CS106L Lecture 15: RAII, Smart Pointers, Building Projects 🔗

Fabio Ibanez, Jacob Roberts-Baca

Attendance

https://tinyurl.com/RAIIS25

Plan

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

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

How many code paths?

```cpp
std::string returnNameCheckPawsome(Pet p) {
    /// NOTE: dogs > cats
    if (p.type() == "Dog" || p.firstName() == "Fluffy") {
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3?

Exceptions

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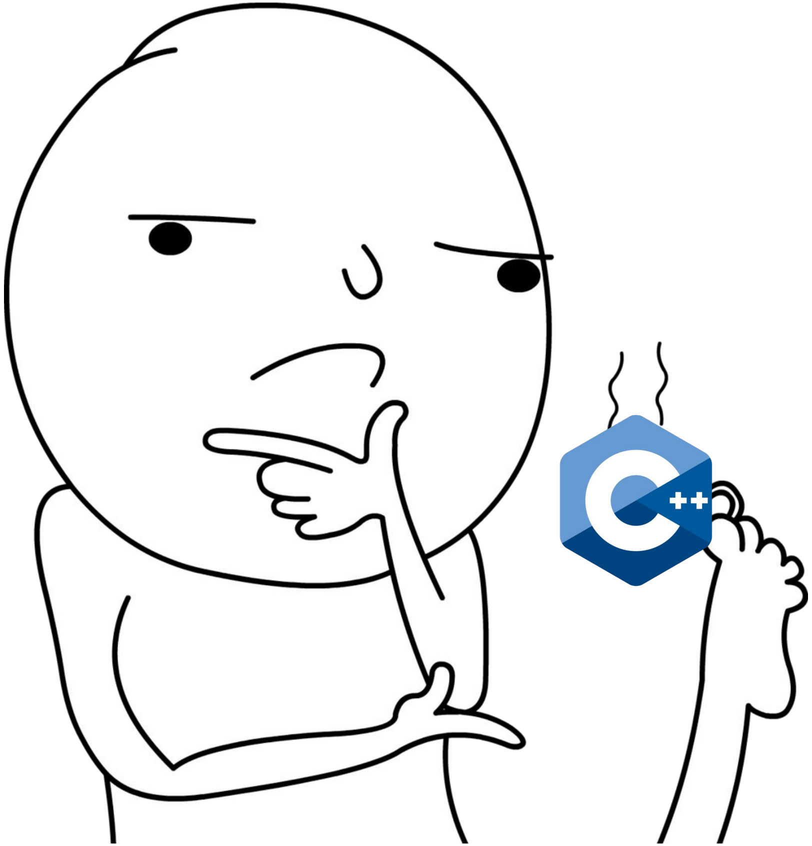
- Exceptions are “thrown”
- However, we can write code that lets
we can continue in our code without
- We call this “***catching***” an exception.

```
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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}
```

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

What could go wrong in this new code?

```
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;
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What could go wrong?

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What if this function threw an exception here?

What could go wrong?

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Or here?

What could go wrong?

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    std::string returnStr = p.firstName() + " " + p.lastName();
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    return 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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    return returnStr;
}
```

exception here means memory leak

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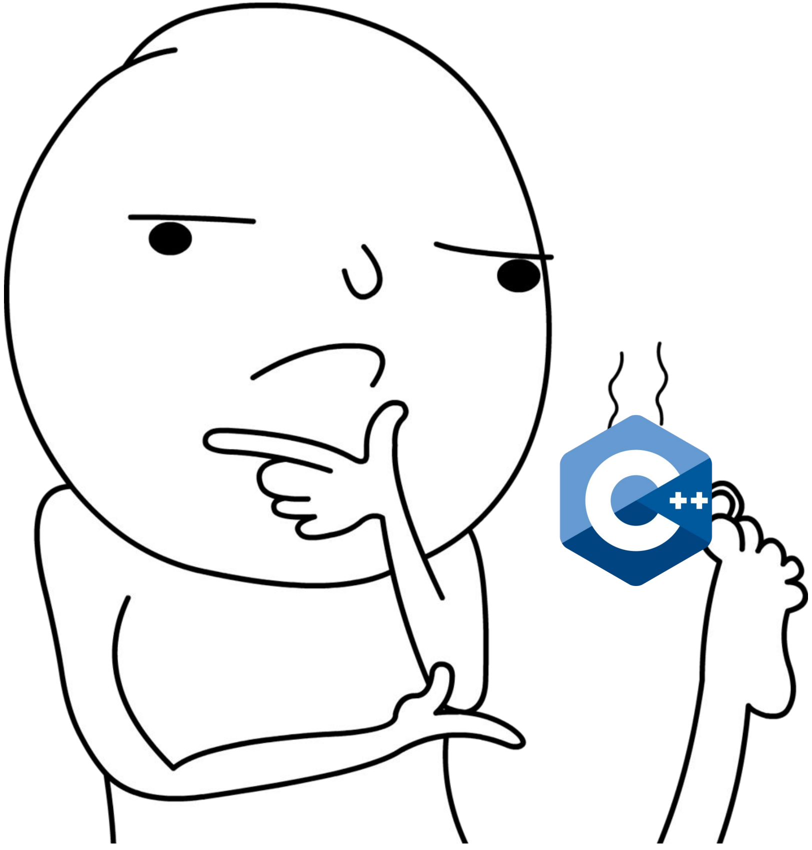
	Acquire	Release
Heap memory	`new`	`delete`
Files	`open`	`close`
	`try_lock`	`unlock`
	`socket`	`close`

How to 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
}
```

