CS106L Lecture 3:
Initialization & References

Autumn 2024

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Attendance

https://tinyurl.com/initandrefF24

Quick reminder

First assignment goes out on **Friday, October 4th** and is due **Friday, October 11th.**

Anonymous Feedback Form

https://tinyurl.com/feedbackF24

On pacing

A quick recap

1. **`auto`:** a keyword that tells the compiler to deduce the type of an object or variable

A quick recap

1. **`auto:`** a keyword that tells the compiler to deduce the type of an object or variable
   a. Use at your discretion
   b. Typically when the type is ***annoyingly*** verbose to write out

```cpp
#include <iostream>
#include <string>
#include <map>
#include <unordered_map>
#include <vector>

int main()
{
    std::map<std::string, std::vector<std::pair<int, std::unordered_map<char, double>>>>
    complexType;

    /// what does this do? We'll find out in the iterators lecture!
    std::map<std::string,std::vector<std::pair<int,std::unordered_map<char,double>>>>::iterator
    it = complexType.begin();

    // vs
    auto it = complexType.begin();

    return 0;
}
```

A quick recap

1. **`auto`:** a keyword that tells the compiler to deduce the type of an object or variable
   a. Use at your discretion
   b. Typically when the type is ***annoyingly*** verbose to write out

2. **Structs** are a way to bundle many variables into one type

Plan

1. Initialization
2. References
3. L-values vs R-values
4. Const
5. Compiling C++ programs

Initialization

What?: “Provides initial values at the time of construction” - *cppreference.com*

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How? 🤔:

1. Direct initialization
2. Uniform initialization
3. Structured Binding

Initialization

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How? 🤔:

1. Direct initialization

2. Uniform initialization

3. Structured Binding

Direct initialization

```cpp
#include <iostream>

int main() {
    int numOne = 12.0;
    int numTwo(12.0);

    std::cout << "numOne is: " << numOne << std::endl;
    std::cout << "numTwo is: " << numTwo << std::endl;

    return 0;
}
```

Notice!!:

is 12.0 an int?

Direct initialization

```cpp
#include <iostream>

int main() {
    int numOne = 12.0;
    int numTwo(12.0);

    std::cout << "numOne is: " << numOne << std::endl;
    std::cout << "numTwo is: " << numTwo << std::endl;

    return 0;
}
```

Notice!!:

is 12.0 an int?

NO

C++ Doesn't Care

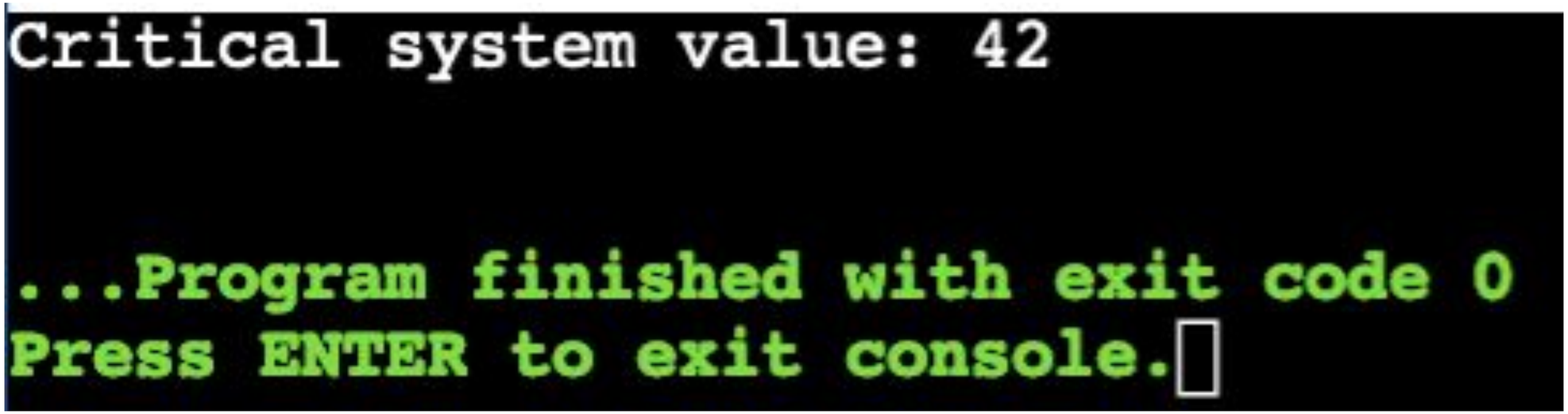
😱

```
numOne is: 12
numTwo is: 12


...Program finished with exit code 0
Press ENTER to exit console.
```

Problem? 🧐

```cpp
#include <iostream>

int main() {
    // Direct initialization with a floating-point value
    int criticalSystemValue(42.5);

    // Critical system operations...
    // ...

    std::cout << "Critical system value: " << criticalSystemValue << std::endl;

    return 0;
}
```

Problem? 🧐


Critical system value: 42
...Program finished with exit code 0
Press ENTER to exit console.

Recall

```cpp
#include <iostream>

int main() {
    int numOne = 12.0;
    int numTwo(12.0);

    std::cout << "numOne is: " << numOne << std::endl;
    std::cout << "numTwo is: " << numTwo << std::endl;

    return 0;
}
```

Notice!!:

is 12.0 an int?

NO

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```
numOne is: 12
numTwo is: 12


...Program finished with exit code 0
Press ENTER to exit console.
```

What happened? 🧐

```cpp
#include <iostream>

int main() {
    // Direct initialization with a floating-point value
    int criticalSystemValue(42.5);

    // Critical system operations...
    // ...

    std::cout << "Critical system value: " << criticalSystemValue << std::endl;

    return 0;
}
```

The user intended to save a float, 42.5, into **`criticalSystemValue`**

What happened? 🧐

```cpp
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int main() {
    // Direct initialization with a floating-point value
    int criticalSystemValue(42.5);

    // Critical system operations...
    // ...

    std::cout << "Critical system value: " << criticalSystemValue << std::endl;

    return 0;
}
```

C++ doesn't care in this case, it doesn't type check with direct initialization

What happened? 🧐

```cpp
#include <iostream>

int main() {
    // Direct initialization with a floating-point value
    int criticalSystemValue(42.5);

    // Critical system operations...
    // ...

    std::cout << "Critical system value: " << criticalSystemValue << std::endl;

    return 0;
}
```

So C++ said “Meh, I’ll store 42.5 as an int,” and we possibly now have an error. This is commonly called a **narrowing conversion**

Initialization

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How? 🤔:

1. Direct initialization
2. **Uniform initialization**
3. Structured Binding

Uniform initialization (C++11)

```cpp
#include <iostream>

int main() {
    // Notice the brackets
    int numOne{12.0};
    float numTwo{12.0};

    std::cout << "numOne is: " << numOne << std::endl;
    std::cout << "numTwo is: " << numTwo << std::endl;

    return 0;
}
```

Notice!!:

the curly braces!

With uniform initialization C++ ***does*** care about types!

Uniform initialization (C++11)

```cpp
#include <iostream>

int main() {
    // Notice the brackets
    int numOne{12.0};
    float numTwo{12.0};

    std::cout << "numOne is: " << numOne << std::endl;
    std::cout << "numTwo is: " << numTwo << std::endl;
}
```

```
narrowing_conversion.cpp:5:16: error: type 'double' cannot be narrowed to 'int' in
 initializer list [-Wc++11-narrowing]
    int numOne{12.0};
               ^~~~
narrowing_conversion.cpp:5:16: note: insert an explicit cast to silence this issue
    int numOne{12.0};
               ^~~~
               static_cast<int>( )
1 error generated.
```

Notice!!:

the curly braces!

With uniform

Uniform initialization (C++11)

```cpp
#include <iostream>

int main() {
    // Notice the brackets
    int numOne{12.0};
    float numTwo{12.0};

    std::cout << "numOne is.                    :endl;
    std::cout << "numTwo is:                    :endl;
}
```

Notice!!:

the curly braces!

With uniform initialization C++

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narrowing_conversion.cpp:5:16: error: type 'double' cannot be narrowed to 'int' in
 initializer list [-Wc++11-narrowing]
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Uniform initialization (C++11)

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int main() {
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    int numOne{12};
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    std::cout << "numOne is: " << numOne << std::endl;
    std::cout << "numTwo is: " << numTwo << std::endl;

    return 0;
}
```

Notice!!:

12 instead of 12.0

Uniform initialization (C++11)

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#include <iostream>

int main() {
    // Notice the brackets
    int numOne{12};
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    std::cout << "numOne is: " << numOne << std::endl;
    std::cout << "numTwo is: " << numTwo << std::endl;

    return 0;
}
```

Notice!!:

12 instead of 12.0


```
numOne is: 12
numTwo is: 12
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Uniform initialization (C++11)

Uniform initialization is awesome because:

1. It's **safe**! It doesn't allow for narrowing conversions—which can lead to unexpected behaviour (or critical system failures :o)

Uniform initialization (C++11)

Uniform initialization is awesome because:

1. It's **safe**! It doesn't allow for narrowing conversions—which can lead to unexpected behaviour (or critical system failures :o)

1. It's **ubiquitous** it works for all types like vectors, maps, and custom classes, among other things!

Uniform initialization (Map)

```cpp
#include <iostream>
#include <map>

int main() {
    // Uniform initialization of a map
    std::map<std::string, int> ages{
        {"Alice", 25},
        {"Bob", 30},
        {"Charlie", 35}
    };

    // Accessing map elements
    std::cout << "Alice's age: " << ages["Alice"] << std::endl;
    std::cout << "Bob's age: " << ages.at("Bob") << std::endl;

    return 0;
}
```

