PROGRAMMAZIONE PROCEDURALE

A.A. 2023/2024

A **pointer** is a variable whose value is the address of another variable, i.e., direct address of the memory location.

DECLARING POINTERS

POINTERS

- A *pointer* represents both the address and the type of an object. If an object or function has the type *T*, then a pointer to it has the derived type "***pointer to T***".
- For example, if **var** is a float variable, then the expression **&var**—whose value is the address of the float variable—has the type *pointer to* float, or in C notation, the type **float** *.
- Because **var** doesn't move around in memory, the expression **&var** is a constant pointer.
- The declaration of a pointer to an object that is not an array has the following syntax:

  type *** [*type-qualifier-list*] *name* [= *initializer*];**

THE & OPERATOR

- The ***address operator*** & yields the address of its operand. If the operand x has the type *T*, then the expression **&x** has the type "**pointer to *T***"
- The operand of the address operator must have an addressable location in memory: the operand must designate either a function or an object (i.e., an *lvalue*) that is not a bit-field.
- You need to obtain the addresses of objects and functions when you want to initialize pointers to them:

```
float x, *ptr;
ptr = &x;          // OK: Make ptr point to x.
ptr = &(x+1);      // Error: (x+1) is not an lvalue.
```

THE INDIRECTION OPERATOR *

- Conversely, when you have a pointer and want to access the object it references, use the ***indirection operator*** *, which is sometimes called the ***dereferencing operator***.
- Its operand must have a pointer type.
- If *ptr* is a pointer, then **ptr* designates the object or function that *ptr* points to.
- If *ptr* is an object pointer, then **ptr* is an *lvalue*, and you can use it as the left operand of an assignment operator:

```
float x, *ptr = &x;
*ptr = 1.7                  // Assign the value 1.7 to the variable x
++(*ptr);                   // and add 1 to it.
```

INDIRECTION AND ARITHMETIC

- Asterisk * with one operand is the **dereference** or **indirection operator**, and with two operands, it is the multiplication sign.
- In each of these cases, the unary operator has higher precedence than the binary operator. For example, the expression ***ptr1 * *ptr2** is equivalent to **(*ptr1) * (*ptr2)**.
- Look at the operator precedence/associativity table

QUESTION

- Given
  - ✓int *p;
- What is its type of p?
  - ✓int?

NO: its type is “pointer to int” or int*

IN MEMORY

- The addresses shown are purely fictitious examples.

```
int iVar = 77;
int *iPtr = &iVar;
```

Variable		iVar	iPtr	
Value in memory	…	77	1000	…
Address		1000	1004	

PRINT POINTERS

- It is often useful to output addresses for verification and debugging purposes.
  - ✓The printf( ) functions provide a format specifier for pointers: %p.

```
printf( "Value of iPtr (i.e. the address of iVar): %p\n"
        "Address of iPtr:                          %p\n", iPtr, &iPtr );
```

- The size of a pointer in memory—given by the expression sizeof(iPtr), for example—is the same regardless of the type of object addressed.
- 8 byte(?)

NULL POINTERS

- A *null pointer constant* is an integer constant expression with the value 0.
- The macro NULL is defined in *stdlib.h.*
- A null pointer is always unequal to any valid pointer to an object or function.

EXAMPLE

- Initialization
  - ✓ int *p = NULL;

```
#include <stdlib.h>

int main() {
    int a= 3;
    int* p= NULL;
    *p= 6;
}
```

Segmentation fault

```
#include <stdio.h>

int main() {
    int a= 3;
    int* p= &a;
    *p= 6;
}
```

