EDAF50 – C++ Programming

11.Low-level details. Loose ends.

Sven Gestegård Robertz
Computer Science, LTH

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Outline

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

Bitwise operators

Bitwise and: `a & b`

Bitwise or: `a | b`

Bitwise xor: `a ^ b`

Bitwise complement: `~a`

shift left: `a << 5`

shift right: `a >> 5`

>> 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
    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

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>

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

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

An **int**[4] is represented as

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

Thus, **int**[3][4] is represented as three **int**[4] objects:

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

Multi-dimensional arrays

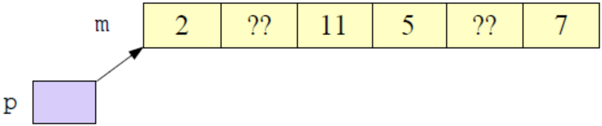
Examples

```
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
```

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{"aaaaaaaaaaaaaaaaa bbbbbb"};
sin >> x;

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

Give the output (on my computer):

```
aaaaaaaaaaaaaaaaaaa : 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

'a'	'b'	...	'p'	70	69	76	33	65	0	0	0
x (16 bytes)				data[0]				data[1]			

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*

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>

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

- integer types with exact with:

  `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;
}
```

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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** (*f)(**int**) declares f as a pointer to function int → 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{};
```

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) {        // better: use &&
  //do something
}
```

```
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!

Example
A class hierarchy

```
struct Foo{
    virtual void print() const {cout << "Foo" << endl;}
};

struct Bar :Foo{
     void print() const override {cout << "Bar" << endl;}
};

struct Qux :Bar{
     void print() const override {cout << "Qux" << endl;}
};
```

Polymorph class
example, *object slicing*

What is printed?

```
void print1(const Foo* f)
{
  f->print();
}
void print2(const Foo& f)
{
  f.print();
}
void print3(Foo f)
{
  f.print();
}
```

```
void test()
{
    Foo* a = new Bar;
    Bar& b = *new Qux;
    Bar  c = *new Qux;

    print1(a);   Bar
    print1(&b);  Qux
    print1(&c);  Bar

    print2(*a);  Bar
    print2(b);   Qux
    print2(c);   Bar

    print3(*a);  Foo
    print3(b);   Foo
    print3(c);   Foo
}
```

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