Pointer and Memory

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Previously

- What is Array?
  - How to
    - create an array? `int a[4];` or `int a[]={1,2,3};`
    - access an array? `a[0] = 1;`
  - How an array is stored in the computer memory?
    - consecutive blocks of memory
- How to pass an array as an input argument of a function?
  - Passing by reference
  - Not, passing by value

Lab 3, Row Major Matrix

- Print a row major matrix A stored in an array.

```
int A[6] = {1,2,3,4,5,6};
for(int i = 0; i < 3; i++){
    for(int j = 0; j < 2; j++){
        // printf("*");
        // what should I put here?
    }
    printf("\n");
}
```

  - What is the array element index for $A_{k,l}$?
  - (1,1) -> 0
  - (1,2) -> 1
  - (2,1) -> 2
  - See a pattern?

Today's Agenda

- **What is a pointer?**
- How to declare and initialize a pointer?
- What are "address of" and "dereference" operators?
- Array and Pointer

A Double-Edged Sword

C is different from many other programming languages, it gives you the ability to directly read/write memory that is allocated to your program.

- Make good use of this feature, your code can run much more efficiently than programming in other languages.
- Abuse this feature, your code can become buggy, unreadable and unpredictable.

Physical Memory and Virtual Memory

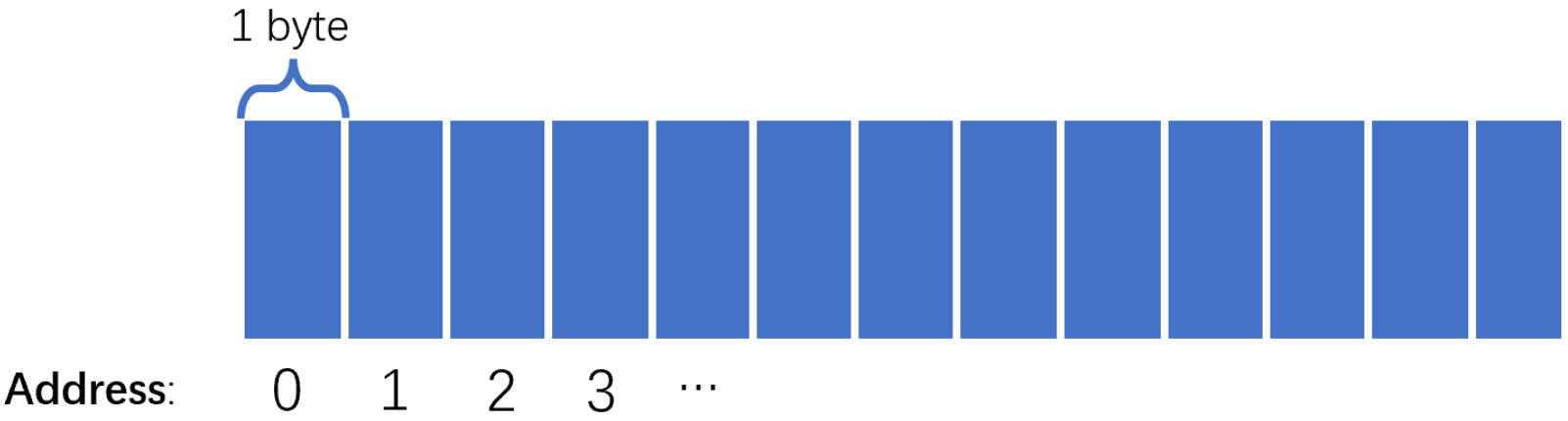
- Modern computers use **Random Access Memory (RAM)** to temporarily store information being used by the CPU. RAM is called the "Physical Memory" of a computer.
    - It stores machine code of programs and their data in small "cells" that are made of MOSFET.

Physical Memory and Virtual Memory

- Physical memory is a precious computational resource thus should be carefully rationed and managed. Poor management of physical memory would lead to errors and severe performance degradation over time.
- Luckily, OS manages physical memory for you so you do not have to.
    - Physical memory is not visible to your program for security reasons anyway.
- Your program can only see "**Virtual Memory**".

