C Programming

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Introduction

C is a *general purpose* programming language, born in early '70

The C Programming Language - 1978 - K&R

To this day, the programming language C underwent several changes to fulfill standars imposed by different organizations **(ANSI, ISO)**

- 1989 :: C89
- 1999 :: C99
- 2011 :: C11
- 2018 :: C18

Applicazioni

Embedded Systems:

- Domotics
- PLC
- Automotive
- Medical equipment
- Security Systems
- Automation Systems

C Language

Imperative !

It allows the user to have complete control of the device through different *instruction*, seen as orders

Procedural

{ Functions }

Composed by block of code, each one identified by a unique name and enclosed by specific delimiters

High Abstraction

Significant abstraction from the operating details of a specific device and from the characteristics of the machine language

```
#include <stdlib.h>
#include <stdio.h>

/* The main thing that this program does. */
int main(void) {
        // Declarations
        double A[5] = {
                [0] = 9.0,
                [1] = 2.9,
                [4] = 3.E+25,
                [3] = .00007,
        };

        // Doing some work
        for (size_t i = 0; i < 5; ++i) {
                printf("element %zu is %g, \tits square is
                %g\n",
                                i,
                                A[i],
                                A[i]*A[i]);
        }

}       return EXIT_SUCCESS;
```

Compilation and Execution

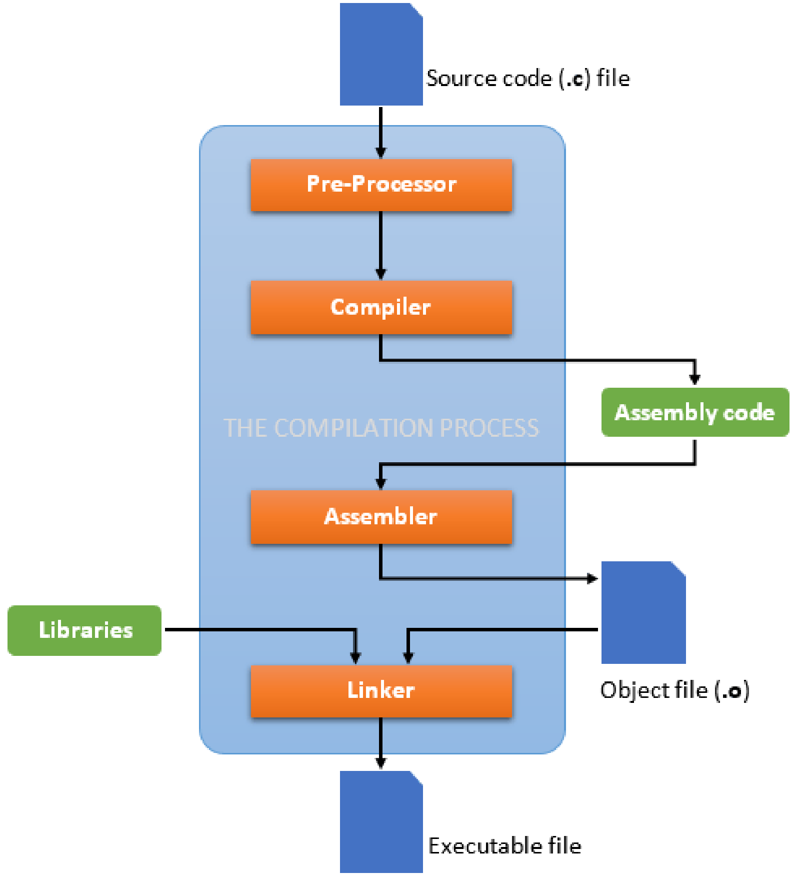
Simple strings, even if very specific, cannot be understood by a computer

C gives a new level of abstraction that can be adapted on different platforms, thanks to **compilers** and **linkers**.

