http://web.stanford.edu/class/cs106l/

Functions and Lambdas

How can we make template functions even more general?

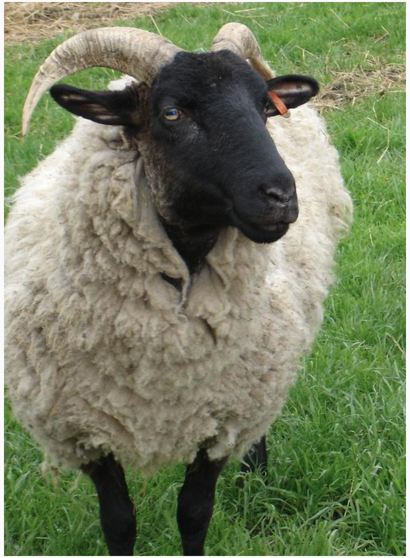
CS106L - Spring 23

Functions and Lambdas

http://web.stanford.edu/class/cs106l/

Attendance!

https://bit.ly/44knqp8



Announcements!

- No class **next week** – midquarter break!
    - Office hours during class time (3-4:30pm)
    - Review material from the lectures so far!
- After this lecture, you will be able to complete Assignment 1!
    - Due **May 12th!**

Functions and Lambdas

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Template functions are completely generic functions!

Just like classes, they work regardless of type!

Let's break it down:

Indicating this function is a template

Specifies that Type is generic

List of your template variables

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

Calling template functions

We can **explicitly** define what type we will pass, like this:

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

// int main() {} will be omitted from future examples
// we'll instead show the code that'd go inside it
cout << myMin<int>(3, 4) << endl; // 3
```

Just like in template classes!

Calling template functions

We can also **implicitly** leave it for the compiler to deduce!

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

// int main() {} will be omitted from future examples
// we'll instead show the code that'd go inside it
cout << myMin(3.2, 4) << endl; // 3.2
```

Template Functions

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Review: Template Functions

- Template functions allow you to parametrize the type of a function to be anything without changing functionality
- Generic programming can solve a complicated conceptual problem for any specifics – powerful and flexible!
- Template code is instantiated at compile time; template metaprogramming takes advantage of this to run code at compile time

Functions and Lambdas

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Let’s review that count_occurrences function!

This is a successfully templated function!

This code will work for any containers with any types, for a single specific target.

```
template <typename InputIt, typename DataType>
int count_occurrences(InputIt begin, InputIt end, DataType val) {
    int count = 0;
    for (auto iter = begin; iter != end; ++iter) {
        if (*iter == val) count++;
    }
    return count;
}
```

Usage:
```
std::string str = "Xadia";
count_occurrences(str.begin(), str.end(), 'a');
```

This is a successfully templated function!

This code will work for any containers with any types, for a single specific target.

Will this work for a more general category of targets than one specific value?

```
template <typename InputIt, typename DataType>
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        if (*iter == val) count++;
    }
    return count;
}
```

Usage:

```
std::string str = "Xadia";
count_occurrences(str.begin(), str.end(), 'a');
```

What if we wanted to find all the vowels in “Xadia”?

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This code will work for any containers with any types, for a single specific target.

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    int count = 0;
    for (auto iter = begin; iter != end;
        if (*iter == val) count++;
    }
    return count;
}
```

isVowel(*iter) ?

Usage: `std::string str = "Xadia";`

```
count_occurrences(str.begin(), str.end(), 'a');
```

Predicate Functions

Any function that returns a boolean value is a predicate!

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```
bool isLowercaseA(char c) {
    return c == 'a';
}

bool isVowel(char c) {
    std::string vowels = "aeiou";
    return vowels.find(c) != std::string::npos;
}
```

```
bool isMoreThan(int num, int limit) {
    return num > limit;
}

bool isDivisibleBy(int a, int b) {
    return (a % b == 0);
}
```

Predicate Functions

Any function that returns a boolean value is a predicate!

