EDAF30 – Programming in C++

11.Low-level details. Loose ends.

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Outline

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 – 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>

```
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`

union

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.

union

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 ^ 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
    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*

Bit-fields
Example

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!

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[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

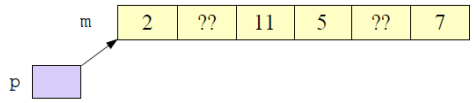
Examples

```
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;
}
```

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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):

```
aaaaaaaaaaaaaaaaa : 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
...	...	...

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