Fundamentals of Programming I

5 Structured Data Types

Grado en Ingeniería Informática

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Data Types

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Data Types

Classification of types

- ✓ Simple Data Types
  - Standard: `int`, `float`, `double`, `char`, `bool` ✓
    Predefined set of values
  - Declared by the user: *enumerated* types ✓
    Set of values defined by the Programmer
- ✓ Structured Data Types
  - Homogeneous collections: *arrays* ✓
    All the elements of the same type
  - Heterogeneous collections: *structures*
    Elements with different types

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Structured Data Types

Collections (agglomerated types)

Data grouping (several elements):

- ✓ All of the same type: *array* (*table*)
- ✓ Different types: *structure* (*register*, *tuple*)

Arrays (tables)

- ➢ Elements organized by position (index): 0, 1, 2, 3, ...
- ➢ Access by index: 0, 1, 2, 3, ...
- ➢ One or several dimensions

Structures (tuples, registers)

- ➢ Elements (*fields*) in any order
- ➢ Access by name

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Fundamentals of Programming I

Arrays Revisited

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Arrays

Sequential structure

Each element in a certain position (*index*):

- ✓ Indexes are positive integers
- ✓ The index of the first element is ALWAYS 0
- ✓ Indexes are incremented by one

sales	125.40	76.95	328.80	254.62	435.00	164.29	0.00
	0	1	2	3	4	5	6

Direct access

Each element is accessed by its index:

`sales[4]` accesses the 5th element (it contains the value `435.00`)

```
cout << sales[4];
sales[4] = 442.75;
```

[ ]

Data of the same base type:
Used like any other variable

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Array Types and Variables

Array type declaration

```
const int Dimension = ...;
typedef base_type tName[Dimension];
```

Example:

```
const int Days = 7;
typedef double tSales[Days];
```

Array types variable declaration: like any other variable

```
tSales sales;
```

Elements ARE NOT automatically initialized!

It's the programmer's responsibility to use valid indexes!

Arrays can't be copied directly ~~`array1 = array2`~~

They must be copied element by element

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Arrays and for Loops

Processing arrays...

- ✓ Traversals
- ✓ Searches
- ✓ Sorts

Etcetera...

Array traversal with for loop

Arrays: fixed size → Fixed number of repetition loop (for)

```
tSales sales;
double mean, total = 0;
...
for (int i = 0; i < Days; i++)
   total = total + sales[i];
mean = total / Days;
```

```
const int Days = 7;
typedef double tSales[Days];
```

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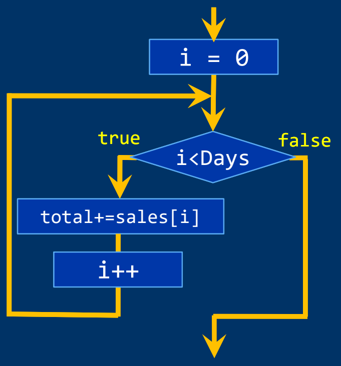
Arrays and for Loops

12.40	10.96	8.43	11.65	13.70	13.41	14.07
0	1	2	3	4	5	6

```
tSales sales;
double mean, total = 0;
...
for (int i = 0; i < Days; i++)
   total = total + sales[i];
```



...

Memory

Days	7
sales[0]	12.40
sales[1]	10.96
sales[2]	8.43
sales[3]	11.65
sales[4]	13.70
sales[5]	13.41
sales[6]	14.07
mean	?
total	84.62
i	7

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More About Arrays

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Array Initialization

Arrays can be initialized at declaration

Assign a value series to the array name:

```
const int DIM = 10;
typedef int tTable[DIM];
tTable t = { 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 };
```

Values are assigned in order:

```
t[0] t[1] t[2] t[3] t[4] ... t[9]
  ↑    ↑    ↑    ↑    ↑         ↑
  1st  2nd  3rd  4th  5th  ...  10th
```

If there are fewer values than elements, `0` is assigned to the rest

```
tTable t = { 0 }; // All the elements to 0
```

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Enumerated Types as Indexes

```
const int Colors = 3,
typedef enum { red, green, blue } tRGB;
typedef int tColor[Colors];
tColor color;
...
cout << "Amount of red (0-255): ";
cin >> color[red];
cout << "Amount of green (0-255): ";
cin >> color[green];
cout << "Amount of blue (0-255): ";
cin >> color[blue];
```

Remember that internally integers are used, starting with 0, for the different symbols of the enumerated type
red ≡ 0   green ≡ 1   blue ≡ 2

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Passing Arrays to Subprograms

Simulation of parameter passing by reference

Without using & in parameter declaration

Subprograms receive the array's memory address

```
const int Max = 10;
typedef int tTable[Max];
void initialize(tTable table); // Without &
```

Changes in array parameter are reflected in the argument

```
initialize(array);
```

If `initialize()` modifies any element of `table`, those elements of `array` are automatically modified

It is the same array!