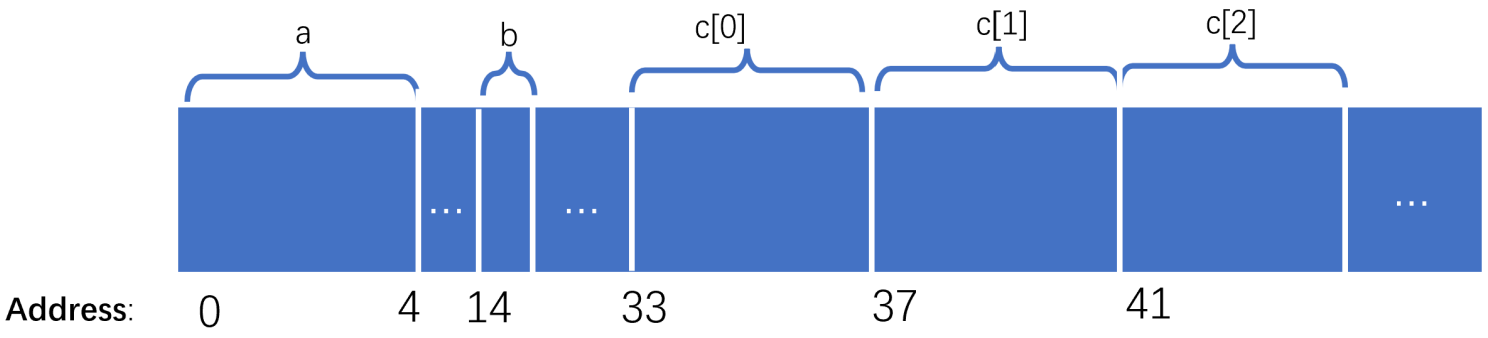
Physical Memory and Virtual Memory

- Virtual Memory is an **abstraction** of the physical memory, made available to your program by the OS.
- You can think of it as a huge library shelf with many small slots next to each other. Each slot is a smallest memory unit, usually **a byte** (8 binary bits).
- You can refer to a byte using its index. The index is called **the address** of the byte.



Multi-byte Variables

- However, we know some of the data types in C occupies more than one byte. For example, `int` occupies 4 bytes.
- These variables will occupy consecutive bytes in virtual memory.
- Elements in an array will also be stored consecutively in the virtual memory.
- Example: `int a; char b; int c[3];`



Pointer

- Pointer is a variable that **stores the address of another variable in the virtual** memory.
- Using a pointer we can access the content stored in that memory location.
    - Like index card to a book in the library.

Today's Agenda

- What is a pointer?
- **How to declare and initialize a pointer?**
- What are "address of" and "dereference" operators?
- Array and Pointer

Declare and Initialize Pointer

- A pointer itself is a variable in C, thus should be declared before use.
  - Syntax: `data_type *var_name;`
  - For example,
    - `int *pa;` declares a `int` pointer
    - `double *pb;` declares a `double` pointer.
    - `int *pa = &a;` initialize `pa` with the address of `a`.
  - `&` is the "address of" operator. `&a` gives you the virtual memory address of `a`.

`&` Operator

```c
#include <stdio.h>
void main(){
    int a = 0;
    printf("The address of a is %p.\n", &a);
    // displays "The address of a
    // is <some memory address>".
}
```

- Use `%p` to print out a pointer.

