Revision

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Lecture 1, Introduction of Computing

Key Objectives

Upon completion of this unit you should:

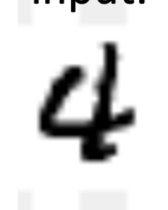
1. *Understand* the workflow of computer programming and appreciate computer as a data processing tool.
2. *Program*, *debug*, *document* and *test* basic algorithms in C(++) and R, with appropriate coding paradigms.
3. *Decide* which programming language to use when faced with a computing task.

Assessed Coursework 1

Deadline: Friday, Week 13.
Task: Given a data set (MNIST) containing images of handwritten digits, implement a simple classification algorithm (k-nearest neighbor), which labels a test image with "0", "1", "2".... "9". Details will be announced in a few weeks.

Dataset:

Input:



Output:

“4”

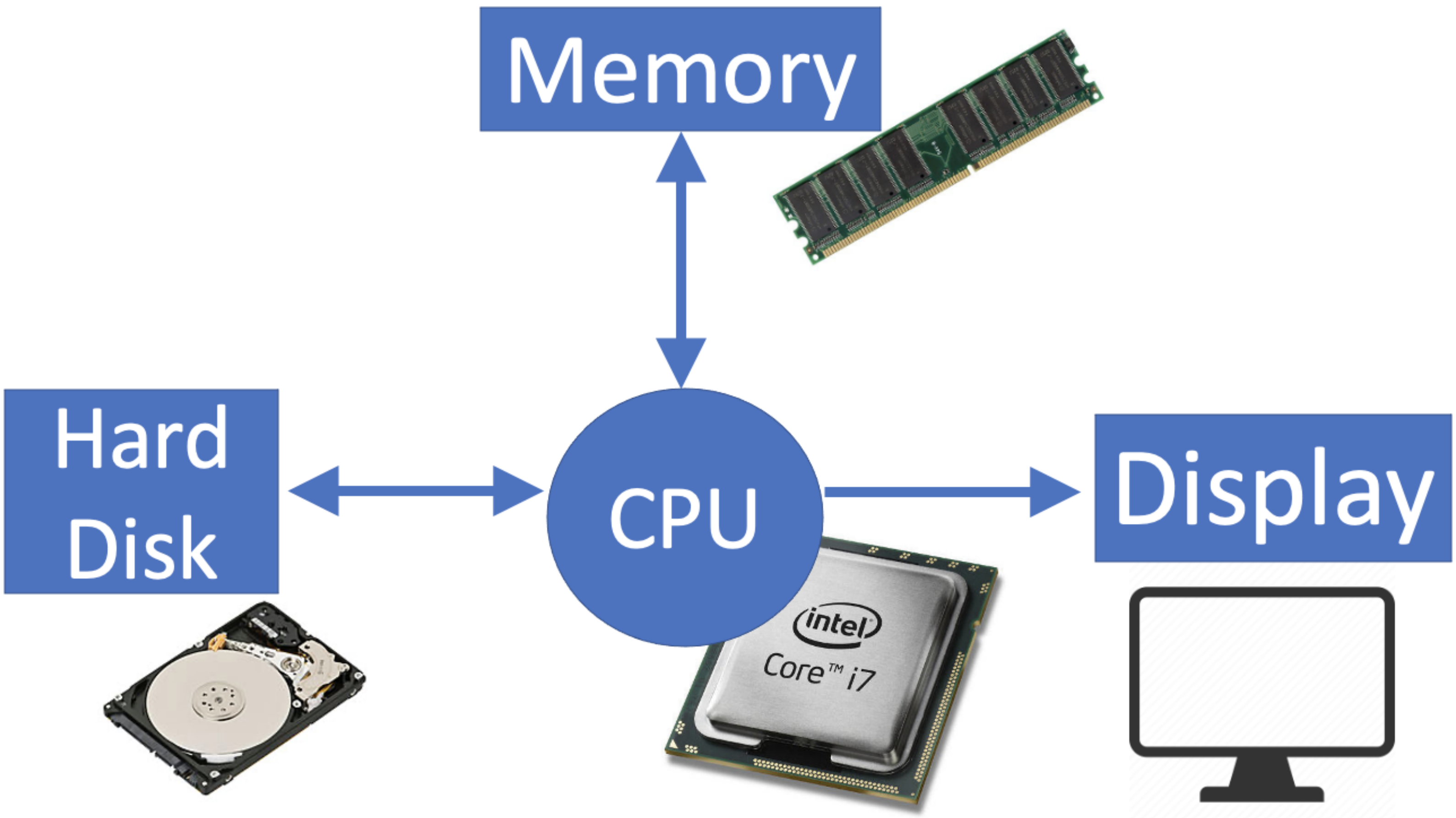
Assessed CW Marking Criteria:

- **5%:** You have submitted a C file.
- **10%:** Your code can compile and run **without any error**.
  - It will be tested using `gcc` in the lab pack.
  - Erratic behavior includes **crash**, **infinite loop**.
- **10-30%:** You have attempted the coursework "toward the right direction". However, your code does not produce any correct output given specific inputs within reasonable amount of runtime.
- **30-50%:** Your code produces partially correct outcome. Though it may suffer from some issues such as memory leak.

Assessed CW Marking Criteria:

- **50%-60%:** Your code produces mostly correct output and uses functions/classes dividing functionalities of your program.
- **60%-70%:** Your code produces the correct output and code is nicely formatted and comments are made to improve the readability of your code.
- **70%+:** Not only your code produces the correct output, but it does so using highly readable and efficient algorithms. Your code is nicely formatted and comments to each function/class. No memory leak or other unpredictable runtime issues.

How does Computer Work?



von Neumann Architecture

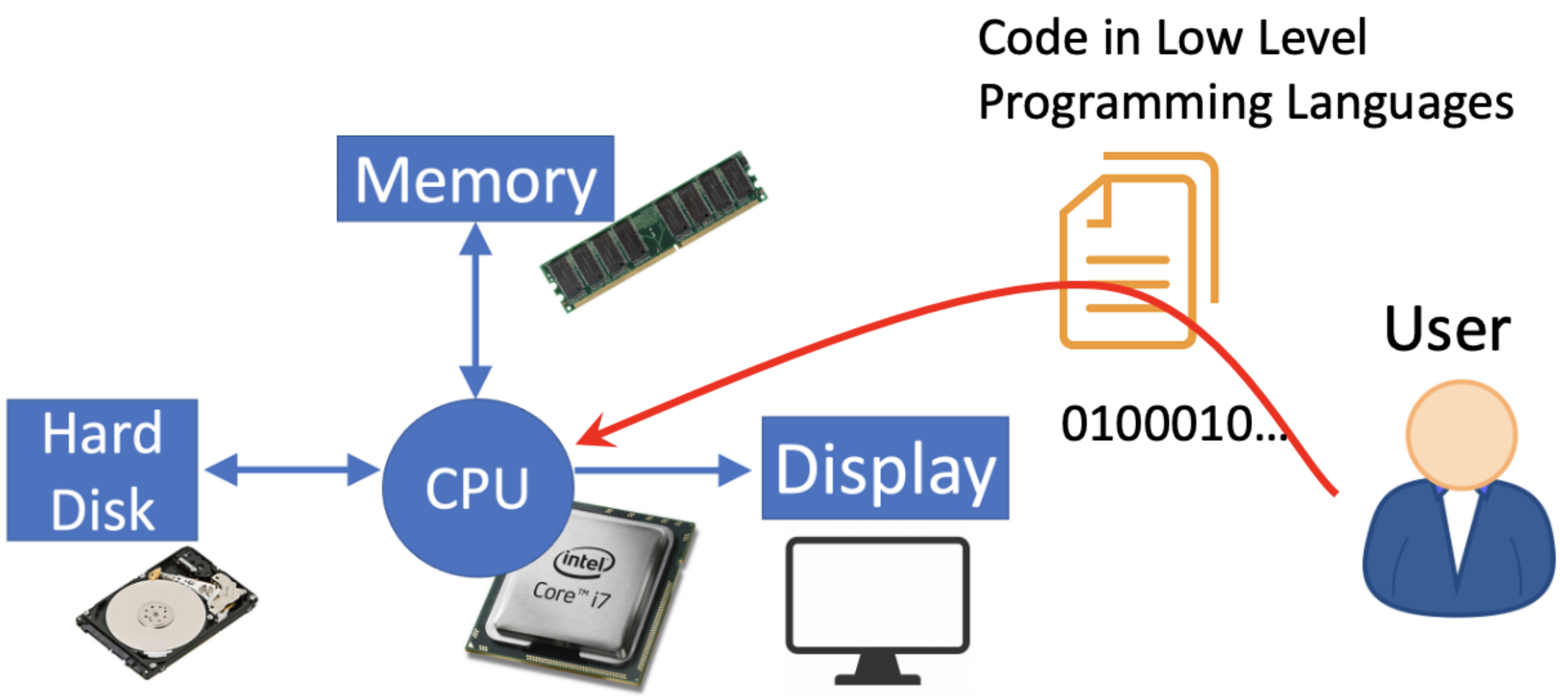
- **Central Processing Unit (CPU)**
  - Performs computational tasks.
  - Controls Input/Output (IO) devices.
  - Maintains data stored in the memory.
- **Memory**
  - Stores program/data being used by CPU temporarily.
- **IO Devices**
  - Hard disk
  - Display
  - Camera
  - Touch Screen, etc.