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Passing Arrays to Subprograms

```
const int Dim = 10;
typedef int tTable[Dim];
void initialize(tTable table); // Without &

void initialize(tTable table) {
   for (int i = 0; i < Dim; i++)
      table[i] = i;
}
int main() {
   tTable array;
   initialize(array); // array is modified
   for (int i = 0; i < Dim; i++)
      cout << array[i] << " ";
   ...
```

```
0 1 2 3 4 5 6 7 8 9
```

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Passing Arrays to Subprograms

How to avoid changes in the array?

Using `const` modifier in parameter declaration:

`const tTable table` An array of constants

`void print(const tTable table);`

The argument will be treated as an array of constants

If in the subprogram there is any instruction that tries to modify any element in the array: *compilation error!*

```
void print(const tTable table) {
   for (int i = 0; i < Dim; i++)
      cout << table[i] << " ";
      // OK. It is accessed, but not modified
}
```

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List Implementation

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List Implementation with Arrays

Lists with a fixed number of elements

Array with the number of elements as the dimension

```
const int NUM = 100;
typedef double tList[NUM];
tList list; // Exactly 100 doubles
```

List traversal:

```
for (int i = 0; i < NUM; i++) {
   ...
```

Searching in the list:

```
while ((i < NUM) && !found) {
   ...
```

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List Implementation with Arrays

Lists with a variable number of elements

Array with the maximum number of elements + Element counter

```
const int MAX = 100;
typedef double tList[MAX];
tList list; // Up to 100 elements
int counter = 0;
```

Array and counter unbound? → Structures

List traversal:

```
for (int i = 0; i < counter; i++) {
   ...
```

Searching in the list:

```
while ((i < counter) && !found) {
   ...
```

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Fundamentals of Programming I

Character Strings

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Character Strings

Character arrays

String: character sequence of variable length

```
"Hello" "Bye" "Supercalifragilistic" "1234 56 7"
```

String variables: contain character sequences

Stored in character arrays: maximum length (dimension)

Not all the array elements are relevant:

✓ String length: number of characters, from the beginning, that actually constitute the string:

H	e	l	l	o																	
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21

Current length: 5

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Character Strings

String length

B	y	e																			
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21

Length: 3

S	u	p	e	r	c	a	l	i	f	r	a	g	i	l	i	s	t	i	c		
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21

Length: 20

We need to know where the relevant characters end:

✓ Keep string length as associated data

✓ Use a termination character at the end (*sentinel*)

B	y	e	\0							
0	1	2	3	4	5	6	7	8	9	10

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Character Strings

Character strings in C++

Two alternatives for string implementation:

- ✓ C style strings (*null terminated*)
- ✓ Type `string`

C style strings *Lesson Supplement*

- ✓ Arrays of type `char` with a maximum length
- ✓ Special character at the end: `'\0'`

Type `string`

- ✓ More sophisticated strings
- ✓ No maximum length (automatic memory management)
- ✓ Many utility subprograms (`string` Library)

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Fundamentals of Programming I

`string`-type Character Strings

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string-type Character Strings

string *Type*

- ✓ Assumes memory management responsibility
- ✓ Defines overloaded operators (i.e., + for appending)
- ✓ Safer and more efficient strings

`string` library

Requires using namespace `std`

- ✓ They are automatically initialized to an empty string
- ✓ They can be initialized at declaration
- ✓ They can be copied with the assignment operator
- ✓ They can be concatenated with + operator
- ✓ There are many utility routines

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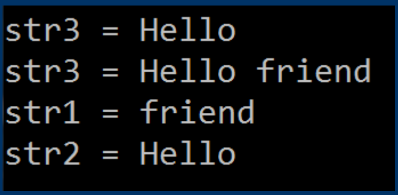
string-type Strings

string.cpp

```cpp
#include <iostream>
#include <string>
using namespace std;

int main() {
   string str1("Hello");   // initialization
   string str2 = "friend"; // initialization
   string str3;
   str3 = str1; // copy
   cout << "str3 = " << str3 << endl;
   str3 = str1 + " "; // concatenation
   str3 += str2;      // concatenation
   cout << "str3 = " << str3 << endl;
   str1.swap(str2);  // interchange
   cout << "str1 = " << str1 << endl;
   cout << "str2 = " << str2 << endl;

   return 0;
}
```



```
str3 = Hello
str3 = Hello friend
str1 = friend
str2 = Hello
```

