CS106L Lecture 16:

RAII, Smart Pointers, Building Projects🔗

Thomas Poimenidis, Rachel Fernandez

Attendance

https://forms.gle/NbtEkfp4gVrnuaqo8

Plan

1. RAII (Resource Acquisition Is Initialization)
2. Smart Pointers
3. Building C++ projects

Plan

1. **RAII (Resource Acquisition Is Initialization)**
2. Smart Pointers
3. Building C++ projects

How many code paths?

```
std::string returnNameCheckPawsome(Pet p) {
    /// NOTE: dogs > cats
    if (p.type() == "Dog" || p.firstName() == "Fluffy") {
        std::cout << p.firstName() << " " <<
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```

3?

Exceptions

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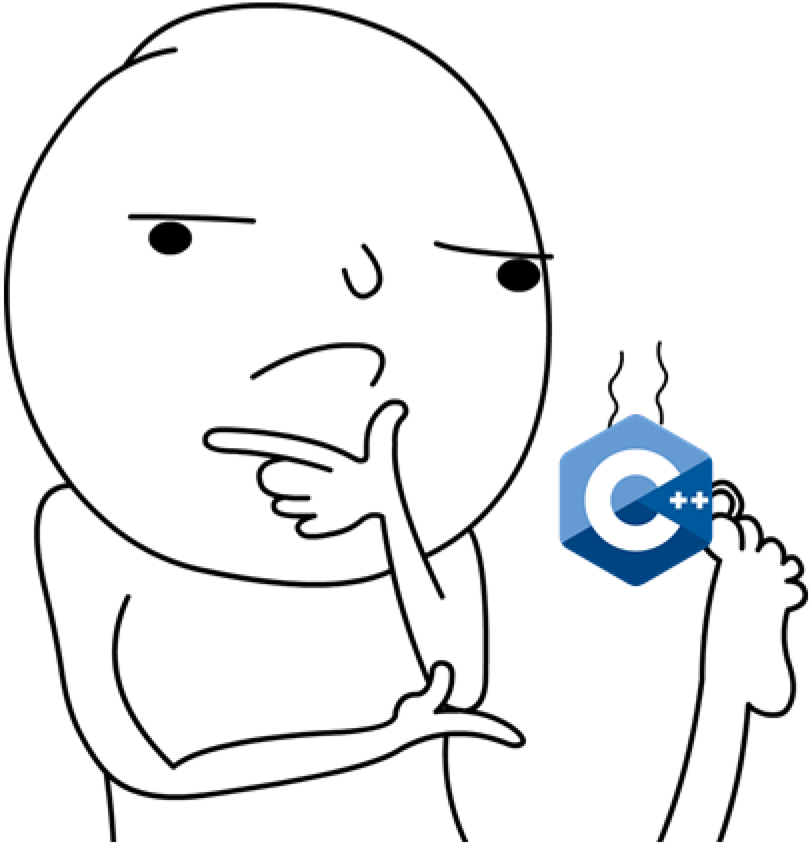
- Exceptions are "thrown"

- However, we can write code that lets
  we can continue in our code without

- We call this "***catching***" an exception.

```
try {
        // code that we check for
exceptions
}
catch([exception type] e1) { // "if"
        // behavior when we encounter an
error
}
catch([other exception type] e2) { // "else if"
        // ...
}
catch { // the "else" statement
        // catch-all (haha)
}
```

What questions do we have?



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    }
    return p.firstName() + " " + p.lastName();
}
```

At least 23 code paths!

- (1): Copy constructor of `Pet` may throw
- (5): Constructor of temp strings may throw
- (6): Call to type, `firstName` (3), `lastName` (2) may throw
- (10): User overloaded operators may throw
- (1): Copy constructor of returned string may throw

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        std::cout << p.firstName() << " " <<
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    }
    return p.firstName() + " " + p.lastName();
}
```

What could go wrong in this new code?

```cpp
std::string returnNameCheckPawsome(int petId) {
    Pet* p = new Pet(petId);
    if (p.type() == "Dog" || p.firstName() == "Fluffy") {
        std::cout << p.firstName() << " " <<
          p.lastName() << " is paw-some!" << '\n';
    }
    std::string returnStr = p.firstName() + " " + p.lastName();
    delete p;
    return returnStr;
}
```

What could go wrong?

```
std::string returnNameCheckPawsome(int petId) {
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    urn returnStr;
```

What if this function threw an exception here?

What could go wrong?

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Or here?

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    urn returnStr;
```

What if this function threw an exception here?

Or here?

Or here?

Or anywhere an exception can be thrown?

What could go wrong?

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}
```

What could go wrong?

exception here means memory leak

