Modern C++ Programming

4. Utilities

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Agenda

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I/O Stream (manipulator) 1/2

some usefull details about outout stream (I/O Stream manipulator):

- `flush` flushes the output stream `cout << flush;`
- `endl` shortcut for `cout << "\n" << flush;`
- `flush` and `endl` force the program to synchronize with the terminal → very slow operation!
- **Set integral representation**: default: dec

  `cout << dec << 0xF;` prints 16

  `cout << hex << 16;` prints 0xF

  `cout << oct << 8;` prints 10

  Print the underlying **bit representation** of a value:

  ```
  #include <bitset>
  std::cout << std::bitset<32>(3.45f); // (32: num. of bits)
  // print 01000000010111001100110011001101
  ```
- **Print true/false text**:

  `cout << boolalpha << 1;` prints true

  `cout << boolalpha << 0;` prints false

I/O Stream (manipulator)

```
#include <iomanip>
```

- **Set decimal precision**: default: 6

  `cout << setprecision(2) << 3.538;` → 3.54

- **Set float representation**: default: `std::defaultfloat`

  `cout << setprecision(2) << fixed << 32.5;` → 32.50

  `cout << setprecision(2) << scientific << 32.5;` → 3.25e+01

- **Set alignment**: default: right

  `cout << right << setw(7) << "abc" << "##";` → ␣␣␣␣abc##

  `cout << left << setw(7) << "abc" << "##";` → abc␣␣␣␣##

  (better than using tab \t)

I/O Stream (std::cin)

`std::cin` is an example of *input* stream. Data coming from a source is read by the program. In this example `cin` is the standard input

```cpp
#include <iostream>

int main() {
    int a;
    std::cout << "Please enter an integer value:" << endl;
    std::cin >> a;

    int b;
    float c;
    std::cout << "Please enter an integer value "
              << "followed by a float value:" << endl;
    std::cin >> b >> c; // read an integer and store into "b",
}                       // then read a float value, and store
                        // into "c"
```

I/O Stream (ofstream/ifstream)

`ifstream`, `ofstream` are output and input stream too

`#include <fstream>`

- **Open a file for reading**
  Open a file in input mode: `ifstream my_file("example.txt")`
- **Open a file for writing**
  Open a file in output mode: `ofstream my_file("example.txt")`
  Open a file in append mode:
  `ofstream my_file("example.txt", ios::out | ios::app)`
- **Read a line** `getline(my_file, string)`
- **Close a file** `my_file.close()`
- **Check the stream integrity** `my_file.good()`

I/O Stream (ofstream/ifstream) 2/7

- **Peek the next character**
  `char current_char = my_file.peek()`

- **Get the next character (and advance)**
  `char current_char = my_file.get()`

- **Get the position of the current character in the input stream**
  `int byte_offset = my_file.tellg()`

- **Set the char position in the input sequence**
  `my_file.seekg(byte_offset)` (absolute position)
  `my_file.seekg(byte_offset, position)` (relative position)
  where position can be: `ios::beg` (the begin), `ios::end` (the end), `ios::cur` (current position)

I/O Stream (ofstream/ifstream)

- **Ignore characters until the delimiter is found**
  `my_file.ignore(max_stream_size, <delim>)`
  e.g. skip until end of line `\n`

- **Get a pointer to the stream buffer object currently associated with the stream**
  `my_file.rdbuf()`
  can be used to redirect file stream

I/O Stream (example 1)

Open a file and print line by line:

```cpp
#include <iostream>
#include <fstream>

int main() {
  std::ifstream fin("example.txt");
  std::string str;
  while (fin.good()) {
     std::getline(fin, str);
     std::cout << str << "\n";
  }
  fin.close();
}
```

An alternative version with redirection:

```cpp
#include <iostream>
#include <fstream>

int main() {
  std::ifstream fin("example.txt");
  std::cout << fin.rdbuf();
  fin.close();
}
```

I/O Stream (example 2)

`example.txt:`

```
23␣70␣␣␣44\n
\t57\t89
```

The input stream is independent from the type of space (multiple space, tab, newline `\n`, `\r\n`, etc.)

