

EDAF30 – Programming in C++

2. Introduction. More on function calls and types.

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2022



Outline

- 1 Function calls and parameter passing
- 2 Pointers, arrays, and references
 - Pointers: Syntax and semantics
 - References
 - Arrays
- 3 The standard library alternatives to C-style arrays
 - `std::string`
 - `std::vector`
- 4 User defined types
 - Structures
 - Classes
- 5 I/O

Functions

Function calls

The semantics of function argument passing is the same as copy initialization: (*Same as for primitive types in Java*)

- ▶ In a function call, the *values of the arguments* are
 - ▶ type checked, and
 - ▶ with implicit type conversion (if needed)
 - ▶ copied to the function parameters

- ▶ Example: with a function `double square(double d)`

```
double s2 = square(2);           // 2 is converted to double
                                   // double d = 2;

double s3 = square("three");    // error
                                   // double d = "three";
```

Functions

Function overloading

- ▶ Overloading (“överlagring”)

```
void print(int);  
void print(double);  
void print(std::string, int);
```

- ▶ Cannot differ only in return type
- ▶ Must not be ambiguous

```
void user()  
{  
    print(42);           // calls print(int);  
    print(1.23);        // calls print(double);  
    print(4.5f);        // calls print(double);  
    print("Hello", 17) // calls print(std::string, int);  
}
```

- ▶ Default arguments (sometimes) similar to overloading

- ▶ `void print(int x, int max_width=20);`
- ▶ The rules are complex. *Only use for trivial cases*
- ▶ Risk of ambiguity if combined with overloading

Functions

Call - ambiguity

- ▶ With overloaded functions, the compiler selects “the best” function (after implicit type conversion)
- ▶ If two alternatives are “equally good matches ” it is an error

```
void print2(int, double);
void print2(double, int);

void user()
{
    print2(0, 0);    // Error! ambiguous
}
```

- ▶ and also (with print() from last slide)

```
void print(int);
void print(double);

long l = 17;
print(l);           // Error! print(int) or print(double)?
```

Functions

Rule of thumb

Factor your code into small functions to

- ▶ give names to activities and document their dependencies
- ▶ avoid writing specific code in the middle of other code
- ▶ facilitate testing
- ▶ A function should perform a single task
- ▶ Keep functions as short as possible
- ▶ Rule of thumb
 - ▶ Max 24 lines
 - ▶ Max 80 columns
 - ▶ Max 3 block levels
 - ▶ Max 5–10 local variables
 - ▶ Inversely proportional to complexity

Call by value and call by reference

Call by value(*värdeanrop*)

In a 'normal' function call, the values of the arguments are copied to the formal parameters (which are local variables)

Example: swap two integer values

```
void swap(int a, int b)
{
    int tmp=a;
    a = b;
    b = tmp;
}
```

... and use:

```
int x = 2;
int y = 10;
```

```
swap(x, y);
```

```
cout << x " ", " << y << endl;
```

2,10 x and y are not changed

Call by value and call by reference

Call by reference(*referensanrop*)

Use *call by reference* instead of *call by value*:

Example: swap two integer values

```
void swap(int& a, int& b)
{
    int tmp=a;
    a = b;
    b = tmp;
} ...and use:
int x = 2; int y = 10;

swap(x, y);
```

Here, *references* to the arguments are used , and the values are actually swapped.

References

- ▶ A reference is *an alias* for a variable

The call `swap(x,15);` gives the error message

```
invalid initialization of non-const reference of type "int&"  
from an rvalue of type 'int'
```

NB! The argument for a reference parameter must be an *lvalue*

Data types

Pointers, Arrays and References

- ▶ References
- ▶ Pointers (similar to Java references)
- ▶ Arrays (“built-in arrays”). Similar to Java arrays of primitive types

Pointers

Similar to references in Java, but

- ▶ a pointer is the *memory address of an object*
- ▶ a pointer *is an object* (a C++ reference is not)
 - ▶ can be assigned and copied
 - ▶ has an address
 - ▶ can be declared without initialization, but then it gets an *undefined value*, as do other variables
- ▶ four possible states
 - 1 point to an object
 - 2 point to the address immediately past the end of an object
 - 3 point to nothing: `nullptr`. Before C++11: `NULL`
 - 4 invalid
- ▶ can be used as an integer value
 - ▶ arithmetic, comparisons, etc.

Be very careful!

