C++ classes

Giuseppe Lipari
http://retis.sssup.it

Scuola Superiore Sant’Anna – Pisa

April 27, 2009
Those types are not abstract: they are as real as int and float

Doug McIlroy
Abstraction

An essential instrument for OO programming is the support for data abstraction

C++ permits to define new types and their operations

Creating a new data type means defining:
  - Which elements it is composed of (*internal structure*);
  - How it is built/destroyed (*constructor/destructor*);
  - How we can operate on this type (*methods/operations*).
Data abstraction in C

- We can do data abstraction in C (and in almost any language)
  - however, the syntax is awkward

```c
typedef struct __complex {
    double real_;  
    double imaginary_;  
} Complex;
void add_to(Complex *a, Complex *b);
void sub_from(Complex *a, Complex *b);
double get_module(Complex *a);
```

- We have to pass the main data to every function name clashing: if another abstract type defines a function `add_to()`, the names will clash! No protection: any user can access the internal data using them improperly
class Complex {
    double real_;  // real part
    double imaginary_;  // imaginary part

public:
    Complex();  // default constructor
    Complex(double a, double b);  // constructor
    ~Complex();  // destructor

    double real() const;  // member function to get the real part
    double imaginary() const;  // member function to get the imaginary part
    double module() const;  // member function to get the module
    Complex &operator =(const Complex &a);  // assignment operator
    Complex &operator+=(const Complex &a);  // sum operator
    Complex &operator-=(const Complex &a);  // sub operator
};
How to use complex

Complex c1; // default constructor
Complex c2(1,2); // constructor
Complex c3(3,4); // constructor

cout << "c1=(" << c1.real() << "," << c1.imaginary() << ")" << endl;
c1 = c2; // assignment
c3 += c1; // operator +=
c1 = c2 + c3; // ERROR: operator + not yet defined
Using new data types

- The new data type is used just like a predefined data type
  - it is possible to define new functions for that type:
    - real(), imaginary() and module()
  - It is possible to define new operators
    - =, += and −=
- The compiler knows automatically which function/operator must be invoked

- C++ is a strongly typed language
  - the compiler knows which function to invoke by looking at the type!
Class

- Class is the main construct for building new types in C++
  - A class is almost equivalent to a struct with functions inside
  - In the C-style programming, the programmer defines structs, and global functions to act on the structs
  - In C++-style programming, the programmer defines classes with functions inside them
Accessing members

- A class contains members
- A member can be
  - any kind of variable (member variables)
  - any kind of function (member functions or methods)

```cpp
class MyClass {
    int a;
    double b;

public:
    int c;

    void f();
    int getA();
    int modify(double b);
};
```
Accessing members

- A class contains members
- A member can be
  - any kind of variable (member variables)
  - any kind of function (member functions or methods)

```cpp
class MyClass {
    int a;
    double b;
    public:
        int c;

        void f();
        int getA();
        int modify(double b);
};
```
Accessing members

- A class contains members
- A member can be
  - any kind of variable (member variables)
  - any kind of function (member functions or methods)

```cpp
class MyClass {
    int a;
    double b;
public:
    int c;
    void f();
    int getA();
    int modify(double b);
};
```
Accessing members

A class contains members
A member can be
- any kind of variable (member variables)
- any kind of function (member functions or methods)

class MyClass {
    int a;
    double b;
    public:
        int c;
    void f();
    int getA();
    int modify(double b);
};
Implementing member functions

- You can implement a member function in a separate .cpp file

**complex.h**

```cpp
class Complex {
    double real_;  
    double imaginary_;  
public:
    ...
    double module() const;
    ...
};
```

**complex.cpp**

```cpp
double Complex::module() const
{
    double temp;
    temp = real_ * real_ + imaginary_ * imaginary_;  
    return temp;
}
```
Accessing internal members

```cpp
double Complex::module() const
{
    double temp;
    temp = real_ * real_ + imaginary_ * imaginary_;
    return temp;
}
```

- The `::` operator is called scope resolution operator.
- Like any other function, we can create local variables.
- Member variables and functions can be accessed without `dot` or `arrow`.

scope resolution

local variable

access to internal variable
Access control

- A member can be:
  - private: only member functions of the same class can access it; other classes or global functions can’t
  - protected: only member functions of the same class or of derived classes can access it; other classes or global functions can’t
  - public: every function can access it

```cpp
class MyClass {
private:
    int a;
public:
    int c;
};

MyClass data;
cout << data.a;  // ERROR: a is private!
cout << data.c;  // OK: c is public;
```
Access control

- Default is private
- An access control keyword defines access until the next access control keyword

```cpp
class MyClass {
    int a;
    double b;
    public:
        int c;
        void f();
        int getA();
    private:
        int modify(double b);
};
```
Access control and scope

```cpp
int xx;

class A {
    int xx;
    public:
        void f();
};

void A::f()
{
    xx = 5;
    ::xx = 3;
    xx = ::xx + 2;
}
```

- Global variable: `int xx;` declared outside any class or function.
- Member variable: `int xx;` declared within class `A`.
- Access local `xx`: `xx` in function `f()`.
- Access global `xx`: `::xx` in function `f()`.
Why access control?

