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更多精彩课程推荐

C++设计模式

课程从设计之道和设计之术两方面，通过大量的代码实践与演练，深入剖析经典GOF 23种设计模式。

C＋＋面向对象开发

助你正确理解面向对象 (OO) 的精神和实现手法，课程涵盖对象模型、关键机制、编程风格、动态分配。

STL标准库与泛型编程

深入剖析标准库之六大部件：分配器、容器、算法、迭代器、仿函数、适配器之间的体系结构，并分析其源码，引导高阶泛

C++新标准C++11–14

使你在极短时间内深刻理解C++2.0的诸多新特性，涵盖语言和标准库两层面，只谈新东西。

內存管理

從平地到萬丈高樓

Memory Management 101

第一講 **primitives**
第二講 **std::allocator**
第三講 **malloc/free**
第四講 **loki::allocator**
第五講 **other issues**

侯捷

萬丈高樓平地起

源碼之前
了無秘密

你應具備的基礎

- 曾經動態分配並使用 **memory**
- 曾經使用過 **C++ 標準庫的容器 (containers)**

我們的目標

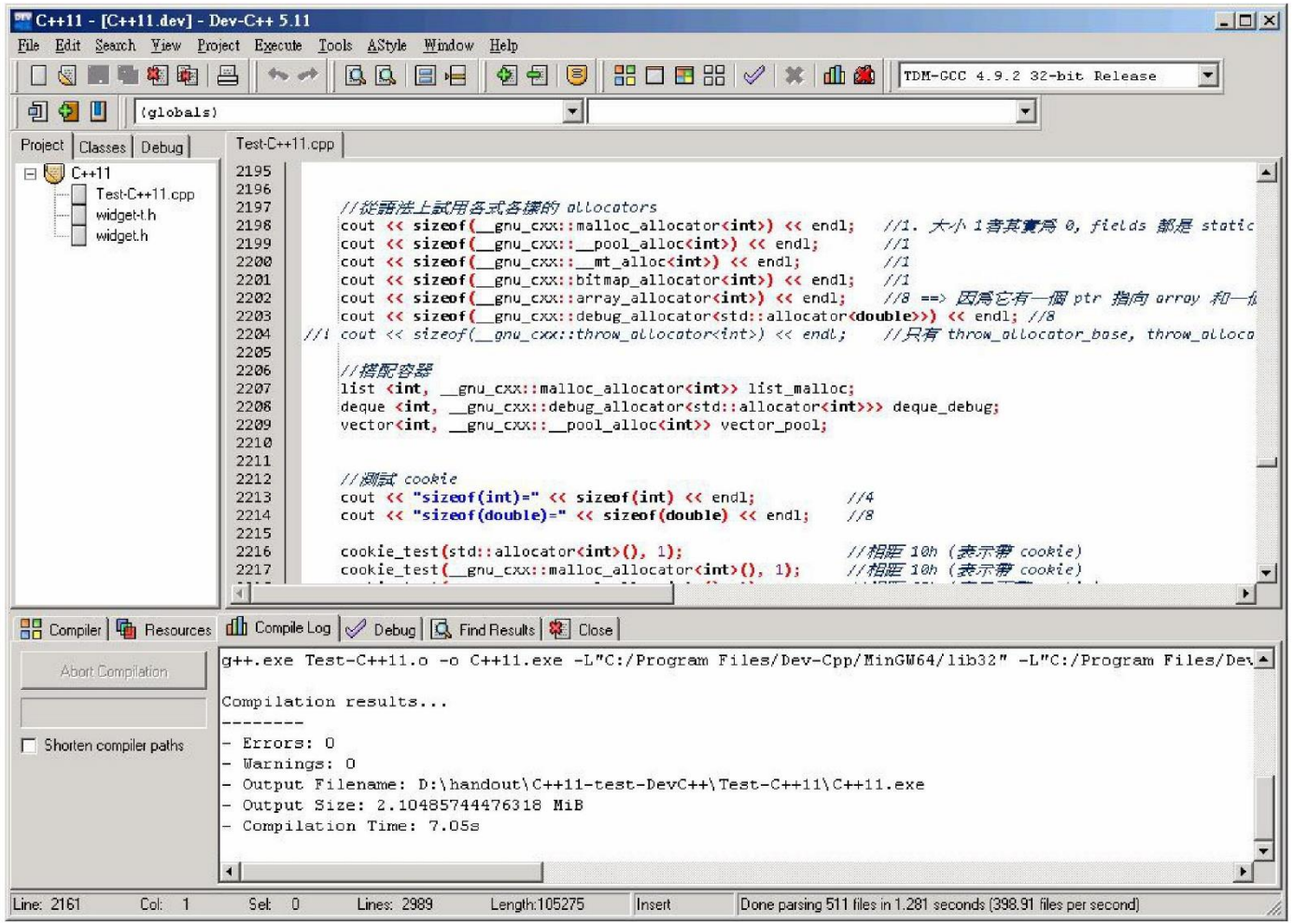
從平地到萬丈高樓，

從最基礎的 C++ 語言構件
到高知名度的內存管理器，

徹底了解高高低低的方方面面。

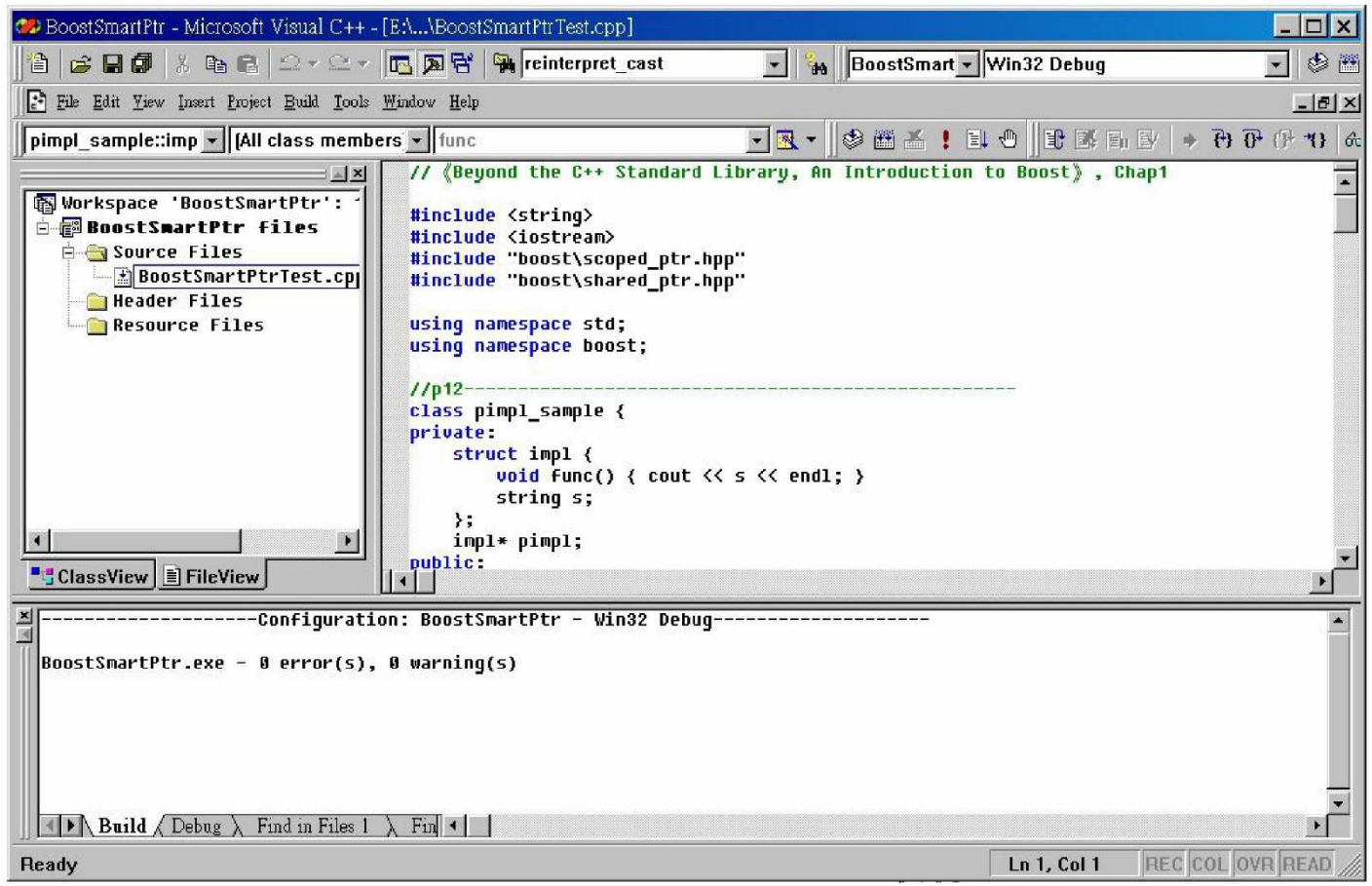
這些工具對你有幫助

(Dev-C++ 5.11 畫面; with GNU 4.9.2)

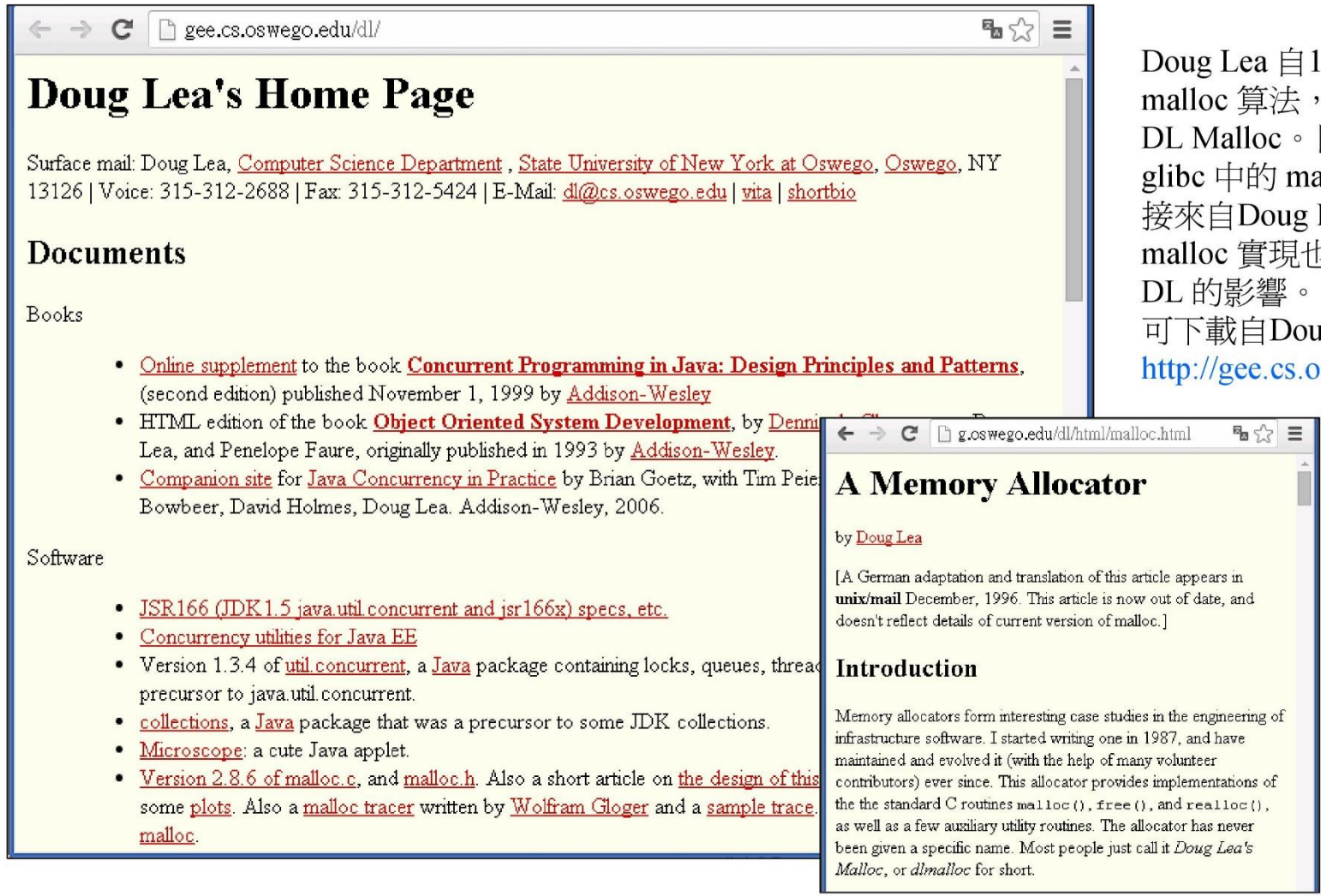


這些工具對你有幫助

(Visual C++ **6.0**)

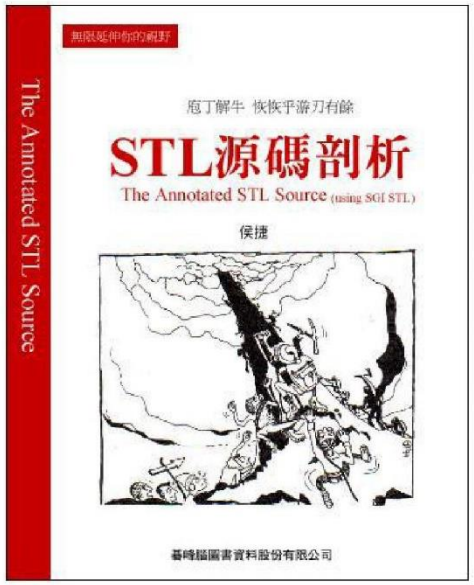


網絡有許多資源 …

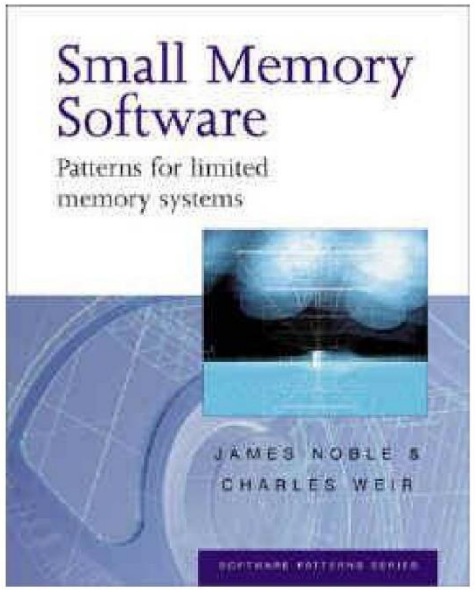


Doug Lea 自1986年起潛心研究 malloc 算法，其作品被稱爲 DL Malloc。目前 Linux 的 glibc 中的 malloc 算法就是直接來自Doug Lea，其他平台的 malloc 實現也或多或少受到 DL 的影響。 DL Malloc 源碼可下載自Doug Lea 個人主頁：http://gee.cs.oswego.edu/dl/

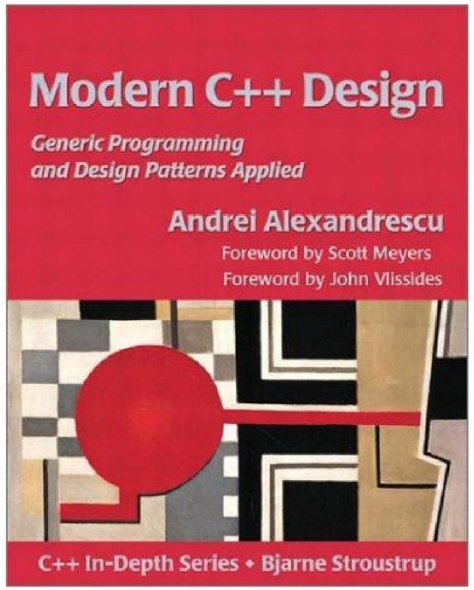
Bibliography



by 侯捷
Chap2 : allocator



By James Noble &
Charles Weir,
AW 2001



by Andrei Alexandrescu,
Chap4: Small-Object Allocation

Libraries :
- STL Allocators
- MFC CPlex+CFixedAlloc
- Boost.Pool
- Loki SmallObjAllocator
- VC malloc/free
- jemalloc
- tcmalloc
- …

你將獲得的代碼

Test-Mem.cpp

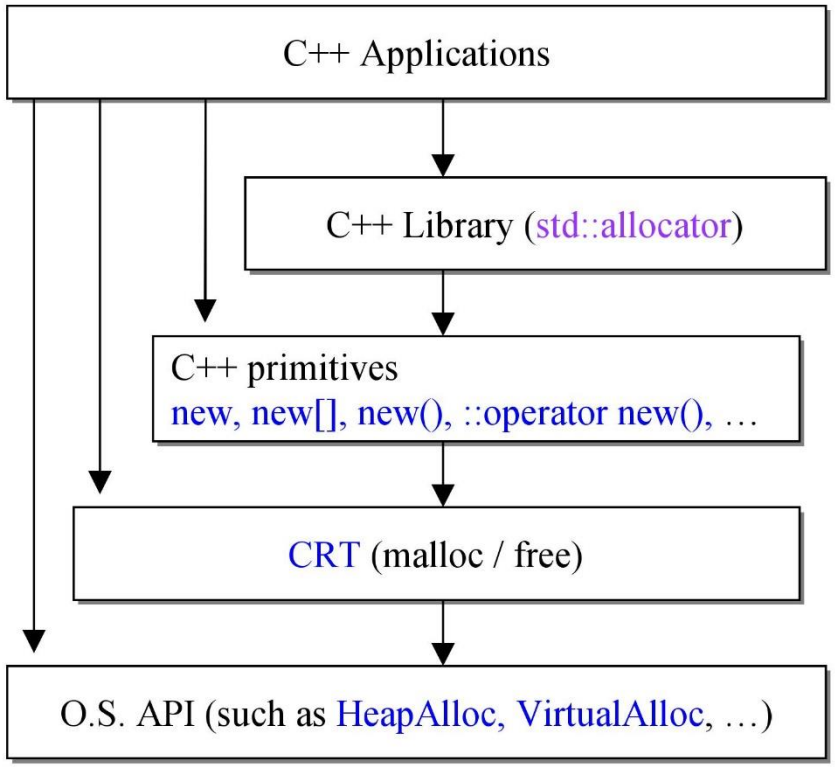
內有出現於本講義中的所有代碼

天寶當年, DOS 640K, extented memory.

錙銖必較

俱往矣 且看今朝

C++應用程序, 使用memory的途徑



C++ memory primitives

分配	釋放	類屬	可否重載
malloc()	free()	C 函數	不可
new	delete	C++表達式 (expressions)	不可
::operator new()	::operator delete()	C++函數	可
allocator<*T*>:: allocate()	allocator<*T*>:: deallocate()	C++標準庫	可自由設計並以之搭配任何容器

C++ memory primitives

```
#01     void* p1 = malloc(512);  //512 bytes
#02     free(p1);
#03
#04     complex<int>* p2 = new complex<int>; //one object
#05     delete p2;
#06
#07     void* p3 = ::operator new(512); //512 bytes
#08     ::operator delete(p3);
#09
#10 //以下使用 C++ 標準庫提供的 allocators。
#11 //其接口雖有標準規格，但實現廠商並未完全遵守；下面三者形式略異。
#12 #ifdef _MSC_VER
#13     //以下兩函數都是 non-static，定要通過 object 調用。以下分配 3 個 ints.
#14     int* p4 = allocator<int>().allocate(3, (int*)0);
#15     allocator<int>().deallocate(p4,3);
#16 #endif
#17 #ifdef __BORLANDC__
#18     //以下兩函數都是 non-static，定要通過 object 調用。以下分配 5 個 ints.
#19     int* p4 = allocator<int>().allocate(5);
#20     allocator<int>().deallocate(p4,5);
#21 #endif
#22 #ifdef __GNUC__
#23     //以下兩函數都是 static，可通過全名調用之。以下分配 512 bytes.
#24     void* p4 = alloc::allocate(512);
#25     alloc::deallocate(p4,512);
#26 #endif
```

無用

C++ memory primitives

```
#01     void* p1 = malloc(512);  //512 bytes
#02     free(p1);
#03
#04     complex<int>* p2 = new complex<int>; //one object
#05     delete p2;
#06
#07     void* p3 = ::operator new(512); //512 bytes
#08     ::operator delete(p3);
#09
#10 #ifdef __GNUC__
#11     //以下兩函數都是 non-static，定要通過 object 調用。以下分配 7 個 ints
#12     void* p4 = allocator<int>().allocate(7);
#13     allocator<int>().deallocate((int*)p4,7);
#14
#15     //以下兩函數都是 non-static，定要通過 object 調用。以下分配 9 個 ints.
#16     void* p5 = __gnu_cxx::__pool_alloc<int>().allocate(9);
#17     __gnu_cxx::__pool_alloc<int>().deallocate((int*)p5,9);
#18 #endif
```

new expression

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

編譯器
轉爲

```
Complex *pc;
try {
  ❶ void* mem  =  operator new( sizeof(Complex) );  //allocate
  ❷ pc = static_cast<Complex*>(mem);                 //cast
  ❸ pc->Complex::Complex(1,2);                       //construct
    //注意：只有編譯器才可以像上面那樣直接呼叫 ctor
}
catch( std::bad_alloc ) {
      //若allocation失敗就不執行constructor
}
```

App. 欲直接調用 ctor, 可運用 placement new :

```
new(p) Complex(1,2);
```

—侯捷—

```
void *operator new(size_t size, const std::nothrow_t&)
                                    _THROW0()
{   // try to allocate size bytes
void *p;
while ((p = malloc(size)) == 0)
  { // buy more memory or return null pointer
    _TRY_BEGIN
        if (_callnewh(size) == 0)  break;
    _CATCH(std::bad_alloc)    return (0);
    _CATCH_END
  }
return (p);
}
```

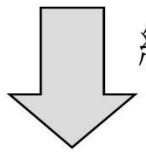
... \vc98\crt\src\newop2.cpp

The struct is used as a function parameter to operator new to indicate that the function should return a null pointer to report an allocation failure, rather than throw an exception.

struct std::nothrow_t {};

delete expression

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



編譯器轉爲...

```
pc->~Complex();          //先析構
operator delete(pc);     //然後釋放內存
```

```
void __cdecl operator delete(void *p) _THROW0()
{  // free an allocated object
   free(p);
}
```

...\vc98\crt\src\delop.cpp

Ctor & Dtor 直接調用

```
96      string* pstr = new string;
97      cout << "str= " << *pstr << endl;
98
99  //! pstr->string::string("jjhou");
100                         //[Error] 'class std::basic_string<char>' has no member named 'string'
101 //! pstr->~string();    //crash
102     cout << "str= " << *pstr << endl;
```

```
84  class A
85  {
86  public:
87    int id;
88    A(int i) : id(i) { cout << "ctor. this="  << this << " id=" << id << endl;  }
89    ~A()             { cout << "dtor. this="  << this << endl;  }
90  };
```

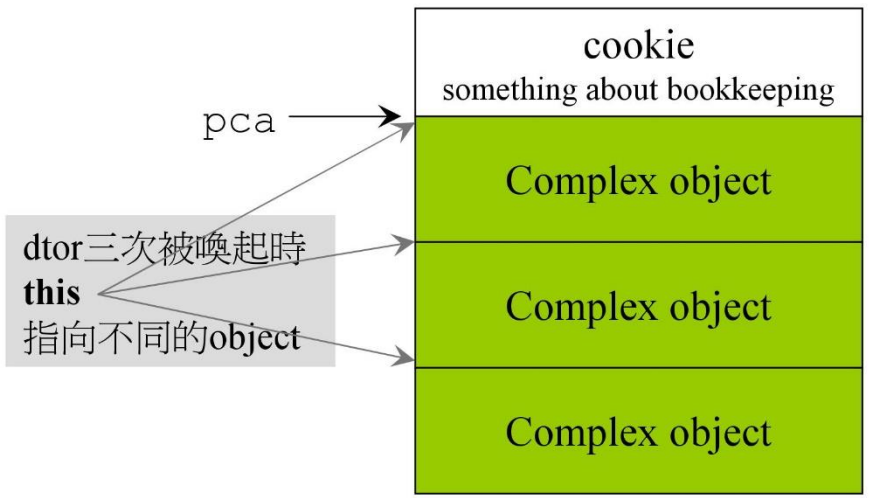
```
107     A* pA = new A(1);           //ctor. this=000307A8 id=1
108     cout << pA->id << endl;     //1
109 //! pA->A::A(3);               //in VC6 : ctor. this=000307A8 id=3
110                                 //in GCC : [Error] cannot call constructor 'jj02::A::A' directly
111
112 //! A::A(5);                   //in VC6 : ctor. this=0013FF60 id=5
113                                 //         dtor. this=0013FF60
114                                 //in GCC : [Error] cannot call constructor 'jj02::A::A' directly
115                                 //         [Note] for a function-style cast, remove the redundant '::A'
116
117     cout << pA->id << endl;     //in VC6 : 3
118                                 //in GCC : 1
119
120     delete pA;                  //dtor. this=000307A8
```

array new, array delete

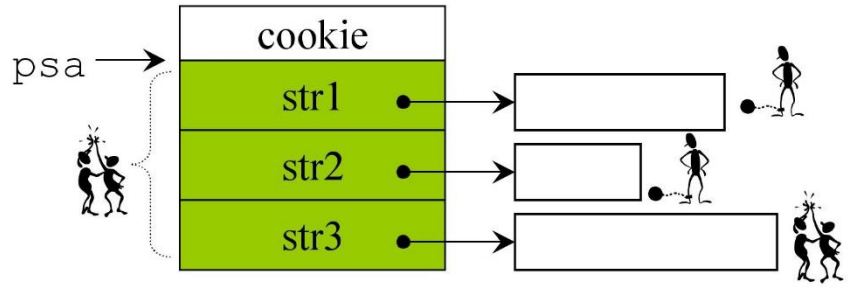
```
Complex* pca = new Complex[3];
//喚起三次ctor。
//無法藉由參數給予初值
...
delete[] pca; //喚起3次dtor
```

沒對每個 object 調用 dtor，有什麼影響？

- 對 class without ptr member 可能沒影響。
- 對 class with pointer member 通常有影響。




```
string* psa = new string[3];
...
delete psa; //喚起1次dtor
```

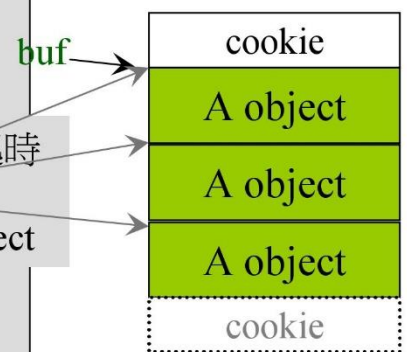


array new, array delete

```
class A
{
public:
  int id;

  A() : id(0)      { cout << "default ctor. this="  << this << " id=" << id << endl;  }
  A(int i) : id(i) { cout << "ctor. this="  << this << " id=" << id << endl;  }
  ~A()             { cout << "dtor. this="  << this << " id=" << id << endl;  }
};
```

```
default ctor. this=0x3e398c id=0
default ctor. this=0x3e3990 id=0
default ctor. this=0x3e3994 id=0
buf=0x3e398c  tmp=0x3e398c
ctor. this=0x3e398c id=0
ctor. this=0x3e3990 id=1
ctor. this=0x3e3994 id=2
buf=0x3e398c  tmp=0x3e3998
dtor. this=0x3e3994 id=2
dtor. this=0x3e3990 id=1
dtor. this=0x3e398c id=0
```

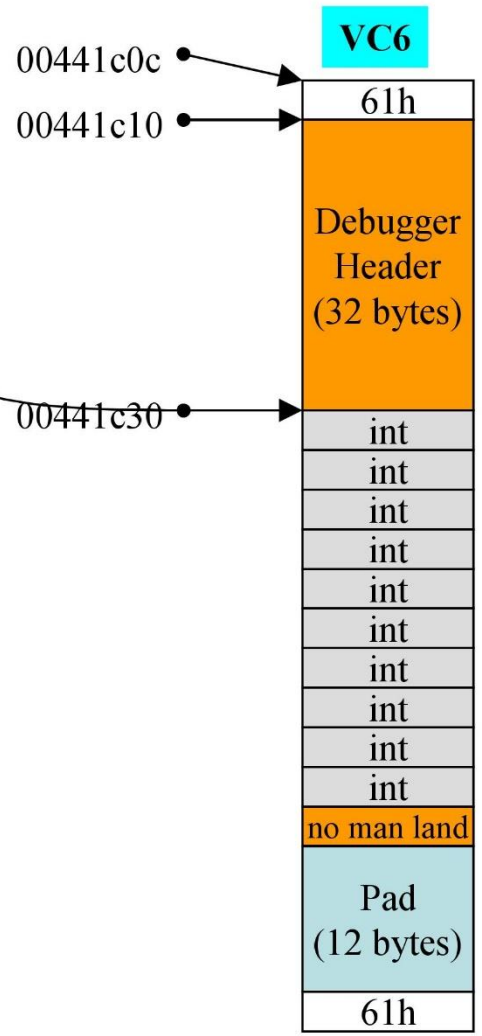
```
A* buf = new A[size];  //default ctor 3 次. [0]先於[1]先於[2])
                       //A必須有 default ctor,
                       //否則 [Error] no matching function for call to 'A::A()'
A* tmp = buf;

cout << "buf=" << buf << "  tmp=" << tmp << endl;

for(int i = 0; i < size; ++i)
    new (tmp++) A(i);     //ctor 3次

cout << "buf=" << buf << "  tmp=" << tmp << endl;

delete [ ] buf;    //dtor 3 次 (次序逆反, [2]先於[1]先於[0])
```



dtor三次被喚起時
this
指向不同的object

array size, in memory block

```
int* pi = new int[10];   //sizeof(pi) : 4
delete pi;
```



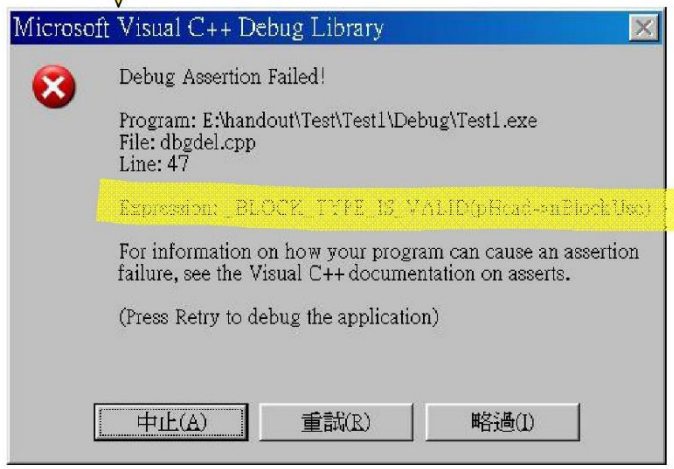

```
int ia[10];              //from stack but not heap
cout << sizeof(ia);      //40
```

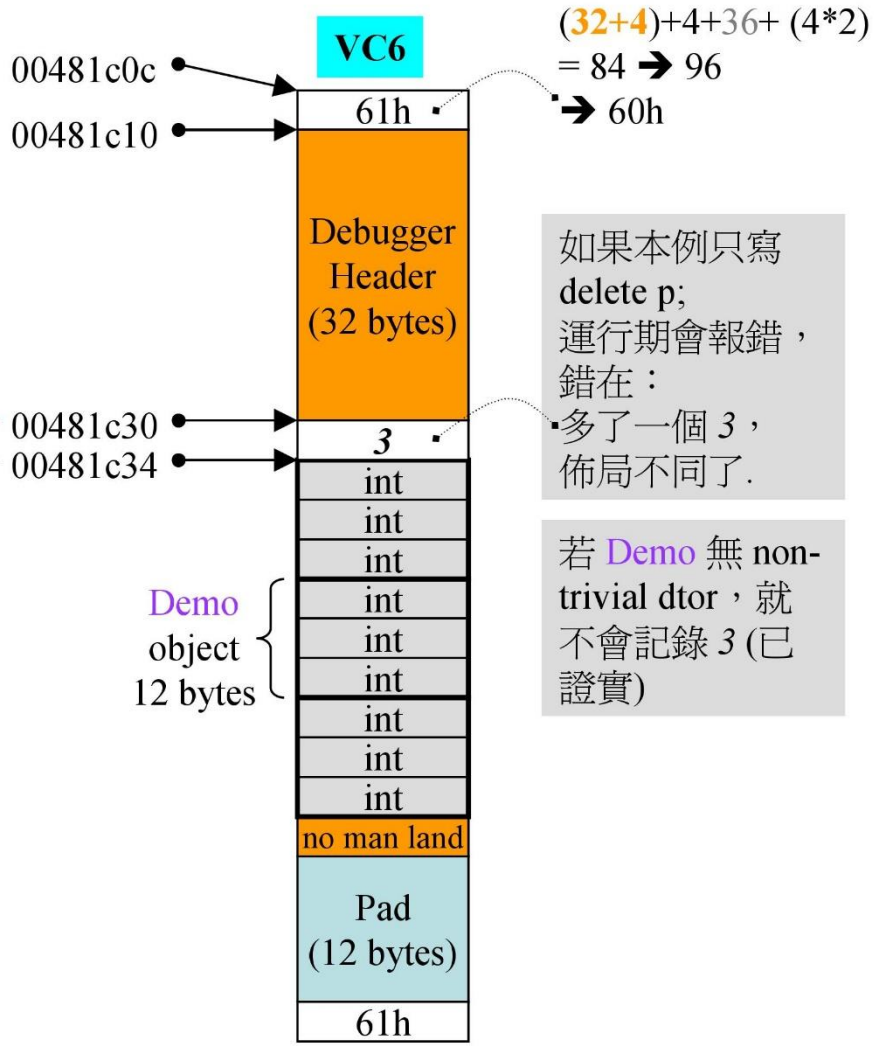
array size, in memory block

```
Demo* p= new Demo[3];
delete [ ] p;
```

若未寫 [ ]，
debug mode 下出現
Assertion Failed.

注意，重載 operator delete[] 後
觀察到傳入的 p 竟指向





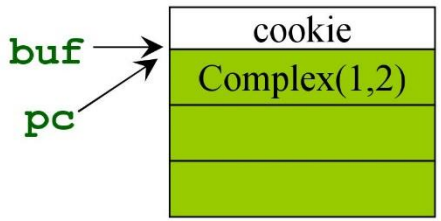

```
Demo d[3];          //from stack but not heap
cout << sizeof(d);  //36
```

placement new

- placement new 允許我們將 object 建構於 allocated memory 中。
- 沒有所謂 placement delete，因爲 placement new 根本沒分配 memory.
  亦或稱呼 與 placement new 對應的 operator delete 爲 placement delete.

注意，關於 “placement new”，
或指 new(p)，
或指 ::operator new(size, void*)

```
#include <new>
char* buf = new char[sizeof(Complex)*3];
Complex* pc = new(buf)Complex(1,2);
...
delete [] buf;  //
```

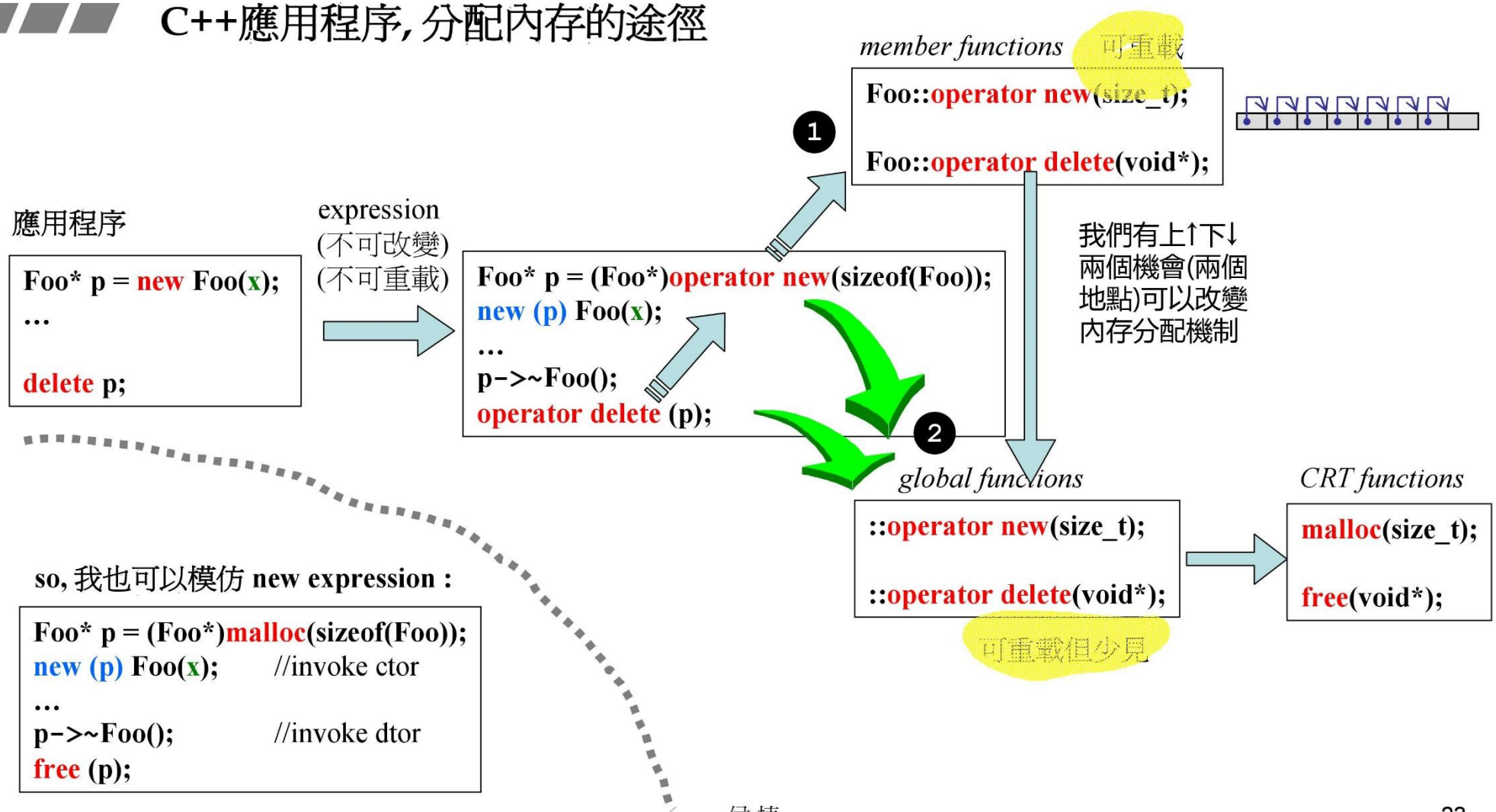


編譯器轉爲

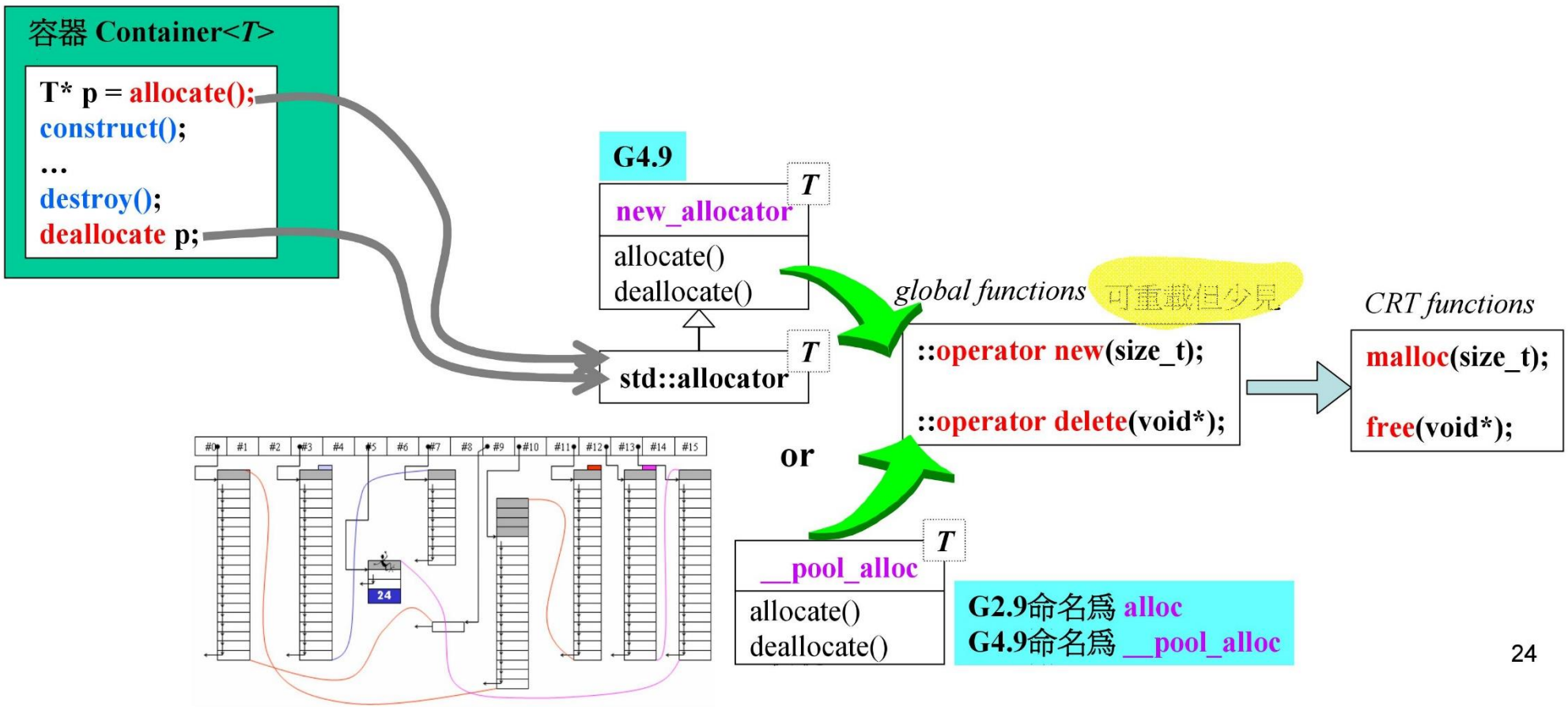
```
void* operator new(size_t, void* loc)
{ return loc; }
```

```
Complex *pc;
try {
 ❶ void* mem = operator new(sizeof(Complex),buf);  //allocate
 ❷ pc = static_cast<Complex*>(mem);                 //cast
 ❸ pc->Complex::Complex(1,2);                       //construct
}
catch( std::bad_alloc ) {
      //若allocation失敗就不執行constructor
}
```

