C++內存管理 101 – 從最基礎到最繁複

課程簡介

內存 (memory, 臺灣術語稱為 “記憶體”) 是電腦中的 “腦” 嗎？CPU 才是腦，CPU 才是計算機的三魂六魄。但若沒有內存，一切只存在於虛無縹緲間，等同於不存在。

內存曾經是最寶貴也最昂貴的週邊資源，現代程序員無法想像 DOS 時代對內存的錙銖必較。

俱往矣，且看今朝。我們(似乎)有用不完的便宜內存。但表象之下是操作系統和標準庫做了大量工作。而如果你開發內存高耗軟件，或處於內存受限環境下 (例如嵌入式系統)，就有必要深刻了解操作系統和標準庫為你所做的內存管理，甚至需要自行管理內存。

本課程分為六講：

第一講：Primitives

C++語言中與內存相關的所有基礎構件 (constructs)，包括 malloc/free, new/delete, operator new/operator delete, placement new/placement delete，我將探討它們的意義、運用方式和重載方式。並以此開發一個極小型內存池 (memory pool)。

第二講：std::allocator

標準庫的興起，意味我們可以擺脫內存管理的繁複瑣屑，直接使用容器。但是容器背後的分配器(allocator)攸關容器的速度效能和空間效能。我將比較 Visual C++, Borland C++, GNU C++標準庫中的 allocator，並深入探索其中最精巧的 GNU C++ allocator 的設計。

第三講：malloc/free

malloc/free 是所有內存管理手段的最後一哩；通過它才和操作系統搭上線。當然你也可以直接調用 system API，但不建議。因此理解 malloc/free 的內部管理至為重要。我將以 Visual C++ 的 CRT (C RunTime Library)所帶的 malloc/free 源代碼為基礎，深度探索這最基礎最關鍵的內存分配與釋放函數。

第四講：loki::allocator

即使知名如 GNU C++ pool allocator，也有其小缺陷。Loki (一套作風前沿的程序庫) 的 allocator 設計精簡功能完整幾無缺點，很值得我們深究。

第五講：其他主題

除了 std::allocator，GNU C++ 還帶不少 allocators，它們不是標準庫的一部分，可視為標準庫的擴充。我將探討這些擴充的 allocator，特別是 bitmap allocator。

我們談的不只是應用，還深入設計原理與實現手法。在理解了這麼多底層 (Windows Heap, CRT malloc/free, C++ new/delete, C++ allocators) 之後，也許你終於恍然大悟，再不需要自行管理內存了；或也許你終於有能力想像，該在何處以何種方式加強內存管理。

你將獲得整個 video 課程的完整講義 (也就是 video 呈現的每一張投影片畫面)，和一個完整程序包括代碼文件.cpp 和可執行文件.exe。你可以在視聽過程中隨時停格仔細閱讀講義，細細咀嚼我所繪製的各種示意圖和源代碼之間的流動路線——這的確很需要時間和腦力，卻能令你腦洞大開。

侯捷簡介：程序員，軟件工程師，臺灣工研院副研究員，教授。曾任教於中壢元智大學、上海同濟大學、南京大學。著有《無責任書評》三卷、《深入淺出 MFC》、《STL 源碼剖析》…，譯有《Effective C++》《More Effective C++》《C++ Primer》《The C++ Standard Library》…。

以下這份不算太細緻的主題劃分，協助您認識整個課程內容，以及在視聽過程中正確翻找講義。內中的編號就是講義的頁碼。

內存管理 101 – 從最基礎到最複雜

主題劃分

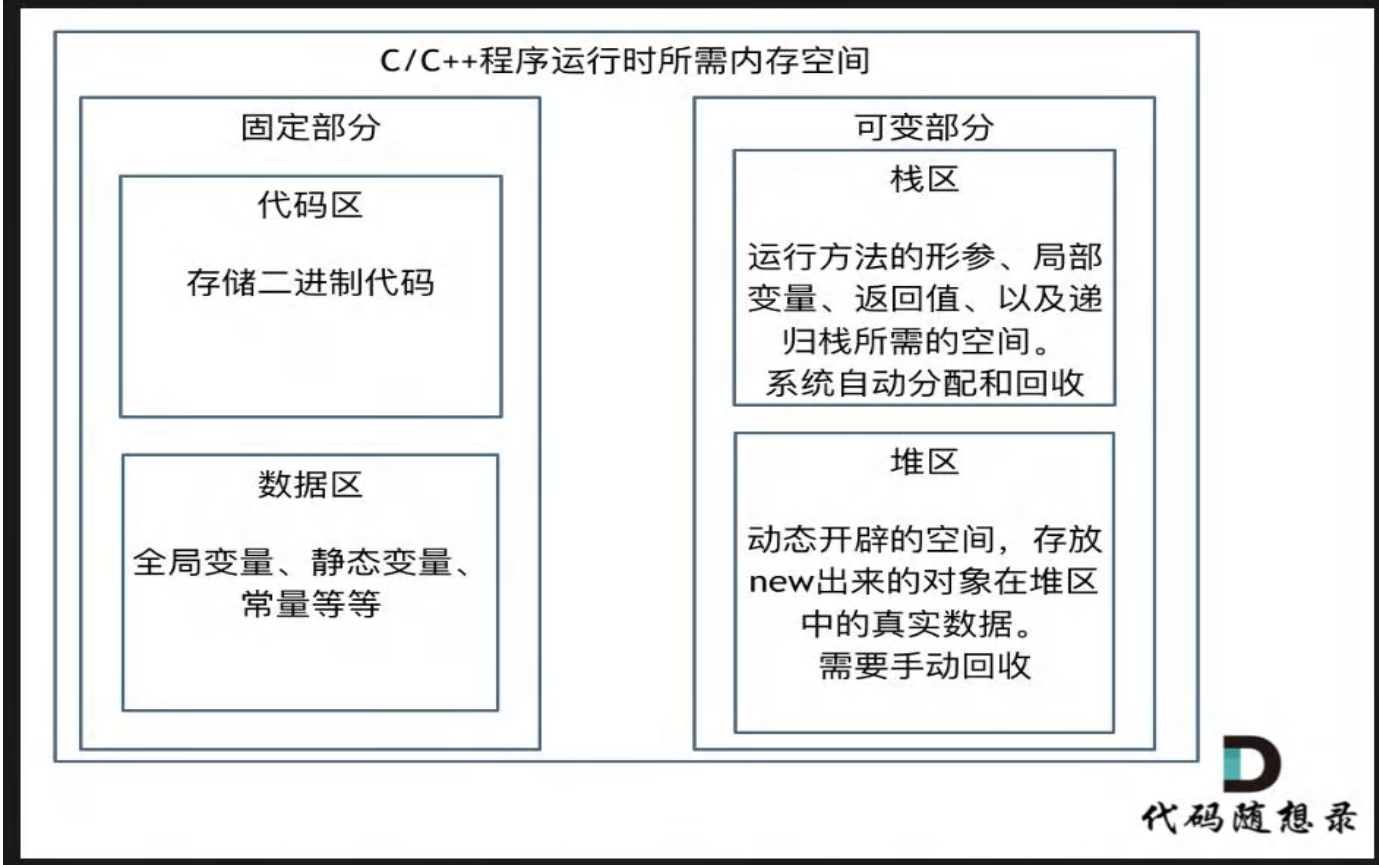
第一講：C++ 內存構件

-- the end

C++的内存管理

以C++为例来介绍一下编程语言的内存管理。

如果我们写C++的程序，就要知道栈和堆的概念，程序运行时所需的内存空间分为 固定部分，和可变部分，如下：



固定部分的内存消耗 是不会随着代码运行产生变化的， 可变部分则是会产生变化的

更具体一些，一个由C/C++编译的程序占用的内存分为以下几个部分：

- 栈区(Stack)： 由编译器自动分配释放，存放函数的参数值，局部变量的值等，其操作方式类似于数据结构中的栈。
- 堆区(Heap)： 一般由程序员分配释放，若程序员不释放，程序结束时可能由OS收回
- 未初始化数据区(Uninitialized Data)： 存放未初始化的全局变量和静态变量
- 初始化数据区(Initialized Data)：存放已经初始化的全局变量和静态变量
- 程序代码区(Text)：存放函数体的二进制代码

代码区和数据区所占空间都是固定的，而且占用的空间非常小，那么看运行时消耗的内存主要看可变部分。

在可变部分中，栈区间的数据在代码块执行结束之后，系统会自动回收，而堆区间数据是需要程序员自己回收，所以也就是造成内存泄漏的发源地。

如何计算程序占用多大内存

想要算出自己程序会占用多少内存就一定要了解自己定义的数据类型的大小，如下：

C/C++的数据类型大小　　$2^{32}=4294967296$

32位编译器：

char	short	int	long	float	double	指针	
1	2	4	4	4	8	4	（单位）Byte

64位编译器：

char	short	int	long	float	double	指针	
1	2	4	8	4	8	8	（单位）Byte

注意图中有两个不一样的地方，为什么64位的指针就占用了8个字节，而32位的指针占用4个字节呢?

1个字节占8个比特，那么4个字节就是32个比特，可存放数据的大小为2^32，也就是4G空间的大小，即：可以寻找4G空间大小的内存地址。

大家现在使用的计算机一般都是64位了，所以编译器也都是64位的。

安装64位的操作系统的计算机内存都已经超过了4G，也就是指针大小如果还是4个字节的话，就已经不能寻址全部的内存地址，所以64位编译器使用8个字节的指针才能寻找所有的内存地址。

注意2^64是一个非常巨大的数，对于寻找地址来说已经足够用了。

内存对齐

再介绍一下内存管理中另一个重要的知识点：**内存对齐**。
而且这是面试中面试官非常喜欢问到的问题，就是：**为什么会有内存对齐?**

主要是两个原因

1. 平台原因：不是所有的硬件平台都能访问任意内存地址上的任意数据，某些硬件平台只能在某些地址处取某些特定类型的数据，否则抛出硬件异常。为了同一个程序可以在多平台运行，需要内存对齐。

2. 硬件原因：经过内存对齐后，CPU访问内存的速度大大提升。

```
struct node{
   int num;
   char cha;
}st;
int main() {
    int a[100];
    char b[100];
    cout << sizeof(int) << endl;    4
    cout << sizeof(char) << endl;   1
    cout << sizeof(a) << endl;      400
    cout << sizeof(b) << endl;      100
    cout << sizeof(st) << endl;     8
}
```

此时会发现，和单纯计算字节数的话是有一些误差的。

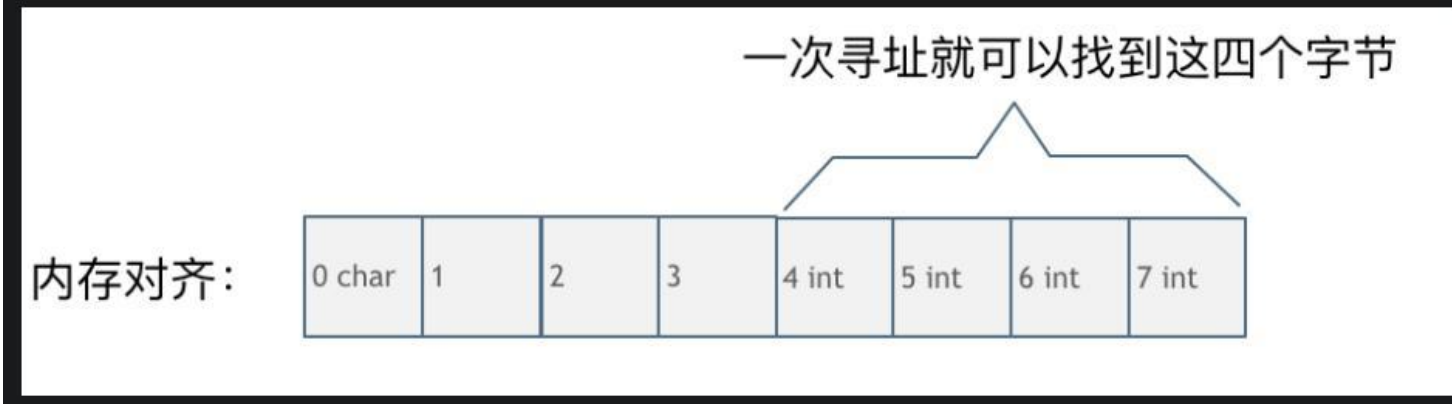
这就是因为内存对齐的原因。

来看一下内存对齐和非内存对齐产生的效果区别。

CPU读取内存不是一次读取单个字节，而是一块一块的来读取内存，块的大小可以是2，4，8，16个字节，具体取多少个字节取决于硬件。

假设CPU把内存划分为4字节大小的块，要读取一个4字节大小的int型数据，来看一下这两种情况下CPU的工作量：

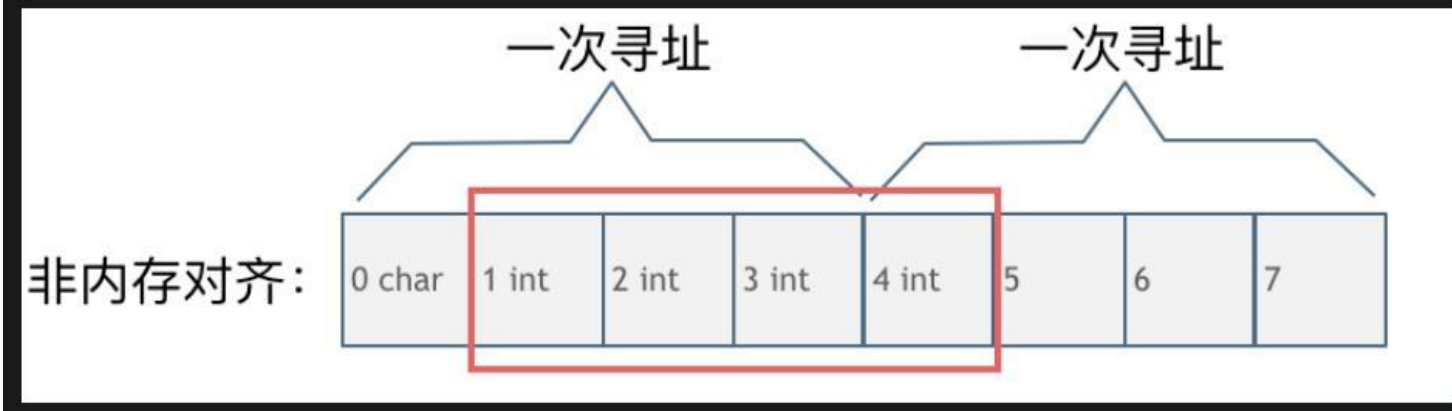
第一种就是内存对齐的情况，如图：



一字节的char占用了四个字节，空了三个字节的内存地址，int数据从地址4开始。

此时，直接将地址4，5，6，7处的四个字节数据读取到即可。

第二种是没有内存对齐的情况如图：



char型的数据和int型的数据挨在一起，该int数据从地址1开始，那么CPU想要读这个数据的话来看看需要几步操作：

1. 因为CPU是四个字节四个字节来寻址，首先CPU读取0，1，2，3处的四个字节数据
2. CPU读取4，5，6，7处的四个字节数据
3. 合并地址1，2，3，4处四个字节的数据才是本次操作需要的int数据

此时一共需要两次寻址，一次合并的操作。

大家可能会发现内存对齐岂不是浪费的内存资源么？

是这样的，但事实上，相对来说计算机内存资源一般都是充足的，我们更希望的是提高运行速度。

编译器一般都会做内存对齐的优化操作，也就是说当考虑程序真正占用的内存大小的时候，也需要认识到内存对齐的影响。

內存管理

從平地到萬丈高樓

Memory Management 101

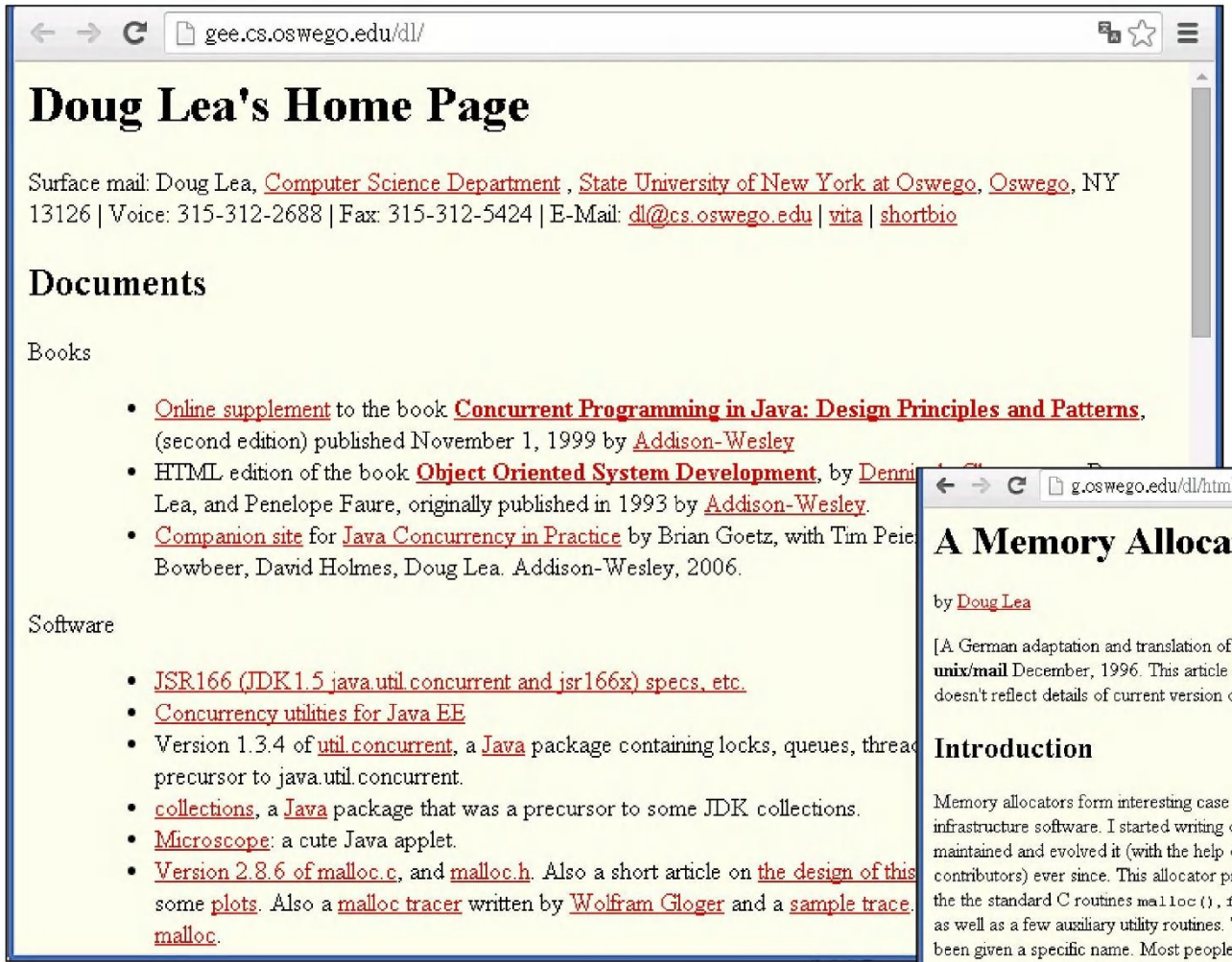
第一講 **primitives**
第二講 **std::allocator**
第三講 **malloc/free**
第四講 **loki::allocator**
第五講 **other issues**

侯捷

萬丈高樓平地起

源碼之前
了無秘密

網絡有許多資源 …



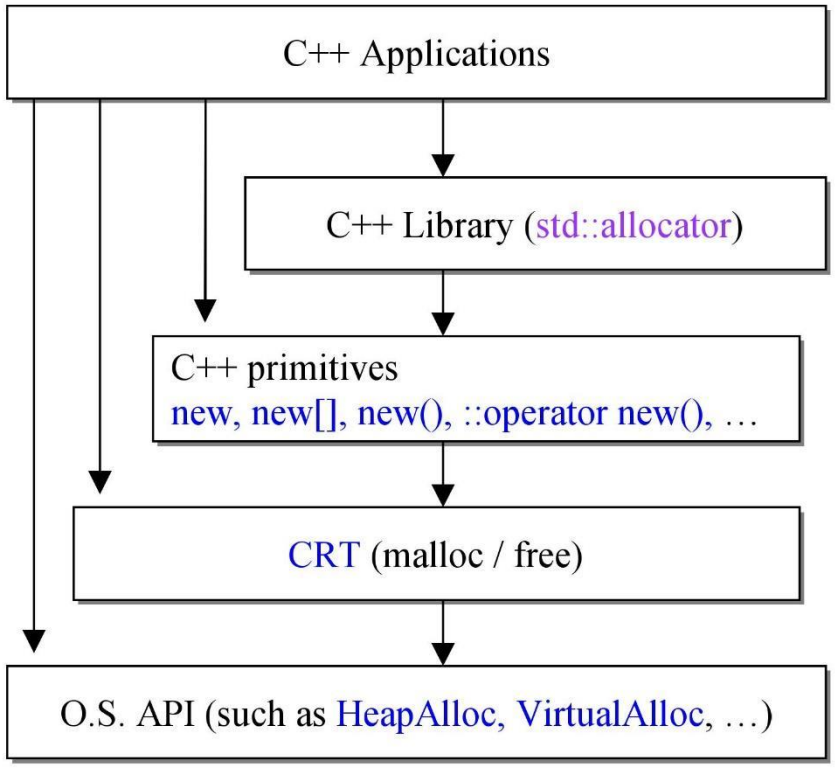
Doug Lea 自1986年起潛心研究 malloc 算法，其作品被稱爲 DL Malloc。目前 Linux 的 glibc 中的 malloc 算法就是直接來自Doug Lea，其他平台的 malloc 實現也或多或少受到 DL 的影響。 DL Malloc 源碼可下載自Doug Lea 個人主頁：
http://gee.cs.oswego.edu/dl/

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);
}
```

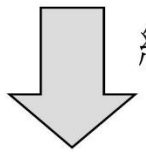
... \vc98\crt\src\newop2.cpp

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  };
```

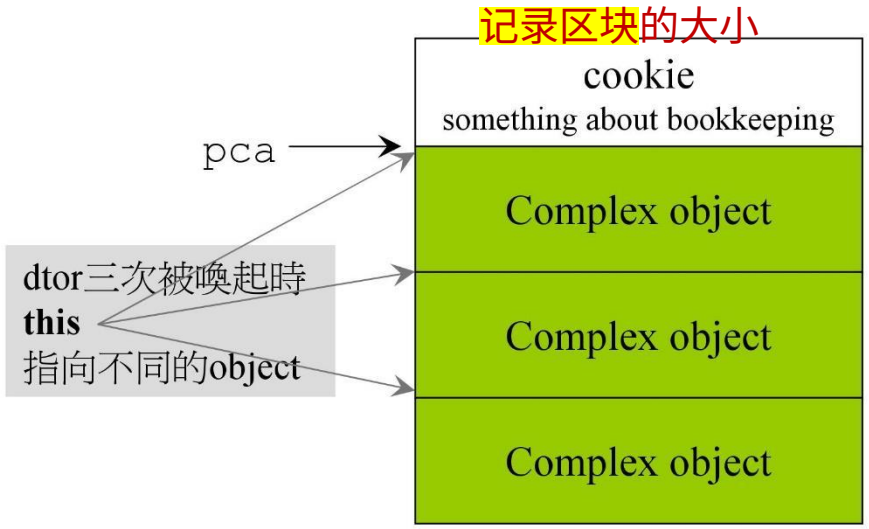
```
107      A* pA = new A(1);           //ctor. this=000307A8 id=1
108      cout << pA->id << endl;     //1
109  //! pA->A::A(3);               //in VC6 : ctor. this=000307A8 id=3
110                                  //in GCC : [Error] cannot call constructor 'jj02::A::A' directly
111
112  //! A::A(5);                   //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

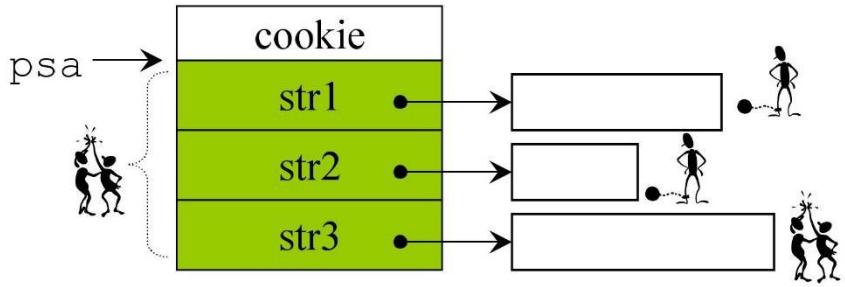
```
Complex* pca = new Complex[3];
//喚起三次ctor。
//無法藉由參數給予初值
...
delete[] pca; //喚起3次dtor
```

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
```

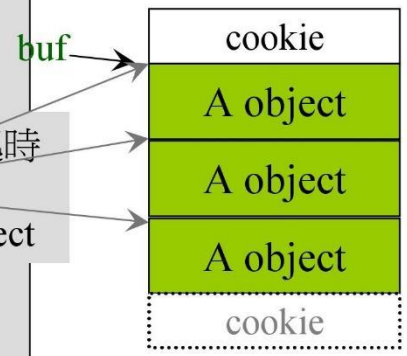


array new, array delete

```
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
```

