CS106L Lecture 15:

RAII and Smart Pointers 🔗

Winter 2024

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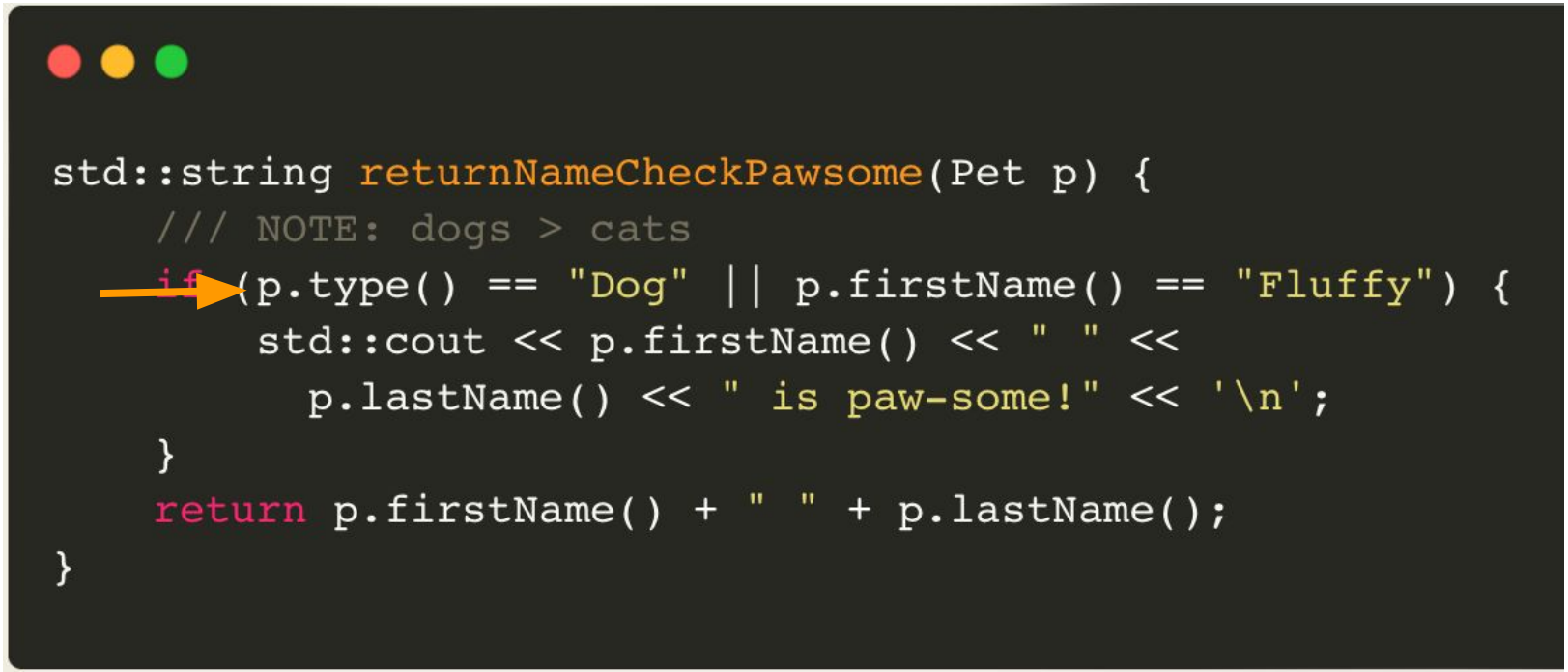
Attendance

http://tinyurl.com/raiiW24

Plan

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

How many code paths?



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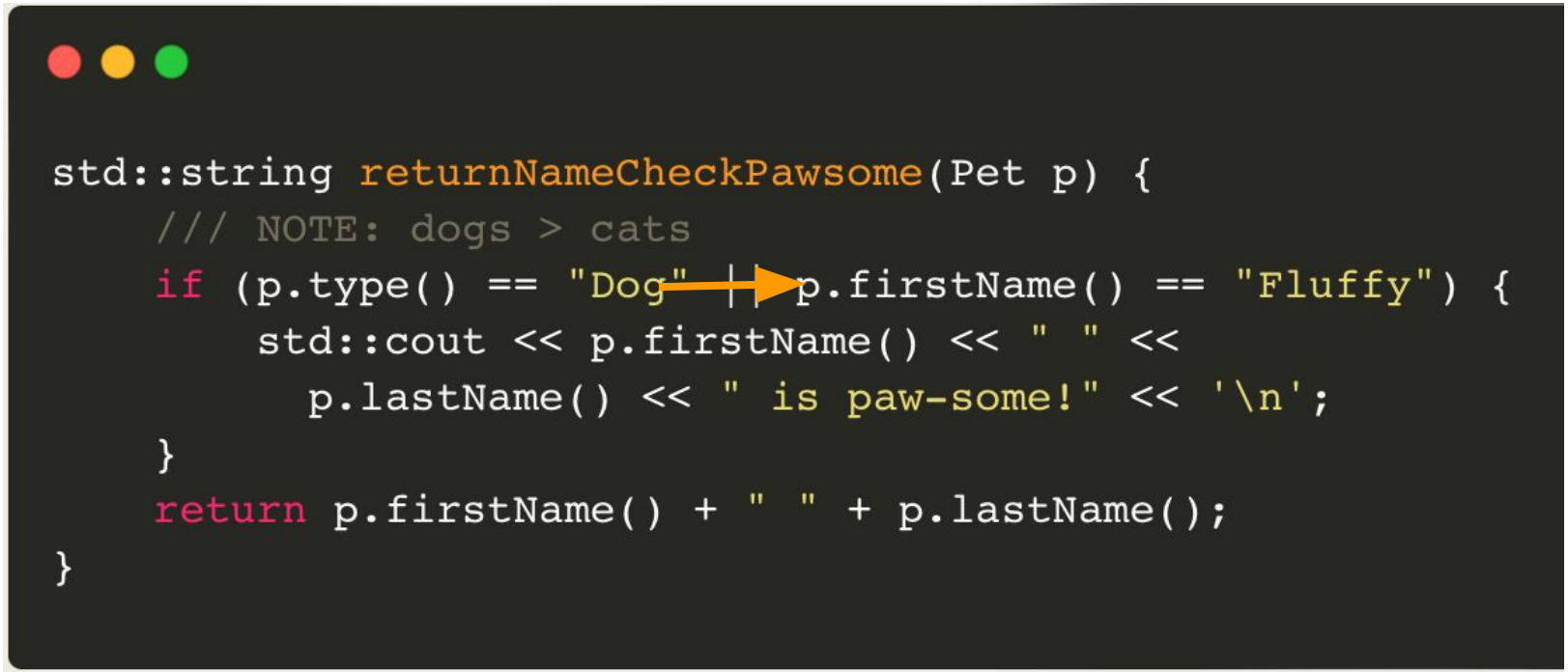

