CMPT 373
Software Development Methods

A Crash Course in
(Some of) Modern C++

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With material from Bjarne Stroustrup & Herb Sutter
C++ *was* complicated/intimidating

- Pointers
  - Arithmetic & indexing
  - dangling
  - when to `new` and `delete`
C++ was complicated/intimidating

- Pointers
  - Arithmetic & indexing
  - dangling
  - when to new and delete

- Nontrivial types
  - inheritance
  - long names & scoping (iterators)
  - templates
C++ was complicated/intimidating

• Pointers
  – Arithmetic & indexing
  – dangling
  – when to `new` and `delete`

• Nontrivial types
  – inheritance
  – long names & scoping (iterators)
  – templates

• Many proposed rules (of varying validity)
  – Rule of 3
  – Don’t pass/return objects to/from functions by value
  – ...
Modern C++

- Significant effort has gone into revising C++ since C++03
  - Identifying & simplifying unnecessary complexity
  - Adopting features that help reduce complexity in large scale projects.
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- Safety
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- Syntactic sugar (with safety benefits)
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• Syntactic sugar (with safety benefits)

• Now developed under a lightweight process with new revisions every ~3 years.
Managing Object Lifetimes

Suppose I have a *Widget* class constructed from an `int` and a string.
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- How might I create one?
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Widget w{0, "fritter"};
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Brace initialization is new in C++11
Suppose I have a `Widget` class constructed from an `int` and a string.

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```cpp
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```

Where does `w` live in memory? Is that good/bad?
Managing Object Lifetimes

Suppose I have a `Widget` class constructed from an `int` and a string.

- How might I create one?

  ```
  Widget w{0, "fritter"};
  ```

  - Automatic variables/management should be the default.
Managing Object Lifetimes

Suppose I have a `Widget` class constructed from an `int` and a string.

- How might I create one?
  ```
  Widget w{0, "fritter"};
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- What about creating one on the heap?
Managing Object Lifetimes

Suppose I have a `Widget` class constructed from an `int` and a string.

- How might I create one?
  
  ```
  Widget w{0, "fritter"};
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  - Automatic variables/management should be the default.

- What about creating one on the heap?

  ```
  Old: Widget* w = new Widget{0, "fritter"};
  ```
Managing Object Lifetimes

Suppose I have a \texttt{Widget} class constructed from an \texttt{int} and a string.

- How might I create one?

  - Automatic variables/management should be the default.

- What about creating one on the heap?

  Old: \texttt{Widget* w = new Widget\{0, "fritter"\};}

  What problems does this create?
Managing Object Lifetimes

Suppose I have a *Widget* class constructed from an *int* and a string.

- **How might I create one?**

  ```
  Widget w{0, "fritter"};
  ```

  - Automatic variables/management should be the default.

- **What about creating one on the heap?**

  ```
  Old: Widget* w = new Widget{0, "fritter"};
  ```

  - Need to delete everything.
  - Need to delete everything only once.
  - Complex object graphs make this harder.
Managing Object Lifetimes

Object graphs/lifetimes are complex
Managing Object Lifetimes

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Which pointers can I delete & when?
Managing Object Lifetimes

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- Are there any downsides to doing so?
  - Unclear?
  - Unnecessary overheads?
  - Mismatched lifetimes?
Managing Object Lifetimes

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- Could this problem be solved using only `std::vector`?
- Are there any downsides to doing so?
  - Unclear?
  - Unnecessary overheads?
  - Mismatched lifetimes?

