

GeekBand 极客班

互联网人才加油站!

C++面向对象高级编程

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C++ 面向對象程序設計

(Object Oriented Programming, OOP)

侯捷





你應具備的基礎

- 曾經學過某種 procedural language (C 語言最佳)
 - 變量 (variables)
 - 類型 (types) : **int, float, char, struct ...**
 - 作用域 (scope)
 - 循環 (loops) : **while, for,**
 - 流程控制 : **if-else, switch-case**
- 知道一個程序需要編譯、連結才能被執行
- 知道如何編譯和連結
(如何建立一個可運程序)




我們的目標

- 培養正規的、大氣的編程習慣
- 以良好的方式編寫 C++ class
 - class without pointer members
 - Complex
 - class with pointer members
 - String
- 學習 Classes 之間的關係
 - 繼承 (inheritance)
 - 複合 (composition)
 - 委託 (delegation)

Object Based
(基於對象)

Object Oriented
(面向對象)



你將獲得的代碼

complex.h

complex-test.cpp

string.h

string-test.cpp



C++ 的歷史

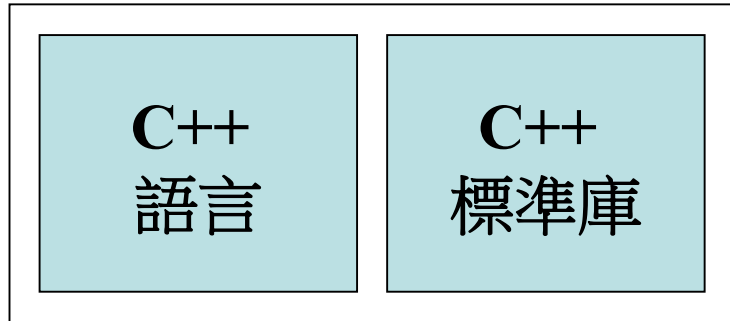
- B 語言 (1969)
- C 語言 (1972)
- C++ 語言 (1983)
(new C → C with Class → C++)

- Java 語言
- C# 語言

/// C++ 演化

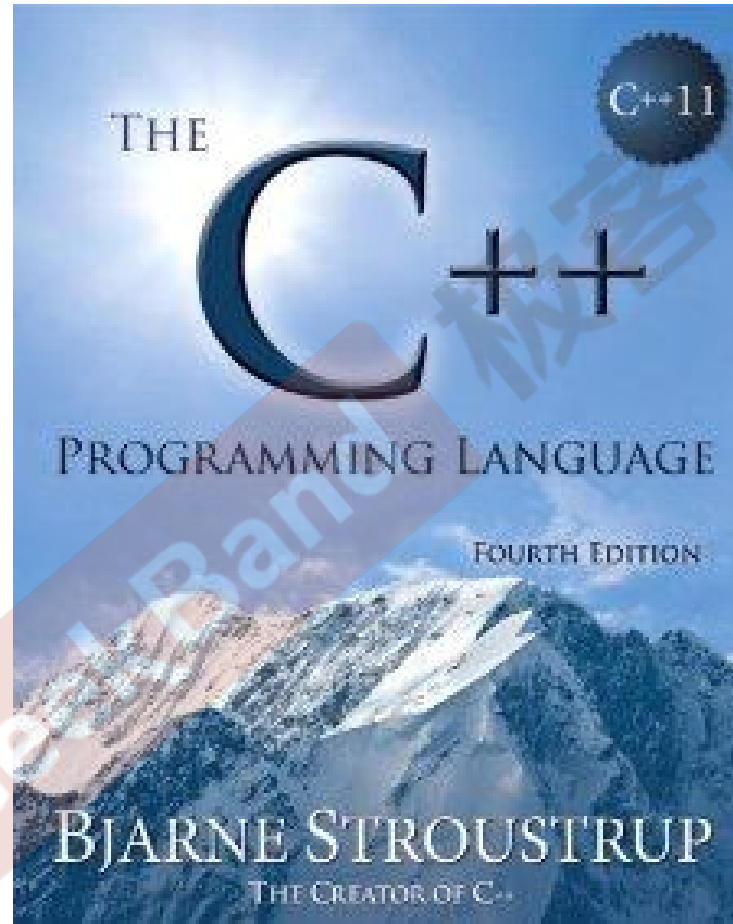
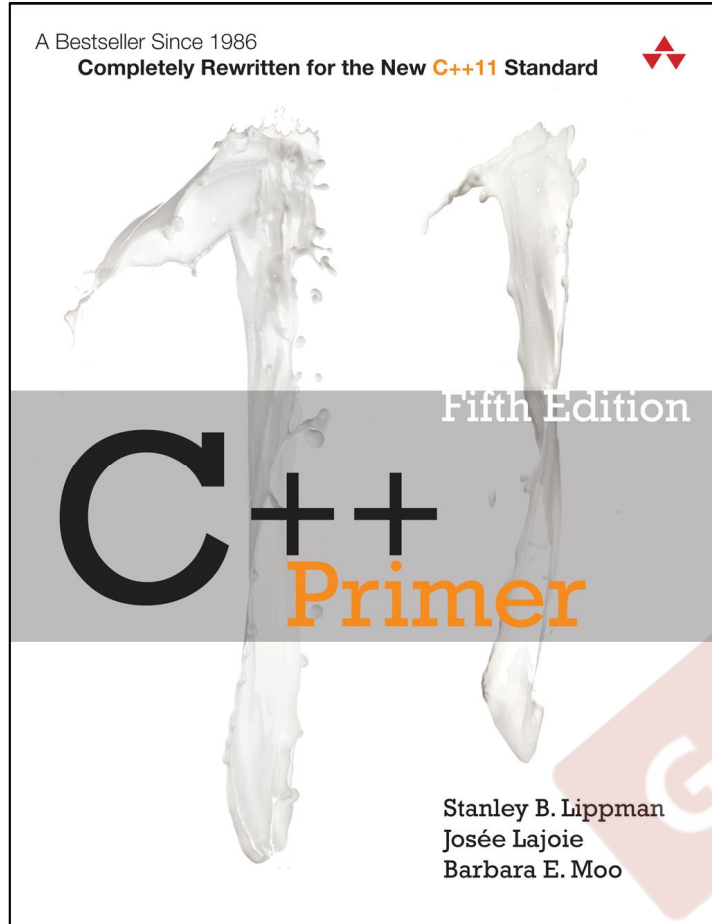
- C++ 98 (1.0)
- C++ 03 (TR1, Technical Report 1)
- C++ 11 (2.0)
- C++ 14

C++



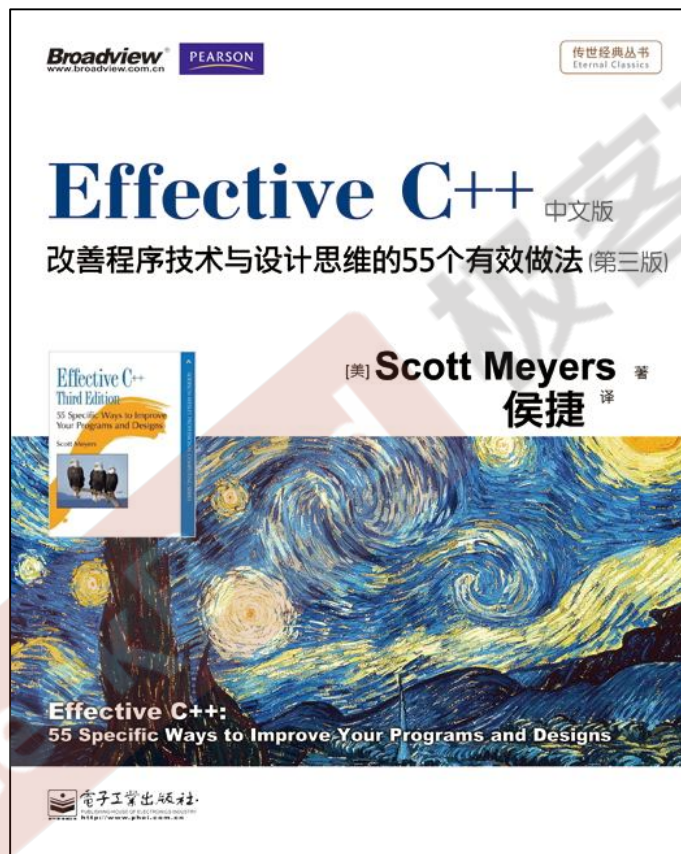
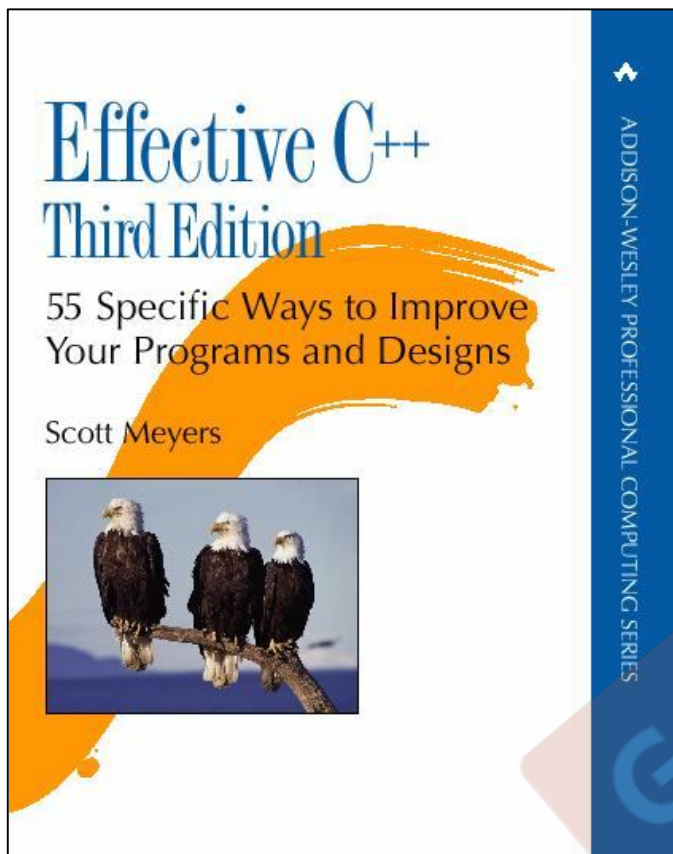


Bibliography (書目誌)

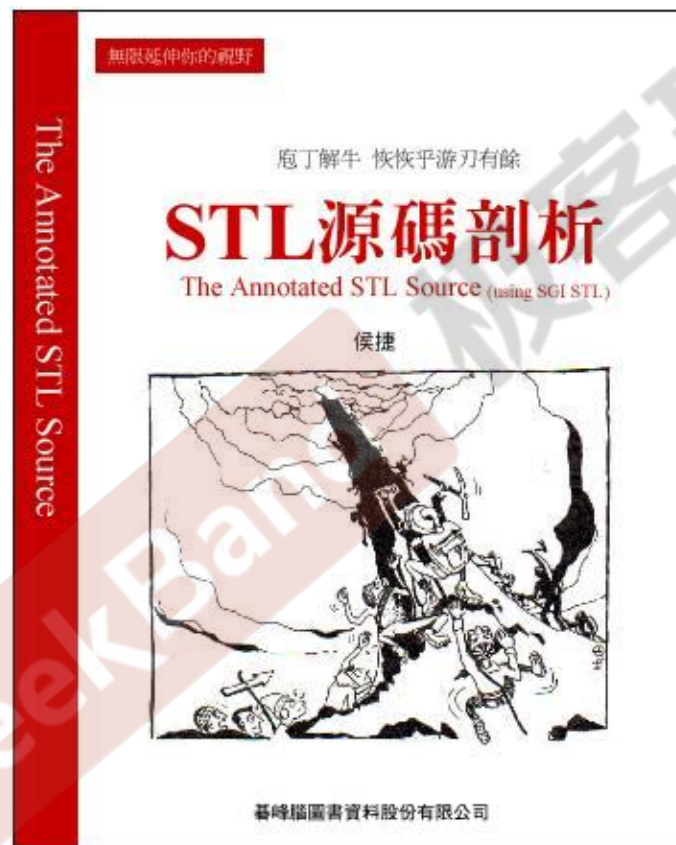
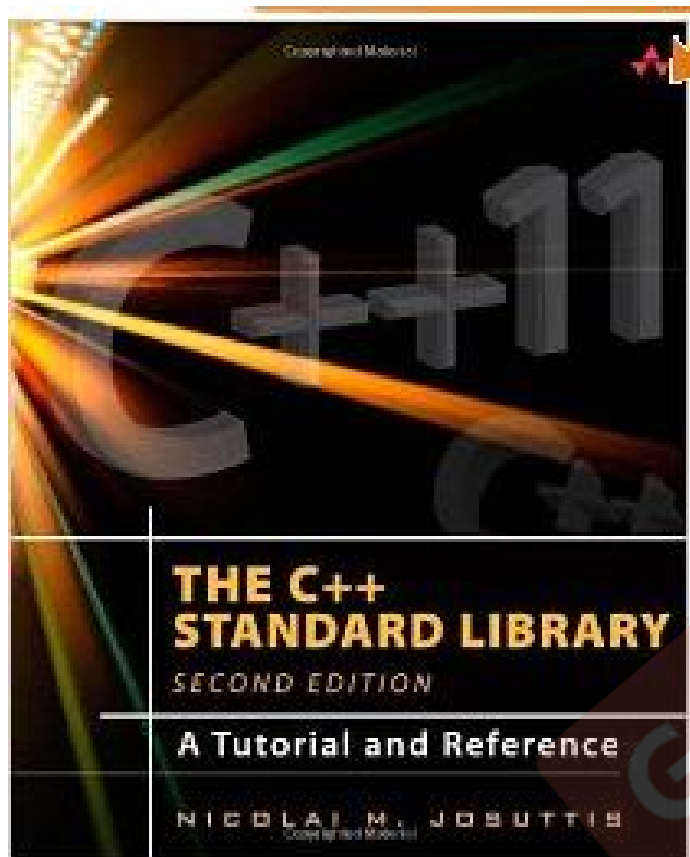




Bibliography (書目誌)