Uniform initialization (Map)

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int main() {
    // Uniform initialization of a map
    std::map<std::string, int> ages{
        {"Alice", 25},
        {"Bob", 30},
        {"Charlie", 35}
    };

    // Accessing map elements
    std::cout << "Alice's age: " << ages["Alice"] << std::endl;
    std::cout << "Bob's age: " << ages.at("Bob") << std::endl;

    return 0;
}
```

```
Alice's age: 25
Bob's age: 30
```

Uniform initialization (Vector)

```cpp
#include <iostream>
#include <vector>

int main() {
    // Uniform initialization of a vector
    std::vector<int> numbers{1, 2, 3, 4, 5};

    // Accessing vector elements
    for (int num : numbers) {
        std::cout << num << " ";
    }
    std::cout << std::endl;

    return 0;
}
```

Uniform initialization (Vector)

```cpp
#include <iostream>
#include <vector>

int main() {
    // Uniform initialization of a vector
    std::vector<int> numbers{1, 2, 3, 4, 5};

    // Accessing vector elements
    for (int num : numbers) {
        std::cout << num << " ";
    }
    std::cout << std::endl;

    return 0;
}
```

```
1 2 3 4 5
```

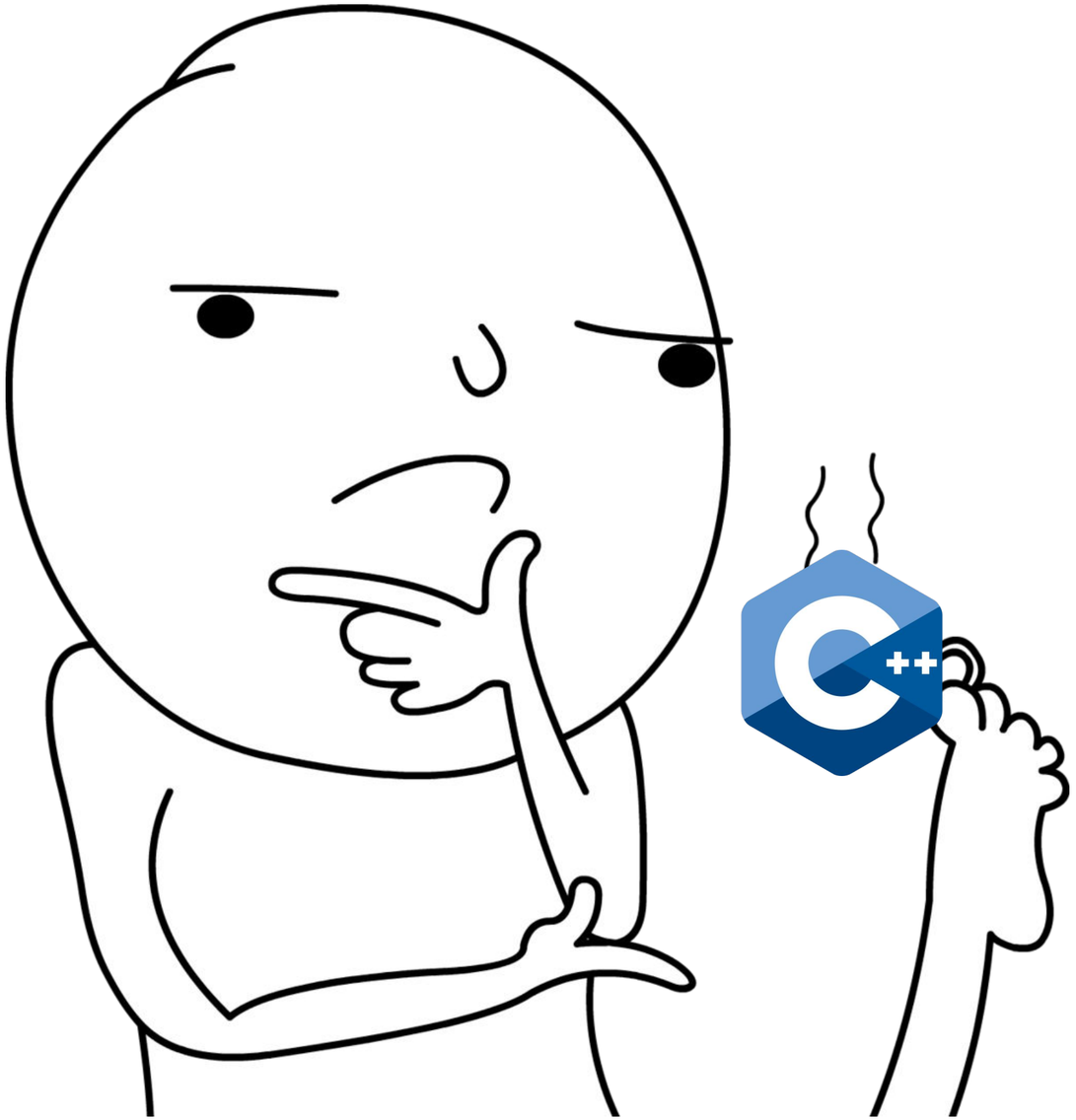
Recall

List Initialization

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


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

What questions do we have?



Initialization

What?: “Provides initial values at the time of construction” - *cppreference.com*

How? 🤔:

1. Direct initialization
2. Uniform initialization
3. **Structured Binding**

Structured Binding (C++ 17)

- A useful way to initialize some variables from data structures with fixed sizes at compile time

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- A useful way to initialize some variables from data structures with fixed sizes at compile time
- Ability to access multiple values returned by a function

Structured Binding (C++ 17)

```cpp
std::tuple<std::string, std::string, std::string> getClassInfo() {
    std::string className = "CS106L";
    std::string buildingName = "Thornton 110";
    std::string language = "C++";
    return {className, buildingName, language};
}

int main() {
    auto [className, buildingName, language] = getClassInfo();
    std::cout << "Come to " << buildingName << " and join us for " << className
              << " to learn " << language << "!" << std::endl;

    return 0;
}
```

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Notice - uniform initialization!

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    std::string className = "CS106L";
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    return {className, buildingName, language};
}

int main() {
    auto [className, buildingName, language] = getClassInfo();
    std::cout << "Come to " << buildingName << " and join us for " << className
              << " to learn " << language << "!" << std::endl;

    return 0;
}
```

Structured Binding (C++ 17)

```cpp
#include <iostream>
#include <tuple>
#include <string>

std::tuple<std::string, std::string, std::string> getClassInfo() {
    std::string className = "CS106L";
    std::string buildingName = "Turing Auditorium";
    std::string language = "C++";
    return {className, buildingName, language};
}

int main() {
    auto classInfo = getClassInfo();
    std::string className = std::get<0>(classInfo);
    std::string buildingName = std::get<1>(classInfo);
    std::string language = std::get<2>(classInfo);

    std::cout << "Come to " << buildingName << " and join us for " << className
              << " to learn " << language << "!" << std::endl;
    return 0;
}
```

Structured Binding (C++ 17)

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std::tuple<std::string, std::string, std::string> getClassInfo() {
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    return {className, buildingName, language};
}

int main() {
    auto classInfo = getClassInfo();
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    return {className, buildingName, language};
}

