

Lecture 2:

Types and Structs

Stanford CS106L, Autumn 2024

Last Time

- Introductions!
- Why you should take 106L?
- Course Logistics

cs106l.stanford.edu

What's one thing you remember from last lecture?

Pair up and discuss!

Today's Agenda

- What is C++?
- Structs bundle data together
- Code demo
- Improving our code

We'll cover a LOT of material in this class

Please ask questions!!!

What questions do you have?



bjarne_about_to_raise_hand

What is C++?

Structure of a C++ Program

```
// Include other libraries, similar to Python's "import"
#include <iostream>
#include <utility>
#include <cmath>

// Main logic of your program goes here
int main() {
    std::cout << "Hello World" << std::endl;
    std::cout << "Welcome to " << std::endl;
    for (char ch : "CS106L")
    {
        std::cout << ch << std::endl;
    }
}
```

```
Hello World
Welcome to
C
S
1
0
6
L
```

Python

```
print("Hello World")  
print("Welcome to ")  
for ch in "CS106L":  
    print(ch)
```

C++

```
std::cout << "Hello World" << std::endl;  
std::cout << "Welcome to " << std::endl;  
for (char ch : "CS106L")  
{  
    std::cout << ch << std::endl;  
}
```

Okay... but what *is* C++?

Q1: How do we run code?

How do we run code?

Source Code

```
print("Hello World")  
print("Welcome to ")  
for ch in "CS106L":  
    print(ch)
```

Translation

Machine Code

```
10110101  
01011010  
10011101  
10110001
```

CPU



Taking a closer look...

Source Code

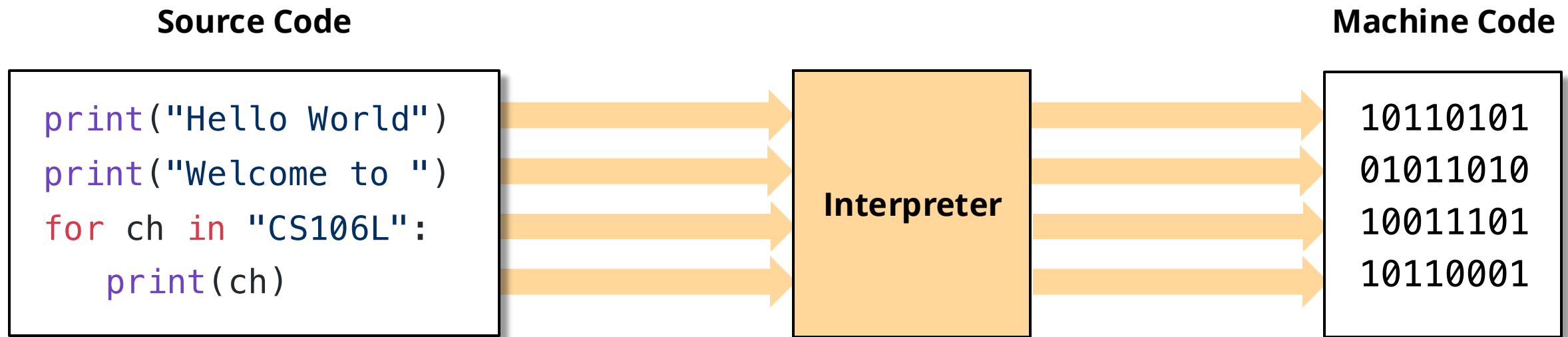
```
print("Hello World")  
print("Welcome to ")  
for ch in "CS106L":  
    print(ch)
```

Translation

Machine Code

```
10110101  
01011010  
10011101  
10110001
```

Interpreted Languages



```
$ python3 main.py # python3 is the interpreter
```

Compiled Languages

Source Code

```
std::cout << "Hello World" << std::endl;  
std::cout << "Welcome to " << std::endl;  
for (char ch : "CS106L")  
{  
    std::cout << ch << std::endl;  
}
```

Compiler

Machine Code

```
10110101  
01011010  
10011101  
10110001
```

```
$ g++ main.cpp -o main    # g++ is the compiler, outputs binary to main  
$ ./main                 # This actually runs our program
```


Why compile over interpret?

- It allows us to generate more efficient machine code!
 - Interpreters only see one small part of code at a time
 - Compilers see everything
- However, compilation takes time!