- The technique of declaring private members is also called encapsulation
  - In this way we can precisely define what is interface and what is implementation
  - The public part is the interface to the external world
  - The private part is the implementation of that interface
  - When working in a team, each group take care of a module
  - To ensure that the integration is done correctly and without problems, the programmers agree on interfaces
Private

- Some people think that private is synonym of secret
  - they complain that the private part is visible in the header file

- private means not accessible from other classes and does not mean secret

- The compiler needs to know the size of the object, in order to allocate memory to it
  - In an hypothetical C++, if we hide the private part, the compiler cannot know the size of the object
class A {
    friend class B;
    int y;
    void f();
public:
    int g();
};

class B {
    int x;
public:
    void f(A &a);
};

void B::f(A &a) {
    x = a.y;
    a.f();
}

B is friend of A
B can access private members of A
Friend functions and operator

- Even a global function or a single member function can be friend of a class

```cpp
class A {
    friend B::f();
    friend h();
    int y;
    void f();
public:
    int g();
};
```

- It is better to use the `friend` keyword only when it is really necessary
Nested classes

- It is possible to declare a class inside another class
- Access control keywords apply

```cpp
class A {
    class B {
        int a;
        public:
            int b;
    }
    B obj;
    public:
        void f();
};
```

- Class B is private to class A: it is not part of the interface of A, but only of its implementation.
- However, A is not allowed to access the private part of B!! (A::f() cannot access B::a).
- To accomplish this, we have to declare A as friend of B
Time to do an example

- Let us implement a Stack of integers class
- At this point, forget about the std library
  - This is a didactic example!

```cpp
Stack stack;
...
stack.push(12);
stack.push(7);
...
cout << stack.pop();
cout << stack.pop();
```

54
37
Time to do an example

- Let us implement a Stack of integers class
- At this point, forget about the std library
  - This is a didactic example!

```
Stack stack;
...
stack.push(12);
stack.push(7);
...
cout << stack.pop();
cout << stack.pop();
```
Time to do an example

- Let us implement a Stack of integers class
- At this point, forget about the std library
- This is a didactic example!

```cpp
Stack stack;
...
stack.push(12);
stack.push(7);
...
cout << stack.pop();
cout << stack.pop();
```
Time to do an example

- Let us implement a Stack of integers class
- At this point, forget about the std library
  - This is a didactic example!

```cpp
Stack stack;
...
stack.push(12);
stack.push(7);
...
cout << stack.pop();
cout << stack.pop();
```
Time to do an example

- Let us implement a Stack of integers class
- At this point, forget about the std library
  - This is a didactic example!

```cpp
Stack stack;
...
stack.push(12);
stack.push(7);
...
cout << stack.pop();
cout << stack.pop();
```
First, define the interface

class Stack {
    ...
    public:
        Stack();
        ~Stack();

        void push(int a);
        int pop();
        int peek();
        int size();
};
First, define the interface

class Stack {
    ...
public:
    Stack();
    ~Stack();

    void push(int a);
    int pop();
    int peek();
    int size();
};
Now the implementation

Now we need to decide:

- how many objects can our stack contain?
- we can set a maximum limit (like 1000 elements)
- or, we can dynamically adapt

Computer memory is the limit

- Let’s first choose the first solution notice that this decision is actually part of the interface contract!
class Stack {
public:
    Stack(int size);
    ~Stack();

    int push(int a);
    void pop();
    int size();

private:
    int *array_
    int top_
    int size_;
};
Constructor

- The constructor is the place where the object is created and initialized
  - Every time an object is defined, the constructor is called automatically
  - There is no way to define an object without calling the constructor
  - Sometime the constructor is called even when you don’t suspect (for example for temporary objects)

- It’s a nice feature
  - it forces to think about initialization
Constructor for stack

- The constructor is a function with the same name of the class and no return value
- It can have parameters:
  - in our case, the max_size of the stack

```cpp
class Stack {
public:
    Stack(int size);
    ...;
};
```
```cpp
Stack::Stack(int size)
{
    array_ = new int[size];
    top = 0;
}
```
The new operator