C++應用程序, 分配內存的途徑



C++容器, 分配內存的途徑


容器 Container<T>
T* p = allocate();
construct();
…
destroy();
deallocate p;
G4.9
new_allocator
T
allocate()
deallocate()
std::allocator
T
global functions
可重載但少見
::operator new(size_t);
::operator delete(void*);
CRT functions
malloc(size_t);
free(void*);
or
__pool_alloc
T
allocate()
deallocate()
G2.9命名爲 alloc
G4.9命名爲 __pool_alloc

重載 ::operator new / ::operator delete

小心，這影響無遠弗屆

```
void* myAlloc(size_t size)
{  return malloc(size); }

void myFree(void* ptr)
{  return free(ptr); }

////它們不可以被聲明於一個 namespace 內
inline void* operator new(size_t size)
  { cout << "jjhou global new()     \n";       return myAlloc( size ); }

inline void* operator new[ ](size_t size)
  { cout << "jjhou global new[]()   \n";       return myAlloc( size ); }

inline void  operator delete(void* ptr)
  { cout << "jjhou global delete()  \n";       myFree( ptr );   }

inline void  operator delete[ ](void* ptr)
  { cout << "jjhou global delete[]()\n";       myFree( ptr );   }
```

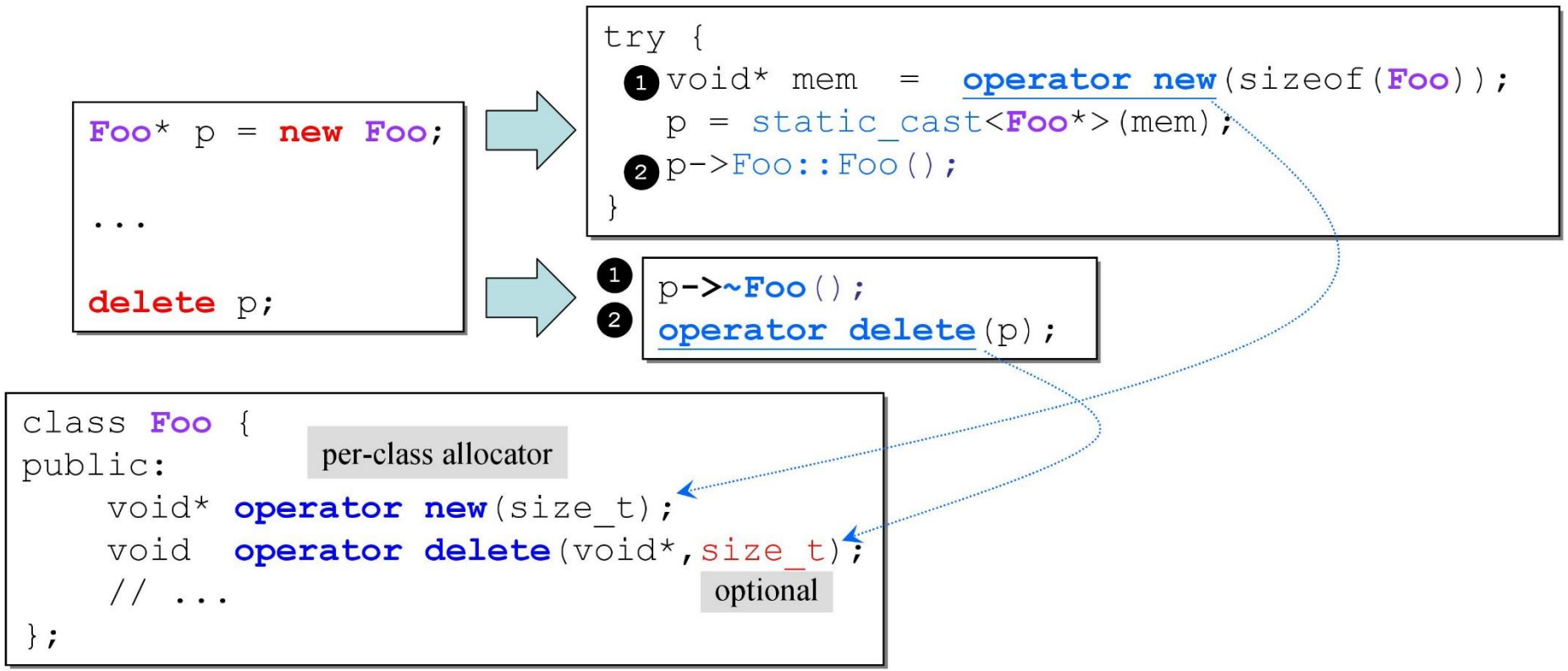
... \vc98\crt\src\newop2.cpp

```
void* operator new(size_t size, const std::nothrow_t&)
                                    _THROW0()
{   // try to allocate size bytes
void *p;
while ((p = malloc(size)) == 0)
  { // buy more memory or return null pointer
    _TRY_BEGIN
        if (_callnewh(size) == 0)  break;
    _CATCH(std::bad_alloc)    return (0);
    _CATCH_END
  }
return (p);
}
```

...\vc98\crt\src\delop.cpp

```
void __cdecl operator delete(void *p) _THROW0()
{  // free an allocated object
   free(p);
}
```

重載 operator new/operator delete



重載 operator new[ ] / operator delete[ ]

```
Foo* p = new Foo[N];

...

delete [ ] p;
```

```
try {
  1 void* mem  =  operator new(sizeof(Foo)*N + 4);
    p = static_cast<Foo*>(mem);
  2 p->Foo::Foo(); //N 次
}
```

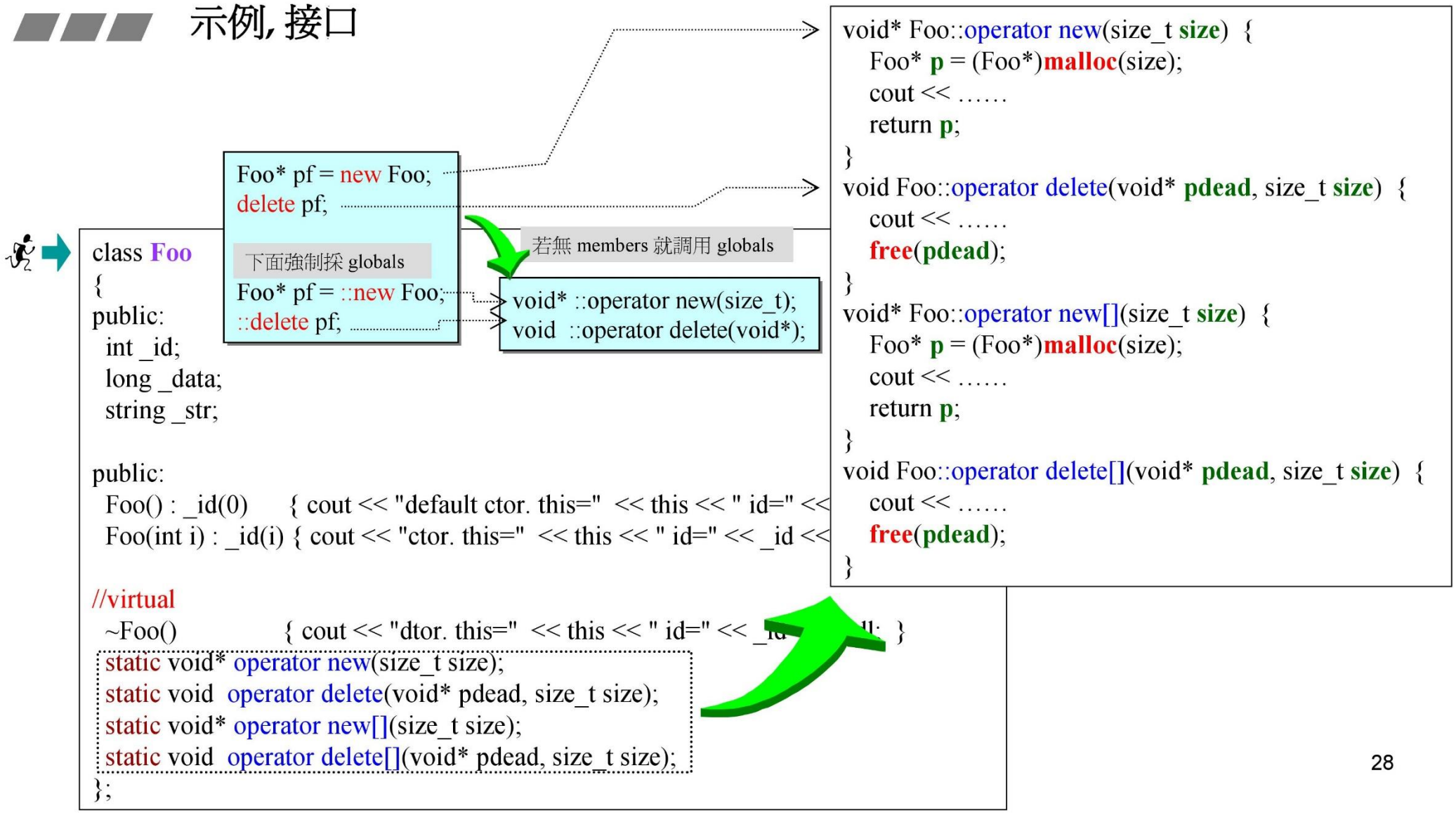
```
1 p->~Foo(); //N 次
2 operator delete(p);
```

```
class Foo {
public:
    void* operator new[](size_t);
    void  operator delete[](void*,size_t);
    // ...
};
```

per-class allocator

optional

示例, 接口

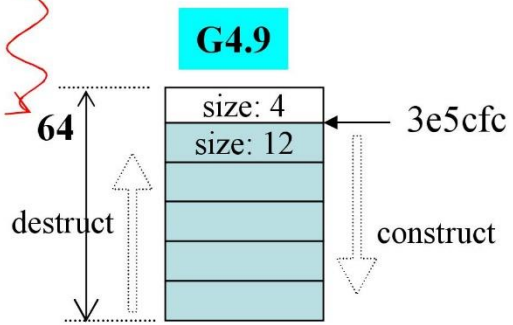

Foo* pf = new Foo;
delete pf;
下面強制採 globals
Foo* pf = ::new Foo;
::delete pf;
若無 members 就調用 globals
void* ::operator new(size_t);
void ::operator delete(void*);
class Foo
{
public:
int _id;
long _data;
string _str;
public:
Foo() : _id(0) { cout << "default ctor. this=" << this << " id=" <<
Foo(int i) : _id(i) { cout << "ctor. this=" << this << " id=" << _id <<
//virtual
~Foo() { cout << "dtor. this=" << this << " id=" <<
static void* operator new(size_t size);
static void operator delete(void* pdead, size_t size);
static void* operator new[](size_t size);
static void operator delete[](void* pdead, size_t size);
};
void* Foo::operator new(size_t size) {
Foo* p = (Foo*)malloc(size);
cout << ……
return p;
}
void Foo::operator delete(void* pdead, size_t size) {
cout << ……
free(pdead);
}
void* Foo::operator new[](size_t size) {
Foo* p = (Foo*)malloc(size);
cout << ……
return p;
}
void Foo::operator delete[](void* pdead, size_t size) {
cout << ……
free(pdead);
}

示例

```
cout << "sizeof(Foo)= " << sizeo

1 Foo* p = new Foo(7);
2 delete p;

3 Foo* pArray = new Foo[5];
4 delete [ ] pArray;
```

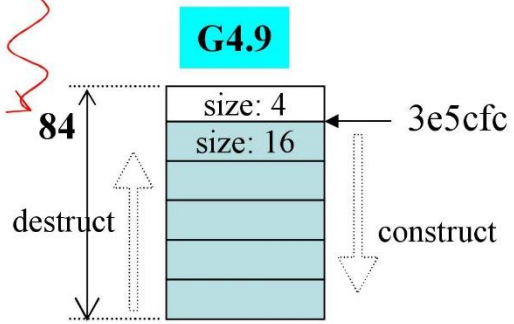
Foo without virtual dtor

```
sizeof(Foo)= 12
1 Foo::operator new(), size=12      return: 0x3e3988
  ctor. this=0x3e3988 id=7
2 dtor. this=0x3e3988 id=7
  Foo::operator delete(), pdead= 0x3e3988  size= 12
  Foo::operator new[](), size=64    return: 0x3e5cf8
3 default ctor. this=0x3e5cfc id=0
  default ctor. this=0x3e5d08 id=0
  default ctor. this=0x3e5d14 id=0
  default ctor. this=0x3e5d20 id=0
  default ctor. this=0x3e5d2c id=0
4 dtor. this=0x3e5d2c id=0
  dtor. this=0x3e5d20 id=0
  dtor. this=0x3e5d14 id=0
  dtor. this=0x3e5d08 id=0
  dtor. this=0x3e5cfc id=0
  Foo::operator delete[](), pdead= 0x3e5cf8  size= 64
```



Foo with virtual dtor

```
sizeof(Foo)= 16
1 Foo::operator new(), size=16      return: 0x3e3988
  ctor. this=0x3e3988 id=7
2 dtor. this=0x3e3988 id=7
  Foo::operator delete(), pdead= 0x3e3988  size= 16
  Foo::operator new[](), size=84    return: 0x3e5cf8
3 default ctor. this=0x3e5cfc id=0
  default ctor. this=0x3e5d0c id=0
  default ctor. this=0x3e5d1c id=0
  default ctor. this=0x3e5d2c id=0
  default ctor. this=0x3e5d3c id=0
4 dtor. this=0x3e5d3c id=0
  dtor. this=0x3e5d2c id=0
  dtor. this=0x3e5d1c id=0
  dtor. this=0x3e5d0c id=0
  dtor. this=0x3e5cfc id=0
  Foo::operator delete[](), pdead= 0x3e5cf8  size= 84
```



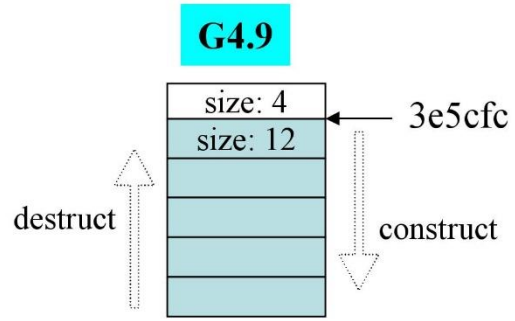
示例

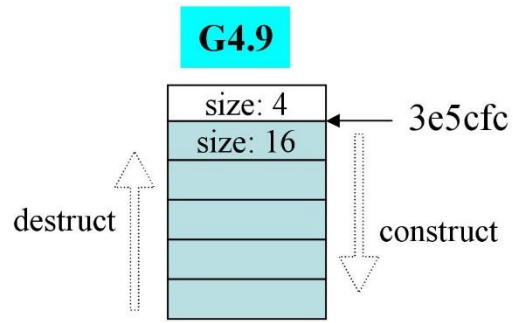
```
1 Foo* p = ::new Foo(7);
2 ::delete p;

3 Foo* pArray = ::new Foo[5];
4 ::delete [ ] pArray;
```

這樣調用 (也就是寫上 global scope operator ::)，會繞過前述所有 overloaded functions, 強迫使用 global version.

```
ctor. this=0x3e5ce0 id=7
dtor. this=0x3e5ce0 id=7
default ctor. this=0x3e5cfc id=0
default ctor. this=0x3e5d08 id=0
default ctor. this=0x3e5d14 id=0
default ctor. this=0x3e5d20 id=0
default ctor. this=0x3e5d2c id=0
dtor. this=0x3e5d2c id=0
dtor. this=0x3e5d20 id=0
dtor. this=0x3e5d14 id=0
dtor. this=0x3e5d08 id=0
dtor. this=0x3e5cfc id=0
```

↑ 都沒有進入我重載的 operator new(), operator delete(), operator new[](), operator delete[]().





重載 new() / delete()

我們可以重載 class member operator new()，寫出多個版本，前提是每一版本的聲明都必須有獨特的參數列，其中第一參數必須是 **size_t**，其餘參數以 **new** 所指定的 placement arguments 爲初值。出現於 **new (.....)** 小括號內的便是所謂 placement arguments。

```
Foo* pf = new (300, 'c') Foo;
```

或稱此爲
placement operator delete.

我們也可以重載 class member operator delete()，寫出多個版本。但它們絕不會被 **delete** 調用。只有當 **new** 所調用的 ctor 拋出 exception，才會調用這些重載版的 operator delete()。它只可能這樣被調用，主要用來歸還未能完全創建成功的 object 所佔用的 memory。

示例

```
class Foo {
public:
  Foo() { cout << "Foo::Foo()" << endl;  }
  Foo(int) { cout << "Foo::Foo(int)" << endl;  throw Bad();  }

  //(1) 這個就是一般的 operator new() 的重載
  void* operator new(size_t size) {
       return malloc(size);
  }
  //(2) 這個就是標準庫已提供的 placement new() 的重載 (的形式)
  //     (所以我也模擬 standard placement new, 就只是傳回 pointer)
  void* operator new(size_t size, void* start) {
       return start;
  }
  //(3) 這個才是嶄新的 placement new
  void* operator new(size_t size, long extra) {
       return malloc(size+extra);
  }
  //(4) 這又是一個 placement new
  void* operator new(size_t size, long extra, char init) {
        return malloc(size+extra);
  }
……(接下頁)
```

```
class Bad { };
```

故意在這兒拋出 expcetion，
測試 placement operator delete.

```
//(5) 這又是一個 placement new, 但故意寫錯第一參數的 type
//       (那必須是 size_t 以符合正常的 operator new)
//!  void* operator new(long extra, char init) {
//            [Error] 'operator new' takes type 'size_t' ('unsigned int')
//                       as first parameter [-fpermissive]
//!      return malloc(extra);
//!  }
…
```

示例 (續)

```
…… (續上頁)
  //以下是搭配上述 placement new 的各個所謂 placement delete.
  //當 ctor 發出異常，這兒對應的 operator (placement) delete 就會被調用.
  //其用途是釋放對應之 placement new 分配所得的 memory.
  //(1) 這個就是一般的 operator delete() 的重載
  void operator delete(void*,size_t)
  { cout << "operator delete(void*,size_t)  " << endl;  }

  //(2) 這是對應上頁的 (2)
  void operator delete(void*,void*)
  { cout << "operator delete(void*,void*)  " << endl;  }

  //(3) 這是對應上頁的 (3)
  void operator delete(void*,long)
  { cout << "operator delete(void*,long)  " << endl;  }

  //(4) 這是對應上頁的 (4)
  void operator delete(void*,long,char)
  { cout << "operator delete(void*,long,char)  " << endl; }

private:
      int m_i;
};
```

即使 operator delete(…) 未能一一對應於 operator new(…), 也不會出現任何報錯.
你的意思是 : 放棄處理 ctor 發出的異常.

```
Foo start;
① Foo* p1 = new Foo;
② Foo* p2 = new (&start) Foo;
③ Foo* p3 = new (100) Foo;
④ Foo* p4 = new (100,'a') Foo;
⑤ Foo* p5 = new (100) Foo(1);
  Foo* p6 = new (100,'a') Foo(1);
  Foo* p7 = new (&start) Foo(1);
  Foo* p8 = new Foo(1);
```

ctor拋出異常

```
Foo::Foo()
① operator new(size_t size), size= 4
Foo::Foo()
② operator new(size_t size, void* start), size= 4  start= 0x22fe8c
Foo::Foo()
③ operator new(size_t size, long extra)  4 100
Foo::Foo()
④ operator new(size_t size, long extra, char init)  4 100 a
Foo::Foo()
⑤ operator new(size_t size, long extra)  4 100
Foo::Foo(int)
terminate called after throwing an instance of 'jj07::Bad'
```

ctor 拋出異常 ⇨ 奇怪, G4.9 沒調用 operator delete (void*,long), 但 G2.9 確實有.

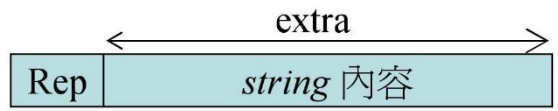
VC6 warning C4291: 'void *__cdecl Foo::operator new(~~~)' no matching operator delete found; memory will not be freed if initialization throws an exception

basic_string 使用 new(*extra*) 擴充申請量

```
template <…>
class basic_string
{
private:
  struct Rep {
    …
    void release () { if (--ref == 0) delete this; }
    inline static void * operator new (size_t, size_t);
    inline static void operator delete (void *);
    inline static Rep* create (size_t);
    …
  };
  …
};
```

```
template <class charT, class traits, class Allocator>
inline void * basic_string <charT, traits, Allocator>::Rep::
operator new (size_t s, size_t extra)
{
  return Allocator::allocate(s + extra * sizeof (charT));
}
template <class charT, class traits, class Allocator>
inline void basic_string <charT, traits, Allocator>::Rep::
operator delete (void * ptr)
{
  Allocator::deallocate(ptr, sizeof(Rep) +
                        reinterpret_cast<Rep *>(ptr)->res *
                        sizeof (charT));
}
```

```
template <class charT, class traits, class Allocator>
inline basic_string <charT, traits, Allocator>::Rep*
basic_string <charT, traits, Allocator>::Rep::
create (size_t extra)
{
  extra = frob_size (extra + 1);
  Rep *p = new (extra) Rep;
  …
  return p;
}
```



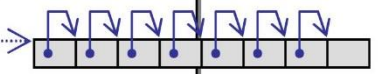
per-class allocator, 1

ref. C++Primer 3/e, p.765

```
#include <cstddef>
#include <iostream>
using namespace std;

class Screen {
public:
   Screen(int x) : i(x) { };
   int get() { return i; }

   void* operator new(size_t);
   void  operator delete(void*, size_t);
   // ...
private:
   Screen* next;
   static Screen* freeStore;
   static const int screenChunk;
private:
   int i;
};
Screen* Screen::freeStore = 0;
const int Screen::screenChunk = 24;
```

這種設計會引發多耗用一個 next 的疑慮。下頁設計更好

```
void* Screen::operator new(size_t size)
{
 Screen *p;
 if (!freeStore) {
    //linked list 是空的，所以申請一大塊
    size_t chunk = screenChunk * size;
    freeStore = p =
       reinterpret_cast<Screen*>(new char[chunk]);
    //將一大塊分割片片, 當做 linked list 串接起來
    for (; p != &freeStore[screenChunk-1]; ++p)
          p->next = p+1;
    p->next = 0;
 }
 p = freeStore;
 freeStore = freeStore->next;
 return p;
}
```



沒有對應的 delete，
但這不算是 memory leak.

```
void Screen::operator delete(void *p, size_t)
{
 //將 deleted object 插回 free list 前端
 (static_cast<Screen*>(p))->next = freeStore;
 freeStore = static_cast<Screen*>(p);
}
```

per-class allocator, 1

ref. C++Primer 3/e, p.765

```
cout << sizeof(Screen) << endl;  //8

size_t const N = 100;
Screen* p[N];

for (int i=0; i< N; ++i)
      p[i] = new Screen(i);

//輸出前 10 個 pointers, 比較其間隔
for (int i=0; i< 10; ++i)
      cout << p[i] << endl;

for (int i=0; i< N; ++i)
      delete p[i];
```

左邊是寫了 member operator new/delete 的結果，
右邊是沒寫因而使用 global operator new/delete 的結果

```
8
0x3e48f0
0x3e48f8
0x3e4900
0x3e4908
0x3e4910
0x3e4918
0x3e4920
0x3e4928
0x3e4930
0x3e4938
```

間隔8

```
8
0x3e48e0
0x3e48f0
0x3e4900
0x3e4910
0x3e4920
0x3e4930
0x3e4940
0x3e4950
0x3e4960
0x3e4970
```

間隔16

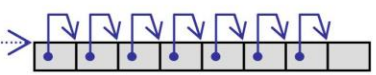
per-class allocator, 2

ref. Effective C++ 2e, item10

```
class Airplane {
private:
  struct AirplaneRep {
     unsigned long miles;
     char type;
  };
private:
  union { AirplaneRep rep;  //此欄針對使用中的objects
          Airplane* next;   //此欄針對 free list 上的object
  };
public:
  unsigned long getMiles() { return rep.miles; }
  char getType() { return rep.type; }
  void set(unsigned long m, char t)  {
          rep.miles = m;    rep.type = t;
  }
public:
  static void* operator new(size_t size);
  static void  operator delete(void* deadObject, size_t size);
private:
  static const int BLOCK_SIZE;
  static Airplane* headOfFreeList;
};

Airplane* Airplane::headOfFreeList;
const int Airplane::BLOCK_SIZE = 512;
```

若加上名稱便是 type 定義式，未加名稱則是 anonymous union，{ } 內便是變數聲明。

```
void* Airplane::operator new(size_t size)
{                    怎會有誤？當繼承發生時
  //如果大小有誤，轉交給 ::operator new()
  if (size != sizeof(Airplane))
     return ::operator new(size);

  Airplane* p = headOfFreeList;
  if (p)  //如果 p 有效，就把 list 頭部下移一個元素
     headOfFreeList = p->next;
  else {
    //free list 已空，申請 (分配) 一大塊
    Airplane* newBlock = static_cast<Airplane*>
      (::operator new(BLOCK_SIZE * sizeof(Airplane)));

    //將小塊串成一個 free list，
    //但跳過 #0，因它將被傳回做爲本次成果
    for (int i = 1; i < BLOCK_SIZE-1; ++i)
        newBlock[i].next = &newBlock[i+1];
    newBlock[BLOCK_SIZE-1].next = 0;   //結束 list
    p = newBlock;
    headOfFreeList = &newBlock[1];
  }
  return p;
}
```



per-class allocator, 2

ref. Effective C++ 2e, item10

```
// operator delete 接獲一個內存塊
// 如果大小正確，就把它加到 free list 前端
void Airplane::operator delete(void* deadObject,
                               size_t size)
{
   if (deadObject == 0) return;
   if (size != sizeof(Airplane)) {
      ::operator delete(deadObject);
      return;
   }

   Airplane* carcass =
      static_cast<Airplane*>(deadObject);

   carcass->next = headOfFreeList;
   headOfFreeList = carcass;
}
```

```
cout << sizeof(Airplane) << endl;
size_t const N = 100;
Airplane* p[N];

for (int i=0; i< N; ++i)
      p[i] = new Airplane;

//隨機測試 object 正常否
p[1]->set(1000,'A');
p[5]->set(2000,'B');
p[9]->set(500000,'C');
…

//輸出前 10 個 pointers,
//用以比較其間隔
for (int i=0; i< 10; ++i)
      cout << p[i] << endl;

for (int i=0; i< N; ++i)
      delete p[i];
```

```
8
0x3e4ce0 A 1000
0x3e4d00 B 2000
0x3e4d20 C 500000
0x3e4cd8
0x3e4ce0
0x3e4ce8
0x3e4cf0
0x3e4cf8
0x3e4d00
0x3e4d08
0x3e4d10
0x3e4d18
0x3e4d20
```

間隔8

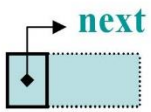
```
8
0x3e4900 A 1000
0x3e4930 B 2000
0x3e4970 C 500000
0x3e4910
0x3e4900
0x3e48f0
0x3e48e0
0x3e4920
0x3e4930
0x3e4940
0x3e4950
0x3e4960
0x3e4970
```

間隔16

左邊是寫了 member operator new/delete 的結果，
右邊是沒寫因而使用 global operator new/delete 的結果

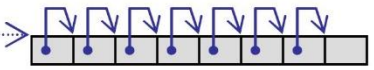
static allocator

當你受困於必須爲不同的 classes 重寫一遍幾乎相同的 member operator new 和 member operator delete 時，應該有方法將一個總是分配特定尺寸之區塊的 memory allocator 概念包裝起來，使它容易被重複使用。以下展示一種作法，每個 allocator object 都是個分配器，它體內維護一個 free-lists；不同的 allocator objects 維護不同的 free-lists。




```
class allocator
{
private:
    struct obj {
        struct obj* next;  //embedded pointer
    };
public:
    void* allocate(size_t);
    void  deallocate(void*, size_t);
private:
    obj* freeStore = nullptr;
    const int CHUNK = 5;   //小一些以便觀察
};
```

```
void
allocator::deallocate(void* p, size_t)
{
    //將 *p 收回插入 free list 前端
    ((obj*)p)->next = freeStore;
    freeStore = (obj*)p;
}
```



```
void* allocator::allocate(size_t size)
{
    obj* p;

    if (!freeStore) {
        //linked list 爲空，於是申請一大塊
        size_t chunk = CHUNK * size;
        freeStore = p = (obj*)malloc(chunk);

        //將分配得來的一大塊當做 linked list 般,
        //小塊小塊串接起來
        for (int i=0; i < (CHUNK-1); ++i) {
            p->next = (obj*)((char*)p + size);
            p = p->next;
        }
        p->next = nullptr;  //last
    }
    p = freeStore;
    freeStore = freeStore->next;
    return p;
}
```

— 侯 捷 —

static allocator

寫法十分制式

```
class Foo {
public:
   long L;
   string str;
   static allocator myAlloc;
public:
   Foo(long l) : L(l) { }
   static void* operator new(size_t size)
      { return myAlloc.allocate(size); }
   static void  operator delete(void* pdead, size_t size)
      { return myAlloc.deallocate(pdead, size); }
};
allocator Foo::myAlloc;
```

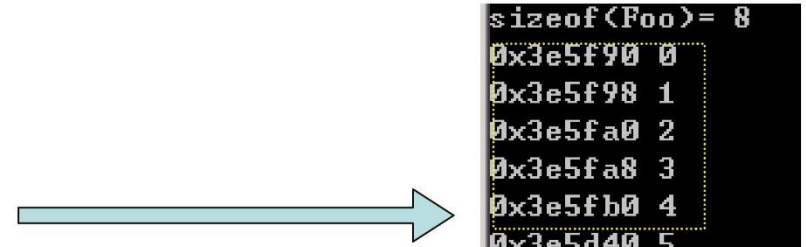
```
class Goo {
public:
   complex<double> c;
   string str;
   static allocator myAlloc;
public:
   Goo(const complex<double>& x) : c(x) { }
   static void* operator new(size_t size)
      { return myAlloc.allocate(size); }
   static void  operator delete(void* pdead, size_t size)
      { return myAlloc.deallocate(pdead, size); }
};
allocator Goo::myAlloc;
```

這比先前的設計乾淨多了，application classes 不再與內存分配細節糾纏不清，所有相關細節都讓 allocator 去操心，我們的工作是讓 application classes 正確運作。

static allocator, 示例與結果

```
Foo* p[100];

cout << "sizeof(Foo)= " << sizeof(Foo) << endl;
for (int i=0; i<23; ++i) { //隨意看看結果
    p[i] = new Foo(i);
    cout << p[i] << ' ' << p[i]->L << endl;
}

for (int i=0; i<23; ++i) {
    delete p[i];
}
```

```
Goo* p[100];

cout << "sizeof(Goo)= " << sizeof(Goo) << endl;
for (int i=0; i<17; ++i) { //隨意看看結果
    p[i] = new Goo(complex<double>(i,i));
    cout << p[i] << ' ' << p[i]->c << endl;
}

for (int i=0; i<17; ++i) {
    delete p[i];
}
```



macro for static allocator

```
class Foo {
public:
   long L;
   string str;
   static allocator myAlloc;
public:
   Foo(long l) : L(l) {  }
   static void* operator new(size_t size)
      {  return myAlloc.allocate(size);  }
   static void  operator delete(void* pdead, size_t size)
      {  return myAlloc.deallocate(pdead, size);  }
};
allocator Foo::myAlloc;
```

寫法十分制式

```
// DECLARE_POOL_ALLOC -- used in class definition
#define DECLARE_POOL_ALLOC() \
public: \
   void* operator new(size_t size) { return myAlloc.allocate(size); } \
   void operator delete(void* p) { myAlloc.deallocate(p, 0); } \
protected: \
   static allocator myAlloc;


// IMPLEMENT_POOL_ALLOC -- used in class implementation file
#define IMPLEMENT_POOL_ALLOC(class_name) \
allocator class_name::myAlloc;
```

```
class Foo {
   DECLARE_POOL_ALLOC()
public:
   long L;
   string str;
public:
   Foo(long l) : L(l) {  }
};
IMPLEMENT_POOL_ALLOC(Foo)
```

```
class Goo {
   DECLARE_POOL_ALLOC()
public:
   complex<double> c;
   string str;
public:
   Goo(const complex<double>& x) : c(x) {  }
};
IMPLEMENT_POOL_ALLOC(Goo)
```

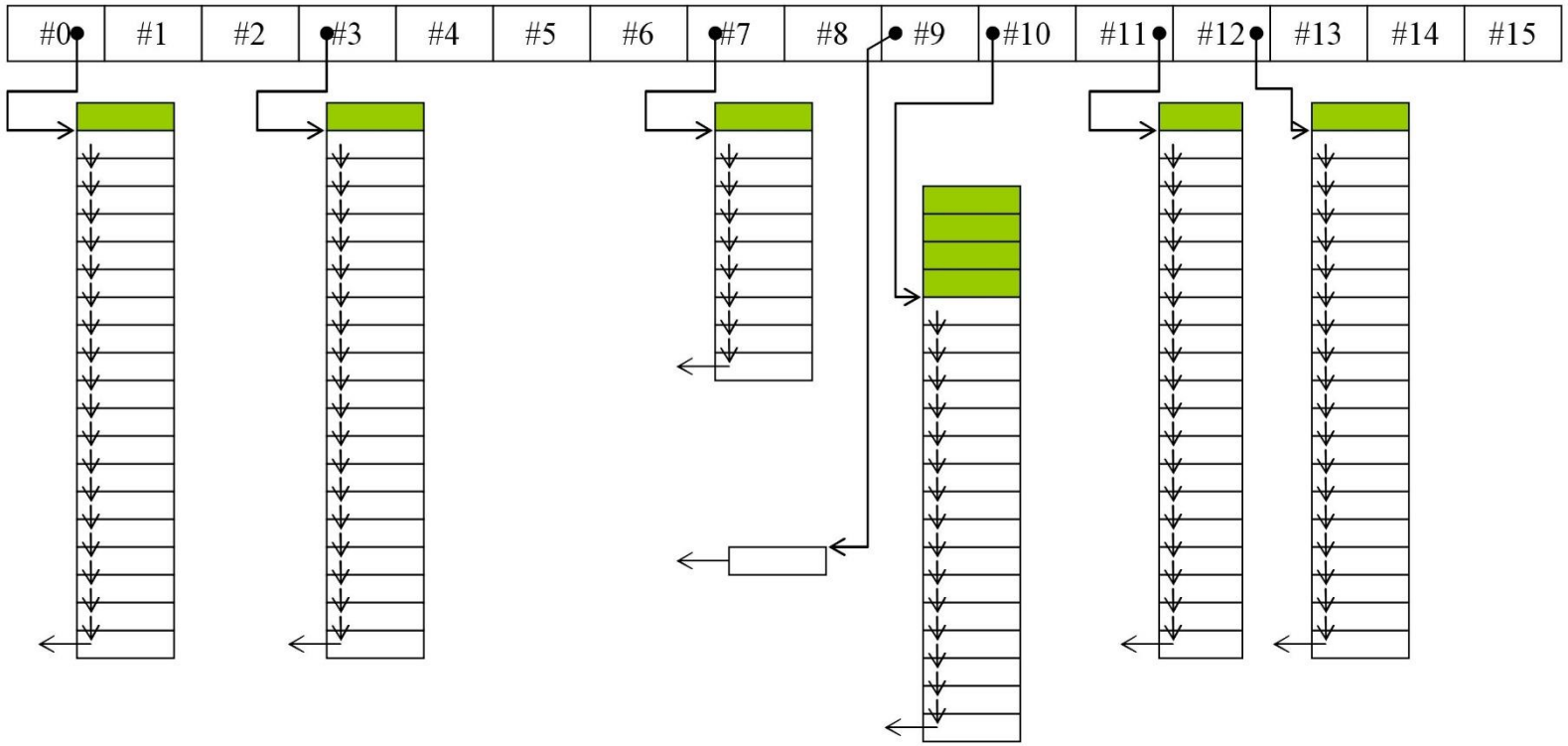
macro for static allocator,示例與結果

```
Foo* pF[100];
Goo* pG[100];

cout << "sizeof(Foo)= " << sizeof(Foo) << endl;
cout << "sizeof(Goo)= " << sizeof(Goo) << endl;

for (int i=0; i<23; ++i) {  //隨意看看結果
    pF[i] = new Foo(i);
    pG[i] = new Goo(complex<double>(i,i));

    cout << pF[i] << ' ' << pF[i]->L << "\t";
    cout << pG[i] << ' ' << pG[i]->c << "\n";
}

for (int i=0; i<23; ++i) {
    delete pF[i];
    delete pG[i];
}
```

```
sizeof(Foo)= 8
sizeof(Goo)= 24
0x3e5fc0 0      0x3e6630 (0,0)
0x3e5fc8 1      0x3e6648 (1,1)
0x3e5fd0 2      0x3e6660 (2,2)
0x3e5fd8 3      0x3e6678 (3,3)
0x3e5fe0 4      0x3e6690 (4,4)
0x3e6158 5      0x3e66b0 (5,5)
0x3e6160 6      0x3e66c8 (6,6)
0x3e6168 7      0x3e66e0 (7,7)
0x3e6170 8      0x3e66f8 (8,8)
0x3e6178 9      0x3e6710 (9,9)
0x3e67d8 10     0x3e6808 (10,10)
0x3e67e0 11     0x3e6820 (11,11)
0x3e67e8 12     0x3e6838 (12,12)
0x3e67f0 13     0x3e6850 (13,13)
0x3e67f8 14     0x3e6868 (14,14)
0x3e6978 15     0x3e69a8 (15,15)
0x3e6980 16     0x3e69c0 (16,16)
0x3e6988 17     0x3e69d8 (17,17)
0x3e6990 18     0x3e69f0 (18,18)
0x3e6998 19     0x3e6a08 (19,19)
0x3e6b18 20     0x3e6b48 (20,20)
0x3e6b20 21     0x3e6b60 (21,21)
0x3e6b28 22     0x3e6b78 (22,22)
```

global allocator (with multiple free-lists)

將前述 allocator 進一步發展為具備 *16* 條 free-lists，並因此不再以 application classes 內的 static 呈現，而是一個 global allocator —— 這就是 G2.9 的 std::alloc 的雛形。



new handler

當 operator new 沒能力爲你分配出你所申請的 memory，會拋一個 std::**bad_alloc** exception。某些老舊編譯器則是返回 0 — 你仍然可以令編譯器那麼做：

```
new (nothrow) Foo;
```

此稱爲 nothrow 形式。

拋出 exception 之前會先（不只一次）調用一個可由 client 指定的 handler，以下是 new handler 的形式和設定方法：

```
typedef void (*new_handler)();
new_handler set_new_handler(new_handler p) throw();
```

設計良好的 new handler 只有兩個選擇：

- 讓更多 memory 可用
- 調用 abort() 或 exit()

... \vc98\crt\src\newop2.cpp

```
void* operator new(size_t size, const std::nothrow_t&)
                                    _THROW0()
{   // try to allocate size bytes
void *p;
while ((p = malloc(size)) == 0)
  { // buy more memory or return null pointer
    _TRY_BEGIN
        if (_callnewh(size) == 0)  break;
    _CATCH(std::bad_alloc)    return (0);
    _CATCH_END
  }
return (p);
}
```

new handler

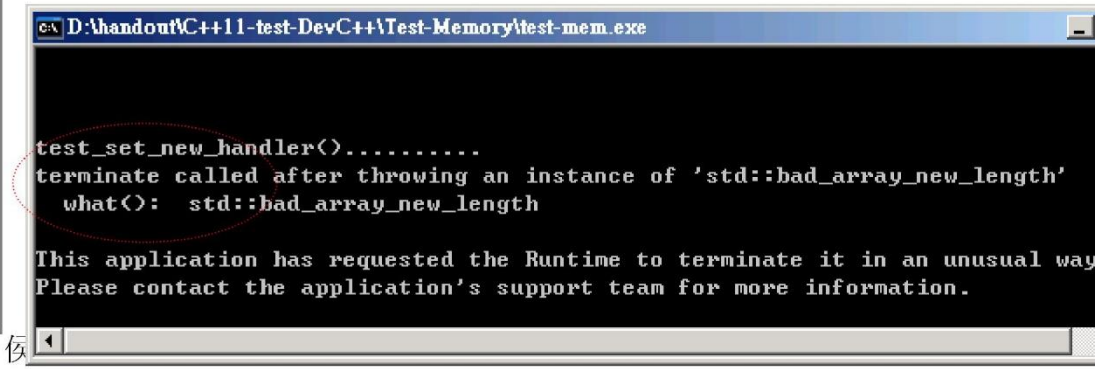
```
#include <new>
#include <iostream>
#include <cassert>
using namespace std;

void noMoreMemory()
{
   cerr << "out of memory";
   abort();
}

void main()
{
   set_new_handler(noMoreMemory);

   int* p = new int[100000000000000];      //well, so BIG!
   assert(p);

   p = new int[10000000000000000000];  //GCC warning.
   assert(
}
```

msdev\vc98\crt\src\setnewh.cpp

```
new_handler
__cdecl set_new_handler (
        new_handler  new_p)
{
   // cannot use stub to register a new handler
   assert(new_p == 0);
   // remove current handler
   _set_new_handler(0);
   return 0;
}
```

本例之 new handler 中若無調用 abort()，執行後 cerr 會不斷出現 “out of memory”，需強制中斷。這樣的表現是正確的，表示當 operator new 無法滿足申請量時，會不斷調用 new handler 直到獲得足夠 memory.

```
// 執行結果：
// BCB4 版會出現 out of memory.
//              Abnormal program termination
// 非常好，符合預期。
```



=default, =delete

```
class Foo {
public:
   Foo() = default;
   Foo(const Foo&) = delete;
   Foo& operator=(const Foo&) = delete;
   ~Foo() = default;
…
};
```

it is not only for constructors and assignments, but also applies to operator new/new[],operator delete/delete[] and their overloads.