What we want is a clear, intentional way to express **ownership**.
Managing Object Lifetimes

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  - Unique ownership (`std::unique_ptr<T>`)
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  - Unique ownership (`std::unique_ptr<T>`)  
    ```cpp
    auto w = std::make_unique<Widget>(0, "cruller");
    ```
    - deletes the object when `w` goes out of scope
    - Automated (even with exceptions)
Managing Object Lifetimes

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  - Unique ownership (`std::unique_ptr<T>`)  
    ```
    auto w = std::make_unique<Widget>(0, "cruller");
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    - deletes the object when `w` goes out of scope
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    - Generally preferred
Managing Object Lifetimes

- **2 types of ownership in modern C++**
  - **Unique ownership** (`std::unique_ptr<T>`)
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    auto w = std::make_unique<Widget>(0, "cruller");
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    - Deletes the object when `w` goes out of scope
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  - **Shared ownership** (`std::shared_ptr<T>`)  
    ```cpp
    auto w = std::make_shared<Widget>(0, "ponchik");
    ```
Managing Object Lifetimes

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  - Unique ownership (std::unique_ptr<T>)
    ```cpp
    auto w = std::make_unique<Widget>(0, "cruller");
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    - deletes the object when w goes out of scope
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    - Generally preferred

  - Shared ownership (std::shared_ptr<T>)
    ```cpp
    auto w = std::make_shared<Widget>(0, "ponchik");
    ```
    - Counts the number of owners
    - delete the object when # owners --> 0
Managing Object Lifetimes

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  - Unique ownership (`std::unique_ptr<T>`)  
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    auto w = std::make_unique<Widget>(0, "cruller");
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    auto w = std::make_shared<Widget>(0, "ponchik");
    ```
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What happens if you have a cycle?
Managing Object Lifetimes

• 2 types of ownership in modern C++
  
  – Unique ownership (`std::unique_ptr<T>`)  
    ```
    auto w = std::make_unique<Widget>(0, "cruller");
    ```
    • **deletes the object when `w` goes out of scope**
    • Automated (even with exceptions)
    • Generally preferred

  – Shared ownership (`std::shared_ptr<T>`)  
    ```
    auto w = std::make_shared<Widget>(0, "ponchik");
    ```
    • Counts the number of owners
    • **deletes the object when # owners --> 0**

• **Ownership can also be transferred**
Managing Object Lifetimes

- A few rules:
  - Every object has (preferably) one owner
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  - Non-owning pointers/references can be unlimited
    - But should not outlive the owning scope by design
Managing Object Lifetimes

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  - Every object has (preferably) one owner
  - No object outlives the scope of its owning pointer
  - Non-owning pointers/references can be unlimited
    - But should not outlive the owning scope by design

Note: Unique owning pointers form a spanning tree within the heap.
Functions (a slight digression)

What is the signature to...

- pass an argument of class type X to a function?
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```cpp
foo(const X&)
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- pass an argument of class type \( X \) to a function?
  
  \[
  \text{foo(const } X&)\]

- pass a \textit{mutable} argument of class type \( X \) to a function?
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  \texttt{foo(X\&)}
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  \text{foo(const X&)}
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- pass a \textit{mutable} argument of class type \(X\) to a function?
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  \text{foo(X&)}
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- pass an instance of \(X\) to a function making a copy?
Functions (a slight digression)

What is the signature to...

- pass an argument of class type X to a function?
  
  \texttt{foo(const X&)}

- pass a \textit{mutable} argument of class type X to a function?
  
  \texttt{foo(X&)}

- pass an instance of X to a function making a copy?
  
  \texttt{foo(X)}
Using What You Know

```cpp
void foo();
void bar() {
    auto w = std::make_unique<Widget>(42, "churro");
    foo();
}
```

- What should go in 1 and 2 to pass w to foo?
  - (It may depend on what you want to do...)
General Resource Management

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  - Properly acquiring & releasing resources
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    - No double acquisition.
    - No double free.
    - No use after free.
    - No leaks
General Resource Management

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  - What *other* resources do you manage?
General Resource Management

- Memory management is just one example of resource management.
  - Properly acquiring & releasing resources
    - No double acquisition.
    - No double free.
    - No use after free.
    - No leaks
  - What other resources do you manage?
    - Files
    - Locks
    - Database connections
    - Printers
    - ...

