



 <http://web.stanford.edu/class/cs106l/>



Special Topics

RAII, smart pointers, building projects, and more!

CS106L - Spring 23



Attendance!

<https://bit.ly/427hqhe>





Announcements!

- **This is our last real class!** Thursday's class will be extra office hours!
- Late days for assignments **are automatic** – no need to let us know if you're using them!
- For assignments, the general guideline for if it counts as completed is **if it runs**. Build errors result in no completion.



CONTENTS



01. RAII

A coding standard and practice

02. Smart Pointers

Putting SMFs to good use

03. Building C++ Projects

`./build_and_run.sh` ... what?





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Identifying code paths

How many code paths exist in this function?

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    if (p.favorite_food() == "chocolate" ||  
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**Code path: A single
run-through of the code that
the computer would see**

Let's consider each possibility!

Case 1: p doesn't like chocolate or milkshakes

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And now we're done!

TOTAL: 3

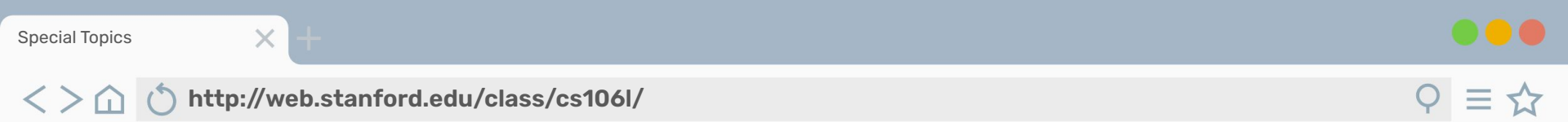
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...are we?

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When a function has an error, it can crash the program.



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However, we can write code to handle these to let us continue!

- This is “catching” the 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)  
}
```

Now, how many code paths do we see?

TOTAL: 3

What happens when a function throws an exception?

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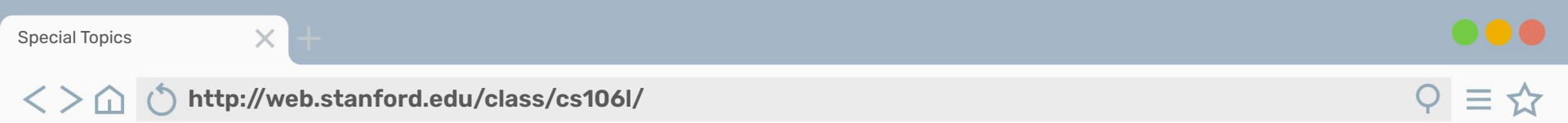
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- (1) copy constructor of Person parameter may throw
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- (10) operators may be user-overloaded, thus may throw
- (1) copy constructor of string for return value may throw



Takeaway

There are often more code paths than meet the eye!



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- Make sure to cover all possible paths in test cases for production code.



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There are often more code paths than meet the eye!

- Make sure to cover all possible paths in test cases for production code.
- Or, catch any errors that could create other potential paths!

What else could go wrong?

Thinking of exceptions, keep an eye out for anything else that could potentially go awry.

Do you see anything suspicious about this code?

```
string get_name_and_print_sweet_tooth(int id_number) {
    Person* p = new Person(id_number); // assume the constructor fills in variables
    if (p->favorite_food() == "chocolate" ||
        p->favorite_drink() == "milkshake") {
        cout << p->first() << " "
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    auto result = p->first() + " " + p->last();
    delete p;

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What else could go wrong?

What happens if an exception is thrown?

Can we guarantee that we won't leak memory?

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This problem isn't unique to pointers!

There are many resources that need to be returned after use:

	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>
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This problem isn't unique to pointers!

