Arrays

Song Liu (song.liu@bristol.ac.uk)
GA 18, Fry Building,
Microsoft Teams (search "song liu").

Previously

- Time Complexity
- Recursion
- Stack Memory Layout

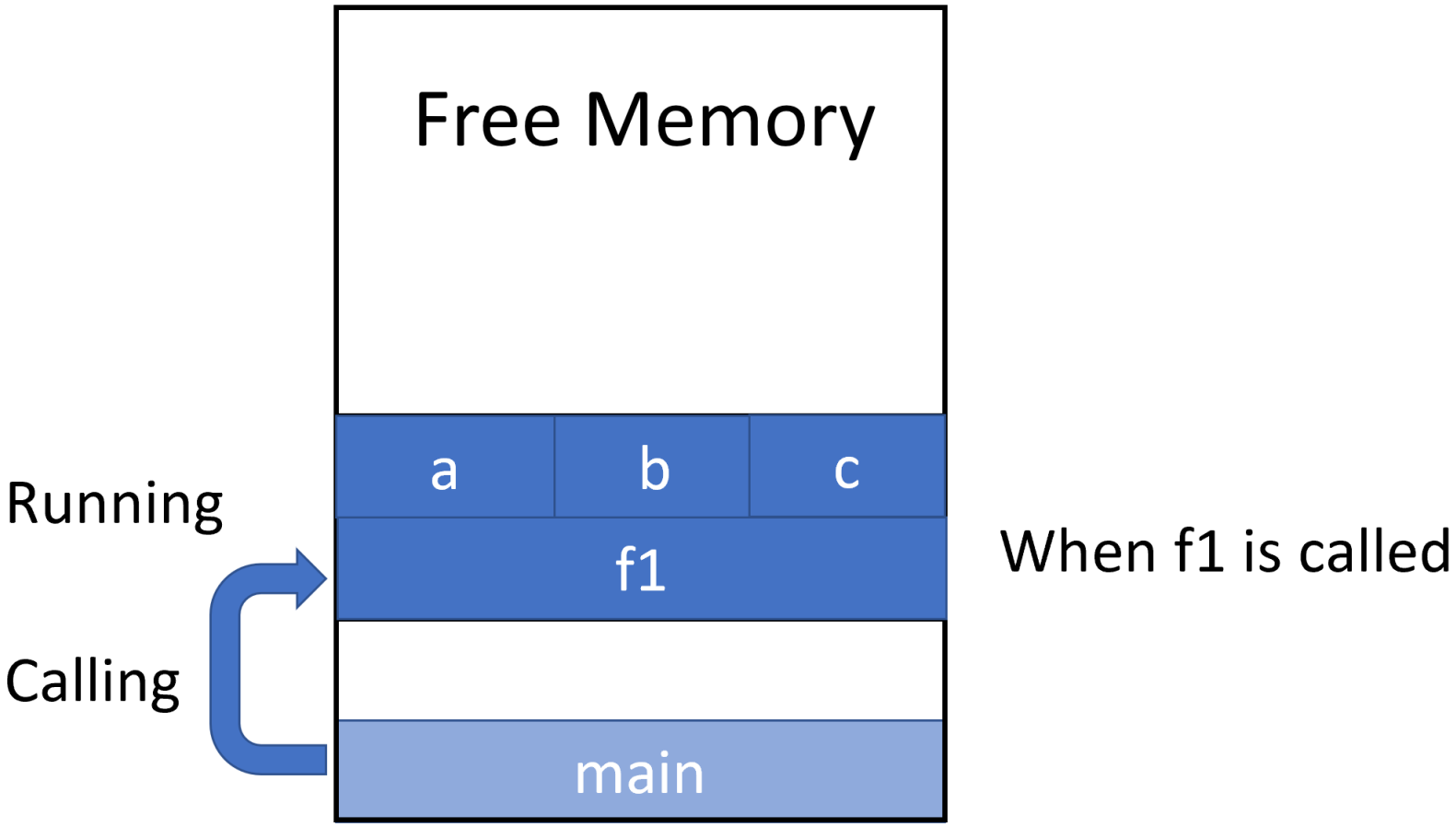
Stack Memory Allocation

Consider a situation where function `f1` calls `f2` and `f2` calls `f3`.

```
#include <stdio.h>
void f3(){
    int d = 6, e = 7;
};
void f2(){
    int a = 4, b = 5;
    f3();
}
void f1(){
    int a = 1, b = 2, c = 3;
    f2();
};
void main(){
    f1();
}
```