The name of the **compiler**, its use and functionalities are specific and related to the platform on which the program runs

```
gcc -Wall -o program_name source_code.c -lm
```

```
arm-linux-gnueabihf-gcc -std=c99 -O1 -g3 -c -
fmessage-length=0 -pthread -MMD -MP program - o
source.c
```



Generic Program Structure

Syntax

How to correctly write code so it is understandable by a compiler

- **Special Key-Words**
  - `#include, int, void, double, for, return`
- **Punctuation**
  - `{ ... }, ( ... ), [ ... ], /* ... */, < ... >`
- **Alpha-numeric values**
- **Specific Identifiers**
  - `main, printf, size_t, EXIT_SUCCESS, A, i`
- **Functions**
  - `main, printf`
- **Operators**
  - `=, *, <, ++, -`

Semantics

How to use programming language to achieve the desired objective

```c
#include <stdlib.h>
#include <stdio.h>

/* The main thing that this program does. */
int main(void) {
        // Declarations
        double A[5] = {
                [0] = 9.0,
                [1] = 2.9,
                [4] = 3.E+25,
                [3] = .00007,
        };

        // Doing some work
        for (size_t i = 0; i < 5; ++i) {
                printf("element %zu is %g, \tits square is %g\n",
                        i,
                        A[i],
                        A[i]*A[i]);
        }

        return EXIT_SUCCESS;
}
```

Program Structure

Definitions and Declarations

Before using any particular identifier, you must provide the compiler with a **declaration** specifying what the identifier represents.

```
int main(void);
double A[5];
size_t i;
```

- **main**, followed by round brackets, it is declared as a *function* of *type* **int**
- **i** it is declared as a numerical *variabile* of *type* **size_t**
- **A** it is declared as an *array* with values of *type* **double**

```
int printf(char const format[static 1], ...);
typedef unsigned long size_t;
#define EXIT_SUCCESS 0
```

Generally, *declarations* specify the type of object to which an identifier refers, but do not attribute any value to this object: this task is entrusted to the *definition* procedures

```
size_t i = 0;
```

This **initialization** defines the object with a corresponding name; this instruction for the compiler means to allocate an area of memory, which will be referred to by a particular name, and to keep inside it (initially) the value 0

Program Structure

Interactions and Function calls

Perform one or more operations several times

```
for (loop-variable; loop-condition; loop-post-exec)
        operations ...
```

```
while (condition)
        operations ...
```

```
do
        operations ...
while(condition);
```