There are many resources that need to be returned after use:

**How do we guarantee
resources are returned
even in the event of
exceptions?**

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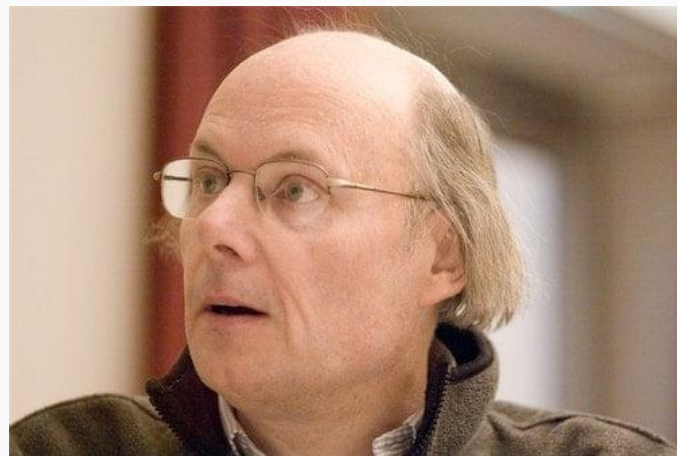
RAII: Resource Acquisition is Initialization

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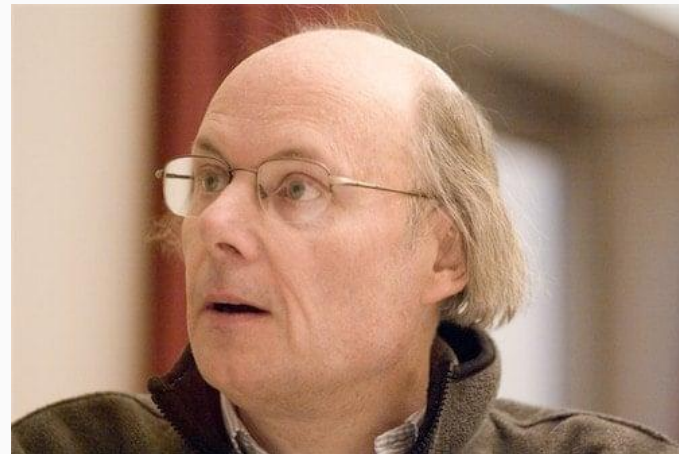
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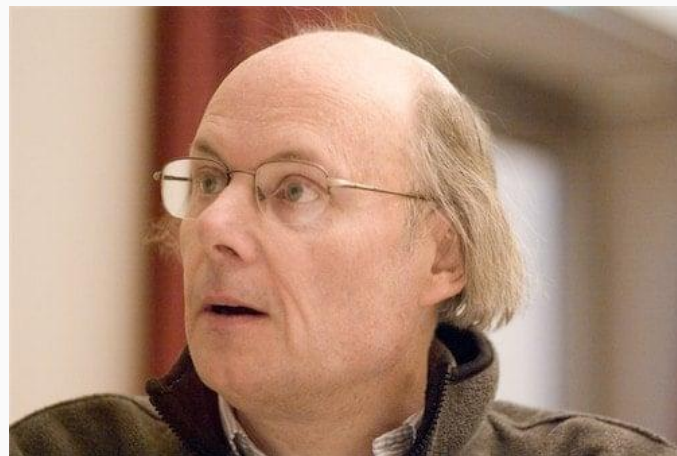


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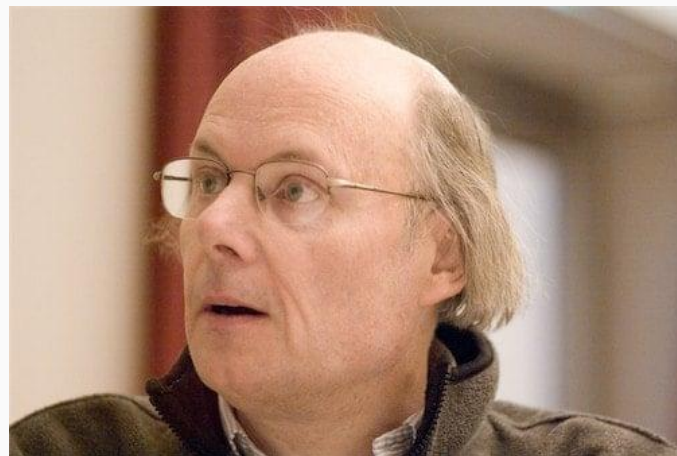


