CS106L Lecture 3:

Initialization & References

Fall 2023

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Attendance

https://forms.gle/pjSgfR32DaEoagKDA

A quick recap

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

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   a. Only use when the type is obvious
   b. Or 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. Only use when the type is obvious
   b. Or when the type is ***annoyingly*** verbose to write out

2. Structs are a way to pack a bunch of variables into one type

Plan

1. Initialization
2. References
3. L-values vs R-values
4. Const

Initialization

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

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

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int main() {
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}
```

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

    // 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;
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    return 0;
}
```

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What happened? 🧐

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}
```

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

What happened? 🧐

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int main() {
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}
```

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

What happened? 🧐

```cpp
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    // ...

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    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**

Uniform initialization (C++11)

```cpp
#include <iostream>

int main() {
    // NOTICE: brackets!
    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 ‼️ :

the curly braces!

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

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Compilation failed due to following error(s).

```
main.cpp: In function ‘int main()’:
main.cpp:13:20: error: narrowing conversion of ‘1.2e+1’ from ‘double’ to ‘int’ [-Wnarrowing]
   13 |     int numOne{12.0};
      |                    ^
main.cpp:14:20: error: narrowing conversion of ‘1.2e+1’ from ‘double’ to ‘int’ [-Wnarrowing]
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```

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    return 0;
}
```

Notice ‼️:

`12` instead of `12.0`

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}
```

Notice ‼️ :

`12` instead of `12.0`

```
numOne is: 12
numTwo is: 12


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Uniform initialization (C++11)

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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)

2. 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;
}
```

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


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

Uniform initialization (Vector)

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

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

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

    return 0;
}
```

```
1 2 3 4 5


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

Structs in code

```
struct Student {
    string name; // these are called fields
    string state; // separate these by semicolons
    int age;
};

Student s;
s.name = "Haven";
s.state = "AR";
s.age = 21; // use . to access fields
```

Structs in code

```
struct Student {
    string name; // these are called fields
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    int age;
};
```

```
Student s;
s.name = "Haven";
s.state = "AR";
s.age = 21; // use . to access fields
```

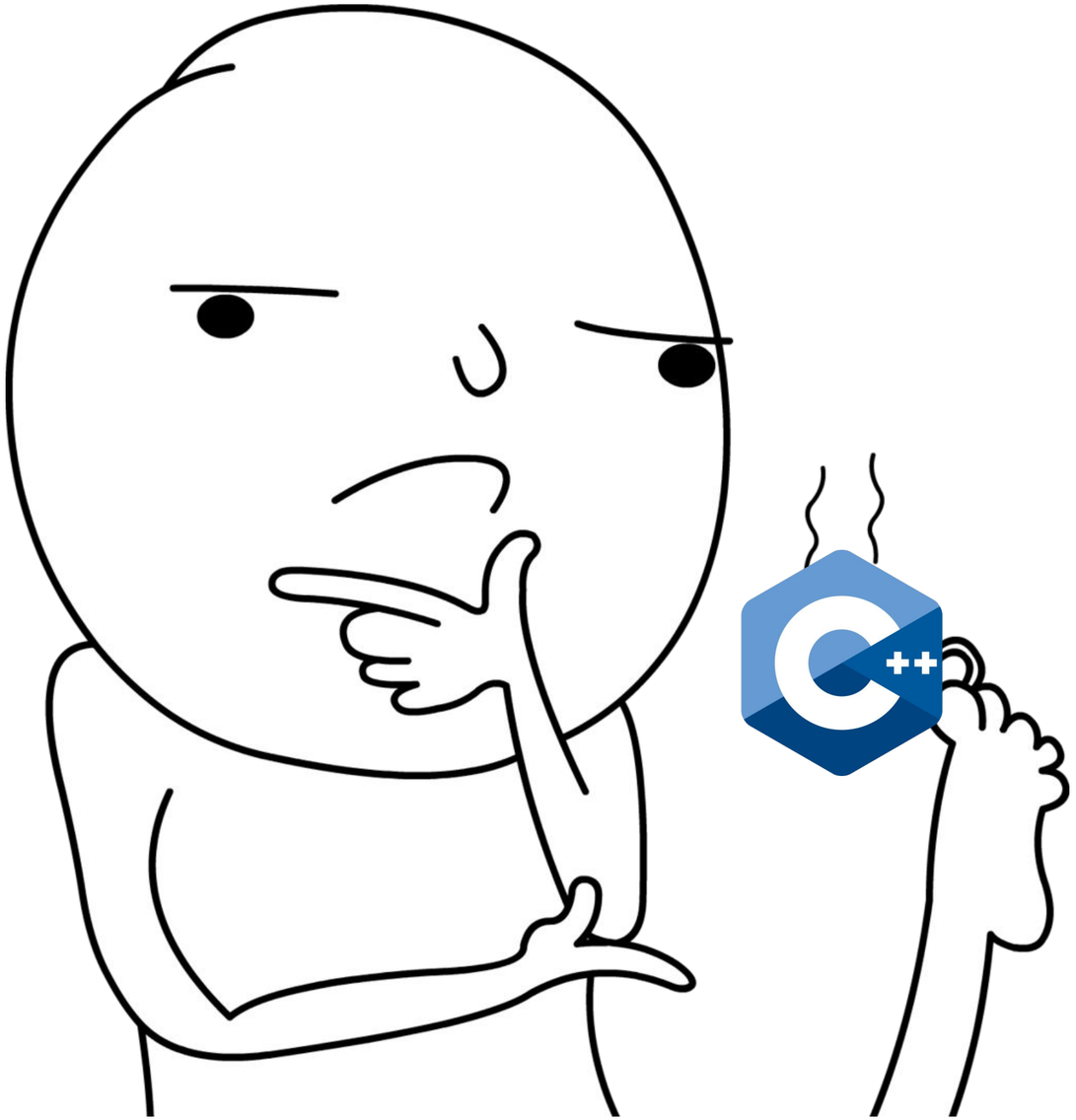
Before! 😪

```
struct Student {
  string name;
  string state;
  int age;
};

Student s{"Haven", "AR", 21};
```

After!

What questions do we have?



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 = "Turing Auditorium";
  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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int main() {
  auto [className, buildingName, language] = getClassInfo();
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```

Structured Binding (C++ 17)

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#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;
}
```