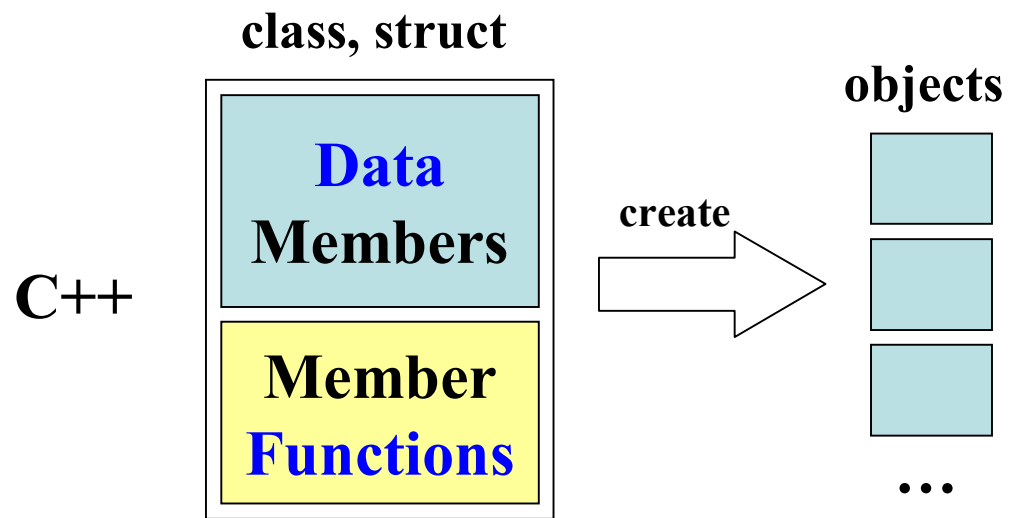
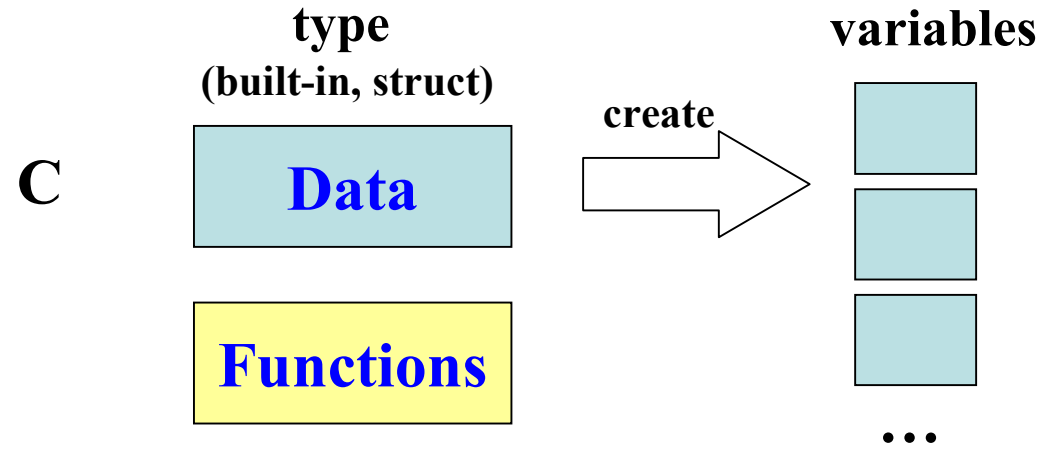


/// Bibliography (書目誌)



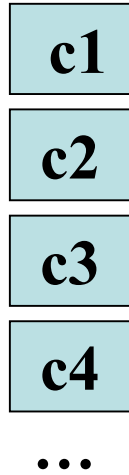
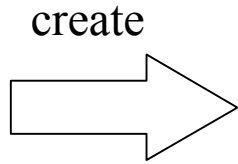
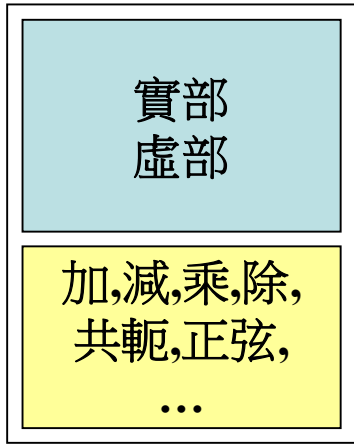


C vs. C++, 關於數據和函數



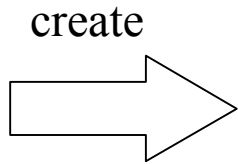
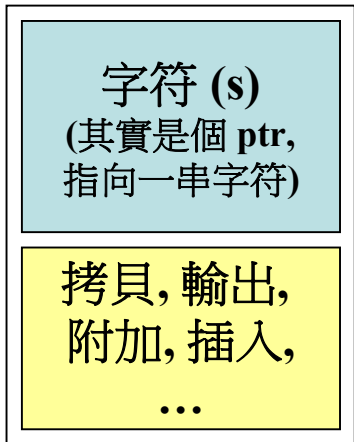
C++, 關於數據和函數

complex



```
complex c1(2,1);  
complex c2;  
complex* pc = new complex(0,1);
```

string



```
string s1("Hello ");  
string s2("World ");  
string* ps = new string;
```

Object Based (基於對象) vs. Object Oriented (面向對象)

Object Based : 面對的是單一 **class** 的設計

Object Oriented : 面對的是多重 **classes** 的設計，
classes 和 **classes** 之間的關係。

/// 我們的第一個 C++ 程序

Classes 的兩個經典分類：

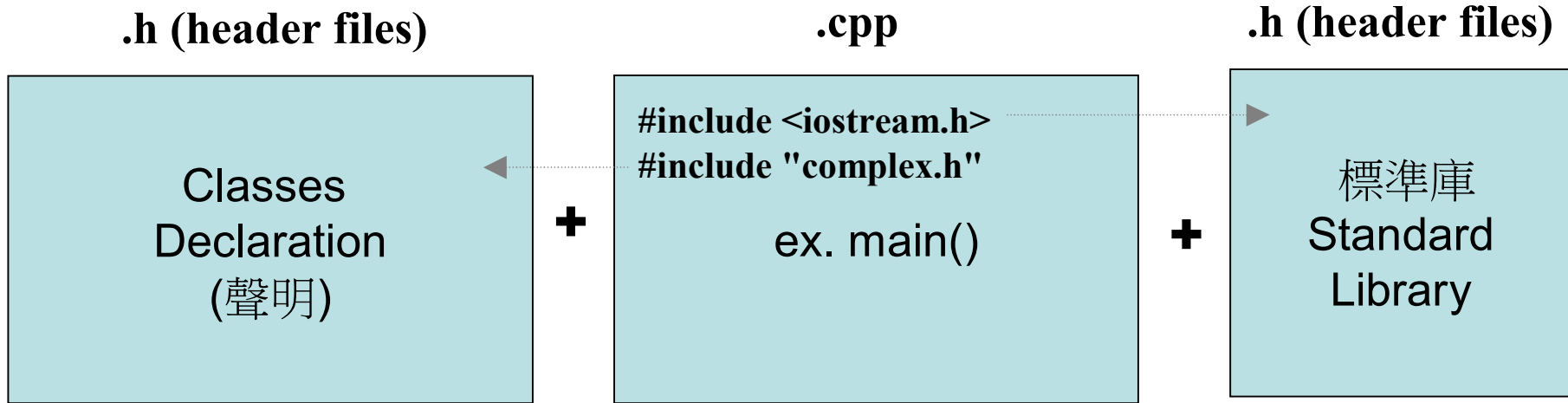
- **Class without pointer member(s)**

complex

- **Class with pointer member(s)**

string

/// C++ programs 代碼基本形式



延伸文件名 (extension file name) 不一定是 .h 或 .cpp，也可能是 .hpp 或其他或甚至無延伸名。



Output, C++ vs. C

C++

```
#include <iostream>
```

```
#include <iostream.h>  
using namespace std;  
  
int main()  
{  
    int i = 7;  
    cout << "i=" << i << endl;  
  
    return 0;  
}
```

C

```
#include <stdio>
```

```
#include <stdio.h>  
  
int main()  
{  
    int i = 7;  
    printf("i=%d \n", i);  
  
    return 0;  
}
```

Header (頭文件) 中的防衛式聲明

complex-test.h

complex.h

```
#ifndef __COMPLEX__  
#define __COMPLEX__
```

guard
(防衛式聲明)

...

```
#endif
```

```
#include <iostream>  
#include "complex.h"  
using namespace std;  
  
int main()  
{  
    complex c1(2,1);  
    complex c2;  
    cout << c1 << endl;  
    cout << c2 << endl;  
  
    c2 = c1 + 5;  
    c2 = 7 + c1;  
    c2 = c1 + c2;  
    c2 += c1;  
    c2 += 3;  
    c2 = -c1;  
  
    cout << (c1 == c2) << endl;  
    cout << (c1 != c2) << endl;  
    cout << conj(c1) << endl;  
    return 0;  
}
```

Header (頭文件) 的佈局

```
#ifndef __COMPLEX__  
#define __COMPLEX__
```

```
#include <cmath>
```

```
class ostream;  
class complex;
```

forward declarations
(前置聲明)

```
complex&  
__doapl (complex* ths, const complex& r);
```

```
class complex  
{  
...  
};
```

class declarations
(類 - 聲明)

```
complex::function ...
```

class definition
(類 - 定義)

```
#endif
```

class 的聲明 (declaration)

1

```
class complex
{
public:
    complex (double r = 0, double i = 0)
        : re (r), im (i)
    { }
    complex& operator += (const complex&);
    double real () const { return re; }
    double imag () const { return im; }
private:
    double re, im;

    friend complex& __doapl (complex*, const complex&);
};
```

class head

class body

有些函數在此直接定義，
另一些在 body 之外定義

```
{
    complex c1(2,1);
    complex c2;
    ...
}
```

class template (模板) 簡介

1

```
template<typename T>
class complex
{
public:
    complex (T r = 0, T i = 0)
        : re (r), im (i)
    { }
    complex& operator += (const complex&);
    T real () const { return re; }
    T imag () const { return im; }
private:
    T re, im;

    friend complex& __doapl (complex*, const complex&);
};
```

```
{
    complex<double> c1 (2.5, 1.5);
    complex<int> c2 (2, 6);
    ...
}
```

inline (內聯) 函數

1

```
class complex
{
public:
    complex (double r = 0, double i = 0)
        : re (r), im (i)
    { }
    complex& operator += (const complex&);
    double real () const { return re; }
    double imag () const { return im; }
private:
    double re, im;

    friend complex& __doapl (complex*, const complex&);
};
```

函數若在 **class body** 內定義完成，便自動成為 **inline** 候選人

2-2

```
inline double
imag(const complex& x)
{
    return x.imag ();
}
```

access level (訪問級別)

1

```
class complex
{
public:
    complex (double r = 0, double i = 0)
        : re (r), im (i)
    { }
    complex& operator += (const complex&);
    double real () const { return re; }
    double imag () const { return im; }
private:
    double re, im;

    friend complex& __doapl (complex*, const complex&);
};
```

X

```
{
    complex c1(2,1);
    cout << c1.re;
    cout << c1.im;
}
```

O

```
{
    complex c1(2,1);
    cout << c1.real();
    cout << c1.imag();
}
```

constructor (ctor, 構造函數)

```
complex (double r = 0, double i = 0)
{ re = r; im = i; }
```

default argument
(默認實參)

1

```
class complex
{
public:
    complex (double r = 0, double i = 0)
        : re (r), im (i)
    { }
    complex& operator += (const complex&);
    double real () const { return re; }
    double imag () const { return im; }
private:
    double re, im;

    friend complex& __doapl (complex*, const complex&);
};
```

initialization list
(初值列, 初始列)

assignments
(賦值)

```
{
    complex c1(2,1);
    complex c2;
    complex* p = new complex(4);
    ...
}
```


ctor (構造函數) 可以有很多個 - overloading (重載)

```
1 class complex
{
public:
1  complex (double r = 0, double i = 0)
   : re (r), im (i)
   { }
2  complex () : re(0), im(0) { } ?!
   complex& operator += (const complex&);
1  double real () const { return re; }
   double imag () const { return im; }
private:
   double re, im;

   friend complex& __doapl (complex*, const complex&);
};
```

```
{
  complex c1;
  complex c2 ();
  ...
}
```

```
2 void real(double r) const { re = r; }
```

real 函數編譯後的實際名稱可能是：


```
?real@Complex@@QBENXZ
?real@Complex@@QAENABN@Z
```

取決於編譯器

constructor (ctor, 構造函數) 被放在 **private** 區

1

```
class complex
{
public:
    complex (double r = 0, double i = 0)
        : re (r), im (i)
    { }
    complex& operator += (const complex&);
    double real () const { return re; }
    double imag () const { return im; }
private:
    double re, im;
    friend complex& __doapl (complex*, const complex&);
};
```



X

```
{
    complex c1(2,1);
    complex c2;
    ...
}
```

ctors 放在 private 區

Singleton

```
class A {  
public:  
    static A& getInstance ();  
    setup() { ... }  
private:  
    A();  
    A(const A& rhs);  
    ...  
};  
  
A& A::getInstance ()  
{  
    static A a;  
    return a;  
}
```

```
A::getInstance ().setup ();
```

const member functions (常量成員函數)

1

```
class complex
{
public:
    complex (double r = 0, double i = 0)
        : re (r), im (i)
    { }
    complex& operator += (const complex&);
    double real () const { return re; }
    double imag () const { return im; }
private:
    double re, im;

    friend complex& __doapl (complex*, const complex&);
};
```

0

```
{
    complex c1(2,1);
    cout << c1.real();
    cout << c1.imag();
}
```

?!

```
{
    const complex c1(2,1);
    cout << c1.real();
    cout << c1.imag();
}
```

參數傳遞：pass by value vs. pass by reference (to const)

1

```
class complex
{
public:
    complex (double r = 0, double i = 0)
        : re (r), im (i)
    { }
    complex& operator += (const complex&);
    double real () const { return re; }
    double imag () const { return im; }
private:
    double re, im;

    friend complex& __doapl (complex*, const complex&);
};
```

2-7

```
ostream&
operator << (ostream& os, const complex& x)
{
    return os << '(' << real (x) << ', '
        << imag (x) << ')';
}
```

```
{
    complex c1(2,1);
    complex c2;

    c2 += c1;
    cout << c2;
}
```