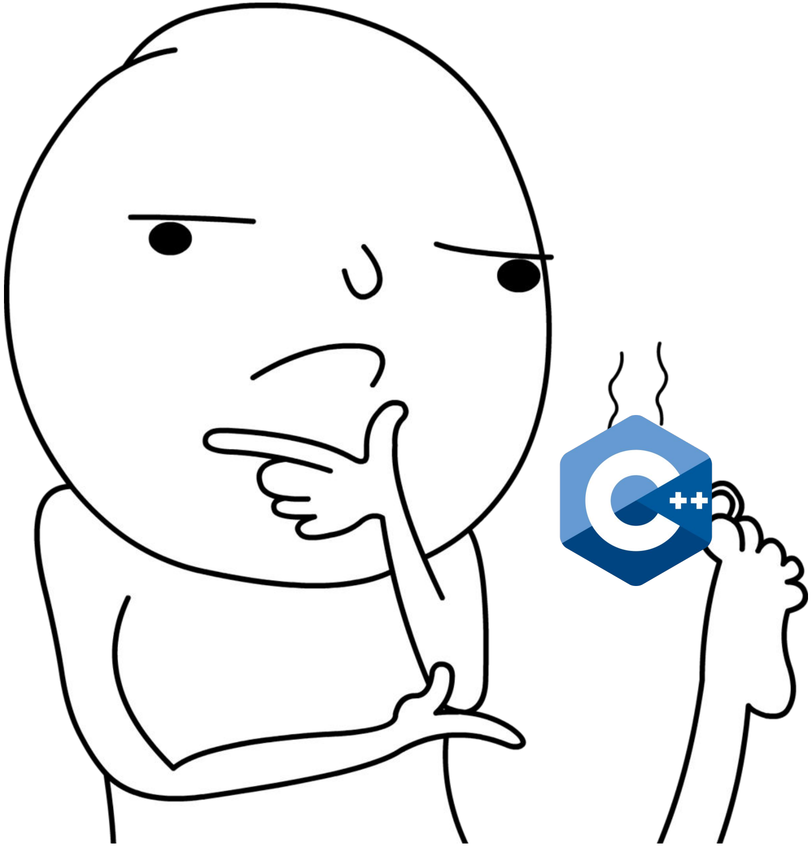
How can we fix this?

```
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, mute

  // 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?

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

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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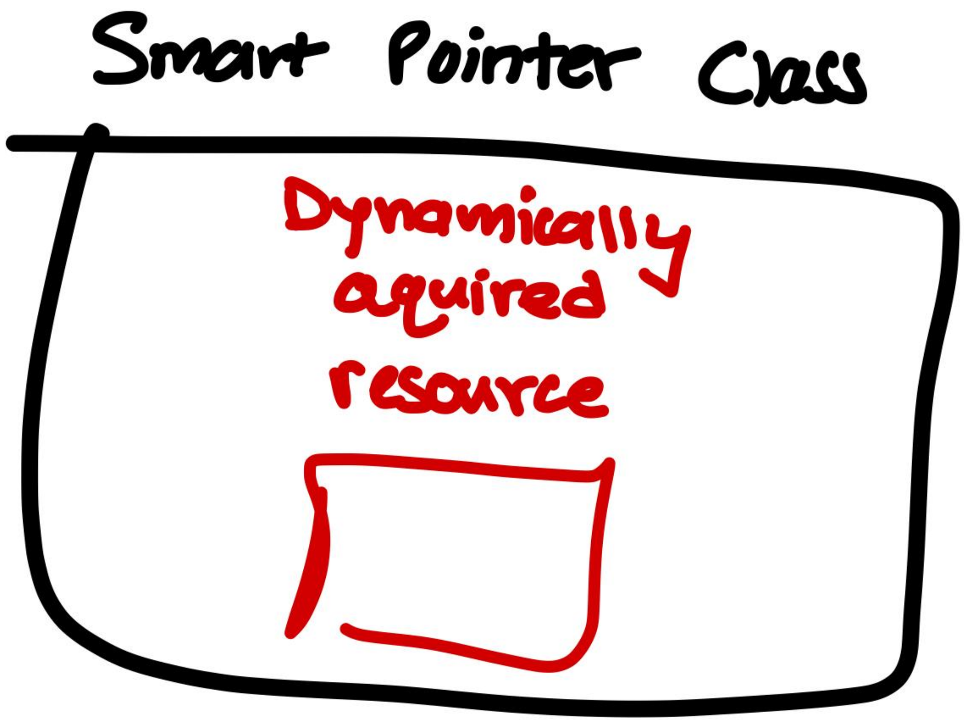
Visualizing smart pointers



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

What does this look like?