=default, =delete

```
class Foo {
public:
   long _x;
public:
   Foo(long x=0) : _x(x) {  }

x  static void* operator new(size_t size) = default;
x  static void  operator delete(void* pdead, size_t size) = default;
   static void* operator new[](size_t size) = delete;
   static void  operator delete[](void* pdead, size_t size) = delete;
};
```

[Error] cannot be defaulted

[Error] use of deleted function …

```
Foo* p1 = new Foo(5);
delete p1;
x Foo* pF = new Foo[10];
x delete [] pF;

x Goo* p2 = new Goo(7);
x delete p2;
Goo* pG = new Goo[10];
delete [] pG;
```

```
class Goo {
public:
   long _x;
public:
   Goo(long x=0) : _x(x) {  }

   static void* operator new(size_t size) = delete;
   static void  operator delete(void* pdead, size_t size) = delete;
};
```

The End

內存管理

從平地到萬丈高樓

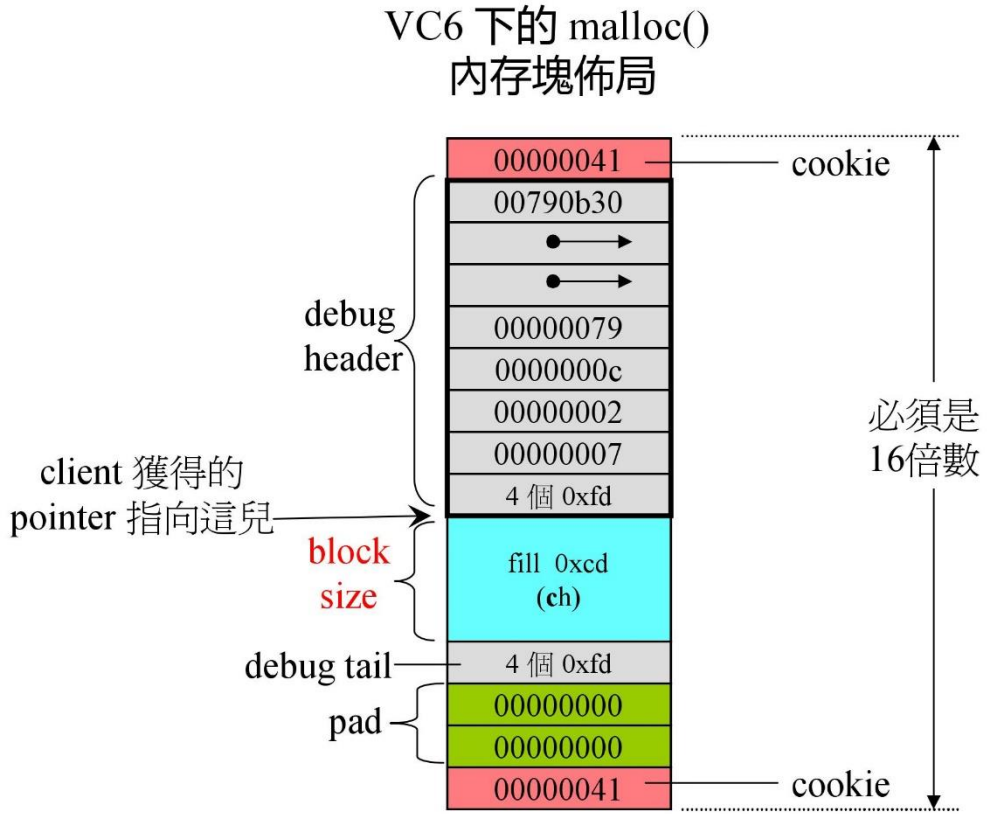
Memory Management 101

第一講 primitives
第二講 std::allocator
第三講 malloc/free
第四講 loki::allocator
第五講 other issues

侯捷

西北有高樓
上與浮雲齊

VC6 malloc()



0xC + (32+4) + 4 * 2
➔0x38
➔0x40

VC6 標準分配器之實現

VC6 所附的標準庫，其 std::**allocator** 實現如下（<xmemory>）

```
#ifndef _FARQ
 #define _FARQ
 #define _PDFT  ptrdiff_t
 #define _SIZT  size_t
#endif
```

```
template<class _Ty>
class allocator {
public:
    typedef _SIZT size_type;
    typedef _PDFT difference_type;
    typedef _Ty _FARQ *pointer;
    typedef _Ty value_type;
    pointer allocate(size_type _N, const void *)
     { return (_Allocate((difference_type)_N,(pointer)0)); }
    void deallocate(void _FARQ *_P, size_type)
     { operator delete(_P); }
};
```

VC6+ 的 **allocator** 只是以 ::operator new 和 ::operator delete 完成 allocate() 和 deallocate()，沒有任何特殊設計。

其中用到的 _Allocate() 定義如下：

```
template<class _Ty> inline
_Ty _FARQ *_Allocate(_PDFT _N, _Ty _FARQ *)
{if (_N < 0) _N = 0;
 return ((_Ty _FARQ*)operator new((_SIZT)_N * sizeof(_Ty))); }
```

```
//分配 512 ints.
int* p = allocator<int>().allocate(512, (int*)0);
allocator<int>().deallocate(p, 512);
```

```
template<class _Ty,
        class _A = allocator<_Ty>>
class vector
{ ...};
```

```
template<class _Ty,
        class _A = allocator<_Ty>>
class list
{ ...};
```

```
template<class _Ty,
        class _A = allocator<_Ty>>
class deque
{ ...};
```

```
template<class _K,
        class _Pr = less<_K>,
        class _A = allocator<_K>>
class set {...};
```

BC5 標準分配器之實現

BC5 所附的標準庫，其 std::**allocator** 實現如下（<memory.stl>）

```
template <class T>
class allocator
{
public:
  typedef size_t     size_type;
  typedef ptrdiff_t  difference_type;
  typedef T*         pointer;
  typedef T          value_type;

  pointer allocate(size_type n,
                   allocator<void>::const_pointer = 0) {
    pointer tmp =
    _RWSTD_STATIC_CAST(pointer,(::operator new
        (_RWSTD_STATIC_CAST(size_t,(n*sizeof(value_type))))));
    _RWSTD_THROW_NO_MSG(tmp == 0, bad_alloc);
    return tmp;
  }
  void deallocate(pointer p, size_type) {
    ::operator delete(p);
  }
  ...
};
```

BC5 的 **allocator** 只是以 ::operator new 和 ::operator delete 完成 allocate() 和 deallocate()，沒有任何特殊設計。

```
template <class T,
      class Allocator=allocator<T>>
class vector
{ ...};

template <class T,
      class Allocator=allocator<T>>
class list
{ ...};

template <class T,
      class Allocator=allocator<T>>
class deque
{ ...};
```

```
//分配 512 ints.
int* p = allocator<int>().allocate(512);
allocator<int>().deallocate(p,512);
```

G2.9 標準分配器之實現

G2.9 所附的標準庫，其 std::**allocator** 實現如下（<defalloc.h>）

G2.9 的 **allocator** 只是以 ::operator new 和 ::operator delete 完成 allocate() 和 deallocate()，沒有任何特殊設計。

```
template <class T>
class allocator {
public:
    typedef T       value_type;
    typedef T*      pointer;
    typedef size_t  size_type;
    typedef ptrdiff_t difference_type;
    pointer allocate(size_type n) {
          return ::allocate((difference_type)n, (pointer)0);
    }
    void deallocate(pointer p) { ::deallocate(p); }
};
```

```
template <class T>
inline T* allocate(ptrdiff_t size, T*) {
    set_new_handler(0);
    T* tmp =(T*)
        (::operator new((size_t)(size*sizeof(T))));
    if (tmp == 0) {
        cerr << "out of memory" << endl;
        exit(1);
    }
    return tmp;
}
template <class T>
inline void deallocate(T* buffer)
    ::operator delete(buffer);
}
```

G++ <defalloc.h> 中有這樣的註釋：DO NOT USE THIS FILE unless you have an old container implementation that requires an allocator with the HP-style interface. SGI STL uses a different allocator interface. SGI-style allocators are not parametrized with respect to the object type; they traffic in void* pointers. **This file is not included by any other SGI STL header**.

G2.9 容器使用的分配器, 不是 std::allocator 而是 std::alloc

```
template <class T,
          class Alloc = alloc>
class vector {
  ...
};
```

```
template <class T,
          class Alloc = alloc>
class list {
  ...
};
```

```
template <class T,
          class Alloc = alloc,
          size_t BufSiz = 0>
class deque {
  ...
};
```

```
template <class Key,
          class T,
          class Compare= less<Key>,
          class Alloc = alloc>
class map {
  ...
};
```

```
template <class Key,
          class Compare = less<Key>,
          class Alloc = alloc>
class set {
  ...
};
```

```
//分配 512 bytes.
void* p = alloc::allocate(512);
                //也可以這樣alloc().allocate(512);
alloc::deallocate(p,512);
```

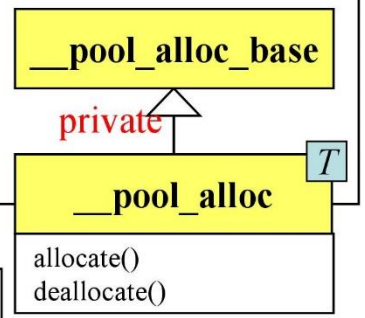
而今安在哉？ G2.9 std::alloc vs. G4.9 __pool_alloc

G4.9 標準庫中有許多 extented allocators,
其中 __pool_alloc 就是 G2.9 alloc 的化身.

G4.9

用例：
```
vector<string,
    __gnu_cxx::__pool_alloc<string>>
vec;
```

```
class __pool_alloc_base
{
protected:
  enum { _S_align = 8 };
  enum { _S_max_bytes = 128 };
  enum { _S_free_list_size = (size_t)_S_max_bytes / (size_t)_S_align };

  union _Obj
  {
    union _Obj* _M_free_list_link;
    char        _M_client_data[1];    // The client sees this.
  };

  static _Obj* volatile  _S_free_list[_S_free_list_size];
  // Chunk allocation state.
  static char*   _S_start_free;
  static char*   _S_end_free;
  static size_t  _S_heap_size;
  ...
```




```
template<typename _Tp>
class __pool_alloc : private __pool_alloc_base
{  ... };
```

— 侯 捷 —

G2.9

用例：
```
vector<string,
       std::alloc<string>>
vec;
```

```
enum {__ALIGN = 8};
enum {__MAX_BYTES = 128};
enum {__NFREELISTS = __MAX_BYTES/__ALIGN};

template <bool threads, int inst>
class __default_alloc_template
{
private:
  union obj {
    union obj* free_list_link;
  };

private:
  static obj* volatile free_list[__NFREELISTS];
…
  // Chunk allocation state.
  static char*  start_free;
  static char*  end_free;
  static size_t heap_size;
…
```

```
typedef __default_alloc_template<false,0> alloc;
```

而今安在哉？ std::alloc vs. __pool_alloc

G4.9 標準庫中有許多 extented allocators,
其中 __pool_alloc 就是 G2.9 的 alloc 的化身.

G4.9

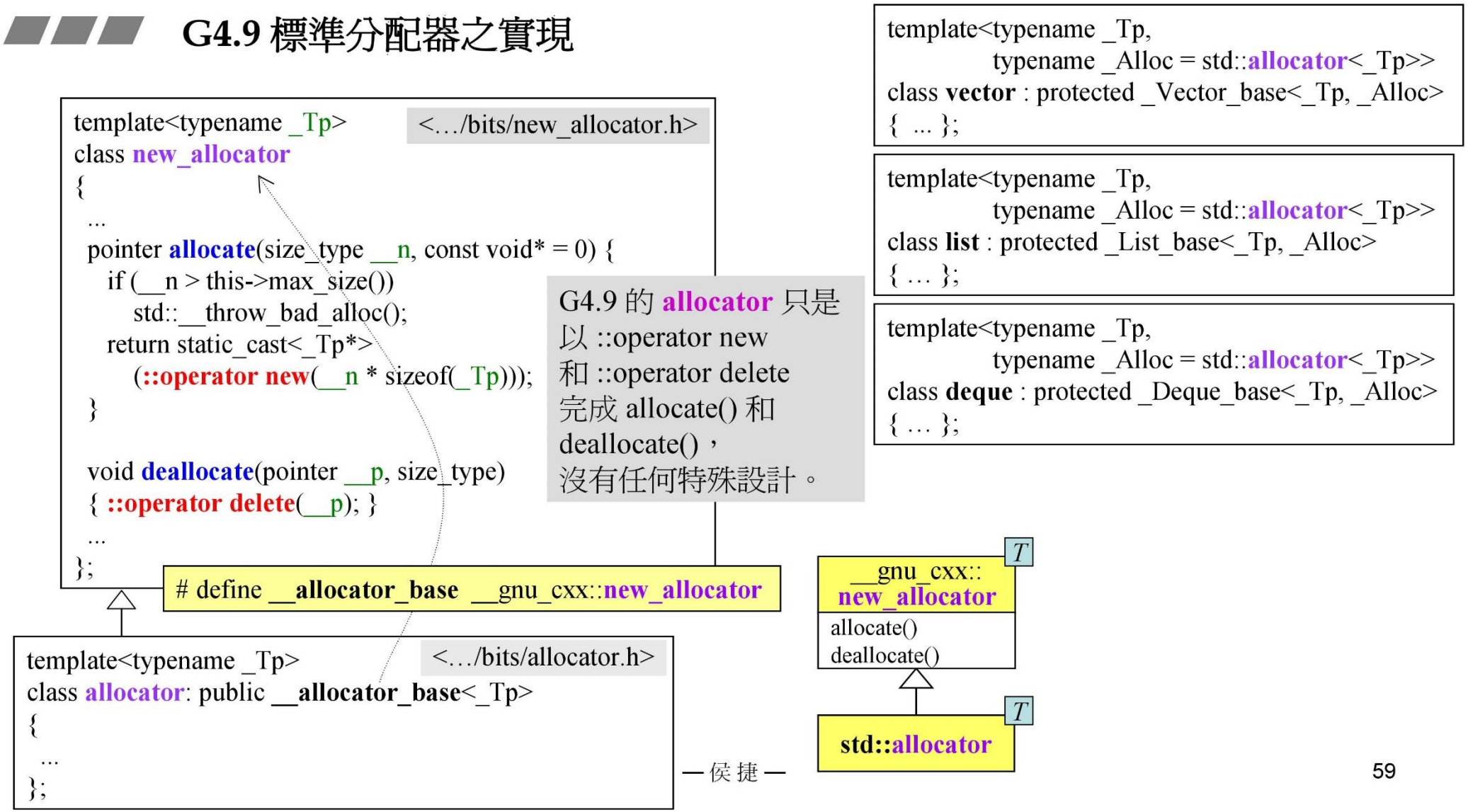
```
// Allocate memory in large chunks in order to avoid fragmenting the
// heap too much.  Assume that __n is properly aligned.  We hold the
// allocation lock.
char*
__pool_alloc_base::_M_allocate_chunk(size_t __n, int& __nobjs)
{
    char* __result;
    size_t __total_bytes = __n * __nobjs;
    size_t __bytes_left = _S_end_free - _S_start_free;
    …
    __try  {
        _S_start_free = static_cast<char*>(::operator new(__bytes_to_get));
    }
    __catch(const std::bad_alloc&)  {
        // Try to make do with what we have.  That can't hurt.  We
        // do not try smaller requests, since that tends to result
        // in disaster on multi-process machines.
        size_t __i = __n;
        for (; __i <= (size_t) _S_max_bytes; __i += (size_t) _S_align)  {
            …
        }
        // What we have wasn't enough.  Rethrow.
        _S_start_free = _S_end_free = 0;   // We have no chunk.
        __throw_exception_again;
    }
    _S_heap_size += __bytes_to_get;
    _S_end_free = _S_start_free + __bytes_to_get;
    return _M_allocate_chunk(__n, __nobjs);
}
```

G2.9

```
template <bool threads, int inst>
char* __default_alloc_template<threads, inst>::
chunk_alloc(size_t size, int& nobjs)
{
  char* result;
  size_t total_bytes = size * nobjs;
  size_t bytes_left = end_free - start_free;
  …
     start_free = (char*)malloc(bytes_to_get);
     if (0 == start_free) {
        int i;
        obj* volatile *my_free_list, *p;

        //Try to make do with what we have. That can't
        //hurt. We do not try smaller requests, since that tends
        //to result in disaster on multi-process machines.
        for (i = size; i <= __MAX_BYTES; i += __ALIGN) {
            …
        }
        end_free = 0;       //In case of exception.
        start_free = (char*)malloc_alloc::allocate(bytes_to_get);
        //This should either throw an exception or
        //remedy the situation. Thus we assume it
        //succeeded.
     }
     heap_size += bytes_to_get;
     end_free = start_free + bytes_to_get;
     return(chunk_alloc(size, nobjs));
}
```

侯

G4.9 標準分配器之實現



G4.9 pool allocator 用例

```
//欲使用 std::allocator 以外的 allocator, 就得自行 #include <ext/...>
#include <ext\pool_allocator.h>

template<typename Alloc>
void cookie_test(Alloc alloc, size_t n)
{
   typename Alloc::value_type *p1, *p2, *p3;
   p1 = alloc.allocate(n);
   p2 = alloc.allocate(n);
   p3 = alloc.allocate(n);

   cout << "p1= " << p1 << '\t' << "p2= " << p2 << '\t' << "p3= " << p3 << '\n';

   alloc.deallocate(p1,sizeof(typename Alloc::value_type));
   alloc.deallocate(p2,sizeof(typename Alloc::value_type));
   alloc.deallocate(p3,sizeof(typename Alloc::value_type));
}
```

```
cout << sizeof(__gnu_cxx::__pool_alloc<int>) << endl;   //1
vector<int, __gnu_cxx::__pool_alloc<int>> vecPool;
cookie_test(__gnu_cxx::__pool_alloc<double>(), 1);
            //相距 08h (表示不帶 cookie)
```

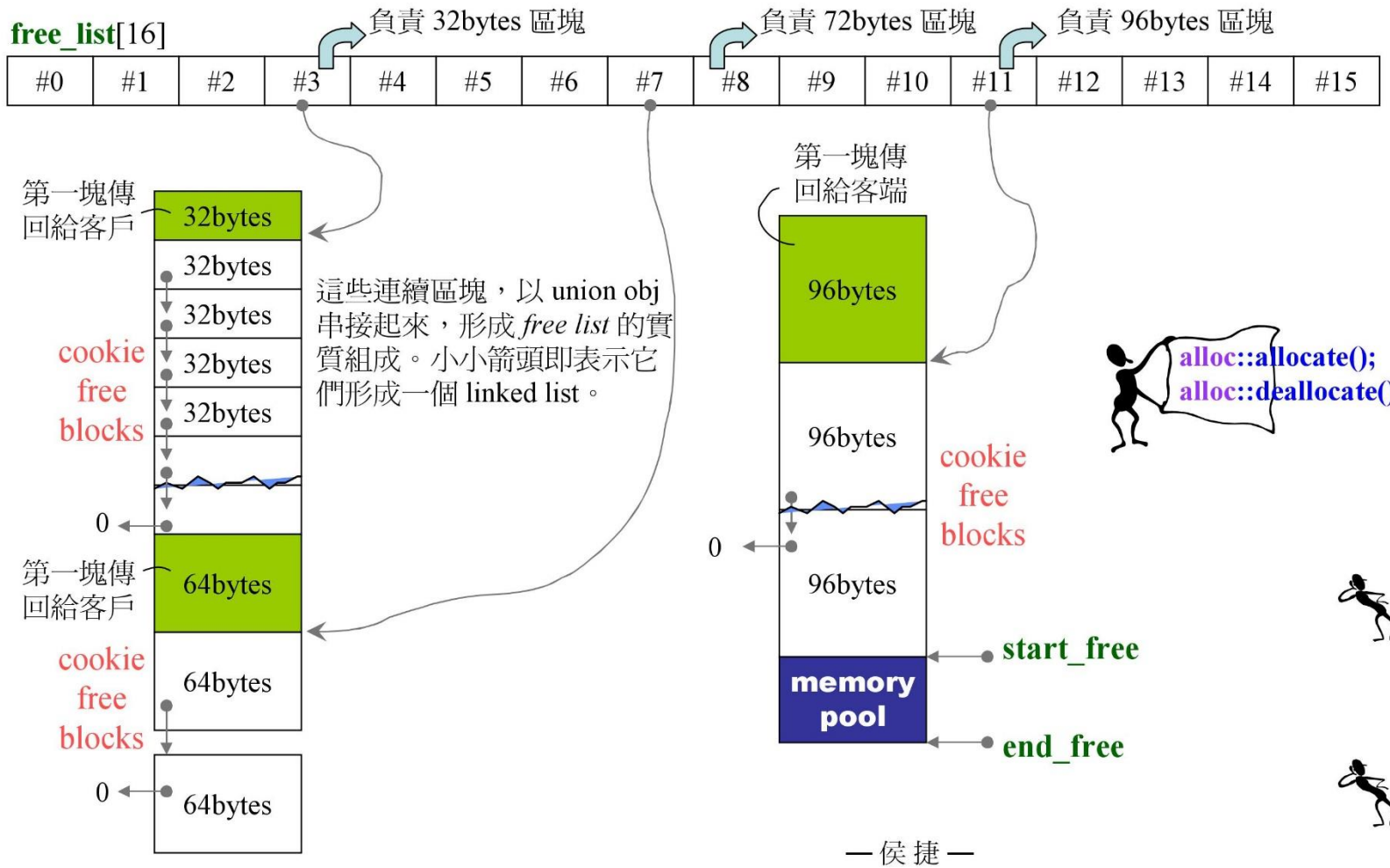
```
p1= 0xae4138   p2= 0xae4140   p3= 0xae4148
```

```
p1= 0xae25e8   p2= 0xadeb50   p3= 0xadd090
```

```
cout << sizeof(std::allocator<int>) << endl;   //1
vector<int, std::allocator<int>> vec;
cookie_test(std::allocator<double>(), 1);
      //相距 10h (表示帶 cookie)
```

```
p1= 0x3e4098   p2= 0x3e4088   p3= 0x3e4078
```

G2.9 std::alloc 運行模式




```
template <class T,
          class Alloc = alloc>
class vector { ...};
```

```
template <class T,
          class Alloc = alloc>
class list { ... };
```

```
template <class T,
          class Alloc = alloc,
          size_t BufSiz = 0>
class deque { ... };
```

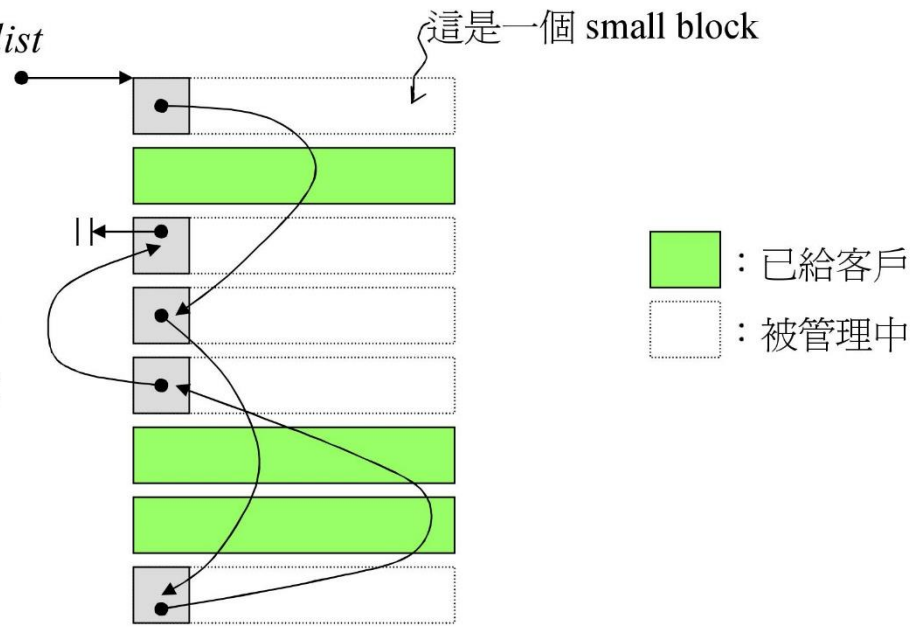
```
template <class Key,
          class T,
          class Compare= less<Key>,
          class Alloc = alloc>
class map { ... };
```

```
template <class Key,
          class Compare = less<Key>,
          class Alloc = alloc>
class set { ... };
```

— 侯 捷 —

embedded pointers

當客戶端獲得小區塊，獲得的即是 char*（指向某個 union obj)。此時雖然客戶端沒有諸如 LString 或 ZString之類的信息可得知區塊大小，但由於這區塊是給 object 所用，相等於 object 大小，object ctor 自然不會逾份。



改用 struct 可

```
union obj {
  union obj* free_list_link;
  char client_data[1];     // client sees this
};
```

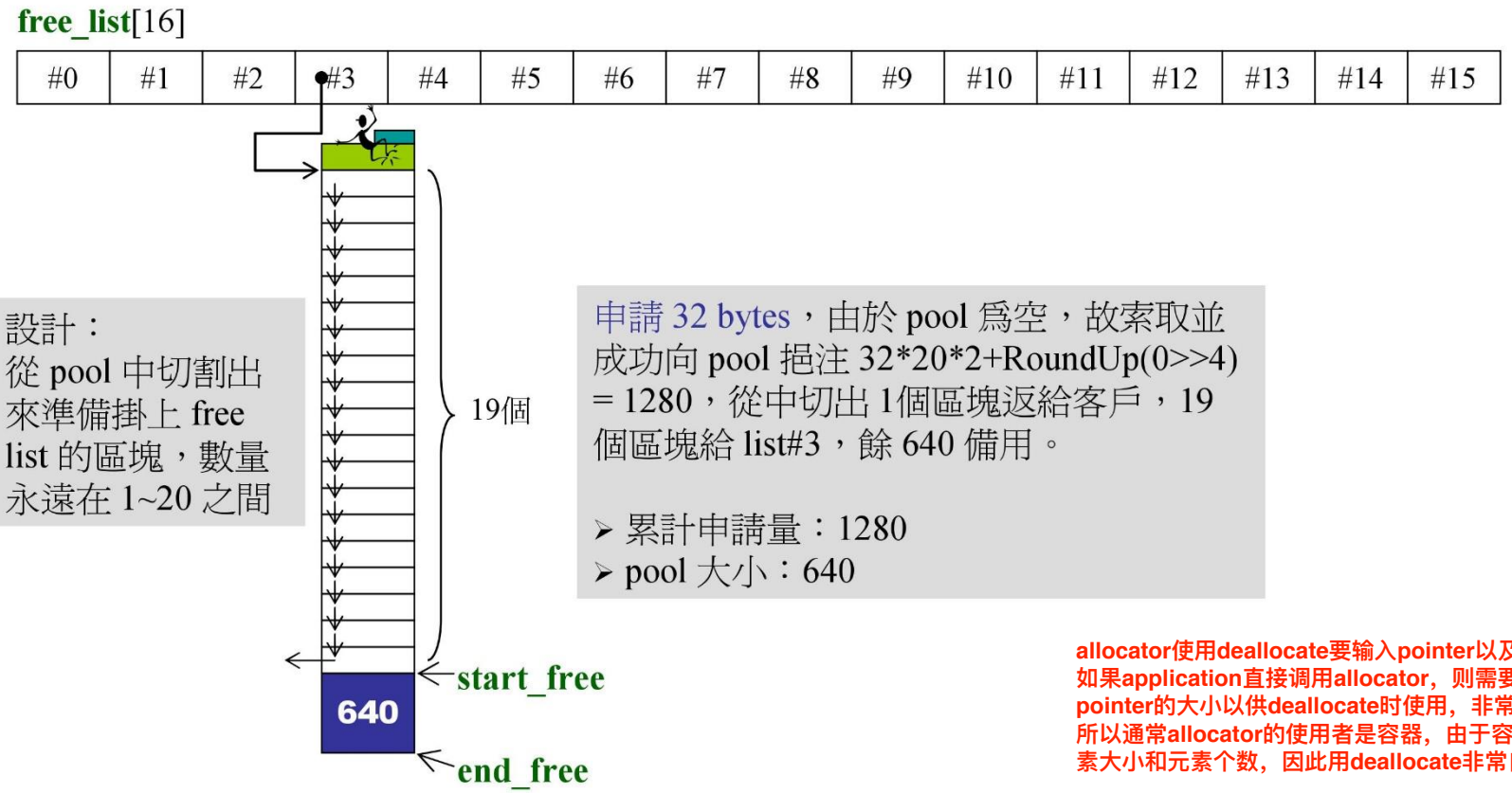
G2.9 std::alloc 運行一瞥.01

free_list[16]

#0	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15

```
#283 template <bool threads, int inst>
#284 __default_alloc_template<threads, inst>::obj* volatile    16
#285 __default_alloc_template<threads, inst>::free_list[__NFREELISTS]
#286       = {0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, };
#287 //------------------------------------------
#288
#289 //令第2級分配器的名稱爲 alloc
#290 typedef __default_alloc_template<false,0> alloc;
```

G2.9 std::alloc 運行一瞥.02



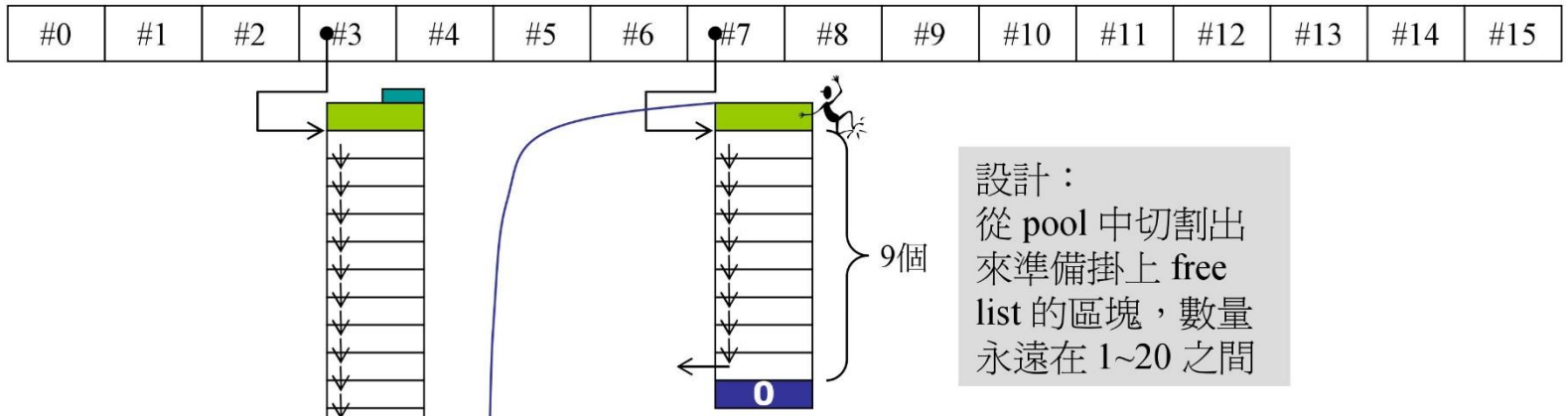
設計：
從 pool 中切割出來準備掛上 free list 的區塊，數量永遠在 1~20 之間

申請 32 bytes，由於 pool 爲空，故索取並成功向 pool 挹注 32*20*2+RoundUp(0>>4) = 1280，從中切出 1個區塊返給客戶，19個區塊給 list#3，餘 640 備用。

- 累計申請量：1280
- pool 大小：640

allocator使用deallocate要输入pointer以及大小。
如果application直接调用allocator，则需要记住pointer的大小以供deallocate时使用，非常不方便。
所以通常allocator的使用者是容器，由于容器知道元素大小和元素个数，因此用deallocate非常自然

G2.9 std::alloc 運行一瞥.03

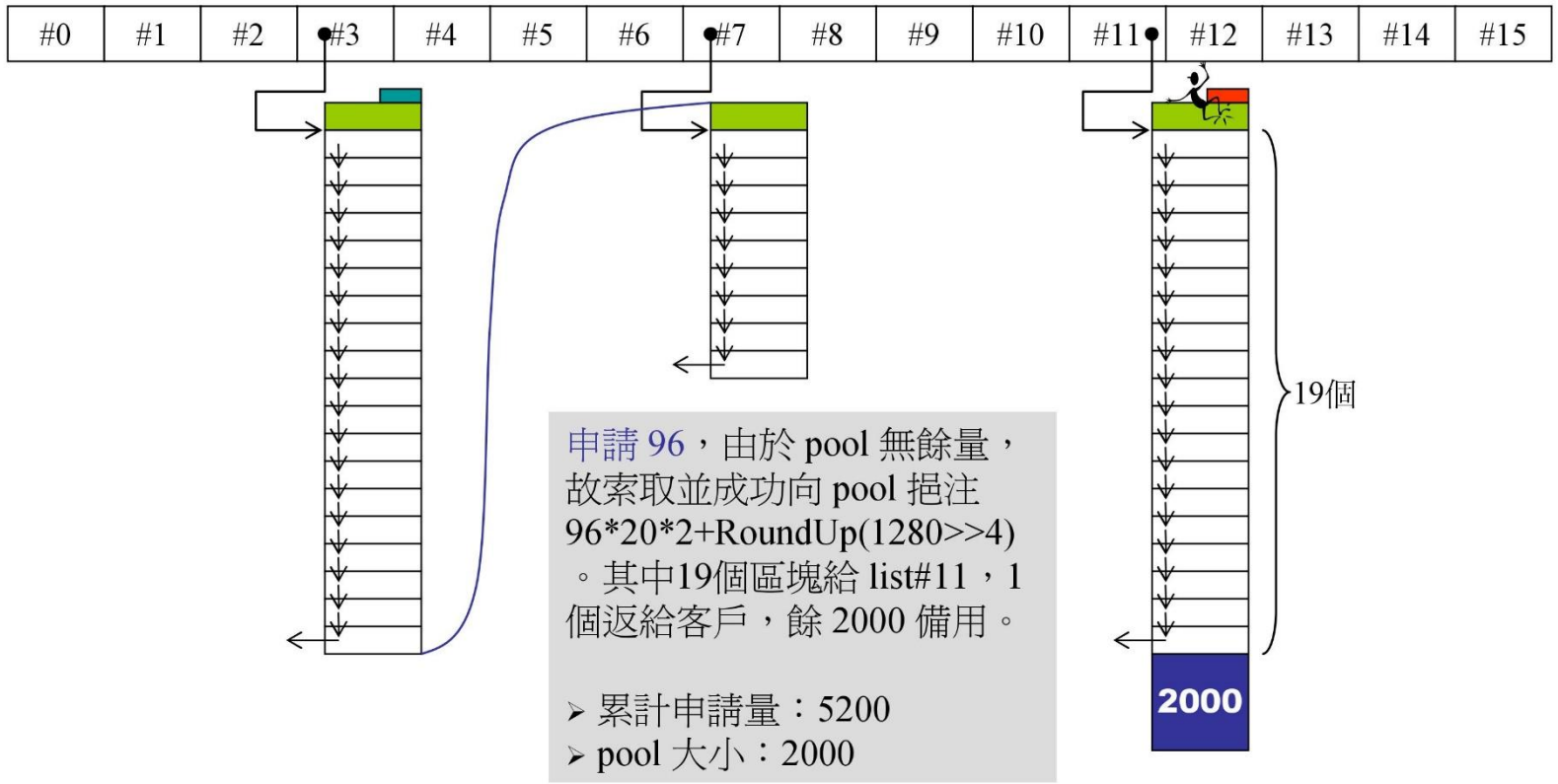


設計：
從 pool 中切割出來準備掛上 free list 的區塊，數量永遠在 1~20 之間

申請 64 bytes，由於 pool 有餘量，故取 pool 劃分爲 640/64=10 個區塊，第 1 個給客戶，餘 9 個掛於 list#7。

- 累計申請量：1280
- pool 大小：0

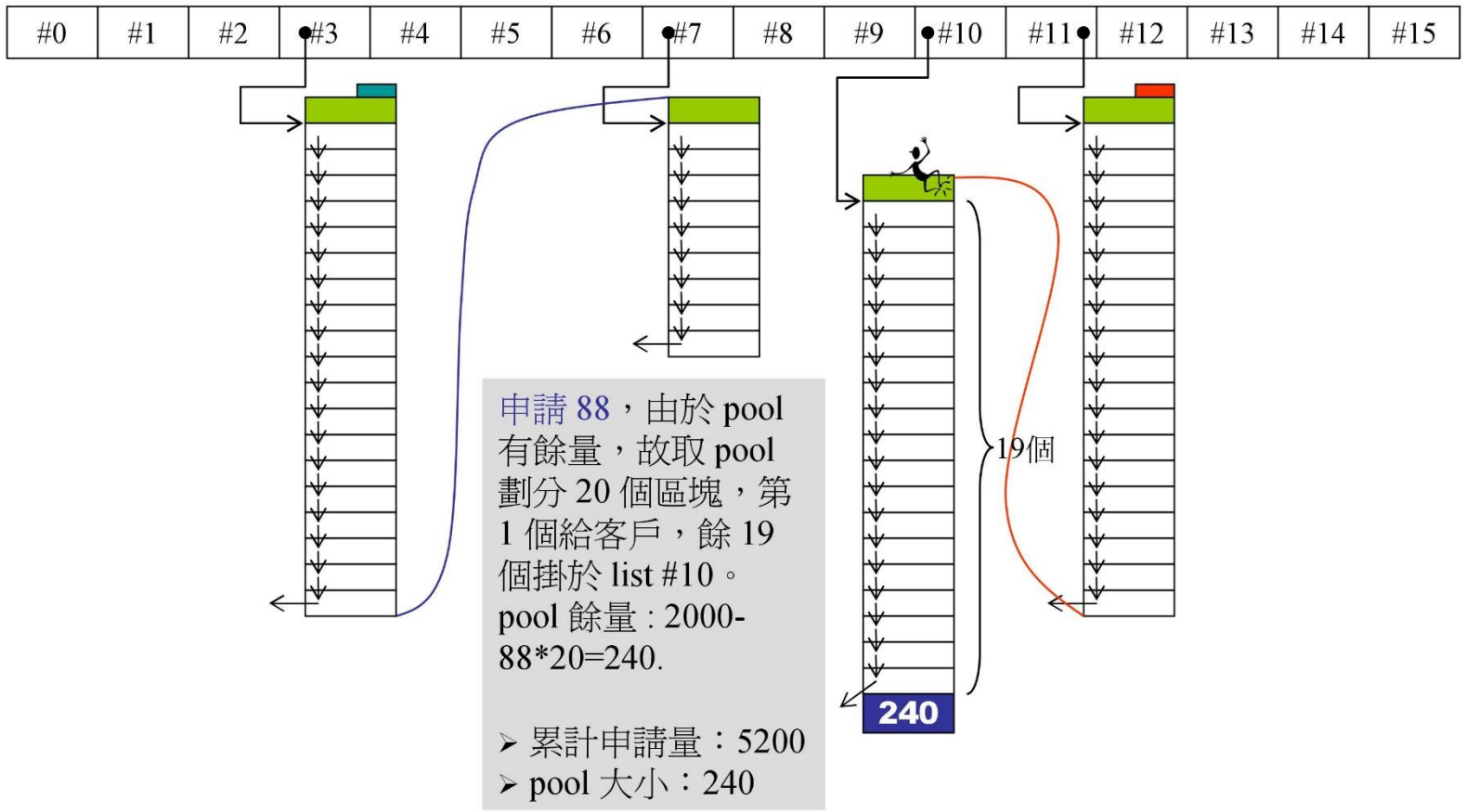
G2.9 std::alloc 運行一瞥.04



申請 96，由於 pool 無餘量，故索取並成功向 pool 挹注 96*20*2+RoundUp(1280>>4) 。其中19個區塊給 list#11，1個返給客戶，餘 2000 備用。

- 累計申請量：5200
- pool 大小：2000

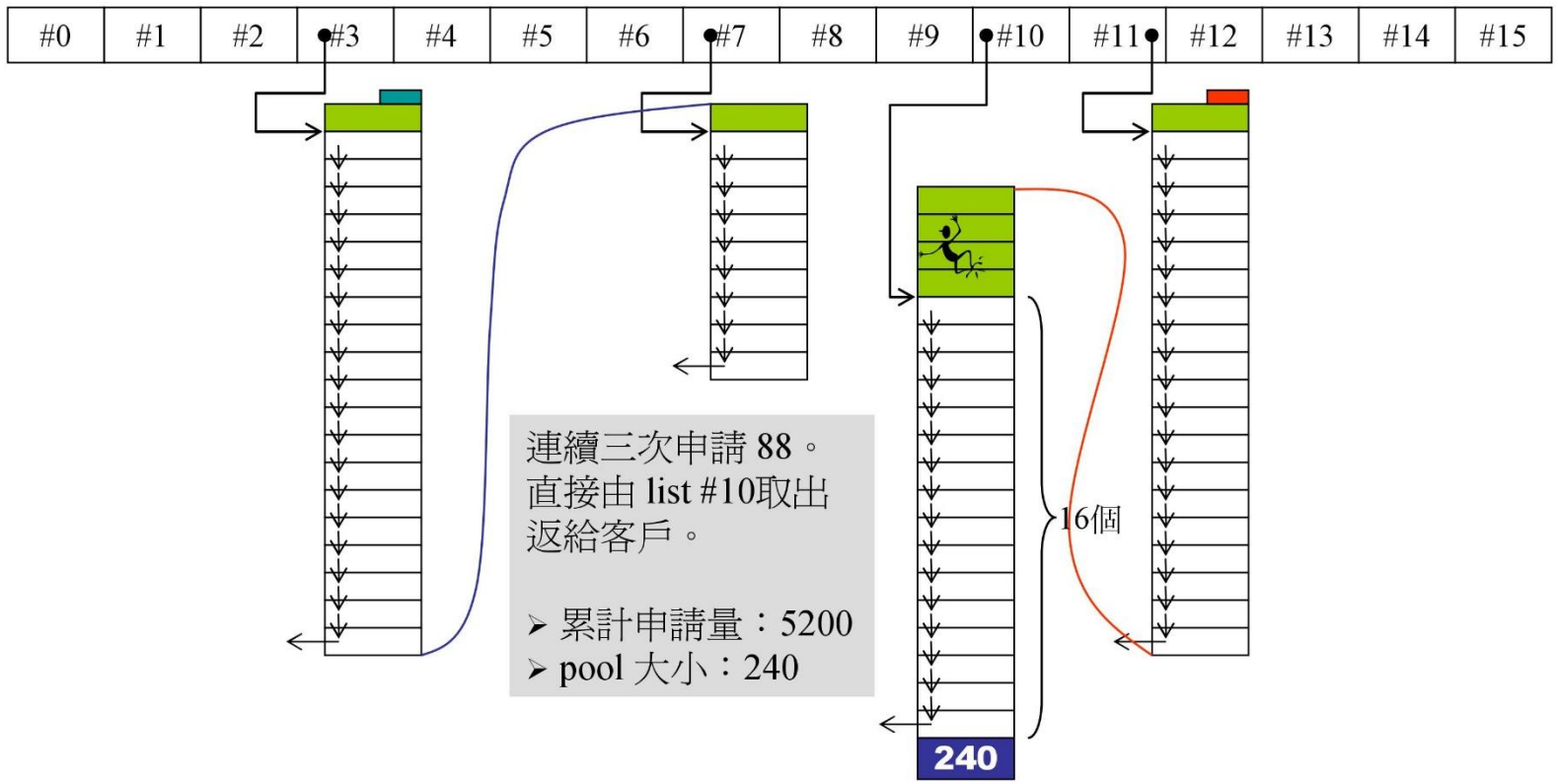
G2.9 std::alloc 運行一瞥.05



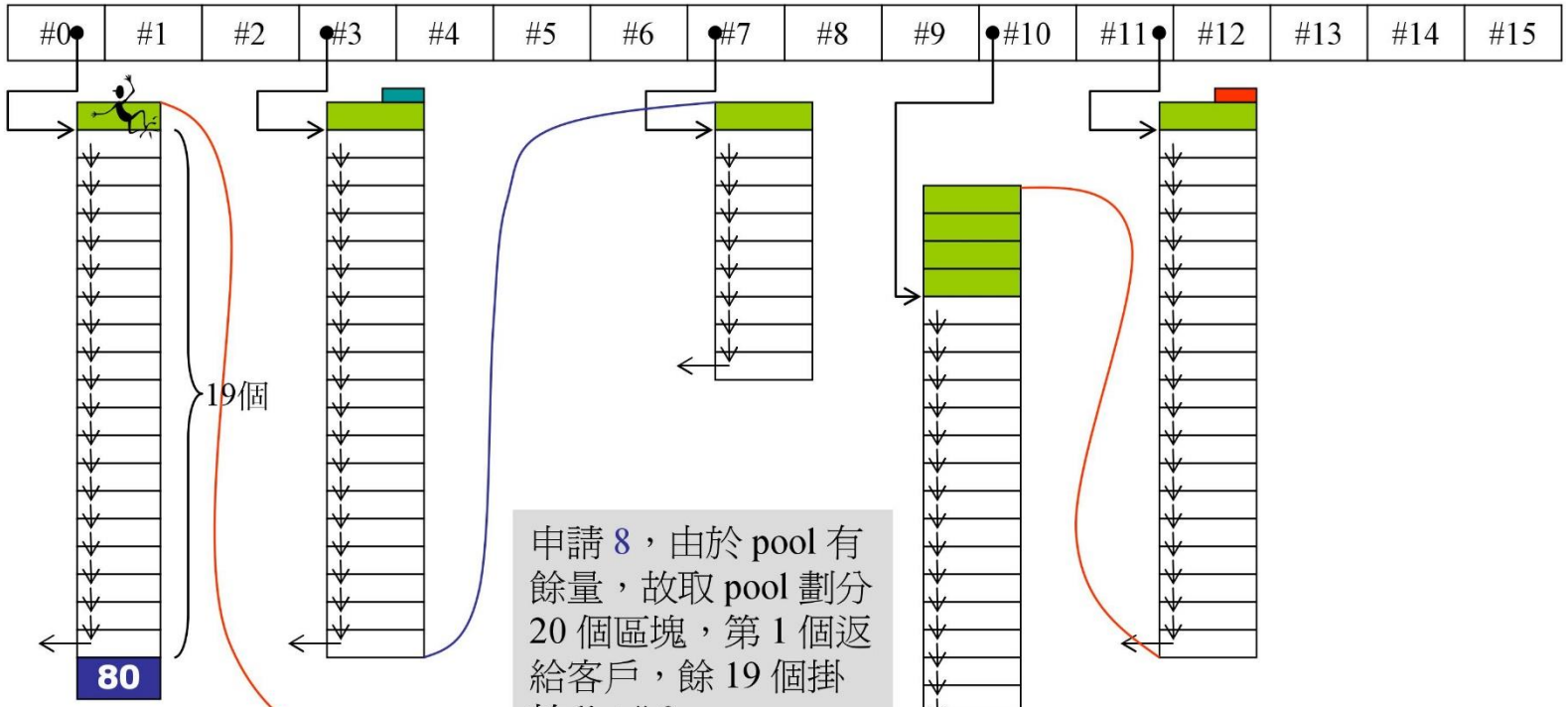
申請 88，由於 pool 有餘量，故取 pool 劃分 20 個區塊，第 1 個給客戶，餘 19 個掛於 list #10。
pool 餘量 : 2000-88*20=240.