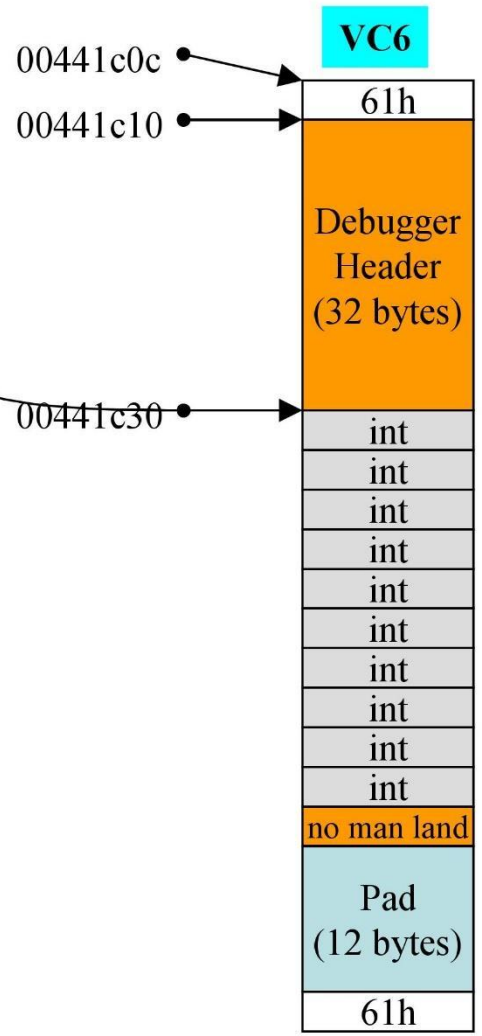
```
A* buf = new A[size];  //default ctor 3 次. [0]先於[1]先於[2])
                       //A必須有 default ctor,
                       //否則 [Error] no matching function for call to 'A::A()'
A* tmp = buf;

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

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



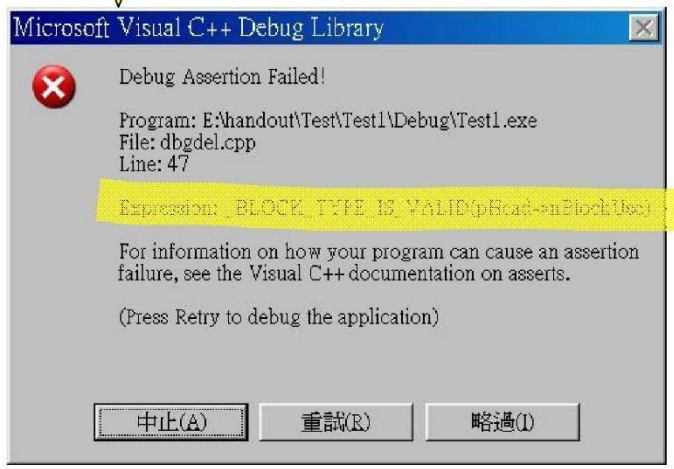

```
int ia[10];              //from stack but not heap
cout << sizeof(ia);      //40
```

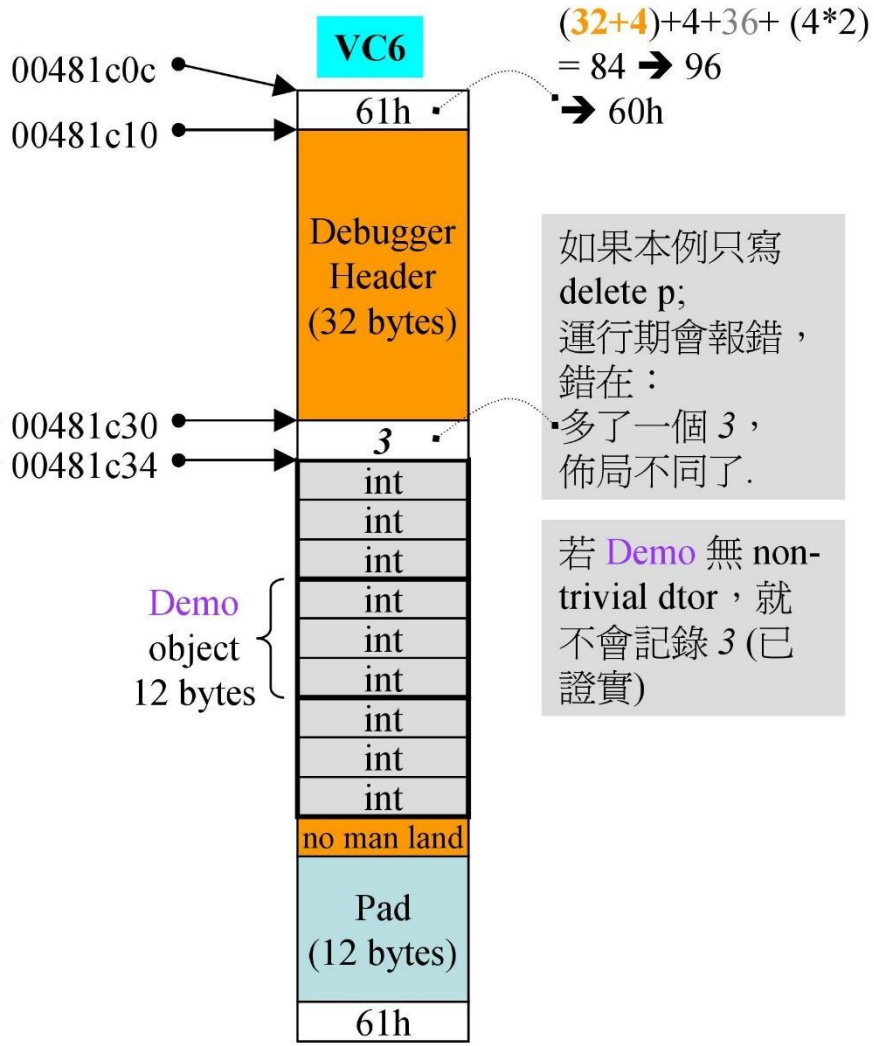
array size, in memory block

```
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
```

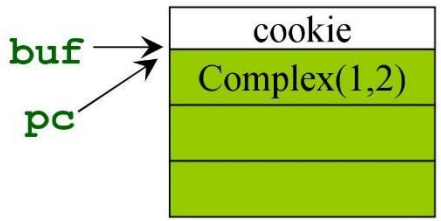
placement new

等同调用构造函数

- 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;  //
```

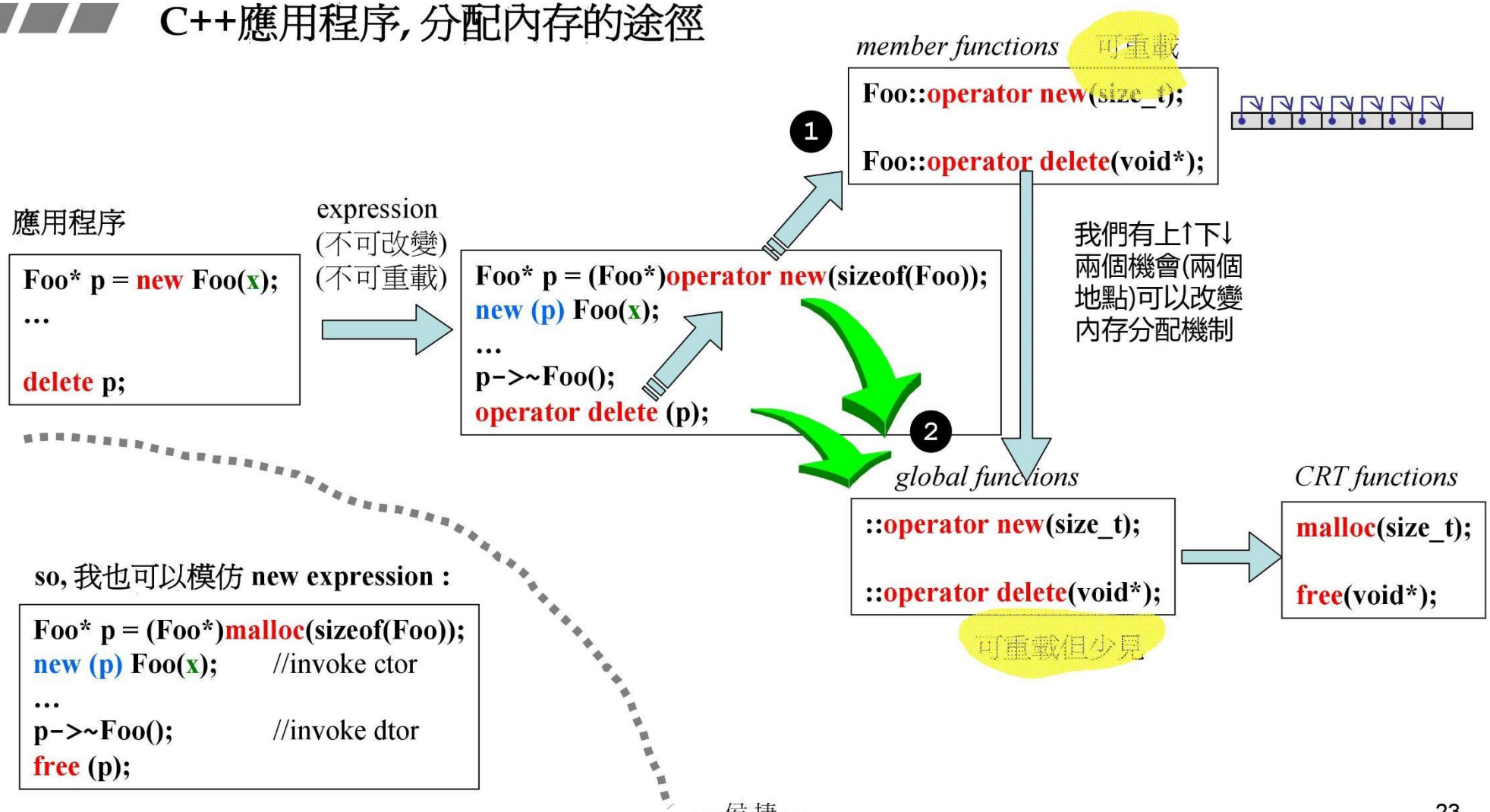


編譯器轉爲

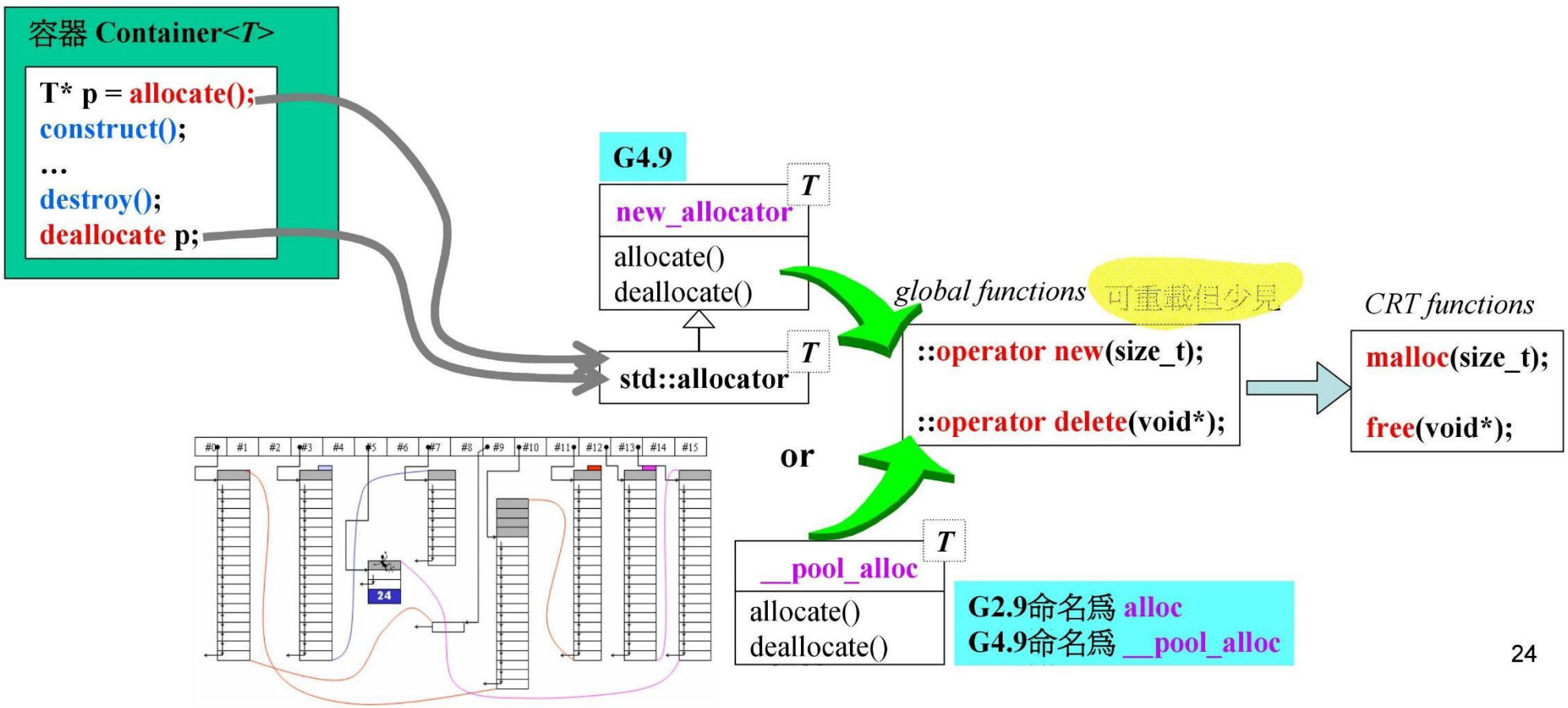
```
void* operator new(size_t, void* loc)
{ return loc; }
```

```
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

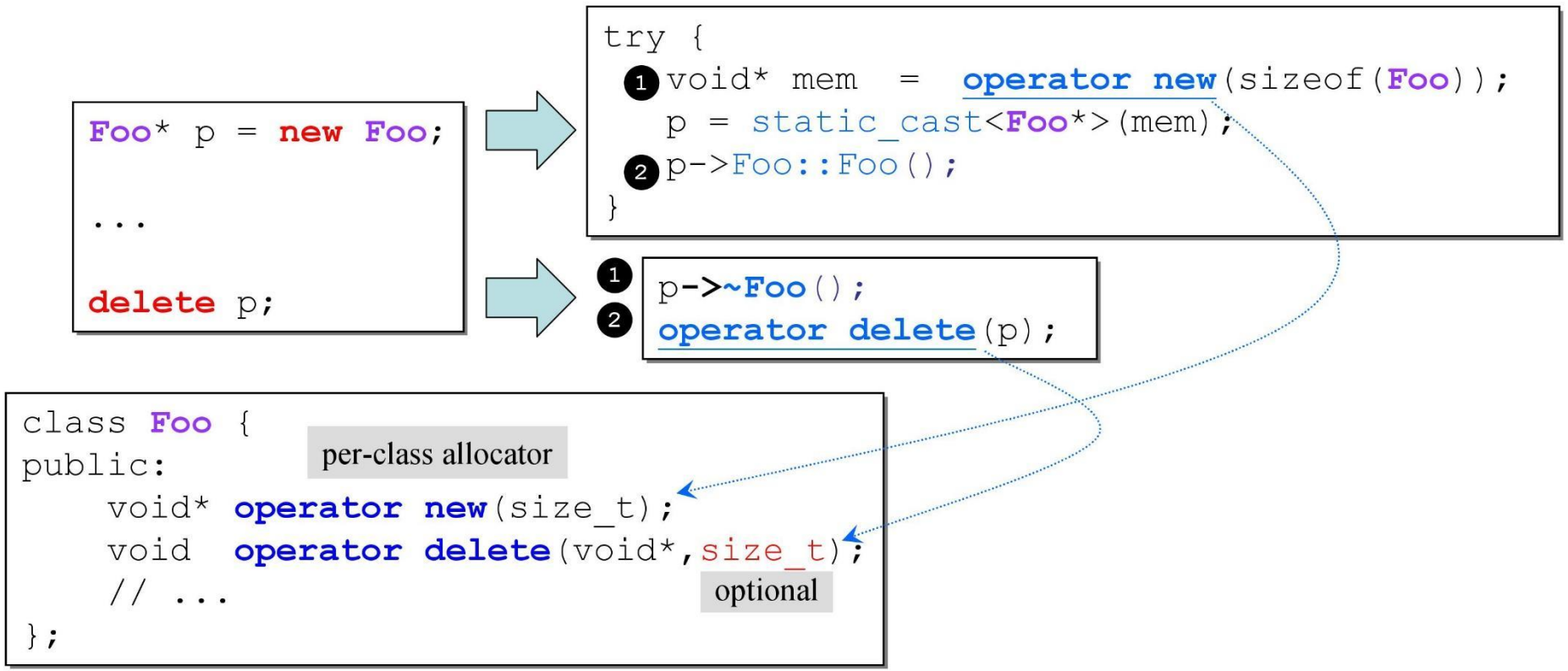
```
void* operator new(size_t size, const std::nothrow_t&)
                                    _THROW0()
{   // try to allocate size bytes
void *p;
while ((p = malloc(size)) == 0)
  { // buy more memory or return null pointer
    _TRY_BEGIN
        if (_callnewh(size) == 0)  break;
    _CATCH(std::bad_alloc)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

類內重載



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
}
```

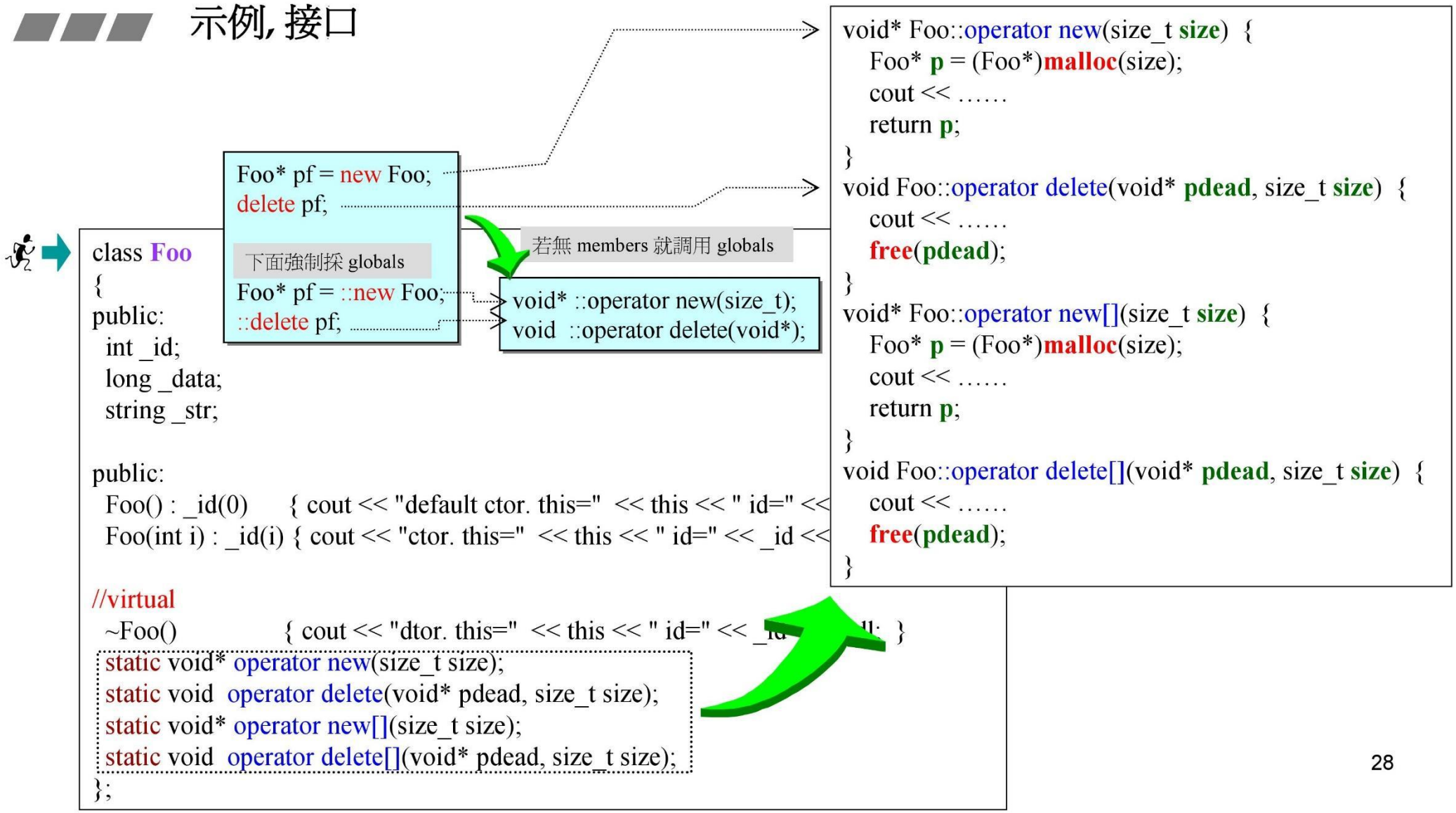
```
1 p->~Foo(); //N 次
2 operator delete(p);
```

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

per-class allocator

optional

示例, 接口

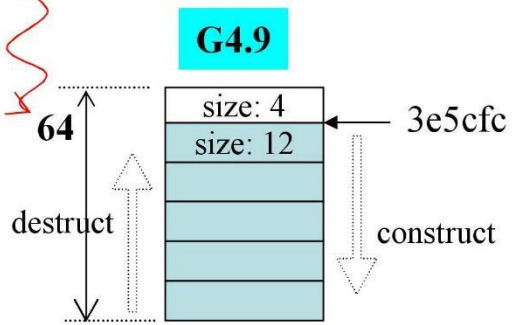

Foo* pf = new Foo;
delete pf;
下面強制採 globals
Foo* pf = ::new Foo;
::delete pf;
若無 members 就調用 globals
void* ::operator new(size_t);
void ::operator delete(void*);
class Foo
{
public:
int _id;
long _data;
string _str;
public:
Foo() : _id(0) { cout << "default ctor. this=" << this << " id=" <<
Foo(int i) : _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;
```

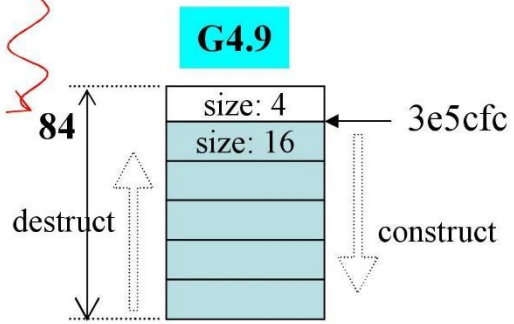
Foo without virtual dtor

```
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
```



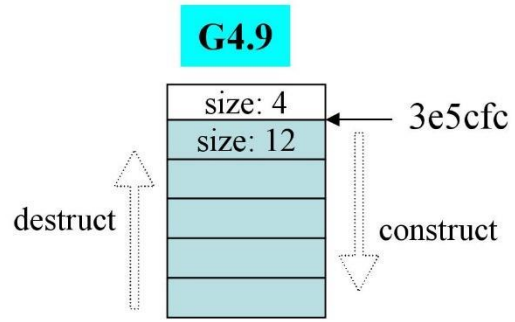
示例

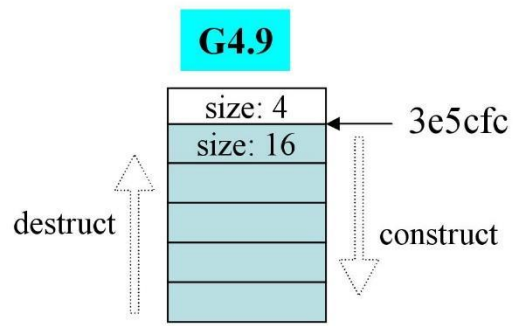
```
1 Foo* p = ::new Foo(7);
2 ::delete p;

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()

在已分配的特定内存创建对象
是c++实现的operator new版本

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.

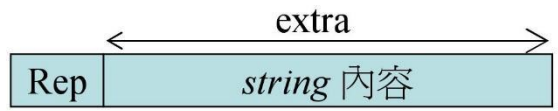
VC6 warning C4291: 'void *__cdecl Foo::operator new(~~~)' no matching operator delete found; memory will not be freed if initialization throws an exception

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;
}
```



内存管理 内存池

per-class allocator, 1

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

减少malloc调用
先分配一大块内存再切

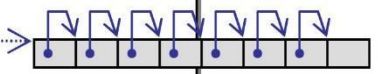
```
#include <cstddef>
#include <iostream>
using namespace std;

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;
```

这種設計會引發多耗用一個 next 的疑慮。下頁設計更好

但多了个指针

```
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;
}
```

链表



```
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);
}
```

沒有對應的 delete，
但這不算是 memory leak.