```
void rawPtrFn() {
  Node* n = new Node;
  // do smth with n
  delete n;
}
```

```
void rawPtrFn() {
  std::unique_ptr<Node> n(new Node);
  // do something with n
  // n automatically freed
}
```

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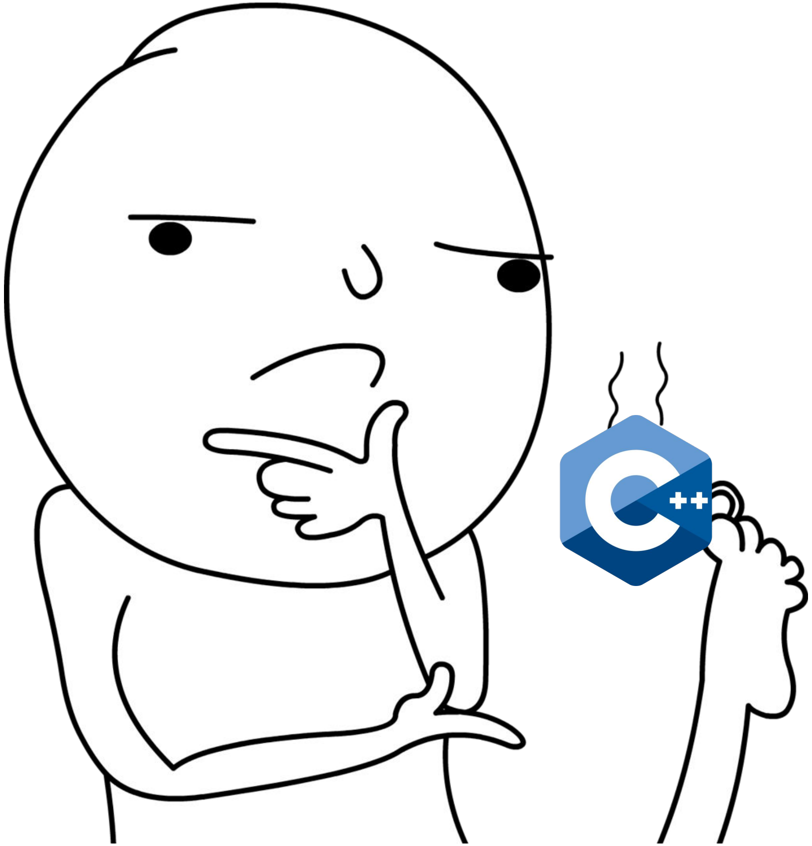

Remember we can’t copy unique pointers