Delegate the execution of chunks of block code located elsewhere

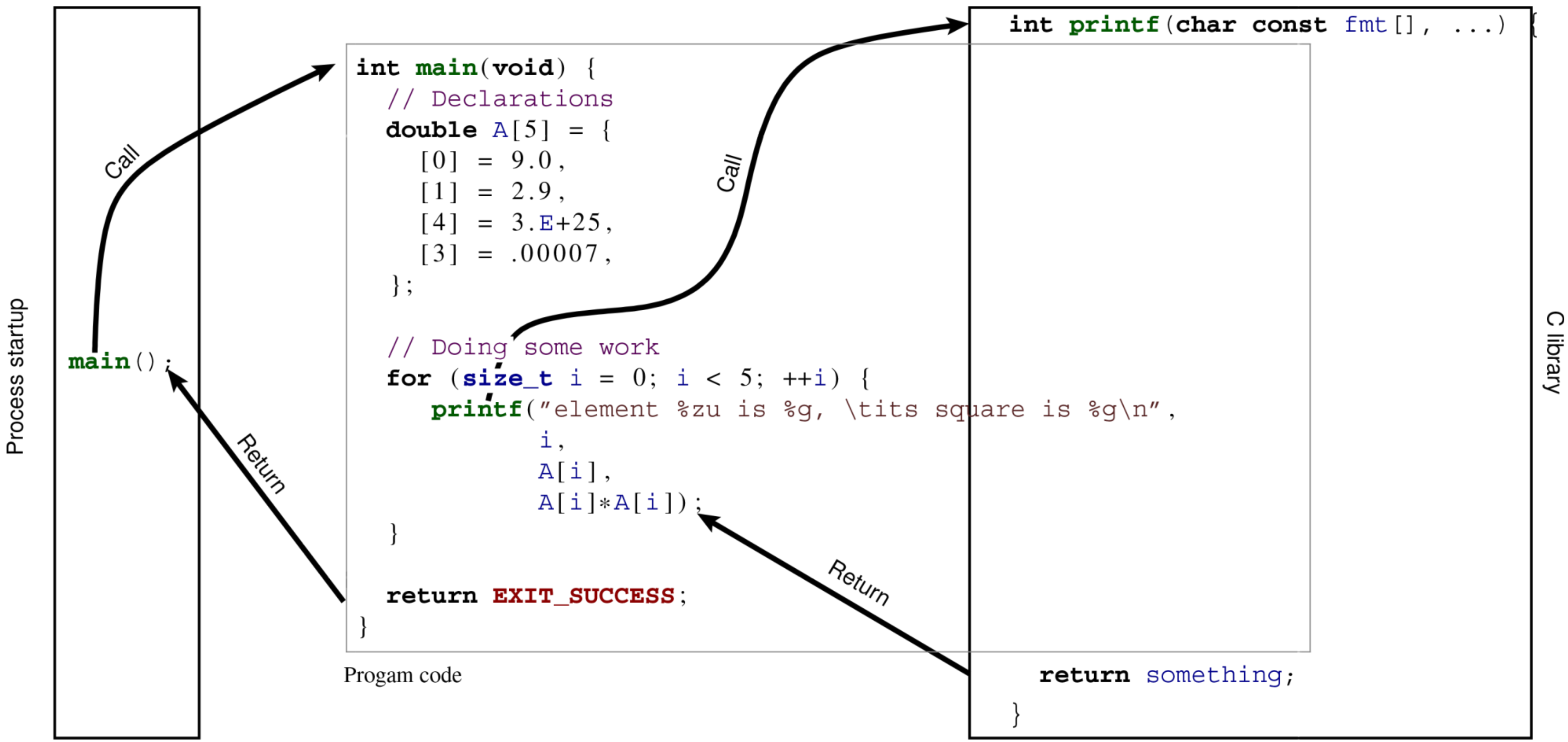
A function is called by passing particular **arguments** to it, and waiting for it to perform its functions by **returning values**

```
#include <stdlib.h>
#include <stdio.h>

/* The main thing that this program does. */
int main(void) {

        double A[5] = {
                [0] = 9.0,
                [1] = 2.9,
                [4] = 3.E+25,
                [3] = .00007,
        };

        // Doing some work
        for (size_t i = 0; i < 5; ++i) {
                printf("element %zu is %g, \tits square is %g\n",
                                i,
                                A[i],
                                A[i]*A[i]);
        }

        return EXIT_SUCCESS;
}
```

- Call by values
- Call by reference (not native but can be achieved through **pointers**)

Program Structure

Function calls



Program Structure

Flow Control

Controlling the flow of a program generally means to manage its behaviour

calling a function is already a flow control mechanism.

Conditional Control

```
if (condition)
   operations ...
else if
   operations ...
else
   operations ...
```

```
switch (arg) {
   case 'arg1':
      operations ...
      break;

   default:
      operations ...
}
```

1. if
2. for
3. do
4. while
5. switch

Furthermore, in **C** there are other constructs for particular conditional control:

Ternary Operator `condition ? A : B`

Pre-processing conditions `#if/#ifdef/#ifndef/#elif/#else/#endif`

Expressions computation

A crucial part of many programs is the processing of expressions, whether they are **arithmetic**, **boolean** or mixed.

