C++ Programming Language

Object-Oriented Programming (OOP) in C++

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1. Why OOP?

Suppose that you want to assemble your own PC, you go to a hardware store and pick up a motherboard, a processor, some RAMs, a hard disk, a casing, a power supply, and put them together. You turn on the power, and the PC runs. You need not worry whether the motherboard is a 4-layer or 6-layer board, whether the hard disk has 4 or 6 plates; 3 inches or 5 inches in diameter, whether the RAM is made in Japan or Korea, and so on. You simply put the hardware *components* together and expect the machine to run. Of course, you have to make sure that you have the correct *interfaces*, i.e., you pick an IDE hard disk rather than a SCSI hard disk, if your motherboard supports only IDE; you have to select RAMs with the correct speed rating, and so on. Nevertheless, it is not difficult to set up a machine from hardware *components*.

Similarly, a car is assembled from parts and components, such as chassis, doors, engine, wheels, brake, and transmission. The components are reusable, e.g., a wheel can be used in many cars (of the same specifications).

Hardware, such as computers and cars, are assembled from parts, which are reusable components.

How about software? Can you "assemble" a software application by picking a routine here, a routine there, and expect the program to run? The answer is obviously no! Unlike hardware, it is very difficult to "assemble" an application from *software components*. Since the advent of computer 60 years ago, we have written tons and tons of programs. However, for each new application, we have to re-invent the wheels and write the program from scratch.

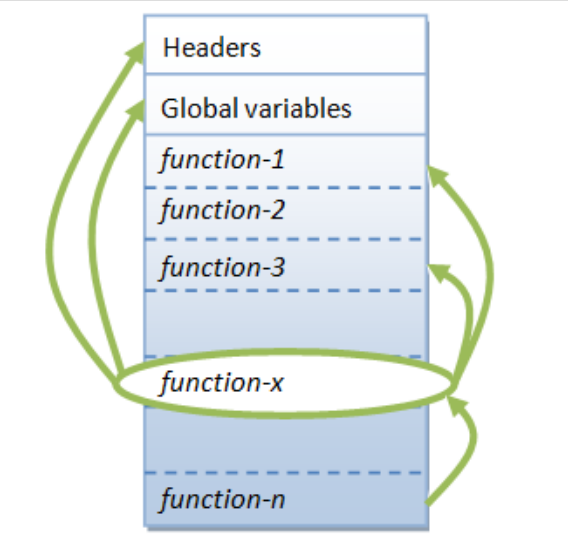
Why re-invent the wheels?

1.1 Traditional Procedural-Oriented languages

Can we do this in traditional procedural-oriented programming language such as C, Fortran, Cobol, or Pascal?

Traditional procedural-oriented languages (such as C and Pascal) suffer some notable drawbacks in creating reusable software components:

1. The programs are made up of functions. Functions are often not *reusable*. It is very difficult to copy a function from one program and reuse in another program because the the



A function (in C) is not well-encapsulated

function is likely to reference the headers, global variables and other functions. In other words, functions are not well-encapsulated as a self-contained *reusable unit*.

2. The procedural languages are not suitable of *high-level abstraction* for solving real life problems. For example, C programs uses constructs such as if-else, for-loop, array, function, pointer, which are low-level and hard to abstract real problems such as a Customer Relationship Management (CRM) system or a computer soccer game. (Imagine using assembly codes, which is a very low level code, to write a computer soccer game. C is better but no much better.)

In brief, the traditional procedural-languages *separate* the data structures and algorithms of the software entities.

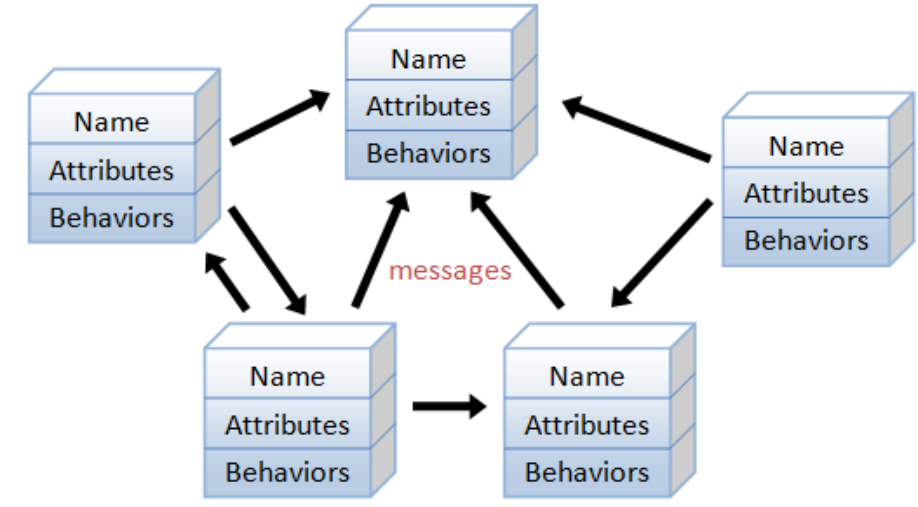
In the early 1970s, the US Department of Defense (DoD) commissioned a task force to investigate why its IT budget always went out of control; but without much to show for. The findings are:

1. 80% of the budget went to the software (while the remaining 20% to the hardware).
2. More than 80% of the software budget went to maintenance (only the remaining 20% for new software development).
3. Hardware components could be applied to various products, and their integrity normally did not affect other products. (Hardware can share and reuse! Hardware faults are isolated!)
4. Software procedures were often non-sharable and not reusable. Software faults could affect other programs running in computers.

The task force proposed to make software behave like hardware OBJECT. Subsequently, DoD replaces over 450 computer languages, which were then used to build DoD systems, with an object-oriented language called Ada.

1.2 Object-Oriented Programming Languages

Object-oriented programming (OOP) languages are designed to overcome these problems.

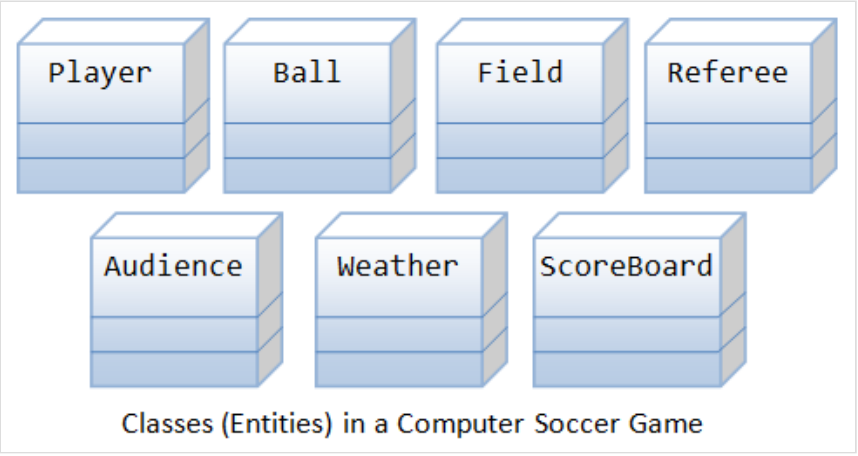


An object-oriented program consists of many well-encapsulated objects and interacting with each other by sending messages

1. The basic unit of OOP is a *class*, which encapsulates both the *static attributes* and *dynamic behaviors* within a "box", and specifies the public interface for using these boxes. Since the class is well-encapsulated (compared with the function), it is easier to reuse these classes. In other words, OOP combines the data structures and algorithms of a software entity inside the same box.
2. OOP languages permit *higher level of abstraction* for solving real-life problems. The traditional procedural language (such as C and Pascal) forces you to think in terms of the structure of the computer (e.g. memory bits and bytes, array, decision, loop) rather than thinking in terms of the problem you are trying to solve. The OOP languages (such

as Java, C++, C#) let you think in the problem space, and use software objects to represent and abstract entities of the problem space to solve the problem.

As an example, suppose you wish to write a computer soccer games (which I consider as a complex application). It is quite difficult to model the game in procedural-oriented languages. But using OOP languages, you can easily model the program accordingly to the "real things" appear in the soccer games.



Classes (Entities) in a Computer Soccer Game

- Player: attributes include name, number, location in the field, and etc; operations include run, jump, kick-the-ball, and etc.
- Ball:
- Reference:
- Field:
- Audience:
- Weather:

Most importantly, some of these classes (such as `Ball` and `Audience`) can be reused in another application, e.g., computer basketball game, with little or no modification.

1.3 Benefits of OOP

The procedural-oriented languages focus on procedures, with function as the basic unit. You need to first figure out all the functions and then think about how to represent data.

The object-oriented languages focus on components that the user perceives, with objects as the basic unit. You figure out all the objects by putting all the data and operations that describe the user's interaction with the data.

Object-Oriented technology has many benefits:

- *Ease in software design* as you could think in the problem space rather than the machine's bits and bytes. You are dealing with high-level concepts and abstractions. Ease in design leads to more productive software development.
- *Ease in software maintenance*: object-oriented software are easier to understand, therefore easier to test, debug, and maintain.
- *Reusable software*: you don't need to keep re-inventing the wheels and re-write the same functions for different situations. The fastest and safest way of developing a new application is to reuse existing codes - fully tested and proven codes.

2. OOP Basics

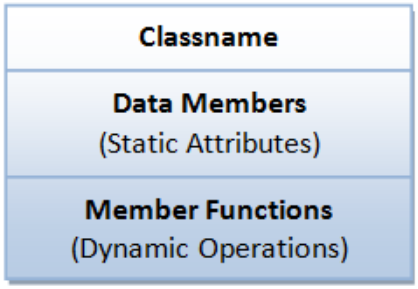
2.1 Classes & Instances

Class: A *class is a definition of objects of the same kind*. In other words, a *class* is a blueprint, template, or prototype that defines and describes the *static attributes* and *dynamic behaviors* common to all objects of the same kind.

Instance: An *instance* is *a realization of a particular item of a class*. In other words, an instance is an *instantiation* of a class. All the instances of a class have similar properties, as described in the class definition. For example, you can define a class called "`Student`" and create three instances of the class "`Student`" for "`Peter`", "`Paul`" and "`Pauline`".

The term "*object*" usually refers to *instance*. But it is often used quite loosely, which may refer to a class or an instance.

2.2 A Class is a 3-Compartment Box encapsulating Data and Functions



A class is a 3-compartment box encapsulating data and functions

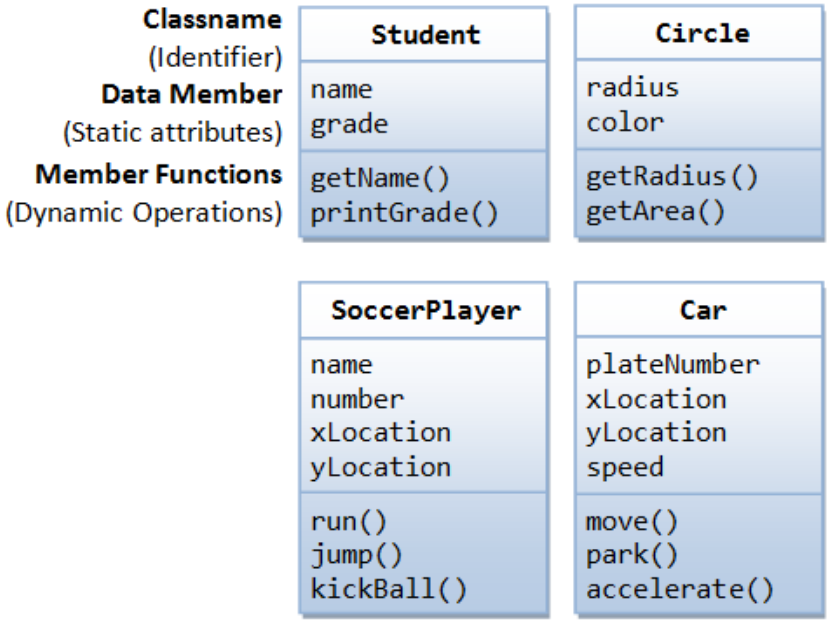
A class can be visualized as a three-compartment box, as illustrated:

1. ***Classname*** (or identifier): identifies the class.
2. ***Data Members*** or ***Variables*** (or *attributes*, *states*, *fields*): contains the *static attributes* of the class.
3. ***Member Functions*** (or *methods*, *behaviors*, *operations*): contains the *dynamic operations* of the class.