```
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    if (p.type() == "Dog" || p.firstName() == "Fluffy") {
        std::cout << p.firstName() << " " <<
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    delete p;
    return returnStr;
}
```

This is not unique to just pointers!

It turns out that there are many resources that you need to ***release*** after ***acquiring***

	Acquire	Release
Heap memory	`new`	`delete`
Files	`open`	`close`
Locks	`try_lock`	`unlock`
Sockets	`socket`	`close`

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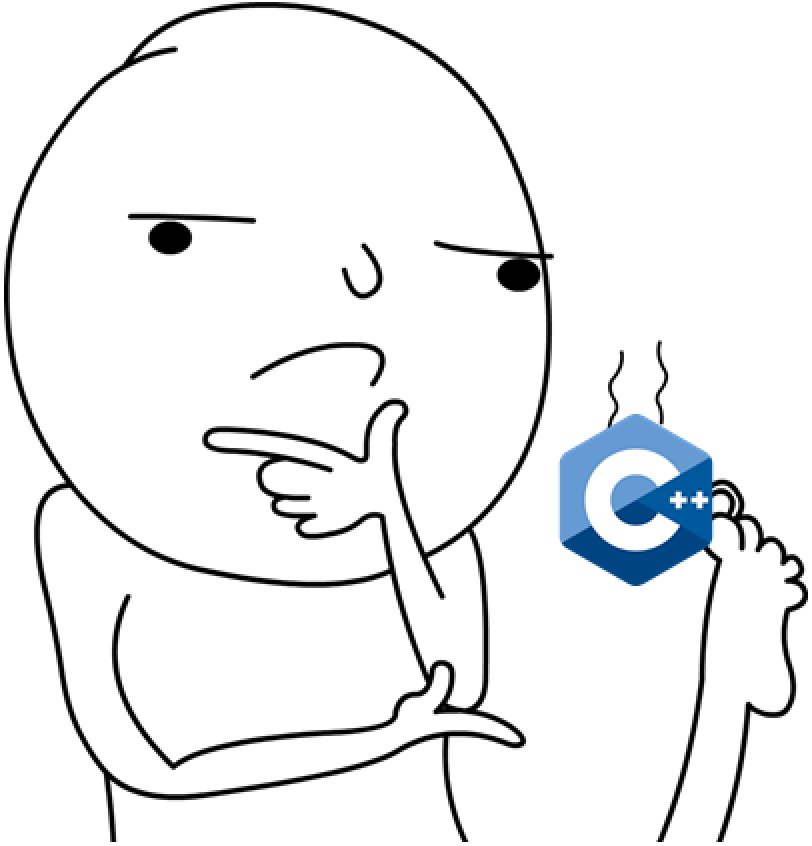
It turns out that there are many resources that you need to ***release*** after ***acquiring***

	Acquire	Release
Heap memory	`new`	`delete`
Files	`open`	`close`
	`try_lock`	`unlock`
	`socket`	`close`

How do we ensure that we properly release resources in the case that we have an exception?

What questions do we have?



RAII

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And it’s a concept that is very emblematic in C++, among other languages.

So what is RAII?

- All resources used by a class should be acquired in the constructor!
- All resources that are used by a class should be released in the destructor.

RAII

RAII: Resource Acquisition is Initialization

RAII: why tho?

RAII: Resource Acquisition is Initialization

- By abiding by the RAII policy we avoid “half-valid” states.
- No matter what, the destructor is called whenever the resource goes out of scope.
- One more thing: the resource/object is usable immediately after it is created.

RAII compliant?

```cpp
void printFile() {
  ifstream input;
  input.open("hamlet.txt");

  string line;
  while(getLine(input, line)) { // might throw an exception
    std::cout << line << std::endl;
  }

  input.close();
}
```

RAII compliant?

```
void printFile() {
    ifstream input;
    input.open("hamlet.txt");

    string line;
    while(getLine(input, line)) { // might throw an exception
        std::cout << line << std::endl;
    }

    input.close();
}
```

the **`ifstream`** is opened and closed in code, not constructor & destructor

Neither is this!

```
void cleanDatabase(mutex& databaseLock, map<int, int>& db) {
  databaseLock.lock();

  // no other thread or machine can change database
  // modify the database
  // if any exception is thrown, the lock never unlocks!

  database.unlock();
}
```

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  database.unlock();
}
```

If any code throws an exception in the red area, which we can call the 'critical section', the `lock` never unlocks!

How can we fix this?

```
void cleanDatabase(mutex& databaseLock, map<int, int>& db) {
  lock_guard<mutex> lg(databaseLock);
  // no other thread or machine can change database
  // modify the database
  // if exception is throw, mutex is UNLOCKED!

  // no explicit unlock necessary, is handled by lock_guard
}
```

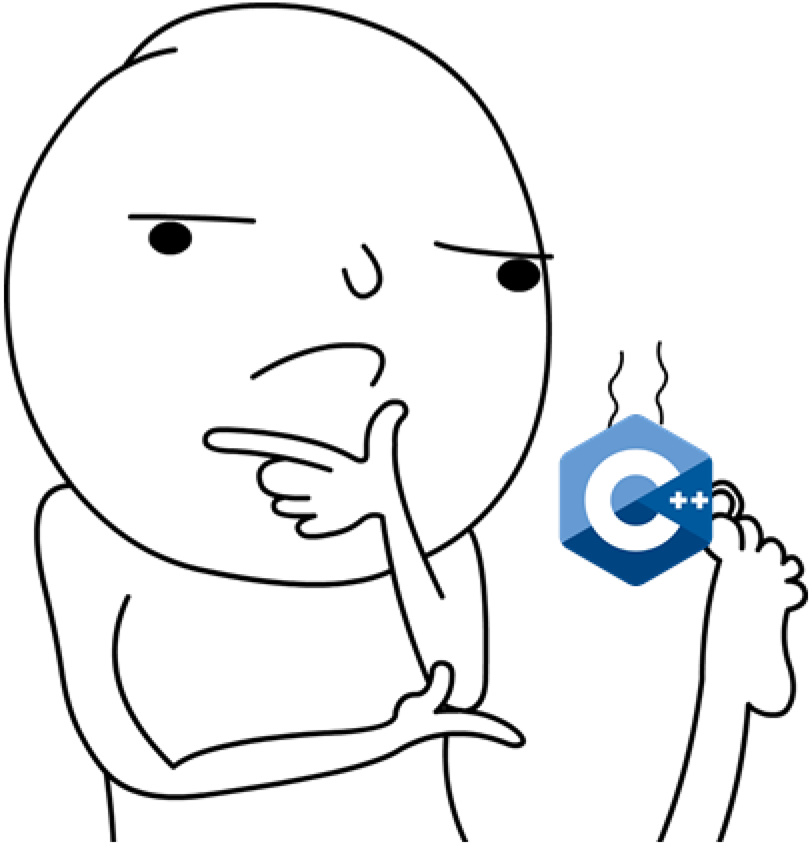
How can we fix this?

```
void cleanDatabase(mutex& databaseLock, map<int, int>& db) {
  lock_guard<mutex> lg(databaseLock);
  // no other thread or machine can change database
  // modify the database
  // if exception is throw, mutex

  // no explicit unlock necessary
}
```

A lock guard is a RAII-compliant wrapper that attempts to acquire the passed in lock. It releases the the lock once it goes out of scope. Read more [here]

What questions do we have?



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Smart Pointers

RAII for locks → `lock_guard`

Smart Pointers

RAII for locks → `lock_guard`

RAII for memory → 🤔

Smart Pointers

R.11: Avoid calling `new` and `delete` explicitly

Reason

The pointer returned by `new` should belong to a resource handle (that can call `delete`). If the pointer returned by `new` is assigned to a plain/naked pointer, the object can be leaked.

