

CS106L Lecture 15:

RAII and Smart Pointers

Spring 2024

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Attendance



<https://tinyurl.com/raiis24>

Plan

1. RAI (Resource Acquisition Is Initialization)
2. Smart Pointers
3. Building C++ projects
 - Compiling
 - Make
 - gdb

How many code paths?



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

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3?

Exceptions

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Exceptions

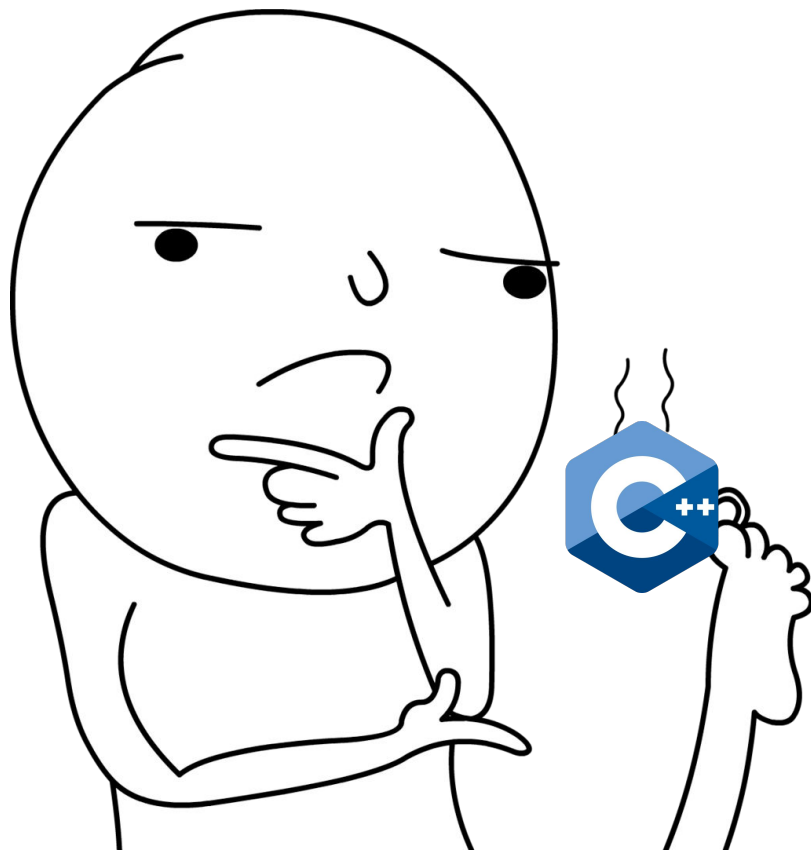
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- However, we can write code that lets us handle exceptions so that we can continue in our code without necessarily erroring.

Exceptions


- Exceptions are a way of handling errors when they arise in code
- Exceptions are “thrown”
- However, we can write code that lets us continue in our code without needing to handle the exception
- 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?



How many code paths?



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

What could go wrong?



```
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    Pet* p = new Pet(petId);  
    if (p.type() == "Dog" || p.firstName() == "Fluffy") {  
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}
```

What if this function
threw an exception
here?