A programming language provides a set of operators to deal with expressions

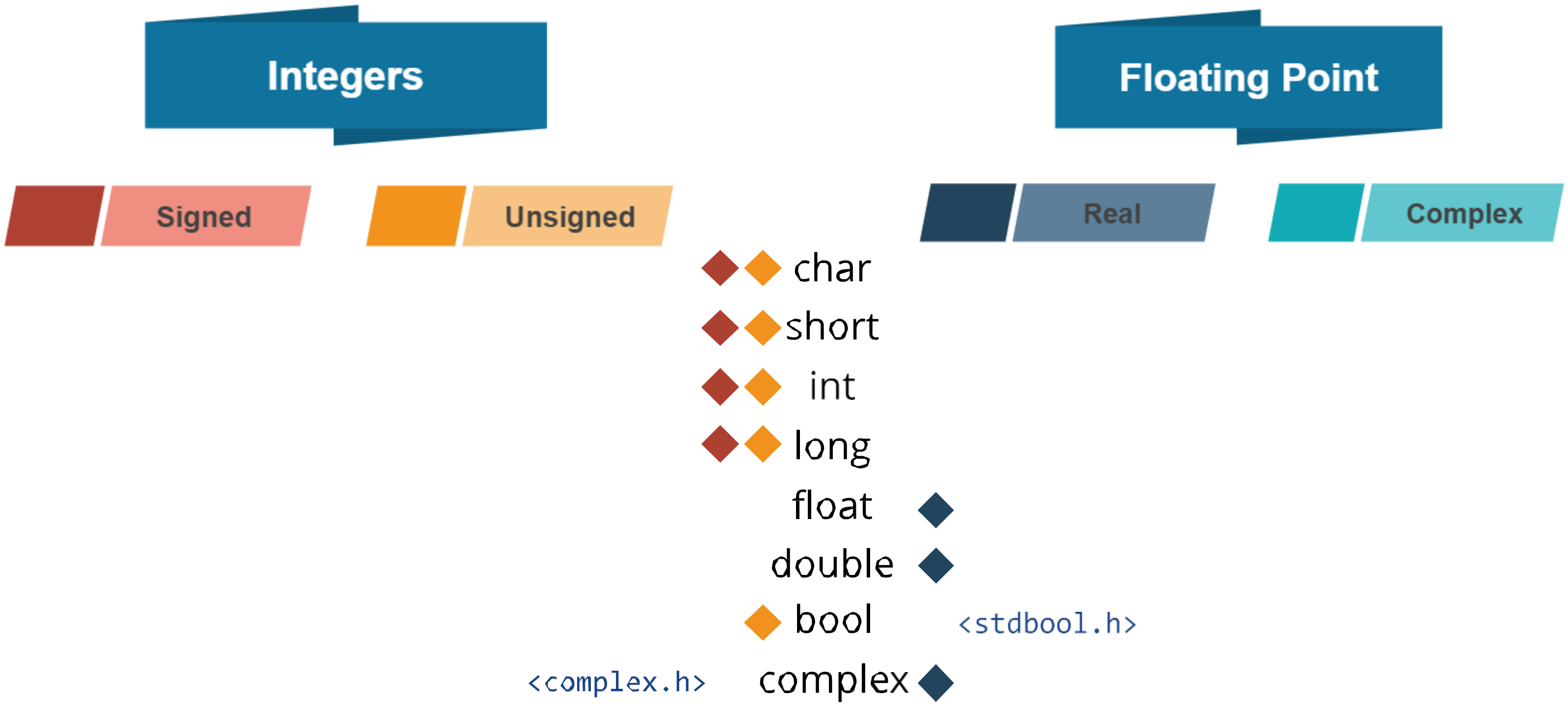
Arithmetic	Comparison	Logic
+	**==**	**&&** *(and)*
-	**!=**	**||** *(or)*
*****	**>**	**!** *(not)*
/	**<**	
�	**<=**	
	>=	

Binary Arithmetics
~ *(complement)*
& *(bit-and)*
| *(bit-or)*
^ *(xor)*
>> , << *(shift)*

Types of Data

A programming language like **C** works with **data**, that during the elaboration phases, may assume different **values**.

