Modern C++ for Computer Vision and Image Processing

Lecture 5: I/O Files, Classes

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C++ Utilities

C++ includes a variety of utility libraries that provide functionality ranging from bit-counting to partial function application.

std::bitset std::bind

These libraries can be broadly divided into two groups:

- language support libraries.
- general-purpose libraries.

Language support

Provide classes and functions that interact closely with language features and support common language idioms.

- Type support(`std::size_t`).
- Dynamic memory management(`std::shared_ptr`).
- Error handling(`std::exception, assert`).
- Initializer list(`std::vector{1, 2}`).
- Much more...

General-purpose Utilities

- Program utilities(`std::abort`).
- Date and Time(`std::chrono::duration`).
- Optional, variant and any(`std::variant`).
- Pairs and tuples(`std::tuple`).
- Swap, forward and move(`std::move`).
- Hash support(`std::hash`).
- Formatting library(coming in C++20).
- Much more...

std::swap

```cpp
int main() {
  int a = 3;
  int b = 5;

  // before
  std::cout << a << ' ' << b << '\n';

  std::swap(a, b);

  // after
  std::cout << a << ' ' << b << '\n';
}
```

Output:

```
3 5
5 3
```

std::variant

```cpp
int main() {
  std::variant<int, float> v1;
  v1 = 12;  // v contains int
  cout << std::get<int>(v1) << endl;
  std::variant<int, float> v2{3.14F};
  cout << std::get<1>(v2) << endl;

  v2 = std::get<int>(v1);  // assigns v1 to v2
  v2 = std::get<0>(v1);    // same as previous line
  v2 = v1;                 // same as previous line
  cout << std::get<int>(v2) << endl;
}
```

Output:

```
12
3.14
12
```

std::any

```cpp
int main() {
  std::any a;  // any type

  a = 1;  // int
  cout << any_cast<int>(a) << endl;

  a = 3.14;  // double
  cout << any_cast<double>(a) << endl;

  a = true;  // bool
  cout << std::boolalpha << any_cast<bool>(a) << endl;
}
```

Output:

```
1
3.14
true
```

std::optional

```cpp
std::optional<std::string> StringFactory(bool create) {
  if (create) {
    return "Modern C++ is Awesome";
  }
  return {};
}

int main() {
  cout << StringFactory(true).value() << '\n';
  cout << StringFactory(false).value_or(":(") << '\n';
}
```

Output:

```
Modern C++ is Awesome
:(
```

std::tuple

```cpp
int main() {
  std::tuple<double, char, string> student1;
  using Student = std::tuple<double, char, string>;
  Student student2{1.4, 'A', "Jose"};
  PrintStudent(student2);
  cout << std::get<string>(student2) << endl;
  cout << std::get<2>(student2) << endl;

  // C++17 structured binding:
  auto [gpa, grade, name] = make_tuple(4.4, 'B', "");
}
```

Output:

```
GPA: 1.4, grade: A, name: Jose
Jose
Jose
```

std::chrono

```cpp
#include <chrono>

int main() {
  auto start = std::chrono::steady_clock::now();
  cout << "f(42) = " << fibonacci(42) << '\n';
  auto end = chrono::steady_clock::now();

  chrono::duration<double> sec = end - start;
  cout << "elapsed time: " << sec.count() << "s\n";
}
```

Output:

```
f(42) = 267914296
elapsed time: 1.84088s
```

std::bind

(ಫಿಂಗರ್‌ಪ್ರಿಂಟ್: ಇದೇ boost::bind ಅನ್ನು ಅನುಕರಿಸಲಿಕ್ಕಿದೆ)

```
int f(int a, int b) { return a+b; } // ಫಿಂಗಾಪ್ಟ್
bind(f, -1, 5)(x)      // ಫಿಂಗಾಲಾಕ್ಷ f(x, 5)
bind(f, 5, -1)(x)      // f(5, x) ಯ
```

ಅನುಕೂಲಕ್ಕಾಗಿ placeholder ಗಳಿಗೆ underscore ಸಹಿತ argument ನ್ನು ಈ function ಗೆ ಅನುವು ಮಾಡಿಕೊಡಲಾಗಿದೆ. (ಹೆಚ್ಚಿನ ವಿವರಗಳಿಗೆ ಅಂತರ್ಜಾಲ)

