Classes in C++

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Program construction in C++ for Scientific Computing

Outline

What is a Class?

- An abstract data type is a (nonempty, finite) set and the collection of operations defined on this set.
- A C++ class is the programmatic description of a data type.
- An object is an instance of a class.

An abstract data type is a suitable model for implementing abstract mathematical structures.

Formal Class Declaration

C++ class declaration

```
class identifier {
public:
  // Public class members
protected:
  // Protected class members
private:
  // Private class members
};  // Do not forget the semicolon here!!
```

where identifier is the name of the class.

- The members can be basic data types, other classes or functions.
- Public members can be accesses from anywhere in the program.
- Private members can only be accessed from member functions of the class.
- Protected members can be accessed from derived classes additionally to member functions of the class.

Class Declaration (cont)

- Instead of class, the reserved word struct can be used. The difference lies in the default access behavior.
- Default access behavior: class = private; struct = public.
- *Convention*: Names of classes start usually with a capital letter.

A Simple Class

- The mathematical notion: *Points in the two-dimensional Cartesian plane*
- The implementation of this mathematical notion should look to the user as if it were a standard type.
- The user of the class does not need to know how the internals look like.
- *Example*: The user should be able to write something like

```
Point P;
Point W(1.0,2.0);
Point Q = P;
```

A C-Style Implementation

```
class Point {
  public:
    double x;
    double y;
};
```

Note: The keyword `class` can be replaced by `struct`. The latter is the way one would do it in C.

- The coordinates can be accessed via `P.x` and `P.y` using explicitly the implementation.
- *What if we instead would use polar coordinates in the implementation?* The user must rewrite his/her code!

A C++-Style Implementation

```
class Point {
  private:        // Can be omitted here
    double x;
    double y;
  public:
    double X() { return x; }  // return x coordinate
    double Y() { return y; }  // return y coordinate
    void zero() { x = y = 0.0; } // set point to origi
};
```

The user can access the Cartesian coordinates via P.X() and P.Y(), respectively.

Another Implementation

```
class Point {
  private:
    double r;
    double phi;
  public:
    double X() { return r*std::cos(phi); }
    double Y() { return r*std::sin(phi); }
    void zero() { r = phi = 0.0; }
};
```

The user interface did not change!

- The variables r, phi are called data members of the class.
- The functions X, Y, zero are the member functions of the class.

Programming Style: Separation of Interface and Implementation

The interface file point.hpp may look like this:

```
#ifndef POINT_HPP
#define POINT_HPP

class Point {
    double x;
    double y;
  public:
    double X();
    double Y();
    void zero();
};

#endif
```

Implementation

```
#include ‘‘point.hpp’’

double Point::X() {
  return x;
}
double Point::Y() {
  return y;
}
void Point::zero() {
  x = y = 0.0;
}
```

The user of the class will most probably never see the implementation!

Efficiency Considerations: Inlining

- The principle of data hiding leads often to very many small member functions.
- Calling a function includes an overhead compared with the simple data member access (e.g., P.x).
- The overhead can lead to low efficiency if calls happen rather often (inside innermost loops).
- This overhead can be avoided by function inlining.
- Note: Inlining is a hint to the compiler. The compiler can do it or not.
- Function bodies defined in header files are inlined be default, while functions defined in the implementation are not. (*Guess why?*)

Efficiency Considerations: `const`

- A compiler can often optimize the code much better if it can use additonal assumptions about the function behavior.
- One important property is if certain objects are constant.
- Example: In the definition

  ```
  const int N = 10;
  ```

  the variable `N` will never change its value. Doing so will result in a compilation error.
- As a byproduct, the user interface may become safer.

const And Pointers

- Consider the definition

```
const double *p;
```

- This construct indicates that the double the pointer p *is pointing to* will never change its value.
- Consider instead

```
double *const p = &q;
```

- Here, *the pointer* p will never change its value.

Efficiency Considerations: `point` Class

For efficiency, the header file should look like this:

```
#ifndef POINT_HPP
#define POINT_HPP
class Point {
  private:        // Can be omitted here
    double x;
    double y;
  public:
    double X() const { return x; }
    double Y() const { return y; }
    void zero() { x = y = 0.0; }
};
#endif
```

The keyword `const` indicates that the object will not change its state when queuried for the coordinates.