```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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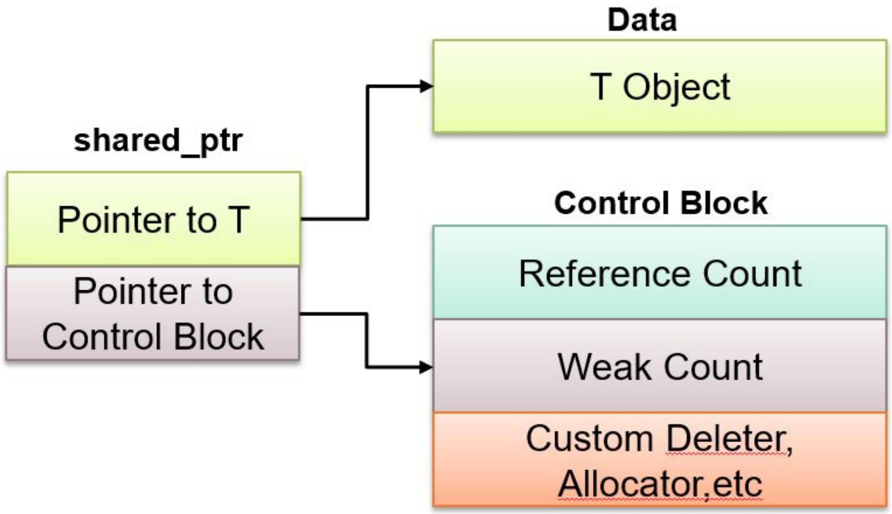