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`string`-type Strings

Length of the string:

`str.length()` or `str.size()`

We can compare two strings with relational operators:

```
if (str1 <= str2) { ...
```

String character access:

- ✓ As a simple character array: *`str`*`[`*`i`*`]`
  No access control for invalid array indexes
  To be used only with indexes absolutely known to be valid
- ✓ Function `at(`*`index`*`)`: *`str`*`.at(`*`i`*`)`
  Execution error if an inexistent position is tried to be accessed

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I/O with `string`-type Strings

- ✓ Displayed on the screen with `cout <<`
- ✓ Input with `cin >>` Skips leading blank space
  Input ends with next blank space (incl. Enter)
- ✓ To discard the rest of characters in the buffer:
  `cin.sync();` or `cin.ignore()`
- ✓ Input including blank spaces:
  `getline(cin,` *`string`*`)`
  Assigns to the *`string`* characters read until the end of the line
  If input is pending at Enter, then an empty string will be read
- ✓ Reading from text files:
  Same as with console; `sync()` has no effect
  `file >> str` `getline(file, str)`

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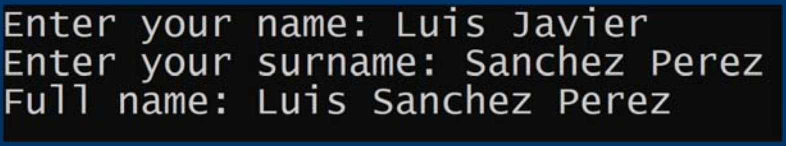
I/O with `string`-type Strings

string2.cpp

```
#include <iostream>
#include <string>
using namespace std;

int main() {
   string name, surname;
   cout << "Enter your name: ";
   cin >> name; // Input ends with the first space or Enter
   cout << "Enter your surname: ";
   cin.sync();
   getline(cin, surname); // Input ends with Enter
   cout << "Full name: " << name << " " << surname << endl;

   return 0;
}
```



```
Enter your name: Luis Javier
Enter your surname: Sanchez Perez
Full name: Luis Sanchez Perez
```

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Operations with `string`-type Strings

✓ *`str.substr(position, length)`*
Substring of *length* characters from *position* (starting at 0)

```
string str = "abcdefg";
cout << str.substr(2, 3); // Prints cde
```

✓ *`str.find(substring)`*
Position of first occurrence of *substring* in *str*

```
string str = "Olala";
cout << str.find("la"); // Prints 1
```

(Remember that character array indexes start at 0)

✓ *`str.rfind(substring)`*
Position of last occurrence of *substring* in *str*

```
string str = "Olala";
cout << str.rfind("la"); // Prints 3
```

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Operations with `string`-type Strings

- ✓ *`str.erase(from, num)`*
  Erases *num* characters from position *from*

```
string str = "abcdefgh";
str.erase(3, 4); // str now contains "abch"
```

- ✓ *`str.insert(where, str2)`*
  Inserts *str2* in position *where*

```
string str = "abcdefgh";
str.insert(3, "123"); // str now contains "abc123defgh"
```

http://www.cplusplus.com/reference/string/string/

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Fundamentals of Programming I

Structures

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Structures

Heterogeneous collections (tuples, registers)

Elements of (possibly) different types: *fields*

Fields identified by name

Related information that can be managed as a unit

Each element is accessed with its name (`.` operator)

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Structure Types

```
struct tType { // type name: after struct!
   ... // field declaration (like variables)
};
```

In the last revision of the C++ language, `typedef` is not used with `struct`

```
struct tPerson {
   string name;
   string surname;
   int age;
   string nif;
};
```

Fields: Any known type (standard or previously declared)

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Structure Variables

```
tPerson person;
```

Variables of type `tPerson` contain four data (fields):

```
name     surname      age      nif
```

Access to fields with dot operator (`.`):

```
  person.name // a string
  person.surname // a string
  person.age    // an integer
  person.nif // a string
```

We can copy two structures directly:

```
tPerson person1, person2;
...
person2 = person1;
```

All fields are copied (*even if they are arrays!*)