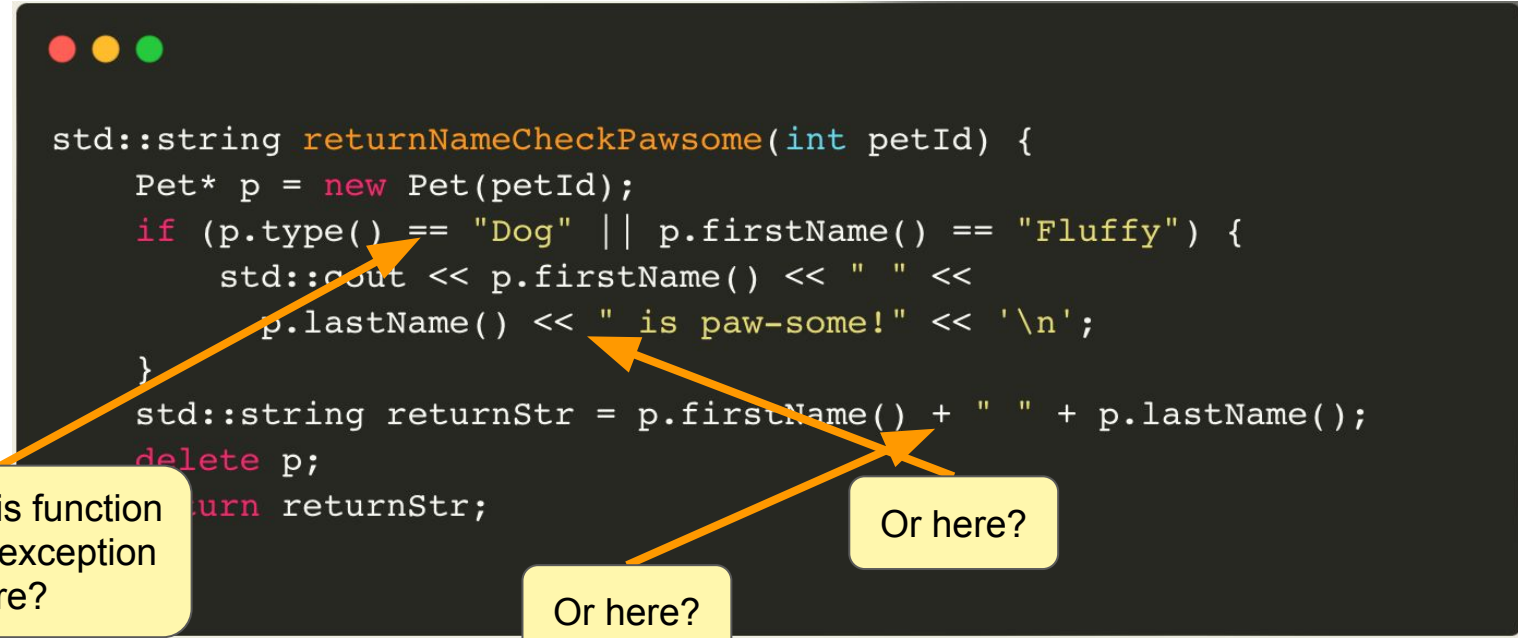
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Or here?

