CSE 374: Intro to C++

Next up: C++ *(Want to read ahead?)*

Best place to start: C++ Primer, Lippman, Lajoie, Moo, 5th ed., Addison-Wesley, 2013

Every serious C++ programmer should also read: Effective C++, Meyers, 3rd ed., Addison-Wesley, 2005

Best practices for standard C++

Effective Modern C++, Meyers, O'Reilly, 2014

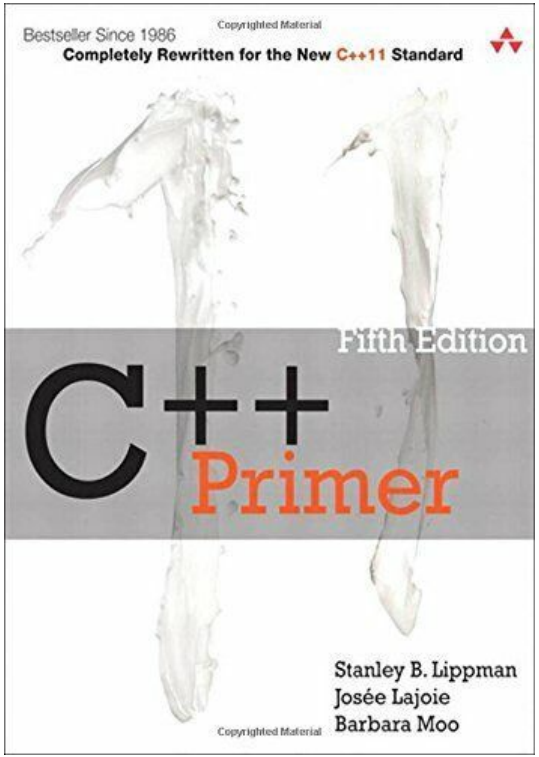
Additional "best practices" for C++11/C++14

Good online source: cplusplus.com

Aside: C++ Primer

It's hard to learn the "why is it done this way" from reference docs, and even harder to learn from random stuff on the web

- Lectures and examples will introduce the main ideas, but aren't everything you'll need to understand
- **Free** access through UW libraries
    - https://orbiscascade-washington.primo.exlibrisgroup.com/permalink/01ALLIANCE_UW/db578v/cdi_askewsholts_vlebooks_9780133053067



What is C++ ?

A big language - much bigger than C

Conveniences in addition to C (new/delete, function overloading, bigger std library)

Namespaces - similar to Java

Extras (casts, exceptions, templates, lambda functions)

Object Oriented - has classes and objects similar to Java

Object Oriented Programming

- **Encapsulation**
  - Discrete portions of code keep state and implementation private while providing public interfaces
- **Abstraction**
  - The high-level interface is exposed to users without detailing underlying code.
- **Inheritance**
  - Classes can be derived from other classes allowing for shared code.
- **Polymorphism**
  - Subclasses implement methods of superclasses to allow for a consistent interface.

Why C++ ?

- C++ is C-like in
  - User-managed memory
  - Header files
  - Still use pointers
- C++ is Java like in
  - Object Oriented
  - Modern additions to language
- Knowing C++ may help understand both C & Java better

C

- We had to work hard to mimic encapsulation, abstraction
  - **Encapsulation:** hiding implementation details
    - Used header file conventions and the “static” specifier to separate private functions from public functions
    - Cast structures to (void*) to hide implementation-specific details
  - **Abstraction:** associating behavior with encapsulated state
    - Function that operate on a LinkedList were not really tied to the linked list structure
    - We passed a linked list to a function, rather than invoking a method on a linked list instance

✨ C++ ✨

- A major addition is support for classes and objects!
  - Classes
    - Public, private, and protected **methods** and **instance variables**
    - (multiple!) inheritance
  - Polymorphism
    - Static polymorphism: multiple functions or methods with the same name, but different argument types (overloading)
      - Works for all functions, not just class members
    - Dynamic (subtype) polymorphism: derived classes can override methods of parents, and methods will be dispatched correctly

C

- We had to emulate generic data structures
  - Generic linked list using `void*` payload
  - Pass function pointers to generalize different “methods” for data structures
    - Comparisons, deallocation, pickling up state, etc.