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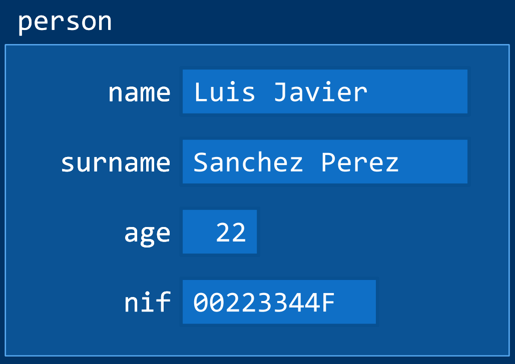
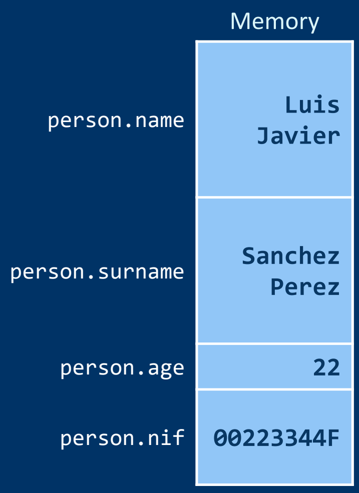
Heterogeneous Data Groupings

```
struct tPerson {
   string name;
   string surname;
   int age;
   string nif;
};
tPerson person;
```





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Elements in any Order

```
struct tPerson {
   string name;
   string surname;
   int age;
   string nif;
};
tPerson person;
```

Fields are not arranged in a specific order

Direct access with field name (operator `.`)

Each field can be used like any other variable of its type

Initial values for the fields:

```
struct tPerson {
   string name;
   string surname;
   int age = 0;
   string nif;
};
```

Each time a `tPerson` is created the field `age` gets the value `0`

Structures are passed by value (without &) or by reference (with &) to subprograms

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Structures Within Structures

```
struct tNif {                    struct tPerson {
   string dni;                      ...
   char letter;                     tNif nif;
};                               };
```

```
tPerson person;
```

Access to entire NIF:

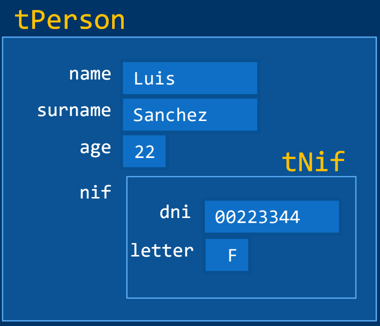
```
person.nif // Another structure
```

Access to NIF's letter:

```
person.nif.letter
```

Access to DNI:

```
person.nif.dni
```



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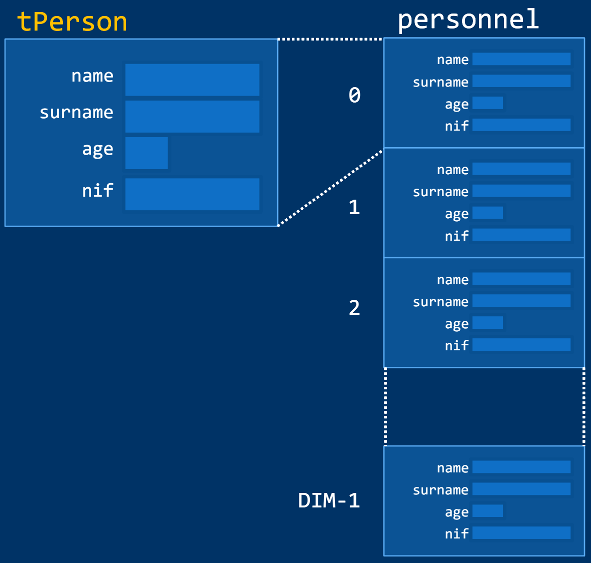
Arrays of Structures

```
struct tPerson {
   string name;
   string surname;
   int age;
   string nif;
};
const int DIM = 100;
typedef tPerson tArray[DIM];
tArray personnel;
```