Another example:

```cpp
#include <iostream>
#include <fstream>

int main() {
    std::ifstream fin("example.txt");
    char c = fin.peek(); // c = '2'
    while (fin.good()) {
        int var;
        fin >> var;
        std::cout << var;
    }         // print 2370445789
    fin.seekg(4);
    c = fin.peek();  // c = '0'
    fin.close();
}
```

I/O Stream (tip - `checkRegularType`) 6/7

Check if a file is a **regular file** and can be read/written (it exists, it is not a directory, it is not a device, you have read/write permissions, etc.)

```
#include <sys/types.h>
#include <sys/stat.h>
bool checkRegularFile(const char* file_path) {
    struct stat info;
    if (::stat( file_path, &info ) != 0)
        return false;        // unable to access
    if (info.st_mode & S_IFDIR)
        return false;             // is a directory
    std::ifstream fin(file_path); // additional checking
    if (!fin.is_open() || !fin.good())
        return false;
    try {                    // try to read
        char c; fin >> c;
    } catch (std::ios_base::failure&) {
        return false;
    }
    return true;
}
```

I/O Stream (tip - File size and Bit representation) 7/7

Get the **file size** in bytes in a **portable** way:

```
long long int fileSize(const char* file_path) {
    std::ifstream fin(file_path);    // open the file
    fin.seekg(0, ios::beg);          // move to the first byte
    std::istream::pos_type start_pos = fin.tellg();
                                     // get the start offset
    fin.seekg(0, ios::end);          // move to the last byte
    std::istream::pos_type end_pos = fin.tellg();
                                     // get the end offset
    return end_pos - start_pos;      // position difference
}
```

Math Functions

CMath Library

```
#include <cmath>
using namespace std;
```

- `fabs(x)` computes absolute value, $|x|$, C++11
- `exp(x)` returns e raised to the given power, e^x
- `exp2(x)` returns 2 raised to the given power, 2^x, C++11
- `log(x)` computes natural (base e) logarithm, $\log_e(x)$
- `log10(x)` computes base 10 logarithm, $\log_{10}(x)$
- `log2(x)` computes base 2 logarithm, $\log_2(x)$, C++11
- `pow(x, y)` raises a number to the given power, x^y
- `sqrt(x)` computes square root, $\sqrt{x}$

Math Library Functions 2/2

- `cqrt(x)` computes cubic root, $\sqrt[3]{x}$, C++11
- `sin(x)` computes sine, $\sin(x)$
- `cos(x)` computes cosine, $\cos(x)$
- `tan(x)` computes tangent, $\tan(x)$
- `ceil(x)` nearest integer not less than the given value, $\lceil x \rceil$
- `floor(x)` nearest integer not greater than the given value, $\lfloor x \rfloor$
- `round|lround|llround(x)` nearest integer, $\left\lfloor x + \frac{1}{2} \right\rfloor$
  (return type: floating point, `long`, `long long` respectively)

Math functions in C++11 can be applied directly to integral types without implicit/explicit casting (return type: floating point).

Full list: `en.cppreference.com/w/cpp/numeric/math`

Numerical Limits

Get numeric limits of a given type: C++11

```
#include <limits>
using namespace std;
```

```
T numeric_limits<T>:: max()  // returns the maximum finite value
                             // representable by the numeric type T

T numeric_limits<T>:: min()  // returns the minimum finite value
                             // representable by the numeric type T

T numeric_limits<T>:: lowest()  // returns the lowest finite value
                                // representable by the numeric type T
```

Integer Division

Integer ceiling division and rounded division:

- **Ceiling Division:** $\left\lceil \frac{\texttt{value}}{\texttt{div}} \right\rceil$

```
unsigned ceil_div(unsigned value, unsigned div) {
    return (value + div - 1) / div;
} // note: may overflow
```

- **Rounded Division:** $\left\lfloor \frac{\texttt{value}}{\texttt{div}} + \frac{1}{2} \right\rfloor$

```
unsigned round_div(unsigned value, unsigned div) {
    return (value + div / 2) / div;
} // note: may overflow
```