返回值傳遞：return by value vs. return by reference (to const)

1

```
class complex
{
public:
    complex (double r = 0, double i = 0)
        : re (r), im (i)
    { }
    complex& operator += (const complex&);
    double real () const { return re; }
    double imag () const { return im; }
private:
    double re, im;

    friend complex& __doapl (complex*, const complex&);
};
```

2-7

```
ostream&
operator << (ostream& os, const complex& x)
{
    return os << '(' << real (x) << ',' <<
        << imag (x) << ')';
}
```

```
{
    complex c1 (2, 1);
    complex c2;

    cout << c1;
    cout << c2 << c1;
}
```

friend (友元)

1

```
class complex
{
public:
    complex (double r = 0, double i = 0)
        : re (r), im (i)
    { }
    complex& operator += (const complex&);
    double real () const { return re; }
    double imag () const { return im; }
private:
    double re, im;

    friend complex& __doapl (complex*, const complex&);
};
```

2-1

```
inline complex&
__doapl (complex* ths, const complex& r)
{
    ths->re += r.re;
    ths->im += r.im;
    return *ths;
}
```

自由取得 friend 的
private 成員

相同 class 的各個 objects 互為 friends (友元)

```
class complex
{
public:
    complex (double r = 0, double i = 0)
        : re (r), im (i)
    { }

    int func(const complex& param)
    { return param.re + param.im; }

private:
    double re, im;
};
```

```
{
    complex c1(2,1);
    complex c2;

    c2.func(c1);
}
```


class body 外的各種定義 (definitions)

什麼情況下可以 pass by reference

什麼情況下可以 return by reference

do assignment plus

2-1

```
inline complex&
__doapl(complex* ths, const complex& r)
{
    ths->re += r.re;
    ths->im += r.im;
    return *ths;
}

inline complex&
complex::operator += (const complex& r)
{
    return __doapl (this, r);
}
```

第一參數將會被改動
第二參數不會被改動

operator overloading (操作符重載-1, 成員函數) **this**

2-1

```
inline complex&
__doapl(complex* ths, const complex& r)
{
    ths->re += r.re;
    ths->im += r.im;
    return *ths;
}

inline complex&
complex::operator += (const complex& r)
{
    return __doapl (this, r);
}
```

```
{
    complex c1(2,1);
    complex c2(5);

    c2 += c1;
}
```

```
inline complex&
complex::operator += (this, const complex& r)
{
    return __doapl (this, r);
}
```

return by reference 語法分析

傳遞者無需知道接收者是以 reference 形式接收

2-1

```
inline complex&
__doapl (complex* ths, const complex& r)
{
    ...
    return *ths;
}
```

```
inline complex&
complex::operator += (const complex& r)
{
    return __doapl (this, r);
}
```

```
c3 += c2 += c1;
```

```
{
    complex c1 (2, 1);
    complex c2 (5);

    c2 += c1;
}
```

class body 之外的各種定義 (definitions)

2-2

```
inline double  
imag(const complex& x)  
{  
    return x.imag ();  
}
```

```
inline double  
real(const complex& x)  
{  
    return x.real ();  
}
```

```
{  
    complex c1(2,1);  
  
    cout << imag(c1);  
    cout << real(c1);  
}
```

operator overloading (操作符重載-2, 非成員函數) (無 this)

2-3 為了對付 client 的三種可能用法，這兒對應開發三個函數

```
inline complex
operator + (const complex& x, const complex& y)
{
    return complex (real (x) + real (y),
                   imag (x) + imag (y));
}
```

```
inline complex
operator + (const complex& x, double y)
{
    return complex (real (x) + y, imag (x));
}
```

```
inline complex
operator + (double x, const complex& y)
{
    return complex (x + real (y), imag (y));
}
```

```
{
    complex c1(2,1);
    complex c2;

    c2 = c1 + c2;
    c2 = c1 + 5;
    c2 = 7 + c1;
}
```

temp object (臨時對象) *typename* ();

2-3

下面這些函數絕不可 `return by reference`，因為，它們返回的必定是個 `local object`。

```
inline complex
operator + (const complex& x, const complex& y)
{
    return complex (real (x) + real (y),
                    imag (x) + imag (y));
}

inline complex
operator + (const complex& x, double y)
{
    return complex (real (x) + y, imag (x));
}

inline complex
operator + (double x, const complex& y)
{
    return complex (x + real (y), imag (y));
}
```

```
{
    int(7);

    complex c1(2,1);
    complex c2;
    complex();
    complex(4,5);

    cout << complex(2);
}
```

class body 之外的各種定義 (definitions)

2-4

```
inline complex  
operator + (const complex& x)  
{  
    return x;  
}
```

```
inline complex  
operator - (const complex& x)  
{  
    return complex (-real (x), -imag (x));  
}
```

negate
反相
(取反)

這個函數絕不可
return by reference，
因為其返回的
必定是個 **local object**。

```
{  
    complex c1(2,1);  
    complex c2;  
    cout << -c1;  
    cout << +c1;  
}
```

operator overloading (操作符重載), 非成員函數

2-5

```
inline bool
operator == (const complex& x,
            const complex& y)
{
    return real (x) == real (y)
        && imag (x) == imag (y);
}

inline bool
operator == (const complex& x, double y)
{
    return real (x) == y && imag (x) == 0;
}

inline bool
operator == (double x, const complex& y)
{
    return x == real (y) && imag (y) == 0;
}
```

```
{
    complex c1(2,1);
    complex c2;

    cout << (c1 == c2);
    cout << (c1 == 2);
    cout << (0 == c2);
}
```


operator overloading (操作符重載), 非成員函數

2-6

```
inline bool
operator != (const complex& x,
             const complex& y)
{
    return real (x) != real (y)
           || imag (x) != imag (y);
}

inline bool
operator != (const complex& x, double y)
{
    return real (x) != y || imag (x) != 0;
}

inline bool
operator != (double x, const complex& y)
{
    return x != real (y) || imag (y) != 0;
}
```

```
{
    complex c1(2,1);
    complex c2;

    cout << (c1 != c2);
    cout << (c1 != 2);
    cout << (0 != c2);
}
```

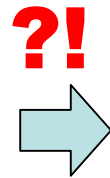
operator overloading (操作符重載), 非成員函數

```
inline complex
conj (const complex& x)
{
    return complex (real (x), -imag (x));
}

#include <iostream.h>
ostream&
operator << (ostream& os, const complex& x)
{
    return os << '(' << real (x) << ', '
        << imag (x) << ')';
}
```

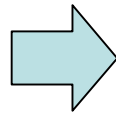
共軛複數

2-7



```
void
operator << (ostream& os,
            const complex& x)
{
    return os << '(' << real (x) << ', '
        << imag (x) << ')';
}
```

```
{
    complex c1(2,1);
    cout << conj(c1);
    cout << c1 << conj(c1);
}
```



(2,-1)
(2,1)(2,-1)

```
{
    complex c1(2,1);
    cout << conj(c1);
    cout << c1 << conj(c1);
}
```



編程示例

```
#ifndef __COMPLEX__
#define __COMPLEX__

class complex
{
public:
    complex (double r = 0, double i = 0)
        : re (r), im (i)
    { }
    complex& operator += (const complex&);
    double real () const { return re; }
    double imag () const { return im; }
private:
    double re, im;

    friend complex& __doapl (complex*,
                             const complex&);
};

#endif
```

```
inline complex&
__doapl (complex* ths, const complex& r)
{
    ths->re += r.re;
    ths->im += r.im;
    return *ths;
}

inline complex&
complex::operator += (const complex& r)
{
    return __doapl (this, r);
}
```

```
inline complex
operator + (const complex& x, const complex& y)
{
    return complex ( real (x) + real (y),
                    imag (x) + imag (y) );
}
```


```
inline complex
operator + (const complex& x, double y)
{
    return complex (real (x) + y, imag (x));
}
```

```
inline complex
operator + (double x, const complex& y)
{
    return complex (x + real (y), imag (y));
}
```

```
#include <iostream.h>
ostream&
operator << (ostream& os,
            const complex& x)
{
    return os << '(' << real (x) << ', '
              << imag (x) << ')';
}
```

?!

```
complex c1(9,8);
cout << c1;
c1 << cout;
cout << c1 << endl;
```



你將獲得的代碼

complex.h
complex-test.cpp

string.h
string-test.cpp

Classes 的兩個經典分類

- **Class without pointer member(s)**

complex

- **Class with pointer member(s)**

string

String class

```
#ifndef __MYSTRING__  
#define __MYSTRING__
```

string.h

1

```
class String  
{  
  ...  
};
```

2

```
String::function(...) ...  
Global-function(...) ...
```

```
#endif
```

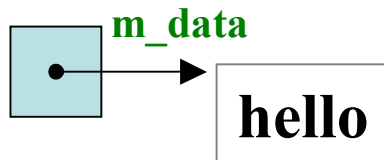
```
int main()  
{  
  String s1(),  
  String s2("hello");  
  
  String s3(s1);  
  cout << s3 << endl;  
  s3 = s2;  
  
  cout << s3 << endl;  
}
```

string-test.cpp

Big Three, 三個特殊函數

1

```
class String
{
public:
    String(const char* cstr = 0);
    String(const String& str);
    String& operator=(const String& str);
    ~String();
    char* get_c_str() const { return m_data; }
private:
    char* m_data;
};
```



ctor 和 dtor (構造函數和析構函數)

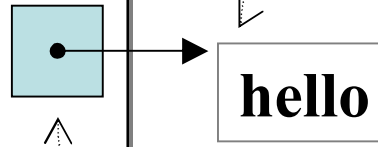
2-1

```
inline
String::String(const char* cstr = 0)
{
    if (cstr) {
        m_data = new char[strlen(cstr)+1];
        strcpy(m_data, cstr);
    }
    else { // 未指定初值
        m_data = new char[1];
        *m_data = '\0';
    }
}
```

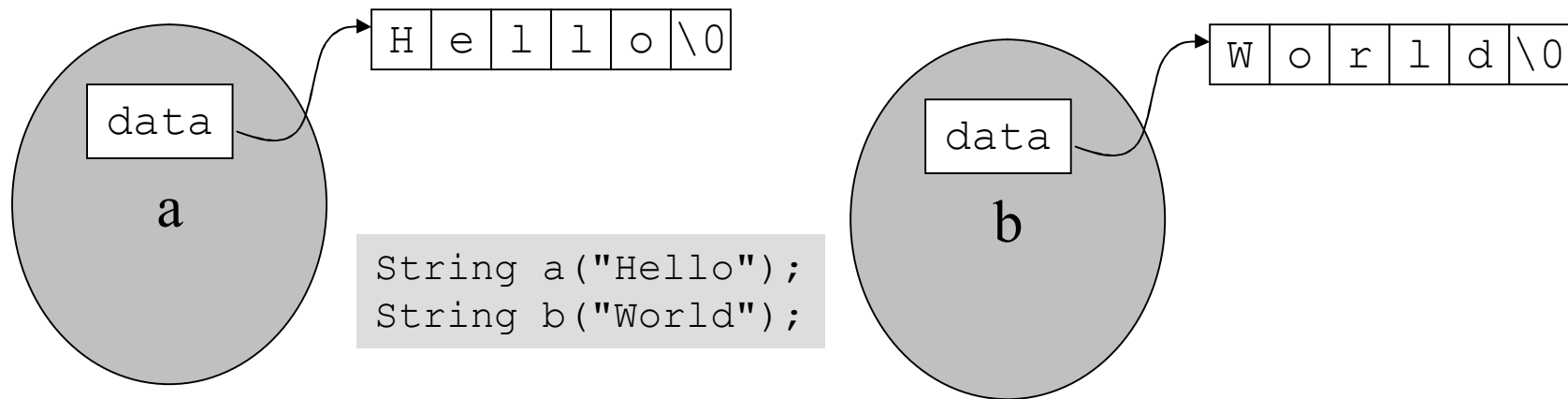
```
inline
String::~~String()
{
    delete[] m_data;
}
```

```
{
    String s1(),
    String s2("hello");

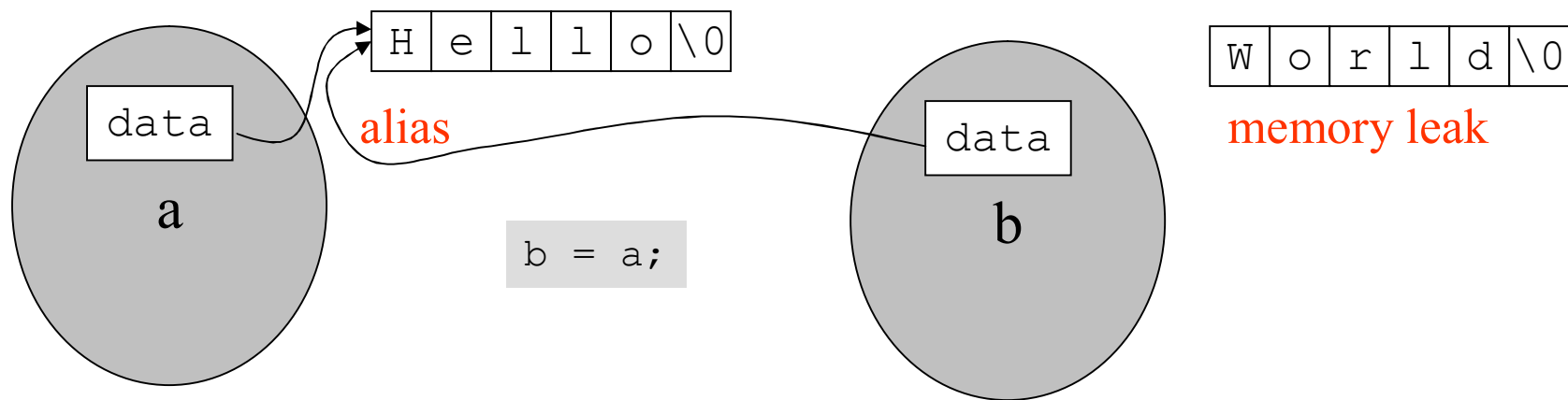
    String* p = new String("hello");
    delete p;
}
```



class with pointer members 必須有 copy ctor 和 copy op=



使用 default copy ctor 或 default op= 就會形成以下局面



copy ctor (拷貝構造函數)