The **values** that a certain type of **data** can assume depends on its **type**



Types of Data

The amount of memory occupied by a **data** of a certain type depends on the platform for which the code is compiled, although there are directives regarding the possible size a **type** can have

Type	Dimension	Use	
char	8 bit	`char c = 'a'`	`unsigned char cu = 254`
short	16 bit	`short x = 3`	
int	16/32 bit	`int x = 350`	
long	32/64 bit	`long l = 123581321`	`unsigned long long llu = 9223372036854775807`
float	16/32 bit	`float f = 3.52`	
double	32/64 bit	`double d = 3.E+25`	
bool	8 bit	`bool b = true`	

Each data in memory is stored inside a **variable**.

Types of Data

Evaluate the range values that the different types can assume

```c
#include <stdio.h>
#include <stdlib.h>
#include <limits.h>
#include <float.h>

int main(int argc, char** argv) {

    printf("CHAR_BIT     :   %d\n", CHAR_BIT);
    printf("CHAR_MAX     :   %d\n", CHAR_MAX);
    printf("CHAR_MIN     :   %d\n", CHAR_MIN);
    printf("INT_MAX      :   %d\n", INT_MAX);
    printf("INT_MIN      :   %d\n", INT_MIN);
    printf("LONG_MAX     :   %ld\n", (long) LONG_MAX);
    printf("LONG_MIN     :   %ld\n", (long) LONG_MIN);
    printf("SCHAR_MAX    :   %d\n", SCHAR_MAX);
    printf("SCHAR_MIN    :   %d\n", SCHAR_MIN);
    printf("SHRT_MAX     :   %d\n", SHRT_MAX);
    printf("SHRT_MIN     :   %d\n", SHRT_MIN);
    printf("UCHAR_MAX    :   %d\n", UCHAR_MAX);
    printf("UINT_MAX     :   %u\n", (unsigned int) UINT_MAX);
    printf("ULONG_MAX    :   %lu\n", (unsigned long) ULONG_MAX);
    printf("USHRT_MAX    :   %d\n", (unsigned short) USHRT_MAX);

```

```c
#include <stdio.h>
#include <stdlib.h>
#include <limits.h>
#include <float.h>

int main(int argc, char** argv) {

    printf("Storage size for float : %d \n",
    printf("FLT_MAX      :   %g\n", (float) FLT_MAX);
    printf("FLT_MIN      :   %g\n", (float) FLT_MIN);
    printf("-FLT_MAX     :   %g\n", (float) -FLT_MAX);
    printf("-FLT_MIN     :   %g\n", (float) -FLT_MIN);
    printf("DBL_MAX      :   %g\n", (double) DBL_MAX);
    printf("DBL_MIN      :   %g\n", (double) DBL_MIN);
    printf("-DBL_MAX      :  %g\n", (double) -DBL_MAX);
    printf("Precision value: %d\n", FLT_DIG );

    return 0;
}
```

Data and Variable

Qualifiers

Qualifiers map to types in terms of attributes for the variable they are associated with

- **const** Associated with a specific data, it specifies that you do not have the rights to modify it

```c
const int x = 2;
x = x+3;
```

- **volatile** It indicates to the compiler that the value thus qualified could change at any time even by means of code that is not "near" the declaration of the variable
- **_Atomic** It is associated with a variable whose reading / writing must take place in a single instruction: during the change of value of the variable nothing else must not occur
- **restrict**

Arrays and Structures

There are other types of data (apparently more complex) which however derive from the basic types presented.
Two of these are called **aggregate types**, since they arise from the combination of several objects (even if not of the same type):

- (***Arrays***)
  - It is an aggregation of objects of the same type

```c
double a[4];
double b[] = { [3] = 42.0,  [2] = 37.0, };
double c[] = { 22.0,  17.0, 1, 0.5, };
```

- (***Structures***)
  - It is an aggregation of objects of different types

```c
struct microcontroller{
    char name[50];
    int bitNo;
    int ramKb;
    float price;
};
struct microcontroller const my_micro = {
  .name = "ARM",
  .bitNo = 32,
  .ramKb = 128,
  .price = 2.87
};
```

Array and Structures

Examples

```c
#include <stdio.h>

void swap_double(double a[2]) {
  double tmp = a[0];
  a[0] = a[1];

  a[1] = tmp;
}

int main(void) {
  double A[2] = { 1.0, 2.0 };
  swap_double(A);
  printf("A[0] = %g, A[1] = %g\n", A[0], A[1]);
}
```

```
$ gcc -o main *.c
$ main

A[0] = 2, A[1] = 1
```

