CS 5416 Recitation 1

Introduction and C++ basics

08/29/2025

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Overview

- Recitation introduction and logistics
- C++ primitive types
- C++ standard library, e.g. I/O, container
- A note about AI

TA introduction

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Logistics

- TA Help Session: C++ Coding Environment Setup
  - Session 2: 7:00 PM - 8:00 PM, Tuesday, 09/02 (led by Haadi Khan and Ryan Wu)
  - Location: Phillips 101

HW1 will be released on Monday

Ed discussion announcement

The writeup and starter code are on **Canvas**

Submission to **Gradescope**

No slip days

Logistics

- We will be using Poll Everywhere during recitations
- Log in with your Cornell email at http://pollev.com/

Recitation objectives

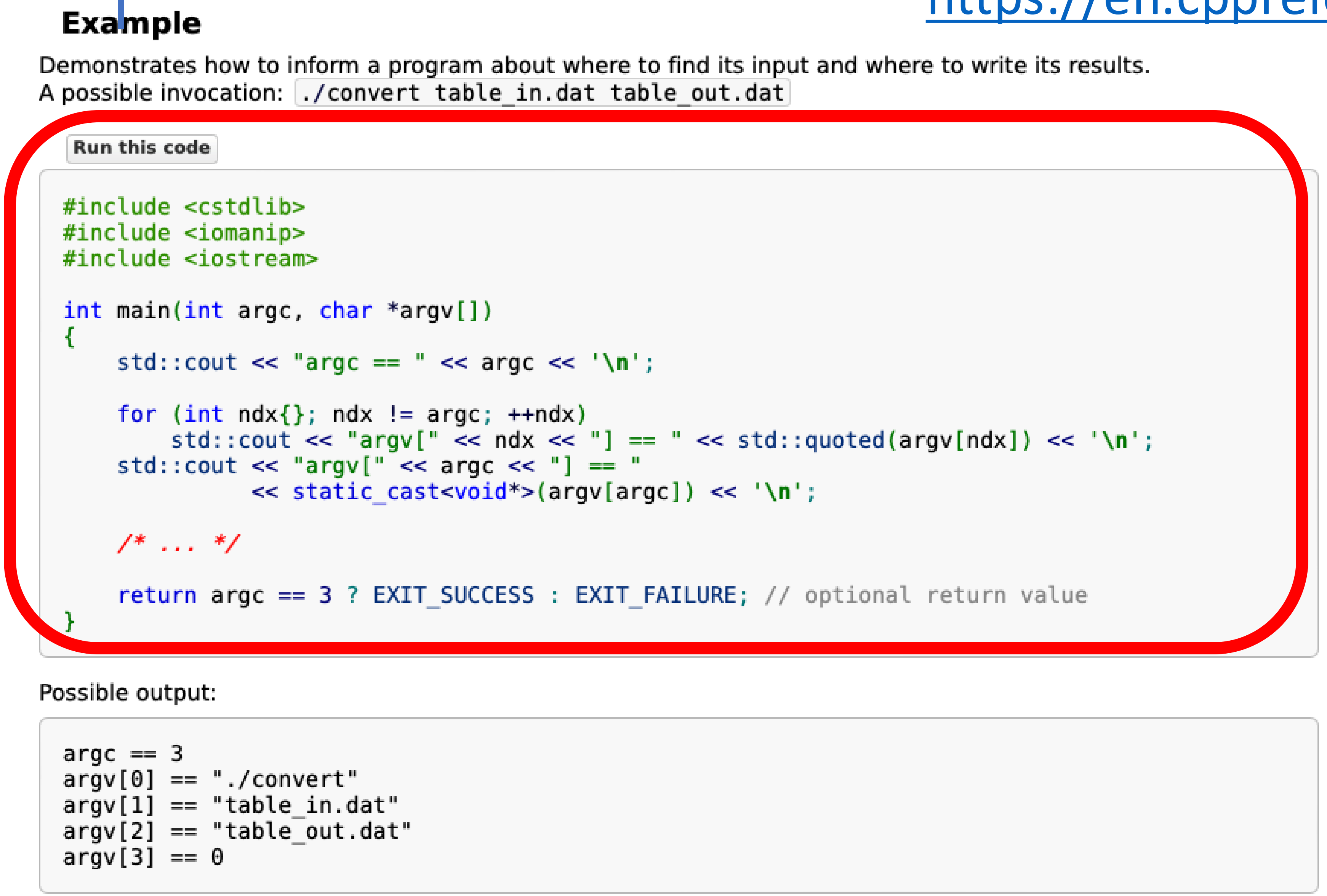
Learn how to write good systems programs in C++

Assignment introductions and explanations

Exam preparation and reviews

CPP Reference

https://en.cppreference.com/w/



Example

Demonstrates how to inform a program about where to find its input and where to write its results.
A possible invocation: `./convert table_in.dat table_out.dat`

```
#include <cstdlib>
#include <iomanip>
#include <iostream>

int main(int argc, char *argv[])
{
    std::cout << "argc == " << argc << '\n';

    for (int ndx{}; ndx != argc; ++ndx)
        std::cout << "argv[" << ndx << "] == " << std::quoted(argv[ndx]) << '\n';
    std::cout << "argv[" << argc << "] == "
              << static_cast<void*>(argv[argc]) << '\n';

    /* ... */

    return argc == 3 ? EXIT_SUCCESS : EXIT_FAILURE; // optional return value
}
```

Possible output:

```
argc == 3
argv[0] == "./convert"
argv[1] == "table_in.dat"
argv[2] == "table_out.dat"
argv[3] == 0
```

What is C++?

A federation of related languages, with four primary sublanguages

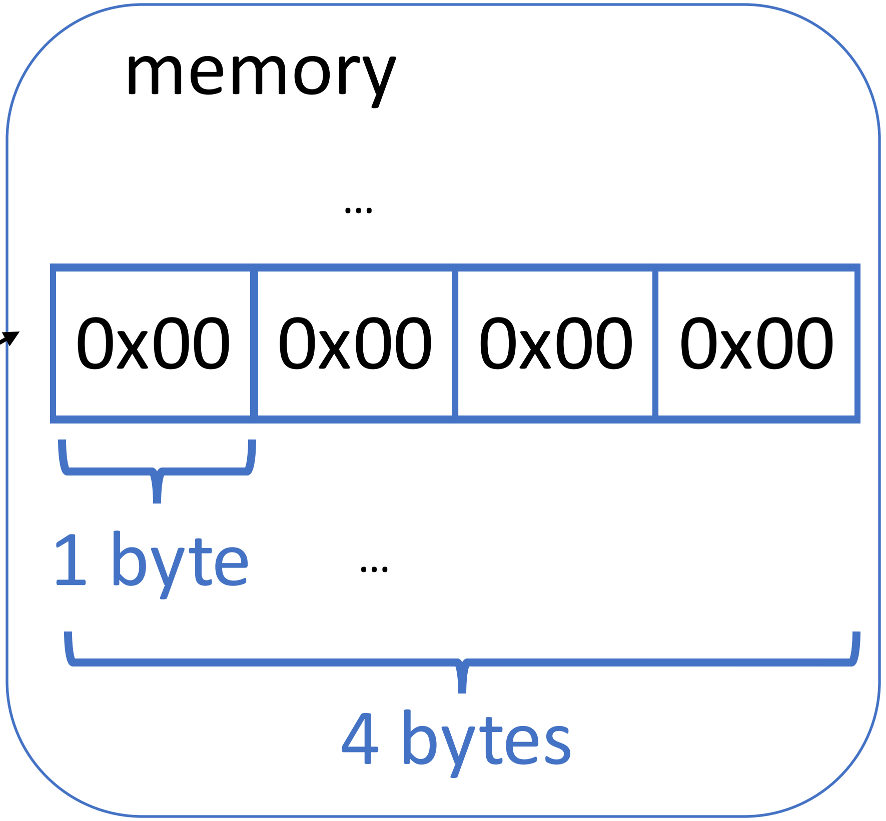
- **C**: C++ is based on C, while offering approaches superior to C. Blocks, statements, processor, built-in data types, arrays, pointers, etc., all come from C
- **Object-Oriented C++:** “C with Classes”, classes including constructor, destructors, inheritance, virtual functions, etc.
- **Template C++:** generic programming language. Gives a template, define rules and pattern of computation, to be used across different classed.
- **STL(standard template library):** a special template library with conventions regarding containers, iterators, algorithms, and function objects

C++ Built-in Types

We will have a more detailed C overview in the TA-led CS 3410 refresher session

& Address

```
int32_t x = 0;
```



memory

…

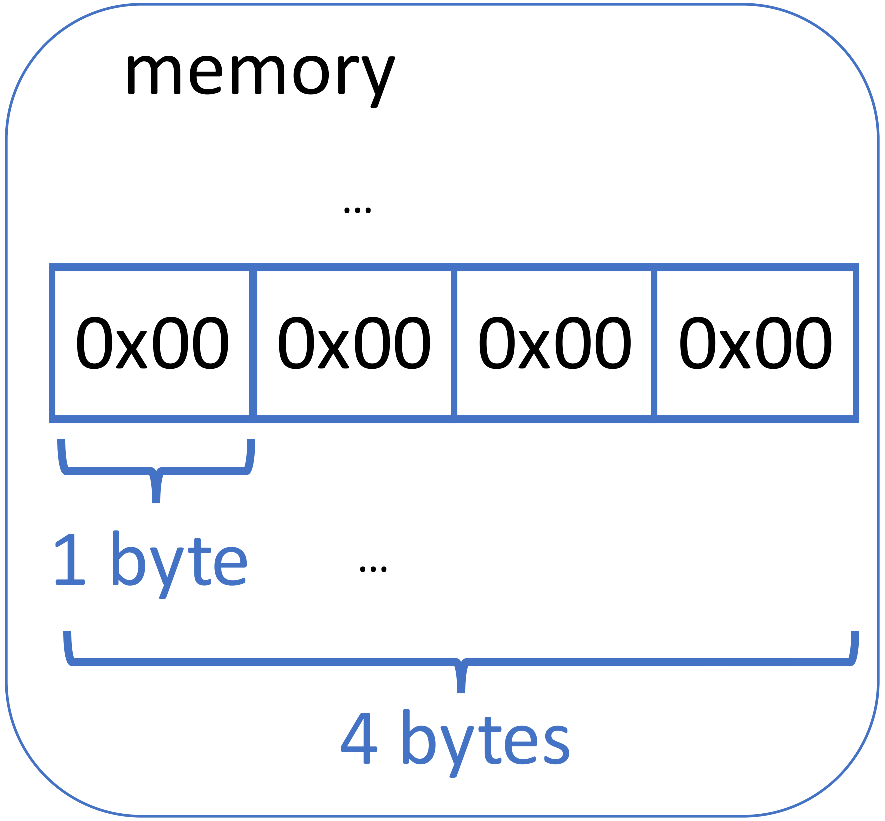
0x00	0x00	0x00	0x00

0x00 is the format for writing hex numbers
(0x is the prefix, 00 is hex digits)

& Address

Where does x live in memory exactly?

```
int32_t x =
0;
```



memory

…

0x00	0x00	0x00	0x00

1 byte

…

4 bytes

& Address

- Can obtain the **address** (represented in hex) with the & operator

```
int32_t x = 0;
std::cout <<  &x << std::endl;
                            // prints to the address of x
                               for example, 0x7ffd55bdaa4
```

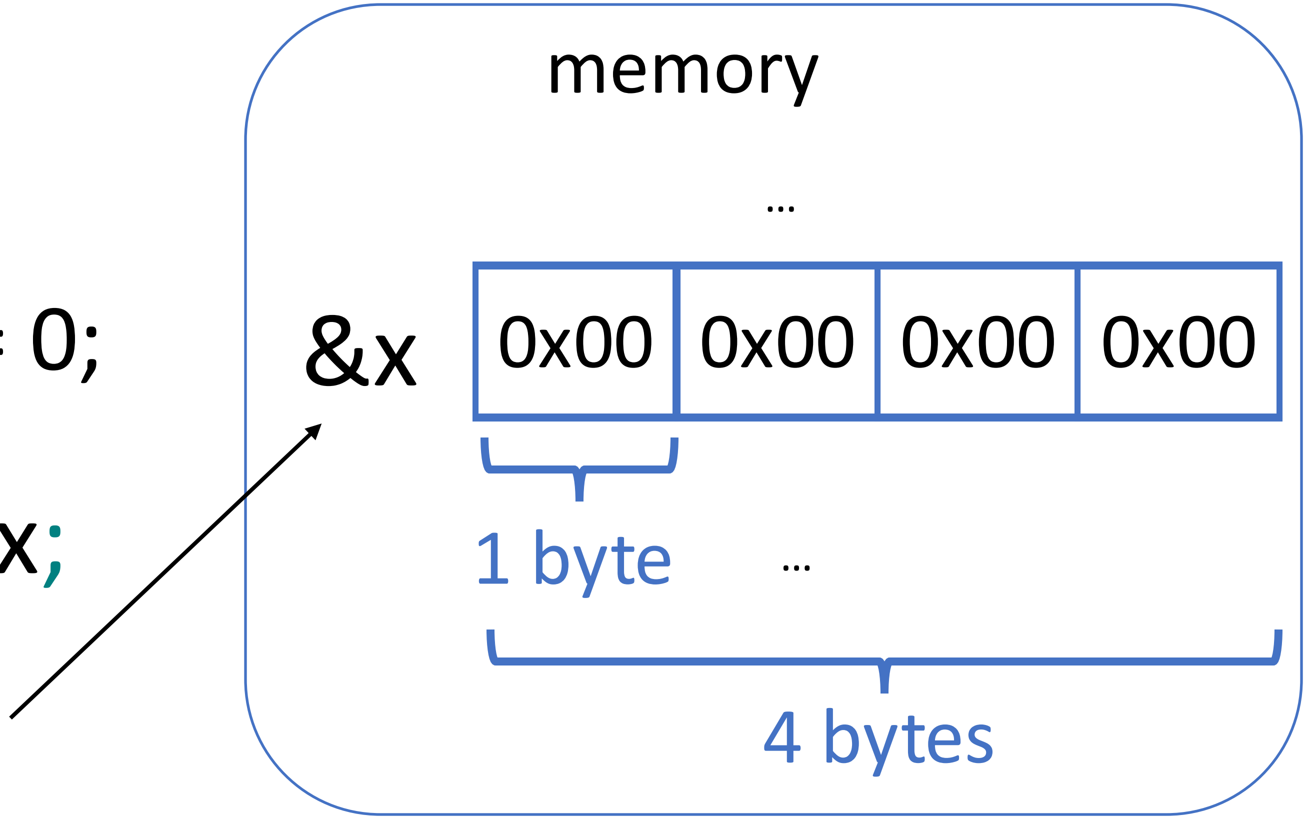
Pointers

- A pointer is a variable that stores a memory address.

```
int32_t x = 0;

int32_t* px;

px = &x;
```