C++ is a compiled language

What questions do you have?



bjarne_about_to_raise_hand

Compile time vs. runtime

```
std::cout << "Hello World" << std::endl;  
std::cout << "Welcome to " << std::endl;  
for (char ch : "CS106L")  
{  
    std::cout << ch << std::endl;  
}
```

**Compile
Time**

```
10110101  
01011010  
10011101  
10110001
```

Runtime



Aside: “compiled language” is a misleading term

Q1: How do we run code?

Q2: How do we verify code?

Python

```
print("Running...")  
hello = "Hello ";  
world = "World!";  
print(hello * world)
```

```
$ python3 program.py
```

Running...

TypeError: can't multiply sequence by
non-int of type 'str'

C++

```
int main() {  
    std::cout << "Running..." << std::endl;  
    std::string hello = "Hello ";  
    std::string world = "World!";  
    std::cout << hello * world << std::endl;  
    return 0;  
}
```

```
$ g++ main.cpp
```

error: no match for 'operator*' (operand
types are 'std::string' and 'std::string')

C++ compilers can be noisy... why?

```
rtmap.cpp: In function `int main()':
rtmap.cpp:19: invalid conversion from `int' to `
std::_Rb_tree_node<std::pair<const int, double> >*'
rtmap.cpp:19: initializing argument 1 of `std::_Rb_tree_iterator<_Val, _Ref,
_Ptr>::_Rb_tree_iterator(std::_Rb_tree_node<_Val>*) [with _Val =
std::pair<const int, double>, _Ref = std::pair<const int, double>&, _Ptr =
std::pair<const int, double>*]'
rtmap.cpp:20: invalid conversion from `int' to `
std::_Rb_tree_node<std::pair<const int, double> >*'
rtmap.cpp:20: initializing argument 1 of `std::_Rb_tree_iterator<_Val, _Ref,
_Ptr>::_Rb_tree_iterator(std::_Rb_tree_node<_Val>*) [with _Val =
std::pair<const int, double>, _Ref = std::pair<const int, double>&, _Ptr =
std::pair<const int, double>*]'
```


Types

- A **type** refers to the “category” of a variable
- C++ comes with built-in types
 - **int** 106
 - **double** 71.4
 - **string** “Welcome to CS106L!”
 - **bool** true false
 - **size_t** 12 // Non-negative

C++ is a statically typed language

Static Typing

- Every variable must declare a type
- Once declared, the type cannot change

Python (Dynamic Typing)

```
a = 3
b = "test"

def foo(c):
    d = 106
    d = "hello world!"
```

C++ (Static Typing)

```
int a = 3;
string b = "test";

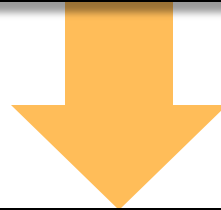
void foo(string c)
{
    int d = 106;
    d = "hello world!"; ❌
}
```

Why static typing?

- More efficient
- Easier to understand and reason about
- Better error checking

Better error checking

```
def add_3(x):  
    return x + 3  
  
add_3("CS106L") # Oops, that's a string. Runtime error!
```



```
int add_3(int x) {  
    return x + 3;  
}  
  
add_3("CS106L"); // Can't pass a string when int expected. Compile time error!
```

What questions do you have?



bjarne_about_to_raise_hand

Your turn

- (int) x **casts** x to an int by dropping decimals
 - E.g. (int) 5.3 = 5

```
string    a = "test";  
double    b = 3.2 * 5 - 1;  
int       c = 5 / 2; // What does this equal?  
int       d(int foo) { return foo / 2; }  
double    e(double foo) { return foo / 2; }  
int       f(double foo) { return (int)(foo + 0.5); } // What's this?  
void      g(double c) { std::cout << c << std::endl; }
```

Aside: Function Overloading

Defining two functions with the same name but different signatures

```
double func(int x) {           // (1)
    return (double) x + 3;     // typecast: int → double
}
```

```
double func(double x) {       // (2)
    return x * 3;
}
```

```
func(2);           // uses version (1), returns 5.0
func(2.0);         // uses version (2), returns 6.0
```


C++ is a compiled, statically typed language

What questions do you have?



bjarne_about_to_raise_hand

Structs

Keeping track of students

- Every student ID has a few properties
 - A name (`string`)
 - A SUNet (`string`)
 - An ID # (`int`)



A fundamental problem

```
_____ issueNewID() {  
    // How can we return all three things?  
    // What should our return type be?  
  
    // Python:  
    // return "Jacob Roberts-Baca", "jtrb", 6504417  
}
```

How do we return more than one value?