- In C, if you needed memory from the heap, you would use `malloc()`
- In C++, there is a special operator, called `new`

```cpp
Stack::Stack(int size)
{
    array_ = new int[size];
    size_ = size;
    top_ = 0;
}
```

Creates an array of `size` integers
Destructor

- When the object goes out of scope, it is destructed
  - among the other things, its memory is de-allocated
- A special function, called destructor, is defined for every class
  - its name is a `∼` followed by the class name
  - takes no parameters

```cpp
class Stack {
    ...
    ~Stack();
    ...
};
```

```cpp
Stack::~Stack()
{
    delete []array_;
}
```
The delete operator

- The opposite of `new` is `delete`
- It frees the memory allocated by `new`

```cpp
Stack::~Stack() {
    delete [] array_;  // deallocates size integers
}
```

- This operation is needed because otherwise the memory pointed by `array_` would remain allocated
- This problem is called memory leak
When are they called?

Stack::Stack(int size)
{
    size_ = size;
    array_ = new int[size_];
    top_ = 0;
    cout << "Constructor has been called\n!";
}

Stack::~Stack()
{
    delete []array_;
    cout << "Destructor has been called\n";
}

int main()
{
    cout << "Before block\n"
    {
        cout << "after constructor\n";
        Stack mystack(20);
        cout << "after constructor\n";
        ...
        cout << "before block end\n"
    }
    cout << "After block\n"
}
Default constructor

- A constructor without parameters is called default constructor
  - if you do not define a constructor, C++ will provide a default constructor that does nothing
  - if you do provide a constructor with parameters, the compiler does not provide a default constructor

```cpp
Stack s1;
Stack s2(20);
```

Error!! No default constructor for Stack!

Ok, calling the user-defined constructor
Default constructor

- We did not define a default constructor on purpose
  - we cannot construct a Stack without knowing its size
  - see how C++ forces a clean programming style?
- However it is possible to define different constructors using overloading
  - usually, we need to provide several constructors for a class
- The compiler always provide a destructor, unless the programmer provides it
Implementing the Stack interface

- see the code in directory stack1/
Implementing the Stack interface

- see the code in directory `stack1/`
- let’s get rid of the size: see `stack2/`
Initializing internal members

- Another feature of C++ is the initialize-list in the constructor
- each member variable can be initialized using a special syntax

```cpp
Stack::Stack()
{
  head_ = 0;
  size_ = 0;
}
```

```cpp
Stack::Stack() : head_(0), size_(0)
{
}
```

- The two code snippets are equivalent
- It is like using a constructor for each internal member
Function overloading

- In C++, the argument list is part of the name of the function
  - this mysterious sentence means that two functions with the same name but with different argument list are considered two different functions and not a mistake
- If you look at the internal name used by the compiler for a function, you will see three parts:
  - the class name
  - the function name
  - the argument list
To the compiler, they are all different functions!
→ beware of the type...
class A {
public:
    void f(int a);
    void f(int a, int b);
    void f(double g);
};
class B {
public:
    void f(int a);
};

A a;
B b;
a.f(5);
b.f(2);
a.f(3.0);
a.f(2,3);
a.f(2.5, 3);
Which one is called?

class A {
public:
    void f(int a);
    void f(int a, int b);
    void f(double g);
};
class B {
public:
    void f(int a);
};

A a;
B b;

a.f(5);
b.f(2);
a.f(3.0);
a.f(2, 3);
a.f(2.5, 3);
class A {
    public:
        void f(int a);
        void f(int a, int b);
        void f(double g);
    }
}
class B {
    public:
        void f(int a);
    }

A a;
B b;
a.f(5);
b.f(2);
a.f(3.0);
a.f(2,3);
a.f(2.5, 3);
class A {
public:
    void f(int a);
    void f(int a, int b);
    void f(double g);
};
class B {
public:
    void f(int a);
};

A a;
B b;
a.f(5);
b.f(2);
a.f(3.0);
a.f(2,3);
a.f(2.5, 3);
Which one is called?

class A {
   public:
      void f(int a);
      void f(int a, int b);
      void f(double g);
   }

class B {
   public:
      void f(int a);
   }

A a;
B b;
a.f(5);
b.f(2);
a.f(3.0);
a.f(2, 3);
a.f(2.5, 3);
Which one is called?

class A {
    public:
        void f(int a);
        void f(int a, int b);
        void f(double g);
    }

class B {
    public:
        void f(int a);
    }

A a;
B b;
a.f(5);
b.f(2);
a.f(3.0);
a.f(2,3);
a.f(2.5, 3);

