CS106L Lecture 13: Operator Overloading ➕

Fabio Ibanez, Jacob Roberts-Baca

Attendance

https://tinyurl.com/OperatorsS25

Today's Agenda

1. Recap
2. Operator Overloading

Today's Agenda

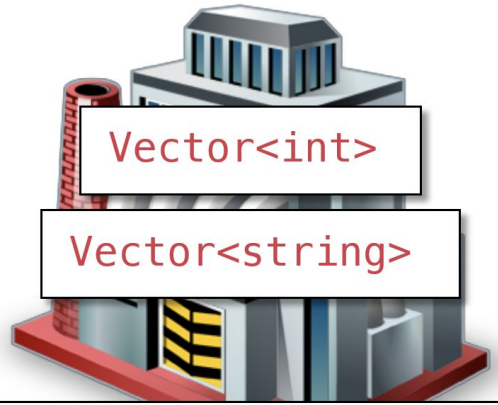
1. **Recap**
2. Operator Overloading

Template Classes

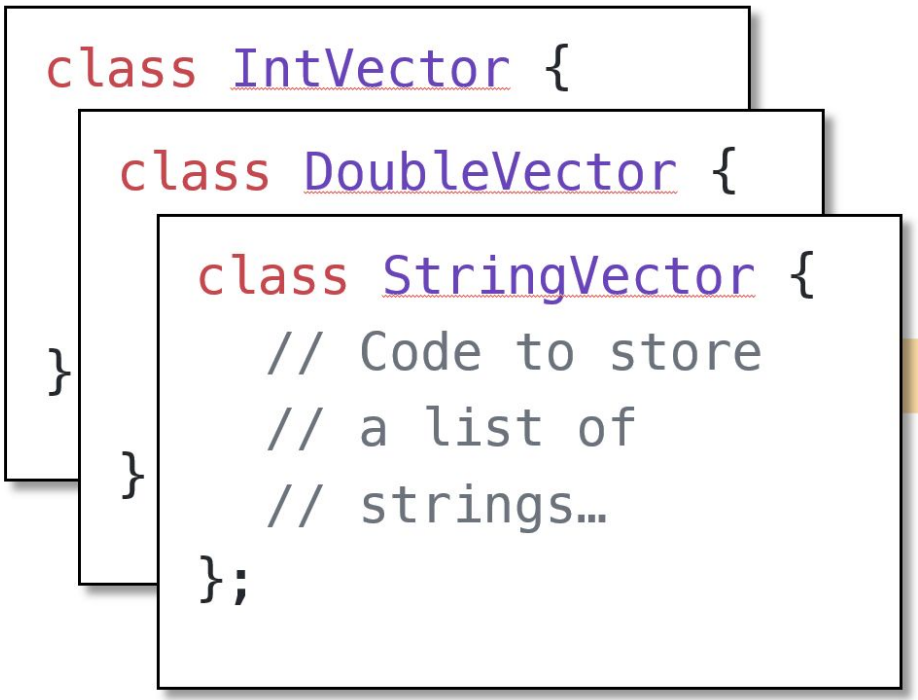
A template is like a factory

`int`

`string`



Template Classes

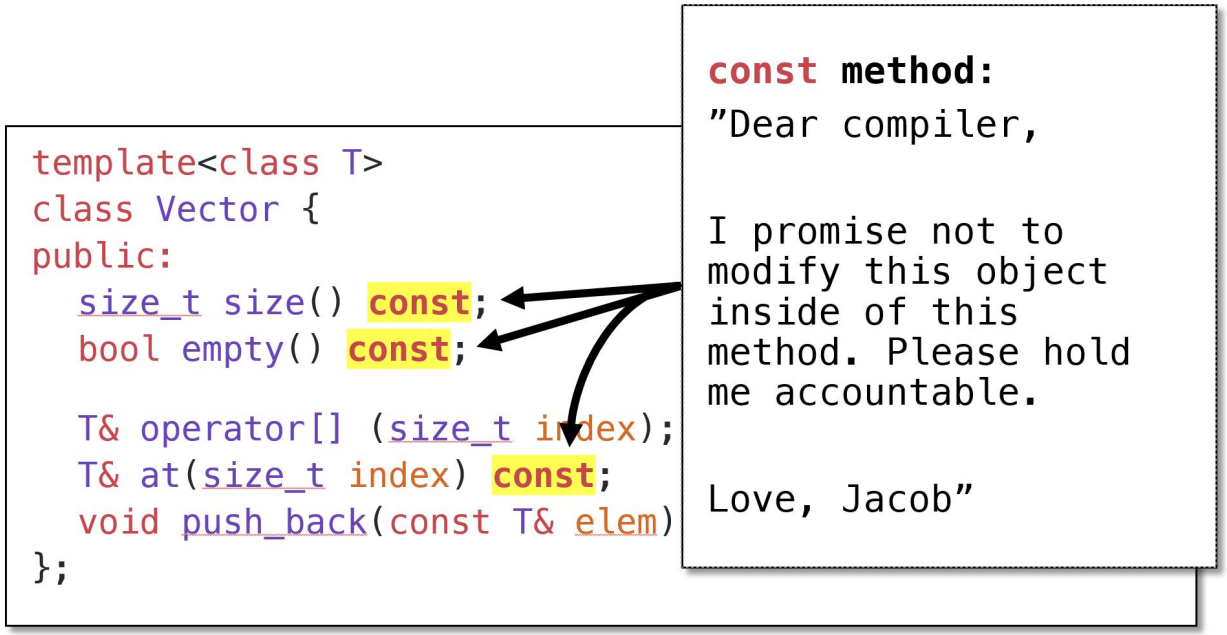



```
template <typename T>
class vector {
  // So satisfying.
};

vector<int> v1;
vector<double> v2;
vector<string> v3;
```

Const Correctness

A **contract** between the class designer and C++ programs.



