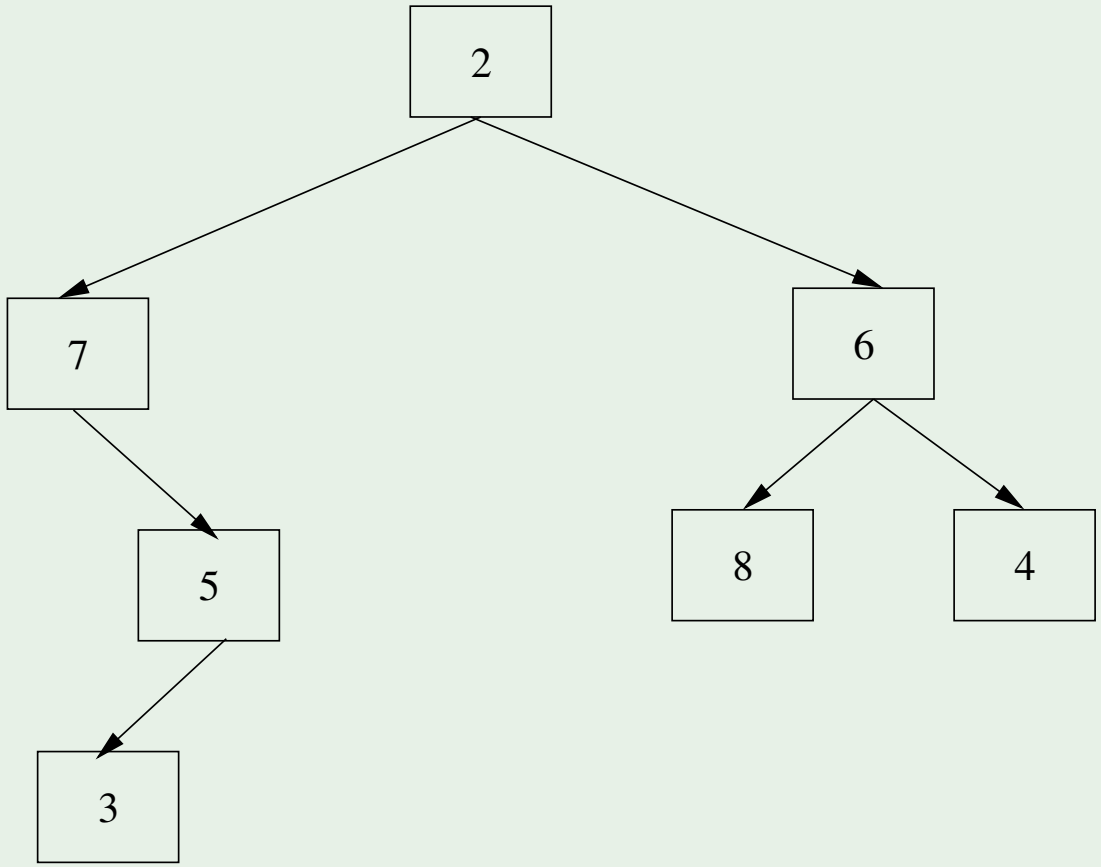
- The `enqueue` and `dequeue` methods are implemented so they preserve the heap property.
- To save space, the complete binary tree is implemented as an array. (The root is at index 1. The children of the node at index `i` are at indexes `2 * i` and `2 * i + 1`.)
- We will use Python and its list class to implement binary heaps, so resizing will not be a problem when items are enqueued.
  We will continue the implementation at the next meeting.