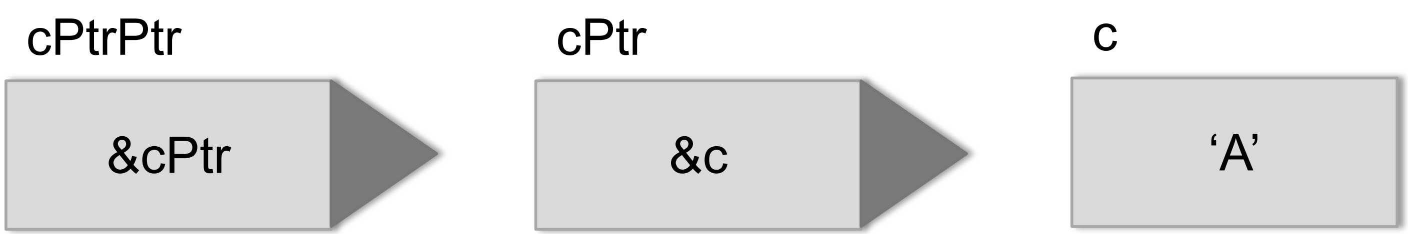
VOID POINTERS

- A pointer to void, or *void pointer* for short, is a pointer with the type void *.
- As there are no objects with the type void, the type void * is used as the all-purpose pointer type.
  - ✓A void pointer can represent the address of any object—but not its type.
- To access an object in memory, you must always convert a void pointer into an appropriate object pointer.

```
void* pA= NULL;
int p= 10;
pA= &p;

printf("%d", *((int*) pA));
```

POINTERS TO POINTERS

- A pointer variable is itself an object in memory, which means that a pointer can point to it.
- To declare a pointer to a pointer, you must use two asterisks
  - ✓ char c = 'A', *cPtr = &c, **cPtrPtr = &cPtr;
- The expression *cPtrPtr now yields the char pointer cPtr, and the value of **cPtrPtr is the char variable c.



EXAMPLE

The address of a is 0x7fff4fca4acc

```
int main(){
    int a= 2, *p= &a;
    printf("%d %d\n", *p, *&*&a);
    printf("%p %p\n", p, &*&a);
}
```

```
MacBook-Francesco:ProgrammI francescosantini$ ./main
2 2
0x7fff4fca4acc 0x7fff4fca4acc
```

OPERATIONS WITH POINTERS

READ AND MODIFY

- If **ptr** is a pointer, then ***ptr** designates the object (or function) that **ptr** points to.
- The type of the pointer determines the type of object that is assumed to be at that location in memory.
- For example, when you access a given location using an **int** pointer, you read or write an object of type **int**.

EXAMPLES

```
double x, y, *ptr;      // Two double variables and a pointer to double.
ptr = &x;               // Let ptr point to x.
*ptr = 2.5;             // Assign the value 2.5 to the variable x.
*ptr *= 2.0;            // Multiply x by 2.
y = *ptr + 0.5;         // Assign y the result of the addition x + 0.5.
```

