CSE 333
Lecture 12 - templates, STL

Hal Perkins
Department of Computer Science & Engineering
University of Washington
Administrivia

HW2 due Thursday night, 11 pm

Midterm Monday

- Closed book, no notes, etc. (We can ask more straightforward questions that way)

- Topics: everything from lectures, exercises, project, etc. up to HW2 + end of this week (i.e., basics of C++ classes, constructors, etc.)

- Review in sections Thursday

- Last chance: review on Sunday? (not much interest on Friday)

- Old exams and topic list posted on web now

- Posted “try this” lecture exercise solutions mostly up to date, will catch up with the rest shortly
Today’s goals

Templates and type-independent code

C++’s standard library
- STL containers, iterators, algorithms
  - A few core ones only - see docs for rest
Suppose that...

You want to write a function to compare two ints:

```cpp
// returns 0 if equal, 1 if value1 is bigger, -1 otherwise
int compare(const int &value1, const int &value2) {
    if (v1 < v2) return -1;
    if (v2 < v1) return 1;
    return 0;
}
```
Suppose that...

You want to write a function to compare two ints, and you also want to write a function to compare two strings:

```cpp
// note the cool use of function overloading!

// returns 0 if equal, 1 if value1 is bigger, -1 otherwise
int compare(const int &value1, const int &value2) {
    if (value1 < value2) return -1;
    if (value2 < value1) return 1;
    return 0;
}

// returns 0 if equal, 1 if value1 is bigger, -1 otherwise
int compare(const string &value1, const string &value2) {
    if (value1 < value2) return -1;
    if (value2 < value1) return 1;
    return 0;
}
```
Hmm....

The two implementations of compare are nearly identical.
- we could write a compare for every comparable type
  ‣ but, that’s obviously a waste; lots of redundant code!

Instead, we’d like to write “generic code”
- code that is **type-independent**
- code that is **compile-time polymorphic** across types
C++: parametric polymorphism

C++ has the notion of templates

- a function or class that accepts a type as a parameter
  ‣ you implement the function or class once, in a type-agnostic way
  ‣ when you invoke the function or instantiate the class, you specify (one
     or more) types, or values, as arguments to it

- at compile-time, when C++ notices you using a template...
  ‣ the compiler generates specialized code using the types you provided
    as parameters to the template
Function template

You want to write a function to compare two things:

```cpp
#include <iostream>
#include <string>

// returns 0 if equal, 1 if value1 is bigger, -1 otherwise
template <class T>
int compare(const T &value1, const T &value2) {
    if (value1 < value2) return -1;
    if (value2 < value1) return 1;
    return 0;
}

int main(int argc, char **argv) {
    std::string h("hello"), w("world");
    std::cout << compare<std::string>(h, w) << std::endl;
    std::cout << compare<int>(10, 20) << std::endl;
    std::cout << compare<double>(50.5, 50.6) << std::endl;
    return 0;
}
```

Function template

Same thing, but letting the compiler infer the types:

```cpp
#include <iostream>
#include <string>

// returns 0 if equal, 1 if value1 is bigger, -1 otherwise
template <class T>
int compare(const T &value1, const T &value2) {
    if (value1 < value2) return -1;
    if (value2 < value1) return 1;
    return 0;
}

int main(int argc, char **argv) {
    std::cout << compare(10, 20) << std::endl;
    std::cout << compare("Hello", "World") << std::endl; // bug!
    std::cout << compare(h, w) << std::endl; // ok
    return 0;
}
```

functiontemplate_infer.cc
Function template

You can use non-types (constant values) in a template:

```cpp
#include <iostream>
#include <string>

template <class T, int N>
void printmultiple(const T &value1) {
    for (int i = 0; i < N; ++i)
        std::cout << value1 << std::endl;
}

int main(int argc, char **argv) {
    std::string h("hello");
    printmultiple<std::string,3>(h);
    printmultiple<const char *,4>("hi");
    printmultiple<int,5>(10);
    return 0;
}
```
What’s going on underneath?