✨ C++ ✨

- Supports templates to facilitate generic data types
  - Parametric polymorphism – same idea as Java generics, but different in details, particularly implementation
  - To declare that x is a vector of ints: `vector<int> x;`
  - To declare that x is a vector of strings: `vector<string> x;`
  - To declare that x is a vector of (vectors of floats): `vector<vector<float>> x;`

C

- We had to be careful about namespace collisions
  - C distinguishes between external and internal linkage
    - Use `static` to prevent a name from being visible outside a source file (as close as C gets to “private”)
    - Otherwise, name is global and visible everywhere
  - We used naming conventions to help avoid collisions in the global namespace
    - *e.g.* **`LL`**`IteratorNext` vs. **`HT`**`IteratorNext`, etc.

✨ C++ ✨

- Permits a module to define its own namespace!
  - The linked list module could define an "`LL`" namespace while the hash table module could define an "`HT`" namespace
  - Both modules could define an Iterator class
    - One would be globally named `LL::Iterator`
    - The other would be globally named `HT::Iterator`
- Classes also allow duplicate names without collisions
  - Namespaces group and isolate names in collections of classes and other "global" things (somewhat like Java packages)
    - Entire C++ standard library is in a namespace `std` (more later…)

C

- C does not provide any standard data structures
  - We had to implement our own linked list and hash table
  - As a C programmer, you often reinvent the wheel… poorly
    - Maybe if you're clever you'll use somebody else's libraries
    - But C's lack of abstraction, encapsulation, and generics means you'll probably end up tinkering with them or tweak your code to use them

✨ C++ ✨

- The C++ standard library is huge!
  - **Generic containers:** bitset, queue, list, associative array (including hash table), deque, set, stack, and vector
    - And iterators for most of these
  - **A `string` class:** hides the implementation of strings
  - **Streams:** allows you to stream data to and from objects, consoles, files, strings, and so on
  - And more…

C

- Error handling is a pain
  - Have to define error codes and return them
  - Customers have to understand error code conventions and need to constantly test return values
  - *e.g.* if `a()` calls `b()`, which calls `c()`
    - `a` depends on `b` to propagate an error in `c` back to it

✨ C++ ✨

- Error handling is STILL a pain, but now we have exceptions
  - `try` / `throw` / `catch`
  - If used with discipline, can simplify error processing
    - But, if used carelessly, can complicate memory management
    - Consider: `a()` calls `b()`, which calls `c()`
      - If `c()` throws an exception that `b()` doesn't catch, you might not get a chance to clean up resources allocated inside `b()`
  - But much C++ code still needs to work with C & old C++ libraries that are not exception-safe, so still uses return codes, exit(), etc.
    - We won't use (and Google style guide doesn't use either)

Some Tasks Still Hurt in ✨ C++ ✨

- Memory management
  - C++ has no garbage collector
    - You have to manage memory allocation and deallocation and track ownership of memory
    - It's still possible to have leaks, double frees, and so on
  - But there are some things that help
    - "Smart pointers"
      - Classes that encapsulate pointers and track reference counts
      - Deallocate memory when the reference count goes to zero
    - C++'s destructors permit a pattern known as "Resource Allocation Is Initialization" (RAII) (terrible name but super useful idea)
      - Useful for releasing memory, locks, database transactions, and more

