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

```cpp
// 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

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

C++

```cpp
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

```python
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

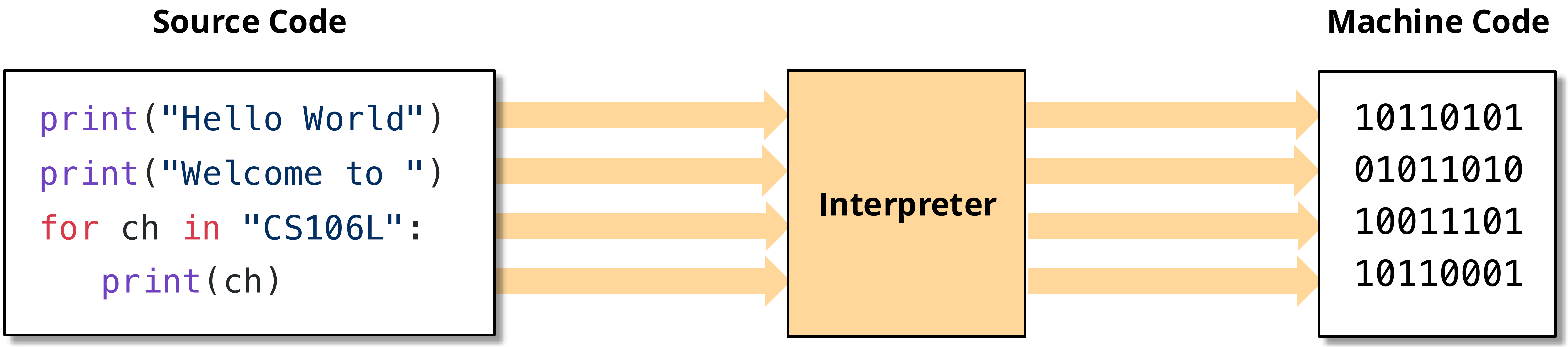
```python
print("Hello World")
print("Welcome to ")
for ch in "CS106L":
   print(ch)
```

Translation

Machine Code

```
10110101
01011010
10011101
10110001
```

Interpreted Languages




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

Compiled Languages

Source Code

```cpp
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

```cpp
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

```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++

```cpp
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>*]'
```

[Source]

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)

```python
a = 3
b = "test"

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

C++ (Static Typing)

```cpp
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

```python
def add_3(x):
    return x + 3

add_3("CS106L") # Oops, that's a string. Runtime error!
```

```cpp
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

```cpp
struct Order {
   std::string item;
   int quantity;
};

Order dozen = { "Eggs", 12 };
```

```cpp
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]!
- 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?