Algorithm Library

Algorithm Library (Part 1) 1/5

`std` algorithms can be applied to **any objects** (see next lectures). In these slides, we focus on primitives types and array only

```
#include <algorithm>
```

- `swap(value1, value2)` Swaps the values of two objects
- `min(x, y)` Finds the minimum value between `x` and `y`
- `max(x, y)` Finds the maximum value between `x` and `y`
- `min_element(begin, end)` (returns a pointer)
  Finds the minimum element in the range [`begin, end`)
- `max_element(begin, end)` (returns a pointer)
  Finds the maximum element in the range [`begin, end`)
- `minmax_element(begin, end)` C++11 (returns pointers <min,max>)
  Finds the minimum and the maximum element in the range [`begin, end`)

full list: en.cppreference.com/w/cpp/algorithm

Algorithm Library (Part 1)

- `equal(begin1, end1, begin2)`
  Determines if two sets of elements are the same in
  `[begin1, end1)`, `[begin2, begin2 + end1 - begin1)`

- `mismatch(begin1, end1, begin2)` (returns pointers <pos1,pos2>)
  Finds the first position where two ranges differ in
  `[begin1, end1)`, `[begin2, begin2 + end1 - begin1)`

- `find(begin, end, value)` (returns a pointer)
  Finds the first element in the range `[begin, end)` equal to `value`

- `count(begin, end, value)`
  Counts the number of elements in the range `[begin, end)` equal to `value`

Algorithm Library (Part 1) 3/5

- `sort(begin, end)` (in-place)
  Sorts the elements in the range [`begin, end`) in ascending order
- `merge(begin1, end1, begin2, end2, output)`
  Merges two sorted ranges [`begin1`, `end1`), [`begin2`, `end2`), and store the results in [`output`, `output` + `end1` - `start1`)
- `unique(begin, end)` (in-place)
  Removes consecutive duplicate elements in the range [`begin`, `end`)
- `binary search(begin, end, value)`
  Determines if an element `value` exists in the (sorted) range [`begin`, `end`)
- `accumulate(begin, end, value)`
  Sums up the range [`begin`, `end`) of elements with initial `value` (common case equal to zero)
- `partial_sum(begin, end)` (in-place)
  Computes the inclusive prefix-sum of the range [`begin`, `end`)

Algorithm Library (Part 1) 4/5

- `fill(begin, end, value)`
  Fills a range of elements [`begin`, `end`) with `value`
- `iota(begin, end, value)` C++11
  Fills the range [`begin`, `end`) with successive increments of the starting `value`
- `copy(begin1, end1, begin2)`
  Copies the range of elements [`begin1, end1`) to the new location [`begin2, begin2 + end1 - begin1`)
- `swap_ranges(begin1, end1, begin2)`
  Swaps two ranges of elements [`begin1, end1`), [`begin2, begin2 + end1 - begin1`)
- `remove(begin, end, value)` (in-place)
  Removes elements equal to `value` in the range [`begin`, `end`)

Algorithm Library (Part 1) 5/5

- `includes(begin1, end1, begin2, end2)`
  Checks if the (sorted) set [`begin1, end1`) is a subset of [`begin2, end2`)
- `set_difference(begin1, end1, begin2, end2, output)`
  Computes the difference between two (sorted) sets
- `set_intersection(begin1, end1, begin2, end2, output)`
  Computes the intersection of two (sorted) sets
- `set_symmetric_difference(begin1, end1, begin2, end2, output)`
  Computes the symmetric difference between two (sorted) sets
- `set_union(begin1, end1, begin2, end2, output)`
  Computes the union of two (sorted) sets
- `make_heap(begin, end)` Creates a max heap out of the range of elements
- `push_heap(begin, end)` Adds an element to a max heap
- `pop_heap(begin, end)` Remove an element (top) to a max heap