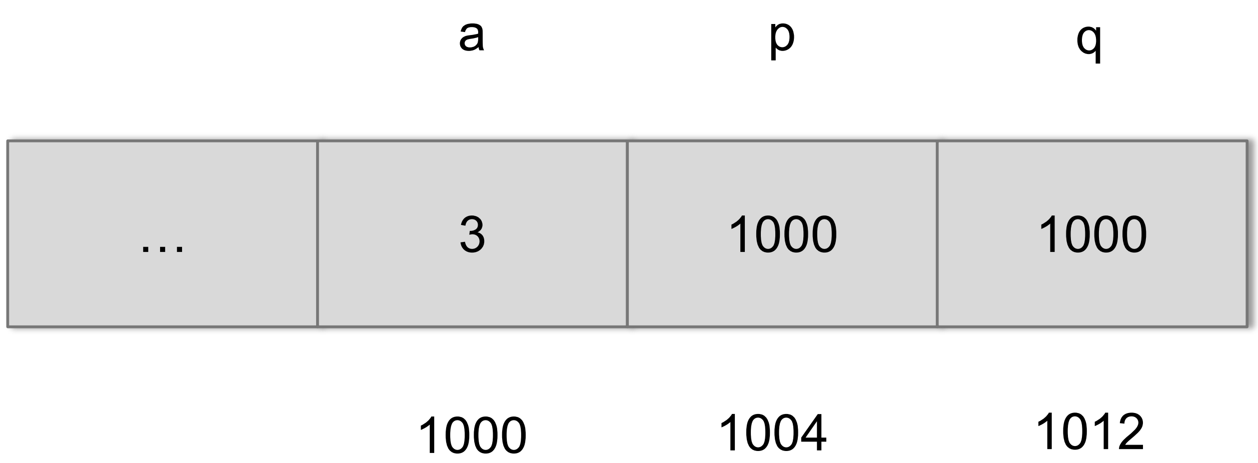
x is equal to 5.0
y is equal to 5.5

QUESTIONS

- int a= 3; int* p= &a;
  - ✓Is “a” an lvalue? Yes
  - ✓Is “p” an lvalue? Yes
  - ✓Is “*p” an lvalue? Yes
  - ✓Is “&a” an lvalue? No

```
int a= 3;
int* q= &a,
int *p = q;
```

&a == 1000



OPERATIONS

- The most important of these operations is accessing the object that the pointer refers to
- You can also
  - ✓ compare pointers, and
  - ✓ use them to iterate through a memory block
- Pointer arithtmetics

POINTER ARITHMETICS

- When you perform *pointer arithmetic*, the compiler automatically adapts the operation to the size of the objects referred to by the pointer type.
- You can perform the following operations on pointers to objects:
  - ✓Adding an integer to, or subtracting an integer from, a pointer.
  - ✓Subtracting one pointer from another.
  - ✓Comparing two pointers.

EXAMPLE ON COMPARING

```
int main() {
    int a= 5;
    int *p= &a;
    int *q= &a;

    if (p == q)
        printf("The two pointers are the same");

}
```

Comparison (== and !=) is used to check if two pointers point to the same location of memory