General Resource Management

- The problem is pervasive enough to have general solutions
  - Python: with
  - C#: using
  - Java: try-with-resources
  - C++: RAlI (Resource Acquisition is Initialization)
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- **Goal:** Simplify & control the lifetimes of resources
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  - Python: `with`
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- RAII
  - Bind the lifetime of the resource to object lifetime
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  - Python: `with`
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- RAII
  - Bind the lifetime of the resource to object lifetime
  - Acquire the resource in the constructor
General Resource Management

- The problem is pervasive enough to have general solutions
  - Python: `with`
  - C#: `using`
  - Java: `try-with-resources`
  - C++: RAIi (Resource Acquisition is Initialization)
- Goal: Simplify & control the lifetimes of resources
- RAIi
  - Bind the lifetime of the resource to object lifetime
  - Acquire the resource in the constructor
  - Release the resource in the destructor
General Resource Management

- Memory

```cpp
void memoryResource() {
    auto w = std::make_unique<Widget>(3, "bofrot");
    foo(*w);
}
```
General Resource Management

- Memory

```cpp
void memoryResource() {
    auto w = std::make_unique<Widget>(3, "bofrot");
    foo(*w);
}
```

`w` is automatically deallocated here.
General Resource Management

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void memoryResource() {
    auto w = std::make_unique<Widget>(3, "bofrot");
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w is automatically deallocated here.

- Files

```cpp
void fileResource() {
    auto out = std::ofstream{"output.txt"};
    out << "Boston cream\n";
}
```
General Resource Management

- Memory

```cpp
void memoryResource() {
    auto w = std::make_unique<Widget>(3, "bofrot");
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}
```

w is automatically deallocated here.

- Files

```cpp
void fileResource() {
    auto out = std::ofstream{"output.txt"};
    out << "Boston cream\n";
}
```

out is automatically flushed & closed here.
General Resource Management

- **Memory**

```cpp
void memoryResource() {
    auto w = std::make_unique<Widget>(3, "bofrot");
    foo(*w);
}
```

- **Files**

```cpp
void fileResource() {
    auto out = std::ofstream{"output.txt"};
    out << "Boston cream\n";
}
```

- Because they are scoped, they handle exceptions & multiple return statements!
General Resource Management

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General Resource Management

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  - In many cases, it is explicitly forbidden

Why?
General Resource Management

- NOTE: What happens when you *copy* a resource object?
  - In many cases, it is explicitly forbidden
  - You can use `std::move()` to *transfer* resource ownership
Operating on Collections

- Iterating over collections can be painful

```cpp
void oops() {
    std::vector<int> numbers = {0, 1, 2, 3, 4};
    for (unsigned i = 0, e = 4; i <= 4; ++i) {
        std::cout << numbers[i] << "\n";
    }
}
```
Operating on Collections

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    std::vector<int> numbers = {0, 1, 2, 3, 4};
    for (unsigned i = 0, e = 4; i <= 4; ++i) {
        std::cout << numbers[i] << "\n";
    }
}
```

- Range based for loops are preferable

```cpp
void nice() {
    std::vector<int> numbers = {0, 1, 2, 3, 4};
    for (auto number : numbers) {
        std::cout << number << "\n";
    }
}
```
Operating on Collections

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void oops() {
    std::vector<int> numbers = {0, 1, 2, 3, 4};
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```cpp
void nice() {
    std::vector<int> numbers = {0, 1, 2, 3, 4};
    for (auto number : numbers) {
        std::cout << number << "\n";
    }
}
```

The collection can be anything with `begin()` and `end()` methods.
Operating on Collections

- Passing collections around can be error prone.

```cpp
void oops(const std::vector<int> numbers) {
    ...
}
```
Operating on Collections

- Passing collections around can be error prone.

```cpp
void oops(const std::vector<int> numbers) {
    ...
}
```

- Avoid unnecessary copies.

```cpp
void better(const std::vector<int>& numbers) {
    ...
}
```
Operating on Collections

• Passing collections around can be error prone.

```cpp
void oops(const std::vector<int> numbers) {
    ...
}
```