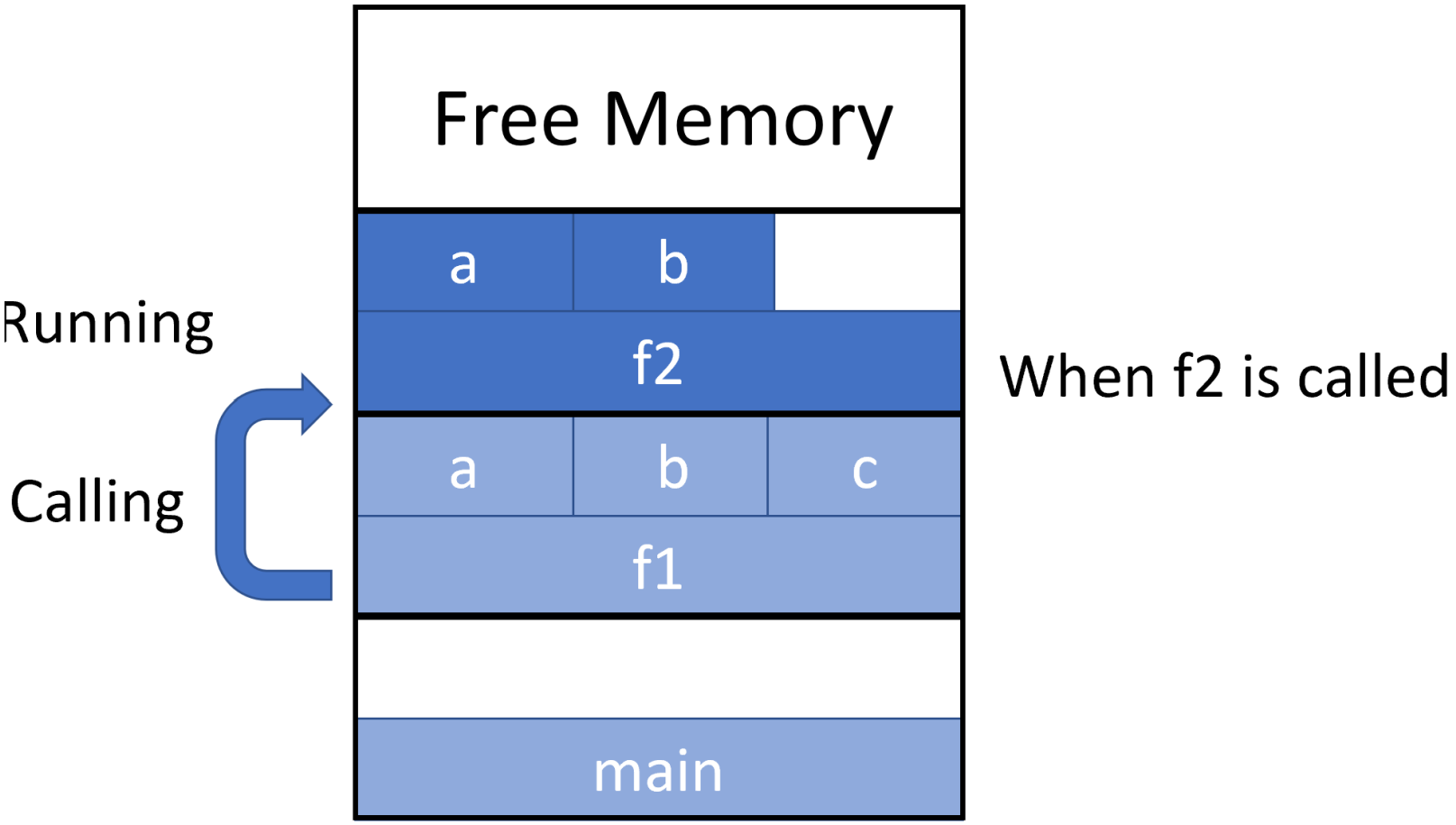
Stack Memory Allocation

Below is the stack while `f1` is called.