Note

In a large program, a naked `delete` (that is a `delete` in application code, rather than part of code devoted to resource management) is a likely bug: if you have N `delete`s, how can you be certain that you don't need N+1 or N-1? The bug may be latent: it may emerge only during maintenance. If you have a naked `new`, you probably need a naked `delete` somewhere, so you probably have a bug.

Enforcement

(Simple) Warn on any explicit use of `new` and `delete`. Suggest using `make_unique` instead.

Remember this?

```
std::string returnNameCheckPawsome(int petId) {
    Pet* p = new Pet(petId);
    if (p.type() == "Dog" || p.firstName() == "Fluffy") {
        std::cout << p.firstName() << " " <<
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    }
    std::string returnStr = p.firstName() + " " + p.lastName();
    delete p;
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```

What did we do for locks?

RAII for locks → `lock_guard`

- Created a new object that acquires the resource in the constructor and releases in the destructor

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- These “wrapper” pointers are called “smart pointers”!

Visualizing smart pointers

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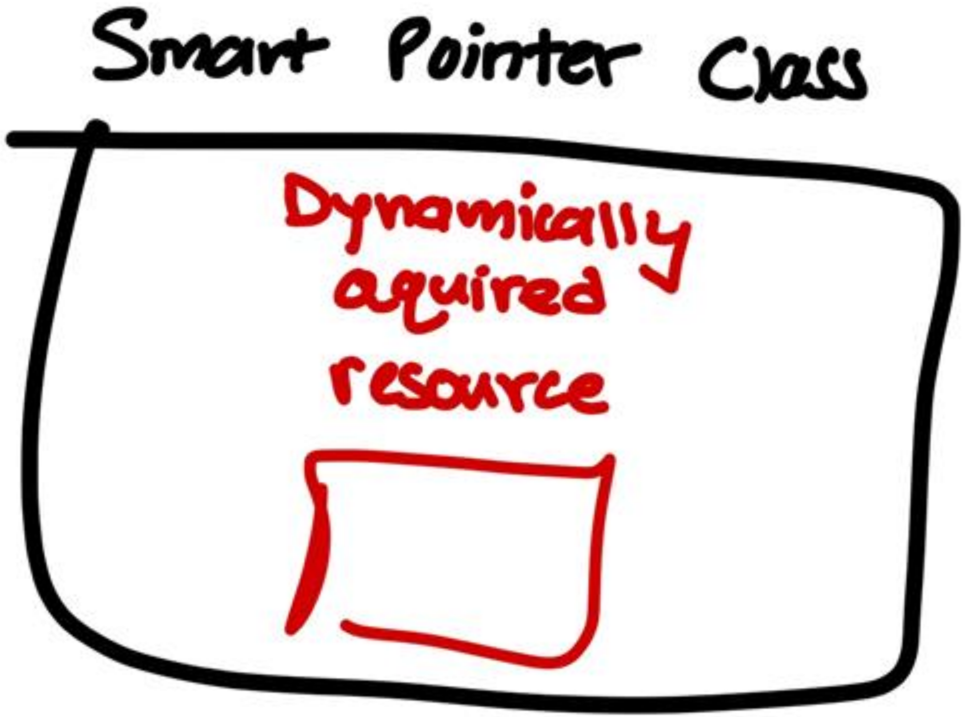
Visualizing smart pointers



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There are three types of RAII-compliant pointers:

- **`std::unique_ptr`**
  - Uniquely owns its resource, can’t be copied

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- **`std::shared_ptr`**
  - Can make copies, destructed when the ***underlying memory*** goes out of scope

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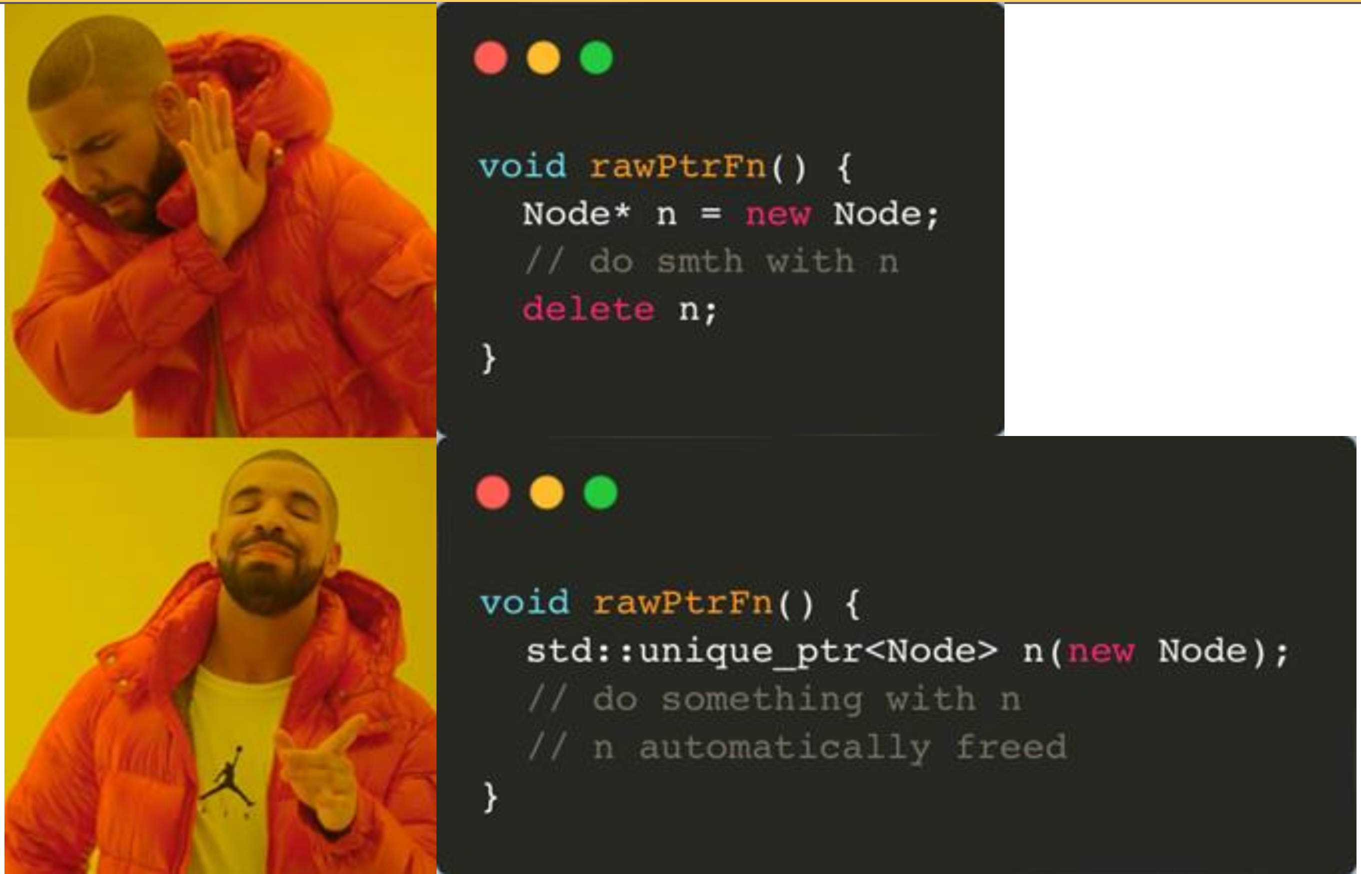
  - Uniquely owns its resource, can't be copied
- **`std::shared_ptr`**
  - Can make copies, destructed when the ***<u>underlying memory</u>*** goes out of scope
- **`std::weak_ptr`**
  - A class of pointers designed to ***<u>mitigate circular dependencies</u>***
    - More on these in a bit

What does this look like?



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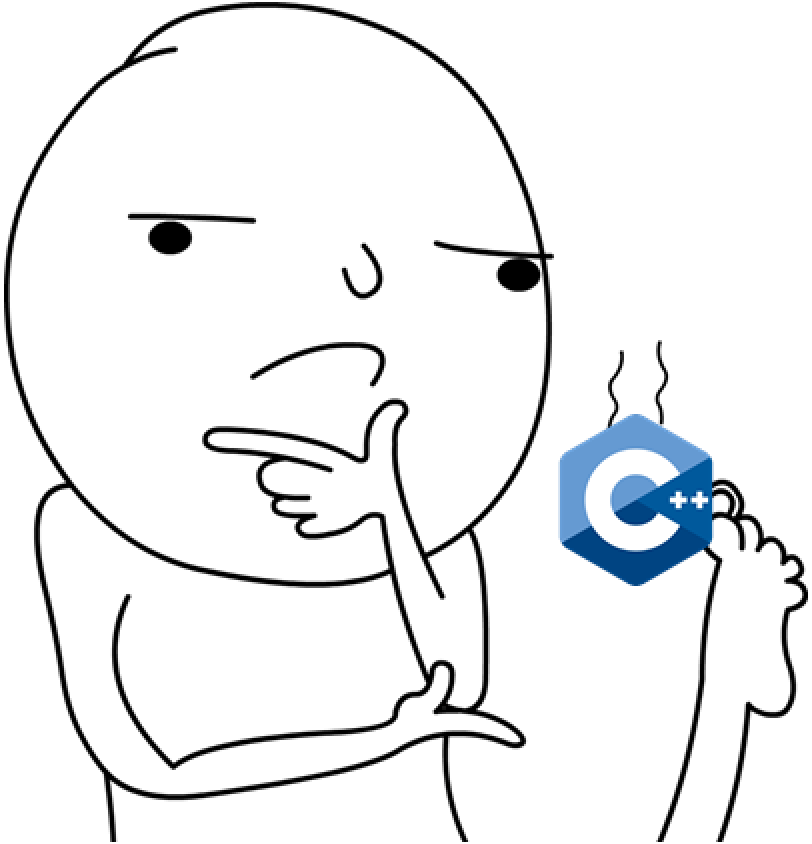

Remember we can’t copy unique pointers