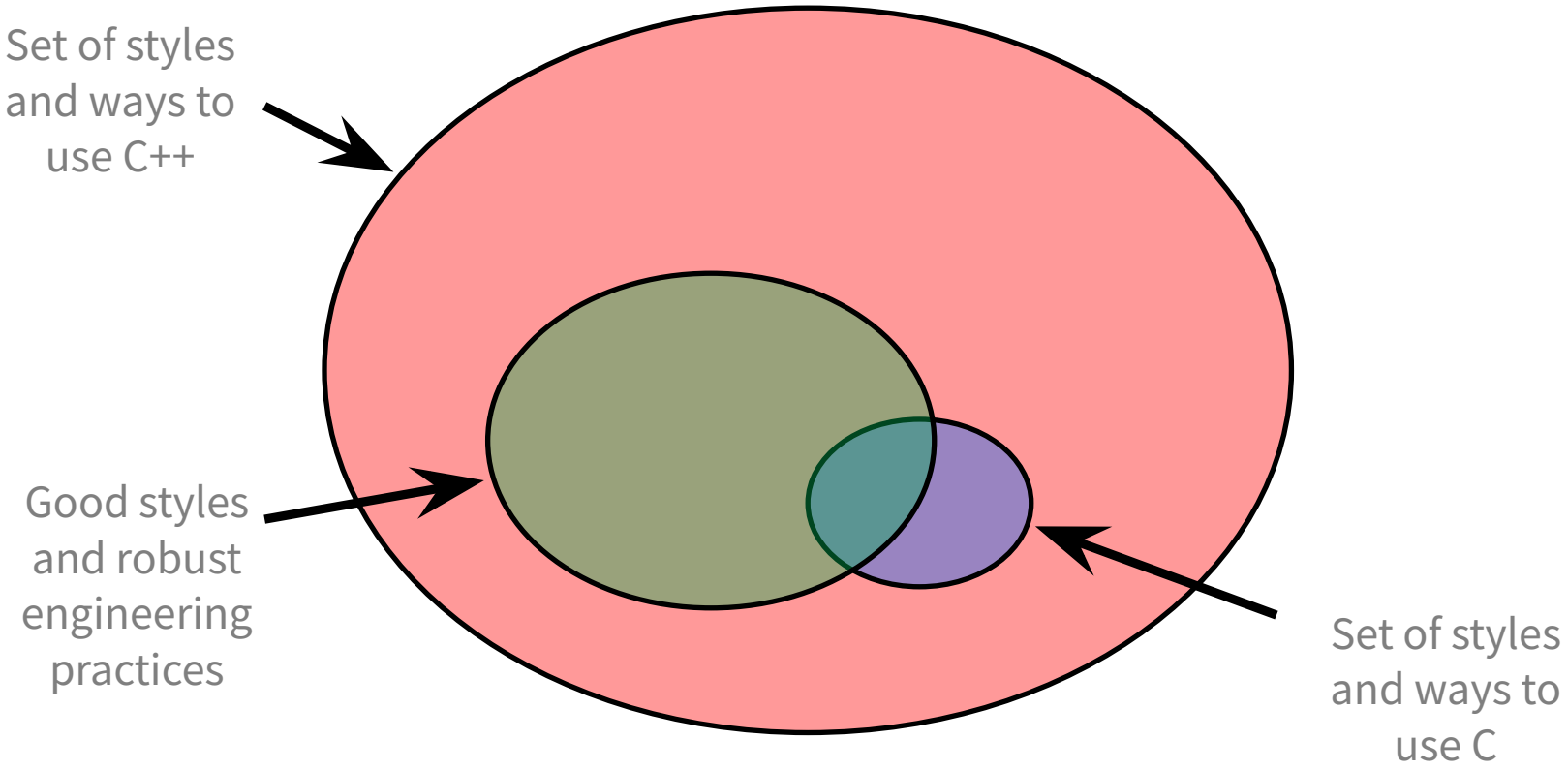
Some Tasks Still Hurt in ✨ C++ ✨

- C++ doesn’t guarantee type or memory safety
  - You can still:
    - Forcibly cast pointers between incompatible types
    - Walk off the end of an array and smash memory
    - Have dangling pointers
    - Conjure up a pointer to an arbitrary address of your choosing

✨ C++ ✨ Has Many, Many Features

- Operator overloading
  - Your class can define methods for handling “+”, “->”, etc.
- Object constructors, destructors
  - Particularly handy for stack-allocated objects
- Reference types
  - True call-by-reference instead of always call-by-value
- Advanced Objects
  - Multiple inheritance, virtual base classes, dynamic dispatch

How to Think About C++



Or…

In the hands of a disciplined programmer, C++ is a powerful tool

But if you're not so disciplined about how you use C++…

Hello World in C

helloworld.c

```c
#include <stdio.h>    // for printf()
#include <stdlib.h>   // for EXIT_SUCCESS

int main(int argc, char** argv) {
  printf("Hello, World!\n");
  return EXIT_SUCCESS;
}
```

