Templates

Object-Oriented Programming with C++

Zhaopeng Cui

Why templates?

- Suppose you need a list of X and a list of Y
  - –The lists would use similar code
  - –They differ by the type stored in the list

- Choices
  - –Clone code
    - preserves type-safety
    - hard to manage
  - –Make a common base class
    - May not be desirable
  - –Untyped lists
    - type unsafe

Templates

- Reuse source code
  - generic programming
  - use types as parameters in class or function definitions

- Function Template
  - Example: `sort` function

- Class Template
  - Example: containers such as `stack,list,queue...`
    - `stack` operations are independent of the type of items in the stack
  - template member functions

Function templates

- Perform similar operations on different types of data.

- Swap function for two int arguments:

```
void Swap ( int& x, int& y ) {
    int temp = x;
    x = y;
    y = temp;
}
```

- What if we want to swap floats, strings, Currency, Person?

Example: Swap function templates

```
template < class T >
void Swap( T& x, T& y ){
    T temp = x;
    x = y;
    y = temp;
}
```

- The `template` keyword introduces the template
- The `class T` specifies a parameterized type name
    - class means any built-in type or user-defined type
- Inside the template, use T as a type name

Function templates syntax

- Type parameters represent:
  - –types of arguments to the function
  - –return type of the function
  - –define variables within the function

Template instantiation

- Generating a definition from a template class/function and template arguments:
  - Types are substituted into template
  - New body of function or class definition is created
    - syntax errors,type checking
  - Specialization -- a version of a template for a particular argument(s)

Example: using swap

```cpp
int i = 3; int j = 4;
Swap(i, j);  // use explicit int Swap

float k = 4.5; float m = 3.7;
Swap(k, m);  // instantiate float Swap

std::string s("Hello");
std::string t("World");
Swap(s, t);  // instantiate std::string Swap
```

- A template function is an instantiation of a function template

Interactions

- Only *exact* match on types is used
- *No* conversion operations are applied
  - `Swap(int, int); // ok`
  - `Swap(double, double); // ok`
  - `Swap(int, double);  // error!`
- Even *implicit* conversions are ignored
- Template functions and regular functions coexist

Overloading rules

- Check first for unique function match
- Then check for unique function template match
- Then implicit conversions on regular functions

```
void f(float i, float k) {};

template <class T>
void f(T t, T u) {};

f(1.0f, 2.0f);
f(1.0, 2.0); // double types, use the template
f(1, 2);
f(1, 2.0);
```

Function instantiation

- The compiler deduces the template type from the actual arguments passed into the function.
- Can be *explicit*:
  – for example, if the parameter is not in the function signature (older compilers won't allow this...)

```
template <class T>
void foo() { /* … */ }

foo<int>();     // type T is int
foo<float>();   // type T is float
```

Class templates

- Classes parameterized by types
  - –Abstract operations from the types being operated upon
  - –Define potentially infinite set of classes
  - –Another step towards reuse!

- Typical use: container classes
  - `stack <int>`
    - is a stack that is parameterized over int
  - `list <Person*>`
  - `queue <Job>`

Example: Vector

```
template <class T>
class Vector{
public:
  Vector(int);
  ~Vector();
  Vector(const Vector&);
  Vector& operator=(const Vector&);
  T& operator[](int);
private:
  T* m_elements;
  int m_size;
};
```

Usage

```
Vector<int> v1(100);
Vector<Complex> v2(256);

v1[20] = 10;
v2[20] = v1[20];  // ok if int->Complex defined
```

Vector members

```
template <class T>
Vector<T>::Vector(int size): m_size(size) {
  m_elements = new T[m_size];
}
template <class T>
T& Vector<T>::operator[](int index)
{
  if(index < m_size && index >= 0) {
    return m_elements[index];
  } else {
    …
  }
}
…
```

