Lecture 12
Object Oriented Programming

CS211 – Fundamentals of Computer Programming II
Branden Ghena – Winter 2022

Slides adapted from:
Jesse Tov, Clayton Price (Missouri S&T), Hal Perkins (University of Washington)

Administrivia

- Lab5 is up and available
  - Please let us know ASAP if you’re having problems running code in CLion
- Homework 5 should be up late tonight

Today's Goals

- Introduce Classes and Objects in C++
  - Why are they an important concept?
  - How do we use them?

- Understand special functions useful for objects
  - Constructors
  - Overloaded operators

- Walk through GE211 to discuss how it works

Getting the code for today

- Download code in a zip file from here: https://nu-cs211.github.io/cs211-files/lec/12_objects.zip
- Extract code wherever
- Open with CLion
    - Make sure you open the folder with the CMakeLists.txt
    - Details on CLion in Lab05

Outline

- **Pass-by-reference**
- Object Oriented Programming
- Writing code with objects
- Constructors
- Example Object: Vectors
- Tour of GE211

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

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 );
}
```

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}
```

x:	3
y:	4

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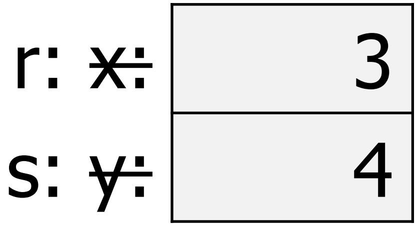

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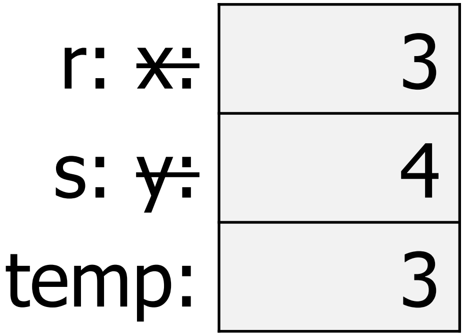

Swap with references in C++

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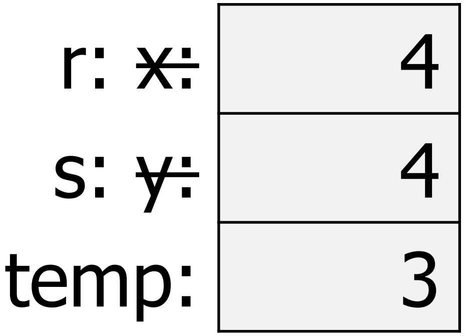

Swap with references in C++

test/reference_examples.cxx

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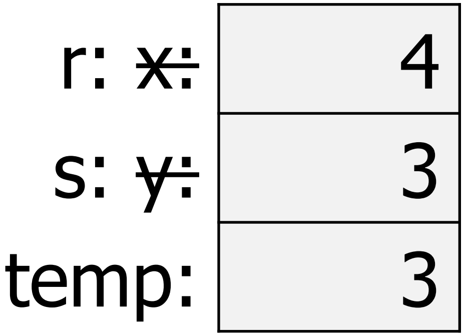
}
```

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



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 );
}
```

x:	4
y:	3
~~temp:~~	

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
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]);
```

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);
}
```

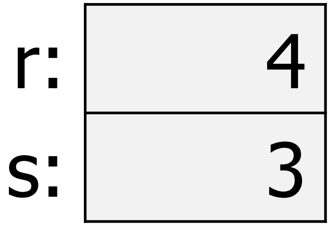
- Note: `std::string` types can be compared with `==`
  - Prefer `std::string` over `char*` in C++

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?

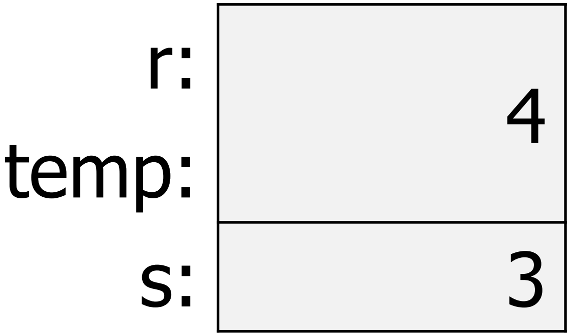
```
void alt_swap(int& r, int& s)
{
  int& temp = r;
  r = s;
  s = temp;
}
```



