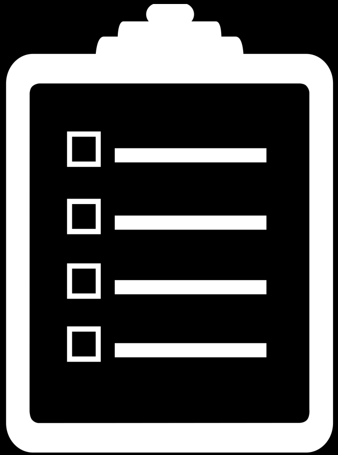
Templates and Iterators

Ali Malik
malikali@stanford.edu

Game Plan



Recap

`auto` Details

Templates

Iterators (pt. II)

Recap

Associative Containers

Useful abstraction for “associating” a key with a value.

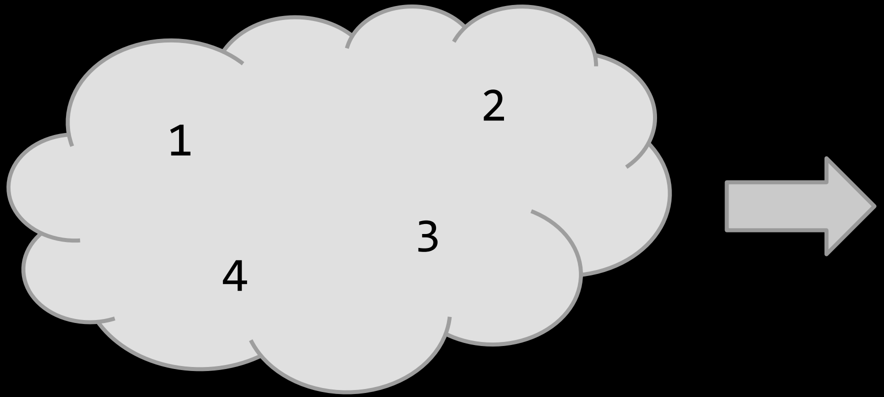
```
std::map
    map<string, int> directory;       // name -> phone number

std::set
    set<string> dict;                 // does it contains a word?
```

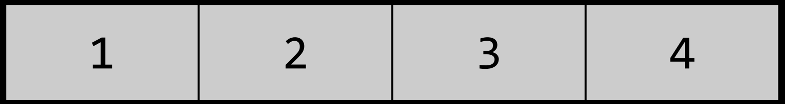
Iterators

Let’s try and get a mental model of iterators:

Say we have a `std::set<int> mySet`

Iterators let us view a non-linear collection in a linear manner.





Map Iterators

Example:

```
map<int, int> m;
map<int, int>::iterator i = m.begin();
map<int, int>::iterator end = m.end();
while(i != end) {
    cout << (*i).first << (*i).second << endl;
    ++i;
}
```

Iterator Uses - Sorting

For example, we sorted a vector using

```
std::sort(vec.begin(), vec.end());
```

Iterator Uses - Find

Finding elements

```
vec<int>::iterator it = std::find(vec.begin(), vec.end());
if(it != vec.end()) {
    cout << "Found: " << *it << endl;
} else {
    cout << "Element not found!" << endl;
}
```

Iterator Uses - Ranges

Iterating through a range

```
set<int>::iterator i = mySet.lower_bound(7);
set<int>::iterator end = mySet.lower_bound(26);
while (i != end) {
    cout << *i << endl;
    ++i;
}
```

auto

Writing iterator types can be unsightly.

Consider a map of deque of strings to vector of strings:

How can we clean this up better?

The auto keyword!

```
map<deque<string>, vector<string>> myMap;
for(map<deque<string>, vector<string>>::iterator iter =
                myMap.begin(); iter != myMap.end(); ++iter) {

    doSomething(*(iter).first, *(iter).second);
}
```

auto

How can we clean this up better?

The auto keyword!

Writing iterator types can be unsightly.