- Compile with gcc:

```
gcc -Wall -g -std=c11 -o hello helloworld.c
```

- You should be able to describe in detail everything in this code

Hello World in C++

helloworld.cc

```
#include <iostream>// for cout, endl
#include <cstdlib>     // for EXIT_SUCCESS

int main(int argc, char** argv) {
  std::cout << "Hello, World!" << std::endl;
  return EXIT_SUCCESS;
}
```

Looks simple enough…

- Compile with **g++** instead of gcc:

```
g++ -Wall -g -std=c++17 -o helloworld helloworld.cc
```

Example: Hello World in C++

Hello World in C++

helloworld.cc

```
#include <iostream>
#include <cstdlib>

int main(int argc, char** argv) {
  std::cout << "Hello, World!" << std::endl;
  return EXIT_SUCCESS;
}
```

`iostream` is part of the ***C++*** standard library

- Note: you don't write "`.h`" when you include C++ standard library headers
  - But you *do* for local headers (*e.g.* `#include "ll.h"`)
- `iostream` declares stream *object* instances in the "`std`" namespace
  - e.g. `std::cin, std::cout, std::cerr`

Hello World in C++

helloworld.cc

```
#include <iostream>
#include <cstdlib>

int main(int argc, char** argv) {
  std::cout << "Hello, World!" << std::endl;
  return EXIT_SUCCESS;
}
```

`cstdlib` is the ***C*** standard library's `stdlib.h`

- Nearly all C standard library functions are available to you
  - For C header `stdlib.h`, you should `#include <cstdlib>`
- We include it here for `EXIT_SUCCESS`, as usual

Hello World in C++

helloworld.cc

```
#include <iostream>
#include <cstdlib>

int main(int argc, char** argv) {
  std::cout << "Hello, World!" << std::endl;
  return EXIT_SUCCESS;
}
```

`std::cout` is the "`cout`" object instance declared by `iostream`, living within the "`std`" namespace

- C++'s name for `stdout`, `std:cout` is an object of class `ostream`
- Used to format and write output to the console
- The entire standard library is in the namespace `std`

Hello World in C++

helloworld.cc

```
#include <iostream>
#include <cstdlib>

int main(int argc, char** argv) {
  std::cout << "Hello, World!" << std::endl;
  return EXIT_SUCCESS;
}
```

C++ has a stronger distinction between objects and primitive types

- These include the familiar ones from C:
  `char`, `short`, `int`, `long`, `float`, `double`, etc.
- C++ also defines `bool` as a primitive type (woo-hoo!)
  - Use it!

Hello World in C++

helloworld.cc

```
#include <iostream>
#include <cstdlib>

int main(int argc, char** argv) {
  std::cout << "Hello, World!" << std::endl;
  return EXIT_SUCCESS;
}
```

"<<" is an operator defined by the C++ language

- Defined in C as well: usually it bit-shifts integers (in C/C++)
- C++ allows classes and functions to overload operators!
  - Here, the `ostream` class overloads "<<"
  - *i.e.* it defines different member functions (methods) that are invoked when an `ostream` is the left-hand side of the << operator

Hello World in C++

helloworld.cc

```
#include <iostream>
#include <cstdlib>

int main(int argc, char** argv) {
  std::cout << "Hello, World!" << std::endl;
  return EXIT_SUCCESS;
}
```

ostream object

still a char*

`ostream` has many different methods to handle `<<`

- The functions differ in the type of the right-hand side (RHS) of `<<`
- *e.g.* if you do `std::cout << "foo";` , then C++ invokes `cout`'s function to handle << with RHS `char*`

Hello World in C++

helloworld.cc

```
#include <iostream>
#include <cstdlib>

int main(int argc, char** argv) {
  std::cout << "Hello, World!" << std::endl;
  return EXIT_SUCCESS;
}
```

This is equivalent to:

```
std::cout <<
"Hello,world!";
std:cout <<
std::endl;
```

The `ostream` class' member functions that handle << return *a reference to themselves*

