

OUTLINE

1 CHAPTER 12: C++ TEMPLATES

- Template Functions
- Template Classes
 - Introduction
 - Vector class
 - User-Defined Template Classes

2 CHAPTER 13: HEAPS, BALANCED TREES, AND HASH TABLES

- Priority Queues and Heaps

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 interpreter 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.

Check out the algorithms library

<http://www.cplusplus.com/reference/algorithm/>. Find [sort](#), [min_element](#) and other functions there and see how to use them.

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;
}
```

The rest see in [test_Stack.cpp](#)

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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.

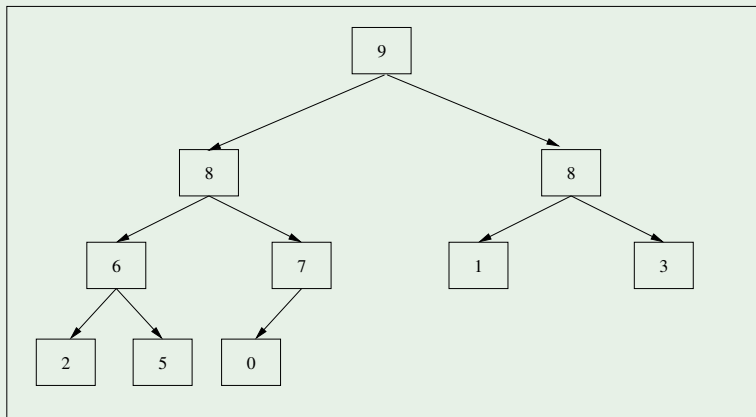
IMPLEMENTING A PRIORITY QUEUE AS A HEAP

For better performance, we will 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.

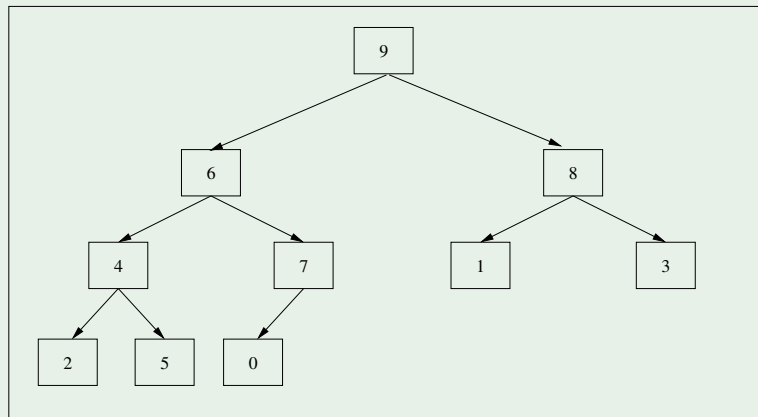
IMPLEMENTING A PRIORITY QUEUE AS A HEAP

A TREE WITH THE HEAP PROPERTY



IMPLEMENTING A PRIORITY QUEUE AS A HEAP

A TREE WITHOUT THE HEAP PROPERTY



IMPLEMENTING A PRIORITY QUEUE AS A HEAP

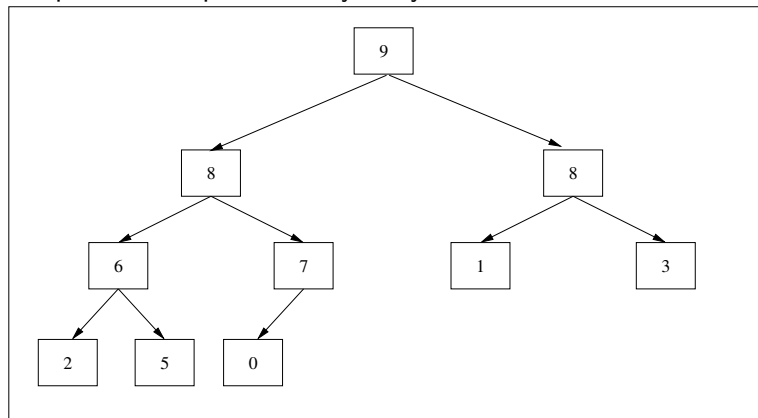
Implementation issues:

- 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 $2 * i + 1$.)
- If we use Python and its list class to implement binary heaps, resizing will not be a problem when items are enqueued. If we use C++ with dynamic arrays then we will have to take care of re-sizing.

We will continue the implementation at the next meeting.

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.