Consider a map of deque of strings to vector of strings:

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map<deque<string>, vector<string>> myMap;
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}
```

auto

How can we clean this up better?

Writing iterator types can be unsightly.

The auto keyword!

Consider a map of deque of strings to vector of strings:

```
map<deque<string>, vector<string>> myMap;
for(auto iter = myMap.begin(); iter != myMap.end(); ++iter) {

    doSomething(*(iter).first, *(iter).second);
}
```

Range Based for Loop

A range based for loop is (more or less) a shorthand for iterator code:

```
map<string, int> myMap;
for(auto thing : myMap) {
    doSomething(thing.first, thing.second);
}
```

↕

```
map<string, int> myMap;
for(auto iter = myMap.begin(); iter != myMap.end(); ++iter) {
    auto thing = *iter;
    doSomething(thing.first, thing.second);
}
```

Some Notes on `auto`

`auto` drops reference

Add them back with `auto&`

```
vector<int> vec{3,1,4,1,5};
vector<int> &vecRef = vec;
auto vecCopy = vecRef; // makes copy of vec
auto &vecRef2 = vecRef;  // reference
```

More Notes on `auto`

More generally, `auto` drops:

- `const`
- &
- `volatile`

`auto&` drops none of these

Announcements

Announcements

Assignment 1

Office Hours

Feedback

- Website tour cs106l.stanford.edu
- Slowing down
- Question forum
- More supplementary material (guides, problems, examples etc.)
- C++ guide
- Explain hotkeys :)

Templates

The Problem

Minimum Function

Let’s write a simple function to find the minimum of two ints.

```
int min(int a, int b) {
    return (a < b) ? a : b;
}
```

```
min(3,5);          // 3

min(13,8);         // 8

min(1.9, 3.7);     // 1?
```

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}
```

```
min(3,5);          // 3
min(13,8);         // 8
min(1.9, 3.7);     // 1?
```

Need more min

A classic C type solution would be to write two functions with different names:

```
int min_int(int a, int b) {
    return (a < b) ? a : b;
}


double min_double(double a, double b) {
    return (a < b) ? a : b;
}
```

And... more

```
int min_int(int a, int b) {
    return (a < b) ? a : b;
}
double min_double(double a, double b) {
    return (a < b) ? a : b;
}
size_t min_sizet(size_t a, size_t b) {
    return (a < b) ? a : b;
}
float min_float(float a, float b) {
    return (a < b) ? a : b;
}
char min_ch(char a, char b) {
    return (a < b) ? a : b;
}
```

uh...

...

And... more

```
int min_int(int a, int b) {
    return (a < b) ? a : b;
}
double min_double(double a, double b) {
    return (a < b) ? a : b;
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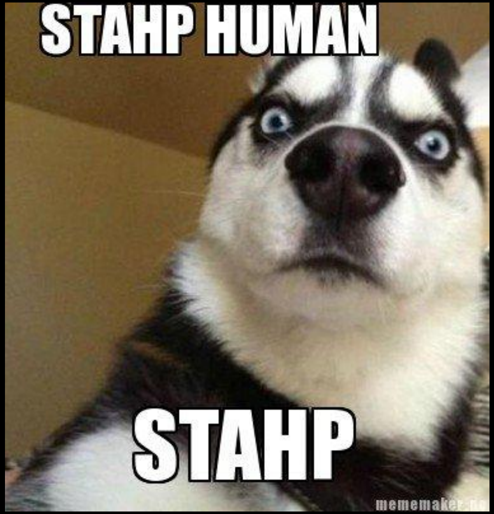

The Problem

Multiple copies of essentially the same function.

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Overloaded Functions

In C++, function overloading lets us have multiple functions with the same name but different parameters.

```
int min(int a, int b) {
    return (a < b) ? a : b;
}

double min(double a, double b) {
    return (a < b) ? a : b;
}
```

When the method is called, the compiler infers which version you mean based on the type of your parameters.

Overloaded Functions

```
int min(int a, int b) {
    return (a < b) ? a : b;
}
```

```
double min(double a, double b) {
    return (a < b) ? a : b;
}
```

```
min(3,5);          // (int, int) version
min(1.9, 3.7);     // (double, double) version
min(3.14, 17);     // uhh.. (double, int) version?
```

Overloaded Functions

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int min(int a, int b) {
    return (a < b) ? a : b;
}
```

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double min(double a, double b) {
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}
```