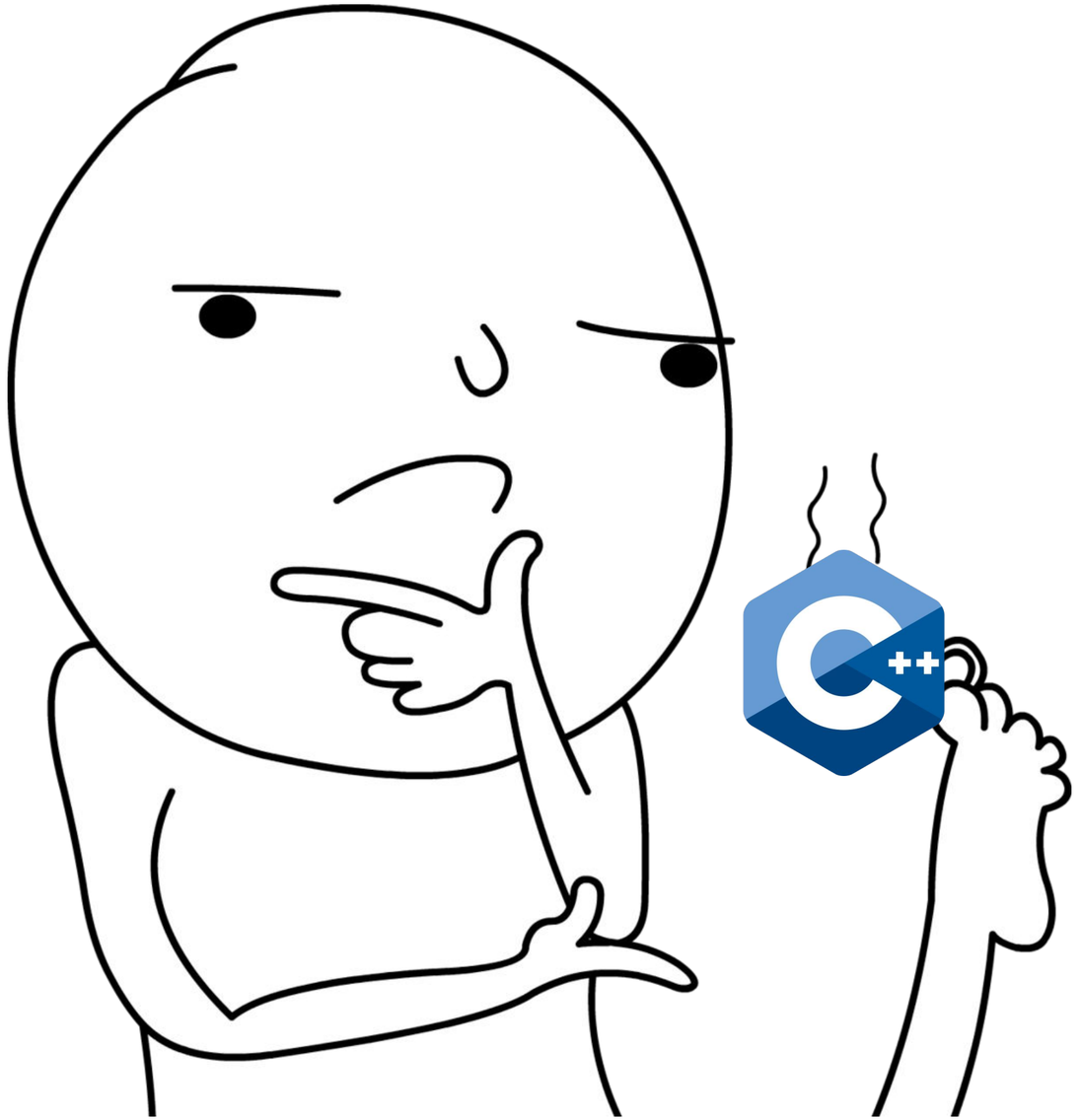
int main() {
    auto [className, buildingName, language] = getClassInfo();
    std::cout << "Come to " << buildingName << " and join us for " << className
              << " to learn " << language << "!" << std::endl;

    return 0;
}
```

Structured Binding (C++ 17)

- A useful way to initialize some variables from data structures with fixed sizes at compile time
- Ability to access multiple values returned by a function
- Can use on objects where the size is **known at compile-time**

What questions do we have?



Plan

1. Initialization
2. **References**
3. L-values vs R-values
4. Const
5. Compiling C++ programs

References

What?: “Declares a name variable as a reference”

tldr: a reference is an alias to an already-existing thing - *cppreference.com*

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How? 🤔:

Use an ampersand (&)

The & and the how

```
int num = 5;
int& ref = num;

ref = 10;  // Assigning a new value through the
reference
std::cout << num << std::endl;  // Output: 10
```

num is a variable of type int, that is assigned to have the value 5

The & and the how

```
int num = 5;
int& ref = num;

ref = 10;  // Assigning a new value through the
reference
std::cout << num << std::endl;  // Output: 10
```

`ref` is a variable of type `int&`, that is an *alias* to num

The & and the how

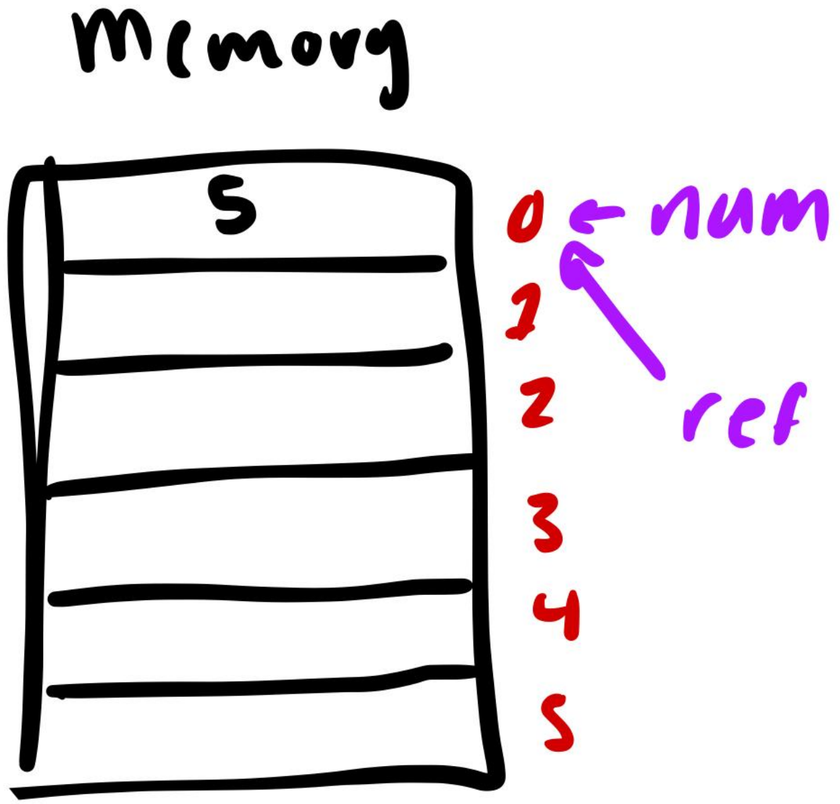
```cpp
int num = 5;
int& ref = num;

ref = 10;  // Assigning a new value through the reference
std::cout << num << std::endl;  // Output: 10
```

So when we assign 10 to ref, we also change the value of num, since `ref` is an *alias* for num

Visually 🖼️

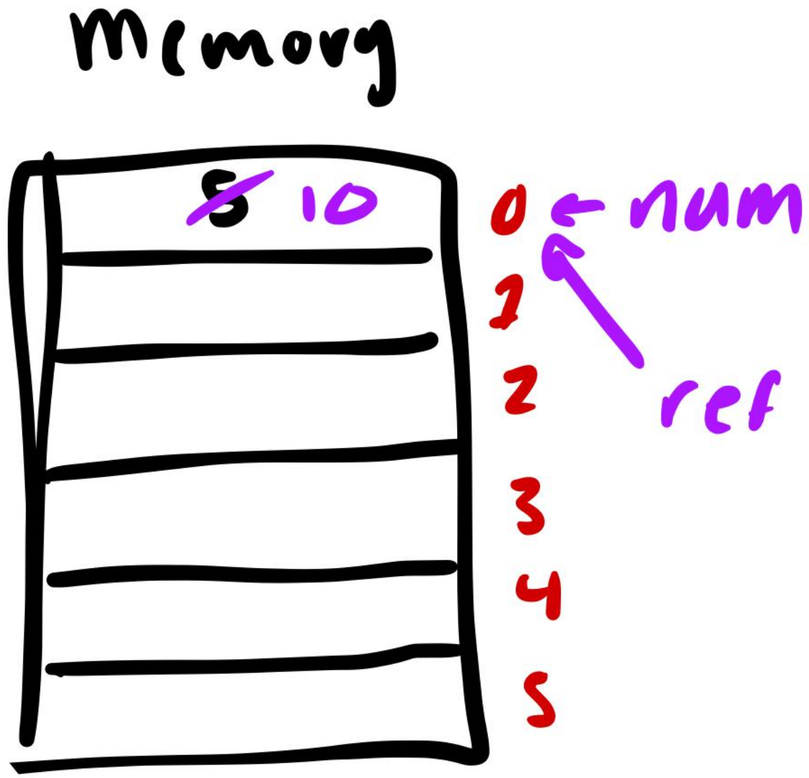
`num` is a variable of type `int`, that is assigned to have the value `5`

Visually 🖼️



`ref` is a variable of type `int&`, that is an *alias* to num

Visually 🖼️



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Pass by reference

In 106B we learn about “pass by reference”. We can apply the same ideas from referenced variables to functions! Take a look:

Pass by reference

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```cpp
#include <iostream>
#include <math.h>

// note the ampersand!
void squareN(int& n) {
    // calculates n to the power of 2
    n = std::pow(n, 2);
}

int main() {
    int num = 2;
    squareN(num);
    std::cout << num << std::endl;

    return 0;
}
```

Pass by reference

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// note the ampersand!
void squareN(int& n) {
    // calculates n to the power of 2
    n = std::pow(n, 2);
}

int main() {
    int num = 2;
    squareN(num);
    std::cout << num << std::endl;

    return 0;
}
```

Pass by reference

In 106B we learn about “pass by reference”. We can apply the same ideas from referenced variables to functions! Take a look:

Notice!!: n is being passed into **squareN** by reference, denoted by the ampersand!