- 累計申請量：5200
- pool 大小：240

G2.9 std::alloc 運行一瞥.06



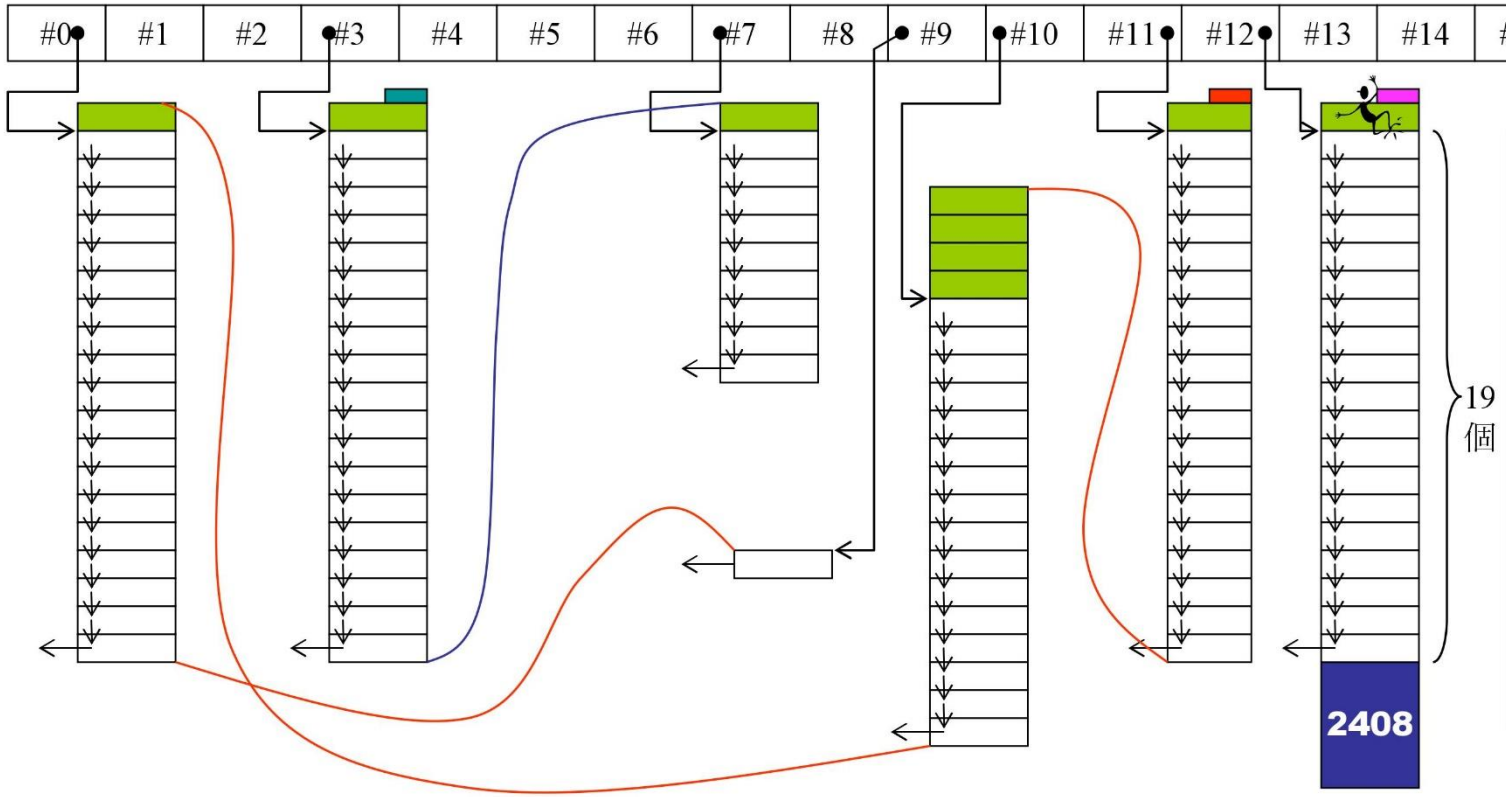
G2.9 std::alloc 運行一瞥.07



申請 8，由於 pool 有餘量，故取 pool 劃分 20 個區塊，第 1 個返給客戶，餘 19 個掛於 list # 0。

- 累計申請量：5200
- pool 大小：80

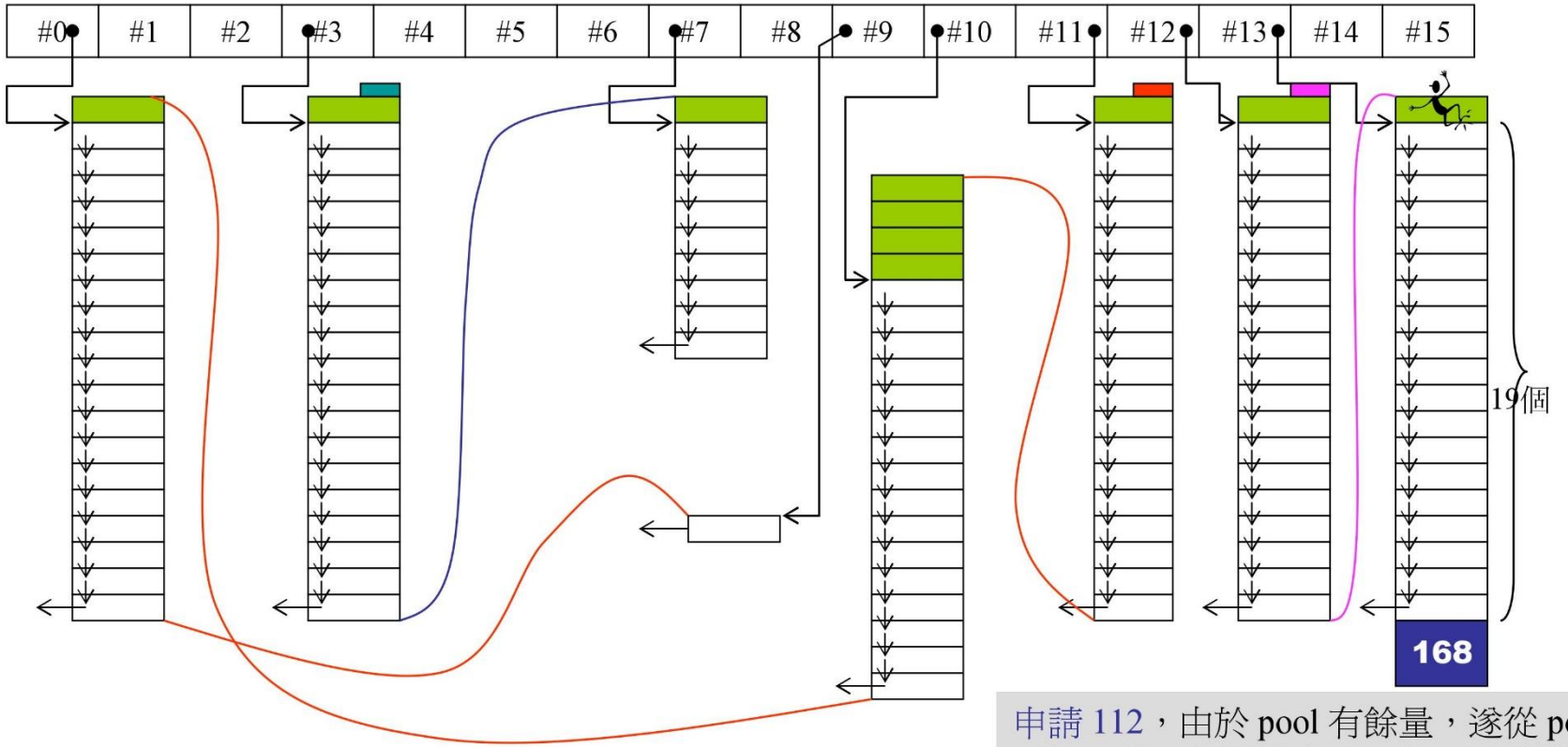
G2.9 std::alloc 運行一瞥.08



申請 104，list #12 無區塊，pool 餘量又不足供應 1 個，於是先將 pool 餘額撥給 list #9 (碎片處理), 然後索取並成功獲得挹注 104*20*2 + RoundUp(5200>>4)，切出 19 個給 list #12，最前頭那個返給客戶，餘 2408 備用。

- 累計申請量：9688
- pool 大小：2408

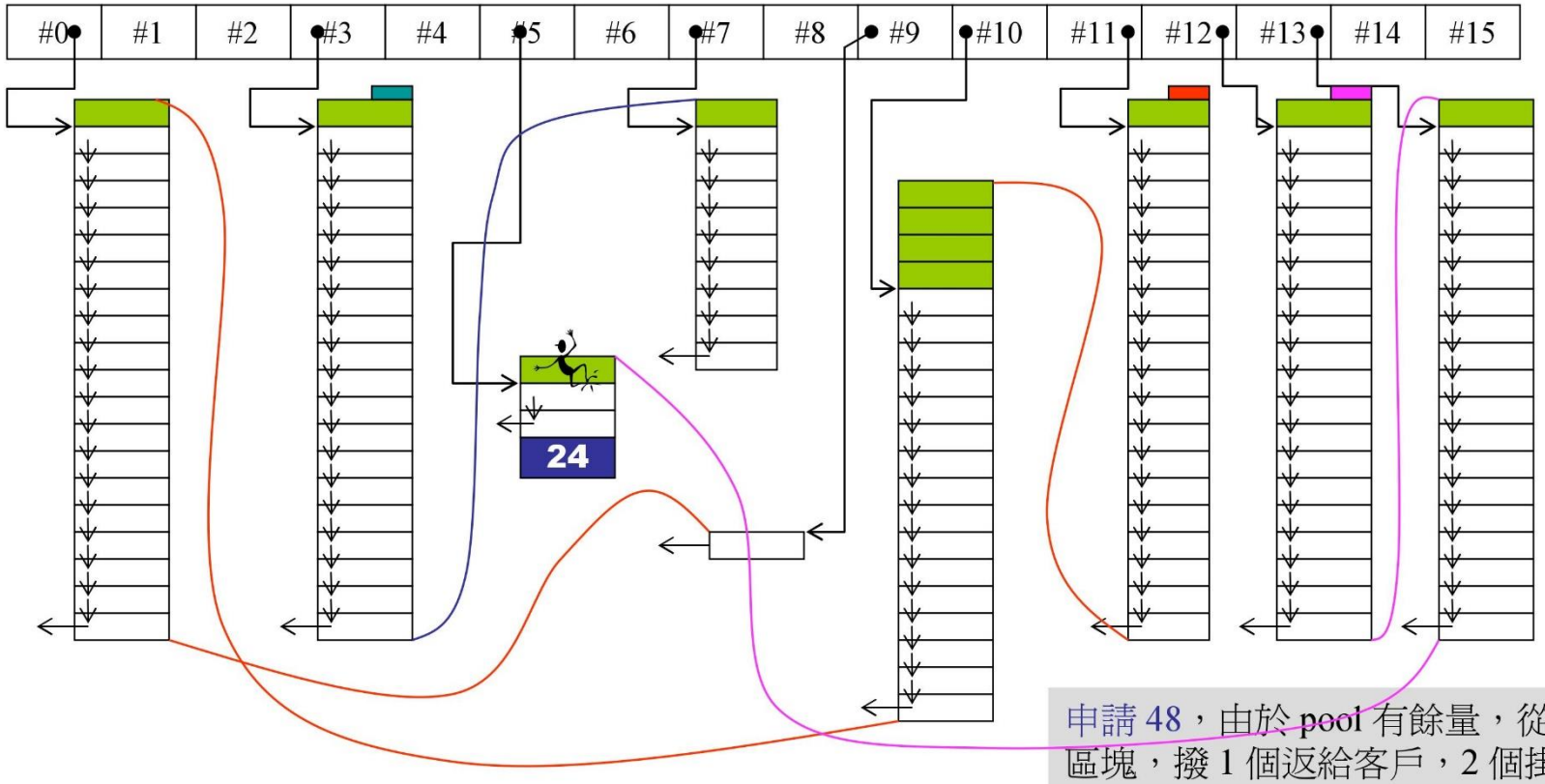
G2.9 std::alloc 運行一瞥.09



申請 112，由於 pool 有餘量，遂從 pool 取 20 個區塊，撥 1 個返給客戶，留 19 個掛於 list #13.

- 累計申請量：9688
- pool 大小： 2408-112*20=168.

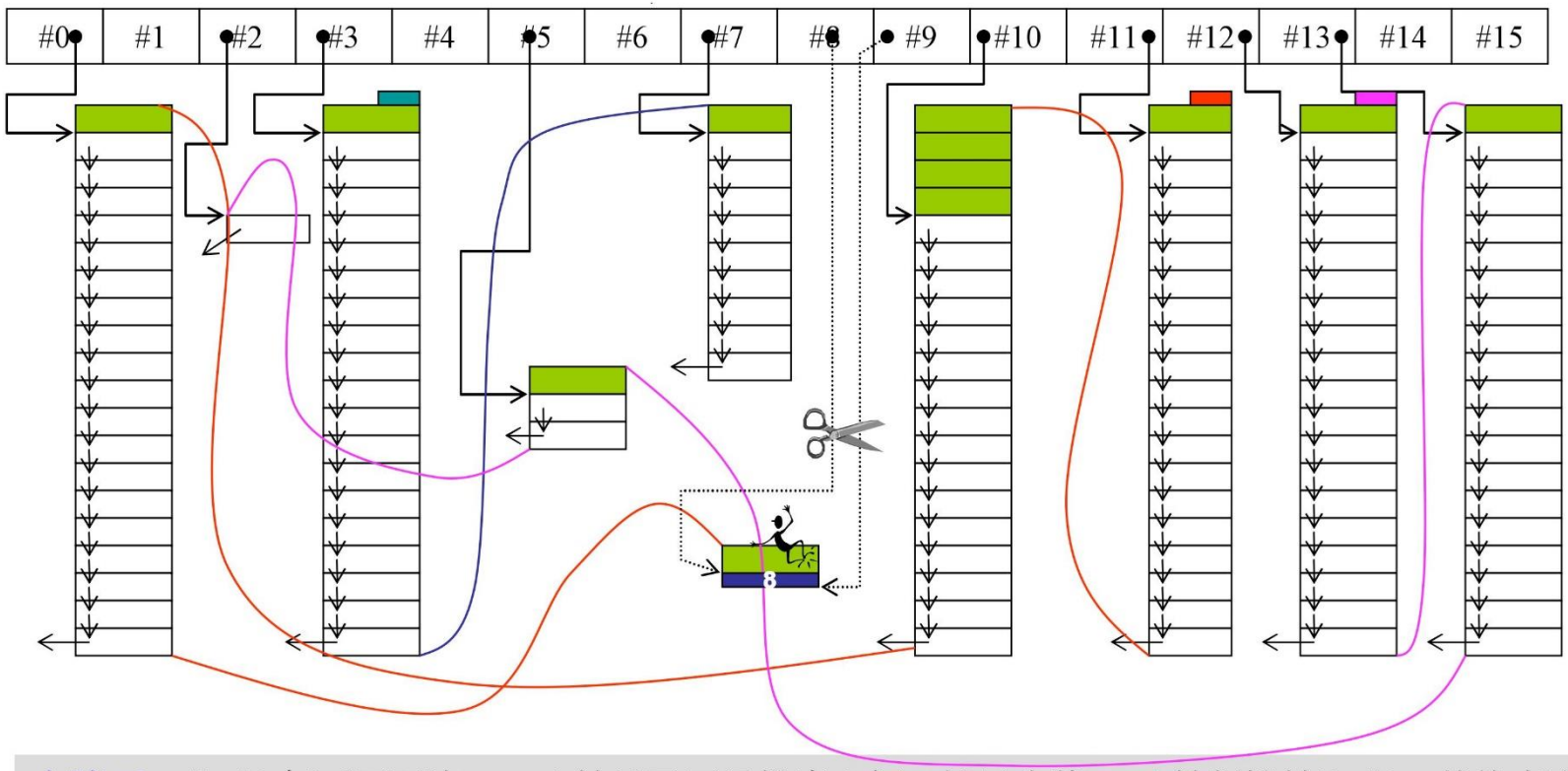
G2.9 std::alloc 運行一瞥.10



申請 48，由於 pool 有餘量，從 pool 取 3 個區塊，撥 1 個返給客戶，2 個掛於 list #5。

- 累計申請量：9688
- pool 大小： 168-48*3=24

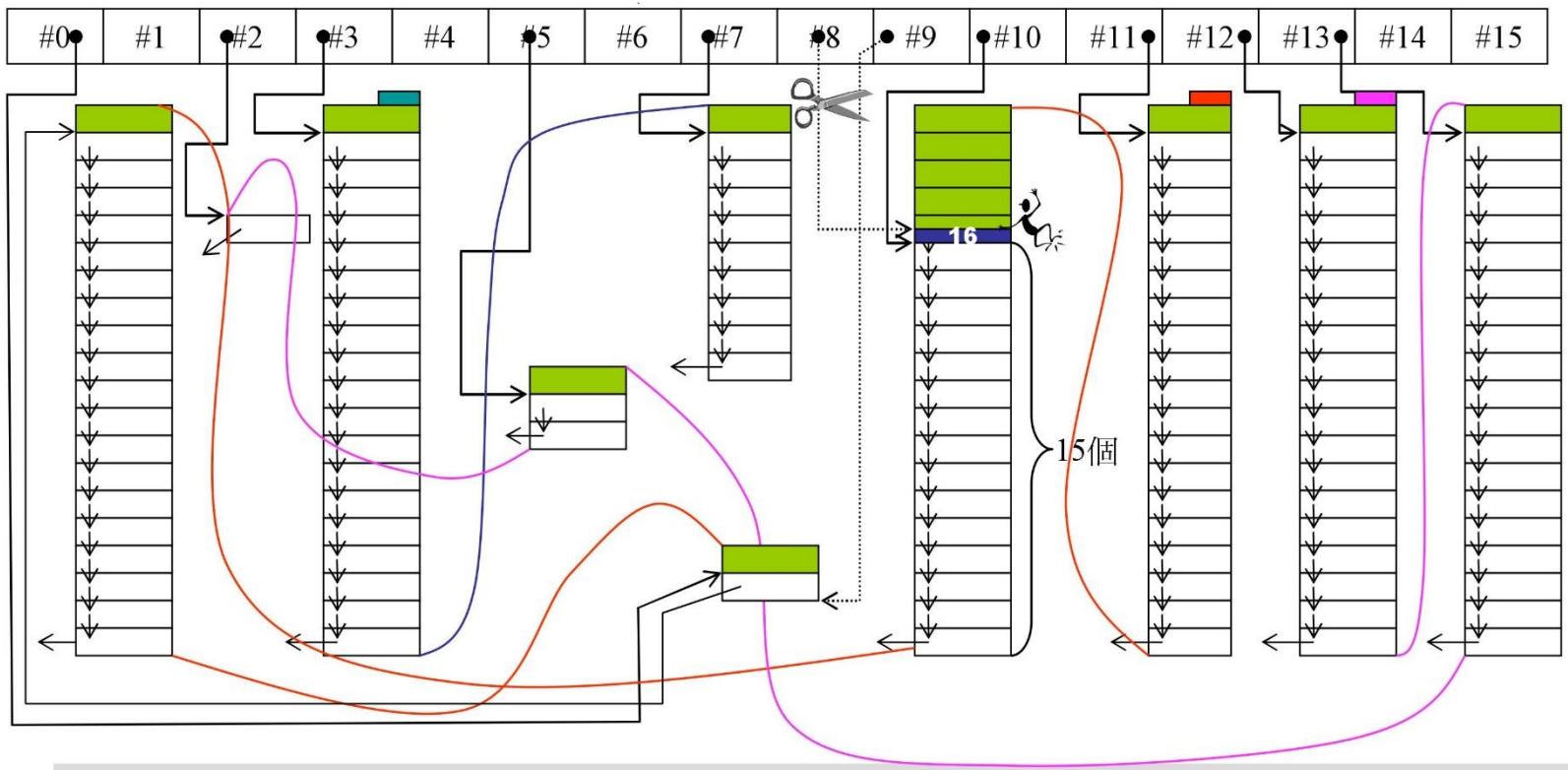
G2.9 std::alloc 運行一瞥.11



申請 72，list#8 無可用區塊，pool 餘量又不足供應 1 個，於是先將 pool 餘額撥給list#2，然後索取 72*20*2+RoundUp(9688>>4)，但爲觀察系統邊界，我將 system heap 大小設爲 10000，目前已索取 9688，因此無法滿足此次索取，於是 **alloc** 從手中資源取最接近之 80 (list#9) 回填 pool，再從中切出 72 返給客戶，餘 8。

- 累計申請量：9688
- pool 大小： 8

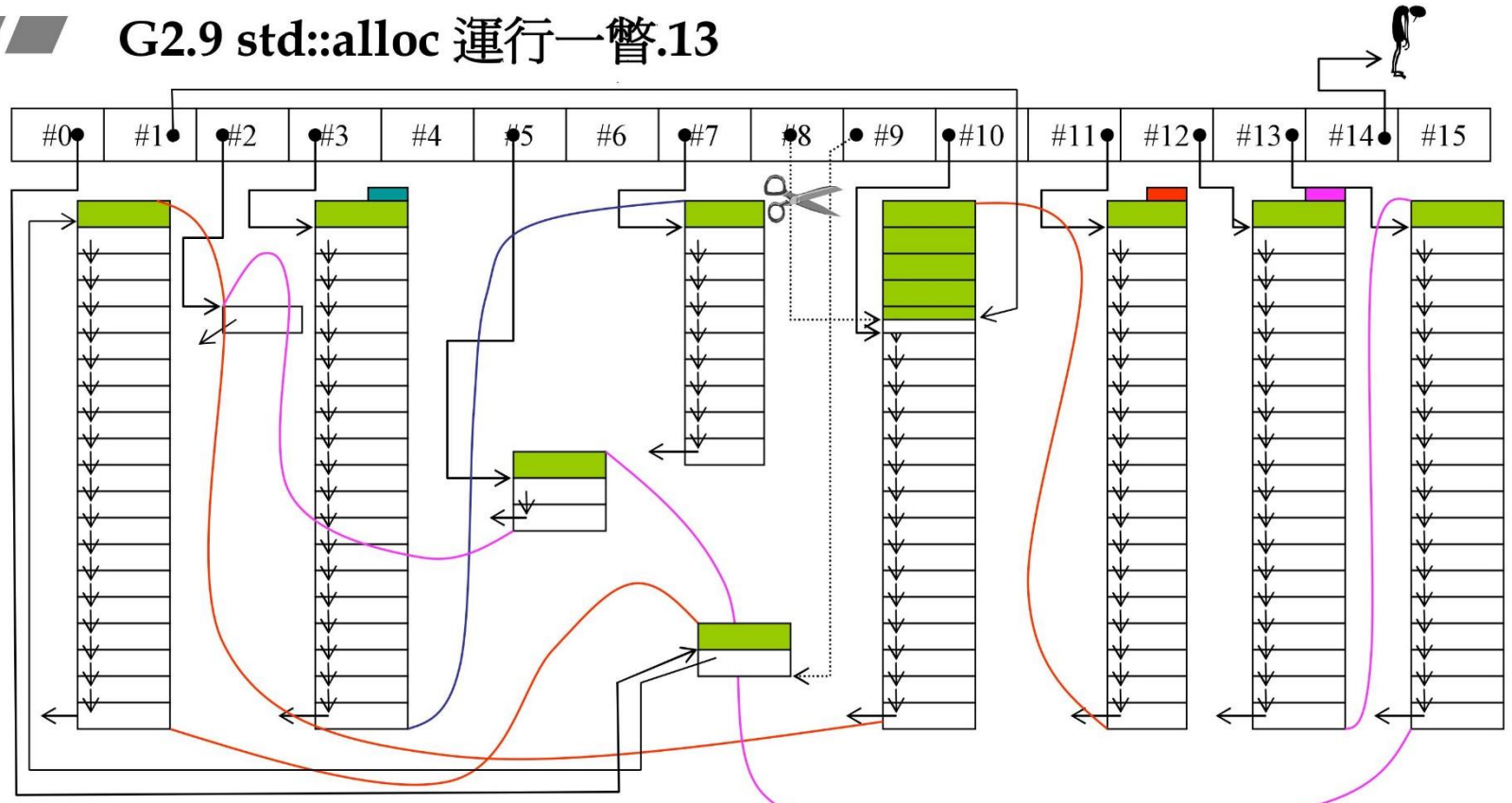
G2.9 std::alloc 運行一瞥.12



申請 72，list#8無可用區塊，pool 餘量又不足供應1個，於是先將 pool 餘額撥給 list#0，然後索取 72*20*2+RoundUp(9688>>4)，但 system heap 大小已被我設爲 10000，目前已索取 9688，因此無法滿足此次索取，於是 **alloc** 從手中資源取最接近之 88 (list#10) 回填 pool，再從中切出 72 返給客戶，餘 16。

- 累計申請量：9688
- pool 大小： 16

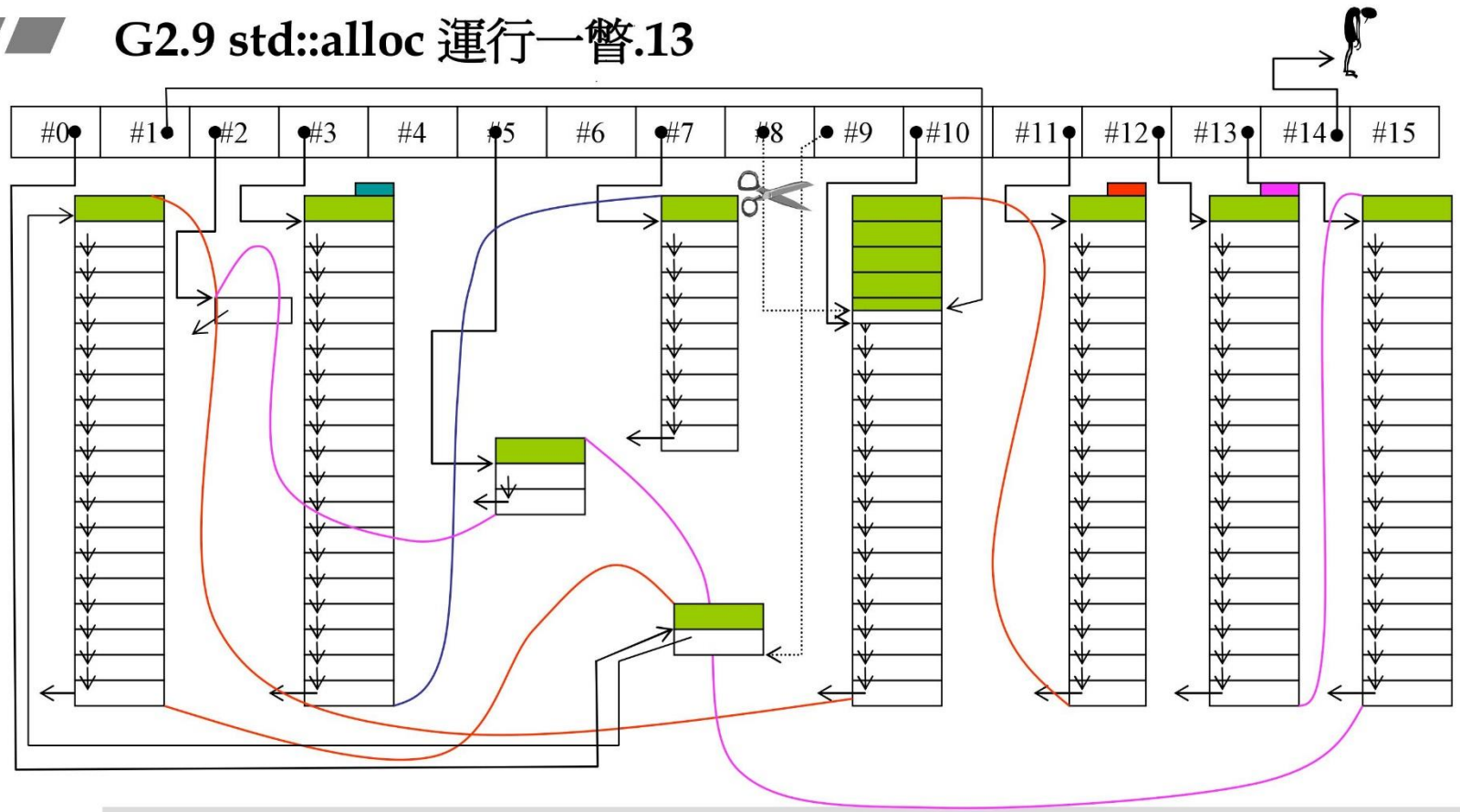
G2.9 std::alloc 運行一瞥.13



申請 120，list#14無可用區塊，pool 餘量又不足供應 1 個，於是先將 pool 餘額撥給 list#1，然後索取 120*20*2+RoundUp(9688>>4)，但 system heap 大小已被我設爲 10000，目前已索取 9688，因此無法滿足此次索取，於是 **alloc** 從手中資源取最接近者回填 pool，但是找不到，終於窮途末路山窮水盡日薄西山。

- 累計申請量：9688
- pool 大小： 0

G2.9 std::alloc 運行一瞥.13



檢討

累計量：9688

- 檢討 1：**alloc** 手中還有多少資源？以上白色皆是。可不可以將白色小區塊合成爲較大區塊供應給客戶？唔，技術難度極高。
- 檢討 2：system heap 手中還剩多少資源？10000 – 9688 = 312。可不可以將失敗的那次索取量折半…再折半…再折半…最終當索取量 <= 312 便能獲得滿足。

G2.9 std::alloc 源碼剖析, 1

```
#001 //#include <cstdlib>
#002 #include <cstddef>
#003 #include <new>
#004
#005 #define __THROW_BAD_ALLOC  \
     cerr << "out of memory"; exit(1)
```

```
#008 // 第一級分配器
#010 template <int inst>
#011 class __malloc_alloc_template {
#012 private:
#013   static void* oom_malloc(size_t);
#014   static void* oom_realloc(void*, size_t);
#015   static void (* __malloc_alloc_oom_handler)();
#016     //上面這個指針用來指向new-handler(if any)
#017 public:
#018   static void* allocate(size_t n)
#019   {
#020     void *result = malloc(n);   //直接使用malloc()
#021     if (0 == result) result = oom_malloc(n);
#022     return result;
#023   }
#024   static void deallocate(void *p, size_t /* n */)
#025   {
#026     free(p);                    //直接使用free()
#027   }
#028   static void* reallocate(void *p, size_t /* old_sz */, size_t new_sz)
#029   {
#030     void * result = realloc(p, new_sz); //直接使用realloc()
#031     if (0 == result) result = oom_realloc(p, new_sz);
#032     return result;
#033   }
#034   static void (*set_malloc_handler(void (*f)()))()
#035   { //類似 C++ 的 set_new_handler().
#036     void (*old)() = __malloc_alloc_oom_handler;  //記錄原new-handler
#037     __malloc_alloc_oom_handler = f; //把f 記起來以便爾後呼叫
#038     return(old);            //把原先的handler傳回以便日後可恢復
#039   }
#040 };
```

如果改用 operator new()，便可直接使用 C++ 的 set_new_handler()，不必寫出這般模擬。

```
typedef void (*H)();
H set_malloc_handler(H f);
```

相當於

my handler
void (f*)()

G2.9 std::alloc 源碼剖析, 2

```
#042 template <int inst>
#043 void (*__malloc_alloc_template<inst>::__malloc_alloc_oom_handler)() = 0;
#044
#045 template <int inst>   //本例template參數'inst'完全沒派上用場
#046 void* __malloc_alloc_template<inst>::oom_malloc(size_t n)
#047 {
#048   void (*my_malloc_handler)();
#049   void* result;
#050
#051   for (;;) {     //不斷嘗試釋放、分配、再釋放、再分配...
#052     my_malloc_handler = __malloc_alloc_oom_handler; //換個名稱
#053     if (0 == my_malloc_handler) { __THROW_BAD_ALLOC; }
#054     (*my_malloc_handler)();      //呼叫handler，企圖釋放memory
#055     result = malloc(n);          //再次嘗試分配memory
#056     if (result) return(result);
#057   }
#058 }
```

有可能在#037被改掉

my handler

```
#060 template <int inst>
#061 void * __malloc_alloc_template<inst>::oom_realloc(void* p, size_t n)
#062 {
#063   void (*my_malloc_handler)();
#064   void* result;
#065
#066   for (;;) {     //不斷嘗試釋放、分配、再釋放、再分配...
#067     my_malloc_handler = __malloc_alloc_oom_handler; //換個名稱
#068     if (0 == my_malloc_handler) { __THROW_BAD_ALLOC; }
#069     (*my_malloc_handler)();      //呼叫hander，企圖釋放memory
#070     result = realloc(p, n);      //再次嘗試分配memory
#071     if (result) return(result);
#072   }
#073 }
```

是爲了 multi-threading ?!