In other words, a class encapsulates the static attributes (data) and dynamic behaviors (operations that operate on the data) in a box.

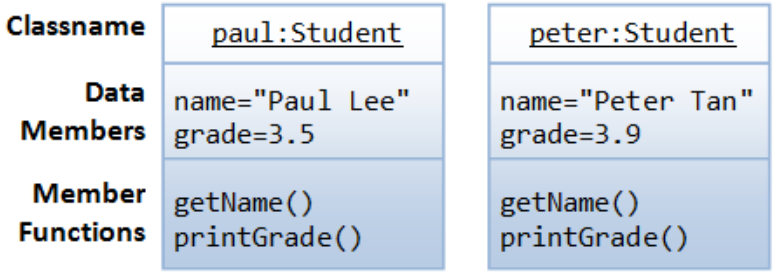
Class Members: The *data members* and *member functions* are collectively called *class members*.

The followings figure shows a few examples of classes:



Examples of classes

The following figure shows two instances of the class `Student`, identified as "`paul`" and "`peter`".



Two instances of the `Student` class

Unified Modeling Language (UML) Class and Instance Diagrams: The above class diagrams are drawn according to the UML notations. A class is represented as a 3-compartment box, containing name, data members (variables), and member functions, respectively. classname is shown in bold and centralized. An instance (object) is also represented as a 3-compartment box, with instance name shown as `instanceName:Classname` and underlined.

Brief Summary

1. A *class* is a programmer-defined, abstract, self-contained, reusable software entity that mimics a real-world thing.
2. A class is a 3-compartment box containing the name, data members (variables) and the member functions.

3. A class encapsulates the data structures (in data members) and algorithms (member functions). The values of the data members constitute its *state*. The member functions constitute its *behaviors*.
4. An *instance* is an instantiation (or realization) of a particular item of a class.

2.3 Class Definition

In C++, we use the keyword `class` to define a class. There are two sections in the class declaration: `private` and `public`, which will be explained later. For examples,

```
class Circle {          // classname
private:
   double radius;       // Data members (variables)
   string color;
public:
   double getRadius(); // Member functions
   double getArea();
}
```

```
class SoccerPlayer {    // classname
private:
   int number;          // Data members (variables)
   string name;
   int x, y;
public:
   void run();          // Member functions
   void kickBall();
}
```

Class Naming Convention: A classname shall be a noun or a noun phrase made up of several words. All the words shall be initial-capitalized (camel-case). Use a *singular* noun for classname. Choose a meaningful and self-descriptive classname. For examples, `SoccerPlayer`, `HttpProxyServer`, `FileInputStream`, `PrintStream` and `SocketFactory`.

2.4 Creating Instances of a Class

To create *an instance of a class*, you have to:

1. Declare an instance identifier (name) of a particular class.
2. Invoke a constructor to construct the instance (i.e., allocate storage for the instance and initialize the variables).

For examples, suppose that we have a class called `Circle`, we can create instances of `Circle` as follows:

```
// Construct 3 instances of the class Circle: c1, c2, and c3
Circle c1(1.2, "red");  // radius, color
Circle c2(3.4);         // radius, default color
Circle c3;              // default radius and color
```

Alternatively, you can invoke the constructor explicitly using the following syntax:

```
Circle c1 = Circle(1.2, "red");  // radius, color
Circle c2 = Circle(3.4);         // radius, default color
Circle c3 = Circle();            // default radius and color
```

2.5 Dot (.) Operator

To reference a *member of a object* (data member or member function), you must:

1. First identify the instance you are interested in, and then
2. Use the *dot operator* (`.`) to reference the member, in the form of *`instanceName.memberName`*.

For example, suppose that we have a class called `Circle`, with two data members (`radius` and `color`) and two functions (`getRadius()` and `getArea()`). We have created three instances of the class `Circle`, namely, `c1`, `c2` and `c3`. To invoke the function `getArea()`, you must first identity the instance of interest, says `c2`, then use the *dot operator*, in the form of `c2.getArea()`, to invoke the `getArea()` function of instance `c2`.

For example,

```
// Declare and construct instances c1 and c2 of the class Circle
Circle c1(1.2, "blue");
Circle c2(3.4, "green");
// Invoke member function via dot operator
cout << c1.getArea() << endl;
cout << c2.getArea() << endl;
// Reference data members via dot operator
c1.radius = 5.5;
c2.radius = 6.6;
```

Calling `getArea()` without identifying the instance is meaningless, as the radius is unknown (there could be many instances of `Circle` - each maintaining its own radius).

In general, suppose there is a class called *`AClass`* with a data member called *`aData`* and a member function called *`aFunction`*`()`. An instance called *`anInstance`* is constructed for *`AClass`*. You use *`anInstance.aData`* and *`anInstance.aFunction`*`()`.

2.6 Data Members (Variables)

A *data member* (*variable*) has a *name* (or *identifier*) and a *type*; and holds a *value* of that particular type (as descried in the earlier chapter). A data member can also be an instance of a certain class (to be discussed later).

Data Member Naming Convention: A data member name shall be a noun or a noun phrase made up of several words. The first word is in lowercase and the rest of the words are initial-capitalized (camel-case), e.g., `fontSize`, `roomNumber`, `xMax`, `yMin` and `xTopLeft`. Take note that variable name begins with an lowercase, while classname begins with an uppercase.

2.7 Member Functions

A member function (as described in the earlier chapter):

1. receives parameters from the caller,
2. performs the operations defined in the function body, and
3. returns a piece of result (or void) to the caller.

Member Function Naming Convention: A function name shall be a verb, or a verb phrase made up of several words. The first word is in lowercase and the rest of the words are initial-capitalized (camel-case). For example, `getRadius()`, `getParameterValues()`.

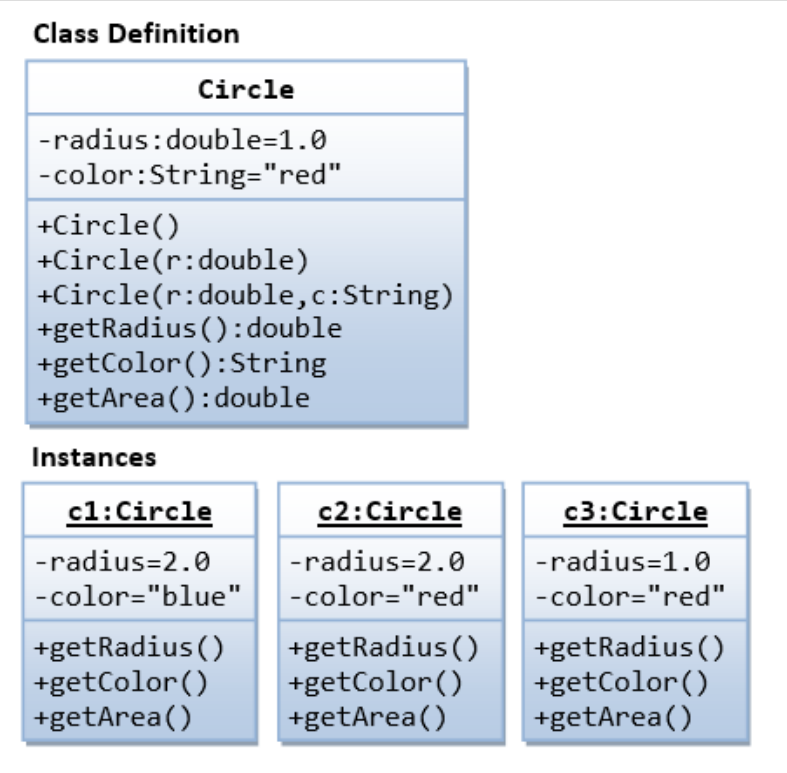
Take note that data member name is a noun (denoting a static attribute), while function name is a verb (denoting an action). They have the same naming convention. Nevertheless, you can easily distinguish them from the context. Functions take arguments in parentheses (possibly zero argument with empty parentheses), but variables do not. In this writing, functions are denoted with a pair of parentheses, e.g., `println()`, `getArea()` for clarity.

2.8 Putting them Together: An OOP Example

A class called `Circle` is to be defined as illustrated in the class diagram. It contains two data members: `radius` (of type `double`) and `color` (of type `String`); and three member functions: `getRadius()`, `getColor()`, and `getArea()`.

Three instances of `Circle`s called `c1`, `c2`, and `c3` shall then be constructed with their respective data members, as shown in the instance diagrams.

In this example, we shall keep all the codes in a single source file called `CircleAIO.cpp`.



CircleAIO.cpp

```
1  /* The Circle class (All source codes in one file) (CircleAIO.cpp) */
2  #include <iostream>    // using IO functions
3  #include <string>      // using string
4  using namespace std;
5
6  class Circle {
7  private:
8     double radius;      // Data member (Variable)
9     string color;       // Data member (Variable)
10
11 public:
12    // Constructor with default values for data members
13    Circle(double r = 1.0, string c = "red") {
14       radius = r;
15       color = c;
16    }
17
18    double getRadius() {  // Member function (Getter)
19       return radius;
20    }
21
22    string getColor() {   // Member function (Getter)
23       return color;
24    }
25
26    double getArea() {    // Member function
27       return radius*radius*3.1416;
28    }
29 };   // need to end the class declaration with a semi-colon
30
31 // Test driver function
32 int main() {
33    // Construct a Circle instance
34    Circle c1(1.2, "blue");
35    cout << "Radius=" << c1.getRadius() << " Area=" << c1.getArea()
36         << " Color=" << c1.getColor() << endl;
37
38    // Construct another Circle instance
```

```
   Circle c2(3.4); // default color
   cout << "Radius=" << c2.getRadius() << " Area=" << c2.getArea()
        << " Color=" << c2.getColor() << endl;

   // Construct a Circle instance using default no-arg constructor
   Circle c3;      // default radius and color
   cout << "Radius=" << c3.getRadius() << " Area=" << c3.getArea()
        << " Color=" << c3.getColor() << endl;
   return 0;
}
```

To compile and run the program (with GNU GCC under Windows):

```
> g++ -o CircleAIO.exe CircleAIO.cpp
   // -o specifies the output file name

> CircleAIO
Radius=1.2 Area=4.5239 Color=blue
Radius=3.4 Area=36.3169 Color=red
Radius=1 Area=3.1416 Color=red
```

2.9 Constructors

A *constructor* is a special function that has the *function name same as the classname*. In the above `Circle` class, we define a constructor as follows:

```
// Constructor has the same name as the class
Circle(double r = 1.0, string c = "red") {
   radius = r;
   color = c;
}
```

A constructor is used to construct and *initialize all the data members*. To create a new instance of a class, you need to declare the name of the instance and invoke the constructor. For example,

```
Circle c1(1.2, "blue");
Circle c2(3.4);      // default color
Circle c3;           // default radius and color
                     // Take note that there is no empty bracket ()
```

A constructor function is different from an ordinary function in the following aspects:

- The name of the constructor is the same as the classname.
- Constructor has no return type (or implicitly returns `void`). Hence, no `return` statement is allowed inside the constructor's body.
- Constructor can only be invoked *once* to initialize the instance constructed. You cannot call the constructor afterwards in your program.
- Constructors are not inherited (to be explained later).