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    delete p;  
    return returnStr;  
}
```

What if this function
threw an exception
here?

Or 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) {  
    Pet* p = new Pet(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	<code>new</code>	<code>delete</code>
Files	<code>open</code>	<code>close</code>
Locks	<code>try_lock</code>	<code>unlock</code>
Sockets	<code>socket</code>	<code>close</code>

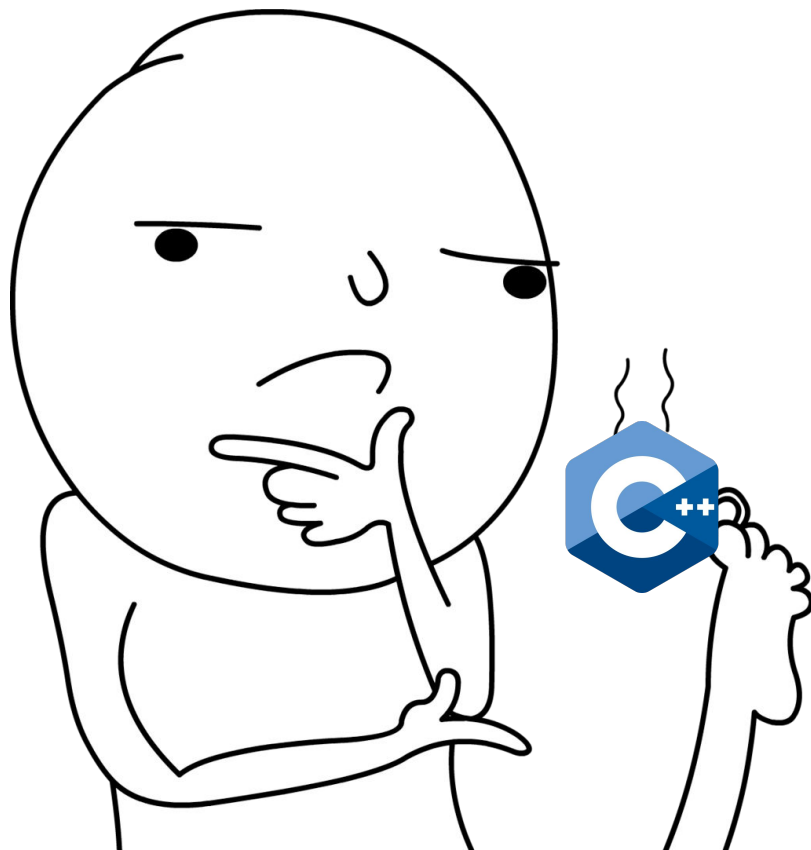
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Heap memory	<code>new</code>	<code>delete</code>
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	<code>try_lock</code>	<code>unlock</code>
	<code>socket</code>	<code>close</code>

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: Resource Acquisition is Initialization (What is this name?)

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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



RAll: why tho?

RAll: Resource Acquisition is Initialization

- By abiding by the RAll policy we avoid “half-valid” states.

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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.

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?



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

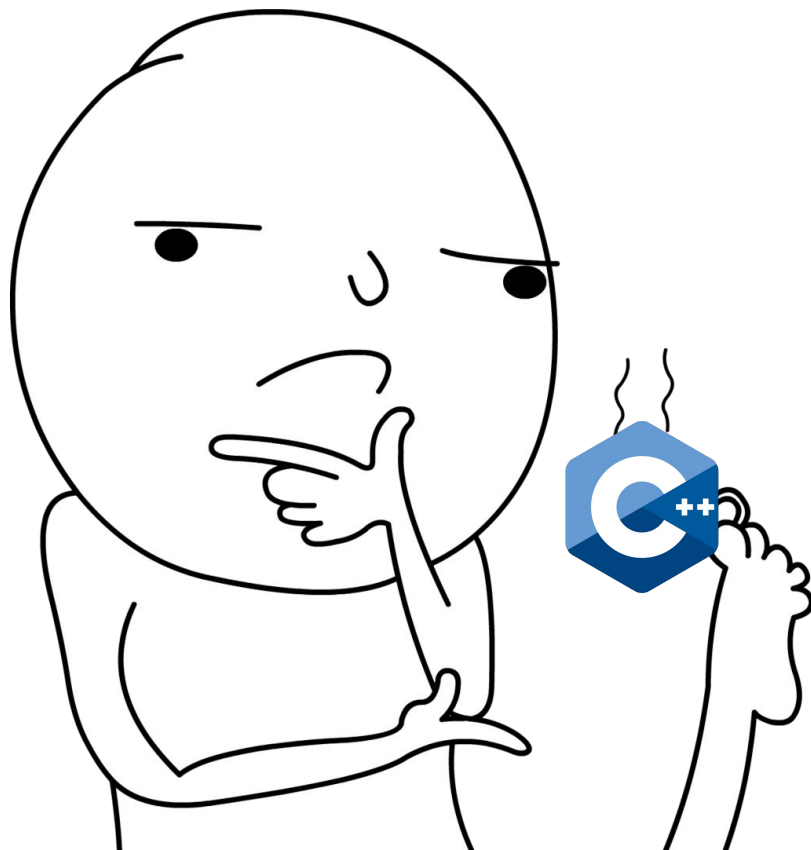


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    // no explicit unlock necessary  
}
```

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

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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`

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RAll for memory → **We can do the same** 🎉