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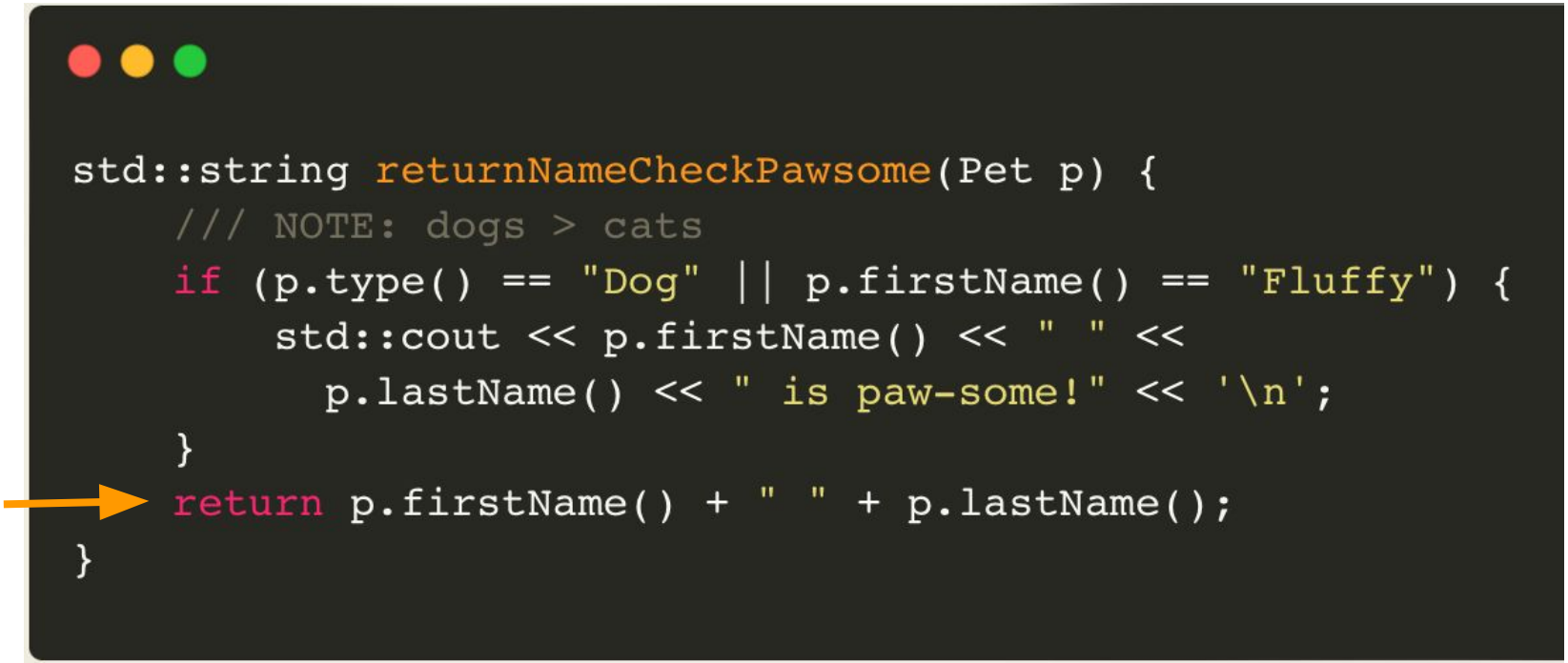

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3?

Exceptions

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- Exceptions are “thrown”
- However, we can write code that lets u
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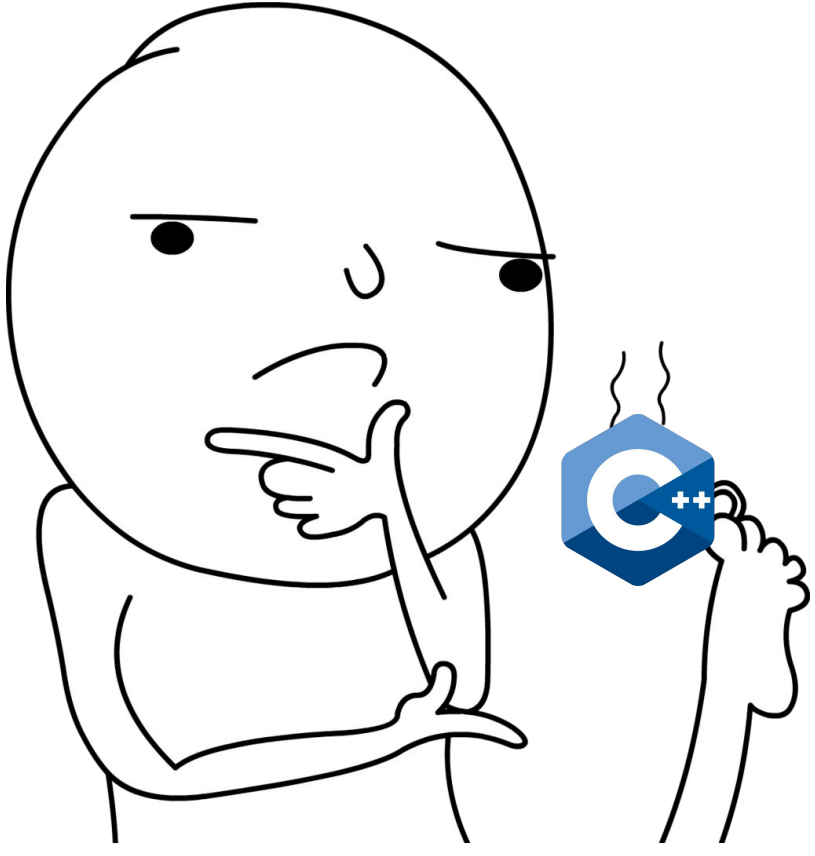
- We call this “***catching***” an exception.

```
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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```

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") {
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```
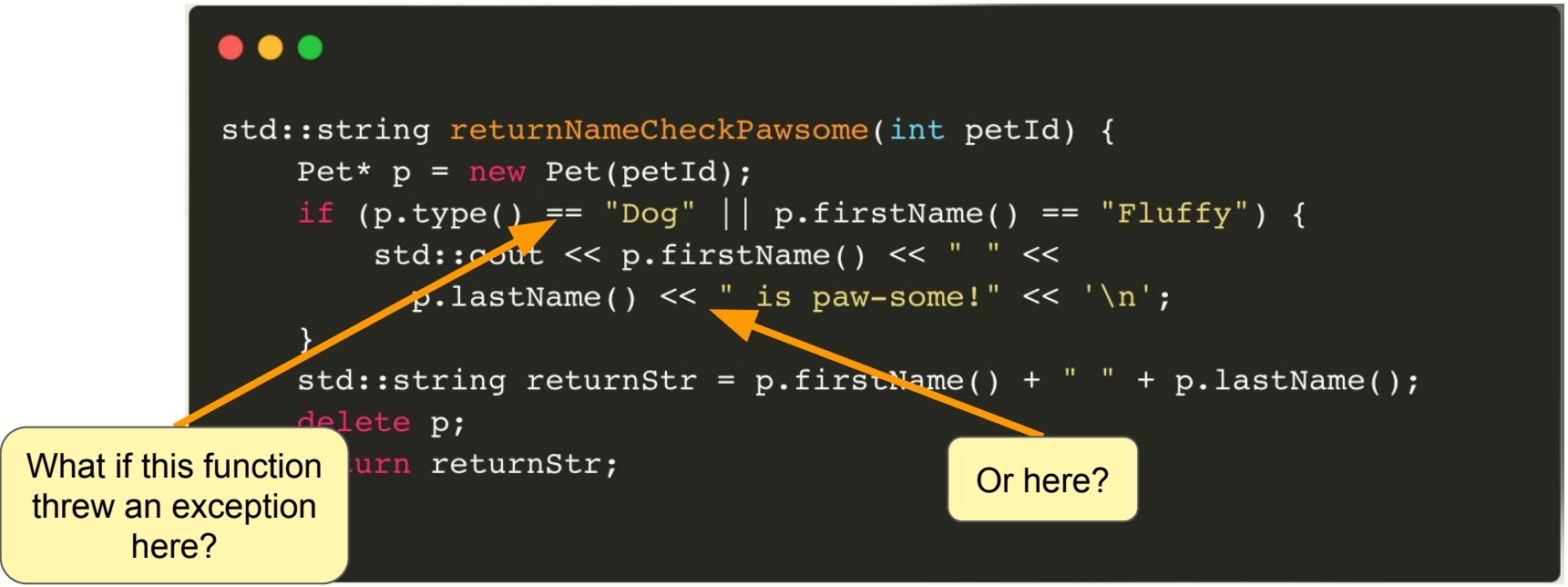

What if this function threw an exception here?

What could go wrong?



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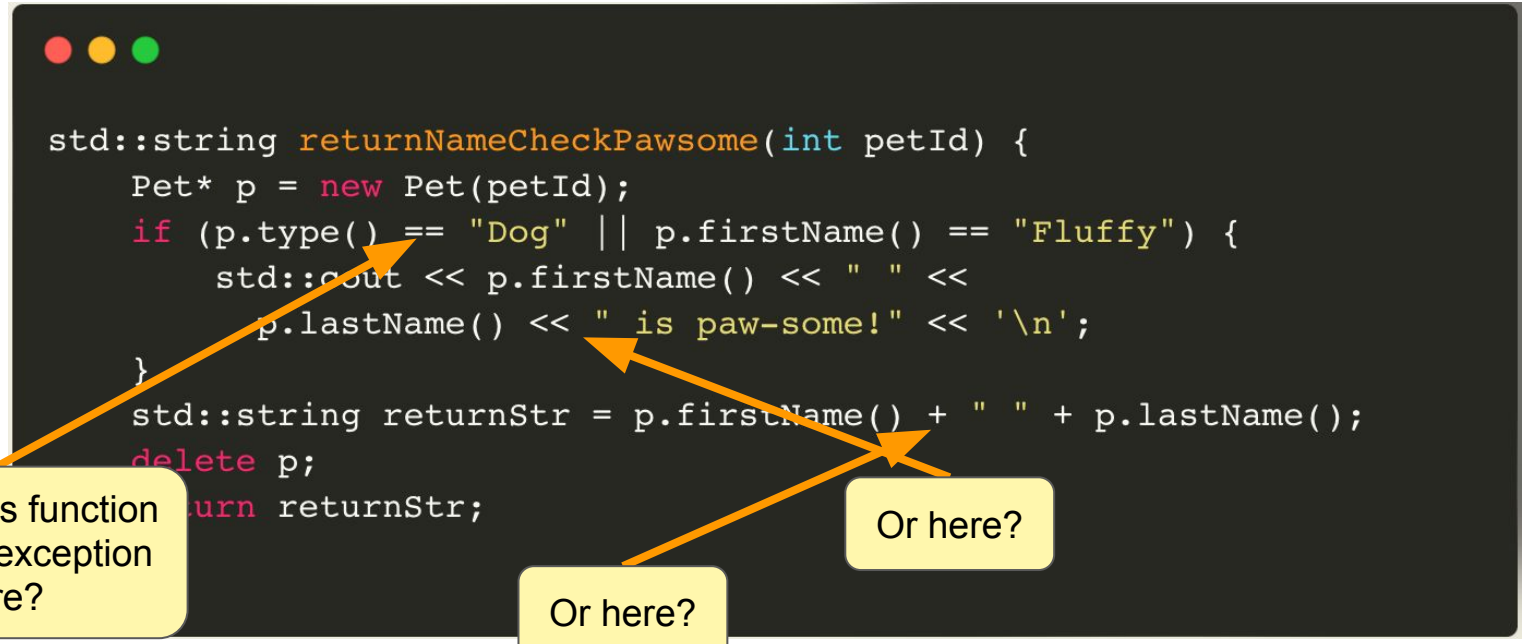

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What could go wrong?

exception here means memory leak