Name of the third person:
`personnel[2].name`

Age of the twelfth person:
`personnel[11].age`

NIF of the first person:
`personnel[0].nif`



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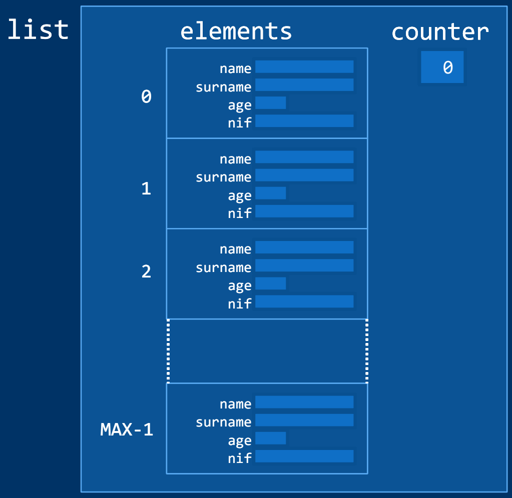
Arrays Within Structures

```
const int MAX = 100;
struct tPerson {
   string name;
   string surname;
   int age;
   string nif;
};
typedef tPerson tArray[MAX];
struct tList {
   tArray elements;
   int counter = 0;
};
tList list;
```

Name of the third person: `list.elements[2].name`

Age of the twelfth person: `list.elements[11].age`

NIF of the first person: `list.elements[0].nif`



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Fundamentals of Programming I

Variable Length Lists

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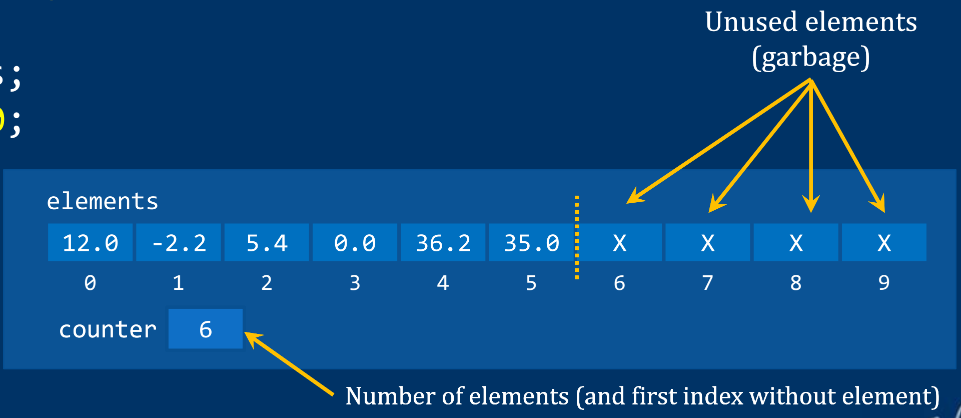
Variable Length Lists

Structure grouping the array and the counter:

```
const int MAX = 10;
typedef double tArray[MAX];
struct tList {
   tArray elements;
   int counter = 0;
};
```


Unused elements (garbage)
elements
12.0
-2.2
5.4
0.0
36.2
35.0
X
X
X
X
0
1
2
3
4
5
6
7
8
9
counter
6
Number of elements (and first index without element)

Main operations: element insertion and deletion

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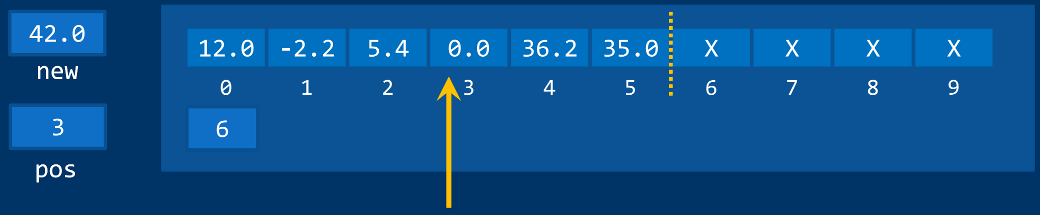
Element Insertion

Inserting a new element in a certain position

Valid positions: 0 to `counter`



Make sure there is place for more elements (counter < maximum)

3 step operation:

1.- Make room for the new element (from the position)

2.- Place new element in the position

3.- Increase counter by one

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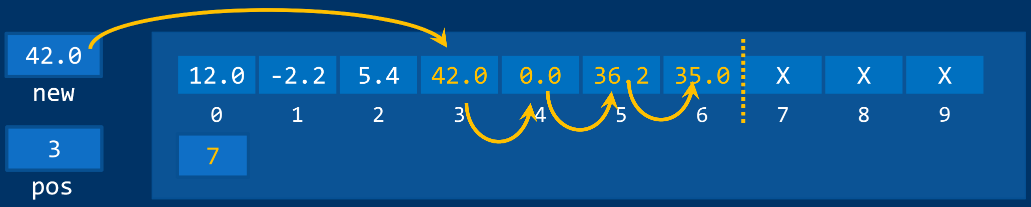
Element Insertion

```
if (list.counter < MAX) {
   // Make room...
   for (int i = list.counter; i > pos; i--)
      list.elements[i] = list.elements[i - 1];
   // Insert and increment counter
   list.elements[pos] = newElement;
   list.counter++;
}
```