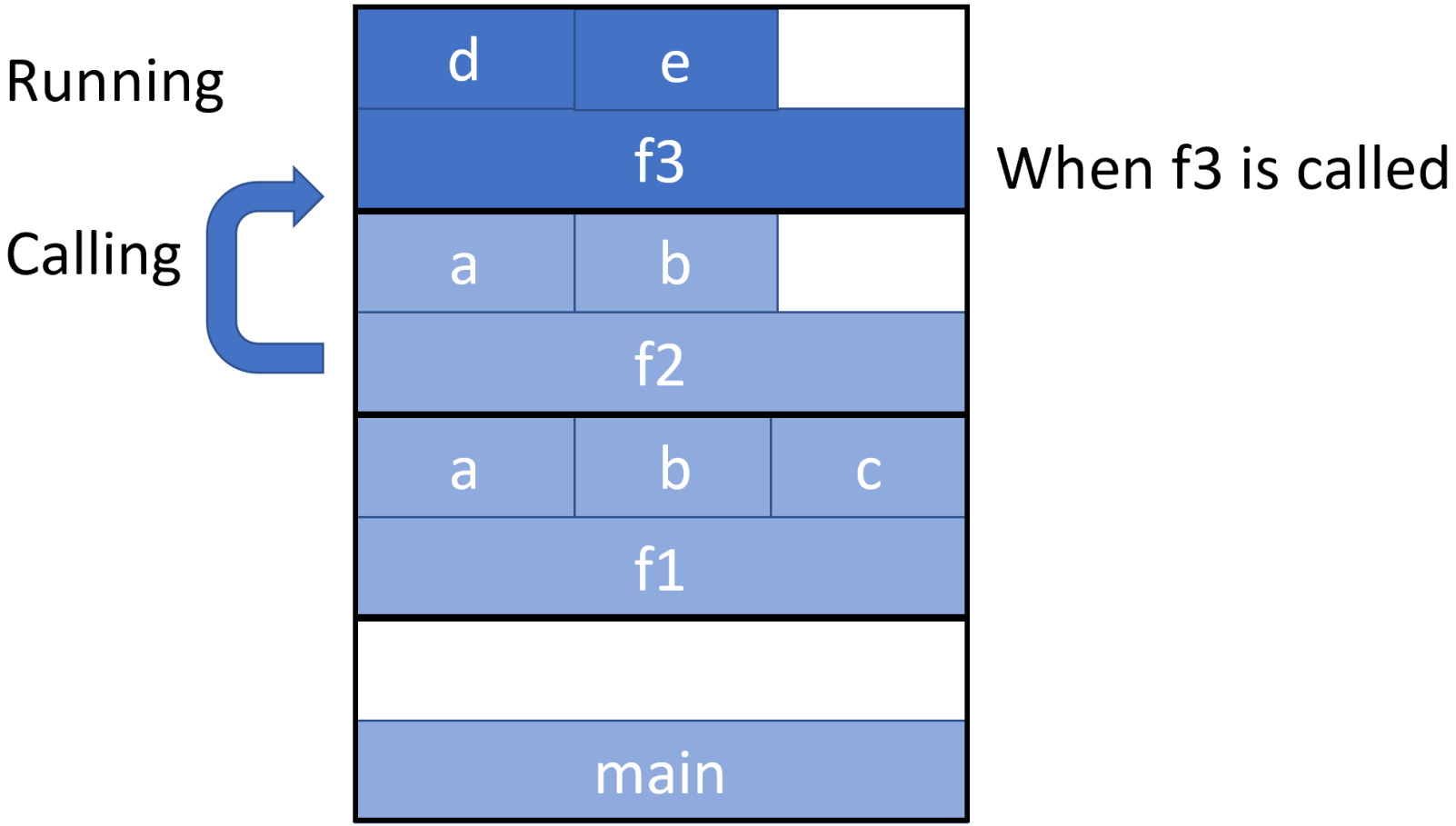
Stack Memory Allocation

Below is the stack while `f2` is called.



