CMPT 373
Software Development Methods

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

Nick Sumner
wsumner@sfu.ca

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
  - types, bounds, lifetimes
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- Safety
  - types, bounds, lifetimes
- Syntactic sugar (with safety benefits)
- Now developed under a lightweight process with new revisions every ~3 years.
Modern C++

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- Safety
  - types, bounds, lifetimes
- Syntactic sugar (with safety benefits)

To get you (re)acquainted, we will explore some of modern C++ for now.

I will assume familiarity with older C++, constructors, destructors, etc.
Managing Object Lifetimes

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

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- How might I create one?
Managing Object Lifetimes

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```cpp
Widget w{0, "fritter"};
```
Suppose I have a **Widget** class constructed from an **int** and a string.

- How might I create one?

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

Brace initialization was new in C++11
Managing Object Lifetimes

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

- How might I create one?

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

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"};
  ```
  
  - Automatic variables/management should be the default.

- 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"};
  ```

  - 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 **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"};
  ```

  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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Managing Object Lifetimes

Object graphs/lifetimes are complex

Stack

Which pointers can I delete & when?
Managing Object Lifetimes

Object graphs/lifetimes are complex

Which pointers can I delete & when?
Managing Object Lifetimes (*Tangent*)

Object graphs/lifetimes are complex

When you *use* a data structure, do you usually worry about these?
Managing Object Lifetimes (Tangent)

```cpp
{ 
    std::vector<Widget> widgets
    widgets.emplace_back(3, "Fritter");
    widgets.emplace_back(2, "Double chocolate");
    widgets.emplace_back(3, "Maple Cream");
}
```
Managing Object Lifetimes (*Tangent*)

```cpp
{  
    std::vector<Widget> widgets
    widgets.emplace_back(3, "Fritter");
    widgets.emplace_back(2, "Double chocolate");
    widgets.emplace_back(3, "Maple Cream");
}
```
Managing Object Lifetimes (Tangent)

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std::vector<Widget> widgets
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std::vector<Widget> widgets
widgets.emplace_back(3, "Fritter");
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widgets.emplace_back(3, "Maple Cream");
```

Stack

![Diagram of a stack with items 3, Frit and 2, Doub]
Managing Object Lifetimes (*Tangent*)

```cpp
std::vector<Widget> widgets
widgets.emplace_back(3, "Fritter");
widgets.emplace_back(2, "Double chocolate");
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```
Managing Object Lifetimes (Tangent)

```cpp
std::vector<Widget> widgets
widgets.emplace_back(3, "Fritter");
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```

Stack
Managing Object Lifetimes (Revisiting)

Object graphs/lifetimes are complex

- Could this problem be solved using only `std::vector`?
Managing Object Lifetimes

Object graphs/lifetimes are complex

- Could this problem be solved using only \texttt{std::vector}?

In a few different ways...
Managing Object Lifetimes

Object graphs/lifetimes are complex

- Could this problem be solved using only `std::vector`?
Managing Object Lifetimes

Object graphs/lifetimes are complex

- Could this problem be solved using only `std::vector`?

Could instead have a, b, c, d be vectors of 1 element.
Managing Object Lifetimes

Object graphs/lifetimes are complex

- Could this problem be solved using only `std::vector`?
- Are there any downsides to doing so?
Managing Object Lifetimes

Object graphs/lifetimes are complex

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

Object graphs/lifetimes are complex

- 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

- 2 types of ownership in modern C++
2 types of ownership in modern C++

- Unique ownership (`std::unique_ptr<T>`)
Managing Object Lifetimes

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

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

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

You can think of this as a vector of 1 item
Managing Object Lifetimes

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  - Unique ownership (`std::unique_ptr<T>`)  
    ```
    auto w = std::make_unique<Widget>(0, "cruller");
    ```
    - `delete` 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");
    ```
Managing Object Lifetimes

- 2 types of ownership in modern C++
  - Unique ownership (`std::unique_ptr<T>`)  
    ```c++
    auto w = std::make_unique<Widget>(0, "cruller");
    ```
    - `delete` the object when `w` goes out of scope
    - Automated (even with exceptions)
    - Generally preferred
  - Shared ownership (`std::shared_ptr<T>`)  
    ```c++
    auto w = std::make_shared<Widget>(0, "ponchik");
    ```
    - Counts the number of owners
    - `delete` the object when # owners --> 0
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
    - `delete`-s the object when # owners --> 0

What happens if you have a cycle?
Managing Object Lifetimes

- 2 types of ownership in modern C++
  - Unique ownership (`std::unique_ptr<T>`)  
    ```cpp
    auto w = std::make_unique<Widget>(0, "cruller");
    ```  
    - `delete` the object when `w` goes out of scope  
    - Automated (even with exceptions)  
    - Generally preferred  
  - Shared ownership (`std::shared_ptr<T>`)  
    ```cpp
    auto w = std::make_shared<Widget>(0, "ponchik");
    ```  
    - Counts the number of owners  
    - `delete`s the object when # owners --> 0  

- Ownership can also be transferred
Managing Object Lifetimes

- A few rules:
  - Every object has (preferably) one owner
Managing Object Lifetimes

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Managing Object Lifetimes

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  - No object outlives the scope of its owning pointer
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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
Managing Object Lifetimes

- A few rules:
  - 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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  \texttt{foo(const X&)}
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  \[
  \text{foo(const X&)}
  \]

- pass a \textit{mutable} argument of class type X to a function?
Functions (a slight digression)

What is the signature to...

• 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?
  \[
  \text{foo(X&)}
  \]
Functions (a slight digression)

What is the signature to...

- pass an argument of class type X to a function?
  
  ```
  foo(const X&)
  ```

- pass a `mutable` argument of class type X to a function?
  
  ```
  foo(X&)
  ```

- pass an instance of X to a function making a copy?
  
  ```
  foo(X&)
  ```
Functions (a slight digression)

What is the signature to...

- 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?
  \[ \text{foo(X&)} \]

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

- What should go in 1 and 2 to pass `w` to `foo`?
  - (It may depend on what you want to do...)
  - Do you just want to give `foo` access to the Widget?
  - Do you want `foo` to modify the ownership?
  - Do you want to transfer ownership to `foo`?

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

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...)
  – Do you just want to give `foo` `access` to the Widget?
  – Do you want `foo` to `modify` the ownership?
  – Do you want to `transfer` ownership to `foo`?

Note: These are behaviors that would already happen. 
`Smart pointers` make them `explicit` and `automatic`. 
• Memory management is just one example of resource management.
General Resource Management

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  - Properly acquiring & releasing resources
General Resource Management

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  - Properly acquiring & releasing resources
    - 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
General Resource Management

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  - Python: ?
General Resource Management

- The problem is pervasive enough to have general solutions
  - Python: `with`
General Resource Management

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  - Python: `with`
  - C#: `using`
  - Java: `try-with-resources`
The problem is pervasive enough to have general solutions

- Python: `with`
- C#: `using`
- Java: `try-with-resources`
- C++: ?
General Resource Management

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  - Python: `with`
  - C#: `using`
  - Java: `try-with-resources`
  - C++: RAIi (`Resource Acquisition is Initialization`)
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
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
General Resource Management

- The problem is pervasive enough to have general solutions
  - Python: `with`
  - C#: `using`
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  - 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
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);
}
```
void memoryResource() {
    auto w = std::make_unique<Widget>(3, "bofrot");
    foo(*w);
}