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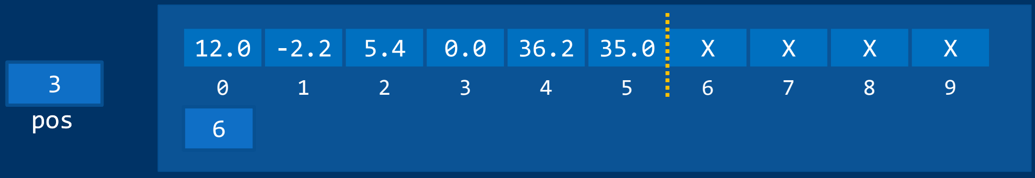
Element Deletion

Deleting the element in a certain position

Valid positions: 0 to counter-1



Shift one position to the left of next one and decrease counter by one:

```
for (int i = pos; i < list.counter - 1 ; i++)
   list.elements[i] = list.elements[i + 1];
list.counter--;
```

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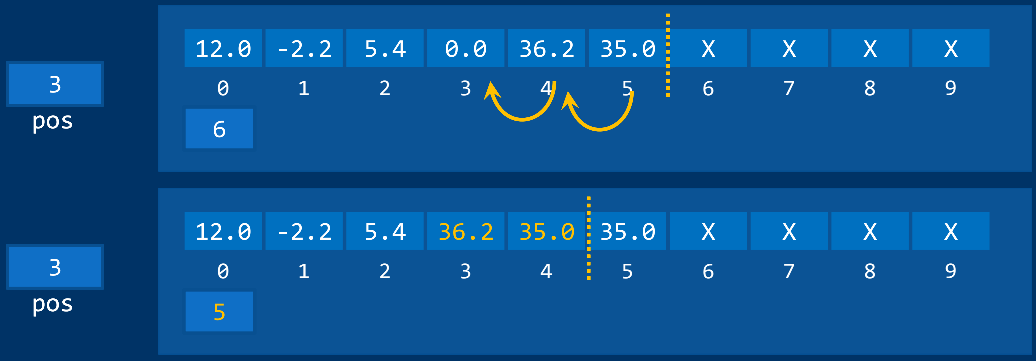
Element Deletion

```
for (int i = pos; i < list.counter - 1 ; i++)
   list.elements[i] = list.elements[i + 1];
list.counter--;
```



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A Complete Example

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Variable Length List Example

Description

Program to manage a list with the students in a class

For each student: name, surname, age, NIF and grade

- ✓ The total number of students is not known (up to 100)
- ✓ List information is maintained in a file `class.txt`

  It will be loaded at the beginning and saved at the end
- ✓ The program should offer these actions to the user:
  - — Add a new student
  - — Delete an existing student
  - — Grade all the students
  - — Get a listing with grades, identifying the highest and displaying the average

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Variable Length List Example

db.cpp

```
#include <iostream>
#include <string>
#include <fstream>
#include <iomanip>
using namespace std;

const int MAX = 100;
struct tStudent {
   string name;
   string surname;
   int age;
   string nif;
   double grade;
};
```

```
typedef tStudent tArray[MAX];
struct tList {
   tArray elements;
   int counter = 0;
};
```

The list counter is automatically initialized to 0!

Global constants and types after the libraries

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Variable Length List Example

```
// Prototypes
int menu(); // Program menu – Returns chosen (valid) option
void load(tList &list, bool &ok); // Loads the info in the file into the list
void save(const tList &list); // Saves the list in the file
void readStudent(tStudent &student); // Reads info for one student
void insertStudent(tList &list, tStudent student, bool &ok);
// Inserts a new student in the list
void deleteStudent(tList &list, int pos, bool &ok);
// Deletes the student in that position
string fullName(tStudent student); // name, space and surname
void goGrade(tList &list); // Grade the students
double classMean(const tList &list); // Average grade
int highestGrade(const tList &list); // Index of student with highest grade
void printStudent(tStudent student);
void listing(const tList &list, double mean, int highest); // Class listing
```