Array and Structures

Examples

```c
#include <stdio.h>

float weighted_mean(int x[], int w[], int n) {
    int w_sum = 0, num = 0;

    for (int i = 0; i < n; i++){
        num = num + x[i] * w[i];
        w_sum = w_sum + w[i];
    }

    return (float)(num / w_sum);

}

int main(){

    int x[] = {1, 2, 3, 4, 5, 6, 7, 8, 9, 10};
    int w[] = {1, 2, 3, 4, 5, 6, 7, 8, 9, 10};

    int n = sizeof(x)/sizeof(x[0]);
    int m = sizeof(w)/sizeof(w[0]);

    if (n == m){
        float result = weighted_mean(x, w, n);
        printf("Weigthed mean: %g\n",result);
    }else{
        printf("n!=m\n");
        return -1;
    }
    return 0;
}
```

```
$ gcc -o main *.c
$ main
Weigthed mean: 7
```

Array and Structures

Examples

```c
#include <time.h>
#include <stdbool.h>
#include <stdio.h>

bool leapyear(unsigned year) {
    return !(year % 4) && ((year % 100) || !(year % 400));
}

#define DAYS_BEFORE                                    \
    (const int[12]){                                   \
    [0] = 0, [1] = 31, [2] = 59, [3] = 90,             \
    [4] = 120, [5] = 151, [6] = 181, [7] = 212,        \
    [8] = 243, [9] = 273, [10] = 304, [11] = 334,      \
    }

struct tm time_set_yday(struct tm t) {
    t.tm_yday += DAYS_BEFORE[t.tm_mon] + t.tm_mday - 1;

    if ((t.tm_mon > 1) && leapyear(t.tm_year+1900)){
        t.tm_yday++;
    }
    return t;
}

int main() {
    struct tm today = {
      .tm_year = 2020-1900,
      .tm_mon  = 2,
      .tm_mday = 19,
      .tm_hour = 10,
      .tm_min  = 0,
      .tm_sec  = 47,
    };
    printf("This year is %d, next year will be %d\n",
        today.tm_year+1900, today.tm_year+1900+1);
    today = time_set_yday(today);
    printf("Day of the year is %d\n", today.tm_yday);

    return EXIT_SUCCESS;
}
```

```c
struct tm{
int tm_sec; /* secondi (0-59) */
int tm_min; /* minuti (0-59) */
int tm_hour; /* ora (0-23) */
int tm_mday; /* giorno del mese (1-31) */
int tm_mon; /* mese dell'anno (0-11) */
int tm_year; /* anno dal 1900 */
int tm_wday; /* giorno della settimana (0-6) */
int tm_yday; /* giorno dell'anno (0-365) */
int tm_isdst; /* Ora legale */
}
```

```
$ gcc -o main *.c
$ ./main
This year is 2020, next year will be 2021
Day of the year is 101
```

Pointers

A **pointer** is a variable that contains the memory address of another variable

It is therefore a variable that does not directly contain the data we are interested in but points to the data by providing the memory address in which it is stored

Direction operator (dereferencing) : *

Returns the contents of the memory area pointed to by the pointer

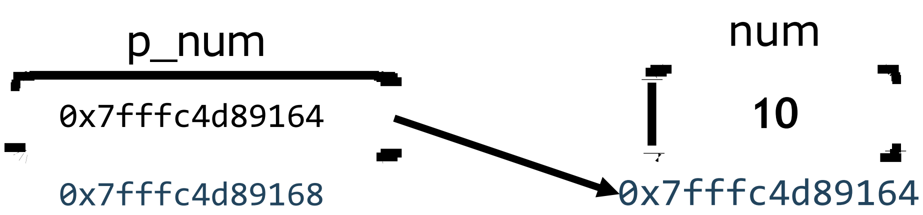
```
int *p1      /* Pointer to an integer */
double *p2   /* Pointer to a double */
char *p3     /* Pointer to a character */
```