Outline

Binary Trees

Binary Trees

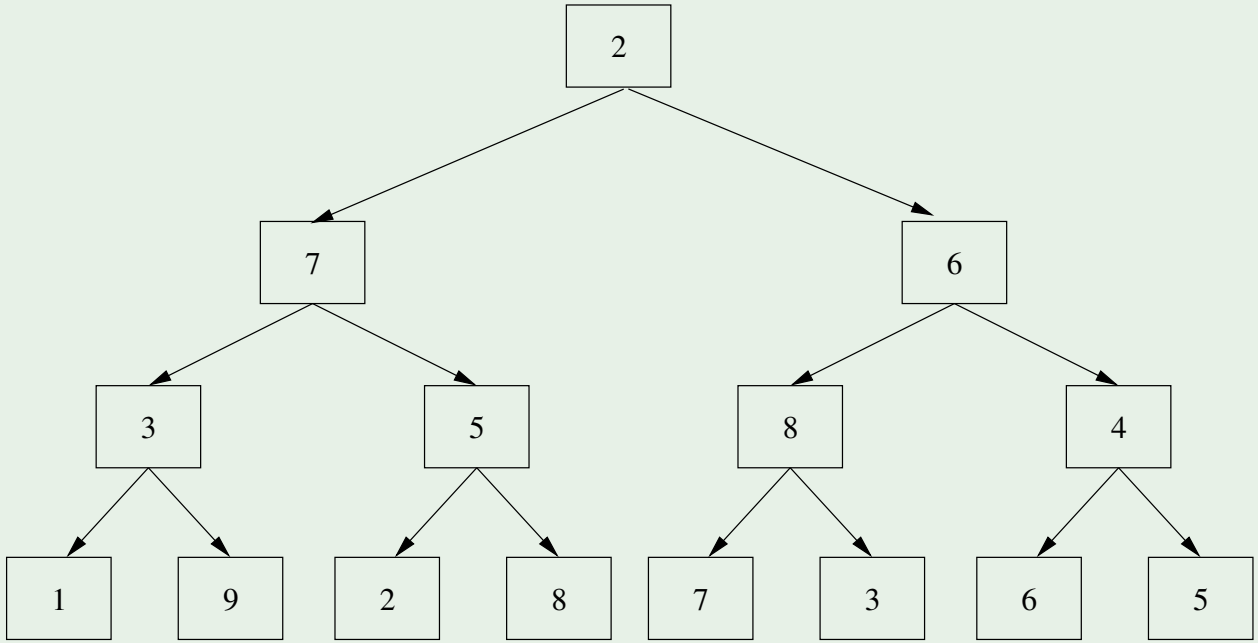
- A tree whose nodes have at most two children is a binary tree.



Binary Trees

Full Binary Trees

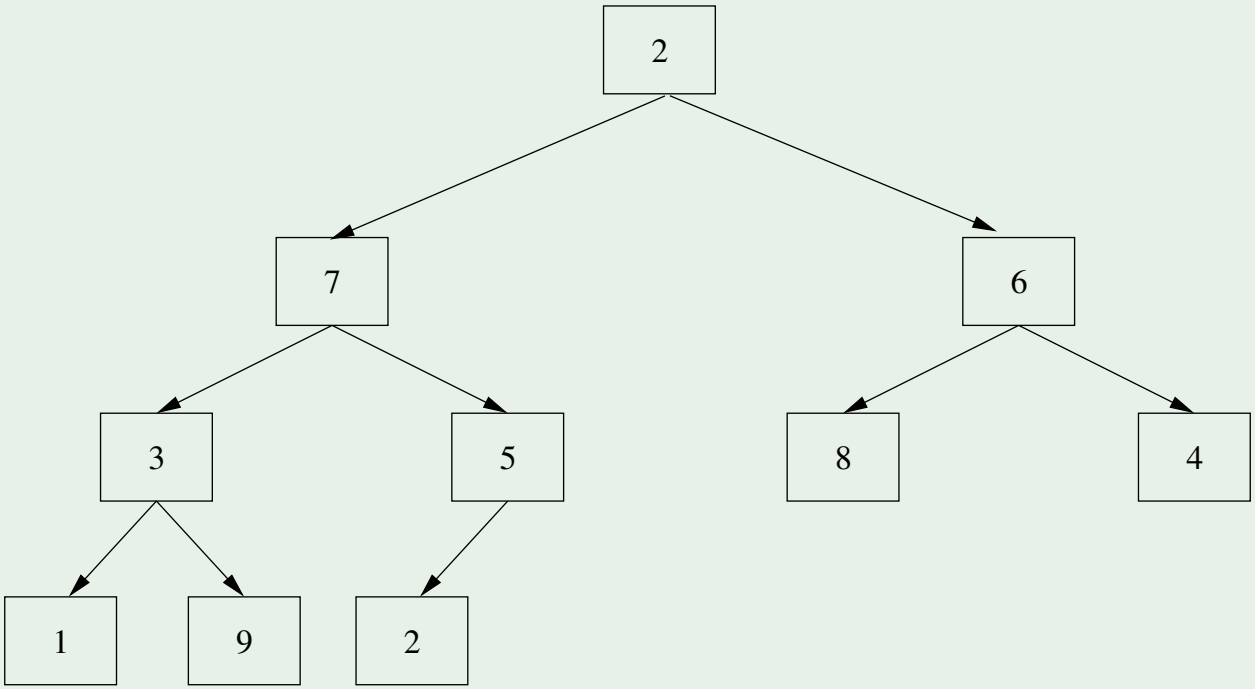
- A full binary tree is one whose levels have every position filled.