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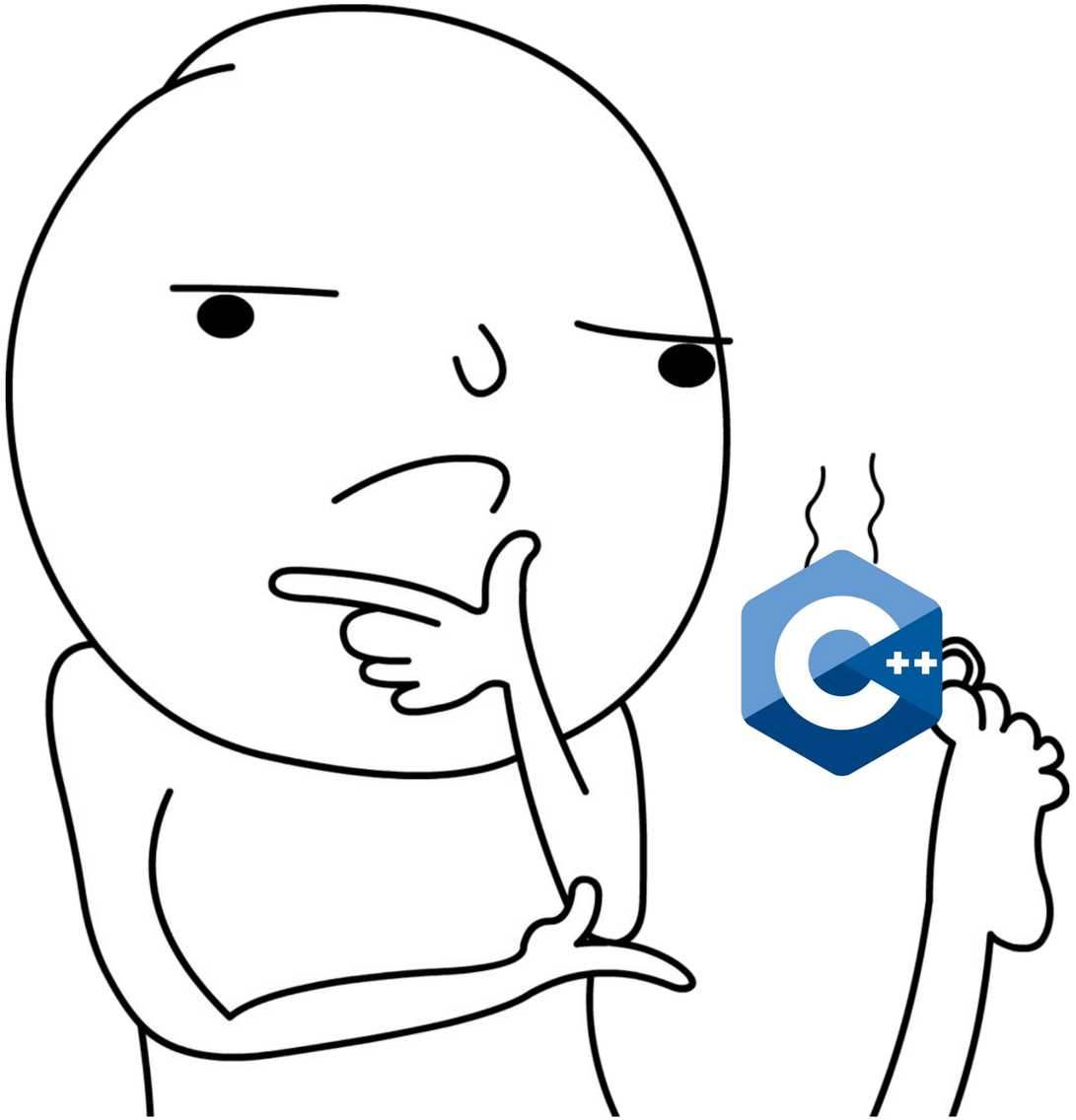
```

What questions do we have?



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

```cpp
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

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int num = 5;
int& ref = num;
ref = 10; // Assigning a new value through the reference
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`ref` is a variable of type `int&`, that is an *alias* to `num`

The & and the how

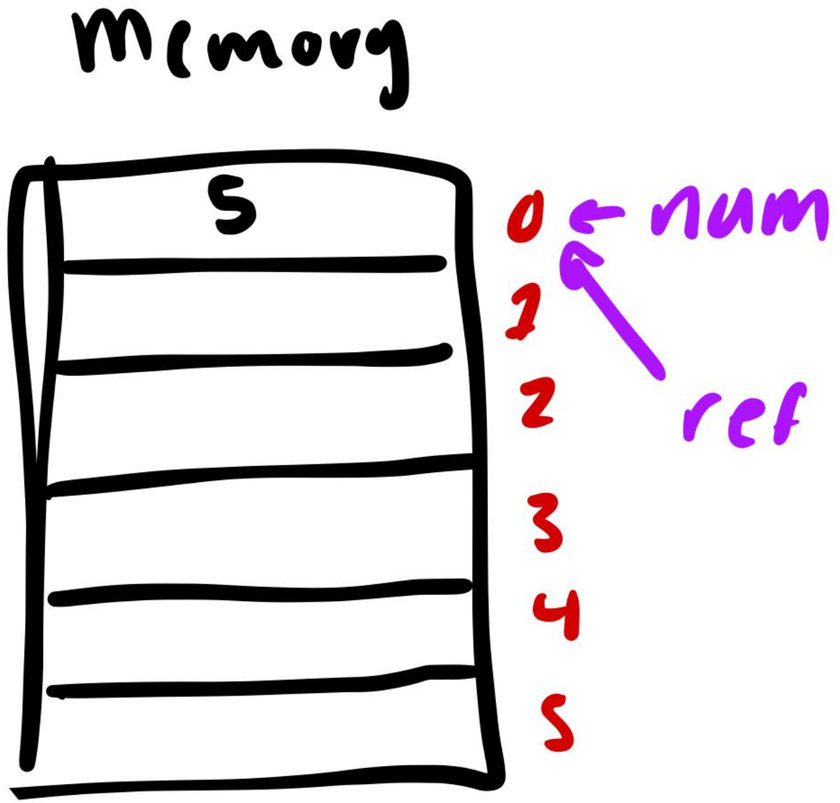
```cpp
int num = 5;
int& ref = num;
ref = 10; // Assigning a new value through the reference
std::cout << num << std::endl; // Output: 10
```

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

Visually 🖼️

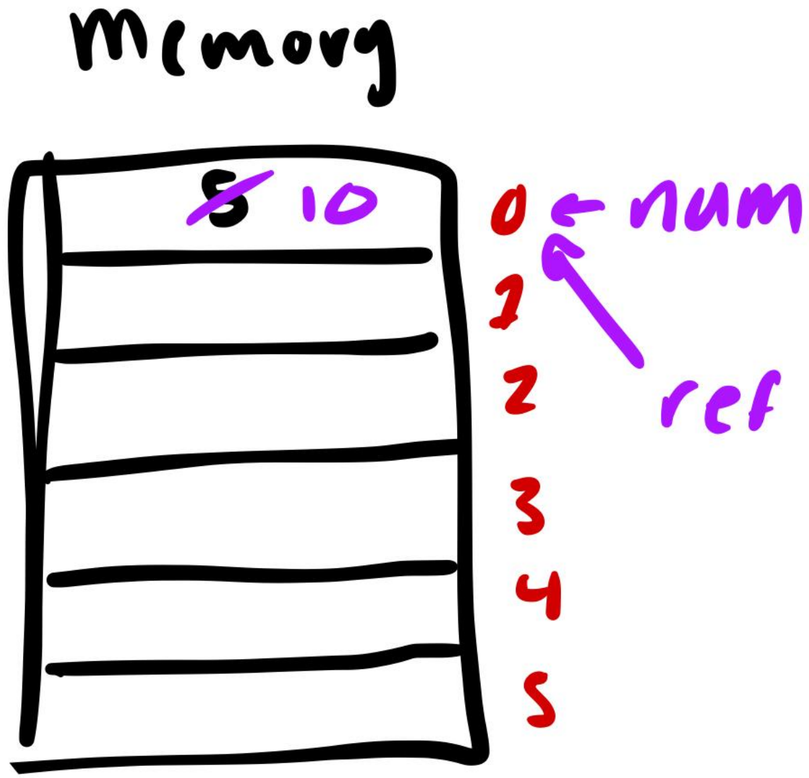
`num` is a variable of type `int`, that is assigned to have the value 5