```
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```

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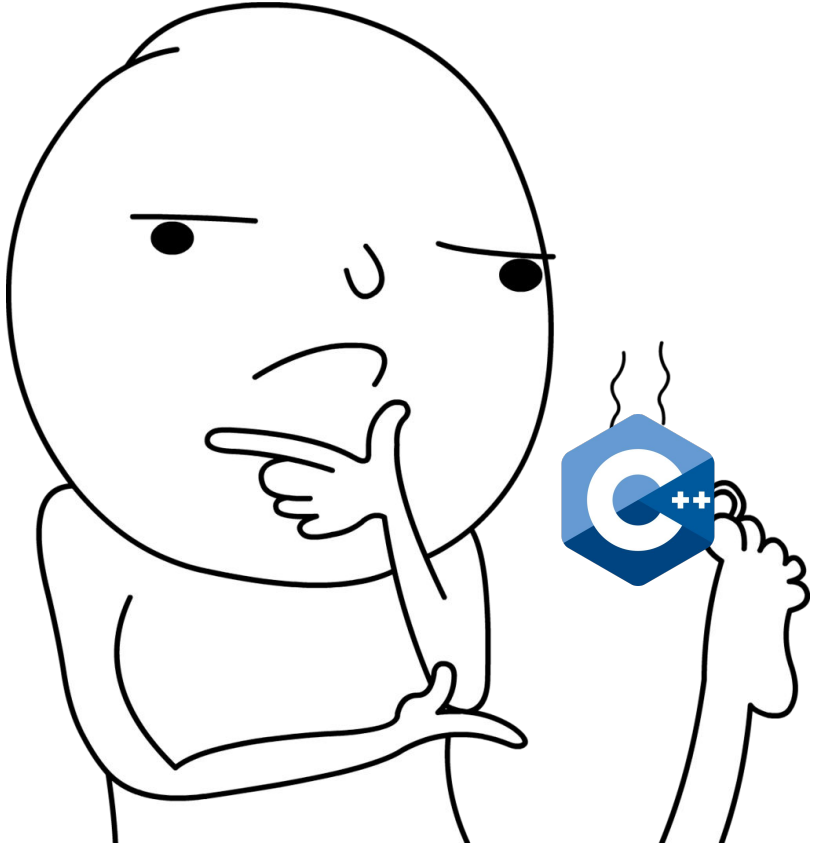
	Acquire	Release
Heap memory	`new`	`delete`
Files	`open`	`close`
	`try_lock`	`unlock`
	`socket`	`close`

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.

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RAII was developed by this lad: 

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?

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It turns out that by abiding by the RAII policy we avoid “half-valid” states.

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- 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.