ಉದಾ

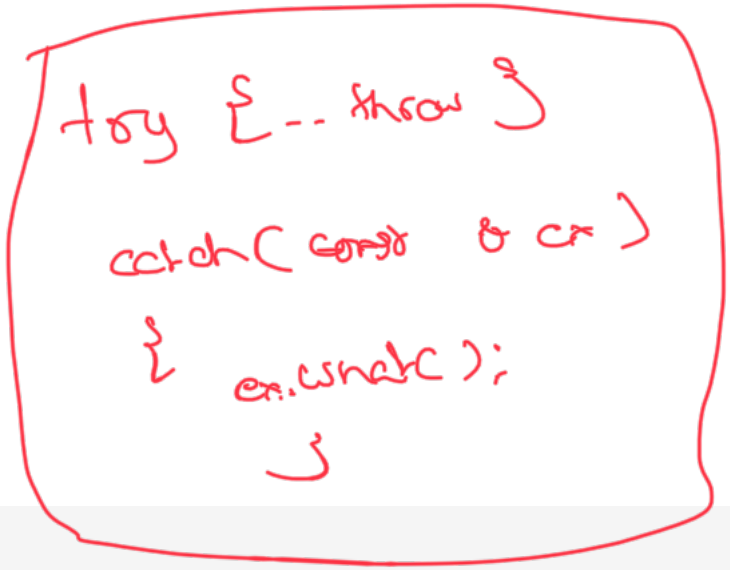
```
bind(f, -2, -1)(x, y);  => f(y, x)
bind(g, -1, 10, -1)(x); => g(x, 10, x)
bind(g, -3, -3, -3)(x, y, z); => g(z, z, z)
bind(g, -1, -1, -1)(x, y, z); => g(x, x, x)
```

08

Error handling with exceptions

- We can **"throw"** an exception if there is an error
- STL defines classes that represent exceptions. Base class: `std::exception`
- To use exceptions: `#include <stdexcept>`
- An exception can be "caught" at any point of the program (`try - catch`) and even "thrown" further (`throw`)
- The constructor of an exception receives a string error message as a parameter
- This string can be called through a member function `what()`

`throw` exceptions



Runtime Error:

```
1 // if there is an error
2 if (badEvent) {
3     string msg = "specific error string";
4     // throw error
5     throw runtime_error(msg);
6 }
7 ... some cool code if all ok ...
```

Logic Error: an error in logic of the user

```
1 throw logic_error(msg);
```

`catch` exceptions

- If we expect an exception, we can "catch" it
- Use `try - catch` to catch exceptions

```
try {
    // some code that can throw exceptions z.B.
    x = someUnsafeFunction(a, b, c);
}
// we can catch multiple types of exceptions
catch ( runtime_error &ex )    {
    cerr << "Runtime error: " << ex.what() << endl;
} catch ( logic_error &ex )    {
    cerr << "Logic error: " << ex.what() << endl;
} catch ( exception &ex )    {
    cerr << "Some exception: " << ex.what() << endl;
} catch ( ... ) { // all others
    cerr << "Error: unknown exception" << endl;
}
```

Intuition

- Only used for **"exceptional behavior"**
- **Often misused**: e.g. wrong parameter should not lead to an exception
- `GOOGLE-STYLE` Don't use exceptions
- https://en.cppreference.com/w/cpp/error

https://google.github.io/styleguide/cppguide.html#Exceptions

Reading and writing to files

- Use streams from STL
- Syntax similar to `cerr, cout`

```
1  #include <fstream>
2  using std::string;
3  using Mode = std::ios_base::openmode;
4
5  // ifstream: stream for input from file
6  std::ifstream f_in(string& file_name, Mode mode);
7
8  // ofstream: stream for output to file
9  std::ofstream f_out(string& file_name, Mode mode);
10
11 // stream for input and output to file
12 std::fstream f_in_out(string& file_name, Mode mode);
```

There are many modes under which a file can be opened

Mode	Meaning
`ios_base::app` ✓	append output
`ios_base::ate` ✓	seek to EOF when opened
`ios_base::binary`	open file in binary mode
`ios_base::in` ✓	open file for reading
`ios_base::out` ✓	open file for writing
`ios_base::trunc`	overwrite the existing file

Mode of opening of file

```
fstream obj;
obj.open("file", ios::in | ios::out);
```

Cursor pointer position of file.

```
obj.seekg( )   // Seek get
obj.seekp( )   // Seek put
```

Regular columns

Use it when:

- The file contains organized data
- Every line has to have all columns

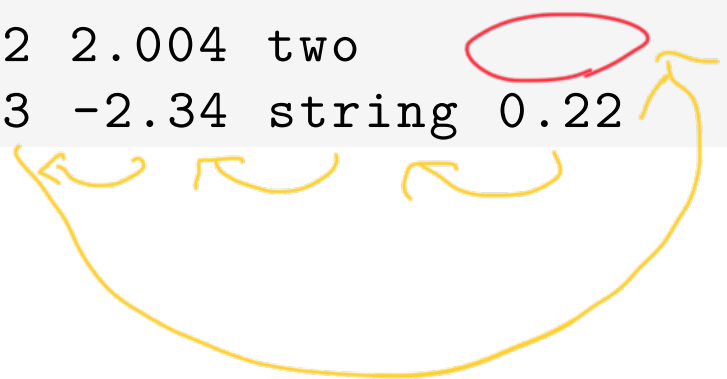
```
1 1 2.34   One     0.21
2 2 2.004  two     0.23
3 3 -2.34  string  0.22
```

O.K.

```
1 1 2.34   One     0.21
2 2 2.004  two     0.23
3 3 -2.34  string  0.22
```