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

Visualizing smart pointers

RAll for locks → `lock_guard`

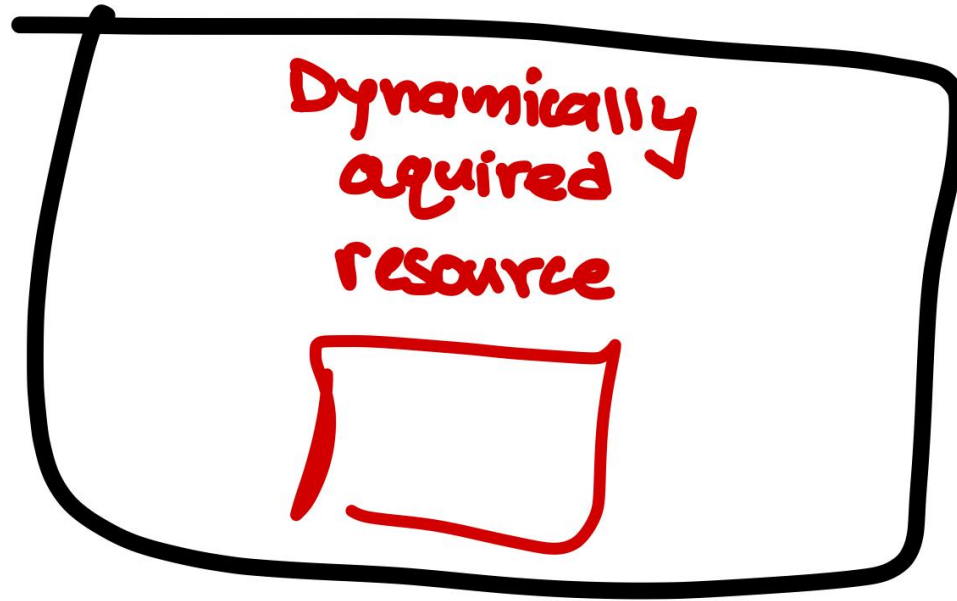
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Visualizing smart pointers

Smart Pointer Class



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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 - Can make copies, destructed when the underlying memory 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?

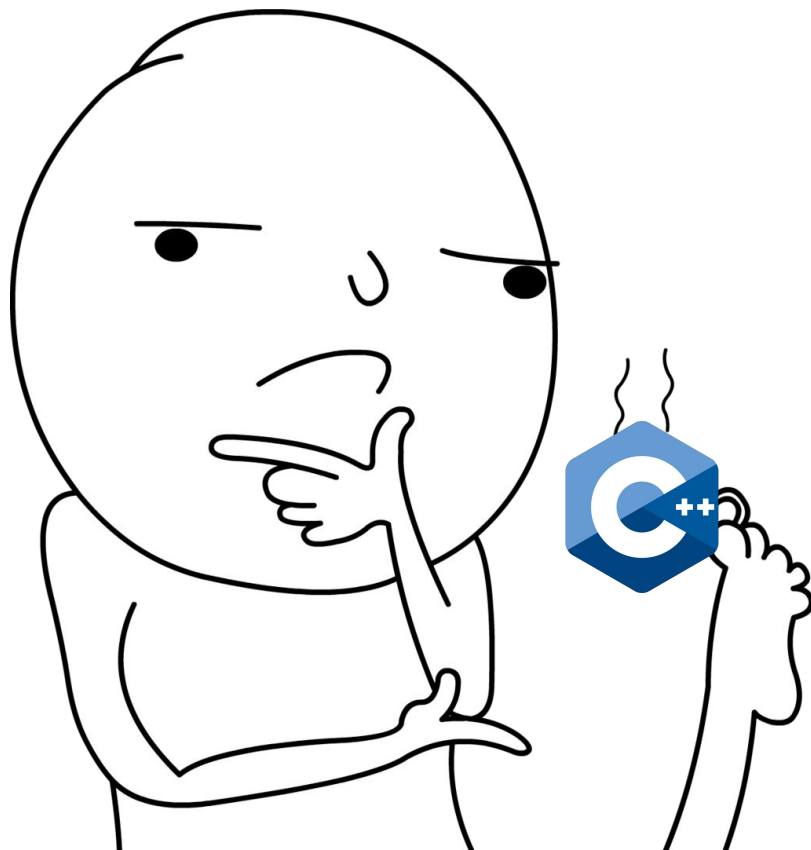


```
void rawPtrFn() {  
    Node* n = new Node;  
    // do smth with n  
    delete n;  
}
```




```