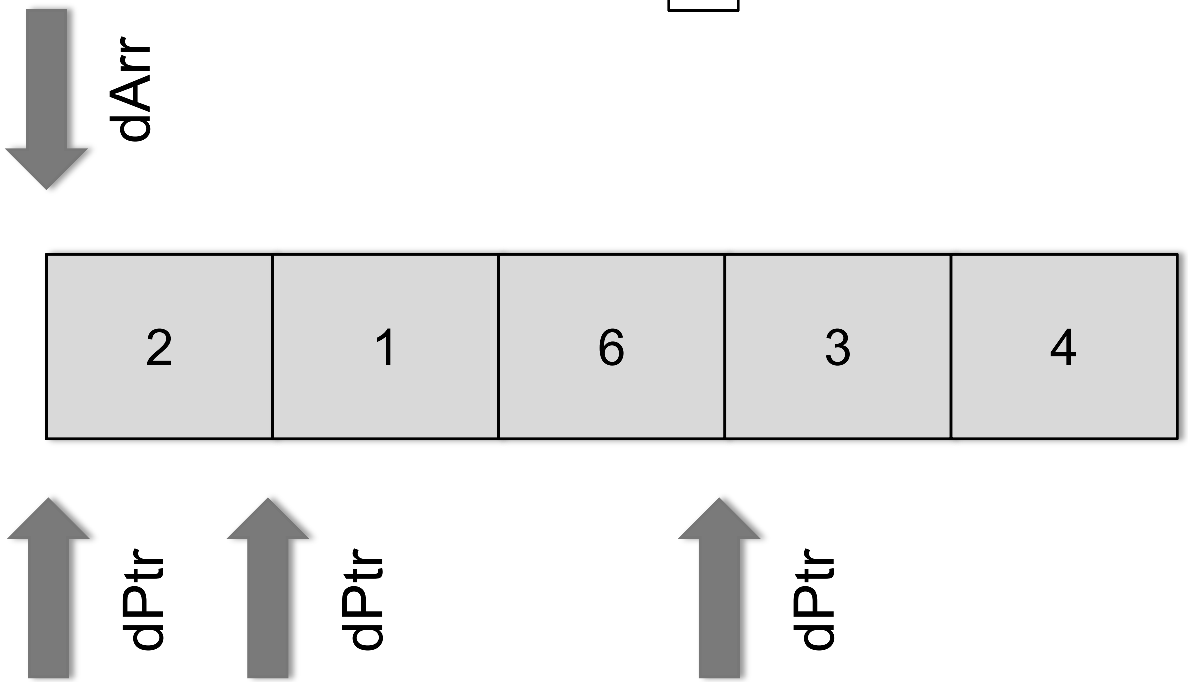
ARITHMETIC AND ARRAY OPERATIONS

- The three pointer operations described here are generally useful only for pointers that refer to the elements of an array. To illustrate the effects of these operations, consider two pointers **p1** and **p2**, which point to elements of an array **a**:
  - ✓If **p1** points to the array element **a[i]**, and **n** is an integer, then the expression **p2 = p1 + n** makes **p2** point to the array element **a[i+n]** (assuming that **i+n** is an index within the array **a**).
  - ✓The subtraction **p2 – p1** yields the number of array elements between the two pointers, with the type **ptrdiff_t**. The type **ptrdiff_t** is defined in the header file *stddef.h*, usually as **int**. After the assignment **p2 = p1 + n**, the expression **p2 – p1** yields the value of **n**.
  - ✓The comparison **p1 < p2** yields **true** if the element referenced by **p2** has a greater index than the element referenced by **p1**. Otherwise, the comparison yields false.

EXAMPLE

```
// Initialize an array and a pointer to its first element.
int dArr[5] = { 2, 1, 6, 3, 4 };
int *dPtr = dArr;

int i = 0;
dPtr = dPtr + 1;
dPtr = 2 + dPtr;

printf( "%d\n", *dPtr );
printf( "%d\n", *(dPtr -1) );

i = dPtr - dArr;

printf( ”%d\n", i );
```

3
6
3



CONSIDERATIONS ON THE EXAMPLE

- The statement dPtr = dPtr + 1; adds the size of one array element to the pointer, so that dPtr points to the next array element, dArr[1].
- Because dPtr is declared as a pointer to int, its value is increased by sizeof(int).
- Subtracting one pointer from another yields an integer value with the type ptrdiff_t. The value is the number of objects that fit between the two pointer values.
  - ✓The type ptrdiff_t is defined in the header file *stddef.h*, usually as int.

MORE ON ARRAYS

- Because the name of an array is implicitly converted into a pointer to the first array element wherever necessary, you can also substitute pointer arithmetic for array subscript notation:
  - ✓The expression **a + i** is a pointer to **a[i]**, and the value of ***(a+i)** is the element **a[i]**.
  - ✓**Arrays “do not exist in C”: they are just pointers**

L VALUES AND POINTERS

- The operators that yield an lvalue include the subscript operator [] and the indirection operator *

Expression	Lvalue?
array[1]	
&array[1]	
ptr	
*ptr	
ptr+1	
*ptr+1	

int* ptr…

ONE MORE EXAMPLE

```
#include <stdio.h>


int main()
{
    // Initialize an array and a pointer to its first element.
    int dArr[5] = { 2, 1, 6, 3, 4 }, *dPtr = dArr;

    int i = 0;
    dPtr = dPtr + 1;
    printf("dArr %p\n", dArr);
    printf(”dPtr %p\n", dPtr);
    dPtr = 2 + dPtr;
    printf(”dPtr %p\n", dPtr);
}
```