The compiler doesn’t generate any code when it sees the templated function

- it doesn’t know what code to generate yet, since it doesn’t know what type is involved

When the compiler sees the function being used, then it understands what types are involved

- it generates the instantiation of the template and compiles it
  - the compiler generates template instantiations for each type used as a template parameter
  - kind of like macro expansion
This creates a problem...

```cpp
#ifndef _COMPARE_H_
#define _COMPARE_H_

template <class T>
int comp(const T& a, const T& b);

#endif // COMPARE_H_

#include "compare.h"

template <class T>
int comp(const T& a, const T& b) {
    if (a < b) return -1;
    if (b < a) return 1;
    return 0;
}

#include <iostream>
#include "compare.h"

using namespace std;

int main(int argc, char **argv) {
    cout << comp<int>(10, 20);  
    cout << endl;
    return 0;
}
```

One solution

```cpp
#ifndef _COMPARE_H_
define _COMPARE_H_

template <class T>
int comp(const T& a, const T& b) {
    if (a < b) return -1;
    if (b < a) return 1;
    return 0;
}
#endif // COMPARE_H_  compare.h
```

```cpp
#include <iostream>
#include "compare.h"

using namespace std;

int main(int argc, char **argv) {
    cout << comp<int>(10, 20);
    cout << endl;
    return 0;
}
```

main.cc
Another solution

```cpp
#include <iostream>
#include "compare.h"

using namespace std;

int main(int argc, char **argv) {
    cout << comp<int>(10, 20) << endl;
    return 0;
}
```

```cpp
# ifndef __COMPARE_H__
# define __COMPARE_H__

template <class T>
int comp(const T& a, const T& b);

#include "compare.cc"

#endif // __COMPARE_H__

```
Class templates

Templating is useful for classes as well! Imagine we want a class that holds a pair of things

- we want to be able to:
  ‣ set the value of the first thing, second thing
  ‣ get the value of the first thing, second thing
  ‣ reverse the order of the things
  ‣ print the pair of things
Pair class

```cpp
#include <iostream>
#include <string>

template <class Thing> class Pair {
public:
    Pair() { }

    Thing &get_first() { return first_; }
    Thing &get_second();
    void set_first(Thing &copyme);
    void set_second(Thing &copyme);
    void Reverse();

private:
    Thing first_, second_; 
};

#include "Pair.cc"
```
template <class Thing> Thing &Pair<Thing>::get_second() {
    return second_; 
}

template <class Thing> void Pair<Thing>::set_first(Thing &copyme) {
    first_ = copyme;
}

template <class Thing> void Pair<Thing>::set_second(Thing &copyme) {
    second_ = copyme;
}

template <class Thing> void Pair<Thing>::Reverse() {
    // makes *3* copies
    Thing tmp = first_; 
    first_ = second_; 
    second_ = tmp;
}
Pair class

```cpp
#include <iostream>
#include <string>
#include "Pair.h"

int main(int argc, char **argv) {
    Pair<std::string> ps;
    std::string x("foo"), y("bar");

    ps.set_first(x);
    ps.set_second(y);
    ps.Reverse();
    std::cout << ps.get_first() << std::endl;

    return 0;
}
```

main.cc
C++’s standard library

Consists of four major pieces:

- the entire C standard library
- C++’s input/output stream library
  ‣ std::cin, std::cout, stringstreams, fstreams, etc.
- C++’s standard template library (STL)
  ‣ containers, iterators, algorithms (sort, find, etc.), numerics
- C++’s miscellaneous library
  ‣ strings, exceptions, memory allocation, localization
STL :)  

Containers!

