Lecture 13
Access Control

CS211 – Fundamentals of Computer Programming II

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Slides adapted from:
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Administrivia

- Homework 5 is underway
  - Remember this is a SOLO ASSIGNMENT
  - Hardest part: getting used to C++ syntax
- Example: calling a function on an object
  - Documentation: `Posn<int>::right_by(…)`
  - Means: `Posn<int>` has a member function called `right_by()`
  - To call it: `pos.right_by(…)`

Warning: CLion isn’t always trustworthy

- CLion tries too hard to be useful
  - And can end up changing files you didn’t mean to
  - When it pops up and asks if you want to do something, usually the answer is “No!”
    - Example: static functions
- This can end up changing code in files you didn’t mean to touch
  - Easiest fix is often to check out the project again and move your files over

Today's Goals

- Continue practice on constructors and objects
  - Discuss operator overloading
  - Discuss using exceptions to signal errors

- Introduce concept of encapsulation and access control
  - How technically it's done in C++
  - Why we care about it

Getting the code for today

- Download code in a zip file from here: https://nu-cs211.github.io/cs211-files/lec/13_access.zip

- Extract code wherever

- Open with CLion
  - Make sure you open the folder with the CMakeLists.txt

Outline

- **Tour of GE211**

- More Constructors
- Operator Overloading
- Exceptions

- Access Control
- Encapsulation Policy

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

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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Today’s working example

- String_Holder
  - Manages strings using a constant-length array to hold characters
  - Members:
    - `int length`
    - `char characters[80]`
  - Rules (invariants)
    - 0 <= `length` <= 80
    - `length` matches the number of valid characters in `characters`

Live Coding: constructors for String_Holder

src/string_holder-implemented.cxx
src/string_holder.cxx

- `String_Holder::String_Holder()`
  - Initialize empty
- `String_Holder::String_Holder(const char* str)`
  - Construct from null-terminated string
- `String_Holder::String_Holder(const char* str, int len)`
  - Construct from a length of characters
- `String_Holder::String_Holder(const String_Holder& other)`
  - Copy constructor (from another `String_Holder`)

Delegating constructors

- One constructor can call another to handle initialization
  - Delegates construction to that other constructor

```
// defined somewhere else
String_Holder::String_Holder(const char* str, int len);


// delegates to other constructor
String_Holder::String_Holder(const String_Holder& other)
  : String_Holder(other.characters, other.length)
{}
```

Explicit constructors

- The `explicit` keyword before a constructor means that the constructor must be manually called by the developer
  - Rather than automatically called by the compiler

- Reason to have compiler automagic:

  - `String_Holder str = “Test”;`

  - Automatically calls `String_Holder::String_Holder(“Test”);`
    - Kind of nice that it just works…

Explicit constructors

- The `explicit` keyword before a constructor means that the constructor must be manually called by the developer
  - Rather than automatically called by the compiler

- Reason to use `explicit`:
  - `void do_complicated_string_stuff(String_Holder str);`
  - `do_complicated_string_stuff("Test");`
  - Also automatically calls the constructor
    - But maybe the user just passed in the wrong argument and a compile error would have been better…

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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 `String_Holder`?
  - 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/string_holder.cxx

Standalone (normal) function

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

```
bool operator==(String_Holder const& lhs, String_Holder const& rhs){
    …
}
```

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

```
bool String_Holder::operator==(String_Holder const& rhs) const{
    …
}
```

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

What might we want to do with our strings?

src/string_holder.cxx

(substitute `String_Holder` for `T`)

- Compare them
  - `bool operator==(T const& lhs, T const& rhs)`
- Concatenate 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 `String_Holder` is not the lhs

List of operator functions: 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)`

    (substitute `String_Holder` for `T`)

```
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)`
    (substitute `String_Holder` for `T`)

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

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Enforcing invariants with constructors

- What if a user violates the rules?
  - 0 <= `length` <= 80
  - `length` matches the number of valid characters in `characters`

- Possibilities
  - Probably length should be an `unsigned int` to start with
  - Truncate length to 80
  - Only copy over as many characters as will fit

  - But what if there's no obvious choice for what to do?
    - Constructor cannot return a value to say it failed

Exceptions conceptually

- Stop running this code and return a special error to the caller
- Things went wrong, so we can’t just keep executing code like normal
- If the caller doesn’t expect the error and can’t handle it, repeat the process
  - Again stop running the code and return the special error

Exceptions are “thrown” by the function

- `throw` keyword performs the special “error return”

- Takes an argument of the error to return
  - Example:

```
throw std::invalid_argument(“String is too long”);
```

- Actually, you can throw anything (for historical reasons)

```
throw 6;
```

  - You should almost certainly throw a class based on `std::exception`
    - https://en.cppreference.com/w/cpp/error/exception

Properly handling exceptions

- If no caller in the "call stack" handles the exception, the program will exit

- Handle exceptions with a try-catch block

```
try {
  // code that could throw an exception goes here
} catch (const std::invalid_argument& ex) {
  // code to handle the exception goes here
}
```

  - This example only catches `std::invalid_argument` exceptions

General try-catch form

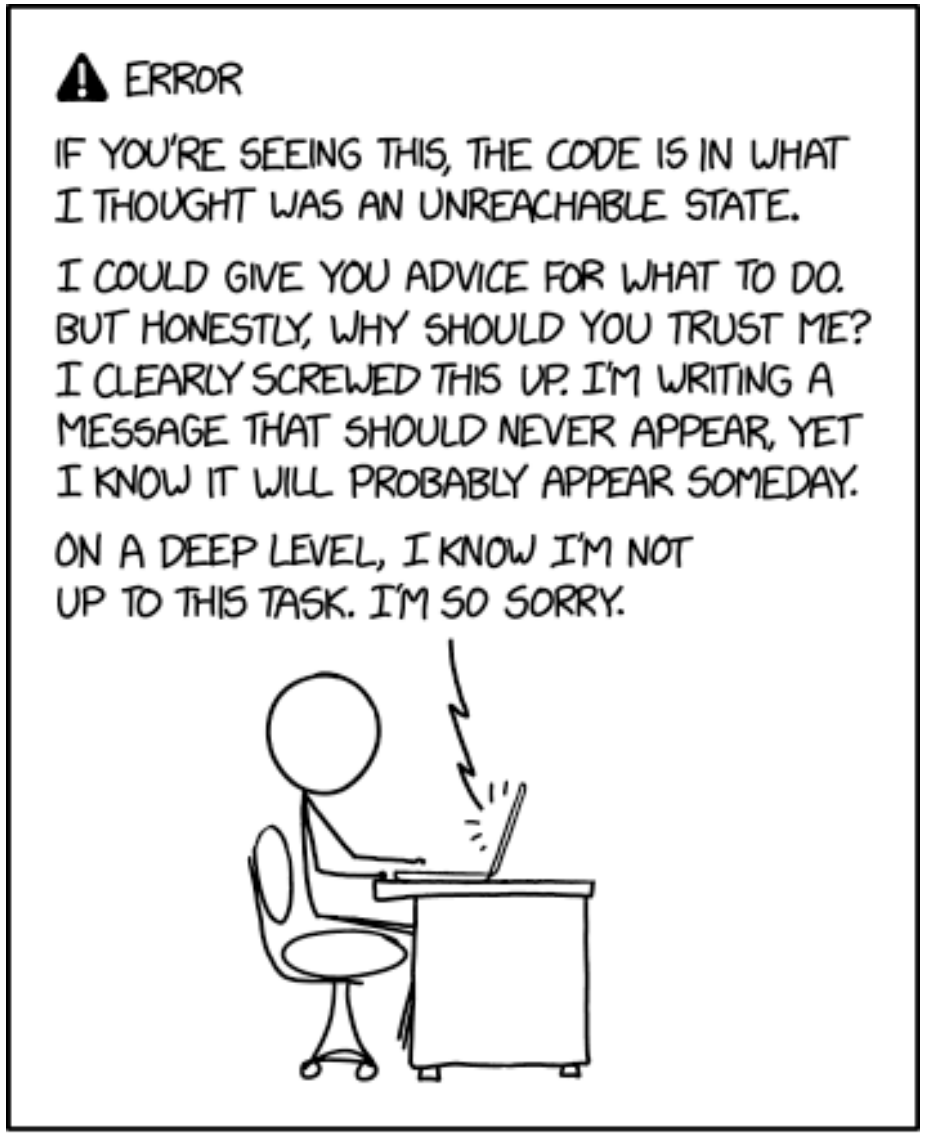
```
try {
   // code that could throw exceptions
} catch ( some specific exception ) {
   // handler code
} catch ( another specific exception ) {
   // handler code
} catch (...) {
   // general case matches all exceptions
   // actually includes the ... in the C++ code
}
```

Live coding: exceptions

src/string_holder-exception.cxx

- Functions to add to:
  - String_Holder::String_Holder(const char*, int)
    - Ensure that int values are:
      - >= 0
      - < MAX_STRING_LENGTH
  - String_Holder::char_at(int)
    - Ensure that int values are:
      - >= 0
      - < length

Break + Relevant XKCD



https://xkcd.com/2200/

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The problem of public access

- Constructors (and other member functions) that enforce rules are insufficient
  - Anyone could access the data member directly