__A_f_int
__B_f_int
__A_f_double
__A_f_int_int
__A_f_int_int
Notice that return values are not part of the name
the compiler is not able to distinguish two functions that
differs only on return values!

```java
class A {
    int floor(double a);
    double floor(double a);
};
```

This causes a compilation error
it is not possible to overload a return value
Default arguments in functions

- Sometime, functions have long argument lists
- some of these arguments do not change often
  - we would like to set default values for some argument
  - this is a little different from overloading, since it is the same function we are calling!

```c
int f(int a, int b = 0);
```

```c
f(12);       // it is equivalent to f(12,0);
```
Example

- see overload/
  - You have also seen some debugging trick
  - when you cannot use more sophisticated debugging ...
  - Simple exercise: write another constructor that takes a `char*` instead of a string
Constants

- In C++, when something is const it means that it cannot change. Period.
- Now, the particular meanings of const are a lot:
  - Don’t to get lost! Keep in mind: const = cannot change
- Another thing to remember:
  - constants must have an initial (and final) value!
As a first use, const can substitute the use of `#define` in C whenever you need a constant global value, use `const` instead of a define, because it is clean and it is type-safe.

```c
#define PI 3.14  // C style

const double pi = 3.14;  // C++ style
```

In this case, the compiler does not allocate storage for `pi`.

In any case, the const object has an *internal linkage*.
You can use `const` for variables that never change after initialization. However, their initial value is decided at run-time.

```cpp
const int i = 100;
const int j = i + 10;

int main()
{
    cout << "Type a character\n";
    const char c = cin.get();
    const char c2 = c + 'a';
    cout << c2;
    c2++; // ERROR! c2 is const!
}
```
Constant pointers

- There are two possibilities
  - the pointer itself is constant
  - the pointed object is constant

```c
int a
int * const u = &a;
const int *v;
```

- the pointer is constant
- the pointed object is constant (the pointer can change and point to another const int!)

Remember: a const object needs an initial value!
const function arguments

- An argument can be declared constant. It means the function can’t change it
  - particularly useful with references

```cpp
class A {
public:
    int i;
};

void f(const A &a) {
    a.i++;  // error! cannot modify a;
}
```

- You can do the same thing with a pointer to a constant, but the syntax is messy.
Passing by const reference

- Remember:
  - we can pass argument by value, by pointer or by reference
  - in the last two cases we can declare the pointer or the reference to refer to a constant object: it means the function cannot change it
  - Passing by constant reference is equivalent, from the user point of view, to passing by value
  - From an implementation point of view, passing by const reference is much faster!!
Constant member functions

class A {
    int i;
public:
    int f() const;
    void g();
};

void A::f() const {
    i++;
    // ERROR! this function cannot
    // modify the object
    return i; // Ok
}
Constant member functions

The compiler can call only const member functions on a const object!

class A {
    int i;
public:
    int f() const;
    void g();
};

void A::f() const
{
    i++;       // ERROR! this function cannot
    // modify the object
    return i; // Ok
}
Constant member functions

```cpp
class A {
    int i;
public:
    int f() const;
    void g();
};
void A::f() const {
    i++;
    // ERROR! this function cannot modify the object
    return i;  // Ok
}
```

The compiler can call only const member functions on a const object!

```cpp
const A a = ...;
a.f();  // Ok
a.g();  // ERROR!!
```
This is tricky! We want to say: “the object we are returning from this function cannot be modified”

This is meaningless when returning predefined types

```cpp
const int f1(int a) { return ++a; }

int f2(int a) { return ++a; }

int i = f1(5);      // legal
i = f2(5);

const int j = f1(5); // also legal
const int k = f2(5); // also legal
```

these two functions are equivalent!
Return mechanism

When returning a value, the compiler copies it into an appropriate location, where the caller can use it.

```c
int f2(int a) { return ++a; }
int i = f2(5);
```

1. a is allocated on the stack
2. the compiler copies 5 into a
3. a is incremented
4. the modified value of a is then copied directly into i
5. a is de-allocated (de-structed)

why const does not matter?