Unary referencing operator : &

Returns the address where the pointed variable is located

```
double a = 10;
double *p;
p = &a; /* Get address of 'a' */
```

```
#include <stdio.h>

int main(){
    int num = 10;
    int *p_num = &num;
    printf("Value of variable num is: %d", num);
printf("\nAddress of variable num is: %p", p_num);

� return 0;
```



Pointers

Examples

```c
#include <stdio.h>

void pointer_test(int val){
     val = 20;
�

int main(){
    int num = 10;
    int *p_num = &num;
    pointer_test(num);
    printf("Value of variable num is: %d", num);
    printf("\nAddress of variable num is: %p", p_num);

    return 0;
�
```

```
$ gcc -o main *.c
$ main
Value of variable num is: 10
Address of variable num is: 0x0061FF18
```

```c
#include <stdio.h>

void pointer_test(int *val){
     *val = 20;
�

int main(){
    int num = 10;
    int *p_num = &num;
    pointer_test(p_num);
    printf("Value of variable num is: %d", num);
printf("\nAddress of variable num is: %p", p_num);

� return 0;
```

```
$ gcc -o main *.c
$ main
Value of variable num is: 20
Address of variable num is: 0x0061FF18
```

Pointers and Array

Pointers and **Arrays** are closely related in C and are often mistakenly interchanged

If you use only the name of the variable associated with an **array**, without any index, you get a **pointer** to its first element

```
int array[2] = { 3, 5 };
```

```
array == &array[0]
```

```c
#include <stdio.h>
#include <stdlib.h>

int main(void){
    char a[7]={'a', 'b', 'c', 'd', 'e', 'f', 'g'};
    printf("a[3]: %c, *(a+3): %c", a[3], *(a+3));
    return 0;
}
```

```
$ gcc -o main *.c
$ main
a[3]: d, *(a+3): d
```

Pointers Arithmetics

The operations are carried out implicitly taking into account the size of the variables pointed to

Pointers and Arrays

You can **dynamically** define an **array** in memory using **pointers**

This definition leads to the creation of a fixed sized array known at compilation time

```
int array[13];
```

Using pointers, you can define an array of known size at runtime

```
int *array = malloc(x * sizeof(int));
```

- malloc Allocate a specific number of bytes in memory
- realloc Increases or decreases the size of the indicated memory block
- calloc Allocate a specific number of bytes in memory initialized to 0
- free Frees specific number of bytes, leaving them back to the system

Particular type: `void*`

Casting operations may be needed

```
int *arr = (int*) malloc(2 * sizeof(int));
arr[0] = 1;
arr[1] = 2;
arr = realloc(arr, 3 * sizeof(int));
arr[2] = 3;
```

Pointers and Array

[Examples](#)

```c
#include <stdio.h>
#include <stdlib.h>

int main(){
    int n, i, *ptr, sum = 0;
    printf("Enter number of elements: ");
    scanf("%d", &n);

    ptr = (int*) calloc(n, sizeof(int));

    if(ptr == NULL){
        printf("Error! memory not allocated.");
        exit(0);
    }

    for(i = 0; i < n; ++i){
        printf("Enter element %d: ",i);
        scanf("%d", ptr + i);
        sum += *(ptr + i);
    }

    printf("Sum = %d\n", sum);
    free(ptr);
    return 0;
}
```

```
$ gcc -o main *.c
$ main
Enter number of elements: 5
Enter element 0: 1
Enter element 1: 2
Enter element 2: 3
Enter element 3: 5
Enter element 4: 8
```

