南方科技大学
SOUTHERN UNIVERSITY OF SCIENCE AND TECHNOLOGY

Advanced Programming

Prof. Shiqi Yu (于仕琪)

yusq@sustech.edu.cn

http://faculty.sustech.edu.cn/yusq/

Integer Numbers

int

- int is the most frequently used integer type

```
int i; //declare a variable
int j = 10; //declare and initialize
int k;
k = 20; //assign a value
```

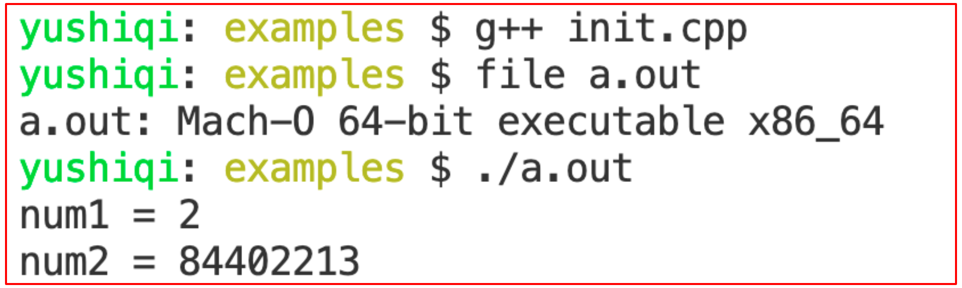
- Remember to initialize a variable!
- Will the compiler give an error?

```
int i;
cout << i; //what is i's value?
```

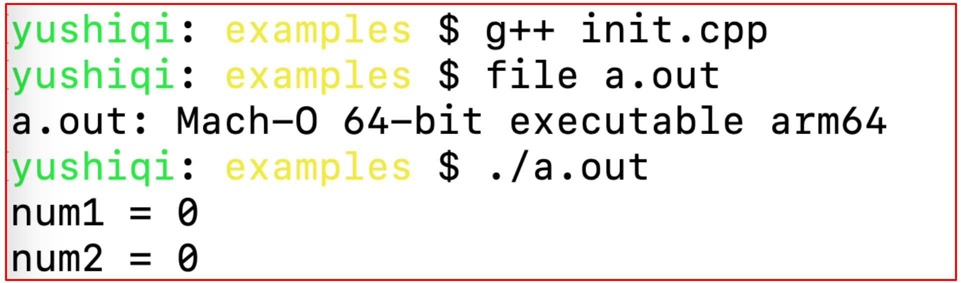
Variable Initialization

init.cpp

```
#include <iostream>
using namespace std;
int main()
{
    int num1; //bad: uninitialized variable
    int num2; //bad: uninitialized variable
    cout << "num1 = " << num1 << endl;
    cout << "num2 = " << num2 << endl;
}
```



```
yushiqi: examples $ g++ init.cpp
yushiqi: examples $ file a.out
a.out: Mach-O 64-bit executable x86_64
yushiqi: examples $ ./a.out
num1 = 2
num2 = 84402213
```



```
yushiqi: examples $ g++ init.cpp
yushiqi: examples $ file a.out
a.out: Mach-O 64-bit executable arm64
yushiqi: examples $ ./a.out
num1 = 0
num2 = 0
```

- Uninitialized variables may have random values
- The behavior depends on the compiler. Clang (x86_64) and Clang (arm64) in the demo.
- Please initialize variables **EXPLICITLY**!