Algorithm Library (Examples) 1/2

```
#include <algorithm>
using namespace std;

int a = max(2, 5); // a = 5
int array1[] = {7, 6, -1, 6, 3};
int array2[] = {8, 2, 0, 3, 7};

int  b = *max_element(array1, array1 + 5);   // b = 7
auto c = minmax_element(array1, array1 + 5);
//c.first = -1, c.second = 7
bool d = equal(array1, array1 + 5, array2); // d = false

sort(array1, array1 + 5);         // [-1, 3, 6, 6, 7]
unique(array1, array1 + 5);       // [-1, 3, 6, 7]
int e = accumulate(array1, array1 + 5, 0); // 15
partial_sum(array1, array1 + 5); // [-1, 2, 8, 15]
iota(array1, array1 + 5, 2);      // [2, 3, 4, 5, 6]
make_heap(array2, array2 + 5);    // [8, 7, 0, 3, 2]
```

String

String

String

C++ Strings are wrappers of character sequences

More flexible and safer than raw char array but can be slower

```cpp
#include <string>

int main() {
    std::string a;          // empty string
    std::string b("first");

    using namespace std::string_literals;  // C++14
    std::string c = "second"s;             // C++14
}
```

String (Capacity and Search) 2/7

- `empty()` returns **`true`** if the string is empty, **`false`** otherwise
- `size()` returns the number of characters in the string
- `find(string)` returns the position of the first substring equal to the given character sequence or **`npos`** if no substring is found
- `rfind(string)` returns the position of the last substring equal to the given character sequence or **`npos`** if no substring is found
- `find_first_of(char_seq)` returns the position of the first character equal to one of the characters in the given character sequence or **`npos`** if no characters is found
- `find_last_of(char_seq)` returns the position of the last character equal to one of the characters in the given character sequence or **`npos`** if no characters is found

`npos` special value returned by string methods

String (Operations) 3/7

- `new_string` `substr(start_pos)`
  returns a substring [start_pos, end]
  `new_string` `substr(start_pos, count)`
  returns a substring [start_pos, start_pos + count)
- `clear()` removes all characters from the string
- `erase(pos)` removes the character at position
  `erase(start_pos, count)`
  removes the characters at positions [start_pos, start_pos + count)
- `replace(start_pos, count, new_string)`
  replaces the part of the string indicated by [start_pos, start_pos + count)
  with `new_string`
- `c_str()`
  returns a pointer to the raw char sequence

String (Overloaded Operators)

- **access specified character** `string1[i]`
- **string copy** `string1 = string2`
- **string compare** `string1 == string2`
  works also with `!=`, `<`, `≤`, `>`, `≥`
- **concatenate two strings**
  `string_concat = string1 + string2`
- **append characters to the end** `string1 += string2`

String (Conversion from/to Numeric Values) 5/7

Converts a string to a numeric value C++11:

- `stoi(string)` string to signed integer
- `stol(string)` string to long signed integer
- `stoul(string)` string to long unsigned integer
- `stoull(string)` string to long long unsigned integer
- `stof(string)` string to floating point value (float)
- `stod(string)` string to floating point value (double)
- `stold(string)` string to floating point value (long double)

Converts a numeric value to a string C++11:

- `to_string(numeric_value)` numeric value to string

String (Examples)

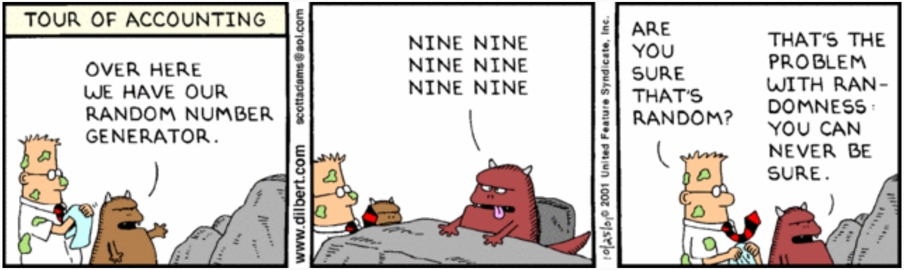
```
std::string str("si vis pacem para bellum");

cout << str.size();       // print 24
cout << str.find("vis"); // print 3
cout << str.find_last_of("bla"); // print 21, 'l' found

cout << str.substr(7, 5);// print "pacem", pos=7 and count=5
cout << str[1];           // print 'i'
cout << (str == "vis");  // print false
cout << (str < "z");      // print true
const char* raw_str = str.c_str();

cout << string("a") + "b";      // print "ab"
cout << string("ab").erase(0); // print 'b'

char*       str2 = "34";
int         a    = std::stoi(str2);   // a = 34;
std::string str3 = std::to_string(a); // str3 = "34"
```