A simple sort function

```
// bubble sort - don't use it!
template <class T>
void Sort(Vector<T>& arr) {
  const size_t last = arr.size() - 1;
  for(int i=0; i<last; i++)
    for(int j = last; j>i; j--) {
      if(arr[j] < arr[j-1]) {
        // which swap?
        Swap(arr[j], arr[j-1]);
      }
  }
}
```

Sorting the Vector

```
Vector<int> vi(4);
vi[0] = 4; vi[1] = 3; vi[2] = 7; vi[3] = 1;
Sort(vi);  // Sort(Vector<int>&)

Vector<string> vs(5);
vs[0] = "Fred";
vs[1] = "Wilma";
vs[2] = "Barney";
vs[3] = "Dino";
vs[4] = "Prince";
Sort(vs); // Sort(Vector<string>&);
//NOTE: Sort use operator< for comparison
```

Templates

- Templates can use multiple types

```
template <class Key, class Value>
class HashTable {
  const Value& lookup (const Key&) const;
  void insert (const Key&, const Value&);
  …
}
```

- Templates nest – they're just new types!

```
Vector<Vector<double*> > //Note space > >
```

- Type arguments can be complicated

```
Vector<int (*) (Vector<double>&, int)>
```

Expression parameters

- Template arguments can be *constant* expressions
- Non-Type parameters
  – can have a default argument

```
template <class T, int bounds = 100>
class FixedVector {
public:
  FixedVector();
  T& operator[](int);
private:
  T elements[bounds]; // fixed-size array!
};
```

Non-Type parameters

```
template <class T, int bounds>
T& FixedVector<T, bounds>::operator[] (int i){
  return elements[i]; //no error checking
}
```

Usage: non-type parameters

- Usage
  - `FixedVector<int, 50> v1;`
  - `FixedVector<int, 10*5> v2;`
  - `FixedVector<int> v3;  // uses default`
- Summary
  - Embedding sizes not necessarily a good idea
  - Can make code faster
  - Makes code more complicated
    - size argument appears everywhere!
  - Can lead to (even more) code bloat

Templates and inheritance

- Templates can inherit from non-template classes

```
template <class A>
class Derived : public Base {…}
```

- Templates can inherit from template classes

```
template <class A>
class Derived : public List<A> {…}
```

- Non-template classes can inherit from templates

```
class SupervisorGroup : public
  List<Employee*> {…}
```

Recurring template pattern

- General form

```cpp
// The Curiously Recurring Template Pattern (CRTP)
template <class T>
class Base
{
  // ...
};
class Derived : public Base<Derived>
{
  // ...
};
```

Recurring template pattern

- Simulate virtual function in generic programming

```
template <class T>
class Base {
  void interface() {
    static_cast<T*>(this)->implementation(); // ...
  }
  static void static_func() {
    T::static_sub_func(); // ...
  }
};
class Derived : public Base<Derived> {
  void implementation();
  static void static_sub_func();
};
```

Notes

- friends

```cpp
template <typename T>
class MyClass {
    friend void myFunction(MyClass<T>& obj) {
        // Now myFunction can access MyClass's private members.
        std::cout << obj.privateData << std::endl;
    }
private:
    T privateData;
public:
    MyClass(T data) : privateData(data) {}
};
```

Notes

- friends

```
template <typename T>
class MyClass {
    template <typename U>
    friend void myFunction(MyClass<U>& obj);
private:
    T privateData;
public:
    MyClass(T data) : privateData(data) {}
};
// Implementation of template function that is a friend of MyClass
template <typename T>
void myFunction(MyClass<T>& obj) {
    // Function can access private data due to friendship.
    std::cout << "Accessing private data: " << obj.privateData <<
std::endl;
}
```

Notes

- friends
- static members
- In general put the definition and the declaration for the template in the header file
  - won't allocate storage for the class at that point
  - compiler/linker has mechanism for removing multiple definitions

Writing templates

- Get a non-template version working first
- Establish a good set of test cases
- Measure performance and tune

- Review implementation
  - Which types should be parameterized?
- Convert non-parameterized version into template
- Test against established test cases