dArr 0x7fff56845b19

dPtr 0x7fff56845b1d

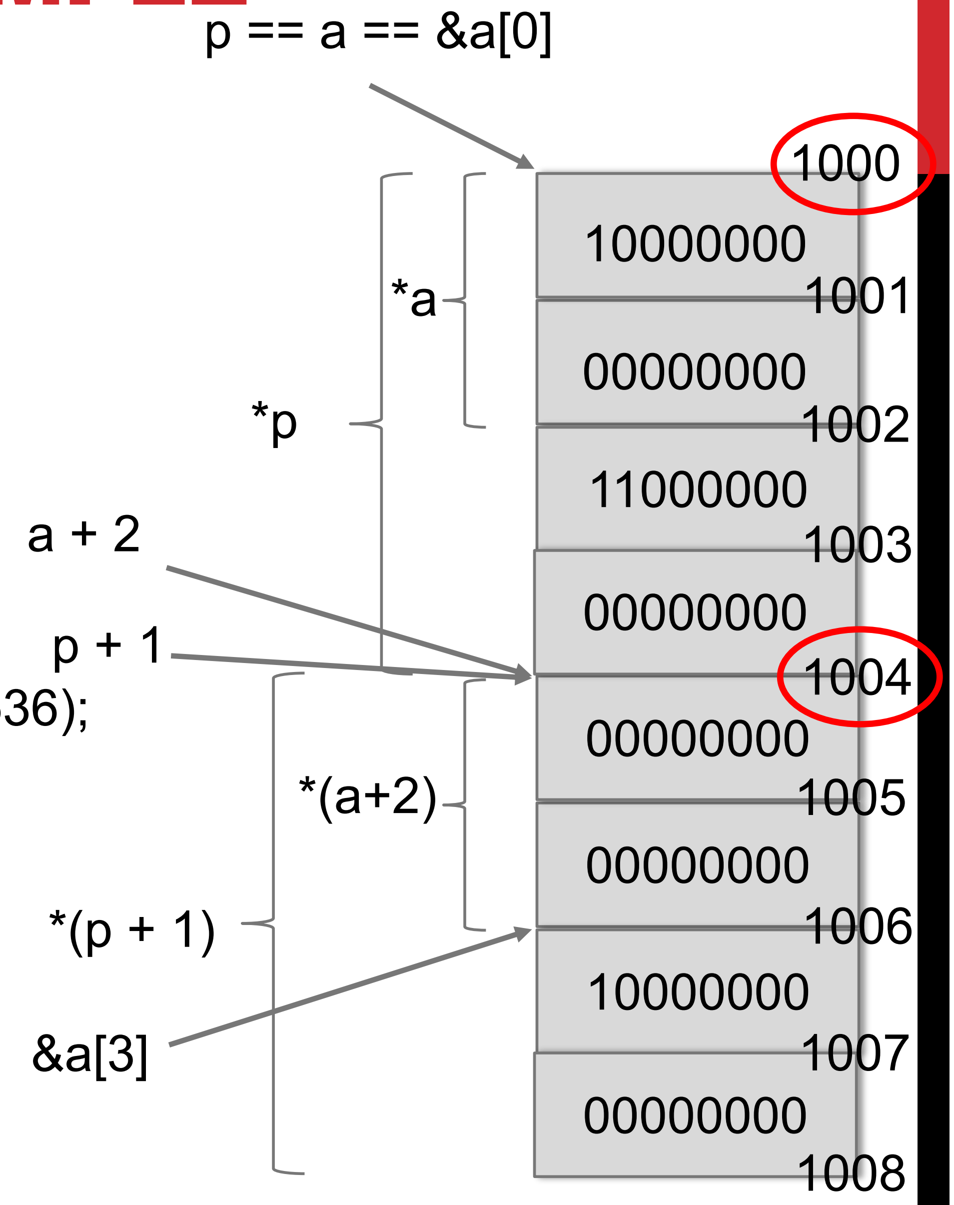
dPtr 0x7fff56845b25

AN ADVANCED EXAMPLE

Little endian

*a == a[0]

```
int main() {
    short int a[4]= {1,3,[3]=1};
    int *p = (int*) a;

    printf("*a is equal to %d\n", *a);
    printf("*p==0 %d\n", *p== 0);
    printf("p == a %d\n", p == a);
    printf("*(a+2) == 0 %d\n", *(a+2) == 0);
    printf("*(p+1)== 65536 %d\n", *(p+1) == 65536);
    printf("&a[3] > (p + 1) %d\n", &a[3] > p+1);
    printf("%ld\n", (a+2) - &a[0]);
    printf("%d\n", ((int) (a+2)) - (int) (&a[0]) );
}
```