Introducing... structs!

Structs bundle data together


```
struct StanfordID {  
    string name;           // These are called fields  
    string sunet;          // Each has a name and type  
    int idNumber;  
};  
  
StanfordID id;             // Initialize struct  
id.name = "Jacob Roberts-Baca"; // Access field with '.'  
id.sunet = "jtrb";  
id.idNumber = 6504417;
```

Returning multiple values

```
StanfordID issueNewID() {  
    StanfordID id;  
    id.name = "Jacob Roberts-Baca";  
    id.sunet = "jtrb";  
    id.idNumber = 6504417;  
    return id;  
}
```


List Initialization

```
StanfordID id;  
id.name = "Jacob Roberts-Baca";  
id.sunet = "jtrb";  
id.idNumber = 6504417;
```



We'll learn more
about this next time!



```
// Order depends on field order in struct. '=' is optional  
StanfordID jrb = { "Jacob Roberts-Baca", "jtrb", 6504417 };  
StanfordID fi { "Fabio Ibanez", "fibanez", 6504418 };
```

Using list initialization

```
StanfordID issueNewID() {  
    StanfordID id = { "Jacob Roberts-Baca", "jtrb", 6504417 };  
    return id;  
}
```

```
StanfordID issueNewID() {  
    return { "Jacob Roberts-Baca", "jtrb", 6504417 };  
}
```

A **struct** bundles **named variables** into a new type

What questions do you have?



bjarne_about_to_raise_hand

Many Possible Structs

```
struct Name {  
    string first;  
    string last;  
};  
  
Name jrb = { "Jacob", "R.B." };
```

```
struct Order {  
    string item;  
    int quantity;  
};  
  
Order dozen = { "Eggs", 12 };
```

Notice anything?

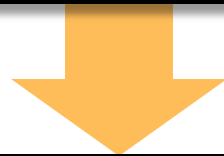
```
struct Point {  
    double x;  
    double y;  
};  
  
Point origin { 0.0, 0.0 };
```

```
struct Circle {  
    Point center;  
    double radius;  
};  
  
Circle circle { {0, 0} , 1.0 };
```

We can use `std::pair`!

std::pair

```
struct Order {  
    std::string item;  
    int quantity;  
};  
  
Order dozen = { "Eggs", 12 };
```



```
std::pair<std::string, int> dozen { "Eggs", 12 };  
std::string item = dozen.first;           // "Eggs"  
int quantity = dozen.second;             // 12
```

std::pair is a template

(We'll learn more about this later)

```
template <typename T1, typename T2>
struct pair {
    T1 first;
    T2 second;
};
std::pair<std::string, int>
```


std::pair is a template

(We'll learn more about this later)

```
struct pair {  
    std::string first;  
    int second;  
};
```

There's something we need to discuss...

What is an std !!?  

What is std !!?

std — The C++ Standard Library

- Built-in types, functions, and more provided by C++
- You need to `#include` the relevant file
 - `#include <string>` → `std::string`
 - `#include <utility>` → `std::pair`
 - `#include <iostream>` → `std::cout`, `std::endl`
- We prefix standard library names with `std::`
 - If we write `using namespace std`; we don't have to, but this is considered bad style as it can introduce ambiguity
 - (What would happen if we defined our own `string`?)

std — The C++ Standard Library

- See the official standard at [cppreference.com](http://en.cppreference.com)!
- Avoid cplusplus.com...
 - It is outdated and filled with ads 😭

To use `std::pair`, you must `#include` it


`std::pair` is defined in a header file called `utility`

```
#include <utility>
```

```
// Now we can use `std::pair` in our code.
```

```
std::pair<double, double> point { 1.0, 2.0 };
```

What does `#include` do?

```
#include <utility>   
std::pair<double, double> p { 1.0, 2.0 };
```

`utility`

```
namespace std {  
  
    template  
    <typename T1, typename T2>  
    struct pair {  
        T1 first;  
        T2 second;  
    };  
  
    // Other utility code...  
}
```

