Programming Software Systems

Introduction to Programming for the Computer Engineering Track

Lecture 2
Introduction

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Innopolis University

Last Tuesday:

- Personal introduction.
- Course introduction.
- Languages' syntax & semantics.
- Program lifecycle: compilation.
- The memory model: code, heap & stack.
- The typical C program structure.
- How C programs are compiled and built.
- C programs and the notion of stack.

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- C programs and the notion of stack.
- Variable scopes and program blocks.

Didn't have time last Tuesday

Outline: Today

- Variable scopes and program blocks.
- The notion of **type**.
- Static and dynamic typing.
- Type categories.
- C type system: predefined & user-defined types.
- **Pointers & arrays**

Scope of a Variable

- The **scope** of a variable is a portion of the (source) code in which that variable is visible
  - the scope is where in the code we can refer to the variable declared
- Scoping rules (of some language, e.g., C) define scopes of variables
- Scoping rules may vary from language to language and also among different declaration types in the same language
  - i.e. scoping rules for variable declarations may be different from those for function declarations

Blocks

- In most structured high-level languages the notion of **block** is central to scope identification
- A block is a portion of code enclosed between two special symbols, which mark the beginning and the end of the block.
  - In C (in Java, C++ etc.) blocks are marked by curly braces:

    { *this is a block* }

  - In some other languages blocks are marked by **begin** and **end** keywords or in some other manner (e.g. implicitly).
- Usually, blocks can be **nested**; but some language-dependent limitations are possible.

Scopes & Blocks

- Variable is visible
  - In the block it is defined
    - Starting from the line of definition
  - In all inner bocks unless a variable of the same name is declared within
- Global variables (if exist in the language)
  - Defined outside the scope of any block
- Hiding a variable
  - A homonymous variable declared within a block makes a variable of the same name declared outside invisible

Scopes & Blocks

- Scope is a **rule** determining existence and visibility of variables.
- Block is a compound language **construct** where variables (and other program entities) are declared.
- Declared entities are valid only within their scope, e.g. a variable exists only in its scope. The system is unaware of these entities in other parts of the code.

Scopes & Blocks: an Example

```
void f()
{
    int i = 3;
    for ( int j=0; j<20; j++ )
    {
        int k;
        if ( condition )
        {
            int i = 7;
            ...i+k...g(k)...
        }
        else
        {
            int j = g(k+i);
            ...
        }
    }
}
int g(int z) {
    int i = z+1;
    ...
    return i*i;
}
```

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The scope of inner i is this block. The local i <u>hides</u> the i from the outer block

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```

The loop body is the block. j and k are declared in the block that is the scope for them

The scope of inner i is this block. The local i hides the i from the outer block

The scope of inner j is this block. The local j hides the j from the outer block

Scopes & Blocks: an Example

Function body is the block

The scope of i starts from its declaration until the end of the block except inner scope where local i is declared

The loop body is the block. j and k are declared in the block that is the scope for them

The scope of inner i is this block. The local i hides the i from the outer block

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    }
}
int g(int z) {
    int i = z+1;
    ...
    return i*i;
}
```

Function body is the block. The scope for z and i is the body. g's i is not related to f's i.

The Notion of Type

Evolution of the Notion of Type (1)

Algol-60, Pascal, C:

Imperative programming

Predefined & user-defined data structures

Clu, Modula-2, Ada-83:

Abstract data types

+Data encapsulation with access control

C++, Ada-95, Eiffel & many followers:

Classes

+Inheritance & polymorphism

Evolution of the Notion of Type (2)

Type (of an object/entity) is:

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Evolution of the Notion of Type (3)

Type (of an object/entity) is:

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```
int i;
```

Evolution of the Notion of Type (3)

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```
int i;
```

The set of **values**:
- Integer numbers within the range …

The set of (predefined) **operators**:
- Creation, destruction, copying, moving
- Arithmetic & comparison operators;
- Shifts; …

The set of (predefined) **relationships**:
- Conversions to boolean, float, …

Evolution of the Notion of Type (3)

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struct S { ... };
```

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int i;
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```
struct S { ... };
```

The set of **values**:
- Cartesian product(*) of struct members' sets

The set of **operators**:
- Creation, destruction, copying, ~~moving~~
- Access to struct members ("fields")
- ~~User-defined operators~~

~~The set of relationships:~~
- ~~Between this type and its base class(es)~~
- ~~User-defined conversion operators~~

C++ only, but not C…

(*) Cartesian product
Декартово произведение

Static vs Dynamic: Pros & Cons

Static typing

C, C++, Java, Scala, C#, Eiffel, …

