Modern C++ Programming

2. Basic Concepts I

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Agenda

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What C++ compiler should I use?

Popular (free) compilers:

- Microsoft Visual C++ (**MSVC**) is the compiler offered by Microsoft
- The GNU Compiler Collection (**GCC**) contains very popular C++ Linux compiler
- **Clang** is a C++ compiler based on LLVM Infrastructure available for linux/windows/apple (default) platforms

Suggested compiler: **Clang**

- Faster compiles, low memory use, and in general faster code (compared to GCC/MSVC). [compiler comparison link]
- Expressive diagnostics (examples and propose corrections)
- Strict C++ compliance. GCC/MSVC compatibility (inverse direction is not ensured)
- Includes many very useful tools: memory sanitizer, static code analyzed, automatic formatting, linter (clang-tidy), etc.
- Easy to install: `releases.llvm.org`

C++ compiler features support: `en.cppreference.com/w/cpp/compiler_support`

What editor/IDE compiler should I use?

Popular C++ IDE (Integrated Development Environment) and editors:

- **Microsoft Visual C++**. (It does not support all C++ features and it not strictly compliant with the standard)
- **QT-Creator** (link). Fast (written in C++), simple
- **Clion** (link). (free for student). Most powerful IDE, but may be slow (written in java) and a lot of options may make it not intuitive
- **Atom** (link). Standalone editor oriented for programming. A lot of useful plugins and modular
- **Sublime Text editor** (link). Standalone editor oriented for programming. Faster than Atom, but less complete

Not suggested:

- `Notepad, Gedit, and other similar editors`
  Lack of support for programming

How to compile?

Compile C++ programs:

```
g++  <program.cpp> -o program
```

Compile C++11 programs:

```
g++ -std=c++11 <program.cpp> -o program
```

- requires g++ version $\geq$ 4.8.1
- requires clang++ version $\geq$ 3.3

Compile C++14 programs:

```
clang++ -std=c++14 <program.cpp> -o program
```

- requires g++ version $\geq$ 5
- requires clang++ version $\geq$ 3.4

C code with `printf`:

```c
#include <stdio.h>

int main() {
    printf("Hello World!\n");
}
```

`printf` prints on standard output

C++ code with streams:

```cpp
#include <iostream>

int main() {
    std::cout << "Hello World!\n";
}
```

`cout` : represent the standard output stream

Hello World 2/2

The previous example can be written with the global `std` namespace:

```cpp
#include <iostream>
using namespace std;

int main() {
    cout << "Hello World!\n";
}
```

I/O Stream

`std::cout` is an example of *output* stream. Data is redirected to a destination, in this case the destination is the standard output

C:

```
#include <stdio.h>

int main() {
    int    a = 4;
    double b = 3.0;
    char*  c = "hello";
    printf("%d %f %s\n", a, b, c);
}
```

C++:

```
#include <iostream>

int main() {
    int    a = 4;
    double b = 3.0;
    char*  c = "hello";
    std::cout << a << " " << b << " " << c << "\n";
}
```

I/O Stream (Why should we prefer I/O stream?) 2/3

- **Type-safe**: The type of object pass to I/O stream is known statically by the compiler. In contrast, `printf` uses "%" fields to figure out the types dynamically
- **Less error prone**: With IO Stream, there are no redundant "%" tokens that have to be consistent with the actual objects pass to I/O stream. Removing redundancy removes a class of errors
- **Extensible**: The C++ IO Stream mechanism allows new user-defined types to be pass to I/O stream without breaking existing code
- **Comparable performance**: If used correctly may be faster than C I/O (`printf`, `scanf`, `etc`)

Forget the number of parameters:

```
printf("long phrase %d long phrase %d", 3);
```

Use the wrong format:

```
int a = 3;
...many lines of code...
printf(" %f", a);
```

The "%c" conversion specifier does not automatically skip any leading whitespace:

```
scanf("%d", &var1);
scanf(" %c", &var2);
```

