C++ - Pre-lecture 4

Introduction to classes

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Credits: Niels Walet, License:

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Part 0.1: in this lecture

In this lecture

- We will take our first steps using *Objects* in Object-Oriented Programming
- Objects ⇔ Classes
    - Think of real objects:
        - defined by their **properties** (nouns)
        - defined by their **functionality** (verbs)
    - Extending this concept to storing and manipulating data:
        - properties = ***data members***
        - functionalities = ***member functions***

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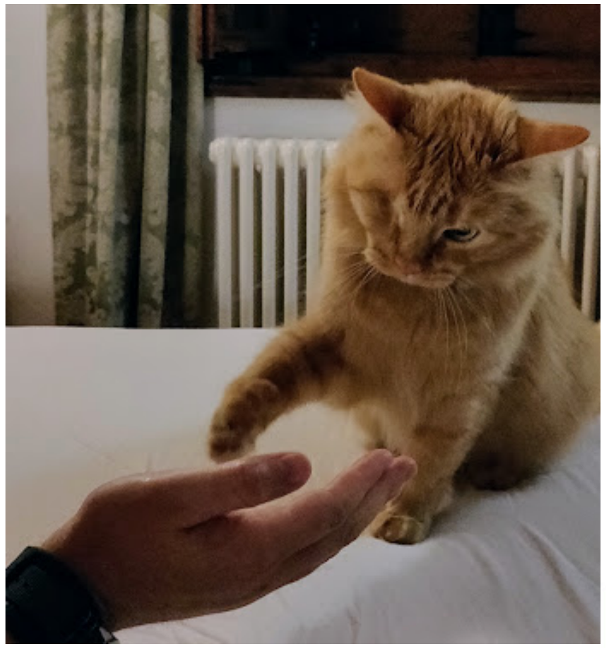
A real-life example

- Class name: **cat**
    - properties = ***data members***
        - ***name**: Bob*
        - ***fur color**: ginger*
        - ***eye(s)**: yellow*
    - functionalities = ***member functions***
        - ***sleep()***
        - ***high_five_with_claws()***



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Our example object: a particle

- **Type**: electron
- **Electric charge**: -1
- **Mass**: 511 MeV
- **Momentum**: xxx
- **Energy**: yyy
- **β-factor**: zzz
  (for non-physics-students: this has to do with special relativity, if the particle is travelling at close to the speed of light then this factor is close to 1)

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Part 1: the struct

A struct

A C-inspired structure that holds properties

- A simple way to capture all the properties of an object (which actually originates in the C language) is the `struct`

- Example: consider a *particle object*.
  - We can define a struct to hold its properties (data)

```
struct particle {
  std::string type;
  double mass;
  double momentum;
  double energy;
}
```

  - Its properties are accessed using its name and the “dot” (.) notation

```
particle p; //make an object of type “particle”
p.type=“electron”;
p.mass=0.511;
```

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struct, functions and data

How to do something with the struct's properties

- Let's have a function to print out the data

```
void print_data(const struct particle &p) {
std::cout.precision(3); // 2 significant figures
std::cout<<"Particle: [type,m,p,E] = ["<<p.type<<","<< p.mass
<<“,"<<p.momentum<<","<<p.energy<<"]"<<std::endl; return;
}
```

- or calculate the Lorentz factor

```
double gamma(const struct particle &p) {
return p.energy/p.mass; }
```

- Those functions can't be stored in the struct (even though they logically belong to it), they can only use the struct as input
- Another disadvantage: the struct declaration can't set up or keep default values for its data members
- Enter **C++ classes**, combining data and functions

Part 2: the class

Our first class

The particle

```
#include<iostream>
#include<string>
#include<cmath>
class particle
{
public:
  std::string type;
  double mass;
  double momentum;
  double energy;
};
void print_data(const struct particle &p)
{
  std::cout.precision(3); // 2 significant figures
  std::cout<<"Particle: [type,m,p,E] = ["<<p.type<<","<< p.mass
      <<","<<p.momentum<<","<<p.energy<<"]"<<std::endl;
  return;
}
double gamma(const struct particle &p)
{
  return p.energy/p.mass;
}
```

Find this code at: Prelecture4/class1.cpp

- This code works exactly as the previous struct
- Advantages:
  - we can decide whether the data in the class is accessible and modifiable by the outside world (*public*) or not (*private*)
    - a struct is a class where all data members are public
  - we can also add functions to this class

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Public/private (for protected, see later lectures)