How to initialize

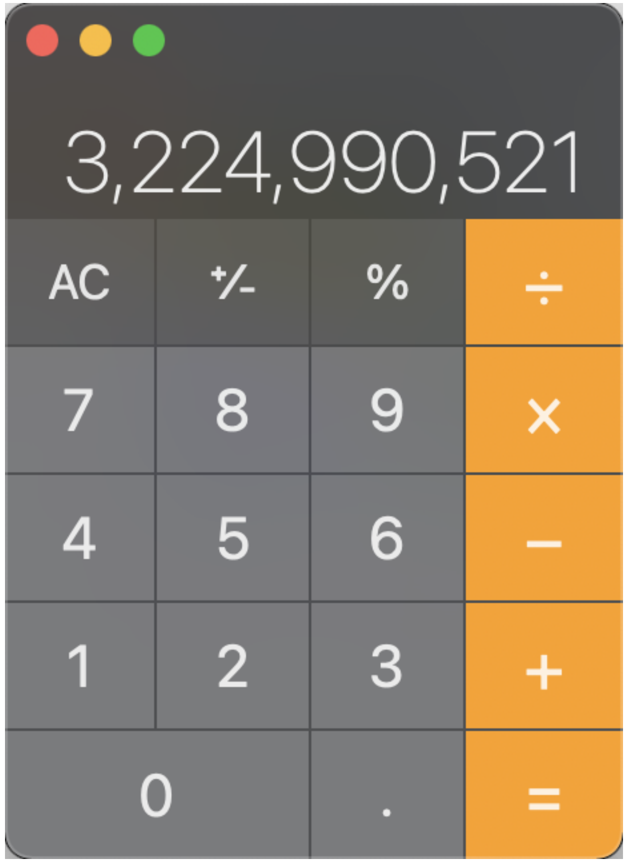
```
int num;
num = 10;//do not forget this line


int num = 10;


int num (10);


int num {10};
```

Overflow



overflow.cpp

```
int a = 56789;
int b = 56789;
int c = a * b;
cout << c << endl;
```

The output is a negative number!

-1069976775

Because 56789 is 0xDDD5, 16 bits

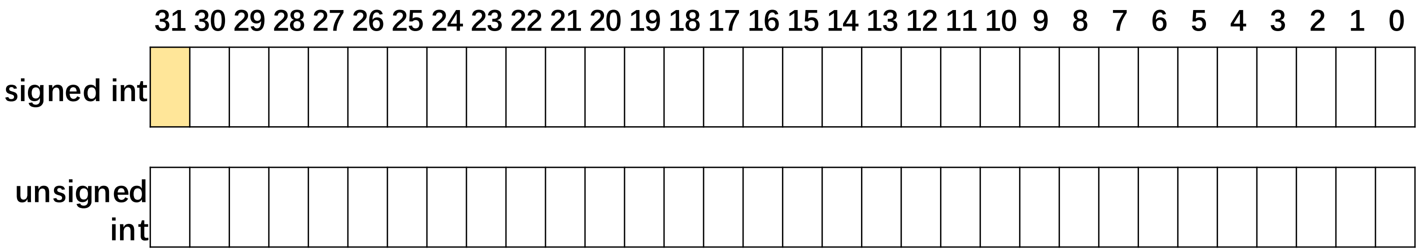
The correct result is 3,224,990,521 (0x C0 39 73 39).

The sign bit is 1!

signed and unsigned

- The following code can give the correct answer.

```
unsigned int a = 56789;
unsigned int b = 56789;
unsigned int c = a * b;
```