```
min(3,5);          // (int, int) version
min(1.9, 3.7);     // (double, double) version
min(3.14, 17);     // uhh.. (double, int) version?
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Overloaded Functions

```
int min(int a, int b) {
    return (a < b) ? a : b;
}
```

```
double min(double a, double b) {
    return (a < b) ? a : b;
}
```

```
min(3,5);                    // (int, int) version
min(1.9, 3.7);               // (double, double) version
min(3.14, 17);               // uhh.. (double, int) version?
min(3.14, static_cast<double>(17));   // (double, double) version!
```

Overloaded Functions

```
int min(int a, int b) {
    return (a < b) ? a : b;
}
```

```
double min(double a, double b) {
    return (a < b) ? a : b;
}
```

```
min(3,5);          // (int, int) version
min(1.9, 3.7);     // (double, double) version
min(3.14, 17);     // uhh.. (double, int) version?
min(3.14, static_cast<double>(17));   // (double, double) version!
```

Lesson:
Be explicit!

The Problems

Multiple copies of essentially the same function.

~~You need to write the type name whenever you use it~~

Every time you want to add a new type, you need to add a new function.

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What really is different in the code?

```c
int min(int a, int b) {
    return (a < b) ? a : b;
}
double min(double a, double b) {
    return (a < b) ? a : b;
}
size_t min(size_t a, size_t b) {
    return (a < b) ? a : b;
}
float min(float a, float b) {
    return (a < b) ? a : b;
}
char min(char a, char b) {
    return (a < b) ? a : b;
}
```

```
int min(int a, int b) {
    return (a < b) ? a : b;
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char min(char a, char b) {
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}
```

The type is the only difference!

```cpp
int min(int a, int b) {
    return (a < b) ? a : b;
}
double min(double a, double b) {
    return (a < b) ? a : b;
}
size_t min(size_t a, size_t b) {
    return (a < b) ? a : b;
}
float min(float a, float b) {
    return (a < b) ? a : b;
}
char min(char a, char b) {
    return (a < b) ? a : b;
}
```

The type is the only difference!

If only there were a better way 🤔

The Solution

Templates

Templates are a blueprint of a function that let you use the same function for a variety of types:

```
template <typename T>
T min(T a, T b) {
    return (a < b) ? a : b;
}
```

Templates

Think about how we wrote all our min functions.

We had a set of rules (a blueprint), and the only thing we did to make different versions was to change the type.

```
int min(int a, int b) {
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double min(double a, double b) {
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Templates

We can give that blueprint to the compiler in the form of a template function by telling it what specific parts need to get replaced.

Just before the function we specify a template parameter.

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Let's make this general.

Templates

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```
T min(T a, T b) {
    return (a < b) ? a : b;
}
```

Some generic type T.

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template <typename T>
T min(T a, T b) {
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Tell compiler T is a generic type.

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Just before the function we specify a template parameter.

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template <typename T>
T min(T a, T b) {
    return (a < b) ? a : b;
}
```

Tell compiler T is a generic type.

It will replace the parameter for us!

Using Templates

Now we can use the template function just like any other function!

We can indicate the type through angle brackets after the function name:

```
int a = 3, b = 9;
int c = min<int>(a, b);

double a = 3.14, b = 1.59;
double c = min<double>(a, b);
```

How does this work?

```
int a = 3, b = 9;
int c = min<int>(a, b);
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I don’t have a `min<int>` :(

But I know how to **make** one!

```
template <typename T>
T min(T a, T b) {
    return (a < b) ? a : b;
}
```

→

Template Instantiation (T = int)

How does this work?

```
int a = 3, b = 9;
int c = min<int>(a, b);
```

I don’t have a `min<int>` :(

But I know how to make one!

```
template <typename T>
T min(T a, T b) {
    return (a < b) ? a : b;
}
```

Template
Instantiation
(T = int)

```
int min<int>(int a, int b) {
    return (a < b) ? a : b;
}
```

Templates - Aside

You can usually omit the angle brackets when using the function.

```
int a = 3, b = 9;
int c = min<int>(a, b);
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```
int a = 3, b = 9;
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Type inferred

Templates - Aside

You can usually omit the angle brackets when using the function.

