Pointers and References

References, Memory 101, Pointers
Pointer Arithmetic, Usages

SoftUni Foundation

Georgi Georgiev

A guy that knows C++

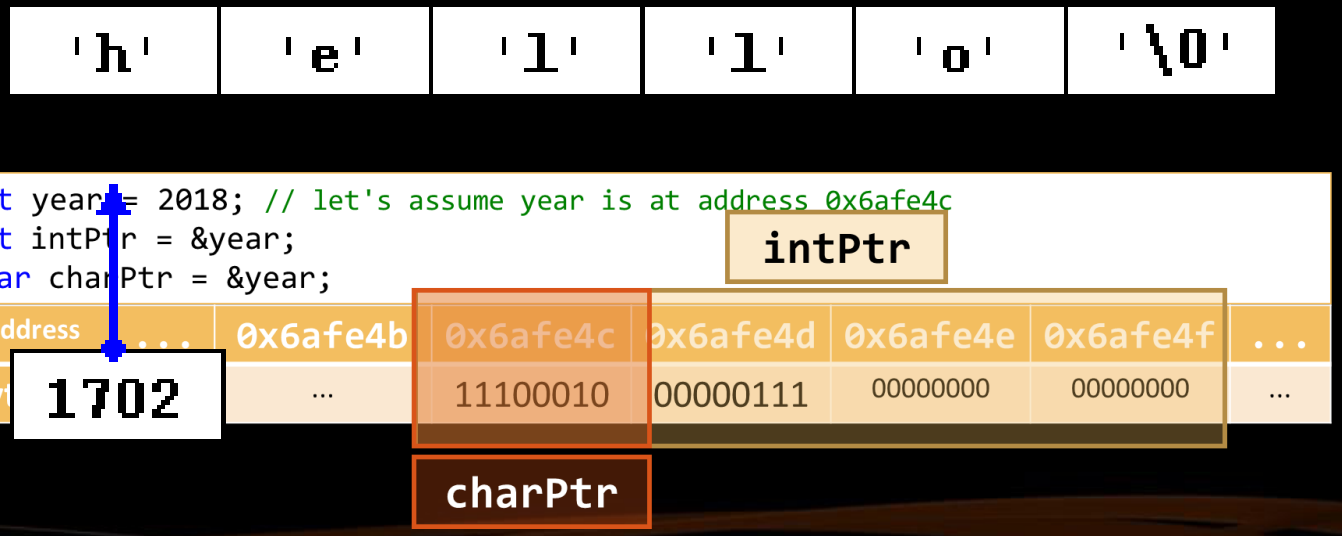


Table of Contents

SoftUni Foundation

Questions

SoftUni Foundation

sli.do

#cpp-softuni

References

Creation, Usages, Limitations

References

- Identifiers assigned to the same memory as other identifiers
  - *Type& name*
  - Sometimes called "pseudonyms"

```
int original = 42;
int& reference = original;
original++; // original == 43; reference == 43
reference++; // original == 44; reference == 44
```

- Assigned on declaration with variable of the same type

```
int& reference; // compilation error
```

```
int original = 42;
double& reference = original; // compilation error
```

Common Reference Usages

SoftUni Foundation

- Re-assigning caller variables

```
void swap(int& a, int& b) {
  int oldA = a;
  a = b;
  b = oldA;
}
```

```
int x = 13, y = 42;
swap(x, y); // x == 42, y == 13
```

- Providing additional "return" values

```
int minValue(vector<int> numbers, int& foundAtIndex) {
  foundAtIndex = 0;
  for (int i = 1; i < numbers.size(); i++) {
    if (numbers[foundAtIndex] > numbers[i]) { foundAtIndex = i; }
  }
  return numbers[foundAtIndex]; // the second parameter now contains the min index
}
```