```
int x;
...
x = 7; // OK
...
x = "string"; // error
```

Static vs Dynamic: Pros & Cons

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int x;
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The binding between the variable and its type is **hard**: x can take any value but the type of the value must be always the same.

Static vs Dynamic: Pros & Cons

C, C++, Java, Scala, C#, Eiffel, …

Static typing

☹ Requires more efforts while writing a program: need to explicitly specify object types.

☺ **The program is (much) more safe**: many bugs are detected before running (in compile time).

☺ The program is more readable; it's easier to read, understand and maintain it.

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int x;
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Static vs Dynamic: Pros & Cons

Dynamic typing

Javascript, Python, Ruby, ...

```
x = 7;          // OK
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x = "string"; // OK!
...
y = x + 7;      // OK!
```

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The binding between the variable and its type is **soft**: x can hold any value of any type.

Static vs Dynamic: Pros & Cons

Dynamic typing

Javascript, Python, Ruby, ...

☺ It's much easier to write a program: no need to take care about object types.

☺ The program is more flexible: no need to introduce different objects for different purposes.

☹ The program often looks cryptic; it's required much more efforts to understand and maintain them.

☹ **Programs are unsafe and inefficient** .

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```

Formally correct, but what the hell does it mean??

The binding between the variable and its type is **soft**: x can hold any value of any type.

Static vs Dynamic: Pros & Cons

Dynamic programs are less safe

A point for discussion

Dynamic programs are less efficient

Why? - Will discuss on tutorial

Type Categories

Types:

- Fundamental (atomic) `int` `char` `long double`
- Structured (compound) `int[10]`

- Predefined (language-defined)
- User-defined `struct` `class`

B. Stroustrup:
Class is a type

C Standard (Predefined) Types

```
char
```

```
_Bool
```

Signed integer types

```
signed char
short int
int
long int
long long int
```

Unsigned integer types

```
unsigned char
unsigned short int
unsigned int
unsigned long int
unsigned long long int
```

Floating types

```
float
double
long double
```

Complex types

```
float _Complex
double _Complex
long double _Complex
```

C Derived ("User-Defined") Types

- Array types
- Structure types
- Union types
- Function types
- Pointer types
- Atomic types

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int A[100];
```

This is a **variable** of array type
(The same is about function & pointer types)

C Derived ("User-Defined") Types

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- Function types
- Pointer types
- Atomic types

- There is no way to declare an array type independently from an array variable

```
int A[100];
```

This is a **variable** of array type
(The same is about function & pointer types)

- Structure & union types can be declared **separately** (as they are):

```
struct S {
    int a;
    int b;
};
```

Having such a declaration we can use it for declaring **variables** of this type:

```
struct S s;
```

Storage Class Specifiers

```
auto
static
extern
```

Are introduced together with type specifiers in object declarations

Storage Class Specifiers

```
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static
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```

Are introduced together with type specifiers in object declarations

```c
int a;
static char b;
extern float c;

void f()
{
    double d;
    static int e;
    auto int f;
}
```

Storage Class Specifiers

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auto
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Are introduced together with type specifiers in object declarations

a is the **global non-static object**
- it "belongs" to the whole program;
- it is available throughout the program;
- it is created only once: before the program starts.

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c is the **global external object**
- this is not a definition but declaration; it's assumed that the object is (really) defined in some other translation unit;
- The memory for the object is not allocated here but in other TU.

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d and f are **automatic local objects**
- it “belongs” to the function in which it’s declared;
- it’s available only from within the function (i.e., it’s local to the function);
- it’s created each time the function is invoked.

Storage Class Specifiers

```
auto
static
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```

Are introduced together with type specifiers in object declarations

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- it's created each time the function is invoked.

e is the **local static object**
- it "belongs" to the function in which it's created;
- it is available only from within the function;
- it is created only once: before the program starts.