2-2

```
inline
String::String(const String& str)
{
    m_data = new char[ strlen(str.m_data) + 1 ];
    strcpy(m_data, str.m_data);
}
```

```
{
    String s1("hello ");
    String s2(s1);
    // String s2 = s1;
}
```

直接取另一個 object 的 private data.
(兄弟之間互為 friend)

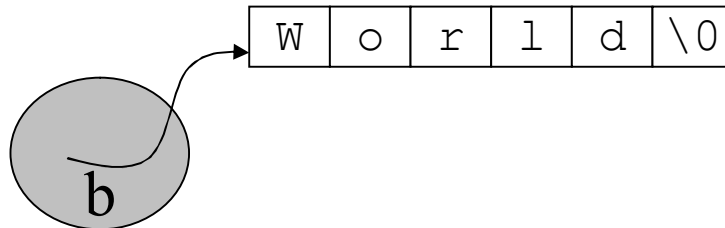
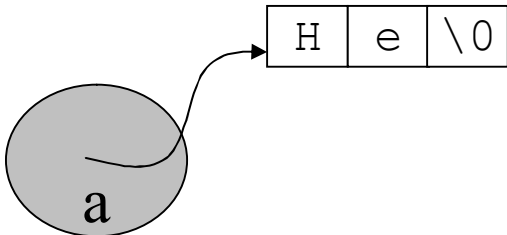
copy assignment operator (拷貝賦值函數)

2-3

```
inline
String& String::operator=(const String& str)
{
    if (this == &str)
        return *this;
    1 delete[] m_data;
    2 m_data = new char[ strlen(str.m_data) + 1 ];
    3 strcpy(m_data, str.m_data);
    return *this;
}
```

檢測自我賦值
(self assignment)

```
{
    String s1("hello ");
    String s2(s1);
    s2 = s1;
}
```



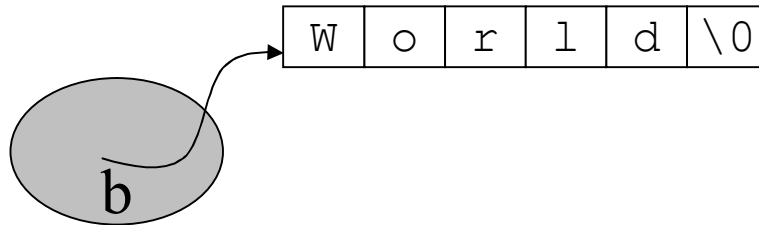
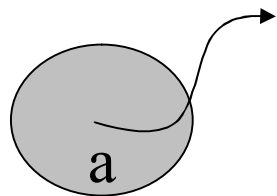
copy assignment operator (拷貝賦值函數)

2-3

```
inline
String& String::operator=(const String& str)
{
    if (this == &str)
        return *this;
    1 delete[] m_data;
    2 m_data = new char[ strlen(str.m_data) + 1 ];
    3 strcpy(m_data, str.m_data);
    return *this;
}
```

檢測自我賦值
(self assignment)

1

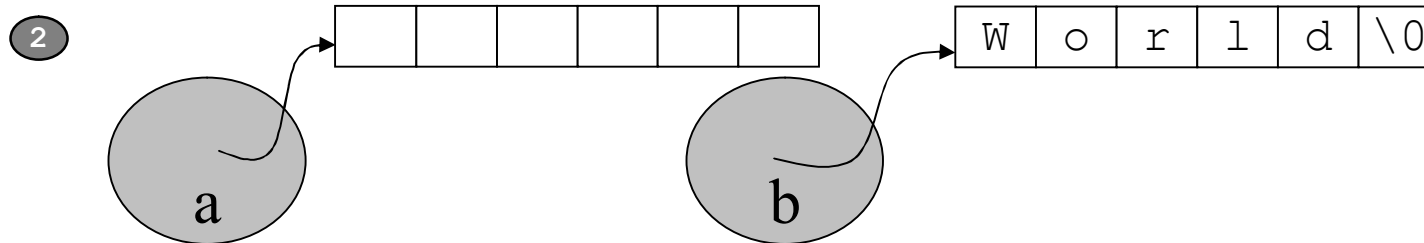


copy assignment operator (拷貝賦值函數)

2-3

```
inline
String& String::operator=(const String& str)
{
    if (this == &str)
        return *this;
    1 delete[] m_data;
    2 m_data = new char[ strlen(str.m_data) + 1 ];
    3 strcpy(m_data, str.m_data);
    return *this;
}
```

檢測自我賦值
(self assignment)

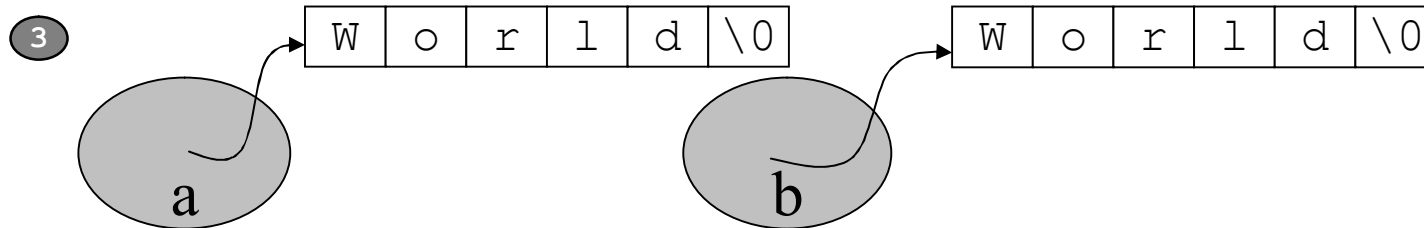


copy assignment operator (拷貝賦值函數)

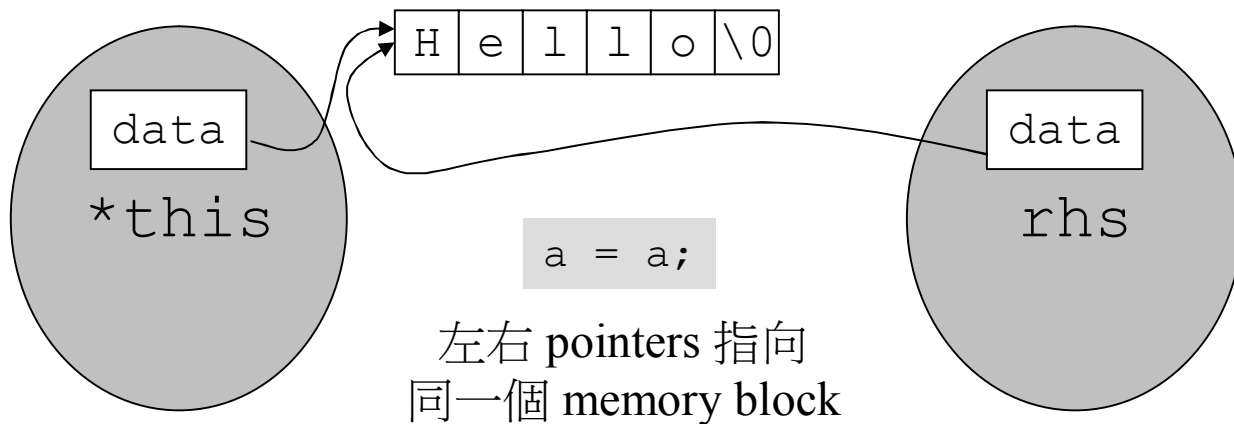
2-3

```
inline
String& String::operator=(const String& str)
{
    if (this == &str)
        return *this;
    1 delete[] m_data;
    2 m_data = new char[ strlen(str.m_data) + 1 ];
    3 strcpy(m_data, str.m_data);
    return *this;
}
```

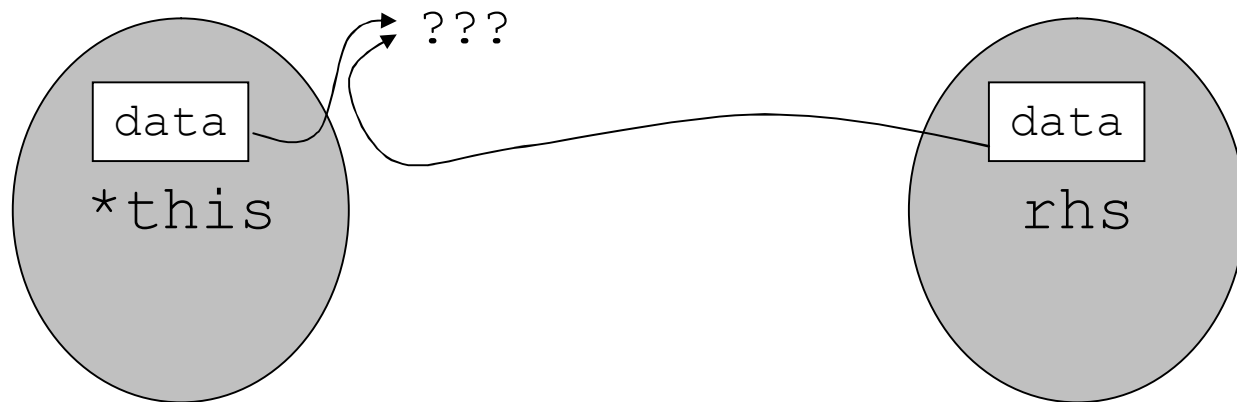
檢測自我賦值
(self assignment)



一定要在 operator= 中檢查是否 self assignment



前述 operator= 的第一件事情就是 delete，造成這般結果：



然後，當企圖存取 (訪問) `rhs`，產生不確定行為 (undefined behavior)

output 函數

2-4

```
#include <iostream.h>
ostream& operator<<(ostream& os, const String& str)
{
    os << str.get_c_str();
    return os;
}
```

```
{
    String s1("hello ");
    cout << s1;
}
```

//// 所謂 stack (棧), 所謂 heap (堆)

Stack，是存在於某作用域 (**scope**) 的一塊內存空間 (**memory space**)。例如當你調用函數，函數本身即會形成一個 **stack** 用來放置它所接收的參數，以及返回地址。

在函數本體 (**function body**) 內聲明的任何變量，其所使用的內存塊都取自上述 **stack**。

Heap，或謂 **system heap**，是指由操作系統提供的一塊 **global** 內存空間，程序可動態分配 (**dynamic allocated**) 從某中獲得若干區塊 (**blocks**)。

```
class Complex { ... };  
...  
{  
    Complex c1(1,2);  
    Complex* p = new Complex(3);  
}
```

c1 所佔用的空間來自 **stack**

Complex(3) 是個臨時對象，其所佔用的空間乃是以 **new** 自 **heap** 動態分配而得，並由 **p** 指向。



stack objects 的生命期

```
class Complex { ... };  
...  
{  
    Complex c1(1,2);  
}
```

c1 便是所謂 **stack object**，其生命在作用域 (**scope**) 結束之際結束。
這種作用域內的 **object**，又稱為 **auto object**，因為它會被「自動」清理。



static local objects 的生命期

```
class Complex { ... };  
...  
{  
    static Complex c2(1,2);  
}
```

c2 便是所謂 **static object**，其生命在作用域 (scope) 結束之後仍然存在，直到整個程序結束。

/// global objects 的生命期

```
class Complex { ... };  
...  
Complex c3(1,2);  
  
int main()  
{  
    ...  
}
```

c3 便是所謂 **global object**，其生命在整個程序結束之後才結束。你也可以把它視為一種 **static object**，其作用域是「整個程序」。

/// heap objects 的生命期

```
class Complex { ... };  
...  
  
{  
    Complex* p = new Complex;  
    ...  
    delete p;  
}
```

p 所指的便是 heap object，其生命在它被 **deleted** 之際結束。

```
class Complex { ... };  
...  
  
{  
    Complex* p = new Complex;  
}
```

以上出現內存洩漏 (memory leak)，因為當作用域結束，**p** 所指的 heap object 仍然存在，但指針 **p** 的生命卻結束了，作用域之外再也看不到 **p** (也就沒機會 **delete p**)

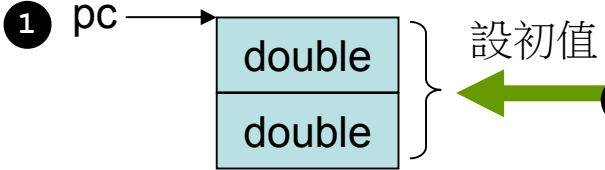


new : 先分配 memory, 再調用 ctor

```

class Complex
{
public:
    Complex(...) {...}
    ...
private:
    double m_real;
    double m_imag;
};

```



```
Complex* pc = new Complex(1, 2);
```



編譯器轉化為

其內部調用 malloc(n)

```

Complex *pc;

① void* mem = operator new( sizeof(Complex) ); //分配內存
② pc = static_cast<Complex*>(mem);           //轉型
③ pc->Complex::Complex(1, 2);                 //構造函數

```

```
Complex::Complex(pc, 1, 2);
```

this

delete : 先調用 dtor, 再釋放 memory

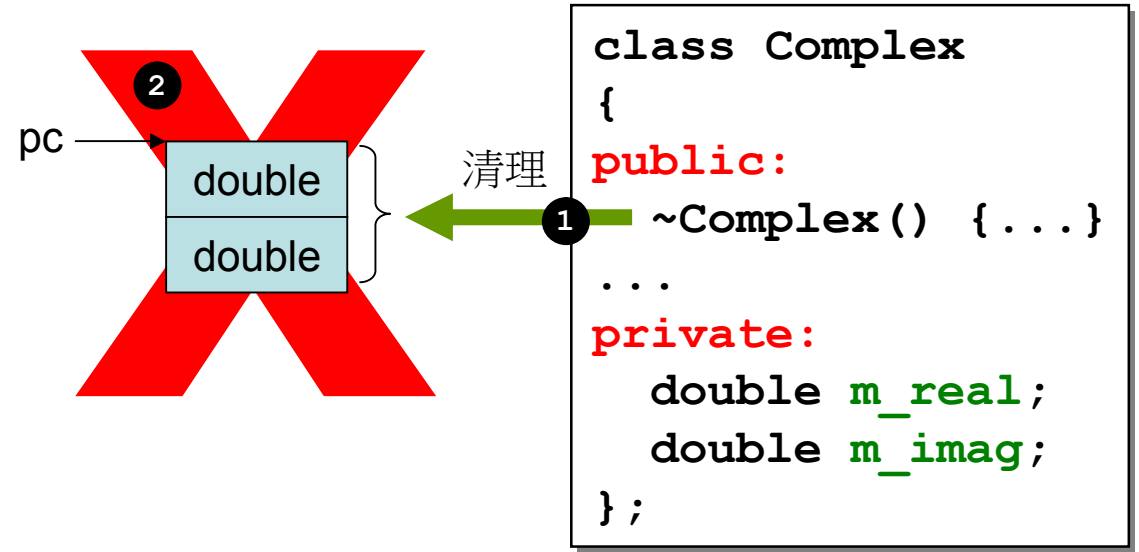
```
Complex* pc = new Complex(1,2);  
...  
delete pc;
```