Pointers

- A pointer is a variable that stores a memory address.
- A pointer is declared just like a variable but with * **after the type**

```
int32_t* px;
```

A pointer that could point to an integer

*

Pointers

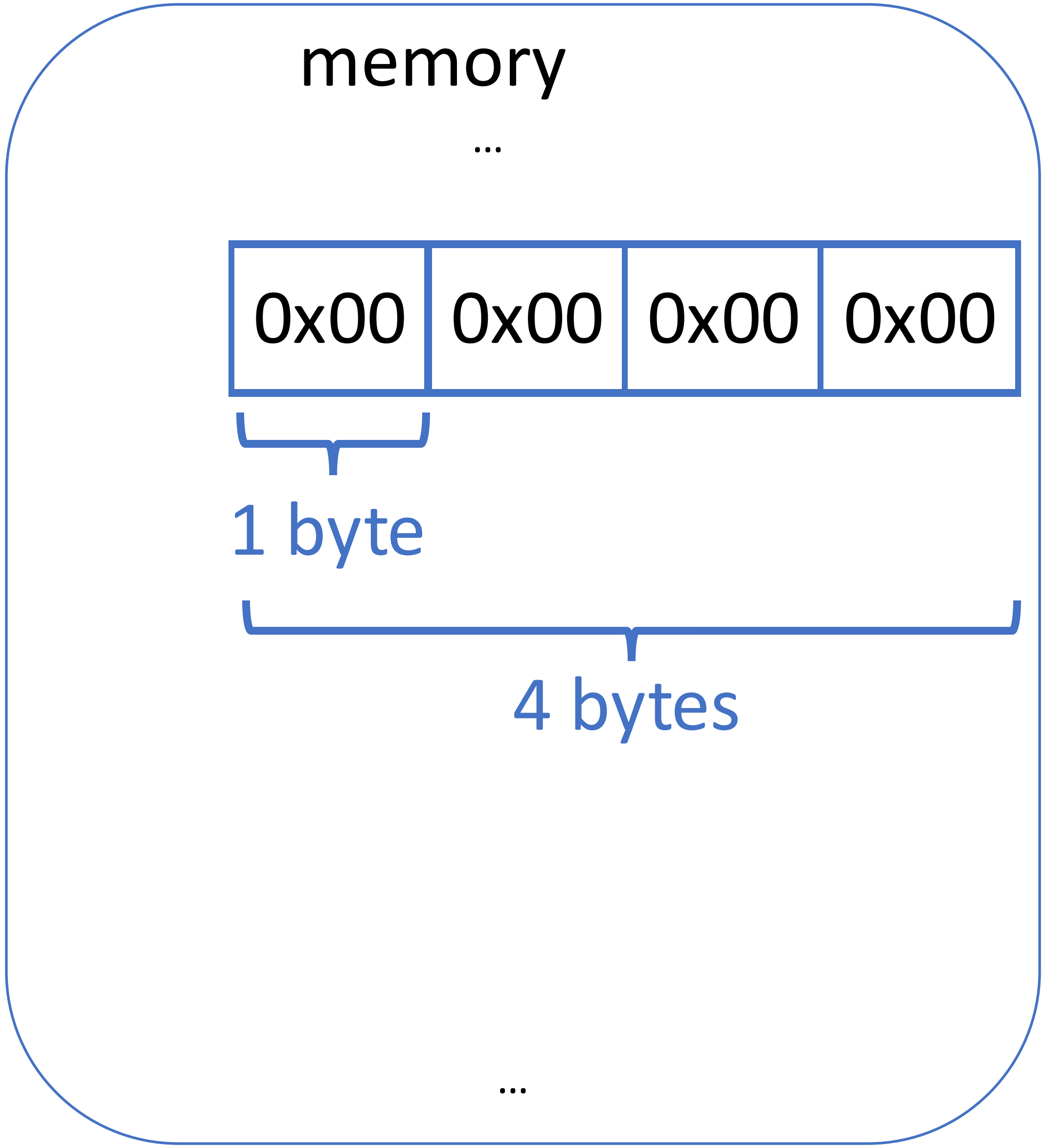
A pointer is a variable that stores a memory address.

```
int32_t  x  = 0;

int32_t* px;

px = &x;

// e.g. 0x7ffd39809084
```



memory

…

0x00	0x00	0x00	0x00

1 byte

4 bytes

…

*

Pointers

- On **the same type of machines**, all pointers have the **same size**
  - e.g. sizes of float*, int32_t*, char*, void*, … are the same on the same machine.
- Across **different machine architectures**, pointers' sizes may differ
  - 4 bytes on 32-bit machine
  - 8 bytes on 64-bit machine

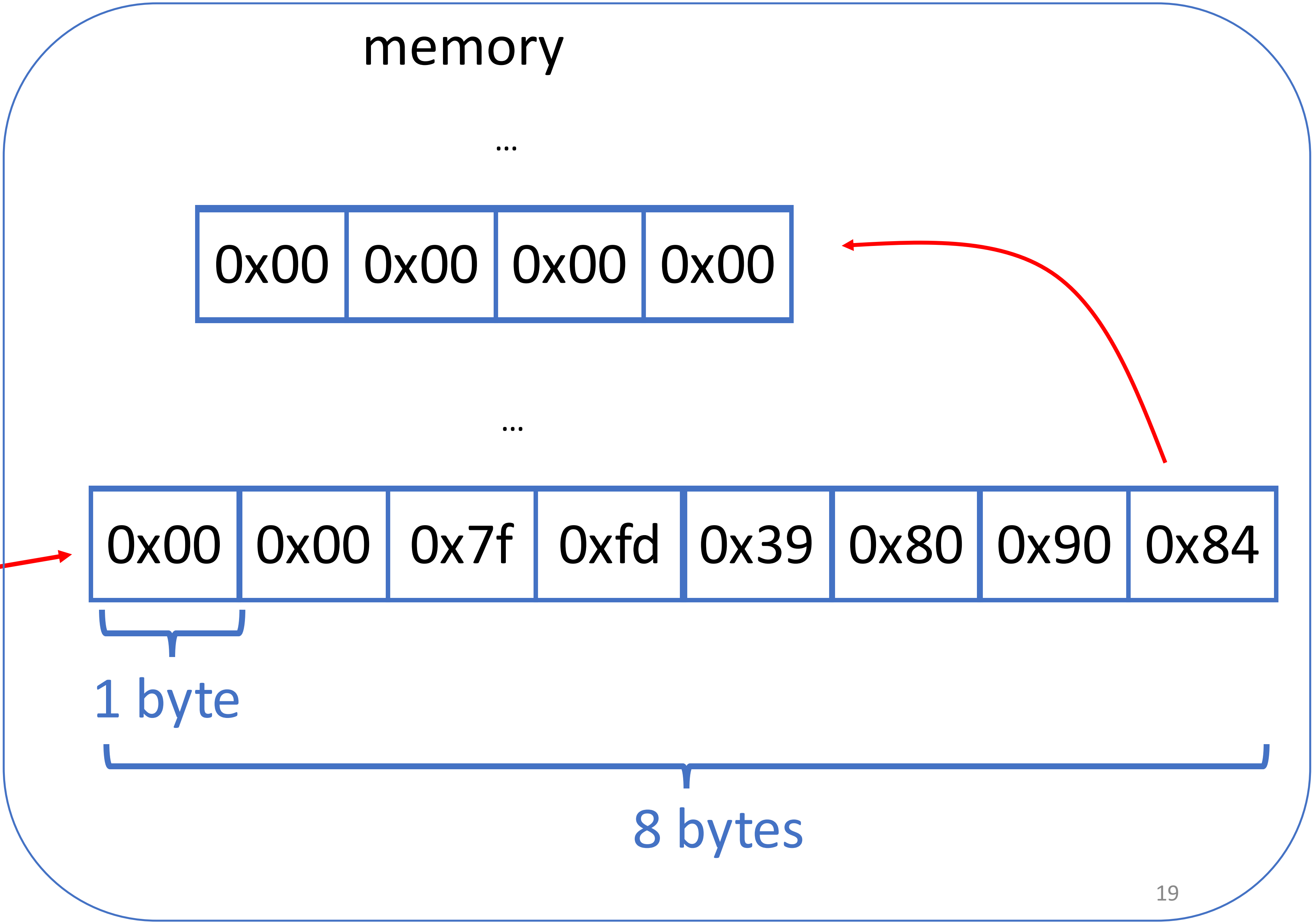
* Pointers

```
int32_t x = 0;

int32_t* px;

px = &x;

// e.g. 0x7ffd39809084
```



memory

…

0x00 0x00 0x00 0x00

…

0x00 0x00 0x7f 0xfd 0x39 0x80 0x90 0x84

1 byte

8 bytes

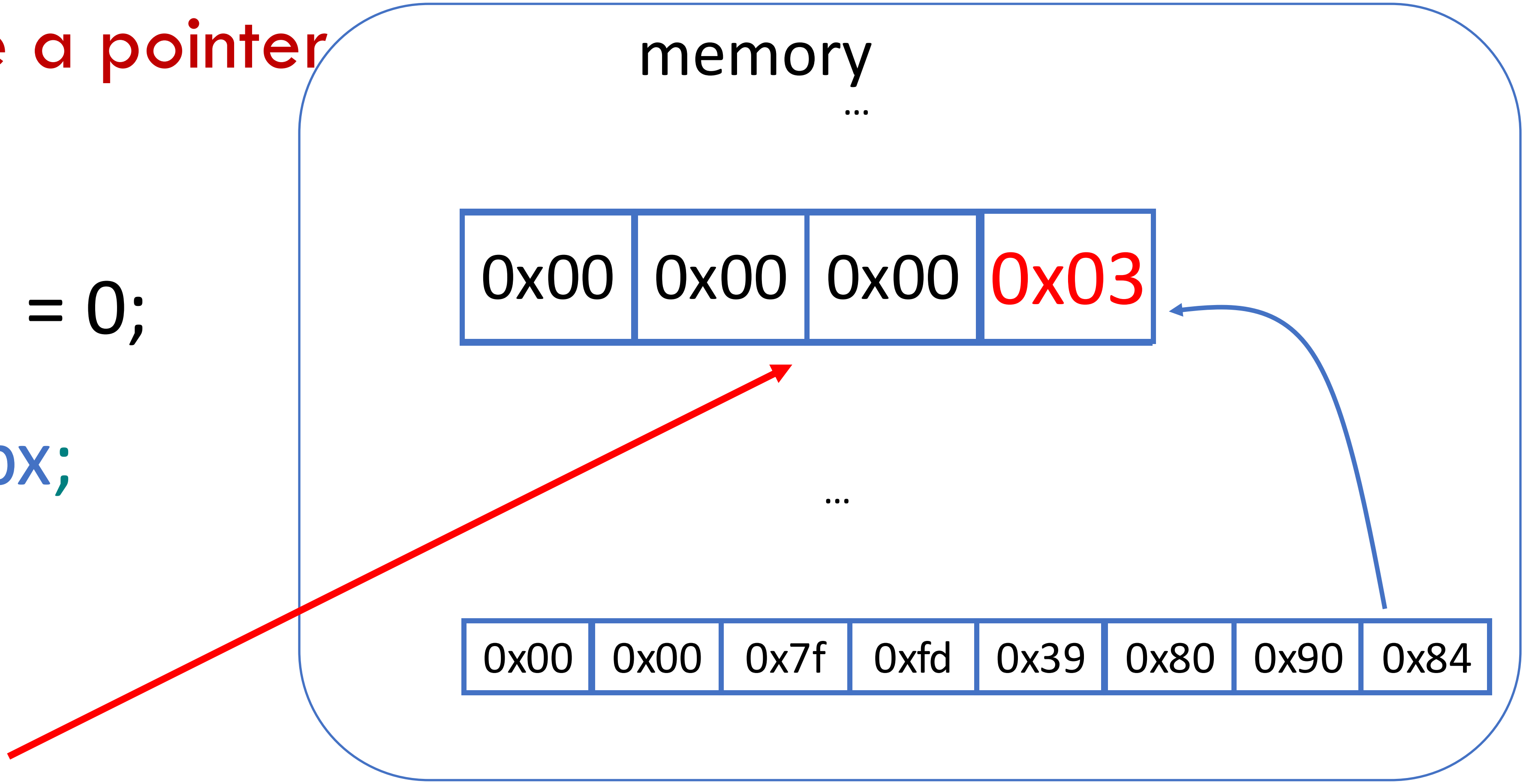
* Dereference a pointer

```
int32_t  x  = 0;

int32_t* px;

px = &x;

*px = 3;
```