Functors

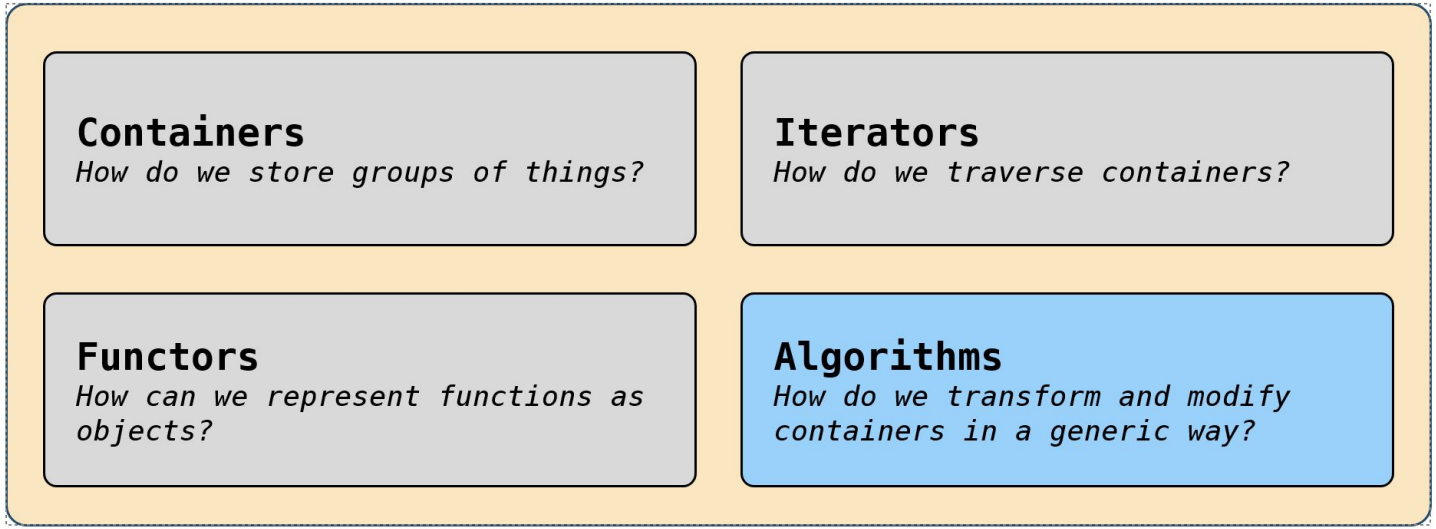
Containers
How do we store groups of things?

Iterators
How do we traverse containers?

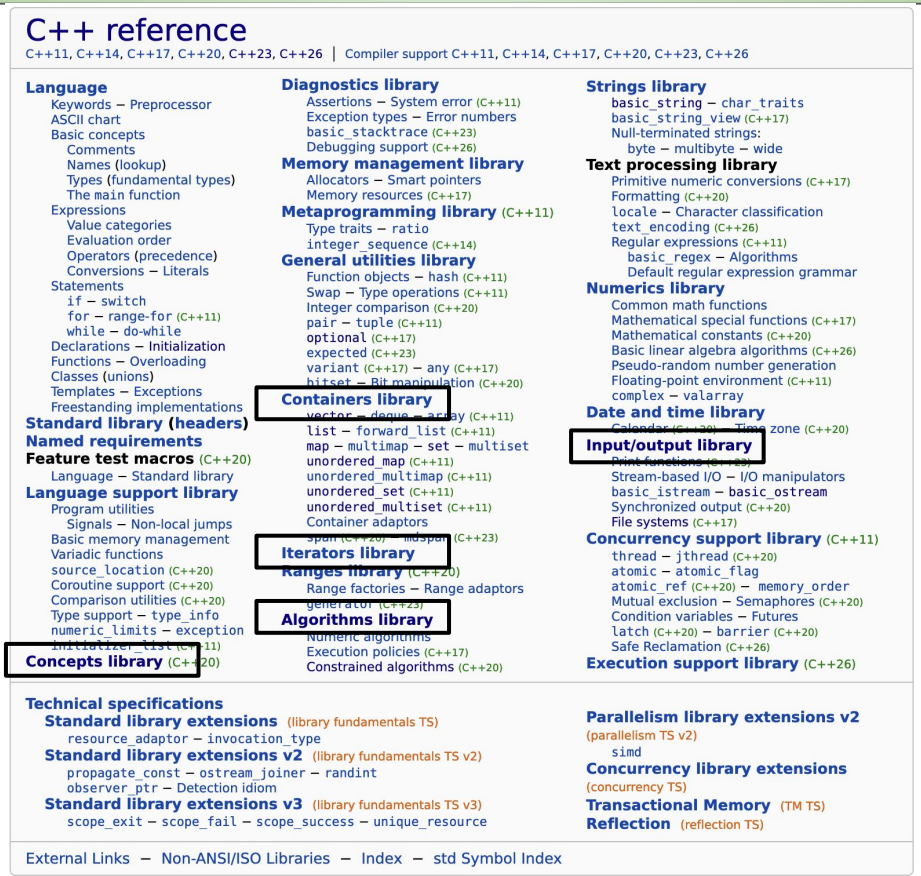
Functors
How can we represent functions as objects?

Algorithms
How do we transform and modify containers in a generic way?