Fail

```
1 1 2.34   One     0.21
2 2 2.004  two
3 3 -2.34  string  0.22
```



Reading from ifstream

```
1  #include <fstream>  // For the file streams.
2  #include <iostream>
3  #include <string>
4  using namespace std;  // Saving space.
5  int main() {
6    int i;
7    double a, b;
8    string s;
9    // Create an input file stream.
10   ifstream in("test_cols.txt", ios_base::in);
11   // Read data, until it is there.
12   while (in >> i >> a >> s >> b) {
13     cout << i << ", " << a << ", "
14          << s << ", " << b << endl;
15   }
16   return (0);
17 }
```

Reading files one line at a time

- Bind every line to a `string`
- Afterwards parse the string

```
1 ================================
2 HEADER
3 a = 4.5
4 filename = /home/ivizzo/.bashrc
5 ================================
6 2.34
7 1 2.23
8 ER SIE ES
```

line by line

std::string::npos is static member constant (const).

```cpp
#include <fstream>
#include <iostream>
using namespace std;
int main() {
  string line, file_name;
  ifstream input("test_bel.txt", ios_base::in);
  // Read data line-wise.
  while (getline(input, line)) {
    cout << "Read: " << line << endl;
    // String has a find method.
    string::size_type loc = line.find("DeepBlue", 0);
    if (loc != string::npos) {
      file_name = line.substr(line.find("=", 0) + 1,
                              string::npos);
    }
  }
  cout << "Filename found: " << file_name << endl;
  return (0);
}
```

static const size_t npos = -1;

position 0부터 시작.

line.substr(0, -1);

find(" ", 7) ← position 7 부터 space 찾기.

11_getline.cpp

Writing into text files

With the same syntax as `cerr` und `cout` streams, with `ofstream` we can write directly into files

```
1  #include <iomanip>  // For setprecision.
2  #include <fstream>
3  using namespace std;
4  int main() {
5    string filename = "out.txt";
6    ofstream outfile(filename);
7    if (!outfile.is_open()) { return EXIT_FAILURE; }
8    double a = 1.123123123;
9    outfile << "Just string" << endl;
10   outfile << setprecision(20) << a << endl;
11   return 0;
12 }
```

Writing to binary files

- We write a **sequence of bytes**
- We must document the structure well, otherwise none can read the file
- Writing/reading is **fast**
- No precision loss for floating point types
- Substantially **smaller** than `ascii`-files
- **Syntax**

```
1 file.write(reinterpret_cast<char*>(&a), sizeof(a));
```

Writing to binary files

```
1  #include <fstream>  // for the file streams
2  #include <vector>
3  using namespace std;
4
5  int main() {
6    string file_name = "image.dat";
7    ofstream file(file_name, ios_base::out | ios_base::binary);
8    int rows = 2;
9    int cols = 3;
10   vector<float> vec(rows * cols);
11   file.write(reinterpret_cast<char*>(&rows), sizeof(rows));
12   file.write(reinterpret_cast<char*>(&cols), sizeof(cols));
13   file.write(reinterpret_cast<char*>(&vec.front()),
14                                      vec.size() * sizeof(float));
15   return 0;
16 }
```

Casting → static_cast
const_cast
reinterpret_cast

Reading from binary files

- We read a **sequence of bytes**
- Binary files are not human-readable
- We must know the structure of the contents
- **Syntax**

```
1 file.read(reinterpret_cast<char*>(&a), sizeof(a));
```

Byte sequence ని structure లో చదువు read ఆపరేషన్ అంటారు!

Reading from binary files

```
1  #include <fstream>
2  #include <iostream>
3  #include <vector>
4  using namespace std;
5  int main() {
6    string file_name = "image.dat";
7    int r = 0, c = 0;
8    ifstream in(file_name,
9                ios_base::in | ios_base::binary);
10   if (!in) { return EXIT_FAILURE; }
11   in.read(reinterpret_cast<char*>(&r), sizeof(r));
12   in.read(reinterpret_cast<char*>(&c), sizeof(c));
13   cout << "Dim: " << r << " x " << c << endl;
14   vector<float> data(r * c, 0);
15   in.read(reinterpret_cast<char*>(&data.front()),
16           data.size() * sizeof(data.front()));
17   for (float d : data) { cout << d << endl; }
18   return 0;
19 }
```

Important facts

Pros

- I/O Binary files is **faster** than ASCII format.
- Size of files is **drastically** smaller.
- There are many libraries to facilitate **serialization**.

Cons

- Ugly Syntax.
- File is not readable by human.
- You need to now the format before reading.
- You need to use this for your homeworks.

