Templates and generic programming

CS 5301
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Jill Seaman

Gaddis: sections 16.2-16.4
Main + Savitch: sections 6.1-6.2
Weiss: chapter 3

Type independence

• Many algorithms like search, sort, or swap do not depend on the type of the elements/items.
• We would like to re-use the same code regardless of the item type...
• without having to maintain duplicate copies:
  - sortIntArray (int a[]; int size)
  - sortFloatArray (float a[]; int size)
  - sortCharArray (char a[]; int size)

Generic programming

• Writing functions and classes that are type-independent is called generic programming.
• These functions and classes will have one (or more) extra parameter to represent the specific type of the components.
• When the stand-alone function is called, or class is instantiated, the programmer provides the specific type:
  vector<string> students (20);
  vector<double> dailySales (365);

Templates

• C++ provides templates to implement generic stand-alone functions and classes.
• A function template is not a function, it is a design or pattern for a function.
• The function template makes a function when the compiler encounters a call to the function.
  - Like a macro, it substitutes appropriate type
Example function template

```cpp
template <class Object>
void swap (Object &lhs, Object &rhs) {
    Object tmp = lhs;
    lhs = rhs;
    rhs = tmp;
}
```

```cpp
int main() {
    int x = 5;
    int y = 7;
    string a = "hello";
    string b = "there";
    swap <int> (x, y);  //int replaces Object
    swap <string> (a, b);  //string replaces Object
    cout << x << "  " << y << endl;
    cout << a << "  " << b << endl;
}
```

Output:
```
7  5
there  hello
```

Notes about the example

- The header: `template <class Object>`
  - `class` is a keyword. You could also use `typename`:
    `template <typename Object>`
- Object is the parameter name. You can call it whatever you like.
  - it is often capitalized (because it is a type)
  - names like T and U are often used
- The parameter name (Object in this case) can be replaced ONLY by a type.

Simple example, class template

```cpp
template <class Object>
class MemoryCell {
    private:
        Object storedValue; //stores the memory cell contents

    public:
        // Construct a MemoryCell.
        MemoryCell (Object initVal) { storedValue = initVal; }

        // public methods
        Object read () { return storedValue; }
        void write (Object x) { storedValue = x; }
};
```

```cpp
#include <iostream>
using namespace std;

int main() {
    MemoryCell<int> m;
    m.write(5);
    cout  << "Cell contents are " << m.read() << endl;
    MemoryCell<string> m1;
    m1.write("abc");
    cout  << "Cell contents are " << m1.read() << endl;
}
```

Output:
```
Cell contents are 5
Cell contents are abc
```
Example 2, class template
vector: class decl

```cpp
// A barebones vector ADT

template <typename T>
class vector {
private:
    T* data; // stores data in dynamically allocated array
    int length; // number of elements in vector
    int capacity; // size of array, to know when to expand
    void expand(); // to increase capacity as needed
public:
    vector(int initial_capacity);
    void push_back(T); // add a T to the end
    T pop_back(); // remove a T from the end and return
    T operator[](int k); // access the T in the kth position
    ...
};
```

Example 2, class template
vector, function definitions

```cpp
template <typename T>
void vector<T>::push_back(T x) {
    if (capacity == length)
        expand();
    data[length] = x;
    length ++;
}
```

```cpp
template <typename T>
T vector<T>::pop_back() {
    assert (length > 0);
    length--;
    return data[length];
}
```

```cpp
template <typename T>
T vector<T>::operator[](int k) {
    assert (k>=0 && k<length);
    return data[k];
}
```

```cpp
template <typename T>
void vector<T>::expand() {
    capacity *= 2;
    T* new_data = new T[capacity];
    for (int k = 0; k < length; k += 1)
        new_data[k] = data[k];
    delete[] data;
    data = new_data;
}
```

Simple example, class template
using vector

```cpp
int main() {
    vector<string> m(2);
    m.push_back("As");
    m.push_back("Ks");
    m.push_back("Qs");
    m.push_back("Js");
    for (int i=0; i<4; i++) {
        cout << m[i] << endl;
    }
}
```

Output:

```
As
Ks
Qs
Js
```
Class Templates and .h files

- Template classes cannot be compiled separately
  - Machine code is generated for a template class only when the class is instantiated (used).
    - When you compile a template (class declarations + functions definitions) it will not generate machine code.
  - When a file using (instantiating) a template class is compiled, it requires the **complete** definition of the template, including the function definitions.
  - Therefore, for a class template, the class declaration AND function definitions must go in the header file.
  - It is still good practice to define the functions outside of (after) the class declaration.