Algorithms


Containers
How do we store groups of things?
Iterators
How do we traverse containers?
Functors
How can we represent functions as objects?
Algorithms
How do we transform and modify containers in a generic way?

It’s week 6!



C++ reference

C++11, C++14, C++17, C++20, C++23, C++26 | Compiler support C++11, C++14, C++17, C++20, C++23, C++26

Language
- Keywords — Preprocessor
- ASCII chart
- Basic concepts
  - Comments
  - Names (lookup)
  - Types (fundamental types)
  - The main function
- Expressions
  - Value categories
  - Evaluation order
  - Operators (precedence)
  - Conversions — Literals
- Statements
  - if — switch
  - for — range-for (C++11)
  - while — do-while
- Declarations — Initialization
- Functions — Overloading
- Classes (unions)
- Templates — Exceptions
- Freestanding implementations

Standard library (headers)

Named requirements

Feature test macros (C++20)
- Language — Standard library

Language support library
- Program utilities
  - Signals — Non-local jumps
- Basic memory management
- Variadic functions
- source_location (C++20)
- Coroutine support (C++20)
- Comparison utilities (C++20)
- Type support — type_info
- numeric_limits — exception
- initializer_list (C++11)

Concepts library (C++20)

Diagnostics library
- Assertions — System error (C++11)
- Exception types — Error numbers
- basic_stacktrace (C++23)
- Debugging support (C++26)

Memory management library
- Allocators — Smart pointers
- Memory resources (C++17)

Metaprogramming library (C++11)
- Type traits — ratio
- integer_sequence (C++14)

General utilities library
- Function objects — hash (C++11)
- Swap — Type operations (C++11)
- Integer comparison (C++20)
- pair — tuple (C++11)
- optional (C++17)
- expected (C++23)
- variant (C++17) — any (C++17)
- bitset — Bit manipulation (C++20)

Containers library
- vector — deque — array (C++11)
- list — forward_list (C++11)
- map — multimap — set — multiset
- unordered_map (C++11)
- unordered_multimap (C++11)
- unordered_set (C++11)
- unordered_multiset (C++11)
- Container adaptors
- span (C++20) — mdspan (C++23)

Iterators library

Ranges library (C++20)
- Range factories — Range adaptors
- generator (C++23)

Algorithms library
- Numeric algorithms
- Execution policies (C++17)
- Constrained algorithms (C++20)

Strings library
- basic_string — char_traits
- basic_string_view (C++17)
- Null-terminated strings:
  - byte — multibyte — wide

Text processing library
- Primitive numeric conversions (C++17)
- Formatting (C++20)
- locale — Character classification
- text_encoding (C++26)
- Regular expressions (C++11)
  - basic_regex — Algorithms
  - Default regular expression grammar

Numerics library
- Common math functions
- Mathematical special functions (C++17)
- Mathematical constants (C++20)
- Basic linear algebra algorithms (C++26)
- Pseudo-random number generation
- Floating-point environment (C++11)
- complex — valarray

Date and time library
- Calendar (C++20) — Time zone (C++20)

Input/output library
- Print functions (C++23)
- Stream-based I/O — I/O manipulators
- basic_istream — basic_ostream
- Synchronized output (C++20)
- File systems (C++17)

Concurrency support library (C++11)
- thread — jthread (C++20)
- atomic — atomic_flag
- atomic_ref (C++20) — memory_order
- Mutual exclusion — Semaphores (C++20)
- Condition variables — Futures
- latch (C++20) — barrier (C++20)
- Safe Reclamation (C++26)

Execution support library (C++26)

Technical specifications

Standard library extensions (library fundamentals TS)
- resource_adaptor — invocation_type

Standard library extensions v2 (library fundamentals TS v2)
- propagate_const — ostream_joiner — randint
- observer_ptr — Detection idiom

Standard library extensions v3 (library fundamentals TS v3)
- scope_exit — scope_fail — scope_success — unique_resource

Parallelism library extensions v2 (parallelism TS v2)
- simd

Concurrency library extensions (concurrency TS)

Transactional Memory (TM TS)

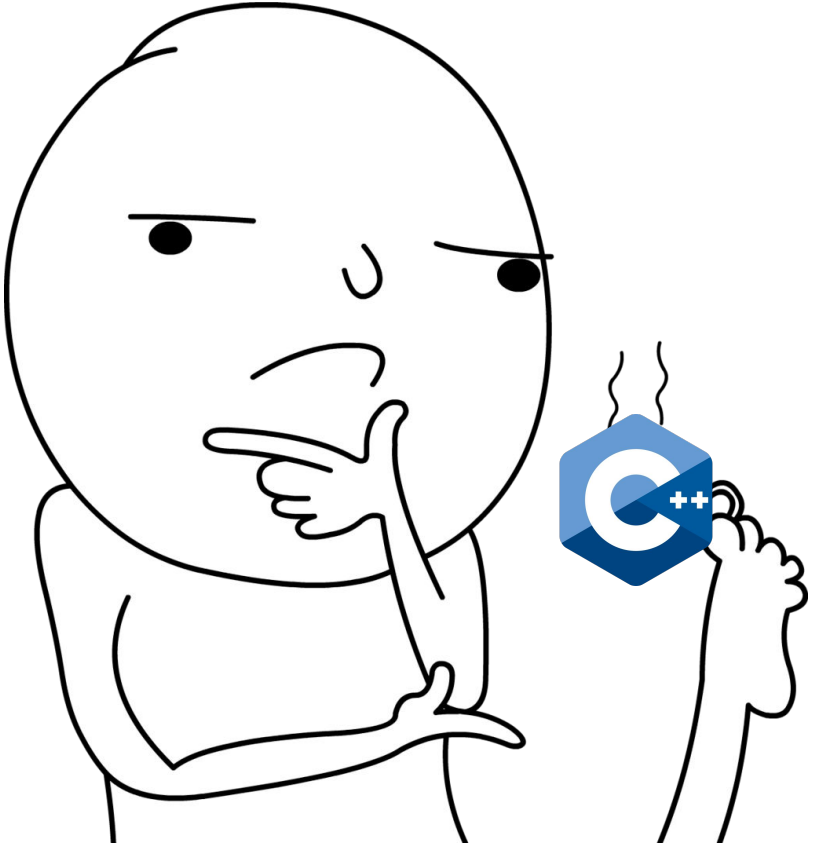
Reflection (reflection TS)