Visually 🖼️



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

Visually 🏞️



When we change `ref`, we therefore also change `num` since it is a reference!

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:

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

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

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

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:

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

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

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!

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

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

int main() {
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  std::cout << num << std::endl;
}
```

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

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#include <math.h>

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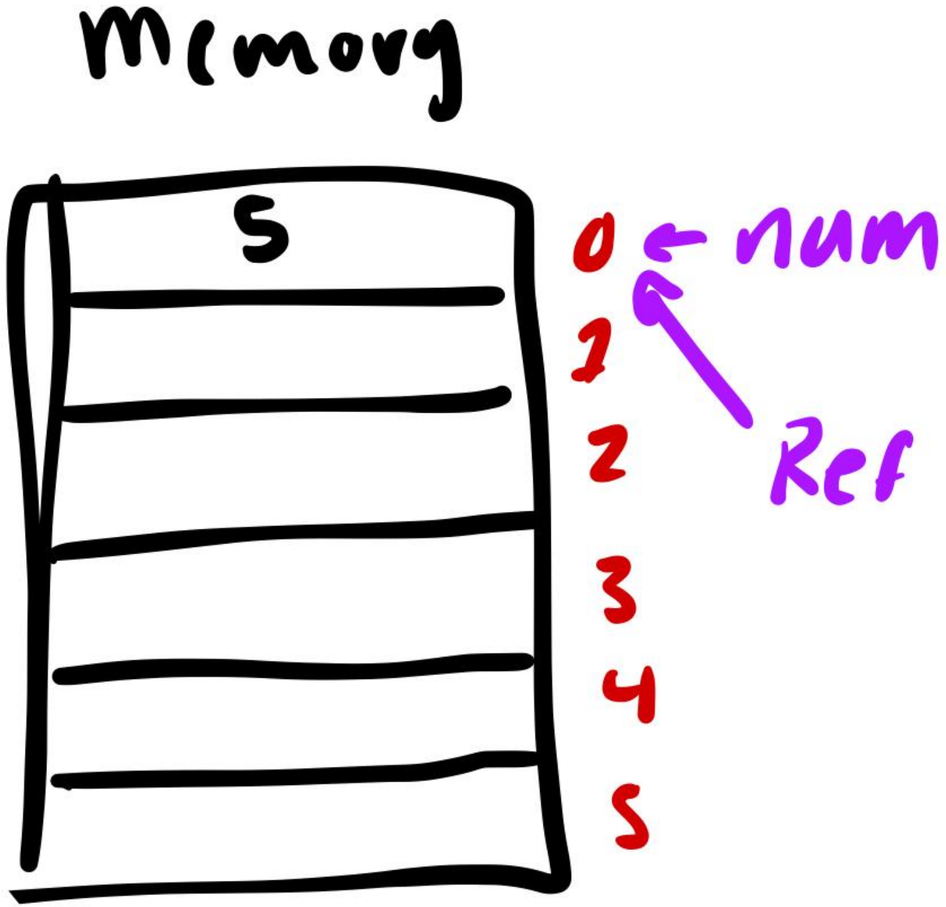
}
```