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

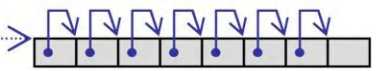
ref. Effective C++ 2e, item10

```
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。

嵌入式指针 借用前四个字节当指针

```
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;
}
```

未还内存 但未泄漏 还在手上

```
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

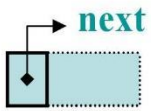
```
8
0x3e4900 A 1000
0x3e4930 B 2000
0x3e4970 C 500000
0x3e4910
0x3e4900
0x3e48f0
0x3e48e0
0x3e4920
0x3e4930
0x3e4940
0x3e4950
0x3e4960
0x3e4970
```

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

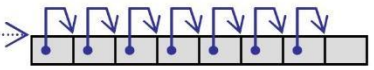
static allocator

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

专属于class

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;
```

指针指着链表

```
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];
}
```

```
sizeof(Foo)= 8
0x3e5f90 0
0x3e5f98 1
0x3e5fa0 2
0x3e5fa8 3
0x3e5fb0 4
0x3e5d40 5
0x3e5d48 6
0x3e5d50 7
0x3e5d58 8
0x3e5d60 9
0x3e6080 10
0x3e6088 11
0x3e6090 12
0x3e6098 13
0x3e60a0 14
0x3e6128 15
0x3e6130 16
0x3e6138 17
0x3e6140 18
0x3e6148 19
0x3e61d0 20
0x3e61d8 21
0x3e61e0 22
```

```
sizeof(Goo)= 24
0x3e6200 (0,0)
0x3e6218 (1,1)
0x3e6230 (2,2)
0x3e6248 (3,3)
0x3e6260 (4,4)
0x3e6498 (5,5)
0x3e64b0 (6,6)
0x3e64c8 (7,7)
0x3e64e0 (8,8)
0x3e64f8 (9,9)
0x3e6518 (10,10)
0x3e6530 (11,11)
0x3e6548 (12,12)
0x3e6560 (13,13)
0x3e6578 (14,14)
0x3e6598 (15,15)
0x3e65b0 (16,16)
```

每五个均相邻

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)
```

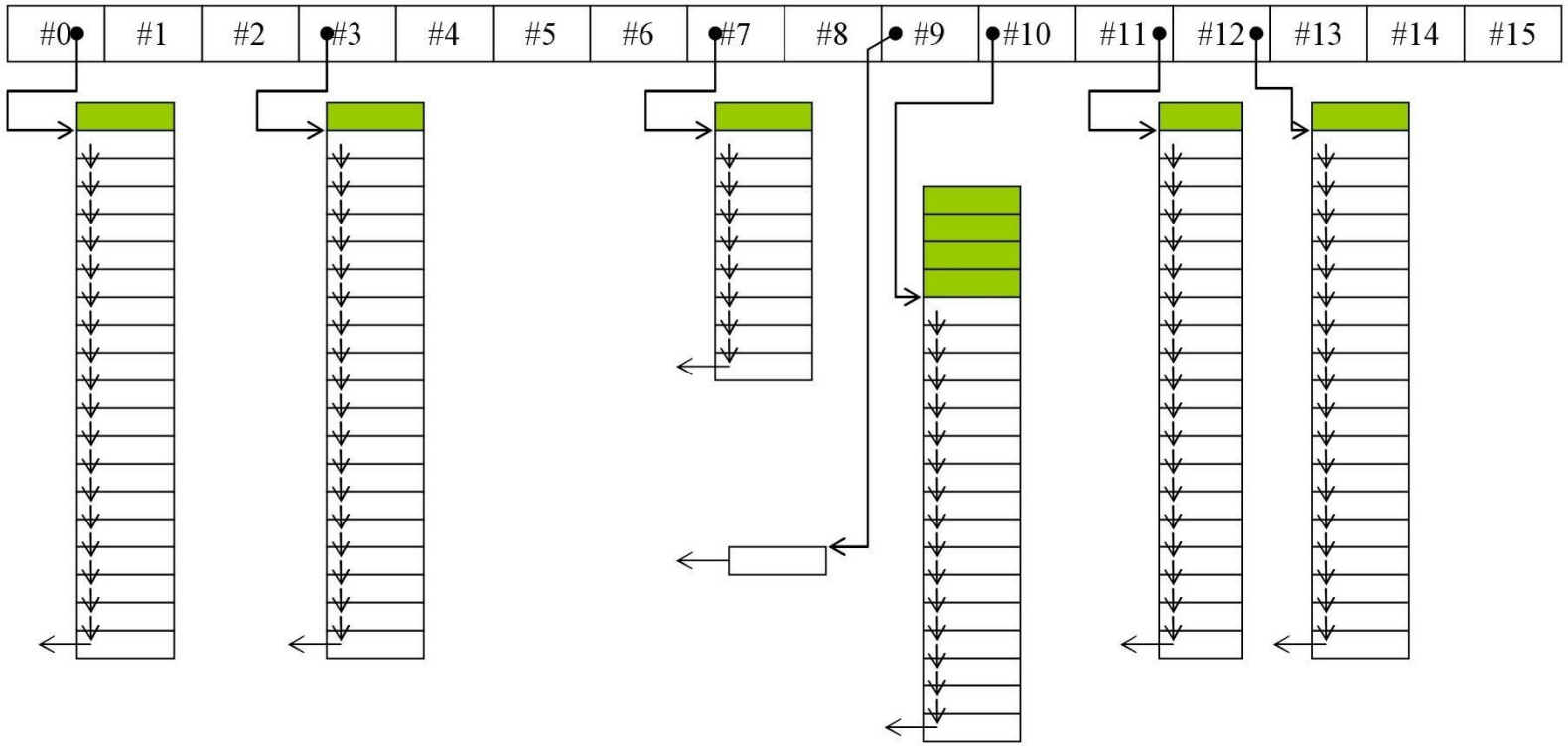
macro for static allocator,示例與結果

```
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

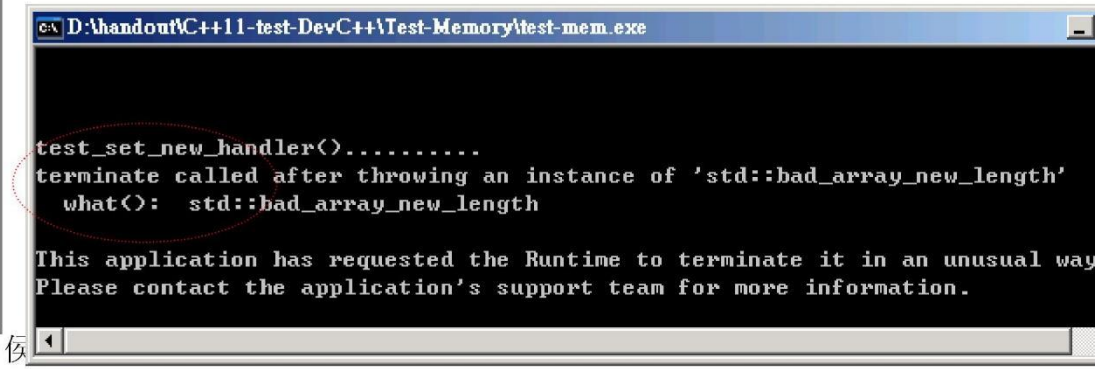
```
#include <new>
#include <iostream>
#include <cassert>
using namespace std;

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;
};
```

內存管理

從平地到萬丈高樓

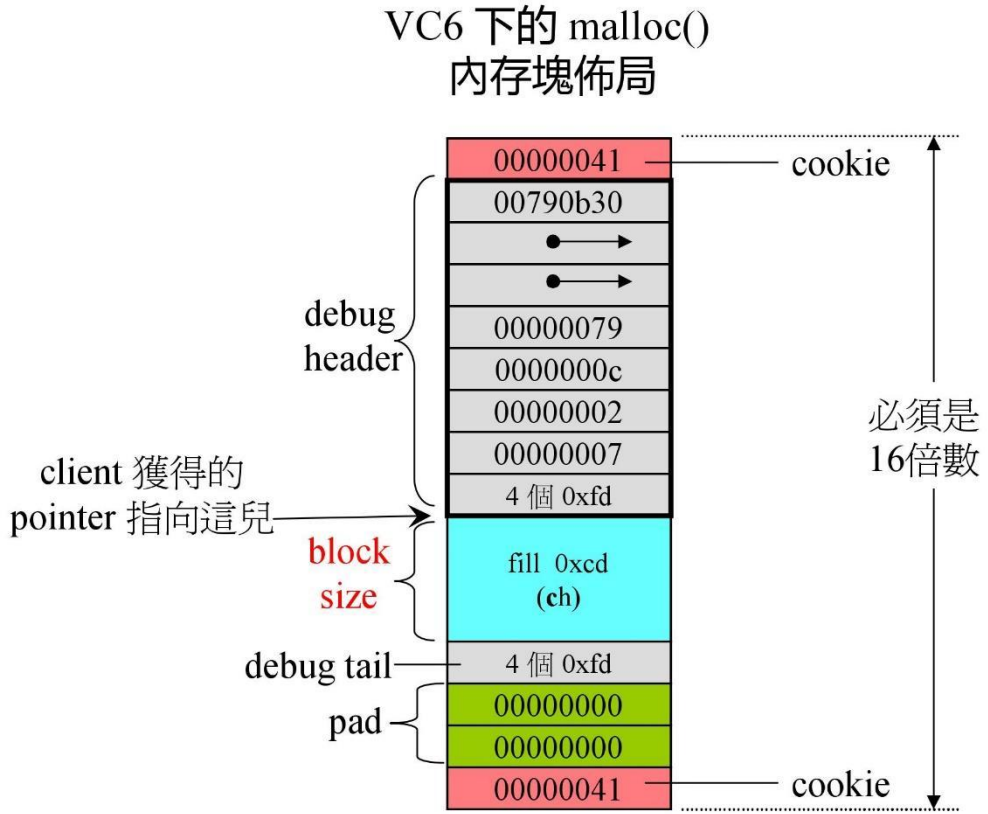
Memory Management 101

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>）

没有做内存管理
只是malloc

```
#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

沒有做內存管理
只是malloc

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

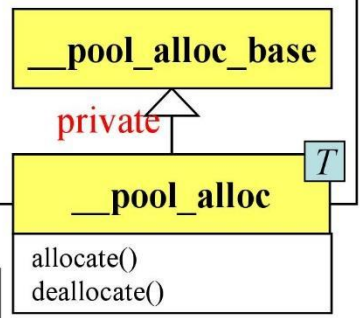
G4.9 標準庫中有許多 extented allocators,
其中 __pool_alloc 就是 G2.9 alloc 的化身.

G4.9

```
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;
  ...
```

用例：

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




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

— 侯 捷 —

G2.9

```
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;
…
```

用例：

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

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

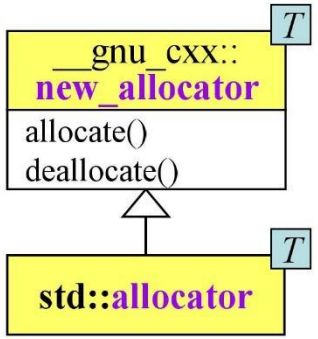
```
template<typename _Tp>                    <…/bits/new_allocator.h>
class new_allocator
{
  ...
  pointer allocate(size_type __n, const void* = 0) {
    if (__n > this->max_size())
      std::__throw_bad_alloc();
    return static_cast<_Tp*>
      (::operator new(__n * sizeof(_Tp)));
  }

  void deallocate(pointer __p, size_type)
  { ::operator delete(__p); }
  ...
};
```

G4.9 的 **allocator** 只是以 ::operator new 和 ::operator delete 完成 allocate() 和 deallocate()，沒有任何特殊設計。

```
# define __allocator_base  __gnu_cxx::new_allocator
```

```
template<typename _Tp>                    <…/bits/allocator.h>
class allocator: public __allocator_base<_Tp>
{
  ...
};
```

— 侯 捷 —




```
template<typename _Tp,
         typename _Alloc = std::allocator<_Tp>>
class vector : protected _Vector_base<_Tp, _Alloc>
{ ... };
```

```
template<typename _Tp,
         typename _Alloc = std::allocator<_Tp>>
class list : protected _List_base<_Tp, _Alloc>
{ … };
```

```
template<typename _Tp,
         typename _Alloc = std::allocator<_Tp>>
class deque : protected _Deque_base<_Tp, _Alloc>
{ … };
```

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)
```

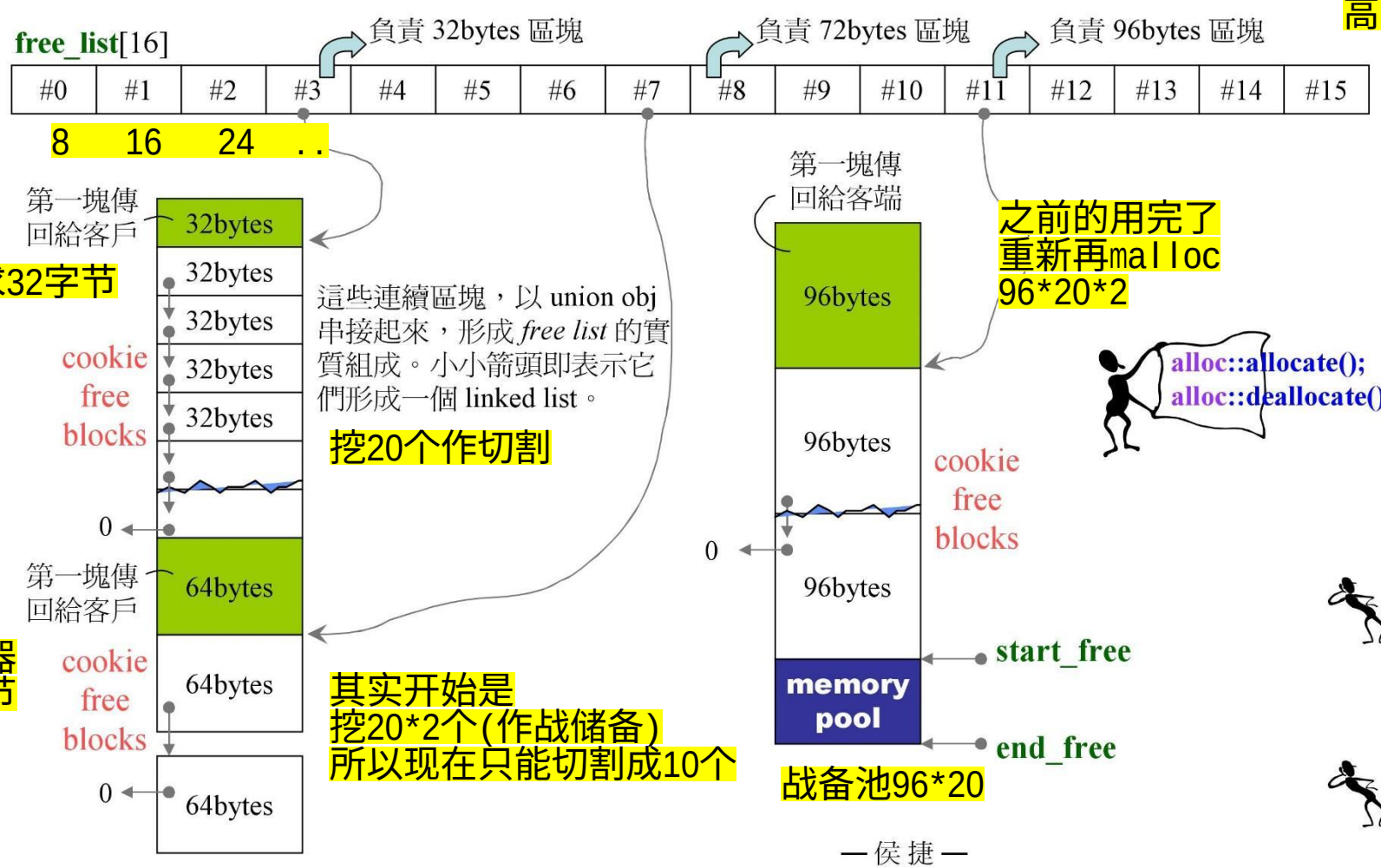
```
p1= 0xae4138   p2= 0xae4140   p3= 0xae4148
```

```
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



容器要求32字节

挖20个作切割

又一个容器要求64字节

其实开始是
挖20*2个(作战储备)
所以现在只能切割成10个

战备池96*20

之前的用完了
重新再malloc
96*20*2

高于上限128则直接调用malloc

```
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 { ... };
```

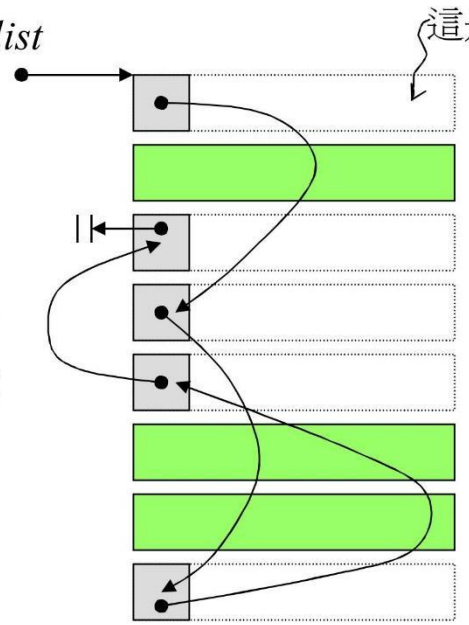
容器发出的需求会自动调到8的边界

— 侯 捷 —

embedded pointers

嵌入式指针

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。



给容器前借用前四个为指针
给容器后可覆盖
归还时再借用前四个字节为指针 加入单向链表

：已給客戶

：被管理中

object多半大于四个字节

改用 struct 可

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

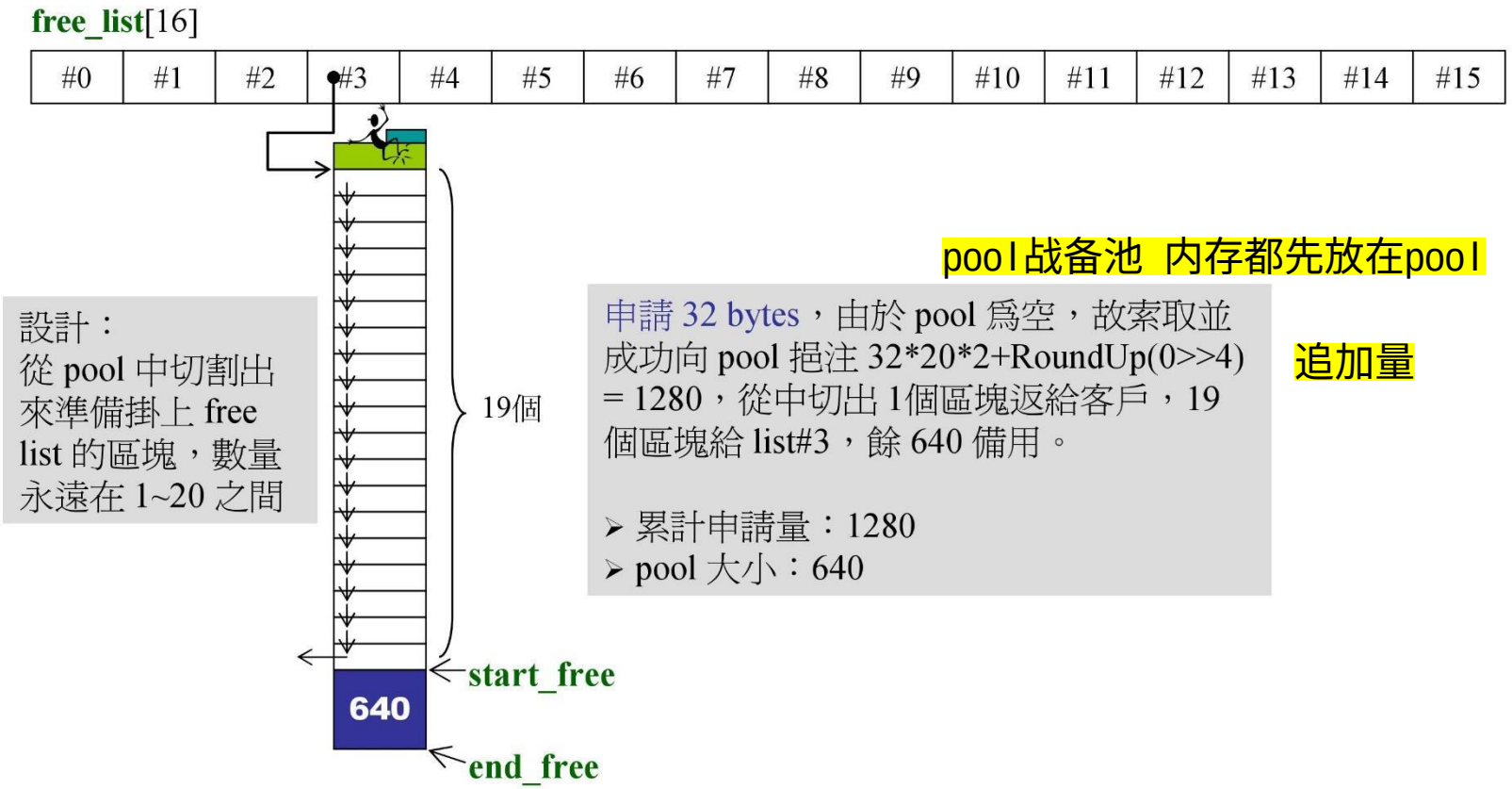
G2.9 std::alloc 運行一瞥.01

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

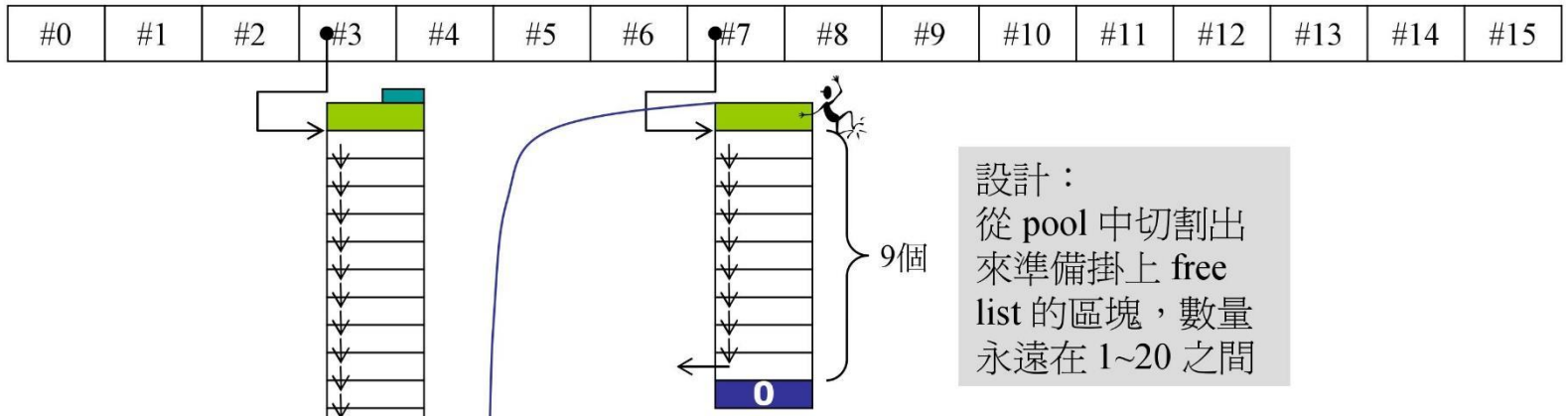
申請 32 bytes，由於 pool 爲空，故索取並成功向 pool 挹注 32*20*2+RoundUp(0>>4) = 1280，從中切出 1個區塊返給客戶，19個區塊給 list#3，餘 640 備用。