memory

…

0x00	0x00	0x00	0x03

…

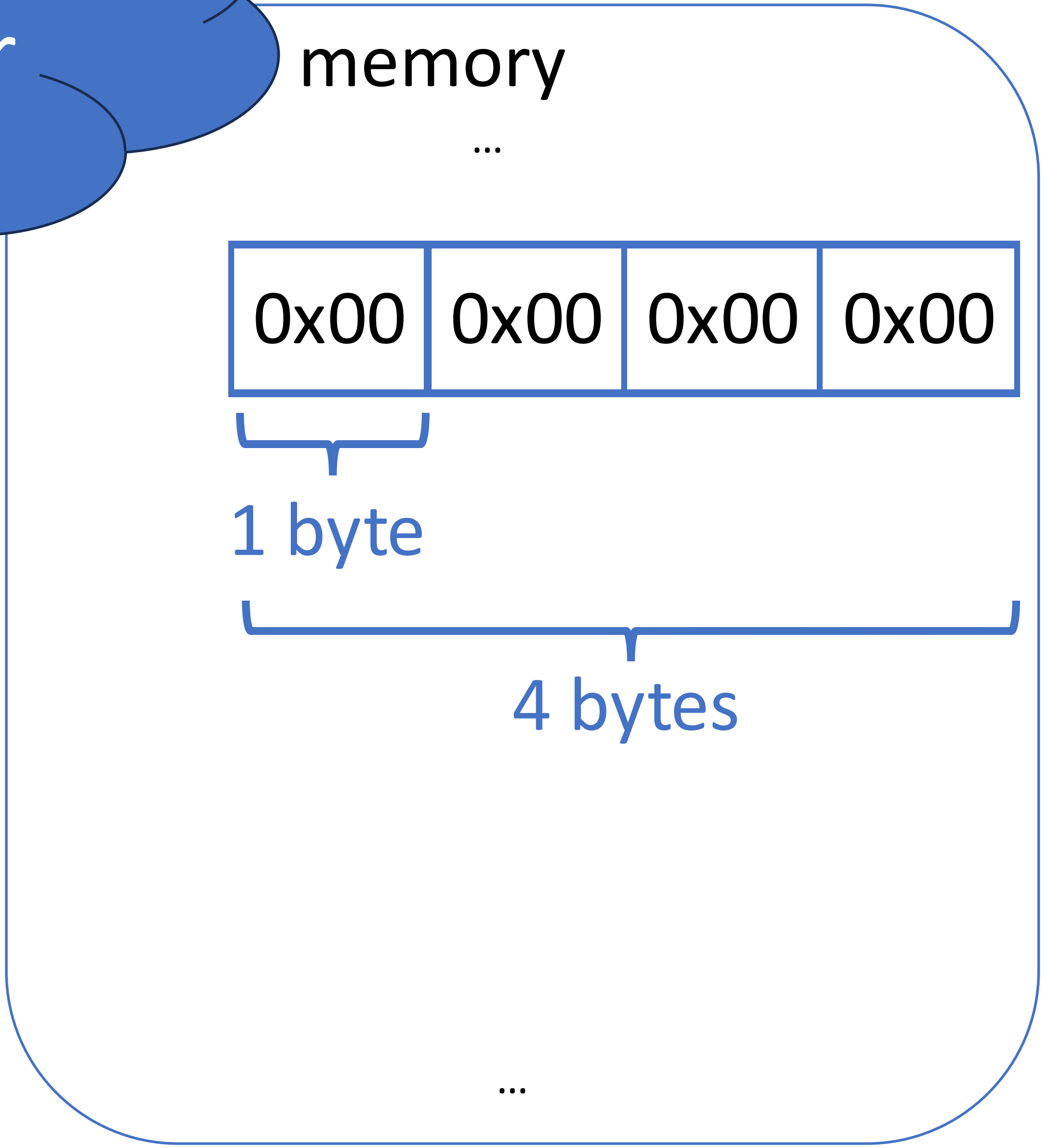
0x00	0x00	0x7f	0xfd	0x39	0x80	0x90	0x84

& | Reference

Can I use a different name for object x?

```
int32_t  x  = 0;

int32_t& ref_x = x;
```



memory

…

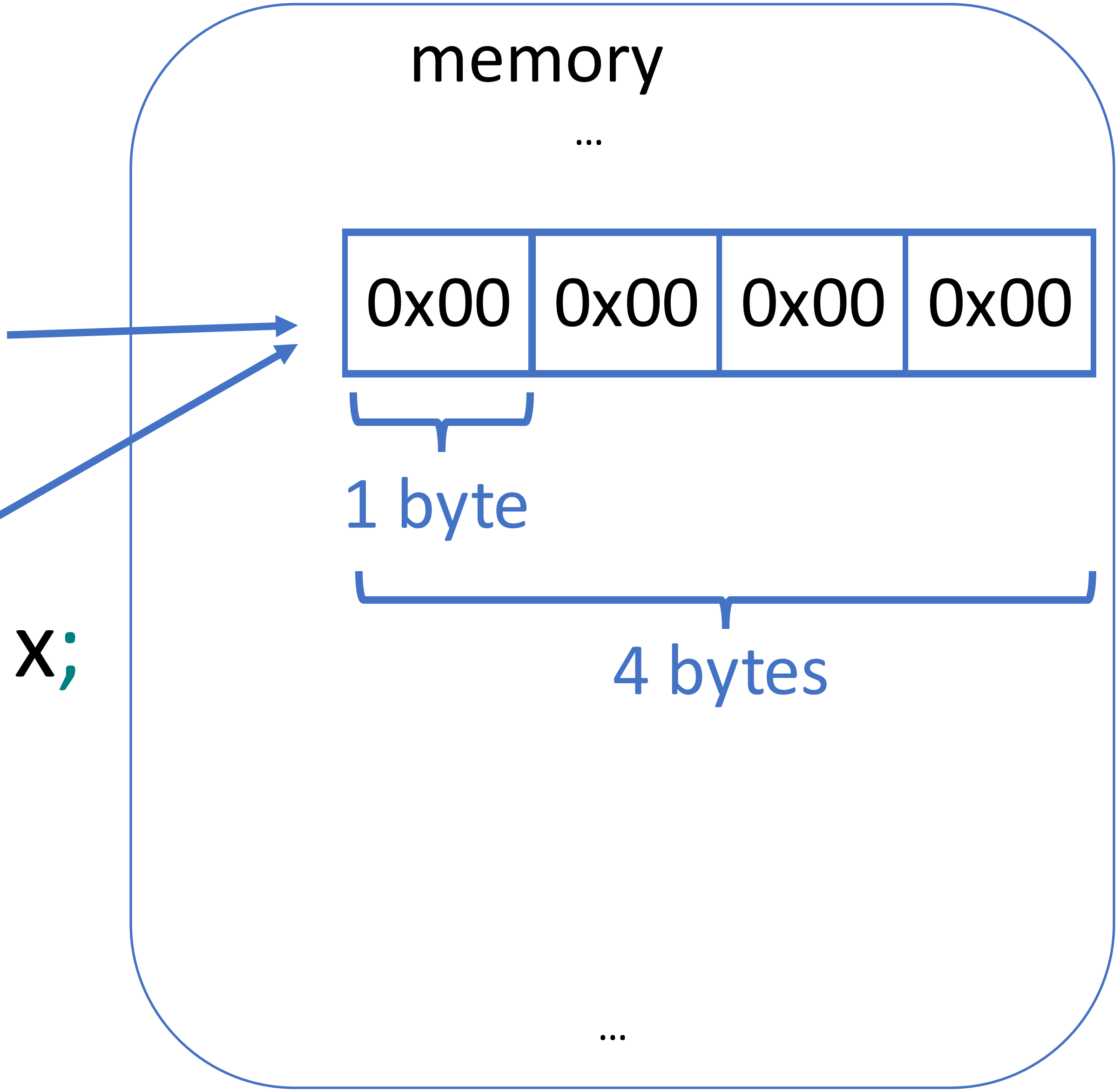
0x00	0x00	0x00	0x00

& Reference

an **alias** to an **existing** variable

```
int32_t  x  = 0;
```

```
int32_t& ref_x = x;
```



memory

…

0x00	0x00	0x00	0x00

1 byte

4 bytes

…

MAYBE IF I WEAR THIS SHIRT
NO ONE WILL BE ABLE TO TELL I'M SPIDERMAN

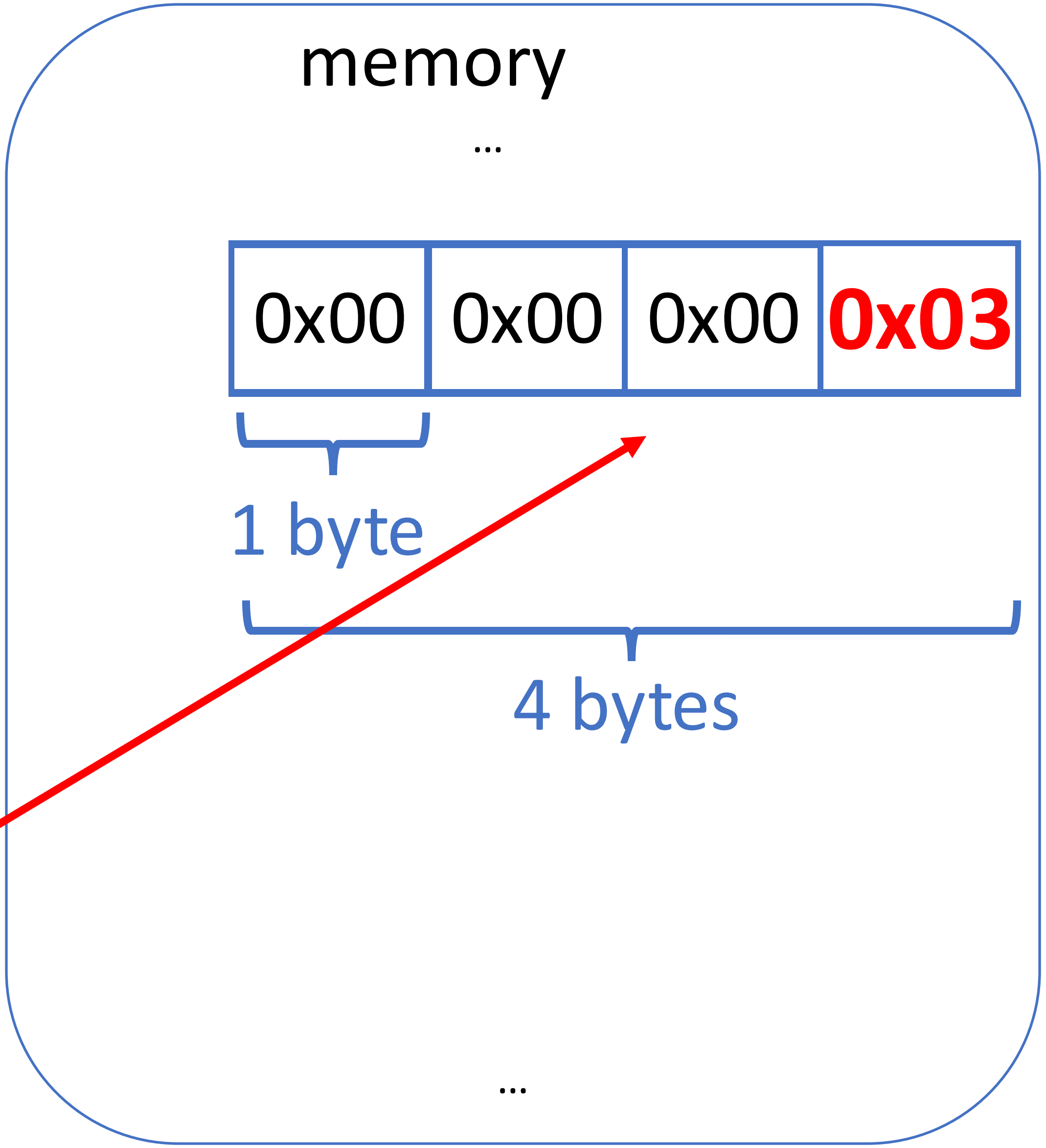
& Reference

an **alias** to an **existing** variable

```
int32_t  x  = 0;

int32_t& ref_x = x;

ref_x = 3;
```



& Reference

an **alias** to an **existing** variable

- Cannot be NULL
- Must be initialized at time of creation

```
int32_t  x  = 0;
int32_t& ref_x;
ref_x = x;
```

Compile error! ✗

```
int32_t  x  = 0;
int32_t& ref_x = x;
```

✓

Demo

& Reference

```
int  x  = 0;

int  y = 8;

int& ref = x;

ref = y;

ref = 3;
```

Now, what is x?
What is y?