```cpp
void rawPtrFn() {
  std::unique_ptr<Node> n(new Node);

  // this is a compile-time error!
  std::unique_ptr<Node> copy = n;
}
```

Why?

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Imagine a case where the original destructor is called ***after*** the copy happens.

Why?

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Problem: The copy points to deallocated memory!

`std::shared_ptr`

Shared pointers get around our issue of trying to copy **`std::unique_ptr`**'s by not deallocating the underlying memory until ***<u>all</u>*** shared pointers go out of scope!

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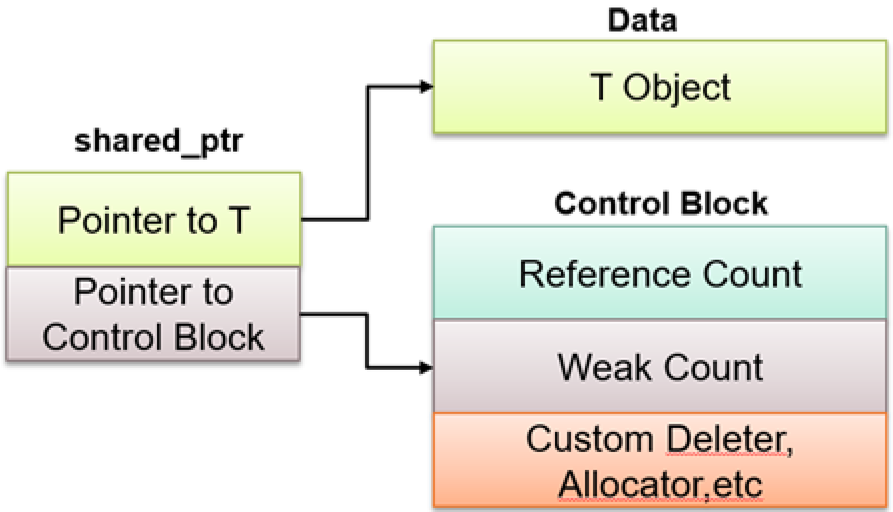

Initializing smart pointers!

```
std::unique_ptr<T> uniquePtr{new T};

std::shared_ptr<T> sharedPtr{new T};

std::weak_ptr<T> wp = sharedPtr;
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```

We're still explicitly calling **new**

no....no

Initializing smart pointers!

```
// std::unique_ptr<T> uniquePtr{new T};
std::unique_ptr<T> uniquePtr = std::make_unique<T>();

// std::shared_ptr<T> sharedPtr{new T};
std::shared_ptr<T> sharedPtr = std::make_shared<T>();

std::weak_ptr<T> wp = sharedPtr;
```

Initializing smart pointers!