Constructors

- Constructors determine what happens if an instance of a class (an object) is created.
- Built-in data types have default constructors: E.g., a statement `int i;` reserves memory for one instance of type integer.
- The initial value of an instance of a built-in type is undefined!
- A definition of the type `int i = 0;` invokes another type of constructor, the so-called copy constructor.
- A definition of the kind *class variable*; invokes a constructor

  ```
  class::class()
  ```

  as a member function of the instance *variable*. (the so-called default constructor)

Constructors (cont)

- If no constructors are defined in a class, the so-called *synthesized default constructor* is automatically defined by the compiler.
- The synthesized default constructor invokes recursively the default constructors of the data members.
- As soon as at least one constructor is defined in the class, the default constructor is not available (unless it is explicitely required by `class() = default;`)
- Be careful: The synthesized default constructor might not be what you want! (Shallow vs deep copy)

point Class Constructors

- We want something like

```
Point();
Point(double xx, double yy);
```

- The default constructor is "do nothing but reserve memory":

```
Point() {}
```

- The next one seems also easy:

```
Point(double xx, double yy) { x = xx; y = yy; }
```

point Class Constructors (cont)

- A more efficient way: Use initialization lists:

```
Point(double xx, double yy) : x(xx), y(yy) { }
```

  (uses the copy constructors)

- And finally: A versatile version (even replacing the default constructor):

```
Point(double xx = 0.0, double yy = 0.0) :
                x(xx), y(yy) { }
```

- Now, we can define:

```
Point P(3.0,5.0);
Point Q(3.0);
Point W;
```

  but even:

```
Point *p; p = new Point(2.0);
```

Constructors: Intialization Lists

We *must* use the constructor initializer list to provide values for members that are const, reference, or of class type that does not have a default constructor.
Example:

```
class ConstRef {
  public:
    ConstRef(int ii);
  private:
    int i;
    const int ci;
    int &ri;
};
```

Initialization Lists (cont)

Correct

```
ConstRef::ConstRef(int ii): i(ii), ci(ii), ri(i) { }
```

Erroneous

```
ConstRef::ConstRef(int ii) {
  i = ii;  // ok
  ci = ii; // wrong since ci is const
  ri = i;  // wrong: ri was never initialized
}
```

The Copy Constructor

- *Aim*: Initialize an instance of a class by another instance of the same class:

```
Point P(3.0,5.0);
Point Q(P);
Point W = Q;
```

- The creation of the objects `Q` and `W` are handled by the *copy constructor*.
- The copy constructor is invoked when
  - objects are defined by = or class(object of that class)
  - objects are passed as actual parameters for non-reference arguments
  - return object from a function that has a non-reference return type.
- This explains why the argument must be of reference type! (*Why?*)

The Default Copy Constructor

- The default copy constructor invokes the copy constructors of all data members.
- For built-in types, this is a simple copy.
- In our example, it is equivalent to:

```
Point(const Point& Q): x(Q.x), y(Q.y) { }
```

Note: This is not identical to

```
Point(const Point& Q) {x = Q.x; y = Q.y; }
```

Why?

- If the class manages its own dynamic memory (e.g. using new type[n]), one must most probably define its own copy constructor!
- Discussion: Should one define one's own copy constructor?

Remark

- In the following, `Q` is constructed via the copy constructor:

```
Point P(3.0,5.0);
Point Q = P;
```

- Compare:

```
Point P(3.0,5.0), Q;
Q = P;
```

This case is handled by the *copy-assignment* constructor! This is different from the previous one!

Copy Constructor: Efficiency

Consider the following ordinary (non-member) function:

```
const Point negative(const Point P) {
  return Point(-P.X(),-P.Y());
}
```

- This version is very expensive, since it uses the constructor 3 times!

It's demo time!

Efficiency (cont)

- Better:

```
const Point negative(const Point& P) {
  return Point(-P.X(),-P.Y());
}
```

- Note: The return type cannot be `const Point&`! *Why?*
- The C++11 and later standards have means to avoid certain copies of temporary objects (move and move-assignment constructors).

The Destructor

- Inverse operation of constructors.
- Destructors do whatever work is needed to free the resources used by an object.
- The destructor is a member function with empty argument list with the name of the class prefixed by a tilde:

  ```
  ~Point() { }
  ```

  In our simple example, it is a no-op. The runtime system releases the memory.
- *In general, releasing resources must be handled very carefully in order to avoid memory leaks etc!*

Type Conversion

- What happens in the following situation?

```
double d = 1;
```

The constant "1" is `int`, the variable defined of type `double`.

- The integer constant is implicitely converted to type double (1.0) and then assigned.
- In case of the definition

```
Point P = 1.0;
```

the constructor Point(1.0) is invoked.

- *This way, the constructor includes an implicit type conversion!*
- Note: Explicit type conversion ("*type casting*") is included in this mechanism:

```
Point P,Q; P = static_cast<Point>(1.0); Q = (Point)
```

Be careful! Avoid explicit type casting!

`static` Class Members

- Any member of a class can be static.
- A static member exists only once for each class. Thus, it is not bound to a concrete object.
- A static member function does not contain a `this` pointer. It can only use static class members.
- Definition of a static member outside of a class body: Omit the `static` keyword.
- Static data members must be initialized outside the class (No constructor will be called!)
- constexpr static data members will be initialized in the class definition.

Summary

What we learned:

- Basic definitions of classes
- Private and public members
- Constructors and destructors
- Constructors: Efficiency considerations

- What comes next:
  - Operator overloading