

EDAF30 – Programming in C++

11.Low-level details. Loose ends.

Sven Gestegård Robertz
Computer Science, LTH

2019



Outline

- 1 Types
 - Integer types
- 2 Saving space
 - union
 - Bit operations
 - bit-fields
 - `<bitset>`
- 3 The comma operator
- 4 Multi-dimensional arrays
- 5 Templates
- 6 Most vexing parse
- 7 C-strings – functions and warnings
 - The C standard library string functions

Integer types

▶ Signed integers

Type	Size	Range (at least)
signed char	8 bits	$[-127, 127]^*$
short	at least 16 bits	$[-2^{15} + 1, 2^{15} - 1]$
int	at least 16 bits, usually 32	$[-2^{15} + 1, 2^{15} - 1]$
long	at least 32 bits	$[-2^{31} + 1, 2^{31} - 1]$
long long	at least 64 bits	$[-2^{63} + 1, 2^{63} - 1]$

*typically $[-128, 127]$, etc.

▶ Unsigned integers

- ▶ same size as corresponding signed type
- ▶ unsigned char: $[0, 255]$, unsigned short: $[0, 2^{16} - 1]$. etc.

▶ special case

- ▶ char (can be *represented* as signed char *or* unsigned char)
- ▶ Use char only for characters
- ▶ Use signed char or unsigned char for integer values

▶ Sizes according to the standard:

char ≤ **short** ≤ **int** ≤ **long** ≤ **long long**

Integer types

Overflow

- ▶ overflow of an **unsigned** n-bit integer is defined as *the value modulo 2^n*
- ▶ overflow of a **signed** integer is *undefined*

Integer types

Example with sizeof

```
#include <iostream>
using namespace std;
int main () {
    cout << "sizeof(char)= \t" << sizeof(char)<<endl;
    cout << "sizeof(short)= \t" << sizeof(short) <<endl;
    cout << "sizeof(int) = \t" << sizeof(int) <<endl;
    cout << "sizeof(long)= \t" << sizeof(long)<<endl;
}
```

```
sizeof(char)= 1
sizeof(short)= 2
sizeof(int) = 4
sizeof(long)= 8
```

Integer types – Example of value range by casting or: *be careful with casts from signed to unsigned types*

```
int main () {  
    cout << "(signed char) -1 = " << +(signed char) -1 << endl;  
    cout << "(unsigned char) -1 = " << +(unsigned char) -1 << endl;  
    cout << "(short int) -1 = " << (short int) -1 << endl;  
    cout << "(unsigned short int) -1 = " << (unsigned short int) -1 << endl;  
    cout << "(int) -1 = " << (int) -1 << endl;  
    cout << "(unsigned int) -1 = " << (unsigned int) -1 << endl;  
    cout << "(long) -1 = " << (long) -1 << endl;  
    cout << "(unsigned long) -1 = " << (unsigned long) -1 << endl;  
}
```

```
(char) -1 = -1  
(unsigned char) -1 = 255  
(short int) -1 = -1  
(unsigned short int) -1 = 65535  
(int) -1 = -1  
(unsigned int) -1 = 4294967295  
(long) -1 = -1  
(unsigned long) -1 = 18446744073709551615
```

Integer types

Sizes are specified in `<climits>`

<code>CHAR_BIT</code>	Number of bits in a char object (byte) (≥ 8)
<code>SCHAR_MIN</code>	Minimum value for an object of type signed char
<code>SCHAR_MAX</code>	Maximum value for an object of type signed char
<code>UCHAR_MAX</code>	Maximum value for an object of type unsigned char
<code>CHAR_MIN</code>	Minimum value for an object of type char (either <code>SCHAR_MIN</code> or <code>0</code>)
<code>CHAR_MAX</code>	Maximum value for an object of type char (either <code>SCHAR_MAX</code> or <code>UCHAR_MAX</code>)
<code>SHRT_MIN</code>	Minimum value for an object of type short int
<code>SHRT_MAX</code>	Maximum value for an object of type short int
<code>USHRT_MAX</code>	Maximum value for an object of type unsigned short int
<code>INT_MIN</code>	Minimum value for an object of type int
<code>INT_MAX</code>	Maximum value for an object of type int
<code>UINT_MAX</code>	Maximum value for an object of type unsigned int
<code>LONG_MIN</code>	Minimum value for an object of type long int
<code>LONG_MAX</code>	Maximum value for an object of type long int
<code>ULONG_MAX</code>	Maximum value for an object of type unsigned long int
<code>LLONG_MIN</code>	Minimum value for an object of type long long int
<code>LLONG_MAX</code>	Maximum value for an object of type long long int
<code>ULLONG_MAX</code>	Maximum value for an object of type unsigned long long