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- 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?

```
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?

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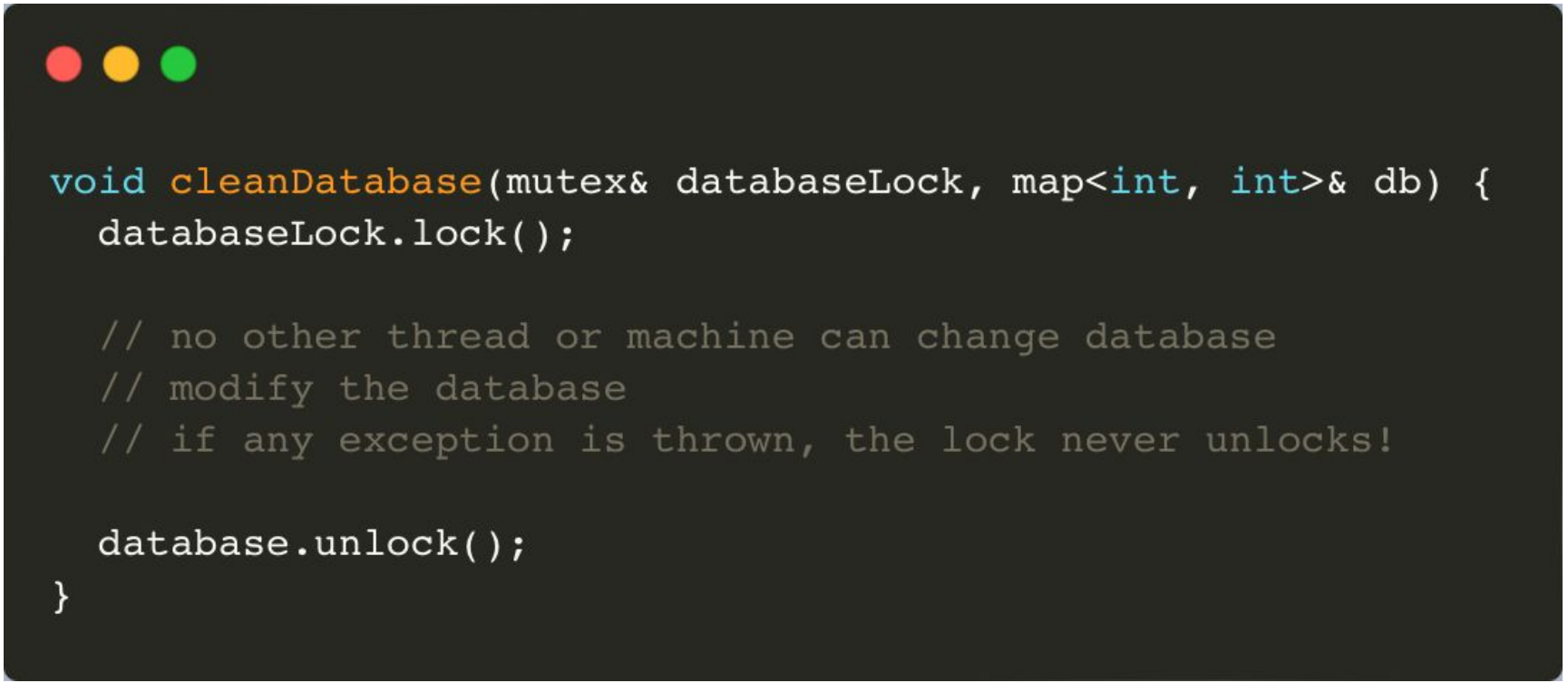
```

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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```