Recall



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

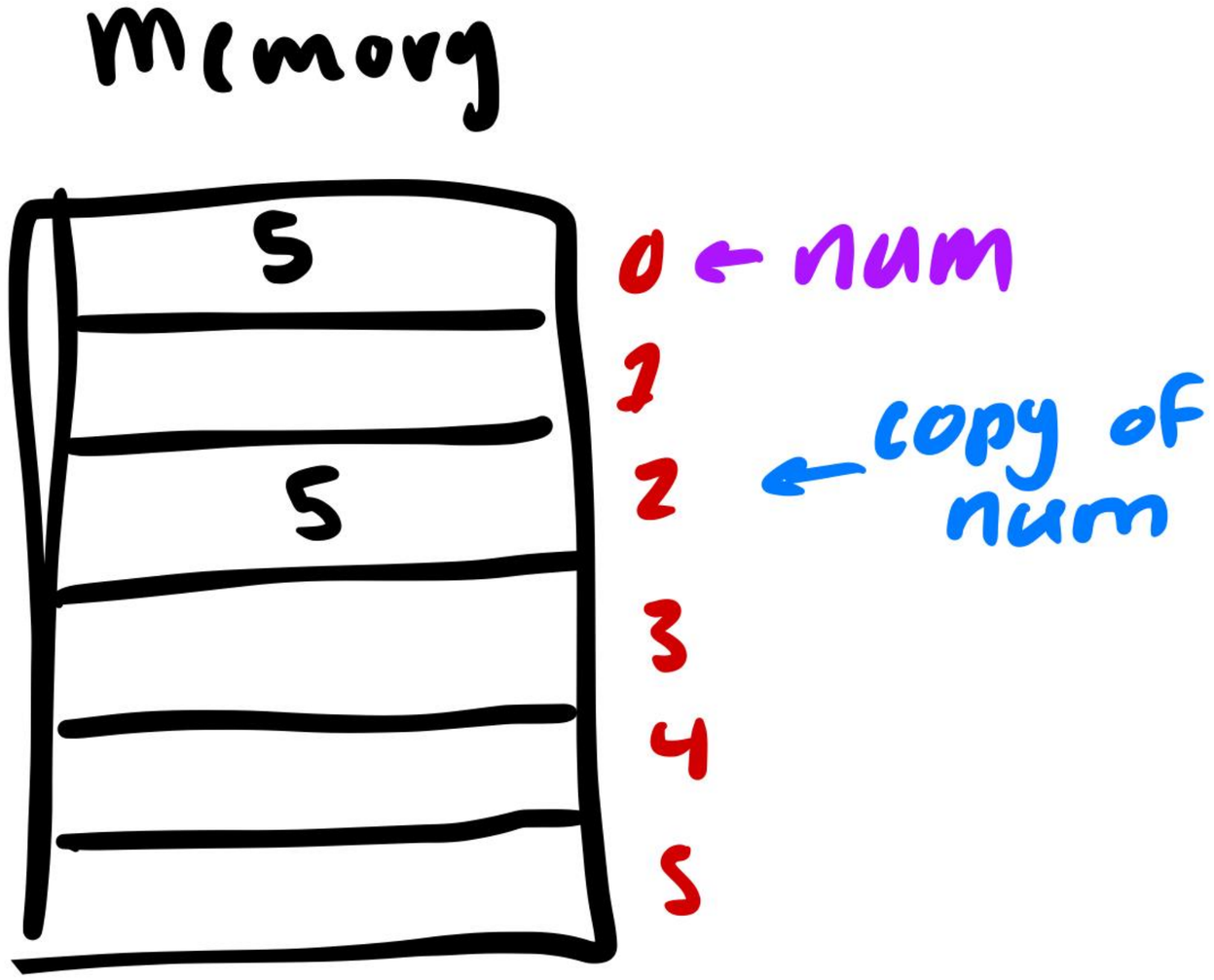
Recall

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

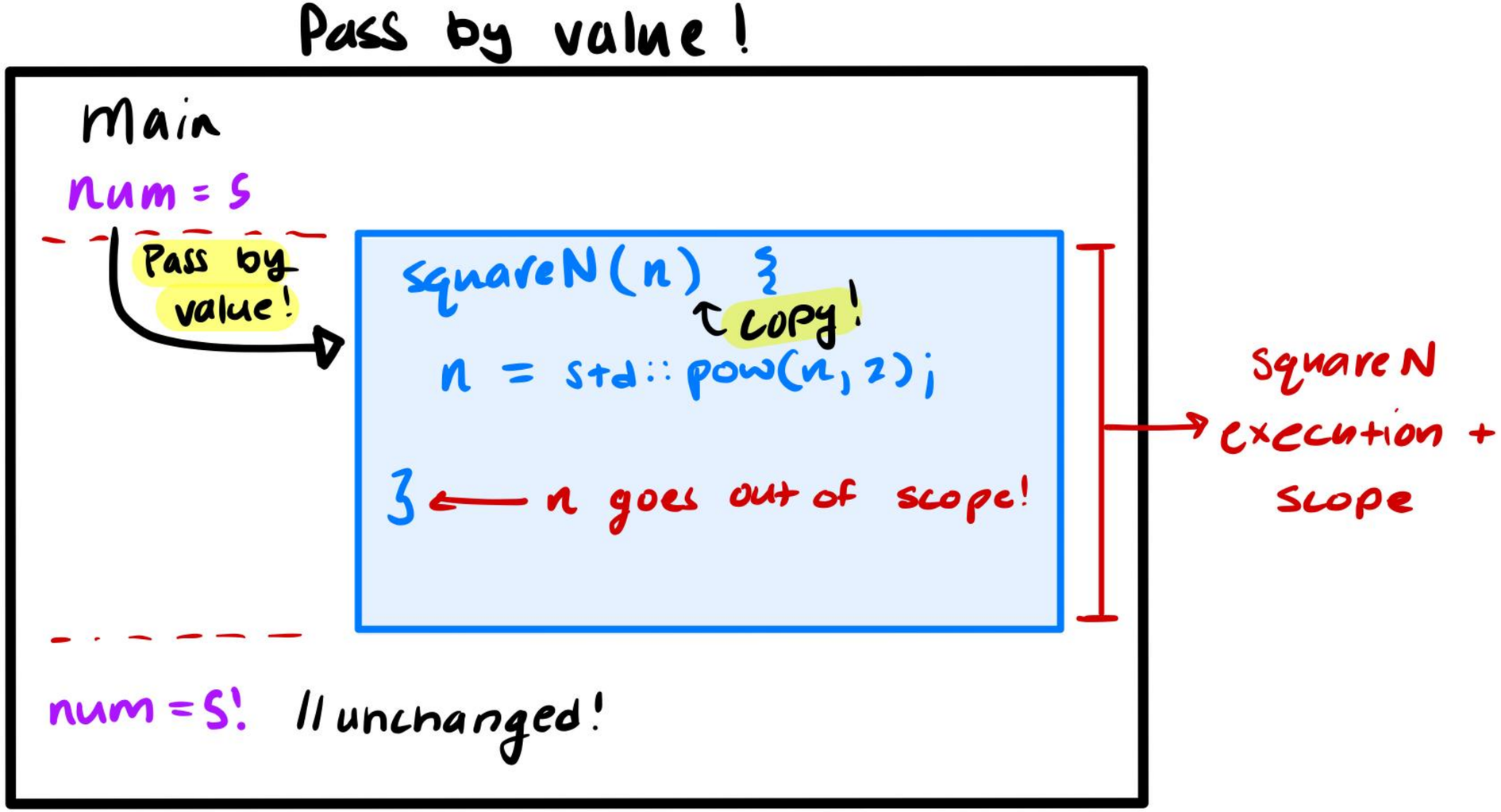
Passing by value

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

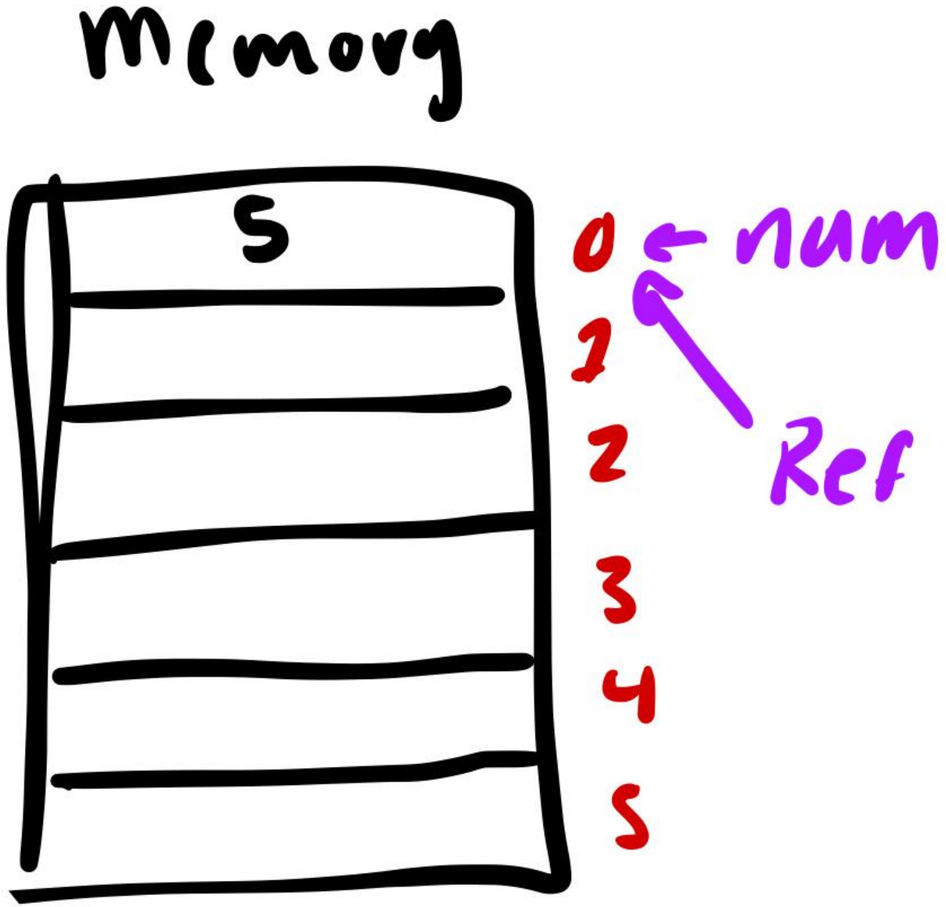
What does that look like?