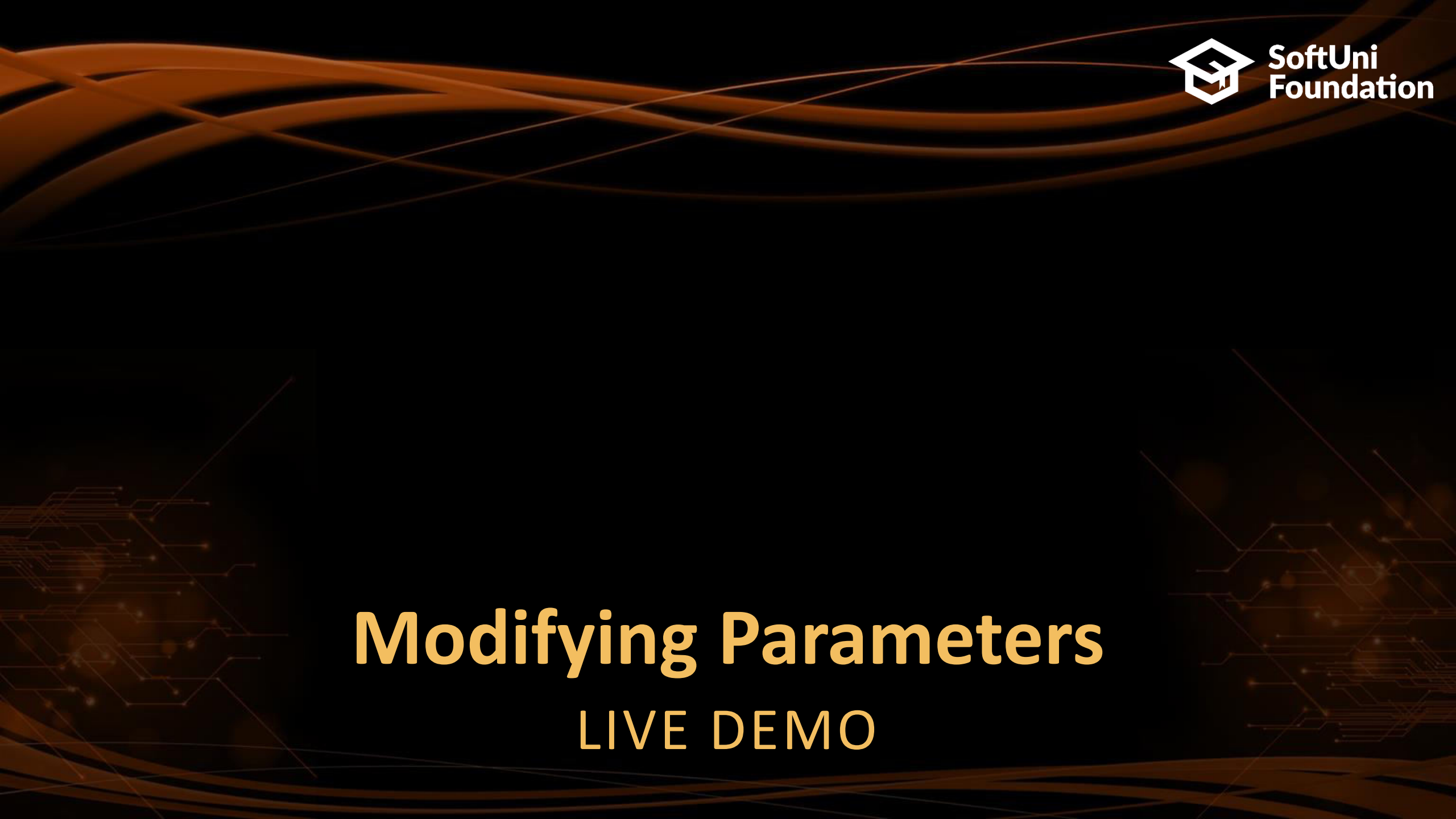
Common Reference Usages

SoftUni Foundation

- Modifying caller's objects
  - NOTE: not re-assigning the entire object, but changing its fields

```
void removeNegative(std::list<int>& numbers) {
  auto i = numbers.begin();
  while (i != numbers.end()) {
    if (*i < 0) {
      i = numbers.erase(i);
    }
    else {
      i++;
    }
  }
}
```

```
list<int> values{ 1, -69, -4, 42, -2, 13, -9 };
removeNegative(values); // values{ 1, 42, 13 }
```


SoftUni
Foundation
Modifying Parameters
LIVE DEMO

const References

SoftUni Foundation

- const references can only be read, not written
  - const *Type& name*

```
int original = 42;
const int& reference = original;
original++; // original == 43; reference == 43
reference++; // compilation error
```

- Used to improve performance for object parameters:
  - Using a reference avoids copying the entire object
  - Using const prevents function from modifying the original

const Reference Parameters – Example

SoftUni Foundation

- Using reference prevents copying the vector

```
void printZeroIndices(const std::vector<int>& numbers) {
  for (int i = 0; i < numbers.size(); i++) {
    if (numbers[i] == 0) { std::cout << i << " "; }
  }
}
```