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;
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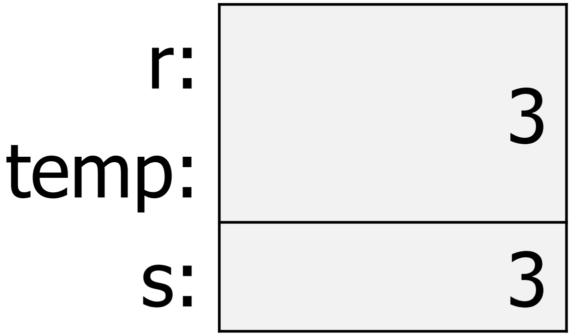
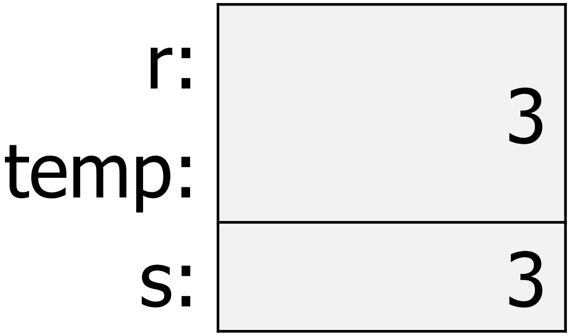


Break + Question: Does this swap work?

```
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

- Pass-by-reference
- **Object Oriented Programming**
- Writing code with objects
- Constructors
- Example Object: Vectors
- Tour of GE211

Object Oriented Programming

- Basic idea
  - Combine data and code that modifies the data together

- In code this takes the form of structs (or classes)
  - Which contain various fields (data)
  - And have various methods (functions)

- When you create one of these, you're create an "object"
  - Unit of data and interaction
  - Big chunk of memory that holds all the fields
    - But also with functions that you can run on it

How we handled this idea in C

- Created a file for dealing with a single "object"
  - i.e. a `ballot_t`

- Functions inside the file operate on that object
  - Each function takes a `ballot_t` as the first argument
  - Functions are named ballot_<action>()
    - `ballot_create`, `ballot_destroy`, `ballot_count`, etc.

- All access to the data must go through the functions
  - Other files couldn't access the ballot fields directly
  - Otherwise they could screw up the rules of the `ballot_t`

What would a ballot_t look like in C++?

- Create a ballot struct
  - With length and entries fields just like the C version

- Add functions to the struct
  - (Couldn’t do this in C)

  - Each function will modify the struct it’s called on

Why do this?

- Keep concepts located together
  - One object for VC, one for ballot, one for ballot_box
  - Could have written it all as one big thing
    - But it would be easy to get lost in the complexity
    - Separating things into smaller parts meant each was easier to write
- Access control
  - Later, we'll see that there are ways to control which data/functions can be publicly accessed versus privately accessed
  - Often there are public functions but private data

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Implementing member functions

src/position.hxx
src/position.cxx

```
struct Position {
  double x;
  double y;
  void print();
};

void Position::print() {
  std::cout << "{" << x << " , " << y << " }\n";
}
```

Accessing data members in member functions

- Within member functions, you can just use the name of any data member
  - Make sure not to make local variables with the same name as data members!!

- The `this` pointer can also be used inside member functions
  - It's a pointer to the object itself
  - `this->member` can access the data member directly
    - Means the same thing as just `member` generally

  - You will almost never need to use `this` in C++

Live coding example: positions

src/position.hxx
src/position.cxx

- Data
  - Doubles for x and y coordinate

- Methods
  - print()
  - set_location()
  - distance_to()

const is used everywhere in C++

- `const` keyword means that the thing cannot be modified
  - Used significantly more in C++ than it was in C
  - Signals intent to the compiler to keep you from making mistakes!

  - `const int x = 0;`
    - Integer `x` cannot be modified

  - `const int& x = y;`
  - `int const& x = y;`
    - Reference to an int now named `x`. `x` cannot be modified
    - These two are identical! Either way is fine

  - `print() const;`
    - There will be a `print()` member function doesn't modify its object

Code organization

- Header files (.hxx)
  - struct definitions, including member functions
  - You can inline simple one-liner functions in the definition
- Source files (.cxx)
  - Implementations of member functions
- Usually a set of cxx/hxx files for each struct/class you make
  - Classes are nearly the same as structs, we’ll talk about them next week

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Contructors initialize newly-created objects

- Written with the class name as the method name, no return value!