What is Programming?

- Programming = **writing a list of instructions to be executed on the CPU.**
- The list of instructions is called the "code".
- The language used to write the code is called **programming language**.

Low-level Programming Language

- Coder can program in machine code.
- Then the code can be **directly executed** on the CPU requiring no (or very little) translation.
- Machine code (and its more human friendly variants) are referred to as "Low-Level Programming Languages".



Low-level Programming Language

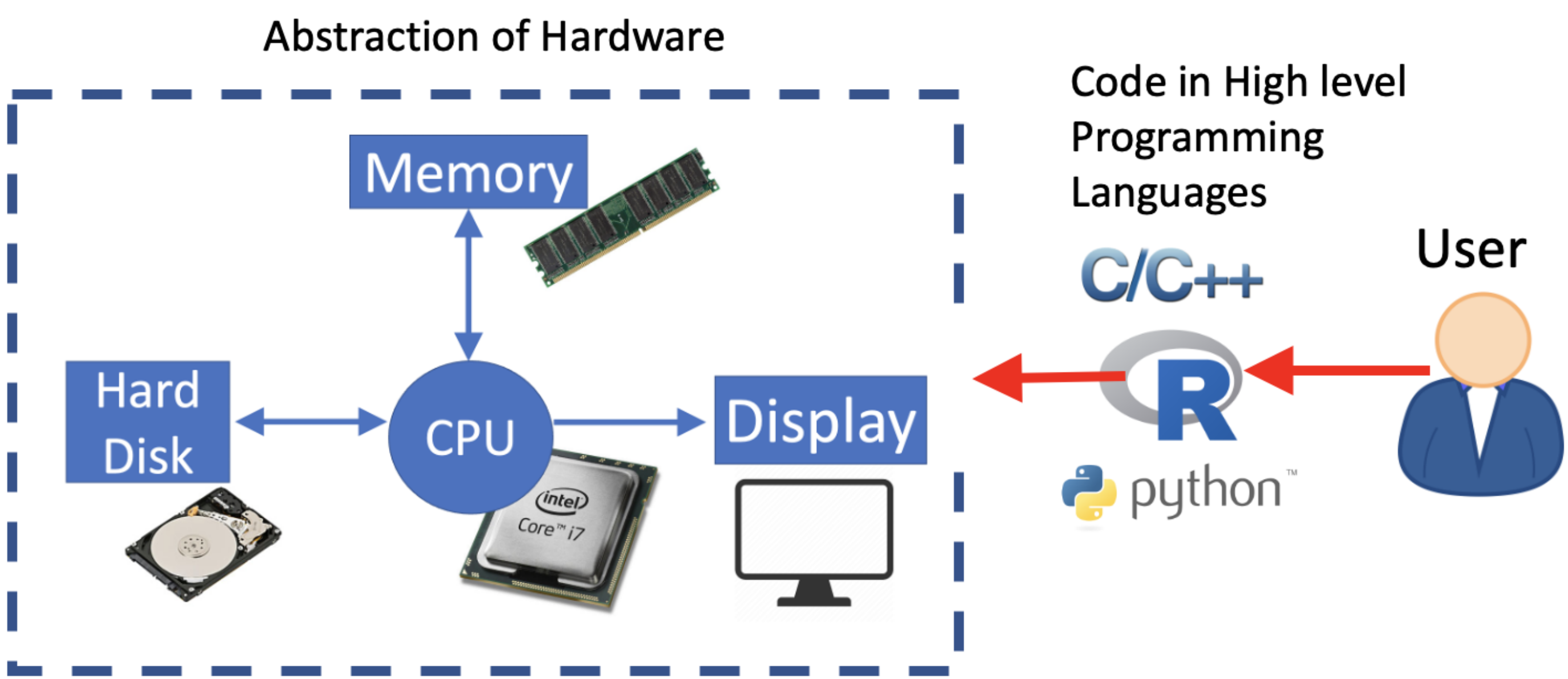
- **Advantages** of Low-level Programming Language:
  - total control of hardware
  - efficient
- **Disadvantages** of Low-level Programming Language:
  - can damage hardware
  - hard to read/learn
  - not portable.