Always use `std::make_unique<T>` and `std::make_shared<T>`

Why?

1. The most important reason: if we don't then we're going to allocate memory twice, once for the pointer itself, and once for the **`new T`**

Initializing smart pointers!

Always use `std::make_unique<T>` and `std::make_shared<T>`

Why?

1. The most important reason: if we don’t then we’re going to allocate memory twice, once for the pointer itself, and once for the **`new T`**

1. We should also be consistent — if you use **`make_unique`** also use **`make_shared`**!

std::weak_ptr

Weak pointers are a way to avoid circular dependencies in our code so that we don’t leak any memory.

```cpp
#include <iostream>
#include <memory>

class B;

class A {
  public:
    std::shared_ptr<B> ptr_to_b;
  ~A() {
    std::cout << "All of A's resources deallocated" << std::endl;
  }
};

class B {
  public:
    std::shared_ptr<A> ptr_to_a;
  ~B() {
    std::cout << "All of B's resources deallocated" << std::endl;
  }
};

int main() {
  std::shared_ptr<A> shared_ptr_to_a = std::make_shared<A>();
  std::shared_ptr<A> shared_ptr_to_b = std::make_shared<B>();
  a->ptr_to_b = shared_ptr_to_b;
  b->ptr_to_a = shared_ptr_to_a;
  return 0;
}
```

`std::weak_ptr` bad example

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class B {
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  }
};

int main() {
  std::shared_ptr<A> shared_ptr_to_a = std::make_shared<A>();
  std::shared_ptr<A> shared_ptr_to_b = std::make_shared<B>();
  a->ptr_to_b = shared_ptr_to_b;
  b->ptr_to_a = shared_ptr_to_a;
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}
```

Both instance a of `class A` and instance b `class B` are keeping a shared pointer to each other.

std::weak_ptr bad example

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  }
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  b->ptr_to_a = shared_ptr_to_a;
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}
```

Both instance a of `class A` and instance b `class B` are keeping a shared pointer to each other.

Therefore, they will never properly deallocate

std::weak_ptr good example

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  public:
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  ~A() {
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  }
};

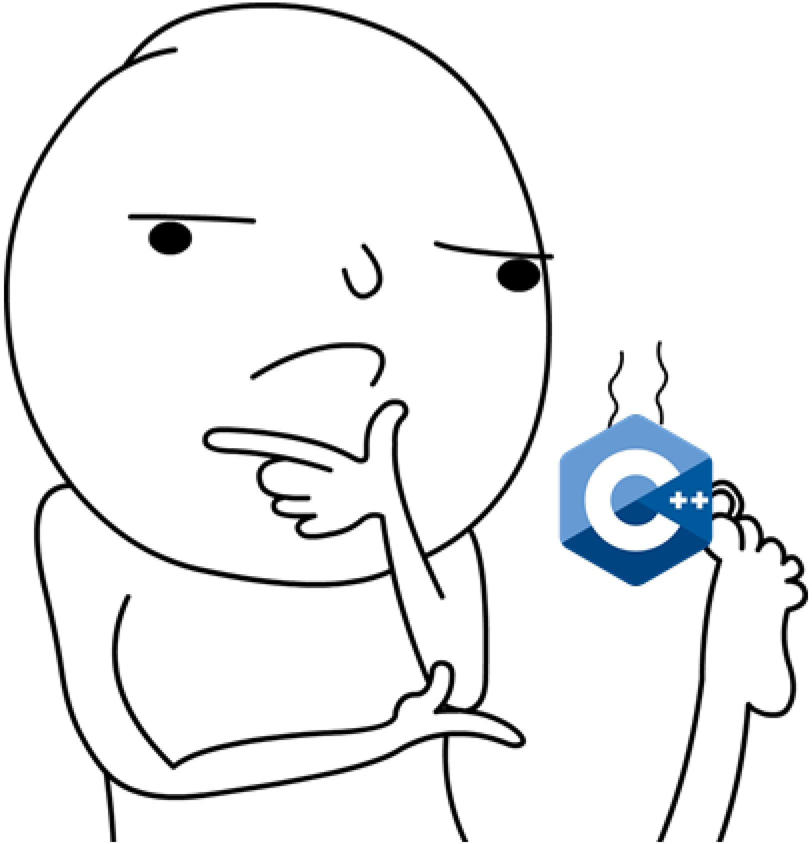
class B {
  public:
    std::weak_ptr<A> ptr_to_a;
  ~B() {
    std::cout << "All of B's resources deallocated" << std::endl;
  }
};

int main() {
  std::shared_ptr<A> shared_ptr_to_a = std::make_shared<A>();
  std::shared_ptr<A> shared_ptr_to_b = std::make_shared<B>();
  a->ptr_to_b = shared_ptr_to_b;
  b->ptr_to_a = shared_ptr_to_a;
  return 0;
}
```

Here, in `class B` we are no longer storing a as a `shared_ptr` so it does not increase the reference count of a.

Therefore a can gracefully be deallocated, and therefore so can b

What questions do we have?



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When we write C++ code, it needs to be translated into a form our computer understands it

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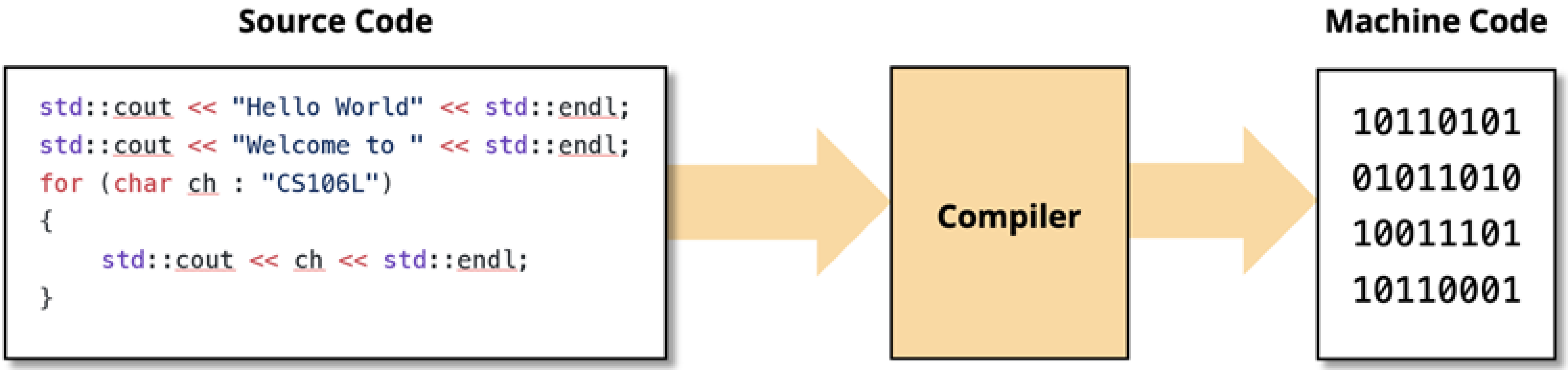