Stack Memory Allocation

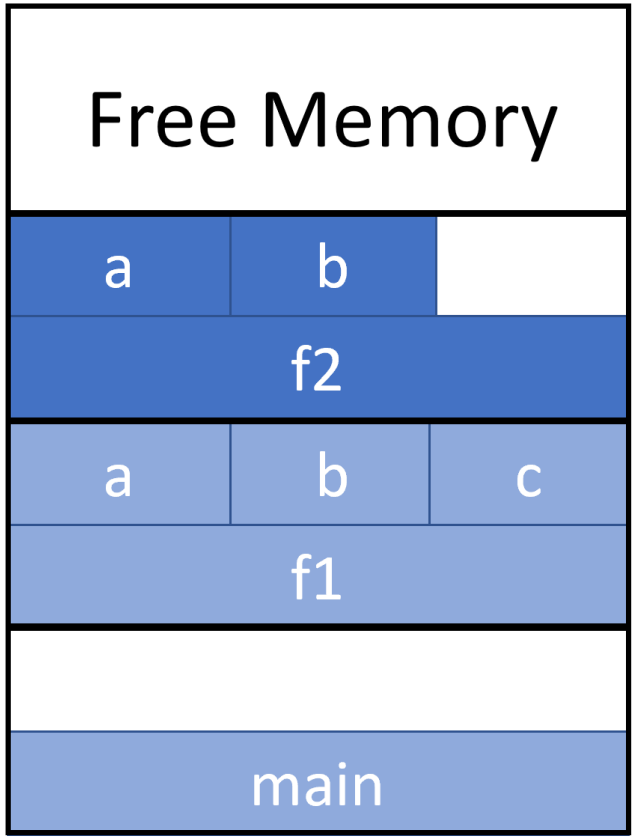
Below is the stack while `f3` is called.



Stack Memory Release

Below is the stack while `f3` is finished.

f3 finished,
memory freed

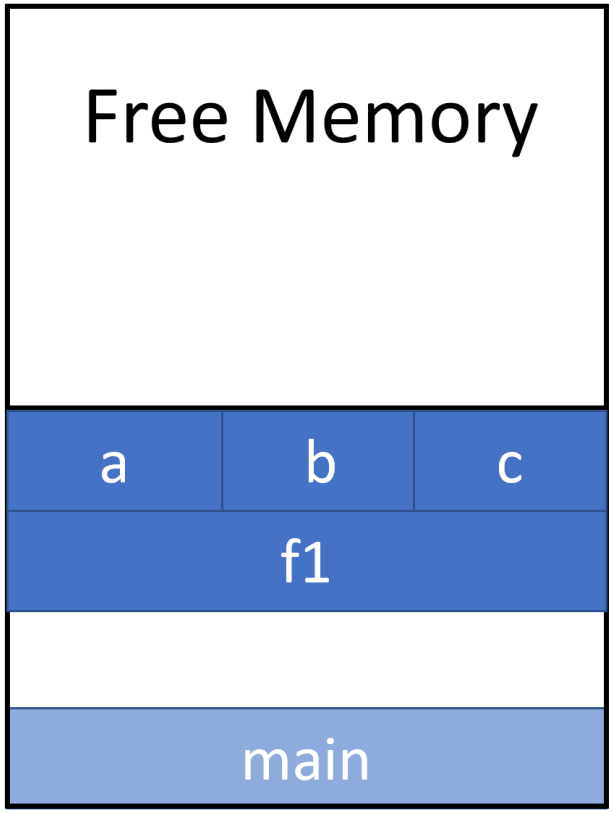


When f3 is finished

Stack Memory Release

Below is the stack while `f2` is finished.

f2 finished,
memory freed

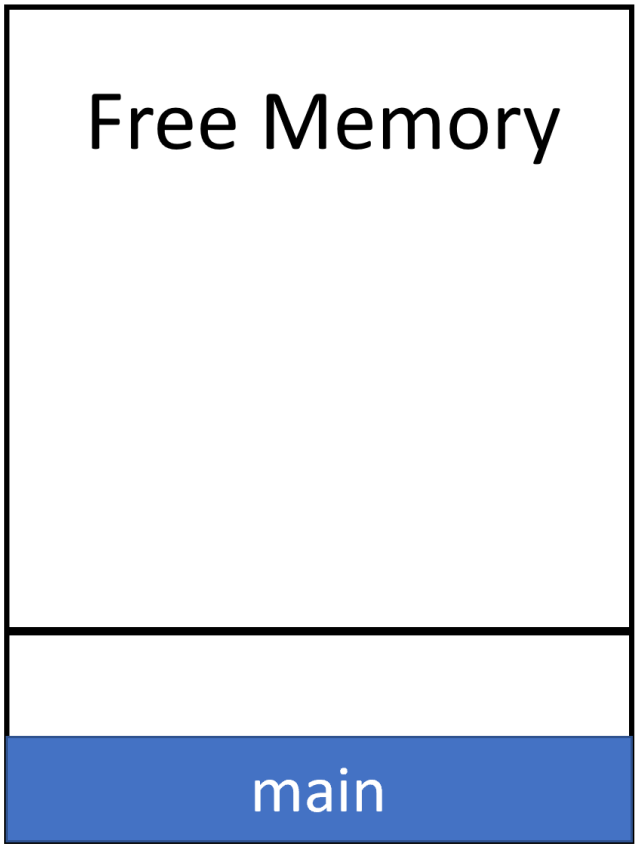


When f2 is finished

Stack Memory Release

Below is the stack while `f1` is finished.