w is automatically deallocated here.
General Resource Management

- Memory

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

*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");
    foo(*w);
}
```

_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);
}
```

`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.

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

- How does RAII relate to managing complexity?
General Resource Management

• How does RAII relate to managing complexity?
  – It makes resource designs explicit
  – It makes managing them automatic
  – It removes temporal coupling
  – It promotes composition & independence
General Resource Management

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• NOTE: What happens when you copy a resource object?
General Resource Management

- How does RAII relate to managing complexity?
  - It makes resource designs explicit
  - It makes managing them automatic
  - It removes temporal coupling
  - It promotes composition & independence

- **NOTE:** What happens when you copy a resource object?
  - In many cases, it is explicitly forbidden

**Why?**
General Resource Management

• How does RAII relate to managing complexity?
  – It makes resource designs explicit
  – It makes managing them automatic
  – It removes temporal coupling
  – It promotes composition & independence

• 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 numbers = {0, 1, 2, 3, 4};
    for (unsigned i = 0, e = 4; i <= 4; ++i) {
        std::cout << numbers[i] << \n;
    }
}
```
Operating on Collections

- Iterating over collections can be painful

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

- Iterating over collections can be painful

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

- Range based for loops are preferable

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

The “collection” can be anything with `begin()` and `end()` methods.
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 `std::span` in C++20 for flexibility & correctness by design

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

Some common classes for better code, specifically:
Guideline Support Library

Some common classes for better code, specifically:

- `std::span<T>`, `gsl::span<T>`
  - Makes interfaces generic & safer if you do not have C++20

[demo]
Guideline Support Library

Some common classes for better code, specifically:

- **std::span<T>, gsl::span<T>**
  - Makes interfaces generic & safer if you do not have C++20
    [demo]

- **std::string_view<T>**
  - Avoid copying strings
  - Avoid conversions to and from C strings (a common mistake!)
Guideline Support Library

Some common classes for better code, specifically:

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

- `std::string_view<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?
λ (Lambdas)

- 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?

```cpp
bool hasGreaterThan3 = false;
for (auto number : numbers) {
    if (number > 3) {
        hasGreaterThan3 = true;
    }
}
```

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

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; });
```
How should you check whether a list contains a number greater than 3?

```
bool hasGreaterThan3 = false;
for (auto number : numbers) {
    if (number > 3) {
        hasGreaterThan3 = true;
    }
}
```

Using a general purpose loop hides the high level intentions.

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

In C++20:

```
bool hasGreaterThan3 = 
    std::ranges::any_of(numbers,
                [](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

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

You can capture arguments from the local scope.
λ (Lambdas)

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

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

Additional arguments are passed in when invoked.
Lambdas allow you to create small, self contained functions local to other code:

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

Lambdas allow you to use generic library functions in a clear, well localized fashion.
**λ (Lambdas)**

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

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

```
auto found =
    std::ranges::find_if(numbers,
        [](auto number) { return number > 3; });
std::cout << *found << " is greater than 3.\n";
```
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 use generic library functions in a clear, well localized fashion.

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auto found =
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See `<algorithm>`
λ (Lambdas)

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

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    // I will expect you to make use of built in algorithms and lambdas instead of raw loops from now on.
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Exceptions

- Not new, but maybe new to you in C++
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```cpp
try {
    throw std::runtime_error("uh oh...");
} catch (const std::runtime_error& e) {
    std::cout << "Exception message: " << e.what();
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} catch (const std::runtime_error& e) {
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}
```

Throw by value.
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```cpp
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    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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} catch (const std::runtime_error& e) {
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Error messages.
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- Or you can create custom exceptions
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    const char * what() const override {
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- ...  

And these are from almost a decade ago.