2.10 Default Arguments for Functions

In C++, you can specify the default value for the trailing arguments of a function (including constructor) in the function header. For example,

```
/* Test function default arguments (TestFnDefault.cpp) */
#include <iostream>
using namespace std;

// Function prototype
int sum(int n1, int n2, int n3 = 0, int n4 = 0, int n5 = 0);

int main() {
   cout << sum(1, 1, 1, 1, 1) << endl; // 5
   cout << sum(1, 1, 1, 1) << endl;    // 4
   cout << sum(1, 1, 1) << endl;       // 3
```

```
   cout << sum(1, 1) << endl;          // 2
// cout << sum(1) << endl;  // error: too few arguments
}

// Function definition
// The default values shall be specified in function prototype,
//   not the function implementation
int sum(int n1, int n2, int n3, int n4, int n5) {
   return n1 + n2 + n3 + n4 + n5;
}
```

2.11 "public" vs. "private" Access Control Modifiers

An *access control modifier* can be used to control the visibility of a data member or a member function within a class. We begin with the following two access control modifiers:

1. **`public`**: The member (data or function) is accessible and available to *all* in the system.
2. **`private`**: The member (data or function) is accessible and available *within this class only*.

For example, in the above `Circle` definition, the data member `radius` is declared `private`. As the result, `radius` is accessible inside the `Circle` class, but NOT outside the class. In other words, you cannot use "`c1.radius`" to refer to `c1`'s `radius` in `main()`. Try inserting the statement "`cout << c1.radius;`" in `main()` and observe the error message:

```
CircleAIO.cpp:8:11: error: 'double Circle::radius' is private
```

Try moving `radius` to the `public` section, and re-run the statement.

On the other hand, the function `getRadius()` is declared `public` in the `Circle` class. Hence, it can be invoked in the `main()`.

UML Notation: In UML notation, `public` members are denoted with a "+", while `private` members with a "-" in the class diagram.

2.12 Information Hiding and Encapsulation

A class encapsulates the static attributes and the dynamic behaviors into a "3-compartment box". Once a class is defined, you can seal up the "box" and put the "box" on the shelve for others to use and reuse. Anyone can pick up the "box" and use it in their application. This cannot be done in the traditional procedural-oriented language like C, as the static attributes (or variables) are scattered over the entire program and header files. You cannot "cut" out a portion of C program, plug into another program and expect the program to run without extensive changes.

Data member of a class are typically hidden from the outside word, with `private` access control modifier. Access to the private data members are provided via `public` assessor functions, e.g., `getRadius()` and `getColor()`.

This follows the principle of *information hiding*. That is, objects communicate with each others using well-defined interfaces (public functions). Objects are not allowed to know the implementation details of others. The implementation details are hidden or encapsulated within the class. Information hiding facilitates reuse of the class.

Rule of Thumb: Do not make any data member `public`, unless you have a good reason.

2.13 Getters and Setters

To allow other to *read* the value of a `private` data member says `xxx`, you shall provide a *get function* (or *getter* or *accessor function*) called `getXxx()`. A getter need not expose the data in raw format. It can process the data and limit the view of the data others will see. Getters shall not modify the data member.

To allow other classes to *modify* the value of a `private` data member says `xxx`, you shall provide a *set function* (or *setter* or *mutator function*) called `setXxx()`. A setter could provide data validation (such as range checking), and transform the raw data into the internal representation.

For example, in our `Circle` class, the data members `radius` and `color` are declared `private`. That is to say, they are only available within the `Circle` class and not visible outside the `Circle` class - including `main()`. You cannot access the `private` data members `radius` and `color` from the `main()` directly - via says `c1.radius` or `c1.color`. The `Circle` class

provides two public accessor functions, namely, `getRadius()` and `getColor()`. These functions are declared `public`. The `main()` can invoke these public accessor functions to retrieve the `radius` and `color` of a `Circle` object, via says `c1.getRadius()` and `c1.getColor()`.

There is no way you can change the `radius` or `color` of a `Circle` object, after it is constructed in `main()`. You cannot issue statements such as `c1.radius = 5.0` to change the `radius` of instance `c1`, as `radius` is declared as `private` in the `Circle` class and is not visible to other including `main()`.

If the designer of the `Circle` class permits the change the `radius` and `color` after a `Circle` object is constructed, he has to provide the appropriate setter, e.g.,

```
// Setter for color
void setColor(string c) {
   color = c;
}

// Setter for radius
void setRadius(double r) {
   radius = r;
}
```

With proper implementation of *information hiding*, the designer of a class has full control of what the user of the class can and cannot do.

2.14 Keyword "this"

You can use keyword "`this`" to refer to *this* instance inside a class definition.

One of the main usage of keyword `this` is to resolve ambiguity between the names of data member and function parameter. For example,

```
class Circle {
private:
   double radius;                // Member variable called "radius"
   ......
public:
   void setRadius(double radius) { // Function's argument also called "radius"
      this->radius = radius;
         // "this.radius" refers to this instance's member variable
         // "radius" resolved to the function's argument.
   }
   ......
}
```

In the above codes, there are two identifiers called `radius` - a data member and the function parameter. This causes naming conflict. To resolve the naming conflict, you could name the function parameter `r` instead of `radius`. However, `radius` is more approximate and meaningful in this context. You can use keyword `this` to resolve this naming conflict. "`this->radius`" refers to the data member; while "`radius`" resolves to the function parameter.

"`this`" is actually a *pointer* to this object. I will explain pointer and the meaning of "`->`" operator later.

Alternatively, you could use a prefix (such as `m_`) or suffix (such as `_`) to name the data members to avoid name crashes. For example,

```
class Circle {
private:
   double m_radius;  // or radius_
   ......
public:
   void setRadius(double radius) {
      m_radius = radius;  // or radius_ = radius
   }
   ......
}
```

C++ Compiler internally names their data members beginning with a leading underscore (`e.g., _xxx`) and local variables with 2 leading underscores (e.g., __xxx). Hence, avoid name beginning with underscore in your program.

2.15 "const" Member Functions

A const member function, identified by a const keyword at the end of the member function's header, cannot modifies any data member of this object. For example,

```
double getRadius() const {  // const member function
   radius = 0;
      // error: assignment of data-member 'Circle::radius' in read-only structure
   return radius;
}
```

2.16 Convention for Getters/Setters and Constructors

The constructor, getter and setter functions for a private data member called xxx of type T in a class Aaa have the following conventions:

```
class Aaa {
private:
   // A private variable named xxx of type T
   T xxx;
public:
   // Constructor
   Aaa(T x) { xxx = x; }
   // OR
   Aaa(T xxx) { this->xxx = xxx; }
   // OR using member initializer list (to be explained later)
   Aaa(T xxx) : xxx(xxx) { }

   // A getter for variable xxx of type T receives no argument and return a value of type T
   T getXxx() const { return xxx; }

   // A setter for variable xxx of type T receives a parameter of type T and return void
   void setXxx(T x) { xxx = x; }
   // OR
   void setXxx(T xxx) { this->xxx = xxx; }
}
```

For a bool variable xxx, the getter shall be named isXxx(), instead of getXxx(), as follows:

```
private:
   // Private boolean variable
   bool xxx;
public:
   // Getter
   bool isXxx() const { return xxx; }

   // Setter
   void setXxx(bool x) { xxx = x; }
   // OR
   void setXxx(bool xxx) { this->xxx = xxx; }
```

2.17 Default Constructor

A default constructor is a constructor with no parameters, or having default values for all the parameters. For example, the above Circle's constructor can be served as default constructor with all the parameters default.

```
Circle c1;   // Declare c1 as an instance of Circle, and invoke the default constructor
Circle c1(); // Error!
             // (This declares c1 as a function that takes no parameter and returns a Circle instance)
```

If C++, if you did not provide ANY constructor, the compiler automatically provides a default constructor that does nothing. That is,

```
ClassName::ClassName() { }  // Take no argument and do nothing
```

Compiler will not provide a default constructor if you define any constructor(s). If all the constructors you defined require arguments, invoking no-argument default constructor results in error. This is to allow class designer to make it impossible to create an *uninitialized* instance, by NOT providing an explicit default constructor.

2.18 Constructor's Member Initializer List

Instead of initializing the private data members inside the body of the constructor, as follows:

```
Circle(double r = 1.0, string c = "red") {
   radius = r;
   color = c;
}
```

We can use an alternate syntax called *member initializer list* as follows:

```
Circle(double r = 1.0, string c = "red") : radius(r), color(c) { }
```

Member initializer list is placed after the constructor's header, separated by a colon (`:`). Each initializer is in the form of *`data_member_name`*`(`*`parameter_name`*`)`. For fundamental type, it is equivalent to *`data_member_name`* `=` *`parameter_name`*. For object, the constructor will be invoked to construct the object. The constructor's body (empty in this case) will be run after the completion of member initializer list.

It is recommended to use member initializer list to initialize all the data members, as it is often more efficient than doing assignment inside the constructor's body.

2.19 *Destructor

A *destructor*, similar to constructor, is a special function that has the same name as the classname, with a prefix ~, e.g., `~Circle()`. Destructor is called implicitly when an object is destroyed.

If you do not define a destructor, the compiler provides a default, which does nothing.

```
class MyClass {
public:
   // The default destructor that does nothing
   ~MyClass() { }
......
}
```

Advanced Notes

- If your class contains data member which is dynamically allocated (via `new` or `new[]` operator), you need to free the storage via `delete` or `delete[]`.

2.20 *Copy Constructor

A *copy constructor* constructs a new object by copying an existing object of the same type. In other words, a copy constructor takes an argument, which is an object of the same class.

If you do not define a copy constructor, the compiler provides a default which copies all the data members of the given object. For example,

```
Circle c4(7.8, "blue");
cout << "Radius=" << c4.getRadius() << " Area=" << c4.getArea()
     << " Color=" << c4.getColor() << endl;
                // Radius=7.8 Area=191.135 Color=blue

// Construct a new object by copying an existing object
// via the so-called default copy constructor
Circle c5(c4);
cout << "Radius=" << c5.getRadius() << " Area=" << c5.getArea()
     << " Color=" << c5.getColor() << endl;
                // Radius=7.8 Area=191.135 Color=blue
```

The copy constructor is particularly important. When an object is passed into a function *by value*, the copy constructor will be used to make a clone copy of the argument.

Advanced Notes

- Pass-by-value for object means calling the copy constructor. To avoid the overhead of creating a clone copy, it is usually better to pass-by-reference-to-`const`, which will not have side effect on modifying the caller's object.
- The copy constructor has the following signature:

```
class MyClass {
private:
   T1 member1;
   T2 member2;
public:
   // The default copy constructor which constructs an object via memberwise copy
   MyClass(const MyClass & rhs) {
      member1 = rhs.member1;
      member2 = rhs.member2;
   }
......
}
```

- The default copy constructor performs *shadow copy*. It does not copy the dynamically allocated data members created via `new` or `new[]` operator.