High-level Programming Language

- Coder can program in a more natural language, which is then **translated** into machine code.
- This translation process is called "compilation" and the software that performs this translation is called **"complier"**.

Abstraction of Hardware

- High-level language provides **an abstraction of hardware**.
- Coder interfaces with this abstraction rather than directly program for the underlying CPU and hardware.



Abstraction of Hardware

- Writing code for the abstraction has many advantages:
    - Code is portable.
    - Coding is easier since less hardware maintenance.
    - Enhancing the security of the system.

High-level Programming Language

- **Advantages** of High-level Programming Languages
  - Easy to learn/read.
  - Code is "Portable".
- **Disadvantages** of High-level Programming Languages
  - Less efficient.
  - Cannot directly communicate with hardware.

Example Code: C

Example C code for printing "Hello World!" on almost all CPUs.

```c
//filename: main.c
#include <stdio.h>

void main(){
  printf("Hello World!\n");
}
```

Compilation:

```
gcc main.c -o main.out
```

Execution:

```
./main.out
Hello World!
```

`printf` function

- Know the basic usage of `printf` function and is able to use it in your C code.
- What are specifiers (`%`) for different types of data. Know at least specifiers for
    - integer
    - float point numbers
    - string
    - character

Lecture 2, Function and Recursion

What is a Function in Programming?

- Functions are individual building blocks of your program that accomplish specific tasks.
    - Function helps you divide your code into smaller, more **manageable and readable** pieces.
    - Code in a function **is only executed when its host function is "called". **
- Some functions take *input arguments*.
- Some functions return *an output value*.
- Some functions do not have input or output.

How to Write a Function Definition?

1. A function definition starts by indicating the **return type** (`void` means no return value will be produced.).
2. Followed by the **function name**.
3. The **Input arguments** come after that, inside `(` and `)`.
4. The **body of the function** is enclosed by `{` and `}`.

```
...
return_type function_name(input argument deceleration){
    function body
}
```

Read Example Code Carefully.

PS: **You CANNOT write a function inside another function!**

You should **NOT** do:

```
void main(){
    int cal_length(...){
        ...
    }
}
```

Instead do

```
int cal_length(...){
    ...
}
void main(){
    ...
}
```

`main` with Inputs and an Output

The `main` function can also take inputs and return output.

```
#include <stdio.h>
int main(int nargs, char* args[]){
    printf("%s\n", args[0]);
    return 0;
}
```

- `main` takes two inputs: `nargs` and `args`. These are passed on to `main` **from** the OS.
- In this example, `main` returns an integer value to OS. It returns 0 if succeeded, otherwise, returns a non-zero value.
- `main` is the only entrance of your program!
    - DO NOT define more than one `main` in your code!!!

Function Body

```
... function_name(...){
    declaration of variables
    ...

    other statements
}
```

Data Types in C

- Some data types are:
  - `int` or `long`: integers
  - `float` or `double`: float point numbers
  - `char`: characters
- Each declaration tells the compiler: "reserve __ bytes of memory for this variable when function is running!".
- On modern PCs (and most smartphones):
  - `int` and `float` occupies 4 bytes of memory.
  - `long` and `double` occupies 8 bytes of memory.
  - `char` occupies 1 byte of memory.

Declarations

Once a variable is declared, **the variable is assigned a memory location by the compiler.** If the variable is uninitialized, **the variable can contain whatever (rubbish) value** that is already in that memory location!

Expressions

- Computing operations are done using **expressions**:
  - `G*m1*m2/dist/dist`
  - Each expression has a value. The value of `G*m1*m2/dist/dist` is its computation outcome.
- `m1 = 1.0, m2 = 2.0`, `gravity = G*m1*m2/dist/dist` are all **assignment expressions**.
  - It assigns the value of expression on the RHS to the variable on the LHS.
  - **The equality sign does not represent equality**.