What does **#include** do?

```
namespace std {  
  
    template <typename T1, typename T2>  
    struct pair {  
        T1 first;  
        T2 second;  
    };  
  
    // Other utility code...  
}  
  
std::pair<double, double> p { 1.0, 2.0 };
```

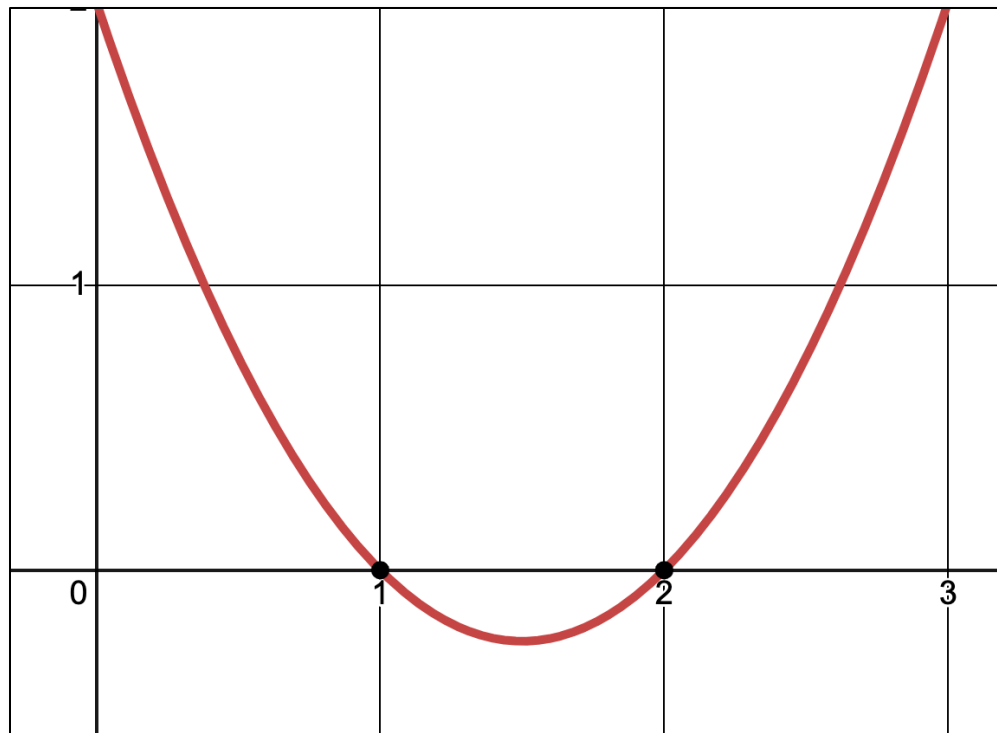

What questions do you have?



