

Lecture 11

Intro to C++

CS211 – Fundamentals of Computer Programming II
Branden Ghen a – Winter 2022

Slides adapted from:
Jesse Tov

Reminder: relative homework difficulties

Homework	Difficulty
Hw01	2
Hw02	5
Hw03	7
Hw04	11
Hw05	6
Hw06	9
Final Project	10ish*



Hw04 is the last in C
one week break
Hw05 is the first in C++

* But really it's up to you

Administrivia

- Nothing is due until Monday next week
 - Lab05, which sets up your C++ environment
 - I'll try to publish this tonight and will let you know when it's up
- Great time to catch up on any concepts you're still muddy about
 - Office hours are mostly empty, but course staff is still there!

Today's Goals

- Introduce C++
 - Goals of the language
 - Basics of how to use it
- Explore some key differences from C
 - Standard I/O
 - References

Getting the code for today

- Download code in a zip file from here:
https://nu-cs211.github.io/cs211-files/lec/11_introCPP.zip
- Extract code wherever
- Open with CLion
 - Make sure you open the folder with the CMakeLists.txt
 - Details on CLion setup in Lab05

Outline

- **Why C++?**
- Simple C++ I/O
- Pass-by-reference

What is C++?

- Feared by many; loved by few; understood by one
 - Bjarne Stroustrup, its designer
- Originally an extension to C called "C with Classes"
- Intended to bring modern (1980s) abstraction mechanisms to C
 - Data hiding
 - Generics
- Adds many other things too:
 - Destructors, Exceptions, Lambda, Dynamic Dispatch, Inheritance, Libraries
- But without slowing things down
 - "Pay (for language features) as you go"

What is C++ used for?

- Many different software areas
 - Browsers: Firefox, Chrome, Edge
 - Interactive software tools: Microsoft Office, Adobe Suite, AutoCAD
 - Language runtimes: Node.js, .NET, Java VMs
 - Major web services: Spotify, YouTube, Bloomberg's financial database
 - Databases: Oracle, MySQL, IBM DB2, MongoDB, SQL Server
 - Game engines: Creation (Skyrim, Fallout), Frostbite (Battlefield, FIFA), Unreal

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 - Databases: Oracle, MySQL, IBM DB2, MongoDB, SQL Server
 - Game engines: Creation (Skyrim, Fallout), Frostbite (Battlefield, FIFA), Unreal
- Generally:
 - Writing, big complicated programs that need to perform well
- You could write them in C, but C++ is more flexible, less work, and provides better ways to manage complexity

Why is CS211 using C++?

- The second half of CS211 focuses on learning to build larger programs and structure them using abstraction mechanisms
- Other popular languages that have the features we want don't let you take advantage of your newly-acquired C skills
 - Java, C#, Kotlin
 - And we do want to teach a *popular* language
- C++ lets you build larger programs with abstractions
 - But the concepts you've been learning about still apply
 - C++ automagically replaces some of the manual drudgery

C++ benefits

C	C++
You must call <code>free()</code> yourself to deallocate heap objects.	Language helpfully frees heap objects when owner goes out of scope.
Need a unique name for every function.	Can overload function for different argument types.
Operators like <code>+</code> and <code>==</code> work only for built-in types.	You can overload operators for user-defined types.

C++ downsides

	C	C++	
You know exactly when things are freed.	You must call <code>free()</code> yourself to deallocate heap objects.	Language helpfully frees heap objects when owner goes out of scope.	Things get freed when you might not expect it.
You always know what function you are calling.	Need a unique name for every function.	Can overload function for different argument types.	Must know argument types to determine which function gets called.
You know that <code>/</code> means "divide".	Operators like <code>+</code> and <code>==</code> work only for built-in types.	You can overload operators for user-defined types.	You know that <code>operator/()</code> takes two arguments.