- isVowel() is an example of a predicate, but there are tons of others we might want!
- A predicate can have any amount of parameters...

```cpp
bool isLowercaseA(char c) {
    return c == 'a';
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```cpp
bool isMoreThan(int num, int limit) {
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Predicate Functions

Any function that returns a boolean value is a predicate!

- isVowel() is an example of a predicate, but there are tons of others we might want!
- A predicate can have any amount of parameters...

Unary

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bool isLowercaseA(char c) {
    return c == 'a';
}

bool isVowel(char c) {
    std::string vowels = "aeiou";
    return vowels.find(c) != std::string::npos;
}
```

Binary

```
bool isMoreThan(int num, int limit) {
    return num > limit;
}

bool isDivisibleBy(int a, int b) {
    return (a % b == 0);
}
```

Let’s use that!

```
template <typename InputIt, typename DataType, typename UniPred>
int count_occurrences(InputIt begin, InputIt end, UniPred pred) {
    int count = 0;
    for (auto iter = begin; iter != end; ++iter) {
        if (*iter == val pred(*iter)) count++;
    }
    return count;
}

bool isVowel(char c) {
    std::string vowels = "aeiou";
    return vowels.find(c) != std::string::npos;
}
```

Usage:

```
std::string str = "Xadia";
count_occurrences(str.begin(), str.end(), isVowel);
```

Let's use that!

```
template <typename InputIt, typename DataType, typename UniPred>
int count_occurrences(InputIt begin, InputIt end, UniPred pred) {
    int count = 0;
    for (auto iter = begin; iter != end; ++iter) {
        if (*iter == val pred(*iter)) count++;
    }
    return count;
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bool isVowel(char c) {
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Usage:

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int count_occurrences(InputIt begin, InputIt end, UniPred pred) {
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bool isVowel(char c) {
    std::string vowels = "aeiou";
    return vowels.find(c) != std::string::npos;
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```

Usage:
```
std::string str = "Xadia";
count_occurrences(str.begin(), str.end(), isVowel);
```

Let's use that!

```
template <typename InputIt, typename DataType, typename UniPred>
int count_occurrences(InputIt begin, InputIt end, UniPred pred) {
    int count = 0;
    for (auto iter = begin; iter != end; ++iter) {
        if (*iter == val pred(*iter)) count++;
    }
    return count;
}

bool isVowel(char c) {
    std::string vowels = "aeiou";
    return vowels.find(c) != std::string::npos;
}
```

Usage:
```
std::string str = "Xadia";
count_occurrences(str.begin(), str.end(), isVowel);
```

What type is UniPred???

Let’s use that!

```
template <typename InputIt, typename DataType, typename UniPred>
int count_occurrences(InputIt begin, InputIt end, UniPred pred) {
    int count = 0;
    for (auto iter = begin; iter != end; ++iter) {
        i
    }
    retur
}

bool isVow
    std::s
    retur
}
```

Usage: `std`
`cou` … `vel);`

What type is UniPred???

Function Pointers

UniPred is what's called a **function pointer!**

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Function Pointers

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- Function pointers can be treated just like other pointers
- They can be passed around like variables as parameters or in template functions!
- They can be called like functions!

Is this good enough?

Are there any ways this could be an issue?

```
template <typename InputIt, typename DataType, typename UniPred>
int count_occurrences(InputIt begin, InputIt end, UniPred pred) {
    int count = 0;
    for (auto iter = begin; iter != end; ++iter) {
        if (*iter == val pred(*iter)) count++;
    }
    return count;
}

bool isVowel(char c) {
    std::string vowels = "aeiou";
    return vowels.find(c) != std::string::npos;
}
```

Usage:
```
std::string str = "Xadia";
count_occurrences(str.begin(), str.end(), isVowel);
```

Poor Generalization

Unary predicates are pretty limited and don't generalize well.

```
bool isMoreThan3(int num) {
    return num > 3;
}

bool isMoreThan4(int num) {
    return num > 4;
}

bool isMoreThan5(int num) {
    return num > 5;
}
```

Poor Generalization

Unary predicates are pretty limited and don't generalize well.

Ideally, we'd like something like this!

```
bool isMoreThan3(int num) {
    return num > 3;
}

bool isMoreThan4(int num) {
    return num > 4;
}

bool isMoreThan5(int num) {
    return num > 5;
}

// a generalized version of the above
bool isMoreThan(int num, int limit) {
    return num > limit;
}
```

Can we use binary predicates?

If we could, it would be nice to use a binary predicate to handle this!