2.21 *Copy Assignment Operator (=)

The compiler also provides a default assignment operator (=), which can be used to assign one object to another object of the same class via memberwise copy. For example, using the `Circle` class defined earlier,

```
Circle c6(5.6, "orange"), c7;
cout << "Radius=" << c6.getRadius() << " Area=" << c6.getArea()
     << " Color=" << c6.getColor() << endl;
                // Radius=5.6 Area=98.5206 Color=orange
cout << "Radius=" << c7.getRadius() << " Area=" << c7.getArea()
     << " Color=" << c7.getColor() << endl;
                // Radius=1 Area=3.1416 Color=red (default constructor)

c7 = c6; // memberwise copy assignment
cout << "Radius=" << c7.getRadius() << " Area=" << c7.getArea()
     << " Color=" << c7.getColor() << endl;
                // Radius=5.6 Area=98.5206 Color=orange
```

Advanced Notes

- You could overload the assignment opeator to override the default.
- The copy constructor, instead of copy assignment operator, is used in declaration:

```
Circle c8 = c6;  // Invoke the copy constructor, NOT copy assignment operator
                 // Same as Circle c8(c6)
```

- The default copy assignment operator performs *shadow copy*. It does not copy the dynamically allocated data members created via `new` or `new[]` operator.
- The copy assignment operator has the following signature:

```
class MyClass {
private:
   T1 member1;
   T2 member2;
public:
   // The default copy assignment operator which assigns an object via memberwise copy
   MyClass & operator=(const MyClass & rhs) {
      member1 = rhs.member1;
      member2 = rhs.member2;
      return *this;
   }
```

```
......
}
```

- The copy assignment operator differs from the copy constructor in that it must release the dynamically allocated contents of the target and prevent self assignment. The assignment operator shall return a reference of this object to allow chaining operation (such as `x = y = z`).
- The default constructor, default destructor, default copy constructor, default copy assignment operators are known as *special member functions*, in which the compiler will automatically generate a copy if they are used in the program and not explicitly defined.

3. Separating Header and Implementation

For better software engineering, it is recommended that the class declaration and implementation be kept in 2 separate files: declaration is a header file "`.h`"; while implementation in a "`.cpp`". This is known as separating the public interface (header declaration) and the implementation. Interface is defined by the designer, implementation can be supplied by others. While the interface is fixed, different vendors can provide different implementations. Furthermore, only the header files are exposed to the users, the implementation can be provided in an object file "`.o`" (or in a library). The source code needs not given to the users.

I shall illustrate with the following examples.

4. Example: The `Circle` Class

Circle
-radius:double = 1.0 -color:string = "red"
+Circle(radius:double,color:string) +getRadius():double +setRadius(radius:double):void +getColor():string +setColor(color:string):void +getArea():double

Instead of putting all the codes in a single file. We shall "separate the interface and implementation" by placing the codes in 3 files.

1. `Circle.h`: defines the public interface of the `Circle` class.
2. `Circle.cpp`: provides the implementation of the `Circle` class.
3. `TestCircle.cpp`: A test driver program for the `Circle` class.

`Circle.h` - Header

```
1  /* The Circle class Header (Circle.h) */
2  #include <string>   // using string
3  using namespace std;
4
5  // Circle class declaration
6  class Circle {
7  private:   // Accessible by members of this class only
8     // private data members (variables)
9     double radius;
10    string color;
11
12 public:    // Accessible by ALL
13    // Declare prototype of member functions
14    // Constructor with default values
15    Circle(double radius = 1.0, string color = "red");
16
17    // Public getters & setters for private data members
18    double getRadius() const;
19    void setRadius(double radius);
20    string getColor() const;
21    void setColor(string color);
22
```

```
   // Public member Function
   double getArea() const;
};
```

Program Notes:

- The header file contains *declaration* statements, that tell the compiler about the names and types, and function prototypes without the implementation details.
- C++98/03 does NOT allow you to assign an initial value to a data member (except `const static` members). Date members are to be initialized via the constructor. For example,

  ```
  double radius = 1.0;
     // error: ISO C++ forbids in-class initialization of non-const static member 'radius'
  ```

  C++11 allows in-class initialization of data members.
- You can provide default value to function's arguments in the header. For example,

  ```
  Circle(double radius = 1.0, string color = "red");
  ```
- Header contains function prototype, the parameter names are ignored by the compiler, but good to serve as documentation. For example, you can leave out the parameter names in the prototype as follows:

  ```
  Circle(double = 1.0, string = "red");   // without identifiers
     // Identifiers not needed in prototype but good to serve as documentation
  ```

Header files shall contains constants, function prototypes, class/struct declarations.

`Circle.cpp` - Implementation

```
/* The Circle class Implementation (Circle.cpp) */
#include "Circle.h" // user-defined header in the same directory

// Constructor
// default values shall only be specified in the declaration,
// cannot be repeated in definition
Circle::Circle(double r, string c) {
   radius = r;
   color = c;
}

// Public getter for private data member radius
double Circle::getRadius() const {
   return radius;
}

// Public setter for private data member radius
void Circle::setRadius(double r) {
   radius = r;
}

// Public getter for private data member color
string Circle::getColor() const {
   return color;
}

// Public setter for private data member color
void Circle::setColor(string c) {
   color = c;
}

// A public member function
double Circle::getArea() const {
   return radius*radius*3.14159265;
}
```

Program Notes:

- The implementation file provides the *definition* of the functions, which are omitted from the *declaration* in the header file.
- `#include "Circle.h"`
  The compiler searches the headers in double quotes (such as `"Circle.h"`) in the *current directory* first, then the system's include directories. For header in angle bracket (such as `<iostream>`), the compiler does NOT searches the current directory, but only the system's include directories. Hence, use double quotes for user-defined headers.
- `Circle::Circle(double r, string c) {`
  You need to include the *`className`*`::` (called *class scope resolution operator*) in front of all the members names, so as to inform the compiler this member belong to a particular class.
  (Class Scope: Names defined inside a class have so-called *class scope*. They are visible within the class only. Hence, you can use the same name in two different classes. To use these names outside the class, the class scope resolution operator *`className`*`::` is needed.)
- You CANNOT place the default arguments in the implementation (they shall be placed in the header). For example,

```
Circle::Circle(double r = 1.0, string c = "red") {   // error!
```

Compiling the `Circle` Class

You can compile the `Circle.cpp` to an object file called `Circle.o`, via option `-c` (compile-only) in GNU GCC:

```
> g++ -c Circle.cpp
    // option -c for compile-only, output is Circle.o
```

To use the `Circle` class, the user needs `Circle.h` and `Circle.o`. He does not need `Circle.cpp`. In other words, you do not need to give away your source codes, but merely the public declarations and the object codes.

`TestCircle.cpp` - Test Driver

Let's write a test program to use the `Circle` class created.

```
1  /* A test driver for the Circle class (TestCircle.cpp) */
2  #include <iostream>
3  #include "Circle.h"   // using Circle class
4  using namespace std;
5
6  int main() {
7     // Construct an instance of Circle c1
8     Circle c1(1.2, "red");
9     cout << "Radius=" << c1.getRadius() << " Area=" << c1.getArea()
10         << " Color=" << c1.getColor() << endl;
11
12    c1.setRadius(2.1);   // Change radius and color of c1
13    c1.setColor("blue");
14    cout << "Radius=" << c1.getRadius() << " Area=" << c1.getArea()
15         << " Color=" << c1.getColor() << endl;
16
17    // Construct another instance using the default constructor
18    Circle c2;
19    cout << "Radius=" << c2.getRadius() << " Area=" << c2.getArea()
20         << " Color=" << c2.getColor()  << endl;
21    return 0;
22 }
```

Compiling the Test Program

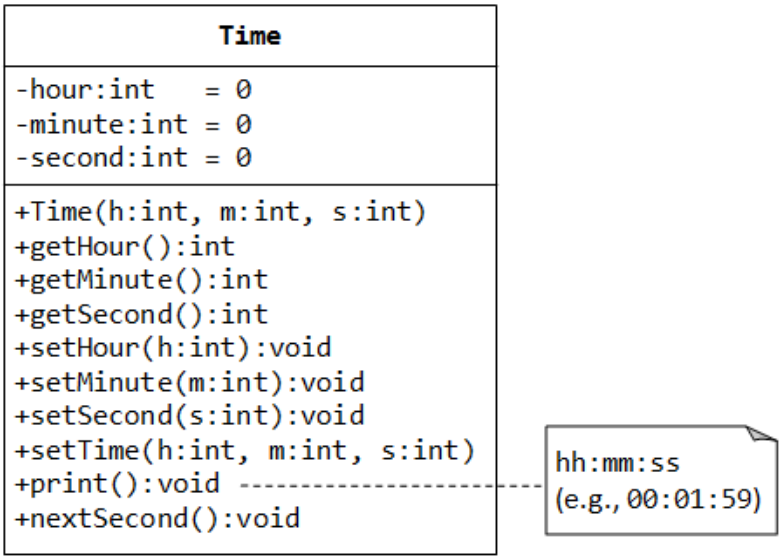
To compile `TestCircle.cpp` with the object code `Circle.o` (and `Circle.h`):

```
> g++ -o TestCircle.exe TestCircle.cpp Circle.o
    // option -o specifies the output filename
```

You can also compile `TestCircle.cpp` with the source code `Circle.cpp` (and `Circle.h`)

```
> g++ -o TestCircle.exe TestCircle.cpp Circle.cpp
```

5. Example: The Time Class



Let's write a class called `Time`, which models a specific instance of time with hour, minute and second values, as shown in the class diagram.

The class `Time` contains the following members:

- Three `private` data members: `hour` (0-23), `minute` (0-59) and `second` (0-59), with default values of 0.
- A `public` constructor `Time()`, which initializes the data members `hour`, `minute` and `second` with the values provided by the caller.
- `public` getters and setters for private data members: `getHour()`, `getMinute()`, `getSecond()`, `setHour()`, `setMinute()`, and `setSecond()`.
- A `public` member function `setTime()` to set the values of `hour`, `minute` and `second` given by the caller.
- A `public` member function `print()` to print this `Time` instance in the format "`hh:mm:ss`", zero-filled, e.g., `01:30:04`.
- A `public` member function `nextSecond()`, which increase this instance by one second. `nextSecond()` of `23:59:59` shall be `00:00:00`.

Let's write the code for the `Time` class, with the header and implementation separated in two files: `Time.h` and `Time.cpp`.

Header - `Time.h`

```
1  /* Header for the Time class (Time.h) */
2  #ifndef TIME_H   // Include this "block" only if TIME_H is NOT defined
3  #define TIME_H   // Upon the first inclusion, define TIME_H so that
4                   //  this header will not get included more than once
5  class Time {
6  private:  // private section
7     // private data members
8     int hour;     // 0 - 23
9     int minute;   // 0 - 59
10    int second;   // 0 - 59
11
12 public:   // public section
13    // public member function prototypes
14    Time(int h = 0, int m = 0, int s = 0); // Constructor with default values
15    int getHour() const;   // public getter for private data member hour
16    void setHour(int h);   // public setter for private data member hour
17    int getMinute() const; // public getter for private data member minute
18    void setMinute(int m); // public setter for private data member minute
19    int getSecond() const; // public getter for private data member second
20    void setSecond(int s); // public setter for private data member second
21    void setTime(int h, int m, int s);   // set hour, minute and second
```

```
22      void print() const; // Print a description of this instance in "hh:mm:ss"
23      void nextSecond();  // Increase this instance by one second
24  };  // need to terminate the class declaration with a semicolon
25
26  #endif  // end of "#ifndef" block
```

Dissecting `Time.h`

```
#ifndef TIME_H
#define TIME_H
......
#endif
```

To prevent an header file from included *more than once* into a source file (which could result in compilation error if an entity is declared twice, e.g., `int i`), we wrap the header codes within a pair of *preprocessor directives* `#ifndef` (if not define) and `#endif`. The codes within the if-block will only be included if the identifier `TIME_H` has not been defined. This is true for the first inclusion, which also defines the identifier `TIME_H` (the first directive in body of the if-block). No subsequent inclusion is possible, since `TIME_H` has been defined during the first inclusion. By convention, use the identifier `XXX_H` (or `XXX_H_INCLUDED`) for header `Xxx.h`.

```
class Time {
private:
......
public:
......
};
```

The header `Time.h` contains the *class declaration* for the class `Time`. It is divided into two sections: `private` and `public`. The `private` members (data or functions) are accessible by members of this class only, while `public` members are visible by all (such as the `main()` function which is outside the class). The class declaration must be terminated by a semicolon.

```
private:
   int hour;
   int minute;
   int second;
public:
   ......
```

We declare 3 private data members called `hour`, `minute` and `second`. In C++98/C++03, you are NOT allow to initialize a data member in the class declaration (except `const static int` data members). For example, setting `hour = 0` causes a compilation error. Instead, the data members are to be initialized in the constructor (to be shown later). The newer C++11 allows initialization of data members.