• Avoid unnecessary copies.

```cpp
void better(const std::vector<int>& numbers) {
    ...
}
```

• Use the Guideline Support Library for flexibility & correctness by design

```cpp
void good(const gsl::span<int> numbers) {
    ...
}
```
Guideline Support Library

Some common classes for better code, specifically:
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- `gsl::span<T>`
  - Makes interfaces generic & safer

[demo]
Guideline Support Library

Some common classes for better code, specifically:

- `gsl::span<T>`
  - Makes interfaces generic & safer
    [demo]

- `gsl::string_span<T>`
  - Avoid copying strings
  - Avoid conversions to and from C strings (a common mistake!)
Guideline Support Library

Some common classes for better code, specifically:

- `gsl::span<T>`
  - Makes interfaces generic & safer

- `gsl::string_span<T>`
  - Avoid copying strings
  - Avoid conversions to and from C strings
    (a common mistake!)

- Both of these abstractions are *non*-owning
How should you check whether a list contains a number greater than 3?

```cpp
bool hasGreaterThan3 = false;
for (auto number : numbers) {
    if (number > 3) {
        hasGreaterThan3 = true;
    }
}
```
How should you check whether a list contains a number greater than 3?

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Using a general purpose loop hides the high level intentions.
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```

Using a general purpose loop hides the high level intentions.

```cpp
bool hasGreaterThan3 = 
    std::any_of(numbers.begin(), numbers.end(),
               [](auto number) { return number > 3; });
```
λ (Lambdas)

- Lambdas allow you to create small, self contained functions local to other code

```cpp
[local1, &local2](auto arg1, auto arg2) {
    ...
}
```
Lambdas allow you to create small, self contained functions local to other code.

You can capture arguments from the local scope.

\[
[\text{local1}, \ &\text{local2}](\text{auto arg1, auto arg2})\ 
\]

\[
\ldots
\]

\[
}\]

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\text{You can capture arguments from the local scope.}
\]
Lambdas allow you to create small, self contained functions local to other code:

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[local1, &local2](auto arg1, auto arg2) {
    ... 
}
```

Additional arguments are passed in when invoked.
λ (Lambdas)

- Lambdas allow you to create small, self contained functions local to other code:

  ```c++
  [local1, &local2](auto arg1, auto arg2) {
    ...
  }
  ```

- Lambdas allow you to use generic library functions in a clear, well localized fashion.

```c++
auto found =
  std::find_if(numbers.begin(), numbers.end(),
               [](auto number) { return number > 3; });
std::cout << *found << " is greater than 3.\n";
```
λ (Lambdas)

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  ```cpp
  [local1, &local2](auto arg1, auto arg2) {
    ...
  }
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- Lambdas allow you to use generic library functions in a clear, well localized fashion.

```cpp
class with_member
{
  void print() { std::cout << number; }
};
```

```cpp
auto found =
    std::find_if(numbers.begin(), numbers.end(), [] (auto number) { return number > 3; });
std::cout << *found << " is greater than 3.\n";
See <algorithm>
```
Exceptions

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- **Can use existing exception types** `<stdexcept>`
Exceptions

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```cpp
try {
    throw std::runtime_error("uh oh...");
} catch (const std::runtime_error& e) {
    std::cout << "Exception message: " << e.what();
}
```
Exceptions

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try {
    throw std::runtime_error("uh oh...");
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}
```

Throw by value.
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try {
    throw std::runtime_error("uh oh...");
} catch (const std::runtime_error& e) {
    std::cout << "Exception message: " << e.what();
}
```

*Catch by reference.*
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try {
    throw std::runtime_error("uh oh...");
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}
```

Error messages.
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```cpp
class MyException : public std::runtime_error {
public:
    const char * what() const override {
        ...
    }
};
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More...

- `std::array<T,N>`
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- `std::array<T,N>`
- `nullptr`
- `auto` (even for return & lambda arg types)
- `constexpr`
- type safe enums
- delegating constructors
- ...