Passing by value (makes a copy)

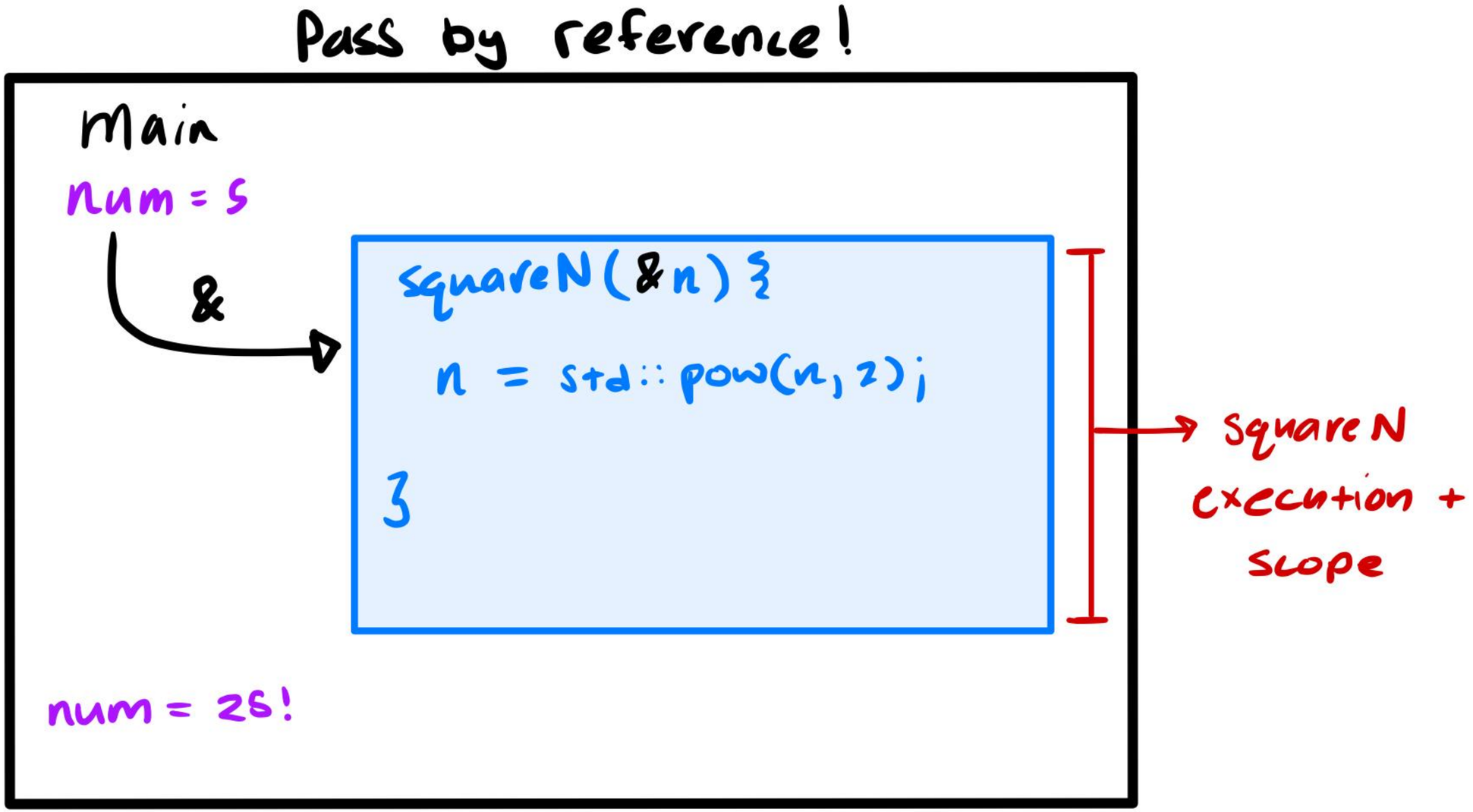


Recall

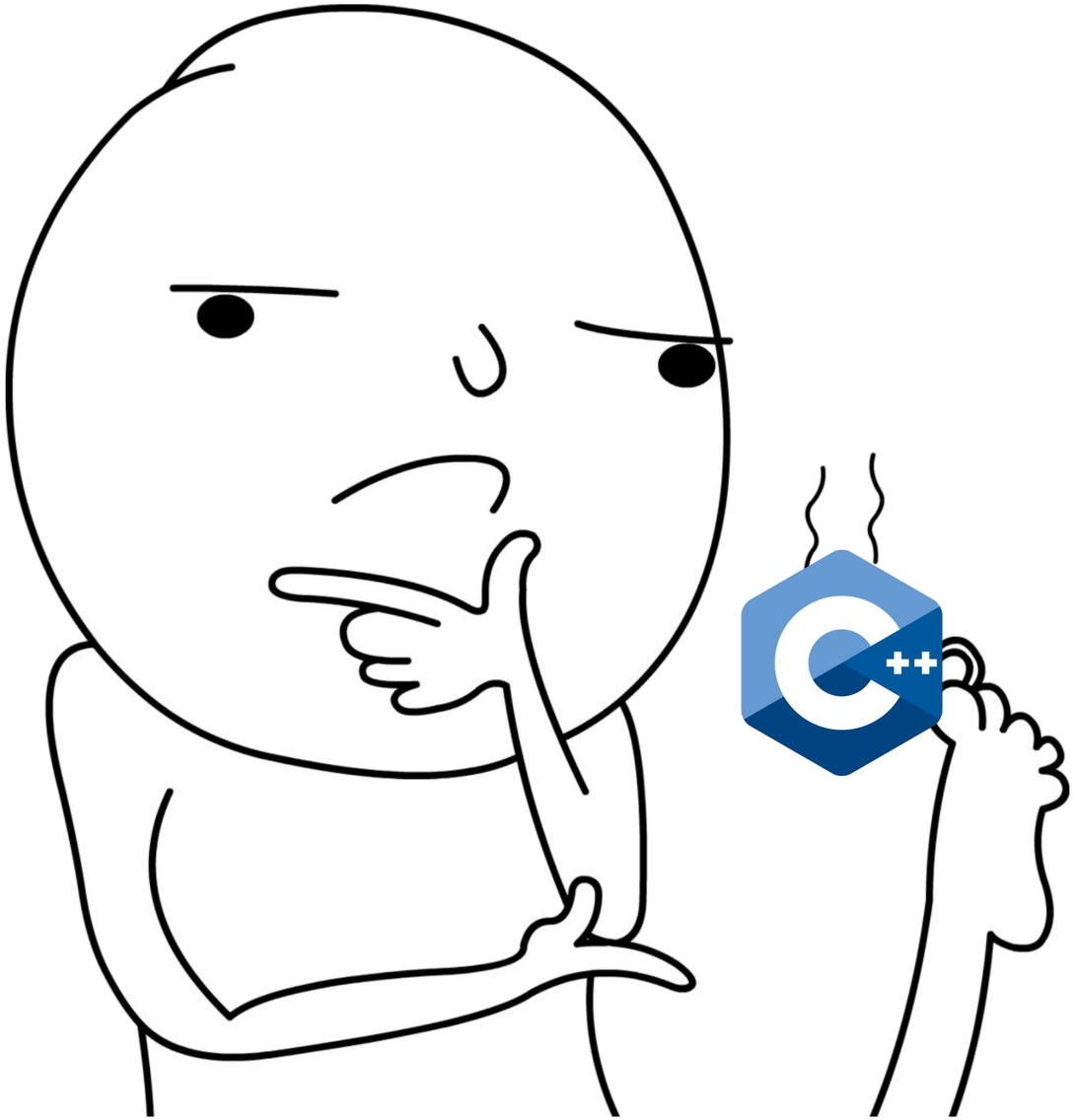


A reference *refers* to the same memory as its associated variable!

Passing by reference



What questions do we have?



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

```cpp
#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

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🤔 But `nums` is passed in by reference…

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🤔 But `nums` is passed in by reference…

Note the structured binding!

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

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    num1++;
    num2++;
  }
}
```

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

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

A classic reference-copy bug: fixed!

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

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

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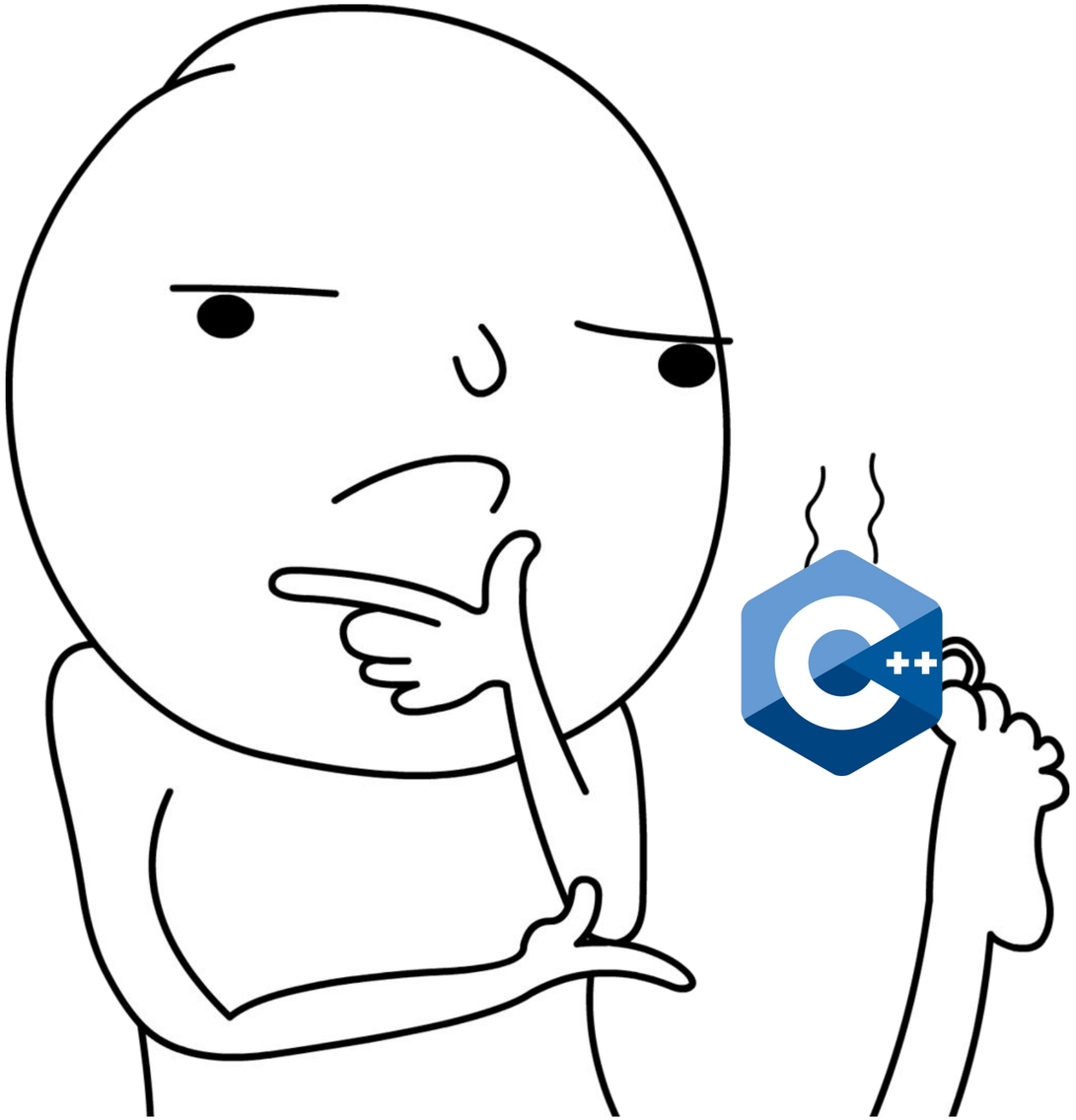

l-values and r-values

An **l-value**

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

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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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l-values and r-values

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An r-value

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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
```

l-values and r-values

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```
x = 344
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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>
#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;
}
```

is `int& num` an l-value?

l-value and r-value PAIN

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


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

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

l-value and r-value PAIN

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

Well what happens?

Compilation failed due to following error(s).