Only *member function prototypes* are listed in the class declaration. A function prototype consists of the return-type, function name and parameter types.

```
Time(int h = 0, int m = 0, int s = 0);
```

declares the so-called *constructor*. A constructor is a special function that has the same name as the class. A constructor has no return type, or implicitly return `void`. No `return` statement is allowed inside the constructor's body. A constructor can only be used during the instance declaration to initialize the data members of the instance. It cannot be invoked thereafter.

In the function prototypes of the header, we can set the default values of the function's parameters for any function member using "`= default-value`". In this case, this constructor can be invoked with 0 to 3 arguments, the omitted *trailing* arguments will be set to their default values, e.g.,

```
Time t1(1, 2, 3); // no default used
Time t2(1, 2);    // s = 0 (default)
Time t3(1);       // m = 0, s = 0 (defaults)
Time t4;          // h = 0, m = 0, s = 0 (all defaults) - no empty parentheses ()
```

The identifiers `h`, `m` and `s` are not needed in the function prototype - you only need to specify the parameters' types. But they serve as proper documentation, and are strongly recommended.

```
int getHour() const;
void setHour(int h);
int getHour() const;
void setHour(int h);
int getHour() const;
void setHour(int h);
```

declare the so-called *getter* and *setter* for the private data member `hour`, `minute` and `second`. Since the data members are `private` and are not accessible outside the class, `public` getters and setters are often provided to read and modify the `private` data members. By convention, a getter receives nothing (`void`) from the caller and returns a value of the type of the data member; a setter receives a value of the type of the data member and returns `void`. Setters may validate the input before setting the value of the data member.

We declare the getter function *constant*, by placing the keyword `const` after the function parameter list. A `const` member function cannot modify any data member of this object. Getter does not need to modify any data member.

```
void setTime(int h, int m, int s);
```

declares a public member function to set the `hour`, `minute` and `second` of this instance in one call.

```
void print() const;
```

declares a public member function to print this instance in the format `HH:MM:SS`, zero-filled, e.g., `01:56:09`. The function `print()` returns `void`.

```
void nextSecond();
```

declares a public member function to increase this instance by one second. For example, `23:59:59` becomes `00:00:00`. The function `nextSecond()` returns `void`.

Implementation - `Time.cpp`

```
1  /* Implementation for the Time Class (Time.cpp) */
2  #include <iostream>
3  #include <iomanip>
4  #include "Time.h"    // include header of Time class
5  using namespace std;
6
7  // Constructor with default values. No input validation
8  Time::Time(int h, int m, int s) {
9     hour = h;
10    minute = m;
11    second = s;
12 }
13
14 // public getter for private data member hour
15 int Time::getHour() const {
16    return hour;
17 }
18
19 // public setter for private data member hour. No input validation
20 void Time::setHour(int h) {
21    hour = h;
22 }
23
24 // public getter for private data member minute
25 int Time::getMinute() const {
26    return minute;
27 }
28
29 // public setter for private data member minute. No input validation
30 void Time::setMinute(int m) {
31    minute = m;
32 }
33
34 // public getter for private data member second
35 int Time::getSecond() const {
36    return second;
37 }
```

```
38
39  // public setter for private data member second. No input validation
40  void Time::setSecond(int s) {
41     second = s;
42  }
43
44  // Set hour, minute and second. No input validation
45  void Time::setTime(int h, int m, int s) {
46     hour = h;
47     minute = m;
48     second = s;
49  }
50
51  // Print this Time instance in the format of "hh:mm:ss", zero filled
52  void Time::print() const {
53     cout << setfill('0');    // zero-filled, need <iomanip>, sticky
54     cout << setw(2) << hour  // set width to 2 spaces, need <iomanip>, non-sticky
55          << ":" << setw(2) << minute
56          << ":" << setw(2) << second << endl;
57  }
58
59  // Increase this instance by one second
60  void Time::nextSecond() {
61     ++second;
62     if (second >= 60) {
63        second = 0;
64        ++minute;
65     }
66     if (minute >= 60) {
67        minute = 0;
68        ++hour;
69     }
70     if (hour >= 24) {
71        hour = 0;
72     }
73  }
```

Dissecting `Time.cpp`

The implementation file `Time.cpp` contains member's definitions (whereas the header file contains the declarations), in particular, member functions.

All member's identifiers in the implementation are preceded by the *classname* and the *scope resolution operator* (`::`), e.g., `Time::Time` and `Time::getHour`, so that the compiler can tell that these identifiers belong to a particular class, in this case, `Time`.

```
Time::Time(int h, int m, int s) {
   hour = h;
   minute = m;
   second = s;
}
```

In the constructor, we initialize the `private` data members `hour`, `minute` and `second` based on the inputs provided by the caller. C++ does NOT initialize fundamental-type (e.g., `int`, `double`) data members. It also does NOT issue an error message if you use an data member before it is initialized. Hence, It is strongly recommended to initialize all the data members in the constructor, so that the constructed instance is complete, instead of relying on the user to set the values of the data members after construction.

The default values of the parameters are specified in the class declaration (in the header), NOT in the function definition. Placing a default value in function definition (e.g., `h = 0`) causes a compilation error.

Take note that we have not included input validation (e.g., hour shall be between 0 and 23) in the constructor (and setters). We shall do that in the later example.

```
int Time::getHour() const {
   return hour;
```

```
}
```

the public getter for private data member `hour` simply returns the value of the data member `hour`.

```
void Time::setHour(int h) {
   hour = h;
}
```

the public setter for private data member `hour` sets the data member `hour` to the given value `h`. Again, there is no input validation for `h` (shall be between 0 to 23).

The rest of the function definitions are self-explanatory.

"this" Pointer

Instead of naming the function parameters `h`, `m` and `s`, we would like to name the parameters `hour`, `minute` and `second`, which are semantically more meaningful. However, these names crashes with the names of private data members. C++ provides a keyword `this` (which is a pointer to this instance - to be discussed later) to differentiate between the data members and function parameters. `this->hour`, `this->minute` and `this->second` refer to the data members; while `hour`, `minute`, and `second` refer to the function parameters. We can rewrite the constructor and setter as follows:

```
Time::Time(int hour, int minute, int second) {  // Constructor
   this->hour = hour;
   this->minute = minute;
   this->second = second;
}

Time::setHour(int hour) {   // Setter for hour
   this->hour = hour;
}

Time::getHour() const {  // Getter for hour
   return this->hour;    // this-> is the default, and hence optional
}
```

Member Initializer List

C++ provide an *alternative syntax* to initialize data members in the constructor called *member initializer list*. For example,

```
Time::Time(int h, int m, int s) : hour(h), minute(m), second(s) {
   // The body runs after the member initializer list
   // empty in this case
}
```

The member initializer list is placed after the function parameter list, separated by a colon, in the form of *`dataMemberName(parameters)`*. For fundamental-type data members (e.g., `int`, `double`), `hour(h)` is the same as `hour = h`. For object data members (to be discussed later), the *copy constructor* will be invoked. The function body will be executed *after* the member initializer list, which is empty in this case.

The data members in the initializer list are initialized in the order of their declarations in the class declaration, not the order in the initializer list.

Test Driver - `TestTime.cpp`

```
1  /* Test Driver for the Time class (TestTime.cpp) */
2  #include <iostream>
3  #include "Time.h"    // include header of Time class
4  using namespace std;
5
6  int main() {
7     Time t1(23, 59, 59);   // Test constructor
8
9     // Test all public member functions
10    t1.print();       // 23:59:59
11    t1.setHour(12);
12    t1.setMinute(30);
13    t1.setSecond(15);
14    t1.print();       // 12:30:15
```

```
15      cout << "Hour is "   << t1.getHour()   << endl;
16      cout << "Minute is " << t1.getMinute() << endl;
17      cout << "Second is " << t1.getSecond() << endl;
18
19      Time t2;     // Test constructor with default values for hour, minute and second
20      t2.print();  // 00:00:00
21      t2.setTime(1, 2, 3);
22      t2.print();  // 01:02:03
23
24      Time t3(12); // Use default values for minute and second
25      t3.print();  // 12:00:00
26
27      // Test nextSecond()
28      Time t4(23, 59, 58);
29      t4.print();
30      t4.nextSecond();
31      t4.print();
32      t4.nextSecond();
33      t4.print();
34
35      // No input validation
36      Time t5(25, 61, 99); // values out of range
37      t5.print();  // 25:61:99
38  }
```

Dissecting `TestTime.cpp`

The test driver tests the constructor (with and without the default values) and all the public member functions. Clearly, no input validation is carried out, as reflected in instance `t5`.

Exercise

Add member functions `previousSecond()`, `nextMinute()`, `previousMinute()`, `nextHour()`, `previousHour()` to the `Time` class.

Compiling the Program

You can compile all the source file together to get the executable file as follows:

```
// Using GCC on Windows
// Compile all source files, -o specifies the output
> g++ -o TestTime.exe Time.cpp TestTime.cpp
// Execute the program
> TestTime
```

Alternatively, you can compile `Time.cpp` into an object file `Time.o`, and then the test driver with the object file. In this way, you only distribute the object file and header file, not the source file.

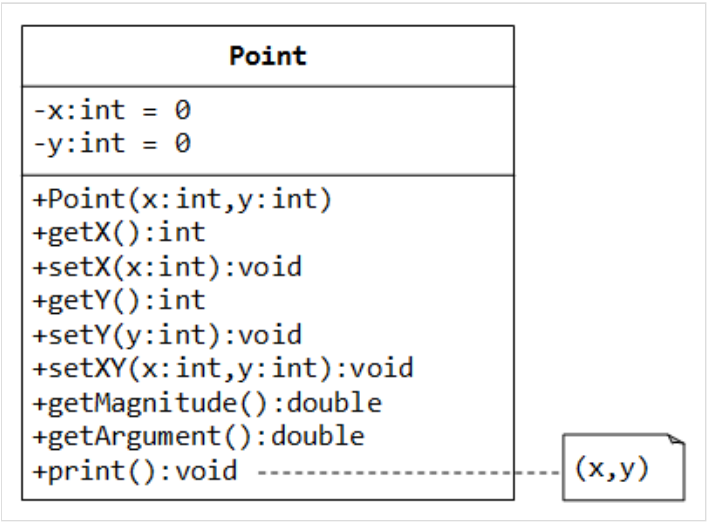
```
// Compile Time.cpp into object file Time.o, with -c option
> g++ -c Time.cpp
// Compile test driver with object file
> g++ -o TestTime.exe TestTime.cpp Time.o
// Execute the test driver
> TestTime
```

6. Example: The `Point` Class

The `Point` class, as shown in the class diagram, models 2D points with x and y co-ordinates.

In the class diagram, "`-`" denotes `private` member; "`+`" denotes `public` member. "`= xxx`" specifies the default value of a data member.