```
$ g++ main.cpp -o main    # g++ is the compiler, outputs binary to main
$ ./main                  # This actually runs our program
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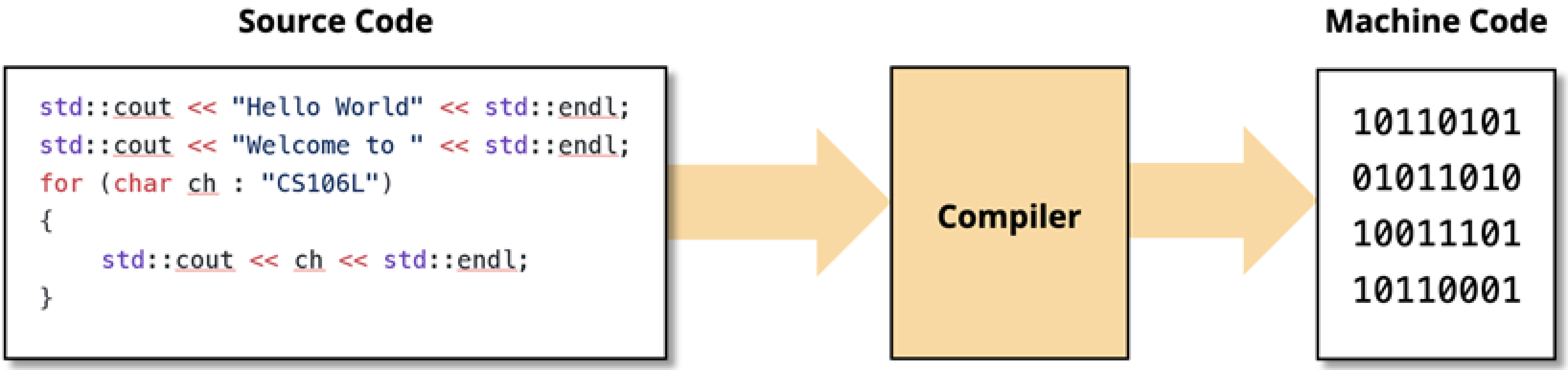


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This is the source file

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This means that you're going to give a specific name to your executable

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```

In this case it's main

Even the masterpiece
among us


TensorFlow

python 3.9 | 3.10 | 3.11 | 3.12 pypi package 2.18.0 DOI 10.5281/zenodo.4724125 openssf best practices passing
openssf scorecard 7.8 oss-fuzz build failing oss-fuzz build failing OSSRank #12 (Top 1%) Contributor Covenant v1.4 adopted
TF Official Continuous 6 passed, 0 failed TF Official Nightly 11 passed, 4 failed