C++ Versions

- C++ is a little less one language and more multiple iterations of a language
 - Where nothing old every leaves, only new things get added
 - “Within C++, there is a much smaller and cleaner language struggling to get out.” – Bjarne Stoustrup
- One major change was C++11 (2011) which introduced a better method for handling dynamic memory
 - We’ll be using C++14 which has some quality-of-life improvements to that
- C++17 and C++20 also exist!
 - But don’t add much that we need

Outline

- Why C++?
- **Simple C++ I/O**
- Pass-by-reference

Hello world in C++

src/hello_world.cxx

```
#include <iostream>
```

```
int main() {
```

```
    std::cout << "Hello World\n";
```

```
    return 0;
```

```
}
```

The standard C headers are renamed

- Every C header loses the `.h` and gets a `c` added to the front

C version of headers	C++ version of headers
<code>#include <ctype.h></code>	<code>#include <cctype></code>
<code>#include <math.h></code>	<code>#include <cmath></code>
<code>#include <stdio.h></code>	<code>#include <cstdio></code>
<code>#include <string.h></code>	<code>#include <cstring></code>

The standard C headers are renamed

- Every C header loses the `.h` and gets a `c` added to the front

C version of headers	C++ version of headers
<code>#include <ctype.h></code>	<code>#include <cctype></code>
<code>#include <math.h></code>	<code>#include <cmath></code>
<code>#include <stdio.h></code>	<code>#include <stdio.h></code>
<code>#include <string.h></code>	<code>#include <string.h></code>

- And new headers support the similar functionality in a C++ way

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

You'll use these instead of the C versions because they are easier and safer to use.

More complicated I/O input example

src/io_example.cxx

```
#include <iostream >

int main() {
    std::cout << "Enter a number to square:\n";

    double x;
    std::cin >> x;
    if (!std::cin) {
        std::cerr << "Error: could not read number!\n";
        return 1;
    }

    std::cout << x << " * " << x << " == " << x * x << "\n";
    return 0;
}
```

More complicated I/O input example

New library for I/O

```
#include <iostream >

int main() {
    std::cout << "Enter a number to square:\n";

    double x;
    std::cin >> x;
    if (!std::cin) {
        std::cerr << "Error: could not read number!\n";
        return 1;
    }

    std::cout << x << " * " << x << " == " << x * x << "\n";
    return 0;
}
```

More complicated I/O input example

```
#include <iostream >
int main() {
    std::cout << "Enter a number to square:\n";

    double x;

    std::cin >> x;

    if (!std::cin) {
        std::cerr << "Error: could not read number!\n";
        return 1;
    }

    std::cout << x << " * " << x << " == " << x * x << "\n";
    return 0;
}
```

`main()` and `main(void)`
are equivalent

Could still get input `argc`
and `argv` if wanted

More complicated I/O input example

C++ standard library is in the `std` namespace

```
#include <iostream >

int main() {
    std::cout << "Enter a number to square:\n";

    double x;

    std::cin >> x;

    if (!std::cin) {
        std::cerr << "Error: could not read number!\n";
        return 1;
    }

    std::cout << x << " * " << x << " == " << x * x << "\n";

    return 0;
}
```

More complicated I/O input example

```
#include <iostream >

int main() {
    std::cout << "Enter a number to square:\n";

    double x;
    std::cin >> x;
    if (!std::cin) {
        std::cerr << "Error: could not read number!\n";
        return 1;
    }

    std::cout << x << " * " << x << " == " << x * x << "\n";
    return 0;
}
```

Stream insertion operator
writes a value to an output
stream

More complicated I/O input example

```
#include <iostream >
int main() {
    std::cout << "Enter a number to square:\n";

    double x;
    std::cin >> x;
    if (!std::cin) {
        std::cerr << "Error: could not read number!\n";
        return 1;
    }

    std::cout << x << " * " << x << " == " << x * x << "\n";
    return 0;
}
```

Stream extraction operator reads from the input stream into an object

More complicated I/O input example

```
#include <iostream >
int main() {
    std::cout << "Enter a number to square:\n";

    double x;
    std::cin >> x;
    if (!std::cin) {
        std::cerr << "Error: could not read number!\n";
        return 1;
    }

    std::cout << x << " * " << x << " == " << x * x << "\n";
    return 0;
}
```

To detect I/O error on a stream, test the stream as if it were a bool.

More complicated I/O input example

```
#include <iostream >
int main() {
    std::cout << "Enter a number to square:\n";

    double x;
    std::cin >> x;
    if (!std::cin) {
        std::cerr << "Error: could not read number!\n";
        return 1;
    }
    std::cout << x << " * " << x << " == " << x * x << "\n";
    return 0;
}
```

Stream operators are left-associative and return their left operand

Stream operator chaining

This:

```
std::cout << x << " * " << x << " == " << x * x << "\n";
```

Is equivalent to this:

```
(((((std::cout << x) << " * ") << x) << " == ") << x * x) << "\n";
```