f1 finished,
memory freed



When f1 is finished

Part II Data Science in C

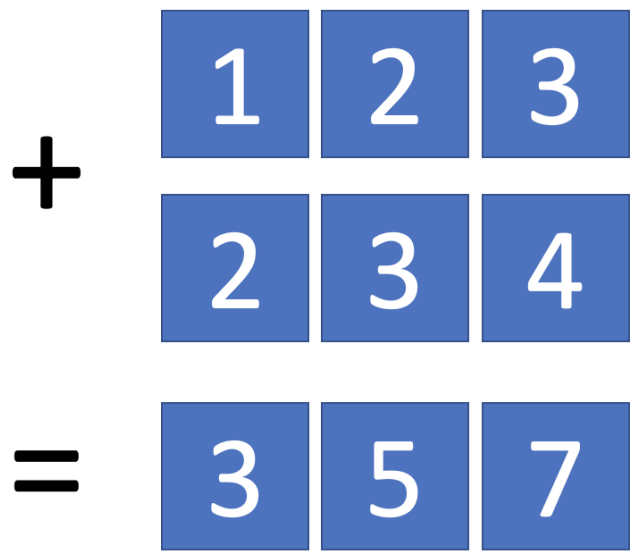
- We have finished the first part of this course, the foundation of C.
- From this lecture, we will progress to the next section, which is using C to perform some basic DS tasks.
- First, we will look at how various types of data are stored in the memory.

Today's Agenda

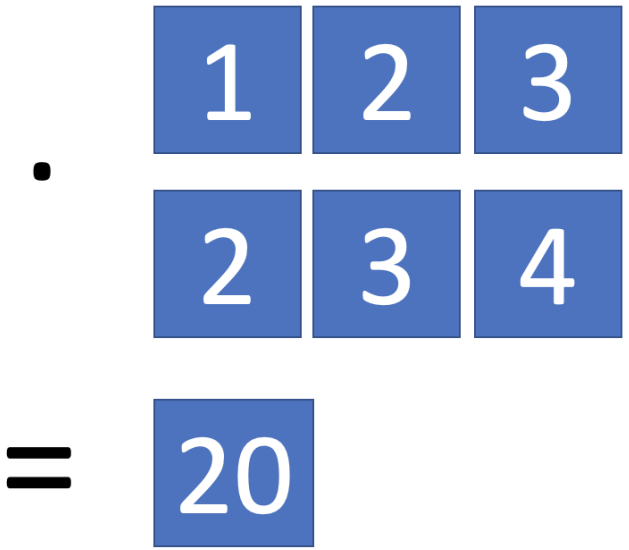
- **What is Array?**
  - How to
    - create an array?
    - access an array?
  - How an array is stored in the computer memory?
- How to pass an array as an input argument of a function?
  - Passing by value vs Passing by reference

Vector Calculation

- Vectors are a sequence of numbers.
  - $\boldsymbol{a} = [1, 2, 3]$ is a three-dimensional vector.
- Vector calculations: addition, subtraction, dot product, etc.



Vector Addition



Dot Product

Vector Calculation

- Consider the following program tries to compute the three dimensional vector addition
  - $c = a + b, a = [1, 2, 3], b = [2, 3, 4].$

```
#include <stdio.h>
void main(){
    double a1=1.0, a2=2.0, a3=3.0;
    double b1=2.0, b2=3.0, b3=4.0;
    double c1, c2, c3;
    c1 = a1+b1; c2 = a2 + b2; c3= a3 + b3;
    ...
}
```

- This program is dumb.
- What if you have a 100-dimension vector?
  - `c1 = a1 + b1; ... c100 = a100 + b100;` ?