- When `std::cout << "Hello, World!";` is evaluated:
  - A member function of the `std::cout` object is invoked
  - It buffers the string `"Hello, World!"` for the console
  - And it returns a reference to `std::cout`

Hello World in C++

helloworld.cc

```
#include <iostream>
#include <cstdlib>

int main(int argc, char** argv) {
  std::cout << "Hello, World!" << std::endl;
  return EXIT_SUCCESS;
}
```

Next, another member function on `std::cout` is invoked to handle `<<` with RHS `std::endl`

- `std::endl` is a pointer to a “manipulator” function
  - This manipulator function writes newline (`'\n'`) to the `ostream` it is invoked on and then flushes the `ostream`’s buffer
  - This *enforces* that something is printed to the console at this point
- If you need to print a `'\n'`, you should probably use `std::endl`

Wow...

helloworld.cc

```
#include <iostream>
#include <cstdlib>

int main(int argc, char** argv) {
  std::cout << "Hello, World!" << std::endl;
  return EXIT_SUCCESS;
}
```

You should be surprised and scared at this point

- C++ makes it easy to hide a significant amount of complexity
  - It's powerful, but really dangerous
  - Once you mix everything together (templates, operator overloading, method overloading, generics, multiple inheritance), it can get *really* hard to know what's actually happening!

Questions?

Let's Refine It a Bit

helloworld2.cc

```
#include <iostream>    // for cout, endl
#include <cstdlib>     // for EXIT_SUCCESS
#include <string>      // for string

using namespace std;

int main(int argc, char** argv) {
  string hello("Hello, World!");
  cout << hello << endl;
  return EXIT_SUCCESS;
}
```

C++'s standard library has a `std::string` class

- Include the `string` header to use it
  - http://www.cplusplus.com/reference/string/

Let's Refine It a Bit

helloworld2.cc

```
#include <iostream>    // for cout, endl
#include <cstdlib>     // for EXIT_SUCCESS
#include <string>      // for string

using namespace std;

int main(int argc, char** argv) {
  string hello("Hello, World!");
  cout << hello << endl;
  return EXIT_SUCCESS;
}
```

The `using` keyword introduces a namespace (or part of) into the current region

- `using namespace std;` imports all names from `std::`
  - Linter will complain, but we will ignore for this class
- `using std::cout;` imports *only* `std::cout` (used as `cout`)

Let's Refine It a Bit

helloworld2.cc

```
#include <iostream>    // for cout, endl
#include <cstdlib>     // for EXIT_SUCCESS
#include <string>      // for string

using namespace std;

int main(int argc, char** argv) {
  string hello("Hello, World!");
  cout << hello << endl;
  return EXIT_SUCCESS;
}
```

Benefits of `using namespace std;`

- We can now refer to `std::string` as `string`, `std::cout` as `cout`, and `std::endl` as `endl`

Let's Refine It a Bit

helloworld2.cc

```
#include <iostream>    // for cout, endl
#include <cstdlib>     // for EXIT_SUCCESS
#include <string>      // for string

using namespace std;

int main(int argc, char** argv) {
  string hello("Hello, World!");
  cout << hello << endl;
  return EXIT_SUCCESS;
}
```

Here we are instantiating a `std::string` object *on the* ***stack*** (an ordinary local variable)

- Passing the C string `"Hello, World!"` to its constructor method
- `hello` is deallocated (and its destructor invoked) when **`main`** returns

Let's Refine It a Bit

helloworld2.cc

```
#include <iostream>    // for cout, endl
#include <cstdlib>     // for EXIT_SUCCESS
#include <string>      // for string

using namespace std;

int main(int argc, char** argv) {
  string hello("Hello, World!");
  cout << hello << endl;
  return EXIT_SUCCESS;
}
```

The C++ string library also overloads the << operator

- Defines a function (*not* an object method) that is invoked when the LHS is `ostream` and the RHS is `std::string`
  - http://www.cplusplus.com/reference/string/string/operator<</