C++ Primitive Types

Type	Size (bytes)	Range	Fixed width types
`bool`	1	true, false	
`char` †	1	-127 to 127	
`signed char`	1	-128 to 127	int8_t
`unsigned char`	1	0 to 255	uint8_t
`short`	2	-2^{15} to 2^{15}-1	int16_t
`unsigned short`	2	0 to 2^{16}-1	uint16_t
`int`	4	-2^{31} to 2^{31}-1	int32_t
`unsigned int`	4	0 to 2^{32}-1	uint32_t
`long int`	4/8*		
`long unsigned int`	4/8*		
`long long int`	8	-2^{63} to 2^{63}-1	int64_t
`long long unsigned int`	8	0 to 2^{64}-1	uint64_t
`float` (IEEE 754)	4	$\pm 1.18 \times 10^{-38}$ to $\pm 3.4 \times 10^{+38}$	
`double` (IEEE 754)	8	$\pm 2.23 \times 10^{-308}$ to $\pm 1.8 \times 10^{+308}$	

* 4 bytes instead 8 bytes in Win64 systems, † one-complement

C++ provides also **long double** (no IEEE-754) of size 8/12/16

Signed Type	short name
`signed char`	`/`
`signed short [int]`	`short`
`signed int`	`int`
`signed long int`	`long`
`signed long long int`	`long long`

Unsigned Type	short name
`unsigned char`	`/`
`unsigned short [int]`	`unsigned short`
`unsigned int`	`unsigned`
`long unsigned int`	`unsigned long`
`long long unsigned int`	`unsigned long long`

en.cppreference.com/w/cpp/language/types

en.cppreference.com/w/cpp/types/integer

C++ provides fixed width integer types. They have the same size on any architecture (`#include <cstdint>`)

int8_t, uint8_t, int16_t, uint16_t, int32_t, uint32_t, int64_t, uint64_t

Warning: I/O Stream interprets `uint8_t` and `int8_t` as `char` and not as integer values

```
int8_t var;
std::cin >> var;        // read '2'
std::cout << var;       // print '2'
std::cout << var * 2;   // print 100 !!
```

`int*_t` types are <u>not</u> “real” types, they are merely *typedefs* to appropriate fundamental types

C++ standard does not ensure an one-to-one mapping:

- There are **five** distinct *fundamental types* (`char`, `short`, `int`, `long`, `long long`)
- There are **four** `int*_t` *overloads* (`int8_t`, `int16_t`, `int32_t`, and `int64_t`)

```
#include <cstddef>
void f(int8_t x)  {}
void f(int16_t x) {}
void f(int32_t x) {}
void f(int64_t x) {}
int main() {
    int x = 0;
    f(x); // compile error!! under 32-bit ARM GCC
} // "int" is not mapped to int*_t type in this (very) particular case
```

Full Story: ithare.com/c-on-using-int_t-as-overload-and-template-parameters

Builtin types suffix:

Type	Suffix	example
`unsigned int`	u	3u
`long int`	l	8l
`long unsigned`	ul	2ul
`long long int`	ll	4ll
`long long unsigned int`	ull	7ull
`float`	f	3.0f
`double`		3.0

Builtin types representation prefix:

Representation	Prefix	example
Binary C++14	0b	0b010101
Octal	0	0308
Hexadecimal	0x or 0X	0xFFA010

size_t

size_t is a data type capable of storing the biggest representable value on the current architecture

- Defined in `<cstddef>`, size_t is a typedef
- size_t is an unsigned integer type (of at least 16-bit)
- In common C++ implementations:
  - size_t is 4 bytes on 32-bit architectures
  - size_t is 8 bytes on 64-bit architectures
- size_t is commonly used for array indexing and loop counting

`void` is an incomplete type (not defined) without a values

- `void` indicates also a function has no return type
  e.g. `void f()`
- `void` indicates also a function has no parameters
  e.g. `f(void)`
- In C `sizeof(void) == 1` (GCC), while in C++ `sizeof(void)` does not compile!!

```
int main() {
//  sizeof(void); // compile error!!
}
```

C++11 introduces the new keyword `nullptr` to represent `null` pointers

```
int* p1 = NULL;    // ok, equal to int* p1 = 0
int* p2 = nullptr; // ok

int n1 = NULL;     // ok, we are assigning 0 to n1
// int n2 = nullptr;  // error! we are assigning a null pointer
                      //        to an integer variable
// int* p2 = true ? 0 : nullptr; // incompatible types
```

Remember: `nullptr` is not a pointer, but an object of type `nullptr_t` → safer

The auto keyword (C++11) specifies that the type of the variable will be automatically deduced by the compiler (from its initializer)

```
auto a = 1 + 2;   // 1 is int, 2 is int, 1 + 2 is int!
                  //    -> 'a' must be int
auto b = 1 + 2.0; // 1 is int, 2.0 is double. 1 + 2.0 is double
                  //    -> 'b' must be double
```

auto keyword may be very useful for maintainability.

```
for (auto i = k; i < size; i++)
    ...
```

On the other hand, it may make the code less readable if excessively used because of type hiding

Conversion rules

Implicit type conversion rules (applied in order) :

$\otimes$: any operations (*, +, /, -, %, etc.)