```
template <typename InputIt, typename BinPred>
int count_occurrences(InputIt begin, InputIt end, BinPred pred) {
    int count = 0;
    for (auto iter = begin; iter != end; ++iter) {
        if (pred(*iter, ???)) count++;
    }
    return count;
}
```

Can we use binary predicates?

How do we know what value to use? What about unary (or any other number of arguments) predicates?

```
template <typename InputIt, typename BinPred>
int count_occurrences(InputIt begin, InputIt end, BinPred pred) {
    int count = 0;
    for (auto iter = begin; iter != end; ++iter) {
        if (pred(*iter, ???)) count++;
    }
    return count;
}
```

We can't pass this in from the predicate!

Usage:
```
std::string str = "Xadia";
count_occurrences(str.begin(), str.end(), isVowel);
```

The Catch-22

We want our function to know more information about our predicate.

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However, we can’t pass in more than one parameter.

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We want our function to know more information about our predicate.

However, we can't pass in more than one parameter.

How can we pass along information without needing another parameter?

Let’s use lambdas!

Lambdas are inline, anonymous functions that can know about functions declared in their same scope!

```
auto var = [capture-clause] (auto param) -> bool
{
    ...
}
```

Let's use lambdas!

Lambdas are **inline**, anonymous functions that can know about variables declared in their same scope!

```
auto var = [capture-clause] (auto param) -> bool
{
    ...
}
```

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auto var = [capture-clause] (auto param) -> bool
{
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}
```

Functions and Lambdas

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Let’s use lambdas!

Lambdas are inline, **anonymous** functions that can know about variables declared in their same scope!

Outside parameters go here

Specifies that Type is generic

```
auto var = [capture-clause] (auto param) -> bool
{
    ...
}
```

Function body goes here!

Let’s use lambdas!

It might look something like this!

```
int limit = 5;
auto isMoreThan = [limit] (int n) { return n > limit; };
isMoreThan(6); // true
```

Functions and Lambdas

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Let’s use lambdas!

It might look something like this!

```
int limit = 5;
auto isMoreThan = [limit] (int n) { return n > limit; };
isMoreThan(6); // true
```

Capture Clauses

You can capture any outside variable, both by reference and by value.

```
[]                  // captures nothing
[limit]             // captures limit by value
[&limit]            // captures limit by reference
[&limit, upper]     // captures limit by reference, upper  by value
[&, limit]          // captures everything except limit by reference
[&]                 // captures everything by reference
[=]                 // captures everything by value
```

Capture Clauses

You can capture any outside variable, both by reference and by value.

- Use just the = symbol to capture everything by value, and just the & symbol to capture everything by reference

```
[]                 // captures nothing
[limit]            // captures limit by value
[&limit]           // captures limit by reference
[&limit, upper]    // captures limit by reference, upper  by value
[&, limit]         // captures everything except limit by reference
[&]                // captures everything by reference
[=]                // captures everything by value
```

We've solved our problem!

```
template <typename InputIt, typename UniPred>
int count_occurrences(InputIt begin, InputIt end, UniPred pred) {
    int count = 0;
    for (auto iter = begin; iter != end; ++iter) {
        if (pred(*iter)) count++;
    }
    return count;
}
```

Usage:

```
int limit = 5;
auto isMoreThan = [limit] (int n) { return n > limit; };
std::vector<int> nums = {3, 5, 6, 7, 9 ,13};

count_occurrences(nums.begin(), nums.end(), isMoreThan);
```

We've solved our problem!

```
template <typename InputIt, typename UniPred>
int count_occurrences(InputIt begin, InputIt end, UniPred pred) {
    int count = 0;
    for (auto iter = begin; iter != end; ++iter) {
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Usage:

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int limit = 5;
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std::vector<int> nums = {3, 5, 6, 7, 9 ,13};

count_occurrences(nums.begin(), nums.end(), isMoreThan);
```

Using Lambdas

Lambdas are pretty computationally cheap and a great tool!

- Use a lambda when you need a short function or to access local variables in your function.
- If you need more logic or overloading, use function pointers.

Let’s do some practice!

Aside: What the Functor?