String Concatenation

concat.cc

```
#include <iostream>   // for cout, endl
#include <cstdlib>    // for EXIT_SUCCESS
#include <string>     // for string

using namespace std;

int main(int argc, char** argv) {
  string hello("Hello");
  hello = hello + ", World!";
  cout << hello << endl;
  return EXIT_SUCCESS;
}
```

The string class overloads the “+” operator

- Creates and returns a new string that is the concatenation of the LHS and RHS

String Assignment

concat.cc

```
#include <iostream>   // for cout, endl
#include <cstdlib>    // for EXIT_SUCCESS
#include <string>     // for string

using namespace std;

int main(int argc, char** argv) {
  string hello("Hello");
  hello = hello + ", World!";
  cout << hello << endl;
  return EXIT_SUCCESS;
}
```

The string class overloads the “=” operator

- Copies the RHS and replaces the string’s contents with it

String Manipulation

concat.cc

```
int main(int argc, char** argv) {
  string hello("Hello");
  hello = hello + ", World!";
  cout << hello << endl;
  return EXIT_SUCCESS;
}
```

This statement is complex!

- First "+" creates a string that is the concatenation of `hello`'s current contents and `", World!"`
- Then "=" creates a copy of the concatenation to store in `hello`
- Without the syntactic sugar:
  - `hello.operator=(hello.operator+(", World!"));`

Operators are just member functions

C and C++

helloworld3.cc

```
#include <cstdio>      // for printf
#include <cstdlib>     // for EXIT_SUCCESS

int main(int argc, char** argv) {
  printf("Hello from C!\n");
  return EXIT_SUCCESS;
}
```

C is (roughly) a subset of C++

- You can still use **`printf`** – but **bad style** in ordinary C++ code
  - E.g Use `std::cerr` instead of `frpintf(stderr, …)`
- Can mix C and C++ idioms if needed to work with existing code, but avoid mixing if you can
  - **Use C++(17)**

Reading

echonum.cc

```
#include <iostream>   // for cout, endl
#include <cstdlib>    // for EXIT_SUCCESS

using namespace std;

int main(int argc, char** argv) {
  int num;
  cout << "Type a number: ";
  cin >> num;
  cout << "You typed: " << num << endl;
  return EXIT_SUCCESS;
}
```

`std::cin` is an object instance of class `istream`

- Supports the >> operator for “extraction”
  - Can be used in conditionals ! (`std::cin>>num`) is `true` if successful
- Has a `getline()` method and methods to detect and clear errors

C++ References

Review: Pointer

Note: Arrow points to *next* instruction.

A **pointer** is a variable containing an address

- Modifying the pointer *doesn't* modify what it points to, but you can access/modify what it points to by *dereferencing*
- These work the same in C and C++

```
int main(int argc, char** argv) {
  int x = 5, y = 10;
  int* z = &x;
  *z += 1;
   x += 1;
   z = &y;
  *z += 1;

  return EXIT_SUCCESS;
}
```

x	5
y	10
z	

pointer.cc

Review: Pointer

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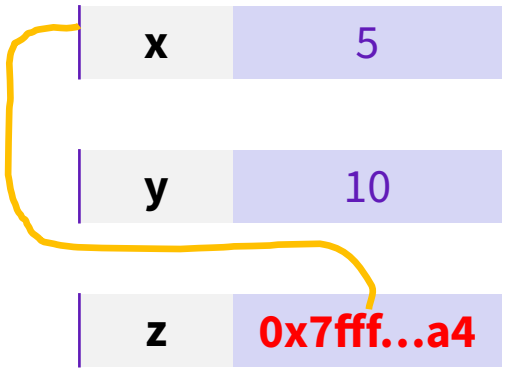
  *z += 1;
  x += 1;
  z = &y;
  *z += 1;

  return EXIT_SUCCESS;
}
```



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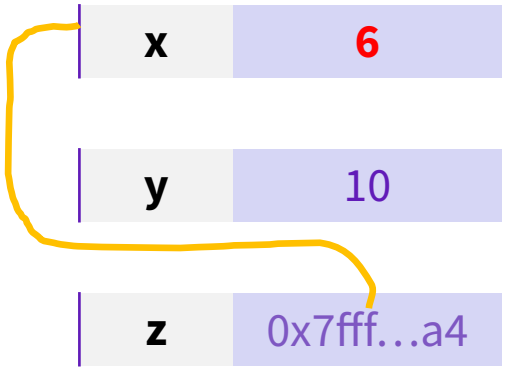
```
int main(int argc, char** argv) {
  int x = 5, y = 10;
  int* z = &x;
  *z += 1;  // sets x to 6
  x += 1;
  z = &y;
  *z += 1;