(a) Floating point promotion

`floating_type` $\otimes$ `integer_type` $=$ `floating_type`

(b) Size promotion

`small_type` $\otimes$ `large_type` $=$ `large_type`

(c) Sign promotion

`signed_type` $\otimes$ `unsigned_type` $=$ `unsigned_type`

Conversion issues

Common errors:

Integers are not floating points!

```
int   b = 7;
float a = b / 2;   // a = 3 not 3.5!!
int   a = b / 2.0; // again  a = 3 not 3.5!!
```

Implicit conversion can be expensive!

```
int b = 5;
int a = 3.5 * b;   // 3.5 is double --> useless overhead!!
//equal to: int a = (int) ( 3.5 * (double) b )
```

Integer type are more accurate than floating types for large numbers!!

```
cout << 16777217;          // print 16777217
cout << (int) 16777217.0f; // print 16777216!!
```

`float` numbers are different from `double` numbers!

```
cout << (1.1 != 1.1f); // print true !!!
```

Overflow/Underflow

Detect overflow/underflow for floating point types is easy (±`inf`).

Detect overflow/underflow for unsigned integral types is **not trivial** !!

```
bool isAddOverflow(unsigned a, unsigned b) {
    return (a + b) < a || (a + b) < b;
}
bool isMulOverflow(unsigned a, unsigned b) {
    unsigned x = a * b;
    return a != 0 && (x / a) != b;
}
```

Overflow/underflow for signed integral types is **not defined** !!

```
#include <limits>
unsigned a = std::numeric_limits<unsigned>::max(); // maximum value
unsigned b = b + 1; // b = 0
int      c = std::numeric_limits<int>::max();      // maximum value
int      d = c + 1; // d can be any int value!!
```

Floating Point

Floating Point

In general, C/C++ adopt IEEE754 floating-point standard.

- Single precision (32-bit) (`float`)

Sign	Exponent (or base)	Mantissa (or significant)
1-bit	8-bit	23-bit

- Double precision (64-bit) (`double`)

Sign	Exponent (or base)	Mantissa (or significant)
1-bit	11-bit	52-bit

Check if the actual C++11 implementation adopts IEEE754 standard:

```
#include <limits>
std::numeric_limits<float>::is_iec559;  // should return true
std::numeric_limits<double>::is_iec559; // should return true
```

Floating point (Exponent Bias)

Exponent Bias

In IEEE 754 floating point numbers, the exponent value is offset from the actual value by the **exponent bias**

- The exponent is stored as an unsigned value suitable for comparison
- Floating point values are lexicographic ordered
- For a single-precision number, the exponent is stored in the range $[1, 254]$ (0 and 255 have special meanings), and is biased by subtracting 127 to get an exponent value in the range $[-126, +127]$

- Example

0	10000111	11000000000000000000000
+	$2^{(135-127)} = 2^8$	$\frac{1}{2^1} + \frac{1}{2^2} = 0.5 + 0.25 = 0.75 \overset{normal}{\rightarrow} 1.75$

$$+1.75 * 2^8 = 448.0$$

Normal number

A **normal** number is a floating point number that can be represented without leading zeros in its significant

Denormal number

Denormal (or subnormal) numbers fill the underflow gap around zero in floating-point arithmetic. Any non-zero number with magnitude smaller than the smallest normal number is subnormal

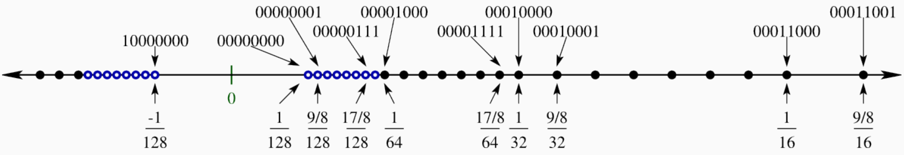
If the exponent is all 0s, but the fraction is non-zero (else it would be interpreted as zero), then the value is a denormal number