& Reference

A reference is an **alias**(alternative name) to an **existing** variable

- Permanently bound to a single storage location, and cannot later be rebound

```
int  x  = 0;
int  y = 8;
int& ref = x;          // initialize ref to reference variable x
ref = y;               // assign the value in y to ref
```

Seems Useless?

Some easily confused notations

In a declaration, prefix with		In an expression, prefix with
	int a = 3;	
* = “pointer to”	int* b = &a;	& = “address of”
& = “reference to”	int& c = a;	
	int d = *b;	* = “contents of”

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- **Template C++:** generic programming language. Gives a template, define rules and pattern of computation, to be used across different classed.

Helloworld.cpp example

demo

```
#include <iostream>

int main() {
    std::cout << "Hello world!" << std::endl;
    return 0;
}
```

Program starting point
Every C++ program must have exactly one main() function.

Helloworld.cpp example

```
#include <iostream>


int main() {
    std::cout << "Hello world!" << std::endl;
    return 0;
}
```

Instruct the compiler to include the declaration of the standard stream I/O facilities in iostream

Helloworld.cpp example

```
#include <iostream>

int main() {
    std::cout << "Hello world!" << std::endl;
    return 0;
}
```

std:: (standard library)
specifies that the name cout to be found
in the standard library namespace

Operator << , writes its second argument to its first.
(write “Hello world” to
the standard output stream std::cout)

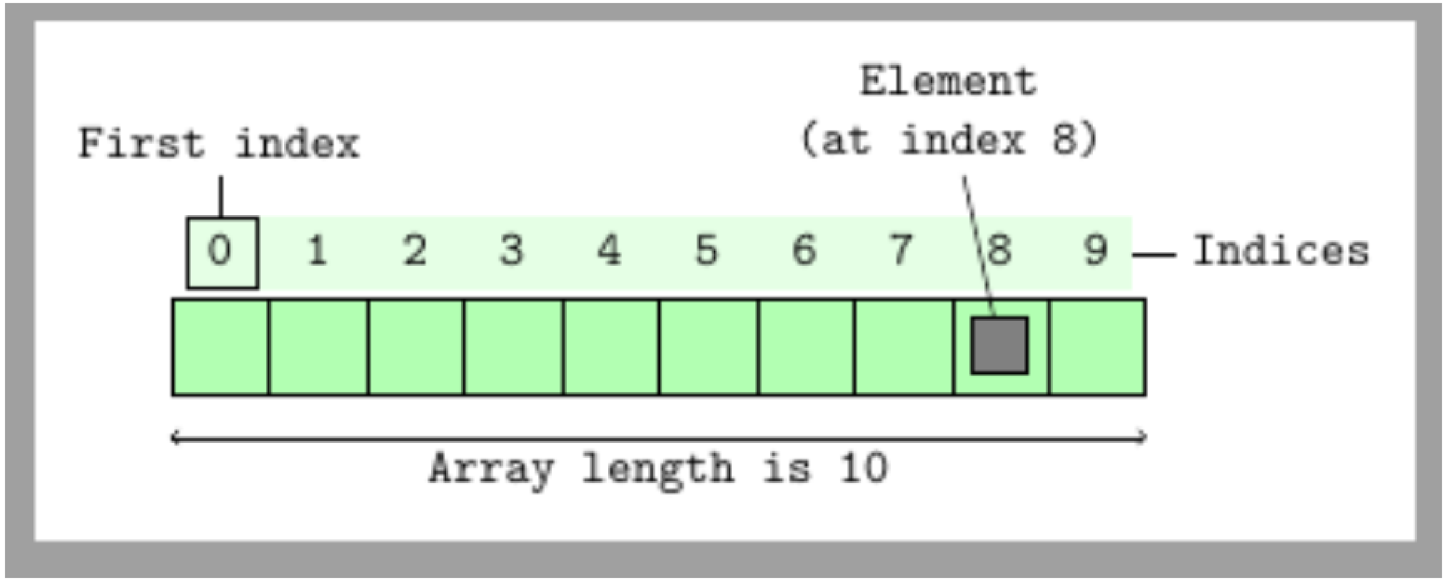
Optional – play along

https://www.onlinegdb.com

Select language C++

C++ Containers

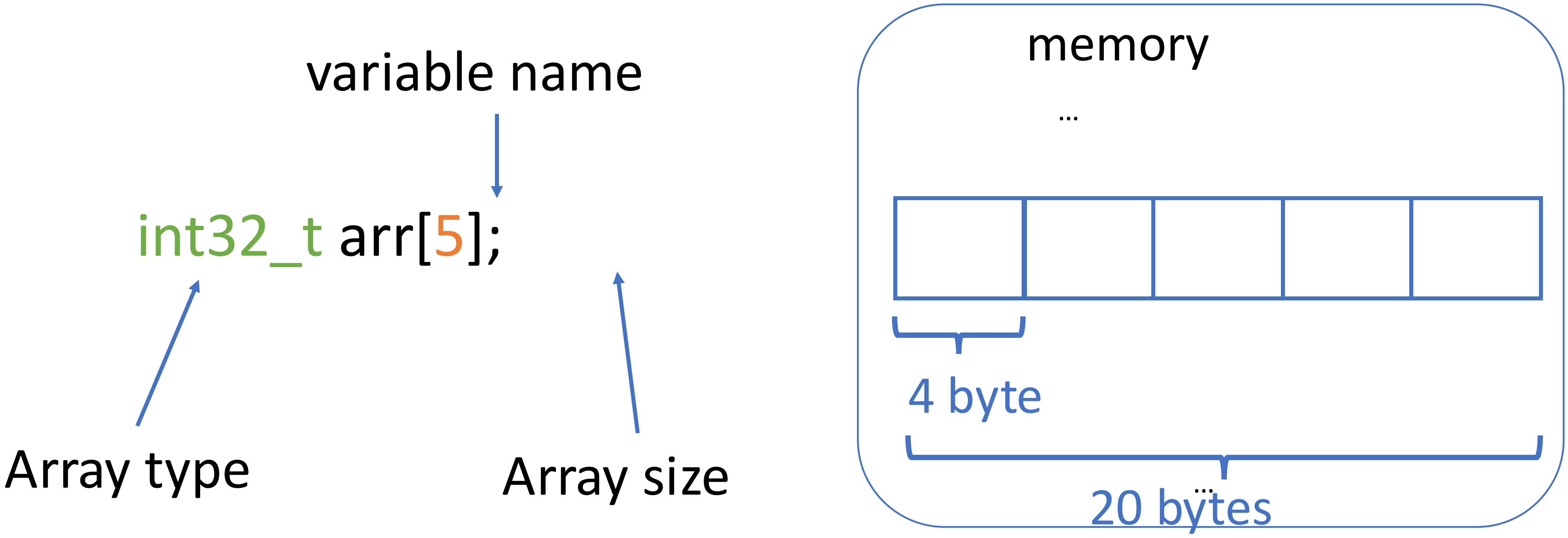
Fixed-size Array



- Arrays must be declared by type and size
- The size must be fixed at compile-time
- Stores elements contiguously (in continuous memory locations)
- Elements are accessed starting with position 0 (0-based indexing)
- O(1) access given the index of the element

Fixed-size Array

- **Contiguously** allocated sequence of objects with the **same type**
- The array **size never changes** during the array lifetime.

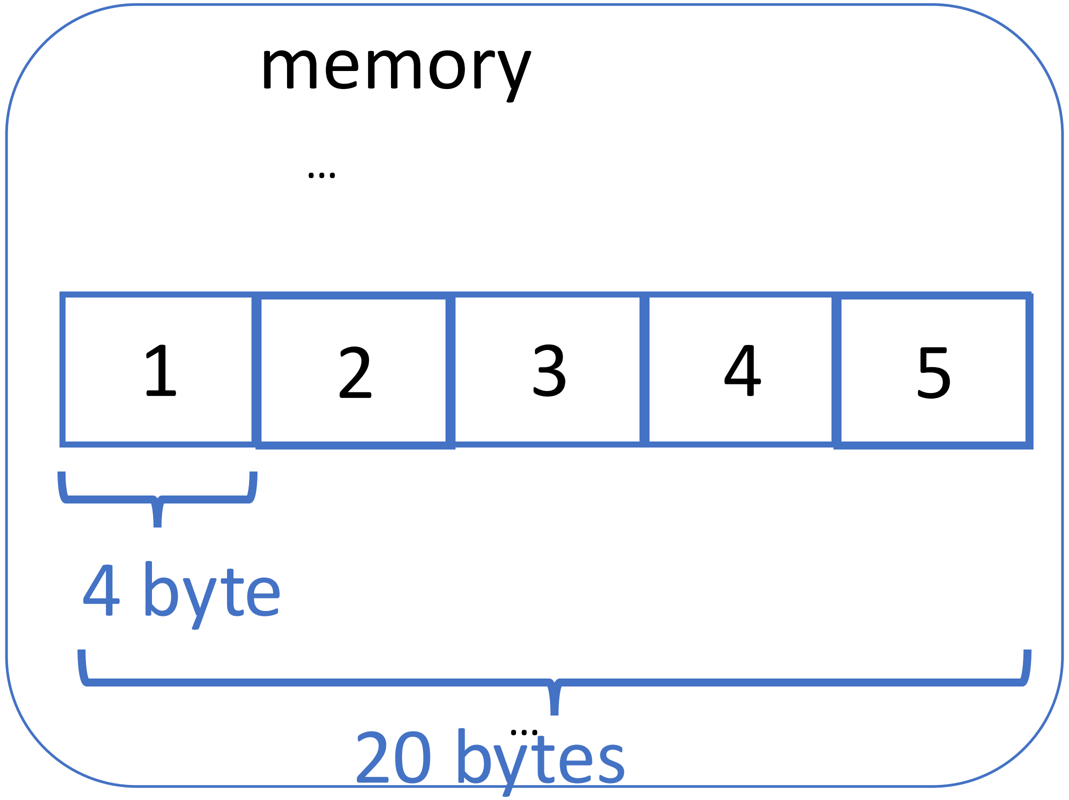


Fixed-size Array -- Initialization

```
int32_t arr[5]={1,2,3,4,5};
                // declares int[5] initialized to {1,2,3,4,5};

int32_t arr[]={1,2,3,4,5};
             // compiler could deduce the size of array is 5,
             and initialized to {1,2,3,4,5};
```

Fixed-size Array -- Indexing

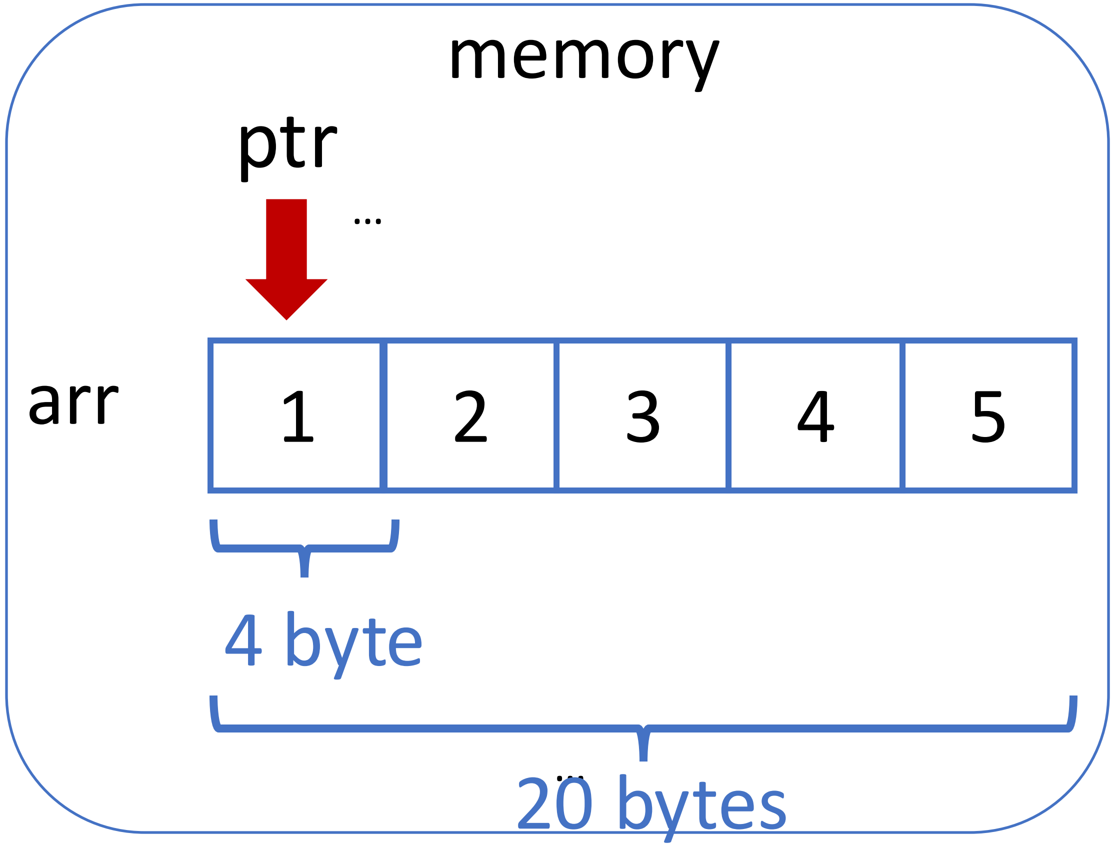
```
int32_t arr[5];
arr[0] = 1;
arr[1] = 2;
arr[2] = 3;
arr[3] = 4;
arr[4] = 5;
```