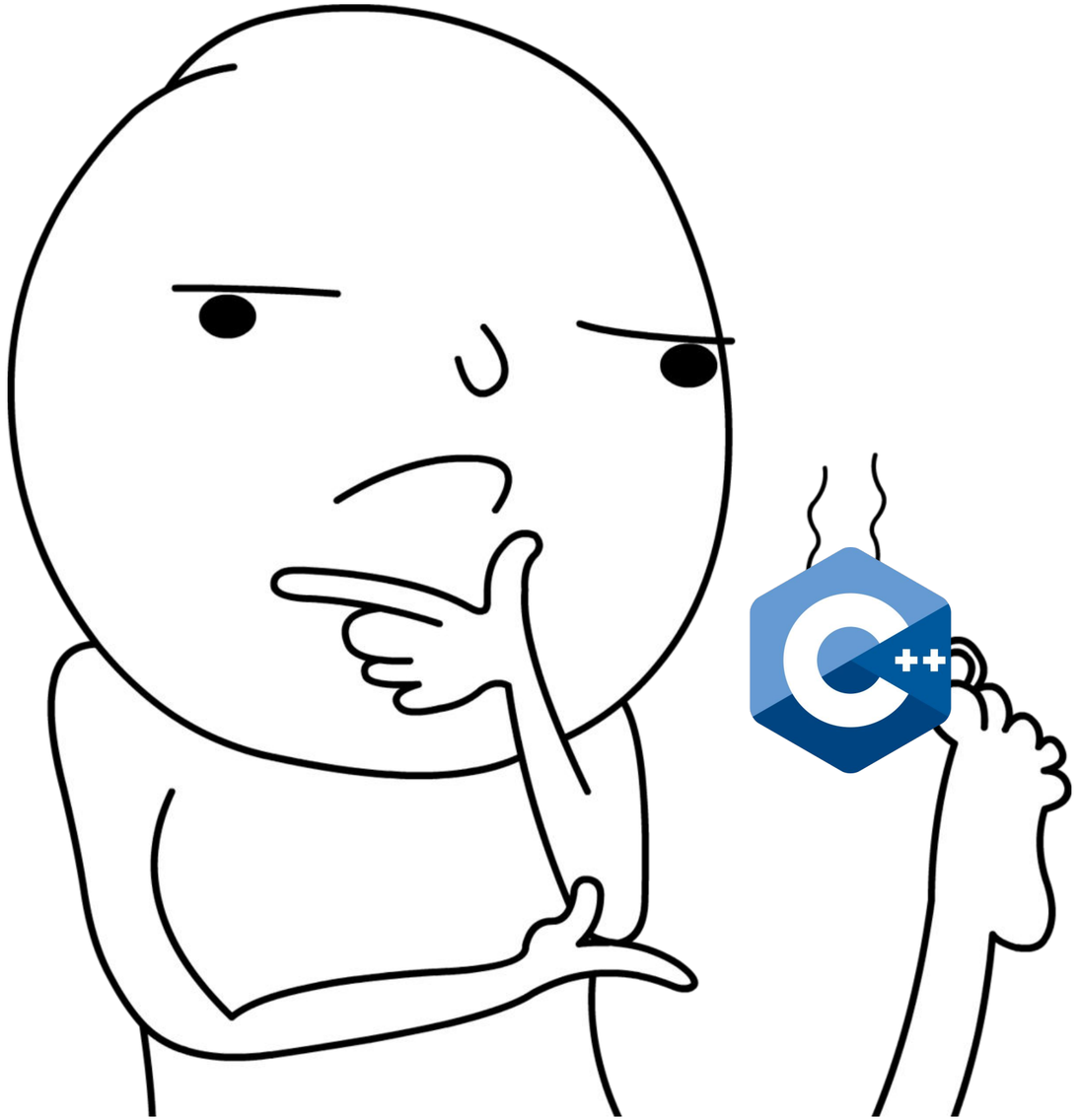
```
main.cpp: In function 'int main()':
main.cpp:22:28: error: cannot bind non-const lvalue reference of type 'int&' to an rvalue of type 'int'
   22 |   auto fourAgain = squareN(2);
      |                            ^
main.cpp:14:18: note:   initializing argument 1 of 'int squareN(int&)'
   14 | int squareN(int& num) {
      |             ~~~~~^~~
```

l-value and r-value PAIN

Compilation failed due to following error(s).

```
main.cpp: In function ‘int main()’:
main.cpp:22:28: error: cannot bind non-const lvalue reference of type ‘int&’ to an rvalue of type ‘int’
   22 |    auto fourAgain = squareN(2);
      |                             ^
main.cpp:14:18: note:   initializing argument 1 of ‘int squareN(int&)’
   14 | int squareN(int& num) {
      |             ~~~~~^~~
```

What questions do we have?



`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 OKAY!
  const_vec.push_back(3);
  ref_vec.push_back(3);
  const_ref.push_back(3);

  return 0;
}
```

const

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#include <iostream>
#include <vector>

int main()
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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 OKAY!
  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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  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);

  return 0;
}
```

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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 OKAY!
  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, compile error :(