A **functor** is any class that provides an implementation of operator().

```
class functor {
public:
    int operator() (int arg) const { // parameters and function body
        return num + arg;
    }
private:
    int num; // capture clause

};

int num = 0;
auto lambda = [&num] (int arg) { num += arg; };
lambda(5);
```

Aside: What the Functor?

A **functor** is any class that provides an implementation of operator().

- They can create **closures** of "customized" functions!

```
class functor {
public:
    int operator() (int arg) const { // parameters and function body
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Closure: a single instantiation of a functor object

Aside: What the Functor?

A **functor** is any class that provides an implementation of operator().

- They can create **closures** of "customized" functions!
- Lambdas are just a reskin of functors!

```
class functor {
public:
    int operator() (int arg) const { // parameters and function body
        return num + arg;
    }
private:
    int num; // capture clause

};

int num = 0;
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Closure: a single instantiation of a functor object

Tying it all together

So far, we've talked about lambdas, functors, and function pointers.

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std::function<return_type(param_types)> func;
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Everything (lambdas, functors, function pointers) can be cast to a standard function!

Tying it all together

So far, we've talked about lambdas, functors, and function pointers.

The STL has an overarching, standard function object!

```
std::function<return_type(param_types)> func;
```

Everything (lambdas, functors, function pointers) can be cast to a standard function!

Much bigger and more expensive than a function pointer or lambda!

Aside: Virtual Functions

Be careful using function pointers with classes, especially if you have a subclass of another class!

```
class Animal {
// constructors and other methods go here!
  void speak() {
      std::cout << "I'm an animal!" << std::endl;
  } // private information and the rest of the class goes here!
}
class Dog : Animal { // this syntax tells us we're a subclass of Animal!
// constructors and private information here!
  void speak() {
      std::cout << "I'm an animal!" << std::endl;
  } // private information and the rest of the class goes here!
}
```

Aside: Virtual Functions

What happens if we try to pass a Dog object to a function that expects an Animal?

```
void func(Animal* animal) {  // can take in any animal and make it speak!
  animal->speak();
}

int main() {
  Animal* myAnimal = new Animal;
  Dog* myDog = new Dog;
  func(myAnimal);
  func(myDog);
}
```

Aside: Virtual Functions

What happens if we try to pass a Dog object to a function that expects an Animal?

```
void func(Animal* animal) {  // can take in any animal and make it speak!
  animal->speak();
}

int main() {
  Animal* myAnimal = new Animal;
  Dog* myDog = new Dog;
  func(myAnimal); \\ I'm an animal!
  func(myDog);    \\ I'm an animal!
}
```

The function expects an Animal, so it will try to use the Animal speak function! It doesn't know it's been overridden!

Aside: Virtual Functions

If you have a function that can take in a pointer to the superclass, it won't know to use the subclass's function!

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To fix this, we can mark the overridden function as **virtual** in the header!

Aside: Virtual Functions

If you have a function that can take in a pointer to the superclass, it won't know to use the subclass's function!

The same issue happens if we create a superclass pointer to an existing subclass object.

To fix this, we can mark the overridden function as **virtual** in the header!

Virtual functions are functions in the superclass we expect to be overridden later on.

Aside: Virtual Functions

Let's change Animal to have a virtual implementation of speak()!

```
class Animal {
// constructors and other methods go here!
  virtual void speak() {
      std::cout << "I'm an animal!" << std::endl;
  } // private information and the rest of the class goes here!
}
class Dog : Animal { // this syntax tells us we're a subclass of Animal!
// constructors and private information here!
  void speak() {
      std::cout << "I'm an animal!" << std::endl;
  } // private information and the rest of the class goes here!
}
```

Aside: Virtual Functions

Let's change Animal to have a virtual implementation of speak()!

```
void func(Animal* animal) {  // can take in any animal and make it speak!
  animal->speak();
}

int main() {
  Animal* myAnimal = new Animal;
  Dog* myDog = new Dog;
  func(myAnimal); \\ I'm an animal!
  func(myDog);    \\ I'm a dog!
}
```

Now calling speak() will use the correct subclass version!

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CONTENTS

Coding Philosophy 101

There are few universal, scientifically proven pieces of wisdom that will lead to a happier life:

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1. Look both ways before crossing the street.