The `Point` class contains the followings:



- Private data members x and y (of type `int`), with default values of 0.
- A constructor, getters and setters for private data member x and y.
- A function setXY() to set both x and y coordinates of a `Point`.
- A function `getMagnitude()` which returns $\sqrt{(x^2+y^2)}$. You can use the built-in `sqrt()` function in `<cmath>` to compute the square root.
- A function `getArgument()` which returns $\tan^{-1}(y/x)$. You can use the built-in `atan2(y, x)` function in `<cmath>` to compute the gradient in radians.
- A function `print()` which prints "(x,y)" of this instance.

`Point.h` - Header

```
/* The Point class Header (Point.h) */
#ifndef POINT_H
#define POINT_H

// Point class declaration
class Point {
private:
   // private data members (variables)
   int x;
   int y;

public:
   // Declare member function prototypes
   Point(int x = 0, int y = 0);  // Constructor with default values
   int getX() const;
   void setX(int x);
   int getY() const;
   void setY(int y);
   void setXY(int x, int y);
   double getMagnitude() const;
   double getArgument() const;
   void print() const;
};

#endif
```

`Point.cpp` - Implementation

```
/* The Point class Implementation (Point.cpp) */
#include "Point.h" // user-defined header in the same directory
#include <iostream>
#include <cmath>
using namespace std;

// Constructor (default values can only be specified in the declaration)
Point::Point(int x, int y) : x(x), y(y) { }  // Use member initializer list

// Public getter for private data member x
int Point::getX() const {
   return x;
}

// Public setter for private data member x
void Point::setX(int x) {
```

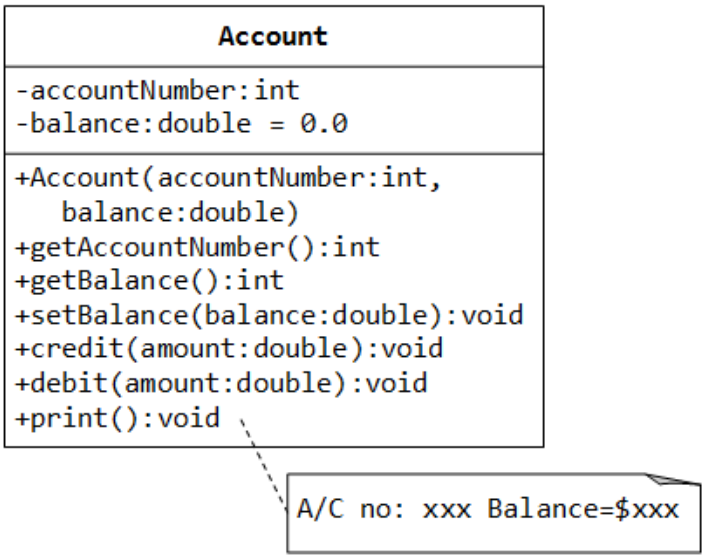
```
   this->x = x;
}

// Public getter for private data member y
int Point::getY() const {
   return y;
}

// Public setter for private data member y
void Point::setY(int y) {
   this->y = y;
}

// Public member function to set both x and y
void Point::setXY(int x, int y) {
   this->x = x;
   this->y = y;
}

// Public member function to return the magitude
double Point::getMagnitude() const {
   return sqrt(x*x + y*y);    // sqrt in <cmath>
}

// Public member function to return the argument
double Point::getArgument() const {
   return atan2(y, x);    // atan2 in <cmath>
}

// Public member function to print description about this point
void Point::print() const {
   cout << "(" << x << "," << y << ")" << endl;
}
```

TestPoint.cpp - Test Driver

```
/* A test driver for the Point class (TestPoint.cpp) */
#include <iostream>
#include <iomanip>
#include "Point.h"   // using Point class
using namespace std;

int main() {
   // Construct an instance of Point p1
   Point p1(3, 4);
   p1.print();
   cout << "x = " << p1.getX() << endl;
   cout << "y = " << p1.getY() << endl;
   cout << fixed << setprecision(2);
   cout << "mag = " << p1.getMagnitude() << endl;
   cout << "arg = " << p1.getArgument() << endl;
   p1.setX(6);
   p1.setY(8);
   p1.print();
   p1.setXY(1, 2);
   p1.print();

   // Construct an instance of Point using default constructor
   Point p2;
   p2.print();
}
```

7. Example: The Account Class

A class called Account, which models a bank account, is designed as shown in the class diagram. It contains:



- Two private data members: `accountNumber` (`int`) and `balance` (`double`), which maintains the current account balance.
- Public functions `credit()` and `debit()`, which adds or subtracts the given amount from the balance, respectively. The `debit()` function shall print "amount withdrawn exceeds the current balance!" if `amount` is more than `balance`.
- A public function `print()`, which shall print "A/C no: xxx Balance=xxx" (e.g., A/C no: 991234 Balance=$88.88), with `balance` rounded to two decimal places.

Header file - `Account.h`

```
1  /* Header for Account class (Account.h) */
2  #ifndef ACCOUNT_H
3  #define ACCOUNT_H
4
5  class Account {
6  private:
7     int accountNumber;
8     double balance;
9
10 public:
11    Account(int accountNumber, double balance = 0.0);
12    int getAccountNumber() const;
13    double getBalance() const;
14    void setBalance(double balance);
15    void credit(double amount);
16    void debit(double amount);
17    void print() const;
18 };
19
20 #endif
```

Implementation file - `Account.cpp`

```
1  /* Implementation for the Account class (Account.cpp) */
2  #include <iostream>
3  #include <iomanip>
4  #include "Account.h"
5  using namespace std;
6
7  // Constructor
8  Account::Account(int no, double b) : accountNumber(no), balance(b) { }
9
10 // Public getter for private data member accountNumber
11 int Account::getAccountNumber() const {
12    return accountNumber;
13 }
14
15 // Public getter for private data member balance
16 double Account::getBalance() const {
17    return balance;
18 }
19
20 // Public setter for private data member balance
21 void Account::setBalance(double b) {
```

```
   balance = b;
}

// Adds the given amount to the balance
void Account::credit(double amount) {
   balance += amount;
}

// Subtract the given amount from the balance
void Account::debit(double amount) {
   if (amount <= balance) {
      balance -= amount;
   } else {
      cout << "Amount withdrawn exceeds the current balance!" << endl;
   }
}

// Print description for this Account instance
void Account::print() const {
   cout << fixed << setprecision(2);
   cout << "A/C no: " << accountNumber << " Balance=$" << balance << endl;
}
```

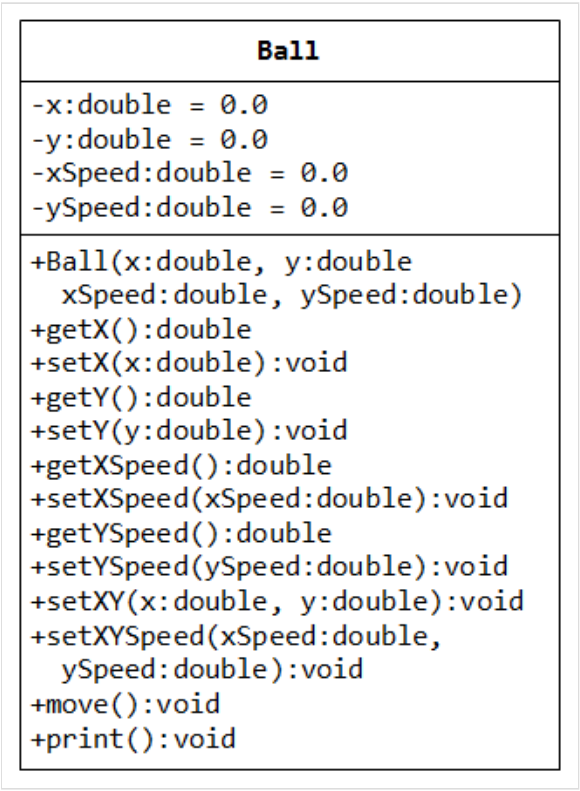
Test Driver - `TestAccount.cpp`

```
/* Test Driver for Account class (TestAccount.cpp) */
#include <iostream>
#include "Account.h"

using namespace std;

int main() {
    Account a1(8111, 99.99);
    a1.print();     // A/C no: 8111 Balance=$99.99
    a1.credit(20);
    a1.debit(10);
    a1.print();     // A/C no: 8111 Balance=$109.99

    Account a2(8222);  // default balance
    a2.print();        // A/C no: 8222 Balance=$0.00
    a2.setBalance(100);
    a2.credit(20);
    a2.debit(200);  // Amount withdrawn exceeds the current balance!
    a2.print();     // A/C no: 8222 Balance=$120.00
    return 0;
}
```

8. Example: The `Ball` class

A `Ball` class models a moving ball, designed as shown in the class diagram, contains the following members:

- Four `private` data members `x`, `y`, `xSpeed` and `ySpeed` to maintain the position and speed of the ball.
- A constructor, and public getters and setters for the private data members.
- A function `setXY()`, which sets the position of the ball and `setXYSpeed()` to set the speed of the ball.
- A function `move()`, which increases `x` and `y` by `xSpeed` and `ySpeed`, respectively.
- A function `print()`, which prints "`Ball @ (x,y) with speed (xSpeed,ySpeed)`", to 2 decimal places.



Header File - `Ball.h`

```
1  /* Header for the Ball class (Ball.h) */
2  #ifndef BALL_H
3  #define BALL_H
4
5  class Ball {
6  private:
7     double x, y;           // Position of the ball
8     double xSpeed, ySpeed; // Speed of the ball
9
10 public:
11    Ball(double x = 0.0, double y = 0.0,  // Constructor with default values
12         double xSpeed = 0.0, double ySpeed = 0.0);
13    double getX() const;
14    void setX(double x);
15    double getY() const;
16    void setY(double y);
17    double getXSpeed() const;
18    void setXSpeed(double xSpeed);
19    double getYSpeed() const;
20    void setYSpeed(double ySpeed);
21    void setXY(double x, double y);
22    void setXYSpeed(double xSpeed, double ySpeed);
23    void move();
24    void print() const;
25 };
26
27 #endif
```

Implementation File - `Ball.cpp`

```
1  /* Implementation for the Ball Class (Ball.cpp) */
2  #include <iostream>
3  #include <iomanip>
4  #include "Ball.h"    // include header of Ball class
5  using namespace std;
6
7  // Constructor with default values. No input validation
8  Ball::Ball(double x, double y, double xSpeed, double ySpeed)
```

```
      : x(x), y(y), xSpeed(xSpeed), ySpeed(ySpeed) { }  // use member initializer list

// public getters/setters for private data members
double Ball::getX() const {
   return x;
}
double Ball::getY() const {
   return y;
}
void Ball::setX(double x) {
   this->x = x;
}
void Ball::setY(double y) {
   this->y = y;
}
double Ball::getXSpeed() const {
   return xSpeed;
}
double Ball::getYSpeed() const {
   return ySpeed;
}
void Ball::setXSpeed(double xSpeed) {
   this->xSpeed = xSpeed;
}
void Ball::setYSpeed(double ySpeed) {
   this->ySpeed = ySpeed;
}

// Set position (x,y)
void Ball::setXY(double x, double y) {
   this->x = x;
   this->y = y;
}

// Set speed (xSpeed,ySpeed)
void Ball::setXYSpeed(double xSpeed, double ySpeed) {
   this->xSpeed = xSpeed;
   this->ySpeed = ySpeed;
}

// Move the ball by increases x and y by xSpeed and ySpeed
void Ball::move() {
   x += xSpeed;   // increment x by xSpeed
   y += ySpeed;   // increment y by ySpeed
}

// Print a description about this Ball instance
void Ball::print() const {
   cout << fixed << setprecision(2);
   cout << "Ball @ (" << x << ',' << y << ") with speed ("
        << xSpeed << ',' << ySpeed << ')' << endl;
}
```