Is equivalent to this:

```
std::cout << x;  
std::cout << " * ";  
std::cout << x;  
std::cout << " == ";  
std::cout << x * x;  
std::cout << "\n";
```

iostream library

- Provides input/output *streams*
 - Sources that you can write characters to or read characters from
 - Same idea as a `FILE*` in C

```
std::cin    - standard in  
std::cout  - standard out  
std::cerr  - standard error
```

- Simple I/O
 - Write using `<<` operator (stream insertion)
 - Read using `>>` operator (stream extraction)

Namespaces in C++

- Namespaces provide additional naming to functions/variables
 - Prevent C problem of “no two functions can have the same name”
 - Refer to `name` as `namespace::name`
 - Defaults to global namespace (just `::name` which is the same as `name`)
- Basically what we were doing in C anyways
 - `vc_create()`, `ballot_create()`, `ballot_box_create()`
- You’ll mostly use these for standard library stuff `std::`
- **Avoid** `using namespace std;`
 - Eliminates the need to use `std::` for library calls!
 - But also means you must never duplicate a library function name
 - Back to the same problem C had!

Break + Open Question

How does this code know you want to read a double?

```
double x;
```

```
std::cin >> x;
```

Break + Open Question

How does this code know you want to read a double?

```
double x;  
std::cin >> x;
```

Operator overloading!

- You can redefine the meaning of operators in C++
- So `operator>>(istream, double)` is defined to read in a double
 - Different function is called for each set of arguments
 - Compiler figures out which one to call
- We'll talk more about this in a future lecture

Outline

- Why C++?
- Simple C++ I/O
- **Pass-by-reference**

In C, all arguments are passed as *values*

```
void f(int x, int* p) { ...
```

- In C, every variable names its own object:
 - `x` names 4 bytes capable of containing an `int`
 - `p` names 8 bytes capable of holding the memory address of an `int`
- C allows you to access other objects with pointers
 - But you are still passing a value into the function (a pointer value)

C++ has pass-by-reference

```
void f(int x, int* p, int& r) { ...
```

- `x` and `p` work the same as in C programs
- `r` refers to some other existing `int` object
 - `r` is an alternative *name* for whatever *object* was passed in
 - `r` is borrowed and cannot be `nullptr`
- Use `r` like an ordinary `int` – no need to dereference

C++ reference example: increment

test/reference_examples.cxx

```
#include <211.h>
```

Our C++ testing framework. Similar to how it worked in C!

```
void inc_ptr(int* p) {  
    *p += 1;  
}
```

```
void c_style_test(void) {  
    int x = 0;  
    inc_ptr(&x);  
    CHECK_INT( x, 1 );  
}
```

```
#include <catch.hpp>
```

```
void inc_ref(int& r) {  
    r += 1;  
}
```

```
TEST_CASE("C++-style") {  
    int x = 0;  
    inc_ref(x);  
    CHECK( x == 1 );  
}
```

Visual representation of references

test/reference_examples.cxx

```
#include <catch.hxx>
```

```
void inc_ref(int& r) {  
    r += 1;  
}
```

```
TEST_CASE("C++-style") {  
→ int x = 0;  
  inc_ref(x);  
  CHECK( x == 1 );  
}
```

x: 

Visual representation of references

test/reference_examples.cxx

```
#include <catch.hxx>

void inc_ref(int& r) {
    r += 1;
}
```

x: 

```
TEST_CASE("C++-style") {
    int x = 0;
    → inc_ref(x);
    CHECK( x == 1 );
}
```

Visual representation of references

test/reference_examples.cxx

```
#include <catch.hxx>
```

```
→ void inc_ref(int& r) {  
    r += 1;  
}
```

```
TEST_CASE("C++-style") {  
    int x = 0;  
    inc_ref(x);  
    CHECK(x == 1);  
}
```

Same object that was
previously named x

r: ~~x~~ 0

Visual representation of references

test/reference_examples.cxx

```
#include <catch.hxx>
```

```
void inc_ref(int& r) {  
→   r += 1;  
}
```

```
TEST_CASE("C++-style") {  
    int x = 0;  
    inc_ref(x);  
    CHECK( x == 1 );  
}
```

r: ✕

1

Visual representation of references

test/reference_examples.cxx

```
#include <catch.hxx>

void inc_ref(int& r) {
    r += 1;
}

TEST_CASE("C++-style") {
    int x = 0;
    inc_ref(x);
    → CHECK( x == 1 );
}
```