Initializing smart pointers!

```cpp
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`**

2. 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 {
  public:
    std::shared_ptr<A> ptr_to_a;
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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 share pointer to each other.

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```

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

Therefore, they will never properly deallocate

`std::weak_ptr` good example

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

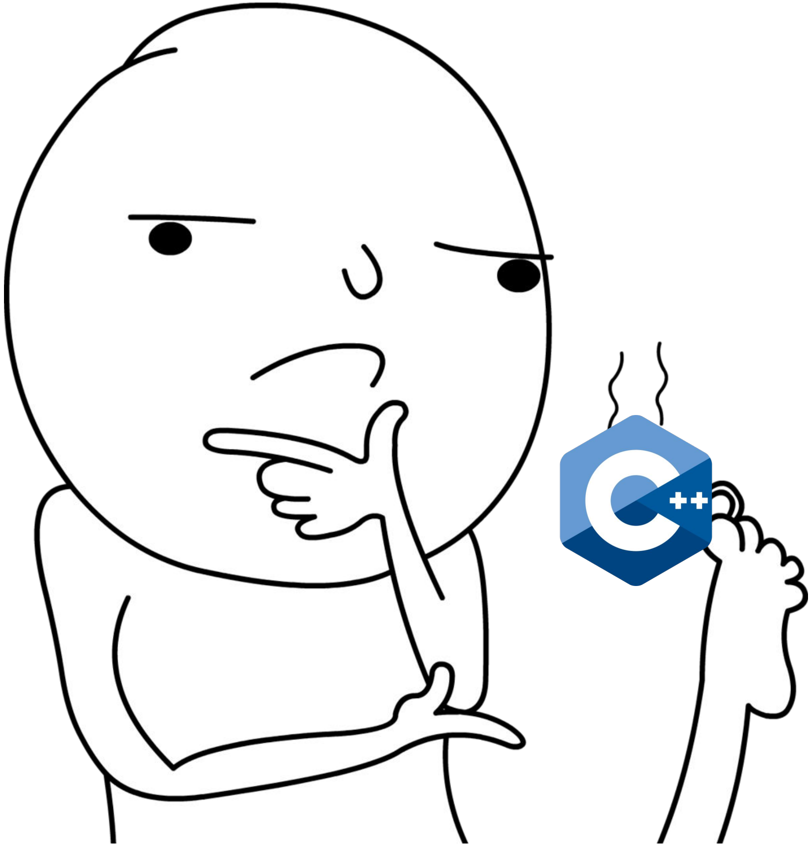
class B {
  public:
    std::weak_ptr<A> ptr_to_a;
  ~B() {
    std::cout << "All of B's resources deallocated" << std::endl;
  }
};