- since the compiler copies the value into the new location, who cares if the original return value is constant? It is deallocated right after the copy!
Returning a reference to an object

- Things get more complicated if we are returning an object, by value or by address, that is by pointer or by reference.
- But before looking into the problem, we have to address two important mechanisms of C++:
  - copy constructors
  - assignment and temporary objects
Outline

1. Classes
2. Constants
3. Copy Constructors
4. Static members
5. Ownership
6. Inlines
7. Operator Overloading
Copy constructor

When defining a class, there is another hidden default member we have to take into account

```cpp
class X {
    int ii;
public:
    X(int i) {ii = i;}
    X(const &X x);

    int get() {return ii;}
    int inc() {return ++ii;}
};
```

If we don’t define it, the compiler will define a standard version. The standard version will perform a copy member by member (bitwise copy).
Copy constructor

- An example

X x1(1);
X x2(x1);

cout << x1.get() << " " << x2.get() << endl;

x1.inc();
cout << x1.get() << " " << x2.get() << endl;

- We should be careful when defining a copy constructor for a class
  - we will address more specific issues on copy constructors later
The copy constructor is implicitly used when passing an object by value

```cpp
void f(X x)
{
    ...
}

X x1;
f(x1);
```

when calling `f()`, the actual argument `x1` is copied into formal parameter `x` by using the copy constructor

This is another reason to prefer passage by const reference!
class Complex {
    double real_;  
    double imaginary_;  

public:
    Complex(); // default constructor
    Complex(const Complex& c); // copy constructor
    Complex(double a, double b); // constructor
    ~Complex(); // destructor

    double real() const; // member function to get the real part
    double imaginary() const; // member function to get the imag. part
    double module() const; // member function to get the module
    Complex& operator=(const Complex& a); // assignment operator
    Complex& operator+(=) (const Complex& a); // sum operator
    Complex& operator-=(const Complex& a)); // sub operator
};
How to implement the copy constructor

```cpp
Complex::Complex(const Complex& c) {
    real_ = c.real_;  
    imaginary_ = c.imaginary_; 
}
```

● Now we can invoke it for initializing c3:

```cpp
Complex c1(2,3);
Complex c2(2);
Complex c3(c1);

cout << c1 << " " << c2 << " " << c3 << "\n";
```
Copy constructor and assignment operator

Remember that we also defined an assignment operator for Complex:

Complex c1(2,3);
Complex c2(2);
Complex c3 = c1;
c2 = c3;
c1 += c2;
cout << c1 << " " << c2 << " " << c3 << "\n";

The difference is that c3 is being defined and initialized, so a constructor is necessary;

- c2 is already initialized
The add function

- Now suppose we want to define a function add that returns the sum of two complex numbers
  - the return type is Complex
- a first try could be

```cpp
Complex add(Complex a, Complex b)
{
    Complex z(a.real() + b.real(), a.imaginary() + b.imaginary());
    return z;
}
```

- This is not very good programming style for many reasons!
  - can you list them?
Using the add

- Let’s see what happens when we use our add

Complex c1(1,2), c2(2,3), c3;
c3 = add(c1, c2);

Complex add(Complex a, Complex b)
{
    Complex z(a.real() + b.real(),
              a.imaginary() + b.imaginary());
    return z;
}

- 7 function calls are involved! (not considering real() and imaginary() ) ...
Using the add

- Let’s see what happens when we use our add

```c
Complex c1(1,2), c2(2,3), c3;
c3 = add(c1, c2);
```
Let's see what happens when we use our add

Complex c1(1,2), c2(2,3), c3;
c3 = add(c1, c2);

Complex add(Complex a, Complex b)
{
    Complex z(a.real() + b.real(),
             a.imaginary() + b.imaginary());
    return z;
}

7 function calls are involved! (not considering real() and imaginary()) ...
Let's see what happens when we use our add

Complex c1(1,2), c2(2,3), c3;
c3 = add(c1, c2);

Complex add(Complex a, Complex b)
{
    Complex z(a.real() + b.real(),
              a.imaginary() + b.imaginary());
    return z;
}

7 function calls are involved! (not considering real() and imaginary() ) ...
Using the add

Let's see what happens when we use our add

```cpp
Complex c1(1,2),c2(2,3),c3;
c3 = add(c1,c2);
```

```cpp
Complex add(Complex a, Complex b)
{
    Complex z(a.real() + b.real(), a.imaginary() + b.imaginary());
    return z;
}
```

7 function calls are involved! (not considering real() and imaginary())...
Using the add

Let’s see what happens when we use our add

Complex c1(1,2), c2(2,3), c3;
c3 = add(c1, c2);

Complex add(Complex a, Complex b)
{
    Complex z(a.real() + b.real(),
               a.imaginary() + b.imaginary());
    return z;
}

The temporary object is destroyed
The temporary object is assigned to c3 calling the assignment operator
Temp is copied into a temporary object
z is constructed
c1 and c2 are copied (through the copy constructor), into a and b

7 function calls are involved! (not considering real() and imaginary())...
First improvement

- Let’s pass by const reference:

```cpp
Complex c1(1,2), c2(2,3), c3;
c3 = add(c1, c2);
```

```cpp
Complex add(const Complex& a, const Complex& b) {
    Complex temp(a.real() + b.real(),
                 a.imaginary() + b.imaginary());
    return temp;
}
```

- only the addresses are copied: much faster!