Integer types

Sizes are specified in <climits>

```
#include <iostream>
#include <climits>
int main()
{
    std::cout << CHAR_MIN << ", " << CHAR_MAX << ", ";
    // std::cout << UCHAR_MAX << std::endl;
    std::cout << SHRT_MIN << ", " << SHRT_MAX << ", ";
    // std::cout << USHRT_MAX << std::endl;
    std::cout << INT_MIN << ", " << INT_MAX << ", ";
    // std::cout << UINT_MAX << std::endl;
    std::cout << LONG_MIN << ", " << LONG_MAX << ", ";
    // std::cout << ULONG_MAX << std::endl;
    std::cout << LLONG_MIN << ", " << LLONG_MAX << ", ";
    // std::cout << ULLONG_MAX << std::endl;

}

128, 127, 255
-32768, 32767, 65535
-2147483648, 2147483647, 4294967295
-9223372036854775808, 9223372036854775807, 18446744073709551615
-9223372036854775808, 9223372036854775807, 18446744073709551615
```


Integer types

Sizes are implementation defined

Typedefs for specific sizes are in `<stdint.h>` (`<stdint.h>`)

- ▶ integer types with exact width:

```
int8_t int16_t int32_t int64_t
```

- ▶ fastest signed integer type with at least the width

```
int_fast8_t int_fast16_t int_fast32_t int_fast64_t
```

- ▶ smallest signed integer type with at least the width

```
int_least8_t int_least16_t int_least32_t int_least64_t
```

- ▶ signed integer type capable of holding a pointer:

```
intptr_t
```

- ▶ unsigned integer type capable of holding a pointer:

```
uintptr_t
```

The corresponding unsigned typedefs are named `uint_..._t`

The size of a normal **struct** (**class**) is *the sum* of its members

```
struct DataS {  
    int nr;  
    double v;  
    char txt[6];  
};
```

All members in a **struct** are laid out after each other in memory.

The size of a **union** is equal to *the size of the largest member*

```
union DataU {  
    int nr;  
    double v;  
    char txt[6];  
};
```

All members in a **union** have *the same address*: only one member can be used at any time.

Example use of DataU

```

union DataU {
    int nr;
    double v;
    char txt[6];
};

DataU a;

a.nr = 57;
cout << a.nr << endl;      57

a.v = 12.345;
cout << a.v << endl;      12.345

strncpy(a.txt, "Tjo",5);
cout << a.txt << endl;    Tjo

```

The programmer is responsible for only using the "right" member

union

Example of wrong use

```
using std::cout;
using std::endl;

union Foo{
    int i;
    float f;
    double d;
    char c[10];
};
int main()
{
    Foo f;

    f.i = 12;
    cout << f.i << ", " << f.f << ", " << f.d << ", " << f.c << endl;

    strncpy(f.c, "Hej, du", 9);
    cout << f.i << ", " << f.f << ", " << f.d << ", " << f.c << endl;
}
```

```
12, 1.68156e-44, 5.92879e-323, ^L
745170248, 3.33096e-12, 1.90387e-306, Hej, du
```