Check if a floating-point number is normal/denormal in C++11:

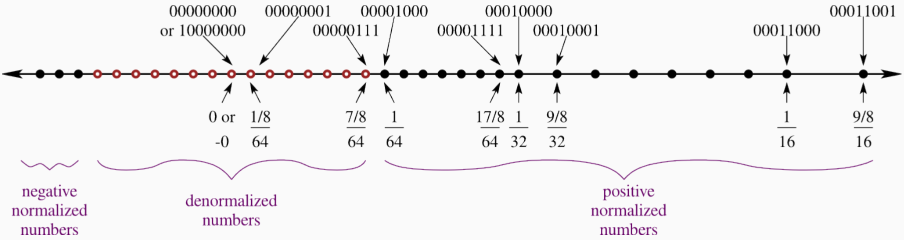
```
#include <cmath>
isnormal(T value); // true if normal, false otherwise
```

Floating point online tool: www.h-schmidt.net/FloatConverter/IEEE754.html

Why denormal number make sense:



The problem: distance values from zero



cit: `www.toves.org/books/float/`

Floating point (special values)

- ± infinity

*	11111111	00000000000000000000000

- `NaN` (mantissa $\neq 0$)

*	11111111	***********************

- ± 0

*	00000000	00000000000000000000000

- Denormal number ($< 2^{-126}$)(minimum: $1.4 * 10^{-45}$)

*	00000000	***********************

- Minimum (normal) ($\pm 1.17549 * 10^{-38}$)

*	00000001	00000000000000000000000

- Lowest/Largest ($\pm 3.40282 * 10^{+38}$)

*	11111110	11111111111111111111111

Floating point issues

The floating point precision is finite!

```
cout << setprecision(20);
cout << 3.33333333f; // print 3.333333254!!
cout << 3.33333333;  // print 3.333333333
cout << (0.1 + 0.1 + 0.1 + 0.1 + 0.1 + 0.1);
// print 0.59999999999999998
```

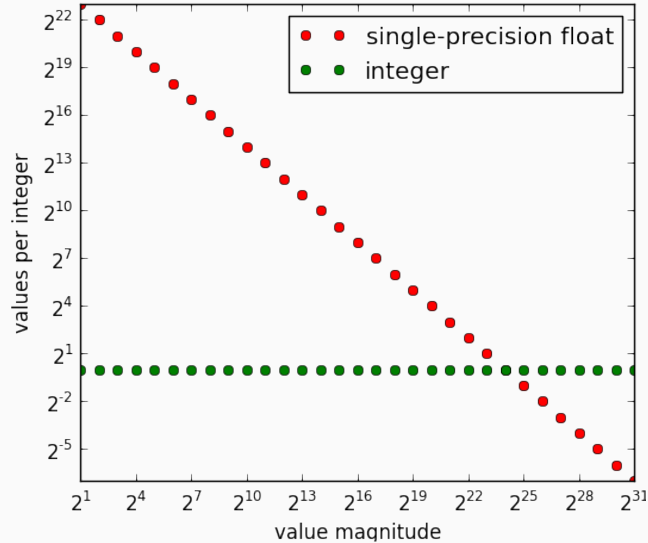
Floating point arithmetic is commutative, but not associative and not reflexive (see `NaN`) !!

```
cout << 0.1 + (0.2 + 0.3) == (0.1 + 0.2) + 0.3; // print false
```

Floating point type has special values:

```
cout << 0 / 0;       // undefined behavior
cout << 0.0 / 0.0;   // print `nan'
cout << 5.0 / 0.0;   // print `inf'
cout << -5.0 / 0.0;  // print `-inf'
cout << ((5.0 / 0.0) == ((5.0 / 0.0) + 9999999.0) // print true
```

Floating point granularity



Intersection $\approx 16,777,217$

NaN properties

NaN

In the IEEE754 standard, `NaN` (not a number) is a numeric data type value representing an undefined or unrepresentable value

Operations generating `NaN`:

- Operations with a `NaN` as at least one operand
- $\pm\infty \mp \infty$
- $0 \cdot \infty$
- $0/0, \infty/\infty$
- $\sqrt{x} \mid x < 0$
- $\log(x) \mid x < 0$
- $\sin^{-1}(x), \cos^{-1}(x) \mid x < -1 \ or \ x > 1$

Comparison: `(NaN == x)` $\rightarrow$ false, for every `x`

`(NaN == NaN)` $\rightarrow$ false!!

