CS106L Lecture 16: RAII, Smart Pointers, Building Projects🔗

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How are you doing today?
meme-arsenal.ru


So, on a 1 to 9 on rubberduck scale, how are things today?
1
2
3
4
5
6
9


HELLO
HOW ARE YOU DOING TODAY
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Attendance

https://forms.gle/bBVRcQGVoaTc1ciL7

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?

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std::string returnNameCheckPawsome(Pet p) {
    /// NOTE: dogs > cats
    if (p.type() == "Dog" || p.firstName() == "Fluffy") {
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          p.lastName() << " is paw-some!" << '\n';
    }
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```

3?

Exceptions

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

Exceptions

We can write code that lets us handle exceptions so that we can continue in our code without necessarily erroring.

```
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)
}
```

Exceptions

```
try {
  int age = 15;
  if (age >= 18) {
    cout << "Access granted - you are old enough.";
  } else {
    throw (age);
  }
}
catch (int myNum) {
  cout << "Access denied - You must be at least 18 years old.\n";
  cout << "Age is: " << myNum;
}
```

What questions do we have?

How many code paths?

```
std::string returnNameCheckPawsome(Pet p) {
    /// NOTE: dogs > cats
    if (p.type() == "Dog" || p.firstName() == "Fluffy") {
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At least 23 code paths!

- (1): Copy constructor of `Pet` may throw

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- (5): Constructor of temp strings may throw

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- (6): Call to type, `firstName` (3), `lastName` (2) may throw

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- (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

```cpp
std::string returnNameCheckPawsome(Pet p) {
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    if (p.type() == "Dog" || p.firstName() == "Fluffy") {
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```

What could go wrong?

```cpp
std::string returnNameCheckPawsome(int petId) {
    Pet* p = new Pet(petId);
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        std::cout << p.firstName() << " " <<
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    }
    std::string returnStr = p.firstName() + " " + p.lastName();
    delete p;
    return returnStr;
```

What if this function threw an exception here?

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What if this function threw an exception here?

Or here?

What could go wrong?

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    std::string returnStr = p.firstName() + " " + p.lastName();
    delete p;
    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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std::string returnNameCheckPawsome(int petId) {
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    std::string returnStr = p.firstName() + " " + p.lastName();
    delete p;
    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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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

RAII: Resource Acquisition is Initialization

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RAII was developed by this lad: 

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

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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();
}
```

Neither is this!

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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 ne

  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?

Plan

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

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() << " " <<
          p.lastName() << " is paw-some!" << '\n';
    }
    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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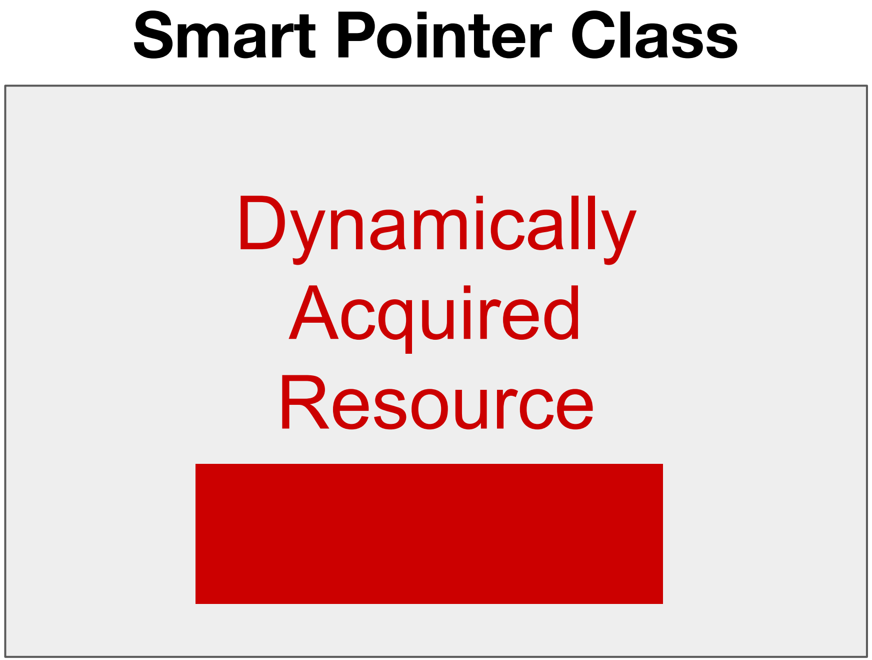
Visualizing smart pointers



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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::unique_ptr`**
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- **`std::shared_ptr`**
  - Can make copies, destructed when the ***<u>underlying memory</u>*** goes out of scope

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There are three types of RAII-compliant pointers:

- **`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
}
```

What questions do we have?