Binary Trees

Complete Binary Trees

- A complete binary tree has every level filled except the bottom, which is filled from left to right.



Linked Representation Of A Binary Tree

A TreeNode Class in Python

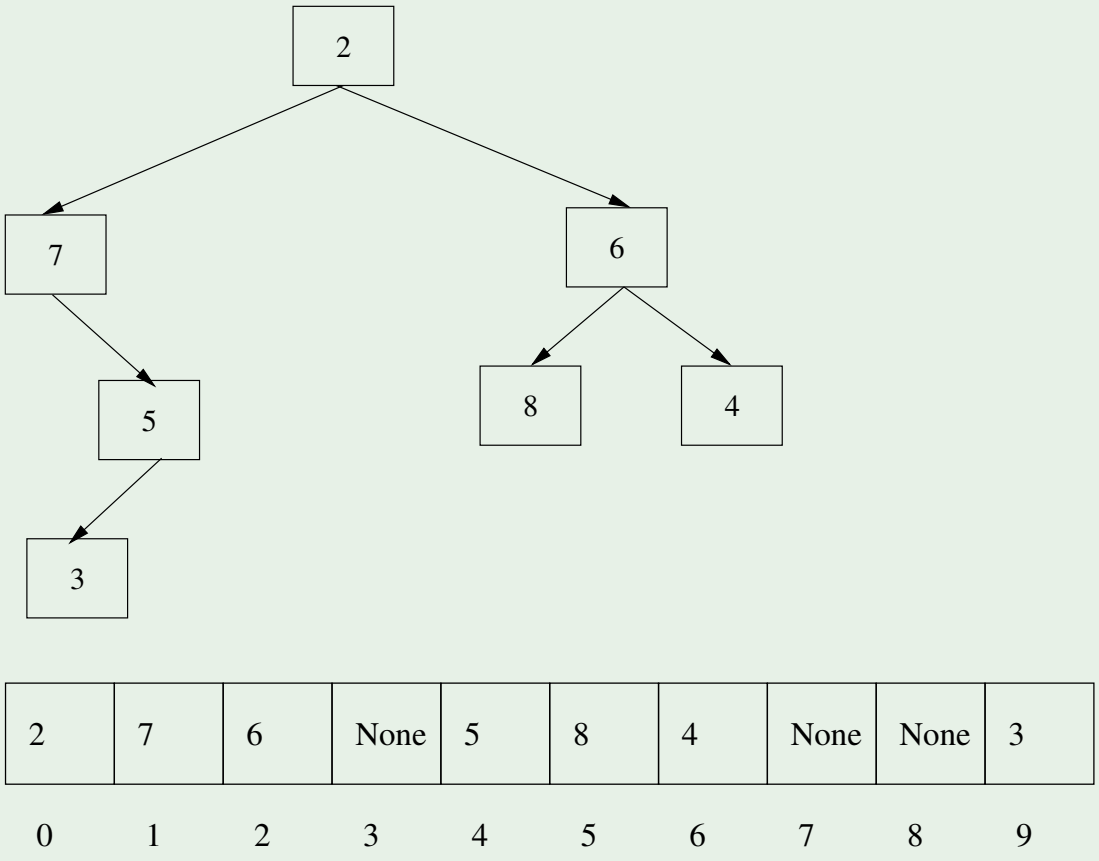
- An empty tree is represented by None.
- A nonempty tree is defined using a TreeNode as root.
- The TreeNode class is defined recursively.