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
}
```

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```

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

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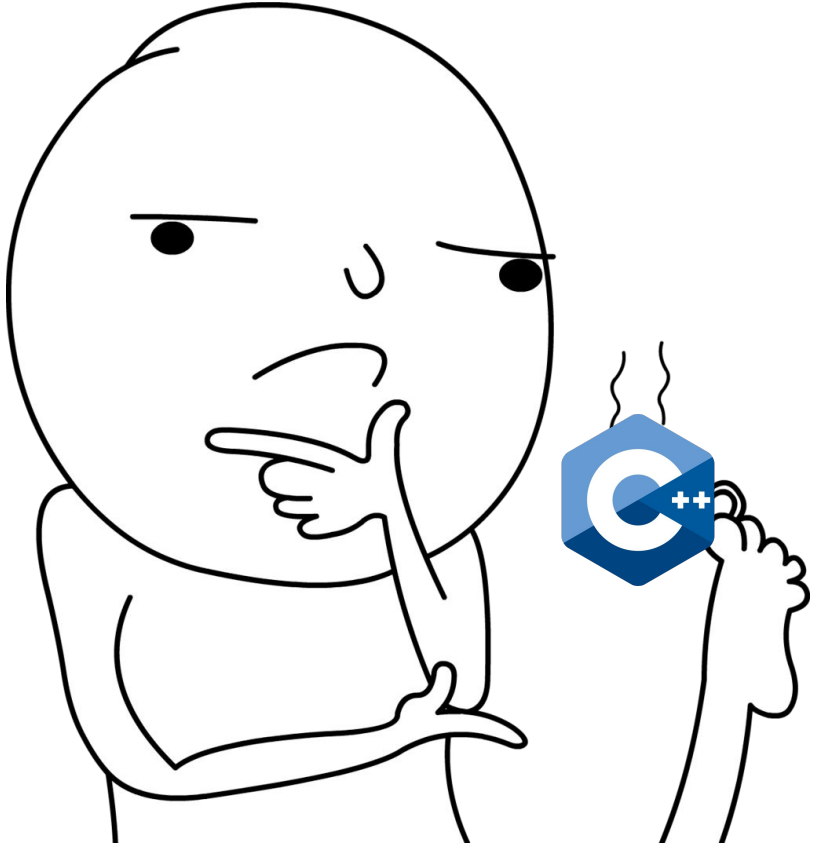

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Smart Pointers

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") {
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What did we do for locks?

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

Visualizing smart pointers

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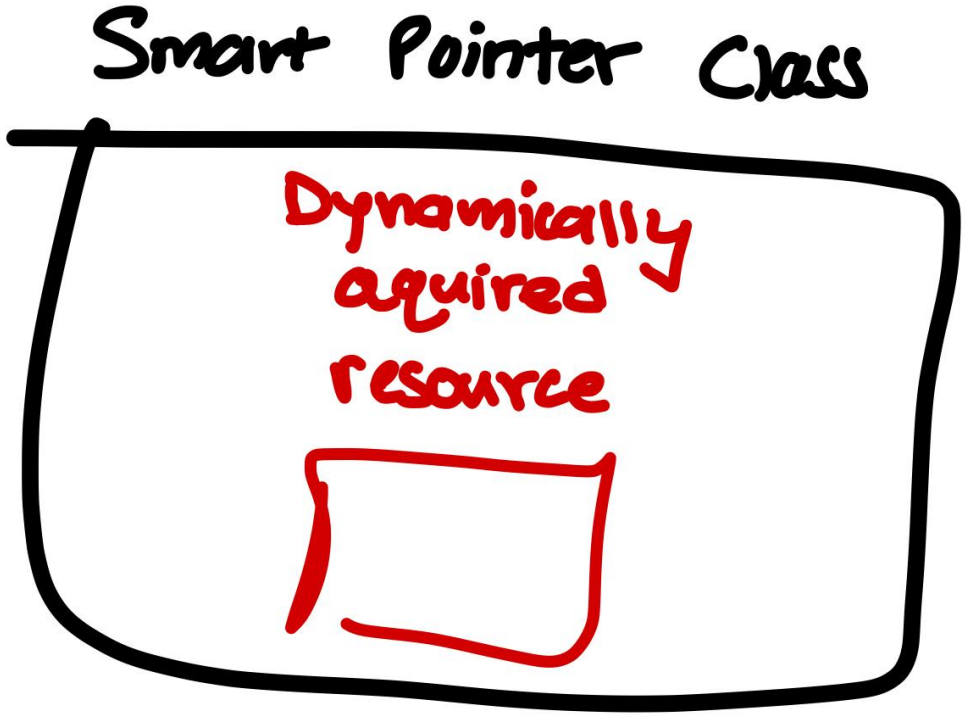

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- `std::unique_ptr`
  - Uniquely owns its resource, can’t be copied

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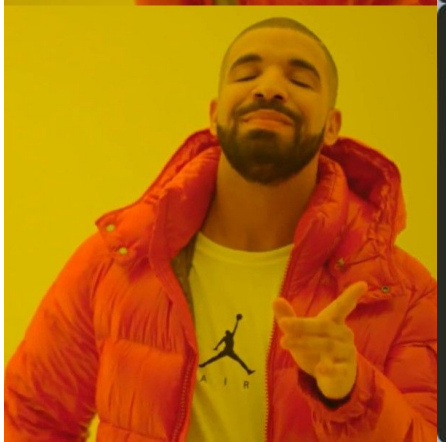
- **`std::shared_ptr`**
  - Can make copies, destructed when the ***underlying memory*** goes out of scope
- **`std::weak_ptr`**
  - This is a way to *try* to have ownership over an object that may or may not exist

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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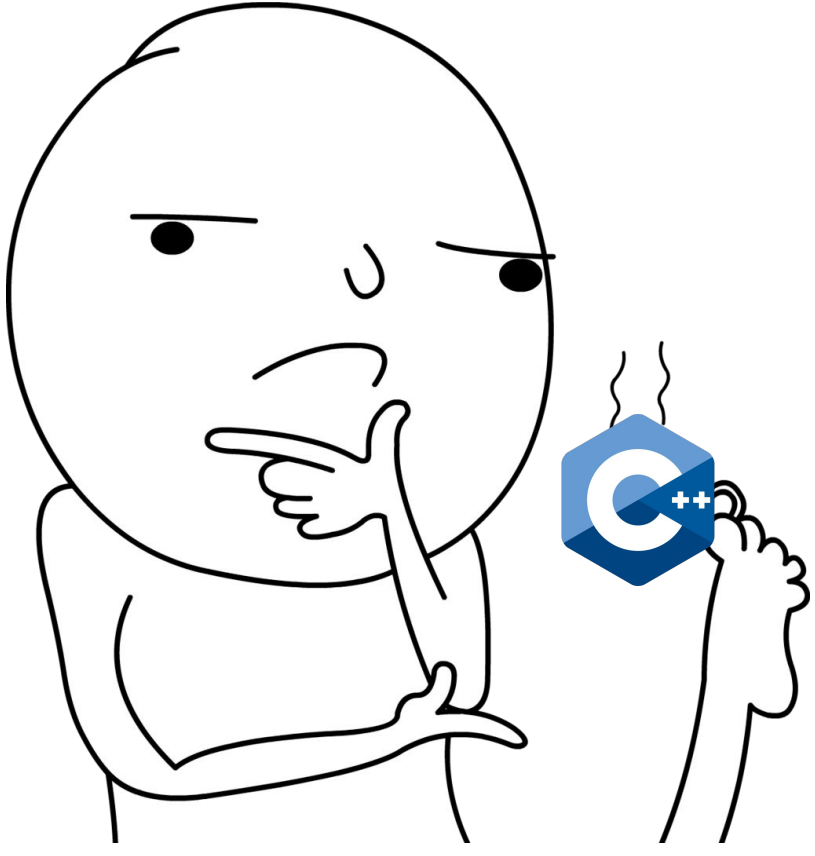
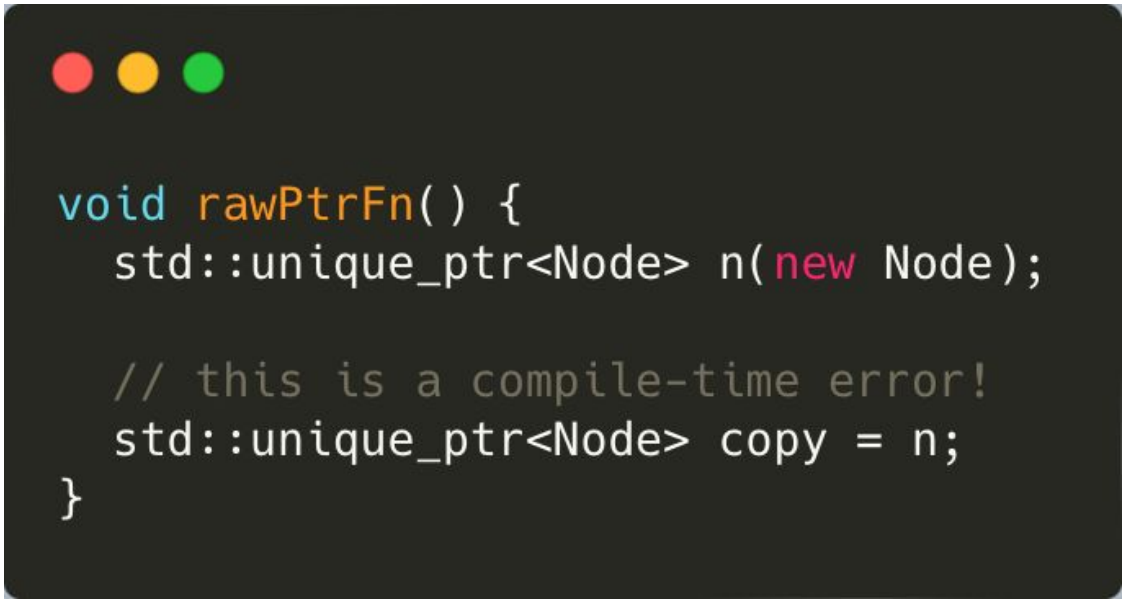


Remember we can’t copy unique pointers



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

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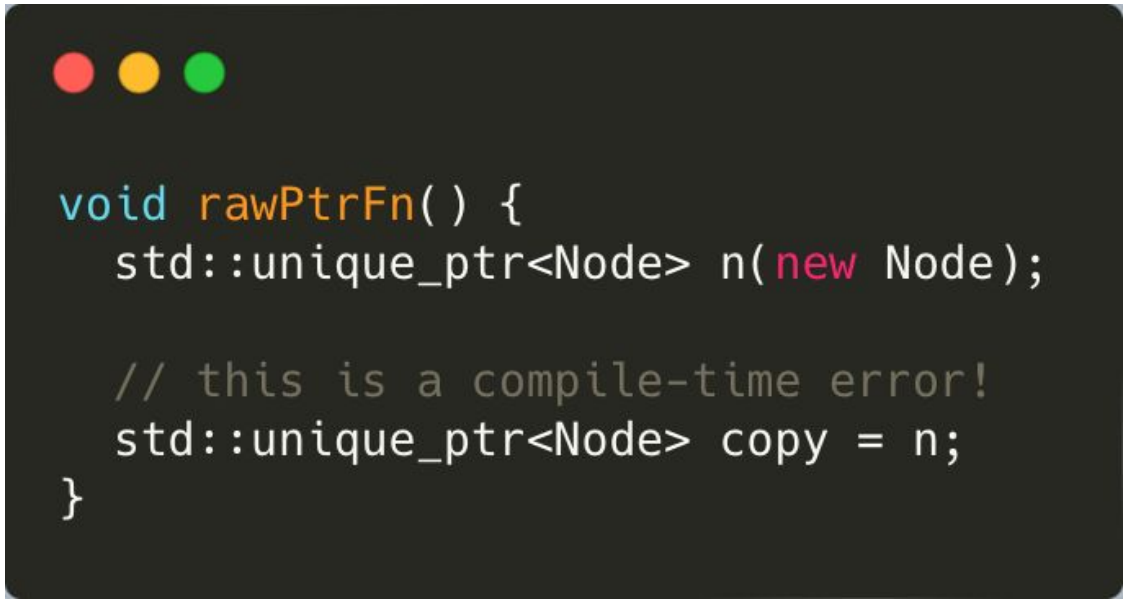
Why?



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

Why?