- 累計申請量：1280
- pool 大小：640

pool战备池 内存都先放在pool

追加量

G2.9 std::alloc 運行一瞥.03

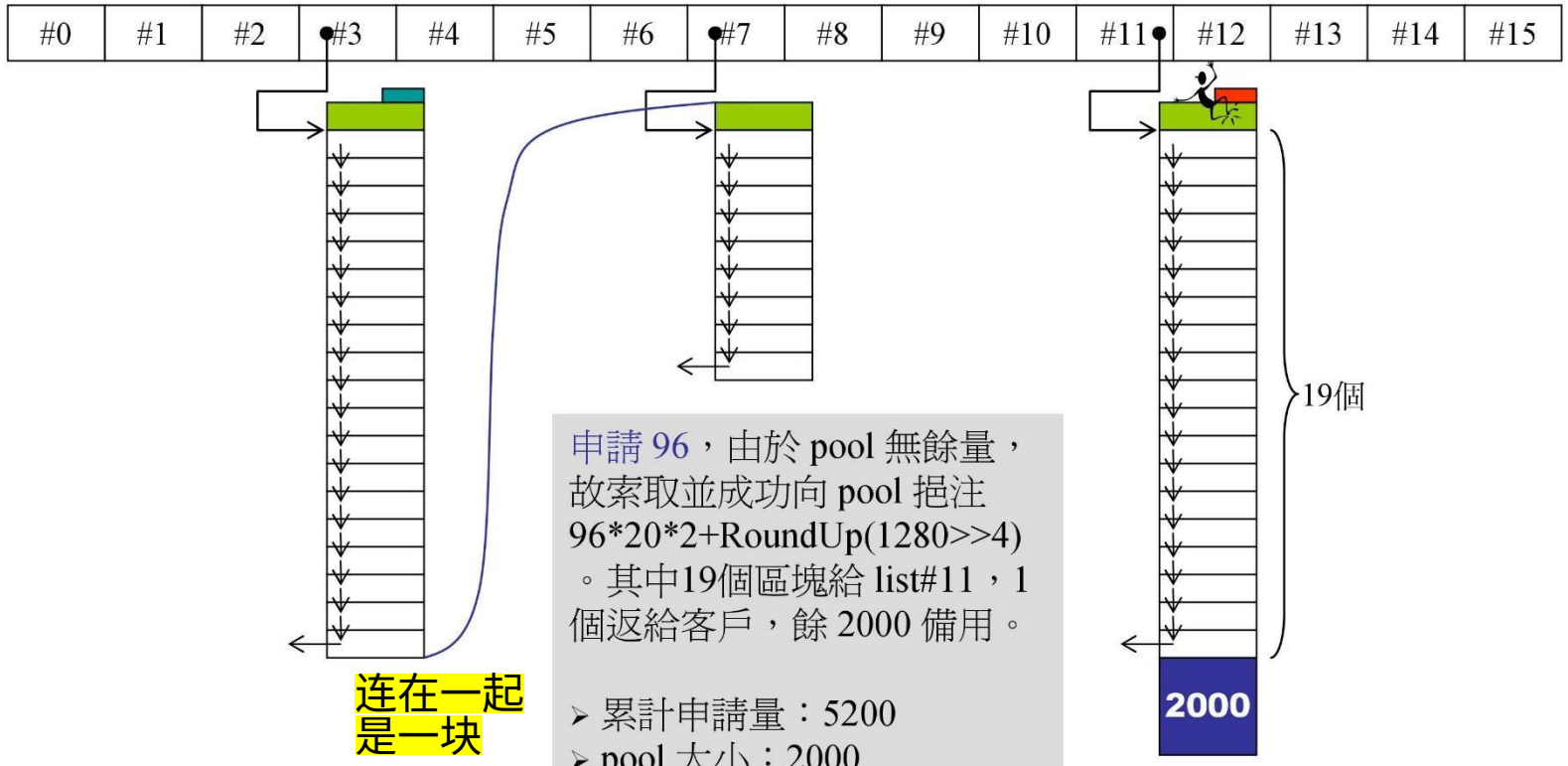


設計：
從 pool 中切割出來準備掛上 free list 的區塊，數量永遠在 1~20 之間

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

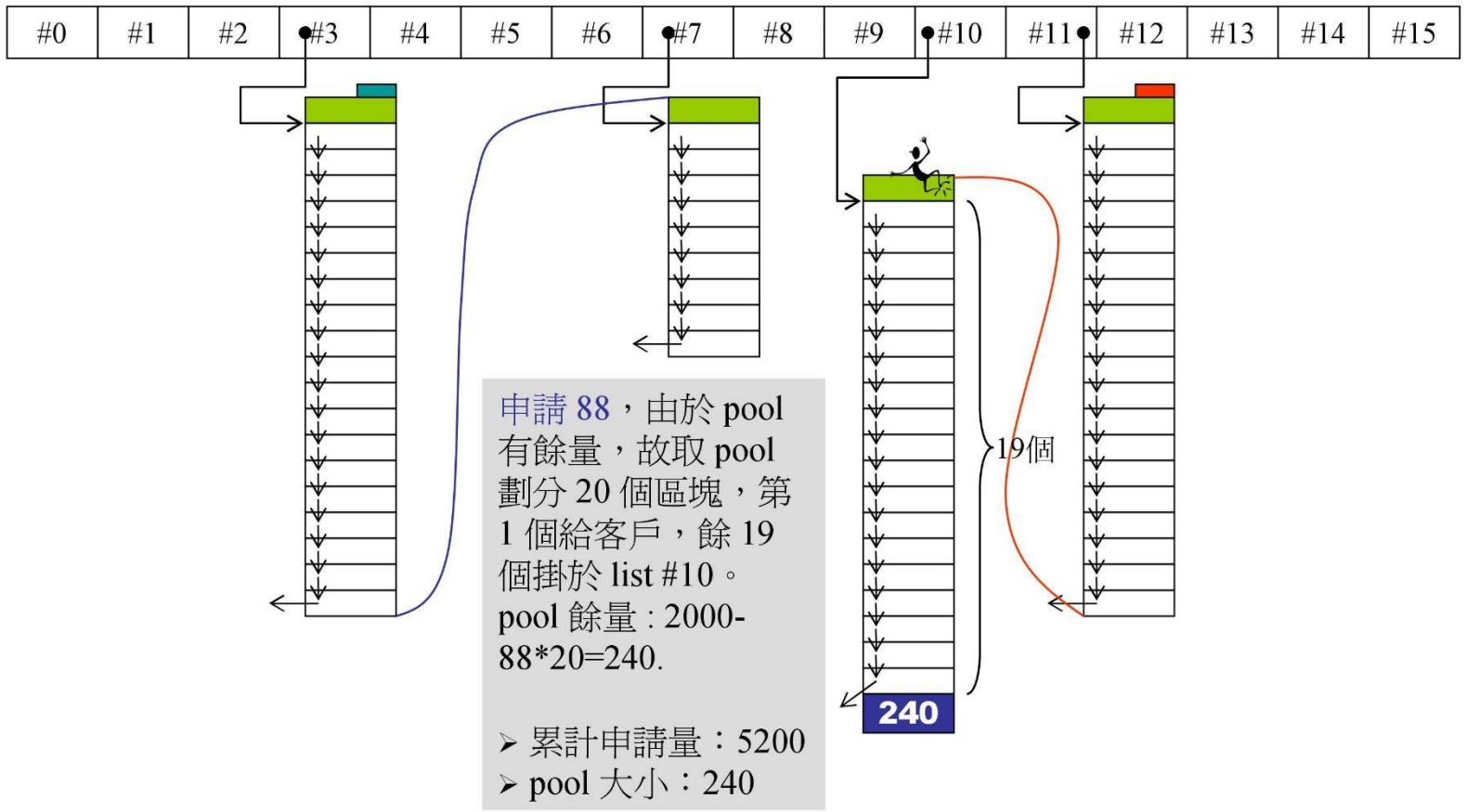
G2.9 std::alloc 運行一瞥.04



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

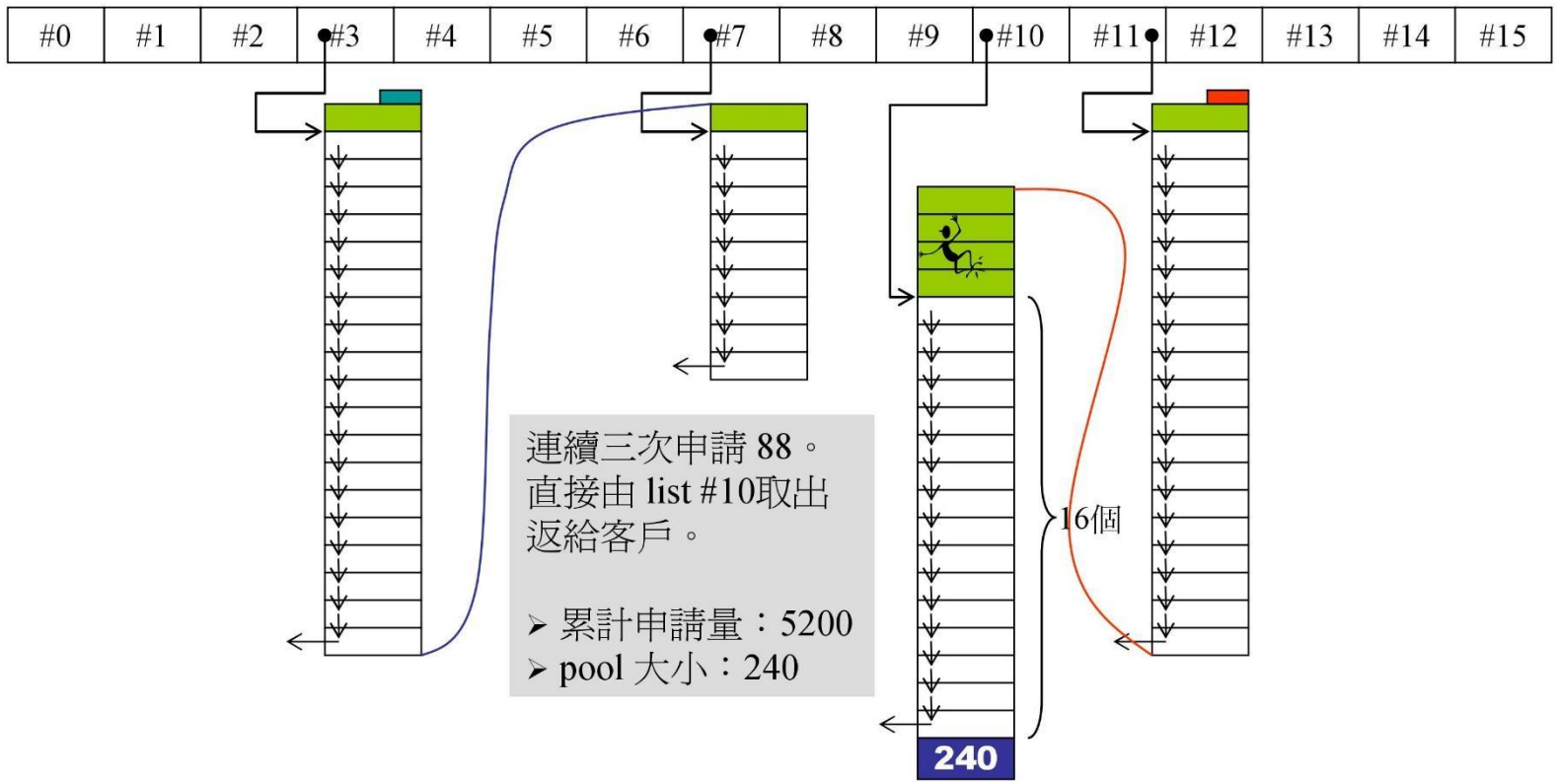
G2.9 std::alloc 運行一瞥.05



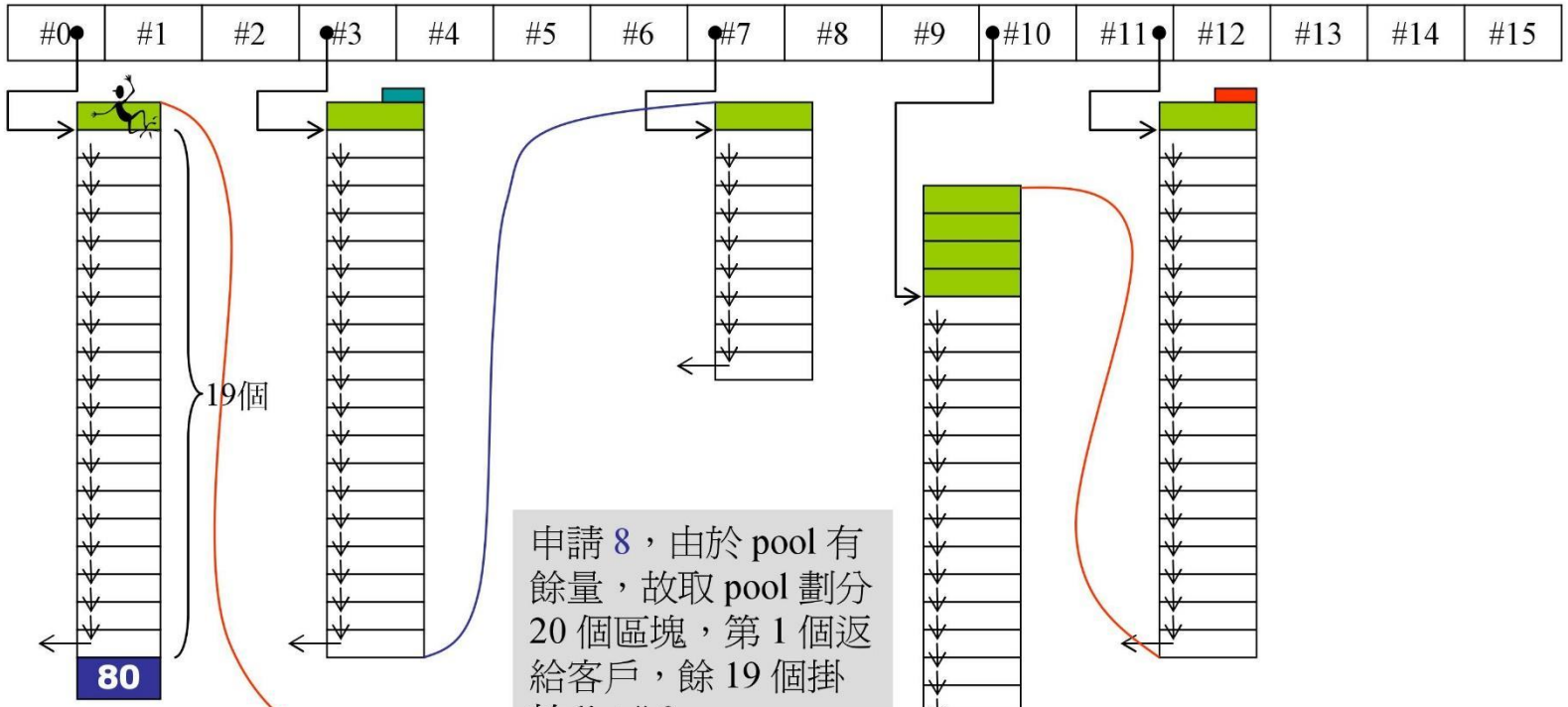
申請 88，由於 pool 有餘量，故取 pool 劃分 20 個區塊，第 1 個給客戶，餘 19 個掛於 list #10。
pool 餘量 : 2000-88*20=240.

- 累計申請量：5200
- pool 大小：240

G2.9 std::alloc 運行一瞥.06



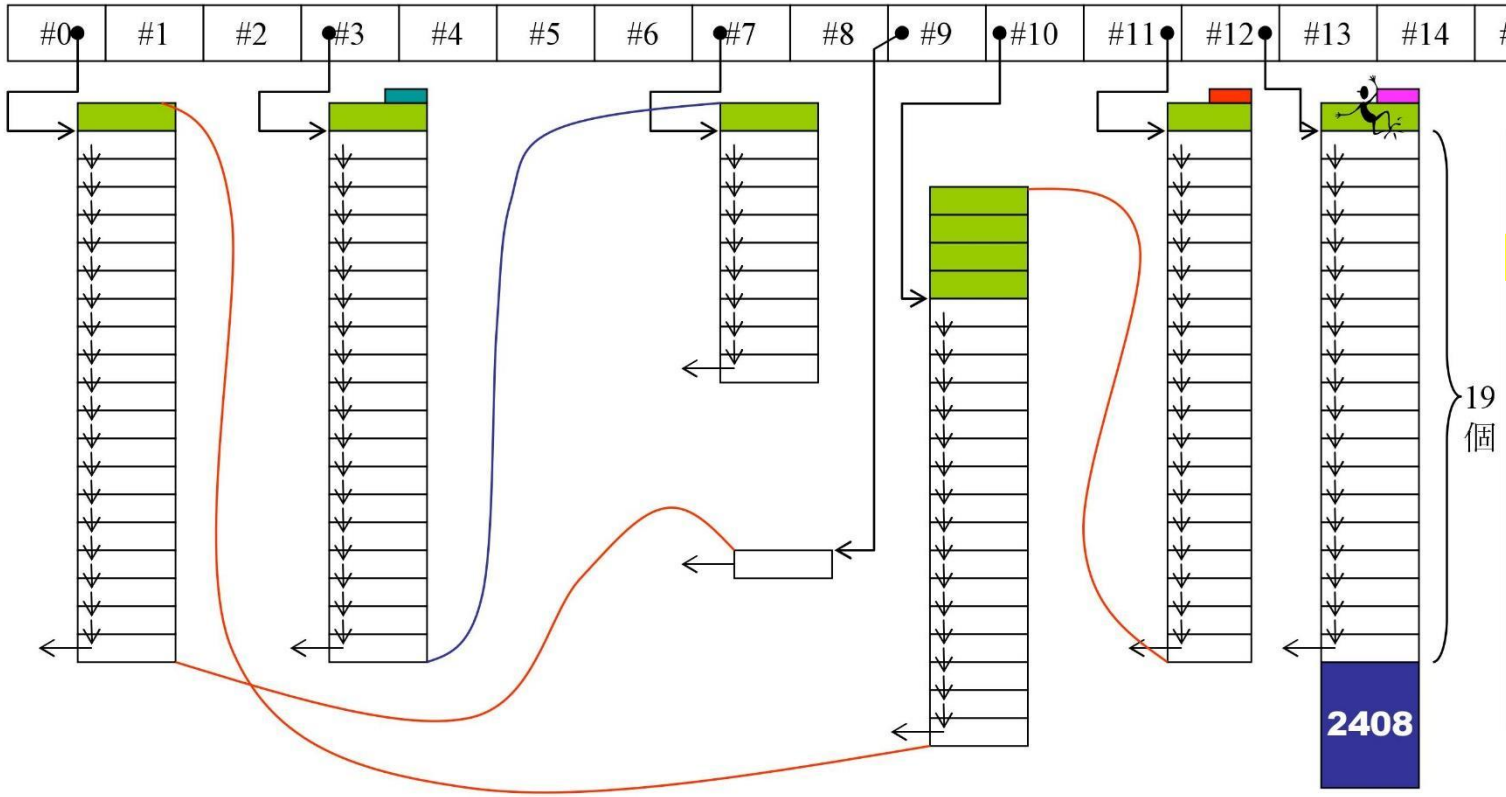
G2.9 std::alloc 運行一瞥.07



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

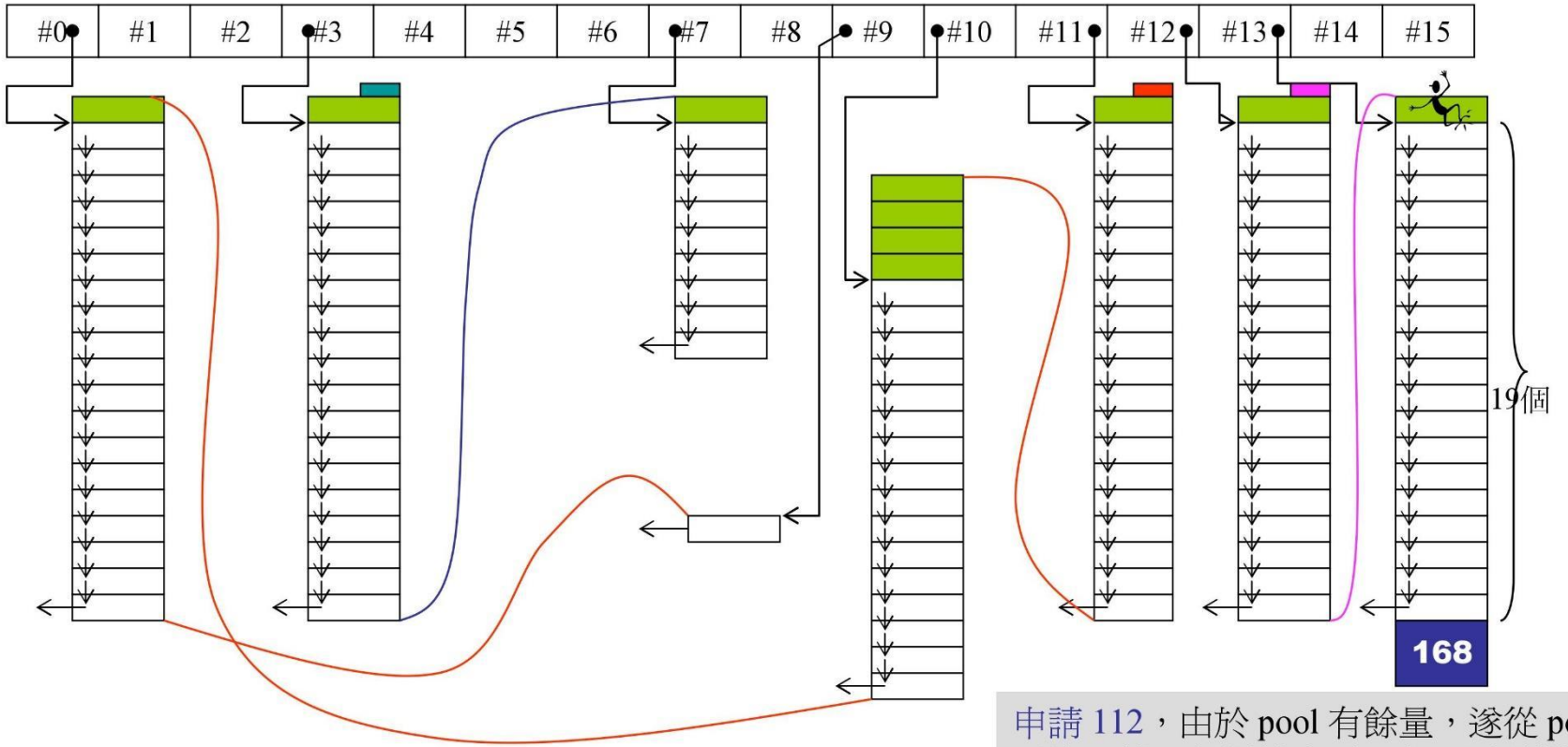
G2.9 std::alloc 運行一瞥.08



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

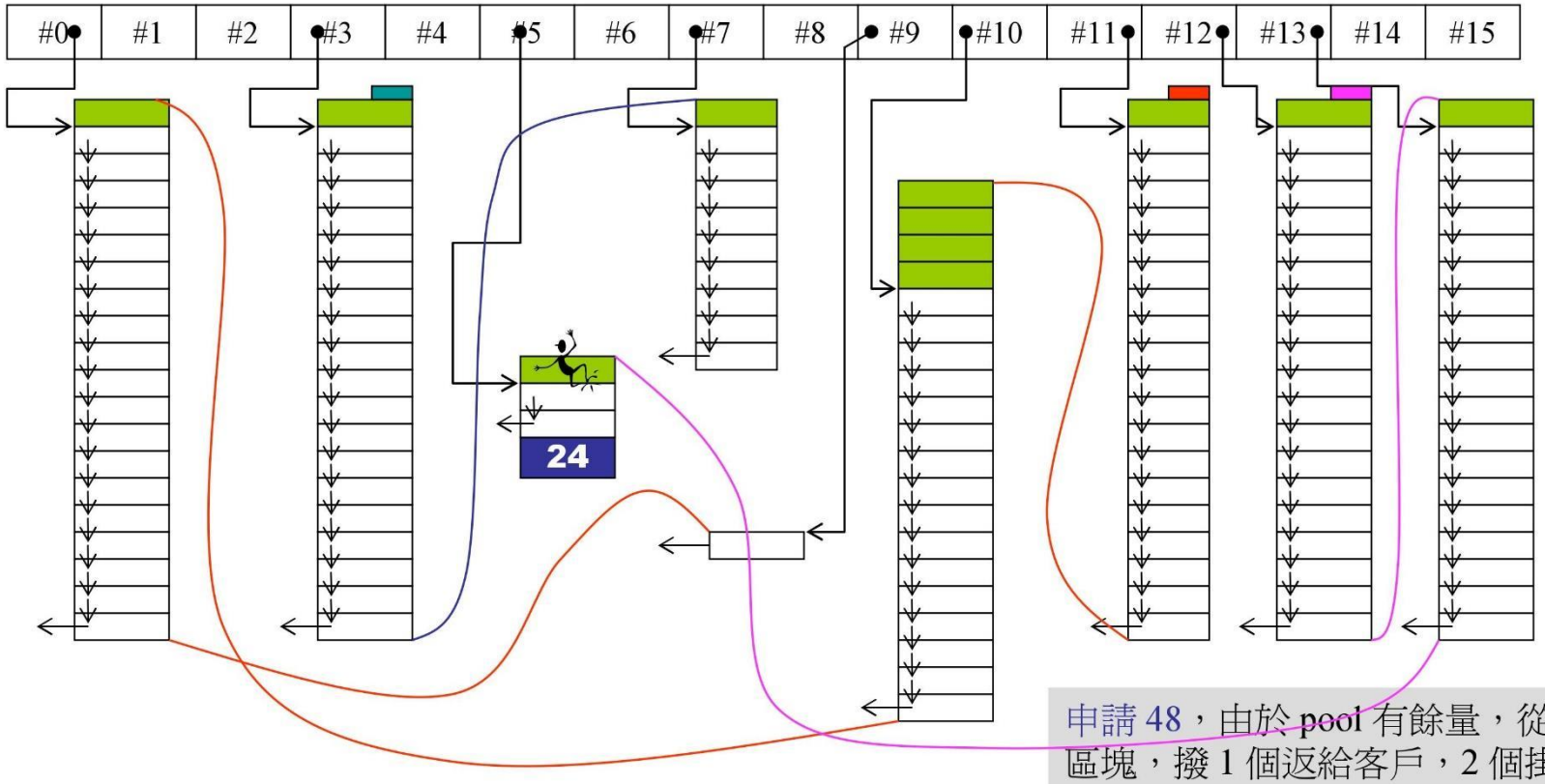


申請 112，由於 pool 有餘量，遂從 pool 取 20 個區塊，撥 1 個返給客戶，留 19 個掛於 list #13.

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

— 侯 捷 —

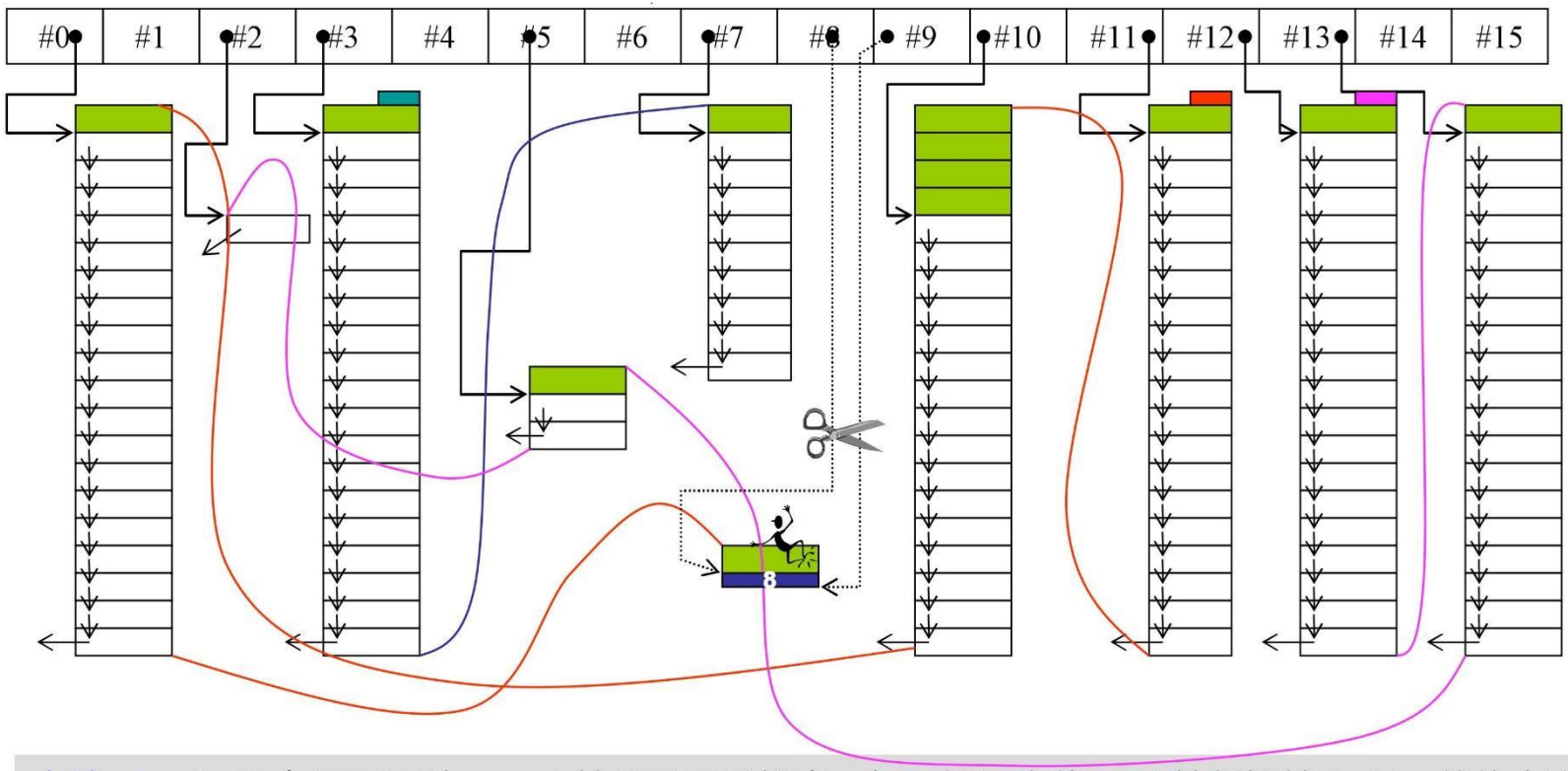
G2.9 std::alloc 運行一瞥.10



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

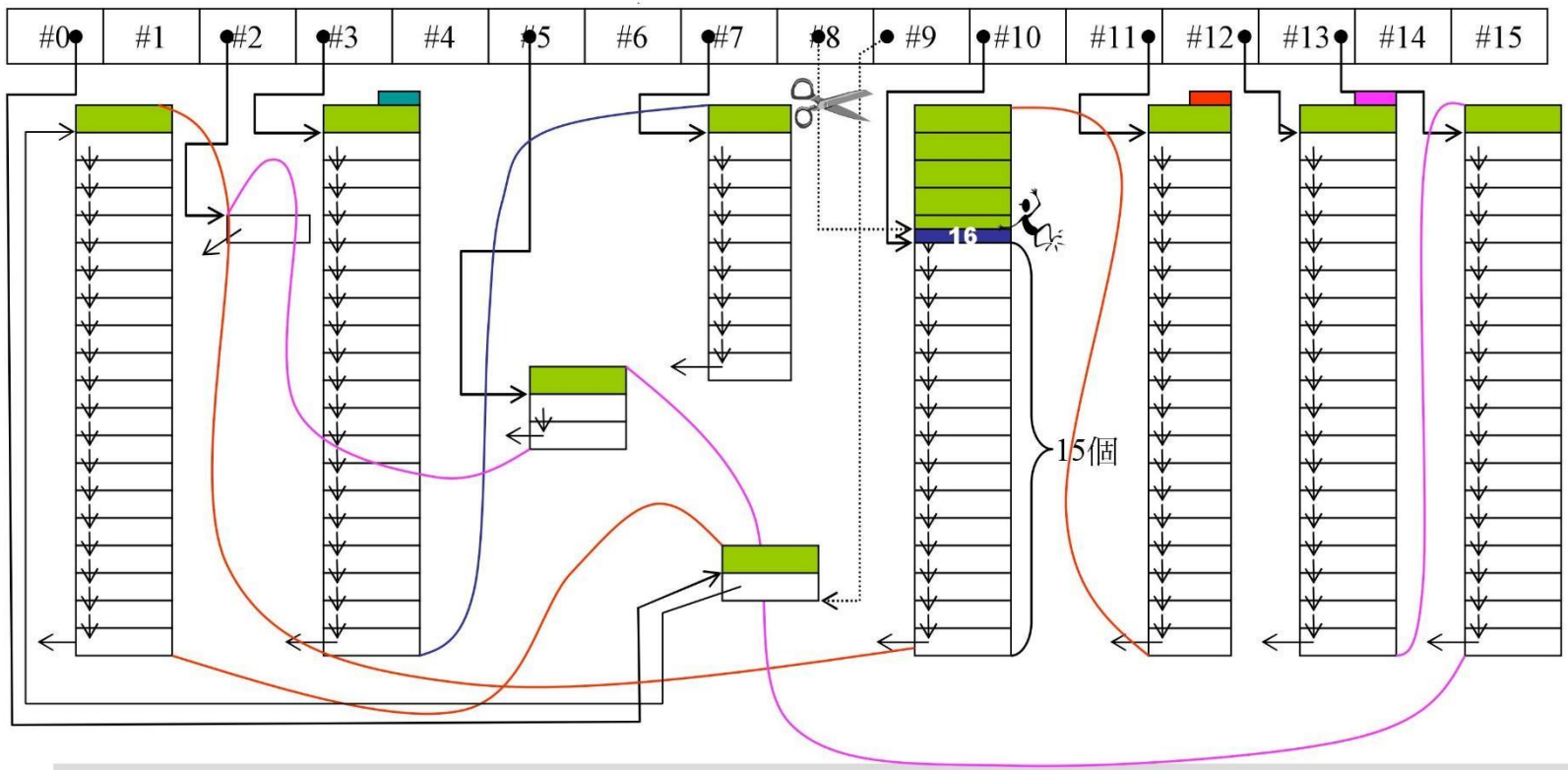


申請 72，list#8 無可用區塊，pool 餘量又不足供應 1 個，於是先將 pool 餘額撥給list#2，然後索取 72*20*2+RoundUp(9688>>4)，但爲觀察系統邊界，我將 system heap 大小設爲 10000，目前已索取 9688，因此無法滿足此次索取，於是 **alloc** 從手中資源取最接近之 80 (list#9) 回填 pool，再從中切出 72 返給客戶，餘 8。