External Links — Non-ANSI/ISO Libraries — Index — std Symbol Index

We've made it really far

3	April 15 5. Streams 📖 Slides 💻 Code	April 17 6. Containers 📖 Slides 📕 Reader A1: SimpleEnroll
4	April 22 7. Iterators and Pointers 📖 Slides 📕 Reader I, II	April 24 8. Classes 📖 Slides 💻 Code A2: Marriage Pact
5	April 29 9. Inheritance 📖 Slides	May 1 10. Const Correctness & Class Templates 📖 Slides 💻 Code 📕 Reader A3: Make a Class!
6	May 6 11. Function Templates 📖 Slides 💻 Code	May 8 12. Functions and Lambdas 📖 Slides 💻 Code A4: Ispell
7	May 13 13. Operator Overloading	May 15 14. Special Member Functions
8	May 20 15. Move Semantics	May 22 16. `std::optional` and Type Safety
9	May 27 17. RAII, Smart Pointers, and Building C++ Projects	May 29 Optional: No Class, Extra Office Hours
10	June 3 Optional: No Class, Extra Office Hours	

What questions do we have?



Today's Agenda

1. Recap
2. **Operator Overloading**

So what have we seen so far

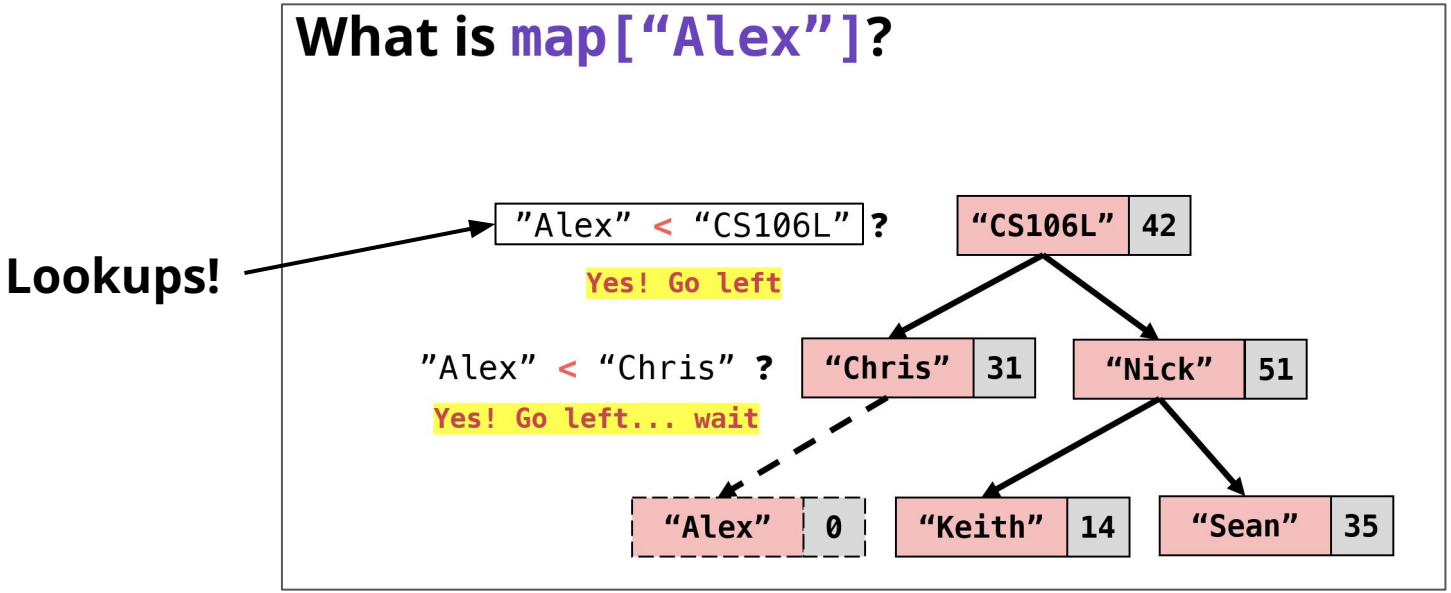
At this point:

1. You know how to create classes!
2. You know to to create *templated* classes!
3. But.....
4. Remember **`maps`** and **`sets`**?

In particular recall that a `std::map<K ,V>` requires `K` to have an `operator<`

Why this requirement?

In particular recall that a `std::map<K ,V>` requires `K` to have an `operator<`



Motivation

Why should we use operators at all?

“Operators allow you to convey meaning about types that functions don’t”

From this this phenomenal cppcon video

Hey Bjarne, I want the min of 2 ???

```
template <typename T>
T min(const T& a, const T& b) {
   return a < b ? a : b;
}

// For which T will the following compile successfully?
T a = /* an instance of T */;
T b = /* an instance of T */;
min<T>(a, b);
```

What **must be true** of a type **T** for us to be able to use **min**?