31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0

signed int

unsigned int

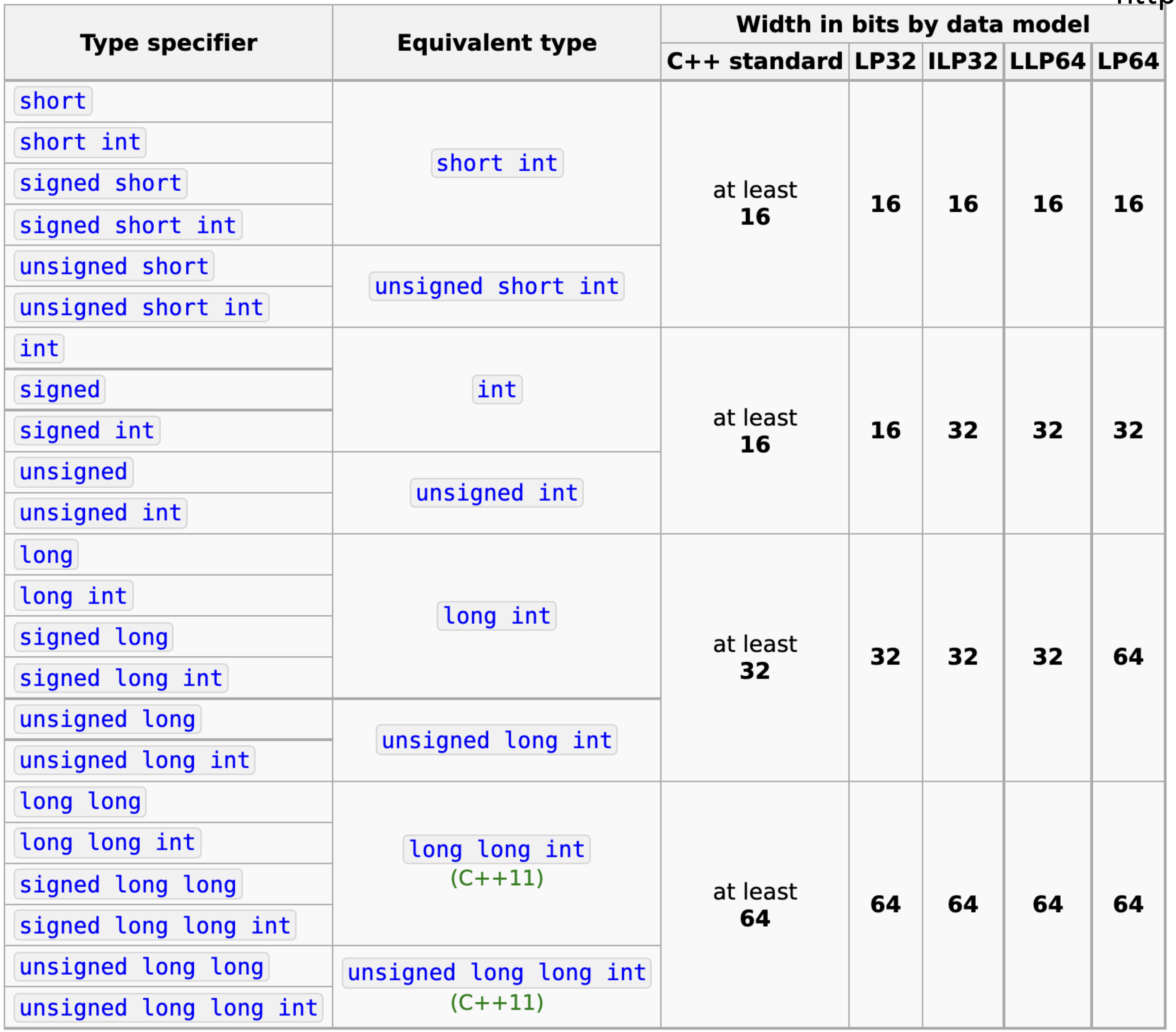
- signed int can be shorten as int. Its range is [-2^{31}, 2^{31}-1] if it's 32-bit.
- unsigned int: Its range is [0, 2^{32}-1] if it's 32-bit.
- 32 bits for most modern systems, 16 for some old ones.

Different Data Types for Integer

- use long int for longer integers.
- use short int for shorter integers.
- and long long

But

- C and C++ standards do not fix the widths of them https://en.cppreference.com/w/cpp/language/types



Type specifier	Equivalent type	Width in bits by data model				
		C++ standard	LP32	ILP32	LLP64	LP64
`short`	`short int`	at least 16	16	16	16	16
`short int`						
`signed short`						
`signed short int`						
`unsigned short`	`unsigned short int`					
`unsigned short int`						
`int`	`int`	at least 16	16	32	32	32
`signed`						
`signed int`						
`unsigned`	`unsigned int`					
`unsigned int`						
`long`	`long int`	at least 32	32	32	32	64
`long int`						
`signed long`						
`signed long int`						
`unsigned long`	`unsigned long int`					
`unsigned long int`						
`long long`	`long long int` (C++11)	at least 64	64	64	64	64
`long long int`						
`signed long long`						
`signed long long int`						
`unsigned long long`	`unsigned long long int` (C++11)					
`unsigned long long int`						

- Width in bits of different data models
- `sizeof` operator can return the width in bytes.

sizeof

- It is an operator, not a function!

size.cpp

```
int i = 0;
short s = 0;
cout << "sizeof(int)=" << sizeof(int) << endl;
cout << "sizeof(i)=" << sizeof(i) << endl;
cout << "sizeof(short)=" << sizeof(s) << endl;
cout << "sizeof(long)=" << sizeof(long) << endl;
cout << "sizeof(size_t)=" << sizeof(size_t) << endl;
```

More Integer Types

char

- `char`: type for character, 8-bit integer indeed!