Pointers

Syntax, operators * and &

► In a *declaration*:

- prefix *: “pointer to”

`int *p;` : p is *a pointer to an int*

`void swap(int*, int*);` : *function taking two pointers*

- prefix &: “reference to”

`int &r;` : r is *a reference to an int*

► In an *expression*:

- prefix *: dereference, “contents of” (*pointer* → *object*)

`*p = 17;` *the object that p points to* is assigned 17

- prefix &: “address of”, “pointer to” (*object* → *pointer*)

```
int x = 17;
```

```
int y = 42;
```

`swap(&x, &y);` Call `swap(int*, int*)` with *pointers to x and y*

Pointers

Be careful with declarations

Advice: One declaration per line

```
int *a;      // pointer to int
int* b;     // pointer to int
int c;      // int

int* d, e;  // d is a pointer, e is an int
int* f, *g; // f and g are both pointers
```

*Choose a style, either `int *a` or `int* b`, and be consistent.*

References are similar to pointers, but

- ▶ A reference is *an alias to* a variable
 - ▶ must be initialized
 - ▶ cannot be changed (*reseated* to refer to another variable)
 - ▶ is not an object (has no address)
- ▶ Dereferencing does not use the operator `*`
 - ▶ Using a reference *is* to use the referenced object.

Use a reference if you don't have (a good reason) to use a pointer.

- ▶ E.g., if it may have the value `nullptr` (“no object”)
- ▶ or if you need to change (“reseat”) the pointer
- ▶ More on this later.

Pointers and references

Call by pointer

In some cases, a *pointer* is used instead of a *reference* to “call by reference:

Example: swap two integers

```
void swap2(int* a, int* b)
{
    if(a != nullptr && b != nullptr) {
        int tmp=*a;
        *a = *b;
        *b = tmp;
    }
} ... and use:           int x, y;
                        ...
                        swap2(&x, &y);
```

NB!:

- ▶ a pointer can be `nullptr` or uninitialized
- ▶ dereferencing such a pointer gives *undefined behaviour*

Pointers and references

Pointer and reference versions of swap

```
// References
void swap(int& a, int& b)
{
    int tmp = a;
    a = b;
    b = tmp;
}
```

```
// Pointers
void swap(int* pa, int* pb)
{
    if(pa != nullptr && pb != nullptr) {
        int tmp = *pa;
        *pa = *pb;
        *pb = tmp;
    }
}
```

```
int m=3, n=4;
swap(m,n); Reference version is called
```

```
swap(&m,&n); Pointer version is called
```

NB! Pointers are *called by value*: the address is copied

Arrays (“C-arrays”, “*built-in arrays*”)

- ▶ A sequence of values of the same type (homogeneous sequence)
- ▶ Similar to Java for primitive types
 - ▶ but *no safety net* – difference from Java
 - ▶ an array does not know its size – the programmer’s responsibility
- ▶ *Can contain elements of any type*
 - ▶ Java arrays *can only contain references* (or primitive types)
- ▶ Can be a local (or member) variable (Difference from Java)
- ▶ Is declared `T a[size];` (Difference from Java)
 - ▶ The size must be *a (compile-time) constant*. (Different from C99 which has VLAs)

Arrays

Representation in memory

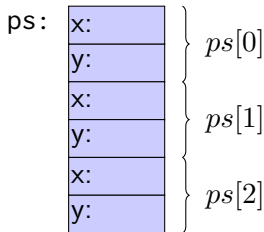
The elements of an array can be of any type

- ▶ Java: only primitive types or a reference to an object
- ▶ C++: an object or a pointer

Example: array of Point

```
class Point{  
    signed char x;  
    signed char y;  
};
```

```
Point ps[3];
```



Important difference from Java: no fundamental difference between built-in and user defined types.

Data types

C strings

- ▶ C strings are `char[]` that are *null terminated*.

Example: `char s[6] = "Hello";`

s:

'H'	'e'	'l'	'l'	'o'	'\0'
-----	-----	-----	-----	-----	------

NB! A *string literal* is a C-style string (not a `std::string`)

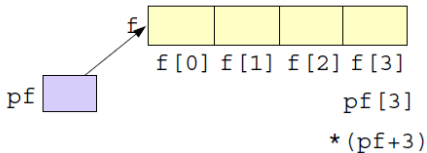
The type of `"Hello"` is `const char[6]`.

Pointers and arrays

Arrays are accessed through pointers

```
float f[4];           // 4 floats
float* pf;           // pointer to float

pf = f;              // same as = &f[0]
float x = *(pf+3);   // Alt. x = pf[3];
x = pf[3];           // Alt. x = *(pf+3);
```



Pointers and arrays

What does array indexing really mean?