Prototypes after global declarations

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Fundamentals of Programming I

do-while Loop

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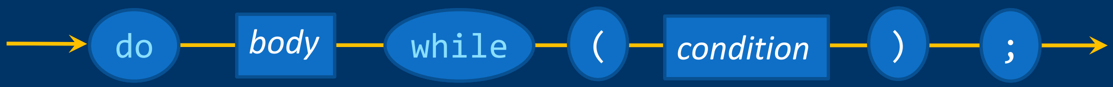
Another C++ Indeterminate Loop

do..while *Loop*

`do` *body* `while (`*condition*`);`

Condition at loop's end



```
int i = 1;
do {
   cout << i << endl;
   i++;
} while (i <= 100);
```

body is always executed at least once

body is a code block

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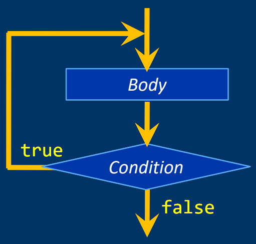
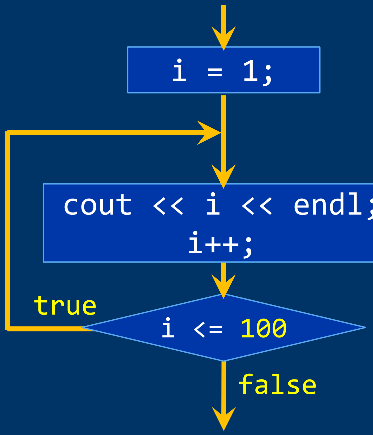
do-while Loop Execution

```
int i = 1;
do {
   cout << i << endl;
   i++;
} while (i <= 100);
```

Body
is executed
at least once





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while *versus* do-while

Does the loop's body have to be executed at least one time?

```
cin >> d; // First reading
while (d != 0) {
   sum = sum + d;
   count++;
   cin >> d;
}
```

```
do {
   cin >> d;
   if (d != 0) { // Final?
      sum = sum + d;
      count++;
   }
} while (d != 0);
```

```
cout << "Option: ";
cin >> op; // First reading
while ((op < 0) || (op > 4)) {
   cout << "Option: ";
   cin >> op;
}
```

```
do { // Simpler
   cout << "Option: ";
   cin >> op;
} while ((op < 0) || (op > 4));
```

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Program Menu with do-while

```
int menu() {
   int op;

   do {
      cout << "1 - Add a new student" << endl;
      cout << "2 - Delete a student" << endl;
      cout << "3 - Grade students" << endl;
      cout << "4 - Class listing" << endl;
      cout << "0 - Exit" << endl;
      cout << "Option: ";
      cin >> op;
   } while ((op < 0) || (op > 4));

   return op;
}
```

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Variable Length List Example

The file `class.txt`

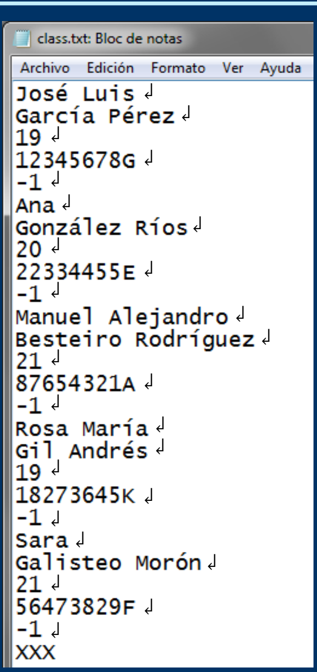
One piece of data in each line

For each student:

- ✓ Name (string)
- ✓ Surname (string)
- ✓ Age (integer)
- ✓ NIF (string)
- ✓ Grade (real number; -1 if not graded)

Ends with XXX as name

The file is supposed to be correct



```
José Luis
García Pérez
19
12345678G
-1
Ana
González Ríos
20
22334455E
-1
Manuel Alejandro
Besteiro Rodríguez
21
87654321A
-1
Rosa María
Gil Andrés
19
18273645K
-1
Sara
Galisteo Morón
21
56473829F
-1
XXX
```

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Variable Length List Example

Reading student information

Name and surname: There may be several words → `getline()`

Age → Extractor (>>)

NIF: One word → Extractor (>>)

Grade → Extractor (>>)

The Enter after the grade number keeps pending
We should skip (read and discard) that character with `get()`
If not so, the next name read will get an empty string (Enter)

Don't read directly in the list:
~~`getline(file, list.elements[list.counter].name);`~~
Read in a temporary variable of type `tStudent`