G2.9 std::alloc 源碼剖析, 3

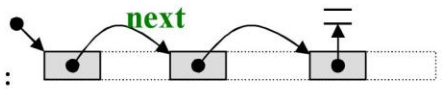
```
#074 //------------------------------------------------
#075 typedef __malloc_alloc_template<0> malloc_alloc;
#076
#077 //一個換膚工程,將分配單位由 bytes 個數改爲元素個數
#078 template<class T, class Alloc>
#079 class simple_alloc {
#080 public:
#081   static T* allocate(size_t n)              //一次分配n個T objects
#082     { return 0 == n? 0 : (T*)Alloc::allocate(n*sizeof(T)); }
#083   static T* allocate(void)                  //一次分配1個T objects
#084     { return (T*)Alloc::allocate(sizeof(T)); }
#085   static void deallocate(T* p, size_t n) //一次歸還n個T objects
#086     { if (0 != n) Alloc::deallocate(p, n*sizeof(T)); }
#087   static void deallocate(T *p)              //一次歸還1個T objects
#088     { Alloc::deallocate(p, sizeof(T)); }
#089 };
```

用例：

```
template <class T, class Alloc = alloc>
class vector {
protected:
  // 專屬之分配器，每次分配一個元素大小
  typedef simple_alloc<T, Alloc>
                data_allocator;

  result = data_allocator::allocate(); //分配1個元素空間
  ...
  data_allocator::deallocate(result);
```

G2.9 std::alloc 源碼剖析, 4

```
#098 //本例兩個template參數完全沒派上用場
#099 template <bool threads, int inst>
#100 class __default_alloc_template {
#101 private:
#102   //實際上應使用 static const int x = N
#103   //取代 #094~#096 的 enum { x = N }, 但目前支援該性質的編譯器不多
#104
#105   static size_t ROUND_UP(size_t bytes) {
#106     return (((bytes) + __ALIGN-1) & ~(__ALIGN - 1));
#107   }
#108
#109 private:
#110   union obj { //type definition
#111     union obj* free_list_link;
#112   }; //改用 struct 亦可
#113
#114 private:
#115   static obj* volatile free_list[__NFREELISTS];
#116   static size_t FREELIST_INDEX(size_t bytes) {
#117     return (((bytes) + __ALIGN-1)/__ALIGN - 1);
#118   }
#119
#120   //  Returns an object of size n, and optionally adds to size n free list.
#121   static void *refill(size_t n);
#122
#123   // Allocates a chunk for nobjs of size "size".  nobjs may be reduced
#124   // if it is inconvenient to allocate the requested number.
#125   static char* chunk_alloc(size_t size, int &nobjs);
#126
#127   // Chunk allocation state.
#128   static char*  start_free; //指向'pool'的頭
#129   static char*  end_free;   //指向'pool'的尾
#130   static size_t heap_size;  //分配累計量
```



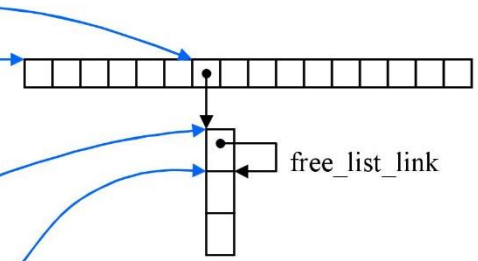
若bytes爲13，則(13+7) & ~(7)
即 10100 & 11000，得 10000即 16

```
#090 //-------------------------------------------------
#091 //第二級分配器
#092 //-------------------------------------------------
#094 enum {__ALIGN = 8};          //小區塊的上調邊界
#095 enum {__MAX_BYTES = 128};    //小區塊的上限
#096 enum {__NFREELISTS = __MAX_BYTES/__ALIGN}; //free-list個數
```

若bytes爲8，則(8+7)/8-1 = 0
若bytes爲16，則(16+7)/8-1 = 1
若bytes爲20，則(20+7)/8-1 = 2
若bytes爲24，則(24+7)/8-1 = 2

G2.9 std::alloc 源碼剖析, 5

```
#132 public:
#133
#134   static void* allocate(size_t n)   //n must be > 0
#135   {
#136     obj* volatile *my_free_list;    //obj**
#137     obj* result;
#138
#139     if (n > (size_t)__MAX_BYTES) { //改用第一級
#140         return(malloc_alloc::allocate(n));
#141     }
#142
#143     my_free_list = free_list + FREELIST_INDEX(n);
#144     result = *my_free_list;
#145     if (result == 0) { //list爲空
#146         void* r = refill(ROUND_UP(n)); //把注之
#147         return r;
#148     } //若往下進行表示list內已有可用區塊
#149     *my_free_list =
#150       result->free_list_link;
#151     return (result);
#152   }
```



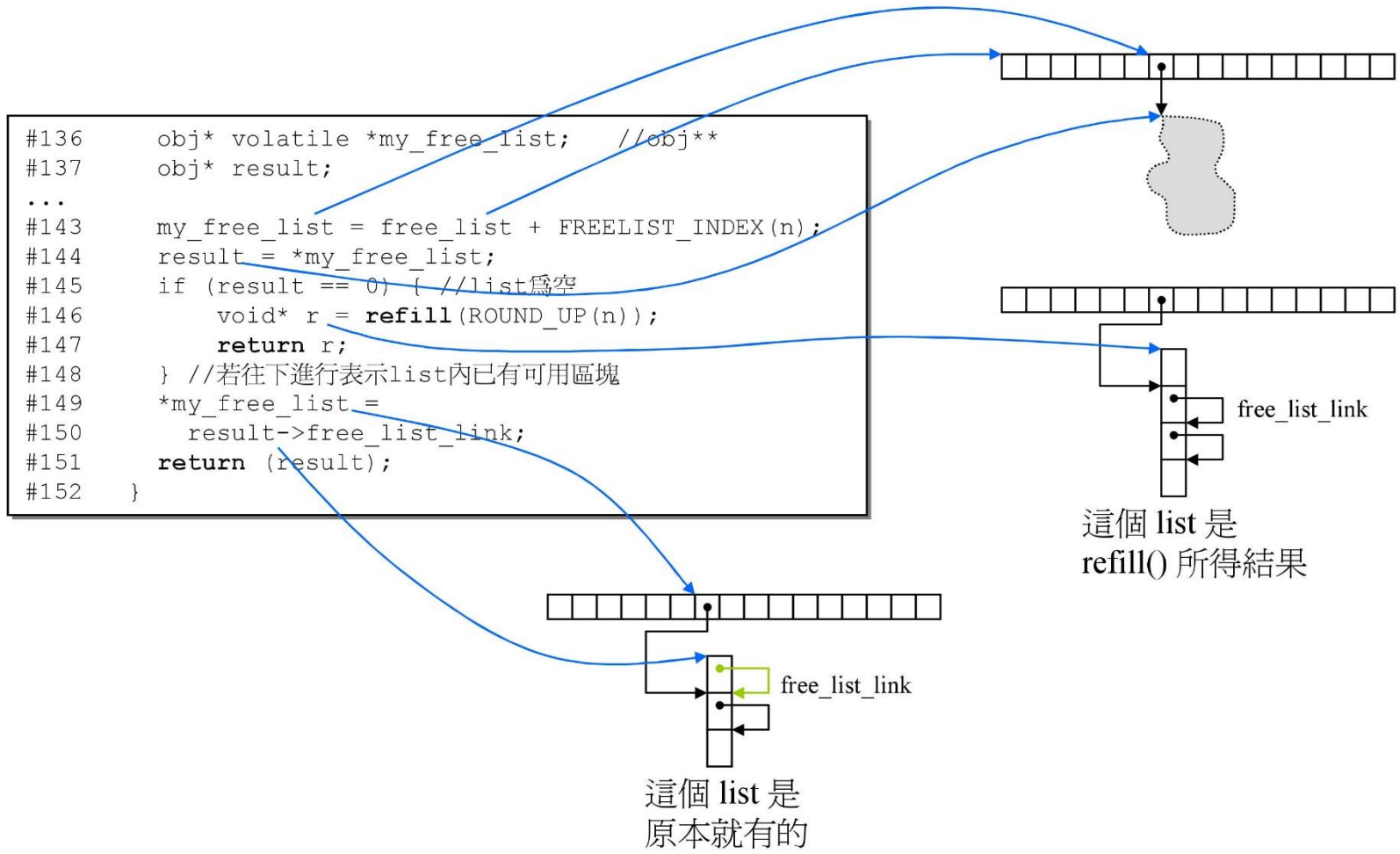
如果這 p 並非當初從 **alloc** 取得，仍可併入 **alloc** 內 (這不好).
如果 p 所指大小不是 8 倍數，甚至會帶來災難

```
#154   static void deallocate(void* p, size_t n)  //p 不爲 0
#155   {
#156     obj* q = (obj*)p;
#157     obj* volatile *my_free_list; //obj**
#158
#159     if (n > (size_t) __MAX_BYTES) {
#160         malloc_alloc::deallocate(p, n); //改用第一級
#161         return;
#162     }
#163     my_free_list = free_list + FREELIST_INDEX(n);
#164     q->free_list_link = *my_free_list;
#165     *my_free_list = q;
#166   }
#167
#168   static void * reallocate(void* p, size_t old_sz,
#169                            size_t new_sz);   //此處略列
#170 };
```

refill() 會充填 free list 並返回一個（其實就是第一個）區塊的起始地址

G2.9 std::alloc 源碼剖析, 5

```
#136     obj* volatile *my_free_list;   //obj**
#137     obj* result;
...
#143     my_free_list = free_list + FREELIST_INDEX(n);
#144     result = *my_free_list;
#145     if (result == 0) { //list爲空
#146         void* r = refill(ROUND_UP(n));
#147         return r;
#148     } //若往下進行表示list內已有可用區塊
#149     *my_free_list =
#150       result->free_list_link;
#151     return (result);
#152   }
```

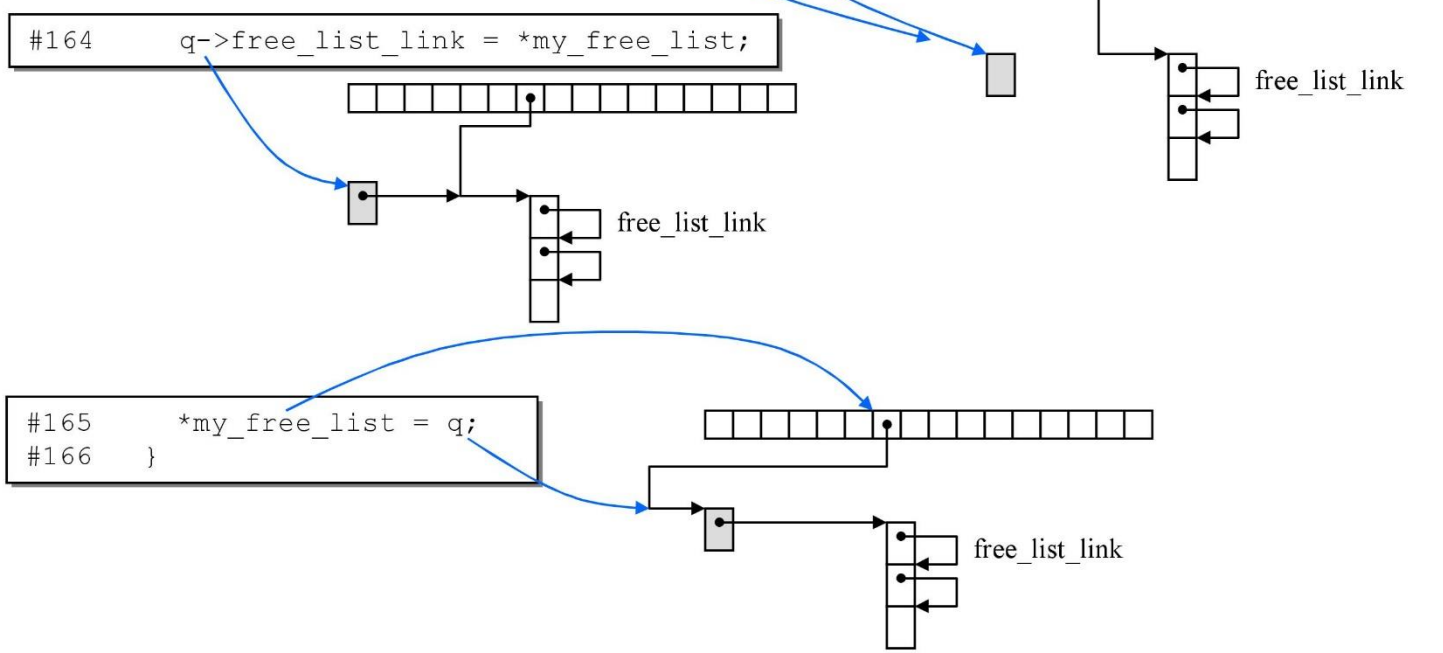


G2.9 std::alloc 源碼剖析, 5

```
#154   static void deallocate(void* p, size_t n)  //p 不爲 0
#155   {
#156     obj* q = (obj*)p;
#157     obj* volatile *my_free_list; //obj**
...
#163     my_free_list = free_list + FREELIST_INDEX(n);
```

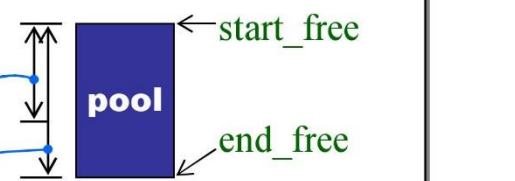
```
#164     q->free_list_link = *my_free_list;
```

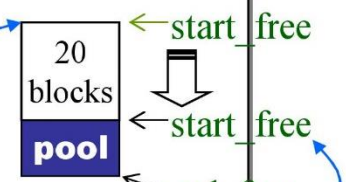
```
#165     *my_free_list = q;
#166   }
```



G2.9 std::alloc 源碼剖析, 6

```
#172 // ------------------------------------------------
#173 // We allocate memory in large chunks in order to avoid fragmenting the
#174 // malloc heap too much. We assume that size is properly aligned.
#175 // We hold the allocation lock.
#176 //------------------------------------------------
#177 template <bool threads, int inst>
#178 char*
#179 __default_alloc_template<threads, inst>::
#180 chunk_alloc(size_t size, int& nobjs)
#181 {
#182   char* result;
#183   size_t total_bytes = size * nobjs;
#184   size_t bytes_left = end_free - start_free;
#185
#186   if (bytes_left >= total_bytes) { //pool空間足以滿足20塊需求
#187       result = start_free;
#188       start_free += total_bytes;    //調整(降低)pool水位
#189       return(result);
#190   } else if (bytes_left >= size) { //pool空間只足以滿足一塊（含）以上需求
#191       nobjs = bytes_left / size;    //改變需求數（注意nobjs是pass-by-reference）
#192       total_bytes = size * nobjs;   //改變需求總量(bytes)
#193       result = start_free;
#194       start_free += total_bytes;    //調整(降低) pool 水位
#195       return(result);
#196   } else {                          //pool空間不足以滿足一塊需求
#197       size_t bytes_to_get =         //現在打算從system free-store取這麼多來挹注
#198             2 * total_bytes + ROUND_UP(heap_size >> 4);
#199       //首先嘗試將 pool 做充份運用
#200       if (bytes_left > 0) {                 //如果pool還有空間，
#201           obj* volatile *my_free_list =     //找出應移轉至第#號free-list（區塊儘可能大）
#202                   free_list + FREELIST_INDEX(bytes_left);
#203           //將pool空間編入第#號free-list（肯定只成1區塊）
#204           ((obj*)start_free)->free_list_link = *my_free_list;
#205           *my_free_list = (obj*)start_free;
#206       }
```





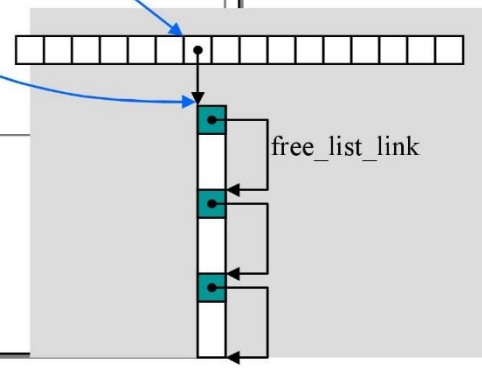
G2.9 std::alloc 源碼剖析, 7

```
#207        start_free = (char*)malloc(bytes_to_get); //從system free-store取這麼多,注入pool
#208        if (0 == start_free) {                    //失敗！以下試從free-list找區塊
#209            int i;
#210            obj* volatile *my_free_list, *p;
#211
#212            //Try to make do with what we have. That can't hurt.
#213            //We do not try smaller requests, since that tends
#214            //to result in disaster on multi-process machines.
#215            for (i = size; i <= __MAX_BYTES; i += __ALIGN) { //例88,96,104,112...
#216                my_free_list = free_list + FREELIST_INDEX(i);
#217                p = *my_free_list;
#218                if (0 != p) {  //該free-list內有可用區塊，以下釋出一塊(only)給pool
#219                    *my_free_list = p -> free_list_link;
#220                    start_free = (char*)p;
#221                    end_free = start_free + i;
#222                    return(chunk_alloc(size, nobjs)); //遞歸再試一次
#223                      //此時的pool定夠供應至少一個區塊
#224                      //而任何殘餘零頭終將被編入適當free-list
#225                }
#226            }
#227            end_free = 0;     //至此，表示 memory 已山窮水盡.
#228                              //改用第一級，看看 oom-handler 能否盡點力
#229            start_free = (char*)malloc_alloc::allocate(bytes_to_get);
#230              //這會導致拋出異常，或導致memory不足的情況得到改善
#231        }
#232        //至此，表示已從system free-store成功取得很多 memory
#233        heap_size += bytes_to_get;                //累計總分配量
#234        end_free = start_free + bytes_to_get;     //挹注pool(調整尾端)
#235        return(chunk_alloc(size, nobjs));         //遞歸再試一次
#236    }
#237 }
```

p易讓人誤解,實爲
obj** my_free_list;
obj* p;

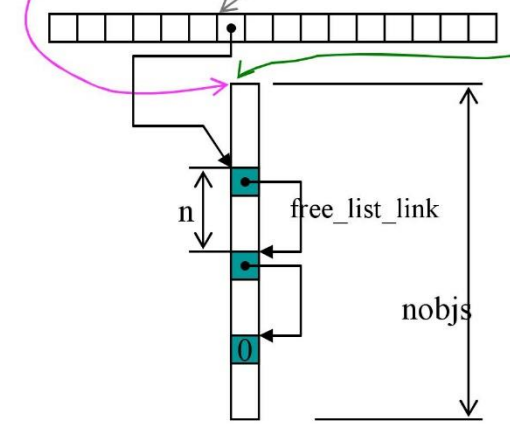
i 從 size + __ALIGN
開始迭代更佳.

把free-list內的目前第一塊當成pool



G2.9 std::alloc 源碼剖析, 8

```
#240 // Returns an object of size n, and optionally adds to size n free list.
#241 // We assume that n is properly aligned. We hold the allocation lock.
#242 //------------------------------------------------
#243 template <bool threads, int inst>
#244 void* __default_alloc_template<threads, inst>::
#245 refill(size_t n)  //n 已調整至 8 的倍數
#246 {
#247     int nobjs = 20;  //預設取 20 個區塊（但不一定能夠）
#248     char* chunk = chunk_alloc(n,nobjs); //nobjs 是 pass-by-reference
#249     obj* volatile *my_free_list;   //obj**
#250     obj* result;
#251     obj* current_obj;
#252     obj* next_obj;
#253     int i;
#254
```




```
#255     if (1 == nobjs) return(chunk); //實際得1，交給客戶
#256     //以下開始將所得區塊掛上 free-list
#257     my_free_list = free_list + FREELIST_INDEX(n);
#258     //在 chunk 內建立 free list
#259     result = (obj*)chunk;
#260     *my_free_list = next_obj = (obj*)(chunk + n);
#261     for (i=1;  ; ++i) {
#262       current_obj = next_obj;
#263       next_obj = (obj*)((char*)next_obj + n);
#264       if (nobjs-1 == i) { //最後一個
#265           current_obj->free_list_link = 0;
#266           break;
#267       } else {
#268           current_obj->free_list_link = next_obj;
#269       }
#270     }
#271     return(result);
#272 }
```

所謂切割就是把指針所指處轉型爲obj，再取其 next_obj 指針繼續行事，一而再三...

G2.9 std::alloc 源碼剖析, 9

```
#273 //------------------------------------------------
#274 template <bool threads, int inst>
#275 char *__default_alloc_template<threads,inst>::start_free = 0;
#276
#277 template <bool threads, int inst>
#278 char *__default_alloc_template<threads,inst>::end_free = 0;
#279
#280 template <bool threads, int inst>
#281 size_t __default_alloc_template<threads,inst>::heap_size = 0;
#282
#283 template <bool threads, int inst>
#284 __default_alloc_template<threads, inst>::obj* volatile
#285 __default_alloc_template<threads, inst>::free_list[__NFREELISTS]
#286      = {0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0 };
#287 //------------------------------------------------
#288
#289 //令第2級分配器的名稱爲 alloc
#290 typedef __default_alloc_template<false,0> alloc;
```

G2.9 std::alloc 觀念大整理

```
list<Foo> c;  //假設 sizeof(Foo)+(4*2) <= 128
c.push_back( Foo(1) );
```

Foo(1)在栈上；c.push_back(Foo(1))copy到堆上

這一塊是通過 **alloc** 取得，
不帶cookie

~~c.push_back(new Foo(2)); //錯誤（元素型別不符）~~

```
Foo* p = new Foo(2);
c.push_back( *p );
```

這一塊是通過 **alloc** 取得，
不帶cookie

```
delete p;
```

G2.9 std::alloc 批鬥大會

```
#136    obj* volatile *my_free_list;
#210        obj* volatile *my_free_list, *p;
```

0写在==左边，好的style，若这样写，==写成=，编译器会通不过，which is good

```
#208        if (0 == start_free) {
#218            if (0 != p) {
#255    if (1 == nobjs) return(chunk);
```

```
    obj* *p1, *p2;
➔ obj** p1, *p2;
➔ obj **p1, *p2; ➔ obj** p1; obj* p2;
➔ obj **p1, **p2;
➔ obj** p1; obj** p2;
```

```
#197        size_t bytes_to_get =
                …
#207        start_free = (char*)malloc(bytes_to_get);
```

typedef void (*new_handler)();
new_handler set_new_handler(new_handler p) throw();

|||

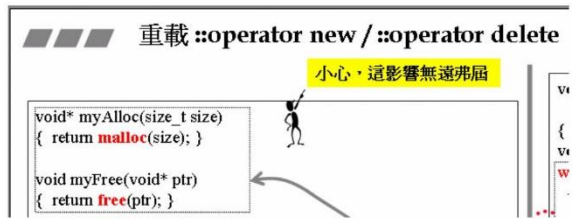
```
#034  static void (*set_malloc_handler(void (*f)()))()
```

```
typedef void (*H)();
static H set_malloc_handler(H f);
```

```
#212        //Try to make do with what we have. That can't hurt.
#213        //We do not try smaller requests, since that tends
#214        //to result in disaster on multi-process machines.
```

deallocate() 完全沒有調用 free() or delete
(源於其設計上的先天缺陷)

G4.9 pool allocator 運行觀察




```
//我要一個可累計總分配量和總釋放量的 operator new/delete.
//除非 user 直接使用 malloc/free,
//否則都避不開它們, 這就可以累計總量.
static long long countNew = 0;
static long long timesNew = 0;

//小心，這影響無遠弗屆
//它們不可被聲明於 namespace 內
inline void* operator new(size_t size)  {
    //cout << "jjhou global new(), \t" << size << "\t";
    countNew += size;
    ++timesNew;
    return myAlloc( size );
}

inline void* operator new[](size_t size) {
    cout << "jjhou global new[](), \t" << size << "\t";
    return myAlloc( size );
}
 … 續右
```

```
void* myAlloc(size_t size)
{  return malloc(size); }
void myFree(void* ptr)
{  return free(ptr); }
```

```
… 接左
//天啊, 以下(1)(2)可並存並由(2)抓住流程 (但它對我這兒測試無用).
//若只存在 (1), 抓不住流程. 爲什麼？
//在 class members 中必須二擇一 (任一均可), 否則編譯報錯.
inline void  operator delete(void* ptr, size_t size) { //(1)
    myFree( ptr );
}
inline void  operator delete(void* ptr) { //(2)
    myFree( ptr );
}
inline void  operator delete[](void* ptr, size_t size) {  //(1)
    myFree( ptr );
}
inline void  operator delete[](void* ptr) {  //(2)
    myFree( ptr );
}
```

G4.9 pool allocator 運行觀察

Q: 我能不能觀察到 malloc() 真正分配出去的總量 (含所有 overhead)？

A: 不能; 除非…

```
//C++/11 alias template
template <typename T>
using listPool = list<T, __gnu_cxx::__pool_alloc<T>>;

//reset countNew
countNew = 0;
timesNew = 0;

listPool<double> lst;
for (int i=0; i< 1000000; ++i)
      lst.push_back(i);
cout << "::countNew= " << ::countNew << endl;
                    //16752832 (注意, node 都不帶 cookie)
cout << "::timesNew= " << ::timesNew << endl;  //122
```

```
list<double, __gnu_cxx::__pool_alloc<double>> lst;
```

```
//reset countNew
countNew = 0;
timesNew = 0;

list<double> lst;
for (int i=0; i< 1000000; ++i)
      lst.push_back(i);
cout << "::countNew= " << ::countNew << endl;
                    //16000000 (注意, node 都帶 cookie)
cout << "::timesNew= " << ::timesNew << endl;  //1000000
```

G2.9 std::alloc 移植至 C

std:alloc 整個由 static data members 和 static member functinos 構成，整體只一個 class 而無分枝，因此移植至 C 很容易。需注意：

```
chunk_alloc(size_t size, int& nobjs);
```

pass by reference 移至 C 時或需改爲 pass by pointer.

移植步驟

- 去除 templates
- 將 union obj 移至 _default_alloc_template class 外部獨立
- 將所有 static data 移爲 global
- 將 __malloc_alloc 改名爲 malloc_alloc, 將 __default_alloc 改名爲 **alloc**
- 將 malloc_alloc 的所有 static functions 移爲 global
- 將 alloc 的所有 static functions 移爲 global
- 將 .cpp 改爲 .c，將上述 pass by reference 改爲 pass by pointer，再將：

```
union obj {
    union obj* free_list_link;
};
```

⇒

```
typedef union __obj {
        union __obj* free_list_link;
} obj;
```

或：

```
typedef struct __obj {
        struct __obj* free_list_link;
} obj;
```

The End

內存管理

從平地到萬丈高樓

Memory Management 101

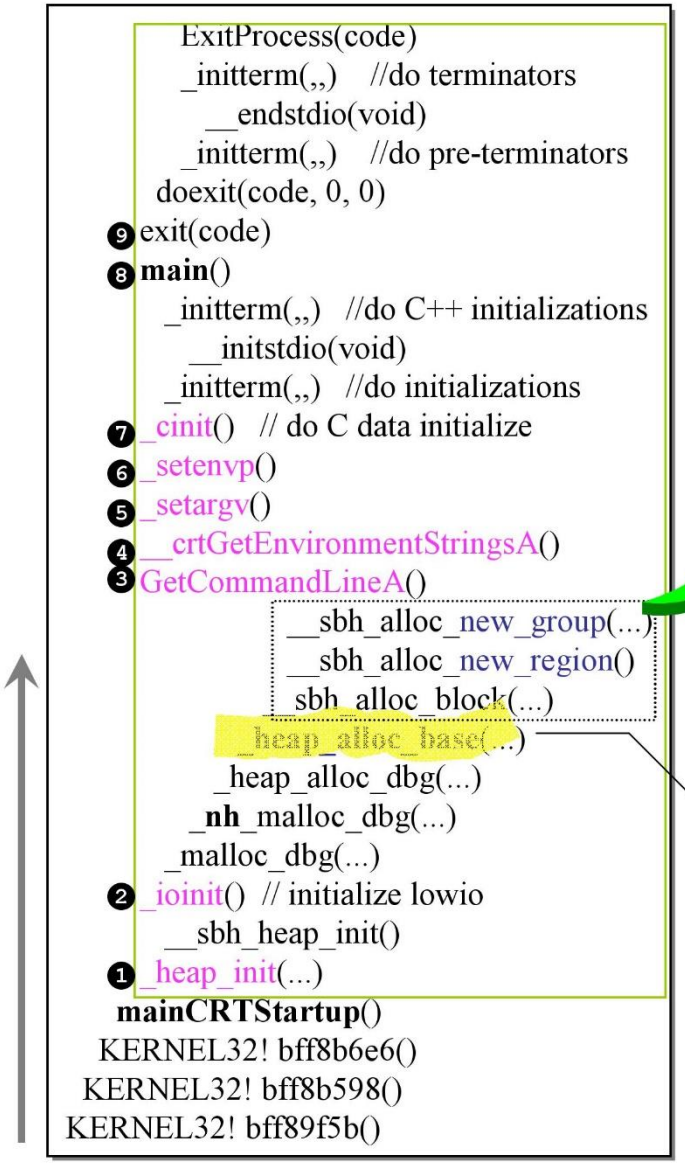
第一講 primitives
第二講 std::allocator
第三講 malloc/free
第四講 loki::allocator
第五講 other issues

侯捷

胸中自有丘壑

觸類旁通

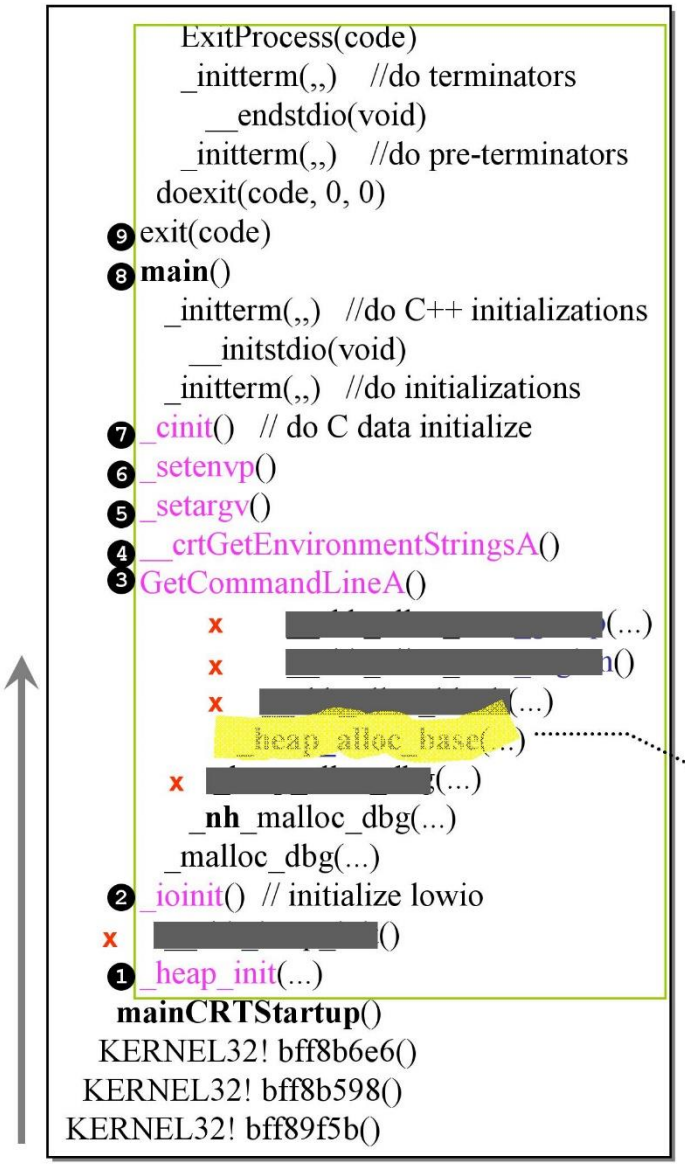
VC6 内存分配



SBH: Small **B**lock **H**eap

```
if (size <= __sbh_threshold) {     //3F8, i.e. 1016
    pvReturn = __sbh_alloc_block(size);
    if (pvReturn)  return pvReturn;
}
if (size == 0)  size = 1;
size = (size + ...) & ~(...);
return HeapAlloc(_crtheap, 0, size);
```

VC10 內存分配




```
24  #ifdef _DEBUG
25  #define _heap_alloc _heap_alloc_base
26  #endif  /* _DEBUG */
27
28  /***
29  *void *_heap_alloc_base(size_t size) - does actual allocation
30  *
31  *Purpose:
32  *       Same as malloc() except the new handler is not called.
33  *
34  *Entry:
35  *       See malloc
36  *
37  *Exit:
38  *       See malloc
39  *
40  *Exceptions:
41  *
42  *******************************************************************************
43
44  __forceinline void * __cdecl _heap_alloc (size_t size)
45
46  {
47
48      if (_crtheap == 0) {
49          _FF_MSGBANNER();    /* write run-time error banner */
50          _NMSG_WRITE(_RT_CRT_NOTINIT);  /* write message */
51          __crtExitProcess(255);  /* normally _exit(255) */
52      }
53
54      return HeapAlloc(_crtheap, 0, size ? size : 1);
55  }
```

所有內存管理機制都繼續存在，只不過，深埋到 O.S. 層面去了 (詳見 Windows Heap 課程)

SBH 之始 – _heap_init() 和 __sbh_heap_init()

CRT 會先爲自己建立一個 _crtheap，然後從中配置 SBH 所需的 headers, regions 做爲管理之用。App. 動態配置時若 size > threshold 就以 HeapAlloc() 從 _crtheap 取。若 size <= threshold 就從 SBH 取 (實際區塊來自 VirtualAlloc())

heapinit.c

```
int __cdecl _heap_init (
        int mtflag
        )
{
        // Initialize the "big-block" heap first.
        if ( (_crtheap = HeapCreate( mtflag ? 0 : HEAP_NO_SERIALIZE,
                                     BYTES_PER_PAGE, 0 )) == NULL )
            return 0;

        // Initialize the small-block heap
        if (__sbh_heap_init() == 0)
        {
            HeapDestroy(_crtheap);
            return 0;
        }
        return 1;
}
```

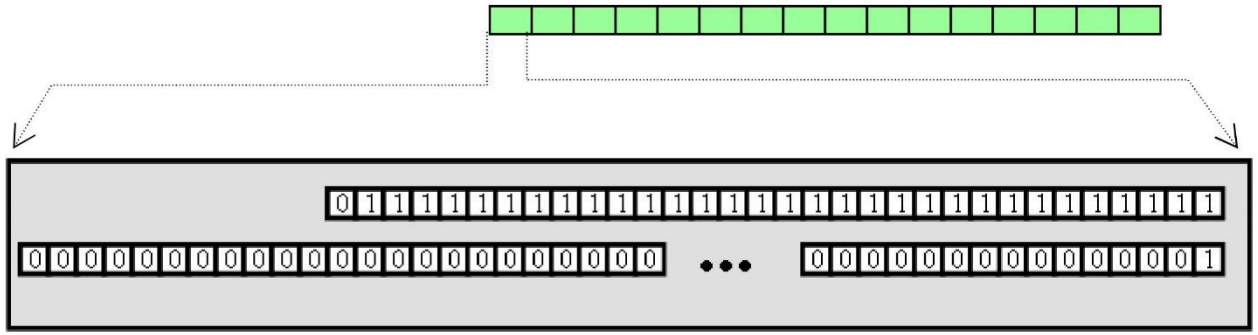
4096

不論 big-block heap or small-block heap，
只要失敗就 return 0，
別玩了。

sbheap.c

```
int __cdecl __sbh_heap_init (void)
{
    if (!(__sbh_pHeaderList =
            HeapAlloc(_crtheap, 0, 16 * sizeof(HEADER))))
        return FALSE;

    __sbh_pHeaderScan = __sbh_pHeaderList;
    __sbh_pHeaderDefer = NULL;
    __sbh_cntHeaderList = 0;
    __sbh_sizeHeaderList = 16;

    return TRUE;
}
```

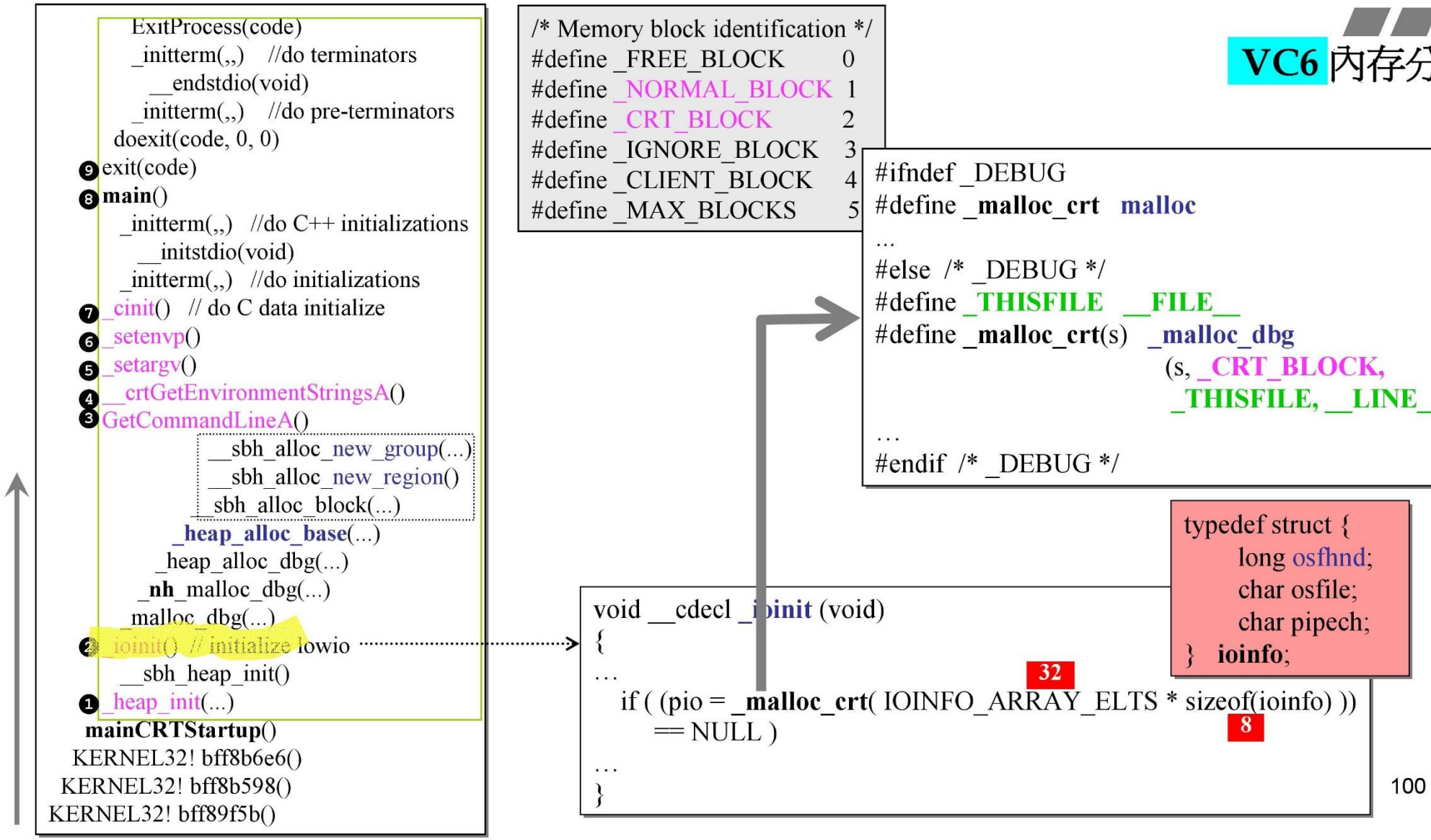
SBH 之始 – _heap_init() 和 __sbh_heap_init()




```
typedef unsigned int    BITVEC;
```

```
typedef struct tagHeader
{
   BITVEC              bitvEntryHi;
   BITVEC              bitvEntryLo;
   BITVEC              bitvCommit;
   void *              pHeapData;
   struct tagRegion *  pRegion;
}
HEADER, *PHEADER;
```

VC6 内存分配

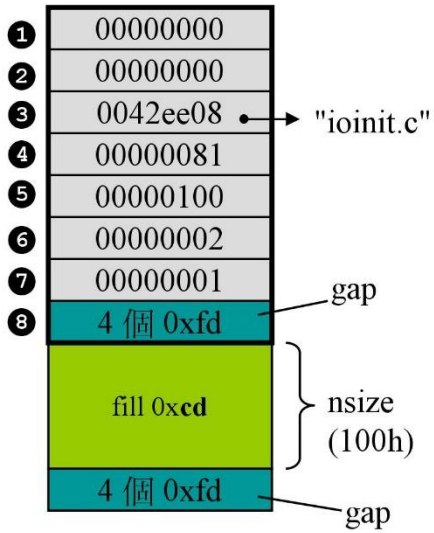

ExitProcess(code)
_initterm(,,) //do terminators
__endstdio(void)
_initterm(,,) //do pre-terminators
doexit(code, 0, 0)
9 exit(code)
8 main()
_initterm(,,) //do C++ initializations
__initstdio(void)
_initterm(,,) //do initializations
7 _cinit() // do C data initialize
6 _setenvp()
5 _setargv()
4 __crtGetEnvironmentStringsA()
3 GetCommandLineA()
__sbh_alloc_new_group(...)
__sbh_alloc_new_region()
__sbh_alloc_block(...)
_heap_alloc_base(...)
_heap_alloc_dbg(...)
_nh_malloc_dbg(...)
_malloc_dbg(...)
2 _ioinit() // initialize lowio
__sbh_heap_init()
1 _heap_init(...)
mainCRTStartup()
KERNEL32! bff8b6e6()
KERNEL32! bff8b598()
KERNEL32! bff89f5b()
/* Memory block identification */
#define _FREE_BLOCK 0
#define _NORMAL_BLOCK 1
#define _CRT_BLOCK 2
#define _IGNORE_BLOCK 3
#define _CLIENT_BLOCK 4
#define _MAX_BLOCKS 5
#ifndef _DEBUG
#define _malloc_crt malloc
...
#else /* _DEBUG */
#define _THISFILE __FILE__
#define _malloc_crt(s) _malloc_dbg
(s, _CRT_BLOCK,
_THISFILE, __LINE__)
...
#endif /* _DEBUG */
typedef struct {
long osfhnd;
char osfile;
char pipech;
} ioinfo;
void __cdecl _ioinit (void)
{
...
if ((pio = _malloc_crt(IOINFO_ARRAY_ELTS * sizeof(ioinfo)))
== NULL)
...
}
32
8

VC6 內存分配

```
ExitProcess(code)
_initterm(,,)    //do terminators
  __endstdio(void)
_initterm(,,)    //do pre-terminators
doexit(code, 0, 0)
9 exit(code)
8 main()
  _initterm(,,)   //do C++ initializations
    __initstdio(void)
  _initterm(,,)   //do initializations
7 _cinit()   // do C data initialize
6 _setenvp()
5 _setargv()
4 __crtGetEnvironmentStringsA()
3 GetCommandLineA()
                    __sbh_alloc_new_group(...)
                    __sbh_alloc_new_region()
                  __sbh_alloc_block(...)
                _heap_alloc_base(...)
              _heap_alloc_dbg(...)
            _nh_malloc_dbg(...)
          _malloc_dbg(...)
2 _ioinit()  // initialize lowio
    __sbh_heap_init()
1 _heap_init(...)
  mainCRTStartup()
KERNEL32! bff8b6e6()
KERNEL32! bff8b598()
KERNEL32! bff89f5b()
```

```
#define nNoMansLandSize 4
typedef struct _CrtMemBlockHeader
{
    struct _CrtMemBlockHeader * pBlockHeaderNext;
    struct _CrtMemBlockHeader * pBlockHeaderPrev;
    char *                  szFileName;
    int                     nLine;
    size_t                  nDataSize;
    int                     nBlockUse;
    long                    lRequest;
    unsigned char           gap[nNoMansLandSize];
    /* followed by:
     *  unsigned char   data[nDataSize];
     *  unsigned char   anotherGap[nNoMansLandSize];
     */
} _CrtMemBlockHeader;
```

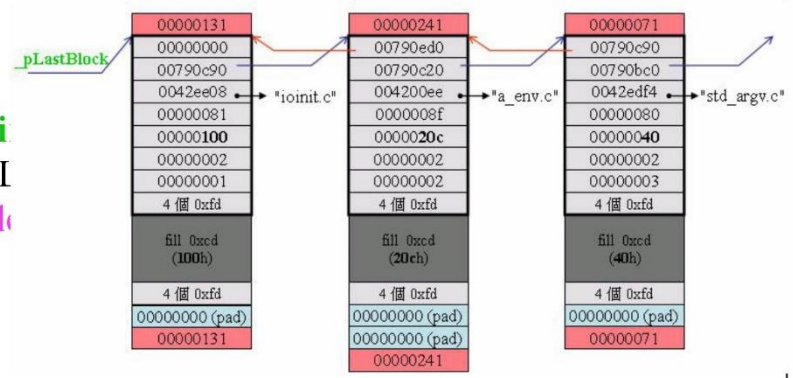
```
…
blockSize = sizeof(_CrtMemBlockHeader) + nSize + nNoMansLandSize;
…
pHead = (_CrtMemBlockHeader *)_heap_alloc_base(blockSize);
… (續下頁)
```



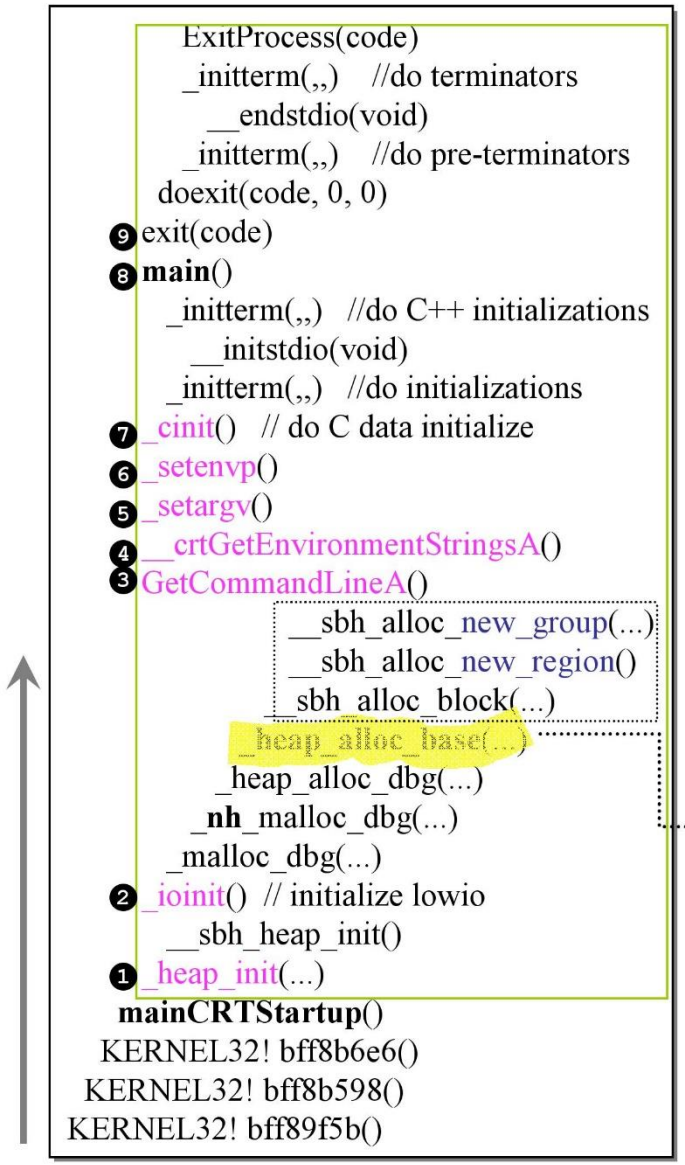
VC6 內存分配

```
ExitProcess(code)
  _initterm(,,)    //do terminators
    __endstdio(void)
  _initterm(,,)    //do pre-terminators
 doexit(code, 0, 0)
❾exit(code)
❽main()
  _initterm(,,)   //do C++ initializations
    __initstdio(void)
  _initterm(,,)   //do initializations
❼_cinit()   // do C data initialize
❻_setenvp()
❺_setargv()
❹__crtGetEnvironmentStringsA()
❸GetCommandLineA()
                    __sbh_alloc_new_group(...)
                    __sbh_alloc_new_region()
                   __sbh_alloc_block(...)
                 _heap_alloc_base(...)
                 _heap_alloc_dbg(...)
               _nh_malloc_dbg(...)
             _malloc_dbg(...)
❷_ioinit()  // initialize lowio
  __sbh_heap_init()
❶_heap_init(...)
 mainCRTStartup()
KERNEL32! bff8b6e6()
KERNEL32! bff8b598()
KERNEL32! bff89f5b()
```

```
… (承上頁)
if (_pFirstBlock)
    _pFirstBlock->pBlockHeaderPrev = pHead;
else
    _pLastBlock = pHead;

pHead->pBlockHeaderNext = _pFi
pHead->pBlockHeaderPrev = NULI
pHead->szFileName = (char *)szFil
pHead->nLine = nLine;
pHead->nDataSize = nSize;
pHead->nBlockUse = nBlockUse;
pHead->lRequest = lRequest;

/* link blocks together */
_pFirstBlock = pHead;

/* fill in gap before and after real block */
memset((void *)pHead->gap, _bNoMansLandFill, nNoMansLandSize);
memset((void *)(pbData(pHead) + nSize), _bNoMansLandFill, nNoMansLandSize);
/* fill data with silly value (but non-zero) */
memset((void *)pbData(pHead), _bCleanLandFill, nSize);
return (void *)pbData(pHead);
```