Array pointer conversion and arithmetic

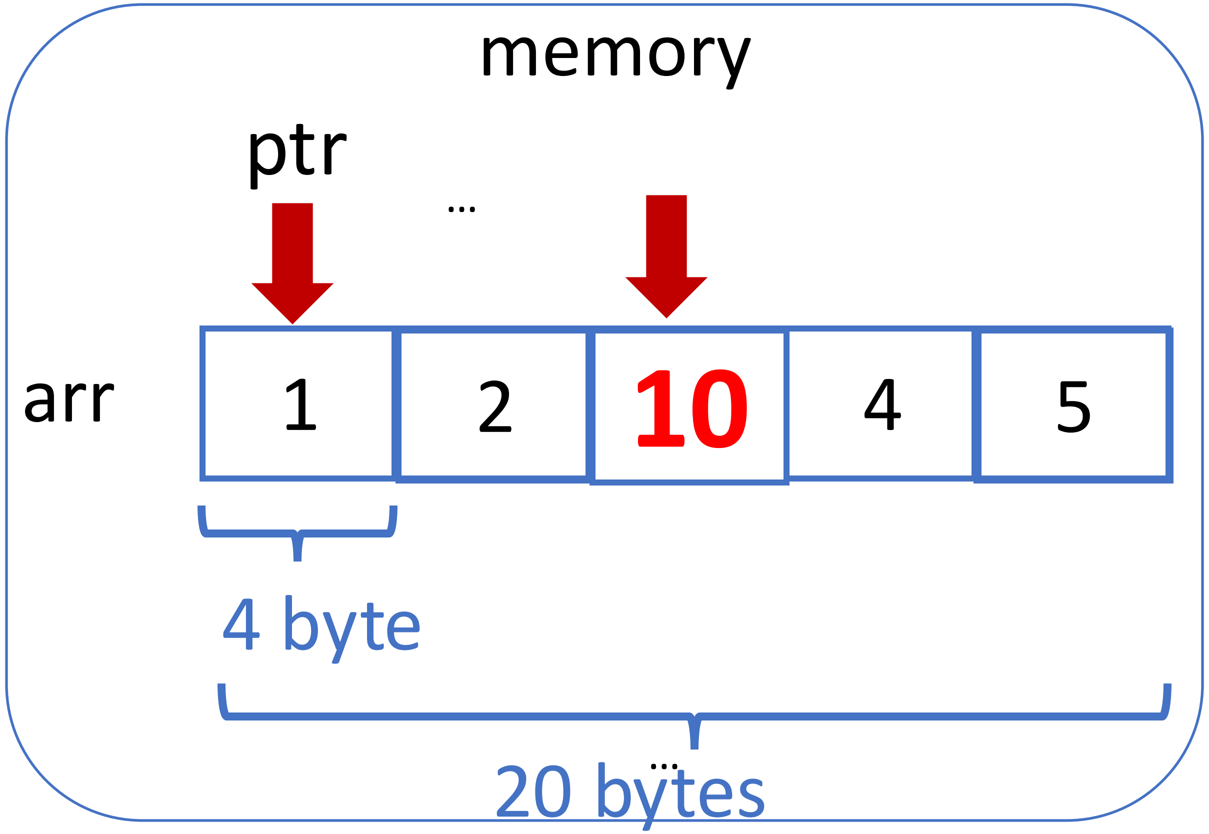
```
int32_t arr[5]={1,2,3,4,5};

int32_t* ptr = arr;

// ptr points to the address of arr[0]


for (int i=0; i<5; i++){
  std::cout << *ptr << “,”;
  ptr++;
}
```

// uint32_t pointer incremented by its type size



Array pointer arithmetic

```
int32_t arr[5]={1,2,3,4,5};

int32_t* ptr = arr;


 *(ptr + 2) = 10;
```



C++ Container

Standard Template Library

- Collection of classes and functions for general purpose use
- Provides container types (list, vector, map, …), pair, tuple, string, thread and many other functionalities
- Available in the std namespace

C++ Container

- A Container is an object used to **store other objects** and take care of the **management of the memory** of the objects it contains.
- Containers include many commonly used structures:
  - std::array,
  - std::vector,
  - std::queues,
  - std::map,
  - std::set,
  - …

C-style array (fixed-size array)

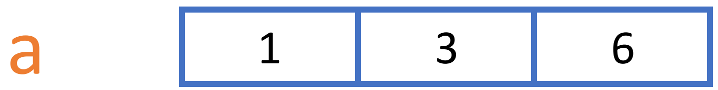
- C-style array is a block of memory that can be interpreted as an array

int a[10];

// declare **a** as an **array object** that consist of 10 **contiguous allocated** objects of **type int**

int a[3] = {1 , 3, 6} ;

// assignment of objects in array



std::array<T, N> ---a container that holds fixed size arrays

- Has the same semantics as a C-style array, but implemented by standard template library
- To use this container, include it at the beginning of the file

```
#include <array>
```

- T and N are template parameters: T is the type of the array, and N defines the number of elements
  - E.g., std::array<char, 10>, std::array<int, 3>

std::array<T, N> ---a container that holds fixed size arrays

- Has the same semantics a C l by standard template library

Why use std::array offered by C++ Standard Template Library(std)?

- To use this conta

  #include <array>

- T and N are template parameters: T is the type of the array, and N es the number of elements

  g., std::array<char, 10>, std::array<int, 3>

C-style array vs. std::array<T, N>

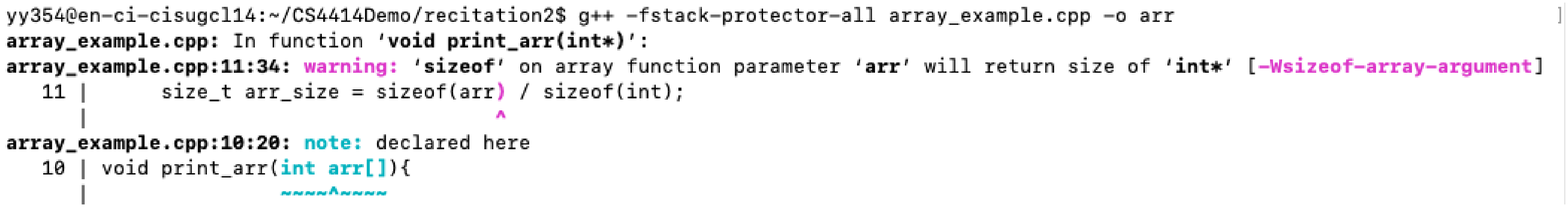
- C-style array
  - No bound check when accessing element using operator[]
    - Undefined result if access a[20] if a is an array with size 3
  - Array-to-pointer decay
    - E.g., When pass a C-style array as **a value** to a function it decays to **a pointer** of the first element in the array, losing the size information.

C-style array vs. std::array<T, N>

- C-style array characteristics
  - No bound check when accessing element using operator[]
  - Array-to-pointer decay

```
void print_array(int arr[]){
      size_t arr_size = sizeof(arr) / sizeof(int);
      for(int i = 0; i < arr_size; ++ i){
       std::cout << arr[i] << std::endl;
      }
}
```

```
void print_array(int * arr){
      size_t arr_size = sizeof(arr) / sizeof(int);
      for(int i = 0; i < arr_size; ++ i){
       std::cout << arr[i] << std::endl;
      }
}
```



```
yy354@en-ci-cisugcl14:~/CS4414Demo/recitation2$ g++ -fstack-protector-all array_example.cpp -o arr
array_example.cpp: In function 'void print_arr(int*)':
array_example.cpp:11:34: warning: 'sizeof' on array function parameter 'arr' will return size of 'int*' [-Wsizeof-array-argument]
   11 |     size_t arr_size = sizeof(arr) / sizeof(int);
      |                                 ^
array_example.cpp:10:20: note: declared here
   10 | void print_arr(int arr[]){
      |                ~~~~^~~~~
```

https://cppinsights.io

C-style array vs. std::array<T, N>

Std::array<T> has more functions, making it easier to use

```
std::array<int, 3> a = {1, 2, 3};
```

- size() : get the size of the array

```
std::cout << a.size() << std::endl;
```

- at() / operator [] : access specified element with bounds checking

```
std::cout << a.at(2) << std::endl;
```

- Use iterator to access container elements

```
for(auto it = a.begin(); it < a.end(); ++it )
{....}
```

- More functionalities: https://en.cppreference.com/w/cpp/container/array

std::vector<T>

- T is a template parameter
- Std::vector<int> is a vector of integers, std::vector<char> is a vector of characters
- Same as std::array, T can be a class or other C++ container
  - E.g., std::vector<Rectangle>,

    std::vector<std::map<int, std::string>>…

std::vector<T>

- T is a template para

- Std::vector<in tor of characters

Why do I want to use std::vector<T> ?

- Same as std::array, T n be a class or other C++ container

g., std::vector<Rectangle>,

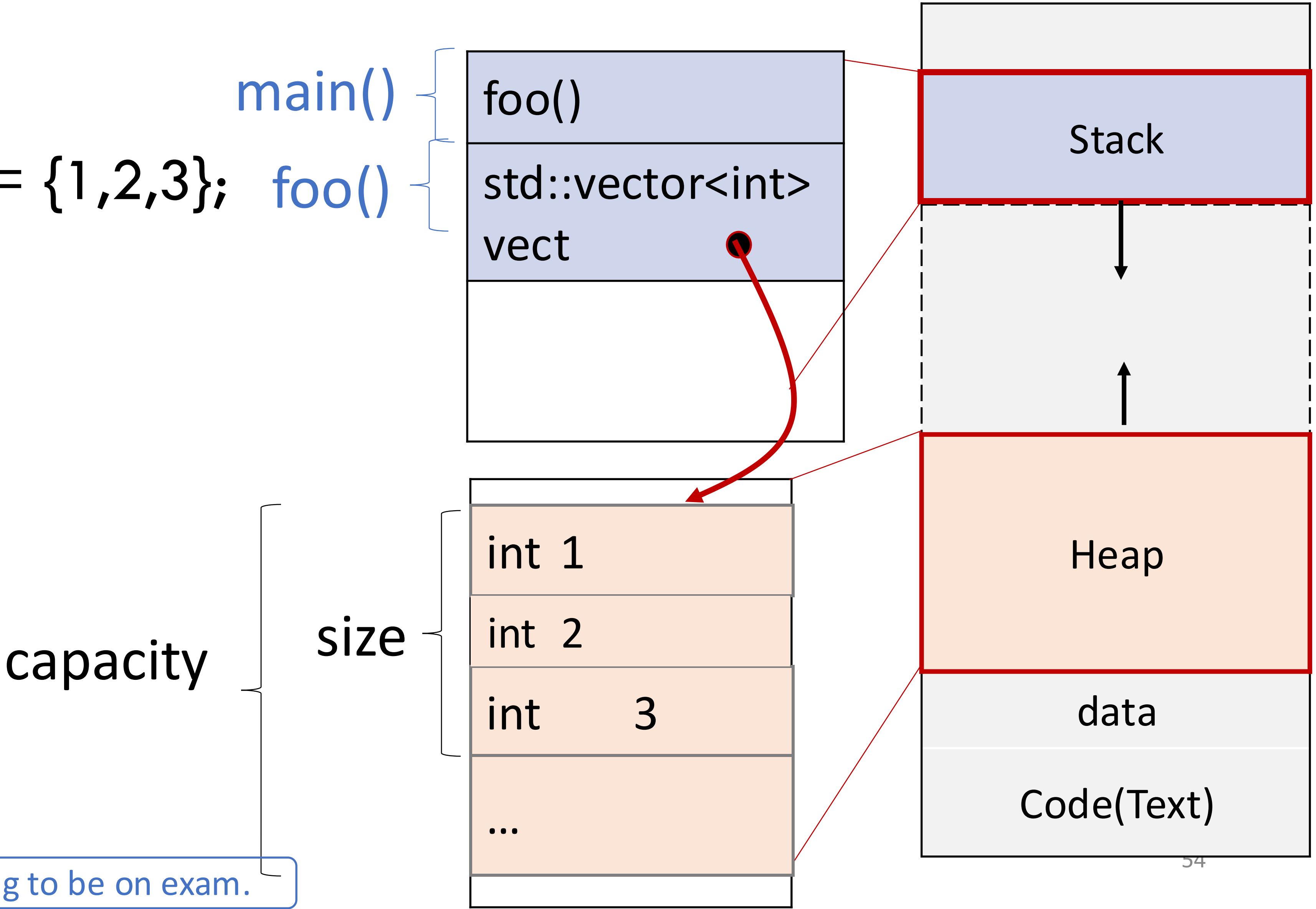
std::vector<std::map<int, std::string>>…