```
String_Holder str("Test String");

str.length = 5000;

std::cout << str; // oops, UNDEFINED BEHAVIOR
```

Access modifiers

By default, all data and functions are “public”

```
struct My_struct {

  // accessible to all parts of the program

}
```

Access modifiers

Can choose to make data/functions “private”

```
struct My_struct {

private:
   // accessible only to member functions

}
```

Access modifiers

Can choose exactly which data / functions are publicly accessibly versus privately accessible!

```
struct My_struct {

public:
 // accessible to all parts of the program

private:
   // accessible only to member functions

}
```

Access modifiers

Can choose exactly which data / functions are publicly accessibly versus privately accessible!

```
struct My_struct {

public:
 // accessible to all parts of the program


private:
  // accessible only to member functions


public:
 // accessible to all parts of the program
}
```

Structs versus Classes

- Struct and Class are interchangeable
  - The difference is the default behavior
  - Both can use `private:` and `public:` access modifiers

```
struct Test {
   // accessible to all parts of the program
}

class Test {
   // accessible only to member functions
}
```

Style convention

- Use classes for abstractions (smart data)
  - Example: String_Holder, Ball
- Use structs for “plain old data”
  - Example: Position, Dimension
- We intentionally violated this in homework 5 to keep things simple
  - And to make transition from C simpler: “structs with functions”

Additional specifier: protected

- Like private, but accessible to classes that inherit from this one
  - i.e., other classes that are based on this one

  - Will talk about more next week
  - If you see it around before then, consider it the same as private

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Encapsulation

- Goal: protect the rules of your data so it remains consistent

- Method:
  1. Make the data private

  2. Add public member functions to let clients do useful things

  3. Don’t add public member functions that let clients do bad things (like break the rules of the data)

Step back: why do we care about consistency?

- Helps us avoid **UNDEFINED BEHAVIOR**
  - Keep track of sizes of arrays, for instance
- Avoids errors
  - Maybe you expect your data to always be sorted
- Improves efficiency
  - Make assumptions about the data that you know MUST be true

Live coding: update String_Holder access control

- Data members should be private
  - Convention: private members end with "_"

- Functions should be public
  - And functions should never allow the rules to be broken

Encapsulation cuts off direct access to data members

- Problem: functions outside of the class can never access data members, even to just read from them

- Options:
  1. Include as a member function

  2. Add "getters" for data variables
     `String_Holder::size()`

  3. Declare function as a `friend`

Allowing specific things access to private members

- friend keyword declares another thing that can access private members from this class

- Example overloaded operator! `operator<<()`
  - Needs to access the private members of String_Holder
  - Inside the String_Holder class definition, add:

```
friend std::ostream& operator<<(std::ostream&, const String_Holder&);
```

Welcome to Encapsulation

- Software engineering principle:
  1. Bundle your data and operations together
  2. Don’t let non-bundled operations mess with your bundled data

- Benefits
  - Correctness
    - Data will never become inconsistent
  - Flexibility
    - Implementation details can change without modifying the API
  - Does NOT improve security
    - Data can still be accessed, just not by accident

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