Back here, the object
is still named `x`

x: 1

Swap with references in C++

test/reference_examples.cxx

```
void swap_ref(int& r, int& s) {  
    int temp = r;  
    r = s;  
    s = temp;  
}
```

```
TEST_CASE("C++-style swap") {  
    int x = 3;  
    int y = 4;  
    swap_ref(x, y);  
    CHECK( x == 4 );  
    CHECK( y == 3 );  
}
```


Swap with references in C++

test/reference_examples.cxx

```
void swap_ref(int& r, int& s) {  
    int temp = r;  
    r = s;  
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}
```

```
TEST_CASE("C++-style swap") {  
    int x = 3;  
    int y = 4;  
    → swap_ref(x, y);  
    CHECK( x == 4 );  
    CHECK( y == 3 );  
}
```

x:	3
y:	4

Swap with references in C++

test/reference_examples.cxx

```
→ void swap_ref(int& r, int& s) {  
    int temp = r;  
    r = s;  
    s = temp;  
}
```

```
TEST_CASE("C++-style swap") {  
    int x = 3;  
    int y = 4;  
    swap_ref(x, y);  
    CHECK( x == 4 );  
    CHECK( y == 3 );  
}
```

r: x :	3
s: y :	4

Swap with references in C++

test/reference_examples.cxx

```
void swap_ref(int& r, int& s) {  
→ int temp = r;  
  r = s;  
  s = temp;  
}
```

```
TEST_CASE("C++-style swap") {  
  int x = 3;  
  int y = 4;  
  swap_ref(x, y);  
  CHECK( x == 4 );  
  CHECK( y == 3 );  
}
```

r: x :	3
s: y :	4
temp:	3

Swap with references in C++

test/reference_examples.cxx

```
void swap_ref(int& r, int& s) {  
    int temp = r;  
    → r = s;  
    s = temp;  
}
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TEST_CASE("C++-style swap") {  
    int x = 3;  
    int y = 4;  
    swap_ref(x, y);  
    CHECK( x == 4 );  
    CHECK( y == 3 );  
}
```

r: x :	4
s: y :	4
temp:	3

Swap with references in C++

test/reference_examples.cxx

```
void swap_ref(int& r, int& s) {  
    int temp = r;  
    r = s;  
    → s = temp;  
}
```

```
TEST_CASE("C++-style swap") {  
    int x = 3;  
    int y = 4;  
    swap_ref(x, y);  
    CHECK( x == 4 );  
    CHECK( y == 3 );  
}
```

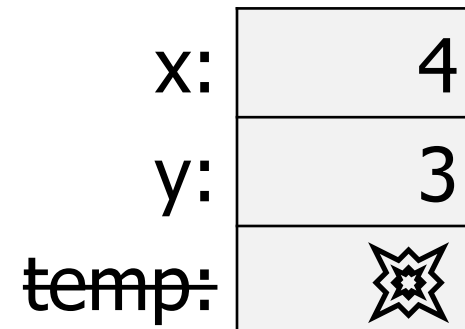
r: x :	4
s: y :	3
temp:	3

Swap with references in C++

test/reference_examples.cxx

```
void swap_ref(int& r, int& s) {  
    int temp = r;  
    r = s;  
    s = temp;  
}
```

```
TEST_CASE("C++-style swap") {  
    int x = 3;  
    int y = 4;  
    swap_ref(x, y);  
    → CHECK( x == 4 );  
    CHECK( y == 3 );  
}
```



References can be thought of as “syntactic sugar”

1. Replace every declared references with a pointer
2. Dereference each use of the variable
3. Take pointer of each variable passed in

```
void swap(int& r, int& s)
{
    int temp = r;
    r = s;
    s = temp;
}
```

```
swap(x, v[3]);
```

```
void swap(int* rp, int* sp)
{
    int temp = *rp;
    *rp = *sp;
    *sp = temp;
}
```

```
swap(&x, &v[3]);
```

References can be thought of as “syntactic sugar”

1. Replace every declared references with a pointer
2. Dereference each use of the variable
3. Take pointer of each variable passed in

```
void swap(int& r, int& s)
{
    int temp = r;
    r = s;
    s = temp;
}
```

```
swap(x, v[3]);
```

```
void swap(int* rp, int* sp)
{
    int temp = *rp;
    *rp = *sp;
    *sp = temp;
}
```

```
swap(&x, &v[3]);
```


References can be thought of as “syntactic sugar”