Remember we can’t copy unique pointers

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

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

Why?

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

  // this is a compile-time error!
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```

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

Why?

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  // this is a compile-time error!
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}
```

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

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 ***all*** shared pointers go out of scope!

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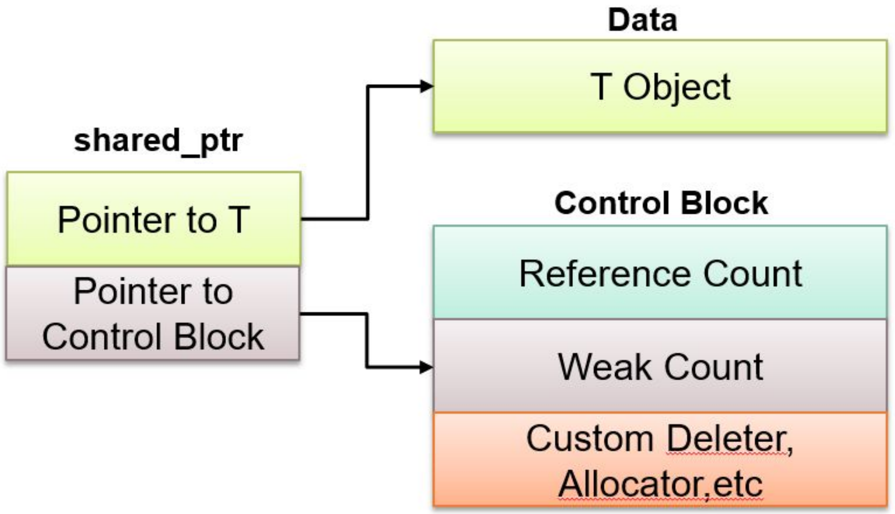

Initializing smart pointers!

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

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

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

Initializing smart pointers!

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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>`

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

std::weak_ptr

- A pointer that can look at an object owned by a shared_ptr without claiming ownership of it
- Does not affect the reference count at all

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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    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;
}
```

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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  a->ptr_to_b = shared_ptr_to_b;
  b->ptr_to_a = shared_ptr_to_a;
  return 0;
}
```

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

```
#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::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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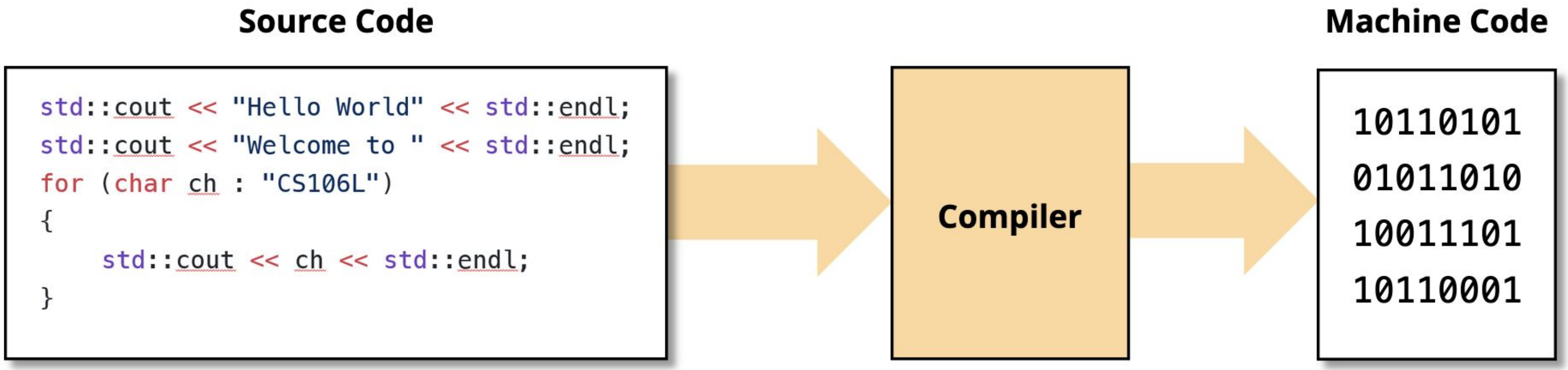


```
$ g++ main.cpp –o main    # g++ is the compiler, outputs binary to main
$ ./main                  # This actually runs our program
```