String (Tips)

- Conversion from integer to char letter (e.g. 3 $\rightarrow$ 'C'):
  `static_cast<char>('A'+ value)`
  `value` $\in$ [0, 25] (English alphabet)
- Conversion from char to integer (e.g. 'C' $\rightarrow$ 3):
  `value - 'A'`
  `value` $\in$ [0, 25]
- Conversion from digit to char number (e.g. 3 $\rightarrow$ '3'):
  `static_cast<char>('0'+ value)`
  `value` $\in$ [0, 9]
- char to string `std::string(1, char_value)`

Random Number

Random


TOUR OF ACCOUNTING
OVER HERE WE HAVE OUR RANDOM NUMBER GENERATOR.
NINE NINE NINE NINE NINE NINE
ARE YOU SURE THAT'S RANDOM?
THAT'S THE PROBLEM WITH RANDOMNESS: YOU CAN NEVER BE SURE.
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Random

The problem:

C rand() function produces poor quality random numbers

- C++14 discourage the use of `rand()` and `srand()`

C++11 introduces pseudo random number generation (PRNG) facilities to produce random numbers by using combinations of generators and distributions

A random generator requires four steps:

(1) **Select the seed**

(2) **Define the random engine**

```
<type_of_random_engine> generator(seed)
```

(3) **Define the distribution**

```
<type_of_distribution> distribution(range_start, range_end)
```

(4) **Produce the random number**

```
distribution(generator)
```

Random

Simplest example:

```
#include <iostream>
#include <random>

int main() {
    unsigned seed = ...;
    std::default_random_engine generator(seed);
    std::uniform_int_distribution<int> distribution(0, 9);
    std::cout << std::distribution(generator);
                  // first random number
    std::cout << std::distribution(generator);
                  // second random number
}
```

It generates two random integer numbers in the range [0, 9] by using the default random engine

Random 4/4

Given a **seed**, the generator produces always the **same sequence**

The seed should be selected randomly by using the actual time:

```cpp
#include <random>
#include <chrono>


int main() {
    unsigned seed = std::chrono::system_clock::now()
                        .time_since_epoch().count();
    std::default_random_engine generator(seed);
}
```

`chrono::system_clock::now()` return an object representing the current point in time

`.time_since_epoch().count()` returns the count of ticks that have elapsed since January 1, 1970 (midnight UTC/GMT)

Pseudorandom Number Generator (PRNG)

PRNG Period

The period (or cycle length) of a PRNG is the length of the sequence of numbers that the PRNG generates before repeating.

PRNG Quality

(informal) If it's hard to distinguish a generator's output from truly random sequences we call it a high quality generator. If it's easy, we call it a low quality generator.

Generator	Quality	Period	Performance
Linear congruential	Poor	10^9	fast
Mersenne Twister	High	10^{6000}	good
Subtract-with-carry	Highest	10^{171}	slow

Random Engines

- **Default random engine** Implementation defined
- **Linear congruential** The simplest generator engine. It implements the following transition algorithm:

  $$x_{i+1} = (\alpha x_i + c) mod\ m$$

  where α, c, m are implementation defined

  The generator has a period of m, where m is $2^{31} - 1$
- **Mersenne Twister** *(M. Matsumoto and T. Nishimura, 1997)*

  Fast generation of high-quality pseudorandom number. It relies on Mersenne prime number. (used as default random generator in linux)

  The generator `mt19937, mt19937_64` has a period of $2^{(n-1)*w} - 1$, where w is 32 and n is 624, $\approx 10^{6000}$
- **Subtract-with-carry** *(G. Marsaglia and A. Zaman, 1991)*

  Pseudo-random generation based on Lagged Fibonacci algorithm (used for example by physicists at CERN)

  The generator `ranlux24_base/ranlux48_base` have a period of 10^{171}

Distribution

Common distributions:

- **Uniform random**

  `uniform_int_distribution<T>(range_start, range_end)`

  where T is integral type

  `uniform_real_distribution<T>(range_start, range_end)`

  where T is floating point type

- **Normal distribution** $P(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$

  `normal_distribution<T>(mean, std_dev)`

  where T is floating point type

- **Exponential distribution** $P(x, \lambda) = \lambda e^{-\lambda x}$

  `exponential_distribution<T>(lambda)`

  where T is floating point type

Examples

```
unsigned seed = chrono::system_clock::now()
                .time_since_epoch().count();

minstd_rand0  lc1_generator(seed);  // original linear congruential
minstd_rand   lc2_generator(seed);  // linear congruential (better tuning)
mt19937       mt_generator(seed);   // standard mersenne twister (32-bit)
mt19937_64    mt64_generator(seed); // standard mersenne twister (64-bit)
ranlux24_base swc24_generator(seed);// subtract with carry (24-bit)
ranlux48_base swc48_generator(seed);// subtract with carry (48-bit)

uniform_int_distribution<int>    int_distribution(0, 10);
uniform_real_distribution<float> real_distribution(-3.0f, 4.0f);
exponential_distribution<float>  exp_distribution(3.5f);
normal_distribution<double>      norm_distribution(5.0, 2.0);

lc1_generator.discart(10);   // advances the internal state by 10 times
// i.e. the sequence start point is equal to apply distribution() 10 times
```

Time Measuring

Time Measuring

Wall-Clock/Real time

It is the human perception of the passage of time from the start to the completion of a task

User/CPU time

The amount of time spent by the CPU to compute in user code

System time

The amount of time spent by the CPU to compute system calls (including I/O calls) executed into kernel code

Note: if the system workload (except the current program) is very low and the program uses only one thread then

`Wall-clock time = User time + System time`

Time Measuring (Wall-Clock Time 1)

`::gettimeofday()` (linux, not portable)

```cpp
#include <time.h>     //struct timeval
#include <sys/time.h> //gettimeofday()
#include <iostream>

int main() {
    struct timeval start, end; // timeval {second, microseconds}
    ::gettimeofday(&start, NULL);
    ...   // code
    ::gettimeofday(&end, NULL);

    long start_time = start.tv_sec * 1000000 + start.tv_usec;
    long end_time   = end.tv_sec * 1000000 + end.tv_usec;
    std::cout << "Elapsed: " << end_time - start_time;
}         // in microsec
```

Problems: not portable, the time is not monotonic increasing (timezone)

Time Measuring (Wall-Clock Time 2)

`std::chrono` C++11

```
#include <iostream>
#include <chrono>

int main() {
    auto start_time = std::chrono::system_clock::now();
    ... // code
    auto end_time   = std::chrono::system_clock::now();

    std::chrono::duration<double> diff = end_time - start_time;
    cout << "Elapsed: " << diff.count(); // in seconds
    cout << std::chrono::duration_cast<milli>(diff).count();
}           // in ms
```

Problems: The time is not monotonic increasing (timezone)

An alternative of `system_clock` is `steady_clock` which ensures monotonic increasing time

Time Measuring (User Time)

`std::clock`

```
#include <iostream>
#include <chrono>

int main() {
    clock_t start_time = std::clock();
    ... // code
    clock_t end_time   = std::clock();

    float diff = static_cast<float>(end_time - start_time)
                 / CLOCKS_PER_SEC;
    cout << "Elapsed: " << diff; // in seconds
}
```

Time Measuring (User/System Time)

`::times` (linux)

```
#include <iostream>
#include <sys/times.h>

int main() {
    struct ::tms start_time, end_time;
    ::times(&start_time);
    ... // code
    ::times(&end_time);

    auto  user_diff = end_time.tmus_utime - start_time.tms_utime;
    auto  sys_diff  = end_time.tms_stime - start_time.tms_stime;
    float user = static_cast<float>(user_diff) / ::sysconf(_SC_CLK_TCK);
    float sys  = static_cast<float>(sys_diff)  / ::sysconf(_SC_CLK_TCK);
    std::cout << "user time: "   << user;  // in seconds
    std::cout << "system time: " << sys;   // in seconds
}
```