1. Replace every declared references with a pointer
2. Dereference each use of the variable
3. Take pointer of each variable passed in

```
void swap(int& r, int& s)
{
    int temp = r;
    r = s;
    s = temp;
}
```

```
swap(x, v[3]);
```

```
void swap(int* rp, int* sp)
{
    int temp = *rp;
    *rp = *sp;
    *sp = temp;
}
```

```
swap(&x, &v[3]);
```

References can be thought of as “syntactic sugar”

1. Replace every declared references with a pointer
2. Dereference each use of the variable
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void swap(int& r, int& s)
{
    int temp = r;
    r = s;
    s = temp;
}
```

```
swap(x, v[3]);
```

```
void swap(int* rp, int* sp)
{
    int temp = *rp;
    *rp = *sp;
    *sp = temp;
}
```

```
swap(&x, &v[3]);
```

This “desugaring” approach can explain more complicated references

References version

```
entry& e = entries[i];  
std::string const& n = e.name;
```

```
if (n == current) {  
    ++(e.count);  
}
```

“Desugared” pointer version

```
entry* pe = &(entries[i]);  
std::string const* pn = &(pe->name);
```

```
if (*pn == current) {  
    ++(pe->count);  
    //++ ((*pe).count);  
}
```

- **Note:** `std::string` types can be compared with `==`
 - Prefer `std::string` over `char*` in C++

Break + Question: Does this swap work?

```
void alt_swap(int& r, int& s)
{
    int& temp = r;
    r = s;
    s = temp;
}
```

Break + Question: Does this swap work?

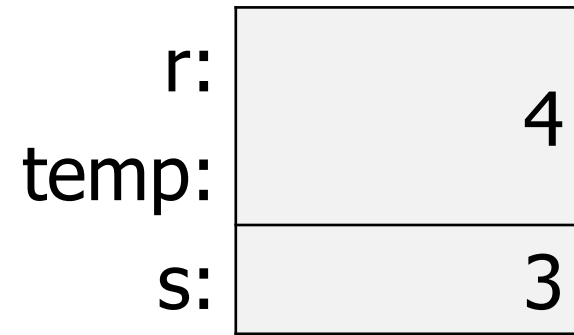
```
→ void alt_swap(int& r, int& s)
{
    int& temp = r;
    r = s;
    s = temp;
}
```

r:	4
s:	3

Break + Question: Does this swap work?

```
void alt_swap(int& r, int& s)
{
    → int& temp = r;
    r = s;
    s = temp;
}
```

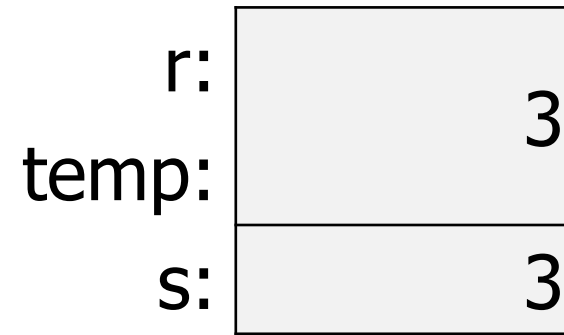
r and temp both
name the same object!



Break + Question: Does this swap work?

```
void alt_swap(int& r, int& s)
{
    int& temp = r;
    → r = s;
    s = temp;
}
```

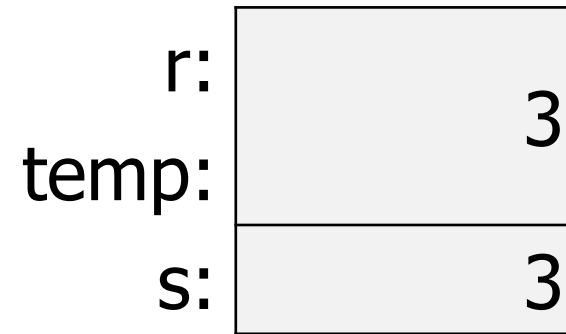
r and temp both
name the same object!



Break + Question: Does this swap work?

```
void alt_swap(int& r, int& s)
{
    int& temp = r;
    r = s;
    → s = temp;
}
```

r and temp both
name the same object!



This version of swap is broken!

Break + Question: Does this swap work?

References version

```
void alt_swap(int& r, int& s)
{
    int& temp = r;
    r = s;
    s = temp;
}
```

"Desugared" pointer version

```
void alt_swap(int* rp, int* sp)
{
    int* tempp = &*rp;
    *rp = *sp;
    *sp = *tempp;
}
```

Outline

- Why C++?
- Simple C++ I/O
- Pass-by-reference