Modern C++ for Computer Vision and Image Processing

Igor Bogoslavskyi

UNIVERSITÄT BONN

igg

Outline

Static variables and methods

Representation of numbers in memory

Raw C arrays

Non-owning pointers in C++

Classes in memory

Static variables and methods

Static member variables of a class

- Exist exactly **once** per class, **not** per object
- The value is equal accross all instances
- Must be defined in `*.cpp` files

Static member functions of a class

- Do not have an object of a class
- Can access private members but need an object
- **Syntax** for calling:
  `ClassName::MethodName(<params>)`

Static variables

```cpp
#include <iostream>
using std::cout; using std::endl;
struct Counted {
  Counted() { Counted::count++; }
  ~Counted() { Counted::count--; }
  static int count;  // Static counter member.
};
int Counted::count = 0;  // Definition.
int main() {
  Counted a, b;
  cout << "Count: " << Counted::count << endl;
  Counted c;
  cout << "Count: " << Counted::count << endl;
  return 0;
}
```

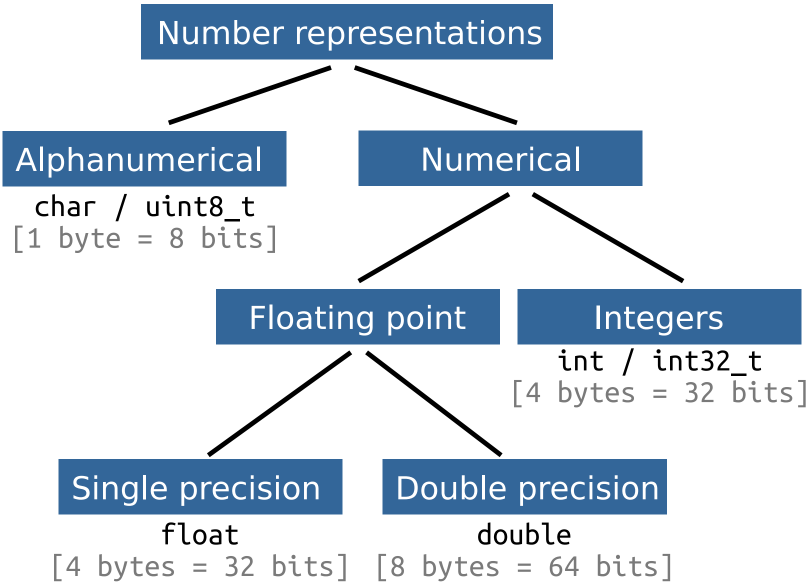
Static member functions

```
#include <math.h>
#include <iostream>
using std::cout; using std::endl;
class Point {
 public:
  Point(int x, int y) : x_(x), y_(y) {}
  static float dist(const Point& a, const Point& b) {
    int diff_x = a.x_ - b.x_;
    int diff_y = a.y_ - b.y_;
    return sqrt(diff_x * diff_x + diff_y * diff_y);
  }
 private:
  int x_ = 0; int y_ = 0;
};
int main() {
  Point a(2, 2), b(1, 1);
  cout << "Dist is " << Point::dist(a, b) << endl;
  return 0;
}
```

Recalling variable declaration

- `int x = 1;`
- `float y = 1.1313f;`

How is the number represented in the memory?


Number representations
Alphanumerical
char / uint8_t
[1 byte = 8 bits]
Numerical
Floating point
Integers
int / int32_t
[4 bytes = 32 bits]
Single precision
float
[4 bytes = 32 bits]
Double precision
double
[8 bytes = 64 bits]

How much memory does a type need?

Get number of bytes for a type:

```
sizeof(<type>)
```

- 1 Bit = {0, 1}
- 1 Byte = 8 Bit
- 1024 Byte = 1 KB
- 1024 KB = 1 MB
- 1024 MB = 1 GB
- 1024 GB = 1 TB

Example sizeof()

```
// machine specific type sizes
sizeof(bool)                 ==      1  byte;
sizeof(char)                 ==      1  byte;
// floating point types
sizeof(float)                ==      4  bytes;
sizeof(double)               ==      8  bytes;
sizeof(long double)          ==      16 bytes;
// integral data types
sizeof(short int)            ==      2  bytes;
sizeof(unsigned short int)   ==      2  bytes;
sizeof(int)                  ==      4  bytes;
sizeof(unsigned int)         ==      4  bytes;
sizeof(long int)             ==      8  bytes;
sizeof(unsigned long int)    ==      8  bytes;
```