- `signed char`: signed 8-bit integer
- `unsinged char`: unsigned 8-bit integer
- `char`: either `signed char` or `unsinged char`

Integers and characters

- How we represent a character?
  - Use an 8-bit integer

char.cpp

```
char c1 = 'C’;  //its ASCII code is 80
char c2 = 80;  //in decimal
char c3 = 0x50; //in hexadecimal
```

- Chinese characters?

```
char16_t c = u'于'; //c++11
char32_t c = U'于'; //c++11
```

bool

- A C++ keyword, but not a C keyword
- bool width: 1 byte (8 bits), NOT 1 bit!
- Value: true (1) or false (0)

What is the output?

bool.cpp

```
bool b = true;
int i = b;
cout << "i=" << i << endl;
cout << "b=" << b << endl;
```

bool

- Boolean data conversion

```
bool b = true;
int i = b; // the value of i is 1.
```

```
bool b = -256; // unrecommended conversion. the value of b is true
```

```
bool b = (-256 != 0); // better choice
```

Boolean in C

- Use `typedef` to create a type

```
typedef char bool;
#define true 1
#define false 0
```

- Defined in `stdbool.h` since C99

```
#include <stdbool.h>
```

size_t

- Computer memory keeps increasing
- 32-bit int was enough in the past to for data length
- But now it is not.

`size_t`:

- Unsigned integer
- Type of the result of `sizeof` operator
- Can store the maximum size of a theoretically possible object of any type
- 32-bit, or 64-bit

Fixed width integer types (since C++11)

Defined in <cstdint>

```
int8_t
int16_t
int32_t
int64_t
uint8_t
uint16_t
uint32_t
uint64_t
...
```

Some useful macros

```
INT8_MIN
INT16_MIN
INT32_MIN
INT64_MIN
INT8_MAX
INT16_MAX
INT32_MAX
INT64_MAX
...
```

intmax.cpp

```
#include <iostream>
#include <cstdint>
using namespace std;
int main()
{
    cout << "INT8_MAX=" << INT8_MAX << endl;
}
```

Choose appropriate integer types

- Wider integers consume more memory, and slower sometimes
- `char`(`byte`) is widely used for image pixels
- Choose a data type carefully, and consider all possibilities (short for wide dynamic range images)

6720 × 3780 ×3 = 76,204,800 = 76M Bytes

Floating-point Numbers

What’s the output?

float.cpp

```cpp
#include <iostream>
#include <iomanip>
using namespace std;
int main()
{
    float f1 = 1.2f;
    float f2 = f1 * 1000000000000000; //1.0e15
    cout << std::fixed << std::setprecision(15) << f1 << endl;
    cout << std::fixed << std::setprecision(1) << f2 << endl;
    return 0;
}
```

- How many numbers in range [0, 1]?

Infinite!

- How many numbers can 32 bits represent?

2^{32}

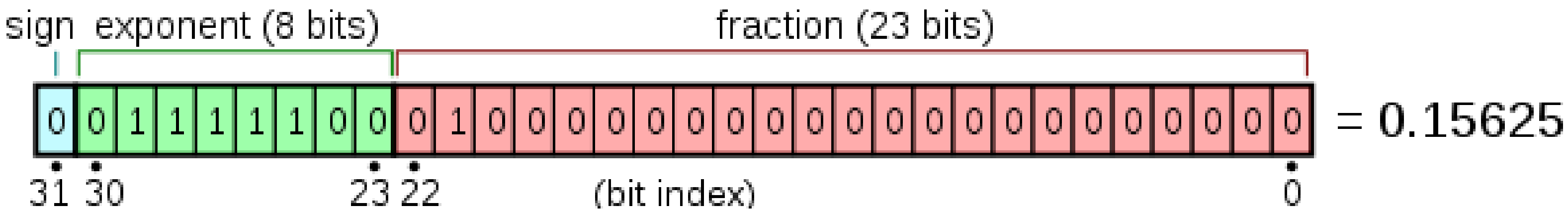
- You want 1.2, but `float` can only provide you 1.20000004768371б...

Understanding Computing

- Are computers always accurate?
- Floating-point operations always bring some tiny errors.
- Those errors cannot be eliminated.
- What we can do: to manage them not to cause a problem.