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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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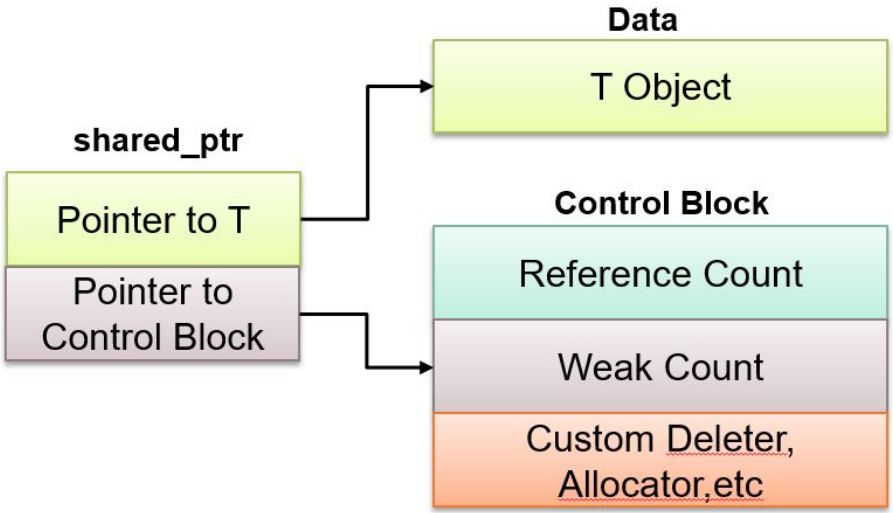
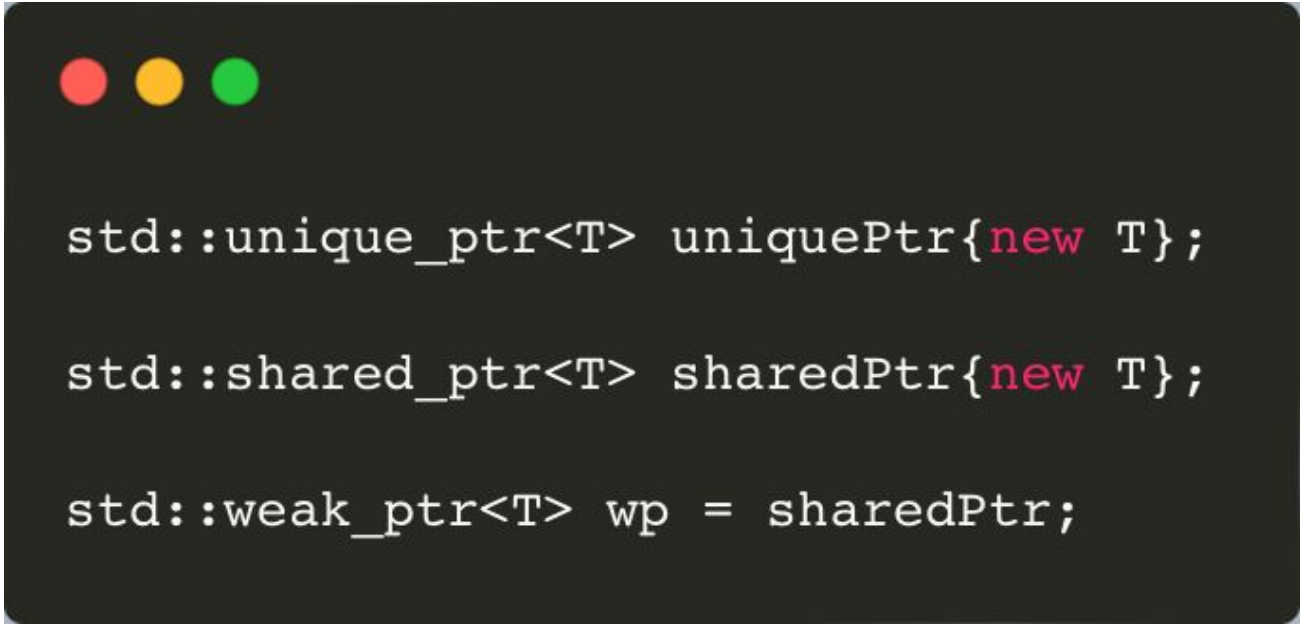


Initializing smart pointers!



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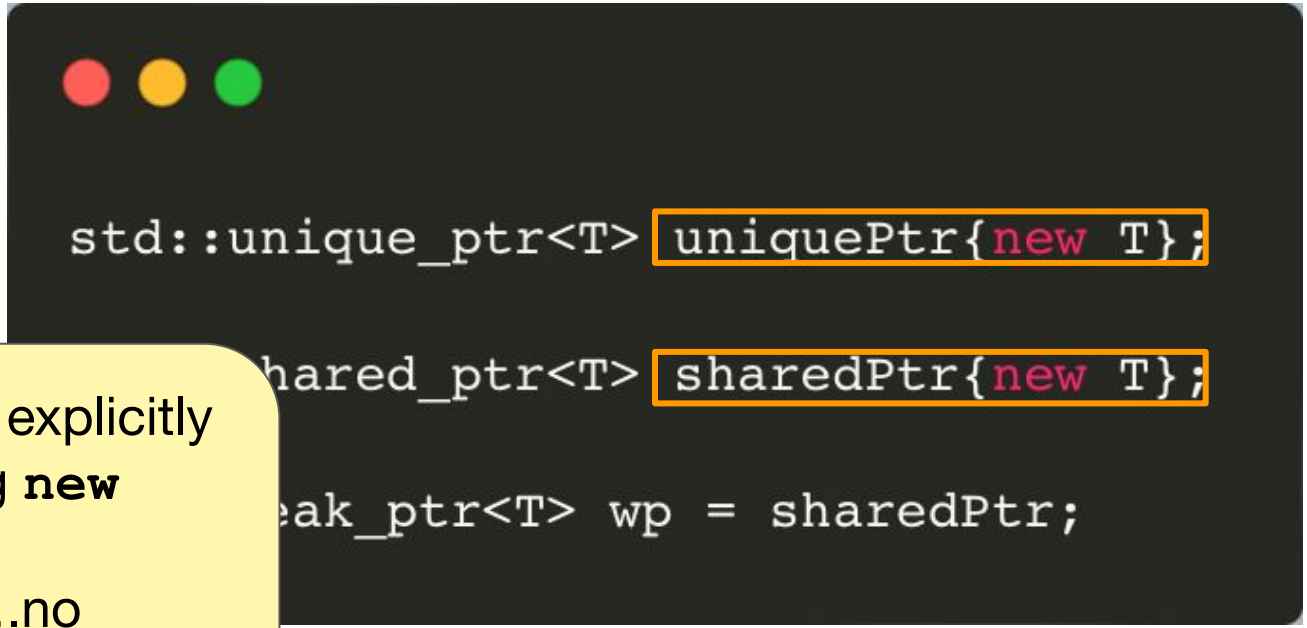

We're still explicitly calling **new**

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!

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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`**!

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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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A compiler does this, and a compiler is just a program that translates code from one language to another

A few common ones include g++ and clang.

What this looks like

Preprocessing

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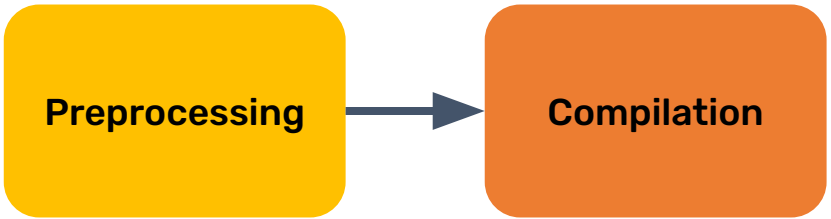
In this stage, the code is cleaned up before actually compiling

- Any preprocessor commands that begin with # are handled
- Comments and excess whitespace are stripped

main.cpp

The compilation stage



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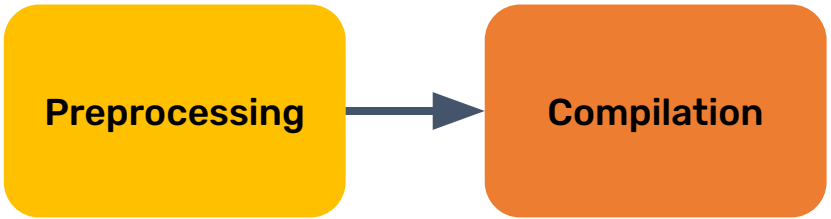

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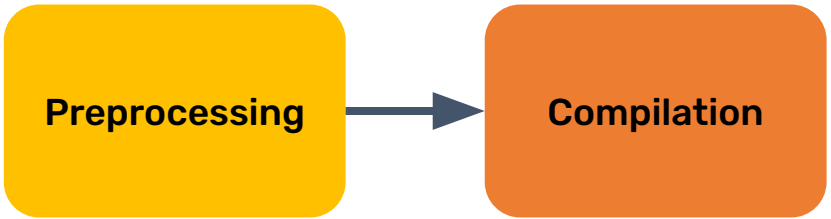

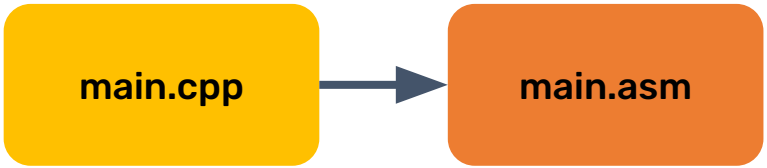

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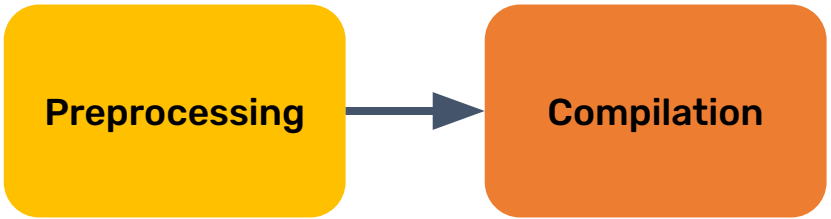
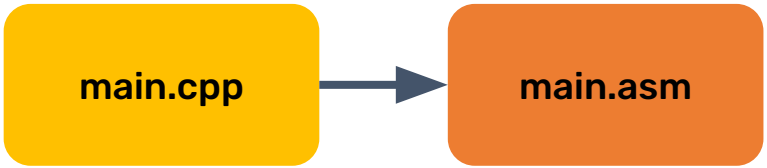
- C++ to assembly translation

The compilation stage

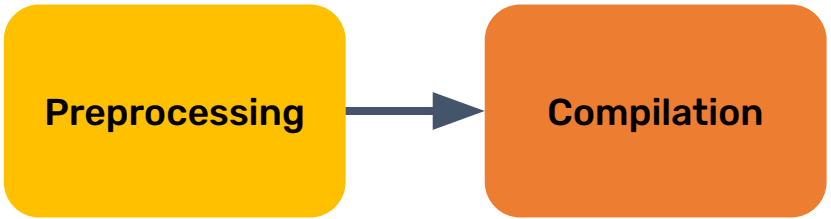


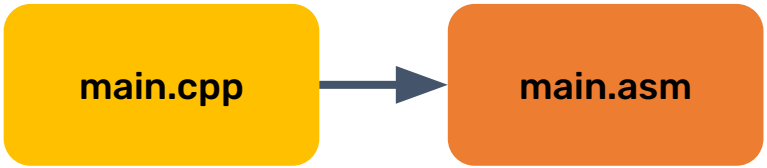