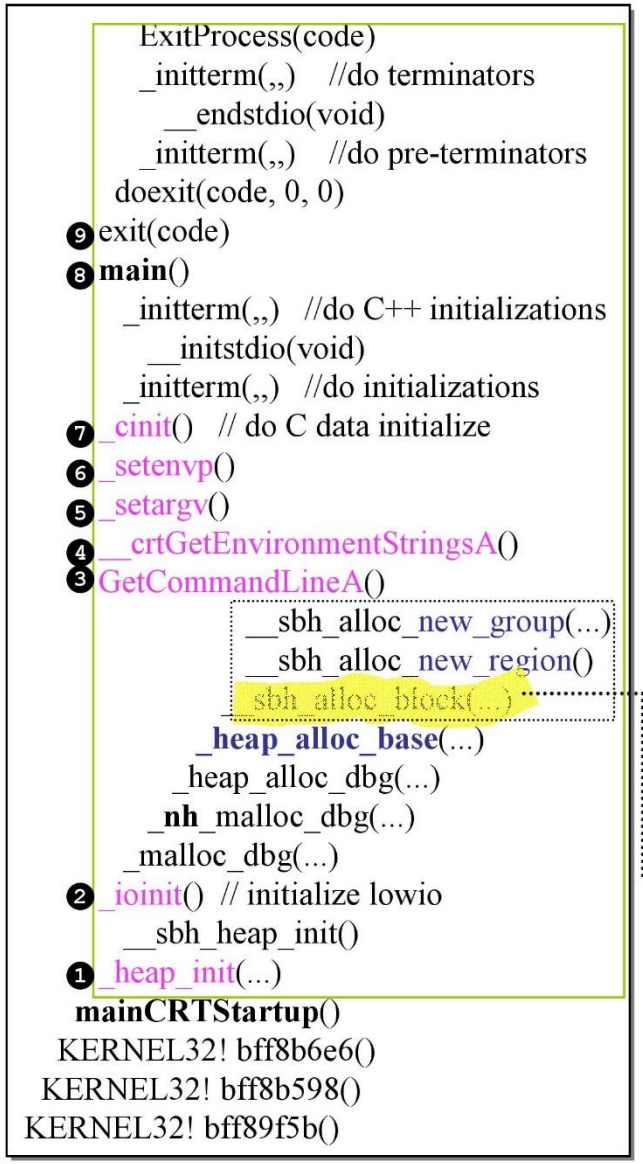



```
static unsigned char _bNoMansLandFill = 0xFD;
static unsigned char _bDeadLandFill   = 0xDD;
static unsigned char _bCleanLandFill  = 0xCD;

static _CrtMemBlockHeader * _pFirstBlock;
static _CrtMemBlockHeader * _pLastBlock;
```

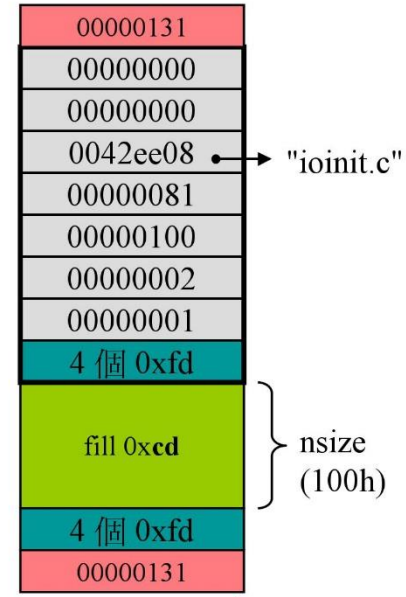



```
if (size <= __sbh_threshold) {     //3F8, i.e. 1016
    pvReturn = __sbh_alloc_block(size);
    if (pvReturn)  return pvReturn;
}
if (size == 0)  size = 1;
size = (size + ...) & ~(...);
return HeapAlloc(_crtheap, 0, size);
```

VC6 內存分配




```
// add 8 bytes entry overhead and round up to next para size
sizeEntry = (intSize + 2 * sizeof(int)      16
                    + (BYTES_PER_PARA - 1))
                    & ~(BYTES_PER_PARA - 1);
```



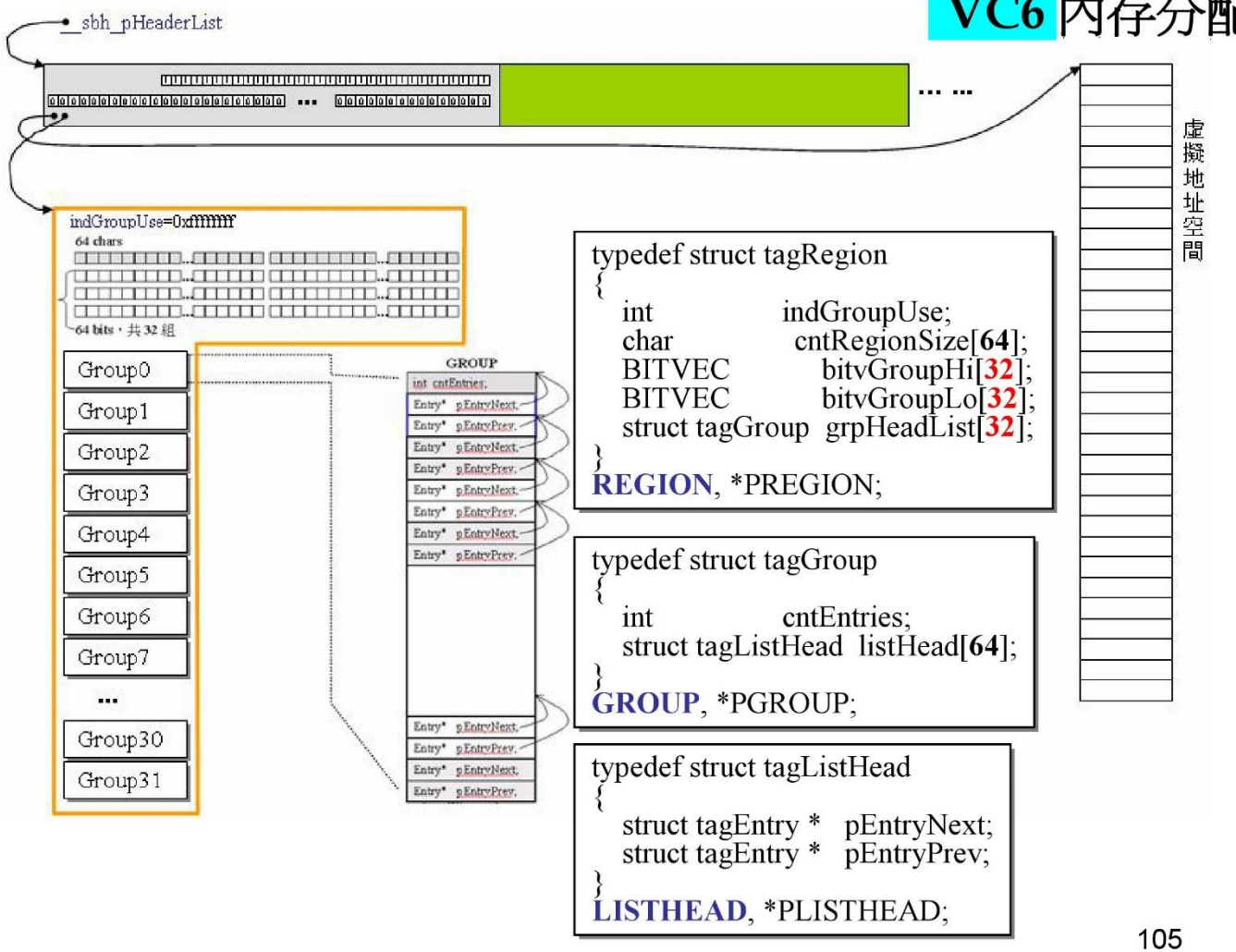
0x100 + 0x24 + 4*2

➔ 0x12C

➔ 0x130

VC6 內存分配

```
ExitProcess(code)
  _initterm(,,)    //do terminators
    __endstdio(void)
  _initterm(,,)    //do pre-terminators
 doexit(code, 0, 0)
❾exit(code)
❽main()
  _initterm(,,)   //do C++ initializations
    __initstdio(void)
  _initterm(,,)   //do initializations
❼_cinit()   // do C data initialize
❻_setenvp()
❺_setargv()
❹__crtGetEnvironmentStringsA()
❸GetCommandLineA()
          __sbh_alloc_new_group(...)
          __sbh_alloc_new_region()
        __sbh_alloc_block(...)
      _heap_alloc_base(...)
    _heap_alloc_dbg(...)
  _nh_malloc_dbg(...)
 _malloc_dbg(...)
❷_ioinit()  // initialize lowio
  __sbh_heap_init()
❶_heap_init(...)
 mainCRTStartup()
KERNEL32! bff8b6e6()
KERNEL32! bff8b598()
KERNEL32! bff89f5b()
```



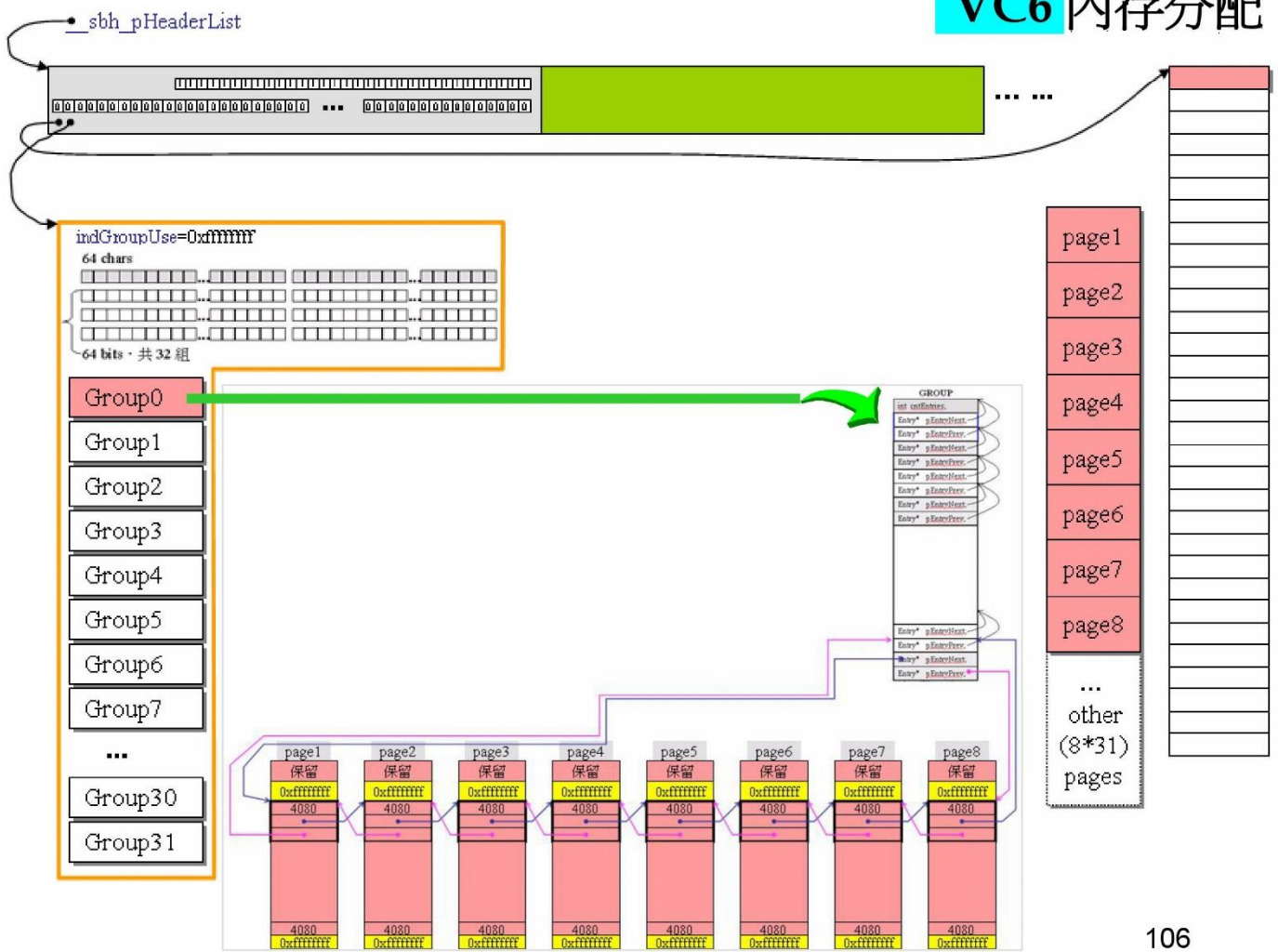

```
typedef struct tagRegion
{
    int             indGroupUse;
    char            cntRegionSize[64];
    BITVEC          bitvGroupHi[32];
    BITVEC          bitvGroupLo[32];
    struct tagGroup  grpHeadList[32];
}
REGION, *PREGION;
```

```
typedef struct tagGroup
{
    int             cntEntries;
    struct tagListHead  listHead[64];
}
GROUP, *PGROUP;
```

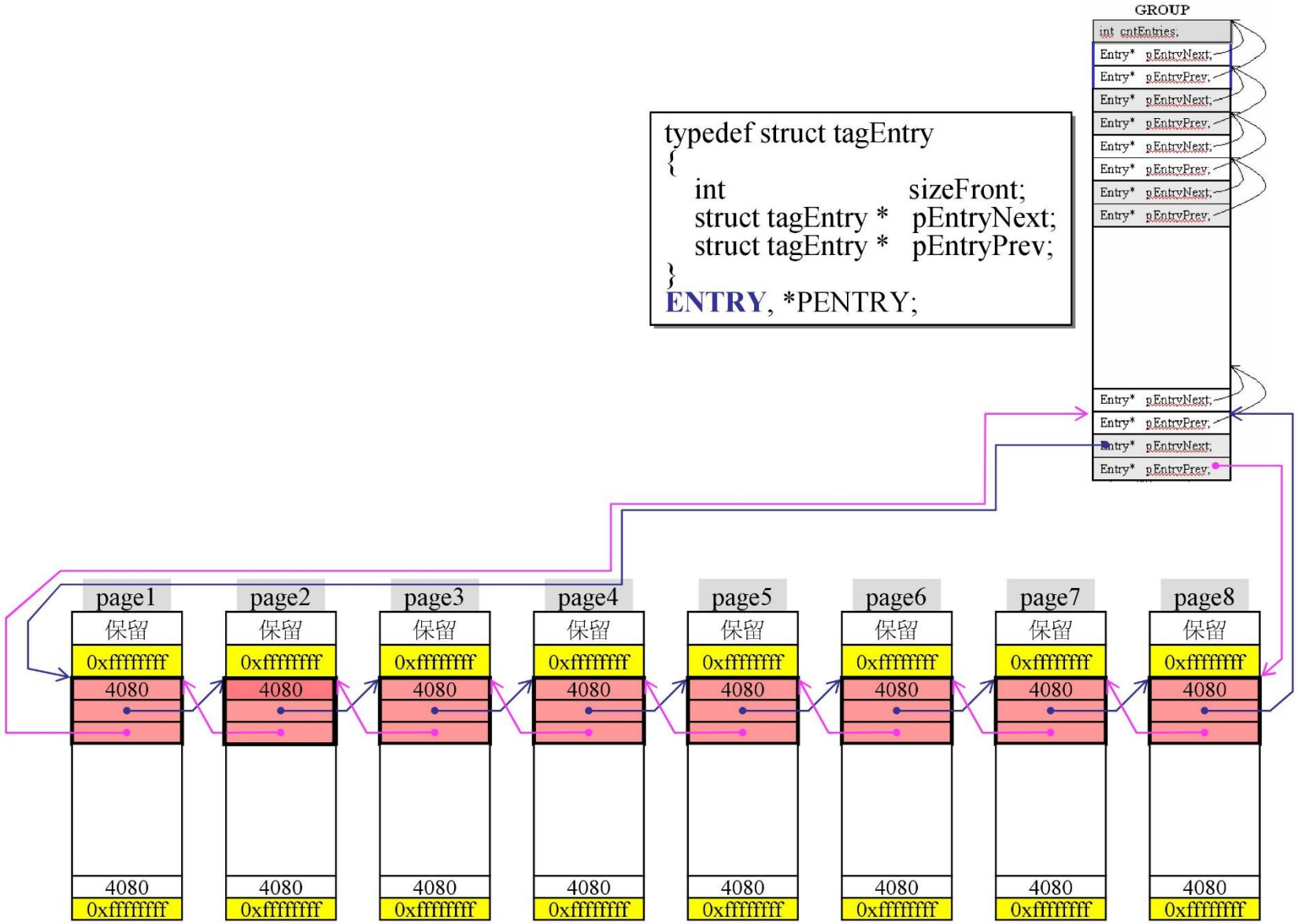
```
typedef struct tagListHead
{
    struct tagEntry *   pEntryNext;
    struct tagEntry *   pEntryPrev;
}
LISTHEAD, *PLISTHEAD;
```

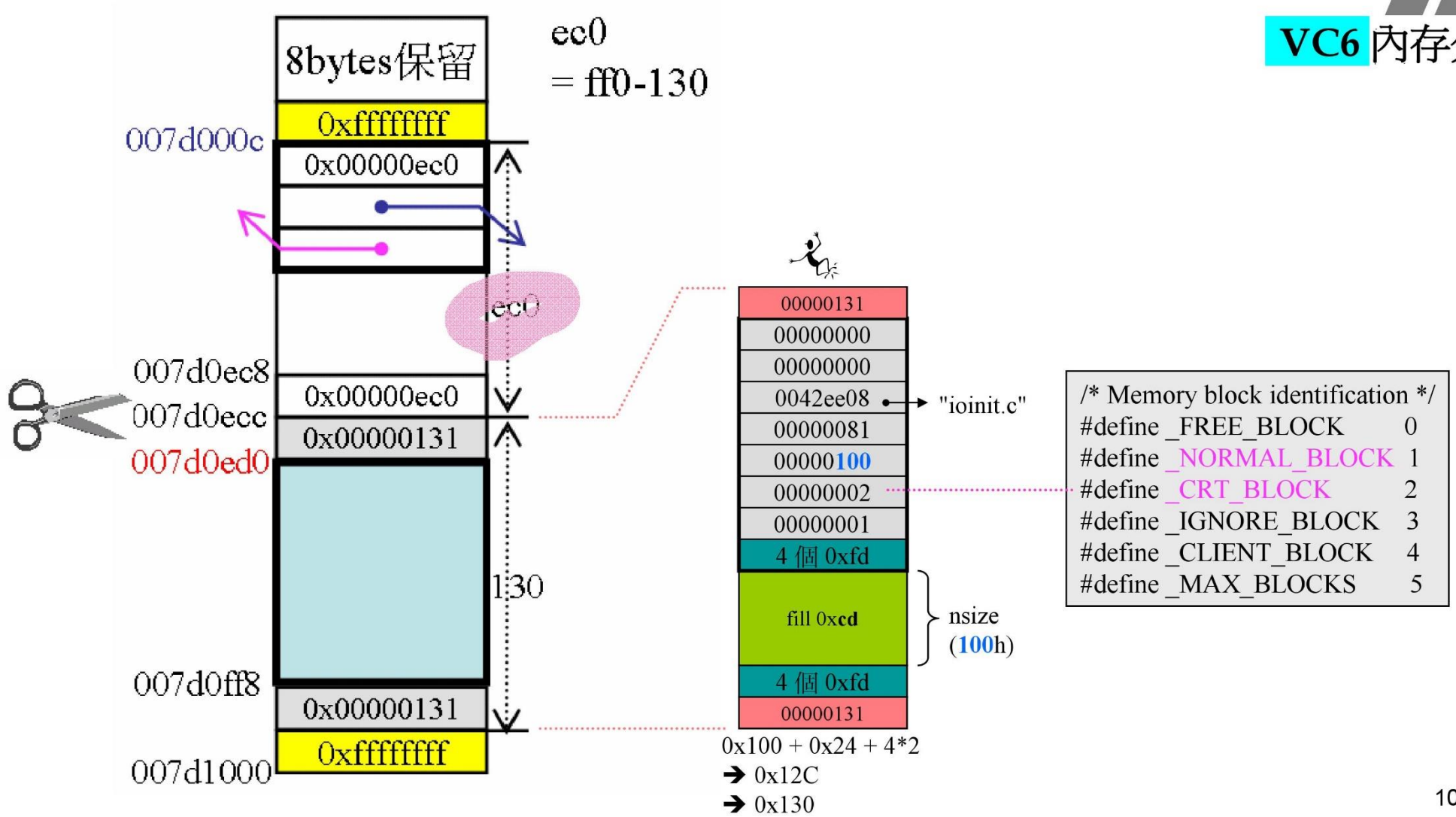
VC6 内存分配

```
ExitProcess(code)
  _initterm(,,)    //do terminators
    __endstdio(void)
  _initterm(,,)    //do pre-terminators
 doexit(code, 0, 0)
9 exit(code)
8 main()
  _initterm(,,)   //do C++ initializations
    __initstdio(void)
  _initterm(,,)   //do initializations
7 _cinit()   // do C data initialize
6 _setenvp()
5 _setargv()
4 __crtGetEnvironmentStringsA()
3 GetCommandLineA()
          __sbh_alloc_new_group(...)
          __sbh_alloc_new_region()
          __sbh_alloc_block(...)
        _heap_alloc_base(...)
       _heap_alloc_dbg(...)
      _nh_malloc_dbg(...)
    _malloc_dbg(...)
2 _ioinit()  // initialize lowio
    __sbh_heap_init()
1 _heap_init(...)
  mainCRTStartup()
KERNEL32! bff8b6e6()
KERNEL32! bff8b598()
KERNEL32! bff89f5b()
```



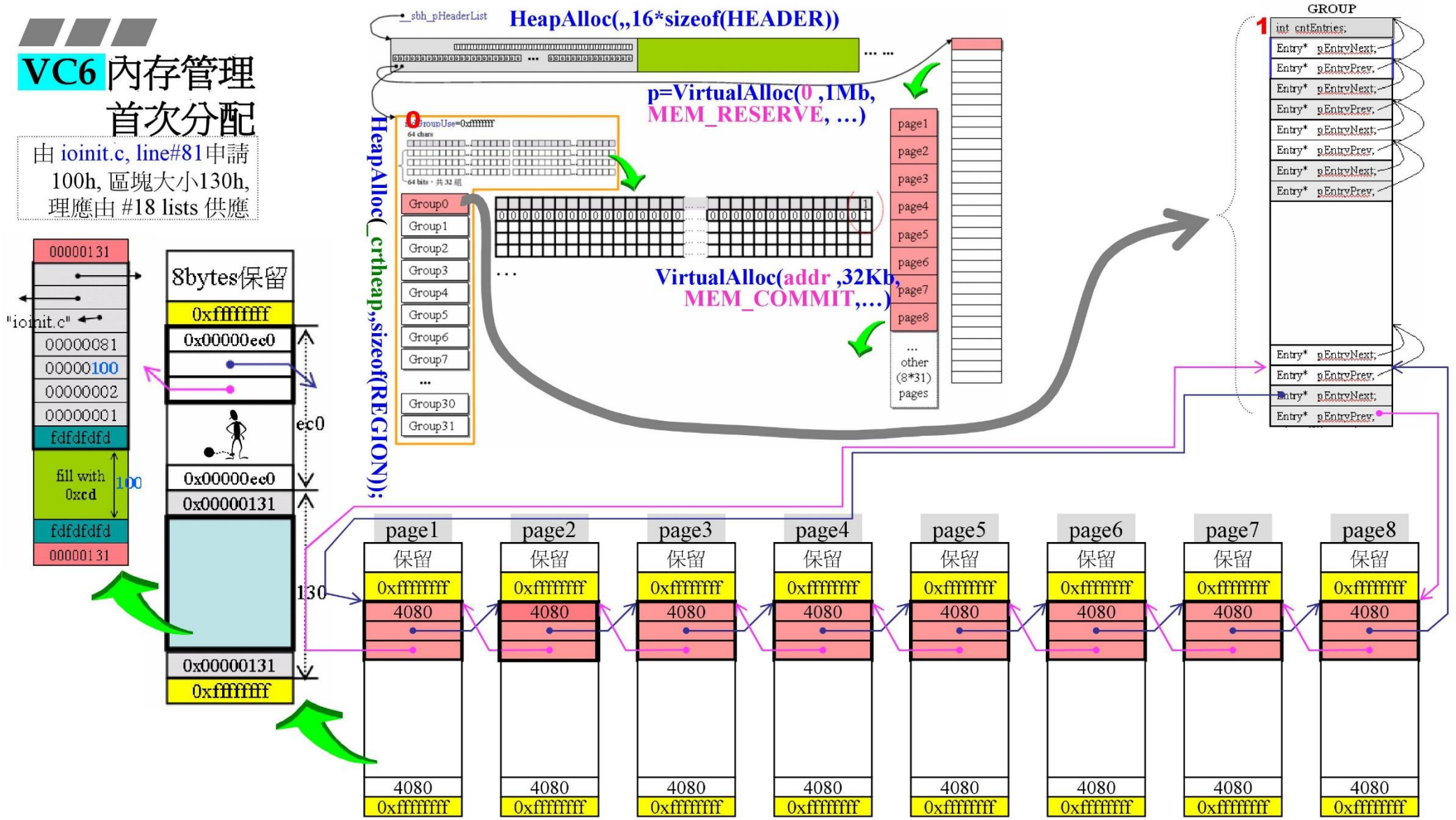
```
typedef struct tagEntry
{
    int                 sizeFront;
    struct tagEntry *   pEntryNext;
    struct tagEntry *   pEntryPrev;
}
ENTRY, *PENTRY;
```



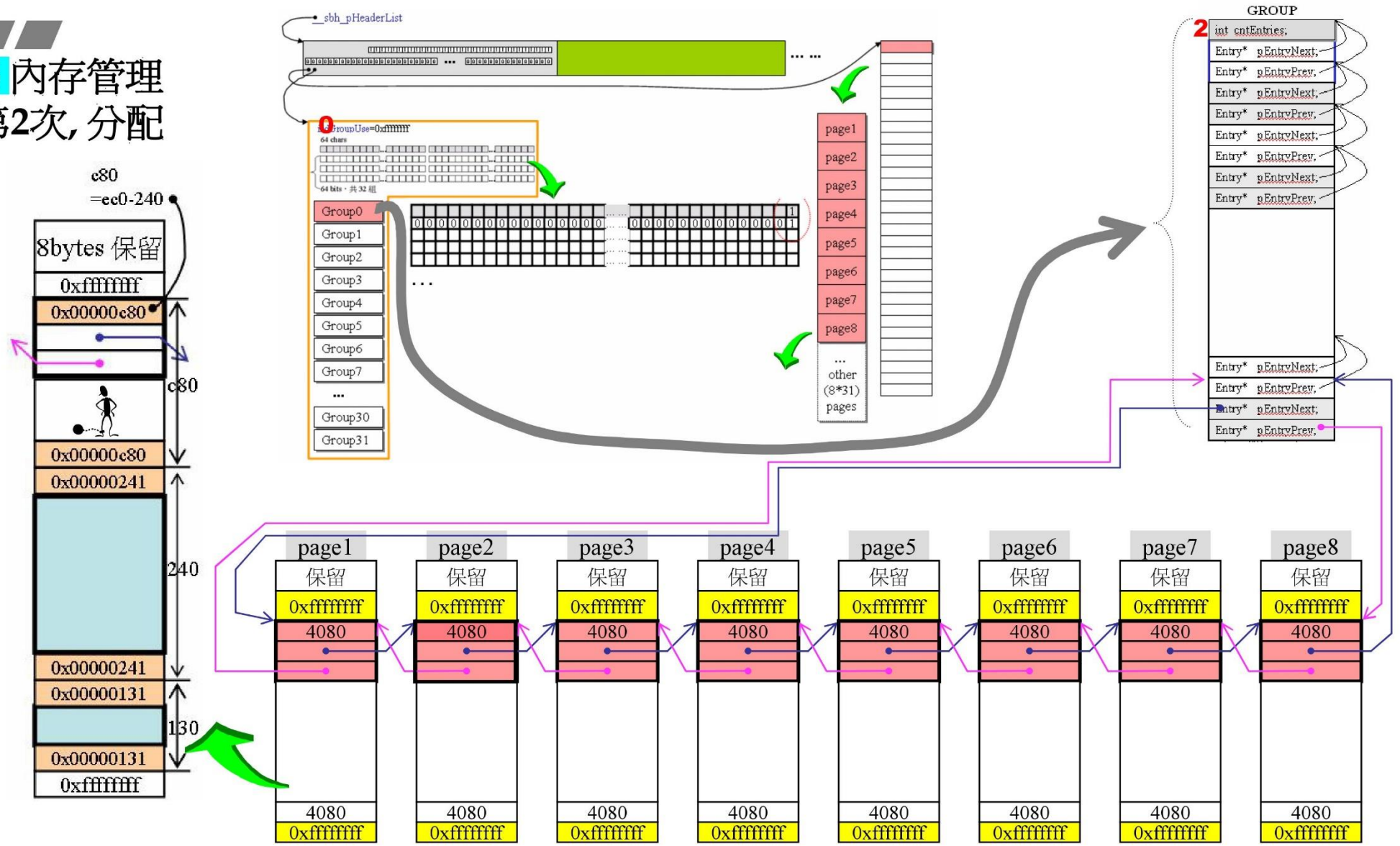

8bytes保留
0xffffffff
0x00000ec0
0x00000ec0
0x00000131
0xffffffff
007d000c
007d0ec8
007d0ecc
007d0ed0
007d0ff8
007d1000
ec0
= ff0-130
130
00000131
00000000
00000000
0042ee08
00000081
00000100
00000002
00000001
4 個 0xfd
fill 0xcd
4 個 0xfd
00000131
"ioinit.c"
nsize
(100h)
0x100 + 0x24 + 4*2
➔ 0x12C
➔ 0x130
/* Memory block identification */
#define _FREE_BLOCK 0
#define _NORMAL_BLOCK 1
#define _CRT_BLOCK 2
#define _IGNORE_BLOCK 3
#define _CLIENT_BLOCK 4
#define _MAX_BLOCKS 5

VC6 內存管理
首次分配

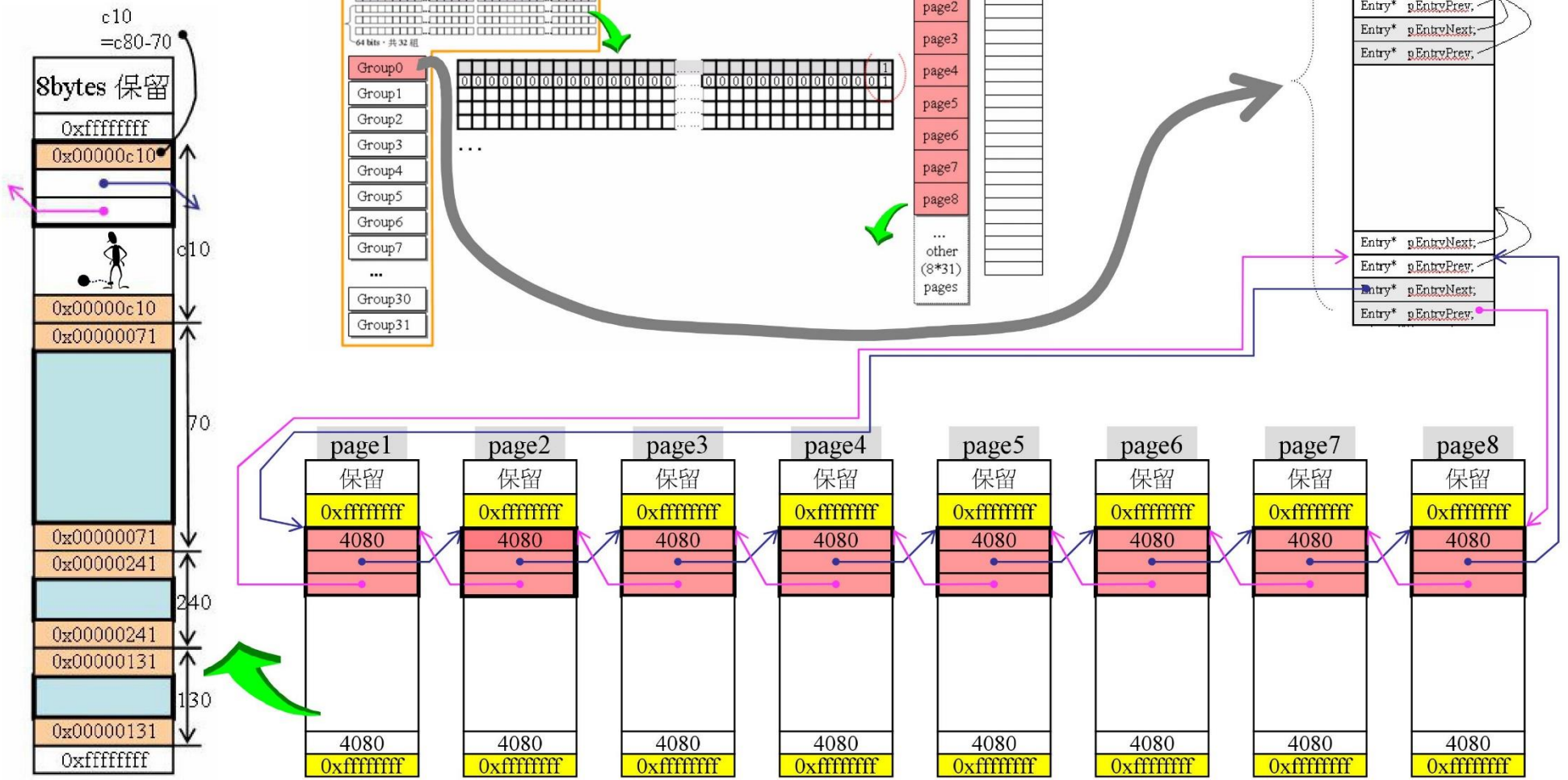
由 ioinit.c, line#81申請
100h, 區塊大小130h,
理應由 #18 lists 供應