C++17 Filesystem library

- Introduced in C++17.
- Use to perform operations on:
  - paths
  - regular files
  - directories
- Inspired in `boost::filesystem`
- Makes your life easier.
- https://en.cppreference.com/w/cpp/filesystem

directory_iterator

```cpp
#include <filesystem>
namespace fs = std::filesystem;

int main() {
  fs::create_directories("sandbox/a/b");
  std::ofstream("sandbox/file1.txt");
  std::ofstream("sandbox/file2.txt");
  for (auto& p : fs::directory_iterator("sandbox")) {
    std::cout << p.path() << '\n';
  }
  fs::remove_all("sandbox");
}
```

Output:

```
"sandbox/a"
"sandbox/file1.txt"
"sandbox/file2.txt"
```

filename_part1

```cpp
#include <filesystem>
namespace fs = std::filesystem;

int main() {
  cout << fs::path("/foo/bar.txt").filename() << '\n'
       << fs::path("/foo/.bar").filename() << '\n'
       << fs::path("/foo/bar/").filename() << '\n'
       << fs::path("/foo/.").filename() << '\n'
       << fs::path("/foo/..").filename() << '\n';
}
```

Output:

```
"bar.txt"
".bar"
""
"."
".."
```

filename_part2

```cpp
#include <filesystem>
namespace fs = std::filesystem;

int main() {
  cout << fs::path("/foo/.bar").filename() << '\n'
       << fs::path(".").filename() << '\n'
       << fs::path("..").filename() << '\n'
       << fs::path("/").filename() << '\n'
       << fs::path("//host").filename() << '\n';
}
```

Output:

```
".bar"
"."
".."
""
"host"
```

extension_part1

```cpp
#include <filesystem>
namespace fs = std::filesystem;

int main() {
  cout << fs::path("/foo/bar.txt").extension() << '\n'
       << fs::path("/foo/bar.").extension() << '\n'
       << fs::path("/foo/bar").extension() << '\n'
       << fs::path("/foo/bar.png").extension() << '\n';
}
```

Output:

```
".txt"
"."
""
".png"
```

extension_part2

```cpp
#include <filesystem>
namespace fs = std::filesystem;

int main() {
  cout << fs::path("/foo/.").extension() << '\n'
       << fs::path("/foo/..").extension() << '\n'
       << fs::path("/foo/.hidden").extension() << '\n'
       << fs::path("/foo/..bar").extension() << '\n';
}
```

Output:

```
""
""
""
".bar"
```

stem

```cpp
#include <filesystem>
namespace fs = std::filesystem;

int main() {
  cout << fs::path("/foo/bar.txt").stem() << endl
       << fs::path("/foo/00000.png").stem() << endl
       << fs::path("/foo/.bar").stem() << endl;
}
```

Output:

```
"bar"
"00000"
".bar"
```

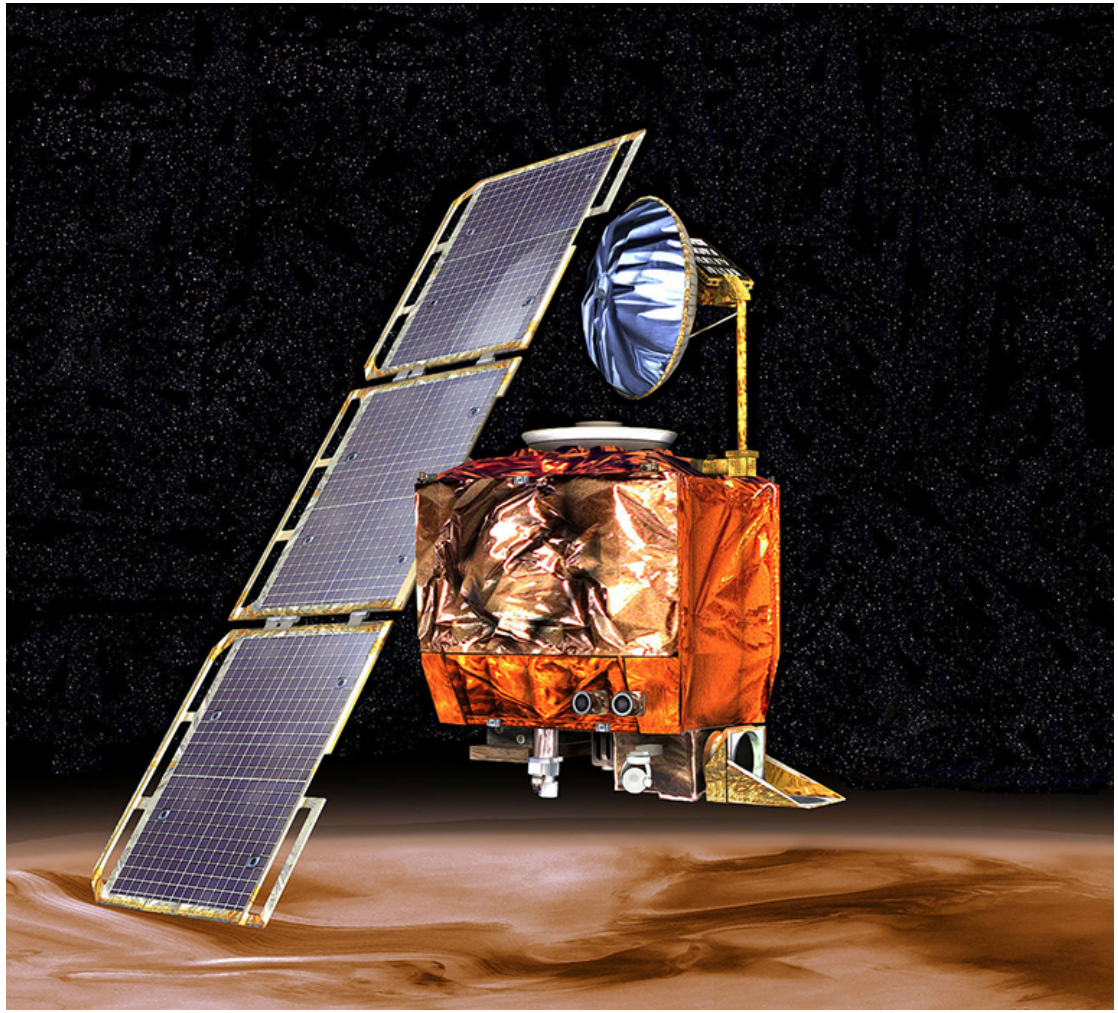
exists

```
1  void demo_exists(const fs::path& p) {
2    cout << p;
3    if (fs::exists(p))   cout << " exists\n";
4    else                 cout << " does not exist\n";
5  }
6
7  int main() {
8    fs::create_directory("sandbox");
9    ofstream("sandbox/file");  // create regular file
10   demo_exists("sandbox/file");
11   demo_exists("sandbox/cacho");
12   fs::remove_all("sandbox");
13 }
```