```
#include <iostream>
#include <math.h>

// note the ampersand!
void squareN(int& n) {
    // calculates n to the power of 2
    n = std::pow(n, 2);
}

int main() {
    int num = 2;
    squareN(num);
    std::cout << num << std::endl;

    return 0;
}
```

Pass by reference

In 106B we learn about “pass by reference”. We can apply the same ideas from referenced variables to functions! Take a look:

So what ❓: This means that **n** is actually going to be modified inside of **squareN**.

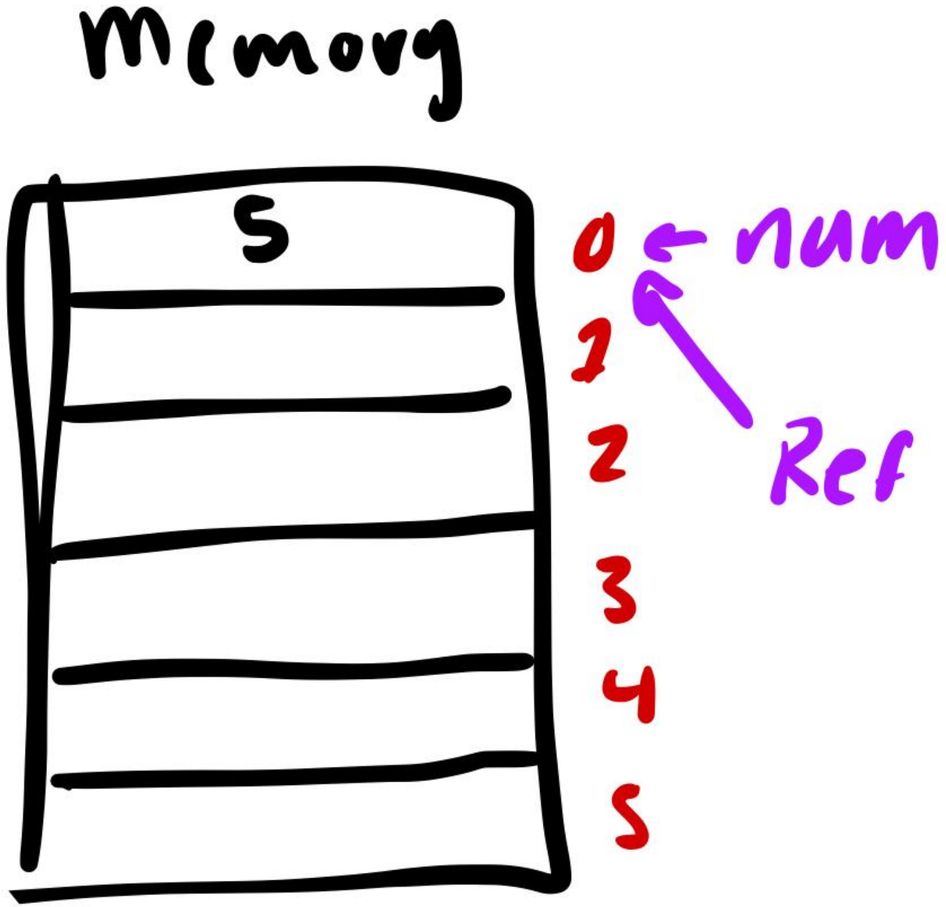
```cpp
#include <iostream>
#include <math.h>

// note the ampersand!
void squareN(int& n) {
    // calculates n to the power of 2
    n = std::pow(n, 2);
}

int main() {
    int num = 2;
    squareN(num);
    std::cout << num << std::endl;