The expression `a[b]` is equivalent to `*(a + b)` (and, thus, to `b[a]`)

Definition

For a pointer, `T* p`, and an integer `i`, the expression `p + i` is defined as `p + i * sizeof(T)`

That is,

- ▶ `p+1` points to the address after the object pointed to by `p`
- ▶ `p+i` is an address *`i` objects of type `T` after `p`*.

Example: confusing code (Don't do this)

```
int a[] {1,4,5,7,9};  
  
cout << a[2] << " == " << 2[a] << endl;  
5 == 5
```

Pointers and arrays

Function calls

Function for zeroing an array

```
void zero(int* x, size_t n) {  
    for (int* p=x; p != x+n; ++p)  
        *p = 0;  
}
```

```
...  
int a[5];
```

```
zero(a,5);
```

- ▶ *The name of an array variable* in an expression is interpreted as “*a pointer to the first element*”:
array decay
- ▶ $a \Leftrightarrow \&a[0]$
- ▶ arrays cannot be copied (passed by value)

Array subscripting

```
void zero(int x[], size_t n) {  
    for (size_t i=0; i != n; ++i)  
        x[i] = 0;  
}
```

- ▶ In function parameters $T\ a[]$ is equivalent to $T^*\ a$. (Syntactic sugar)
- ▶ T^* is more common

- ▶ An array is passed as *a pointer and a size*.

Two types from the standard library

Alternatives to C-style arrays

Do not use built-in arrays unless you have (a strong reason) to.
Instead of

- ▶ `char[]` – Strings – use `std::string`
- ▶ `T[]` – Sequences – use `std::vector<T>`

More like in Java:

- ▶ more functionality – *“behaves like a built-in type”*
- ▶ safety net

Strings: `std::string`

`std::string` has operations for

- ▶ assigning
- ▶ copying
- ▶ concatenation
- ▶ comparison
- ▶ input and output (`<<` `>>`)

and

- ▶ knows its size

Similar to `java.lang.String` *but is mutable*.

Sequences: `std::vector<T>`

A `std::vector<T>` is

- ▶ an ordered collection of objects (of the same type, `T`)
- ▶ every element has an index

which, in contrast to a built-in array

- ▶ knows its size
 - ▶ `vector<T>::operator[]` does no bounds checking
 - ▶ `vector<T>::at(size_type)` throws `out_of_range`
- ▶ can grow (and shrink)
- ▶ can be assigned, compared, etc.

Similar to `java.util.ArrayList`

Is a *class template*

Example: `std::string`

```
#include <iostream>
#include <string>
using std::string;
using std::cout;
using std::endl;

string make_email(string fname,
                  string lname,
                  const string& domain)
{
    fname[0] = toupper(fname[0]);
    lname[0] = toupper(lname[0]);
    return fname + '.' + lname + '@' + domain;
}

void test_string()
{
    string sr = make_email("sven", "robertz", "cs.lth.se");

    cout << sr << endl;
}
```

`Sven.Robertz@cs.lth.se`

Example: `std::vector<int>` initialisation

```
void print_vec(const std::string& s, const std::vector<int>& v)
{
    std::cout << s << " : " ;
    for(int e : v) {
        std::cout << e << " ";
    }
    std::cout << std::endl;
}

void test_vector_init()
{
    std::vector<int> x(7);
    print_vec("x", x);

    std::vector<int> y(7,5);
    print_vec("y", y);

    std::vector<int> z{1,2,3};
    print_vec("z", z);
}
```

x: 0 0 0 0 0 0 0

y: 5 5 5 5 5 5 5

z: 1 2 3

Example: `std::vector<int>` assignment

```
void test_vector_assign()
{
    std::vector<int> x {1,2,3,4,5};
    print_vec("x", x);
    std::vector<int> y {10,20,30,40,50};
    print_vec("y", y);
    std::vector<int> z;
    print_vec("z", z);
    z = {1,2,3,4,5,6,7,8,9};
    print_vec("z", z);
    z = x;
    print_vec("z", z);
}
```

x : 1 2 3 4 5

y : 10 20 30 40 50

z :

z : 1 2 3 4 5 6 7 8 9

z : 1 2 3 4 5

Example: `std::vector<int>` insertion and comparison

```
void test_vector_eq()
{
    std::vector<int> x {1,2,3};
    std::vector<int> y;
    y.push_back(1);
    y.push_back(2);
    y.push_back(3);

    if(x == y) {
        std::cout << "equal" << std::endl;
    } else {
        std::cout << "not equal" << std::endl;
    }
}
```