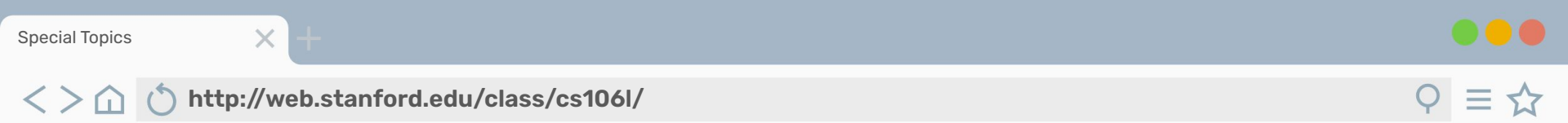
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In RAII:

- All resources used by a class should be acquired in the constructor
- All resources used by a class should be released in the destructor





Why RAI?

Why care about this?



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Why RAI?

Why care about this?

- Objects should be usable immediately after creation.
- There should never be a "half-valid" state of an object, where it exists in memory but is not accessible to/used by the program.
- The destructor is always called (when the object goes out of scope), so the resource is always freed!

Is this RAI-compliant?

You've seen this in 106B!

```
void printFile() {  
    ifstream input;  
    input.open("hamlet.txt");  
  
    string line;  
    while (getline(input, line)) { // might throw exception  
        cout << line << endl;  
    }  
  
    input.close();  
}
```

No!

The ifstream is not opened and closed in the constructor and destructor.

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void printFile() {  
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    input.close();  
}
```

Neither is a naked mutex!

Check out CS111 for more on what this is!

```
void cleanDatabase (mutex& databaseLock,  
                   map<int, int>& database) {  
    databaseLock.lock();  
  
    // other threads will not modify database  
    // modify the database  
    // if exception thrown, mutex never unlocked!  
  
    databaseLock.unlock();  
}
```

How do we fix it?

Let's implement a class whose entire job is to acquire the lock in the constructor and release it in the destructor.

```
void cleanDatabase (mutex& databaseLock,  
                    map<int, int>& database) {  
    lock_guard<mutex> lg(databaseLock);  
  
    // other threads will not modify database  
    // modify the database  
    // if exception thrown, mutex is unlocked!  
  
    // no need to unlock at end, as it's handle by the lock_guard  
}
```



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What about RAII for memory?

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.

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- These wrapper pointers are called “smart pointers.”



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 - Models temporary ownership: when an object only needs to be accessed if it exists (convert to `shared_ptr` to access)

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Weak pointers are observers of an object, not owners!



In practice

From this...

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

...to this!

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



Why can't we copy `unique_ptr`?

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`shared_ptr` gets around this for us by only deallocating memory when all of the `shared_ptr`s have gone out of scope.



Creating smart pointers...

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

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

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

**This is still explicitly
calling new!**

We can fix it!

```
std::unique_ptr<T> up{new T};  
std::unique_ptr<T> up = std::make_unique<T>();  
  
std::shared_ptr<T> sp{new T};  
std::shared_ptr<T> sp = std::make_shared<T>();  
  