    return 0;
}
```

Recall



A reference *refers* to the same memory as its associated variable!

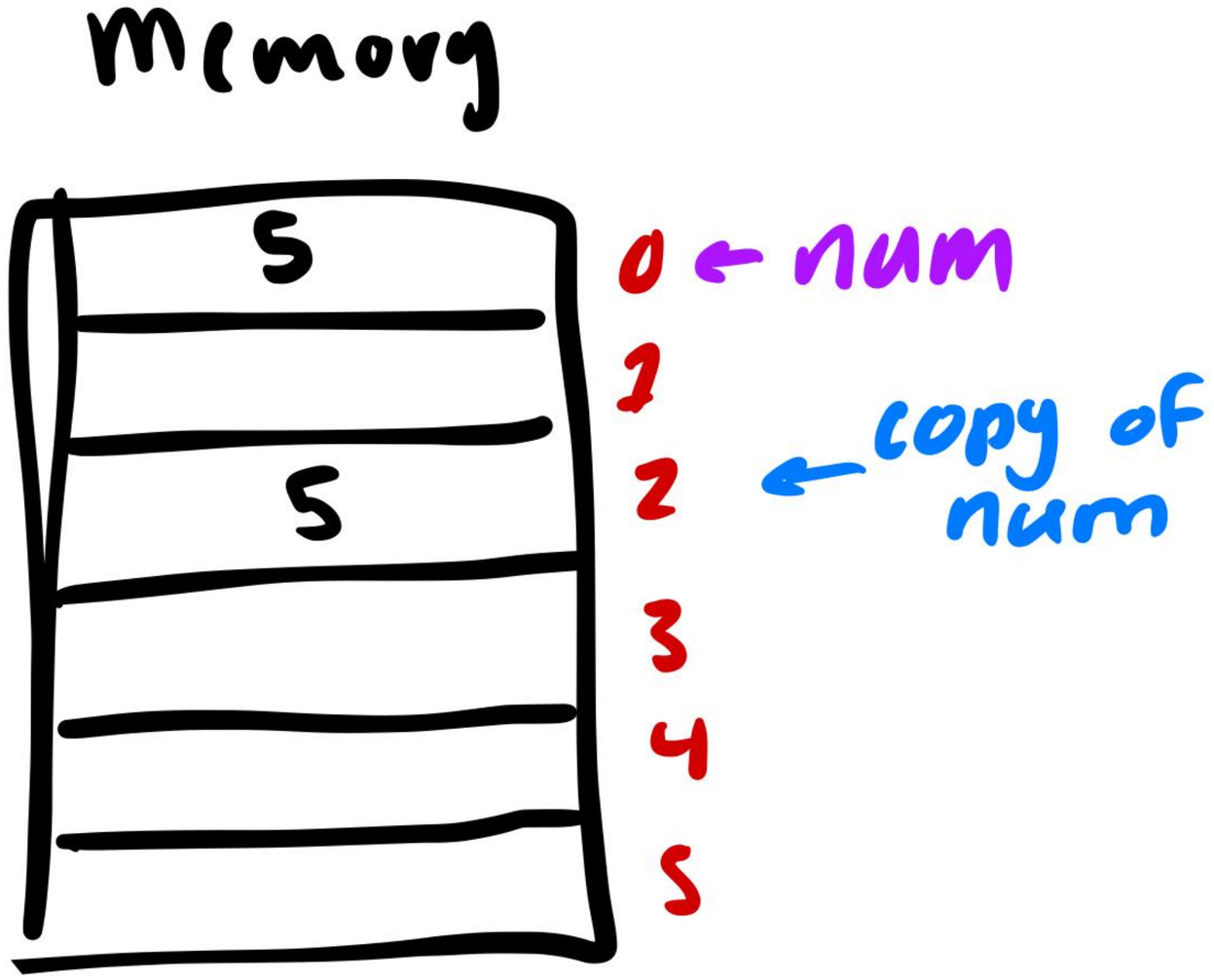
Recall

Passing in a variable by ***reference*** into a function just means "**Hey take in the actual piece of memory, don't make a copy!**"

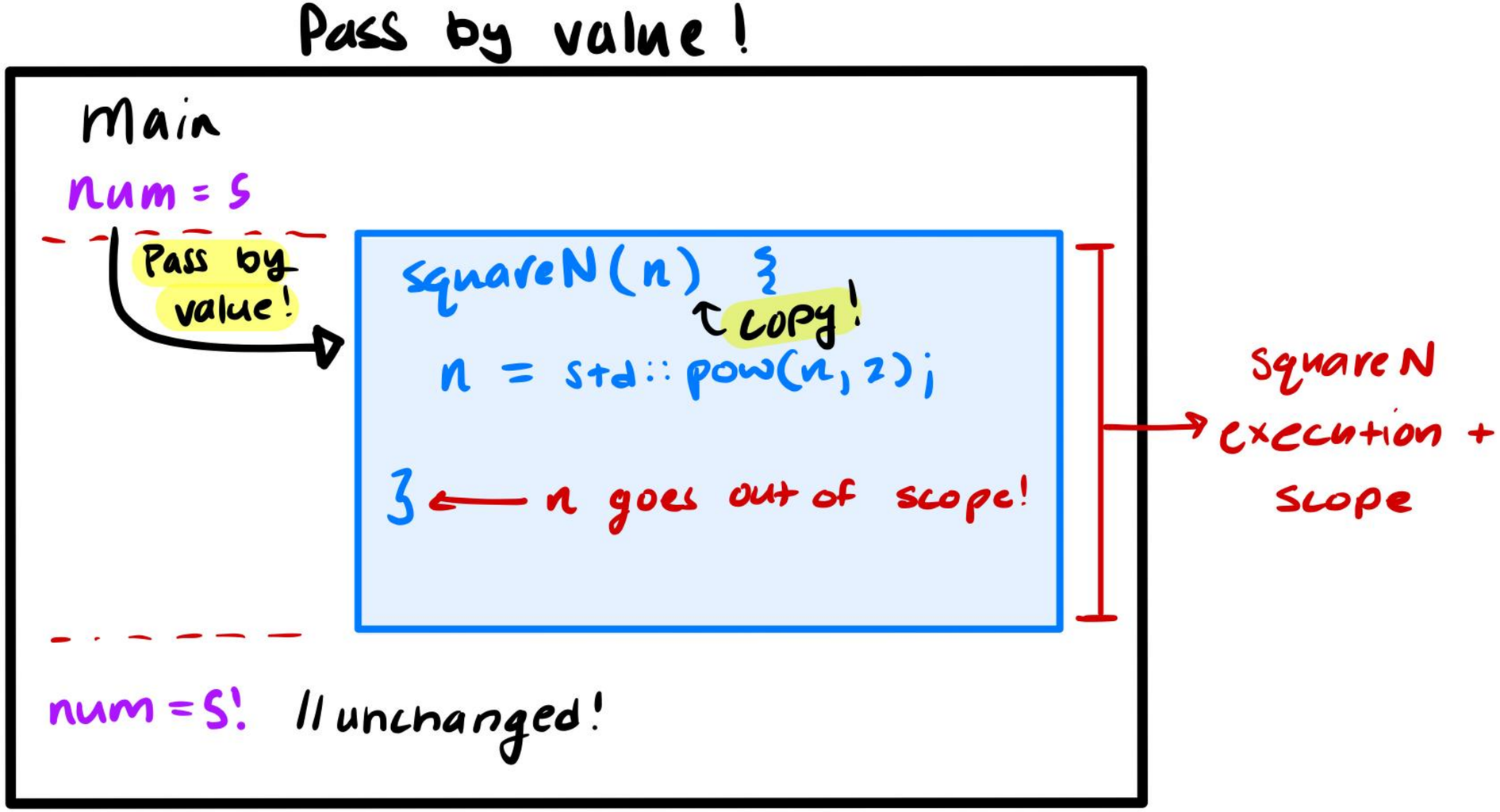
Passing by value

Passing in a variable by ***value*** into a function just means "**Hey make a copy, don't take in the actual variable!**"

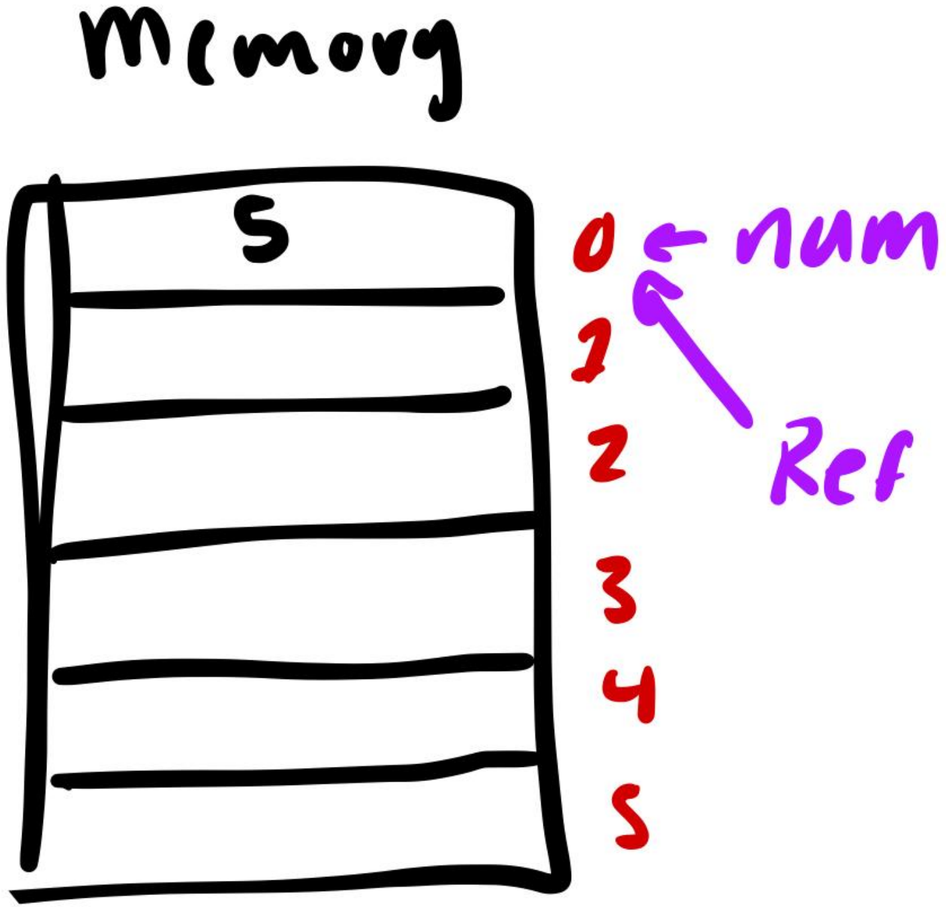
What does that look like?



Passing by value (makes a copy)

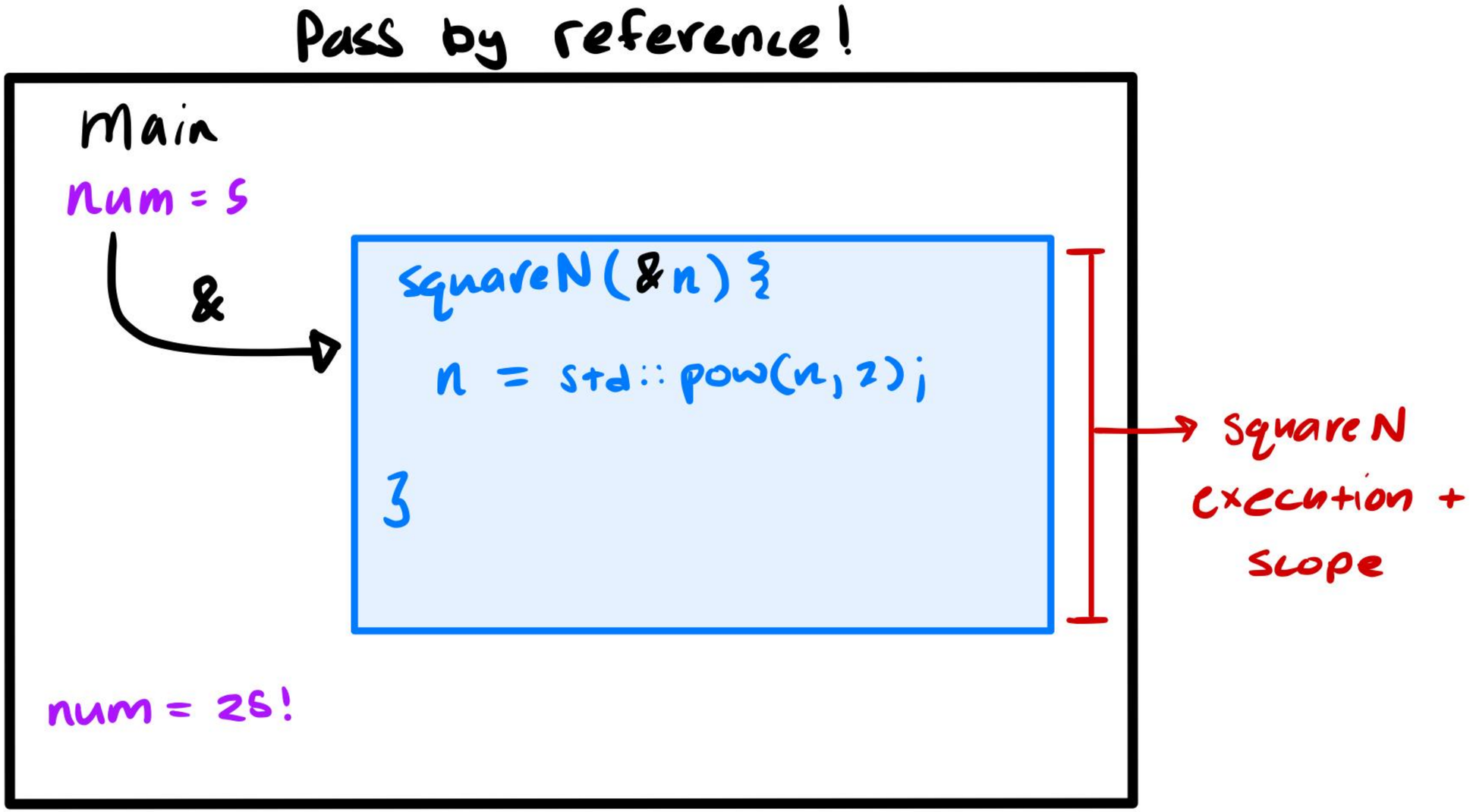


Recall

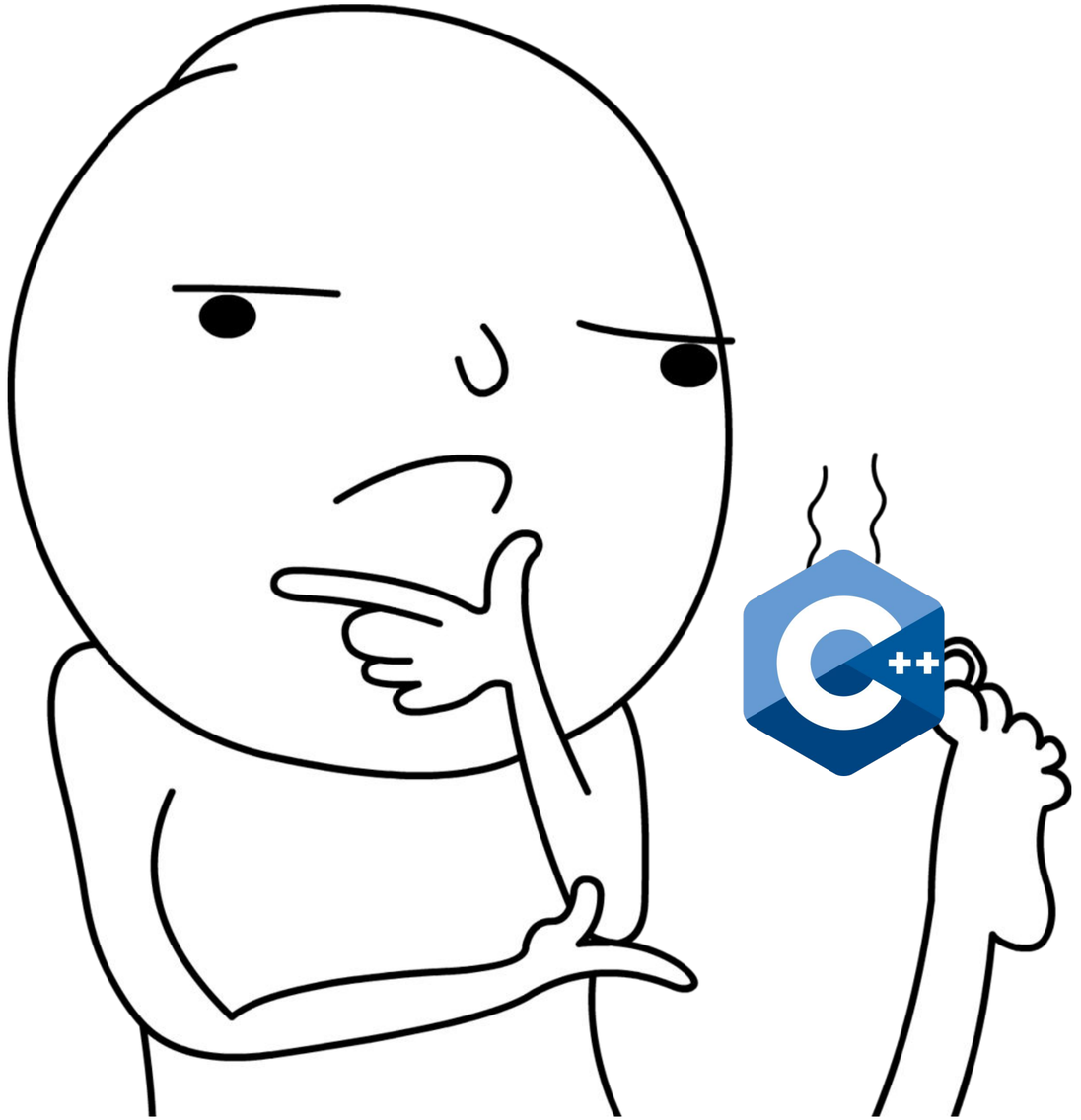


A reference *refers* to the same memory as its associated variable!

Passing by reference



What questions do we have?



OK! Let’s take a look at an edge case!