Pointers

1. **Pointer**:
   <u>An object</u> containing an address to some other object

```
int x;
int* p;
...
p = &x;
```

Unary "address-of" operator

Pointers

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   <u>An object</u> containing an address to some other object

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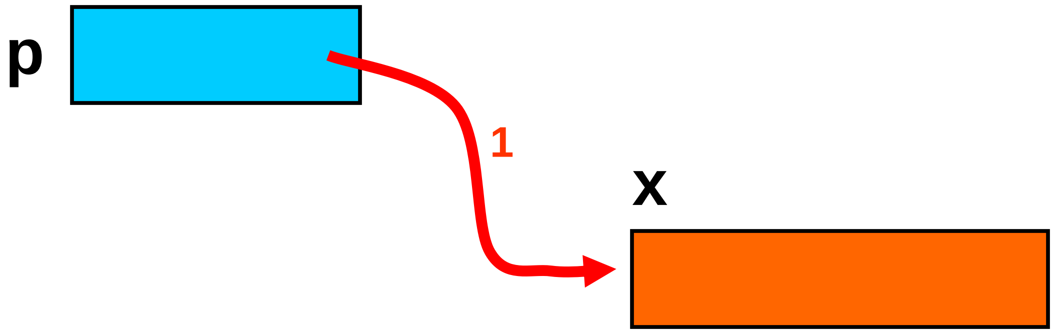
Unary “address-of” operator



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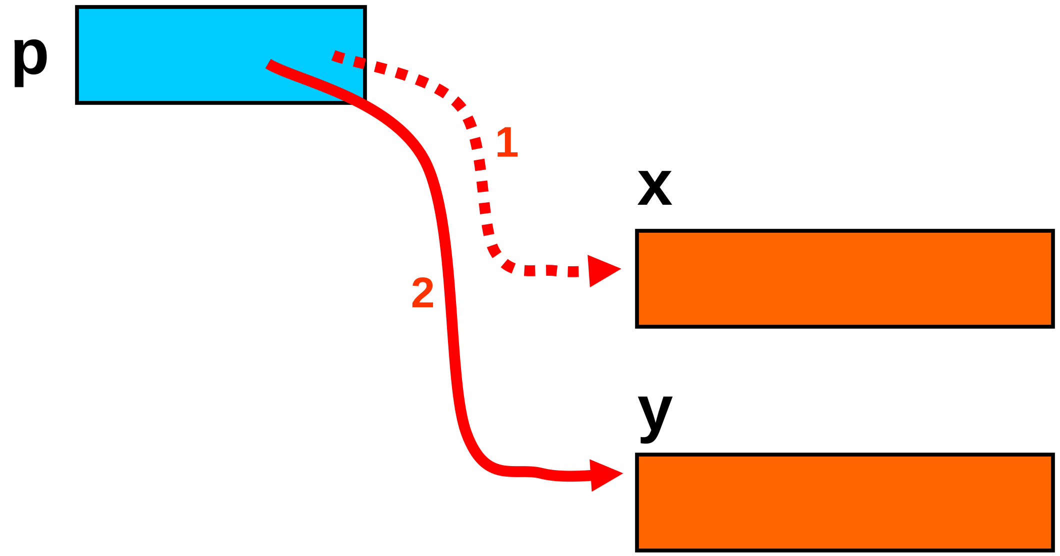


```
int y;
...
p = &y; 2
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Pointers

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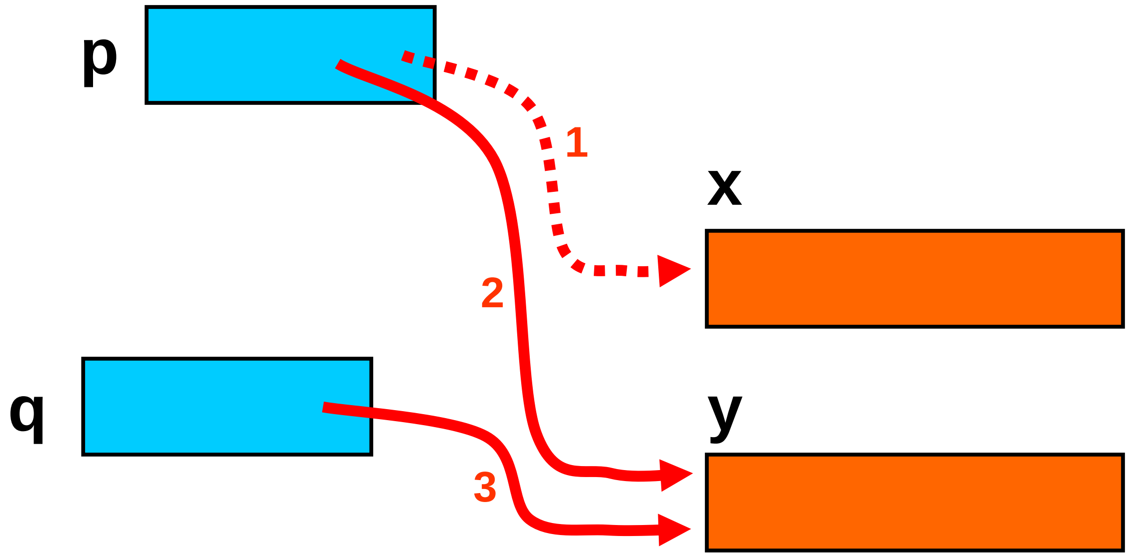