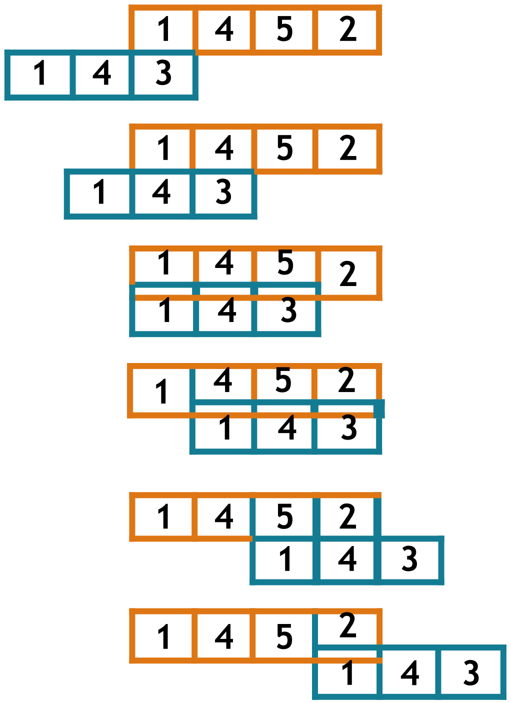
Programming

[Convolution]

In mathematics and, in particular, functional analysis, **convolution** is a mathematical operation on two functions *f* and *g*, producing a third function that is typically viewed as a modified version of one of the original functions

(from wikipedia.com)

$f = \boxed{1}\boxed{4}\boxed{5}\boxed{2}$ $\quad g = \boxed{3}\boxed{4}\boxed{1}$ $\quad h = f * g$



$h[0] = 1*3$

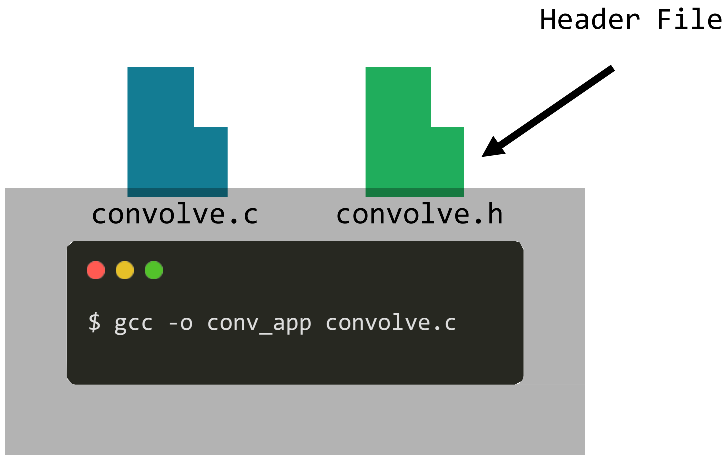
$h[1] = 1*4+4*3$

$h[2] = 1*1+4*4+5*3$

$h[3] = 4*1+5*4+2*3$

$h[4] = 5*1+2*4$

$h[5] = 2*1$



Programming

A **moving average** is a form of a convolution often used in time series analysis to smooth out noise in data by replacing a data point with the average of neighboring values in a moving window: it operates by taking the arithmetic mean of a number of past input samples in order to produce each output sample.

$$\bar{y}_n = \frac{1}{N}\sum_{i=0}^{N-1} x_{n-i} \longrightarrow y_n = (y_{n-1} + x_n - x_{n-N+1})$$

$x =$	1	0	0	0	0	0	0	$\bar{y}_1 = \frac{1}{5}$
$x =$	1	2	0	0	0	0	0	$\bar{y}_2 = (1+2)\frac{1}{5}$
$x =$	1	2	3	0	0	0	0	$\bar{y}_3 = (1+2+3)\frac{1}{5}$
$x =$	1	2	3	5	0	0	0	$\bar{y}_4 = (1+2+3+5)\frac{1}{5}$
$x =$	1	2	3	5	8	0	0	$\bar{y}_5 = (1+2+3+5+8)\frac{1}{5}$
$x =$	1	2	3	5	8	13	0	$\bar{y}_6 = (2+3+5+8+13)\frac{1}{5}$
$x =$	1	2	3	5	8	13	21	$\bar{y}_7 = (3+5+8+13+21)\frac{1}{5}$

```
$ gcc main.c moving_average_filter.c -o maf_app
$ maf_app
```