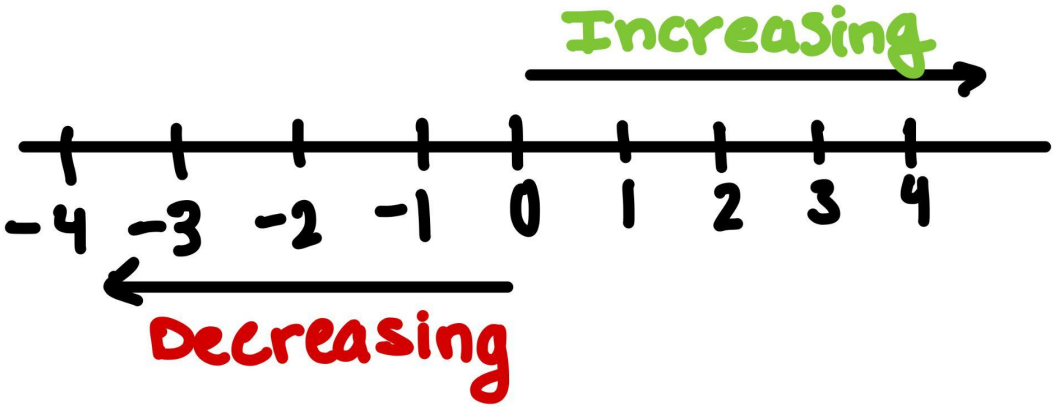
Hey Bjarne, I want the min of 2 ???

What **must be true** of a type `T` for us to be able to use `min`?

1. T should have an ordering relationship that makes sense.

2. T should represent something **comparable** where a “minimum” can be logically determined

Hey Bjarne, I want the min of 2 int



1. T should have an ordering relationship that makes sense.

2. T should represent something **comparable** where a “minimum” can be logically determined

Hey Bjarne, I want the min of 2 StanfordIDs

```
StanfordID jacob;
StanfordID fabio;

auto minStanfordID = min<StanfordID>(jacob, fabio);
```

Hey Bjarne, I want the min of 2 StanfordIDs

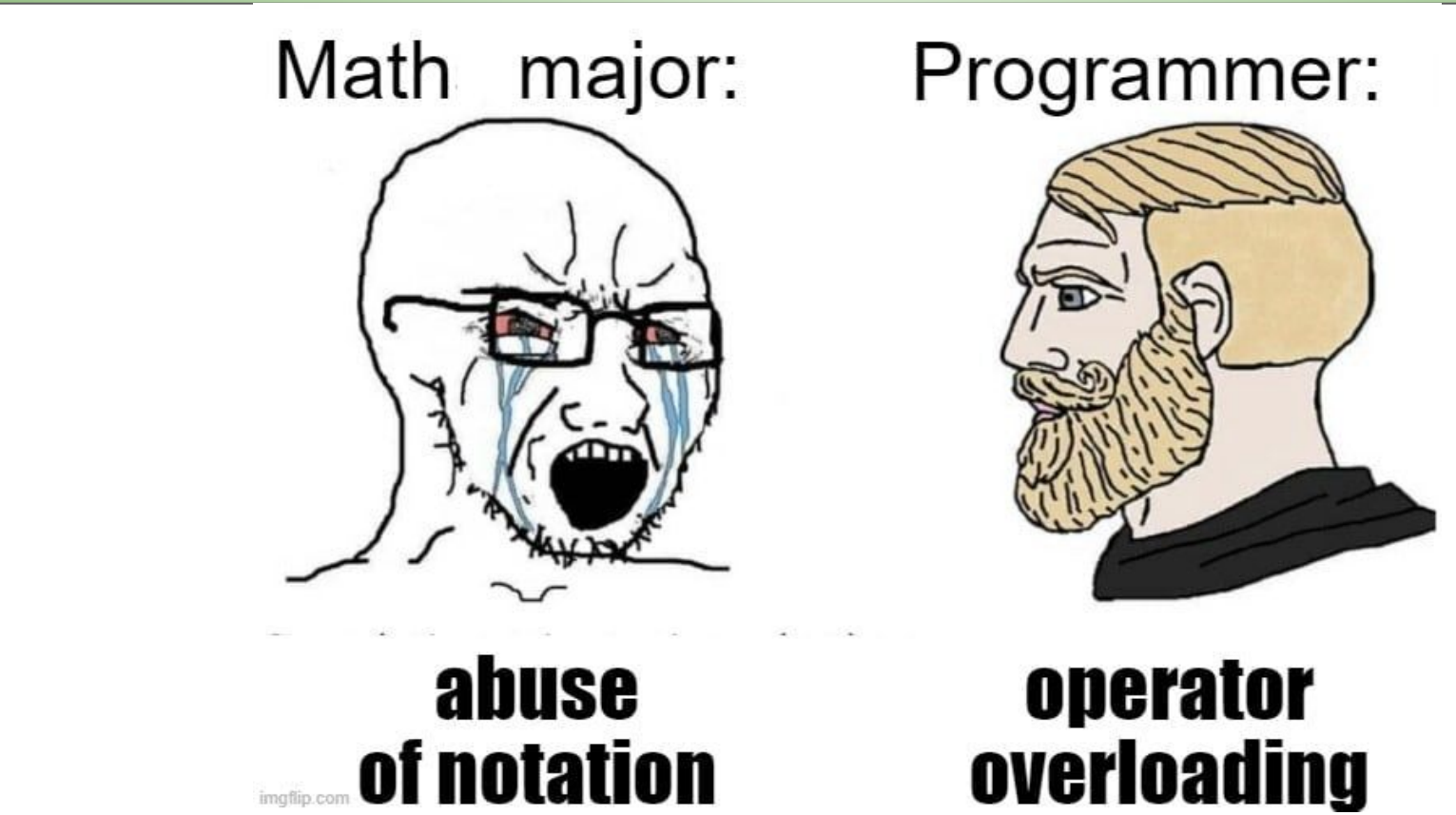
```
StanfordID jacob;
StanfordID fabio;

auto minStanfordID = min<StanfordID>(jacob, fabio);


StanfordID min(const StanfordID& a, const StanfordID& b)
{
   return a < b ? a : b;
}
```

Compiler: “Hey, I don’t know what to do here!”