Recursive Definition Of A TreeNode Class

```
class TreeNode(object):
   def __init__(self, data = None, left=None, right=None):
      self.item = data
      self.left = left # TreeNode or None
      self.right = right # TreeNode or None
```

Array Representation of Binary Trees

Abstract View - array representation



Array Representation of Binary Trees

Implementation

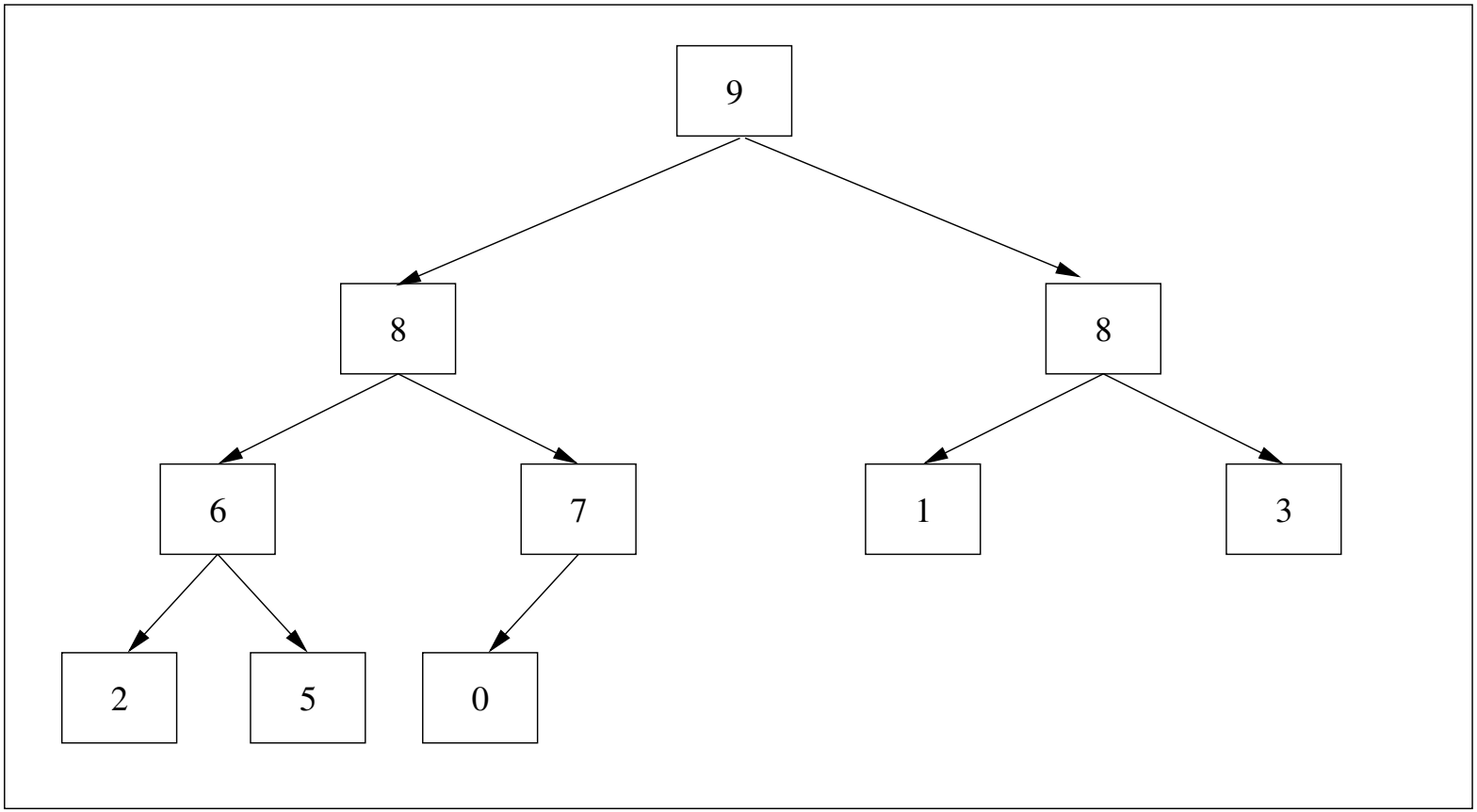
2	7	6	None	5	8	4	None	None	3
0	1	2	3	4	5	6	7	8	9

The node at position `i` has:

```
def left_child(i):
    return 2 * i + 1
def right_child(i):
    return 2 * i + 2
def parent(i):
    return (i - 1) // 2
```

Heaps representation

Heaps will be represented by arrays, with the root at index 1.



	9	8	8	6	7	1	3	2	5	0	...
0	1	2	3	4	5	6	7	8	9	10	...

In-Class Work

1. Implement a template minimum function and test it on int and double type values.
2. Implement a Queue using templates along with the code to test it.