編譯器轉化為



```
1 Complex::~~Complex(pc); // 析構函數  
2 operator delete(pc); // 釋放內存
```

其內部調用 free(pc)





new : 先分配 memory, 再調用 ctor

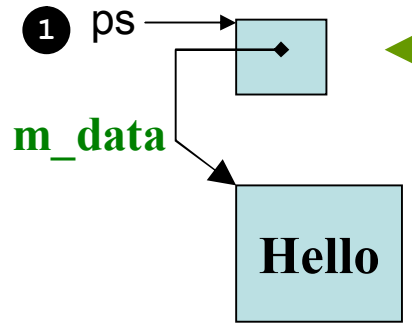
```
String* ps = new String("Hello");
```

編譯器轉化為

```
String* ps;  
  
1 void* mem = operator new( sizeof(String) ); //分配內存  
2 ps = static_cast<String*>(mem); //轉型  
3 ps->String::String("Hello"); //構造函數
```

其內部調用 malloc(n)

```
String::String(ps, "Hello");
```



```
class String  
{  
public:  
String(...)  
{...  
m_data =  
new char[n];  
...  
}  
private:  
char* m_data;  
};
```

this

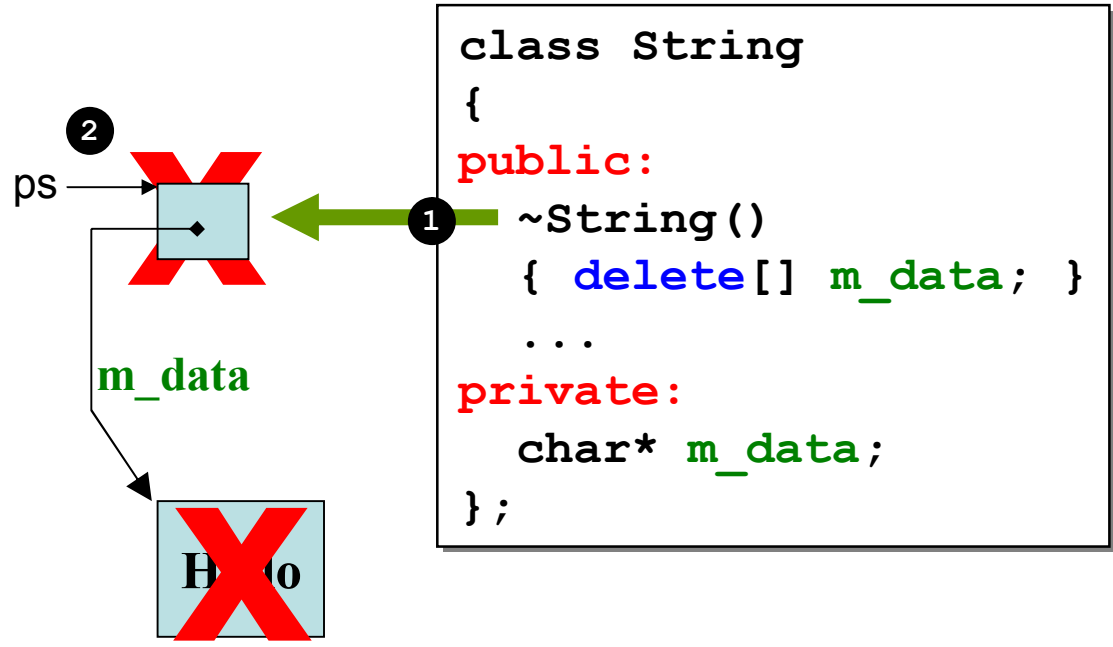
delete : 先調用 dtor, 再釋放 memory

```
String* ps = new String("Hello");  
...  
delete ps;
```

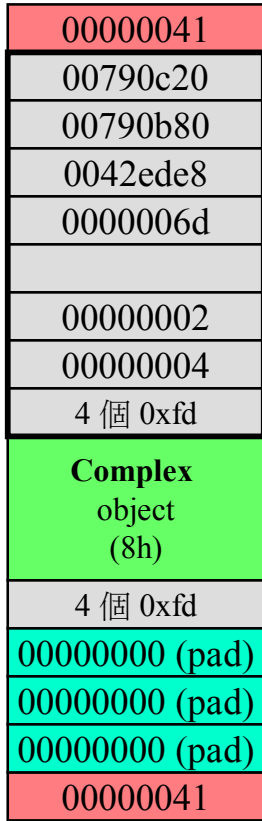
↓ 編譯器轉化為

```
1 String::~~String(ps); // 析構函數  
2 operator delete(ps); // 釋放內存
```

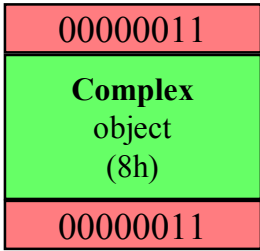
其內部調用 free(ps)



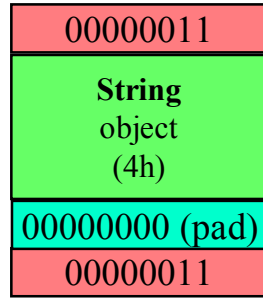
動態分配所得的內存塊 (memory block), in VC



$$8+(4*2) \rightarrow 16$$



$$4+(32+4)+(4*2) \rightarrow 48$$



$$4+(4*2) \rightarrow 12$$

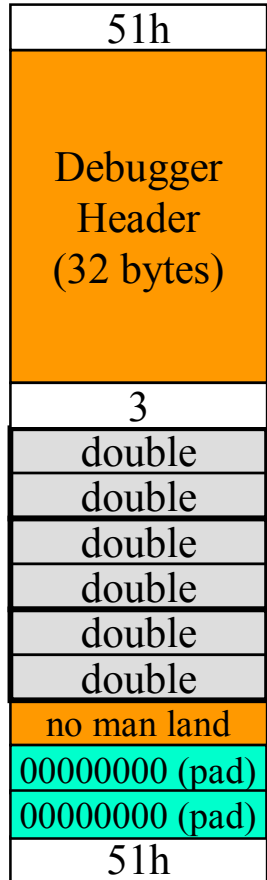
$$\rightarrow 16$$

$$8+(32+4)+(4*2) \rightarrow 52$$

$$\rightarrow 64$$

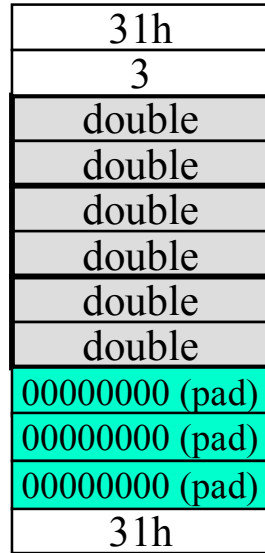
動態分配所得的 array

Complex* p = new Complex[3];



$$(8*3)+(32+4)+(4*2)+4$$

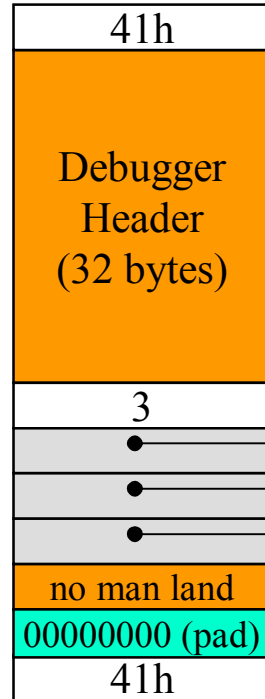
→ 72
→ 80



$$(8*3)+(4*2)+4$$

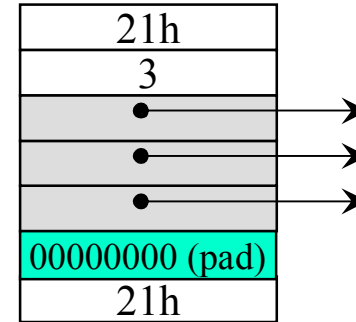
→ 36
→ 48

String* p = new String[3];



$$(4*3)+(32+4)+(4*2)+4$$

→ 60
→ 64

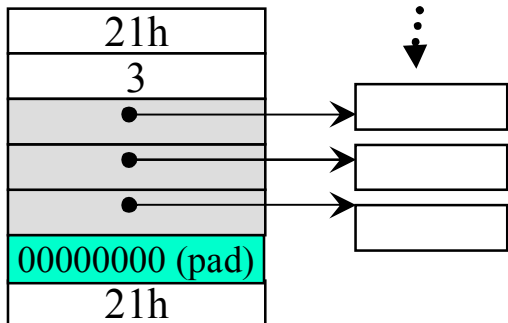


$$(4*3)+(4*2)+4$$

→ 24
→ 32

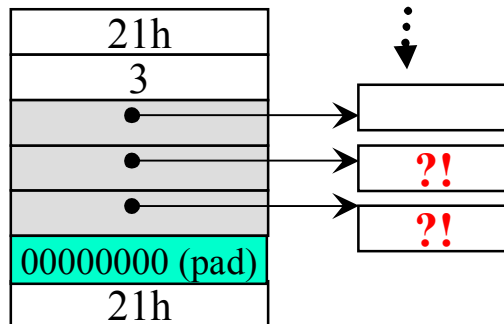
array new 一定要搭配 array delete

```
String* p = new String[3];  
...  
delete[] p; //喚起3次dtor
```



```
String* p = new String[3];  
...  
delete p; //喚起1次dtor
```

不正確的使用法
少了 []





編程示例

```
class String
{
public:
    String(const char* cstr = 0);
    String(const String& str);
    String& operator=(const String& str);
    ~String();
    char* get_c_str() const { return m_data; }
private:
    char* m_data;
};
```


```
inline
String::String(const char* cstr = 0)
{
    if (cstr) {
        m_data = new char[strlen(cstr)+1];
        strcpy(m_data, cstr);
    }
    else { // 未指定初值
        m_data = new char[1];
        *m_data = '\0';
    }
}

inline
String::~~String()
{
    delete[] m_data;
}
```

```
inline
String::String(const String& str)
{
    m_data = new char[ strlen(str.m_data) + 1 ];
    strcpy(m_data, str.m_data);
}
```

```
inline
String& String::operator=(const String& str)
{
    if (this == &str)
        return *this;

    delete[] m_data;
    m_data = new char[ strlen(str.m_data) + 1 ];
    strcpy(m_data, str.m_data);
    return *this;
}
```



你將獲得的代碼

complex.h

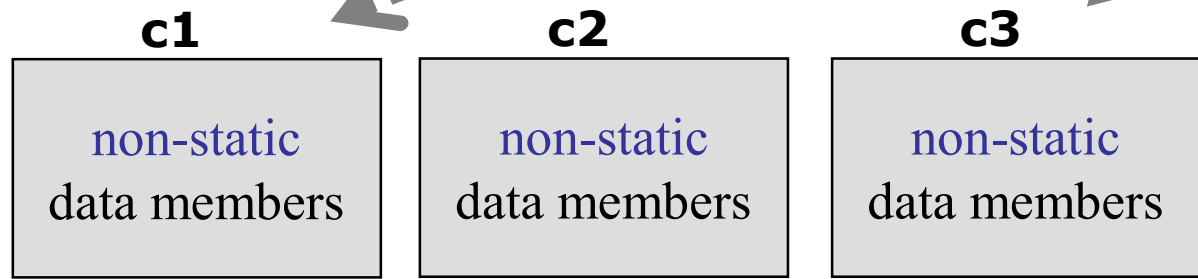
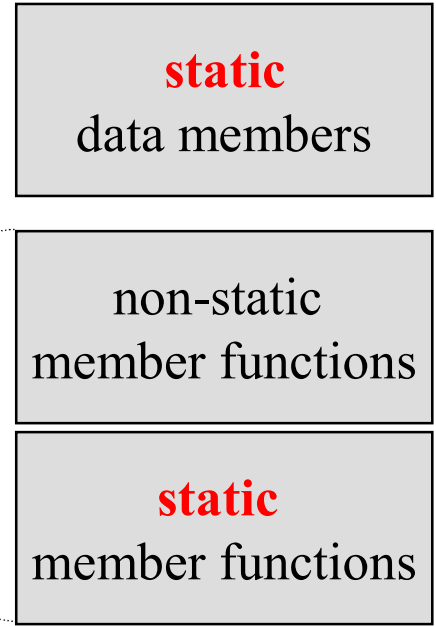
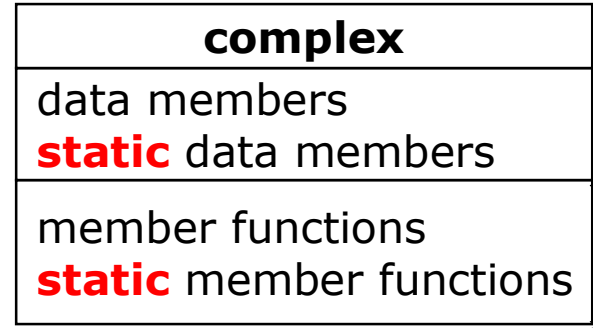
complex-test.cpp

string.h

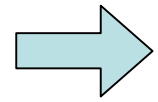
string-test.cpp



進一步補充：static

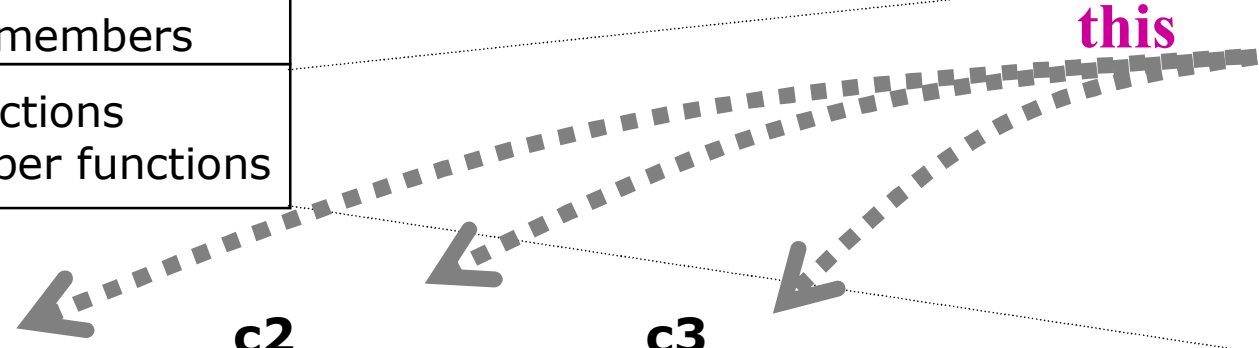


```
complex c1, c2, c3;
cout << c1.real();
cout << c2.real();
```



```
complex c1, c2, c3;
cout << complex::real(&c1);
cout << complex::real(&c2);
```

this



```
class complex
{
public:
    double real () const
        { return this->re; }
private:
    double re, im;
};
```