This is where the translation actually happens – code is translated into assembly which our computer can read.

- C++ to assembly translation
- If code is already in assembly, it is not translated

The compilation stage





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- C++ to assembly translation
- If code is already in assembly, it is not translated
- Assembly is oftentimes machine-specific.

The assembly stage

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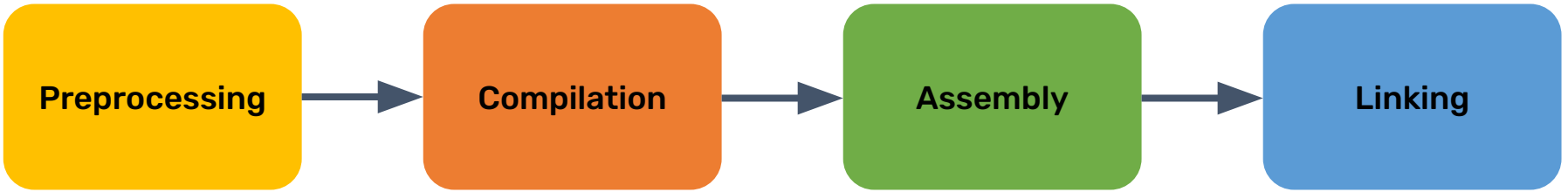
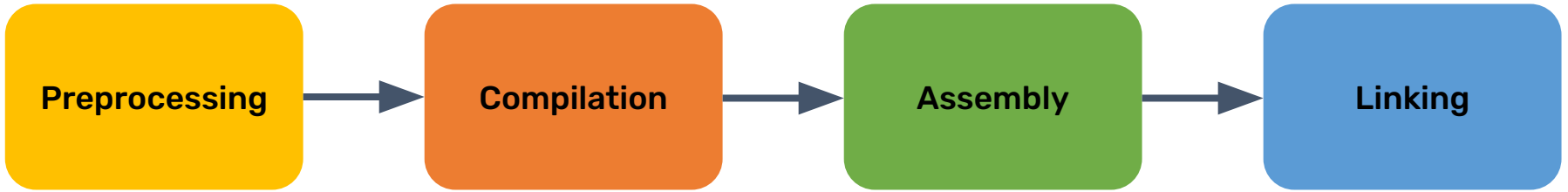
- Object code is actual machine readable code the processor can run.
- Assembly is the human-readable version of the object code

The linking stage

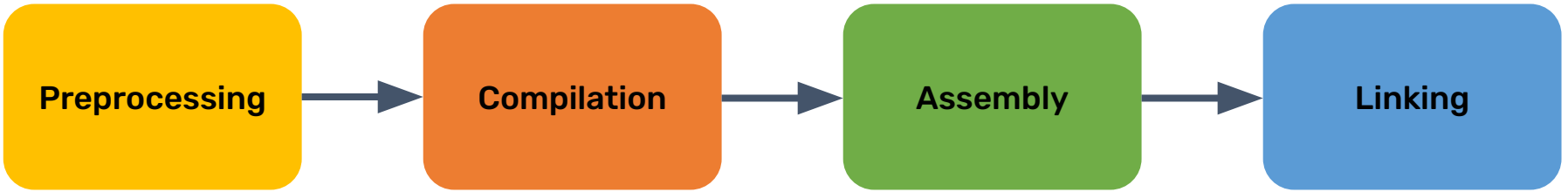


The linking stage



The linker takes each piece of object code and arranges it into one program

The linking stage



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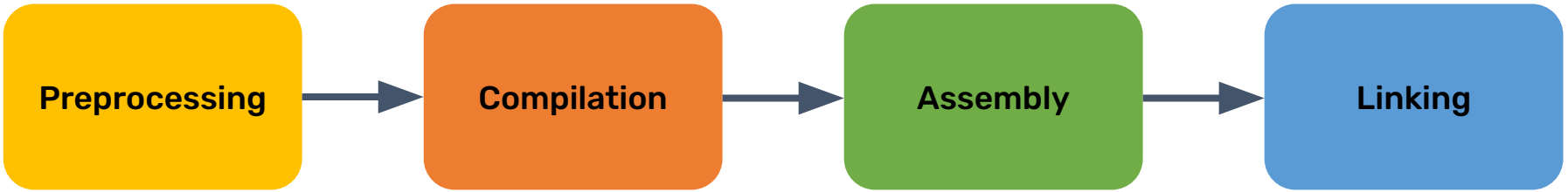
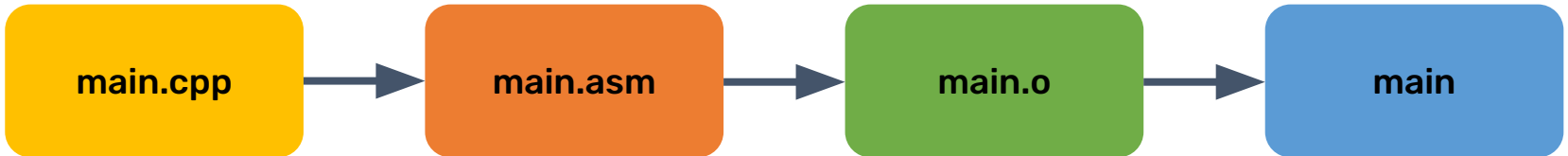
The linking stage

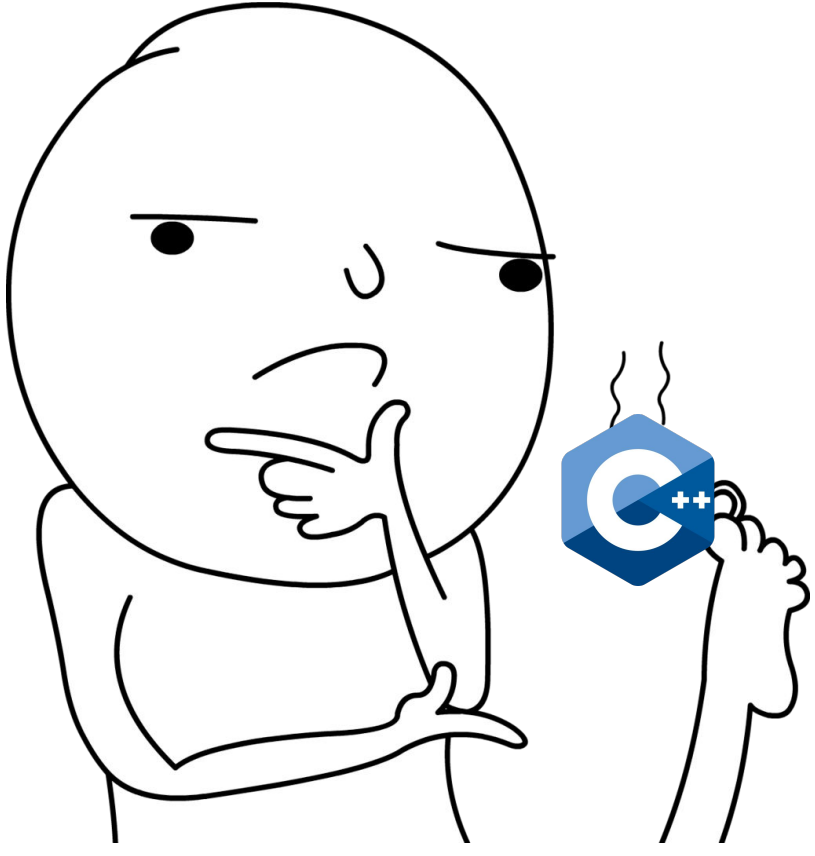


The linker takes each piece of object code and arranges it into one program

- Think about this stage as “stitching” things together
- At this point we get an executable program



What questions do we have?



`Makefiles` and `make`

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

`Makefile` and `make`

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

- It makes use of the `g++` compiler
- In order to use **`make`** you need to have a **`Makefile`**

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

Makefile and make