Output:

```
1  "sandbox/file" exists
2  "sandbox/cacho" does not exist
```

Types are indeed important



https://www.simscale.com/blog/2017/12/nasa-mars-climate-orbiter-metric/

Type safety

bad – the unit is ambiguous

```
1 void blink_led_bad(int time_to_blink) {
2   // do something with time_to_blink
3 }
```

- What if I call `blink_led_bad()` with wrong units?
- When I will detect the error?

good – the unit is explicit

```
1 void blink_led_good(miliseconds time_to_blink) {
2   // do something with time_to_blink
3 }
```

Example taken from: https://youtu.be/fX2W3nNjJIo

Type safety

good – the unit is explicit

```
1 void blink_led_good(miliseconds time_to_blink) {
2   // do something with time_to_blink
3 }
```

Usage

```
1 void use() {
2   blink_led_good(100);     // ERROR: What unit?
3   blink_led_good(100ms);   //
4   blink_led_good(5s);      // ERROR: Bad unit
5 }
```

Example taken from: https://youtu.be/fX2W3nNjJIo

Want more flexibilty?

```
1  template <class rep, class period>
2  void blink_led(duration<rep, period> blink_time) {
3    // millisecond is the smallest relevant unit
4    auto x_ms = duration_cast<miliseconds>(blink_time);
5    // do something else with x_ms
6  }
7
8  void use() {
9    blink_led(2s);      // Works fine
10   blink_led(150ms);   // Also, works fine
11   blink_led(150);     // ERROR, which unit?
12 }
```

Example taken from: https://youtu.be/fX2W3nNjJIo

Type safety in our field

BAD Example: ROS 1

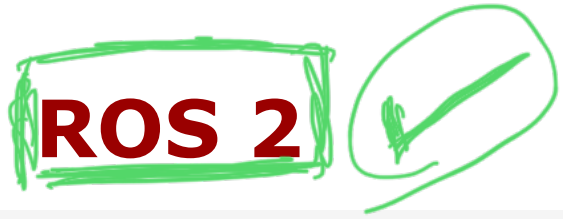
```
1 // ...
2 //
3 // %Tag(LOOP_RATE)%
4 ros::Rate loop_rate(10);
5 // %EndTag(LOOP_RATE)%
6 //
7 // ...
```

`loop_rate` in which units? `Hz`, `ms` ???

https://github.com/ros/ros_tutorials/blob/noetic-devel/roscpp_tutorials/talker/talker.cpp

Type safety in our field

GOOD Example: ROS 2



```
1 // ...
2 //
3 timer_ = create_wall_timer(100ms, timer_callback);
4 //
5 // ...
```

- Same functionality as previous example
- Better code, better readability
- Safer
- Guaranteed to run every 100ms(10 Hz)