The principle of least privilege (or: C++'s GDPR)

- Public: can access all data members from "the outside"

```
class particle
{
public:

std::string type;
double mass;
double momentum;
double energy;

};
```

- Private: cannot access data members from "the outside"

```
class particle
{
private:

std::string type;
double mass;
double momentum;
double energy;

//How to access data members: 'accessor' functions
//These must be inside the class!

public:
// Function to set type of particle
void set_type(const string &ptype) {type=ptype;}
// Function to print type of particle
void print_type() {cout<<"Particle is of type "<<type<< endl;}

};
```

- **Principle of least privilege** - *elements of a class (data or functions) should be private unless proven to be needed to be public*
  - This also means that users should not need to rely on / look at the implementation of a class: use **interface** only
  - Advantage: you can change the internal behaviour of a class without affecting its users, as they only use the public interface and functions

Find code that does not compile at: Prelecture4/class2.cpp and modify it so that it does!

Access functions / accessors

How to set/get private member data

- Here, we added two public functions. This is because we wish to access these functions from outside the class.
  - When a new object is created, we use the functions to refer to that particular object.
  - We access these functions in a similar way to accessing the object's (public) data: `myObject.myFunction(myArgument)`; making clear that the function is associated with the object
  - Example for earlier code (this would go in the `main()` function):
    ```
    string type("electron"); particle p1;
    p1.set_type(type); p1.print_type();
    ```
- We only allow access to the data through access functions/accessors. We can protect our data from any undesirable consequences in designing these functions.

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Our particle class

Now with member functions

```
#include<iostream>
#include<string>
#include<cmath>
class particle
{
private:
  std::string type {"Ghost"};
  double mass {0.0};
  double momentum {0.0};
  double energy {0.0};
public:
// Default constructor
  particle() = default ;
// Parameterized constructor
  particle(std::string particle_type, double particle_mass, double particle_momentum) :
    type{particle_type}, mass{particle_mass}, momentum{particle_momentum},
    energy{sqrt(mass*mass+momentum*momentum)}
  {}
  ~particle(){std::cout<<"Destroying "<<type<<std::endl;}  // Destructor
  double gamma() {return energy/mass;}
  void print_data();
};

void particle::print_data()
{
  std::cout.precision(3); // 2 significant figures
  std::cout<<"Particle: [type,m,p,E] = ["<<type<<","<< mass
      <<","<<momentum<<","<<energy<<"]"<<std::endl;
  return;
}
```

Find this code at: Prelecture4/class4.cpp

Constructors and destructors

Special member functions

- Constructors are required in C++ classes to create new objects
  - they must have the same name as the class
  - they also initialise data members
  - there is a default constructor (can "do nothing, leaving things as defaults)…

```
// Default constructor
  particle() = default ;
```

  - as well as constructors that can take arguments, same as any other function in C++
    - the syntax using : and { } assigns data members (including calculations!)

```
// Parameterized constructor
  particle(std::string particle_type, double particle_mass, double particle_momentum) :
    type{particle_type}, mass{particle_mass}, momentum{particle_momentum},
    energy{sqrt(mass*mass+momentum*momentum)}
  {}
```

    - this is done using overloading - to be seen in later lectures
- Destructors 'destroy' the class object

```
~particle(){std::cout<<"Destroying "<<type<<std::endl;}  // Destructor
```

  - They are called when the object of that class goes out of scope, or they can be called by the user
  - Implementation particularly important if dynamical allocation of memory in the class, otherwise memory leak

Find this code at: Prelecture4/class4.cpp

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Functions in classes

And function prototypes inside the class

- So far, all functions were defined within the class itself (e.g. constructors), but we have not specified the details for `print_data`!
- Such a larger member function, included in full detail, can make the code look clumsy
- Solution: put implementation of such member functions outside of the class (or even in a separate file…see bonus content)
- Important note: member functions must be prototyped inside the class
- Example: define a function to print an object's data.
    - We first declare its existence inside class using function prototype
    - And define what it does outside the class, remembering the scope resolution operator ::
        - Common compiler error if that is forgotten: function cannot access data members

Find this code at: Prelecture4/class4.cpp

Refinement of classes

Return values for functions, using vectors

- If we have a large number of particle objects, we can store them into a vector
  - Then we can iterate on the vector using iterators

auto pointers:
we are keeping the best for last…

```
int main()
{
  vector<particle> particle_data;
  particle_data.push_back(particle("electron",5.11e5,1.e6));
  particle_data.push_back(particle("proton",0.938e9,3.e9));
  //vector<particle>::iterator particle_it;
  for(auto particle_it=particle_data.begin();
      particle_it<particle_data.end();
      ++particle_it){
    particle_it->print_data();
    cout<<"has Lorentz factor gamma="<<particle_it->gamma()<<endl;
  }
  return 0;
}
```

