

EDAF50 – C++ Programming

11.Low-level details. Loose ends.

Sven Gestegård Robertz
Computer Science, LTH

2023



Outline

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

Bit-fields

Can be used to save memory

Specify explicit size in bits with `var : bit_width`

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

`sizeof(Car) = 8` on my computer

Bit-fields

Example

Access of members

```
Car c;
```

```
strncpy(c.reg_nr, "ABC123", Car::reg_sz);
```

```
c.model_year = 2011;
```

```
c.tax_paid = true;
```

```
c.inspected = true;
```

```
cout << "Year: " << c.model_year << '\n';
```

```
if (c.tax_paid && c.inspected)
```

```
    cout << std::string(c.reg_nr, c.reg_nr+Car::reg_sz) << " is OK\n";
```

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**
- ▶ access can be slower than a “normal” struct
- ▶ integer variables and bitwise operations is an alternative

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
```

`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
```

Multidimensional arrays

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

Representation of arrays in memory

An array `T array[3]` is represented in memory by a sequence of three elements of type `T`:
`| T | T | T |`

An array `int a1[4]` is represented as
`| int | int | int | int |`

Thus, `int a2[3][4]` is represented as three `int[4]` objects:
`| int | int | int | int | int | int | int | int | int | int | int | int |`

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

Examples

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

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

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

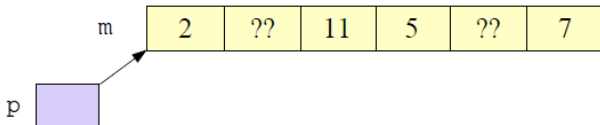
```
int* p = &m[0][0];
```

```
*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

Declarations and parentheses

- ▶ Parentheses matter in declarations of pointers to arrays and functions
 - ▶ `int *a[10]` declares `a` as an array of `int*`
 - ▶ `int (*a)[10]` declares `a` as a pointer to `int[10]`
 - ▶ `int (&a)[10]` declares `a` as a reference to `int[10]`
 - ▶ `int (*f)(int)` declares `f` as a pointer to function $int \rightarrow int$
- ▶ BUT may be used anywhere

```
struct Foo;  
  
Foo test;  
Foo(f);           // Foo f;  
  
int x;  
int(y);           // int y;  
int(z){17};       // int z{17};  
int(q){}:         // int q{};
```


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`.

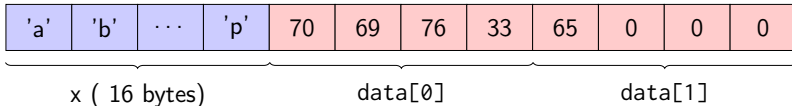
Copying strings

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
...

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 \leq **short** \leq **int** \leq **long** \leq **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* (*until C++-17*)

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

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 0)
<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>`

- ▶ integer types with exact width (if such a type exists):

`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`

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
```

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

```
string s;  
while(cin >> s, s.length() > 5) {           // better: use &&  
    //do something  
}  
  
template <class _OutputIterator, class _Size, class _Generator>  
_OutputIterator  
generate_n(_OutputIterator __first, _Size __n, _Generator __gen)  
{  
    for (; __n > 0; ++__first, --__n)  
        *__first = __gen();  
    return __first;  
}
```

Avoid using the comma operator!

Suggested reading

References to sections in Lippman

C-style strings 3.5.4

Multi-dimensional arrays 3.6

Bitwise operations 4.8

The comma operator 4.10

Bit-fields 19.8.1