Hello Operator Overloading



Hello Operator Overloading

So how do operators work with classes?

- Just like we declare functions in a class, we can declare an operator's functionality
- When we use that operator with our new object, it performs a custom function or operation
- Just like in function overloading, if we give it the same name, it will override the operator's behavior!

What operators can we overload?

It turns out, most of them!

```
+ - * / % ^ & | ~ ! , = < > <= >=
++ -- << >> == != && || += -= *=
/= %= ^= &= |= <<= >>= [] () ->
->* new new[] delete delete[]
```

What operators can’t be overloaded?

- Scope Resolution
- Ternary
- Member Access
- Pointer-to-member access
- Object size, type, and casting

```
::   ?   .   .*   sizeof()
     typeid()   cast()
```

What operators can’t be overloaded?

- Scope Resolution
- Ternary
- Member Access
- Pointer-to-member access
- Object size, type, and casting

```
::   ?   .   .*   sizeof()
     typeid()   cast()
```

What operators can’t be overloaded?

- Scope Resolution
- Ternary
- Member Access
- Pointer-to-member access
- Object size, type, and casting

```
::   ?   .   .*   sizeof()
     typeid()   cast()
```

What operators can’t be overloaded?

- Scope Resolution
- Ternary
- Member Access
- Pointer-to-member access
- Object size, type, and casting

```
::   ?   .   .*   sizeof()
     typeid()   cast()
```

Hey Bjarne, I want the min of 2 StanfordIDs

.h file

```
class StanfordID {
private:
std::string name;
std::string sunet;
int idNumber;

public:
    // constructor for our StanfordID
    StanfordID(std::string name, std::string sunet, int idNumber);
    .
    .
    .
    bool operator < (const StanfordID& rhs) const;
}
```

Hey Bjarne, I want the min of 2 StanfordIDs

.cpp file

```
#include StanfordID.h

std::string StanfordID::getIdNumber() {
    return idNumber;
}


bool StanfordID::operator< (const StanfordID& rhs) const {
    ?
}
```

Think about it with a partner!

Say that you want to compare `StanfordID` objects by their `idNumber` member, how could you implement this?

106l.vercel.app/comparable

Hey Bjarne, I want the min of 2 StanfordIDs

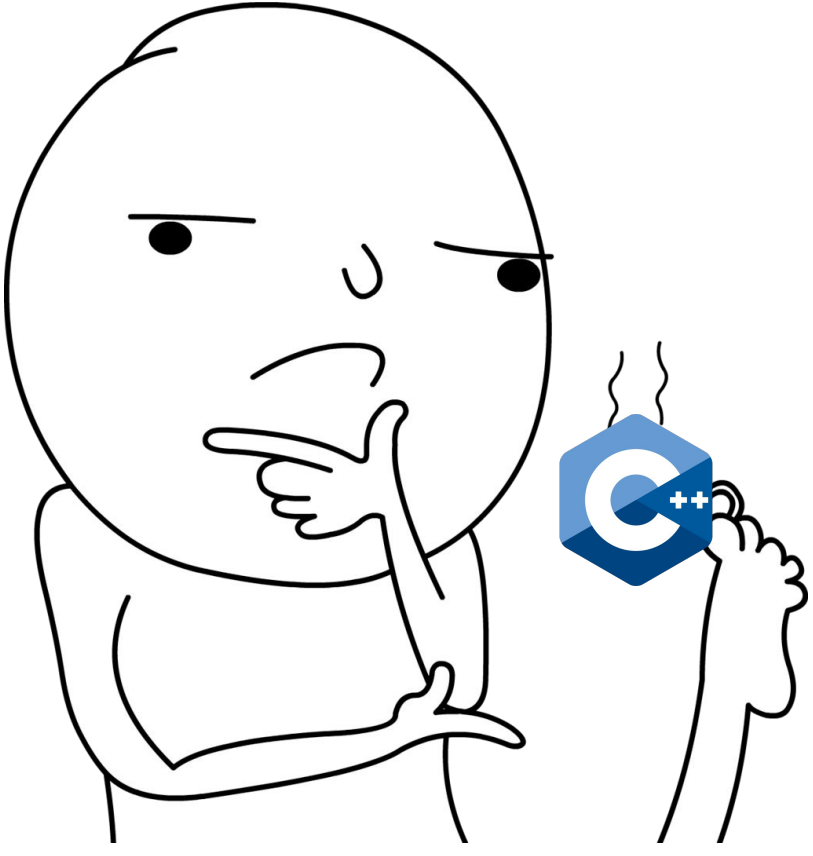
.cpp file

```
#include StanfordID.h

std::string StanfordID::getIdNumber() {
    return idNumber;
}


bool StanfordID::operator<(const StanfirdID& other) const {
    return idNumber < other.getIdNumber();
}
```

What questions do we have?