Representing integer types

```cpp
#include <iostream>
using std::cout;
int main() {
  unsigned short int k = 37;
  cout << "sizeof(" << k << ") is " << sizeof(k)
       << " bytes or " << sizeof(k) * 8 << " bits.";
}
```

```
sizeof(37) is 2 bytes or 16 bit
```

Representation in memory:

1 byte								1 byte							
0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1
32768			...							32	16	8	4	2	1
2^{15}			...							2^5	2^4	2^3	2^2	2^1	2^0

$$37 = 0 \cdot 2^{15} + \ldots + 1 \cdot 2^5 + 0 \cdot 2^4 + 0 \cdot 2^3 + 1 \cdot 2^2 + 0 \cdot 2^1 + 1 \cdot 2^0$$

Representable intervals

- **2 Byte**
  - `short int` — $[-2^{15}, +2^{15})$
  - `unsigned short int` — $[0, +2^{16})$
- **4 Byte**
  - `int` — $[-2^{31}, +2^{31})$
  - `unsigned int` — $[0, +2^{32})$
- **8 Byte**
  - `long int` — $[-2^{63}, +2^{63})$
  - `unsigned long int` — $[0, +2^{64})$

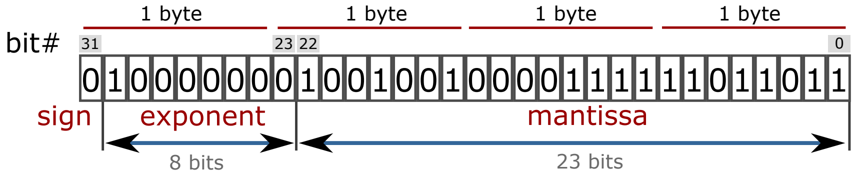
Floating point numbers

```
#include <iostream>
using std::cout;
int main( int argc, char *argv[] ) {
  float k = 3.14159;
  cout << "sizeof(" << k << ") is " << sizeof(k)
       << " bytes or " << sizeof(k) * 8 << " bits.";
}
```

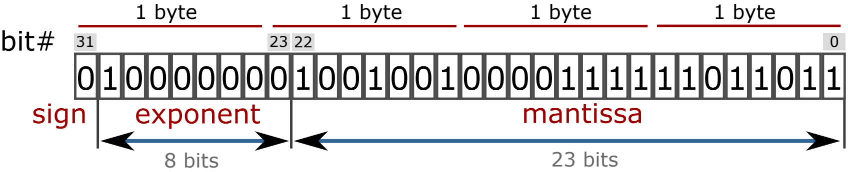
Output:

```
sizeof(3.141590) is 4 bytes or 32 bit
```

Representation in memory:



Floating point numbers



- **In memory:**
  - Sign $s = 0$
  - Exponent $e = 1 \cdot 2^7 + 0 \cdot 2^6 + \ldots + 0 \cdot 2^0 - 127 = 1$
  - Mantissa $m = 1\frac{1}{2^0} + 1\frac{1}{2^1} + 0\frac{1}{2^2} + \ldots 1\frac{1}{2^{22}} = 1.5707964$
  - Number: $k = -1^s \cdot 2^e \cdot m$
- **Representable interval:**
  - `binary`: $\pm[1.7 \cdot 2^{-126}, 2.2 \cdot 2^{127}]$
  - `decimal`: $\pm[1.2 \cdot 10^{-38}, 3.4 \cdot 10^{38}]$

float vs. double

- Same representation as `float`
- `double` takes 8 bytes instead of 4 for `float`
- Longer Exponent und Mantissa.
  - Exponent = **11** Bits instead of 8 for `float`
  - Mantissa = **53** Bits instead of 23 for `float`

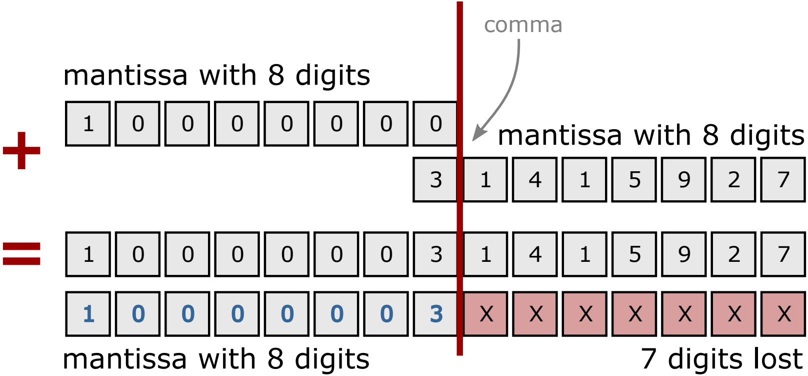
What can we represent?