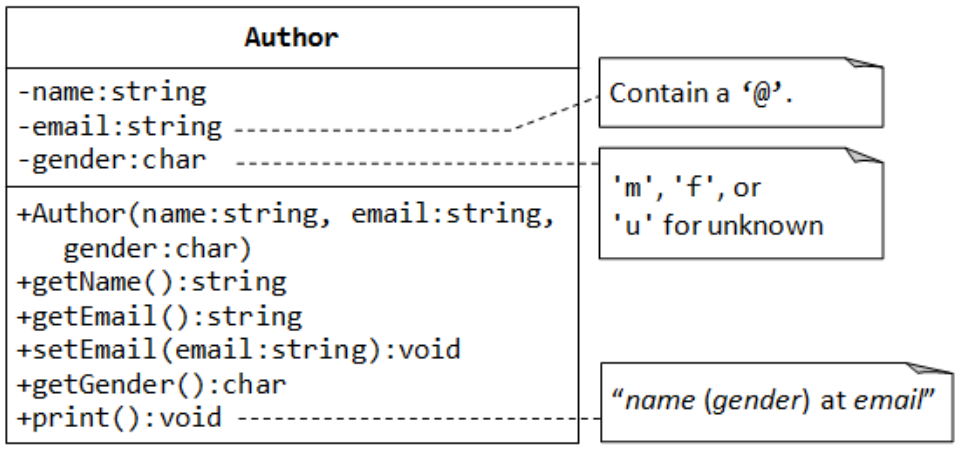
Test Driver - `TestBall.cpp`

```
/* Test Driver for the Ball class (TestBall.cpp) */
#include <iostream>
#include "Ball.h"    // include header of Ball class
using namespace std;

int main() {
   Ball ball;
   ball.print();    // Ball @ (0.00,0.00) with speed (0.00,0.00)
   ball.setXY(1.1, 2.2);
   ball.setXYSpeed(3.3, 4.4);
   ball.print();    // Ball @ (1.10,2.20) with speed (3.30,4.40)
```

```
   ball.setX(5.5);
   ball.setY(6.6);
   cout << "x is " << ball.getX() << endl;  // x is 5.50
   cout << "y is " << ball.getY() << endl;  // y is 6.60
   ball.move();
   ball.print();    // Ball @ (8.80,11.00) with speed (3.30,4.40)
}
```

9. Example: The Author and Book Classes (for a Bookstore)

9.1 Let's start with the Author class



Let's begin with a class called `Author`, designed as shown in the class diagram. It contains:

- Three `private` data members: `name` (`string`), `email` (`string`), and `gender` (`char` of `'m'`, `'f'` or `'u'` for unknown).
- A constructor to initialize the `name`, `email` and `gender` with the given values. There are no default values for data members.
- Getters for `name`, `email` and `gender`, and setter for `email`. There is no setter for `name` and `gender` as we assume that these attributes cannot be changed.
- A `print()` member function that prints "*name* (*gender*) at *email*", e.g., "Peter Jones (m) at peter@somewhere.com

Header File - `Author.h`

```
/* Header for the Author class (Author.h) */
#ifndef AUTHOR_H
#define AUTHOR_H

#include <string>
using namespace std;

class Author {
private:
   string name;
   string email;
   char gender;   // 'm', 'f', or 'u' for unknown

```

```
14  public:
15     Author(string name, string email, char gender);
16     string getName() const;
17     string getEmail() const;
18     void setEmail(string email);
19     char getGender() const;
20     void print() const;
21  };
22
23  #endif
```

Implementation File - `Author.cpp`

```
1   /* Implementation for the Author class (Author.cpp) */
2   #include <iostream>
3   #include "Author.h"
4   using namespace std;
5
6   // Constructor, with input validation
7   Author::Author(string name, string email, char gender) {
8      this->name = name;
9      setEmail(email);  // Call setter to check for valid email
10     if (gender == 'm' || gender == 'f') {
11        this->gender = gender;
12     } else {
13        cout << "Invalid gender! Set to 'u' (unknown)." << endl;
14        this->gender = 'u';
15     }
16  }
17
18  string Author::getName() const {
19     return name;
20  }
21
22  string Author::getEmail() const {
23     return email;
24  }
25
26  void Author::setEmail(string email) {
27     // Check for valid email. Assume that a valid email contains
28     //  a '@' that is not the first nor last character.
29     size_t atIndex = email.find('@');
30     if (atIndex != string::npos && atIndex != 0 && atIndex != email.length()-1) {
31        this->email = email;
32     } else {
33        cout << "Invalid email! Set to empty string." << endl;
34        this->email = "";
35     }
36  }
37
38  char Author::getGender() const {
39     return gender;
40  }
41
42  // print in the format "name (gender) at email"
43  void Author::print() const {
44     cout << name << " (" << gender << ") at " << email << endl;
45  }
```

Dissecting the `Author.cpp`

```
Author::Author(string name, string email, char gender) {
   this->name = name;
   setEmail(email);
```

In this example, we use identifier `name` in the function's parameter, which crashes with the data member's identifier `name`.

To differentiate between the two identifiers, we use the keyword `this`, which is a pointer to this instance. `this->name` refers to the data member; while `name` refers to the function's parameter.

No input validation is done on the parameter `name`. On the other hand, for `email`, we invoke setter `setEmail()` which performs input validation.

```
   if (gender == 'm' || gender == 'f') {
      this->gender = gender;
   } else {
      cout << "Invalid gender! Set to 'u' (unknown)." << endl;
      this->gender = 'u';
   }
}
```

We validate the input for `gender` (`'m'`, `'f'`, or `'u'` for unknown). We assign `'u'` for any other inputs.

```
void Author::setEmail(string email) {
   size_t found = email.find('@');
   if (found != string::npos && found != 0 && found != email.length()-1) {
      this->email = email;
   } else {
      cout << "Invalid email! Set to empty string." << endl;
      this->email = "";
   }
}
```

To validate `email`, we assume that there is an `'@'` which is not the first or last character (there are other stricter email validation criteria). We use the `string` class function `find()` to find the position of the character `'@'`, which returns a value of type `size_t` (typically same as `unsigned int`). The function `find()` returns a special constant `string::npos` (which is typically set to -1) to indicate "not found"; 0 for the first character and `length()-1` for the last character (where `string`'s function `length()` returns the length of the string).

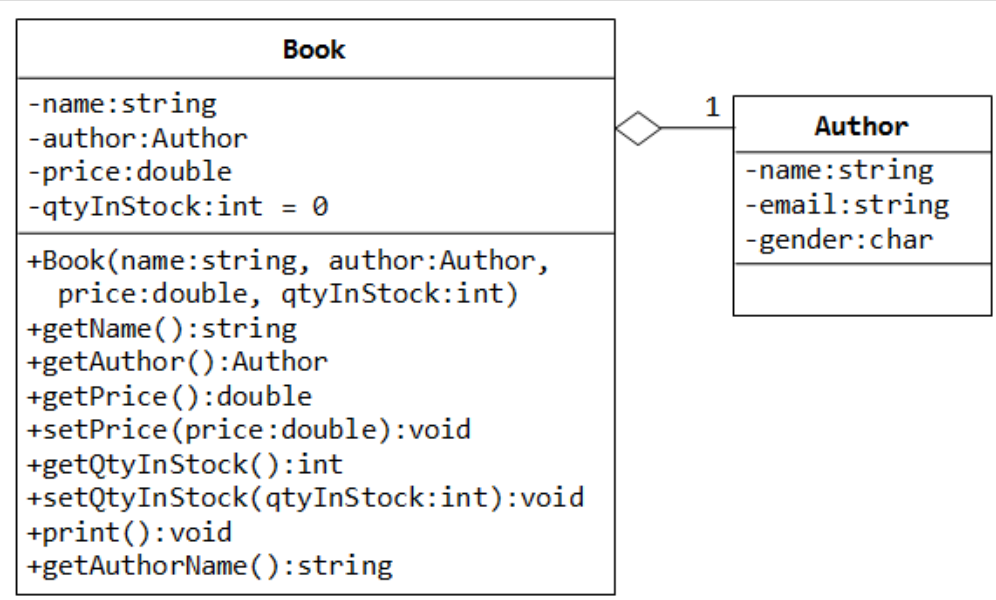
TestAuthor.cpp

```
1  /* Test Driver for the Author class (TestAuthor.cpp) */
2  #include "Author.h"
3
4  int main() {
5     // Declare and construct an instance of Author
6     Author peter("Peter Jones", "peter@somewhere.com", 'm');
7     peter.print();
8        // Peter Jones (m) at peter@somewhere.com
9     peter.setEmail("peter@xyz.com");
10    peter.print();
11       // Peter Jones (m) at peter@xyz.com
12
13    Author paul("Paul Jones", "@somewhere.com", 'n');
14       // Invalid email! Set to empty string.
15       // Invalid gender! Set to 'u' (unknown).
16    paul.setEmail("paul@");
17       // Invalid email! Set to empty string.
18    paul.print();
19       // Paul Jones (u) at
20 }
```

9.2 A Book is written by an Author - Using an "Object" Data Member

Let's design a Book class. Assume that a book is written by one and only one author. The Book class (as shown in the class diagram) contains the following members:

- Four `private` data members: `name` (`string`), `author` (an instance of the class



`Author` that we have created earlier), `price` (`double`), and `qtyInStock` (`int`, with default value of 0). The `price` shall be positive and the `qtyInStock` shall be zero or positive.
Take note that data member `author` is an instance (object) of the class `Author`, instead of a fundamental types (such as `int`, `double`). In fact, `name` is an object of the class `string` too.

- The `public` getters and setters for the `private` data members. Take note that `getAuthor()` returns an object (an instance of class `Author`).
- A `public` member function `print()`, which prints "'*book-name*' by *author-name* (*gender*) @ *email*".
- A `public` member function `getAuthorName()`, which returns the `name` of the author of this `Book` instance.

The *hallow diamond shape* in the class diagram denotes *aggregation* (or *has-a*) association relationship. That is, a `Book` instance *has* one (and only one) `Author` instance as its component.

Header File - `Book.h`

```
1  /* Header for the class Book (Book.h) */
2  #ifndef BOOK_H
3  #define BOOK_H
4
5  #include <string>
6  #include "Author.h"   // Use the Author class
7  using namespace std;
8
9  class Book {
10 private:
11    string name;
12    Author author; // data member author is an instance of class Author
13    double price;
```

```
   int qtyInStock;

public:
   Book(string name, Author author, double price, int qtyInStock = 0);
      // To recieve an instance of class Author as argument
   string getName() const;
   Author getAuthor() const;  // Returns an instance of the class Author
   double getPrice() const;
   void setPrice(double price);
   int getQtyInStock() const;
   void setQtyInStock(int qtyInStock);
   void print() const;
   string getAuthorName() const;
};

#endif
```

`#include "Author.h"`

We need to include the "`Author.h`" header, as we use the `Author` class in this class `Book`.

```
private:
   Author author;
```

We declare a `private` data member `author` as an instance of class `Author`, defined earlier.