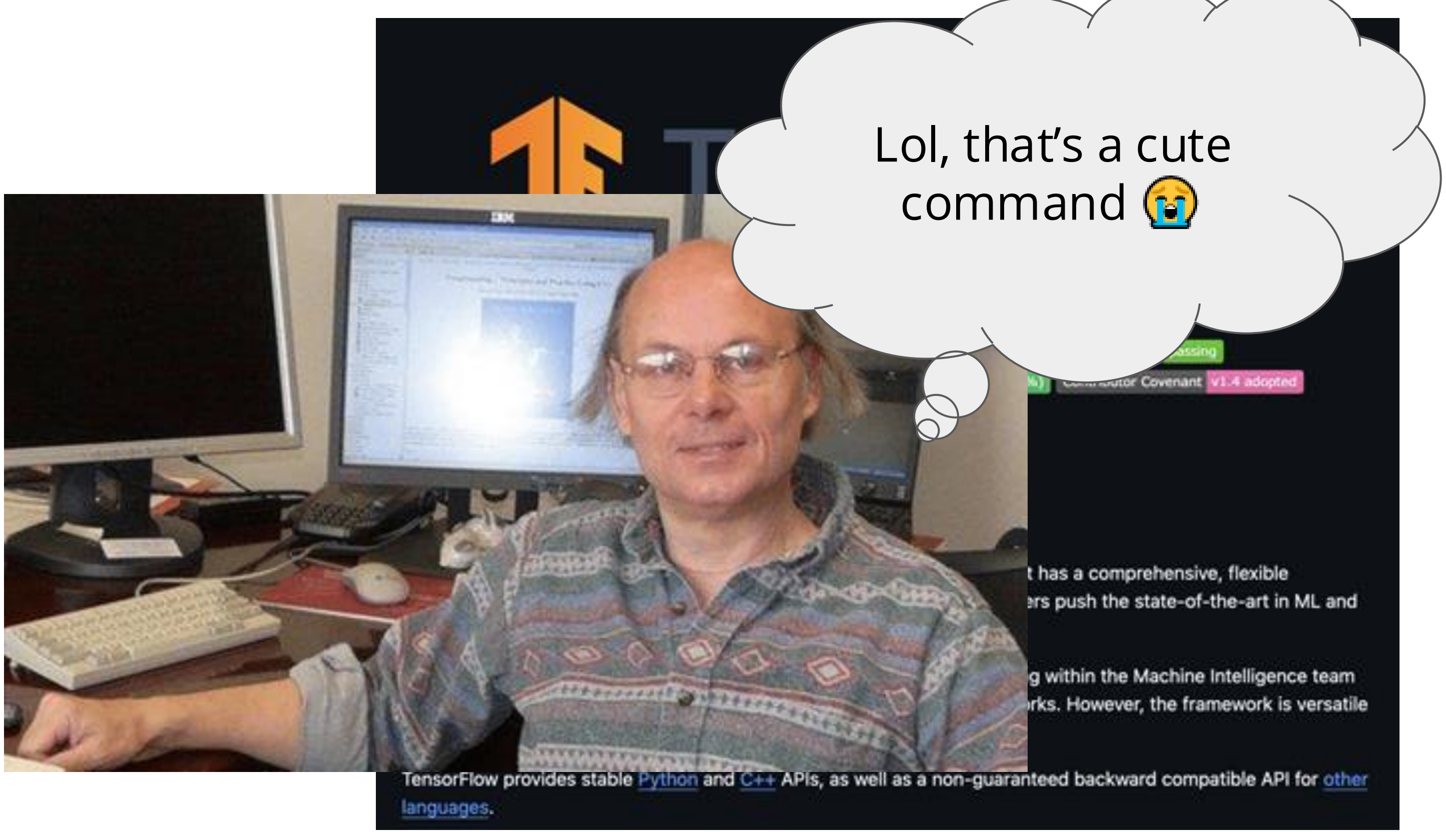
Documentation
api reference

TensorFlow is an end-to-end open source platform for machine learning. It has a comprehensive, flexible ecosystem of tools, libraries, and community resources that lets researchers push the state-of-the-art in ML and developers easily build and deploy ML-powered applications.

TensorFlow was originally developed by researchers and engineers working within the Machine Intelligence team at Google Brain to conduct research in machine learning and neural networks. However, the framework is versatile enough to be used in other areas as well.

TensorFlow provides stable Python and C++ APIs, as well as a non-guaranteed backward compatible API for other languages.

The TensorFlow Core is written largely in C++ and it is composed of 2,000+ **source files**




```
$ g++ main.cpp -o main    # g++ is the compiler, outputs binary to main
$ ./main                  # This actually runs our program
```

Makefiles and make

`make` is a "build system" program that helps you compile!

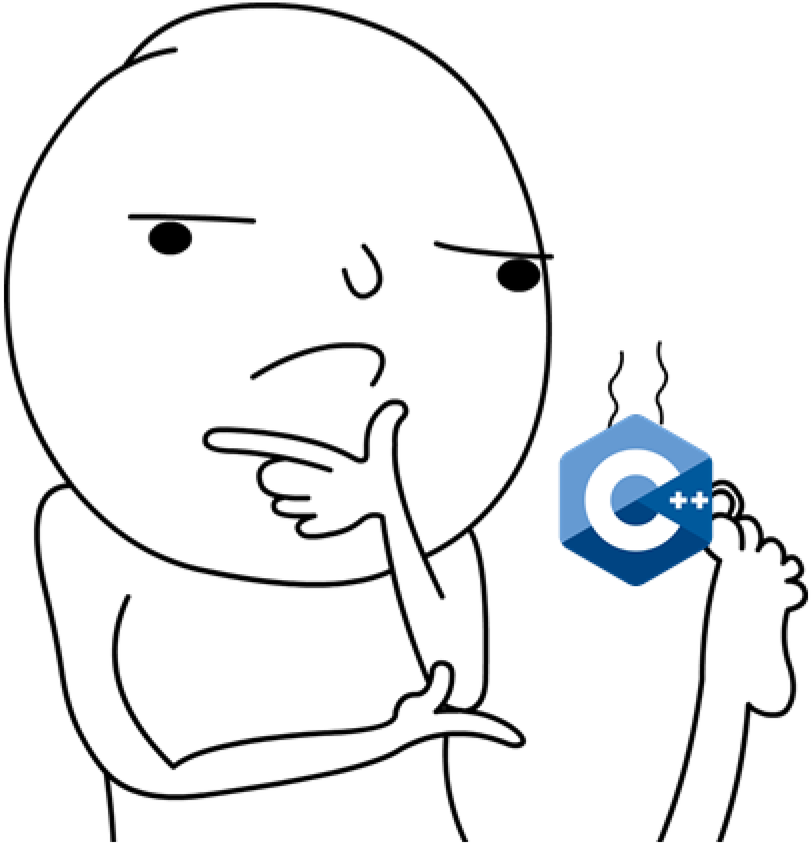
- You can specify what compiler you want to use
- In order to use **`make`** you need to have a **`Makefile`**

What does a **`Makefile`** look like? Let's take a look!

```makefile
# Compiler
CXX = g++

# Compiler flags
CXXFLAGS = -std=c++20

# Source files and target
SRCS = $(wildcard *.cpp)
TARGET = main

# Default target
all:
	$(CXX) $(CXXFLAGS) $(SRCS) -o $(TARGET)

# Clean up
clean:
	rm -f $(TARGET)
```

This is an example `Makefile` for our lecture 8 code

What questions do we have?



CMake

CMake is a build system generator.

So you can use **CMake** to generate `Makefiles`

Is like a higher level abstraction for `Makefiles`

CMakeLists.txt

```
cmake_minimum_required(VERSION 3.10)

project(cs106l_classes)

set(CMAKE_CXX_STANDARD 20)

file(GLOB SRC_FILES "*.cpp")

add_executable(main ${SRC_FILES})
```

CMakeLists.txt

```
cmake_minimum_required(VERSION 3.10)

project(cs106l_classes)

set(CMAKE_CXX_STANDARD 20)

file(GLOB SRC_FILES "*.cpp")

add_executable(main ${SRC_FILES})
```

This command tells CMAKE to set the C++ compiler to C++20

CMakeLists.txt

```
cmake_minimum_required(VERSION 3.10)

project(cs106l_classes)

set(CMAKE_CXX_STANDARD 20)

file(GLOB SRC_FILES "*.cpp")

add_executable(main ${SRC_FILES})
```

This GLOB command is telling the CMAKE program to do a wildcard search for all files that have the pattern “*.cpp”

CMakeLists.txt

```
cmake_minimum_required(VERSION 3.10)

project(cs106l_classes)

set(CMAKE_CXX_STANDARD 20)

file(GLOB SRC_FILES "*.cpp")

add_executable(main ${SRC_FILES})
```