- Marking it `const` prevents accidental editing

```
void printZeroIndices(const std::vector<int>& numbers) {
  ...
  if (numbers[i] = 0) { // accidental "=" gives compilation error
  ...
}
```


SoftUni
Foundation
References for Performance
LIVE DEMO

Quick Quiz TIME:

SoftUni Foundation

- What will the following code do?

```
vector<int>& generateRoots(int toNumber) {
  std::vector<int> roots;
  for (int i = 0; i < toNumber; i++) {
    roots.push_back(sqrt(i));
  }
  return roots;
}
```

```
int main() {
  cout << generateRoots(100)[4] << endl;
}
```

a) cause a compile-time error

b) cause a runtime error due to index being out of bounds

c) summon demons

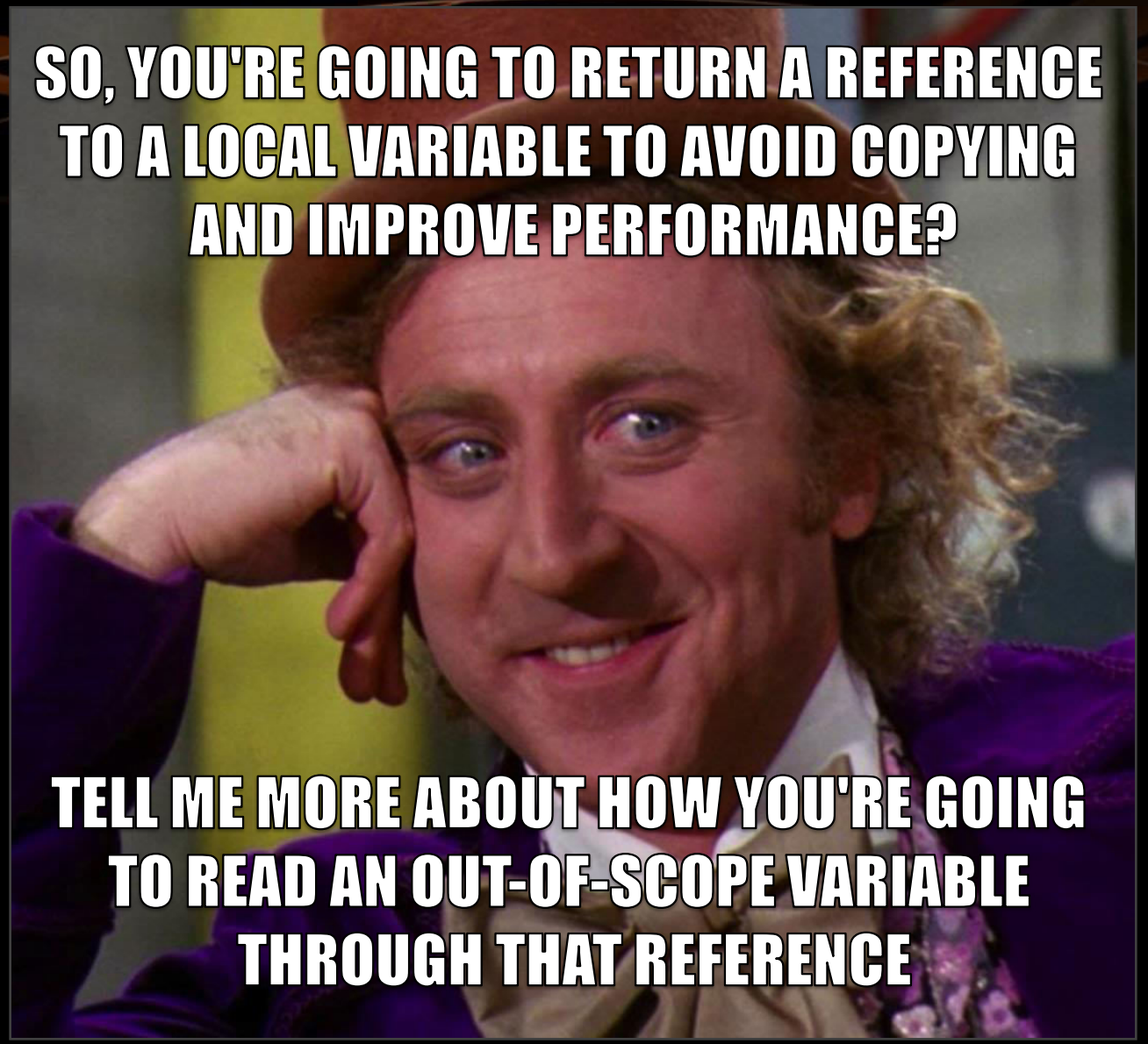
d) behavior is undefined

C++ PITFALL: REFERENCES TO VARIABLES THAT WERE FREED FROM MEMORY

If a variable goes out of scope, its memory is returned to the system.