std::weak_ptr<T> wp = sp;  
// can only be copy/move constructed (or empty)!
```



Which is better?

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



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Which is better?

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

- If we don't use `make_shared`, then we're allocating memory twice (once for `sp`, and once for `new T`)!
- We should be consistent across smart pointers – if we use `make_shared`, also use `make_unique`!



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`./build_and_run.sh` ... what?





Compilation Crash Course

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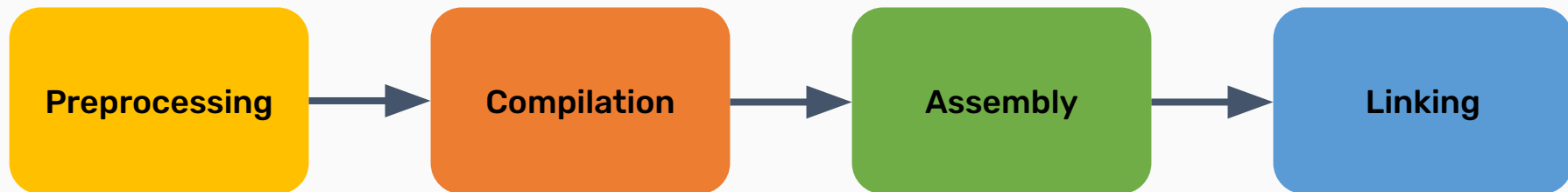
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A compiler is just any program that turns translates code from one language to another.

A common one for C++ to machine-readable code is g++!

Compilation Crash Course

There are four main stages in a compiler:



Preprocessing

During this stage, the code is cleaned up before compilation.

- Any preprocessor commands (starting with # in C++ and C) are handled.
- Comments and excess white space are stripped.

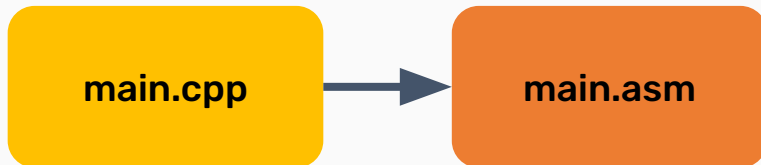
main.cpp

Compilation

This (weirdly named) stage involves the actual translation to assembly!

- Code written in C++ is converted to assembly code.
- Code originally written in assembly can stay the same!
- The assembly is specific to the machine's architecture.

At this point, the code is still human readable.



Assembly

Here, the assembler converts assembly to object code.

- Object code is the actual machine readable code (i.e binary) the processor runs.
- Assembly code is the human-readable equivalent, with mappings for these machine instructions to something we can understand.

The assembler converts each file/piece of the program individually; they are not yet combined properly into a program.

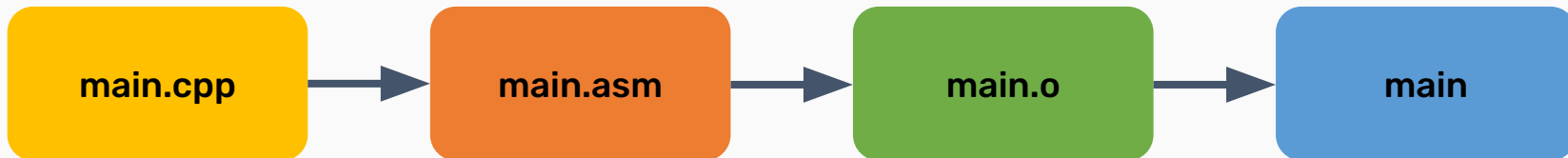


Linking

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

- Individual files are “stitched” together in order!
- Symbols are filled in so functions can be called and variables referenced across file boundaries.

We finally have an executable program!





What do make and Makefiles do?

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

- It uses `g++` as its main engine.
- It can be utilized by creating a configuration file known as a **Makefile**!
- Let's take a look at a simple **Makefile** to get some practice!

CS111 Example

```
TARGET = sh111

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

CPPFLAGS =
LIBS =

OBS = sh111.o
HEADERS =

all: $(TARGET)

$(OBS): $(HEADERS)

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

clean:
    rm -f $(TARGET) $(LIB) $(OBS) $(LIBOBS) *~ .*~ _test_data*

.PHONY: all clean starter
```

CS111 Example

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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)
```

Flags

Targets

Rules

```
$(TARGET) $(LIB) *~ .*~ _test_data*  
.PHONY: all clean starter
```



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If we have Makefiles already, why use cmake?

- cmake is a cross-platform make!
- make is a build system, and cmake creates entire build systems!
 - Another level of abstraction that takes in an even higher-level config file, ties in external libraries, and outputs a Makefile, which is then run.



Example cmake file

```
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)
```



Example cmake file (ours!)

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**Looks closer to a coding
language as we know it!**

Summary

- Exceptions are errors in your code at runtime that can crash the program if you don't catch them.
- RAII says you should only acquire dynamically allocated resources (like memory, locks, sockets, etc) in the constructor, and you should release them in the destructor.
 - This is what some STL classes do to handle memory using smart pointers!
- To build our own projects, we must go through compilation with either a Makefile or using another build system!



<http://web.stanford.edu/class/cs106l/>



Thanks!

Next up: End of the class! :(