向右找 有空的則借来

- 累計申請量：9688
- pool 大小： 8

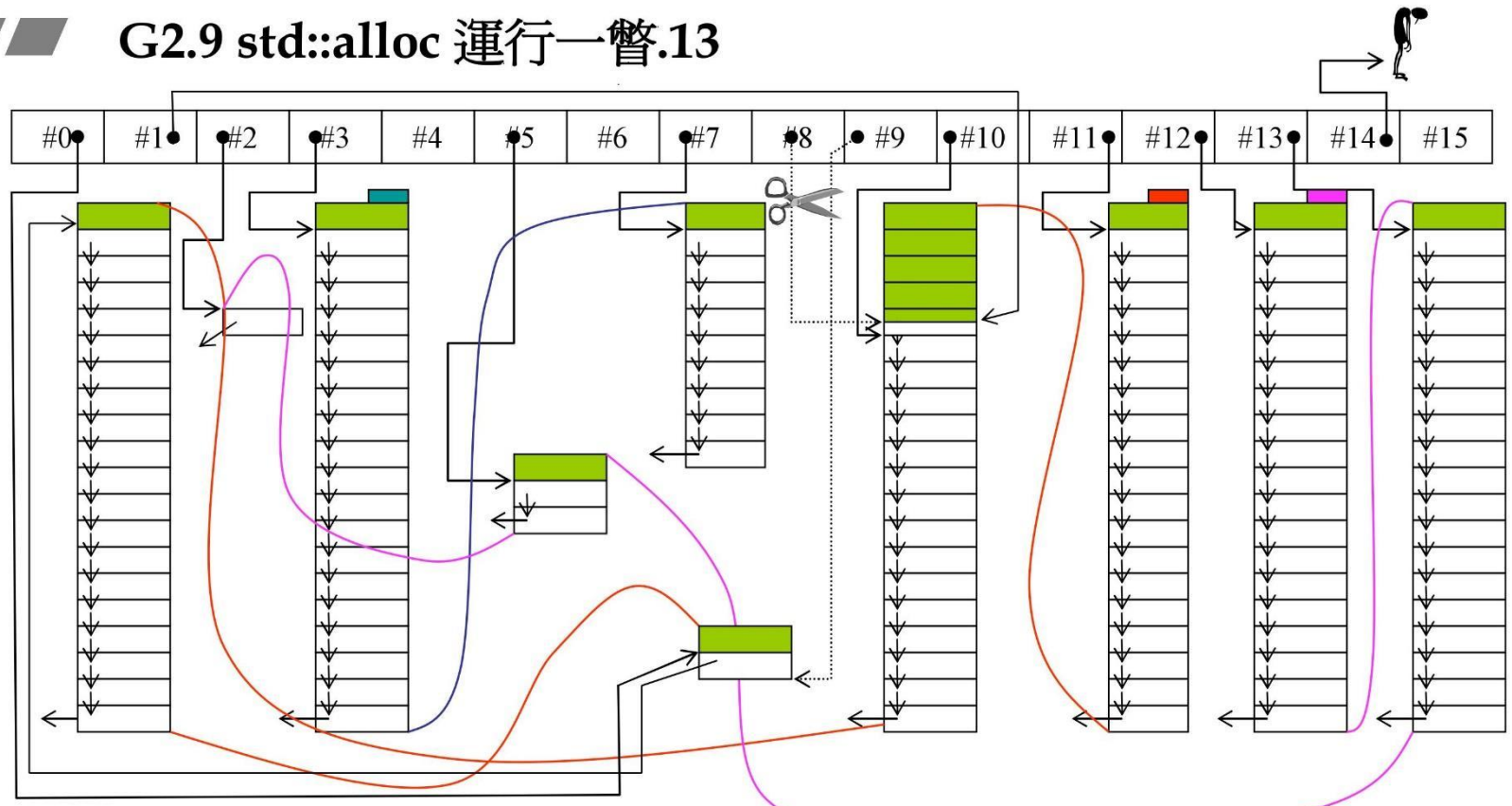
G2.9 std::alloc 運行一瞥.12



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

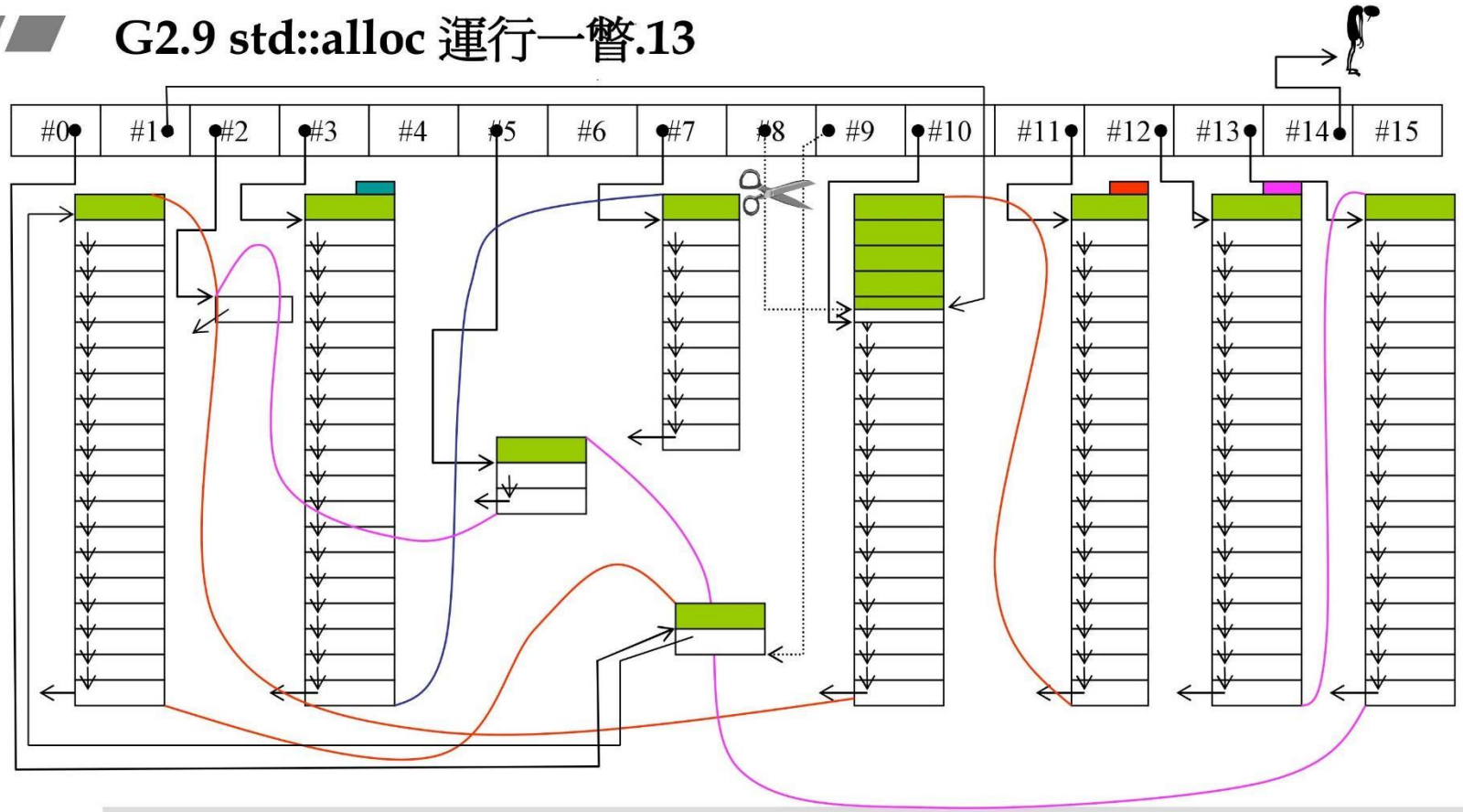
G2.9 std::alloc 運行一瞥.13



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

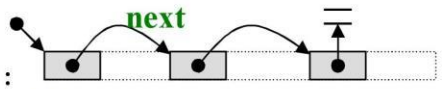
```
#074 //------------------------------------------------
#075 typedef __malloc_alloc_template<0> malloc_alloc;
#076
#077 //一個換膚工程,將分配單位由 bytes 個數改爲元素個數
#078 template<class T, class Alloc>
#079 class simple_alloc {
#080 public:
#081   static T* allocate(size_t n)              //一次分配n個T objects
#082     { 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
```



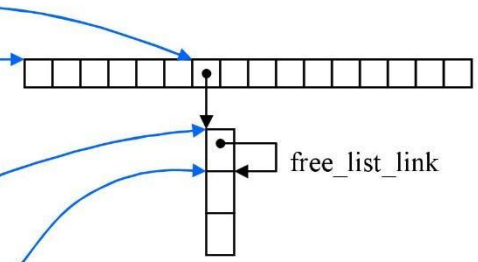
若bytes爲13，則(13+7) & ~(7)
即 10100 & 11000，得 10000即 16

```
#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

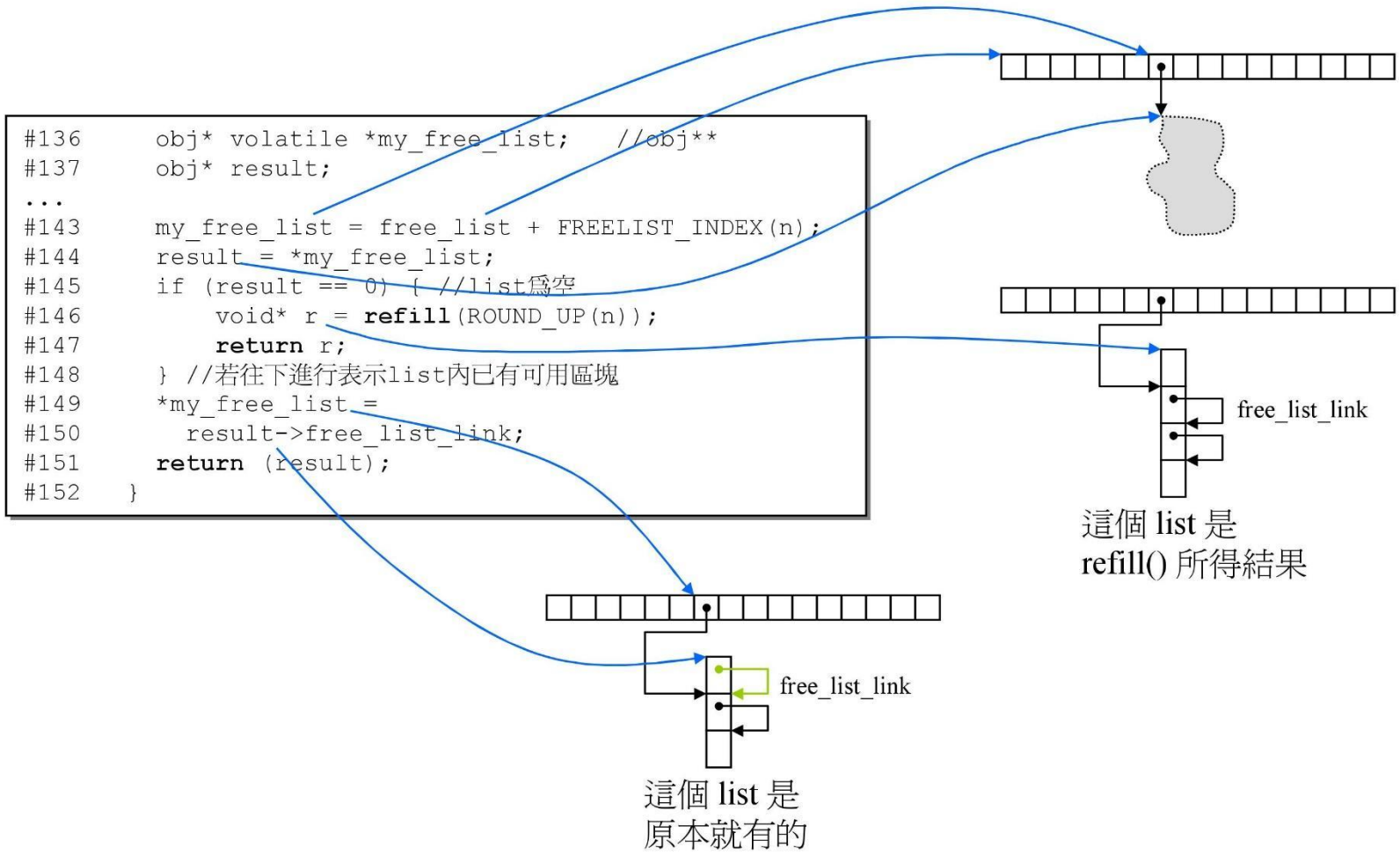
```
#154   static void deallocate(void* p, size_t n)   //p 不爲 0
#155   {
#156     obj* q = (obj*)p;
#157     obj* volatile *my_free_list; //obj**
#158
#159     if (n > (size_t) __MAX_BYTES) {
#160         malloc_alloc::deallocate(p, n); //改用第一級
#161         return;
#162     }
#163     my_free_list = 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 };
```

没有free

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   }
```

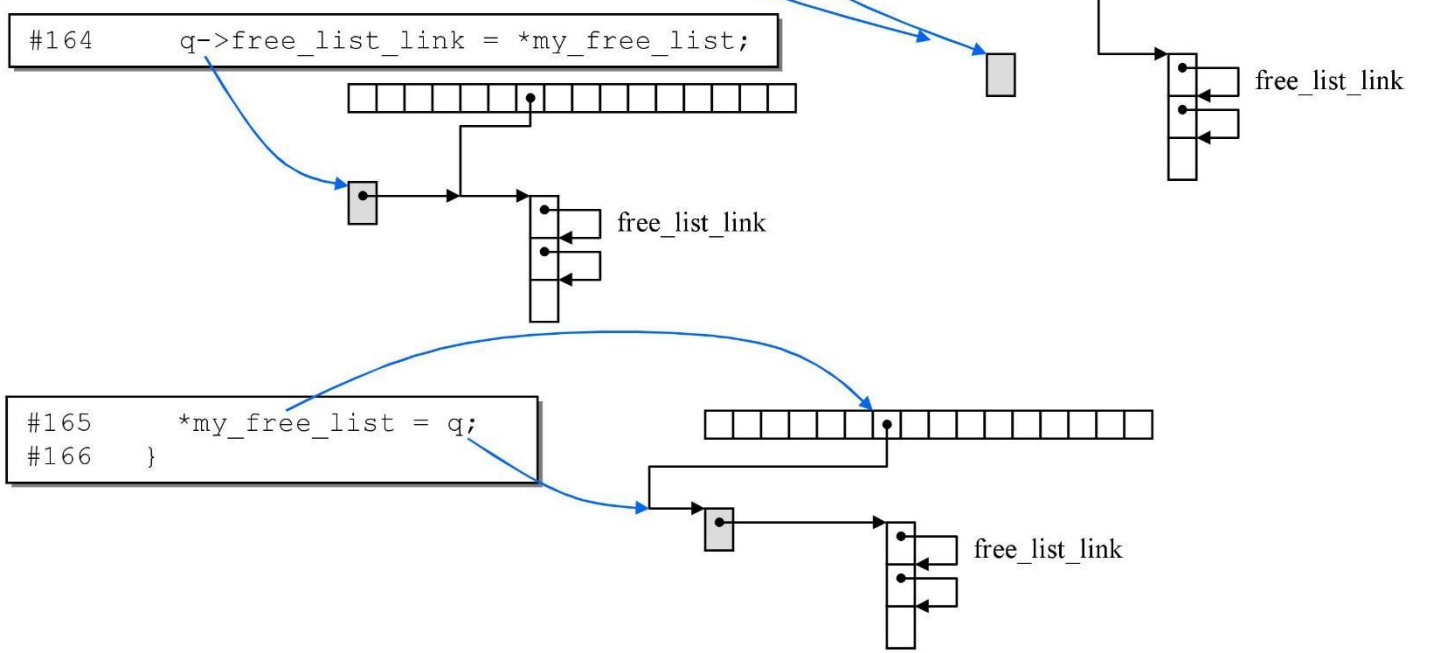


G2.9 std::alloc 源碼剖析, 5

```
#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);
```

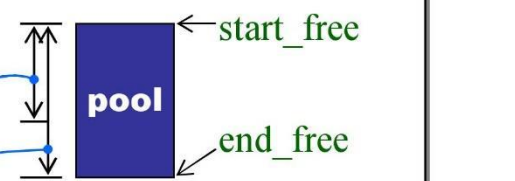
```
#164     q->free_list_link = *my_free_list;
```

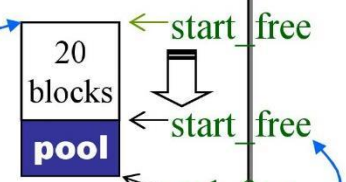
```
#165     *my_free_list = q;
#166   }
```



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       }
```





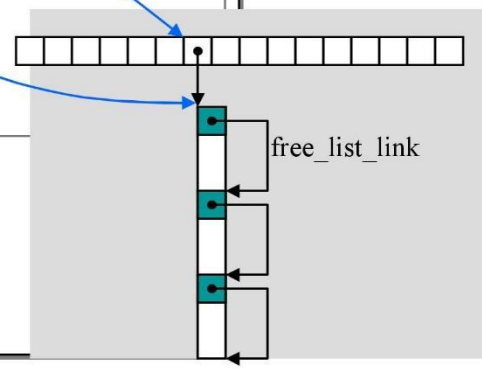
G2.9 std::alloc 源碼剖析, 7

```
#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;

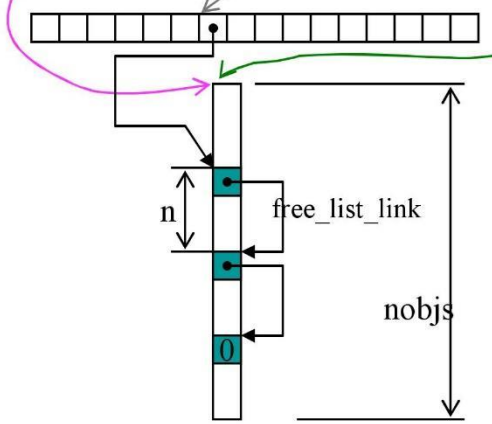
i 從 size + __ALIGN
開始迭代更佳.

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

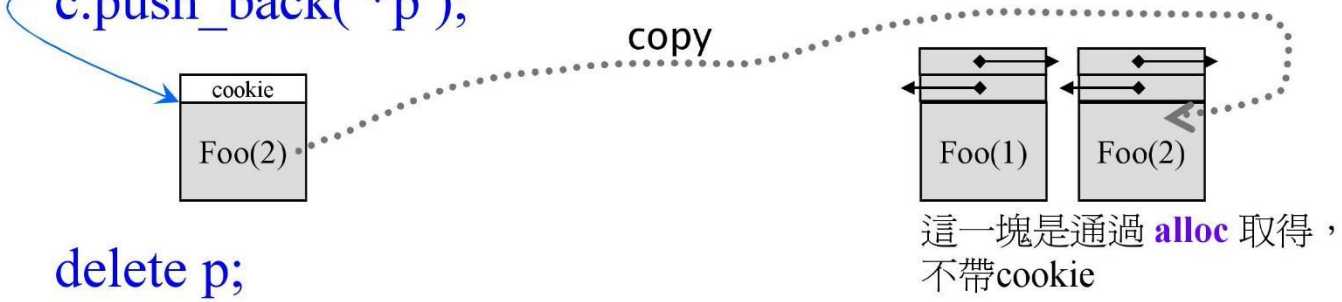
```
#273 //------------------------------------------------
#274 template <bool threads, int inst>
#275 char *__default_alloc_template<threads,inst>::start_free = 0;
#276
#277 template <bool threads, int inst>
#278 char *__default_alloc_template<threads,inst>::end_free = 0;
#279
#280 template <bool threads, 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) );
```

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

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




```
delete p;
```

G2.9 std::alloc 批鬥大會

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

```
    obj* *p1, *p2;

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

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

==不小心写成一个= 这样反过来写编译器就会报错 值得学习

```
#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)()))()
```

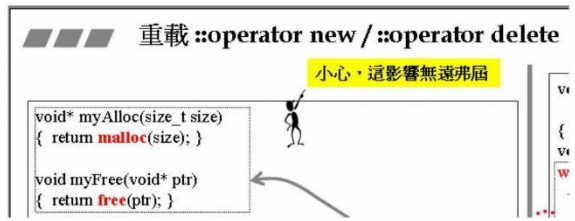
```
typedef void (*H)();
static H set_malloc_handler(H f);
```

```
#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)

没有变量记录给出去的指针

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

```
//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;
```

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…

```
//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;
```

內存管理

從平地到萬丈高樓

Memory Management 101

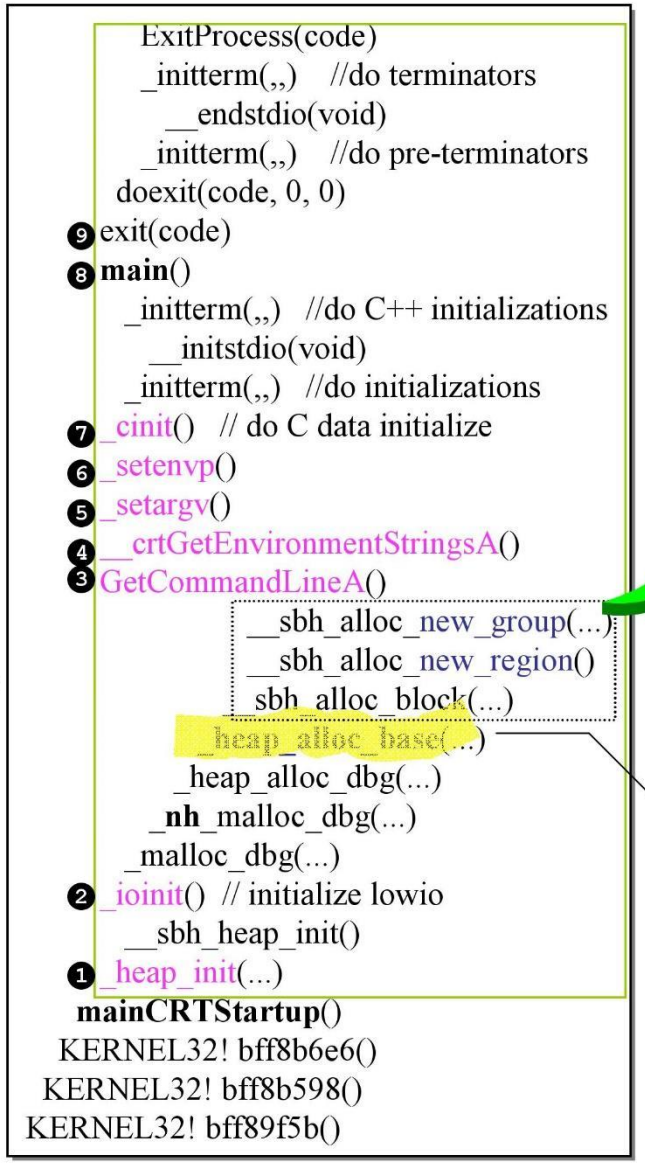
第一講 primitives
第二講 std::allocator
第三講 malloc/free
第四講 loki::allocator
第五講 other issues