Non-member overloading

There are two ways to overload:

1. Member overloading
    a. Declares the overloaded operator within the scope of your class

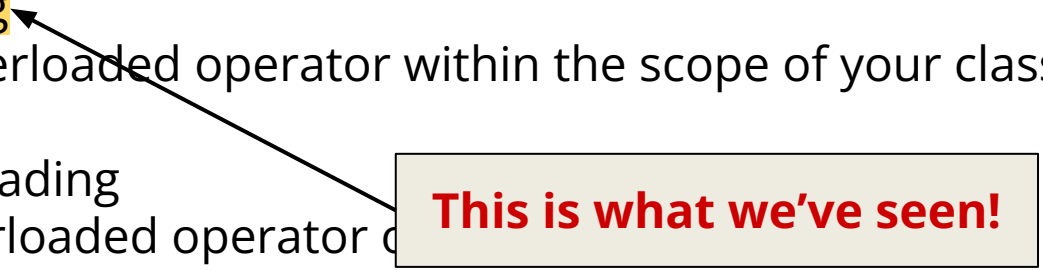
2. Non-member overloading
    a. Declare the overloaded operator outside of class definitions
    b. Define both the left and right hand objects as parameters

Non-member overloading

There are two ways to overload:

1. Member overloading
   a. Declares the overloaded operator within the scope of your class

2. Non-member overloading
   a. Declare the overloaded operator o
   b. Define both the left and right hand objects as parameters



Non-member overloading

This is actually preferred by the STL, and is more idiomatic C++

Why:

1. Allows for the **left-hand-side** to be a **non-class type**

2. Allows us to overload operators with classes we don't own
   a. We could define an operator to compare a `StanfordID` to other custom classes you define.

Non-member overloading

Non-member Operator Overloading

```
bool operator< (const StanfordID& lhs, const StanfordID& rhs);
```

Member Operator Overloading

```
bool StanfordID::operator< (const StanfordID& rhs) const {...}
```

Non-member overloading

Non-member Operator Overloading

```
bool operator< (const StanfordID& lhs, const StanfordID& rhs);
```

Note both the left and right hand side of the operator are passed in in non-member operator overloading!

```
bool StanfordID:                                    ..}
```

What about the member variables?

Non-member Operator Overloading

```
bool operator< (const StanfordID& lhs, const StanfordID& rhs);
```

With member operator overloading we have access to `this->` and the variables of the class.

Can we access these with non-member operator overloading? 🤔

What about the member variables?

Non-member Operator Overloading

```
bool operator< (const StanfordID& lhs, const StanfordID& rhs);
```

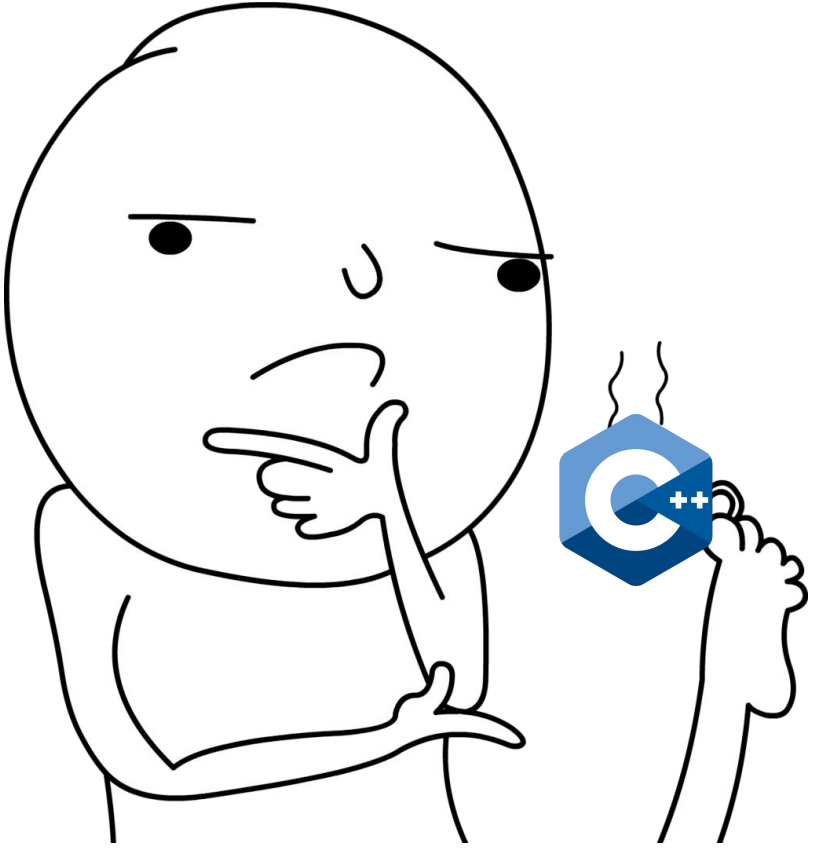
With member operator overloading we have access to `this->` and the variables of the class.

Car

It is also undefined behavior to have both of these because the < operator is acting on two `StanfordID`s

Remember ambiguity baddddddd

What questions do we have?



Hello `friend`!

Non-member Operator Overloading

```
bool operator< (const StanfordID& lhs, const StanfordID& rhs);
```

The **`friend`** keyword allows non-member functions or classes to access private information in another class!

Hello `friend`!

Non-member Operator Overloading

```
bool operator< (const StanfordID& lhs, const StanfordID& rhs);
```

The **`friend`** keyword allows non-member functions or classes to access private information in another class!

How do you use `friend`?