union

encapsulate a union in a class to reduce the risk of mistakes

```
struct Bar{
    enum {undef, i, f, d, c} kind;
    Foo u;
};
void print(Bar b) {
    switch(b.kind){
    case Bar::i:
        cout << b.u.i << endl;
        break;
    case Bar::f:
        cout << b.u.f << endl;
        break;
    case Bar::d:
        cout << b.u.d << endl;
        break;
    case Bar::c:
        cout << b.u.c << endl;
        break;
    default:
        cout << "???" << endl;
        break;
    }
}
```

```
void test_kind()
{
    Bar b{};

    b.kind = Bar::i;
    b.u.i = 17;

    print(b);

    Bar b2{};
    print(b2);
}
17
???
```

union

anonymous union – removes one level

An alternative to the previous example:

```
struct FooS{
    enum {undef, k_i, k_f, k_d, k_c} kind;
    union{
        int i;
        float f;
        double d;
        char c[10];
    };
};
```

```
FooS test;
```

```
test.kind = FooS::k_c;
strncpy(test.c, "Testing", 9);
if(test.kind == FooS::k_c)
    cout << test.c << endl;
```

Testing

Exposing the tag to the users is brittle.

Tagged union

A class with anonymous union and access functions

```
struct FooS{
    enum {undef, k_i, k_f, k_d, k_c} kind;
    union{
        int i;
        float f;
        double d;
        char c[10];
    };
    FooS() :kind{undef} {}
    FooS(int ii) :kind{k_i},i{ii} {}
    FooS(float fi) :kind{k_f},f{fi} {}
    FooS(double di) :kind{k_d},d{di} {}
    FooS(const char* ci) :kind{k_c} {strncpy(c,ci,10);}
    int get_i() {assert(kind==k_i); return i;}
    float get_f() {assert(kind==k_f); return f;}
    double get_d() {assert(kind==k_d); return d;}
    char* get_c() {assert(kind==k_c); return c;}
    FooS& operator=(int ii) {kind=k_i; i = ii; return *this;}
    FooS& operator=(float fi) {kind=k_f; f = fi; return *this;}
    FooS& operator=(double di) {kind=k_d; d = di; return *this;}
    FooS& operator=(const char* ci){kind=k_c; strncpy(c,ci,10);
        return *this;}
};
```

Bitwise operators

Bitwise and: $a \& b$

Bitwise or: $a | b$

Bitwise xor: $a \wedge b$

Bitwise complement: $\sim a$

shift left: $a \ll 5$

shift right: $a \gg 5$

*\gg on signed types is
implementation defined*

Common operations:

set 5th bit

```
a = a | (1 << 4);  
a |= (1 << 4);
```

clear 5th bit

```
a = a & ~(1 << 4);  
a &= ~(1 << 4);
```

toggle 5th bit

```
a = a ^ (1 << 4);  
a ^= (1 << 4);
```


Bitwise operators

Example:

Low-level operations: Bitwise operators

All variables are unsigned 16 bit integers

```
a = 77;           // a = 0000 0000 0100 1101
b = 22;           // b = 0000 0000 0001 0110
c = ~a;           // c = 1111 1111 1011 0010
d = a & b;        // d = 0000 0000 0000 0100
e = a | b;        // e = 0000 0000 0101 1111
f = a ^ b;        // f = 0000 0000 0101 1011
g = a << 3;       // g = 0000 0010 0110 1000
h = c >> 5;       // h = 0000 0111 1111 1101
i = a & 0x000f;   // i = 0000 0000 0000 1101
j = a | 0xf000;   // j = 1111 0000 0100 1101
k = a ^ (1 << 4); // k = 0000 0000 0101 1101
```

Bit-fields

Can be used to save memory

Specify explicit size in bits with `var : bit_width`

```
struct Car { // record in a car database
    char reg_nr[6]; NB! not null-terminated.
    unsigned int model_year : 12;
    unsigned int tax_paid : 1;
    unsigned int inspected : 1;
};
```