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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Compilation Crash Course

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

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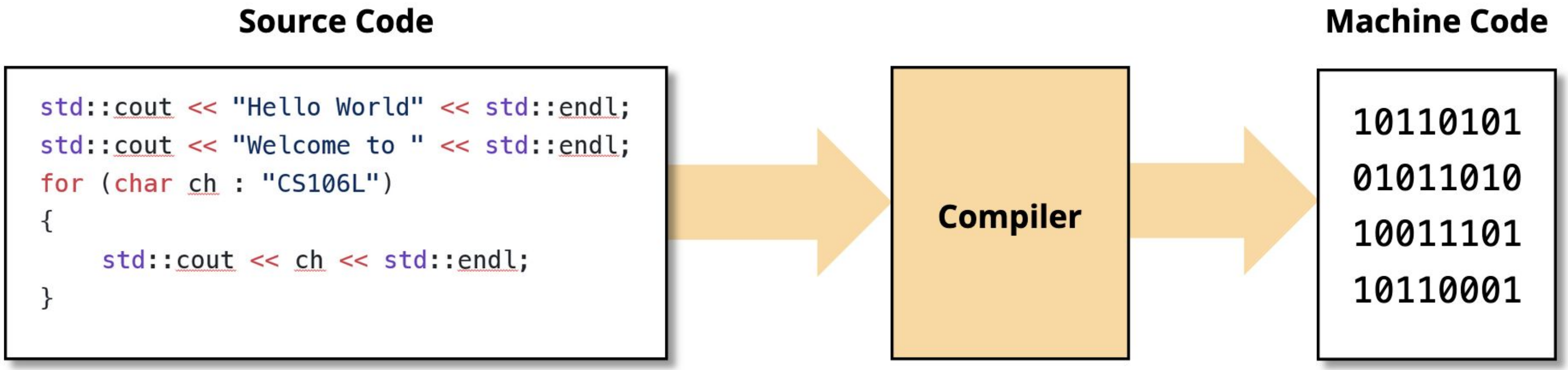


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$ ./main                  # This actually runs our program
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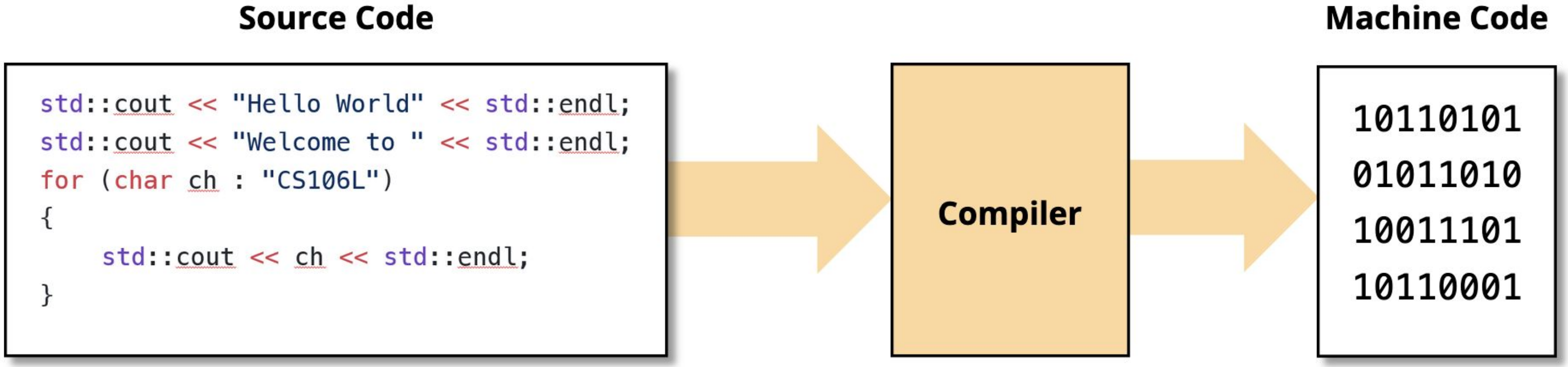


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This is the source file

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

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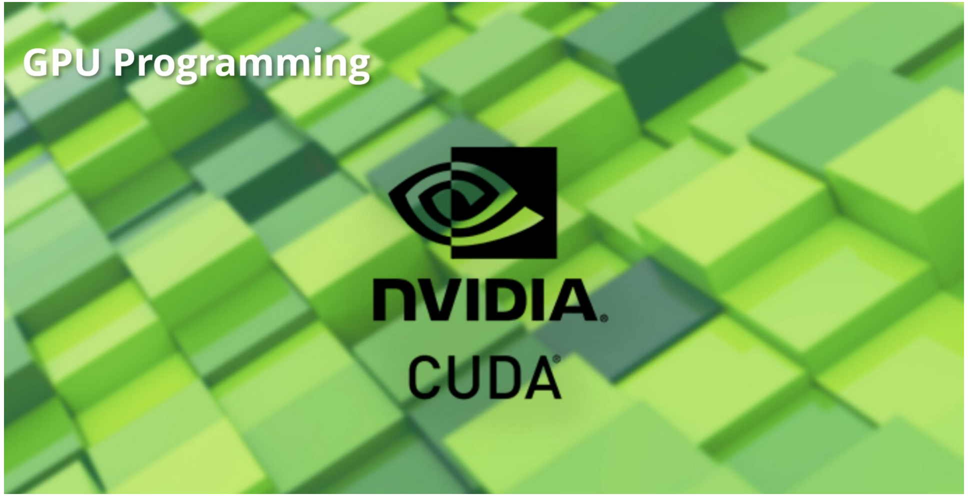
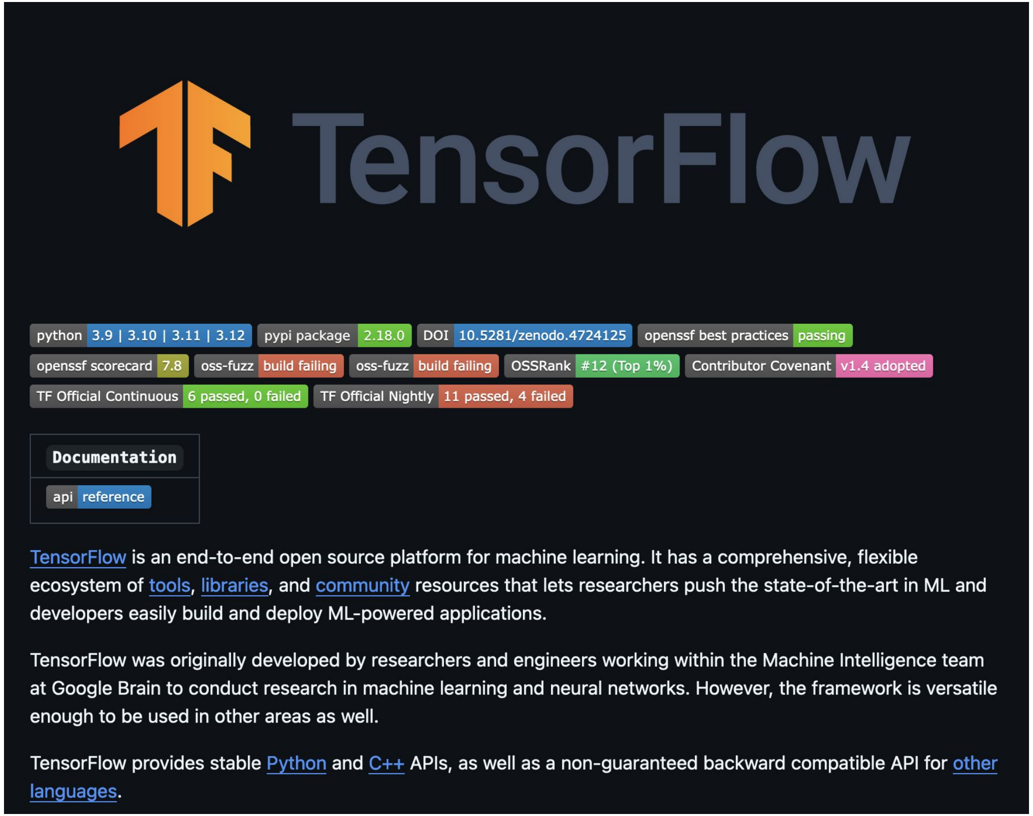
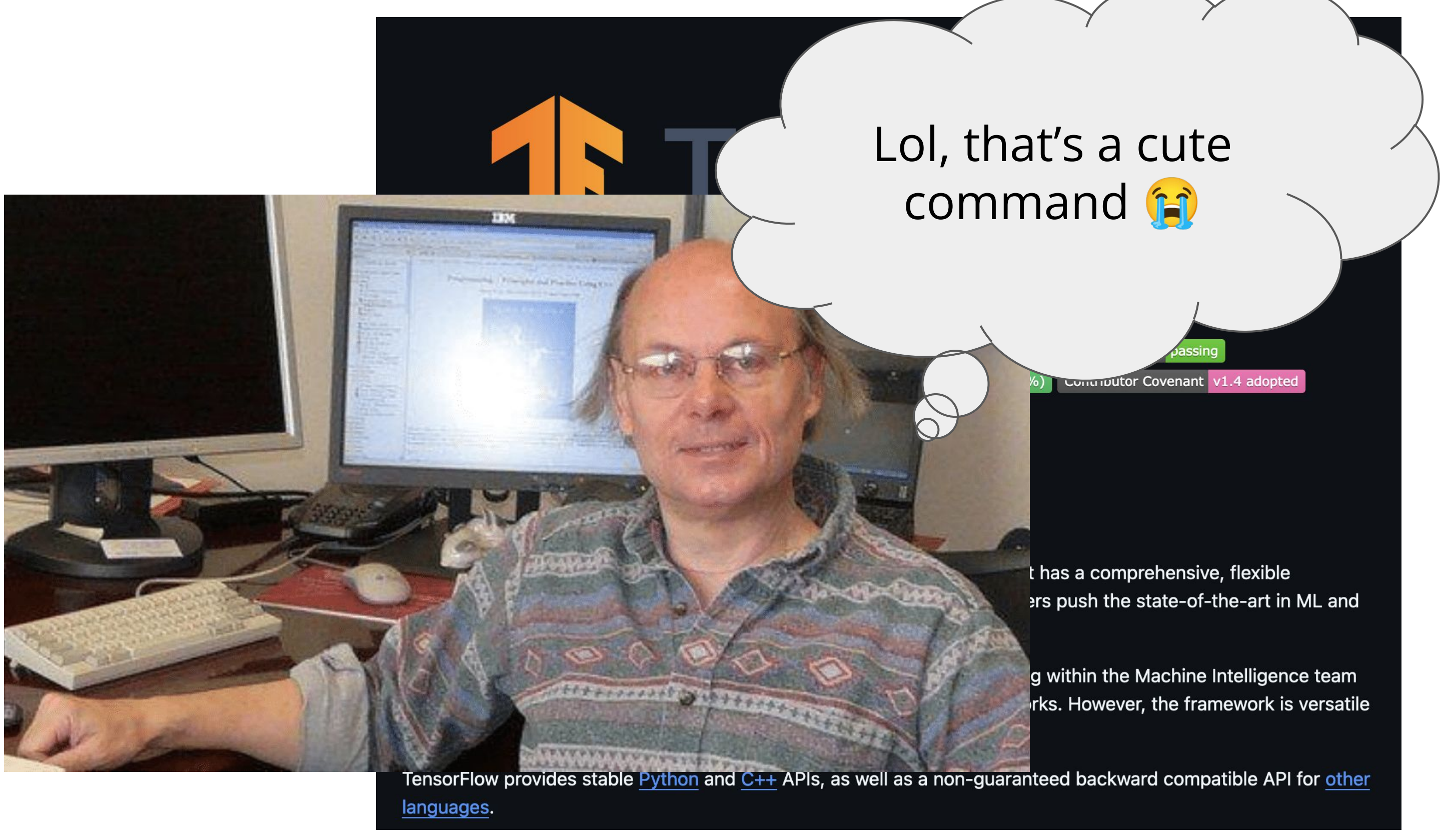
In this case it's `main`