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?



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void rawPtrFn() {  
    std::unique_ptr<Node> n(new Node);  
  
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Imagine a case where the original destructor is called **after** the copy happens.

Why?



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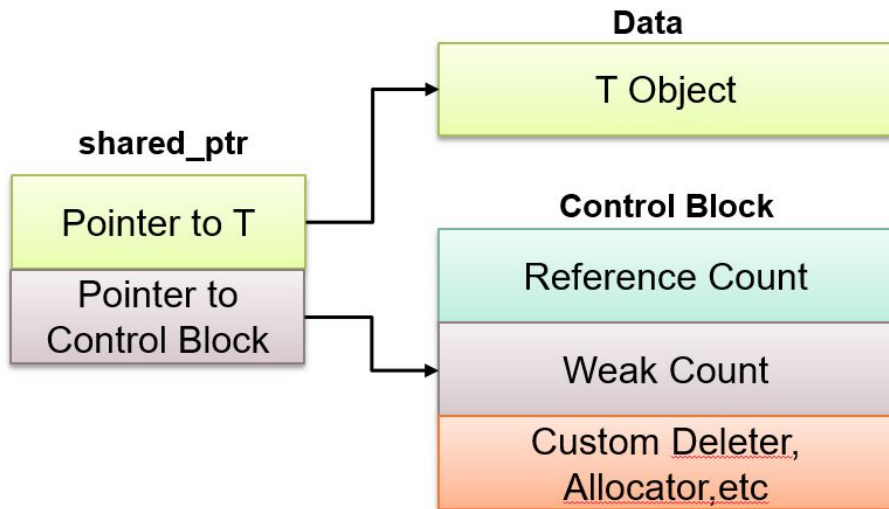
Problem: The copy points to deallocated memory!

`std::shared_ptr`

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

std::shared_ptr

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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;
```