`sizeof(Car) = 8` *on my computer*

Access of members

```
Car c;  
  
strncpy(c.reg_nr, "ABC123", 6);  
c.model_year = 2011;  
c.tax_paid = true;  
c.inspected = true;  
  
cout << "Year: " << c.model_year << endl;  
if (c.tax_paid && c.inspected)  
    cout << std::string(c.reg_nr, c.reg_nr+6) << " is OK";
```

Bit-fields

Warnings

Bit-fields can be useful in special cases, but they are *not portable*

- ▶ the layout of the object is *implementation defined*
- ▶ the compiler can add *padding*
- ▶ bit-field members *have no address*
 - ▶ cannot use the address-of operator &
- ▶ always specify **signed** or **unsigned**
 - ▶ use **unsigned** for members of size 1
- ▶ access can be slower than a “normal” struct
- ▶ integer variables and bitwise operations is an alternative

`std::bitset (<bitset>)`

- ▶ efficient class for storing a set of bits
 - ▶ compact
 - ▶ fast
- ▶ has convenient functions
 - ▶ test, **operator**[]
 - ▶ set, reset, flip
 - ▶ any, all, none, count
 - ▶ conversion to/from string
 - ▶ I/O operators
- ▶ cf. `std::vector<bool>`
 - ▶ `std::bitset` has fixed size
 - ▶ a `std::vector` can grow
 - ▶ but does not quite behave like a normal `std::vector<T>`

bitset

Example: store 50 flags in 8 bytes

```
void test_bitop(){
    bool status;
    cout << std::boolalpha;

    unsigned long quizA = 0;

    quizA |= 1UL << 27 ;
    status = quizA & (1UL << 27);
    cout << "student 27: " ;
    cout << status << endl;

    quizA &= ~(1UL << 27);
    status = quizA & (1UL << 27);
    cout << "student 27: " ;
    cout << status << endl;
}

student 27: true
student 27: false
```

```
void test_bitset(){
    bool status;
    cout << std::boolalpha;

    std::bitset<50> quizB;

    quizB.set(27);
    status = quizB[27];
    cout << "student 27: " ;
    cout << status << endl;

    quizB.reset(27);
    status = quizB[27];
    cout << "student 27: " ;
    cout << status << endl;
}

student 27: true
student 27: false
```

The comma operator

(Introduction and warning)

The comma operator expression expression1, expression2

- ▶ First evaluates expression1, then expression2
- ▶ the expression has the value of expression2
- ▶ NB! The comma separating function parameters or arguments is *not* the comma operator
- ▶ Examples:

```
string s;  
while(cin >> s, s.length() > 5) {  
    //do something  
}
```

*This ignores the value of cin >> s
use && instead of ,*

```
std::vector<int> v(10);
```

```
vector<int>::size_type cnt = v.size();  
for(vector<int>::size_type i=0; i < v.size(); ++i, --cnt) {  
    v[i]=cnt;  
}
```

v now contains 10 9 8 7 6 5 4 3 2 1

Do not use the comma operator!

multi-dimensional arrays

- ▶ Does not (really) exist in C++
 - ▶ are arrays of arrays
 - ▶ Look like in Java
- ▶ Java: array of *references to arrays*
- ▶ C++: two alternatives
 - ▶ Array of arrays
 - ▶ Array of *pointers* (to the first element of an array)

Multi-dimensional arrays

Initializing a matrix with an initializer list:

3 rows, 4 columns

```
int a[3][4] = {  
    {0, 1, 2, 3} , /* initializer list for row 0 */  
    {4, 5, 6, 7} , /* initializer list for row 1 */  
    {8, 9, 10, 11} /* initializer list for row 2 */  
};
```

Instead of nested lists one can write the initialization as a single list:

```
int a[3][4] = {0,1,2,3,4,5,6,7,8,9,10,11};
```

- ▶ Multi-dimensional arrays are stored like an array in memory.
- ▶ The dimension *closest to the name* is the size of the array
- ▶ The remaining dimensions belong to the element type

Multi-dimensional arrays

Representation of arrays in memory

An array `T array[4]` is represented memory by a sequence of four elements of type `T`: `| T | T | T | T |`