equal

User defined types

- ▶ Built-in types (e.g., `char`, `int`, `double`, pointers, ...) and operations
 - ▶ Rich, but deliberately low-level
 - ▶ Directly and efficiently reflect the capabilities of conventional computer hardware
- ▶ User-defined types
 - ▶ Built using the *built-in types* and *abstraction mechanisms*
 - ▶ `struct`, `class` (cf. `class` in Java)
 - ▶ Examples from the standard library
 - ▶ `std::string` (cf. `java.lang.String`)
 - ▶ `std::vector`, `std::list` ... (cf. corresponding class in `java.util`)
 - ▶ `enum class`: enumeration (cf. `enum` in Java)
- ▶ A *concrete type* can behave “just like a built-in type”.

Structures

The first step in building a new type is to organize the elements it needs into a data structure, a *struct*.

Exempel: Person

```
struct Person{
    string first_name;
    string last_name;
};
```

A variable of the type Person is created with

```
Person p;
```

but now *the member variables* have *default initialized values*.

NB! that sometimes means *undefined*

More on object initialization later.

Structures

Initialization

A function for initializing a Person:

```
void init_person(Person& p, const string& fn, const string& ln)
{
    p.first_name = fn;
    p.last_name = ln;
}
```

A variable of type Person, can be created and initialized with

```
Person sven;
init_person(sven, "Sven", "Robertz");
```

► call by reference: the object sven is changed

Use:

```
std::cout << sven.first_name << " " << sven.last_name << '\n'.
```


Structures

Use

Now we can use our type Person:

```
#include <iostream>
Person read_person()
{
    cout << "Enter first name:" << endl;
    string fn;
    cin >> fn;

    cout << "Enter last name:" << endl;
    string ln;
    cin >> ln;

    Person p;
    init_person(p, fn, ln);
    return p;
}
```

- ▶ `>>` is *the input operator*
- ▶ the standard library `<iostream>`
- ▶ `std::cin` is *standard input*

Make a type behave like a built-in type

- ▶ Tight coupling of data and operations
- ▶ Often make the representation inaccessible to users

A class has

- ▶ data members (“attributes”)
- ▶ member functions (“methods”)
- ▶ members can be
 - ▶ **public**
 - ▶ **private**
 - ▶ **protected**
 - ▶ like in Java

Classes

Example

```
class Person{
public:
    Person(string fn, string ln) : first_name{fn}, last_name{ln} {}
    string get_name();
    string get_initials();
private:
    string first_name;
    string last_name;
};
```

▶ *constructor*, like in Java

- ▶ Creates an object and *initializes members*

- ▶ the statements `Person sven;`
`init_person(sven, "Sven", "Robertz");`

become `Person sven("Sven", "Robertz");`

class and struct are (mostly) synonyms in C++.

Classes

Example

```
Person read_person()
{
    cout << "Enter first name:" << endl;
    string fn;
    cin >> fn;
    cout << "Enter last name:" << endl;
    string ln;
    cin >> ln;
    return Person(fn, ln);
}

void test_read()
{
    Person p = read_person();
    cout << p.get_initials() << " : " << p.get_name() << endl;
}
```

Class definitions

Declarations and definitions of member functions

Member functions (\Leftrightarrow methods in Java)

Definition of a class

```
class Foo {  
public:  
    int fun(int, int);    // Declaration of member function  
  
    int times_two(int x) {return 2*x;} // ... incl definition  
};
```

NB! Semicolon after class

Definition of member function (outside the class)

```
int Foo::fun(int x, int y) {  
    // ...  
}
```

No semicolon after function

File structure for classes

- ▶ The class definition is put in a header file (.h or .hpp)
- ▶ To avoid defining a class more than once, use *include guards*:

```
#ifndef FOO_H
#define FOO_H
//...
class Foo {
//...
};
#endif
```

- ▶ Member function definitions are put in a source file (.cc)

- ▶ The C++ standard library contains facilities for
 - ▶ Structured I/O (“formatted I/O”)
 - ▶ reading values of a certain type, T
 - ▶ overload **operator**>>(istream&, T&) and
 - ▶ **operator**<<(ostream&, **const** T&)
 - ▶ Character I/O (“raw I/O”)
 - ▶ istream& getline(istream&, string&)
 - ▶ istream& istream::getline(**char***, streamsize)
 - ▶ **int** istream::get()
 - ▶ istream& istream::ignore()
 - ▶ ...
- ▶ NB! getline() as free function and member of istream.
- ▶ std::getline() has an overload for using another delimiter than newline.
- ▶ Choose raw or formatted I/O based on your application

Variables

Automatic type inference

auto: The compiler deduces the type from the initialization.