Relational and Logical Expressions

- Relational Expression
  - expressions like `a>b`, `a!=1` and `a==1 && b = 2` are relational expressions. They have values 0 or 1.
  - `2>1` has value 1,
  - `2>=3` has value 0.
  - `1 == 1` has value 1, where `==` means equal.
  - `1 != 1` has value 0, where `!=` means not equal.
- Logical Expression
  - `1==1 && 1 > 2` has value 0, where `&&` means logical AND.
  - `1==1 || 1 > 2` has value 1, where `||` means logical OR.

Relational and Logical Expressions

- In C, logical FALSE is expressed by an integer 0.
- Logical TRUE is expressed by any non-zero integer.
- Read this tutorial Operators in C.
- Precedence of Operators

Calling a Function

- You can call a function and obtain its returned value **after its definition**.
- Calls are made using the function name with all input values **in the same order they are declared**!
- Read the code example in the original slides.

Calling a Function: Recursion

- A function can call itself!
    - This is called **recursive call**.

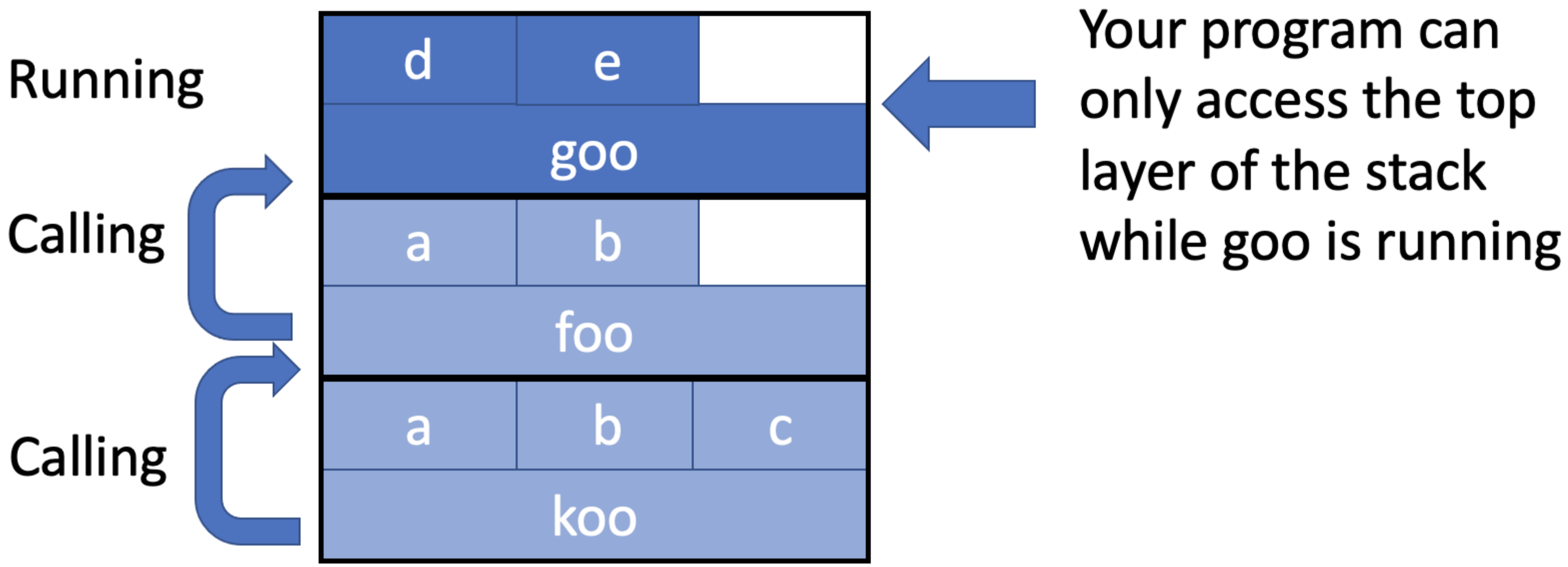
```
#include <stdio.h>
void countdown_to_1(int n){
    if (n<1) {;}
    else{
        printf("%d\n",n);
        countdown_to_1(n-1);
    }
}
void main(){
    //It prints 10, 9, 8 ... 1
    countdown_to_1(10);
}
```

Stack Memory Allocation

- When the function is being executed on the CPU, its data (such as variables declared in the function) are temporarily stored in the memory.
- The memory region for storing function data in the current program is called "stack".
- When a function is called, its data is added to the top of the stack. You program can access them.
- When a function finishes its execution, its data is removed from the stack and the space it occupies is freed for future calls of functions.