An `int[4]` is represented as

`| int | int | int | int |`

Thus, `int[3][4]` is represented as

`| int | int | int | int | int | int | int | int | int | int | int | int |`

Multi-dimensional arrays

Examples

```
int m[2][3]; // A 2x3-matrix
```

```
m[1][0] = 5;
```

```
int* e = m; // Error! cannot convert 'int [2][3]' to 'int*'
```

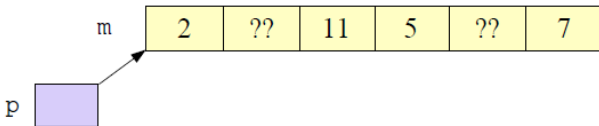
```
int* p = &m[0][0];
```

```
*p = 2;
```

```
p[2] = 11;
```

```
int* q=m[1]; // OK: int[3] decays to int*
```

```
q[2] = 7;
```



Multi-dimensional arrays

Parameters of type multi-dimensional arrays

```
// One way of declaring the parameter
void printmatr(int (*a)[4], int n);

// Another option
void printmatr(int a[][4], int n) {
{
    for (int i=0;i!=n;++i) {
        for (const auto& x : a[i]) { The elements of a are int[4]
            cout << x << " ";
        }
        cout << endl;
    }
}
}
```

Multi-dimensional arrays

Initialization and function call

```
int a[3][4] {1,2,3,4,5,6,7,8,9,10,11,12};  
int b[3][4] {{1,2,3,4},{5,6,7,8},{9,10,11,12}};  
  
printmatr(a,3);  
cout << "-----" << endl;  
printmatr(b,3);
```

1	2	3	4
5	6	7	8
9	10	11	12

1	2	3	4
5	6	7	8
9	10	11	12

Template metaprogramming

- ▶ Write code that is executed *by the compiler, at compile-time*
- ▶ Common in the standard library
 - ▶ As optimization: move computations from run-time to compile-time
 - ▶ As utilities: e.g., `type_traits`, `iterator_traits`
- ▶ Metafunction: a class template containing the result
- ▶ Standard library conventions:
 - ▶ Type results: type member named `type`
 - ▶ Value results: value member named `value`

Template metaprogramming

Example of compile-time computation

```
template <int N>
struct Factorial{
    static constexpr int value = N * Factorial<N-1>::value;
};

template <>
struct Factorial<0>{
    static constexpr int value = 1;
};

void example()
{
    Show<int, Factorial<5>::value>{};
}
```

Result of the *meta-function call* as a compiler error:

```
error: invalid use of incomplete type 'struct Show<int, 120>'
    Show< int, Factorial<5>::value >{};
```

Template metaprogramming

Example of templates for getting values as compiler errors

- ▶ Trick: use a template that doesn't compile to get information about the template parameters through a compiler error.
- ▶ Can be useful for debugging templates.
- ▶ To get the type parameter T:

```
template <typename T>  
struct ShowType;
```

- ▶ To get a value (N) of type T:

```
template <typename T, T N>  
struct Show;
```


std::tuple
less than for point:

```
struct Point {  
    int x;  
    int y;  
    int z;  
    bool operator<(const Point& p) const {  
        using std::tie;  
        return tie(x,y,z) < tie(p.x, p.y, p.z);  
    }  
};
```

std::tuple get of type

```
auto t = std::make_tuple<17, 42.1, "Hello">;  
  
auto i = std::get<int>(t);  
auto d = std::get<double>(t);
```

Most vexing parse Example 1

```
struct Foo {
    int x;
};

int main()
{
#ifdef ERROR1
    Foo f(); // function declaration
#else
    Foo f{}; // Variable declaration C++11
    // Foo f; //C++98 (but not initialized)
#endif
    cout << f.x << endl; // Error

    Foo g = Foo(); // OK // C++11: auto g = Foo();
    cout << g.x << endl;
}
```

error: request for member 'x' in 'f', which is of non-class type 'Foo()'