References to it are invalidated.

Hence, we can't use a reference to a function's local variable outside the function.



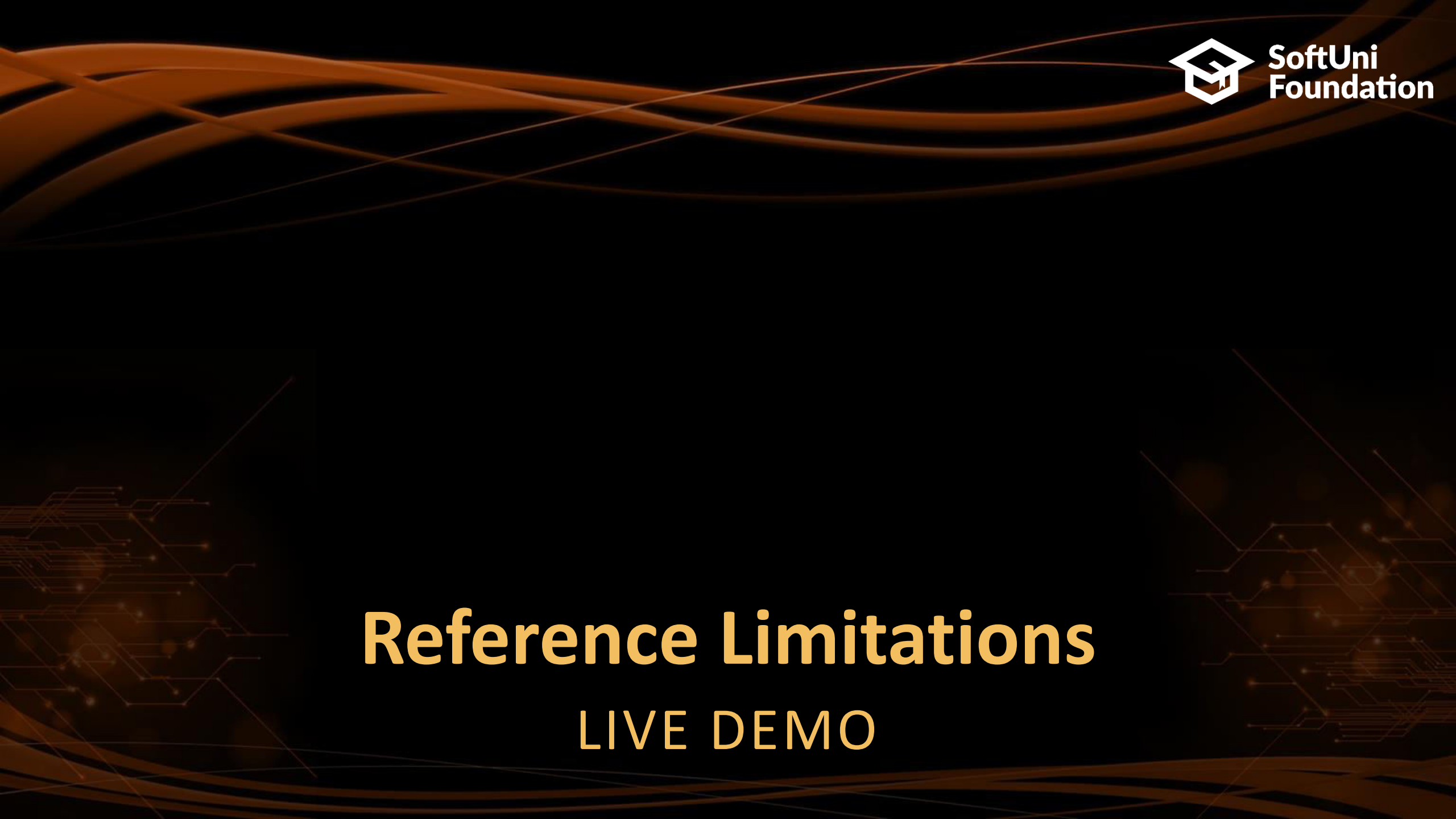
Reference Limitations

SoftUni Foundation

- If original variable goes out of scope, reference is undefined
- Can't change to reference other variable
- Initialized on creation – in `class`, must be set in initializer list

```
class LetterFilter {
  const std::string& s;  int index;
public:
  LetterFilter(const std::string& s)
    : s(s), index(0) { }
  char nextLetterOrNull() {
    while (index < s.size() && !isalpha(s[index])) {
      this->index++;
    }
    if (index == s.size()) { return 0; }
    letter = s[index]; this->index++;
    return s[index];
  }
};
```

```
class LetterFilter {
  const std::string& s;  int index;
public:
  LetterFilter(const std::string& s) {
    // compilation error, no initializer
    // for reference this->s
    this->s = s;
    this->index = 0;
  }
  ...
};
```



Reference Limitations

LIVE DEMO

SoftUni Foundation

Computer Memory 101

Memory Structure, Variables in Memory