bjarne_about_to_raise_hand

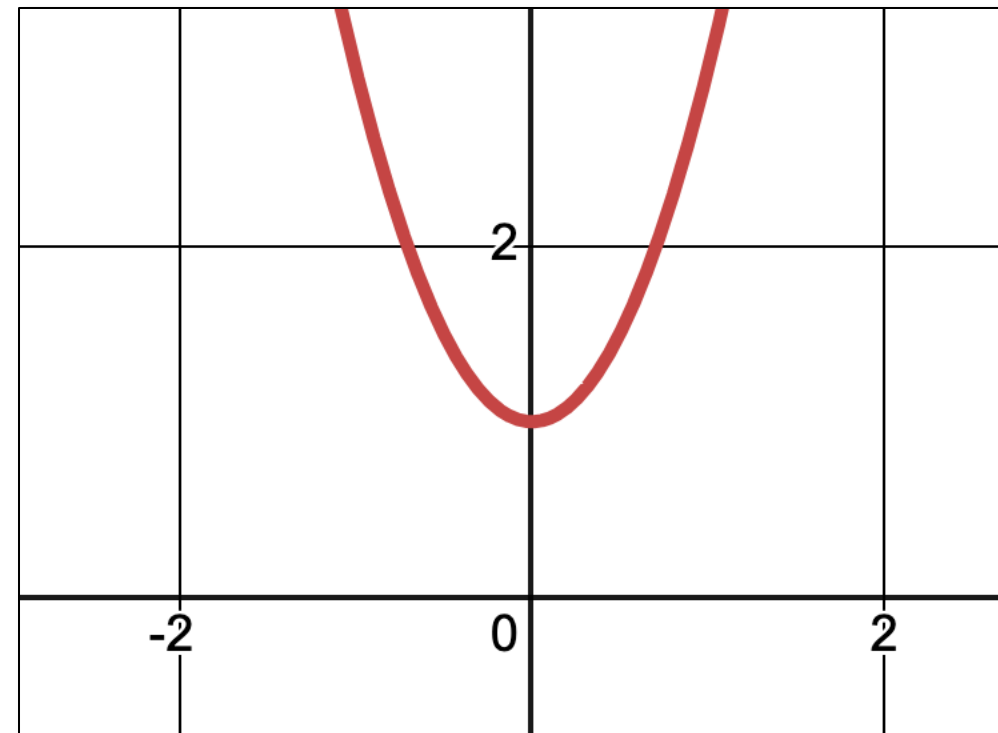
Code Demo

Solving a Quadratic Equation



$$x^2 - 3x + 2 = 0$$

$$x = 1, x = 2$$



$$2x^2 + 1 = 0$$

no solution

Solving a Quadratic Equation

- If we have $ax^2 + bx + c = 0$
- Solutions are $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$
- If $b^2 - 4ac$ is negative, there are no solutions

What are the
solutions (if any)?

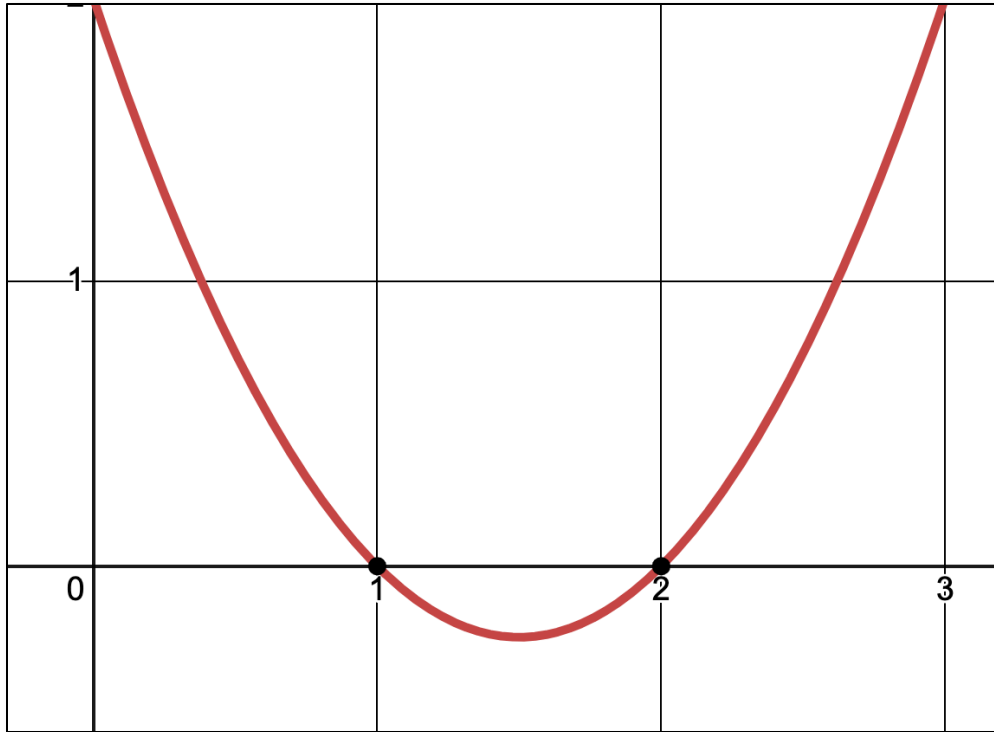
Our return
value :D

```
std::pair<bool, std::pair<double, double>> solveQuadratic(double a, double b, double c);
```