Initializing smart pointers!

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


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

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

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.

std::weak_ptr bad 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::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;
    ~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 share pointer to each other.

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    ~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 share pointer to each other.

Therefore, they will never properly deallocate

std::weak_ptr good example

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

class B;

class A {
public:
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    ~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**.

We can test this!

[Replit link](#)

Plan

~~1. RAII (Resource Acquisition Is Initialization)~~

~~2. Smart Pointers~~

3. Building C++ projects

- Compiling
- Make
- gdb

Compilation Crash Course

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

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

This is called compiling

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

Preprocessing

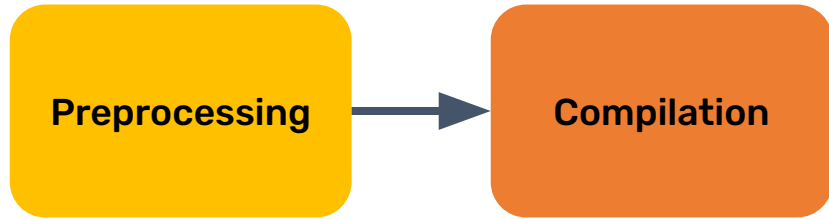
Preprocessing

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

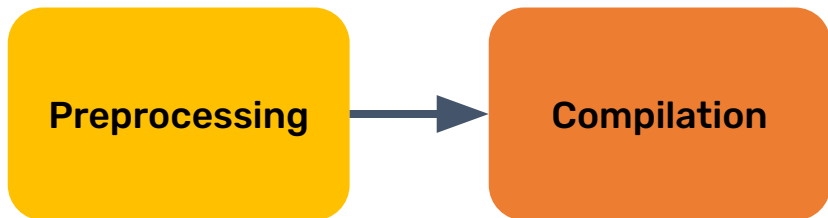
`main.cpp`

The compilation stage



The compilation stage

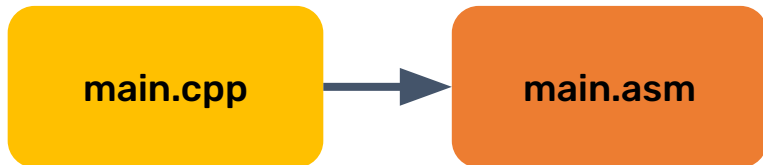
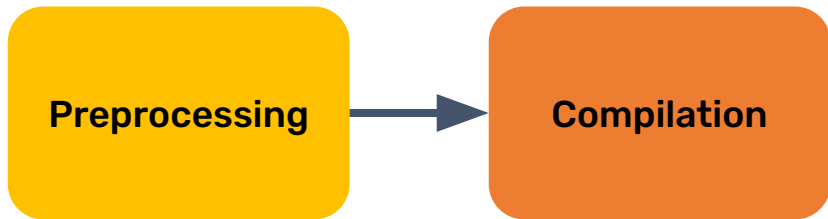
This is where the translation actually happens – code is translated into assembly which our computer can read.



The compilation stage

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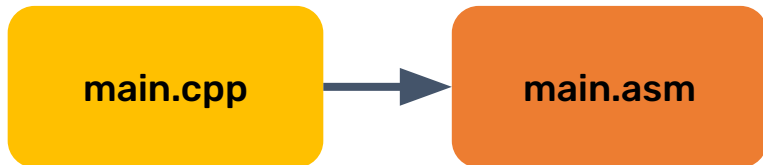
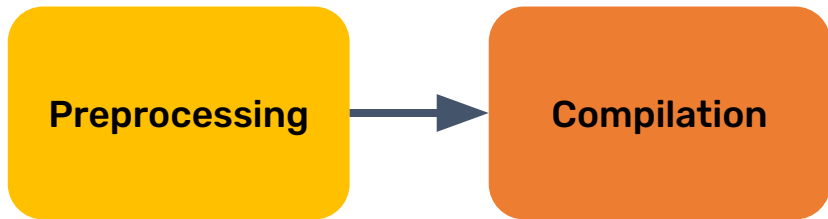
- C++ to assembly translation



The compilation stage

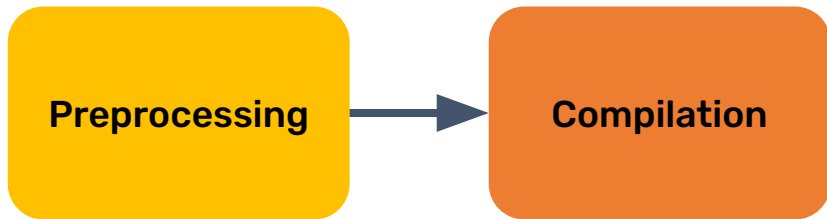
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- C++ to assembly translation
- If code is already in assembly, it is not translated

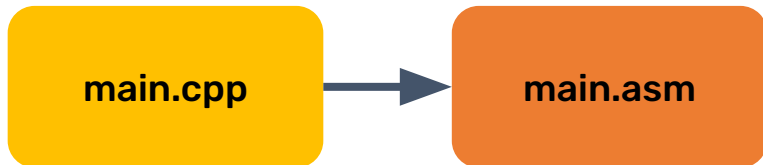


The compilation stage

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
- Assembly is oftentimes machine-specific.



The assembly stage



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The assembly stage

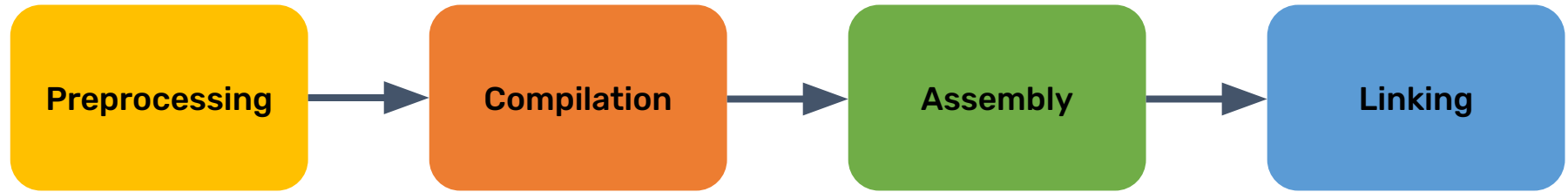


In the assembly stage the assembler converts assembly to object code!