Floating-point types

- float: single precision floating-point type, 32 bits



$$(-1)^{b_{31}} \times 2^{(b_{30}b_{29}\ldots b_{23})_2 - 127} \times (1.b_{22}b_{21}\ldots b_0)_2$$

- double: double precision floating-point type, 64 bits
- long double: extended precision floating-point type
  - ➢ 128 bits if supported
  - ➢ 64 bits otherwise
- half precision floating-point, 16 bits

  (popular in deep learning, but not a C++ standard)

https://en.wikipedia.org/wiki/Single-precision_floating-point_format

Floating-point VS integers

- Represent values between integers
- A much greater range of values
- Floating-point operations are slower than integer operations
- Lose precision

- `double` operations is slower than `float`

Precision

- Will f2 be greater than f1?

precision.cpp

```
float f1 = 23400000000;
float f2 = f1 + 10; // but f2 = f1
```

- Why?

- Can we use == operator to compare two floating point numbers?

```
if (f1 == f2) //bad
if (fabs(f1 - f2) < FLT_EPSILON) // good
```

inf and nan

- What will f1 and f2 be?

nan.cpp

```
float f1 = 2.0f / 0.0f;
float f2 = 0.0f / 0.0f;
```

- ±inf: infinity (Exponent=11111111, fraction=0)
- nan: not a number (Exponent=11111111, fraction!=0)

Arithmetic Operators

Constant numbers

```
95 // decimal
0137// octal
0x5F // hexadecimal
```

```
95 // int
95u // unsigned int
95l // long
95ul // unsigned long
95lu // unsigned long
```

```
3.14159 // 3.14159
6.02e23 // 6.02 x 10^23
1.6e-19 // 1.6 x 10^-19
3.0 // 3.0
```

```
6.02e23L // long double
6.02e23f // float
6.02e23 // double
```

const type qualifier

```
const float pi = 3.1415926f;
pi += 1; //error!
```

- If a variable/object is const-qualified, it cannot be modified.
- It must be initialized when you define it.

auto (since C++11)

auto is placeholder type specifier.

The type of the variable will be deduced from its initializer.

```
auto a = 2; // type of a is int
auto bc = 2.3; // type of b is double
auto c ; //valid in C, error in C++
auto d = a * 1.2;
```

- Question:

```
auto a = 2; // type of a is int

// will a be converted to a
//   double type variable?
a = 2.3;
```

No! 2.3 will be converted to a `int` 2, then assigned to `a`

Arithmetic operators

Operator name	Syntax
unary plus	`+a`
unary minus	`-a`
addition	`a + b`
subtraction	`a - b`
multiplication	`a * b`
division	`a / b`
modulo	`a % b`
bitwise NOT	`~a`
bitwise AND	`a & b`
bitwise OR	`a | b`
bitwise XOR	`a ^ b`
bitwise left shift	`a << b`
bitwise right shift	`a >> b`

- Operator Precedence

  If you cannot remember the precedence, use parentheses!

  - ➢ a++
  - ➢ ++a
  - ➢ * /
  - ➢ + -
  - ➢ << >>

Other operators

Assignment Operators

```
a = b
a += b
a -= b
a *= b
a /= b
a %= b
a &= b
a |= b
a ^= b
a <<= b
a >>= b
```

Increment/decrement

```
a++
++a
a--
--a
```

```
int a = 3;
int b = a++; // What's the value of b?
int c = ++a; // What's the value of c?
```