Find this code at: Prelecture4/class5.cpp

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Refinement of classes

Return values for functions, using vectors

- This code used a few refinements. If we have a large number of particles, it is much easier to use a vector to contain all of them
- We can then use iterators over the data to output all the information
- Here we use the arrow -> operator to get a class member of a dereferenced pointer `particle_it->print_data();`
  - `particle_it->print_data()` is the same as `(*particle_it).print_data()`, but easier to read.
- Remember, the iterator `particle_it` is like a pointer!

Find this code at: Prelecture4/class5.cpp

Summary of classes so far

“Buzzword summary”

- A **class** is the set of rules used to **define our C++ objects**. It specifies which types of **data** and **functions** are created and their **scope** (private or public)
- An **object** is an **instance of a class**. Each object will have specified its own set of data (values of the data members).
- A **member** refers to either **data** or a **function** belonging to a particular class, e.g. a constructor will be a member function. Member functions are sometimes called **methods**
- A **constructor** is a special function called when a class is instantiated, usually to **initialise** an object’s member data. If not user generated, generated by compiler.
- A **destructor** is the function called when an object is **destroyed** (usually automatically when exiting a function; we say “the object goes **out of scope**”– this happens when we can no longer access the object). If not user generated, generated by compiler.

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Bonus content

[not in assignments/projects, unless you feel brave]

In Visual Studio / Visual Studio Code we always deal with one .cpp file at a time, b
ut how do we deal with separate headers and implementations?

Proper answer: via Makefile / CMake…
Working answer: see next slide

Headers and implementation

A reminder

- C++ classes are usually split into two different parts, often in different files
  - *Header* (file extension: .h, .hpp) = where things are defined
    - Think of it as the index of a book
    - Usually headers contain *interfaces* that help you get an overview of what something (e.g a function) does, without the clutter of the full implementation
  - *Implementation* (file extension: .cxx, .cpp) = where things are implemented
    - Think of it as the book content
    - The implementation of the class's functions go here

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Our particle class, split in .cxx and .h

Compilation will have to change slightly…

```
#ifndef PARTICLE_H
#define PARTICLE_H

#include<iostream>
#include<string>
#include<cmath>
class particle
{
private:
  std::string type {"Ghost"};
  double mass {0.0};
  double momentum {0.0};
  double energy {0.0};
public:
// Default constructor
  particle() = default ;
// Parameterized constructor
  particle(std::string particle_type, double particle_mass, double particle_momentum) :
    type{particle_type}, mass{particle_mass}, momentum{particle_momentum},
    energy{sqrt(mass*mass+momentum*momentum)}
  {};
  ~particle(){std::cout<<"Destroying "<<type<<std::endl;}  // Destructor (in-line)
  double gamma() {return energy/mass;} // One-line functions are OK in-line
  void print_data();
};

#endif
```

Find this code at: Prelecture4/particle.h

```
#include<iostream>
#include "particle.h"

void particle::print_data()
{
  std::cout.precision(3); // 2 significant figures
  std::cout<<"Particle: [type,m,p,E] = ["<<type<<","<< mass
    <<","<<momentum<<","<<energy<<"]"<<std::endl;
  return;
}
```

Find this code at: Prelecture4/particle.cpp

```
#include<iostream>
#include<string>
#include<cmath>
#include "particle.h"

int main()
{
  // Set values for the two particles
  particle electron("electron",5.11e5,1.e6);
  particle proton("proton",0.938e9,3.e9);
  // Print out details
  electron.print_data();
  proton.print_data();
  // Calculate Lorentz factors
  std::cout.precision(2);
  std::cout<<"Particle 1 has Lorentz factor gamma="
    <<electron.gamma()<<std::endl;
  std::cout<<"Particle 2 has Lorentz factor gamma="
    <<proton.gamma()<<std::endl;
  return 0;
}
```

Find this code at: Prelecture4/main_class4.cpp

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How do we compile this?

Make sure all .cpp are compiled,
the .h are included automatically

- [yourCompilerDir]/g++-11 -fdiagnostics-color=always -g [yourdir]/main_class4.cpp [yourdir]/particle.cpp -o [yourdir]/main_class4