This command adds all of the source files of our program into the executable

To use `CMAKE`

1. You need to have a `CMakeLists.txt` file in your project's root directory

2. Make a `build` folder (`mkdir build`) within your project!

3. Go into the `build` folder (`cd build`)

4. Run '`cmake ..`'
   a. This command runs `cmake` using the `CMakeLists.txt` in your project's root folder!
   b. This generates a `Makefile`

5. Run `make`

6. Execute your program using `./main` as usual

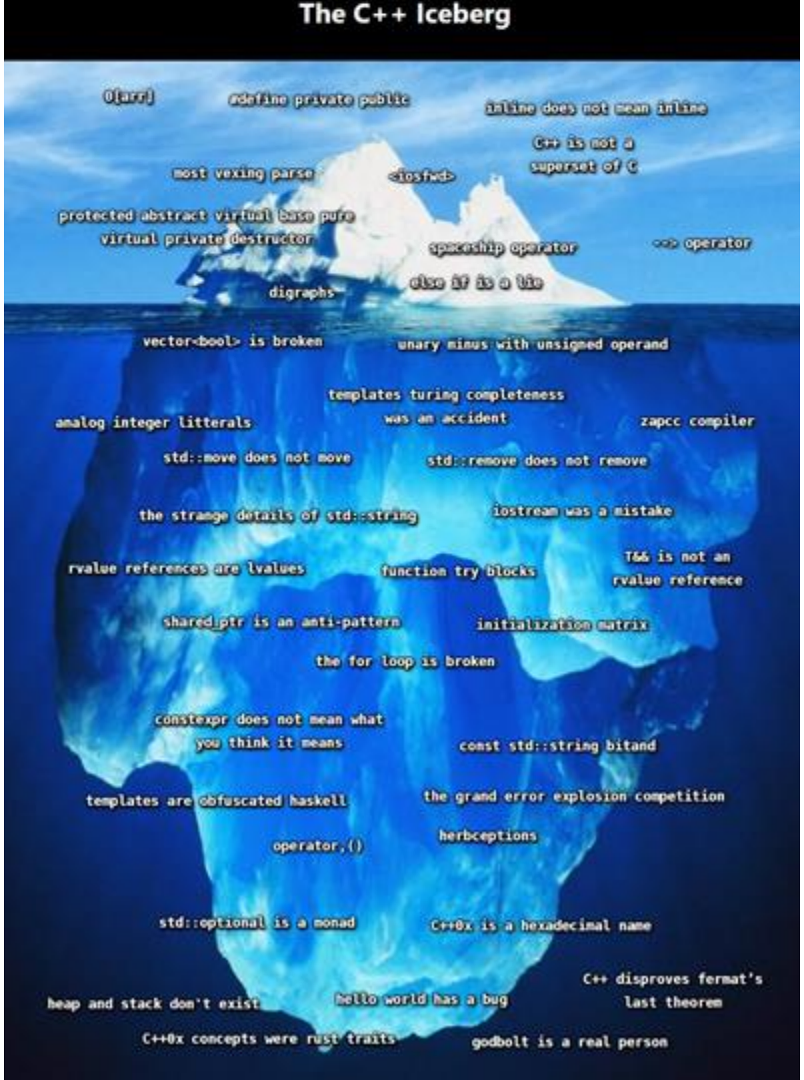
A recap

- RAII says that dynamically allocated resources should be acquired inside of the constructor and released inside the destructor.
    - This is what smart pointers do for example
- For compiling our projects we can and should use `Makefiles`
- For making our `Makefiles` we can and should use `CMAKE`

Last (mandatory) lecture 😢

Schedule

Week	Tuesday	Thursday
1	September 23 1. Welcome! 📖 Slides 📃 Policies	September 25 2. Types & Structs 📖 Slides
2	September 30 3. Initialization & References 📖 Slides	October 2 4. Streams 📖 Slides A0: Setup
3	October 7 5. Containers 📖 Slides	October 9 6. Iterators & Pointers 📖 Slides A1: SimpleEnroll
4	October 14 7. Classes 📖 Slides	October 16 8. Inheritance 📖 Slides A2: Marriage Pact
5	October 21 9. Class Templates & Const Correctness 📖 Slides	October 23 10. Function Templates 📖 Slides A3: Make a Class!
6	October 28 11. Functions & Lambdas 📖 Slides	October 30 12. Operator Overloading 📖 Slides A4: Ispell
7	November 4 Democracy Day: No Class	November 6 13. Special Member Functions 📖 Slides A5: Treebook
8	November 11 14. Move Semantics 📖 Slides	November 13 15. std::optional & Type Safety 📖 Slides A6: ExploreCourses
9	November 18 16. RAII, Smart Pointers, & Building C++ Projects	November 20 Optional: No Class, Extra Office Hours
10	December 2 Optional: No Class, Extra Office Hours	December 4 Optional: No Class, Extra Office Hours



The C++ Iceberg
0[arr]
#define private public
inline does not mean inline
C++ is not a
superset of C
most vexing parse
<iosfwd>
protected abstract virtual base pure
virtual private destructor
spaceship operator
--> operator
else if is a lie
digraphs
vector<bool> is broken
unary minus with unsigned operand
templates turing completeness
was an accident
analog integer litterals
zapcc compiler
std::move does not move
std::remove does not remove
the strange details of std::string
iostream was a mistake
rvalue references are lvalues
function try blocks
T&& is not an
rvalue reference
shared_ptr is an anti-pattern
initialization matrix
the for loop is broken
constexpr does not mean what
you think it means
const std::string bitand
templates are obfuscated haskell
the grand error explosion competition
herbceptions
operator,()
std::optional is a monad
C++0x is a hexadecimal name
C++ disproves fermat's
last theorem
heap and stack don't exist
hello world has a bug
C++0x concepts were rust traits
godbolt is a real person

[source]

Announcements

- Optional Lecture (Topic TBD) held Tuesday of Week 10
- Come join us for fun or if you need to make up an attendance!
- Other class times will be used as extra office hours. Come stop by if you have the time!

- Assignment 6 due Saturday, 11/22
- Assignment 7 due Friday, 12/5 (will be released this weekend)

- Check your grade on the website and let us know if something looks off. This is what we use to determine C/NC for this course.

Thank you for a great quarter!

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