Data type conversions

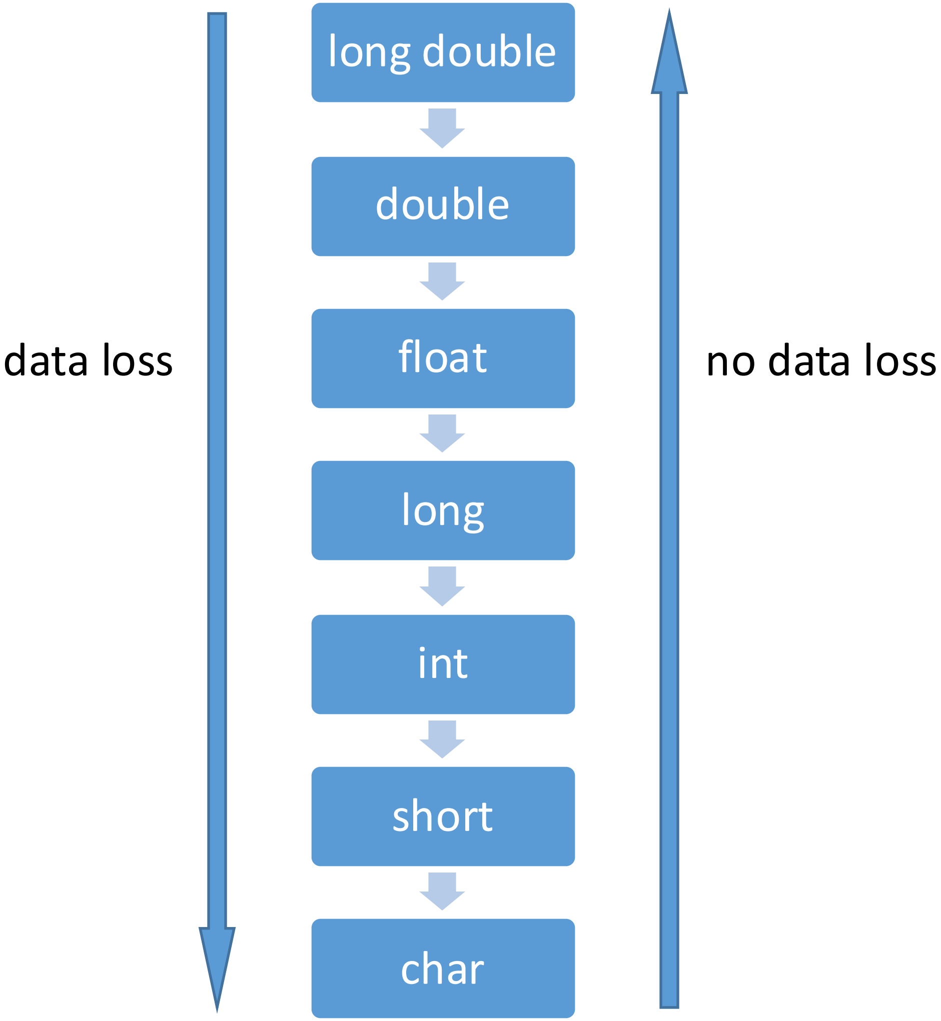
conversion.cpp

```
int num_int1 = 9; // initializing an int value to num_int1
int num_int2 = 'C'; // implicit conversion
int num_int3 = (int)'C'; // explicit conversion, C-style
int num_int4 = int('C'); // explicit conversion, function style
int num_int5 = 2.8; //implicit conversion
float num_float = 2.3; //implicit conversion from double to float
short num_short = 650000;
```

DANGER:

- The source code can be compiled successfully (even with warning messages) when the data types do not match.
- Please use explicit conversion if possible

Data loss



But

conversion.cpp

```
int num_int1 = 100000004;
float num_int_float = num_int1;
int num_int2 = (int)(num_int_float);
```

Will num_int2 be the same with num_int1?

Operator Associativity

- Left-to-right associativity or a right-to-left associativity
  - Ref: https://en.cppreference.com/book/operator_precedence
- The following two lines are equivalent.

```
int i = 17 / 5 * 5;
int i = (17 / 5) * 5;
```

Divisions

- Both operands are integers
  - ➢ Perform integer division
  - ➢ Any fractional part of the answer is discarded to make the result an integer

```
float f = 17 / 5; // f will be 3.f, not 3.4f.
```

- One or both operands are floating-point numbers
  - ➢ Perform floating-point division

```
float f = 17 / 5.f; // f will be 3.4f.
```

Distinct Operations for Different Types

- `int, long, float, double`: four kinds of operations
- If the operands are not the four types, automatic convert their types

```
unsigned char a = 255;
unsigned char b = 1;
int c = a + b; // c = ?
```

- The operands will be converted to one of the four types without losing data: `int, long, float, double`
  - ➢ Ref: https://en.cppreference.com/w/cpp/language/implicit_conversion

C/C++ Supposes

- You (the programmer) are smart enough!
- You know what exactly the source code means!