Vector Calculation

To automate vector calculations, we need two things:

- A way to access an element in vector via an integer index.
  - e.g. `a[i]` represents the `i`-th element of vector a.
- A loop to perform calculations on all elements in a vector

Imagine we can do something like:
(pseudo code)

```
For i from 1 to 100
    c[i] = a[i] + b[i]
```

This program is much more scalable and understandable.

Array

- Array is a fundamental data structure in C programming language that **stores a sequence of elements**.
- You can declare an array using the syntax:
  - `data_type variable_name[array_size];` .
  - ```
    // declares an int array with 100 elements.
    int a[100];
    ```
- `array_size` can **NOT** be a variable.
  - ```
    int c = 100;
    int b[c]; // compilation error!
    ```
  - `array_size` must be determined at the time of compilation.

Accessing Array

- **The first element in the array is** `a[0]`.
- **The second element in the array is** `a[1]`.
- and so on.
- e.g., `a[2] = 5;` assigns 5 to **the third element** of `a`.
- You can access multiple elements using a loop:

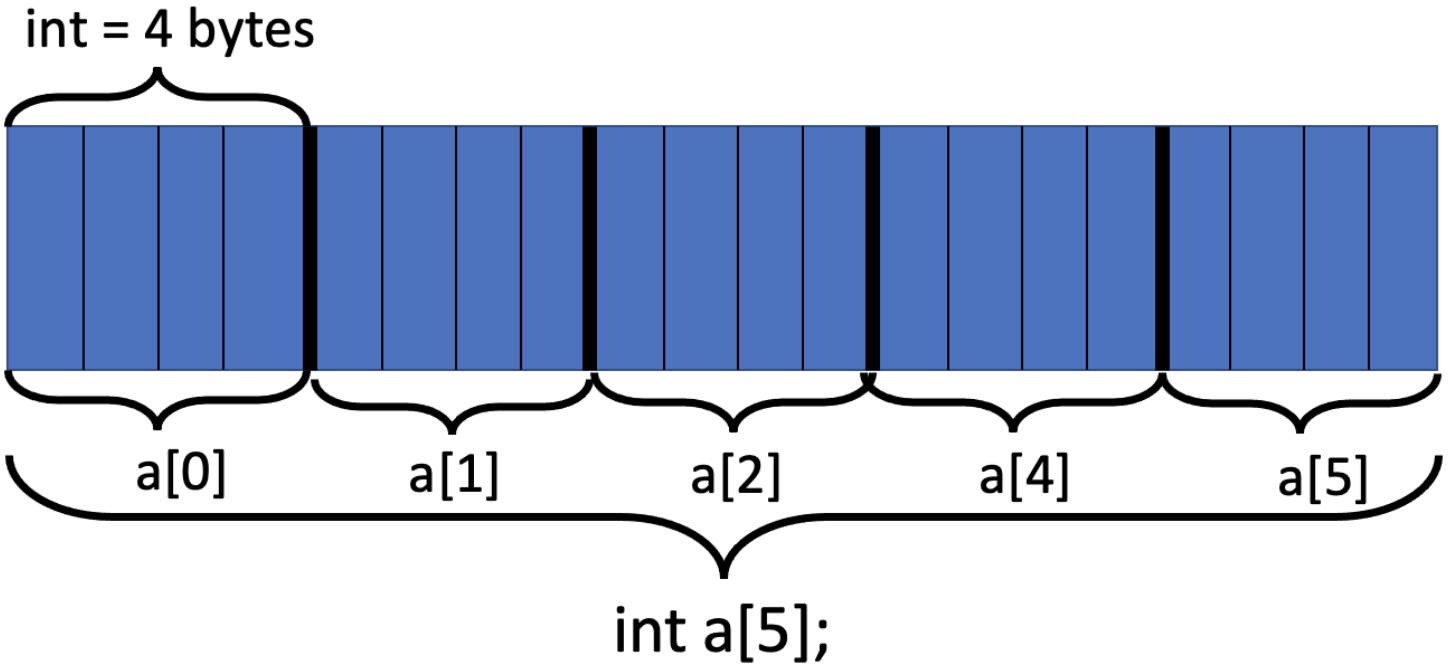
```c
int a[10];
for(int i = 0; i < 10; i = i+1){
    a[i] = 123; // assigning the i+1-th element
}
for(int i = 0; i < 10; i = i+1){
    printf("%d ", a[i]); // print the i+1-th element
}
```