Compilation Crash Course

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

Source Code

```
std::cout << "Hello World" << std::endl;
std::cout << "Welcome to " << std::endl;
for (char ch : "CS106L")
{
    std::cout << ch << std::endl;
}
```

Compiler

Machine Code

```
10110101
01011010
10011101
10110001
```

```
$ g++ main.cpp –o main      # g++ is the compiler, outputs binary to main
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This is the source file

Compilation Crash Course

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

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

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

Compilation Crash Course

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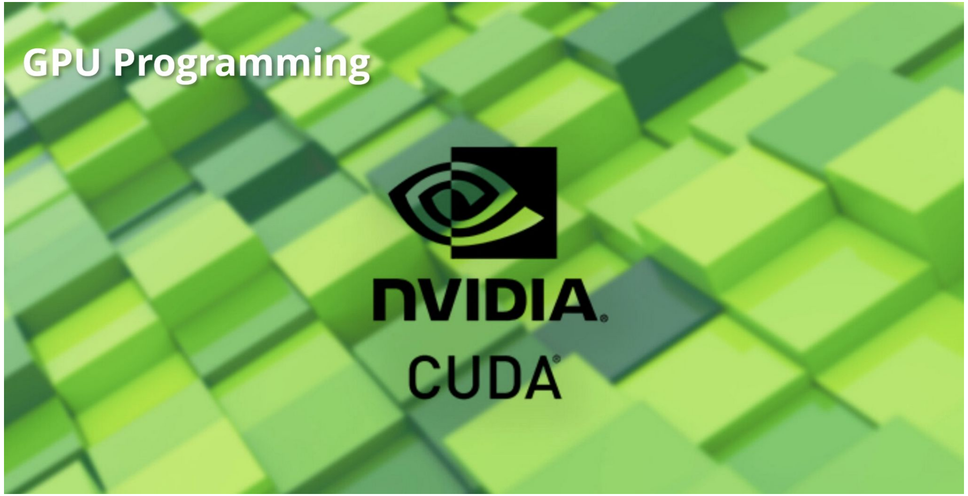
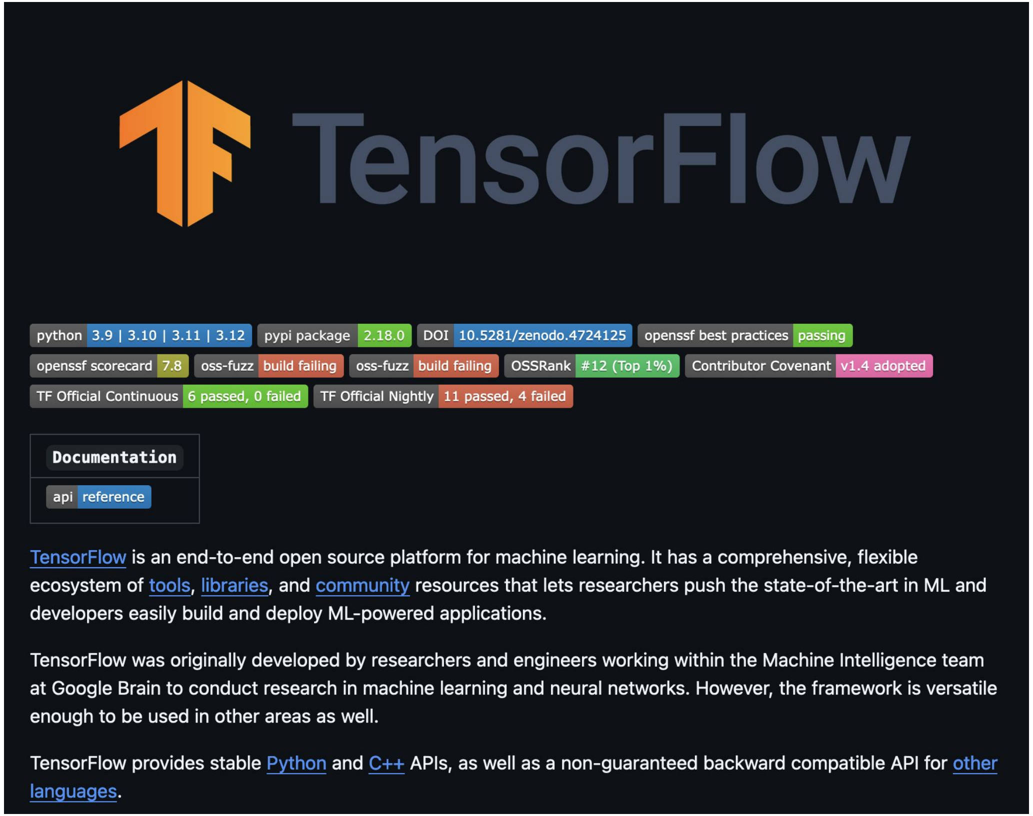
```
$ g++ main.cpp -o main    # g++ is the compiler, outputs binary to main
$ ./main                  # This actually runs our program
```

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

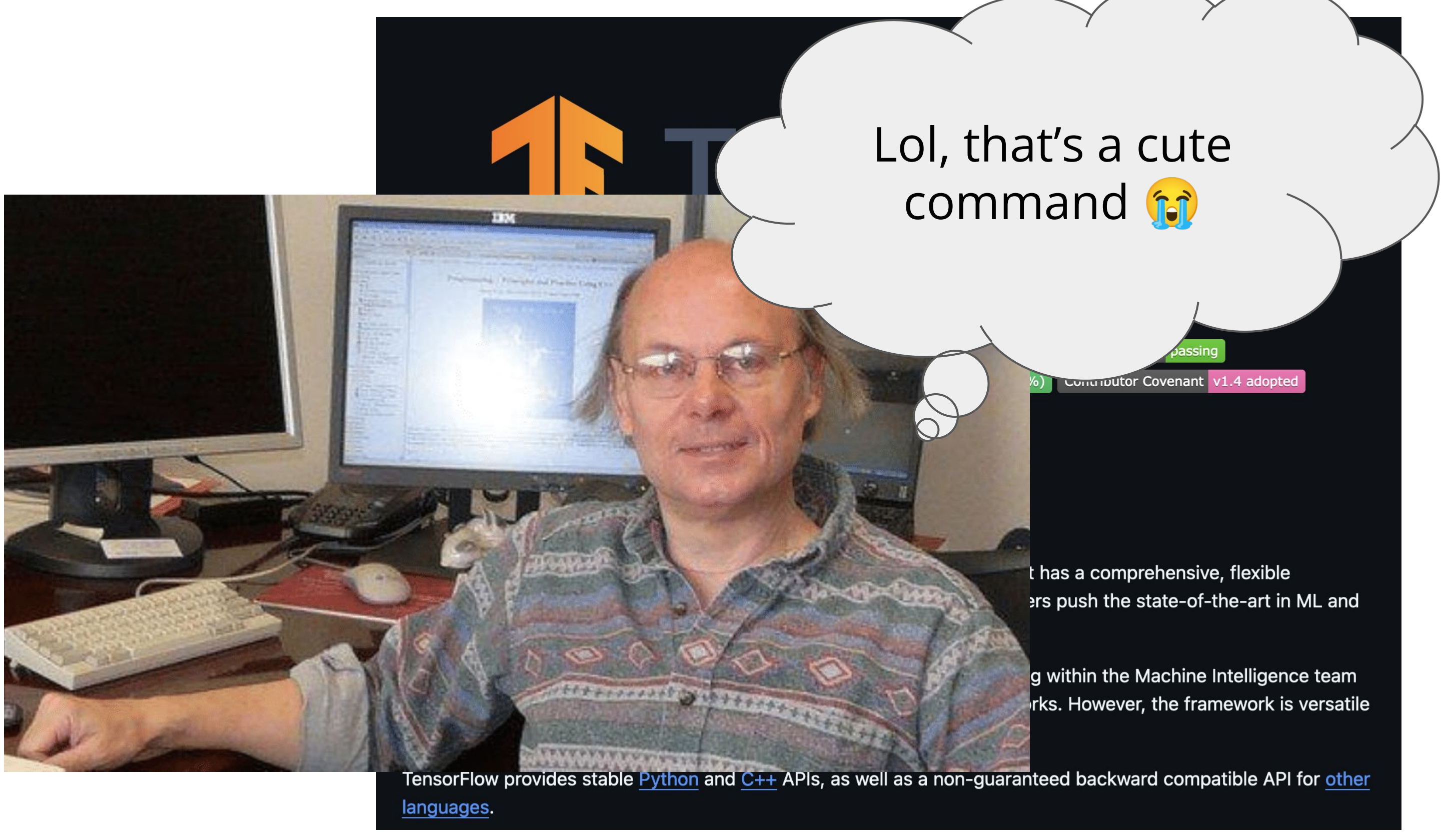
Documentation
api reference

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!

- This way you don't have to have to manually compile every single file in your project
- You can specify what compiler you want to use
- In order to use **`make`** you need to have a **`Makefile`**
- Make tracks which files have changed since last compile

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