  return 0;
}
```

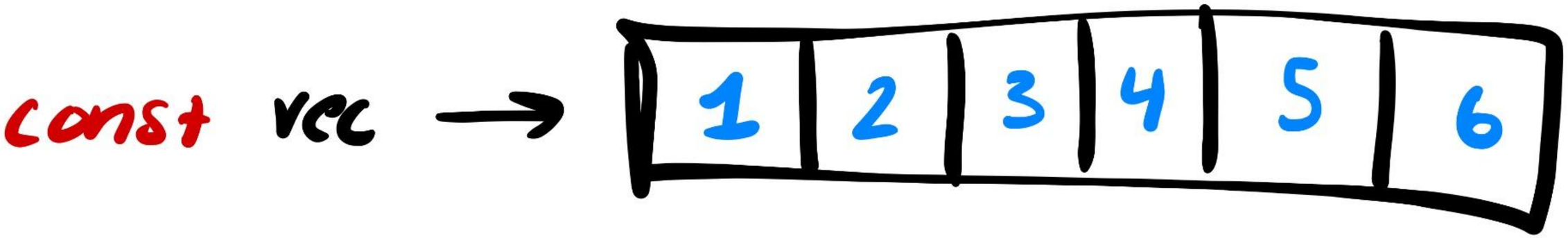
You can’t declare a non-const reference to a const variable

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

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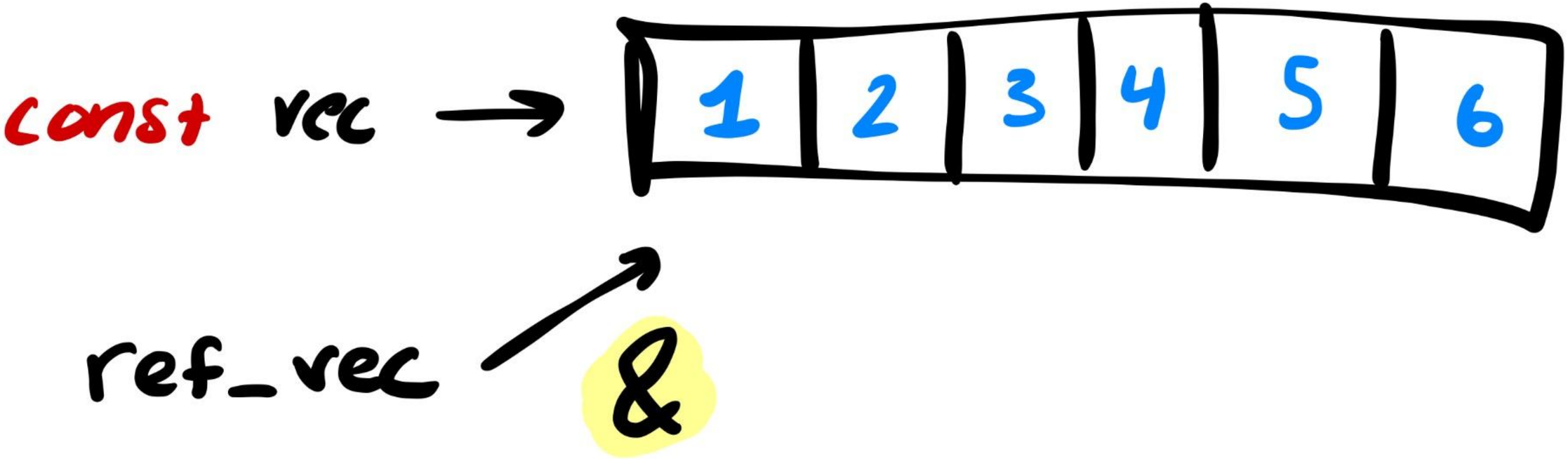
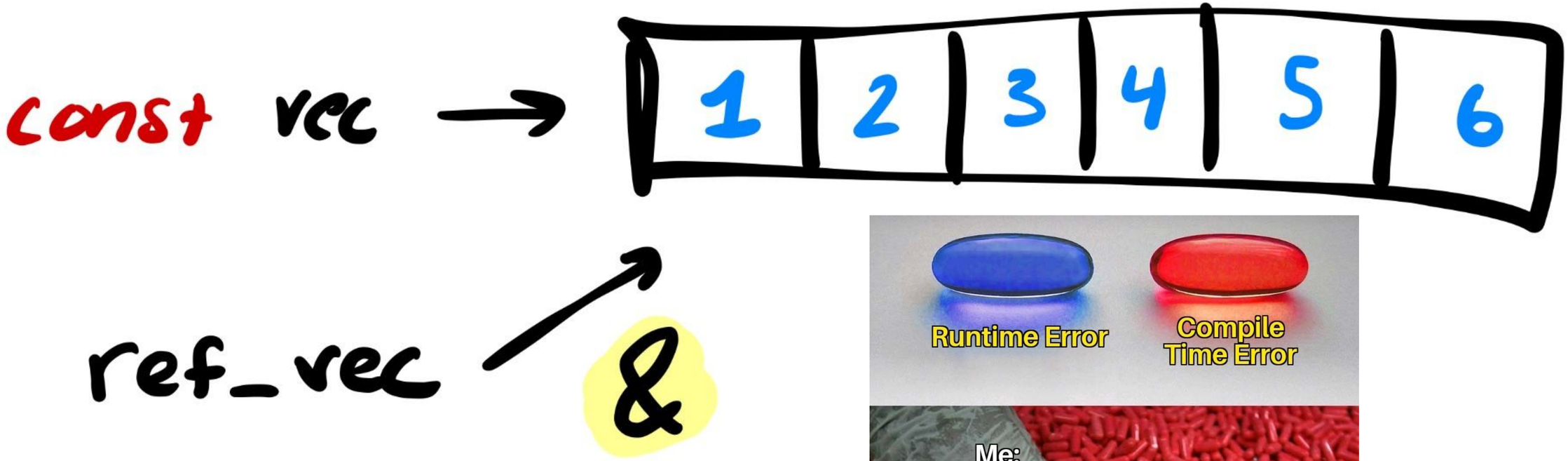


You can’t declare a non-const reference to a const variable



[meme sauce]

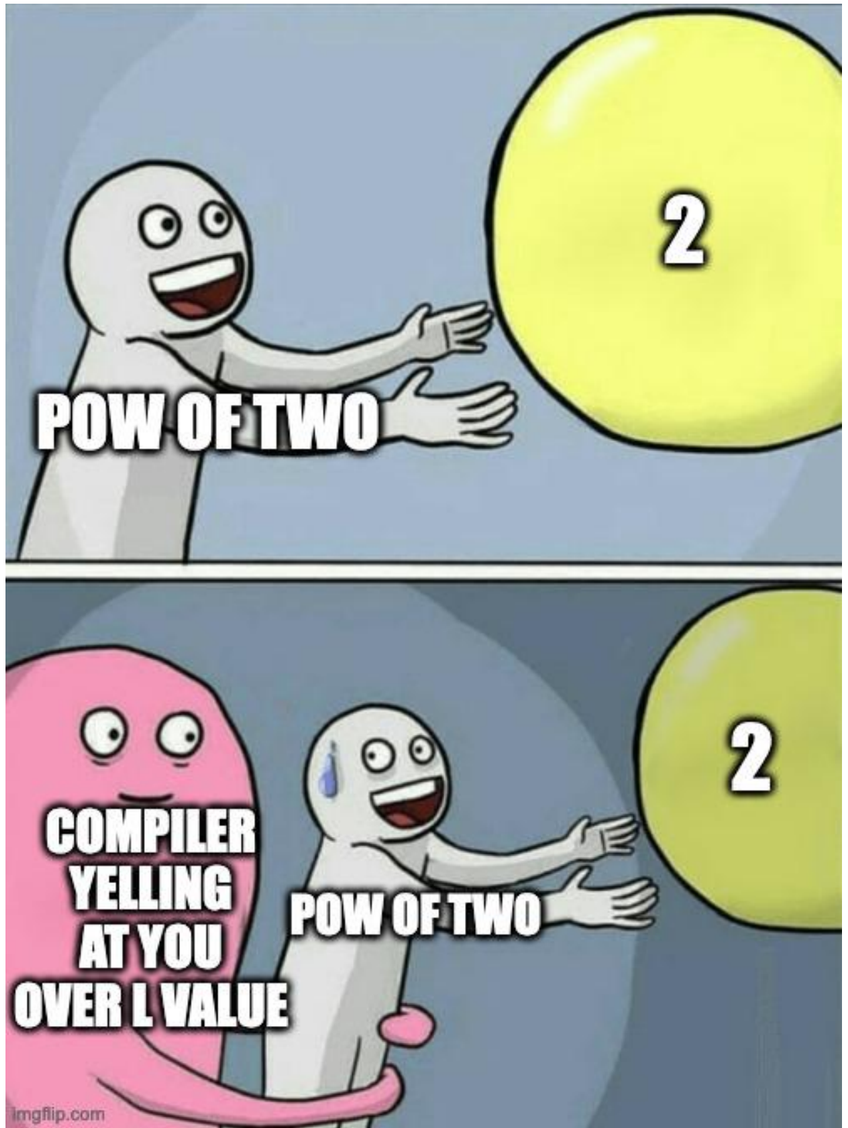
You can’t declare a non-const reference to a const variable

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

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

   return 0;
}
```

A recap of today!



In conclusion

1. Use uniform initialization — it works for all types and objects!

2. References are a way to alias variables!

3. You can only reference an l-value!

4. Const is a way to ensure that you can’t modify a variable