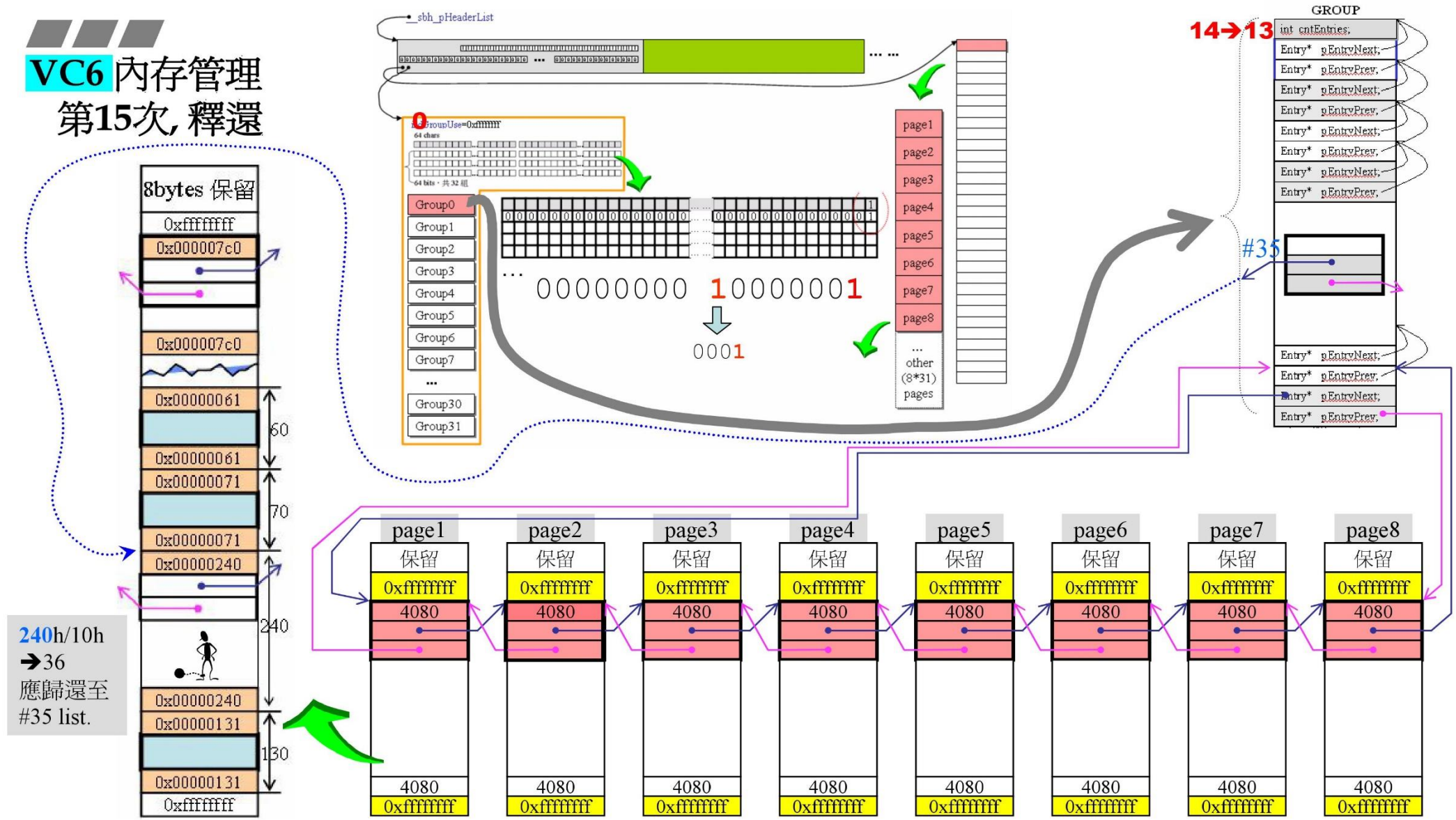
VC6 内存管理
第2次，分配



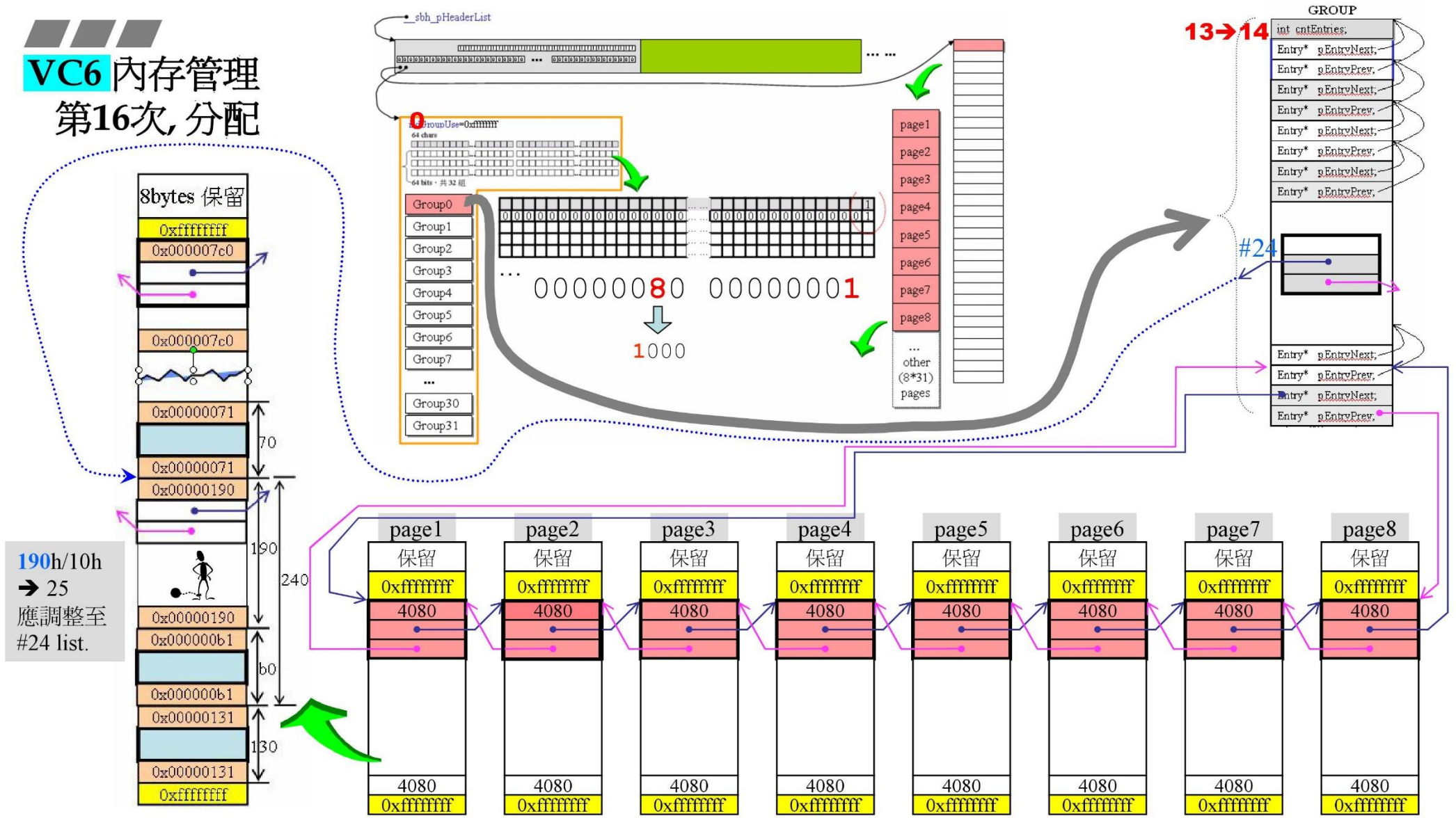
VC6 内存管理
第3次，分配



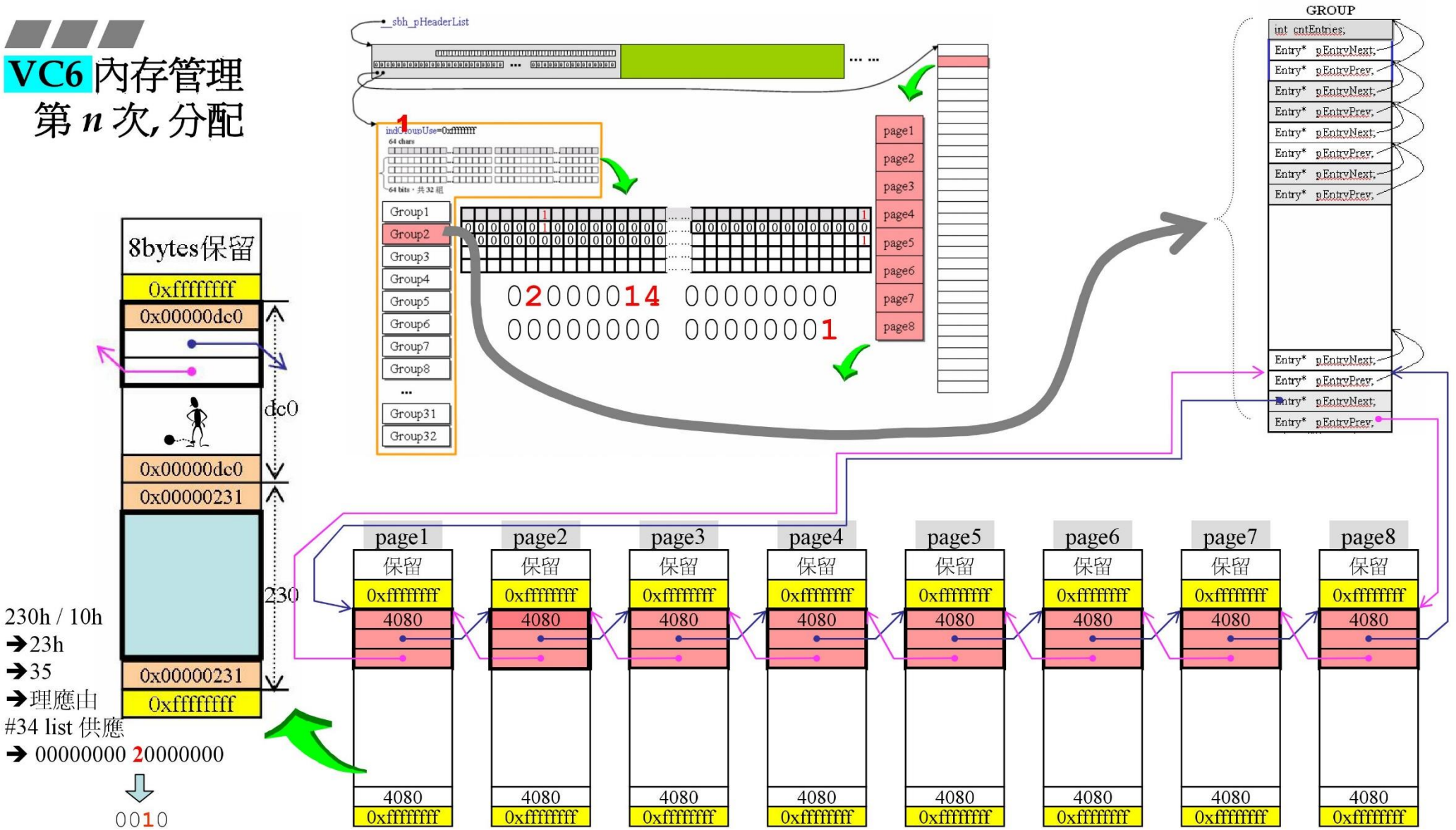
VC6 內存管理
第15次, 釋還



VC6 內存管理
第16次, 分配



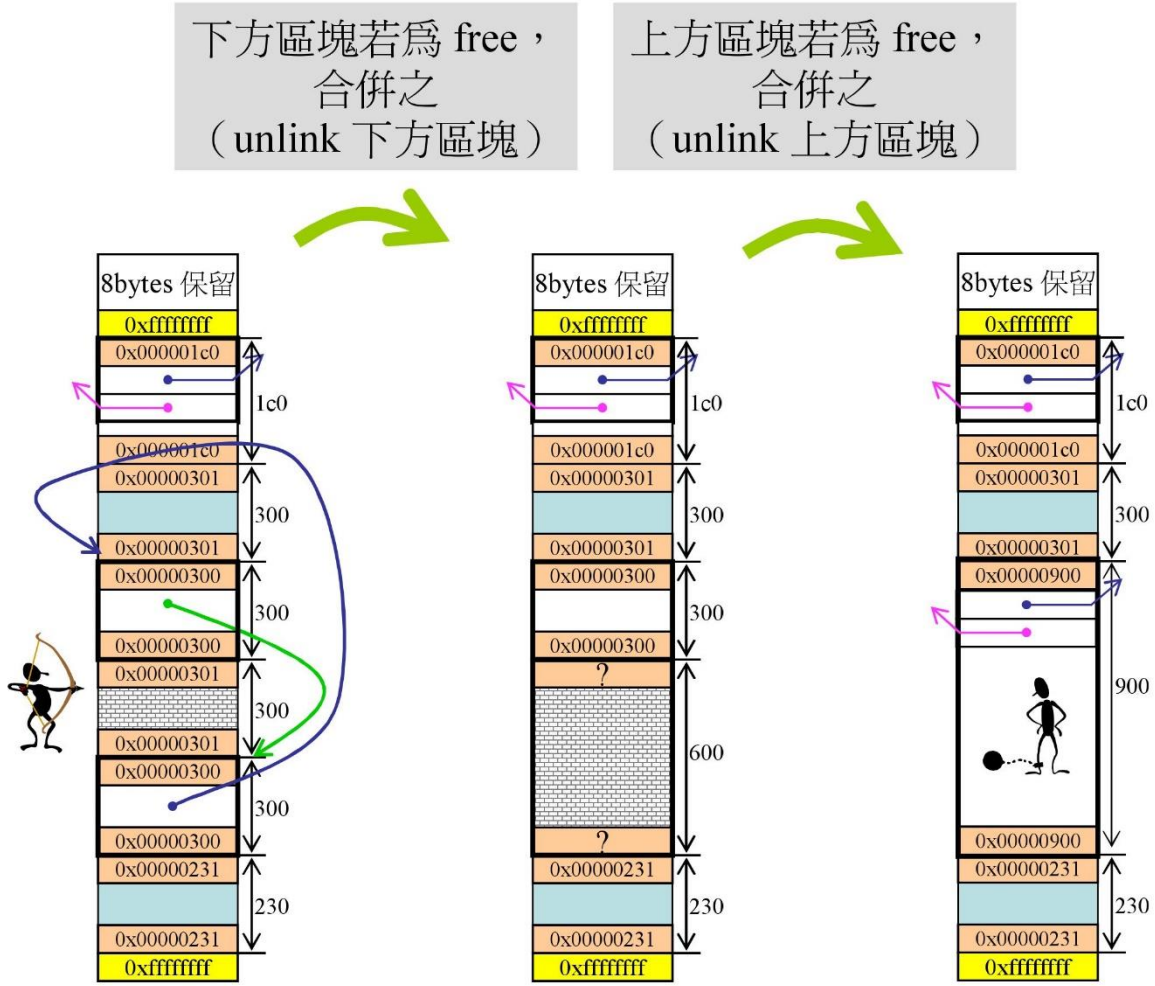
VC6 內存管理
第 n 次, 分配



VC6 內存管理

區塊之合併

上 cookie
與
下 cookie
的作用

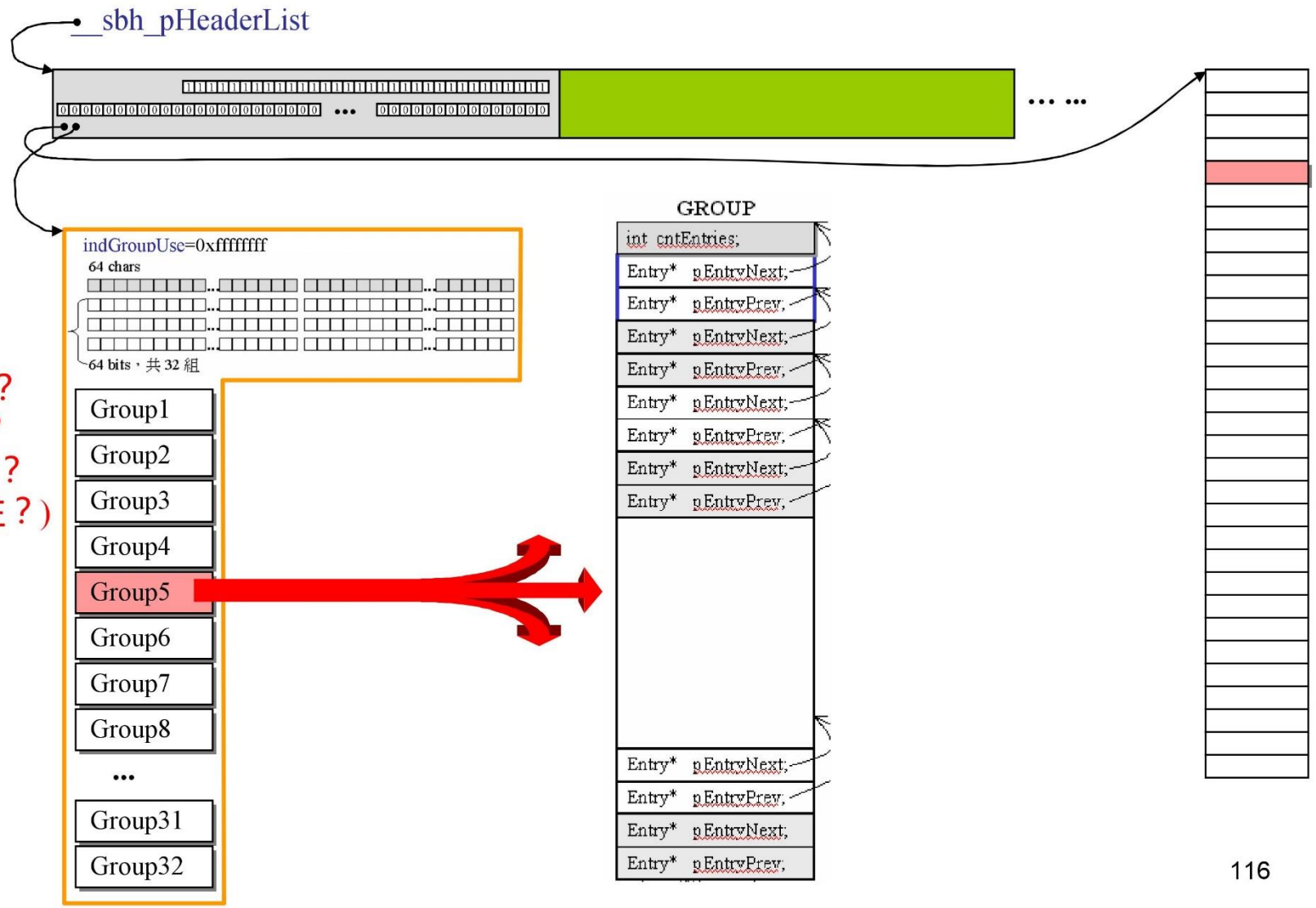


VC6 內存管理

free(p)

p 花落誰家？

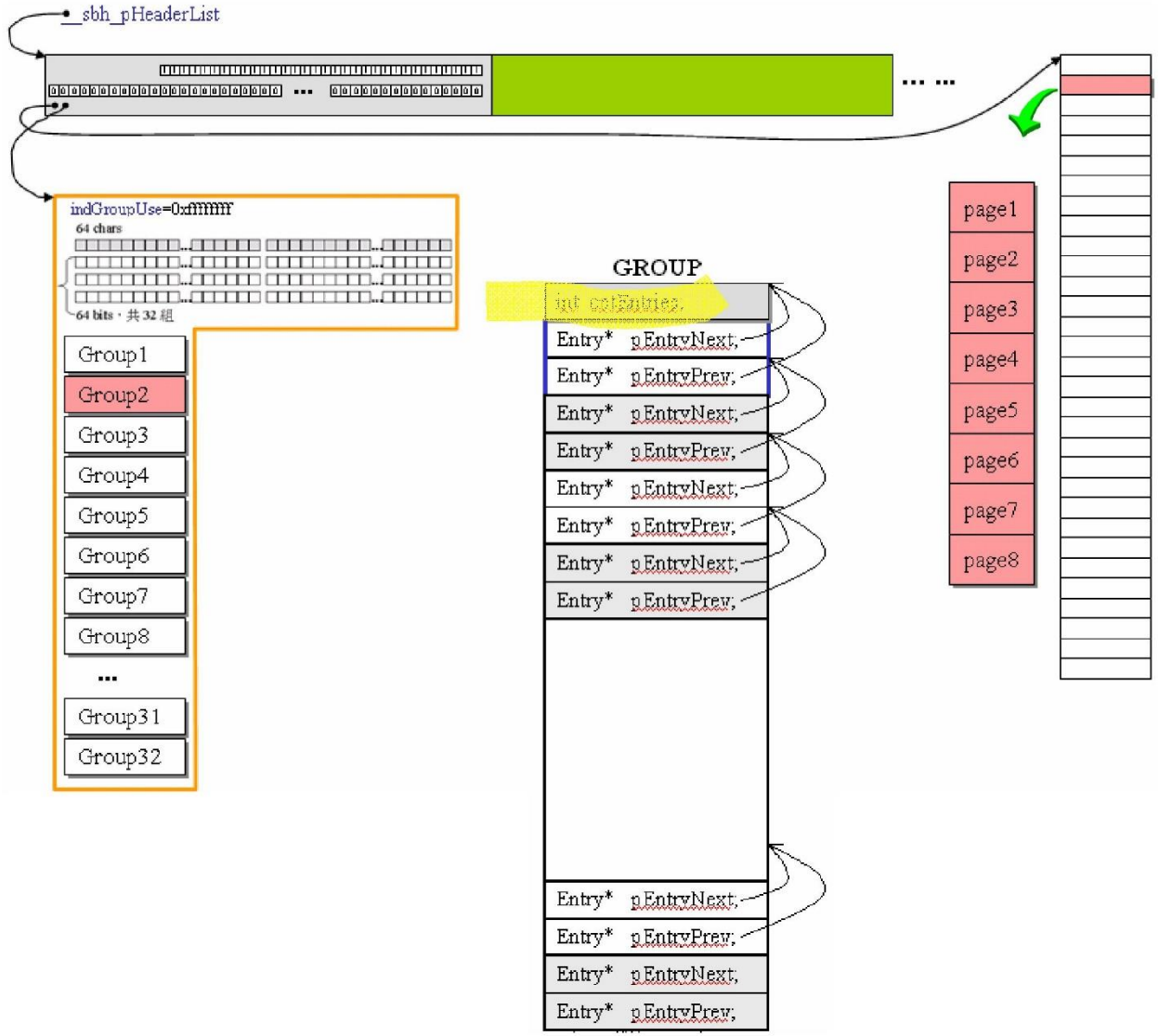
落在哪個 Header 內？
落在哪個 Group 內？
落在哪個 free-list 內？
(被哪個 free-list 鏈住？)



VC6 內存管理

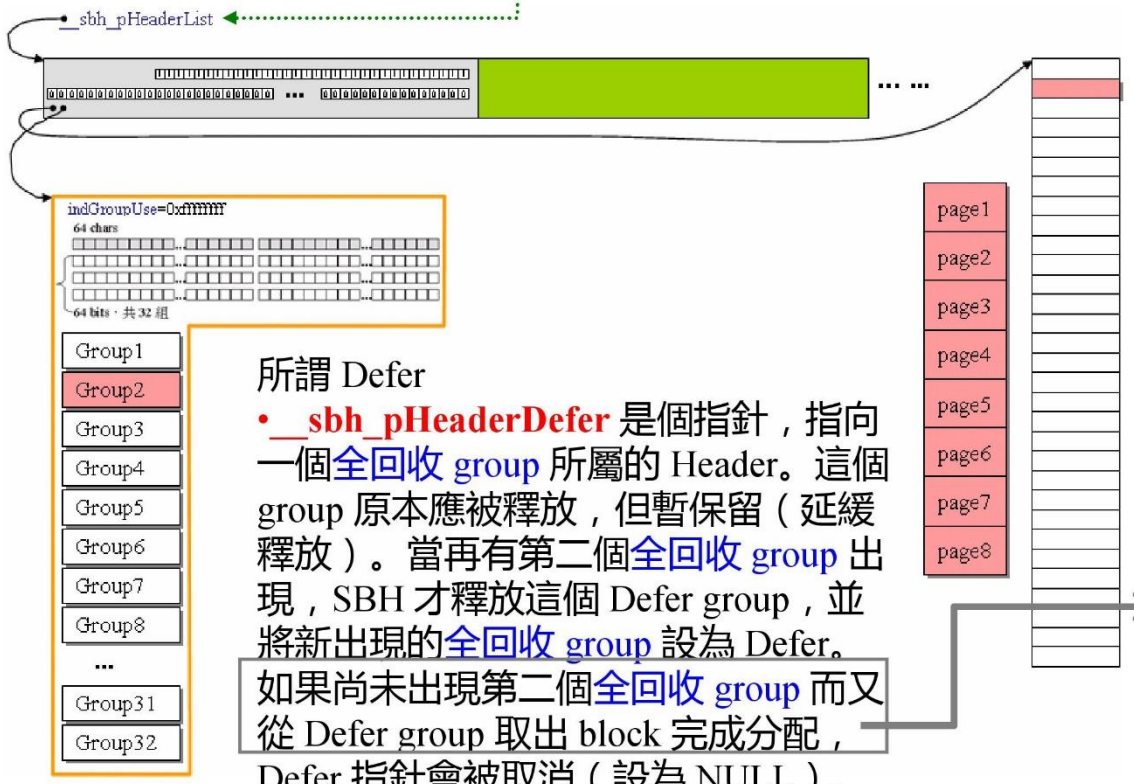
分段管理之妙
利於歸還O.S.

1, 如何判斷全回收？
2, 不要躁進！



VC6 內存管理

歸還 O.S. *Defering*



所謂 Defer

- **__sbh_pHeaderDefer** 是個指針，指向一個全回收 group 所屬的 Header。這個 group 原本應被釋放，但暫保留（延緩釋放）。當再有第二個全回收 group 出現，SBH 才釋放這個 Defer group，並將新出現的全回收 group 設為 Defer。

如果尚未出現第二個全回收 group 而又從 Defer group 取出 block 完成分配，Defer 指針會被取消（設為 NULL）。

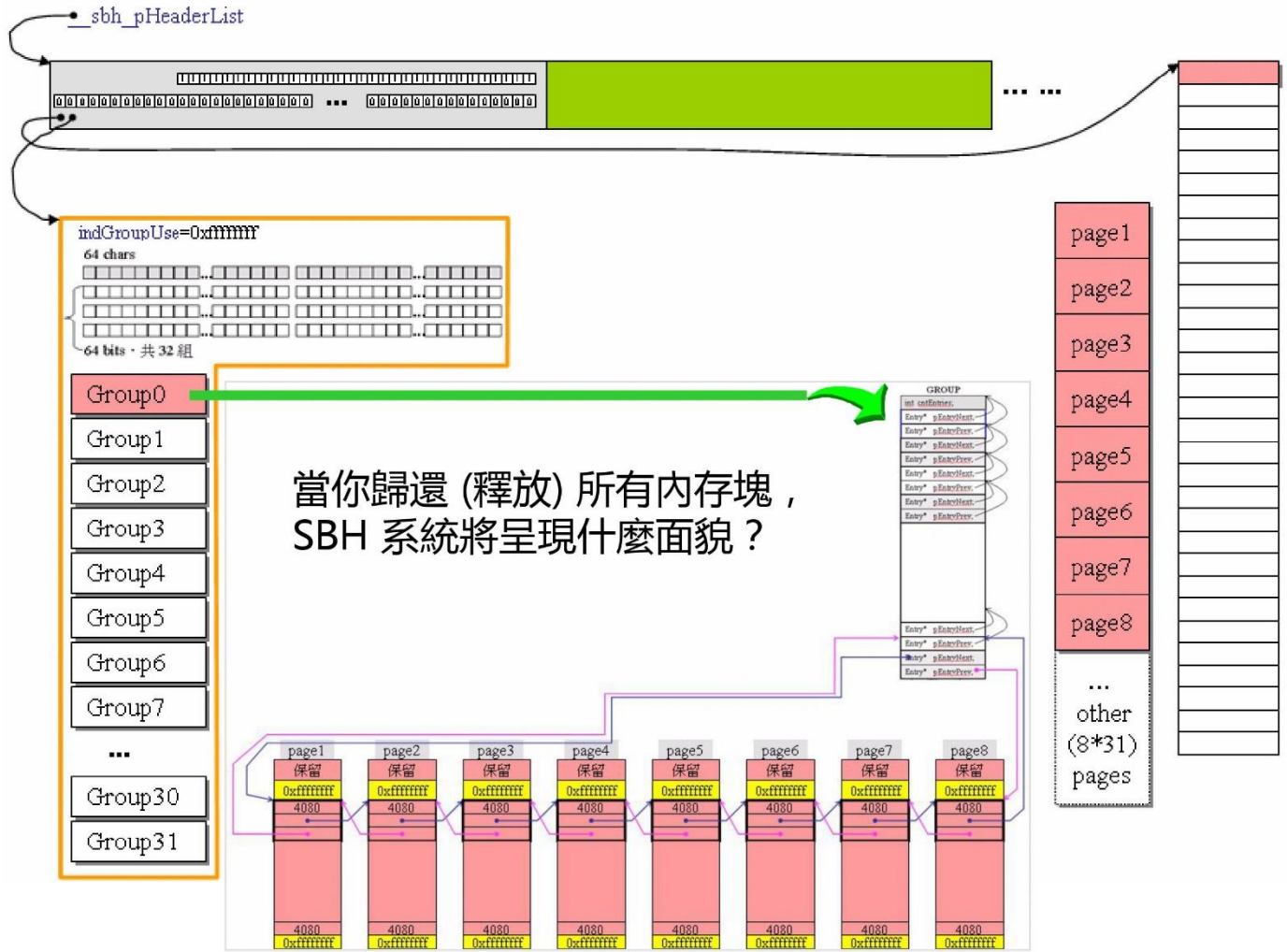
- **__sbh_indGroupDefer** 是個索引，指出 Region 中哪個 group (#0~#31) 是 Defer.

```
int __cdecl __sbh_heap_init (void)
{
   if (!(__sbh_pHeaderList =
         HeapAlloc(_crtheap, 0, 16 * sizeof(HEADER))))
      return FALSE;

   __sbh_pHeaderScan = __sbh_pHeaderList;
   __sbh_pHeaderDefer = NULL;
   __sbh_cntHeaderList = 0;
   __sbh_sizeHeaderList = 16;

   return TRUE;
}
```

SBH 分配好 block 後，最終準備將 cntEntries 累加 1, 但會先檢查它原本是否為 0; 若成立, 再看此次所在之 Header 是否 Defer 且此次所用之 Group 是否 Defer？都吻合就取消其 Defer 身份 (令 **__sbh_pHeaderDefer** = NULL).

此意味 Defer 必定是個全回收 Group。全新 Group 不會是Defer，因為 Defer 指針不可能指向全新 Group。

VC6 內存管理


_sbh_pHeaderList
indGroupUse=0xffffffff
64 chars
64 bits，共 32 組
Group0
Group1
Group2
Group3
Group4
Group5
Group6
Group7
...
Group30
Group31
page1
page2
page3
page4
page5
page6
page7
page8
...
other
(8*31)
pages
當你歸還 (釋放) 所有內存塊，
SBH 系統將呈現什麼面貌？
GROUP
保留
0xffffffff
4080

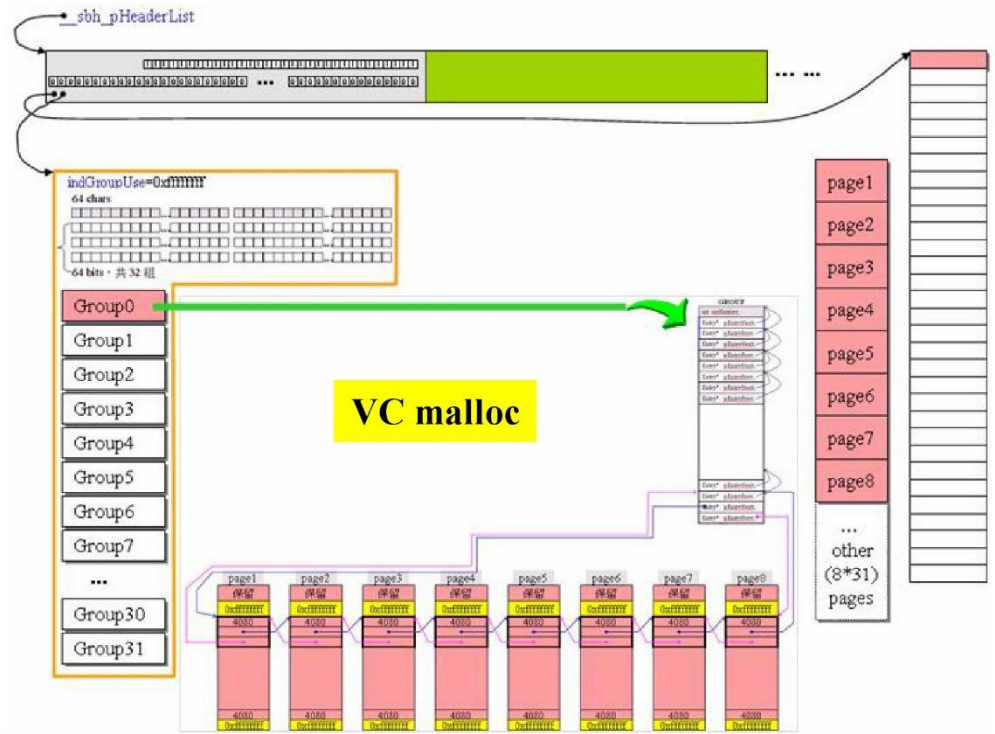
VC6, Heap State Reporting Functions

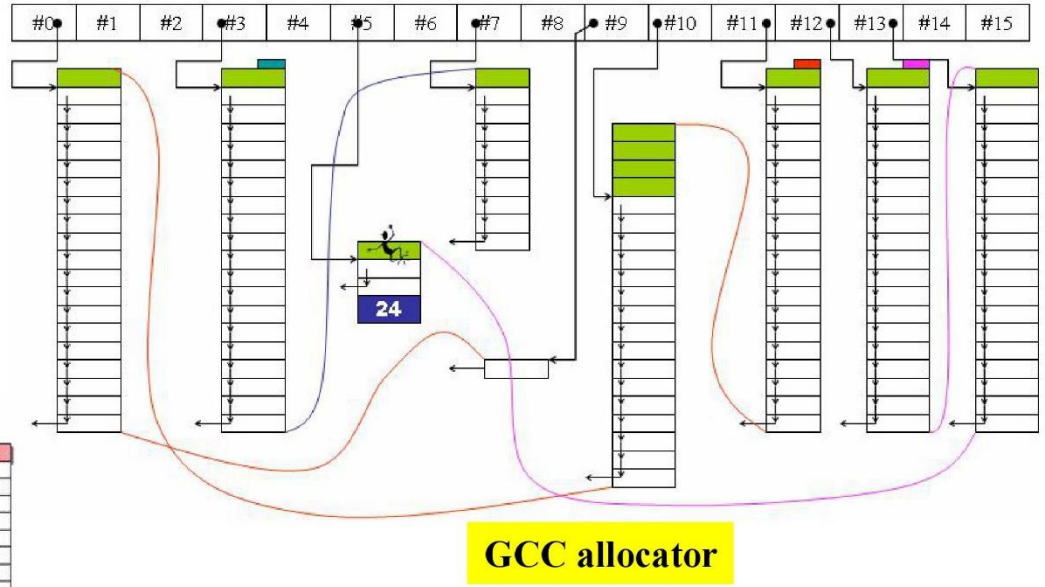
The following functions report the state and contents of the heap, and use the information to help detect memory leaks and other problems:

Function	Description
_CrtMemCheckpoint	Saves a snapshot of the heap in a **_CrtMemState** structure supplied by the application.
_CrtMemDifference	Compares two memory state structures, saves the difference between them in a third state structure, and returns **TRUE** if the two states are different.
_CrtMemDumpStatistics	Dumps a given **_CrtMemState** structure. The structure may contain a snapshot of the state of the debug heap at a given moment, or the difference between two snapshots. "Dumping" means reporting the data in a form that a person can understand.
_CrtMemDumpAllObjectsSince	Dumps information about all objects allocated since a given snapshot was taken of the heap, or from the start of execution. Every time it dumps a **_CLIENT_BLOCK** block, it calls a hook function supplied by the application, if one has been installed using **_CrtSetDumpClient**.
_CrtDumpMemoryLeaks	Determines whether any memory leaks occurred since the start of program execution, and if so, it dumps all allocated objects. Every time it dumps a **_CLIENT_BLOCK** block, it calls a hook function supplied by the application, if one has been installed using **_CrtSetDumpClient**.

VC malloc + GCC allocator

亂點鴛鴦譜？





疊床架屋, 有必要嗎？

C++ Applications

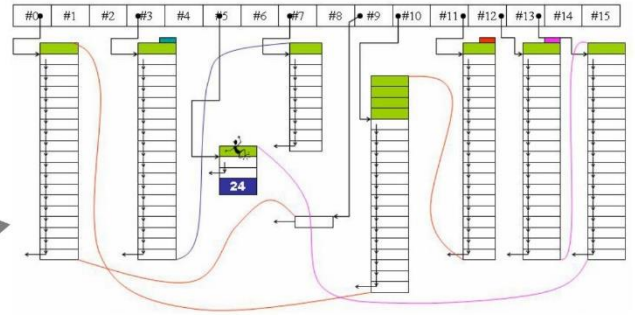
C++ Library (std::allocator)

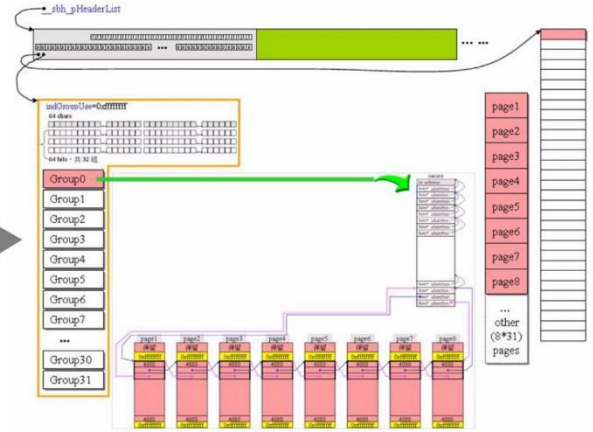
C++ primitives
new, new[], new(), ::operator new(), …

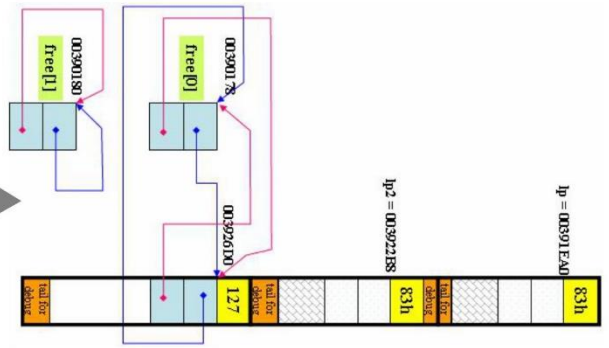
CRT (malloc / free)

O.S. API (such as HeapAlloc, VirtualAlloc, …)

?







The End

內存管理

從平地到萬丈高樓

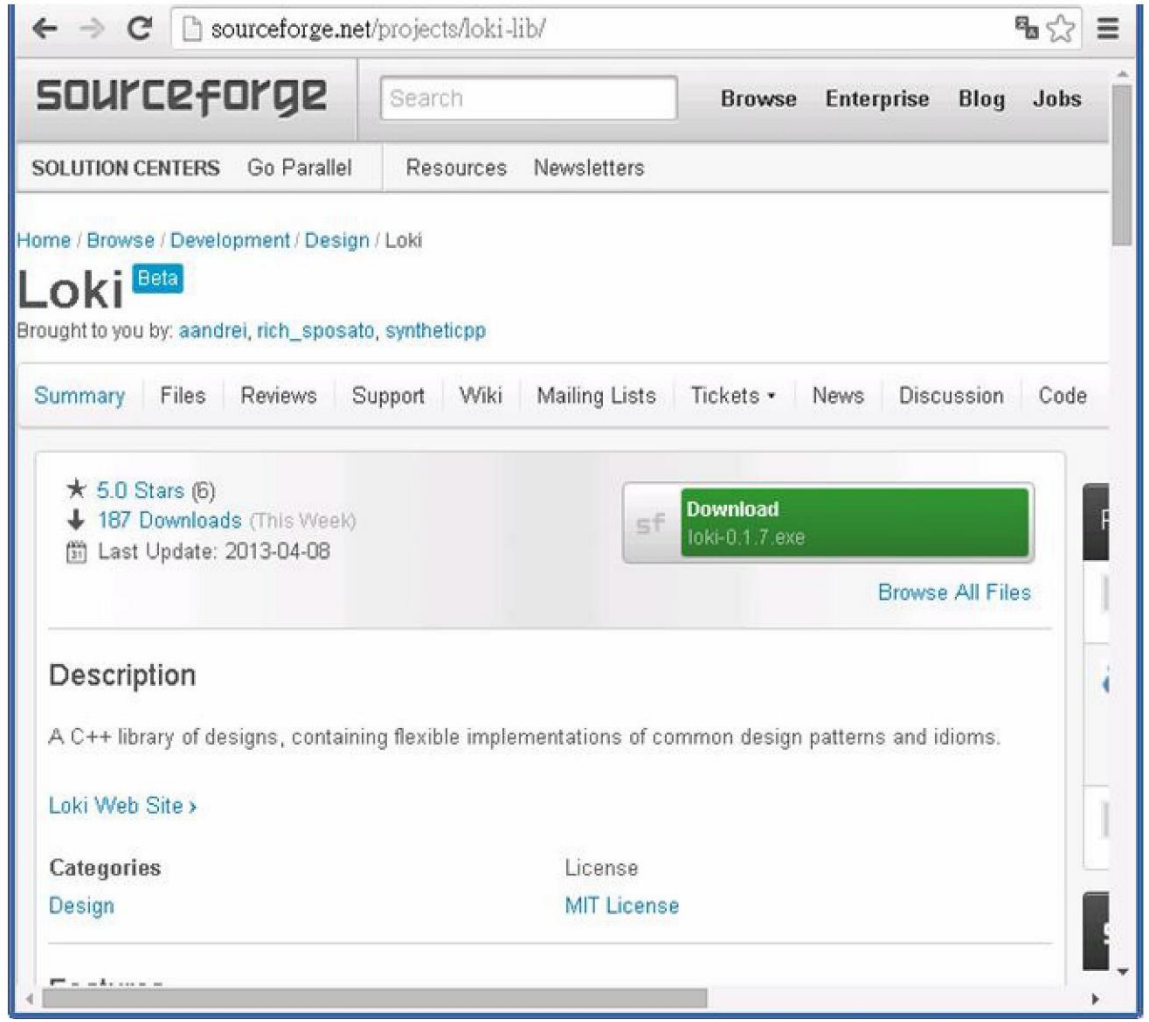
Memory Management 101

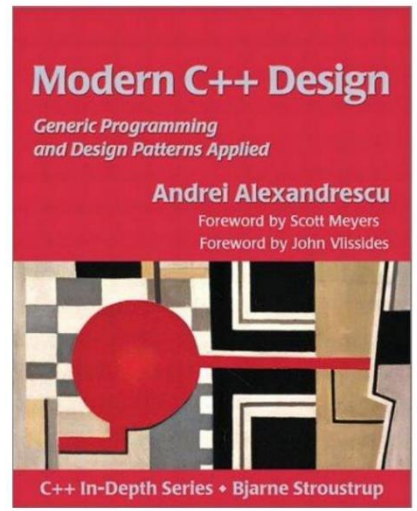
第一講 primitives
第二講 std::allocator
第三講 malloc/free
第四講 loki::allocator
第五講 other issues