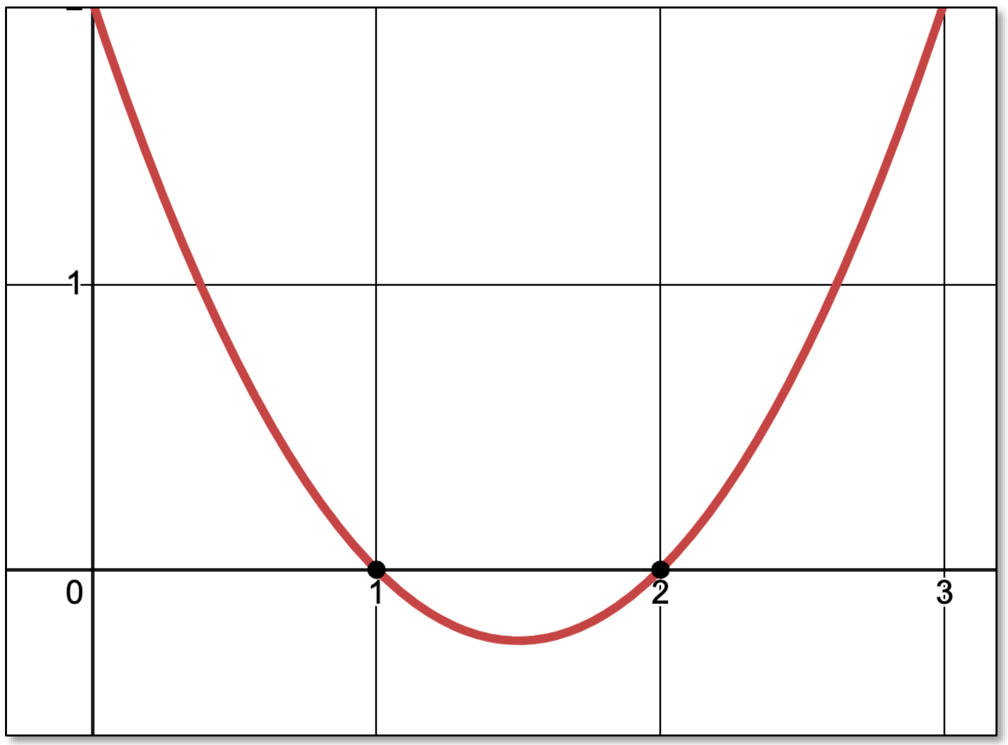
```
namespace std {

    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

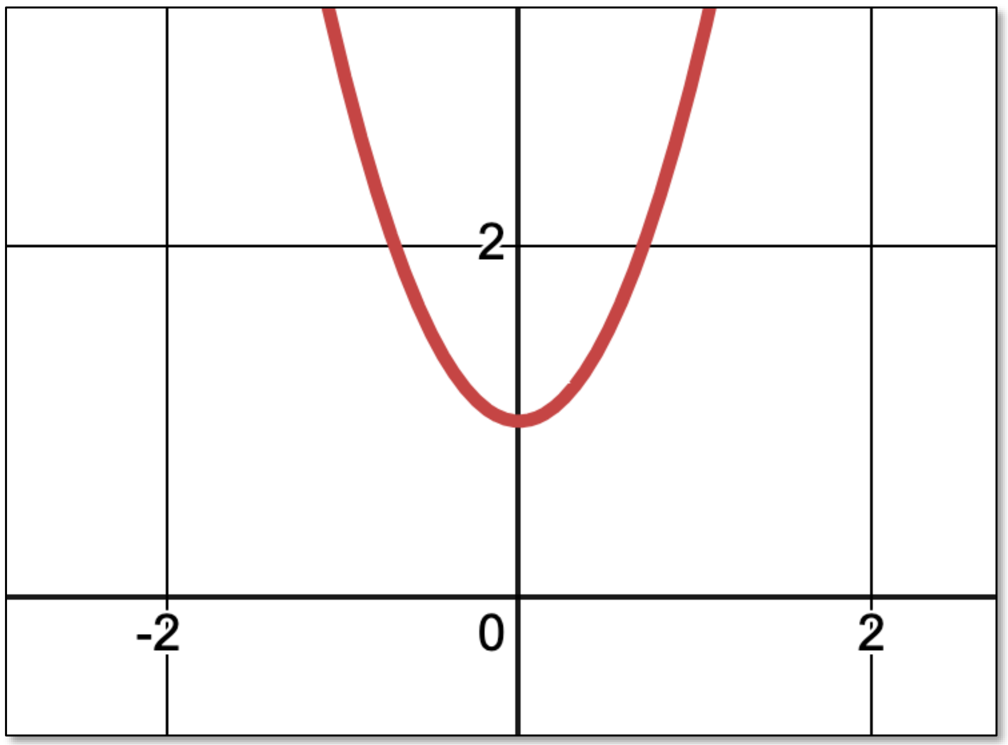
Code Demo

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)?