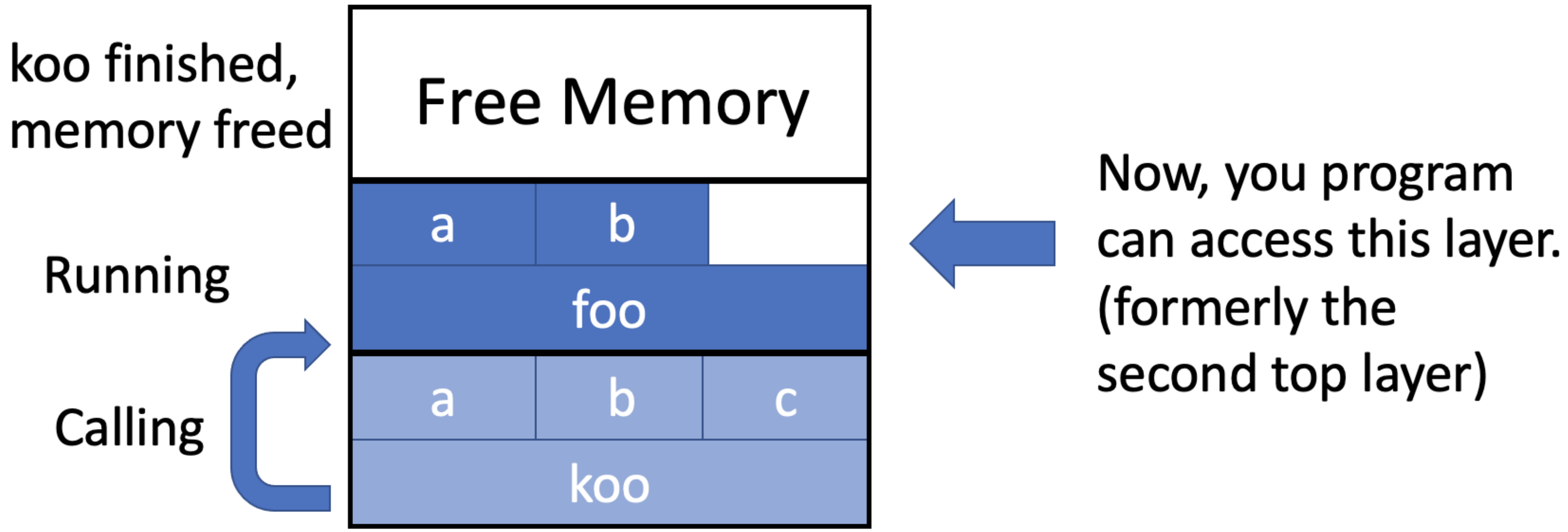
Stack Memory Allocation

Consider a situation where function `koo` calls `foo` and `foo` calls `goo`. Below is the stack while `goo` is running.



Stack Memory Allocation

When `goo` finishes running, its memory is freed.



When `foo` finishes running, its memory will be freed too and only variables in `koo` will be accessible.

Local Variables

Variables declared inside the function are called **local variables** (This includes all input argument variables!).

- They can only be accessed by the function where it is defined.
  - They cannot be accessed by other functions.
- **Why?** The program can only access the top layer of the stack, which stores variables of the function that is **currently running**.
- In the "koo-foo-goo" example, your program cannot access a and b defined in `koo` while `foo` is running.

Stack Memory Allocation

Stack is a highly efficient memory allocation/release mechanism.

- The memory allocation and release are all automatically handled by the OS.
- However, there is only a limited stack space for each program (determined by the OS). If a single function occupies a large memory space, or the call stack gets too "tall", we may run out of stack memory and an execution error will be raised by the OS.
    - This out-of-memory error is called "Stack Overflow".