進一步補充：static

```
class Account {
public:
    static double m_rate;
    static void set_rate(const double& x) { m_rate = x; }
};
double Account::m_rate = 8.0;

int main() {
    Account::set_rate(5.0);

    Account a;
    a.set_rate(7.0);
}
```

調用 static 函數的方式有二：

- (1) 通過 object 調用
- (2) 通過 class name 調用

進一步補充：把 ctors 放在 private 區

Meyers Singleton

```
class A {  
public:  
    static A& getInstance ();  
    setup() { ... }  
private:  
    A();  
    A(const A& rhs);  
    ...  
};  
  
A& A::getInstance ()  
{  
    static A a;  
    return a;  
}
```

```
A::getInstance ().setup ();
```

進一步補充：把 ctors 放在 private 區

Singleton

```
class A {  
public:  
    static A& getInstance ( return a; );  
    setup() { ... }  
private:  
    A();  
    A(const A& rhs);  
    static A a;  
    ...  
};
```

```
A::getInstance().setup();
```

進一步補充：cout

```
class ostream : virtual public ios
{
public:
    ostream& operator<<(char c);
    ostream& operator<<(unsigned char c) { return (*this) << (char)c; }
    ostream& operator<<(signed char c) { return (*this) << (char)c; }
    ostream& operator<<(const char *s);
    ostream& operator<<(const unsigned char *s)
        { return (*this) << (const char*)s; }
    ostream& operator<<(const signed char *s)
        { return (*this) << (const char*)s; }
    ostream& operator<<(const void *p);
    ostream& operator<<(int n);
    ostream& operator<<(unsigned int n);
    ostream& operator<<(long n);
    ostream& operator<<(unsigned long n);
    ...
}
```

```
class _IO_ostream_withassign
    : public ostream {
    ...
};

extern _IO_ostream_withassign cout;
```

進一步補充：class template, 類模板

```
template<typename T>
class complex
{
public:
    complex (T r = 0, T i = 0)
        : re (r), im (i)
    { }
    complex& operator += (const complex&);
    T real () const { return re; }
    T imag () const { return im; }
private:
    T re, im;

    friend complex& __doapl (complex*, const complex&);
};
```

```
{
    complex<double> c1 (2.5, 1.5);
    complex<int> c2 (2, 6);
    ...
}
```

進一步補充：function template, 函數模板

```
stone r1(2,3), r2(3,3), r3;  
r3 = min(r1, r2);
```

編譯器會對 function template 進行
引數推導 (argument deduction)

```
template <class T>  
inline  
const T& min(const T& a, const T& b)  
{  
    return b < a ? b : a;  
}
```

```
class stone  
{  
public:  
    stone(int w, int h, int we)  
        : _w(w), _h(h), _weight(we)  
        { }  
    bool operator< (const stone& rhs) const  
        { return _weight < rhs._weight; }  
private:  
    int _w, _h, _weight;  
};
```

引數推導的結果，T 為 stone，於是調用 stone::operator<

/// 進一步補充：namespace

```
namespace std
{
    ...
}
```

using directive

```
#include <iostream.h>
using namespace std;

int main()
{
    cin << ...;
    cout << ...;

    return 0;
}
```

using declaration

```
#include <iostream.h>
using std::cout;

int main()
{
    std::cin << ...;
    cout << ...;

    return 0;
}
```

```
#include <iostream.h>

int main()
{
    std::cin << ;
    std::cout << ...;

    return 0;
}
```

更多細節與深入

- **operator *type*() const;**
- **explicit** `complex(...)` : *initialization list* { }
- pointer-like object
- function-like object
- **Namespace**
- **template** specialization
- Standard Library
- variadic **template** (since C++11)
- move ctor (since C++11)
- Rvalue reference (since C++11)
- **auto** (since C++11)
- lambda (since C++11)
- range-base for loop (since C++11)
- unordered containers (Since C++)
- ...

革命尚未成功

同志仍需努力

Object Oriented Programming, Object Oriented Design

OOP, OOD

- **Inheritance (繼承)**
- **Composition (複合)**
- **Delegation (委託)**

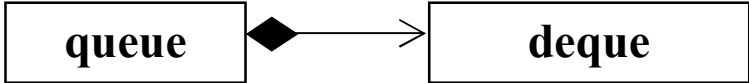
Composition (複合), 表示 has-a

```
template <class T, class Sequence = deque<T> >
class queue {
    ...
protected:
    Sequence c;    // 底層容器
public:
    // 以下完全利用 c 的操作函數完成
    bool empty() const { return c.empty(); }
    size_type size() const { return c.size(); }
    reference front() { return c.front(); }
    reference back() { return c.back(); }
    // deque 是兩端可進出，queue 是末端進前端出（先進先出）
    void push(const value_type& x) { c.push_back(x); }
    void pop() { c.pop_front(); }
};
```

Composition (複合), 表示 has-a

Adapter

```
template <class T>
class queue {
    ...
protected:
    deque<T> c;      // 底層容器
public:
    // 以下完全利用 c 的操作函數完成
    bool empty() const { return c.empty(); }
    size_type size() const { return c.size(); }
    reference front() { return c.front(); }
    reference back() { return c.back(); }
    //
    void push(const value_type& x) { c.push_back(x); }
    void pop() { c.pop_front(); }
};
```



```
classDiagram
    class queue
    class deque
    queue "1" *-- "1" deque
```

Composition (複合), 表示 has-a

Sizeof : 40

```
template <class T>
class queue {
protected:
  deque<T> c;
  ...
};
```

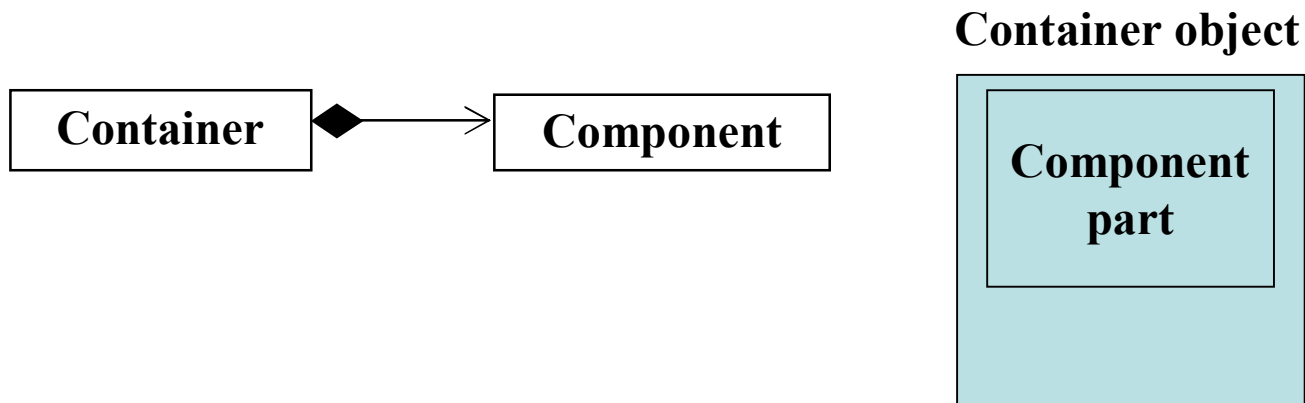
Sizeof : $16 * 2 + 4 + 4$

```
template <class T>
class deque {
protected:
  Itr<T> start;
  Itr<T> finish;
  T** map;
  unsigned int map_size;
};
```

Sizeof : $4 * 4$

```
template <class T>
struct Itr {
  T* cur;
  T* first;
  T* last;
  T** node;
  ...
};
```

Composition (複合) 關係下的構造和析構



構造由內而外

Container 的構造函數首先調用 **Component** 的 default 構造函數，然後才執行自己。

```
Container::Container(...) : Component() { ... };
```

析構由外而內

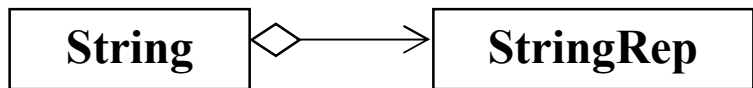
Container 的析構函數首先執行自己，然後才調用 **Component** 的析構函數。

```
Container::~~Container(...) { ... ~Component() };
```

Delegation (委託). Composition by reference.

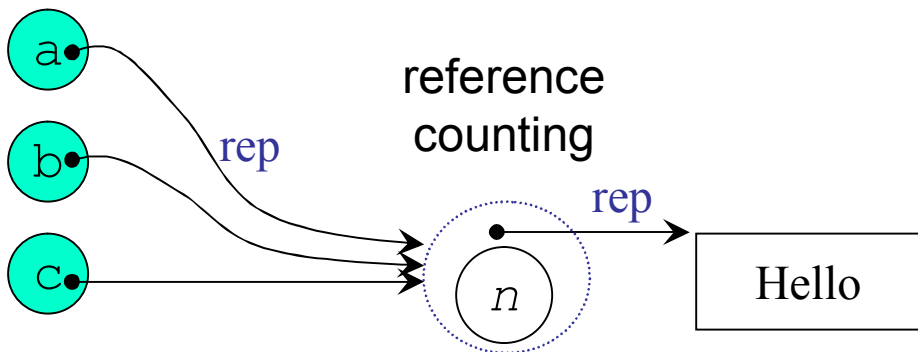
Handle / Body (pImpl)

```
// file String.hpp
class StringRep;
class String {
public:
    String();
    String(const char* s);
    String(const String& s);
    String &operator=(const String& s);
    ~String();
    . . .
private:
    StringRep* rep; // pimpl
};
```



```
// file String.cpp
#include "String.hpp"
namespace {
class StringRep {
friend class String;
    StringRep(const char* s);
    ~StringRep();
    int count;
    char* rep;
};
}

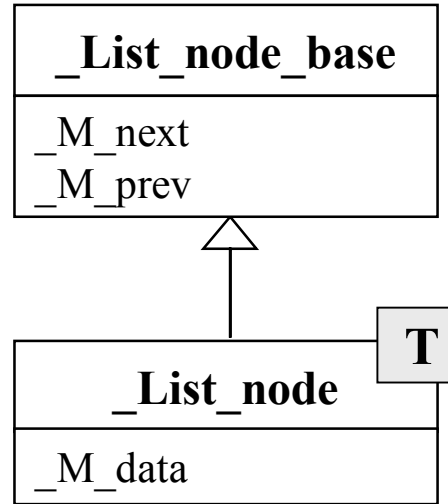
String::String() { ... }
...
```



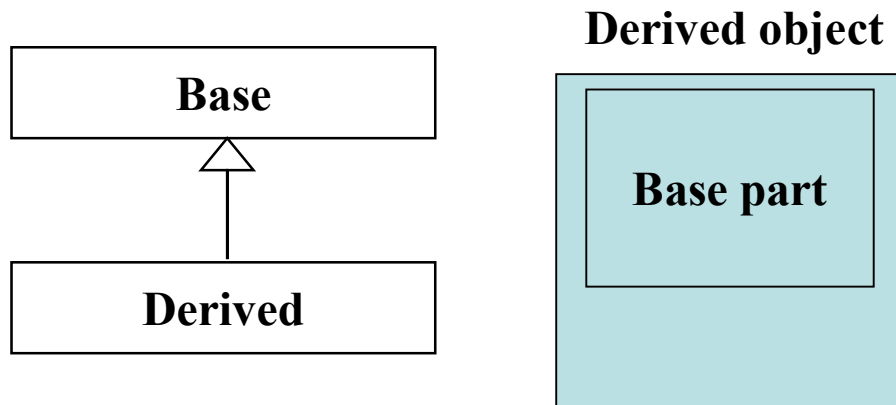
Inheritance (繼承), 表示 is-a

```
struct _List_node_base
{
    _List_node_base* _M_next;
    _List_node_base* _M_prev;
};

template<typename _Tp>
struct _List_node
    : public _List_node_base
{
    _Tp _M_data;
};
```



Inheritance (繼承) 關係下的構造和析構



base class 的 dtor
必須是 **virtual** ，
否則會出現
undefined behavior

構造由內而外

Derived 的構造函數首先調用 **Base** 的 default 構造函數，然後才執行自己。

```
Derived::Derived(...) : Base() { ... };
```

析構由外而內

Derived 的析構函數首先執行自己，然後才調用 **Base** 的析構函數。

```
Derived::~~Derived(...) { ... ~Base() };
```