What Do We Call Memory?

SoftUni Foundation

- In computer science, memory usually is:
  - a continuous, numbered – aka addressed – sequence of bytes
  - storage for variables and functions created in programs
  - random-access – equally fast accessing `5`th and `500`th byte
  - addresses numbered in hexadecimal, prefixed with `0x`

Address	`0x0`	`0x1`	`0x2`	`...`	`0x6afe4c`	`...`
Byte$_{(binary)}$	00001101	00101010	01000101	...	00000011	...

Memory Usage by Variables

- A primitive data type takes up a sequence of bytes
  - `char` is `1` byte, `1` address – often used for reading byte by byte

```
char alpha = 'A'; // let's assume alpha is at address 0x6afe4c
```

Address	...	0x6afe4b	0x6afe4c	...	...	...	...
Byte(binary)	...	...	01000001	...	...	...	...

  - Other types & arrays use consecutive bytes, e.g. `4`-byte `int`:

```
int year = 2018; // let's assume year is at address 0x6afe4c
```

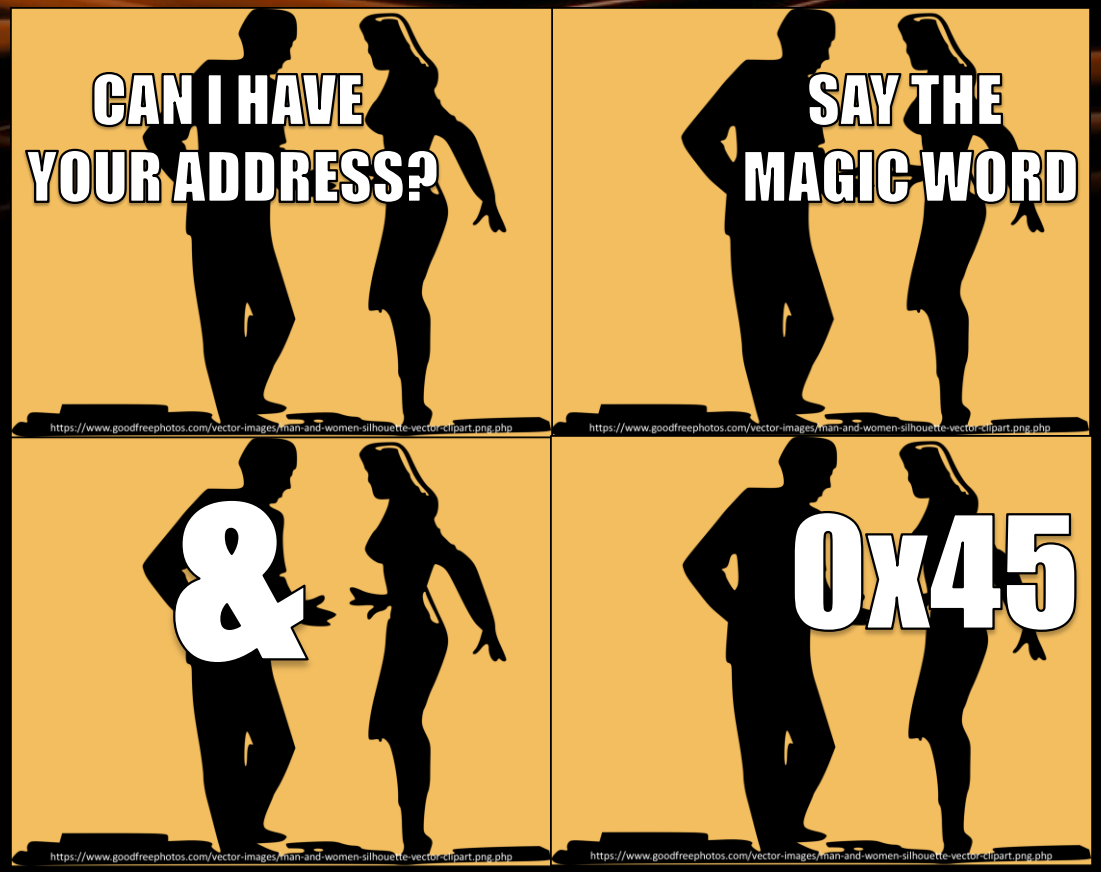
Address	...	0x6afe4b	0x6afe4c	0x6afe4d	0x6afe4e	0x6afe4f	...
Byte(binary)	...	...	11100010	00000111	00000000	00000000	...

