

CSE 333

Lecture 12 - templates, STL

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Administrivia

HW2 due Thursday night, 11 pm.

<panic>if not started yet</panic> <celebrate>if done</celebrate>

BE SURE TO CHECK YOUR WORK (git clone/checkout, make, tests, ...)

Exam Monday, in class

Closed book, no notes — exam questions can be more straightforward that way;
reference info on test as needed

Topics: everything from lectures, exercises, project, etc. up to HW2 & basics of C++
(including references, const, classes, constructors, destructors, new/delete, nothing
after that)

Old exams and topic list on the web now

Review Sunday, 2 pm, location TBA

No more exercises until (right) after the exam

Today's goals

Templates and type-independent code

C++'s standard library

STL containers, iterators, algorithms

A few core ones only - see docs & Primer for others

Suppose that...

You want to write a function to compare two ints:

```
// 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:

```
// 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:

```
#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:

```
#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(10, 20) << std::endl;
    std::cout << compare("Hello", "World") << std::endl; // hmmm...
    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:

```
#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;
}
```

nontypeparameter.cc

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 types are 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...

```
#ifndef _COMPARE_H_
#define _COMPARE_H_

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

#endif // COMPARE_H_ 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;
} compare.cc
```

```
#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
```

One solution

```
#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
```

```
#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

```
#ifndef _COMPARE_H_
#define _COMPARE_H_

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

#include "compare.cc"

#endif // COMPARE_H_ 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;
} compare.cc
```

```
#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
```

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

```
#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"
```

Pair.h

Pair class

```
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

```
#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 ctr, or copy is \$\$)?

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-cons'ed

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

Type inference [C++11]

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

```
// Calculate and return a vector  
// containing all factors of n  
std::vector<int> Factors(int n);  
  
void foo(void) {  
    // Manually identified type  
    std::vector<int> facts1 =  
        Factors(324234);  
  
    // Inferred type  
    auto facts2 = Factors(12321);  
  
    // Compiler error here  
    auto facts3;  
}
```

Type inference [C++11]

Auto and iterators

life becomes much simpler!

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

|

```
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

```
// 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.

Example

see [vectoralgorithms.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

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

New in C++ 11

`unordered_map`, `unordered_set`

and related classes: `unordered_multimap`, `unordered_multiset`

average case for key access is $O(1)$

But range iterators can be less efficient than ordered map/set

See C++ Primer, online references for details

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: $\log(\text{word number})$, y-axis: $\log(\text{word count})$

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!