```
#include <iostream>
#include <math.h>
#include <vector>

void shift(std::vector<std::pair<int, int>> &nums) {
    for (auto [num1, num2] : nums) {
        num1++;
        num2++;
    }
}
```

A classic reference-copy bug

```
#include <iostream>
#include <math.h>
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void shift(std::vector<std::pair<int, int>> &nums) {
    for (auto [num1, num2] : nums) {
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🤔 But nums is passed in by reference...

A classic reference-copy bug

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void shift(std::vector<std::pair<int, int>> &nums) {
    for (auto [num1, num2] : nums) {
        num1++;
        num2++;
    }
}
```

Note the structured binding!

🤔 But nums is passed in by reference...

A classic reference-copy bug

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#include <math.h>
#include <vector>

void shift(std::vector<std::pair<int, int>> &nums) {
    for (auto [num1, num2] : nums) {
        num1++;
        num2++;
    }
}
```

We're **not** modifying nums in this function!

A classic reference-copy bug

```
#include <iostream>
#include <math.h>
#include <vector>

void shift(std::vector<std::pair<int, int>> &nums) {
    for (auto [num1, num2] : nums) {
        num1++;
        num2++;
    }
}
```

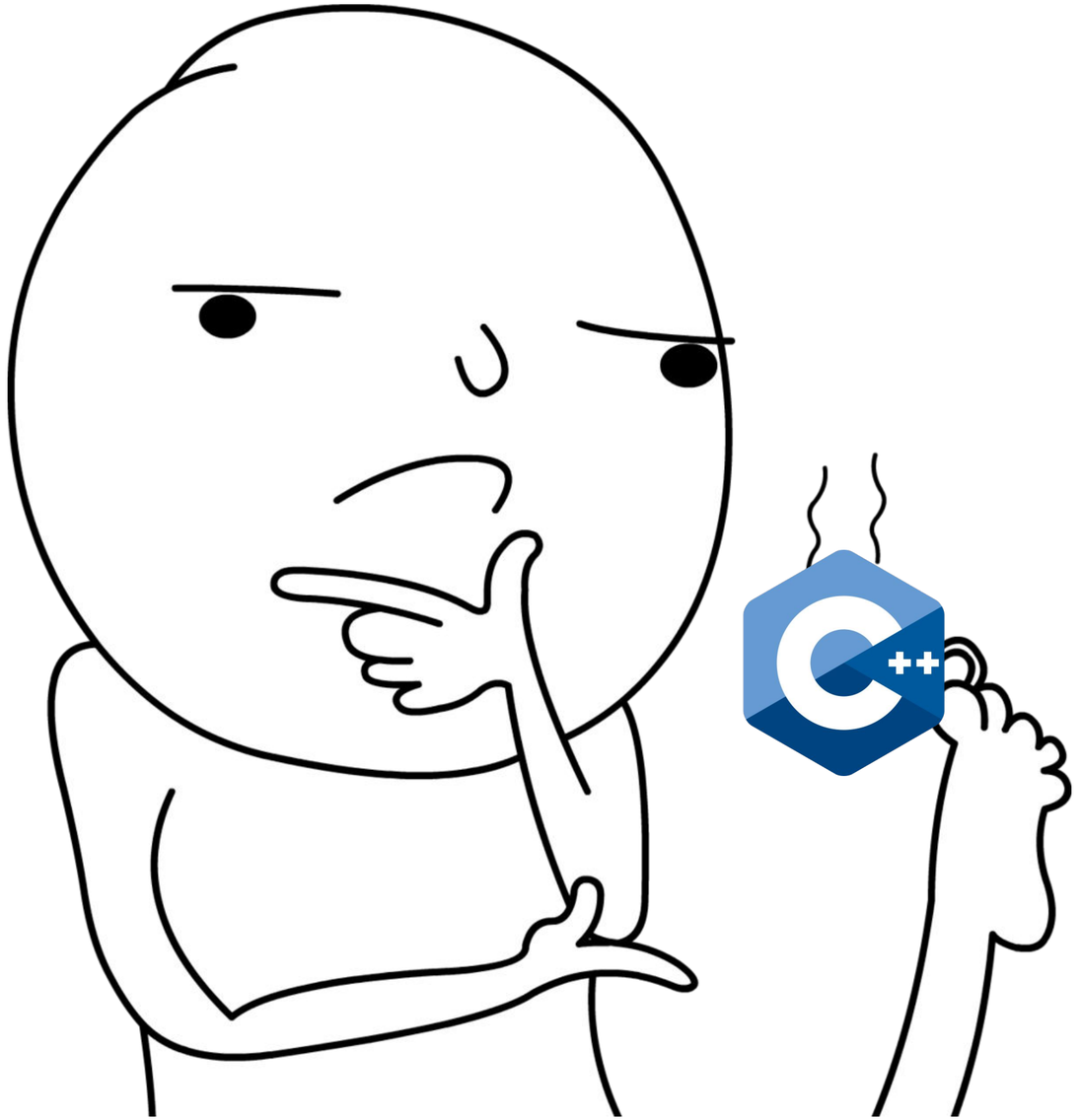
We are modifying the `std::pair`'s inside of nums

A classic reference-copy bug: fixed!

```
#include <iostream>
#include <math.h>
#include <vector>

void shift(std::vector<std::pair<int, int>> &nums) {
    for (auto& [num1, num2] : nums) {
        num1++;
        num2++;
    }
}
```

What questions do we have?



Plan

1. Initialization
2. References
3. **L-values vs R-values**
4. Const
5. Compiling C++ programs

l-values and r-values

An **l-value**

An **l-value** can be to the left ***or*** the right of an equal sign!

l-values and r-values

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What's an example?
x can be an l-value for instance because you can have something like:
int y = **x**

✅ **AND** ✅

x = 344

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21 can be an r-value for instance because you can have something like:
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l-values and r-values

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An **r-value**

An **r-value** can be ⭐***ONLY***⭐ to the right of an equal sign!

What's an example?
21 can be an r-value for instance because you can have something like:
int y = **21**

❌ **BUT NOT** ❌

21 = x

l-value and r-value PAIN

```cpp
#include <stdio.h>
#include <cmath>
#include <iostream>

int squareN(int& num) {
    return std::pow(num, 2);
}

int main()
{
    int lValue = 2;
    auto four = squareN(lValue);
    auto fourAgain = squareN(2);
    std::cout << four << std::endl;
    return 0;
}
```

l-value and r-value PAIN

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#include <cmath>
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is int& num an l-value?