Inheritance (繼承) with **virtual** functions (虛函數)

non-virtual 函數：你不希望 **derived class** 重新定義 (**override**, 覆寫) 它。

virtual 函數：你希望 **derived class** 重新定義 (**override**, 覆寫) 它，且你對它已有默認定義。

pure virtual 函數：你希望 **derived class** 一定要重新定義 (**override** 覆寫) 它，你對它沒有默認定義。

```
class Shape {  
public:  
    virtual void draw( ) const = 0;  
    virtual void error(const std::string& msg);  
    int objectID( ) const;  
    ...  
};
```

pure virtual

impure virtual

non-virtual

```
class Rectangle: public Shape { ... };  
class Ellipse: public Shape { ... };
```


Inheritance (繼承) with virtual



Check file name

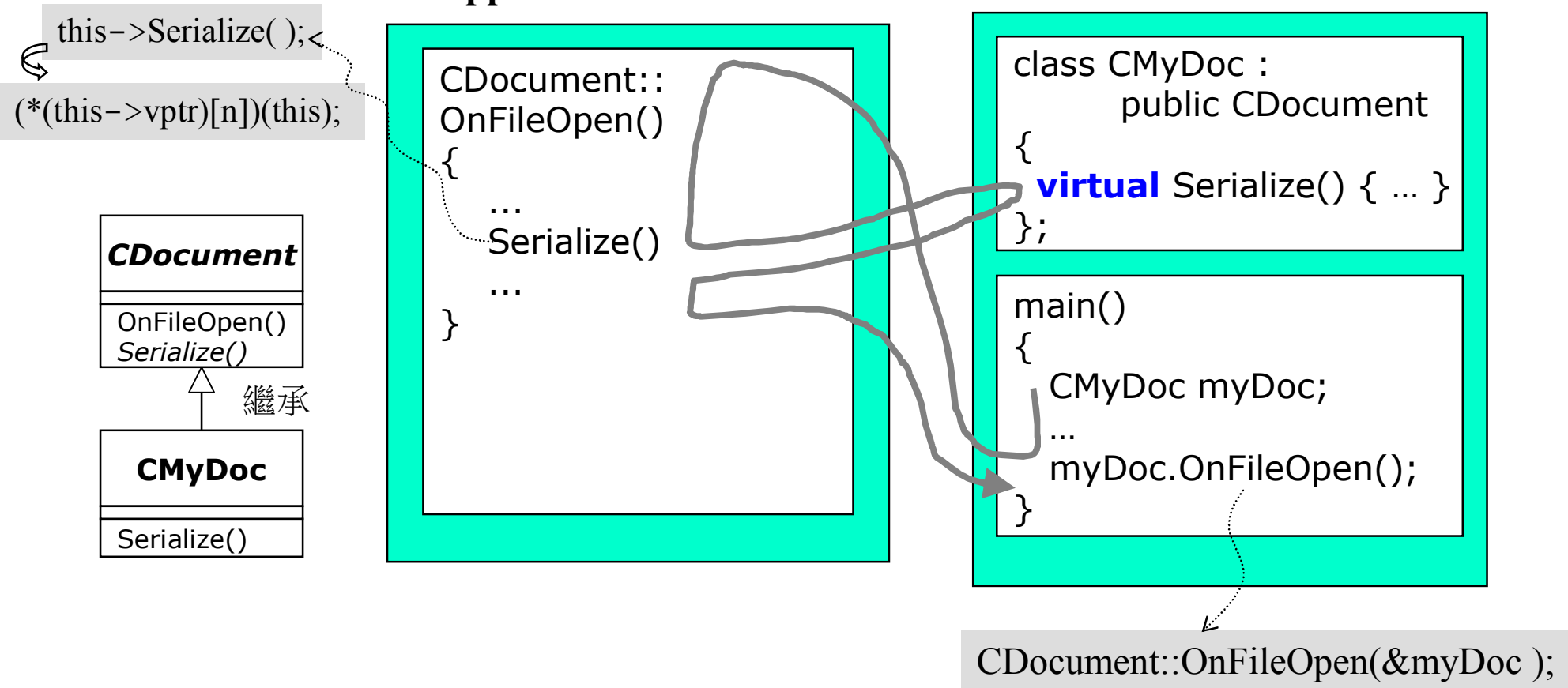
Search file

Open file



Inheritance (繼承) with **virtual**

Template Method



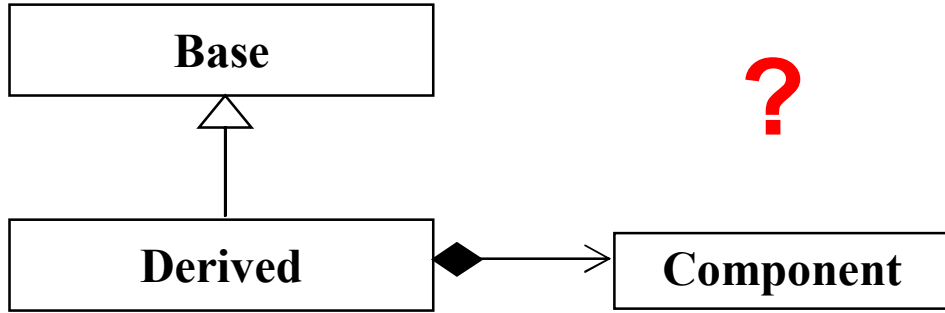
Inheritance (繼承), 表示 is-a

```
01 #include <iostream>
02 using namespace std;
03
04
05 class CDocument
06 {
07 public:
08     void OnFileOpen()
09     {
10         // 這是個算法，每個 cout 輸出代表一個實際動作
11         cout << "dialog..." << endl;
12         cout << "check file status..." << endl;
13         cout << "open file..." << endl;
14         Serialize();
15         cout << "close file..." << endl;
16         cout << "update all views..." << endl;
17     }
18
19     virtual void Serialize() { };
20 };
```

```
22 class CMyDoc : public CDocument
23 {
24 public:
25     virtual void Serialize()
26     {
27         // 只有應用程序本身才知道如何讀取自己的文件(格式)
28         cout << "CMyDoc::Serialize()" << endl;
29     }
30 };
```

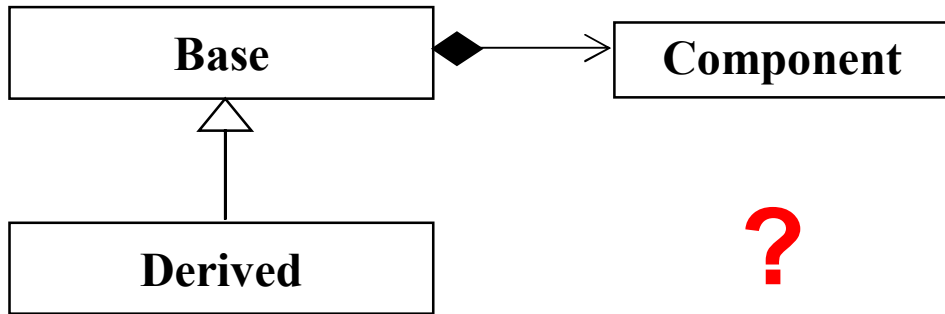
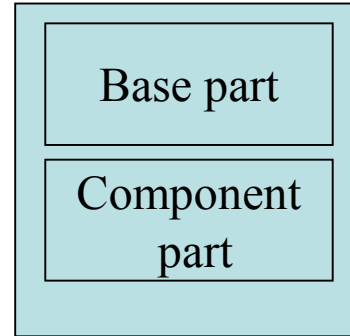
```
31 int main()
32 {
33     CMyDoc myDoc; // 假設對應[File/Open]
34     myDoc.OnFileOpen();
35 }
```

Inheritance+Composition 關係下的構造和析構



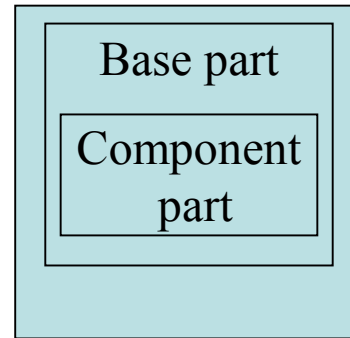
?

Derived object

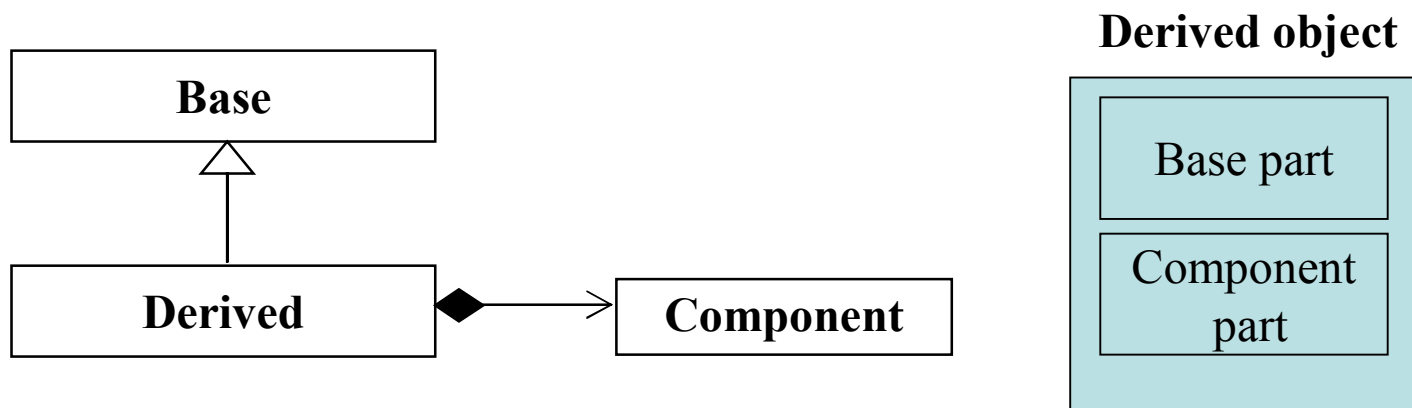


?

Derived object



Inheritance+Composition 關係下的構造和析構



構造由內而外

Derived 的構造函數首先調用 **Base** 的 default 構造函數，然後調用 **Component** 的 default 構造函數，然後才執行自己。

```
Derived::Derived(...) : Base(), Component() { ... };
```

析構由外而內

Derived 的析構函數首先執行自己，然後調用 **Component** 的析構函數，然後調用 **Base** 的析構函數。

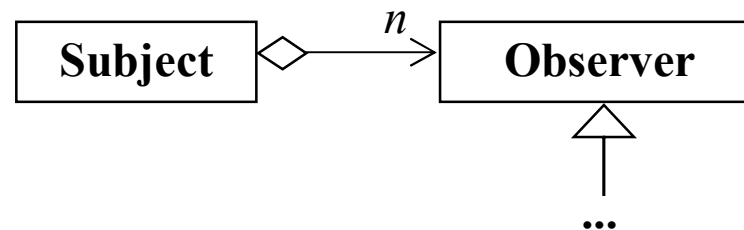
```
Derived::~~Derived(...) { ... ~Component(), ~Base() };
```

Delegation (委託) + Inheritance (繼承)

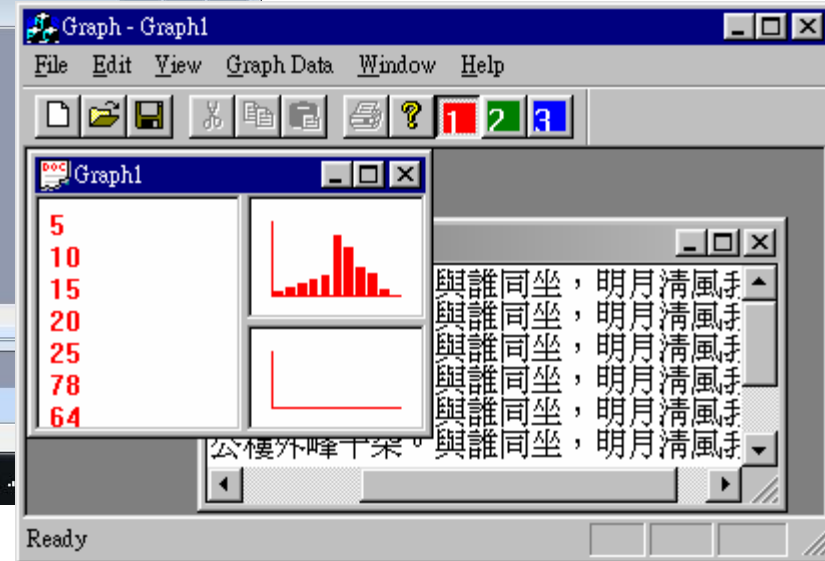
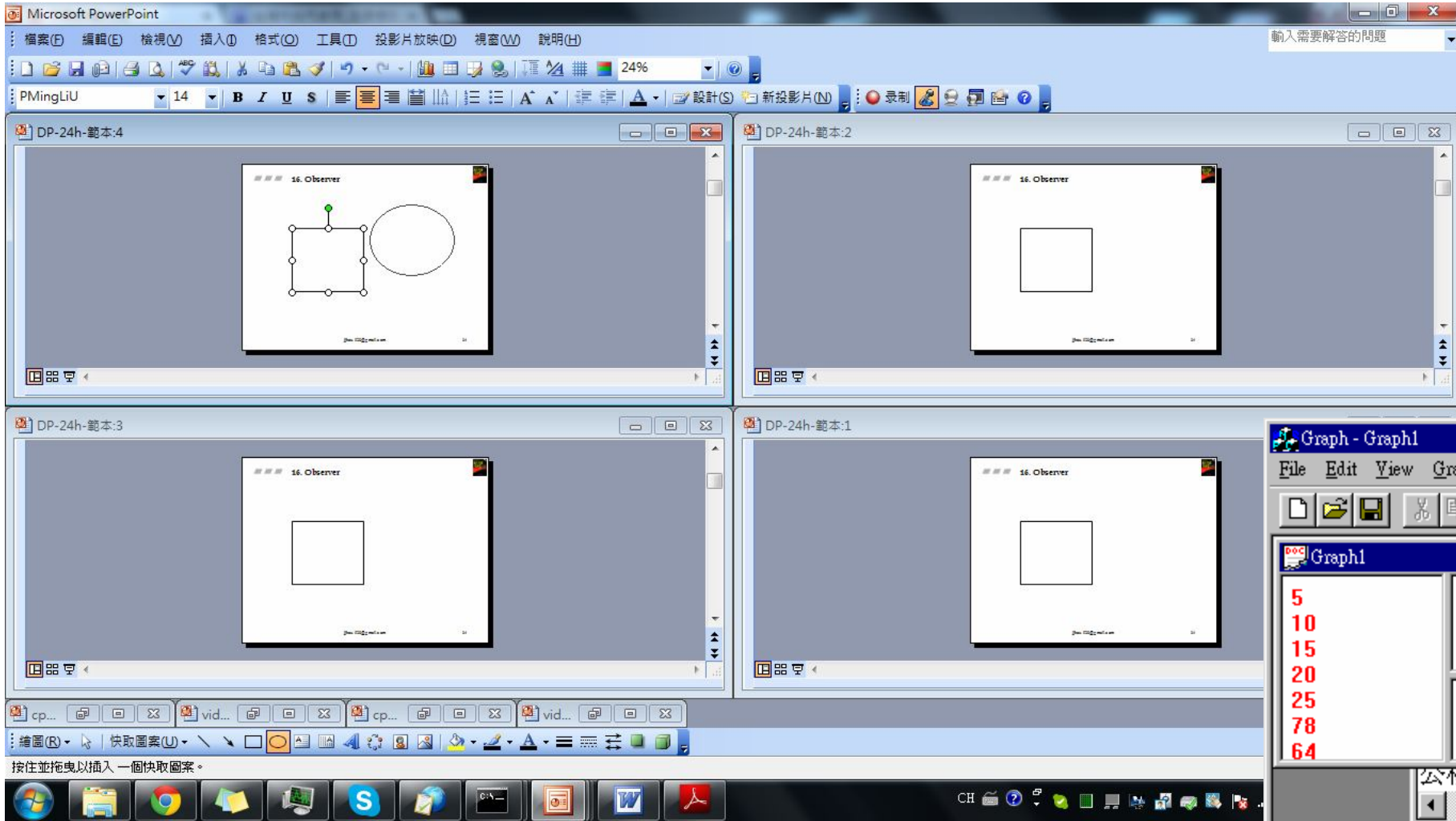
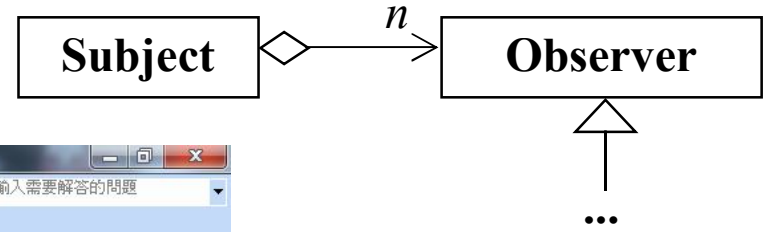
```
class Subject
{
    int m_value;
    vector<Observer*> m_views;
public:
    void attach(Observer* obs)
    {
        m_views.push_back(obs);
    }
    void set_val(int value)
    {
        m_value = value;
        notify();
    }
    void notify()
    {
        for (int i = 0; i < m_views.size(); ++i)
            m_views[i]->update(this, m_value);
    }
};
```