- We already saved 2 function calls!
- notice that c1 and c2 cannot be modified anyway ...
Temporaries

Why the compiler builds a temporary?
- because he doesn’t know what we are going to do with that object
- consider the following expression:

```c
Complex c1(1,2), c2(2,3), c3(0,0);
c3 += add(c1,c2);
```

- the compiler is forced to build a temporary object of type Complex and pass it to `operator+=` by reference, which will be destroyed soon after `operator+=` completes
Temporary objects

- A temporary should always be constant!
  - otherwise we could write things like:

  ```cpp
  add(c1, c2) += c1;
  ```

- It is pure non-sense!
- To avoid this let us, return a const

```cpp
const Complex add(const Complex& a, const Complex& b) {
    Complex temp(a.real() + b.real(),
                 a.imaginary() + b.imaginary());
    return temp;
}
```
Returning a const

Thus, now it should be clear why sometime we need to return a const object:

- the previous example was trivial, but when things get complicated, anything can happen.
- by using a const object, we avoid stupid errors like modifying a temporary object.
- the compiler will complain if we try to modify a const object!
More on add

- there is a way to save on another copy constructor

```cpp
const Complex add(const Complex& a, const Complex& b)
{
    return Complex(a.real() + b.real(),
                   a.imaginary() + b.imaginary());
}
```

- It means: create a temporary object and return it
- Now we have 4 function calls:
  - add, temporary constructor, assignment, temporary destructor
More on copy constructors

Exercise

class A {
   int ii;
public:
   A(int i) : ii(i) { cout << "A(int)\n"; }
   A(const A& a) { ii = a.ii; cout << "A(A&)\n"; }
};

class B {
   int ii;
   A a;
public:
   B(int i) : ii(i), a(i+1) {cout << "B(int)\n"; }
};

int main()
{
   A a1(3);
   B b1(5);
   B b2(b1);
}

What does it print?
More on copy constructors

Exercise

class A {
    int ii;
public:
    A(int i) : ii(i) { cout << "A(int)\n"; }
    A(const A& a) { ii = a.ii; cout << "A(A&)\n"; }
};

class B {
    int ii;
    A a;
public:
    B(int i) : ii(i), a(i+1) {cout << "B(int)\n"; }
};

int main()
{
    A a1(3);
    B b1(5);
    B b2(b1);
}

What does it print?

A(int)
A(int)
B(int)
A(A&)
A(A&)
B(int)
Changing the copy constructor

- We can change the behavior of B...

```cpp
class A {
    int ii;
public:
    A(int i) : ii(i) { cout << "A(int)\n"; }
    A(const A& a) { ii = a.ii; cout << "A(A&)\n"; }
};

class B {
    int ii;
    A a;
public:
    B(int i) : ii(i), a(i+1) { cout << "B(int)\n"; }
    B(B& b) : ii(b.ii), a(b.ii+1) { cout << "B(B&)\n"; }
};

int main()
{
    A a1(3);
    B b1(5);
    B b2(b1);
}
```

- What does it print?
Changing the copy constructor

- We can change the behavior of B...

```cpp
class A {
    int ii;
public:
    A(int i) : ii(i) { cout << "A(int)\n"; }
    A(const A& a) { ii = a ii; cout << "A(A&)\n"; }
};

class B {
    int ii;
    A a;
public:
    B(int i) : ii(i), a(i+1) { cout << "B(int)\n"; }
    B(B& b) : ii(b ii), a(b ii+1) { cout << "B(B&)\n"; }
};

int main()
{
    A a1(3);
    B b1(5);
    B b2(b1);
}
```

- What does it print?

```
A(int)
A(int)
B(int)
A(int)
B(B&)
```
Outline

1. Classes
2. Constants
3. Copy Constructors
4. Static members
5. Ownership
6. Inlines
7. Operator Overloading
Static

- **static** is another keyword that is overloaded with many meanings
- Here, we will discuss only one of them: how to build static class members
  - sometime, we would like to have a member that is common to all objects of a class
  - for doing this, we can use the static keyword
We would like to implement a counter that keeps track of the number of objects that are around