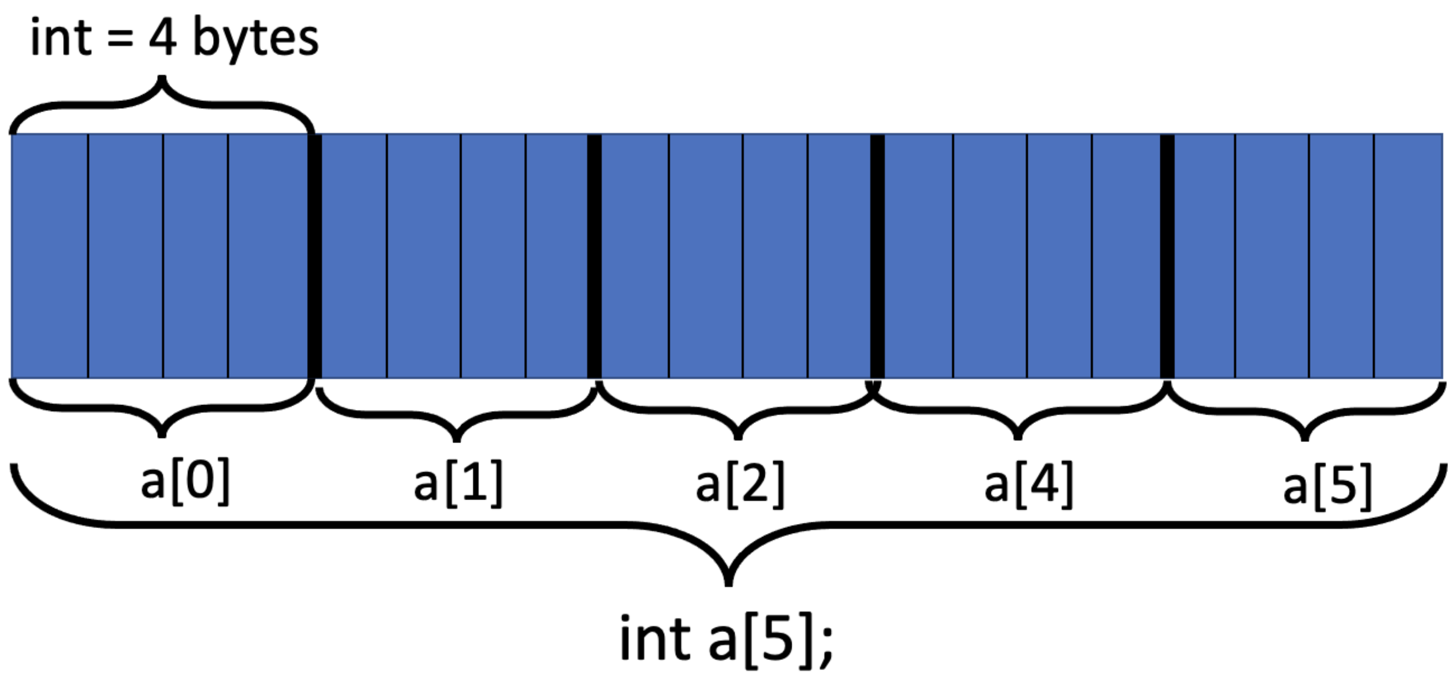
Lecture 3: Array and Loops

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];`.
  - e.g., `int a[100];` declares an 100 int elements array.
- You can initialize it using the syntax:
  - `data_type variable_name[] = {elements};`.
  - e.g., `int a[] = {1,2,3};`. No need to specify the array size.

Array

- **You refer to the first element in the array as** `a[0]`, the second element as `a[1]`, and so on.
    - e.g., `a[2] = 3;` assigns 3 to **the third element** of `a`.
- Array is stored in the memory as a continuous chunk of bytes.



Loops

- When encounter loops, the CPU will continue to execute a block of code, until certain exit conditions are met.
  - If the exit conditions are not set properly, CPU may stuck in a loop and will not exit, wasting computational resources.
  - This situation is called infinite loop.

While Loop

The simplest loop is while-loop and its syntax is:

```
while(expression){
    statements
}
```

The statements inside of the brackets will only run if `expression` is true. 3D vector addition can be written as

```
int i = 0;
while(i<3){
    c[i] = a[i] + b[i];
    i = i + 1;
}
```

For Loop

- In previous examples, we all maintained a variable `i`, which increases by one at each iteration.
- The initialization of `i`, exit condition check and increment of `i` are all scattered in the code and are difficult to spot.
- for loop would gather these three pieces all in one place.

```
for(init; exit_condition_check; increment){
    ...
}
```

Vector Addition, Revisited 2

```c
#include <stdio.h>
void main(){
    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]);
    }
}
```

- This code does the exactly the same thing as the previous `while` loop, but is arguably more compact.
- Notice `i` is only accessible inside each for loop!

Early Loop Exit

Using `break` statement to exit the loop immediately.

```c
// finding the smallest number <= 1000000 that
// can be divided by 32 and 23.
int i = 1;
while(i <= 1000000){
    if(i%32 == 0 && i%23== 0){ // & is logical "AND"
        break;
    }
    i = i + 1;
}
printf("%d\n", i);
//displays "736"
```

Early Loop Restart

Use the `continue` to restart the next loop immediately.

```c
// print numbers < 1000 that can be divided by 39.
for(int i = 1; i<  1000; i++){
    if(i % 39 != 0){
        continue;
        // this statement immediately
        // finishes the current iteration
        // and move on to the next iteration.
    }
    printf("%d\n", i);
}
```

You can rewrite this program without using `continue`. How?