Floating Point - Useful Functions

where T is a numeric type C++11

```
#include <cmath>

bool isnormal(T value); // true if normal, false otherwise

bool isnan(T value) // returns true if value is nan, false otherwise

bool isinf(T value) // returns true if value is ±inf, false otherwise

bool isfinite(T value) // returns true if value is not nan or infinite,
                       // false otherwise

T ldexp(T x, p) // multiplies a number by 2 raised to a power.
                // returns x * 2^p

int ilogb(T value) // extracts exponent of the number
```

Floating point comparison

The problem

```
cout << (0.11f + 0.11f < 0.22f); // print true!!
cout << (0.1f + 0.1f > 0.2f);    // print true!!
```

Do not use absolute error margins!!

```
bool areFloatNearlyEqual(float a, float b) {
    if (std::abs(a - b) < epsilon); // epsilon is fixed by the user
        return true
    return false;
}
```

Problems:

- Fixed `epsilon` "looks small" but, it could be too large when the numbers being compared are very small
- If the compared numbers are very large, the epsilon could end up being smaller than the smallest rounding error, so that the comparison always returns `false`.

Solution: Use relative error $\frac{|a-b|}{b} < \varepsilon$

```
bool areFloatNearlyEqual(float a, float b) {
    if (std::abs(a - b) / b < epsilon); // epsilon is fixed
        return true
    return false;
}
```

Problems:

- **`a=0, b=0`** The division is evaluated as `0.0/0.0` and the whole `if` statement is `(nan < espilon)` which always returns `false`
- **`b=0`** The division is evaluated as `abs(a)/0.0` and the whole `if` statement is `(+inf < espilon)` which always returns `false`
- **`a and b very small.`** The result should be `true` but the division by `b` may produces wrong results
- **`It is not commutative.`** We always divide by `b`

Possible solution: $\frac{|a-b|}{\max(|a|,|b|)} < \varepsilon$

```
bool areFloatNearlyEqual(float a, float b) {
    const float epsilon = <user_defined>
    float abs_a = std::abs(a);
    float abs_b = std::abs(b);

    if (a == b) // a=0,b=0 and a = ±∞, b = ±∞
        return true;

    float diff = std::abs(a - b);
    return (diff / std::max(abs_a, abs_b)) < epsilon; // relative error
}
```


References:

[1] floating-point-gui.de/errors/comparison

[2] www.cygnus-software.com/papers/comparingfloats

Floating Point (In)Accuracy

Machine epsilon

Machine epsilon ε (or *machine accuracy*) is defined to be the smallest number that can be added to 1.0 to give a number other than one.

IEEE 754 Single precision : $\varepsilon = 1.17549435 * 10^{-38}$

```
#include <limits>
T std::numeric_limits<T>:: epsilon() // returns the machine epsilon
```

Truncation error

A number x that is **Truncated** (or *Chopped*) at the m^{th} digit means that all $n - m$ digits after the n^{th} digit are removed.

- Machine floating-point representation of x is denoted **fl(x)**

The relative error as a result of truncation is

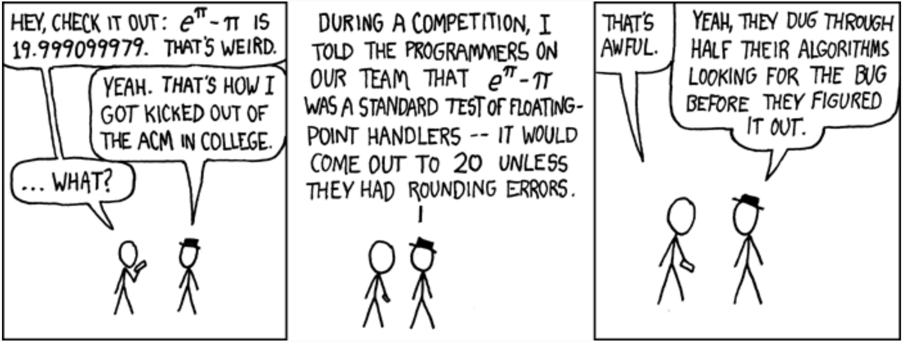
$$\left|\frac{fl\left(x\right) - x}{x}\right| \leq \frac{1}{2}\varepsilon \qquad fl\left(x\right) = x\left(1 + \delta\right) \qquad |\delta| \leq \frac{1}{2}\varepsilon$$