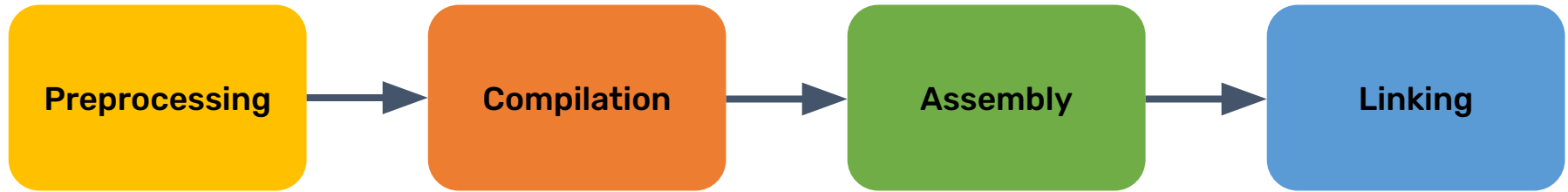
- Object code is actual machine readable code the processor can run.
- Assembly is the human-readable version of the object code



The linking stage

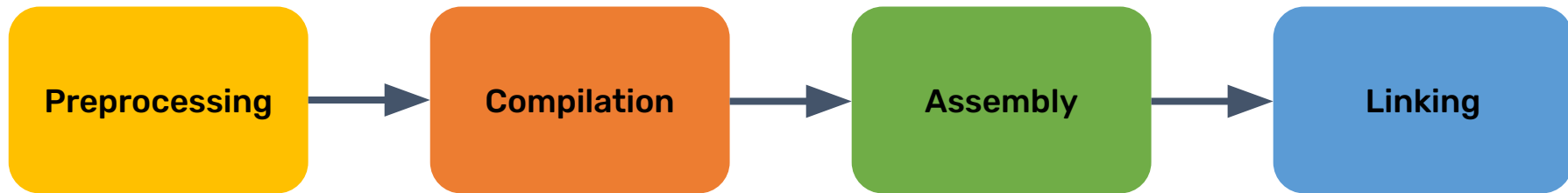


The linking stage



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

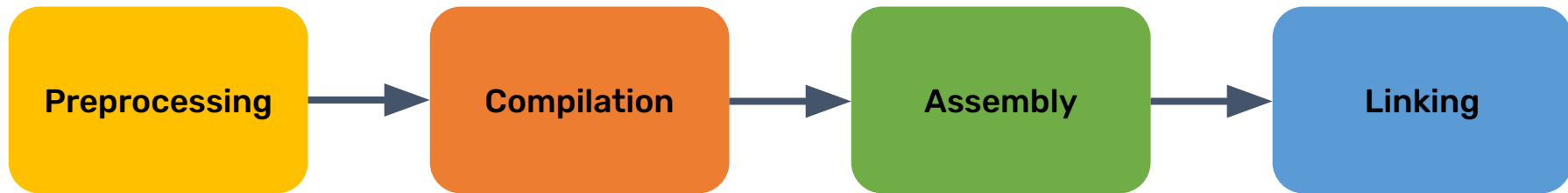
The linking stage



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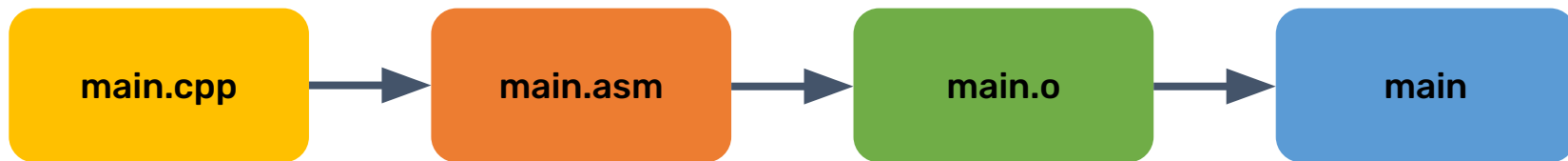
- Think about this stage as “stitching” things together