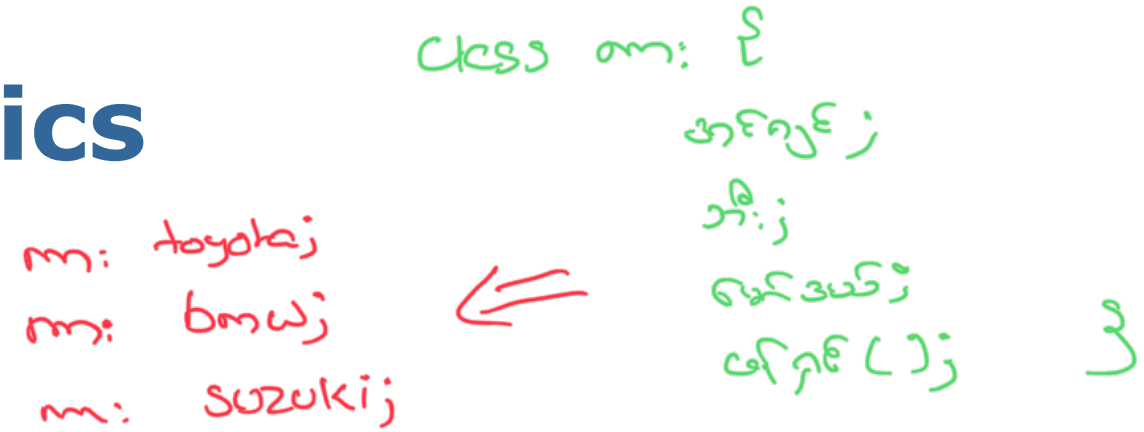
https://github.com/ros2/examples/blob/master/rclcpp/topics/minimal_publisher/lambda.cpp

Class Basics

"C++ classes are a **tools** for creating **new types** that can be used as conveniently as the built-in types. In addition, derived classes and templates allow the programmer to express **relationships** among classes and to take advantage of such relationships."

Extract from: Section 16 of "The C++ Programming Language Book by Bjarne Stroustrup"

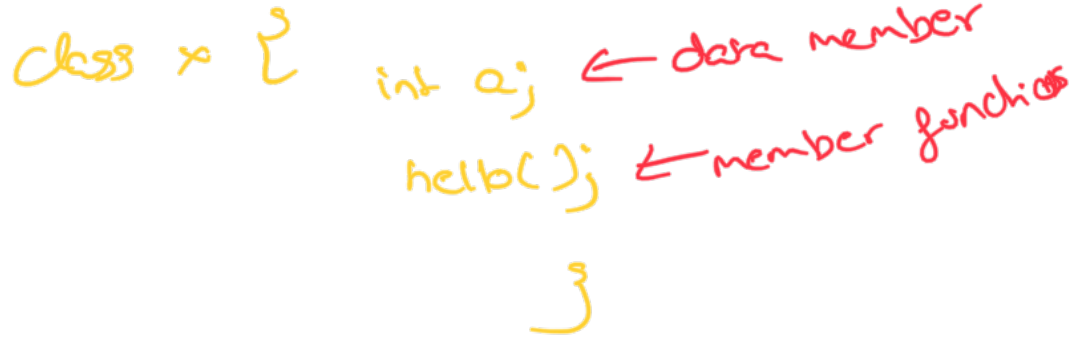
Class Basics



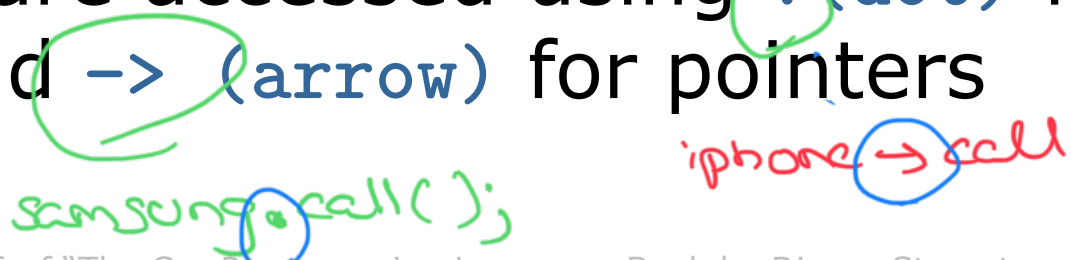
"A type is a concrete representation of a **concept** (an idea, a notion, etc.). A program that provides types that closely match the concepts of the application tends to be easier to **understand**, easier to **reason** about, and easier to **modify** than a program that does not."

Extract from: Section 16 of "The C++ Programming Language Book by Bjarne Stroustrup"

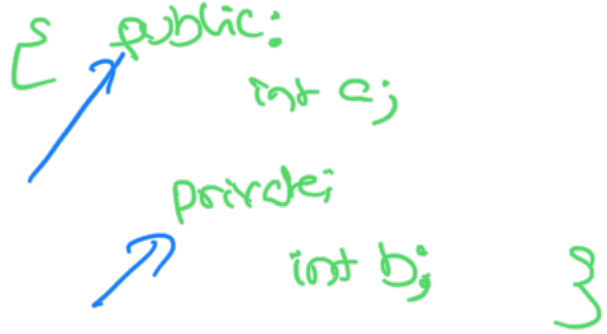
Class Basics



- A `class` is a user-defined type
- A `class` consists of a set of members. The most common kinds of members are data members and member functions
- Member functions can define the meaning of initialization (creation), copy, move, and cleanup (destruction)
- Members are accessed using `.(dot)` for objects and `->` `(arrow)` for pointers