```
# 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

Quizziz

https://wayground.com/join?gc=20919921

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

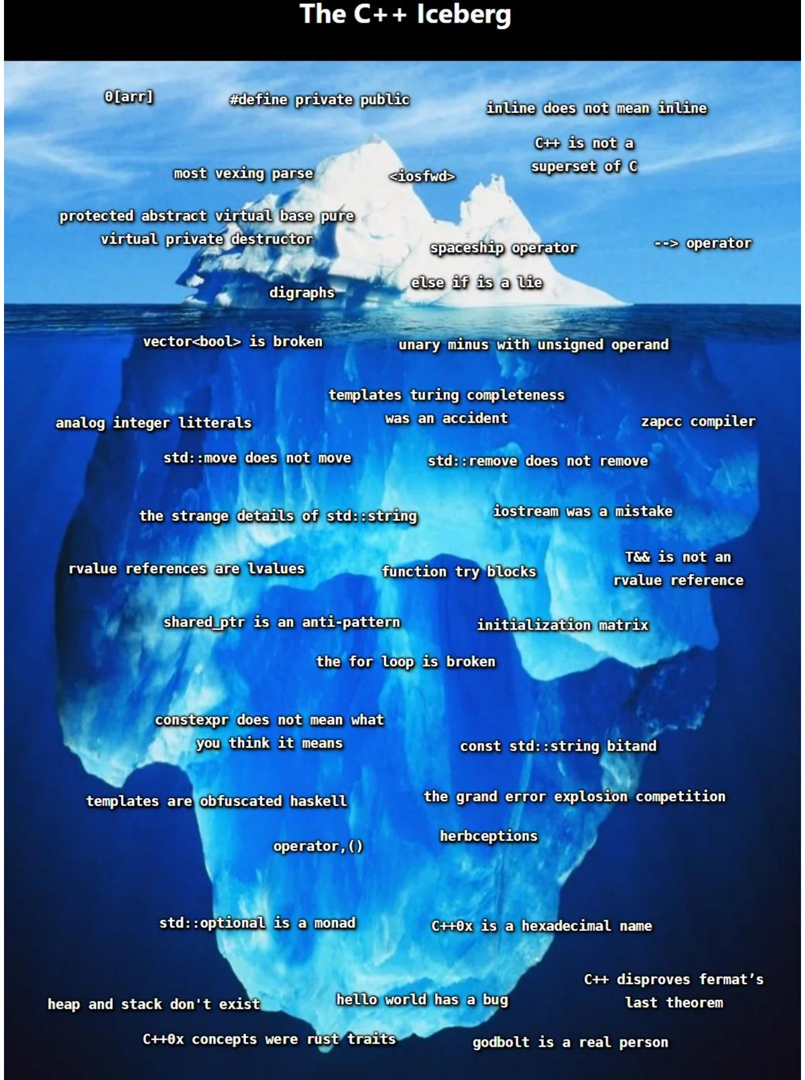
- For compiling our projects we can and should use `Makefiles`

- 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
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]

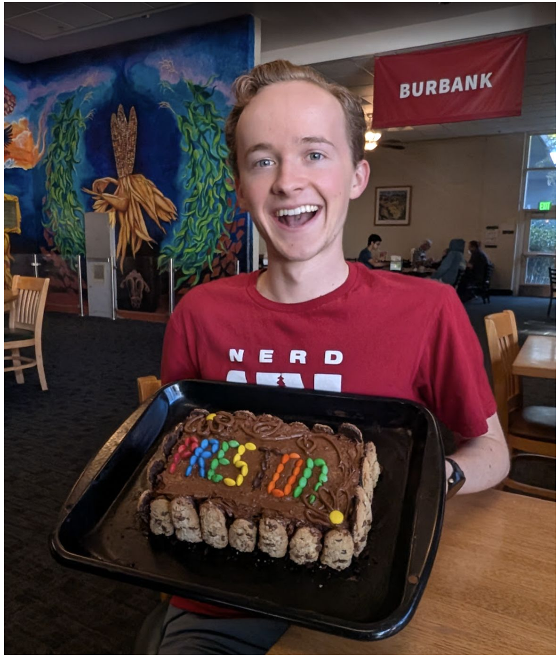
Announcements

- Optional Lecture on C++ Iceberg **held Tuesday of Week 9**
  - Come join us for fun or if you need to make up an attendance!

- Assignment 6 due Friday, 05/22
- Assignment 7 due Friday, 05/29 (will be released this on Friday)

- 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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