```
int y;
...
p = &y; 2
```

```
int* q;
...
q = p;  3
```

Pointers

2. Pointer types

`T* p;`

Declaration of an object of a pointer type, where *T* denotes a type pointed

Examples:

- Pointers to (simple) variables; `int* pv;`
- Pointers to objects of class types; `struct S* ps;`
- Pointers to functions; `int (*pf)(int);`
- Pointers to pointers; `int** p;`
- Pointers to values of any type `void* p;`

Pointers

3. Operators on pointers

&object

Unary prefix operator

Taking address of object

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***pointer**

Unary prefix operator

Dereferencing:
Getting object pointed to by "pointer"

```
int x;
int* p = &x;
...
*p = 777;       // x is 777
int z = *p+1; // z is 778
```

Pointers

3. Operators on pointers

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int x;
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***pointer**

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Dereferencing:
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See tutorial for other operators on pointers

```
int x;
int* p = &x;
...
*p = 777;      // x is 777
int z = *p+1; // z is 778
```

Notice
The same token * is used for two different purposes:
a) for specifying a pointer type
b) as dereferencing operator.

...and for multiplication! ☺

A fixed-size indexed group of variables of the same type

Arrays

```
T A[size];
```

`T` is the type of array elements

`A` is the array identifier

`size` specifies the number of array elements; this is an expression of an integer type

In general, `size` should be a **constant expression**

A fixed-size indexed group of variables of the same type

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In general, size should be a **constant expression**

```
int Array[10];

const int x = 7;
void* Ptrs[x*2+5];

int Matrix[10][100];
```

The only operator on arrays:

- ***Getting access to an element***

```
int el5 = Array[5];

Array[7] = 7;
```

A fixed-size indexed group of variables of the same type

Arrays

Arrays are very low-level and non-safe language feature

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```

The Program Example

The task:
- Find a given value in an array.

Version 1

```
int find1 ( float array[20], int x )
{
   for ( int i = 0; i<20; i++ )
   {
       if ( array[i] == x ) return i;  // success
   }
   return -1;  // fail
}
```

The Program Example

The task:

- Find a given value in an array.

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```

Are you happy with this solution?

Arrays & Pointers

```
int Array[10];
```

By definition, array name is treated as a **pointer** to the first array element.

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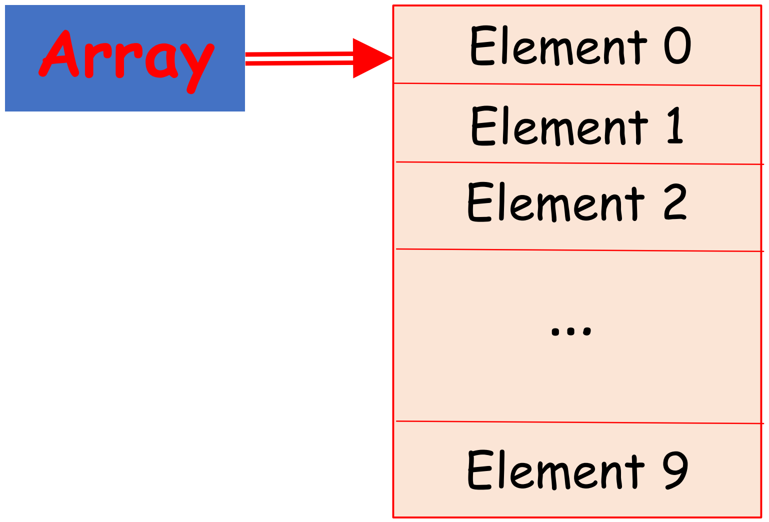

Arrays & Pointers

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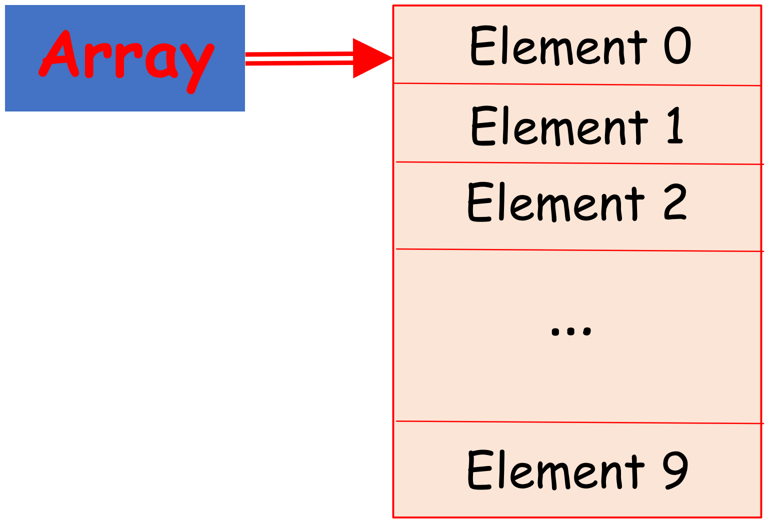

To be more precise, array name is a **constant pointer**