The linking stage

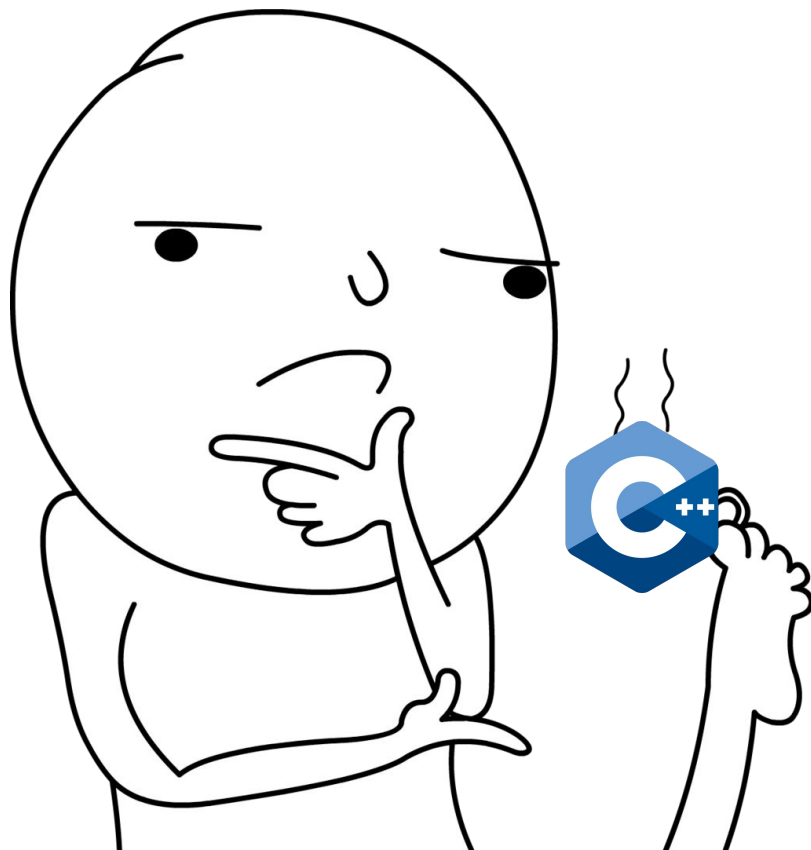


The linker takes each piece of object code and arranges it into one program

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



What questions do we have?



Makefiles and make

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

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

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!

Makefiles and make

```
TARGET = sh111

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

CPPFLAGS =
LIBS =

OBJJS = sh111.o
HEADERS =

all: $(TARGET)

$(OBJJS): $(HEADERS)

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

clean:
    rm -f $(TARGET) $(LIB) $(OBJJS) $(LIBOBJJS) *~ .*~ _test_data*

.PHONY: all clean starter
```


Makefiles and make

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```
all: $(TARGET)
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```
$(OBJS): $(HEADERS)
```

```
$(TARGET): $(OBJS)
```

```
$(CXX) -o $@ $(OBJS) $(LIBS)
```

Targets

```
$(TARGET) $(LIB)
```

Rules

```
*~ .*~ _test_data*
```

```
.PHONY: all clean starter
```

Flags

CMake

CMake is a build system generator.



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So you can use CMake to generate Makefiles



CMake

CMake is a build system generator.

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

Is like a higher level abstraction for Makefiles



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

CMake

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

If time

`gdb walkthrough`

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 do for example
- To build our own projects we can and should use Makefiles or another build system.
- gdb is useful for debugging C++, it has a bit of a learning curve but once you get it, it really 10Xs your development.

Last lecture