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Coding Philosophy 101

There are few universal, scientifically proven pieces of wisdom that will lead to a happier life:

1. Look both ways before crossing the street.
2. Never tell a pre-med you're stressed.
3. When coding, never reinvent the wheel.

New toys!

The STL implements an entire library of algorithms written by C++ developers!

- To utilize, `#include <algorithm>` in your file!
- All algorithms are **fully generic**, **templated** functions!

Constrained algorithms and algorithms on ranges (C++20)

Constrained algorithms, e.g. ranges::copy, ranges::sort, ...

Execution policies (C++17)

is_execution_policy (C++17)	execution::seq (C++17)	execution::sequenced_policy
	execution::par (C++17)	execution::parallel_policy
	execution::par_unseq (C++17)	execution::parallel_unsequenc
	execution::unseq (C++20)	execution::parallel_unsequenc

Non-modifying sequence operations

all_of (C++11)	count	search
any_of (C++11)	count_if	search_n
none_of (C++11)	mismatch	lexicographical_compare
for_each	equal	lexicographical_compare_three
for_each_n (C++17)	adjacent_find	

Modifying sequence operations

copy	fill	remove
copy_if (C++11)	fill_n	remove_if
copy_n (C++11)	generate	replace
copy_backward	generate_n	replace_if
move (C++11)	swap	reverse
move_backward (C++11)	iter_swap	rotate
shift_left (C++20)	swap_ranges	unique
shift_right (C++20)	sample (C++17)	random_shuffle (until C++17)
transform		

Partitioning operations

is_partitioned (C++11)	partition	stable_partition
partition_point (C++11)	partition_copy (C++11)	

Sorting operations

is_sorted (C++11)	sort	partial_sort
is_sorted_until (C++11)	stable_sort	partial_sort_copy

Binary search operations

lower_bound	upper_bound	binary_search

Set operations (on sorted ranges)

merge	set_difference	set_symmetric_difference
inplace_merge	set_intersection	set_union

Heap operations

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What kind of algorithms?

With the algorithm library, we can...

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- check if a condition is true across any elements

#include <algorithm> :

`any_of` `all_of` `none_of`

What kind of algorithms?

With the algorithm library, we can…

- check if a condition is true across any elements
- apply a function to all elements in a container

#include <algorithm> :

`any_of` `all_of` `none_of`

`for_each`

What kind of algorithms?

With the algorithm library, we can…

- check if a condition is true across any elements
- apply a function to all elements in a container
- search for specific elements or a range

#include <algorithm> :

`any_of` `all_of` `none_of`

`for_each`

`find` `search`

What kind of algorithms?

With the algorithm library, we can…

- check if a condition is true across any elements
- apply a function to all elements in a container
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What kind of algorithms?

With the algorithm library, we can…

- check if a condition is true across any elements
- apply a function to all elements in a container
- search for specific elements or a range
- copy, remove, add elements from one container to another

#include <algorithm> :

`any_of` `all_of` `none_of`

`for_each`

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What kind of algorithms?

With the algorithm library, we can...

- check if a condition is true across any elements
- apply a function to all elements in a container
- search for specific elements or a range
- copy, remove, add elements from one container to another
- and much, much more!

#include <algorithm> :

`any_of` `all_of` `none_of`

`for_each`

`find` `search`

`copy`

Look familiar?

count_occurrences

```
template <typename InputIt, typename UniPred>
int count_occurrences(InputIt begin, InputIt end, UniPred pred);
```

Look familiar?

count_occurrences

```
template <typename InputIt, typename UniPred>
int count_occurrences(InputIt begin, InputIt end, UniPred pred);
```

std::count_if

```
template< class InputIt, class T >
typename iterator_traits<InputIt>::difference_type
    count( InputIt first, InputIt last, const T& value );
```

Algorithms

All standard algorithms work on iterators.

- Efficient searching, sorting, complex data structure operations, smart pointers, and more are all there for you to use!
- Check out the documentation to get more information!

Functions and Lambdas

http://web.stanford.edu/class/cs106l/

Summary

- Lambda functions are inline functions that let you pass outside variables in using capture clauses!
- Lambdas can be used to pass predicate function pointers to template functions for more generalizability.
- The STL implements tons of cool algorithms that we can use without rewriting them!

Functions and Lambdas

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Thanks!

Next up: Operators!