  return EXIT_SUCCESS;
}
```



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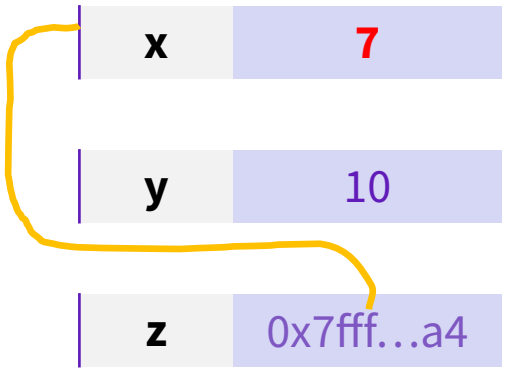
```
int main(int argc, char** argv) {
  int x = 5, y = 10;
  int* z = &x;
  *z += 1;  // sets x to 6
  x += 1;  // sets x (and *z) to 7
  z = &y;
  *z += 1;

  return EXIT_SUCCESS;
}
```



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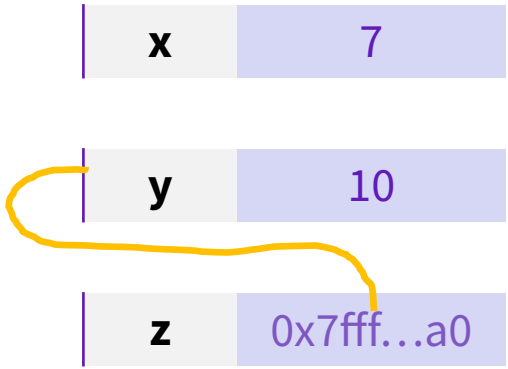

pointer.cc

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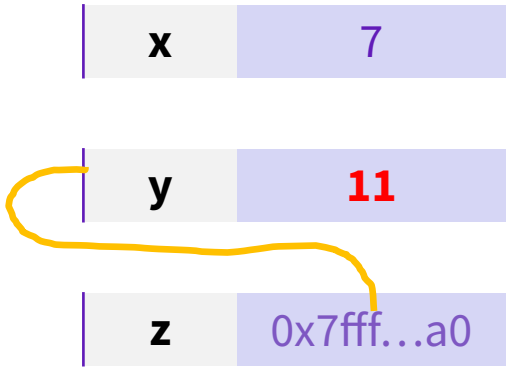

pointer.cc

References

A **reference** is an alias for another variable

- *Alias*: another name that is bound to the aliased variable
  - Mutating a reference ***is*** mutating the aliased variable
- Introduced in C++ as part of the language

```
int main(int argc, char** argv) {
  int x = 5, y = 10;
  int& z = x;
  z += 1;
  x += 1;
  z = y;
  z += 1;

  return EXIT_SUCCESS;
}
```

When we use '`&`' in a type declaration, it is a reference.

`&var` is still "address of var"

x	5

y	10

reference.cc

References

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- Introduced in C++ as part of the language

```
int main(int argc, char** argv) {
  int x = 5, y = 10;
  int& z = x; // binds the name "z" to x
  z += 1;
  x += 1;
  z = y;
  z += 1;

  return EXIT_SUCCESS;
}
```

x, z	5

y	10

reference.cc

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  int x = 5, y = 10;
  int& z = x; // binds the name "z" to x
  z += 1;  // sets z (and x) to 6
  x += 1;
  z = y;
  z += 1;

  return EXIT_SUCCESS;
}
```

x, z	6

y	10

reference.cc

References

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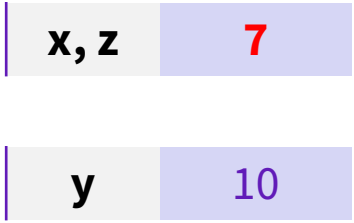
  int& z = x; // binds the name "z" to x
  z += 1;  // sets z (and x) to 6
  x += 1;  // sets x (and z) to 7
  z = y;
  z += 1;

  return EXIT_SUCCESS;
}
```



reference.cc

References

A **reference** is an alias for another variable

- *Alias*: another name that is bound to the aliased variable
  - Mutating a reference ***is*** mutating the aliased variable
- Introduced in C++ as part of the language