Array as Input Argument

You can pass array as input variables of a function:

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

If you specify the size of array,

```
double dot(double a[3], double b[3]){
    ...
}
```

The size will be ignored by the compiler.

Array as Input Argument

If I do not know the length of the array, what can I do?

- Pass another input argument, specifying the array length.

```
//compute dot product between 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.

```
double square(double a){
    a = a*a;
    return a;
}
void main(){
    double in = 2;
    double out = square(in);
    printf("%f %f\n", out, in);
    //display 4 2
    //square function does not change the value of
    //its input variable.
}
```

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

Pass by Reference

- However, comparing to ordinary variables, the array occupies a much bigger memory space, thus pass by value can be inefficient.
- 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
}
```

Multidim. Array

Matrix is a rectangle of numbers, arranged in rows and columns.

$$\boldsymbol{A} = \begin{bmatrix} 1, & 2, & 3 \\ 4, & 5, & 6 \\ 7, & 8, & 9 \end{bmatrix}.$$

We can use multidimensional array to store a matrix.

```
//an integer 2D array used to store a 3 by 3 matrix.
//The initialization is row-first.
int A[3][3] = {{1,2,3}, {4,5,6}, {7,8,9}};
```

Multidim. Array Example

We can use multidimensional array to store a matrix. The following function `trace` computes the trace of a matrix.

```c
#include<stdio.h>
int trace(int nrow, int ncol, int A[nrow][ncol]){
    if (nrow != ncol) {
        printf("not a square matrix!\n");
        return 0;
    }
    int tr = 0;
    for(int i =0; i<nrow; i++){
        tr += A[i][i];
    }
    return tr;
}
void main(){
    int A[3][3] = {{1,2,3}, {4,5,6}, {7,8,9}};
    printf("%d\n", trace(3, 3, A));
}
```

Multidim. Array Example

- It is important to perform a sanity check at your code!
  - Trace operation is only defined on square matrices!
- The compiler does need to know all dimensions of the array!
  - If you want to use other arguments (`nrow` and `ncol` in the example above) to specify the dimensions, make sure they are declared **before** the array.
  - `int trace(int A[nrow][ncol],int nrow, int ncol)` will not work!
- Multidimensional array is also passed by reference.

Week 4 Lab,

1. Write a function that prints out elements in a matrix A.

   ```
   void print_matrix(int nr, int nc, int A[nr][nc])
   ```

   - Remember to add a space between elements in the same row and add line breaks between rows.
   - For example, a matrix

$$\boldsymbol{A} = \begin{bmatrix} 1, & 20, & 3 \\ 4, & 5, & 6 \end{bmatrix}$$

Should be printed out as

```
1.00 20.00 3.00
4.00 5.00 6.00
```

Week 4 Lab,

2. Write a function performs the matrix multiplication using multi-dimensional arrays

```
//This function computes A*B
//and stores the result in C
void mult(int nrowA, int ncolA, int nrowB, int ncolB,
          double A[nrowA][ncolA],
          double B[nrowB][ncolB],
          double C[nrowA][ncolB])
```

   - Use the skeleton function that is already provided in the lab pack.
   - Test your function with dummy inputs, using the function you just wrote in Q1 to print out the outcome and check the correctness of your function.

Week 4 Lab,

3. (submit) Write a function, that "flattens" a 2D array into 1D array. For example, 2D array `{{1,2},{3,4}}` is flattened into `{1,2,3,4}`.
   i. `void flatten(int nrow, int ncol, int a[nrow][ncol], int a_f[]);`
   ii. After the execution, `a_f` stores the flattened array.

Week 4 Lab

4. Write a function that reads an element from the flattened array as if it is reading from the corresponding 2D array.
   i. `double get_elem(int nc, double a_f[], int i, int j)`, where `nc` is the number of columns of the unflattend 2D array and `i,j` are indices of the unflattend 2D array.
   ii. For example, given a 2D array `a`, and its flattened version `a_f`, `get_elem(nc, a_f, i, j)` should output the value `a[i][j]`.
   iii. Write no more than one line of code in your `get_elem` function.