```
int a = 3, b = 9;
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Type inferred

The template parameter name can be anything. I used T but a more descriptive name is usually better.

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T min(T a, T b) {
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You can usually omit the angle brackets when using the function.

```
int a = 3, b = 9;
int c = min(a, b);
```

Type inferred

The template parameter name can be anything. I used T but a more descriptive name is usually better.

```
template <typename Type>
Type min(Type a, Type b) {
    return (a < b) ? a : b;
}
```

Templates - Aside

You can usually omit the angle brackets when using the function.

```
int a = 3, b = 9;
int c = min(a, b);
```

Type inferred

The template parameter name can be anything. I used T but a more descriptive name is usually better.

```
template <typename DataType>
DataType min(DataType a, DataType b) {
    return (a < b) ? a : b;
}
```

Questions?

Templates in Action

Let’s do a very realistic example of templates. Could be useful in assignments!

Generic Input

(GenInput`.pro`)

When Templates Go Wrong

Any time template instantiation occurs, the compiler will check that all operations used on the templatised type are supported by that type.

Generic Input

(GenInput.`pro`)

> “*With great power comes great responsibility*”
>
> \- Uncle Ben

Errors

The start of the error is usually the most informative. For example, we got:

```
../Input/main.cpp:63:19: error: invalid operands to binary expression ('istringstream' (aka
'basic_istringstream<char>') and 'std::__1::vector<int, std::__1::allocator<int> >')
converter >> ret;
~~~~~~~~~ ^ ~~~
../Input/main.cpp:93:27: note: in instantiation of function template specialization
'getInput<std::__1::vector<int, std::__1::allocator<int> > >' requested here
vector<int> vec_inp = getInput<vector<int>>("Enter a vector (yolo): ");
```

Invalid operands to binary expression “>>” tells us we are using the stream operator on a type that doesn’t know how to work with them (in this case, vector).

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~~~~~~~~~~ ^ ~~~
../Input/main.cpp:93:27: note: in instantiation of function template specialization
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```

Invalid operands to binary expression “>>” tells us we are using the stream operator on a type that doesn’t know how to work with them (in this case, vector).

Implicit Interface

What types are valid to use with a templatized function?

Any that satisfy its implicit interface.

Implicit Interface

```
template <typename T>
int foo(T input) {
    int i;
    if(input >> i && input.size() > 0) {
        input.push_back(i);
        return i;
    } else {
        return 5;
    }
}
```

Implicit Interface

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template <typename T>
int foo(T input) {
    int i;
    if(input >> i && input.size() > 0) {
        input.push_back(i);
        return i;
    } else {
        return 5;
    }
}
```

```
input >> int
```

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    }
}
```

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input >> int

input.size()
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}
```

```
input >> int

input.size()

input.push_back(int)
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Implicit Interface

```
template <typename T>
int foo(T input) {
    int i;
    if(input >> i && input.size() > 0) {
        input.push_back(i);
        return i;
    } else {
        return 5;
    }
}
```

```
input >> int

input.size()

input.push_back(int)
```

Implicit Interface

Can type T perform these operations?

```
template <typename T>
int foo(T input) {
     int i;
      if(input >> i && input.size() > 0) {
          input.push_back(i);
          return i;
     } else {
          return 5;
     }
}
```

```
input >> int

input.size()

input.push_back(int)
```

Implicit Interface

Basically, if we replace all instances of `T` with the actual type we want to use, would it compile?

Let’s take a moment

Templates ft. Iterators

Templates ft. Iterators

Every different collection comes equipped with its own type of iterator:

```
vector<int> v;
vector<int>::iterator itr = v.begin();

vector<double> v;
vector<double>::iterator itr = v.begin();

deque<int> d;
deque<int>::iterator itr = d.begin();
```

Templates ft. Iterators

The whole point of iterators was to have a standard interface to iterate over data in any container.

But we still had to specify what type of data this iterator was pointing to.

We want to ultimately write generic functions to work with iterators over any sequence.

With templates we can!

Templates ft. Iterators

With this newfound power, let's write our first generic algorithm!

Count Occurences

(IterAlgorithms`.pro`)

Next Time

Algorithms