- we could use a global variable, but it is not C++ style
- we can use a static variable

```cpp
class ManyObj {
    static int count;
    int index;

public:
    ManyObj();
    ~ManyObj();

    int getIndex();
    static int howMany();
};

static int ManyObj::count = 0;

ManyObj::ManyObj() { index = count++;}
ManyObj::~ManyObj() {count--;

int ManyObj::getIndex() { return index;
int ManyObj::howMany() { return count;
```
int main()
{
    ManyObj a, b, c, d;
    ManyObj *p = new ManyObj;
    ManyObj *p2 = 0;
    cout << "Index of p: " << p->getIndex() << "\n";
    {
        ManyObj a, b, c, d;
        p2 = new ManyObj;
        cout << "Number of objs: " << ManyObj::howMany() << "\n";
    }
    cout << "Number of objs: " << ManyObj::howMany() << "\n";
    delete p2; delete p;
    cout << "Number of objs: " << ManyObj::howMany() << "\n";
}

Index of p: 4
Number of objs: 10
Number of objs: 6
Number of objs: 4
static members

- There is only one copy of the static variable for all the objects
- All the objects refer to this variable
- How to initialize a static member?
  - cannot be initialized in the class declaration
  - the compiler does not allocate space for the static member until it is initialized
  - So, the programmer of the class must define and initialize the static variable
Initialization

- It is usually done in the .cpp file where the class is implemented

```cpp
static int ManyObj::count = 0;

ManyObj::ManyObj() { index = count++;}
ManyObj::~ManyObj() {count--;
int ManyObj::getIdx() {return index;}
int ManyObj::howMany() {return count;}
```

- There is a famous problem with static members, known as the static initialization order failure
  - We will not study it here. See Bruce Eckel book.
What happens if the copy constructor is called?

```cpp
void func(ManyObj a)
{
    ...
}
void main()
{
    ManyObj a;
    func(a);
    cout << "How many: " << ManyObj::howMany() << "\n";
}
```

What is the output?
Copy constructors and static members

- What happens if the copy constructor is called?

```c++
void func(ManyObj a)
{
    ...
}

void main()
{
    ManyObj a;
    func(a);
    cout << "How many: " << ManyObj::howMany() << "\n";
}
```

- What is the output?
- Solution in manyobj/
Again on copy constructors

- If we want to prevent passing by value we can hide the copy constructor
- You hide copy constructor by making it private
  - in this way the user of the class cannot call it

```c++
class ManyObj {
    static int count;
    int index;
    ManyObj(ManyObj &);
public:
    ManyObj();
    ~ManyObj();
    static int howMany();
};

void func(ManyObj a)
{
    ...
}

void main()
{
    ManyObj a;
    func(a);
    //ERROR! No copy constructor
}
```
A singleton is an object that can exist in only one copy we want to avoid that a user creates more than one of these objects

We can make a singleton by combining static members and constructor hiding

```cpp
class Singleton {
    static Singleton s;
    Singleton();
    Singleton(Singleton &);  
public:
    static Singleton & instance();
};
```
Singleton object

- First, we hide both constructors, so no user can create a singleton object
  - we also hide assignment operator
- We define one singleton object as static
- To obtain the singleton object, users must invoke member instance();

```
Singleton &s = Singleton::instance(); // ok
Singleton s2 = Singleton::instance(); // ERROR! No copy constructor!
```

- see oneobj/
If you are designing a class for a library, always think about what does it mean to copy an object of your class
  a user could try to pass the object to a function by value, and obtain an inconsistent behavior
For example, consider that your class contains pointers to objects of other classes
  when you clone your object, do you need to copy the pointers or the pointed classes? Depends on the class!
  The default copy constructor will copy the pointer
Ownership

A class can contain pointers to other objects;
  suppose they were created dynamically (with new), so they are allocated on the heap
At some point, your object is deallocated (destructed)
  should your object destroy the other objects?
  It depends on ownership: if your object is owner of the other objects, then it is responsible for destruction
Example

- Here the caller of the function is responsible for deleting the string:

```cpp
string *getNewName()
{
    string *t = new string(...);
    ...
    return t;
}

int main()
{
    string *s = getNewName();
    ...
    delete s;
}
```

- Inside the function call, the function is the owner
- After the return, the main function becomes the owner
- Ownership is very important in order to avoid memory leaks
Notice that compiler does not know anything about ownership!
- It is the logic of the program that says who is the owner of the object each time

The general rule that I apply is
- If an object creates another object, he is responsible for destruction
- of course there are zillion of exceptions to this rule
- pay attention to ownership!!
Outline

1. Classes
2. Constants
3. Copy Constructors
4. Static members
5. Ownership
6. Inlines
7. Operator Overloading
Performance is important