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{
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    auto four = squareN(lValue);
    auto fourAgain = squareN(2);
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}
```

is int& num an l-value?

It turns out that num is an l-value! But Why?

1. Remember what we said about r-values are temporary. Notice that num is being passed in by reference!

1. We ***cannot*** pass in an r-value by reference because they're temporary!

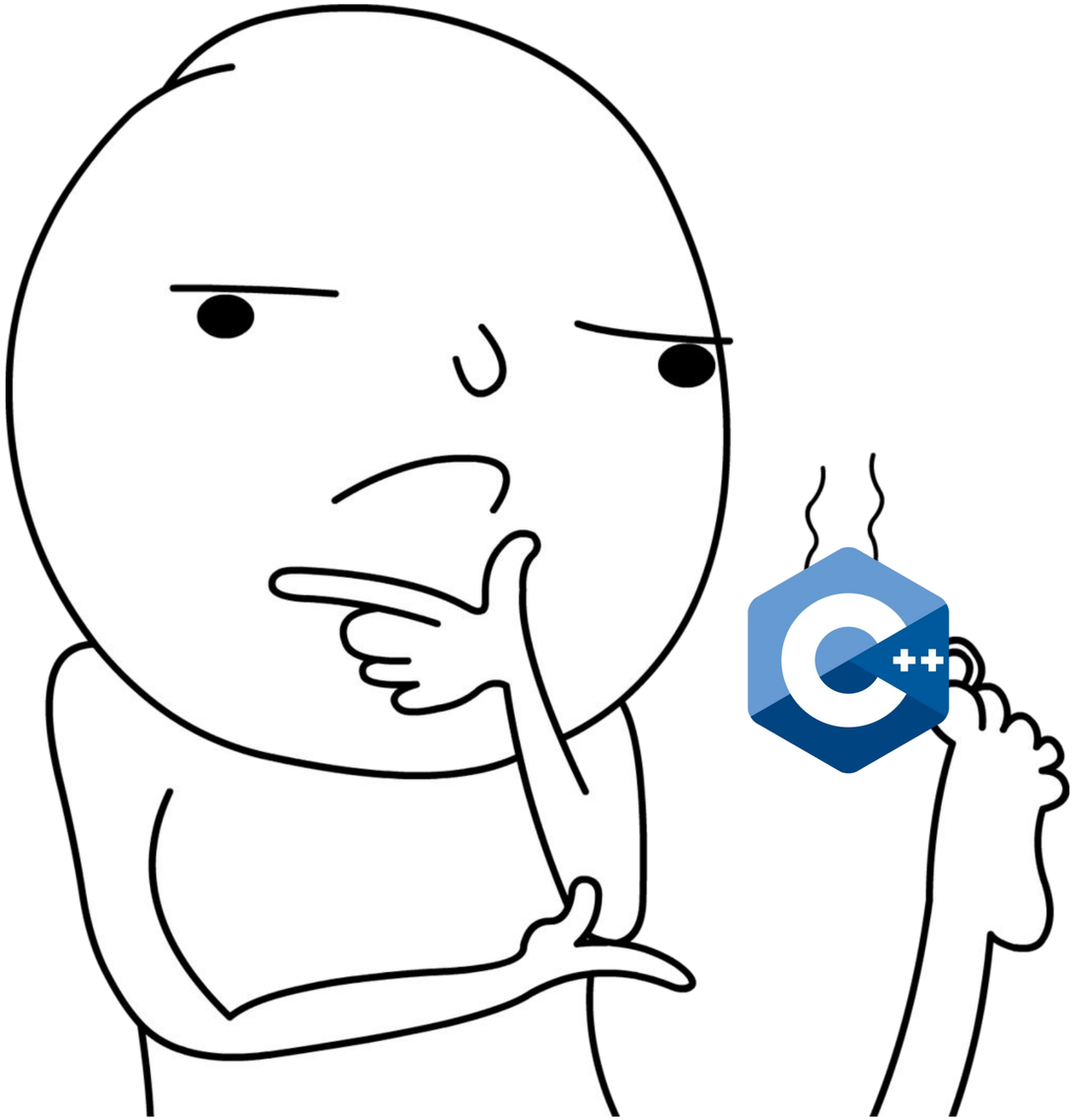
l-value and r-value PAIN

```cpp
#include <stdio.h>
#include <cmath>
#include <iostream>

int squareN(int& num) {
    return std::pow(num, 2);
}

int main()
{
    int lv
    auto f
    auto f
    std::cout << four << std::endl;
    return 0;
}
```

Well what happens?

```
lvalue_pain.cpp:5:5: note: candidate function not viable: expects an lvalue for 1st
argument
int squareN(int& num) {
    ^
1 error generated.
```

What questions do we have?



Plan

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`const`

What?:

A qualifier for objects that declares they cannot be modified – *cppreference.com*

const

```cpp
#include <iostream>
#include <vector>

int main()
{
    std::vector<int> vec{ 1, 2, 3 };  /// a normal vector
    const std::vector<int> const_vec{ 1, 2, 3 };  /// a const vector
    std::vector<int>& ref_vec{ vec };  /// a reference to 'vec'
    const std::vector<int>& const_ref{ vec };  /// a const reference

    vec.push_back(3);
    const_vec.push_back(3);
    ref_vec.push_back(3);
    const_ref.push_back(3);

    return 0;
}
```

const

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    std::vector<int>& ref_vec{ vec };  /// a reference to 'vec'
    const std::vector<int>& const_ref{ vec };  /// a const reference

    vec.push_back(3); /// this is ok!
    const_vec.push_back(3);
    ref_vec.push_back(3);
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    const_vec.push_back(3); /// no, this is const!
    ref_vec.push_back(3);
    const_ref.push_back(3);

    return 0;
}
```

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```cpp
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    vec.push_back(3); /// this is ok!
    const_vec.push_back(3); /// no, this is const!
    ref_vec.push_back(3); /// this is ok, just a reference!
    const_ref.push_back(3);

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    const std::vector<int>& const_ref{ vec };  /// a const reference

    vec.push_back(3); /// this is ok!
    const_vec.push_back(3); /// no, this is const!
    ref_vec.push_back(3); /// this is ok, just a reference!
    const_ref.push_back(3); /// this is const, compiler error!

    return 0;
}
```

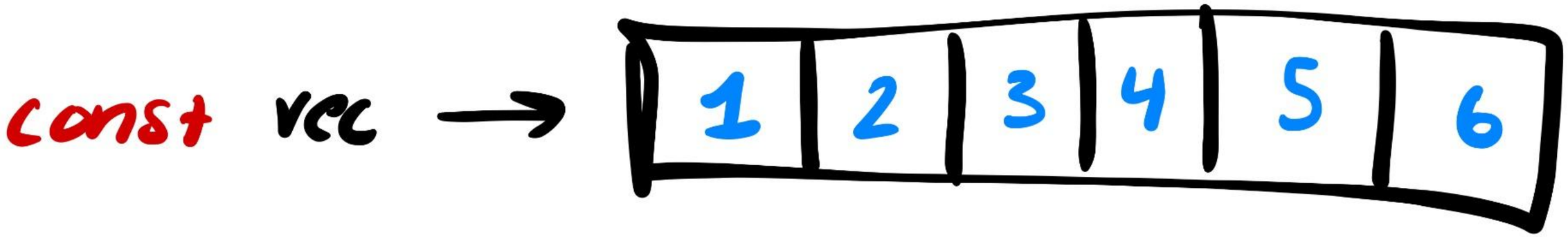
You can’t declare a non-const reference to a const variable

```cpp
#include <iostream>
#include <vector>

int main()
{
    /// a const vector
    const std::vector<int> const_vec{ 1, 2, 3 };
    std::vector<int>& bad_ref{ const_vec };  /// BAD