In the header of the target class you declare the operator overload function as a `friend`

Hey Bjarne, I want the min of 2 StanfordIDs

.h file

```
class StanfordID {
private:
std::string name;
std::string sunet;
int idNumber;

public:
    // constructor for our StudentID
    StanfordID(std::string name, std::string sunet, int idNumber);
    .
    .
    .
    friend bool operator < (const StanfordID& lhs, const StanfordID& rhs);
}
```

Hey Bjarne, I want the min of 2 StanfordIDs

.cpp file

```
#include StanfordID.h

bool operator< (const StanfordID& lhs, const StanfordID& rhs)
{
    return lhs.idNumber < rhs.idNumber;
}
```

Note: this also works!

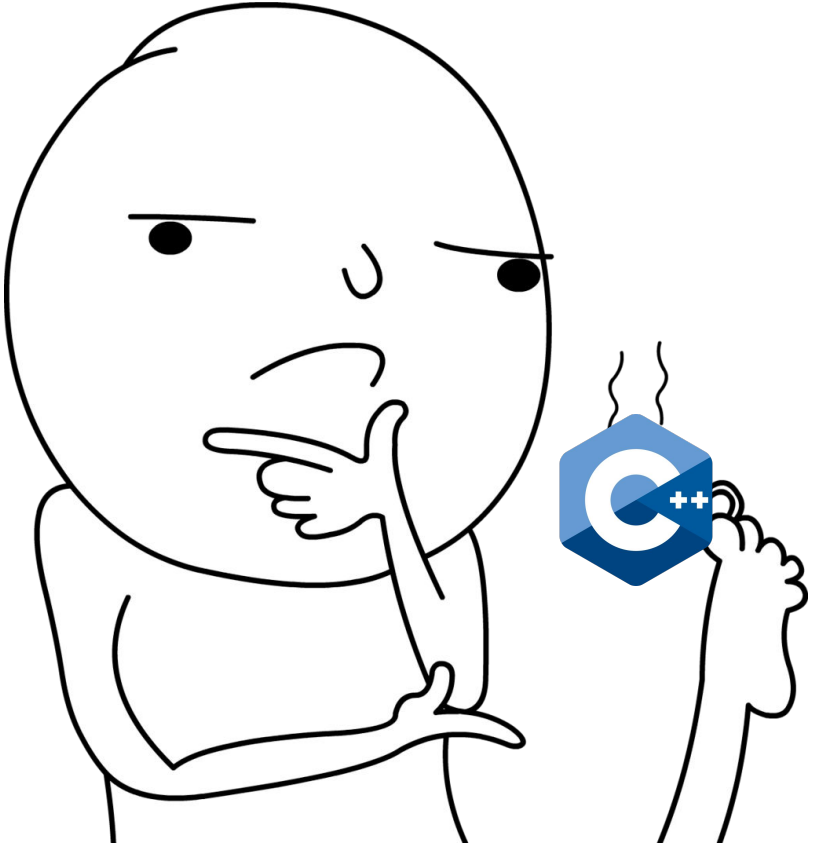
.cpp file

```
#include StanfordID.h

bool operator< (const StanfordID& lhs, const StanfordID& rhs)
{
    return lhs.getIdNumber() < rhs.getIdNumber();
}
```

In this case the `friend` keyword is not required since we're not using a private member function or variable

What questions do we have?



So why is this even meaningful?

```
StanfordID jacob;
StanfordID fabio;

auto minStanfordID = min<StanfordID>(jacob, fabio);


StanfordID min(const StanfordID& a, const StanfordID& b)
{
   return a < b ? a : b;
}
```

Compiler: “Hey, now I know what to do here! 😀”

So why is this even meaningful?

- There are many operators that you can define in C++ like we saw

```
+ - * / % ^ & | ~ ! , = < > <= >=
++ -- << >> == != && || += -= *=
/= %= ^= &= |= <<= >>= [] () ->
->* new new[] delete delete[]
```

So why is this even meaningful?

- There are many operators that you can define in C++ like we saw
- There’s a lot of functionality we can unlock with operators

```
+ - * / % ^ & | ~ ! , = < > <= >=
++ -- << >> == != && || += -= *=
/= %= ^= &= |= <<= >>= [] () ->
->* new new[] delete delete[]
```

More importantly

“Operators allow you to convey meaning about types that functions don’t”

Rules and Philosophies

- Because operators are intended to convey meaning about a type, the meaning should be **obvious**

- The operators that we can define are oftentimes arithmetic operators. The functionality should be **reasonably similar** to their corresponding operations
  - You don't want to define `operator+` to be set subtraction

- If the meaning is not obvious, then maybe define a function for this

This is known as the Principle of Least Astonishment (PoLA)

In general

- There are some good practices like the **rule of contrariety**
- For example when you define the `operator==` use the rule of contrariety to define `operator!=`

```
bool StanfordID::operator==(const StanfordID& other) const {
    return (name == other.name) && (sunet == other.sunet) &&
    (idNumber == other.idNumber);
}

bool StanfordID::operator!=(const StanfordID& other) const {
    return !(*this == other);
}
```

<<

- However there's a lot of flexibility in implementing operators
- For example << stream insertion operator

```
std::ostream& operator << (std::ostream& out, const StanfordID& sid) {
    out << sid.name << " " << sid.sunet << " " << sid.idNumber;
    return out;
}

std::ostream& operator << (std::ostream& out, const StanfordID& sid) {
    out << "Name: " << sid.name << " sunet: " <<
    << sid.idNumber;
    return out;
}
```

The way you use this operator may influence how you implement it

Final thoughts

1. Operator overloading unlocks a new layer of functionality and meaning within objects that we define

2. Operators should *make sense*, the entire point is that convey some meaning that functions don't about the type itself.

3. You should overload when you need to, for example if you're not using a stream with your type, then don't overload << or >>.