侯捷

胸中自有丘壑

觸類旁通

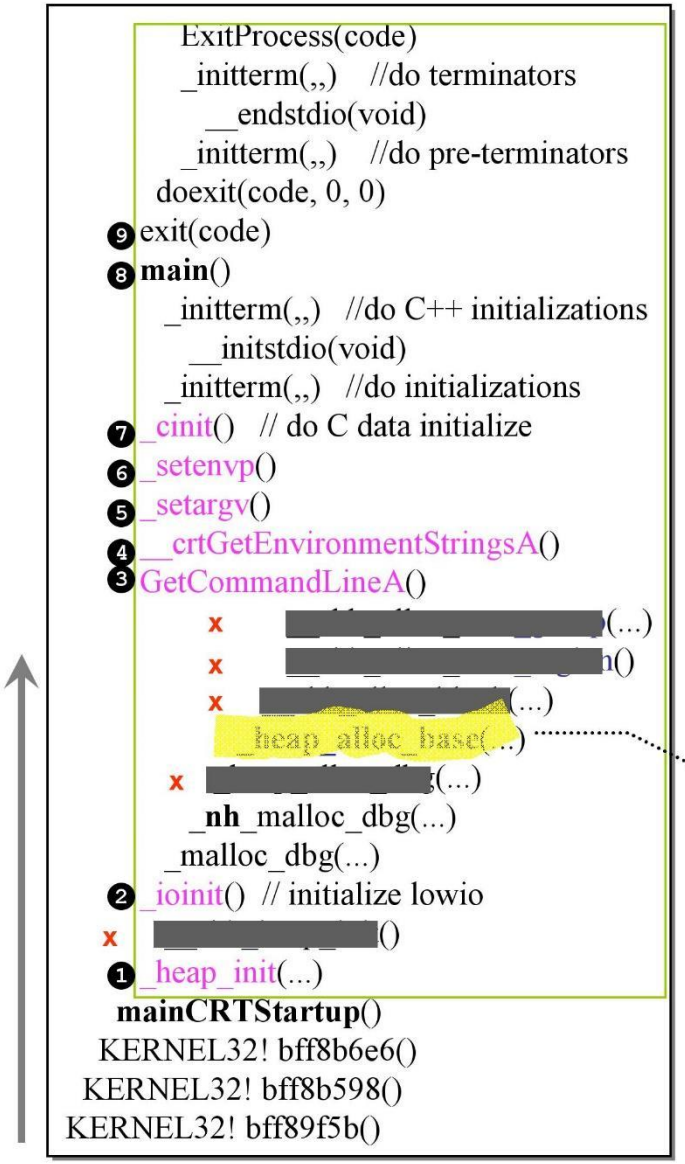
VC6 内存分配



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;
}
```

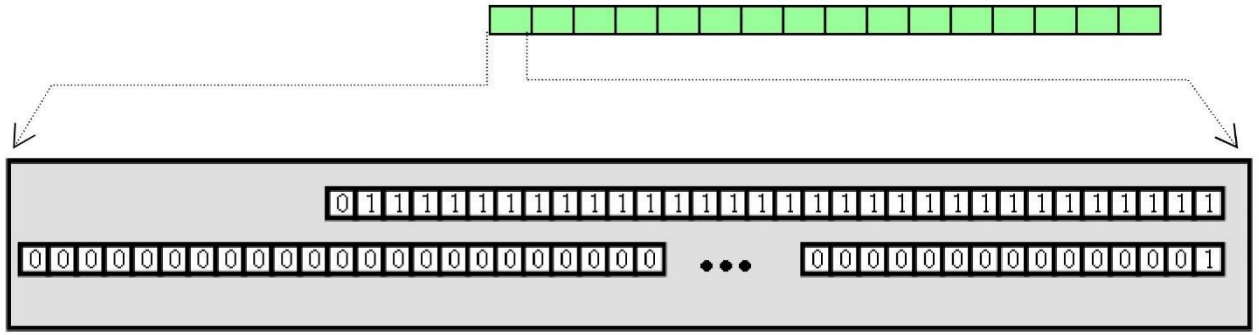
4096

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;
}
```

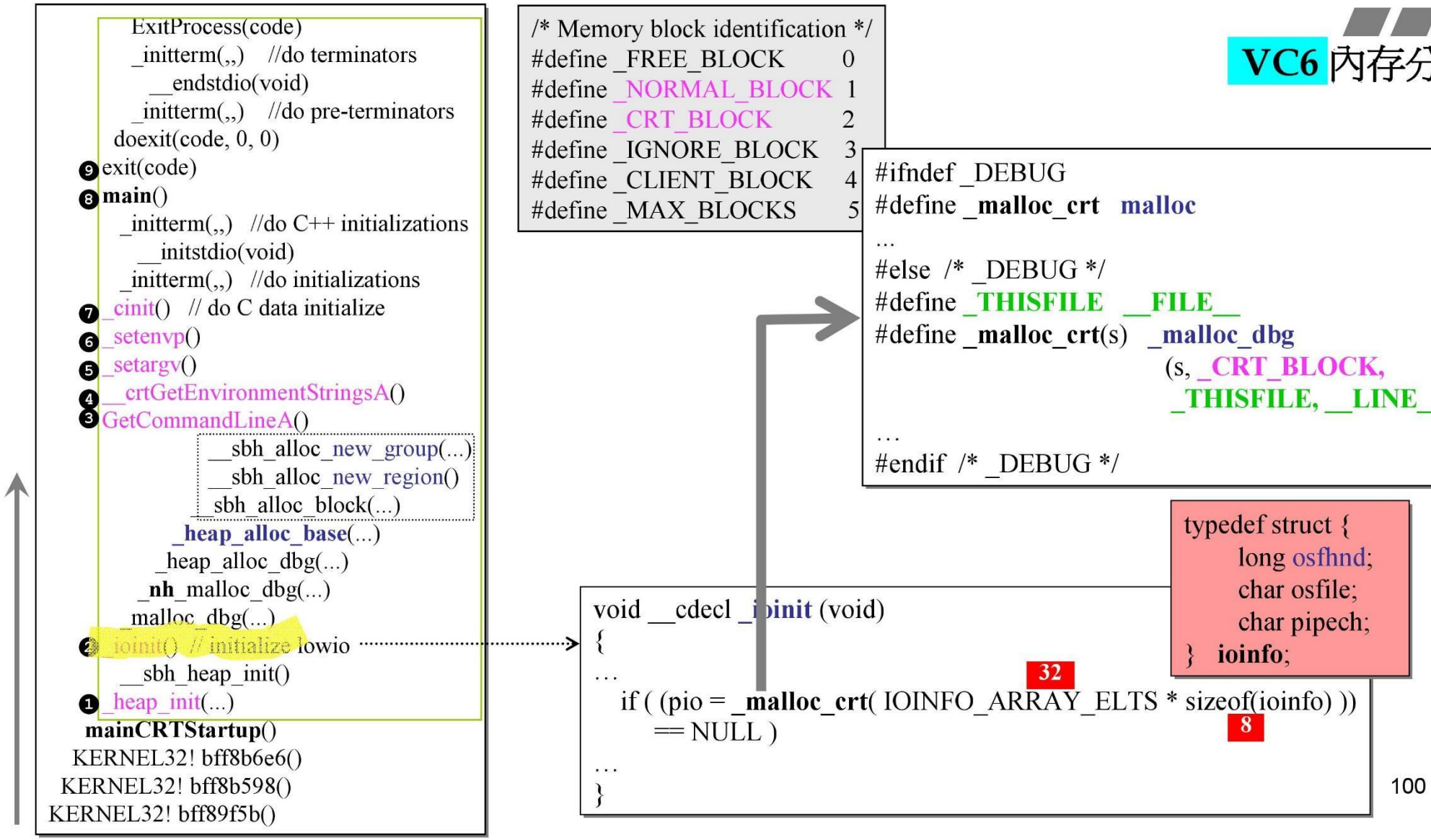
SBH 之始 – _heap_init() 和 __sbh_heap_init()




```
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

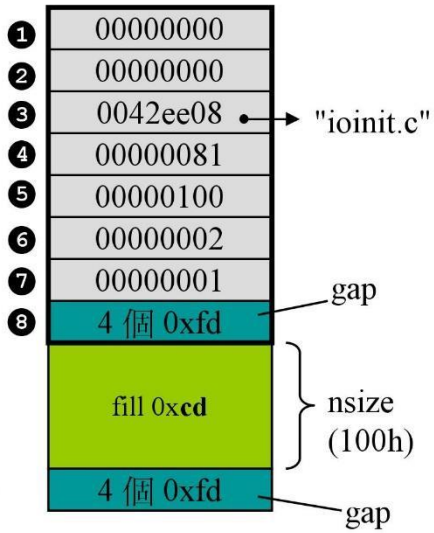

ExitProcess(code)
_initterm(,,) //do terminators
__endstdio(void)
_initterm(,,) //do pre-terminators
doexit(code, 0, 0)
9 exit(code)
8 main()
_initterm(,,) //do C++ initializations
__initstdio(void)
_initterm(,,) //do initializations
7 _cinit() // do C data initialize
6 _setenvp()
5 _setargv()
4 __crtGetEnvironmentStringsA()
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;
```

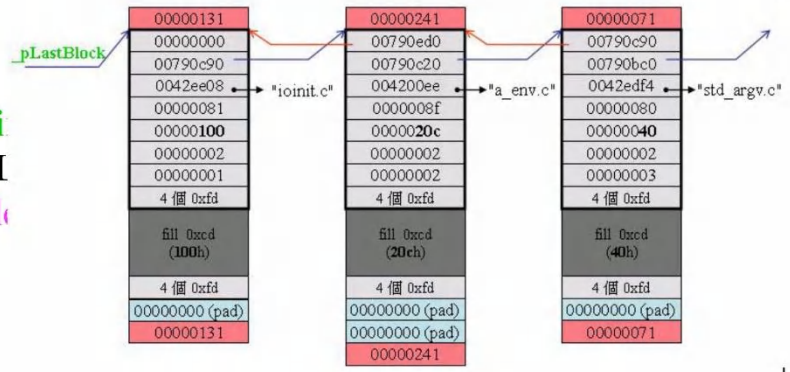
```
…
blockSize = sizeof(_CrtMemBlockHeader) + nSize + nNoMansLandSize;
…
pHead = (_CrtMemBlockHeader *)_heap_alloc_base(blockSize);
… (續下頁)
```



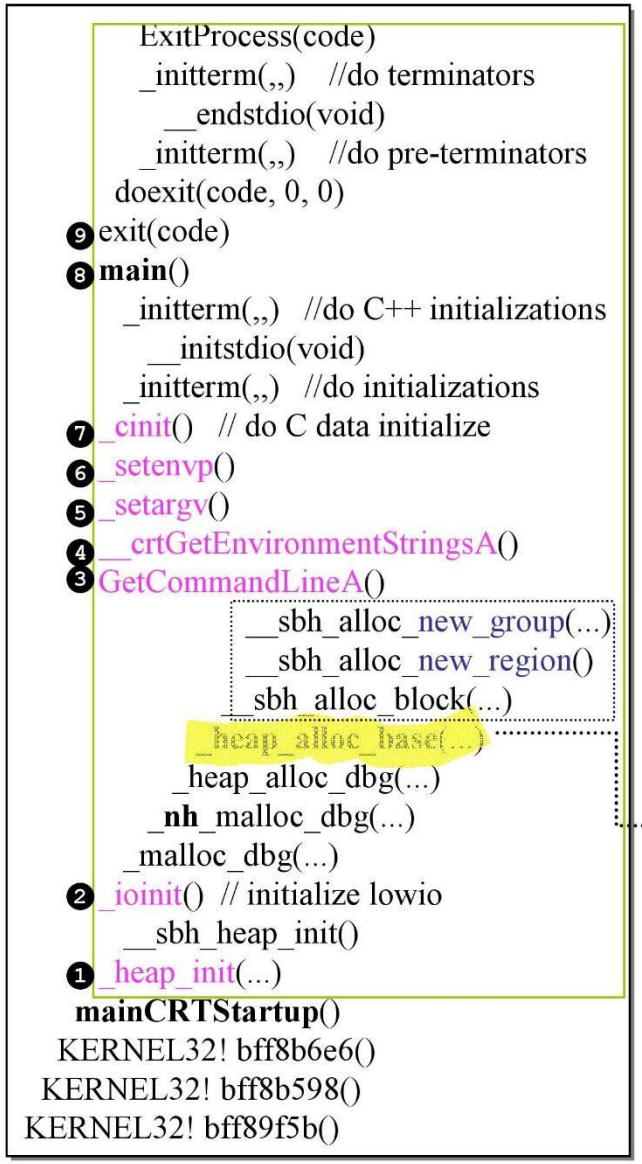
VC6 內存分配

```
ExitProcess(code)
  _initterm(,,)   //do terminators
    __endstdio(void)
  _initterm(,,)   //do pre-terminators
 doexit(code, 0, 0)
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()
```

```
... (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);
```



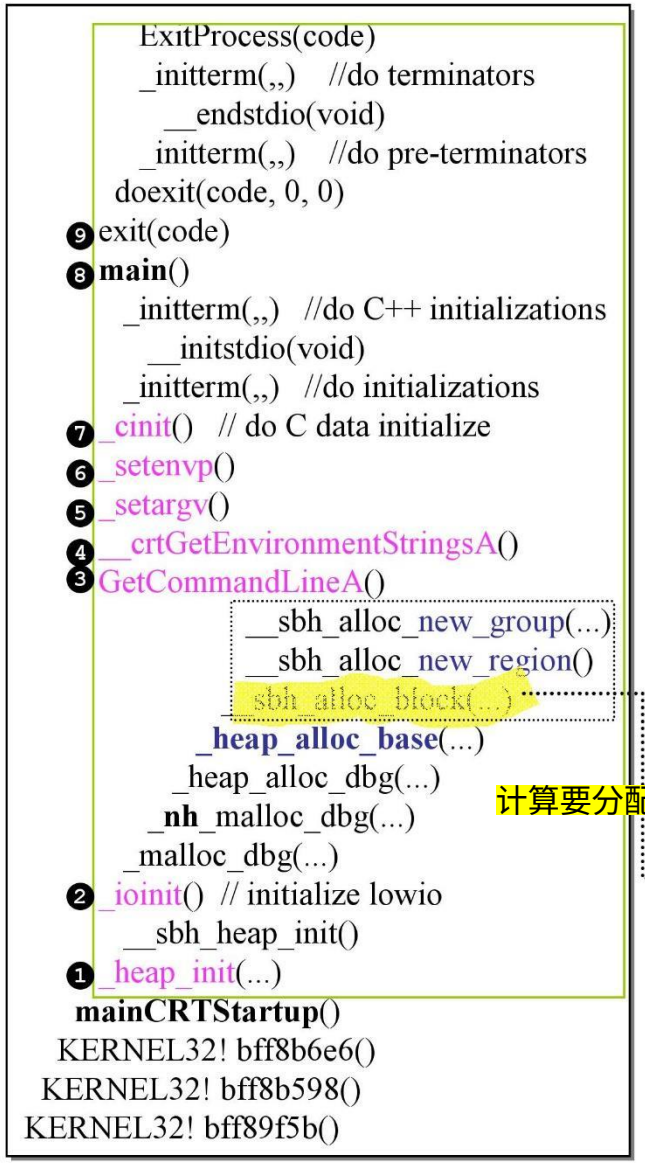

```
static unsigned char _bNoMansLandFill = 0xFD;
static unsigned char _bDeadLandFill   = 0xDD;
static unsigned char _bCleanLandFill  = 0xCD;

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);
```

1024-8 8为cookie大小

VC6 内存分配

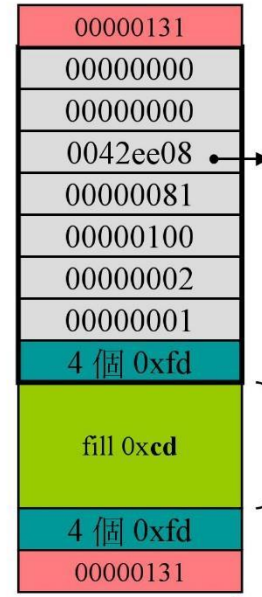


计算要分配的内存的大小

```
//  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);
```

调到16的倍数　　类似之前的RoundUp

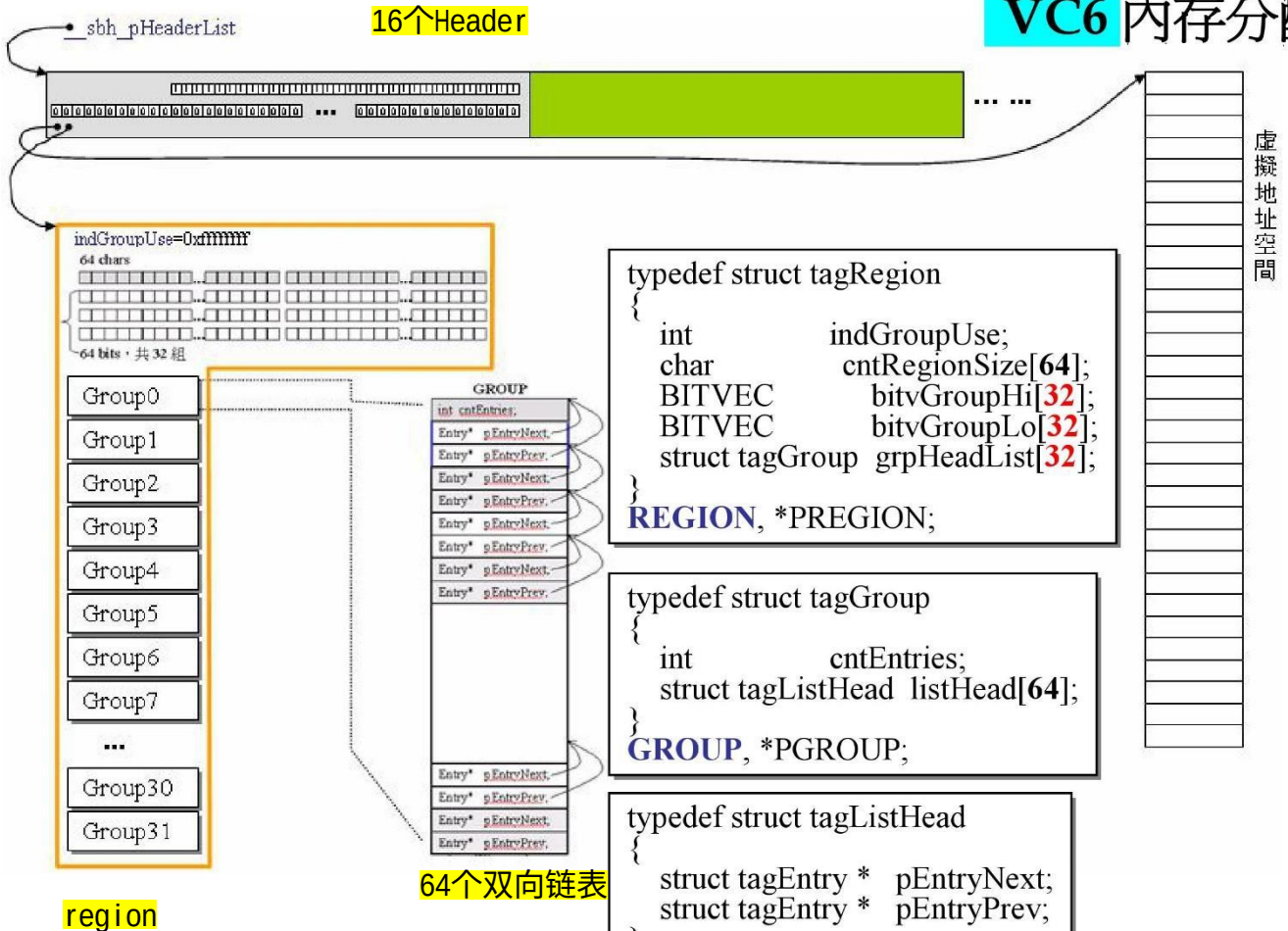
Debug给调试器用
BlockHeader



0x100 + 0x24 + 4*2
➔ 0x12C
➔ 0x130

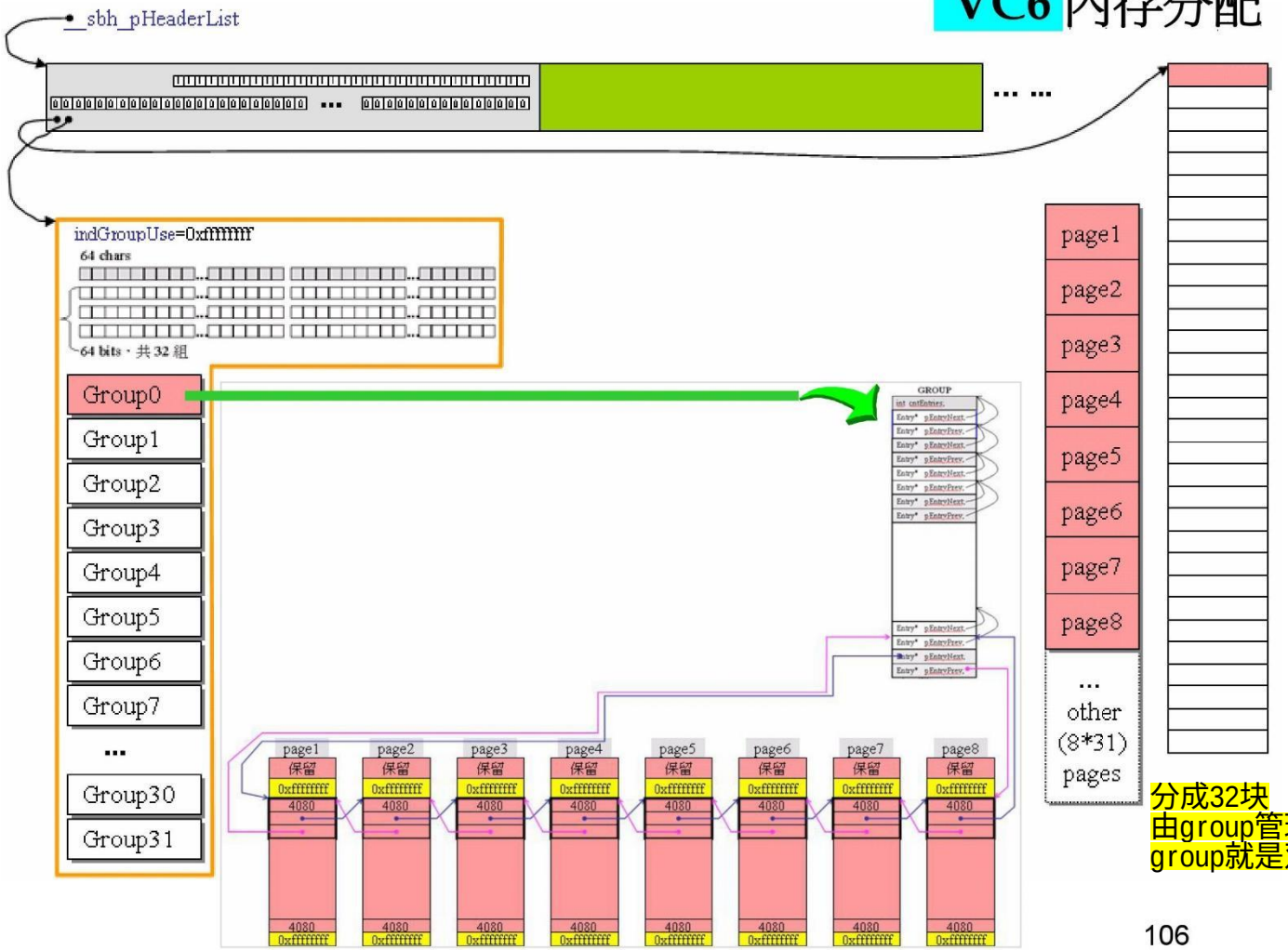
VC6 内存分配

```
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(...)
内存管理            __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()
```