侯捷

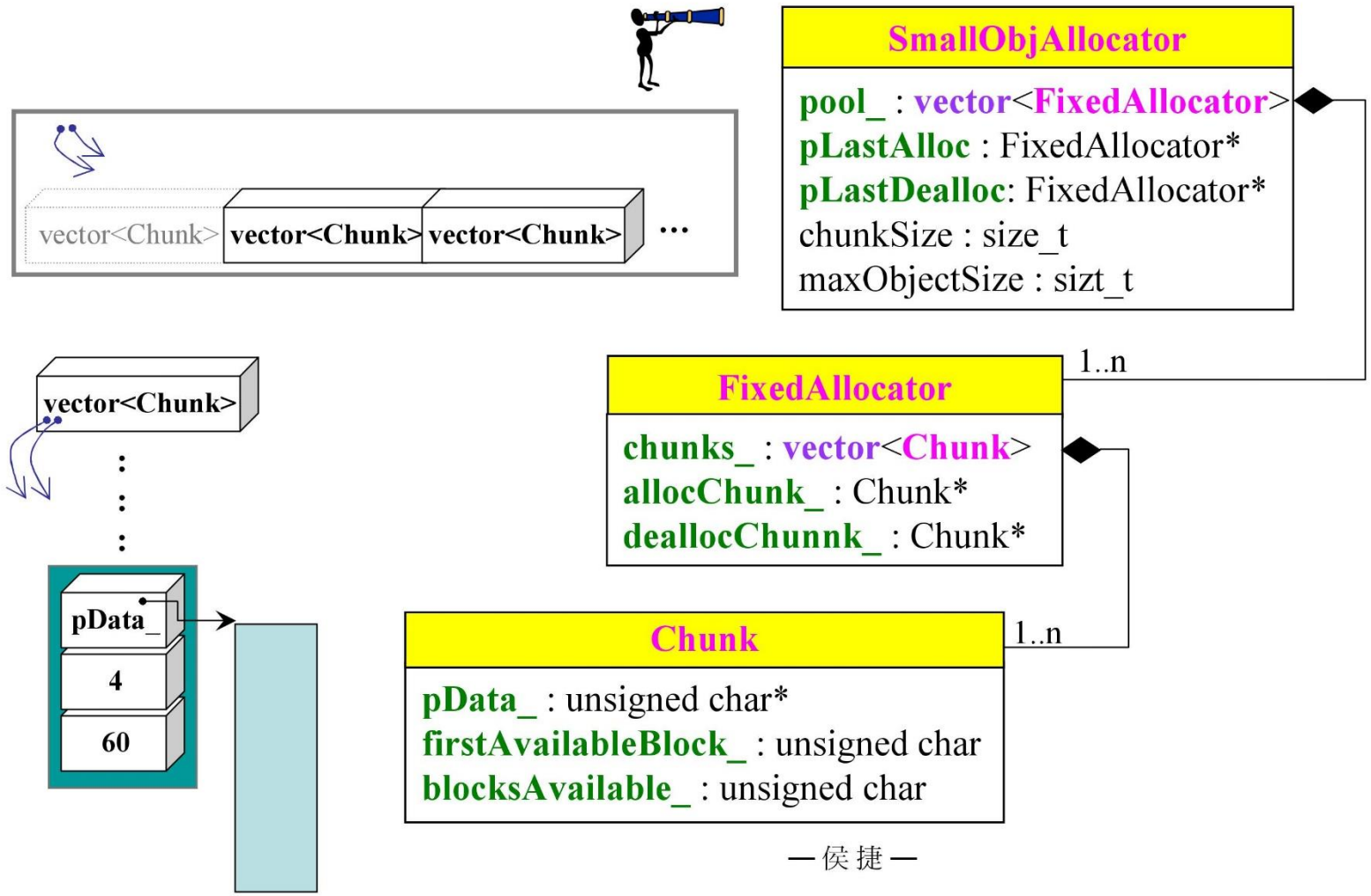
成竹在胸

Loki Library

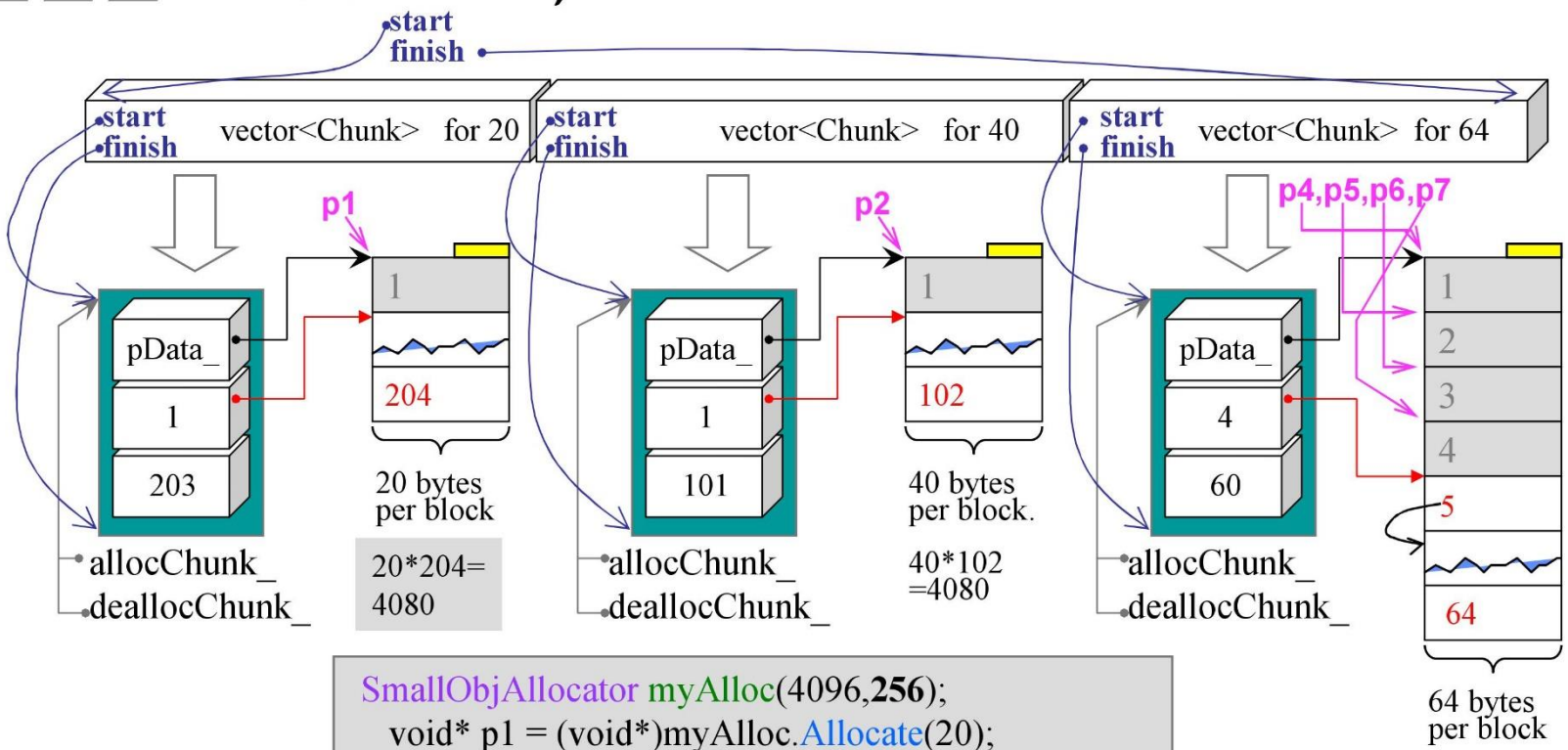




Loki allocator, 3 classes

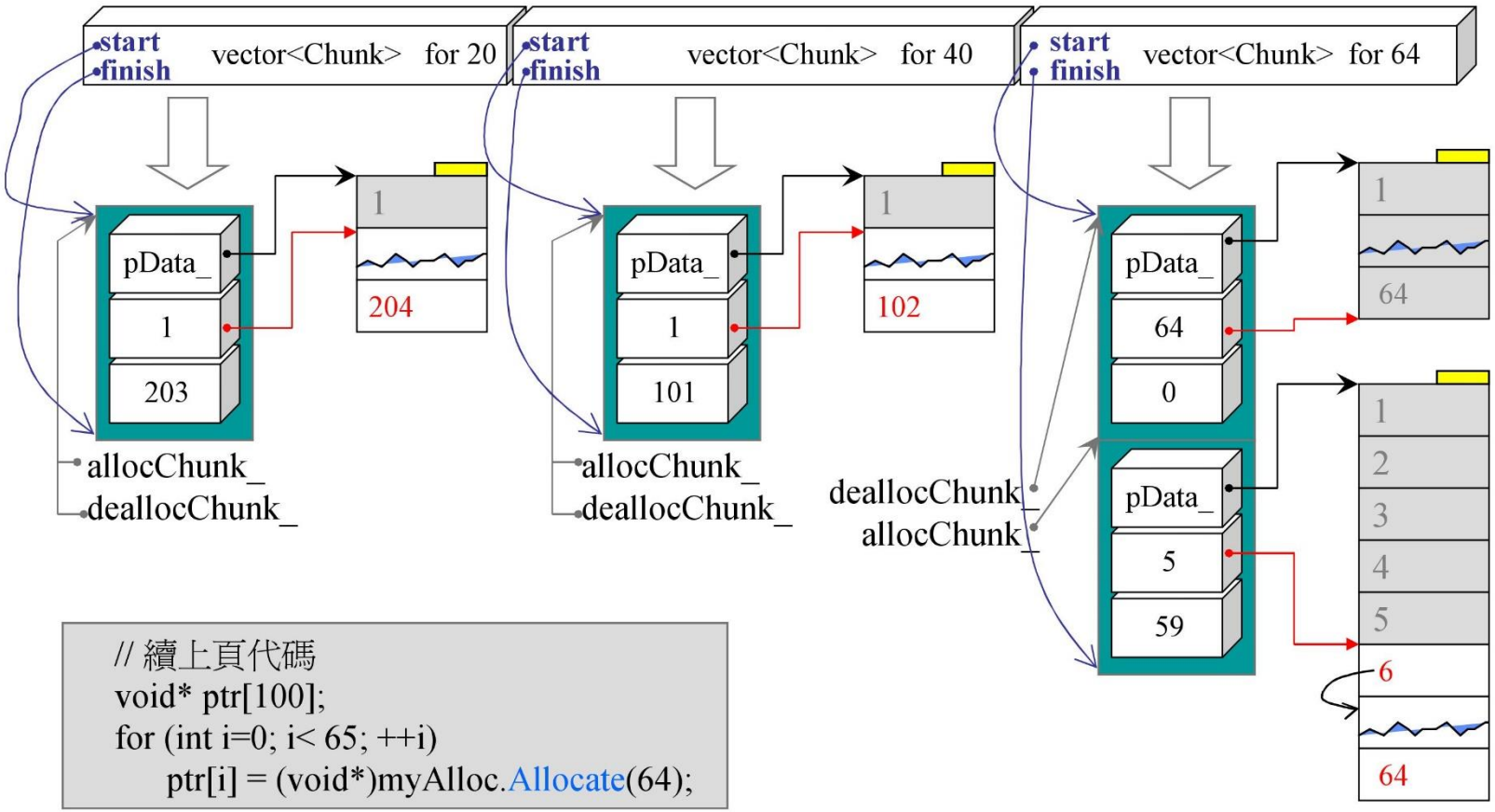


Loki allocator, 1



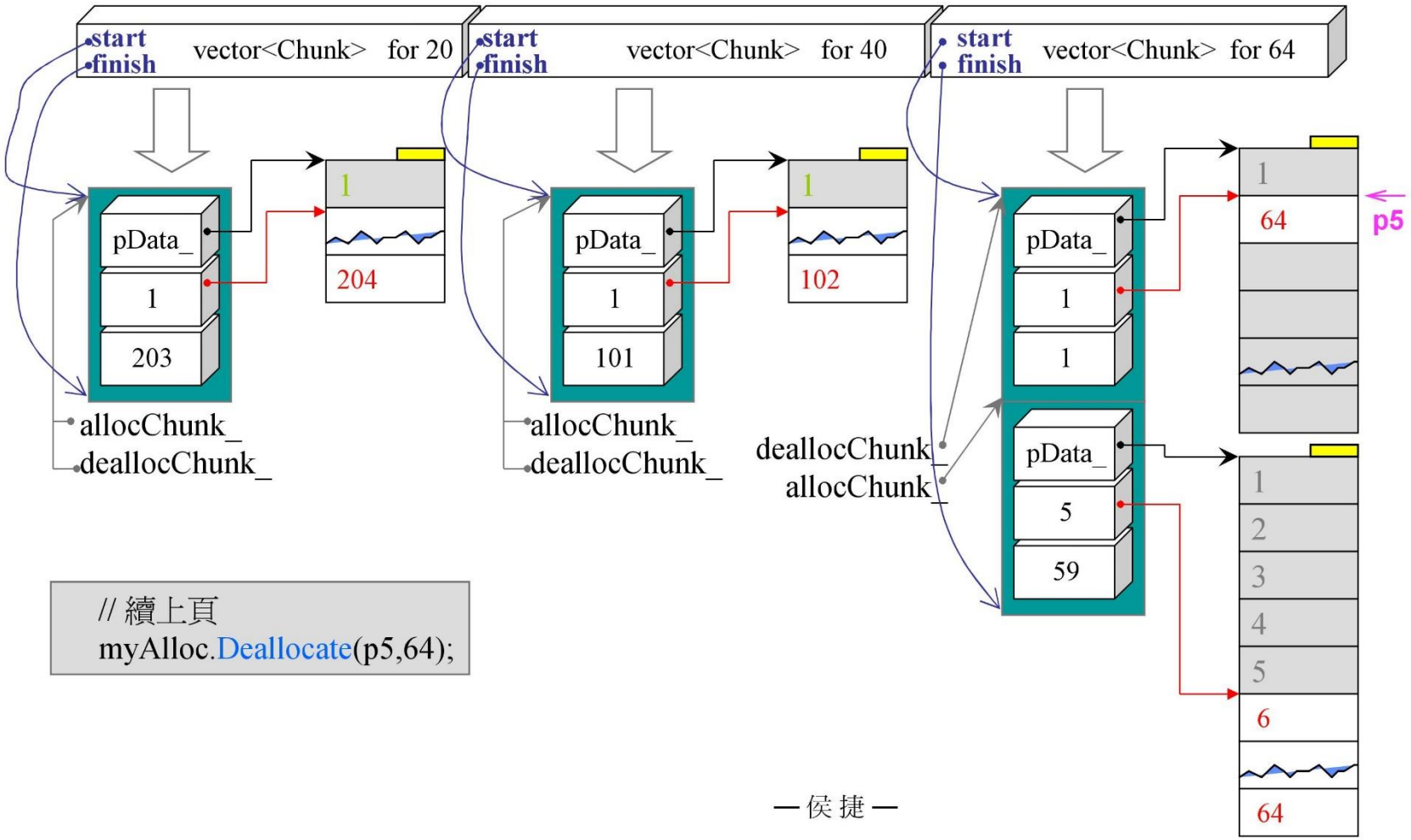

```
SmallObjAllocator myAlloc(4096,256);
  void* p1 = (void*)myAlloc.Allocate(20);
  void* p4 = (void*)myAlloc.Allocate(64);
  void* p2 = (void*)myAlloc.Allocate(40);
  void* p3 = (void*)myAlloc.Allocate(300);  // > 256
  void* p5 = (void*)myAlloc.Allocate(64);
  void* p6 = (void*)myAlloc.Allocate(64);
  void* p7 = (void*)myAlloc.Allocate(64);
```

Loki allocator, 2



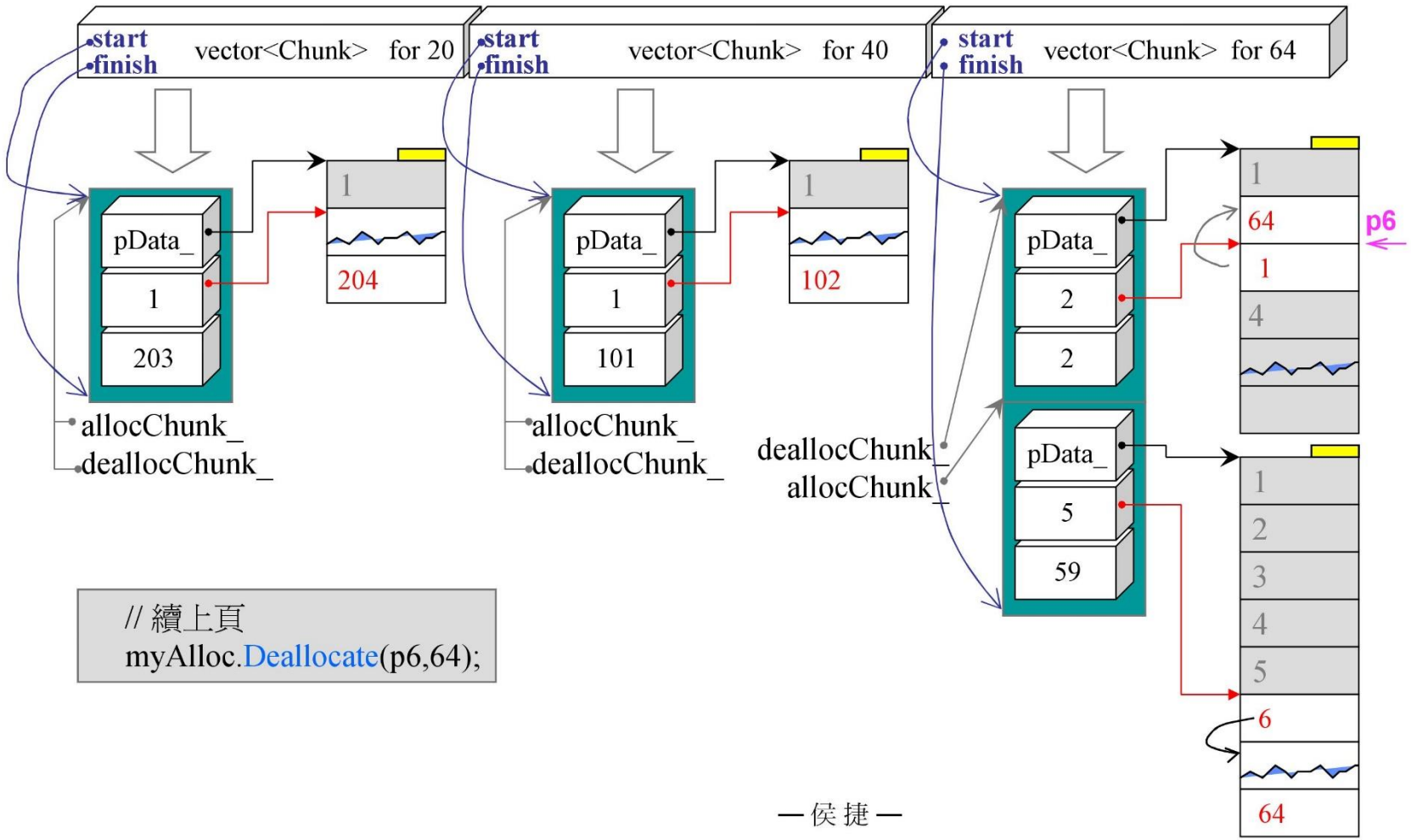

```
// 續上頁代碼
void* ptr[100];
for (int i=0; i< 65; ++i)
    ptr[i] = (void*)myAlloc.Allocate(64);
```

Loki allocator, 3



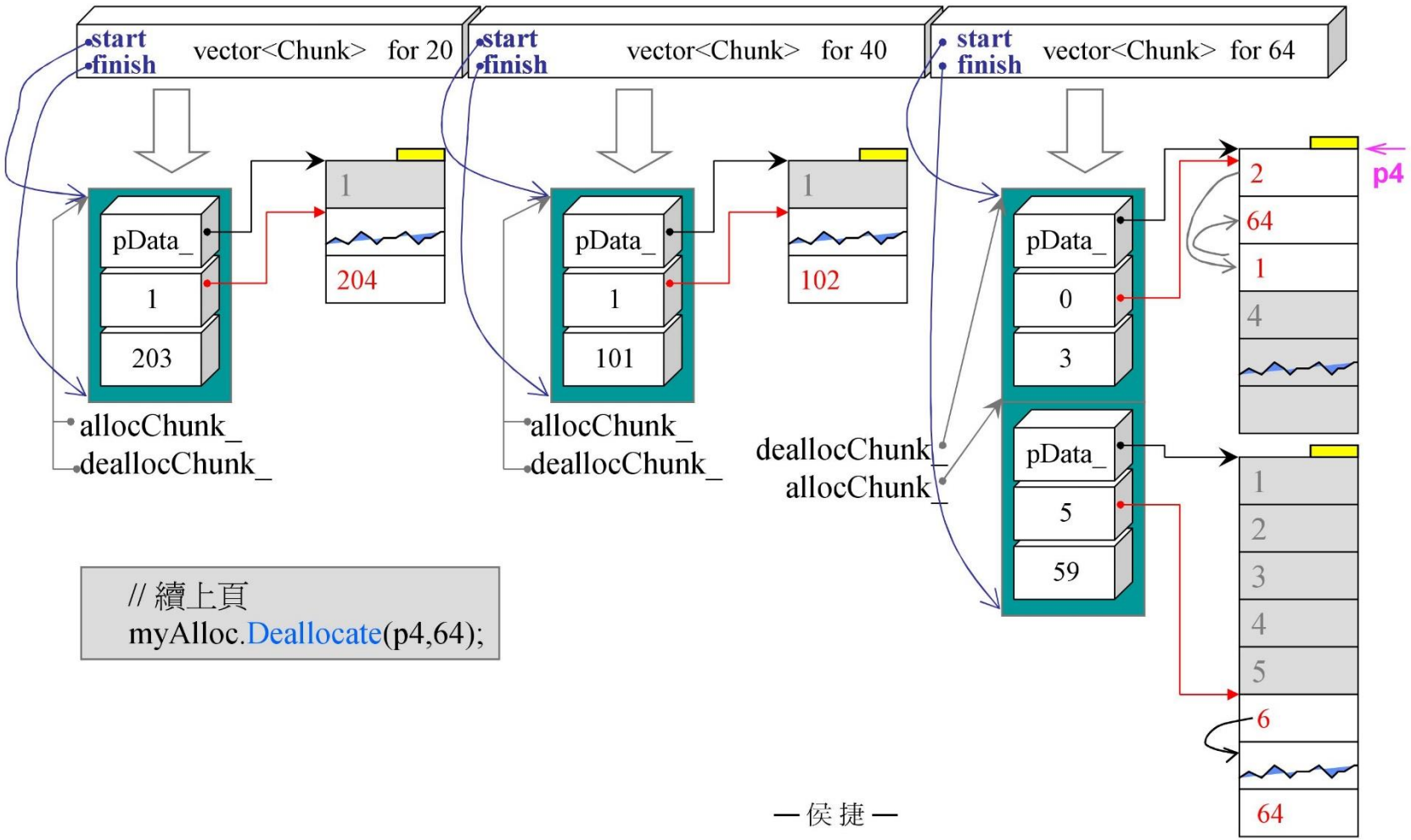

```
// 續上頁
myAlloc.Deallocate(p5,64);
```

Loki allocator, 4



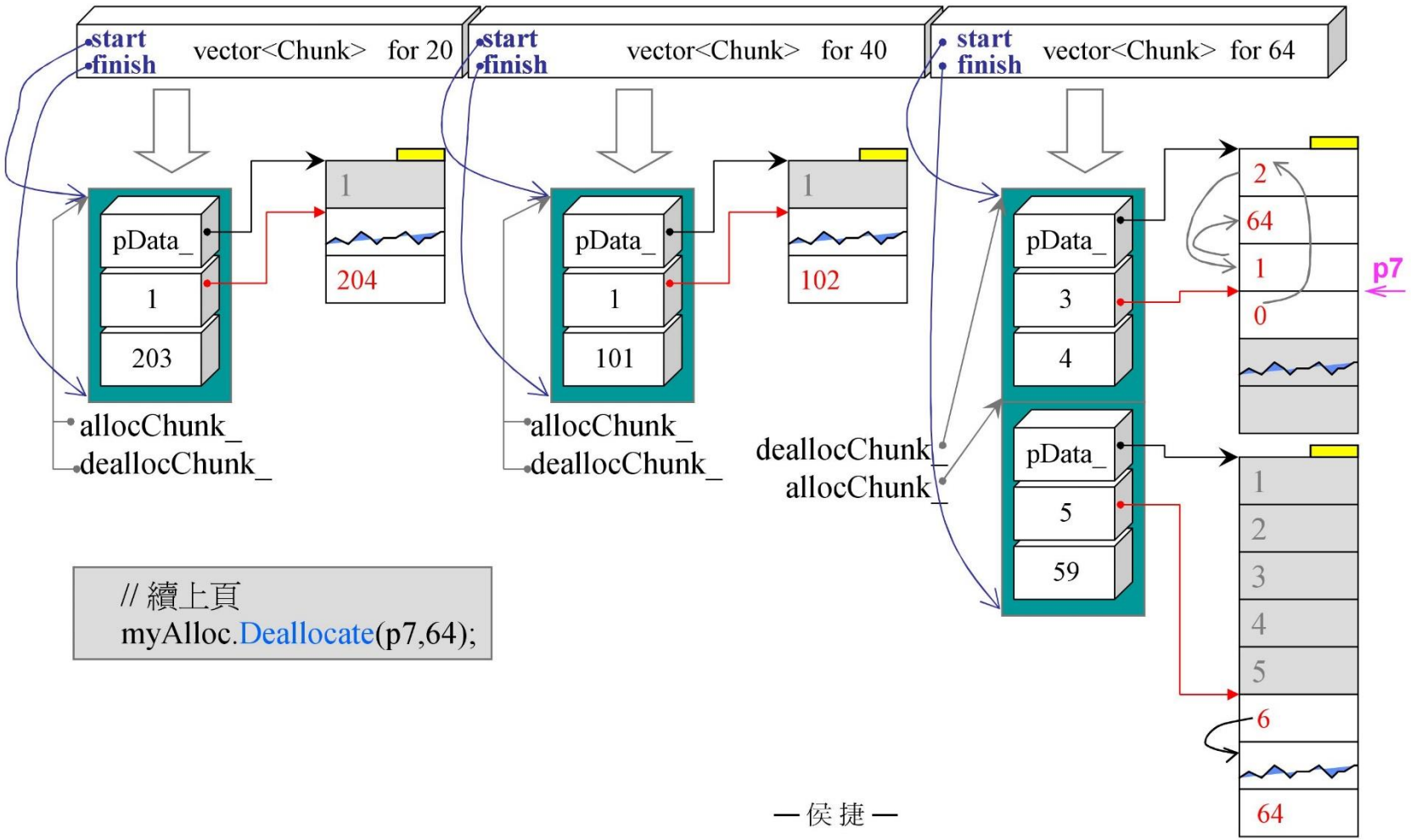

```
// 續上頁
myAlloc.Deallocate(p6,64);
```

Loki allocator, 5



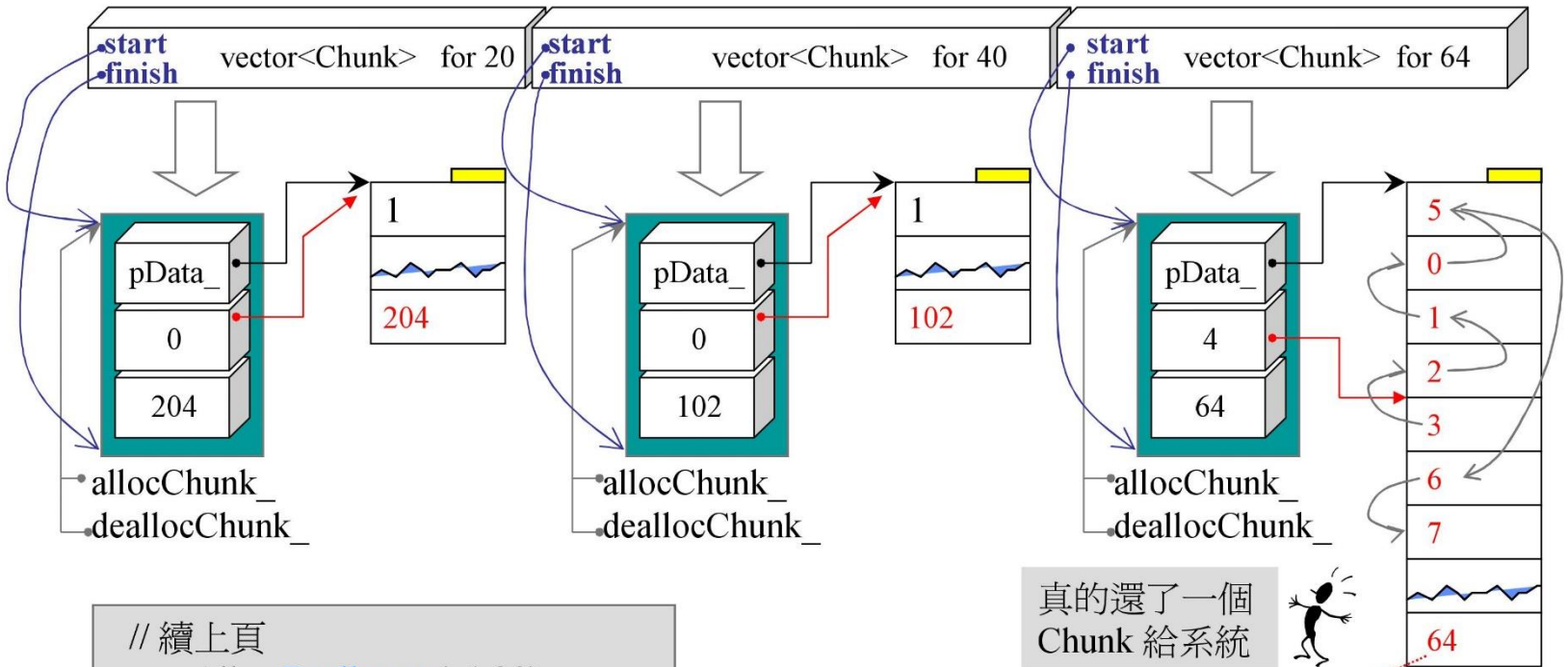

```
// 續上頁
myAlloc.Deallocate(p4,64);
```

Loki allocator, 6




```
// 續上頁
myAlloc.Deallocate(p7,64);
```

Loki allocator, 7



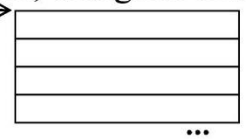
真的還了一個 Chunk 給系統


```
// 續上頁
  myAlloc.Deallocate(p1,20);
  myAlloc.Deallocate(p2,40);
  myAlloc.Deallocate(p3,300);
  for (int i=0; i< 65; ++i)
     myAlloc.Deallocate(ptr[i], 64);
```

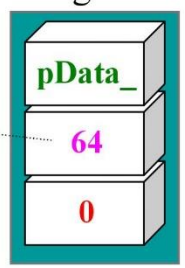
64 對本系統而言是錯誤數字，但它永遠不會被拿取 (因爲當它被拿取必是 blocksAvailable_ 爲 0 的狀態, 那就放棄拿取了)

Loki allocator, Chunk

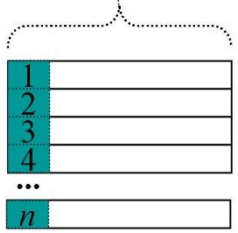
```
void FixedAllocator::Chunk::Init(std::size_t blockSize, unsigned char blocks)
{
   pData_ = new unsigned char[blockSize * blocks];
   Reset(blockSize, blocks);
}
```



```
void FixedAllocator::Chunk::Reset(std::size_t blockSize,
                                  unsigned char blocks)
{
   firstAvailableBlock_ = 0;
   blocksAvailable_ = blocks;

   unsigned char i = 0;
   unsigned char* p = pData_;
   for (; i != blocks; p += blockSize) //流水號標示索引
         *p = ++i;
}
```

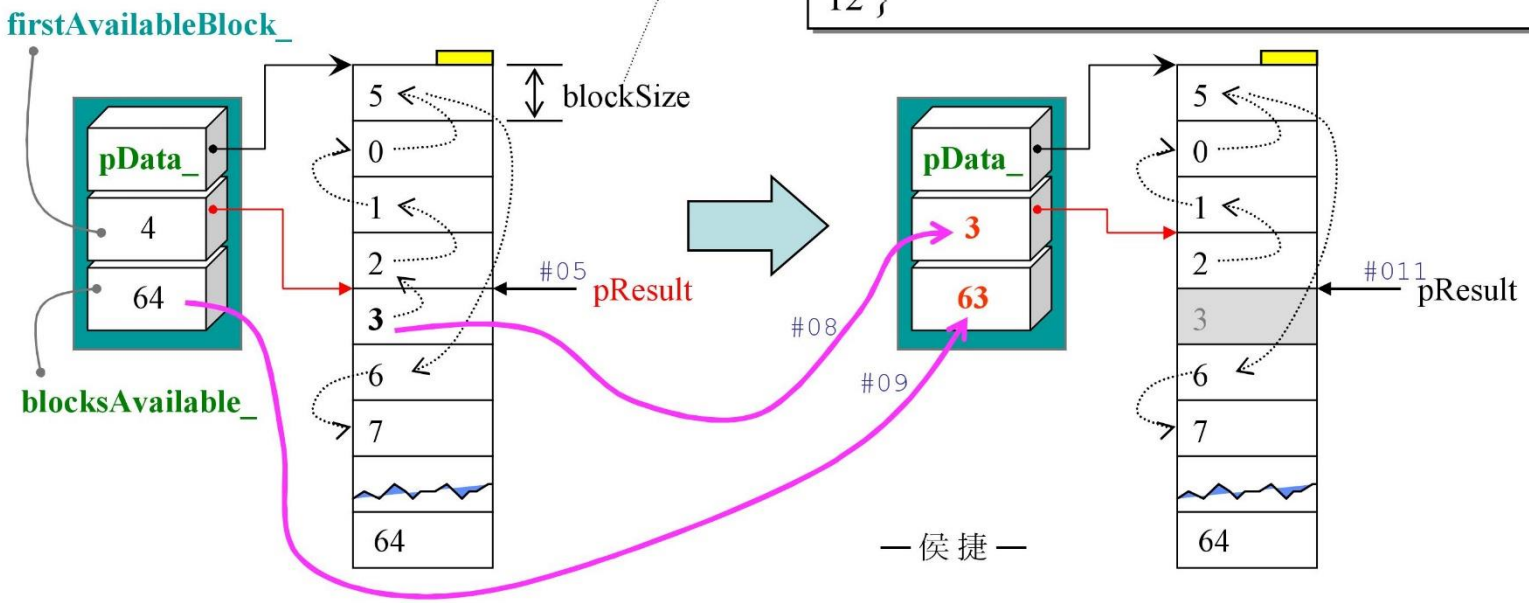



```
void FixedAllocator::Chunk::Release()
{
   delete[ ] pData_;  //釋放自己
} //此函數被上一層調用
```



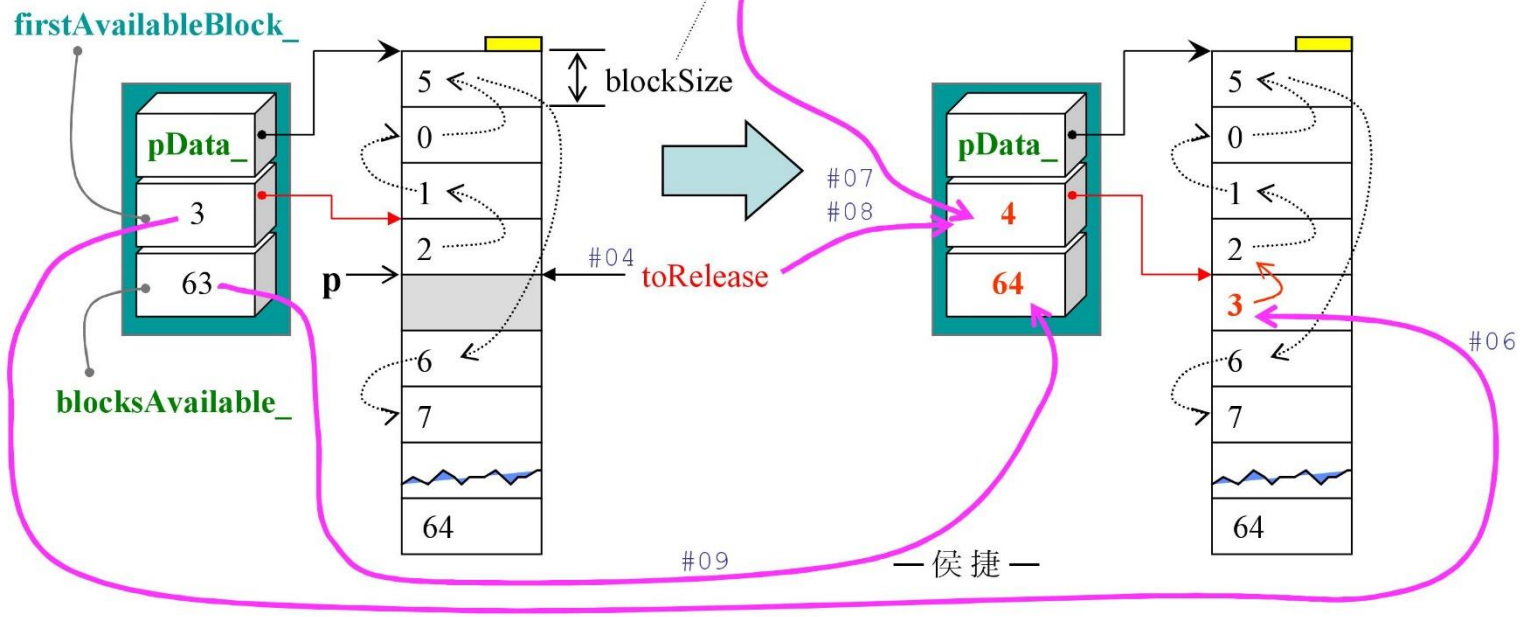
Chunk::Allocate()

```
01 void* FixedAllocator::Chunk::Allocate(std::size_t blockSize)
02 {
03   if (!blocksAvailable_) return 0;  //此地無銀
04
05   unsigned char* pResult =      //指向第一個可用區塊
06     pData_ + (firstAvailableBlock_ * blockSize);
07
08   firstAvailableBlock_ = *pResult;  //右側索引便是下一個可用區塊
09   --blocksAvailable_;
10
11   return pResult;
12 }
```



Chunk::Deallocate()

```
01 void FixedAllocator::Chunk::Deallocate(void* p,
02                                        std::size_t blockSize)
03 {
04     unsigned char* toRelease = static_cast<unsigned char*>(p);
05
06     *toRelease = firstAvailableBlock_;
07     firstAvailableBlock_ = static_cast<unsigned char>(
08                            (toRelease - pData_) / blockSize);
09     ++blocksAvailable_; //可用區塊數加 1
10 }
```



FixedAllocator::Allocate()

```
#01 void* FixedAllocator::Allocate()
#02 {
#03   if (allocChunk_ == 0 || allocChunk_->blocksAvailable_ == 0)
#04   {  //目前沒有標定chunk或該chunk已無可用區塊
#05     Chunks::iterator i = chunks_.begin();  //打算從頭找起
#06     for (;; ++i)  //找遍每個chunk 直至找到擁有可用區塊者.
#07     {
#08       if (i == chunks_.end())   //到達尾端，都沒找著
#09       {
#10         // Initialize
#11         chunks_.push_back(Chunk( ));  //產生 a new chunk 掛於末端
#12         Chunk& newChunk = chunks_.back();       //指向末端 chunk
#13         newChunk.Init(blockSize_, numBlocks_); //設好索引
#14         allocChunk_ = &newChunk;                //標定,稍後將對此 chunk 取區塊
#15         deallocChunk_ = &chunks_.front();       //另一標定
#16         break;
#17       }
#18       if (i->blocksAvailable_ > 0)
#19       {  //current chunk 有可用區塊
#20         allocChunk_ = &*i;  //取其位址
#21         break;              //不找了,退出 for-loop
#22       }
#23     }
#24   }
#25   return allocChunk_->Allocate(blockSize_); //向這個chunk 取區塊
#26 }
```

創建 temp object 拷貝至容器然後結束生命

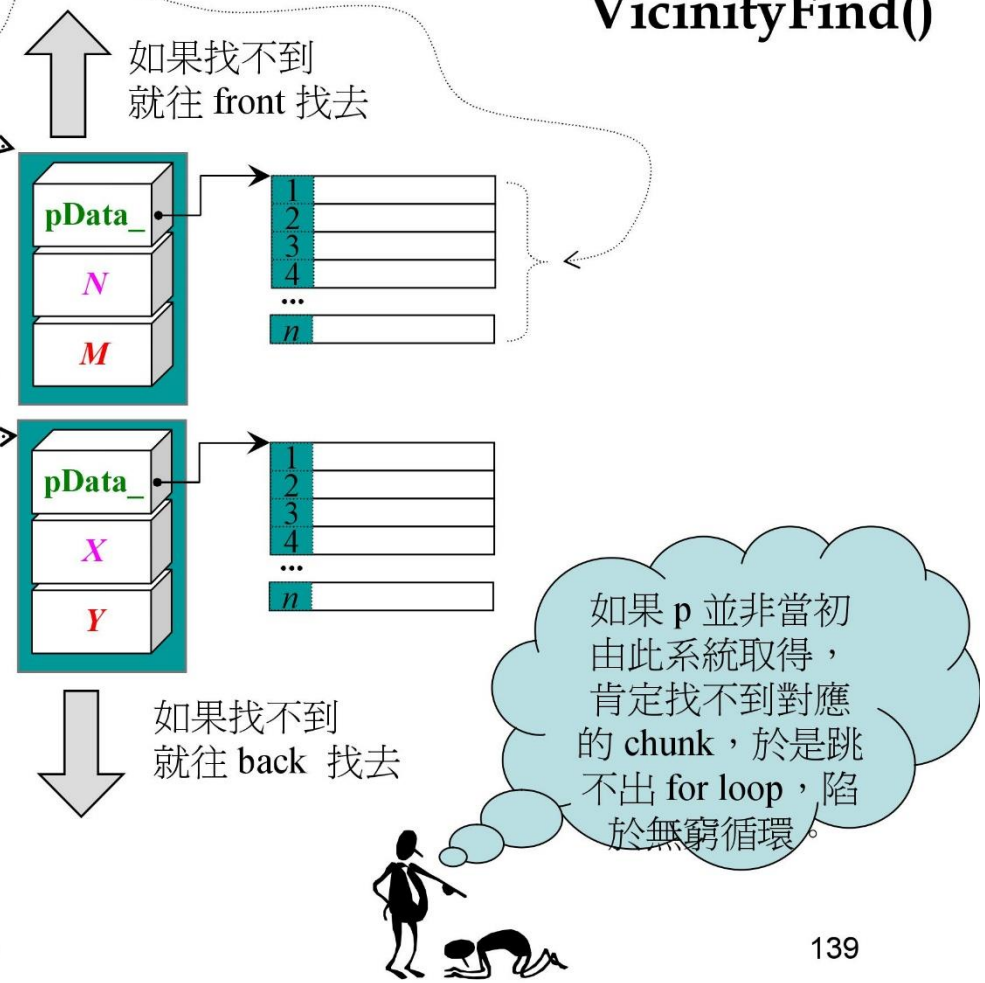
在此 chunk 找到可用區塊，
下次就優先由此找起

FixedAllocator::Deallocate()

```
void FixedAllocator::Deallocate(void* p)
{
  deallocChunk_ = VicinityFind(p);
  DoDeallocate(p);
}
```

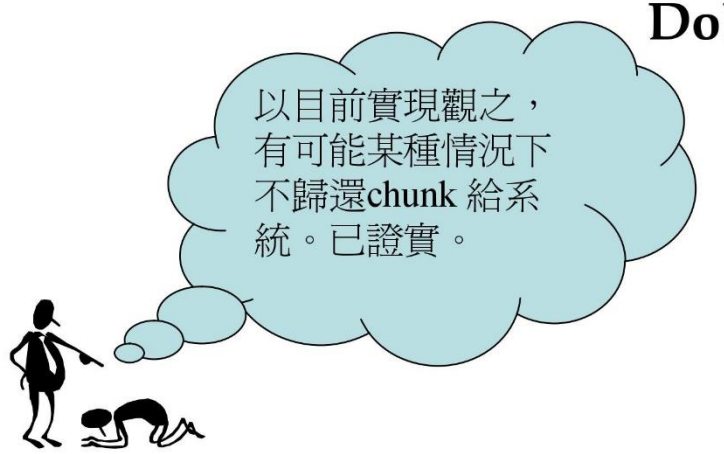
FixedAllocator::VicinityFind()

```
#01 // FixedAllocator::VicinityFind (internal)
#02 // Finds the chunk corresponding to a pointer, using an efficient search
#03 FixedAllocator::Chunk* FixedAllocator::VicinityFind(void* p)
#04 {
#05     const std::size_t chunkLength = numBlocks_ * blockSize_;
#06
#07     Chunk* lo = deallocChunk_;
#08     Chunk* hi = deallocChunk_ + 1;
#09     Chunk* loBound = &chunks_.front();
#10     Chunk* hiBound = &chunks_.back() + 1;
#11
#12     for (;;)   {  //兵分兩路
#13       if (lo)  { //上路未到盡頭
#14         if (p >= lo->pData_ && p < lo->pData_ + chunkLength)
#15           return lo;    //p 落於 lo 區間內
#16         if (lo == loBound)   lo = 0;   //到頂了，讓 loop 結束
#17         else   --lo;                   //否則往 lo 的 front 繼續找
#18       }
#19
#20       if (hi)  { //下路未到盡頭
#21         if (p >= hi->pData_ && p < hi->pData_ + chunkLength)
#22           return hi;    //p 落於 hi 區間內
#23         if (++hi == hiBound)  hi = 0;  //往 hi 的 back 繼續找
#24       }                                //若到最尾則讓 loop 結束
#25     }
#26     return 0;
#27 }
```



FixedAllocator::DoDeallocate()

```
#0001 void FixedAllocator::DoDeallocate(void* p)
#0002 {
#0003   //
#0004   deallocChunk_->Deallocate(p, blockSize_);
#0005
#0006   if (deallocChunk_->blocksAvailable_ == numBlocks_) {
#0007     // 確認全回收, 那麼, 該 release 它嗎？
#0008     // 注意，以下三種情況都重新設定了allocChunk_
#0009     Chunk& lastChunk = chunks_.back(); //標出最後一個
#0010     //如果 “最後一個” 就是 "當前 chunk"
#0011     if (&lastChunk == deallocChunk_) {
#0012     ❶ // 檢查是否擁有兩個 last chunks empty
#0013       //  這只需往 front 方向看前一個 chunk 便知.
#0014       if (chunks_.size() > 1 &&
#0015           deallocChunk_[-1].blocksAvailable_ == numBlocks_) {
#0016         // 是的，有 2 free chunks, 拋棄最後一個
#0017         lastChunk.Release();
#0018         chunks_.pop_back();
#0019         allocChunk_ = deallocChunk_ = &chunks_.front();
#0020       }
#0021       return;
#0022     }
#0023
```




```
#0024     if (lastChunk.blocksAvailable_ == numBlocks_) {
#0025   ❷   //兩個 free chunks, 拋棄最後一個
#0026       lastChunk.Release();
#0027       chunks_.pop_back();
#0028       allocChunk_ = deallocChunk_;
#0029     }
#0030     else {
#0031   ❸   //將free chunk 與最後一個chunk 對調
#0032       std::swap(*deallocChunk_, lastChunk
#0033       allocChunk_ = &chunks_.back();
#0034     }
#0035   }
#0036 }
```

Loki allocator 檢討

- 曾經有兩個 bugs, 新版已修正.
- 精簡強悍; 手段暴力 (關於 for-loop).
- 使用「以 array 取代 list, 以 index 取代 pointer」的特殊實現手法.
- 能夠以很簡單的方式判斷「chunk 全回收」進而將 memory 歸還給操作系統.
- 有 Deferring (暫緩歸還) 能力
- 這是個 allocator，用來分配大量小塊不帶 cookie 的 memory blocks，它的最佳客戶是容器，但它本身卻使用 vector，What happens？雞生蛋 蛋生雞？

The End

內存管理

從平地到萬丈高樓

Memory Management 101

第一講 primitives
第二講 std::allocator
第三講 malloc/free
第四講 loki::allocator
第五講 other issues

侯捷