Getting Addresses of Variables in C++

- Prefix **operator&** returns a variable's address
  - **int x = 42; cout << &x; // prints e.g. 006AFE4C**
  - Functions also have addresses – where their code is in memory

```
void f() {}

int main() {
  int x = 42;
  auto addressX = &x;
  cout << x << " at " << addressX << endl;
  cout << "f()" << " code at " << &f << endl;
  return 0;
}
```



Getting Addresses in C++

LIVE DEMO

Array Address Values

SoftUni Foundation

- C++ Array – a **Type**, a **start** address and a **length**
  - Index **i** is at address: **start + i * sizeof(Type)**

```
int arr[] = { 2018, 310 }; // assume &arr[0] == 0x6afe4c
```

Address	...	0x6afe4b	0x6afe4c…0x6afe4f				0x6afe50…0x6afe53				0x6afe554
Byte(binary)	…	…	11100010	00000111	00000000	00000000	00110110	00000001	00000000	00000000	…
Value	…	…	2018				310				…

  - array, it's address, and first element address are the same

```
cout << arr << " " << &arr << " " << &arr[0]; // 006AFE4C 006AFE4C 006AFE4C
cout << &arr[1]; // 006AFE50
```

Addresses Are Integer Numbers

SoftUni Foundation

- *We can store an address in* `size_t position;`
  - `int` *might be small – a* `4`*-byte* `int` *can only "address"* `4GB` *RAM*
- *We can change* `position` to indicate another address
- *But how can we change the value (bytes) at that address?*
- *What type does the* `operator&` *return?*

SoftUni Foundation

Pointers

Using and Representing Memory Addresses

A Memory-Address Type

SoftUni Foundation

- C++ Pointers – store and can access a memory address
  - *Type* name*
  - *Type* – the type of value the pointer "points to"
  - A pointer is to memory what an index is to an array

```
char a = 'A';
char* addressA = &a;
```

```
int x = 42;
int* addressX = &x;
```

Referencing and Dereferencing

SoftUni Foundation

- "Referencing" – setting what a pointer points to

```
int a = 42, b = 13; // let's assume &b == 0x69fef4
int* ptr = &a; // points to a
ptr = &b; // points to b
```

- "Dereferencing" – **operator*** – access memory, not pointer

```
int a = 42; int* ptr = &a;
*ptr = 7 // a is now 7
cout << *ptr; // prints 7
```

- **operator->** – access member of pointed object

```
string s = "world"; string* ptr = &s;
ptr->insert(0, "hello "); // makes s == "hello world"
```


SoftUni
Foundation
Referencing and Dereferencing
LIVE DEMO

Quick Quiz TIME:

SoftUni Foundation

- What will the following code print?

```
int number = 42;
int* ptr = &number;
*ptr++;
std::cout << *ptr << std::endl;
```

a) 43

b) 42

c) there will be a runtime error

d) behavior is undefined

C++ PITFALL: INCREMENTING POINTER INSTEAD OF POINTED OBJECT

`operator++` has higher precedence, and is applied to the pointer, then the dereference operator executes on the old pointer value.