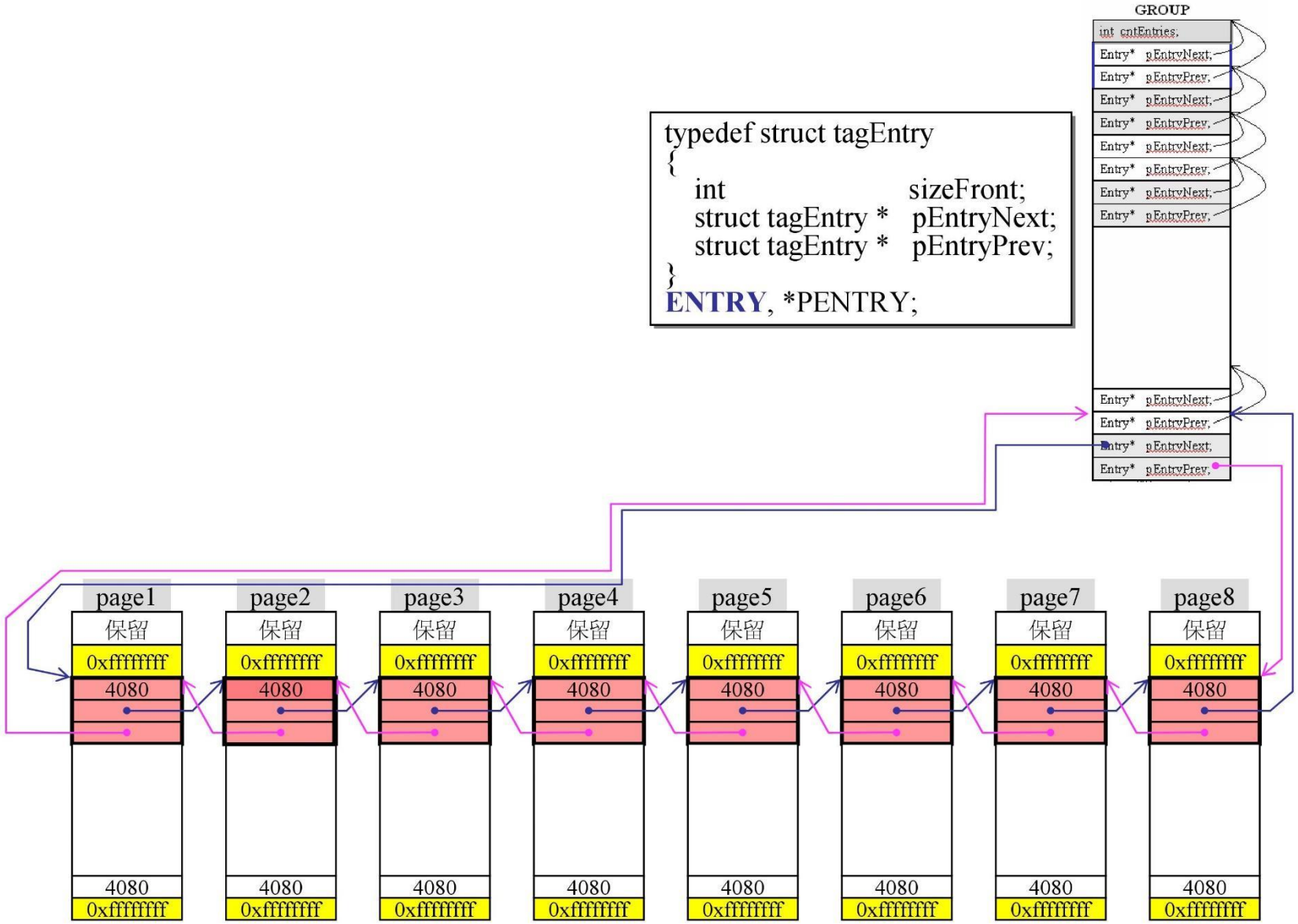
VC6 内存分配

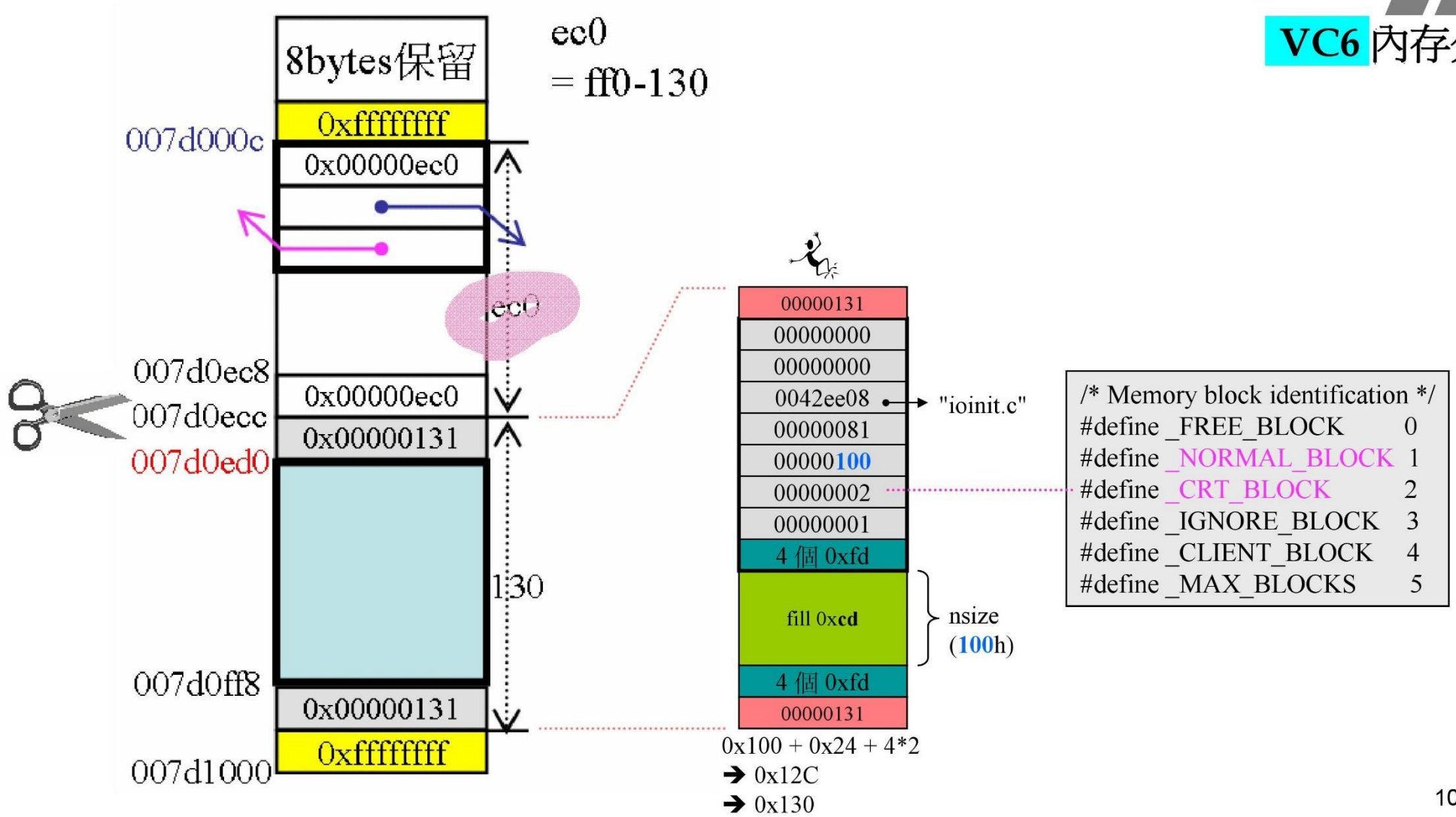
```
ExitProcess(code)
  _initterm(,,)    //do terminators
    __endstdio(void)
  _initterm(,,)    //do pre-terminators
 doexit(code, 0, 0)
9 exit(code)
8 main()
  _initterm(,,)   //do C++ initializations
    __initstdio(void)
  _initterm(,,)   //do initializations
7 _cinit()   // do C data initialize
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()
```

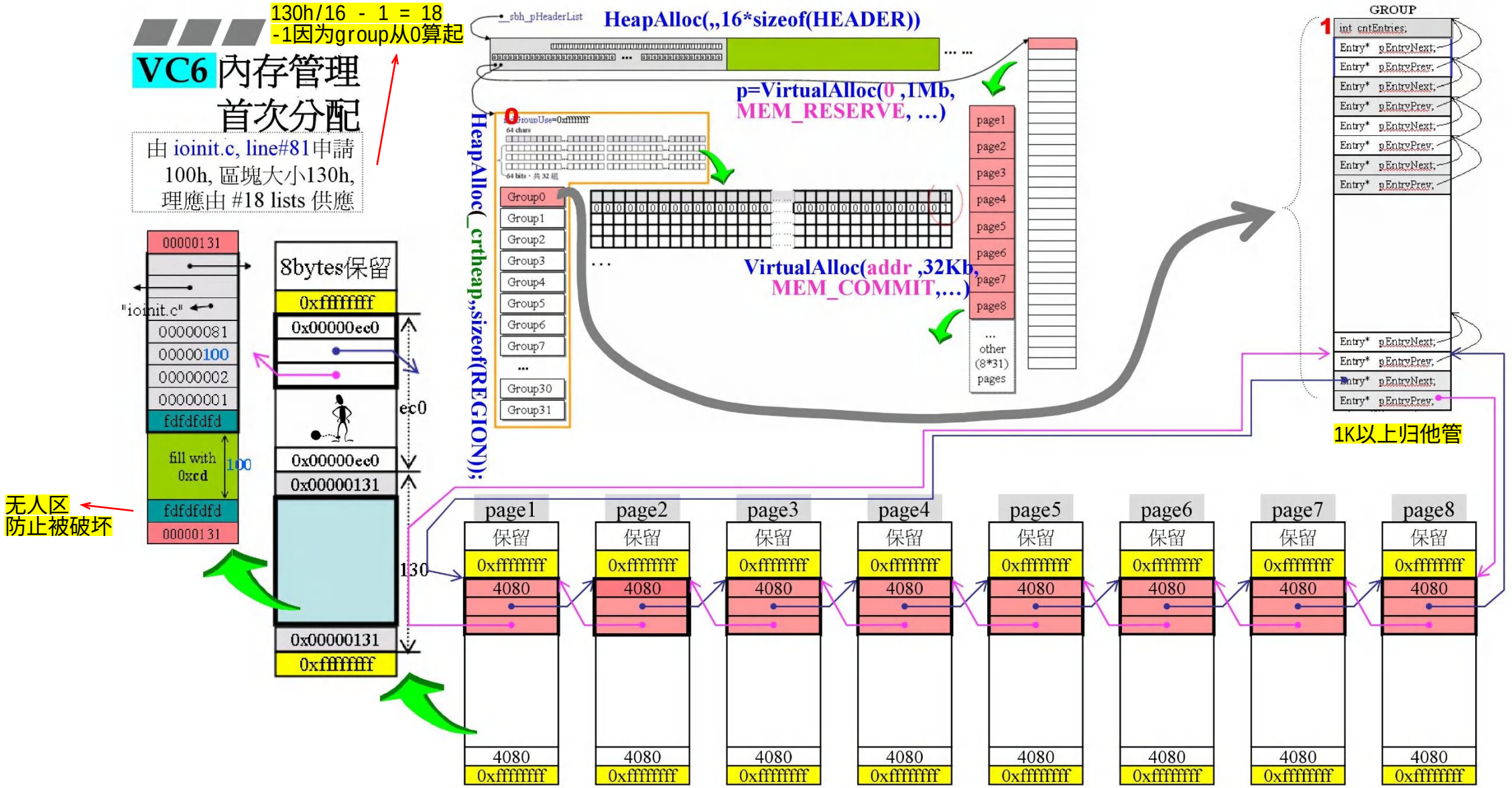


分成32块
由group管理
group就是双向链表

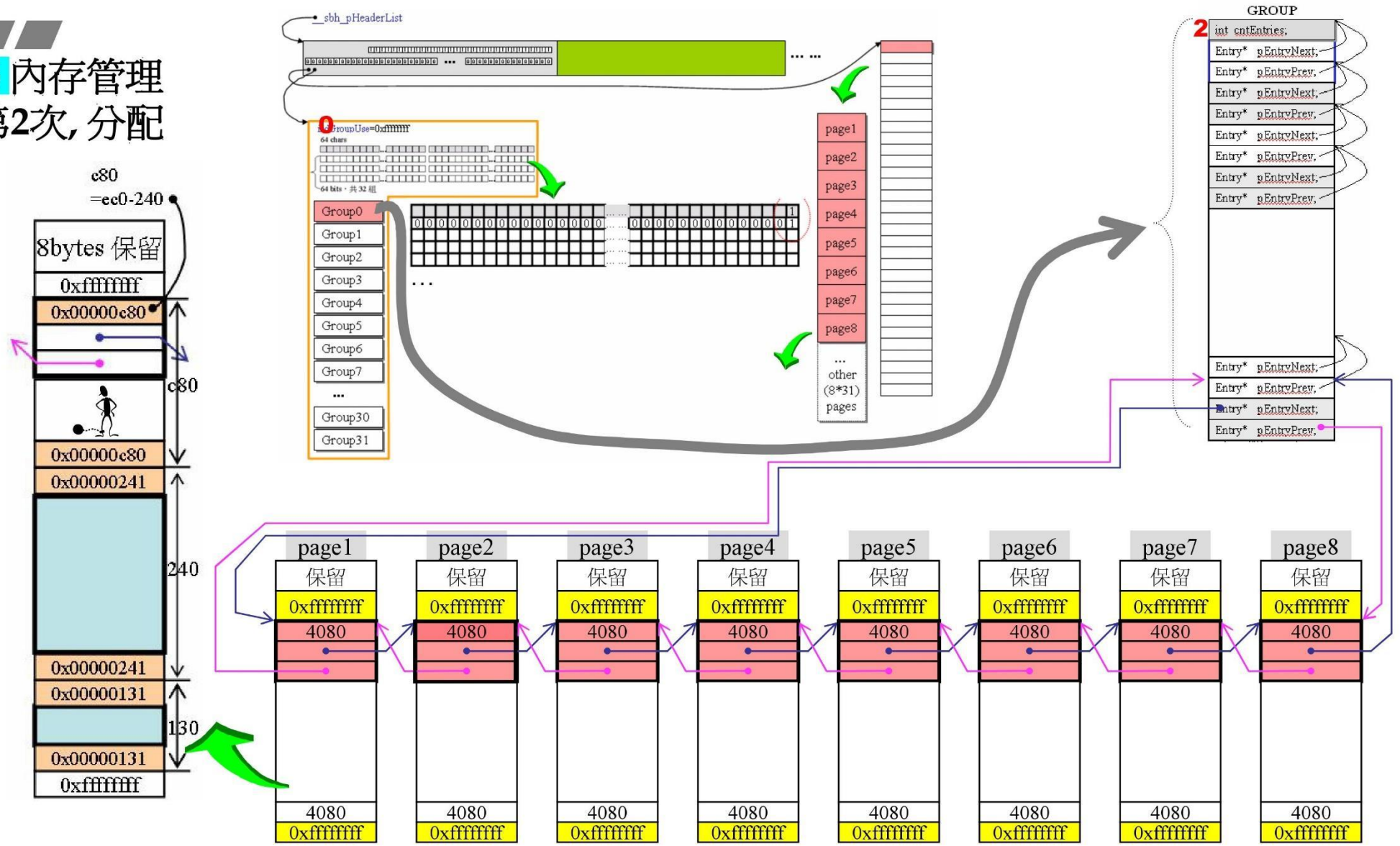
```
typedef struct tagEntry
{
    int                 sizeFront;
    struct tagEntry *   pEntryNext;
    struct tagEntry *   pEntryPrev;
}
ENTRY, *PENTRY;
```



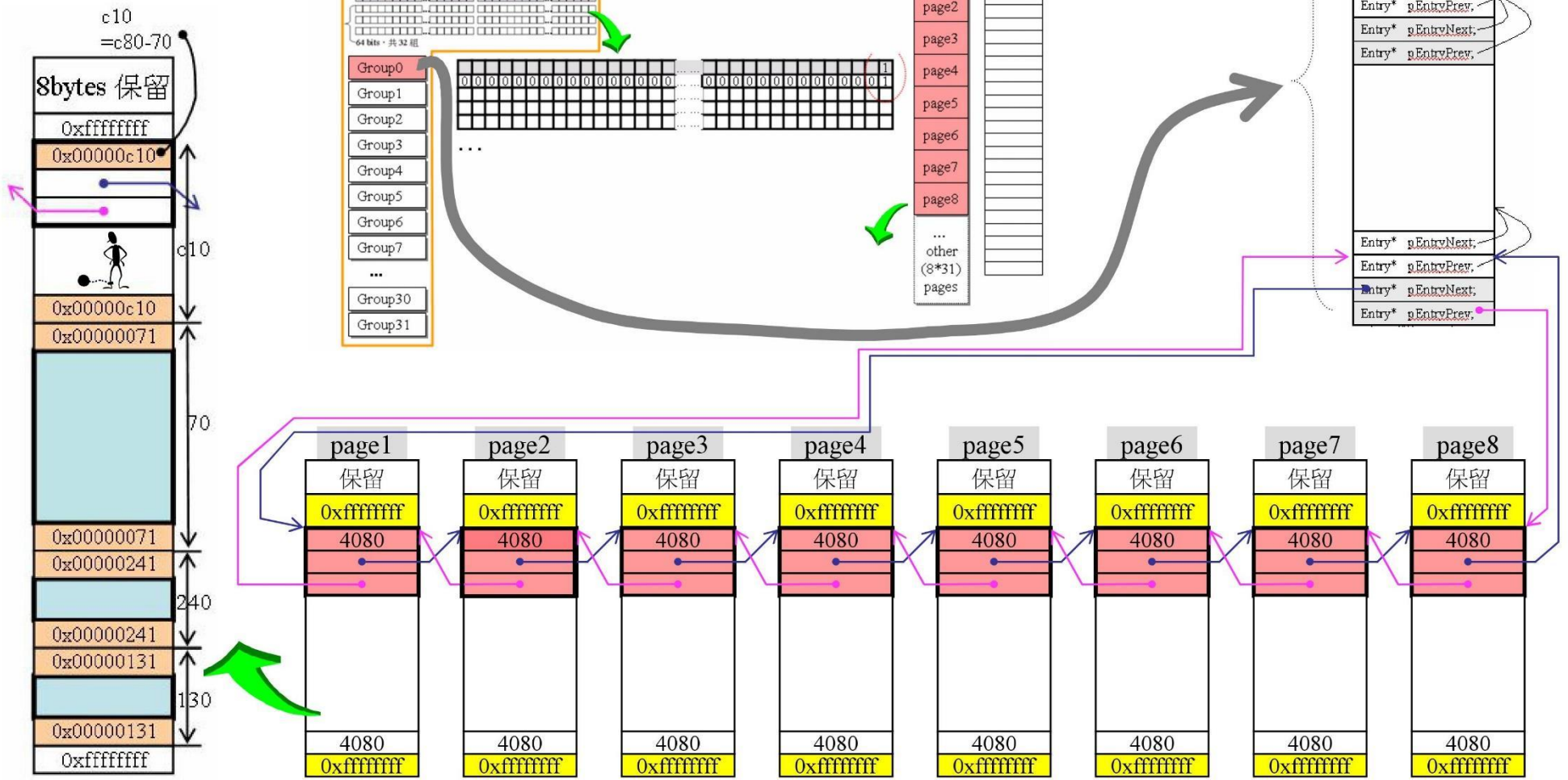

8bytes保留
0xffffffff
0x00000ec0
0x00000ec0
0x00000131
0xffffffff
ec0
= ff0-130
007d000c
007d0ec8
007d0ecc
007d0ed0
007d0ff8
007d1000
130
00000131
00000000
00000000
0042ee08
00000081
00000100
00000002
00000001
4 個 0xfd
fill 0xcd
4 個 0xfd
00000131
"ioinit.c"
nsize
(100h)
0x100 + 0x24 + 4*2
➔ 0x12C
➔ 0x130
/* 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


130h/16 - 1 = 18
-1因为group从0算起
VC6 内存管理
首次分配
由 ioinit.c, line#81申請
100h, 區塊大小130h,
理應由 #18 lists 供應
HeapAlloc(,,16*sizeof(HEADER))
p=VirtualAlloc(0 ,1Mb,
MEM_RESERVE, …)
VirtualAlloc(addr ,32Kb,
MEM_COMMIT,…)
HeapAlloc(_crtheap,,sizeof(REGION));
Group0
Group1
Group2
Group3
Group4
Group5
Group6
Group7
Group30
Group31
page1
page2
page3
page4
page5
page6
page7
page8
other
(8*31)
pages
GROUP
int cntEntries;
Entry* pEntryNext;
Entry* pEntryPrev;
1K以上归他管
00000131
"ioinit.c"
00000081
00000100
00000002
00000001
fdfdfdfd
fill with
0xcd
100
fdfdfdfd
00000131
8bytes保留
0xffffffff
0x00000ec0
ec0
0x00000ec0
0x00000131
130
0x00000131
0xffffffff
无人区
防止被破坏
保留
4080