Datatype	Memory	Interval
`int`	4 *Byte*	$[0, 4.3 \cdot 10^9)$
`float`	4 *Byte*	$[1.18 \cdot 10^{-38}, 3.4 \cdot 10^{38}]$

- `int`: Every number $|x| \in [0, 2^{32})$ with an increment of 1 can be represented
- `float`: Increment depends on the magnitude of the Exponent!
  - **Exponent:** Defines the size of representable interval, 8 *Bit* $\rightarrow [2^{-126}, 2^{127}] = [1.2 \cdot 10^{-38}, 1.7 \cdot 10^{38}]$
  - **Mantissa:** Generates a constant with 8 significant digits, 23 *Bits* long

Limited number of significant digits

Addition of 10 000 000 to π



Digits extinction

```cpp
#include <cmath>
#include <iostream>
using std::cout; using std::endl;
int main() {
  float pi = M_PI;
  float big_number = 1e7;
  cout << "Pi before: " << pi << endl;
  pi += big_number;
  pi -= big_number;
  cout << "Pi after: " << pi << endl;
  cout << "Difference: " << M_PI - pi << endl;
  return 0;
}
```

Result:

```
Pi before: 3.14159
Pi after: 3
Difference: 0.141593
```

C style arrays

- Base for `std::array`, `std::vector`, `std::string`
- The length of the array is **fixed**
- **Indexing begins with `0`!**
- Elements of an array lie in continuous memory.

Declaration:

```
Type array_name[length];
Type array_name[length] = {n0, n1, n2, ..., nX};
Type array_name[] = { n1, n2, n3};
```

Arrays are simple data containers

```
int main() {
  int shorts[5] = {5, 4, 3, 2, 1};
  double doubles[10];
  char chars[] = {'h', 'a', 'l', 'l', 'o'};
  shorts[3] = 4;
  chars[1] = 'e';
  chars[4] = chars[2];
  doubles[1] = 3.2;
}
```

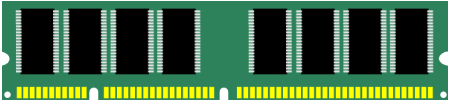
- Have no methods
- Do not explicitly store their size

Arrays and sizeof()

`sizeof()` of an array is
`sizeof(<type>) * <array_length>`

```
int     shortA[5] = {5, 4, 3, 2, 1};
double longA[4] = {1.0, 1.1, 1.2, 1.3};
sizeof(shortA)                        = 20
sizeof(shortA) / sizeof(shortA[0])    = 5
sizeof(longA)                         = 32
sizeof(longA) / sizeof(longA[0])      = 4
```

Working memory or RAM



http://www.clipartkid.com

- Working memory has **linear addressing**
- Every byte has an **address** usually presented in hexadecimal form, e.g. `0x7fffb7335fdc`
- Any address can be accessed at random
- **Pointer** is a type to store memory addresses

Pointer

- `<TYPE>*` defines a pointer to type `<TYPE>`
- The pointers **have a type**
- Pointer `<TYPE>*` can point **only** to a variable of type `<TYPE>`
- Uninitialized pointers point to a random address
- Always initialize pointers to an address or a `nullptr`

Example:

```
int* a = nullptr;
double* b = nullptr;
YourType* c = nullptr;
```

Non-owning pointers

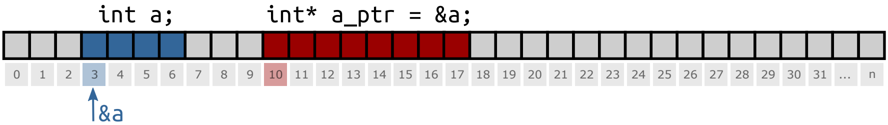
- Memory pointed to by a raw pointer is not removed when pointer goes out of scope
- Pointers can either own memory or not
- Owning memory means being responsible for its cleanup
- **Raw pointers should never own memory**
- We will talk about **smart pointers** that own memory later

Address operator for pointers

- Operator & returns the address of the variable in memory
- Return value type is "pointer to value type"

Example:

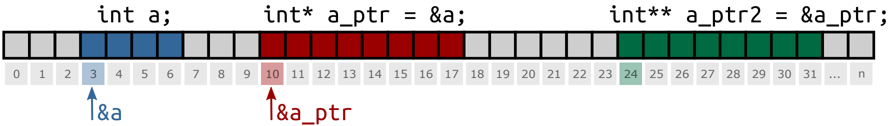
```
int a = 42;
int* a_ptr = &a;
```



Pointer to pointer

Example:

```
int a = 42;
int* a_ptr = &a;
int** a_ptr_ptr = &a_ptr;
```



Pointer dereferencing

- Operator `*` returns the value of the variable to which the pointer points
- Dereferencing of `nullptr`:
  Segmentation Fault
- Dereferencing of unitialized pointer:
  Undefined Behavior

Pointer dereferencing

```cpp
#include <iostream>
using std::cout; using std::endl;
int main() {
  int a = 42;
  int* a_ptr = &a;
  int b = *a_ptr;
  cout << "a = " << a << " b = " << b << endl;
  *a_ptr = 13;
  cout << "a = " << a << " b = " << b << endl;
  return 0;
}
```

Output:

```
a = 42, b = 42
a = 13, b = 42
```

Uninitialized pointer

```cpp
#include <iostream>
using std::cout;
using std::endl;
int main() {
  int* i_ptr;  // BAD! Never leave unitialized!
  cout << "ptr address: " << i_ptr << endl;
  cout << "value under ptr: " << *i_ptr << endl;
  i_ptr = nullptr;
  cout << "new ptr address: " << i_ptr << endl;
  cout << "ptr size: " << sizeof(i_ptr) << " bytes";
  cout << " (" << sizeof(i_ptr) * 8 << "bit) " << endl;
  return 0;
}
```

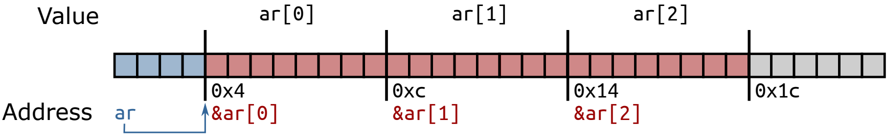
```
ptr address: 0x400830
value under ptr: -1991643855
new ptr address: 0
ptr size: 8 bytes (64bit)
```

Important

- Always initialize with a value or a `nullptr`
- Dereferencing a `nullptr` causes a **Segmentation Fault**
- Use `if` to avoid Segmentation Faults

```
if(some_ptr) {
  // only enters if some_ptr != nullptr
}
if(!some_ptr) {
  // only enters if some_ptr == nullptr
}
```

Arrays in memory and pointers



- Array elements are **continuous in memory**
- Name of an array is an alias to a pointer:

```
double ar[3];
double* ar_ptr = ar;
double* ar_ptr = &ar[0];
```

- Get array elements with operator `[]`

Careful! Overflow!

CODING HORROR

```cpp
#include <iostream>
int main() {
  int ar[] = {1, 2, 3};
  // WARNING! Iterating too far!
  for (int i = 0; i < 6; i++){
    std::cout << i << ": value: " << ar[i]
              << "\t addr:" << &ar[i] << std::endl;
  }
  return 0;
}
```

```
0: value: 1   addr:0x7ffd17deb4e0
1: value: 2   addr:0x7ffd17deb4e4
2: value: 3   addr:0x7ffd17deb4e8
3: value: 0   addr:0x7ffd17deb4ec
4: value: 4196992   addr:0x7ffd17deb4f0
5: value: 32764   addr:0x7ffd17deb4f4
```

Custom objects in memory

- How the parts of an object are stored in memory is not strongly defined
- Usually sequentially
- The compiler can optimize memory

```
class MemoryTester {
 public:
  int i;
  double d;
  void SetData(float data) { data_ = data; }
  float* GetDataAddress() { return &data_; }
 private:
  float data_;  // position of types is important
};
```

Where is what?

```
#include "class_memory.h"
#include <iostream>
using std::cout; using std::endl;
int main() {
  MemoryTester tester;
  tester.i = 1; tester.d = 2; tester.SetData(3);
  cout << "Sizeof tester: " << sizeof(tester) << endl;
  cout << "Address of i: " << &tester.i << endl;
  cout << "Address of d: " << &tester.d << endl;
  cout << "Address of _data: "
       << tester.GetDataAddress() << endl;
  return 0;
}

// memory:     |i|i|i|i|_|_|_|_|d|d|d|d|d|d|d|d|...
// who is who: | int i |padding|    double d   |...
```