```
TARGET = sh111

CXXBASE = g++
CXX = $(CXXBASE) -std=c++17
CXXFLAGS = -ggdb -O -Wall -Werror

CPPFLAGS =
LIBS =

OBJS = sh111.o
HEADERS =

all: $(TARGET)

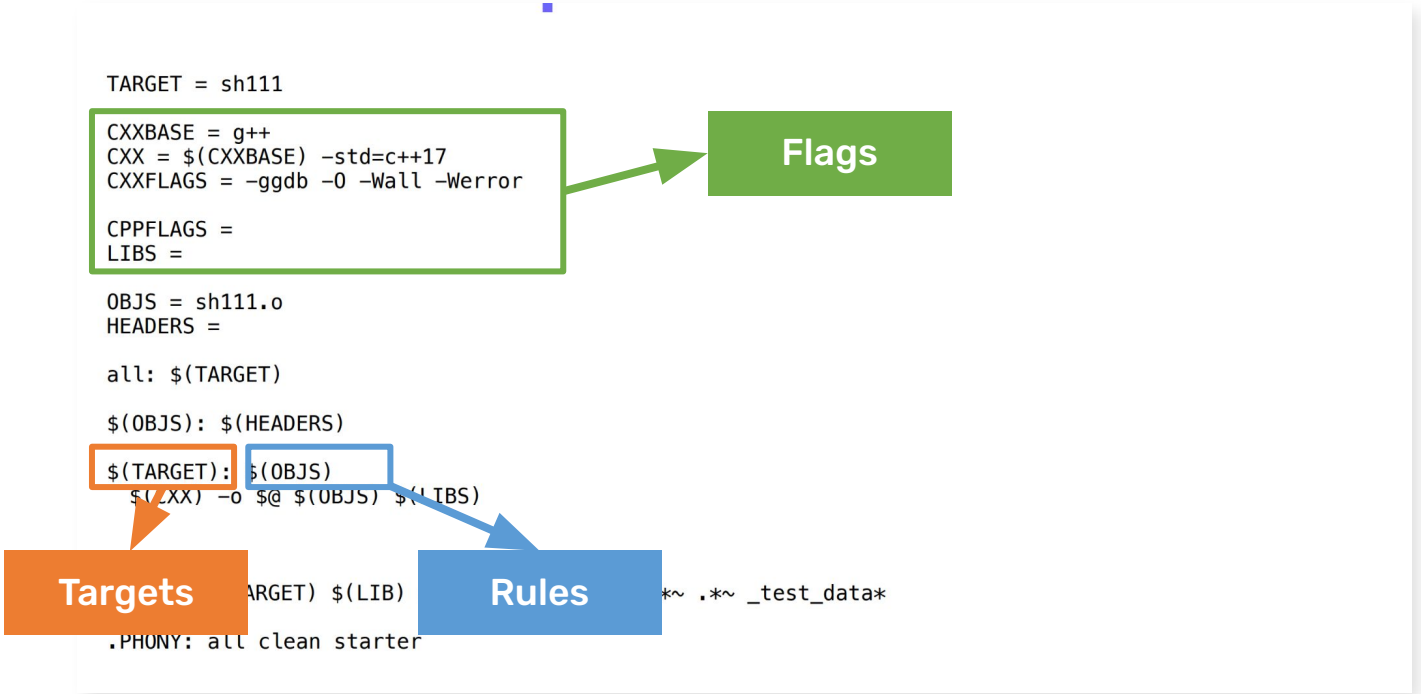
$(OBJS): $(HEADERS)

$(TARGET): $(OBJS)
  $(CXX) -o $@ $(OBJS) $(LIBS)


clean:
  rm -f $(TARGET) $(LIB) $(OBJS) $(LIBOBJS) *~ .*~ _test_data*

.PHONY: all clean starter
```

Makefile and make



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

Also can be thought about as a cross-platform **make**

CMake

```
cmake_minimum_required(VERSION 3.0)
project(wikiracer)

set(CMAKE_CXX_STANDARD 17)
set(CMAKE_CXX_STANDARD_REQUIRED True)

find_package(cpr CONFIG REQUIRED)

# adding all files
add_executable(main main.cpp wikiscraper.cpp.o error.cpp)

target_link_libraries(main PRIVATE cpr)
```

Here's an example of of a **cmake** file

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```

This is the cmake file for our assignment – it looks more like a programming language!

In summary

- Exceptions in your code during runtime can cause your resources to ‘leak’
- 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
- To build our own projects we can and should use `Makefiles` or another build system.

Last lecture