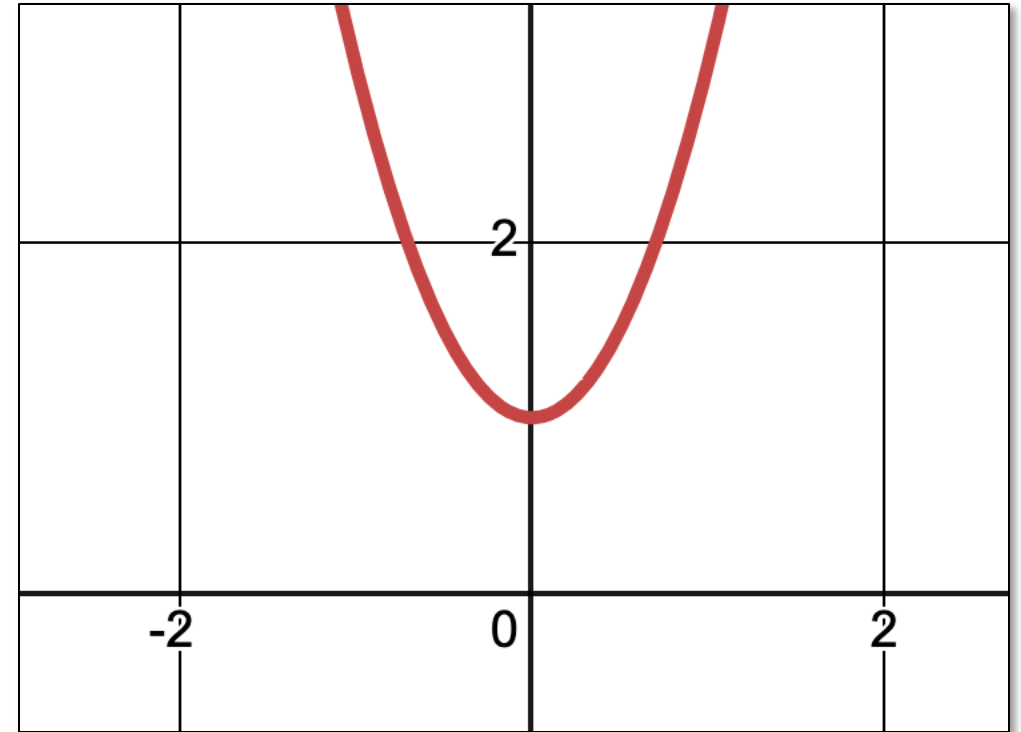
Is there a
solution?

Our coefficients.
Yay!

`std::pair<bool, std::pair<double, double>>`



`{ true, { 1.0, 2.0 } }`



`{ false, doesnt_matter }`

Solving a Quadratic Equation

- If we have $ax^2 + bx + c = 0$
- Solutions are $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$
- If $b^2 - 4ac$ is negative, there are no solutions
- **Your task:** Write a function to solve a quadratic equation:

```
std::pair<bool, std::pair<double, double>> solveQuadratic(double a, double b, double c);
```



The `sqrt` function from the `<cmath>` header can calculate the square root

Let's code this together 

`106l.vercel.app/quadratic`

Improving Our Code

The `using` keyword

The **using** keyword

- Typing out long type names gets tiring
- We can create **type aliases** with the **using** keyword

```
std::pair<bool, std::pair<double, double>> solveQuadratic(double a, double b, double c);
```



```
using Zeros = std::pair<double, double>;  
using Solution = std::pair<bool, Zeros>;
```

using is kind of like a variable for types!

The `auto` keyword

The **auto** keyword

- The **auto** keyword tells the compiler to infer the type

```
std::pair<bool, std::pair<double, double>> result = solveQuadratic(a, b, c);
```



```
auto result = solveQuadratic(a, b, c);
```

```
// This is exactly the same as the above!
```

```
// result still has type std::pair<bool, std::pair<double, double>>
```

```
// We just told the compiler to figure this out for us!
```

auto is still statically typed!

```
auto i = 1;    // int inferred  
i = "hello!"; // ❌ Doesn't compile
```

Which one is clearer?

```
std::pair<bool, std::pair<double, double>> result = ...;  
    auto result = ...;
```


Which one is clearer?

```
auto i = 1;  
int i = 1;
```

What questions do you have?



bjarne_about_to_raise_hand

Recap

Recap

- C++ is a compiled, statically typed language
- Structs bundle data together into a single object
- **std::pair** is a general purpose struct with two fields
- `#include` from the C++ Standard Library to use built-in types
 - And use the `std::` prefix too!
- Quality of life features to improve your code
 - `using` creates type aliases
 - `auto` infers the type of a variable