`*` Operator

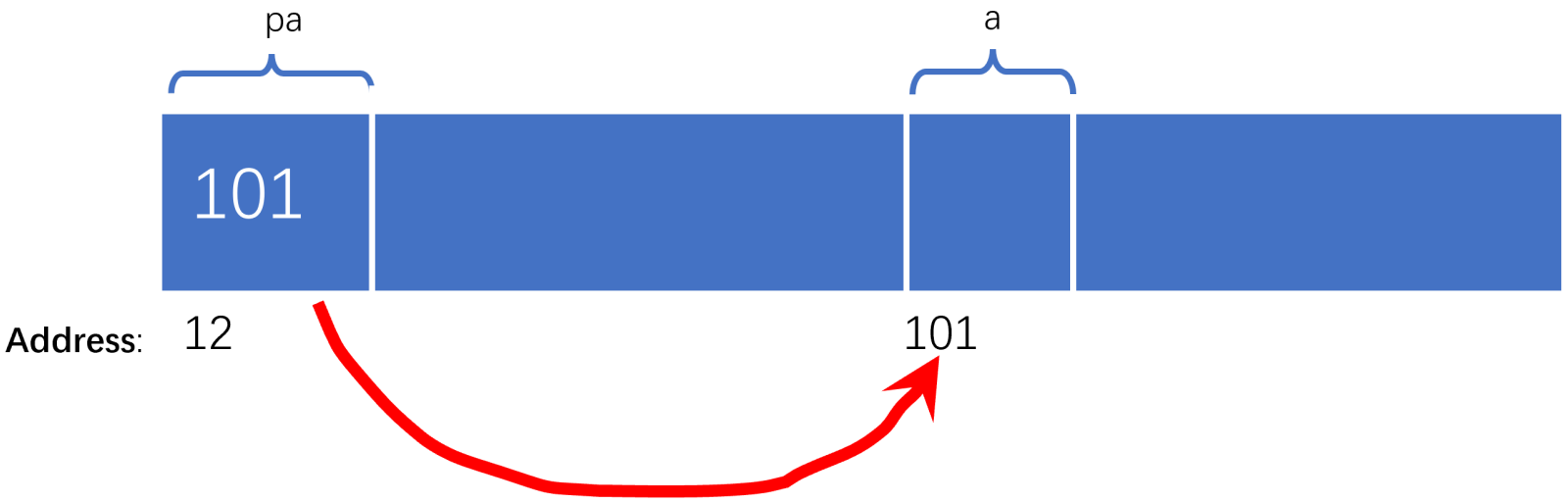
- `*` is the opposite of `&`, called dereference operator.
- `*` takes the value from a certain memory address.

```c
#include <stdio.h>
void main(){
    //initialize the pointer to be the address of a.
    int a = 1;
    int *pa = &a;
    int b = *pa;
    printf("My value is %d.\n", b);
    // displays "My value is 1."
}
```

Memory Diagram of Pointer

```
int a = 0;
int *pa = &a;
```

- `pa` is an `int` pointer pointing to an `int` variable `a`.
- `pa` itself is also a variable and is stored in the memory.



Pointer

- Without any initialization or assignment, the pointer points to a random memory location.

```
#include <stdio.h>
void main(){
    int *pa; //BAD!
    printf("I point to %p.\n", pa);
    // displays "I point to <some random memory space>".
}
```

- Trying to access memory in such random location will result in unpredictable behaviors!!!

`NULL` Pointer

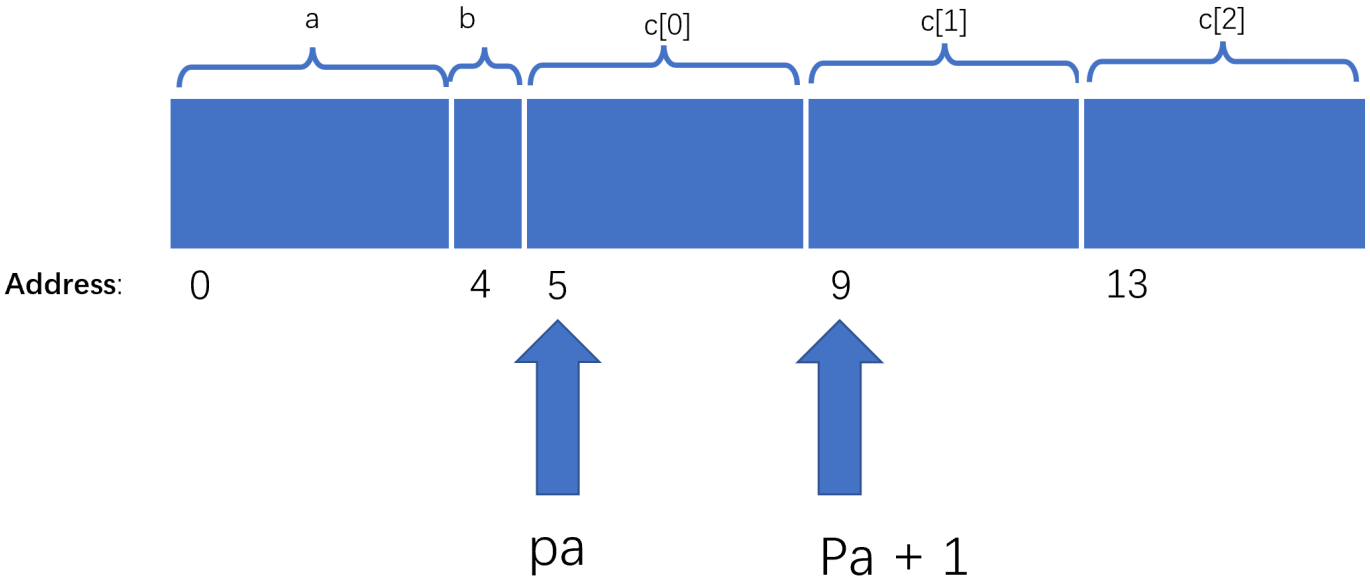
- It is dangerous to use an uninitialized pointer:
  - You may overwrite important information at some random memory address.
- If you do not know how to initialize a pointer, the convention is to initialize it as a `NULL` pointer.

  ```
  int *pa = NULL;
  ```
- `NULL` is a preprocessor macro and has a value zero.

  ```c
  printf("%d\n", NULL); // prints "0".
  ```