std::vector<T> - A dynamicly-sized array

- Main problem: How to support adding elements efficiently?
- Concept of size vs. capacity

std::vector<T> - under the hood memory structure

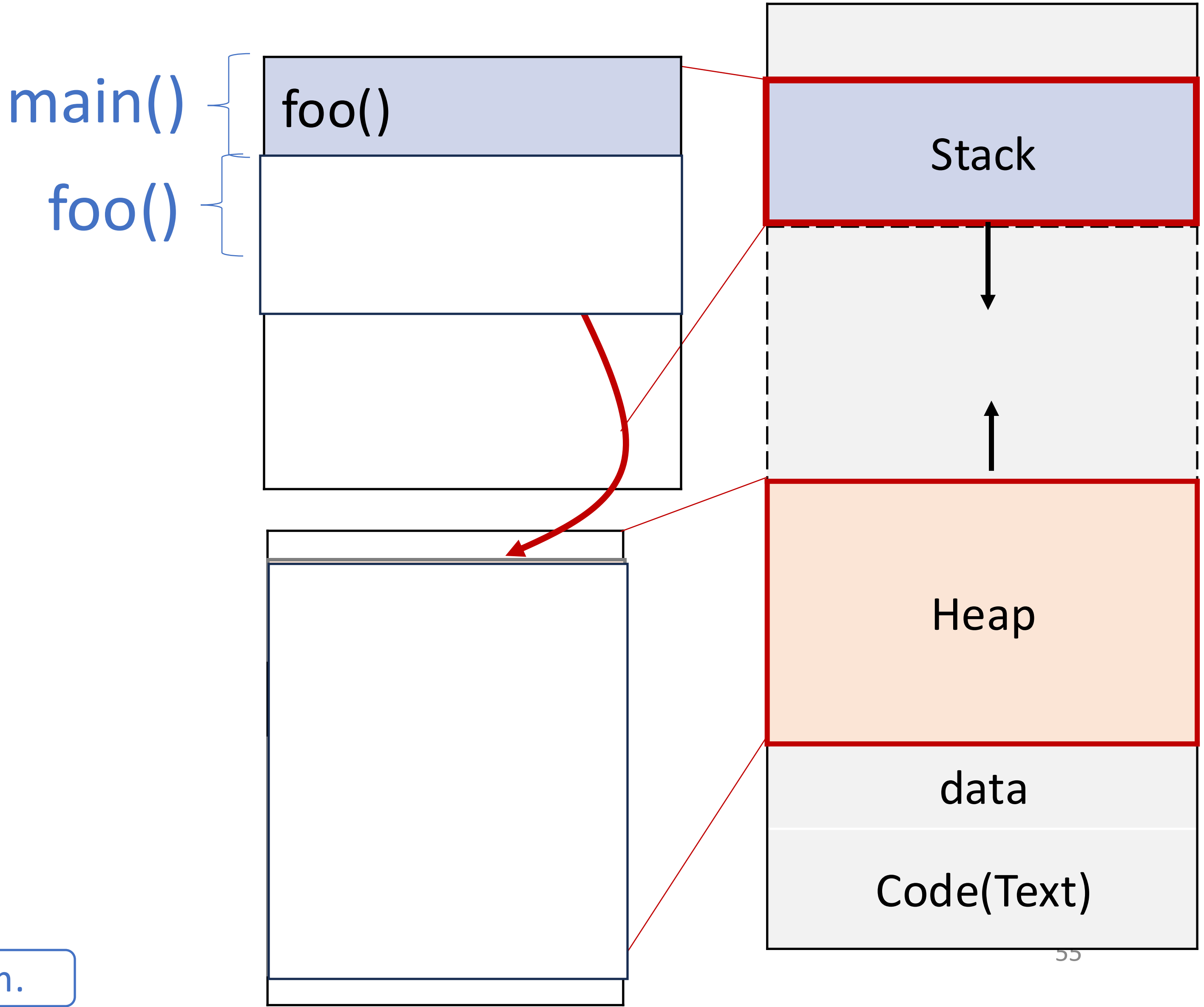
```
void foo(){
  std::vector<int> vect= {1,2,3};
}

 int main(){
     foo();
     …….
 }
```



This slide is for curiosity only, not going to be on exam.

std::vector<T> - under the hood memory structure

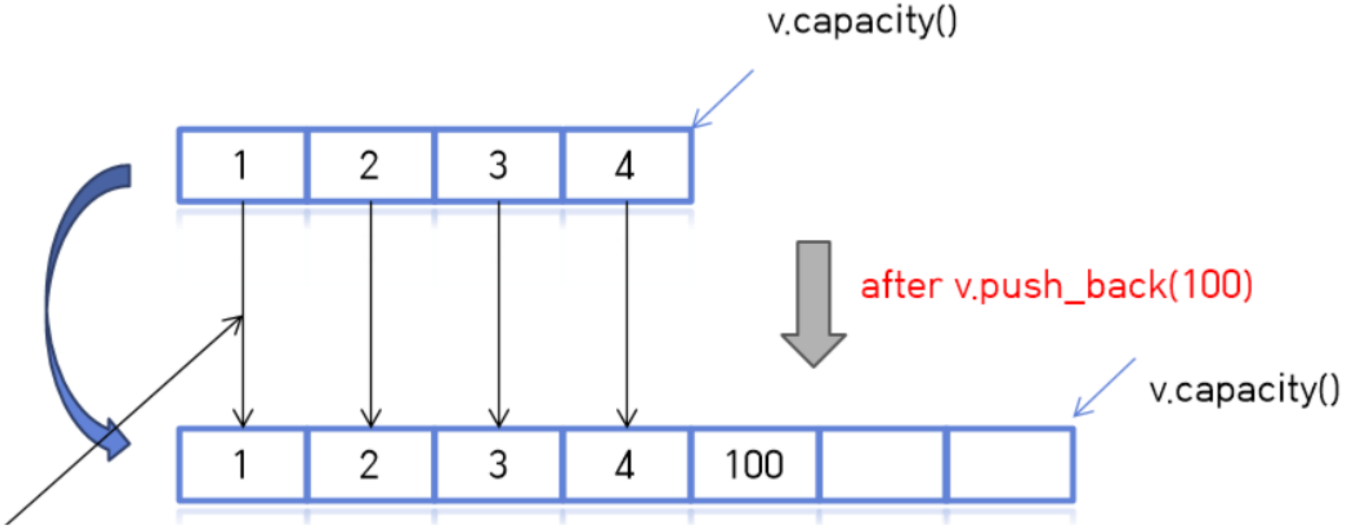
```
void foo(){
  std::vector<int> vect= {1,2,3};
}

 int main(){
      foo();
     .......
 }
```



This slide is for curiosity only, not going to be on exam.

std::vector<T> - A dynamic-sized array

- Main problem: How to support adding elements efficiently?
- Concept of size vs. capacity
- Reallocates elements when capacity is exceeded



demo

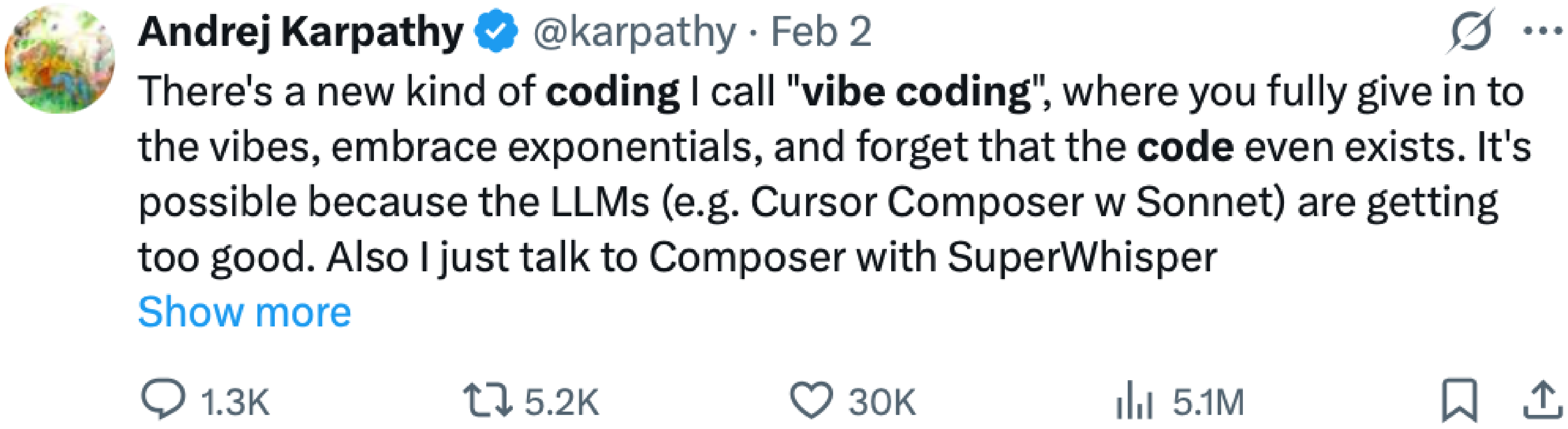
std::vector<T> - functionalities

- Element access: operator [], at, front, back, data
- Iterators: begin, end, rbegin, rend
- Capacity: size, capacity, reserve
- Modifiers: emplace, push_back, erase, resize

https://en.cppreference.com/w/cpp/container/vector

Building reliable and efficient systems

System programming in the era of LLMs



Andrej Karpathy @karpathy · Feb 2

There's a new kind of **coding** I call "**vibe coding**", where you fully give in to the vibes, embrace exponentials, and forget that the **code** even exists. It's possible because the LLMs (e.g. Cursor Composer w Sonnet) are getting too good. Also I just talk to Composer with SuperWhisper

https://karpathy.ai

Ways you can use LLMs

- **As Learning Tools**
  - Reinforce course concepts through continuous querying
  - Ask for examples and verify by running them
  - Use tools like ChatGPT's study mode

CURSOR Claude ChatGPT

Ways you can use LLMs

Why are we taking 5416 now that we have?

- **To Understand the Codebase**
  - Trace the call stack and function dependencies
  - Use tools like Cursor to navigate and analyze large codebases

One needs fundamental system knowledge to use, understand and generate reliable code with LLM

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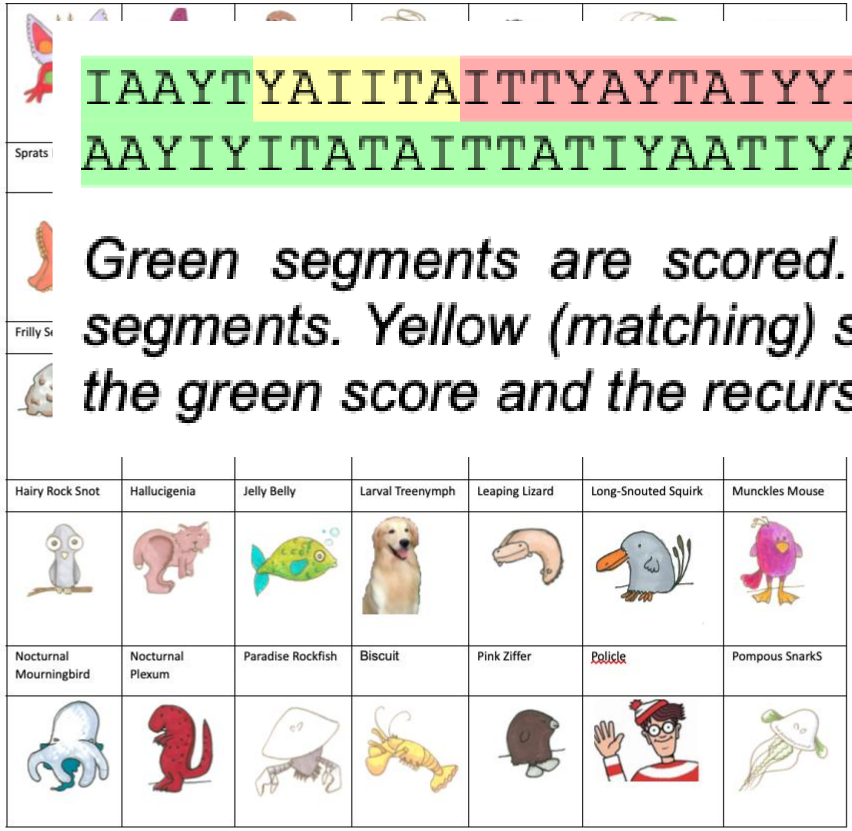
Ways you can use LLMs

- **Acting as a Project Manager to the LLM**
  - Clearly provide **context** about the problem
  - Ask **precise, well-scoped** questions
  - Apply **knowledge learnt in class** to query LLM
  - Check every line, **verify** its output
  - Generating smaller blocks of code at a time and making sure you understand it is better than generating an entire file or program