    return 0;
}
```

You can’t declare a non-const reference to a const variable



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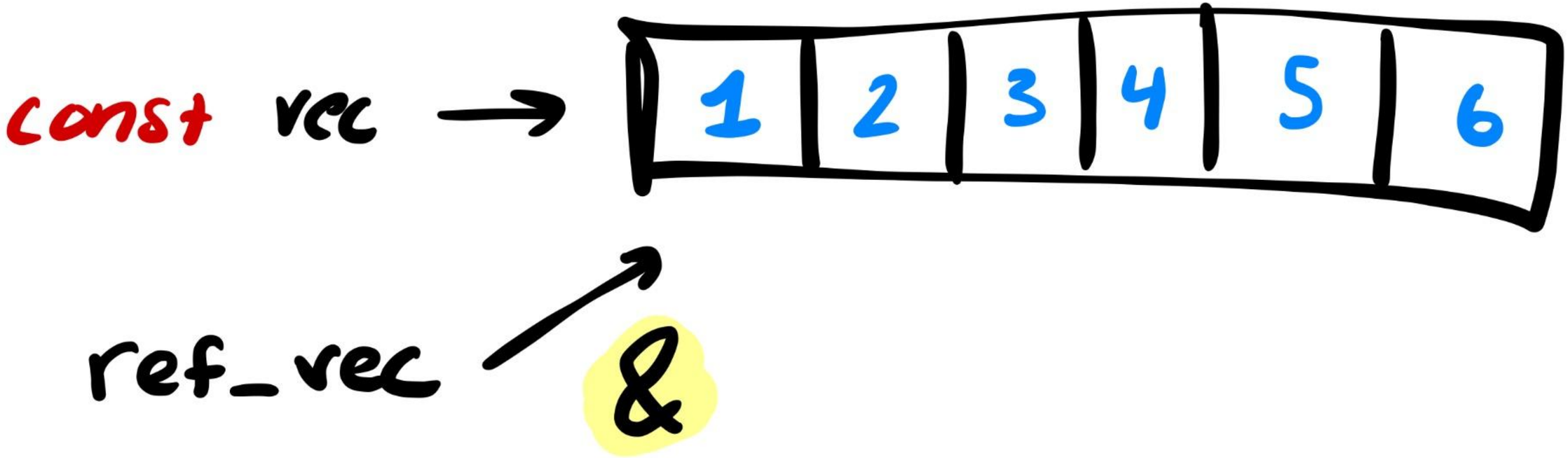

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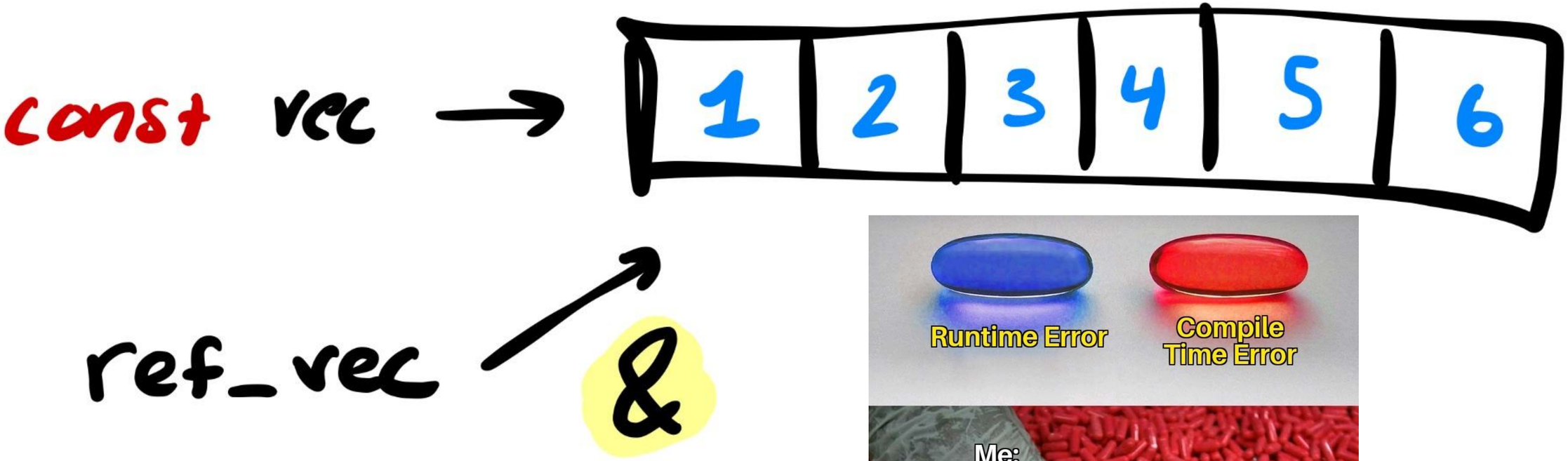

[meme sauce]

You can’t declare a non-const reference to a const variable

```cpp
#include <iostream>
#include <vector>

int main()
{
    /// a const vector
    const std::vector<int> const_vec{ 1, 2, 3 };
    const std::vector<int>& bad_ref{ const_vec }; /// Good!

    return 0;
}
```

Plan

1. Initialization
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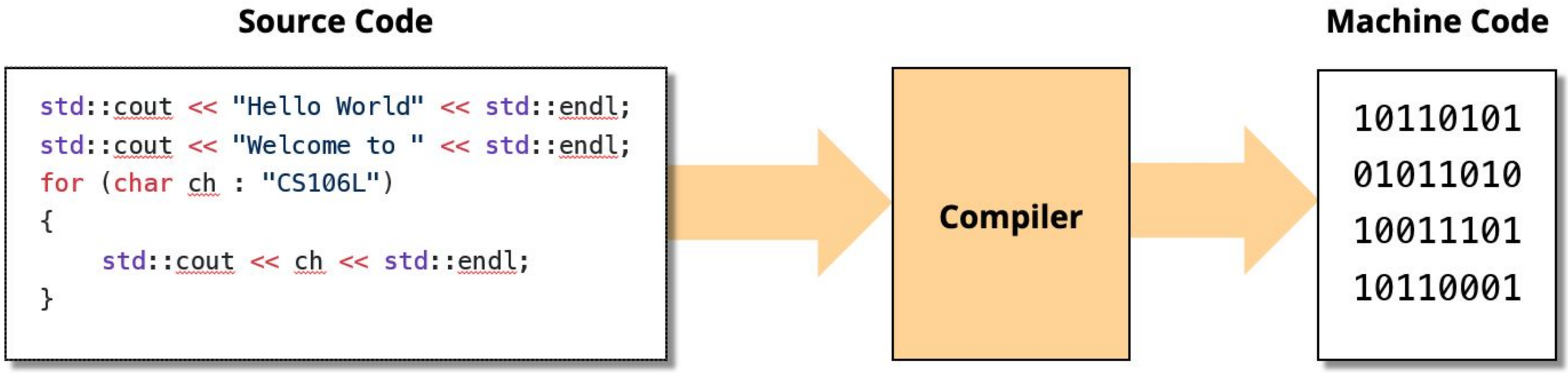
5. **Compiling C++ programs**

Compiling C++ Programs

Everything you need to know about compiling a program for your first assignment.

We'll be making use of VSCode which makes C++ compilation quite easy.

Compiling C++ Programs



What you need to know

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```
g++ -std=c++11 main.cpp -o main
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This is the compiler command

What you need to know

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g++ -std=c++11 main.cpp -o main
```

This specifies the c++ version you want to compile in

What you need to know

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This is the source file

What you need to know

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```
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```

This means that you're going to give a specific name to your executable

What you need to know

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- ***Here is how to compile a program using g++***

```
g++ -std=c++11 main.cpp -o main
```

In this case it's `main`

What you need to know

- C++ is a compiled language
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- A few popular compilers include clang and g++
- ***Here is how to compile a program using g++***

```
g++ -std=c++11 main.cpp
```

This is also valid, your executable will be something like `a.out`

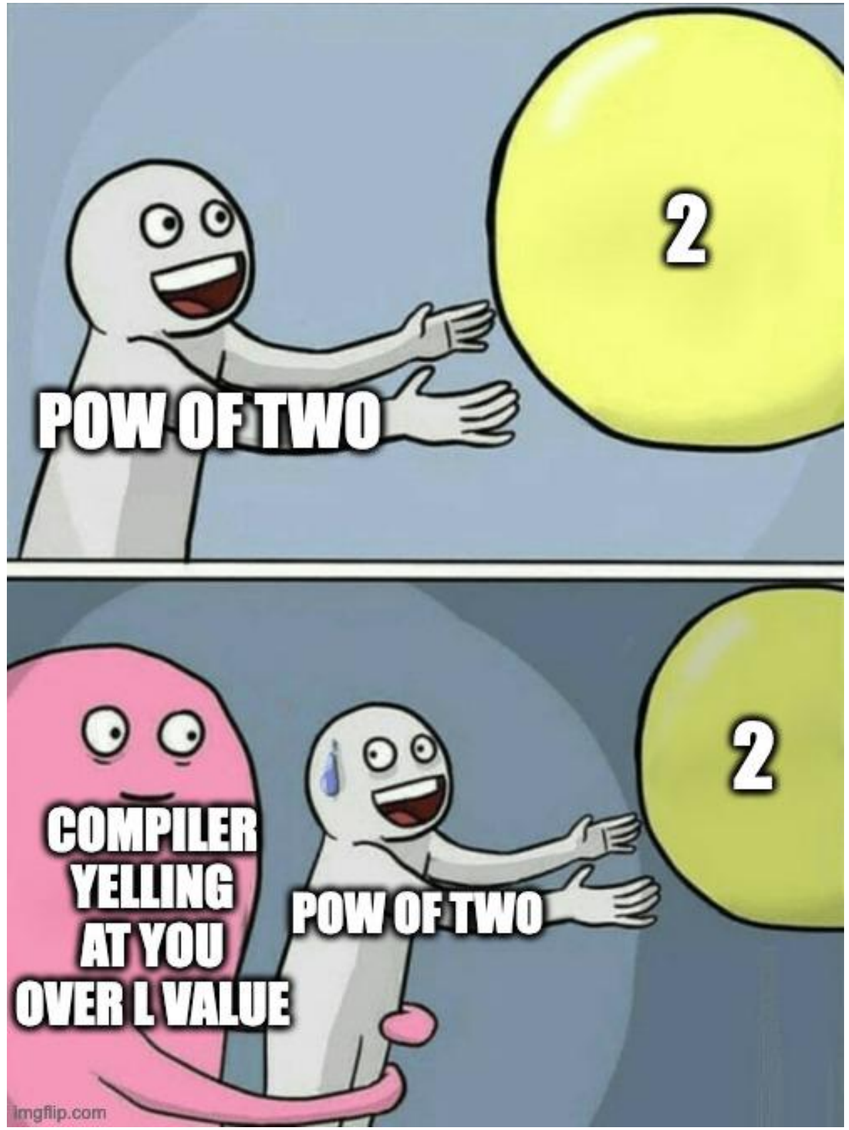
What you need to know

- C++ is a compiled language
- There are computer programs called compilers
- A few popular compilers include clang and g++
- ***Here is how to compile a program using g++***

```
g++ -std=c++11 main.cpp
```

- This is all you need for now! We will talk about large project compilation in another lecture and explore things like **`CMAKE`** and **`make`**!

A recap of today!



In conclusion

- Use uniform initialization — it works for all types and objects!
- References are a way to alias variables!
- You can only reference an l-value!
- Const is a way to ensure that you can’t modify a variable