- if C++ programs were not fast, probably nobody would use it (too complex!)
- Instead, by knowing C++ mechanisms in depth, it is possible to optimize a lot
- One possible optimizing feature is inline function
class Complex {
    double real_;          
    double imaginary_;     
public:                  
    Complex();             // default constructor
    Complex(const Complex& c);  // copy constructor
    Complex(double a, double b = 0);  // constructor
    ~Complex();          // destructor

    inline double real() const {return real_;}
    inline double imaginary() const {return imaginary_;}
    inline double module() const {return real_*real_ + imaginary_*imaginary_;}
    Complex& operator=(const Complex& a);    // assignment operator
    Complex& operator+=(const Complex& a);   // sum operator
    Complex& operator-=(const Complex& a));  // sub operator
};
What is inlining

- when the compiler sees inline, tries to substitute the function call with the actual code
  - in the complex class, the compiler substitutes a function call like `real()` with the member variable `real_`

```c
Complex c1(2,3), c2(3,4), c3;
c1.real();
```

- we save a function call!
- in C this was done through macros
  - macros are quite bad. Better to use the inlining!
  - again, the compiler is much better than the pre-compiler
Of course, inline function must be defined in the header file

- otherwise the compiler cannot see them and cannot make the substitution
- sometime the compiler refuses to make inline functions
Excessive use of inlines

- People tend to use inlines a lot
  - first, by using inline you expose implementation details
  - second, you clog the interface that becomes less readable
  - Finally, listen to what D.Knuth said:
    
    \textit{Premature optimization is the root of all evil}

- So,
  - first design and program,
  - then test,
  - then optimize ...
Excessive use of inlines

- People tend to use inlines a lot
  - first, by using inline you expose implementation details
  - second, you clog the interface that becomes less readable
  - Finally, listen to what D. Knuth said:
    
    *Premature optimization is the root of all evil*

- So,
  - first design and program,
  - then test,
  - then optimize ...
  - ... and test again!
Operator overloading

- After all, an operator is like a function
  - binary operator: takes two arguments
  - unary operator: takes one argument
- The syntax is the following:
  - `Complex &operator+=(const Complex &c);`
- Of course, if we apply operators to predefined types, the compiler does not insert a function call

```c
int a = 0;
a += 4;

Complex b = 0;
b += 5; // function call
```
In general, operators that modify the object (like `++`, `+=`, `--`, etc...) should be member.

Operators that do not modify the object (like `+`, `−`, etc,) should not be member, but friend functions.

Let’s write `operator+` for complex (see `complex/`)

Not all operators can be overloaded:
- We cannot "invent" new operators,
- We can only overload existing ones
- We cannot change number of arguments
- We cannot change precedence
- `. (dot)` cannot be overloaded
Strange operators

- You can overload
  - `new` and `delete`
    - used to build custom memory allocate strategies
  - `operator[]`
    - for example, in `vector<>`...
  - `operator`
    - `You can write very funny programs!`
  - `operator->`
    - used to make smart pointers!!
How to overload operator []

- the prototype is the following:

```cpp
class A {
    ...

public:
    A& operator[](int index);
};
```

- Exercise:
  - add operator [] to your Stack class
  - the operator must never go out of range
How to overload new and delete

```cpp
class A {
    ...
public:
    void* operator new(size_t size);
    void  operator delete(void *);
};
```

- Everytime we call new for creating an object of this class, the overloaded operator will be called
- You can also overload the global version of new and delete
How to overload * and ->

- This is the prototype

```cpp
class Iter {
    ...
public:
    Obj operator*() const;
    Obj *operator->() const;
};
```

- Why should I overload `operator*()`?
  - to implement iterators!

- Why should I overload `operator->()`?
  - to implement smart pointers
Example

- A simple iterator for stack
  - It is a forward iterator
Exercises

- Build a Iterator class for your list of strings
  - You can define an object of type Iterator, that can point to objects inside the List container
  - Write operator++() the Iterator
  - Write operator* for Iterator that de-reference the pointed object;
  - Compare your implementation with the list<> container of the std library
  - Try to call foreach() on your container. What happens?
A more complex exercise

- Define aSmartPointer for objects of class A
  - This pointer must always be initialized
  - When no object points to the object, the object is automatically destroyed

```c++
class A { ... }
class SSP { ... }

SSP p1 = A::getNew(); // p1 points to a new obj
SSP p2 = p1;          // p1 and p2 point to obj

p1 = 0;               // only p2 points to obj
p2 = 0;               // destroy the object
```

- Hint: you should create a static repository
- This will become a template soon!