```
Position(double x, double y);
```

- Allow us to define how data is initialized
  - Might use inputs as values for some data members
  - Might give default values to some data members
  - Might do some computation to decide what data members should be

  - Any and all of the above

Default constructor

- If you do not create a constructor, C++ will attempt a default
  - Leave all basic types initialized
  - Call the default constructor on all data members that are objects

- This is how we’ve been using Position so far

- C++ notation
  - Basic data types: plain old data (POD)
  - Object data types: non-POD

Writing our own constructor

src/position.hxx
src/position.cxx

```
struct Position {
  double x;
  double y;
  Position(double in_x, double in_y);
}
```

Note: doesn't return `void`
Has no return at all!

```
Position::Position(double in_x, double in_y) {
  x = in_x;
  y = in_y;
}
```

Initialization lists

- C++ lets you optionally declare an initialization list as part of your constructor definition
  - Lists fields and initializes them, one-by-one
  - **MUST** be in same order as the data members are in the struct

```
Position::Position(double in_x, double in_y)
    : x(in_x),
      y(in_y)
{ } // must have function body, even if empty
```

Initialization lists

- **Always** write initializer lists for constructors
  - *Nearly* identical to doing it manually
  - But that nearly can really hurt

- Examples:
  - Data members that don’t have a default constructor need to be created in the initializer list

  - Data members that are references can never be NULL, so they don’t have a default! But the initializer list can still set them

Must use exclusively default constructors or defined ones

- Once you create a single constructor, C++ will no longer allow default ones
  - So if you want more options, you'll need to make them!

- Remember: C++ allows multiple functions with the same name, as long as their input arguments are different
  - We can create multiple constructors!

Multiple constructors make objects easier to use

src/position.hxx
src/position.cxx

- Default constructor

```
Position::Position()
      : x(0),
        y(0)
{ }
```

- Constructor with arguments

```
Position::Position(double in_x, double in_y)
      : x(in_x),
        y(in_y)
{ }
```

Copy constructor

src/position.hxx
src/position.cxx

- Makes a copy of an existing object

```
Position::Position(const Position& orig)
    : x(orig.x),
      y(orig.y)
{ }
```

- Can be called automatically or used via assignment

```
Position x;

Position y(x);

Position z = x;
```

When do copies happen?

- The copy constructor is invoked if:

1. You *initialize* an object from another object of the same type

```
Position x;      // default constructor
Position y(x);  // copy constructor
Position z = y;// copy constructor
```

2. You pass a non-reference object as a value parameter to a function

```
void foo(Position x) { ... }

Position y; // default constructor
foo(y);     // copy constructor
```

3. You return a non-reference object value from a function

```
Position foo() {
  Position y; // default constructor
  return y;   // copy constructor
}
```

Destructors

src/position.hxx
src/position.cxx

- Same concept as constructors: used to clean up an object
  - Automatically called when the object goes out of scope
  - Note: you never call the destructor yourself!

- Handles any cleanup, including freeing necessary resources

```
Position::~Position() {
  // nothing to clean here since we don't use
  // dynamic memory
}
```

Break + Open Question

- How would you have written libvc using C++ objects?

Break + Open Question

- How would you have written libvc using C++ objects?

  - Add the vc_ functions to the struct vote_count
  - Maybe make a few operators to make your life easier

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C++ libraries provide various useful structures for you

- C libraries had some functions that would let you interact with things like files or the user

- C++ has those, but also has libraries with data structures and with various algorithms (such as sorting)
  - C++ data structures (containers): https://cplusplus.com/reference/stl/
  - C++ algorithms: https://cplusplus.com/reference/algorithm/

C++ Vectors

- One example C++ library: Vector
  - An automatically expanding “array” capable of holding any type
  - std::vector<TYPE> to choose what type it should hold
    - std::vector<int>, std::vector<double>, etc.
    - This idea is known as “generics”. We’ll discuss in a later lecture

- Creating a vector (there are many ways)

```
std::vector<TYPE> myvector(); //empty vector of with no size
std::vector<TYPE> myvector(len); //vector of size len with uninitialized values
std::vector<TYPE> myvector(len, val); //vector of size len with values set to val

std::vector<TYPE> myvector{val1, val2, val3, ...};
//vector with initial values, set to a size to hold them all
```

Other useful Vector operations

- `vec[n]` is used to get the value at index `n`
  - Works just like a C array
  - Still **UNDEFINED BEHAVIOR** if `n` is out of bounds for the Vector

- `vec.at(n)` accesses value at index `n`
  - Just like square brackets, but throws an exception if out-of-bounds
  - Exceptions: new way of signaling errors. Will talk about in later lecture

- `vec.size()` returns the length of the Vector

- `vec.push_back()` and `vec.pop_back()` add/remove items
  - And resize the Vector automatically as needed

Example vector code

test/vector_examples.cxx

- Play around with vectors

C++ allows for simpler iteration (like Python)