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Loading the List from the File `class.txt`

```
void load(tList &list, bool &ok) {
   tStudent student; // Temporary variable to read in
   ifstream file;
   char aux;
   file.open("class.txt");
   if (!file.is_open())
      ok = false;
   else {
      ok = true;
      getline(file, student.name); // Reads the first name
      while ((student.name != "XXX") && (list.counter < MAX)) {
         getline(file, student.surname);
         file >> student.age >> student.nif >> student.grade;
         file.get(aux); // Skips Enter
         list.elements[list.counter] = student; // At the end
         list.counter++;
         getline(file, student.name); // Next name
      } // If more than MAX students, we ignore the rest
      file.close();
   }
}
```

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Saving the List in the File class.txt

One piece of data in each line (name, surname, age, NIF, grade):

```
void save(const tList &list) {
   ofstream file;
   file.open("class.txt");
   for (int i = 0; i < list.counter; i++) {
      file << list.elements[i].name << endl;
      file << list.elements[i].surname << endl;
      file << list.elements[i].age << endl;
      file << list.elements[i].nif << endl;
      file << list.elements[i].grade << endl;
   }
   file << "XXX" << endl; // Final sentinel
   file.close();
}
```

`const tList &list` → Constant reference
Passed by reference but as a constant ≡ Passed by value
Avoids copying the argument into the parameter (big structures)

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Reading Student Data from the Keyboard

```
void readStudent(tStudent &student) {
   cin.sync(); // Discards any pending input
   cout << "Name: ";
   getline(cin, student.name);
   cout << "Surname: ";
   getline(cin, student.surname);
   cout << "Age: ";
   cin >> student.age;
   cout << "NIF: ";
   cin >> student.nif;
   student.grade = -1; // No grade yet
   cin.sync(); // Discards any pending input
}
```

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Inserting a New Student

```
void insertStudent(tList &list, tStudent student, bool &ok) {
   ok = true;
   if (list.counter == MAX)
      ok = false;
   else {
      list.elements[list.counter] = student;
      // Inserts at the end
      list.counter++;
   }
}
```

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Deleting a Student

```
void deleteStudent(tList &list, int pos, bool &ok) {
// Expects the element index in pos
   if ((pos < 0) || (pos > list.counter - 1))
      ok = false; // Inexistent element
   else {
      ok = true;
      for (int i = pos; i < list.counter - 1; i++)
         list.elements[i] = list.elements[i + 1];
      list.counter--;
   }
}
```

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Grading the Students

```
string fullName(tStudent student) {
   return student.name + " " + student.surname;
}

void goGrade(tList &list) {
   for (int i = 0; i < list.counter; i++) {
      cout << "Grade for the student "
         << fullName(list.elements[i]) << ": ";
      cin >> list.elements[i].grade;
   }
}
```

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More subprograms

```
double classMean(const tList &list) {
   double total = 0.0;
   for (int i = 0; i < list.counter; i++)
      total = total + list.elements[i].grade;
   return total / list.counter;
}

int highestGrade(const tList &list) {
   double max = 0;
   int pos = 0;
   for (int i = 0; i < list.counter; i++)
      if (list.elements[i].grade > max) {
         max = list.elements[i].grade;
         pos = i;
      }
   return pos;
}
```

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The Listing

```
void printStudent(tStudent student) {
   cout << setw(38) << left << fullName(student) << student.nif << " "
        << setw(2) << right << student.age << " " << fixed
        << setprecision(1) << student.grade;
}

void listing(const tList &list, double mean, int highest) {
   for (int i = 0; i < list.counter; i++) {
      cout << setw(3) << right << i + 1 << ": ";
      printStudent(list.elements[i]);
      if (i == highest)
         cout << " <<< Highest grade!";
      cout << endl;
   }
   cout << "Class average grade: " << fixed
        << setprecision(1) << mean << endl << endl;
}
```

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The Main Program

```
int main() {
   tList list;
   tStudent student;
   bool success;
   int op, pos;

   load(list, success);
   if (!success)
      cout << "Couldn't open the file!" << endl;
   else {
      do { // do loop doesn't need to have read the first option
         op = menu();
         switch (op) {
         case 1:
            readStudent(student);
            insertStudent(list, student, success);
            if (!success)
                  cout << "List full: Impossible to insert!" << endl;
            break;
```

.../...

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The Main Program

```
         case 2:
            cout << "Position: ";
            cin >> pos;
            deleteStudent(list, pos - 1, success);
            if (!success)
               cout << "Inexistent element!" << endl;
            break;
         case 3:
            goGrade(list);
            break;
         case 4:
            listing(list, classMean(list), highestGrade(list));
         }
      } while (op != 0);
      save(list);
   }
   return 0;
}
```

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