Observer

```
class Observer
{
public:
    virtual void update(Subject* sub, int value) = 0;
};
```



Delegation (委託) + Inheritance (繼承)



Delegation (委託) + Inheritance (繼承)

```
class Subject
{
  int m_value;
  vector<Observer*> m_views;
public:
  void attach(Observer* obs)
  {
    m_views.push_back(obs);
  }
  void set_val(int value)
  {
    m_value = value;
    notify();
  }
  void notify()
  {
    for (int i = 0; i < m_views.size(); ++i)
      m_views[i]->update(m_value);
  }
};
```

```
class Observer
{
public:
  virtual void update(int value) = 0;
};
```

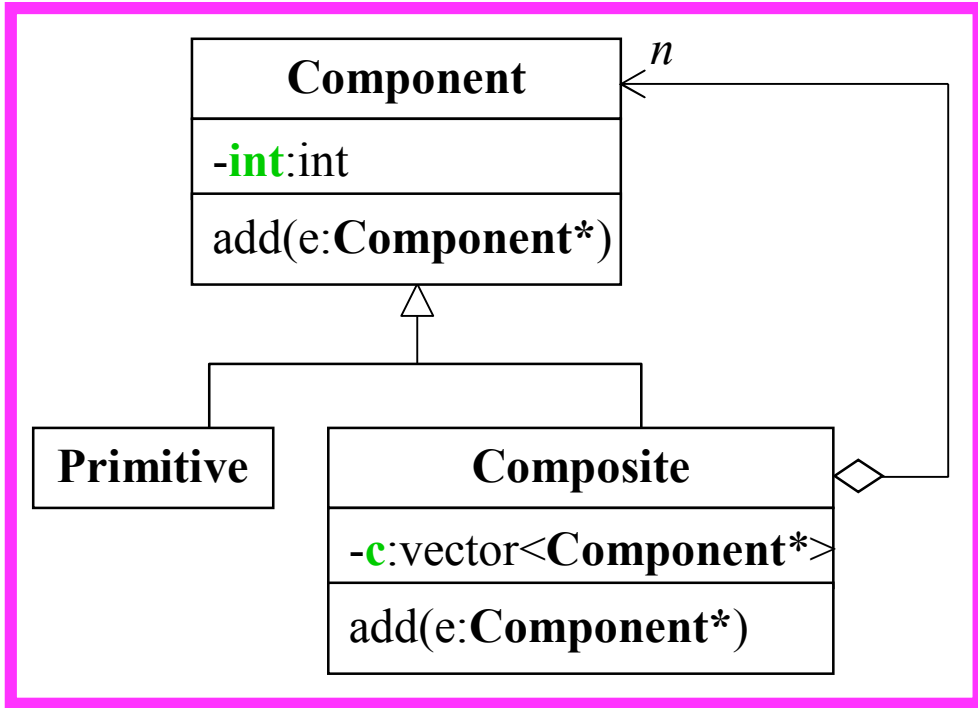
```
class Observer1: public Observer
{
  int m_div;
public:
  Observer1(Subject *model, int div)
  {
    model->attach(this);
    m_div = div;
  }
  /* virtual */void update(int v)
  { ... }
};
```

```
class Observer2: public Observer
{
  int m_mod;
public:
  Observer2(Subject *model, int mod)
  {
    model->attach(this);
    m_mod = mod;
  }
  /* virtual */void update(int v)
  { ... }
};
```

```
{
  Subject subj;
  Observer1 o1(&subj, 4);
  Observer1 o2(&subj, 3);
  Observer2 o3(&subj, 3);
  subj.set_val(14);
}
```


Delegation (委託) + Inheritance (繼承)

Composite



```
class Component
{
    int value;
public:
    Component(int val) { value = val; }
    virtual void add( Component* ) { }
};
```

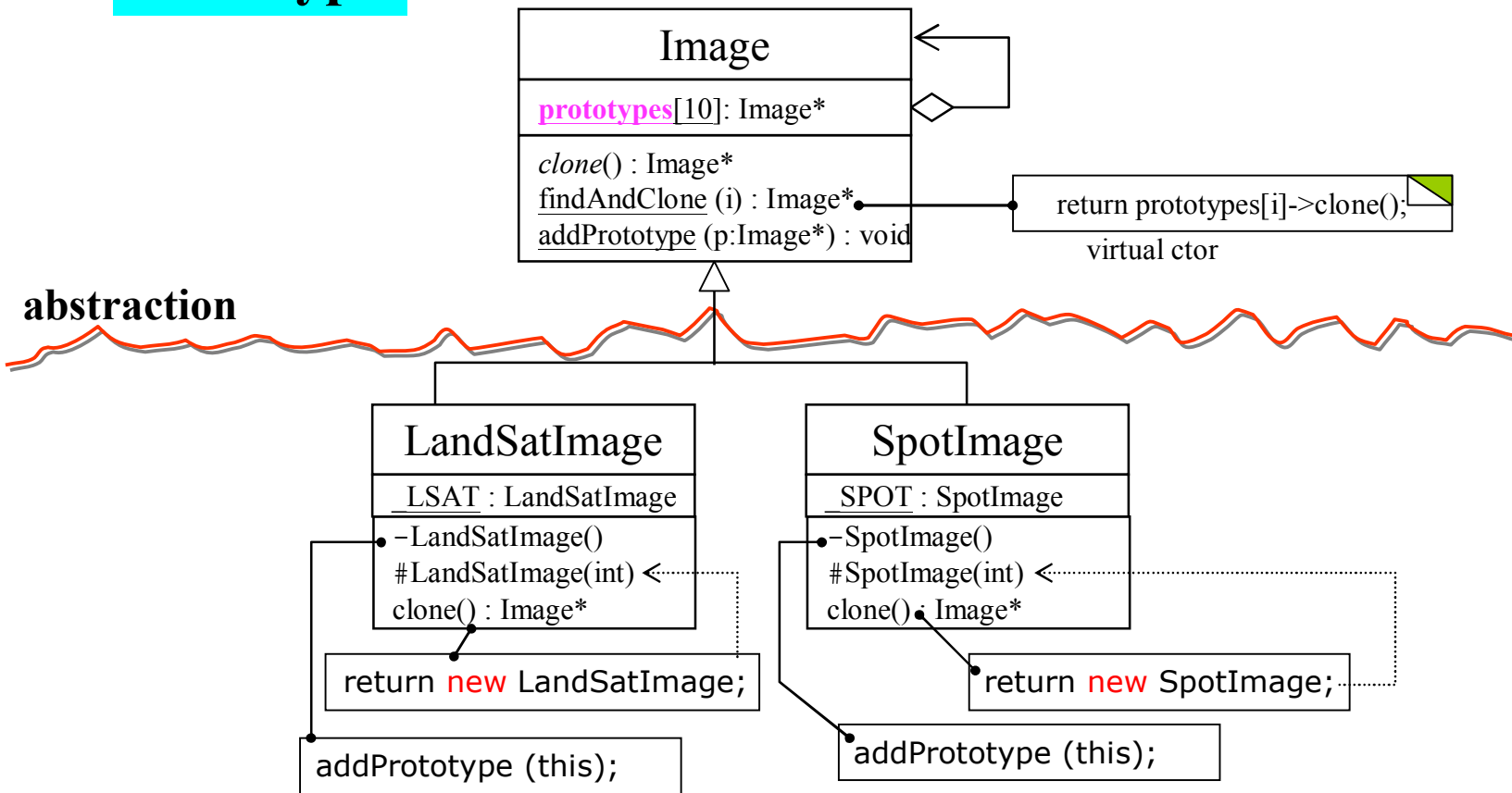
```
class Composite: public Component
{
    vector <Component*> c;
public:
    Composite(int val): Component(val) { }

    void add(Component* elem) {
        c.push_back(elem);
    }
    ...
};
```

```
class Primitive: public Component
{
public:
    Primitive(int val): Component(val) { }
};
```

Delegation (委託) + Inheritance (繼承)

Prototype





```
01 #include <iostream.h>
02 enum imageType
03 {
04     LSAT, SPOT
05 };
06 class Image
07 {
08     public:
09     virtual void draw() = 0;
10     static Image *findAndClone(imageType);
11     protected:
12     virtual imageType returnType() = 0;
13     virtual Image *clone() = 0;
14     // As each subclass of Image is declared, it registers its prototype
15     static void addPrototype(Image *image)
16     {
17         _prototypes[_nextSlot++] = image;
18     }
19     private:
20     // addPrototype() saves each registered prototype here
21     static Image *_prototypes[10];
22     static int _nextSlot;
23 };
24 Image *Image::_prototypes[];
25 int Image::_nextSlot;
```

```
// Client calls this public static member function when it needs an instance
// of an Image subclass
Image *Image::findAndClone(imageType type)
{
    for (int i = 0; i < _nextSlot; i++)
        if (_prototypes[i]->returnType() == type)
            return _prototypes[i]->clone();
}
```



Prototype



```

01 class LandSatImage: public Image
02 {
03     public:
04         imageType returnType() {
05             return LSAT;
06         }
07         void draw() {
08             cout << "LandSatImage::draw " << _id << endl;
09         }
10         // When clone() is called, call the one-argument ctor with a dummy arg
11         Image *clone() {
12             return new LandSatImage(1);
13         }
14     protected:
15         // This is only called from clone()
16         LandSatImage(int dummy) {
17             _id = _count++;
18         }
19     private:
20         // Mechanism for initializing an Image subclass - this causes the
21         // default ctor to be called, which registers the subclass's prototype
22         static LandSatImage landSatImage;
23         // This is only called when the private static data member is initied
24         LandSatImage()
25             addPrototype(this);
26         }
27         // Nominal "state" per instance mechanism
28         int _id;
29         static int _count;
30 };
31 // Register the subclass's prototype
32 LandSatImage LandSatImage::landSatImage;
33 // Initialize the "state" per instance mechanism
34 int LandSatImage::_count = 1;

```

```

enum imageType
{ LSAT, SPOT };

```

```

01 class SpotImage: public Image
02 {
03     public:
04         imageType returnType() {
05             return SPOT;
06         }
07         void draw() {
08             cout << "SpotImage::draw " << _id << endl;
09         }
10         Image *clone() {
11             return new SpotImage(1);
12         }
13     protected:
14         SpotImage(int dummy) {
15             _id = _count++;
16         }
17     private:
18         SpotImage() {
19             addPrototype(this);
20         }
21         static SpotImage spotImage;
22         int _id;
23         static int _count;
24 };
25 SpotImage SpotImage::_spotImage;
26 int SpotImage::_count = 1;

```

Prototype

```
// Simulated stream of creation requests
const int NUM_IMAGES = 8;
imageType input[NUM_IMAGES] =
{
    LSAT, LSAT, LSAT, SPOT, LSAT, SPOT, SPOT, LSAT
};
```

```
01 int main()
02 {
03     Image *images[NUM_IMAGES];
04     // Given an image type, find the right prototype, and return a clone
05     for (int i = 0; i < NUM_IMAGES; i++)
06         images[i] = Image::findAndClone(input[i]);
07     // Demonstrate that correct image objects have been cloned
08     for (i = 0; i < NUM_IMAGES; i++)
09         images[i]->draw();
10     // Free the dynamic memory
11     for (i = 0; i < NUM_IMAGES; i++)
12         delete images[i];
13 }
```



The End