Minimize Error Propagation

- Prefer **multiplication/division** than addition/subtraction
- Scale by a **power of two** is safe
- Try to reorganize the computation to **keep near** numbers with the same scale (maybe sorting numbers)
- Consider to **put a zero** very small number (under a threshold). Common application: iterative algorithms
- **Switch to log scale**. Multiplication becomes Add, and Division becomes Subtraction

Suggest reading:
D. Golberg, *"What Every Computer Scientist Should Know About Floating-Point Arithmetic*, 1991, link

Minimize Error Propagation



Enumerators

Enumerator

An **enumerator** (`enum`) is a data type that groups a set of named integral constants

```
enum color_t { BLACK, BLUE, GREEN = 2 };

color_t color = BLUE;
cout << (color == BLACK); // print false
```

The problem:

```
enum color_t { BLACK, BLUE, GREEN };
enum fruit_t { APPLE, CHERRY };

color_t color = BLUE;
fruit_t fruit = APPLE;
cout << (color == fruit); // generally true, but undefined !!
// and, most importantly, does the match between a color and
// a fruit makes any sense?
```

C++11 introduces the `enum class` (scoped enum) data type that are not implicitly convertible to `int`

Type safe enumerator: `enum class`

Syntax: `<enum_class>::<enum_value>`

```
enum class color_t { BLACK, BLUE, GREEN = 2 };
enum class fruit_t { APPLE, CHERRY };

color_t color = color_t::BLUE;
fruit_t fruit = fruit_t::APPLE;
// cout << (color == fruit); // compile error!!
//     we are trying to match colors with fruits
//     BUT, they are different things entirely

// int a = color_t::GREEN;  // compile error!!
```

- Strongly typed enumerators can be compared:

```
enum class Colors { RED = 1, GREEN = 2, BLUE = 3 };

cout << (Colors::RED < Colors::GREEN); // print true
```

- Strongly typed enumerators do not support other operations:

```
enum        WColors { RED = 1, GREEN = 2, BLUE = 3 };
enum class SColors { RED = 1, GREEN = 2, BLUE = 3 };

int v = RED + GREEN; // ok
// int v = SColors::RED + SColors::GREEN; // compile error!
```

- The size of `enum class` can be set:

```
#include <cstdint>
enum class Colors : int8_t { RED = 1, GREEN = 2, BLUE = 3 };
```

Enumerated types (tips)

- Strongly typed enumerators can be converted:

```
int a = (int) color_t::GREEN; // ok
```

- Enum class objects should be always initialized:

```
enum class SColors { RED = 1, GREEN = 2, BLUE = 3 };

int main() {
    SColors my_color;  // my_color maybe 0!!
}
```

Math Operators

Math Operators (Precedence) 1/3

<table>
<tr><th>Precedence</th><th>Operator</th><th>Description</th><th>Associativity</th></tr>
<tr><td>1</td><td>a++ a--</td><td>Suffix/postfix increment and decrement</td><td>Left-to-right</td></tr>
<tr><td>2</td><td>++a --a</td><td>Prefix increment and decrement</td><td>Right-to-left</td></tr>
<tr><td>3</td><td>a*b a/b a%b</td><td>Multiplication, division, and remainder</td><td>Left-to-right</td></tr>
<tr><td>4</td><td>a+b a−b</td><td>Addition and subtraction</td><td>Left-to-right</td></tr>
<tr><td>5</td><td>≪ ≫</td><td>Bitwise left shift and right shift</td><td>Left-to-right</td></tr>
<tr><td>6</td><td>< <= > >=</td><td>Relational operators</td><td>Left-to-right</td></tr>
<tr><td>7</td><td>== !=</td><td>Equality operators</td><td>Left-to-right</td></tr>
<tr><td>8</td><td>&</td><td>Bitwise AND</td><td>Left-to-right</td></tr>
<tr><td>9</td><td>ˆ</td><td>Bitwise XOR</td><td>Left-to-right</td></tr>
<tr><td>10</td><td>|</td><td>Bitwise OR</td><td>Left-to-right</td></tr>
<tr><td>11</td><td>&&</td><td>Logical AND</td><td>Left-to-right</td></tr>
<tr><td>12</td><td>||</td><td>Logical OR</td><td>Left-to-right</td></tr>
</table>