```
int Array[10];
```

```
const int* Array;
```

Arrays & Pointers

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int Array[10];
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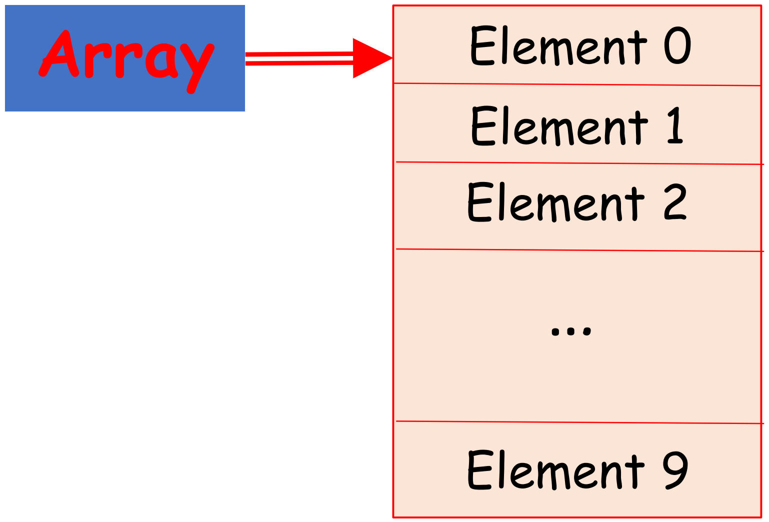


By definition, array name is treated as a **pointer** to the first array element.

To be more precise, array name is a ***constant* pointer**

```
int Array[10];   <->   const int* Array;
```

Therefore, these two constructs are semantically identical:

```
Array[0]
```

```
*Array
```

Do you see a problem here?

Arrays & Pointers

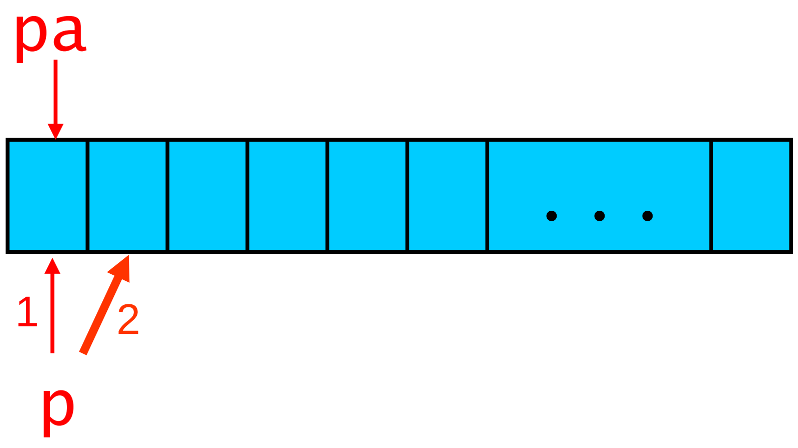
Operators on pointers: pointer arithmetic

```
pointer+i
pointer-i
pointer++
pointer--
ptr1-ptr2
```

```
int pa[10];
int* p = pa;   1

p++;           2
```

A question: Why pa++ is illegal?




```
T* p;
...
p+i;
```

The same as

$\boxed{(T*)((\texttt{char*})p + \texttt{sizeof}(T)*i)}$

The Program Example

Version 2

```
float* find2 ( float* array, int n, int x )
{
   const int* p = array;
   for ( int i = 0; i<n; i++ )
   {
       if ( *p == x ) return p;  // success
       p++;
   }
   return nullptr;  // fail
}
```

```
float A[20];
...
float* res = find2(A, 20, 5.5);
```