Most vexing parse

Example 2

```
struct Foo {
    int x;
};

struct Bar {
    int x;
    Bar(Foo f) :x{f.x} {}
};

int main()
{
#ifdef ERROR2
    Bar b(Foo()); // function declaration
#else
    Bar b{Foo()}; // Variable declaration (C++11)
    // Bar b((Foo())); // C++98 : extra parentheses --> expression
#endif
    cout << b.x << endl; // Error!
```

error: request for member 'x' in 'b', which is of non-class type 'Bar(Foo (*)())'

Most vexing parse

Example: actual function

```
struct Foo {  
    Foo(int i=0) :x{i} {}  
    int x;  
};
```

```
struct Bar {  
    int x;  
    Bar(Foo f) :x{f.x} {}  
};
```

```
Bar b(Foo()); // forward declaration
```

```
Foo make_foo()  
{  
    return Foo(17);  
}
```

```
Bar b(Foo(*f)())  
{  
    return Bar(f());  
}
```

```
void test()  
{  
    Bar tmp = b(make_foo());  
    cout << tmp.x << endl;  
}  
17
```

C-strings – library functions

functions in <cstring>

```
strcpy(dest,src) // Copies src to dest
strncpy(dest,src,n) // Copies at most n chars
                    NB! dest is not null-terminated when truncating

strcat(s,t) // Appends a copy of t to the end of s
strncat(s,t,n) // Appends at most n chars

strlen(s) // Gives the length of s
strlen(s,n) // Gives the length of s, max n chars

strcmp(s,t) // Compare s and t
strncmp(s,t,n) // ... at most n chars
// s<t, s==t, s>t returns <0, =0, >0 respectively
```

(even more) unsafe, avoid when possible!

String input

Example mistake

The read string does not fit in `x`

The statements

```
char z[] {"zzzz"};
char y[] {"yyyy"};
char x[5];

stringstream sin{"aaaaaaaaaaaaaaaaaaaaa bbbbbb"};
sin >> x;

cout << x << " : " << y << " : " << z << endl;
```

Give the output (on my computer):

```
aaaaaaaaaaaaaaaaaaaaa : aa : zzzz
```

- ▶ C-strings don't do bounds checking
- ▶ the input to `x` has overwritten (part of) `y`
- ▶ `getline()` is safer

Copying strings

Failing example

The statements

```
char s[20];

strncpy(s, "abc", 4);
cout << s << endl;

strncpy(s, "kalle anka", 20);
cout << s << endl;

strncpy(s, "def", 3);
cout << s << endl;
```

produce the output

```
abc
kalle anka
defle anka
```

The statements

```
int data[] {558646598, 65, 66};
char x[16];
char t[30] {"test"};

strncpy(x, "abcdefghijklmnop", 16);
strcpy(t, x);
cout << t << endl;
```

produce the output

```
abcdefghijklmnopFEL!A
```

Note

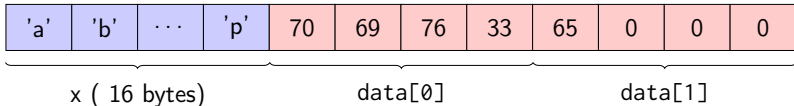
- ▶ `strncpy` does not terminate the string with a `\0` when truncating.
- ▶ `strcpy` copies until it finds a `\0` in `src`.

Copying strings

Failing example: explanation

```
int data[] {558646598, 65, 66};  
char x[16];
```

- ▶ the bytes of `data` is interpreted as `char`.
- ▶ representaton in memory



Hexadecimal representation:

$$558646598_{10} = 214c4546_{16}$$

$$65_{10} = 41_{16}$$

Byte order: *little-endian*

hex	ASCII)	dec
46	F	70
45	E	69
4c	L	76
21	!	33
41	A	65
0	\0	0
0	\0	0
0	\0	0
...

Suggested reading

References to sections in Lippman

C-style strings 3.5.4–3.5.5

Multi-dimensional arrays 3.6

Bitwise operations 4.8

The comma operator 4.10

Union 19.6

Bit-fields 19.8.1