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
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:

```python
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.
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:

```python
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.
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.

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

```cpp
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.

```cpp
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;
}
```
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.
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.
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.
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.
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.
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.
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.
One of the simpler STL classes is the Vector class. It provides functionality similar to the dynamic array classes we developed.

```cpp
#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

```cpp
#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;
    }
}
```
#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 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 *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/](http://www.cplusplus.com/reference/algorithm/). Find *sort*, *min_element* and other functions there and see how to use them.
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:

```cpp
bool pop(Item &item);
```

The last line of the header file includes the implementation file:

```cpp
#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);
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_Sanck.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_Sanck.cpp
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
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**.)
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:

```python
class PQueue:
    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'''
```
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.
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

```
2 5 0
7
9
1 3
86
4
```
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 $2 \times i$ and $2 \times i + 1$.)

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