```
int main(int argc, char** argv) {
  int x = 5, y = 10;
  int& z = x; // binds the name "z" to x
  z += 1;  // sets z (and x) to 6
  x += 1;  // sets x (and z) to 7
  z = y;   Normal assignment
  z += 1;

  return EXIT_SUCCESS;
}
```

There is no way to rebind a reference to refer to a different object. Because there is no way to rebind a reference, references must be initialized.

x, z	7

y	10

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  z = y;  // sets z (and x) to the value of y
  z += 1;

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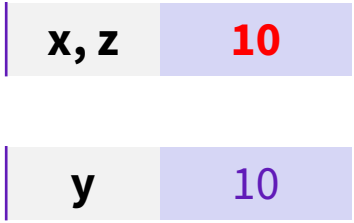
```



reference.cc

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  int& z = x; // binds the name "z" to x
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  x += 1;  // sets x (and z) to 7
  z = y;  // sets z (and x) to the value of y
  z += 1;  // sets z (and x) to 11

  return EXIT_SUCCESS;
}
```

x, z	11

y	10

reference.cc

Some Symbols Have Multiple Meanings

`&` and `*` are used as both an operator in an expression and as part of a declaration. The context in which a symbol is used determines what the symbol means:

```
int i = 42;
int& r = i;          // & follows a type and is part of a declaration; r is a reference
int* p;              // * follows a type and is part of a declaration; p is a pointer
p = &i;              // & is used in an expression as the address-of operator
*p = i;              // * is used in an expression as the dereference operator
int& r2 = *p;        // & is part of the declaration; * is the dereference operator
```

In declarations, & and * are used to form *compound* types. In expressions, these same symbols are used to denote an operator.

Pass-By-Reference

C++ allows you to use real pass-by-*reference*

- Client passes in an argument with normal syntax
  - Function uses reference parameters with normal syntax
  - Modifying a reference parameter modifies the caller's argument!

```
void swap(int& x, int& y) {
  int tmp = x;
  x = y;
  y = tmp;
}

int main(int argc, char** argv) {
  int a = 5, b = 10;
  swap(a, b);
  cout << "a: " << a << "; b: " << b << endl;
  return EXIT_SUCCESS;
}
```

(main) **a**	5

(main) **b**	10

passbyreference.cc

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  cout << "a: " << a << "; b: " << b << endl;
  return EXIT_SUCCESS;
}
```

Parameters are attached to variables provided by caller

(main) **a**	5

(main) **b**	10

passbyreference.cc

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}
```

passbyreference.cc

(main) **a** (swap) **x**	5
(main) **b** (swap) **y**	10
(swap) **tmp**	

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```

passbyreference.cc

(main) **a** (swap) **x**	5
(main) **b** (swap) **y**	10
(swap) **tmp**	**5**

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```

(main) **a** (swap) **x**	**10**
(main) **b** (swap) **y**	10
(swap) **tmp**	5

passbyreference.cc

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  int a = 5, b = 10;
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  cout << "a: " << a << "; b: " << b << endl;
  return EXIT_SUCCESS;
}
```

(main) **a** (swap) **x**	10
(main) **b** (swap) **y**	**5**
(swap) **tmp**	5

passbyreference.cc

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int main(int argc, char** argv) {
  int a = 5, b = 10;
  swap(a, b);
  cout << "a: " << a << "; b: " << b << endl;
  return EXIT_SUCCESS;
}
```

(main) **a**	10

(main) **b**	5

passbyreference.cc

Best Practices

Programmers accustomed to programming in C often use pointer parameters to access objects outside a function. In C++, programmers generally use reference parameters instead.