Class Basics



- Operators, such as `+`, `!`, and `[]`, can be defined for a `class`
- A `class` is a namespace containing its members
- The public members provide the class's interface and the private members provide implementation details
- A `struct` is a `class` where members are by default `public`

Extract from: Section 16 of "The C++ Programming Language Book by Bjarne Stroustrup"

Example class definition

```
1  class Image {  // Should be in Image.hpp
2   public:
3    Image(const std::string& file_name);
4    void Draw();
5
6   private:
7    int rows_ = 0;  // New in C+=11
8    int cols_ = 0;  // New in C+=11
9  };
10
11 // Implementation omitted here, should be in Image.cpp
12 int main() {
13   Image image("some_image.pgm");
14   image.Draw();
15   return 0;
16 }
```

Classes in our field

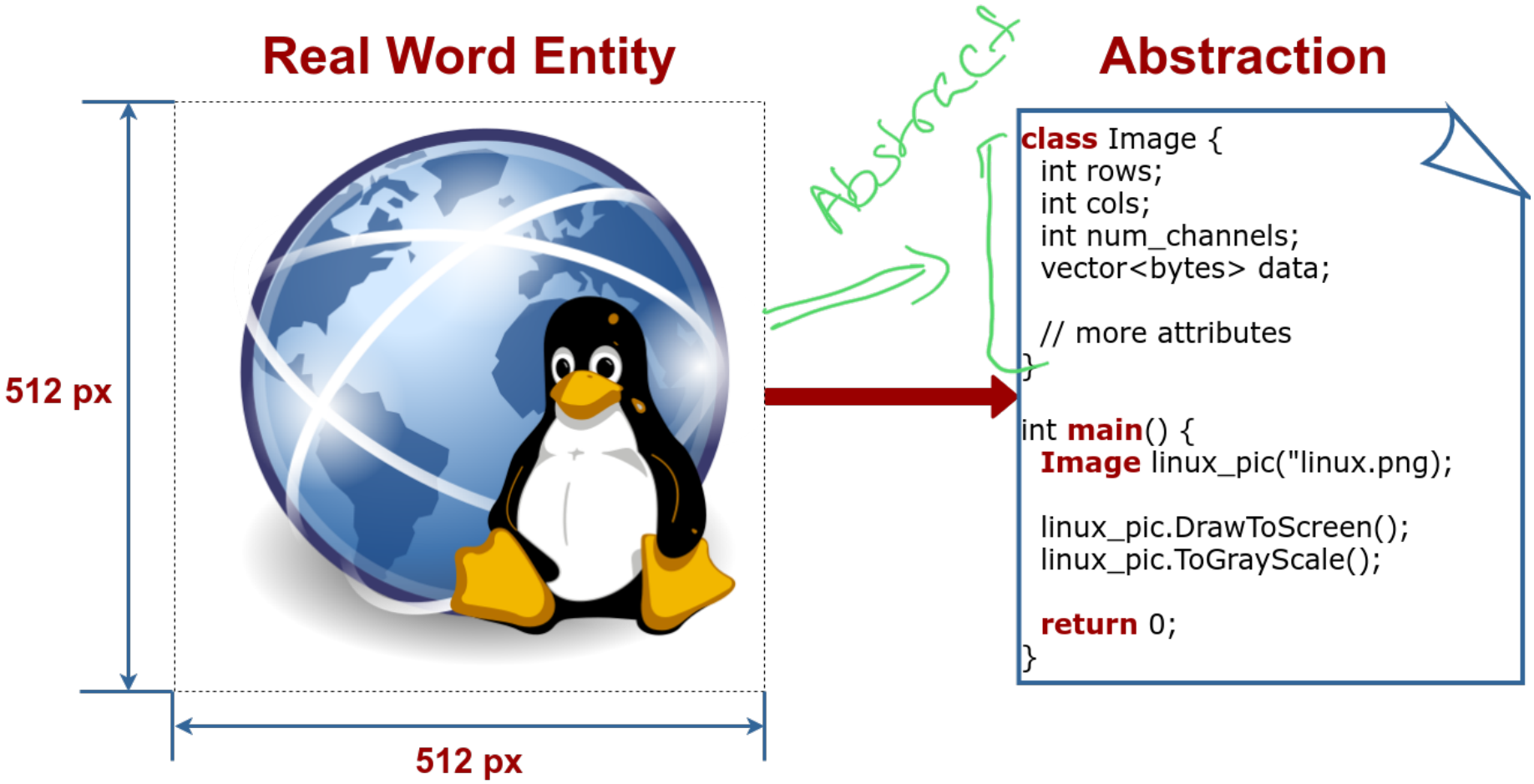
Inheritance

Child Class (Derived class)