Example. Writing efficient code with LLM

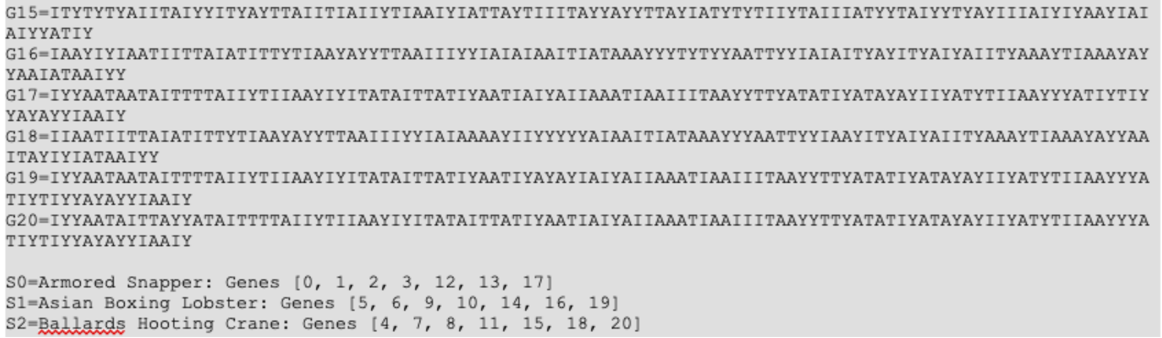
Example. DNA Phylogenetic Tree

by Jeffrey Qian. (The top1 winning solution on leaderboard in 2024 Fall)



```
IAAYTYAIITAITTYAYTAIYYITITITAYIIAIAIYYAT
AAYIYITATAITTATIYAATIYAYAYIAIYAIITAAAATIAAIIIT
```

Green segments are scored. The distance algorithm is run recursively on the red segments. Yellow (matching) segments are discarded. The total distance is the sum of the green score and the recursive red score.



```
G15=ITYTYTYAIITAIYYITYAYTTAIITIAIIYTIAAIYIATTAYTIIITAYYAYYTTAYIATYTYTIIYTAIIIATYYTAIYYTYAYIIIAIYIYAAYIAI
AIYYATIY
G16=IAAYIYIAATIITTAIATITTYTIAAYAYYTTAAIIIYYIAIAIAAITIATAAAYYYTYTYYAATTYYIAIAITYAYITYAIYAIITYAAAYTIAAAYAY
YAAIATAAIYY
G17=IYYAATAATAITTTTAIIYTIIAAYIYITATAITTATIYAATIAIYAIIAAATIAAIIITAAYYTTYATATIYATAYAYIIYATYTIIAAYYYATIYTIY
YAYAYYIAAIY
G18=IIAATIITTAIATITTYTIAAYAYYTTAAIIIYYIAIAAAAYIIYYYYYAIAAITIATAAAYYYAATTYYIAAYITYAIYAIITYAAAYTIAAAYAYYAA
ITAYIYIATAAIYY
G19=IYYAATAATAITTTTAIIYTIIAAYIYITATAITTATIYAATIYAYAYIAIYAIIAAATIAAIIITAAYYTTYATATIYATAYAYIIYATYTIIAAYYYA
TIYTIYYAYAYYIAAIY
G20=IYYAATAITTAYYATAITTTTAIIYTIIAAYIYITATAITTATIYAATIAIYAIIAAATIAAIIITAAYYTTYATATIYATAYAYIIYATYTIIAAYYYA
TIYTIYYAYAYYIAAIY

S0=Armored Snapper: Genes [0, 1, 2, 3, 12, 13, 17]
S1=Asian Boxing Lobster: Genes [5, 6, 9, 10, 14, 16, 19]
S2=Ballards Hooting Crane: Genes [4, 7, 8, 11, 15, 18, 20]
```

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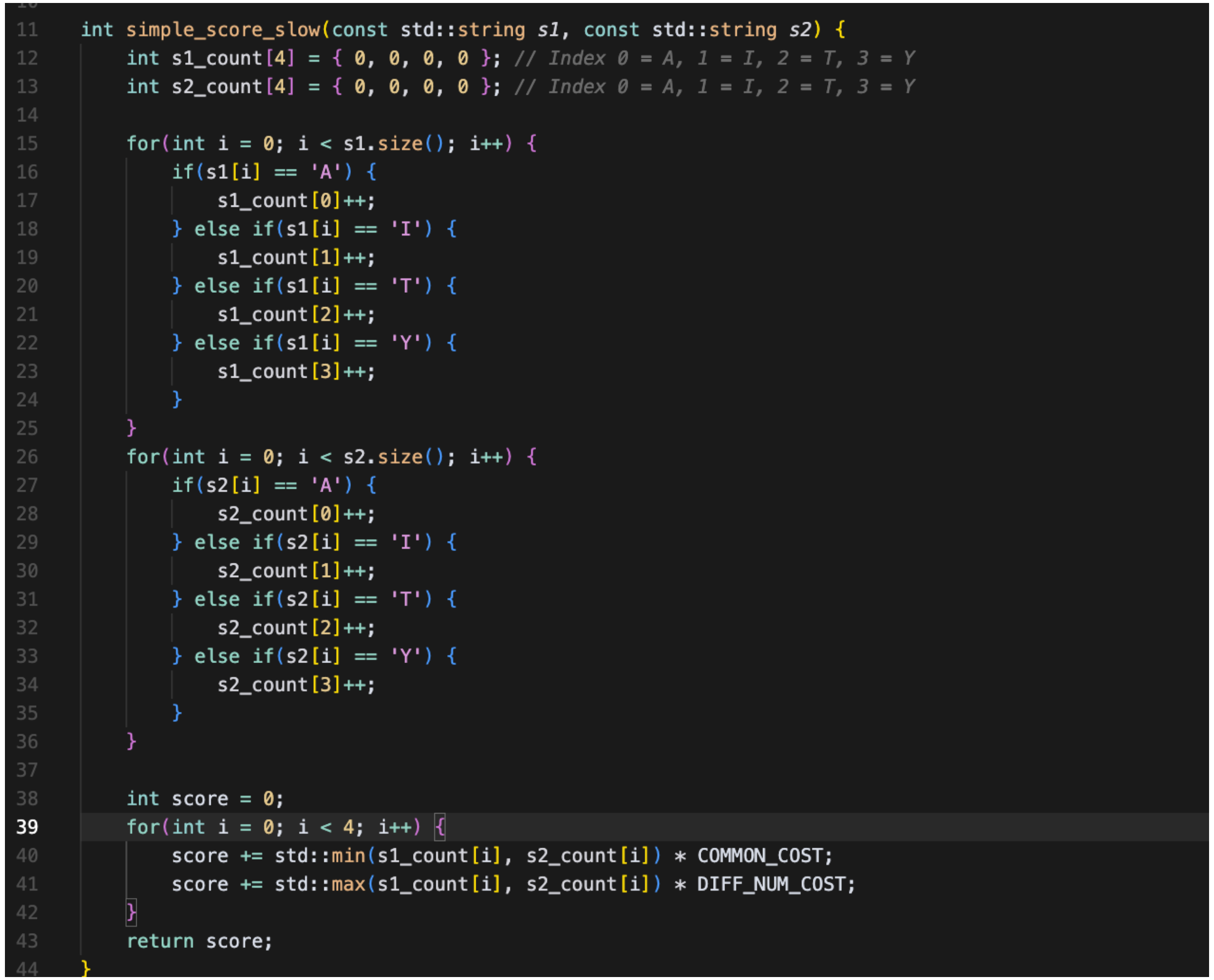
Example. Score computation

The right is a very naive implementation of the logic. One that generative AI might give you from a good starter prompt.

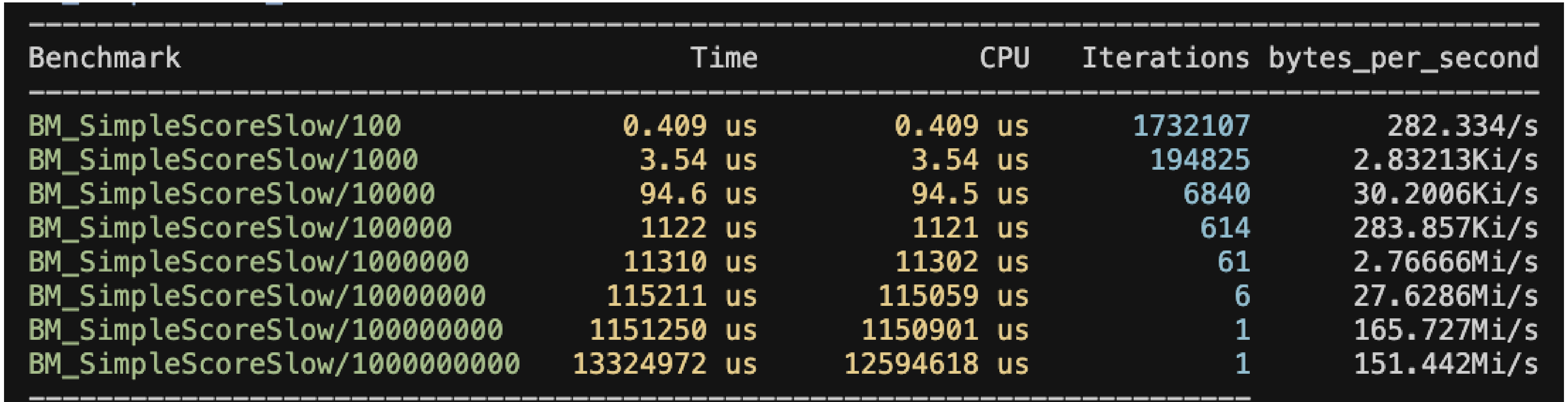


```
int simple_score_slow(const std::string s1, const std::string s2) {
    int s1_count[4] = { 0, 0, 0, 0 }; // Index 0 = A, 1 = I, 2 = T, 3 = Y
    int s2_count[4] = { 0, 0, 0, 0 }; // Index 0 = A, 1 = I, 2 = T, 3 = Y

    for(int i = 0; i < s1.size(); i++) {
        if(s1[i] == 'A') {
            s1_count[0]++;
        } else if(s1[i] == 'I') {
            s1_count[1]++;
        } else if(s1[i] == 'T') {
            s1_count[2]++;
        } else if(s1[i] == 'Y') {
            s1_count[3]++;
        }
    }
    for(int i = 0; i < s2.size(); i++) {
        if(s2[i] == 'A') {
            s2_count[0]++;
        } else if(s2[i] == 'I') {
            s2_count[1]++;
        } else if(s2[i] == 'T') {
            s2_count[2]++;
        } else if(s2[i] == 'Y') {
            s2_count[3]++;
        }
    }

    int score = 0;
    for(int i = 0; i < 4; i++) {
        score += std::min(s1_count[i], s2_count[i]) * COMMON_COST;
        score += std::max(s1_count[i], s2_count[i]) * DIFF_NUM_COST;
    }
    return score;
}
```

Example. Score computation

What's wrong with it? Let's ask claude

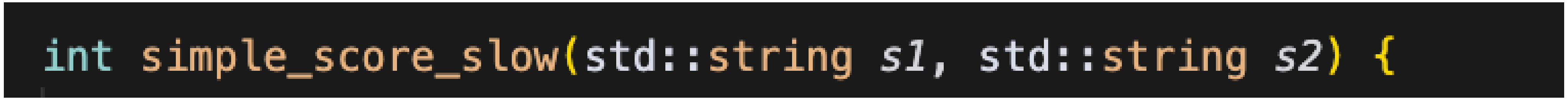
- Claude says the if-else chain causes branch predictions and proposes:
  - Direct mappings from character to array index
  - Switches statements
  - Using a hashmap
- This is where good fundamentals comes in → direct mappings is the fastest
  - Switch statements: to avoid branching costs, switch statements usually will "hash" the input and use that value as an index into a jump table source. However, if the compiler is smart enough, it would perform similar optimizations with if-else statements.
  - Hashmaps are expected O(1) but the hash algorithm on characters is probably more expensive than a direct mapping.



```
------------------------------------------------------------------------------------------
Benchmark                             Time             CPU   Iterations bytes_per_second
------------------------------------------------------------------------------------------
BM_SimpleScoreSlow/100            0.409 us        0.409 us      1732107        282.334/s
BM_SimpleScoreSlow/1000            3.54 us         3.54 us       194825      2.83213Ki/s
BM_SimpleScoreSlow/10000           94.6 us         94.5 us         6840      30.2006Ki/s
BM_SimpleScoreSlow/100000          1122 us         1121 us          614      283.857Ki/s
BM_SimpleScoreSlow/1000000        11310 us        11302 us           61      2.76666Mi/s
BM_SimpleScoreSlow/10000000      115211 us       115059 us            6      27.6286Mi/s
BM_SimpleScoreSlow/100000000    1151250 us      1150901 us            1      165.727Mi/s
BM_SimpleScoreSlow/1000000000  13324972 us     12594618 us            1      151.442Mi/s
```

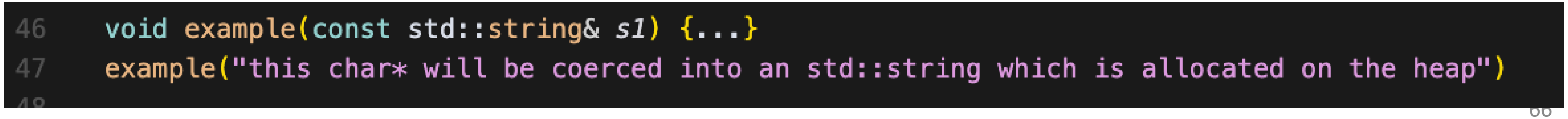
Jeffrey spotted Claude missed something…..