Array

- Array declaration only reserves memory space for the array. The array will not be initialized automatically.
- If you do not initialize an array yourself, **it will contain rubbish value**, similar how variable declaration is handled in C.
- You can initialize an array using the syntax:
  - `data_type variable_name[] = {elements};`.
  - ```
    int a[] = {1,2,3};
    ```
  - No need to specify the `array_size`.
    ```

Array's Memory Layout

- Array is stored in a **contiguous section memory**.



Vector Addition, Revisited

```
#include <stdio.h>
void main(){
    //declare and initialize array a and b.
    double a[] = {1.0, 2.0, 3.0},
           b[] = {2.0, 3.0, 4.0};
    double c[3];
    //addition
    for(int i = 0; i< 3; i=i+1){
        c[i] = a[i] + b[i];
    }
    //display each element in the array c
    for(int i = 0; i< 3; i=i+1){
        printf("%f\n", c[i]);
    }
}
```

Increment

- Since we are going to write `i = i + 1` a lot,
- Use `i++` as a shorthand for `i = i + 1` .

```
for(int i = 0; i< 3; i++){
    printf("%f\n", c[i]);
}
// is the same as
for(int i = 0; i< 3; i = i + 1){
    printf("%f\n", c[i]);
}
```

- Similarly, `i += k` is short for `i = i + k` .

```
for(int i = 1; i< 10; i += 2){
    printf("%d\n", i);
}
//prints out 1,3,5,7,9
```

Today's Agenda

- What is Array?
  - How to
    - create an array?
    - access an array?
  - How an array is stored in the computer memory?
- **How to pass an array as an input argument of a function?**
  - Passing by value vs Passing by reference

Array as Input Argument

- You can pass array as input variables of a function.
- Simply write `datat_ype variable_name[]` inside the parenthesis following the function name.
- `array_size` is not needed.

Dot Product

- Consider a function `dot` computes the dot product between two vectors a, b: $a \cdot b = \sum_i a_i b_i$.

```
//compute dot product between a and b.
//a and b are two input arrays
double dot(double a[], double b[]){
    double s = 0;
    for(int i = 0; i< 3; i++){
        s+ = a[i]*b[i];
    }
    return s;
}
```

- What if you do not known the size of `a` and `b`?

Dot Product

- Pass another input argument, specifying the array length.

```
//compute dot product between a and b.
//a and b are two input arrays
//len is the length of both a and b.
double dot(double a[], double b[], int len){
    double s = 0;
    for(int i = 0; i< len; i++){
        s+ = a[i]*b[i];
    }
    return s;
}
```

Pass by Value

When you pass an input argument to a function, you are passing by value: The program will copy the value to the input variable.

```
#include <stdio.h>
double square(double a){
    a = a*a;
    return a;
}
void main(){
    double n = 2;
    double nn = square(n);
    printf("%f %f\n", nn, n);
    //display 4 2
}
```

The value of `n` is copied to the input argument `a`, thus operations on `a` has no effect on `n`.

Pass by Reference

- However, comparing to ordinary variables, the array occupies a much bigger memory space, thus pass by value can be expensive.
- In C, array is passed by reference.
    - If callee changes the array, caller's array will also be changed.

Pass by Reference, Example

```
//add all elements in an array by 1
void addone(double a[], int len){
    for(int i = 0; i< len; i++){
        a[i] += 1;
    }
}
void main(){
    double a[] = {1.0, 2.0};
    addone(a,2);
    printf("%f %f\n", a[0], a[1]);
    //display 2 3, NOT 1, 2!!
}
```

Return an Array

- Array cannot be returned by a function.
- However, since a function can make changes to caller's array, you can pass an array as input argument, and store results in that array.

```
//compute a+b and store the result in c
void add(double a[], double b[], double c[], int len){
    for(int i = 0; i< len; i++){
        c[i] = a[i] + b[i];
    }
}
void main(){
    double a[] = {1.0, 2.0}, b[] = {2.0, 3.0};
    double c[2];
    add(a,b,c,2);
    printf("%f %f\n", c[0], c[1]);
    //display 3 5
}
```

String = `char` Array!

In C, a string is simply a `char` array that ends with `0`.

For example,

```
char a[] = {'A', 'B', 'C', 0}; // Notice the 0 at the end
char b[] = "ABC";
printf("%s\n", a);
printf("%s\n", b);
printf("%s\n", "ABC");
//all prints out "ABC"
```