Implementation File - `Book.cpp`

```
/* Implementation for the class Book (Book.cpp) */
#include <iostream>
#include "Book.h"
using namespace std;

// Constructor, with member initializer list to initialize the
//  component Author instance
Book::Book(string name, Author author, double price, int qtyInStock)
      : name(name), author(author) {   // Must use member initializer list to construct object
   // Call setters to validate price and qtyInStock
   setPrice(price);
   setQtyInStock(qtyInStock);
}

string Book::getName() const {
   return name;
}

Author Book::getAuthor() const {
   return author;
}

double Book::getPrice() const {
   return price;
}

// Validate price, which shall be positive
void Book::setPrice(double price) {
   if (price > 0) {
      this->price = price;
   } else {
      cout << "price should be positive! Set to 0" << endl;
      this->price = 0;
   }
}

int Book::getQtyInStock() const {
   return qtyInStock;
}

```

```
// Validate qtyInStock, which cannot be negative
void Book::setQtyInStock(int qtyInStock) {
   if (qtyInStock >= 0) {
      this->qtyInStock = qtyInStock;
   } else {
      cout << "qtyInStock cannot be negative! Set to 0" << endl;
      this->qtyInStock = 0;
   }
}

// print in the format ""Book-name" by author-name (gender) at email"
void Book::print() const {
   cout << "'" << name << "' by ";
   author.print();
}

// Return the author' name for this Book
string Book::getAuthorName() const {
   return author.getName();   // invoke the getName() on instance author
}
```

```
Book::Book(string name, Author author, double price, int qtyInStock)
      : name(name), author(author) {
   setPrice(price);
   setQtyInStock(qtyInStock);
}
```

In the constructor, the caller is supposed to create an instance of `Author`, and pass the instance into the constructor. We use *member initializer list* to initialize data members `name` and `author`. We call setters in the body, which perform input validation to set the `price` and `qtyInStock`. The body is run after the member initializer list. The `author(author)` invokes the default *copy constructor* of the `Author` class, which performs memberwise copy for all the data members. Object data member shall be constructed via the member initializer list, not in the body. Otherwise, the default constructor will be invoked to construct the object.

```
void Book::setPrice(double price) {
   if (price > 0) {
      this->price = price;
   } else {
      cout << "price should be positive! Set to 0" << endl;
      this->price = 0;
   }
}
```

The setter for `price` validates the given input.

```
string Book::getAuthorName() const {
   return author.getName();
}
```

Invoke the `getName()` of the data member `author`, which returns the author's name of this `Book` instance.

`TestBook.cpp`

```
/* Test Driver for the Book class (TestBook.cpp) */
#include <iostream>
#include "Book.h"
using namespace std;

int main() {
   // Declare and construct an instance of Author
   Author peter("Peter Jones", "peter@somewhere.com", 'm');
   peter.print();  // Peter Jones (m) at peter@somewhere.com

   // Declare and construct an instance of Book
   Book cppDummy("C++ for Dummies", peter, 19.99);
   cppDummy.setQtyInStock(88);
```

```
   cppDummy.print();
      // 'C++ for Dummies' by Peter Jones (m) at peter@somewhere.com

   cout << cppDummy.getQtyInStock() << endl;  // 88
   cout << cppDummy.getPrice() << endl;       // 19.99
   cout << cppDummy.getAuthor().getName() << endl;  // "Peter Jones"
   cout << cppDummy.getAuthor().getEmail() << endl; // "peter@somewhere.com"
   cout << cppDummy.getAuthorName() << endl;        // "Peter Jones"

   Book moreCpp("More C++ for Dummies", peter, -19.99);
      // price should be positive! Set to 0
   cout << moreCpp.getPrice() << endl;   // 0
}
```

The Default Copy Constructor

The initializer `author(author)` in the constructor invokes the so-called *copy constructor*. A *copy constructor* creates a new instance by copying the given instance of the same class. If you do not provide a copy constructor in your class, C++ provides a *default copy constructor*, which construct a new object via memberwise copy. For example, for `Author` class, the default copy constructor provided by the compiler is as follows:

```
// Default copy constructor of Author class provided by C++
Author::Author(const Author& other)
      : name(other.name), email(other.email), gender(other.gender) { }  // memberwise copy
```

9.3 Pass-by-Reference for Objects Function Parameters `Author` and `string`

By default, objects are pass-by-value into functions. That is, a clone copy is created and pass into the function, instead of the original copy. Pass-by-value for huge objects depicts performance due to the overhead of creating a clone copy.

Instead, we could pass an object into function *by reference*, via the reference (&) declaration in the parameter list. If we do not intend to modify the object inside the function (with side effect to the original copy), we set it as `const`.

In the `Book` class, data members of `string` and `Author` are objects. `Author` class was defined earlier; `string` is a class provided in C++ header `<string>`, belonging to the namespace `std`. Instead of including "`using namespace std;`" in the header (which is a poor practice as this statement will be included in all the files using this header), we shall use the scope resolution operator and refer to it as `std::string`.

Let's modify our `Book` class to illustrate pass-by-reference (for performance).

`Author.h`

```
/* Header for Author class (Author.h) */
#ifndef AUTHOR_H
#define AUTHOR_H

#include <string>

class Author {
private:
   std::string name;
   std::string email;
   char gender;   // 'm', 'f', or 'u' for unknown

public:
   Author(const std::string & name, const std::string & email, char gender);
          // & specifies pass by reference, const for non-mutable
   std::string getName() const;
   std::string getEmail() const;
   void setEmail(const std::string & email);
   char getGender() const;
   void print() const;
};

#endif
```

Program Notes:

- In C++, `string` is a class in the standard library (in header <string>, belonging to namespace `std`), just like `Point`, `Circle` classes that we have defined.
- Instead of including "`using namespace std;`", which is a poor practice as this statement will be included in all the files using this header, we use the fully-qualified name `std::string`.
- Instead of passing `string` objects by value into function, which affects performance as a clone copy needs to be made. We pass the `string` objects by reference (indicated by &).
- However, in pass-by-reference, changes inside the function will affect the caller's copy outside the function.
- If we do not intend to change the object inside the function, we could use keyword `const` to indicate immutability. If the object is inadvertently changed inside the function, compiler would issue an error.

Author.cpp

```
1  /* Implementation for the Author class (Author.cpp) */
2  #include <iostream>
3  #include "Author.h"
4  using namespace std;
5
6  // Constructor, with input validation
7  Author::Author(const string & name, const string & email, char gender) : name(name) {
8     setEmail(email);  // Call setter to check for valid email
9     if (gender == 'm' || gender == 'f') {
10       this->gender = gender;
11    } else {
12       cout << "Invalid gender! Set to 'u' (unknown)." << endl;
13       this->gender = 'u';
14    }
15 }
16
17 string Author::getName() const {
18    return name;
19 }
20
21 string Author::getEmail() const {
22    return email;
23 }
24
25 void Author::setEmail(const string & email) {
26    // Check for valid email. Assume that a valid email contains
27    //  a '@' that is not the first nor last character.
28    size_t atIndex = email.find('@');
29    if (atIndex != string::npos && atIndex != 0 && atIndex != email.length()-1) {
30       this->email = email;
31    } else {
32       cout << "Invalid email! Set to empty string." << endl;
33       this->email = "";
34    }
35 }
36
37 char Author::getGender() const {
38    return gender;
39 }
40
41 // print in the format "name (gender) at email"
42 void Author::print() const {
43    cout << name << " (" << gender << ") at " << email << endl;
44 }
```

Program Notes:

- `Author::Author(const string & name, const string & email, char gender) { ..... }`
  In the constructor, the `string` objects are passed by reference. This improves the performance as it eliminates the need of creating a temporary (clone) object. The constructor then invokes the *copy constructor* of the `string` class to

memberwise copy the arguments into its data members `name` and `email`.

We make the parameters `const` to prevent them from modifying inside the function (with side effect to the original copies).

`Book.h`

```
/* Header for the class Book (Book.h) */
#ifndef BOOK_H
#define BOOK_H

#include <string>
#include "Author.h"   // Use the Author class
using namespace std;

class Book {
private:
   string name;
   Author author;
   double price;
   int qtyInStock;

public:
   Book(const string & name, const Author & author, double price, int qtyInStock = 0);
   string getName() const;
   Author getAuthor() const;
   double getPrice() const;
   void setPrice(double price);
   int getQtyInStock() const;
   void setQtyInStock(int qtyInStock);
   void print() const;
   string getAuthorName() const;
};

#endif
```

Program Notes:

- `Book(const string & name, const Author & author, double price, int qtyInStock = 0);`
  `string` and `Author` objects are passed into the constructor via reference. This improves performance as it eliminates the creation of a temporary clone copy in pass-by-value. The parameters are marked `const` as we do not intend to modify them inside the function (with side effect to the original copies).
- **`Author`** `getAuthor() const;`
  The getter returns a *copy* of the data member `author`.

`Book.cpp`

```
/* Implementation for the class Book (Book.cpp) */
#include <iostream>
#include "Book.h"
using namespace std;

// Constructor, with member initializer list to initialize the
//  component Author instance
Book::Book(const string & name, const Author & author, double price, int qtyInStock)
      : name(name), author(author) { // Init object reference in member initializer list
   // Call setters to validate price and qtyInStock
   setPrice(price);
   setQtyInStock(qtyInStock);
}

string Book::getName() const {
   return name;
}

Author Book::getAuthor() {
```

```
   return author;
}

double Book::getPrice() const {
   return price;
}

// Validate price, which shall be positive
void Book::setPrice(double price) {
   if (price > 0) {
      this->price = price;
   } else {
      cout << "price should be positive! Set to 0" << endl;
      this->price = 0;
   }
}

int Book::getQtyInStock() const {
   return qtyInStock;
}

// Validate qtyInStock, which cannot be negative
void Book::setQtyInStock(int qtyInStock) {
   if (qtyInStock >= 0) {
      this->qtyInStock = qtyInStock;
   } else {
      cout << "qtyInStock cannnot be negative! Set to 0" << endl;
      this->qtyInStock = 0;
   }
}

// print in the format ""Book-name" by author-name (gender) at email"
void Book::print() const {
   cout << "'" << name << "' by ";
   author.print();
}

// Return the author' name for this Book
string Book::getAuthorName() const {
   return author.getName();   // invoke the getName() on instance author
}
```

- `Book::Book(const string & name, Author & author, double price, int qtyInStock)`
  `: name(name), author(author) { ..... }`

  `name(name)` and `author(author)` invoke the default copy constructors to construct new instances of `string` and `Author` by memberwise copy the parameters.

- `Author Book::getAuthor() { return author; }`

  A copy of the data member `author` is returned to the caller.

  You should avoid returning a reference of a private data member to the caller (e.g., `Author & Book::getAuthro() { return author; }`), as the caller can change the private data member via the reference, which breaks the concept of "information hiding and encapsulation".

Test Driver - `TestBook.cpp`

```
/* Test Driver for the Book class (TestBook.cpp) */
#include <iostream>
#include "Book.h"
using namespace std;

int main() {
   // Declare and construct an instance of Author
   Author peter("Peter Jones", "peter@somewhere.com", 'm');
   peter.print();  // Peter Jones (m) at peter@somewhere.com

   // Declare and construct an instance of Book
```

```
12      Book cppDummy("C++ for Dummies", peter, 19.99);
13      cppDummy.print();
14         // 'C++ for Dummies' by Peter Jones (m) at peter@somewhere.com
15
16      peter.setEmail("peter@xyz.com");
17      peter.print();   // Peter Jones (m) at peter@xyz.com
18      cppDummy.print();
19         // 'C++ for Dummies' by Peter Jones (m) at peter@somewhere.com
20
21      cppDummy.getAuthor().setEmail("peter@abc.com");
22      cppDummy.print();
23         // 'C++ for Dummies' by Peter Jones (m) at peter@somewhere.com
24  }
```

In the above test program, an instance of `Author` called `peter` is constructed (in Line 8). This instance is passed by reference into `Book`'s constructor (Line 12) to create the `Book`'s instance `cppDummy`.

Summary

All the codes in this version of example (using references) is exactly the same as the previous version (without using references), except that the object function parameters are marked with "`const` *`classname`* `&`" (e.g., `const string &`, `const Author &`). This eliminates the creation of temporary clone object as in the pass-by-value, which improves the performance. Take note that the constructor actually invokes the copy constructor to make a copy for its data member, instead of referencing the copy provided by the caller.

Link to "C++ References & Resources"

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