A short int is 2 bytes, an int is 4 bytes

$1x\ 2^{16} + 1 \times 2^{17} + 1 \times 2^{0} = 196609$

EXAMPLE

```
int main() {
    short int a[4]= {1,3,[3]=1};
    int *p = (int*) a;

    printf("*a is equal to %d\n", *a);
    printf("*p == 0 %d\n", *p== 0);
    printf("p == a %d\n", p == a);
    printf("*(a+2)= %d\n", *(a+2) == 0);
    printf("*p == 65536 %d\n", *(p+1) == 65536);
    printf("&a[3] > (p+1) %d\n", &a[3]> (p+1));
    printf("%ld\n", (a+2) - &a[0]);
    printf("%d\n", ((int) (a+2)) - (int) (&a[0]) );
}
```

```
MacBook-Francesco:esercizi francescosantini$ ./main
*a is equal to 1
*p == 0 0
p == a 1
*(a+2)== 0 1
*p == 65536 1
&a[3] > (p+1) 1
2
4
```

CONST POINTERS AND POINTERS TO CONST

CONSTANT POINTERS AND POINTERS TO CONSTANT VARS

- It is possible to also define constant pointers.
- When you define a constant pointer, you must also initialize it, because you can’t modify it later.

```
int var, var2;               // Two objects with type int.
int *const c_ptr = &var;     // A constant pointer to int.
*c_ptr = 123;                // OK: we can modify the object referenced, but ...
c_ptr= &var2;                // error: we can't modify the pointer.
```

POINTERS TO CONST

- You can modify a pointer that points to an object that has a const-qualified type (also called a *pointer to* const).
- However, you can use such a pointer only to read the referenced object, not to modify it
  - ✓For this reason, pointers to const are commonly called “read-only pointers.
- You can use them if you want to be sure to not modify a variable through its pointer

EXAMPLE

```
int var;                          // An object with type int.

const int c_var = 100;            // A constant int object.
const int *ptr_to_const;          // A pointer to const int:
                                  // the pointer itself is not constant!

ptr_to_const = &c_var;            // OK: Let ptr_to_const point to c_var.

var = 2 * *ptr_to_const;          // OK. Equivalent to: var = 2 * c_var;

ptr_to_const = &var;              // OK: Let ptr_to_const point to var.

if ( c_var < *ptr_to_const )      // OK: "read-only" access.
    *ptr_to_const = 77;           // Error: we can't modify var using
                                  // ptr_to_const, even though var is
                                  // not constant.
```

The assignment ptr_to_const = &var entails an implicit conversion: the int pointer value &var is automatically converted to the left operand’s type, pointer to const int.

ONE MORE EXAMPLE

- If you want to convert a pointer into a pointer to a less-qualified type, you must use an explicit type conversion.

```
int var;
const int c_var = 100, *ptr_to_const;

int *ptr = &var;              // An int pointer that points to var.
*ptr = 77;                    // OK: ptr is not a read-only pointer.
ptr_to_const = ptr;           // OK: implicitly converts ptr from "pointer to int”
                              // into "pointer to const int".

*ptr_to_const = 77;           // Error: can't modify a variable through a read-only
                              // pointer.
ptr = &c_var;                 // Error: can't implicitly convert "pointer to const
                              // int" into "pointer to int".

ptr = (int *) &c_var;         // OK: Explicit pointer conversions are always
                              // possible.
```

SU LIBRO

- Sezioni 7.1-7.3, 7.5, 7.8, 7.9, 7.10