Math Operators (Precedence) 2/3

In general:

- **Unary** operators have higher precedence than **binary operators**
- **Standard math operators** (`+, *, etc.`) have higher precedence than **comparison**, **bitwise**, and **logic** operators
- **Comparison** operators have higher precedence than **bitwise** and **logic operators**
- **Bitwise** operators have higher precedence than **logic** operators

Full table

`en.cppreference.com/w/cpp/language/operator_precedence`

Examples:

```
a + b * 4;          // a + (b * 4)

a * b / c % d;      // ((a * b) / c) % d

a + b < 3 >> 4;     // (a + b) < (3 >> 4)

a && b && c || d; // (a && b && c) || d

a | b & c || e && d;  // ((a | (b & c)) || (e && d)
```

Important: sometimes parenthesis can make expression worldly... but they can help!

Statements and Control Flow

- Assignment operations and control flow (special cases):

```
int a;
int b = a = 3;  // (a = 3) return value 3
if (b = 4)      // it is not an error, but BAD programming
    ...
if (<true expression> || array[-1] == 0)
    ... // no error!! even though index is -1
        // left-to-right short-circuiting evaluation
```

- C++ allows “in loop” definitions:

```
for (int i = 0, k = 0; i < 10; i++, k += 2)
    ...
```

- Jump statements:

```
for (int i = 0; i < 10; i++) {
    if (<condition>)
        break;    // exit from the loop
    if (<condition>)
        continue; // continue with a new iteration
    return;       // exit from the function
}
```

- Infinite loop:

```
for (;;)
    ...
```

- Range loop: C++11

```
int values[] = { 3, 2, 1 };
for (int v : values)
    cout << v << " ";    // print: 3 2 1

char letters[] = "abcd";
for (auto c : letters)
    cout << c << " ";    // print: a b c d
```

- Ternary operator: `<cond> ? <expression1> : <expression2>`

<expression1> and <expression2> must return a value of the same type

```
int value = (a == b) ? a : (b == c ? b : 3); // nested
```

Expressions with undefined (implementation-defined) behavior:

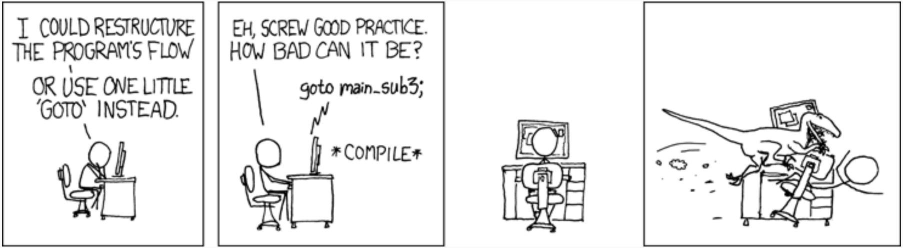
```
int i = 0;
i = ++i + 2;         // undefined behavior until C++11,
                     // otherwise i = 3
i = 0;
i = i++ + 2;         // undefined behavior until C++17,
                     // modern compilers (clang, gcc): i = 3

f(i = 2, i = 1);     // undefined behavior until C++17
                     // modern compilers (clang, gcc): i = 2
i = 0;
a[i] = i++;          // undefined behavior until C++17
                     // modern compilers (clang, gcc): a[1] = 1

f(++i, ++i);         // undefined behavior
i = ++i + i++;       // undefined behavior

n = ++i + i;         // undefined behavior
```

When it is useful:

```
bool flag = true;
for (int i = 0; i < N && flag; i++) {
    for (int j = 0; j < M && flag; j++) {
        if (<condition>)
            flag = false;
    }
}
```

become:

```
for (int i = 0; i < N; i++) {
    for (int j = 0; j < M; j++) {
        if (<condition>)
            goto LABEL;
    }
}
LABEL: ;    // can be also implemented as a function
```


I COULD RESTRUCTURE THE PROGRAM'S FLOW
OR USE ONE LITTLE 'GOTO' INSTEAD.
EH, SCREW GOOD PRACTICE. HOW BAD CAN IT BE?
goto main_sub3;
COMPILE