Even the masterpiece among us



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!

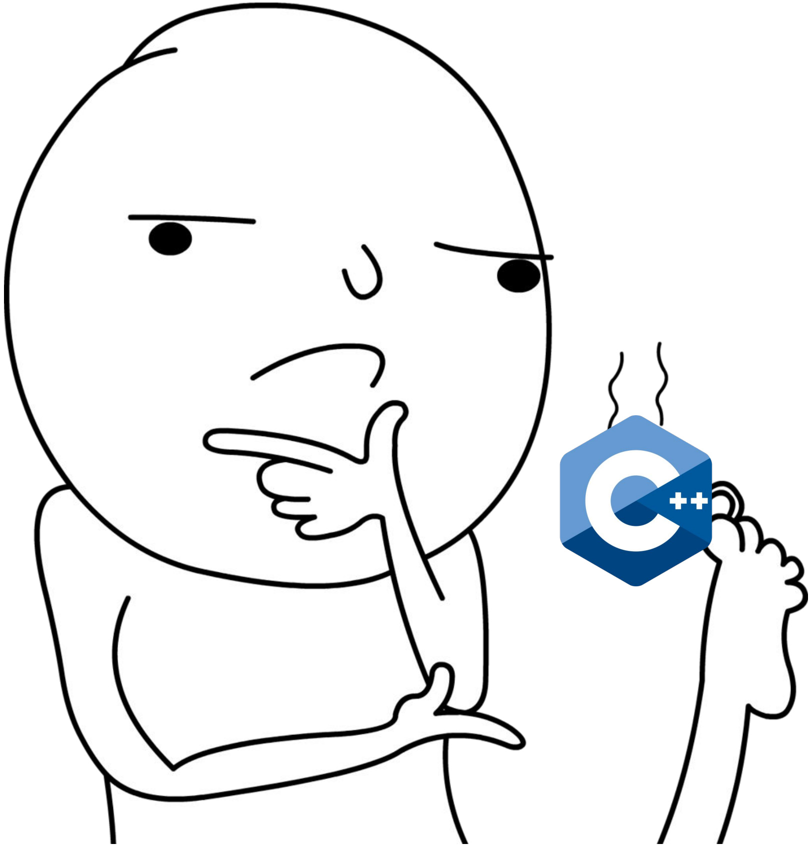
- You can specify what compiler you want to use
- In order to use **`make`** you need to have a **`Makefile`**

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

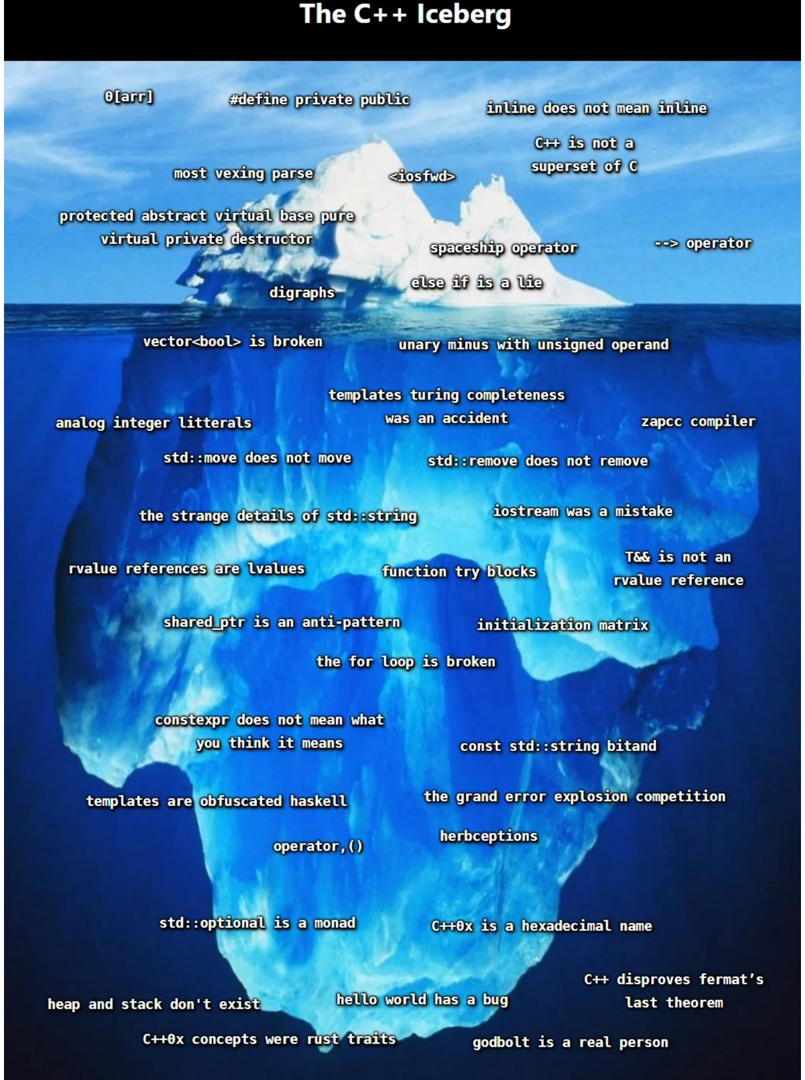
A recap

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

Last lecture

Schedule

Week	Tuesday	Thursday
1	April 1 1. Welcome! Slides Policies	April 3 2. Types and Structs Slides Code Reader
2	April 8 3. Initialization and References Slides Code Reader	April 10 4. Guest Lecture Slides A0: Setup
3	April 15 5. Streams Slides Code	April 17 6. Containers Slides Reader A1: SimpleEnroll
4	April 22 7. Iterators and Pointers Slides Reader I, II	April 24 8. Classes Slides Code A2: Marriage Pact
5	April 29 9. Inheritance Slides	May 1 10. Const Correctness & Class Templates Slides Code Reader A3: Make a Class!
6	May 6 11. Function Templates Slides Code	May 8 12. Functions and Lambdas Slides Code A4: Ispell
7	May 13 13. Operator Overloading Slides Code	May 15 14. Special Member Functions Slides A5: Treebook
8	May 20 15. Move Semantics Slides Code	May 22 16. `std::optional` and Type Safety Slides Code A6: ExploreCourses
9	May 27 17. RAII, Smart Pointers, and Building C++ Projects	May 29 Optional: No Class, Extra Office Hours
10	June 3 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
operator,()
herbceptions
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]

Thank you for a great quarter!

fabioi@stanford.edu

jtrb@stanford.edu