Parent Class (Base class)

```
1  // 2D entities
2  class Image : public Geometry2D;
3  class RGBDImage : public Geometry2D;
4
5  // 3D entities
6  class Image : public Geometry2D;
7  class OrientedBoundingBox : public Geometry3D;
8  class AxisAlignedBoundingBox : public Geometry3D;
9  class LineSet : public Geometry3D;
10 class MeshBase : public Geometry3D;
11 class Octree : public Geometry3D;
12 class PointCloud : public Geometry3D;
13 class VoxelGrid : public Geometry3D;
14
15 // 3D surfaces
16 class TetraMesh : public MeshBase;
17 class TriangleMesh : public MeshBase;
```

Image class


Real Word Entity
Abstraction
512 px
512 px
Abstract
class Image {
int rows;
int cols;
int num_channels;
vector<bytes> data;
// more attributes
}
int main() {
Image linux_pic("linux.png);
linux_pic.DrawToScreen();
linux_pic.ToGrayScale();
return 0;
}

One possible realization

Open3D::Geometry::Image

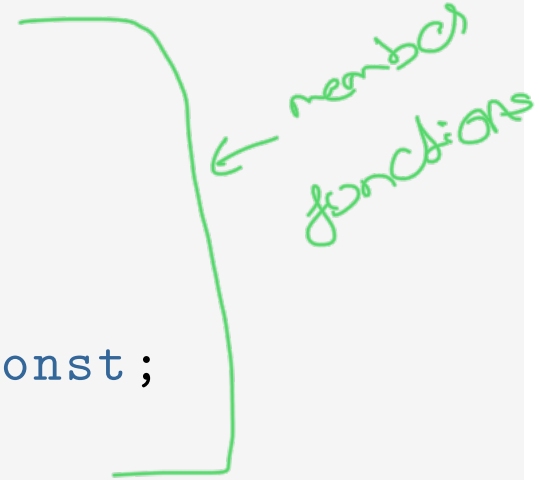
```
1  class Image : public Geometry2D {
2   public:
3    /// Width of the image.
4    int width_ = 0;
5    /// Height of the image.
6    int height_ = 0;
7    /// Number of chanels in the image.
8    int num_of_channels_ = 0;
9    /// Image storage buffer.
10   std::vector<uint8_t> data_;
11 };
```

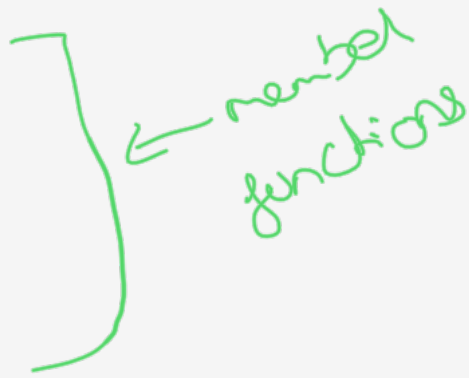
public data members

One possible realization

Open3D::Geometry::Image

```
1  class Image : public Geometry2D {
2   public:
3    void Clear() const override;
4    bool IsEmpty() const override;
5
6    Image FlipHorizontal() const;
7    Image FlipVertical() const;
8    Image Filter(Image::FilterType type) const;
9
10  protected:
11   void AllocateDataBuffer() {
12     data_.resize(width_ *
13                  height_ *
14                  num_of_channels_);
15   }
16 }
```





C++ Visibility Modes

Public If we derive a class from a public base class, Then the public members of the parent class will become public in the derived class and protected member of the base class will become protected in derived class.

Protected If we derive a child-class from a protected-base class, Then both public members and protected member of a base class will become protected in derived class.

Private If we derive a subclass from a private base class, both public & protected members of the base class will become private in derived class:

```
class B: public A
{ }
```

```
class B: protect A
{ }
```

```
class B : private A
{ };
```

Public :

သူ့အထဲက member တွေကို ဘယ်နေရာကပဲ ဖြစ်ဖြစ် ယူသုံးရတယ်။ open to all ပေါ့။ derived class, other class တွေကရောပေါ့။

Protected :

ဒီအထဲက member တွေကိုတော့ derived class တွေကသာ သာလျှင် ရယူသုံးစွဲခွင့်ရှိပါတယ်။

Private :

ဒီအထဲက data member တွေကိုတော့ မိမိရဲ့ class / Object ကလွဲရင် ကျန်တဲ့ကောင်တွေက ရယူသုံးစွဲခွင့် မရှိပါဘူး။

Must Watch

Bag of Visual Words Introduction

SLAM Tutorials

https://youtu.be/a4cFONdc6nc

Suggested Video

Features Descriptors

https://youtu.be/CMolhcwtGAU

References

- **Utility Library**
  https://en.cppreference.com/w/cpp/utility
- **Error handling**
  https://en.cppreference.com/w/cpp/error
- **IO Library**
  https://en.cppreference.com/w/cpp/io
- **Filesystem Library**
  https://en.cppreference.com/w/cpp/filesystem
- **Classes**
  https://en.cppreference.com/w/cpp/classes