```
double sum_vec(std::vector<double> const& vec){
  double result = 0;
  for (double val : vec) {
    result += val;
  }
  return result;
}
```

Iterates over elements in the vector, not indices!

Modifying elements inside the vector

- Warning: make sure you're modifying the actual vector element

```
void dec_vec_wrong(std::vector<int> &vec){
  for (int val : vec){
    --val;
  }
}
```

Each `val` is a copy of the value in the vector

Modifying elements inside the vector

- Warning: make sure you're modifying the actual vector element

```
void dec_vec_wrong(std::vector<int> &vec){
  for (int val : vec){
    --val;
  }
}
```

Each `val` is a copy of the value in the vector

```
void dec_vec_right(std::vector<int> &vec){
  for (int& val : vec){
    --val;
  }
}
```

Each `val` is a reference to the value in the vector.

So modifying it works!

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GE211

- A simple game engine designed by Jesse Tov at Northwestern!
  - Game Engine for CS211

- Source:
  - https://github.com/tov/ge211

- Docs:
  - https://tov.github.io/ge211/

High-level overview

- GE211 has a big while loop that runs 60 times per second

- Each time through the loop:
  - Checks for user inputs (mouse and keyboard)
    - Calls functions in your code providing you those details

  - Draws everything on screen
    - Calls the `draw()` function in your code to get the sprites to draw

- All of this works through C++ objects
  - Some details rely on inheritance, which we'll discuss later

Game application code structure

- Model
  - Keeps track of “game” state
  - Might have multiple helper files for various objects it needs
- Controller
  - Reads inputs from user and changes the model
- View
  - Reads from model and sets the drawing
- Lab05 combines Controller and View into a single UI

Live coding: open up Lab05

- https://nu-cs211.github.io/cs211-files/lab/lab05.pdf

- https://nu-cs211.github.io/cs211-files/lab/lab05.zip

ge211::geometry::Posn

- Docs: https://tov.github.io/ge211/structge211_1_1geometry_1_1_posn.html

- Keeps track of a 2D position!
  - Defines various constructors
  - Methods that shift the coordinate
  - Operators for comparison and modification

ge211::geometry::Dims

- Docs: https://tov.github.io/ge211/structge211_1_1geometry_1_1_dims.html

- Keeps track of the dimensions of an object
  - Width and height
  - Returned as the difference between two Posn

  - Defines constructors and operators

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Outline

- **Bonus: Operator Overloading**

Defining operators for our objects

- One strength of C++ is that we can define how normal operators work on our objects
  - +, -, +=, ==, <<, etc.

- Most of these are not defined for you
  - How would the compiler know what they mean for a `Position`?
  - An exception is assignment (=), which is defined as a copy of all fields

  - We can implement the operators ourselves though!
  - Can be implemented as standalone functions or member functions

Example overloaded operator

src/position.hxx
src/position.cxx

Standalone (normal) function

Note: lhs - left-hand side, rhs - right-hand side

```
bool operator==(Position const& lhs, Position const& rhs){
    return (lhs.x == rhs.x) && (lhs.y == rhs.y);
}
```

Member function (assumes the first argument is `*this`)

```
bool Position::operator==(Position const& rhs) const{
    return (x == rhs.x) && (y == rhs.y);
}
```

Either is fine, but can’t do both! That would be a duplicate function

What might we want to do with our positions?

src/position.hxx
src/position.cxx

- Compare them
  - `bool operator==(T const& lhs, T const& rhs)`

- Add them
  - `T operator+(T const& lhs, T const& rhs)`
  - `T& operator+=(T& lhs, T const& rhs)`

- Print them through `std::cout` (which is type `std::ostream`)
  - `std::ostream& operator<<(std::ostream& os, T const& value)`
  - Note: cannot be a member function because `Position` is not the lhs

https://gist.github.com/beached/38a4ae52fcadfab68cb6de05403fa393

Break + Question

- If we wanted to write operator+ as a member function, what would its signature be?
  - `T operator+(T const& lhs, T const& rhs)`

```
struct position {
    …
    ???
}
```

Break + Question

- If we wanted to write operator+ as a member function, what would its signature be?
  - `T operator+(T const& lhs, T const& rhs)`

```
struct position {
    …
    T operator+(T const& rhs) const;
}
```