On the next dereference, we could get an error, or a "random" value – undefined behavior

Use brackets to apply `operator++` over the pointed memory: `(*number)++`

The NULL Pointer

SoftUni Foundation

- Special pointer value of **`0`**, **`NULL`** or **`nullptr`** (C++11)
  - Dereferencing is undefined behavior
- Indicates a lack of value
  - E.g. "find" function returning **`nullptr`** when no result found

```
int* findFirstNegativePtr(int numbers[], int length) {
  for (int i = 0; i < length; i++) {
    if (numbers[i] < 0) {
      return &numbers[i];
    }
  }
  return nullptr;
}
```

```
int* negativePtr = findFirstNegativePtr(numbers, 4);
if (negativePtr != nullptr) { cout << *negativePtr; }
else { cout << "no negative numbers" << endl; }
```

Exercise 1: FollowPointers

SoftUni Foundation

- You are given the following `main.cpp` file and a `Node.h` file
  - `main.cpp` declares a function `int getSumFrom(Node* node)`
  - `The Node.h file defines what a Node is`
  - Create a `FollowPointers.h` that implements the function
- The function should calculate the sum
  - Of the `value` fields, from the provided `node`
  - Moving by going to the `next` field, until `nullptr` is reached
- Write `#include "Node.h"` in your file to use the Node code

SoftUni Foundation

Pointers and const

Constant Pointers and Constant Data

Pointers and const

SoftUni Foundation

- Two things can change for a pointer
  - The pointed address
  - The data at the address

Pointer	Memory editable?	Address editable?
`Type * ptr`	YES	YES
`const Type * ptr`	NO	YES
`Type * const ptr`	YES	NO
`const Type * const ptr`	NO	NO

  - *What do the last 2 in the table match logically?*

Pointers to const Data

SoftUni Foundation

- Used similarly to **const** references
  - Pointer usage avoids object copy – only the address is copied
  - **const** on the **Type** prevents changing the pointed data

```
void printZeroIndices(const std::vector<int>* numbers) {
  for (int i = 0; i < numbers.size(); i++) {
    if (numbers[i] == 0) { std::cout << i << " "; }
  }
}
```

```
vector<int> numbers{ 1, 0, -2, 7, 0, 10, -100, 42 };
printZeroIndices(&numbers);
```


SoftUni
Foundation
Pointers to const Data
LIVE DEMO

SoftUni Foundation

Pointer Arithmetic and Arrays

Type-Defined Pointer Calculations

Pointer Type Significance

- Pointer operations are based on their **Type**
  - Reading accesses exactly **sizeof(Type)** bytes
  - Writing sets exactly **sizeof(Type)** bytes

```
int year = 2018; // let's assume year is at address 0x6afe4c
int intPtr = &year;
char charPtr = &year;
```

Pointer Arithmetic with Integers

SoftUni Foundation

- Typed pointers support integer addition/subtraction
- For a `Type* pointer` with address `x`
  - `pointer + value` calculates `x + sizeof(Type) * value`
  - `pointer - value` calculates `x - sizeof(Type) * value`

```
int number = 42; // assume &number == 0x6afe4c
int * intPtr = &number; char * charPtr = (char*)&number;

// NOTE: casting the char* to int* to avoid printing as a string
cout << intPtr << " " << (int*)charPtr << endl; // 0x6afe4c 0x6afe4c
intPtr++; charPtr++;
cout << intPtr << " " << (int*)charPtr << endl; // 0x6afe50 0x6afe4d
```

Pointers as Arrays

- Array `operator[]` is actually defined with pointer arithmetic
- For an array `arr` and an integer `i`:
  - `arr[i]` compiles to `*(arr + i)`
- Array parameters in functions "degenerate" into pointers
  - `void f(int[] arr, int length)` is the same as `void f(int* arr, int length)`

```
int arr[3]{ 13, 42, 69 };
int* p = arr;
p[1] = -42;
cout << arr[1]; // -42
cout << *(p + 1); // -42
cout << p[1]; // -42
```

Quick Quiz TIME:

SoftUni Foundation

- What will the following code print?

```
int arr[3]{ 13, 42, 69 };
cout << 1[arr] << endl;
```

a) 42

b) there will be a compilation error

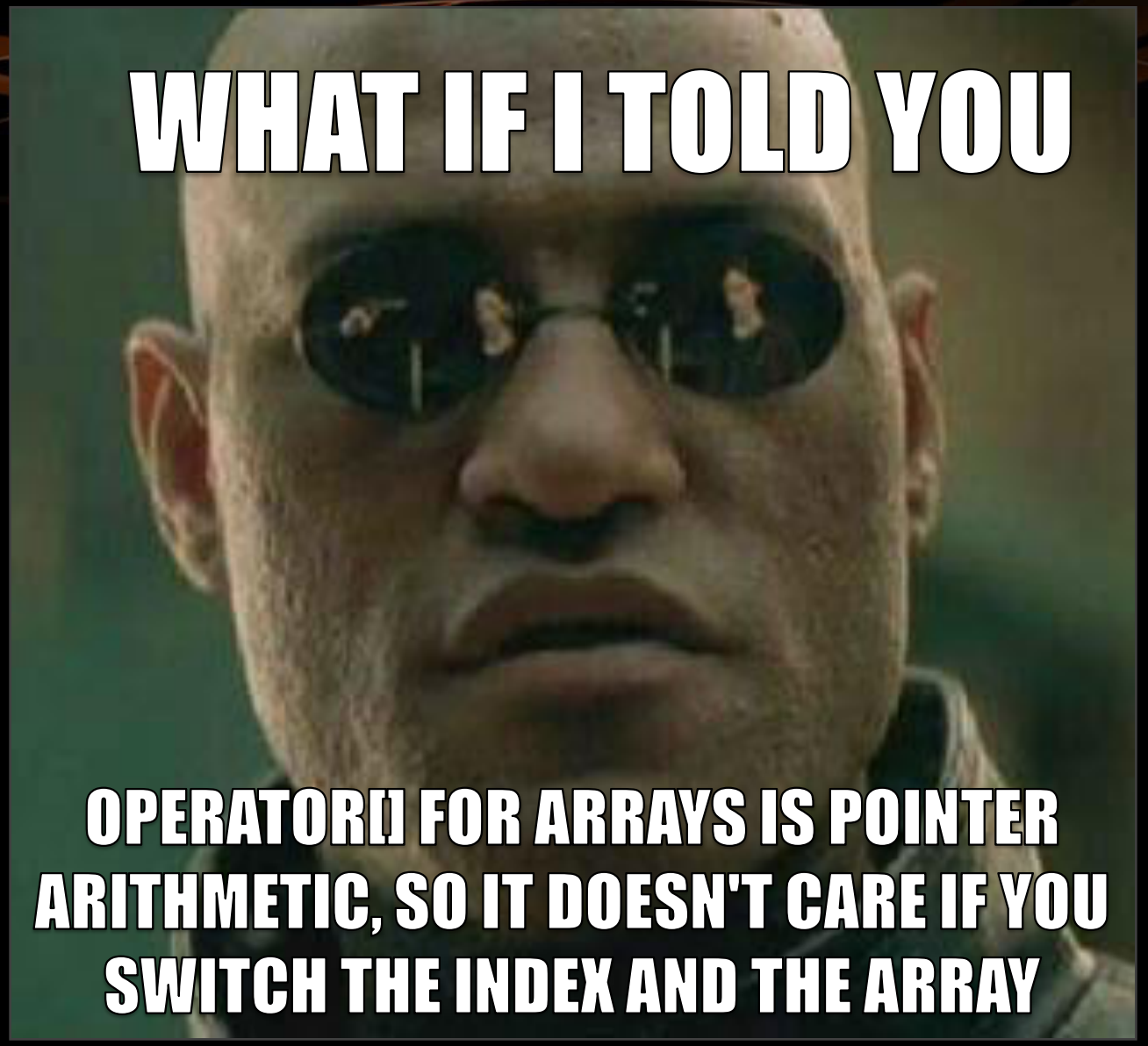
c) there will be a runtime error

d) behavior is undefined

C++ FUN FACT: CAN SWITCH INDEX AND ARRAY IN OPERATOR[]

Array `operator[]` is just pointer arithmetic.

`*(a + b)` is the same as `*(b + a)`, so `operator[]` works even if you switch the index and array. But don't ☺



Summary

- References allow setting new identifiers for existing variables
- Computer memory is essentially an array of bytes
- Variables occupy consecutive bytes of memory
- Pointers are to memory what indices are to arrays
  - Used to read/write memory
  - Can change to point to other memory
- Pointer arithmetic allows pointers to work like arrays

Pointers and References

Questions?