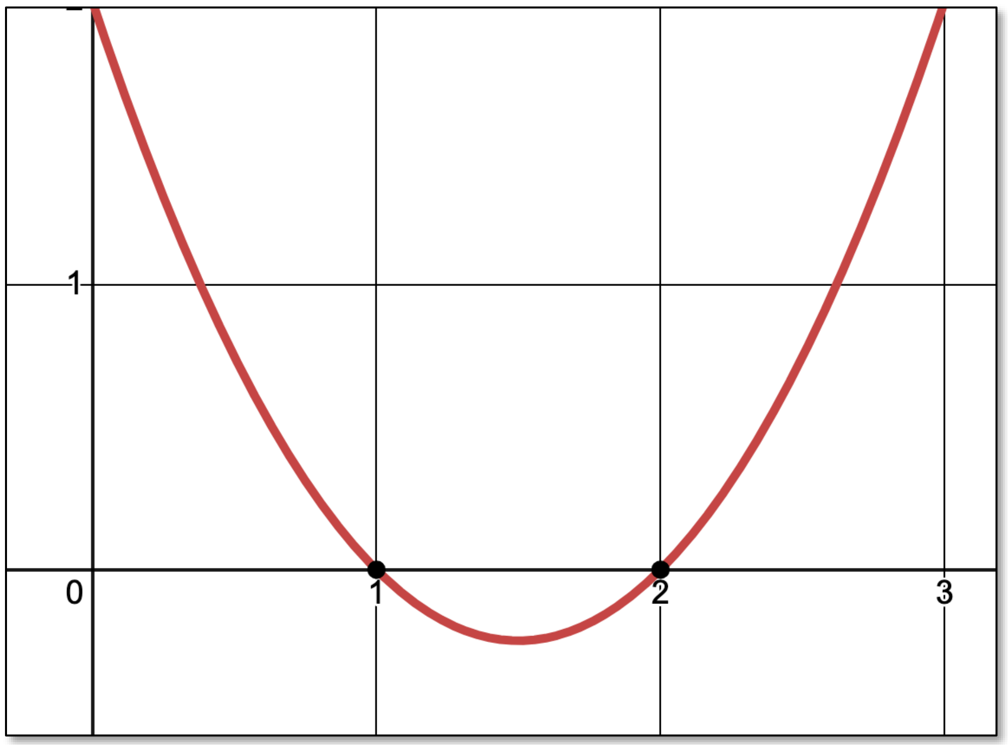
Our return
value :D

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

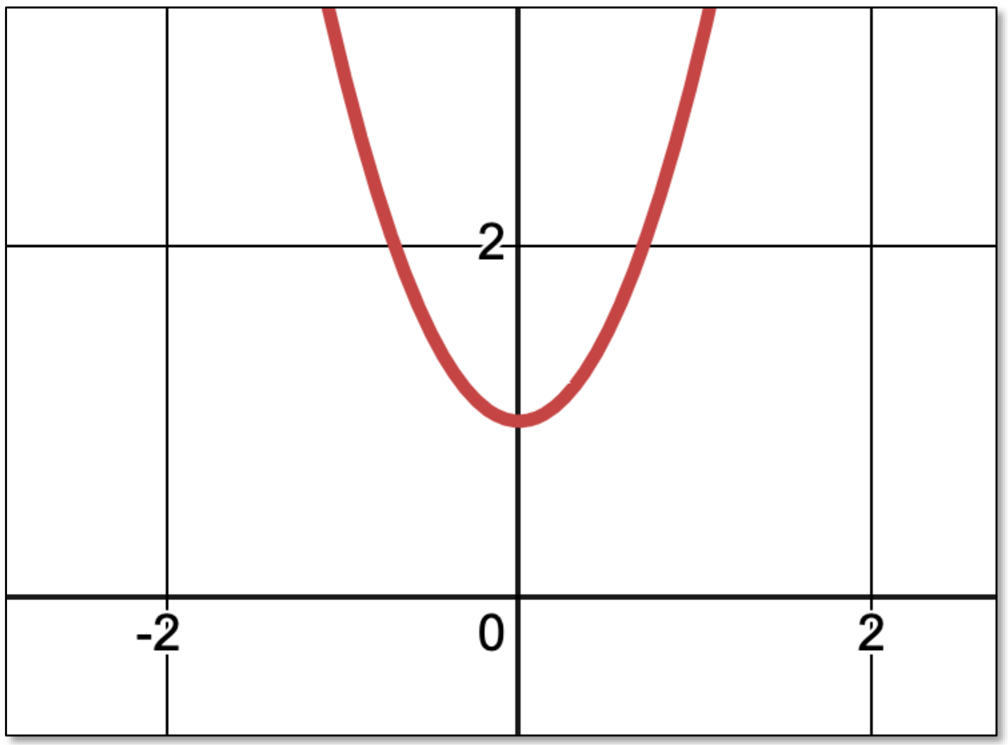
Is there a
solution?

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