- a container is an object that stores (in memory) a collection of other objects (elements)
  ‣ implemented as class templates, so hugely flexible

- several different classes of container
  ‣ sequence containers (vector, deque, list)
  ‣ associative containers (set, map, multiset, multimap, bitset)

- differ in algorithmic cost, supported operations
STL :(

STL containers store by value, not by reference

- when you insert an object, the container makes a copy
- if the container needs to rearrange objects, it makes copies
  ▸ e.g., if you sort a vector, it will make many many copies
  ▸ e.g., if you insert into a map, that may trigger several copies
- what if you don’t want this (disabled copy con, or copy $$)?
  ▸ you can insert a wrapper object with a pointer to the object
  ▸ we’ll learn about these “smart pointers” later
STL vector

A generic, dynamically resizable array

- elements are stored in contiguous memory locations
  - elements can be accessed using pointer arithmetic if you like
  - random access is $O(1)$ time
- adding / removing from the end is cheap (constant time)
- inserting / deleting from middle or start is expensive ($O(n)$)

Example

see Tracer.cc, Tracer.h, vectorfun.cc
STL iterator

Each container class has an associated iterator class

- used to iterate through elements of the container (duh!)
- some container iterators support more operations than others
  ‣ all can be incremented (++ operator), copied, copy-constructed
  ‣ some can be dereferenced on RHS (e.g., x = *it;)
  ‣ some can be dereferenced on LHS (e.g., *it = x;)
  ‣ some can be decremented (-- operator)
  ‣ some support random access ([], +, -, +=, -=, <, > operators)
Example

see vectoriterator.cc
the ‘auto’ keyword can be used to infer types

- simplifies your life if, for example, functions return complicated types
- the expression using auto must contain explicit initialization for it to work
Type inference [C++11]

Auto and iterators
  - life becomes much simpler!

```cpp
for (vector<Tracer>::iterator it = vec.begin(); it < vec.end(); it++) {
    cout << *it << endl;
}
```

```cpp
for (auto it = vec.begin(); it < vec.end(); it++) {
    cout << *it << endl;
}
```
Range “for” statements [C++11]

Syntactic sugar that emulates Java’s “foreach”

- works with any sequence-y type
  - strings, initializer lists, arrays with an explicit length defined, STL containers that support iterators

```cpp
// Prints out a string, one character per line
std::string str("hello");
for (auto c : str) {
    std::cout << c << endl;
}
```
combining auto with range for

see vectoriterator_2011.cc
STL algorithms

A set of functions to be used on ranges of elements

- range: any sequence that can be accessed through iterators or pointers, like arrays or some of the containers

- algorithms operate directly on values using assignment or copy constructors, rather than modifying container structure

- some do not modify elements
  
  » find, count, for_each, min_element, binary_search, etc.

- some do modify elements
  
  » sort, transform, copy, swap, etc.

http://www.cplusplus.com/reference/algorithm/
Example

see vectoralgos.cc
STL list

A generic doubly-linked list

- elements are *not* stored in contiguous memory locations
  - does not support random access (cannot do list[5])
- some operations are much more efficient than vectors
  - constant time insertion, deletion anywhere in list
  - can iterate forward or backwards
- has a built-in sort member function
  - no copies; manipulates list structure instead of element values

http://www.cplusplus.com/reference/stl/list/
Example

see listexample.cc
STL map

A key/value table, implemented as a tree
- elements stored in sorted order
  ‣ key value must support less-than operator
- keys must be unique
  ‣ multimap allows duplicate keys
- efficient lookup (O(log n)) and insertion (O(log n))
Example

see mapexample.cc
Exercise 1

Take one of the books from HW2’s test_tree, and:

- read in the book, split it into words (you can use your HW2)
- for each word, insert the word into an STL map
  ‣ the key is the word, the value is an integer
  ‣ the value should keep track of how many times you’ve seen the word, so each time you encounter the word, increment its map element
  ‣ thus, build a histogram of word count
- print out the histogram in order, sorted by word count
- bonus: plot the histogram on a log/log scale (use excel, gnuplot, ...)
  ‣ xaxis: log(word number), y-axis: log(word count)
Exercise 2

Using the Tracer.cc/.h file from lecture:

- construct a vector of lists of Tracers
  ‣ i.e., a vector container, each element is a list of Tracers
- observe how many copies happen. :)
  ‣ use the “sort” algorithm to sort the vector
  ‣ use the “list.sort()” function to sort each list
See you on Friday!