Pointer arithmetic

- Compiler knows the type of variable a pointer points to.
- Adding "1" to a pointer would move the pointer by `x` bytes where `x` is the variable size in bytes.
- Consider the following memory layout for
  - `int a; char b; int c[] = {1,2,3};`



Pointer arithmetic

```c
#include <stdio.h>
void main(){
    int a = 0;
    int *pa = &a;
    int *pa_plus_one = pa + 1;

    printf("pa is %p.\n", pa);
    printf("pa + 1 is %p.\n", pa_plus_one);

    //pa is 000000d7785ffbfc.
    //pa + 1 is 000000d7785ffc00.
}
```

The outputs have a difference of 4.

Today's Agenda

- What is a pointer?
- How to declare and initialize a pointer?
- What are "address of" and "dereference" operators?
- **Array and Pointer**

Pointer and Array

Pointers are suitable for manipulating array variables.

- Arrays occupies contiguous bytes of memory.
- If `pa` points at the first element of an array, `pa+1` points at the 2nd element of the array...

```c
#include <stdio.h>
void main(){
    int a[3] = {2,3,4}; int *pa = &a[0];

    printf("%p\n", pa); // the pointer points to the first element
    printf("%p\n", pa+1); // the pointer + 1

    printf("\n");

    printf("%p\n", &a[0]); // the address of the first element
    printf("%p\n", &a[1]); // the address of the 2nd element

    //the print outs are the same!
}
```

Pointer and Array

- If `pa + k` points to the `k+1` element in the array, then `*(pa+k)` is equivalent to `a[k]`?
- YES!!

```c
#include <stdio.h>
void main(){
    int a[3] = {2,3,4}; int *pa = &a[0];

    printf("%d\n", a[2]);
    printf("%d\n", *(pa+2));
    //prints out, 4, 4.
}
```

Pointer and Array

In fact, in C, array name is a pointer pointing to the first element of the array!!

```c
#include <stdio.h>
void main(){
    int a[3] = {2,3,4};
    int *pa = &a[0];
    printf("%p\n", a);
    printf("%p\n", pa);
    //prints out
    // 000000c0db3ffbec,
    // 000000c0db3ffbec, the same thing.
}
```

Pass by Reference, Revisited

- Do you remember we mentioned that when arrays are passed as input arguments of a function, they are passed by reference rather than by value?
- When passing an array as an input argument, **the array name represents a pointer to the first element to the array so it is actually this pointer get passed to the function, rather than the array elements themselves**.
    - `swap(a)`, where `a` is the array name, AND a pointer to its first element.
    - This is why, arrays are passed by reference, not by value.

Conclusions

- A pointer is a variable stores the address of another variable.
- A pointer needs to be declared before use.
- `&` "address of" operator takes the address from a variable.
- `*` "dereference" operators takes the content from an address.
- You can use a pointer to access an array.
    - The array name and the pointer pointing to the first element of the array is interchangeable.

Homework 1.

1. Download the lab file and put them into your labpack.
2. Read `operators.c` and pay attention to the usage of `&` and `*`.
3. Complete the TODO tasks specified in the file.

Homework 2.

1. Read `pointers_and_arrays_2.c` and run the code.
2. Explain why the code prints out such an outcome.
3. Complete the TODO tasks specified in the file.

Homework 3.

1. Open `swap.c`.
2. Write a function `swap`, that takes two `int` **pointer** inputs.
3. `swap` function swaps the contents of variables which `pa` and `pb` point to.

Homework 4.

1. Open `domainname.c`.
2. Read and run the code first. Answer questions in the code.
3. Write a function `getdomain` which extracts the domain name in an email address.
    i. Domain name in email is the string after `@`.

You can leave the lab after you finish. However, please find TA/me to check your code before leaving!