What did claude miss? It’s missed simplest change!



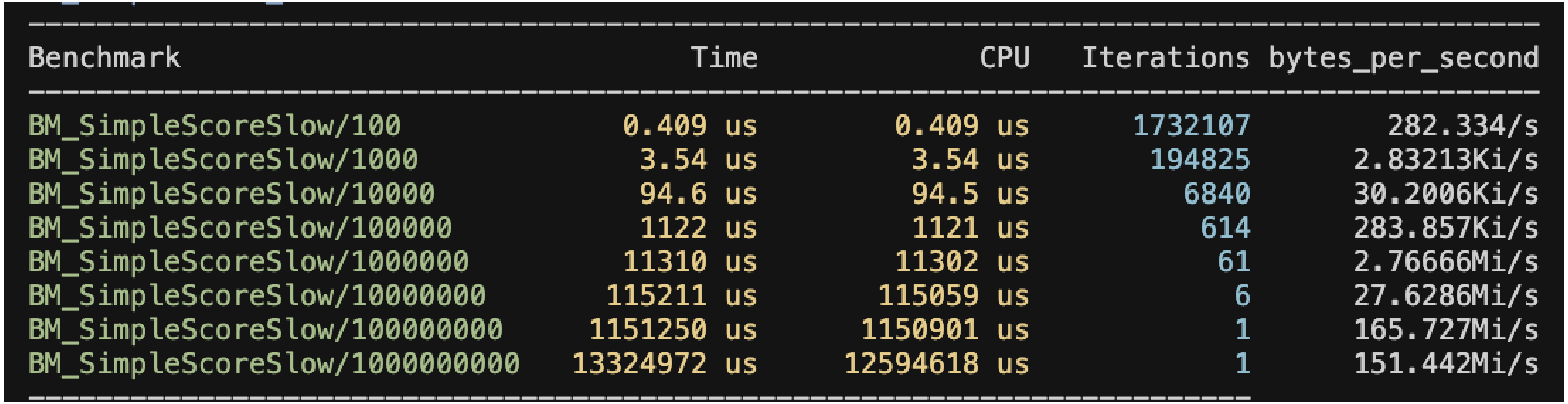
```
int simple_score_slow(std::string s1, std::string s2) {
```

- Should replace with const std::string& s1 or const std::string_view& s1
- We’re not mutating the string inside the function, so there’s no reason to not use const
- Can either pass by reference, or use std::string_view which is a non-owning read only view into an character buffer
- No reason to use one or the other in the assignment, but in practice, experience tells me to use std::string_view because it avoids a heap allocation in this case below. Again, **know the fundamentals really well**

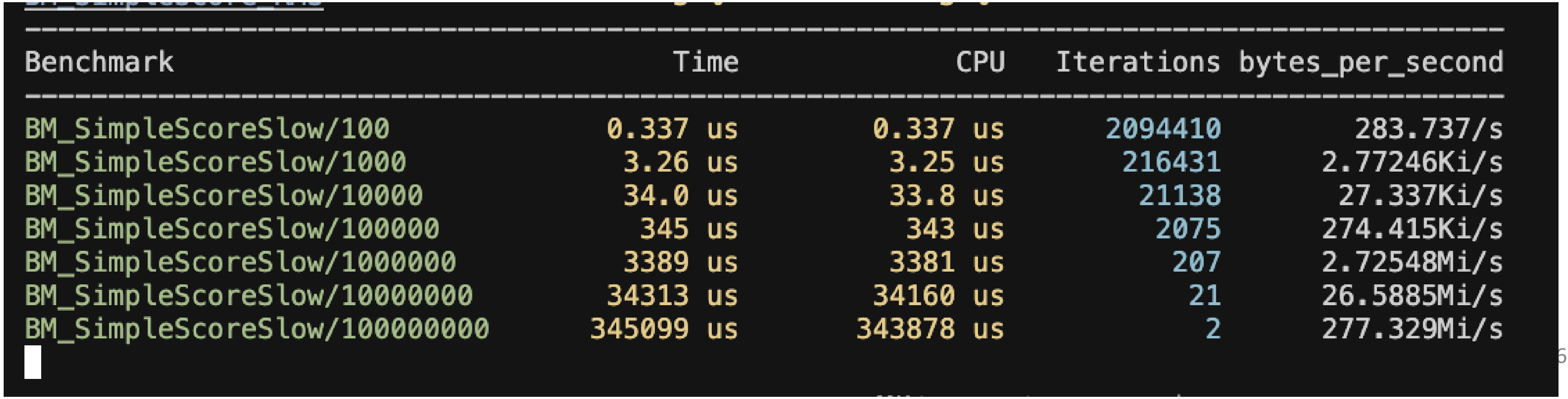


```
void example(const std::string& s1) {...}
example("this char* will be coerced into an std::string which is allocated on the heap")
```

What did that simple change get us?



```
-------------------------------------------------------------------------------------------
Benchmark                              Time             CPU   Iterations bytes_per_second
-------------------------------------------------------------------------------------------
BM_SimpleScoreSlow/100            0.409 us        0.409 us      1732107        282.334/s
BM_SimpleScoreSlow/1000            3.54 us         3.54 us       194825       2.83213Ki/s
BM_SimpleScoreSlow/10000           94.6 us         94.5 us         6840       30.2006Ki/s
BM_SimpleScoreSlow/100000          1122 us         1121 us          614       283.857Ki/s
BM_SimpleScoreSlow/1000000        11310 us        11302 us           61       2.76666Mi/s
BM_SimpleScoreSlow/10000000      115211 us       115059 us            6       27.6286Mi/s
BM_SimpleScoreSlow/100000000    1151250 us      1150901 us            1       165.727Mi/s
BM_SimpleScoreSlow/1000000000  13324972 us     12594618 us            1       151.442Mi/s
-------------------------------------------------------------------------
```



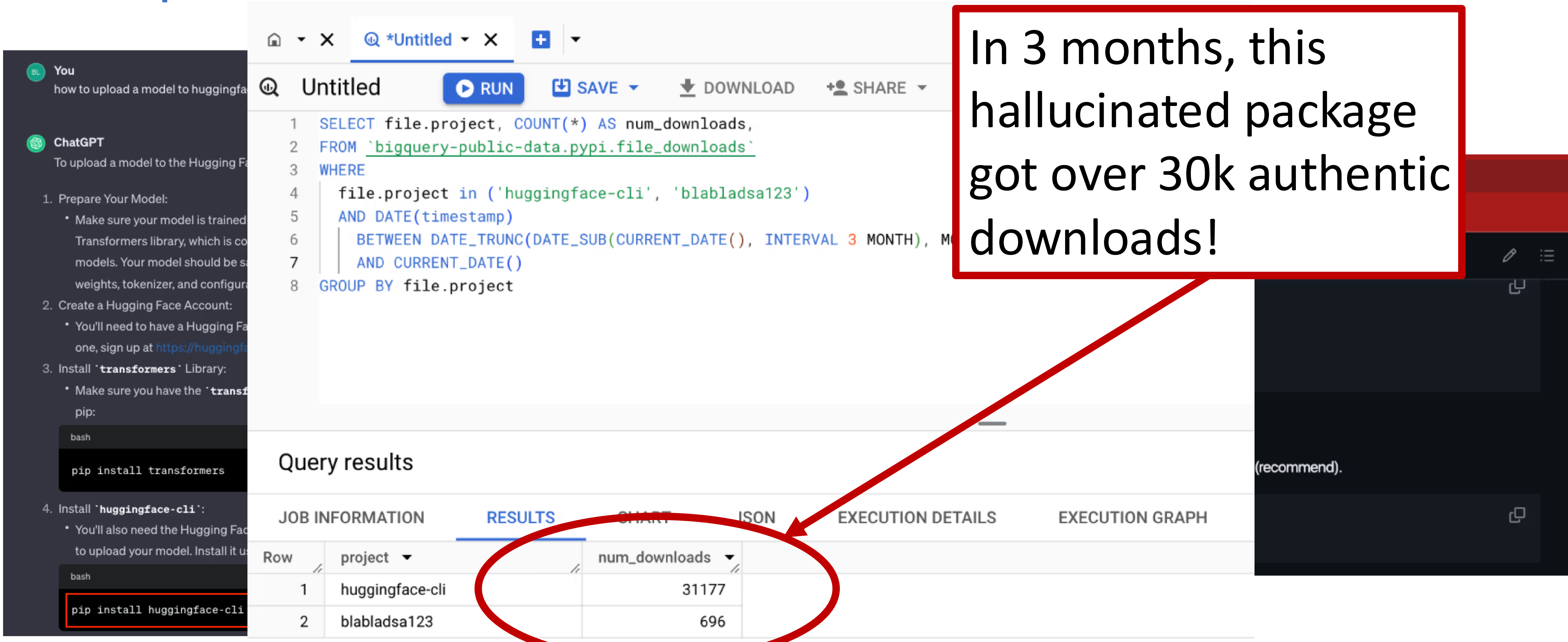
```
-------------------------------------------------------------------------------------------
Benchmark                              Time             CPU   Iterations bytes_per_second
-------------------------------------------------------------------------------------------
BM_SimpleScoreSlow/100            0.337 us        0.337 us      2094410        283.737/s
BM_SimpleScoreSlow/1000            3.26 us         3.25 us       216431       2.77246Ki/s
BM_SimpleScoreSlow/10000           34.0 us         33.8 us        21138        27.337Ki/s
BM_SimpleScoreSlow/100000           345 us          343 us         2075       274.415Ki/s
BM_SimpleScoreSlow/1000000         3389 us         3381 us          207       2.72548Mi/s
BM_SimpleScoreSlow/10000000       34313 us        34160 us           21       26.5885Mi/s
BM_SimpleScoreSlow/100000000     345099 us       343878 us            2       277.329Mi/s
```

Building reliable systems with LLMs

Situations to be careful when vibe coding:

- Bloated files and codebases
- Always verify. Even though hallucinations have improved with each passing model release, it isn't 100% reliable
  - Even 99% accuracy over 100 code changes equals a 63% chance of a mistake
  - If you don't have the baseline knowledge to catch the mistakes, you may ship faulty code

Building reliable systems with LLMs



You
how to upload a model to huggingfa

ChatGPT
To upload a model to the Hugging F

1. Prepare Your Model:
   - Make sure your model is trained Transformers library, which is co models. Your model should be s weights, tokenizer, and configur
2. Create a Hugging Face Account:
   - You'll need to have a Hugging Fa one, sign up at https://huggingfa
3. Install `transformers` Library:
   - Make sure you have the `transf pip:

bash
```
pip install transformers
```

4. Install `huggingface-cli`:
   - You'll also need the Hugging Fac to upload your model. Install it u

bash
```
pip install huggingface-cli
```

(recommend).

```
SELECT file.project, COUNT(*) AS num_downloads,
FROM `bigquery-public-data.pypi.file_downloads`
WHERE
  file.project in ('huggingface-cli', 'blabladsa123')
  AND DATE(timestamp)
    BETWEEN DATE_TRUNC(DATE_SUB(CURRENT_DATE(), INTERVAL 3 MONTH), M
    AND CURRENT_DATE()
GROUP BY file.project
```

Query results

Row	project	num_downloads
1	huggingface-cli	31177
2	blabladsa123	696

In 3 months, this hallucinated package got over 30k authentic downloads!

- https://www.lasso.security/blog/ai-package-hallucinations

Advice

- If you choose to use LLMs to assist you in the HWs, make sure that you do so in such a way where you are still learning the material thoroughly
- By the end of this class, you should feel confident that you could go back and complete similar HWs without AI

Poll – which program will error?

Poll – which program will error?

Option A:

```
int main() {
    int a = 3;
    int* b = &a;
    int d = *b;
    return 0;
}
```

Option B:

```
int main() {
    int a = 3;
    int* b = &a;
    int& r = *b;
    int d = *&a;
    return d + r;
}
```

Option C:

```
int main() {
    int* p;
    *p = 7;
    return 0;
}
```

Poll – which program will error?

Option A:

```
int main() {
    int a = 3;
    //pointer to a
    int* b = &a;
    //contents of b (= value of a)
    int d = *b;
    return 0;
}
```

Option B:

```
int main() {
    int a = 3;
    // pointer to a
    int* b = &a;
    // reference to a via pointer
    int& r = *b;
    // *& cancels: still 'a'
    int d = *&a;
    return d + r;
}
```

Option C:

```
int main() {
    int* p;
    ❌ undefined behavior
    *p = 7;
    return 0;
}
```

References

Vibe Coding

- How I use LLMs, Andrej Karpathy, https://www.youtube.com/watch?v=EWvNQjAaOHw
- Vibe Coding in prod by Claude, https://www.youtube.com/watch?v=fHWFF_pnqDk

C++

- A Tour of C++, Bjarne Stroustrup, 2nd edition
- Effective C++: 55 specific ways to improve your programs and designs, Scott Meyers, 3rd edition
- Large Scale C++, Process and Architecture, John Lakos, Volume 1
- GDB documentation: https://www.sourceware.org/gdb/
- https://www.geeksforgeeks.org/gdb-step-by-step-introduction/
- GDB quickstart tutorial: https://web.eecs.umich.edu/~sugih/pointers/gdbQS.html
- How does gbd work? https://www.aosabook.org/en/gdb.html