Declaration and initialization

```
auto x = 7;           // int x
auto c = 'c';        // char c
auto b = true;      // bool b
auto d = 7.8;        // double d

std::vector<int> v;
auto it = v.begin(); // std::vector<int>::iterator it

double calc_epsilon();
auto ep = static_cast<float>(calc_epsilon()); // float ep
```

In `float ep = calc_epsilon();` the narrowing is not obvious NB!
with **auto** there is no risk of narrowing type conversion, so using = is safe.

Exception to 'almost always auto'

Don't use `auto` if you need to be explicit about the declared type:

- ▶ if naming the type makes the code more readable.
- ▶ to specify the value range or precision
(e.g., `int/ long` OR `float/ double`)

But that can also be achieved by using a cast to fix the type.

Data types

Two kinds of constants

- ▶ A variable declared `const` must not be changed (`final` in Java)
 - ▶ Roughly: "I promise not to change this variable."
 - ▶ Is checked by the compiler
 - ▶ Use when specifying function interfaces
 - ▶ A function that does not change its (reference) argument
 - ▶ A member function ("method") that does not change the state of the object.
 - ▶ Important for function overloading
 - ▶ `T` and `const T` are different types
 - ▶ One can overload `int f(T&)` and `int f(const T&)` (for some type `T`)
- ▶ A variable declared `constexpr` must have a value that can be computed at compile time.
 - ▶ Use to specify constants
 - ▶ Functions can be `constexpr`
 - ▶ Introduced in C++-11

`char[]`, `char*` or `const char*` const is important for C-strings

A *string literal* (e.g., "I am a string literal") is **const**.

- ▶ Can be stored in read-only memory
- ▶ `char* str1 = "Hello";` — *deprecated* in C++ — gives a warning
- ▶ `const char* str2 = "Hello";` — OK, the string is **const**
- ▶ `char str3[] = "Hello";` — `str3` can be modified

const modifies everything to the left (exception: if **const** is first, it modifies what is directly after)

Example

```
int* ptr;
const int* ptrToConst; //NB! (const int) *
int const* ptrToConst, // equivalent, clearer?

int* const constPtr; // the pointer is constant

const int* const constPtrToConst; // Both pointer and object
int const* const constPtrToConst; // equivalent, clearer?
```

Be careful when reading:

```
char *strcpy(char *dest, const char *src);
```

(const char)*, not const (char*)

const and pointers

Example:

```
void Exempel( int* ptr,
              int const * ptrToConst,
              int* const constPtr,
              int const * const constPtrToConst )
{
    *ptr = 0;                // OK: changes the value of the object
    ptr = nullptr;          // OK: changes the pointer

    *ptrToConst = 0;         // Error! cannot change the value
    ptrToConst = nullptr;    // OK: changes the pointer

    *constPtr = 0;           // OK: changes the value
    constPtr = nullptr;      // Error! cannot change the pointer

    *constPtrToConst = 0;    // Error! cannot change the value
    constPtrToConst = nullptr; // Error! cannot change the pointer
}
```

Pointers to constant and constant pointer

```
int k;           // int that can be modified
int const c = 100; // constant int
int const * pc;  // pointer to constant int
int *pi;         // pointer to modifiable int

pc = &c;        // OK
pc = &k;        // OK, but k cannot be changed through *pc
pi = &c;        // Error! pi may not point to a constant
*pc = 0;       // Error! pc is a pointer to const int

int* const cp = &k; // Constant pointer
cp = nullptr;      // Error! The pointer cannot be reseated
*cp = 123;         // OK! Changes k to 123
```

Suggested reading

References to sections in Lippman

Literals 2.1.3

Pointers and references 2.3

`std::string` 3.2

`std::vector` 3.3

Arrays and pointers 3.5

Classes 2.6, 7.1.4, 7.1.5, 13.1.3

Scope and lifetimes 2.2.4, 6.1.1

I/O 1.2, 8.1–8.2, 17.5.2

Next lecture

Classes

References to sections in Lippman

Variable initialization 2.2.1

Classes 2.6, 7.1.4, 7.1.5

Constructors 7.5–7.5.4

(Aggregate classes) ("C structs" without constructors) 7.5.5

Operator overloading 14.1 – 14.3, 14.5 – 14.6

const, constexpr 2.4

this and const p 257–258

inline 6.5.2, p 273

friend 7.2.1

static members 7.6