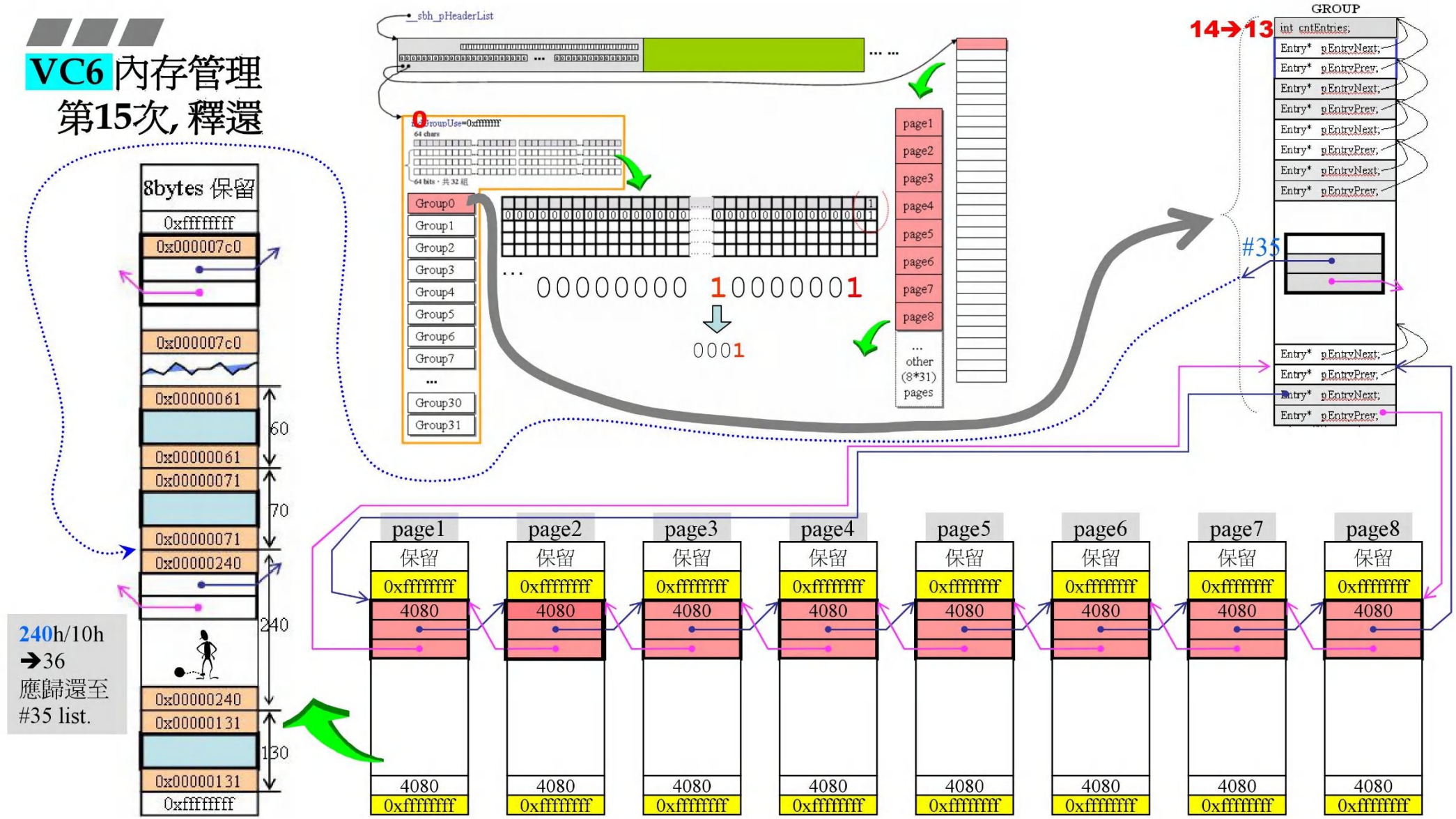
VC6 内存管理
第2次，分配



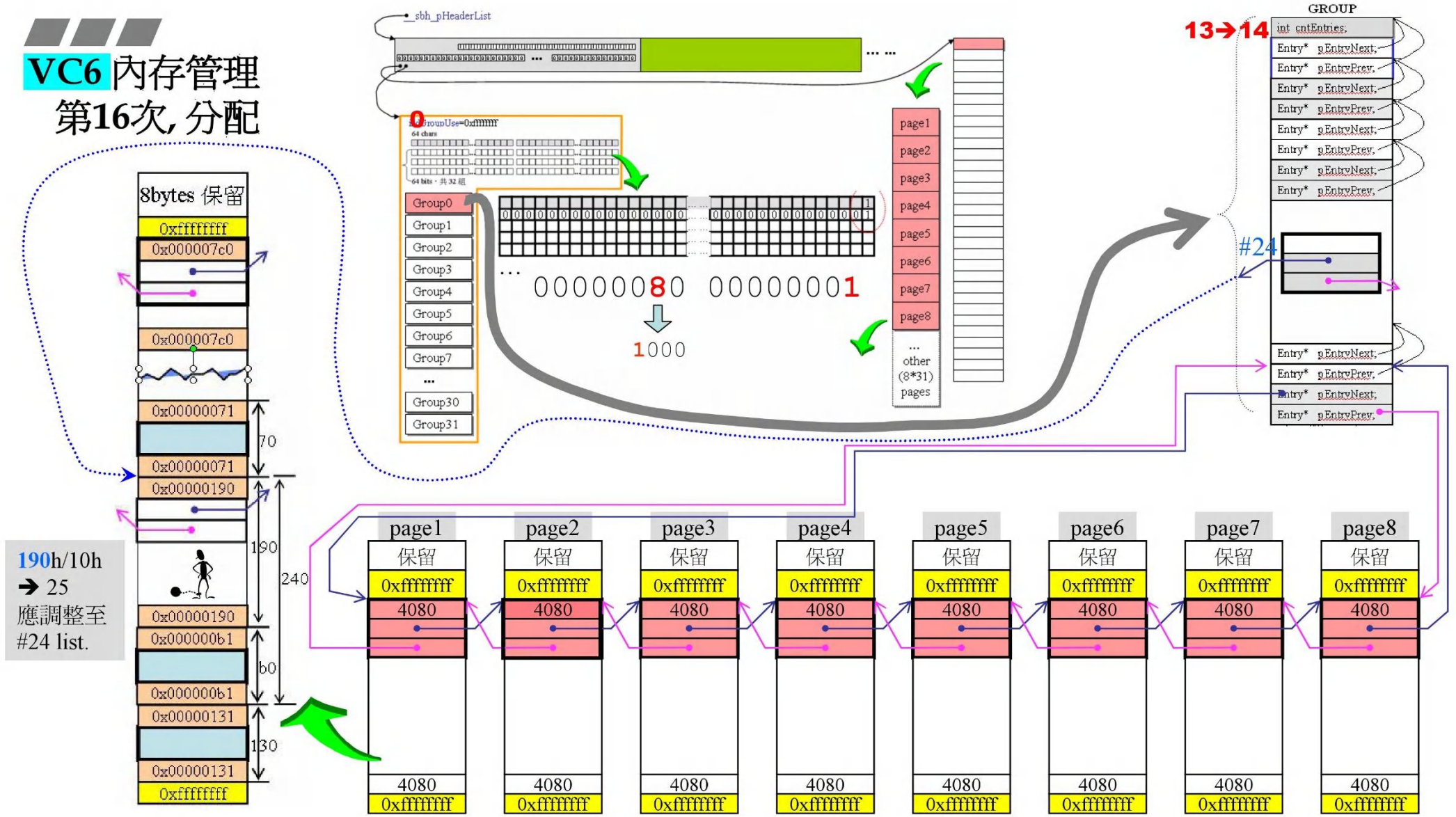
VC6 内存管理
第3次，分配



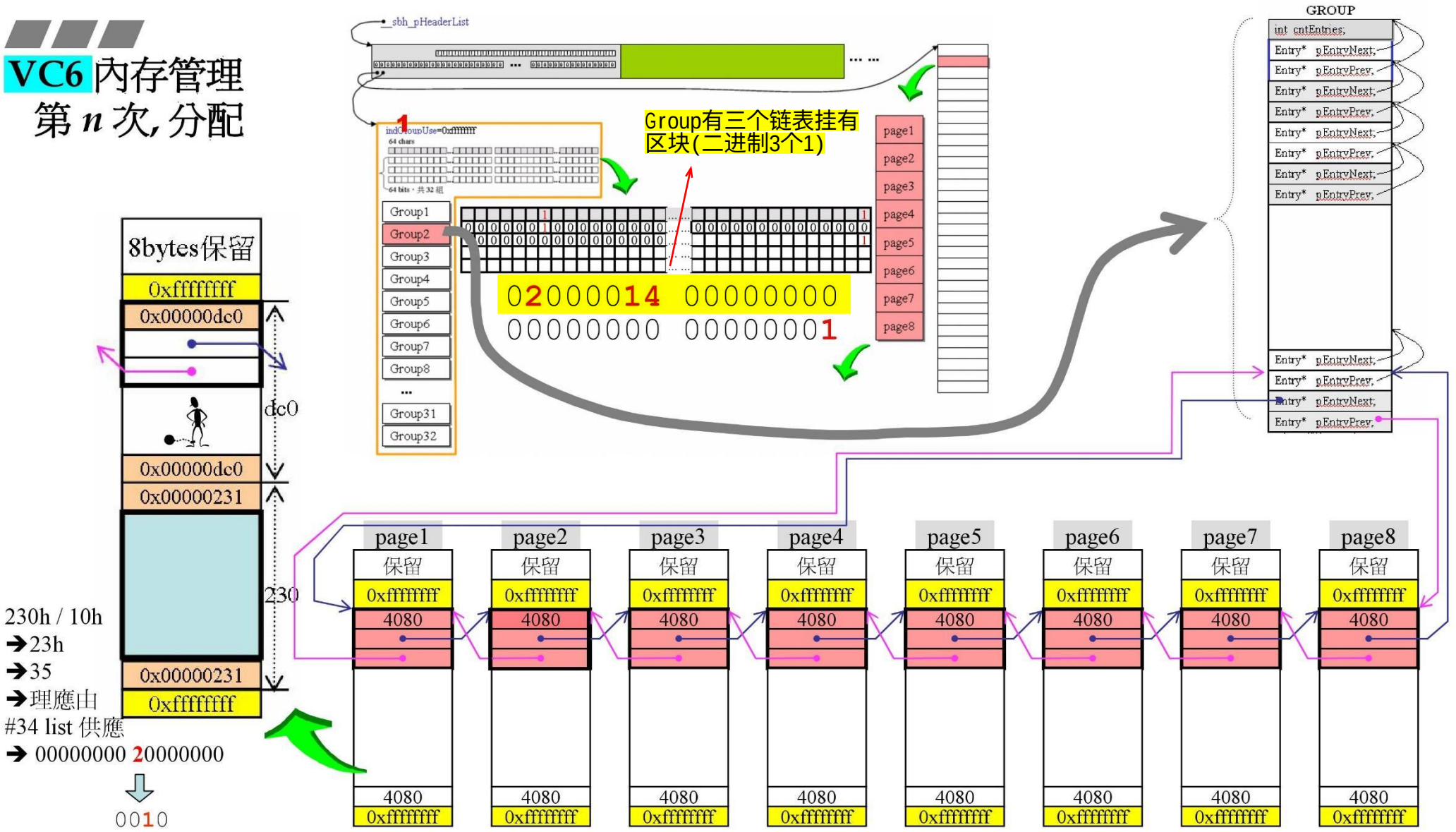
VC6 內存管理
第15次, 釋還



VC6 內存管理
第16次, 分配



VC6 內存管理
第 n 次, 分配

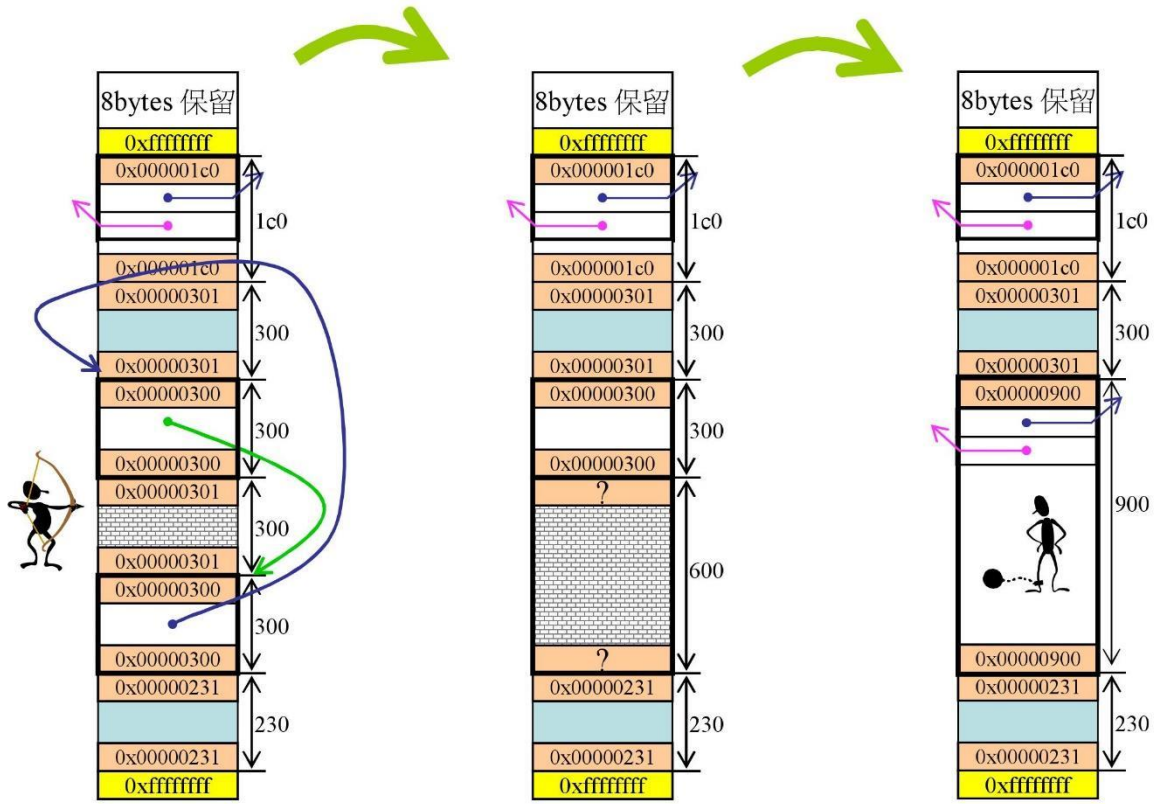


VC6 內存管理

區塊之合併

上 cookie
與
下 cookie
的作用

往上合并

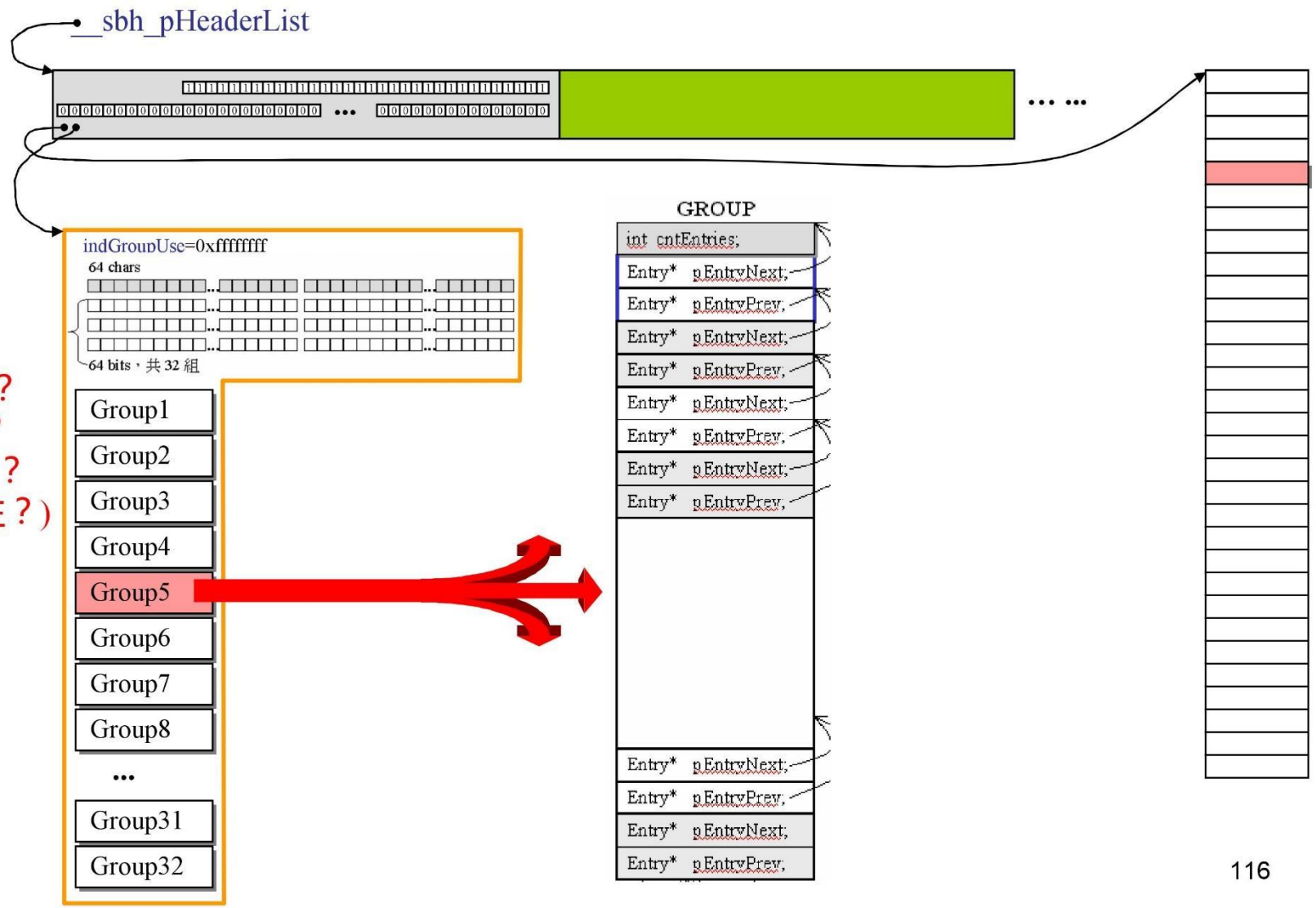


VC6 內存管理

free(p)

p 花落誰家？

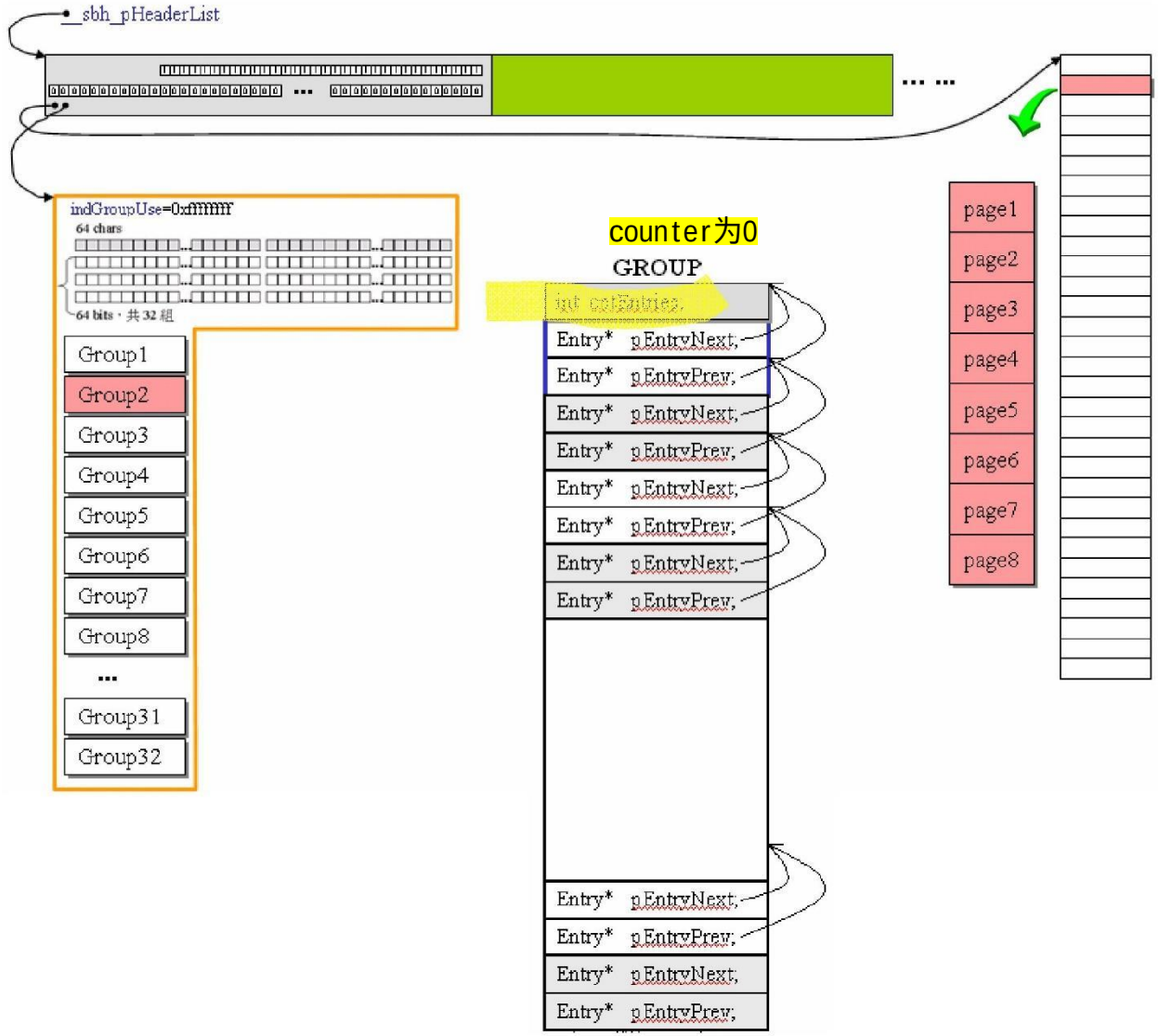
落在哪個 Header 內？
落在哪個 Group 內？
落在哪個 free-list 內？
(被哪個 free-list 鏈住？)



VC6 內存管理

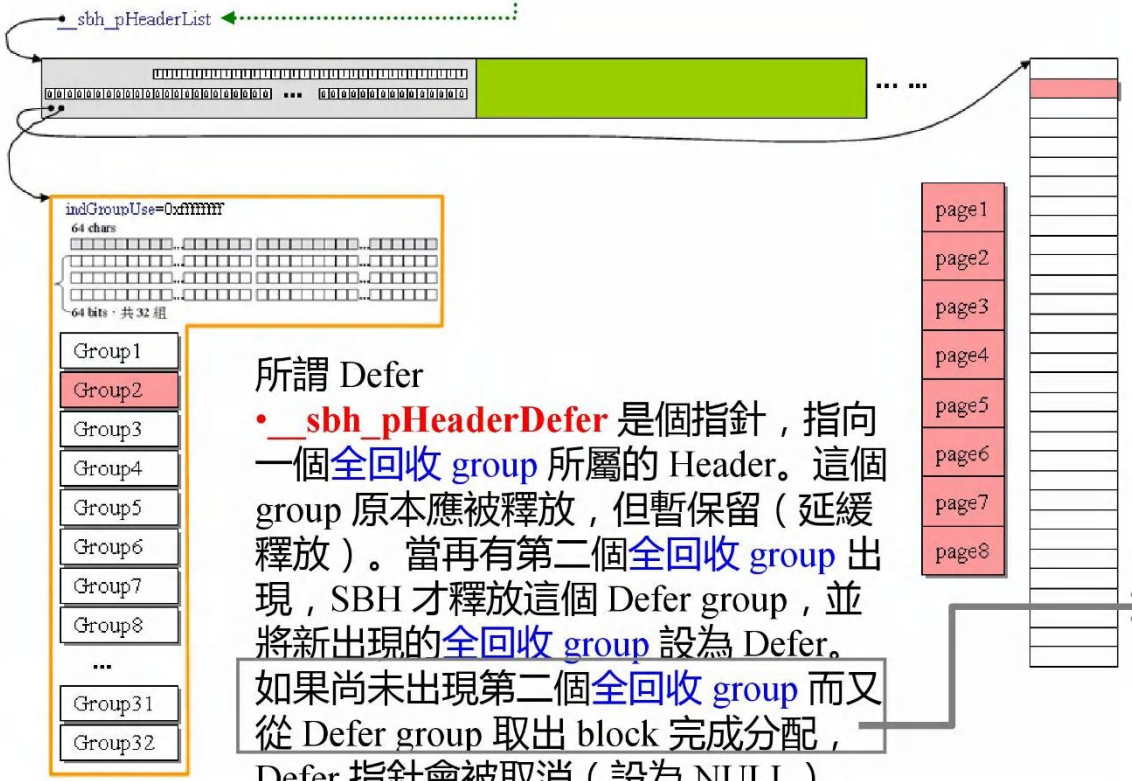
分段管理之妙
利於歸還O.S.

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）。

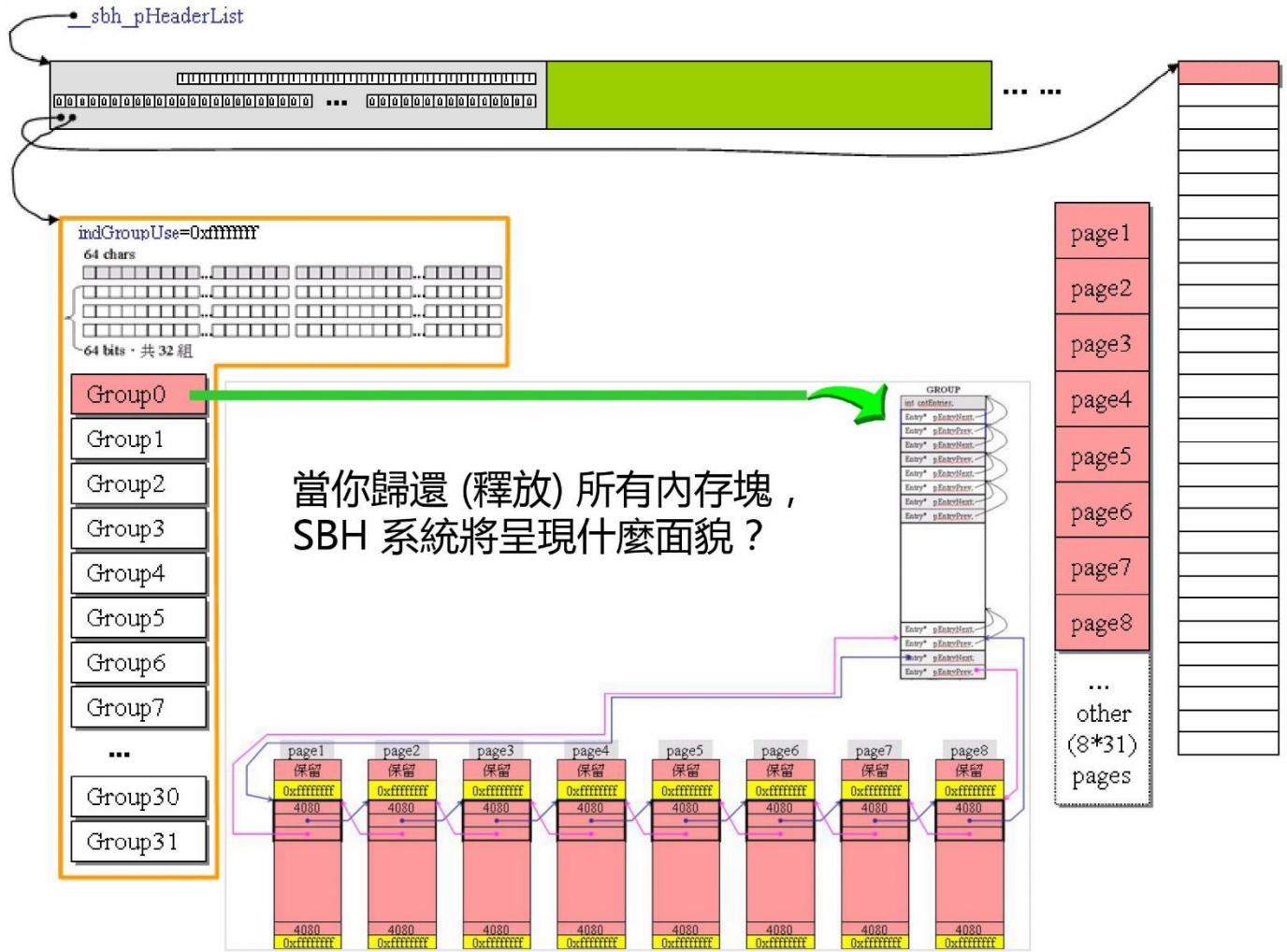
- **__sbh_indGroupDefer** 是個索引，指出 Region 中哪個 group (#0~#31) 是 Defer.

```
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

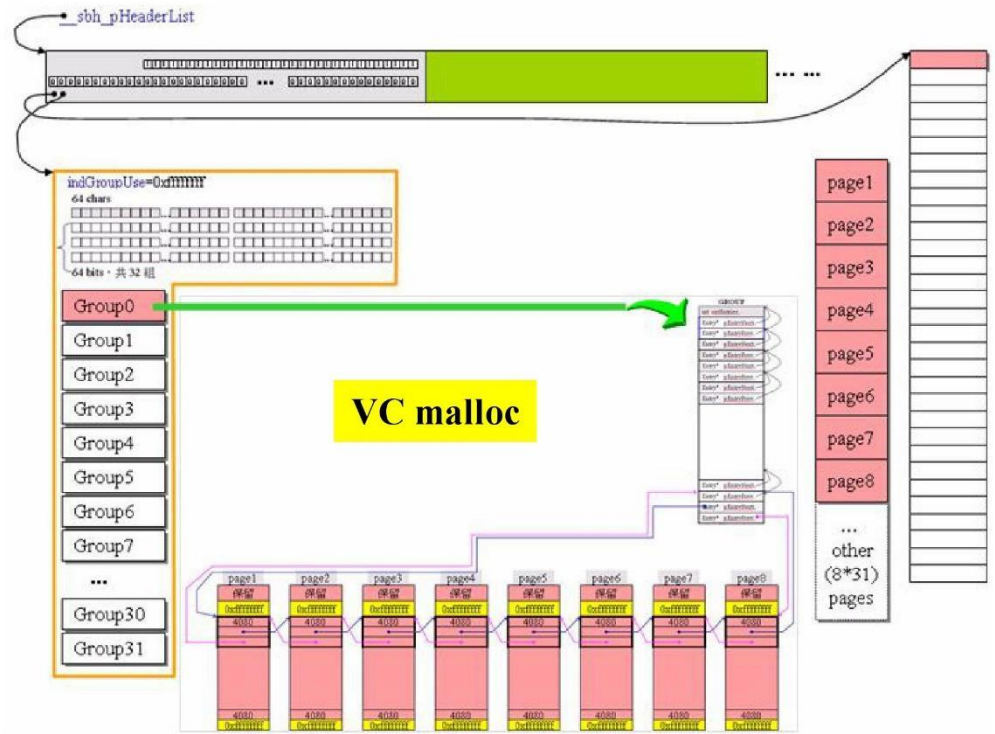
VC6, Heap State Reporting Functions

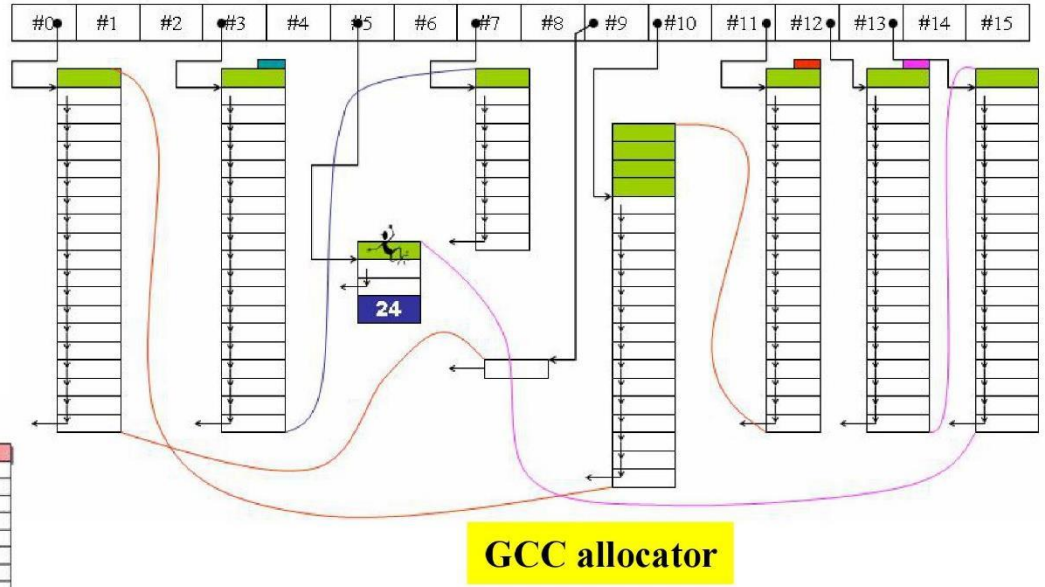
The following functions report the state and contents of the heap, and use the information to help detect memory leaks and other problems:

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

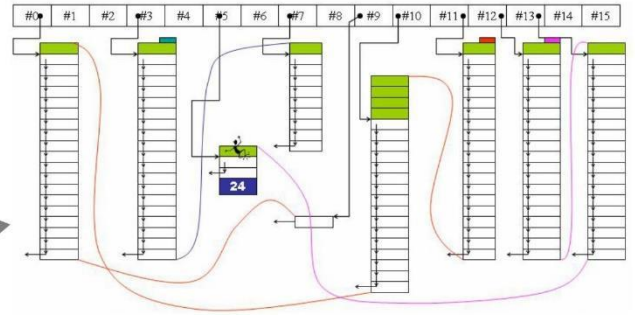
C++ Library (std::allocator)

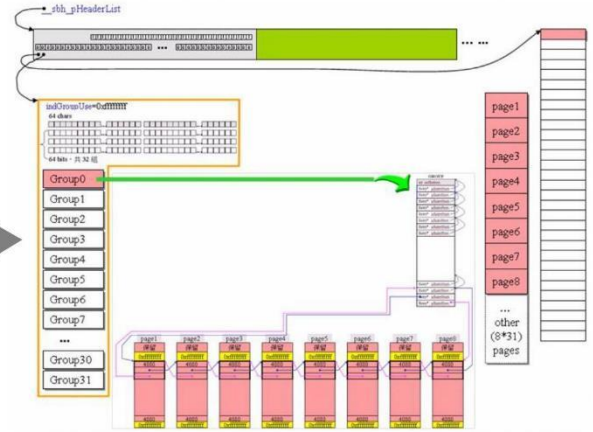
C++ primitives
new, new[], new(), ::operator new(), …

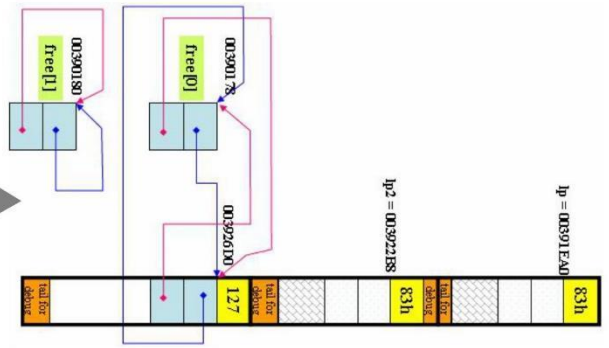
CRT (malloc / free)

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

?







內存管理

從平地到萬丈高樓

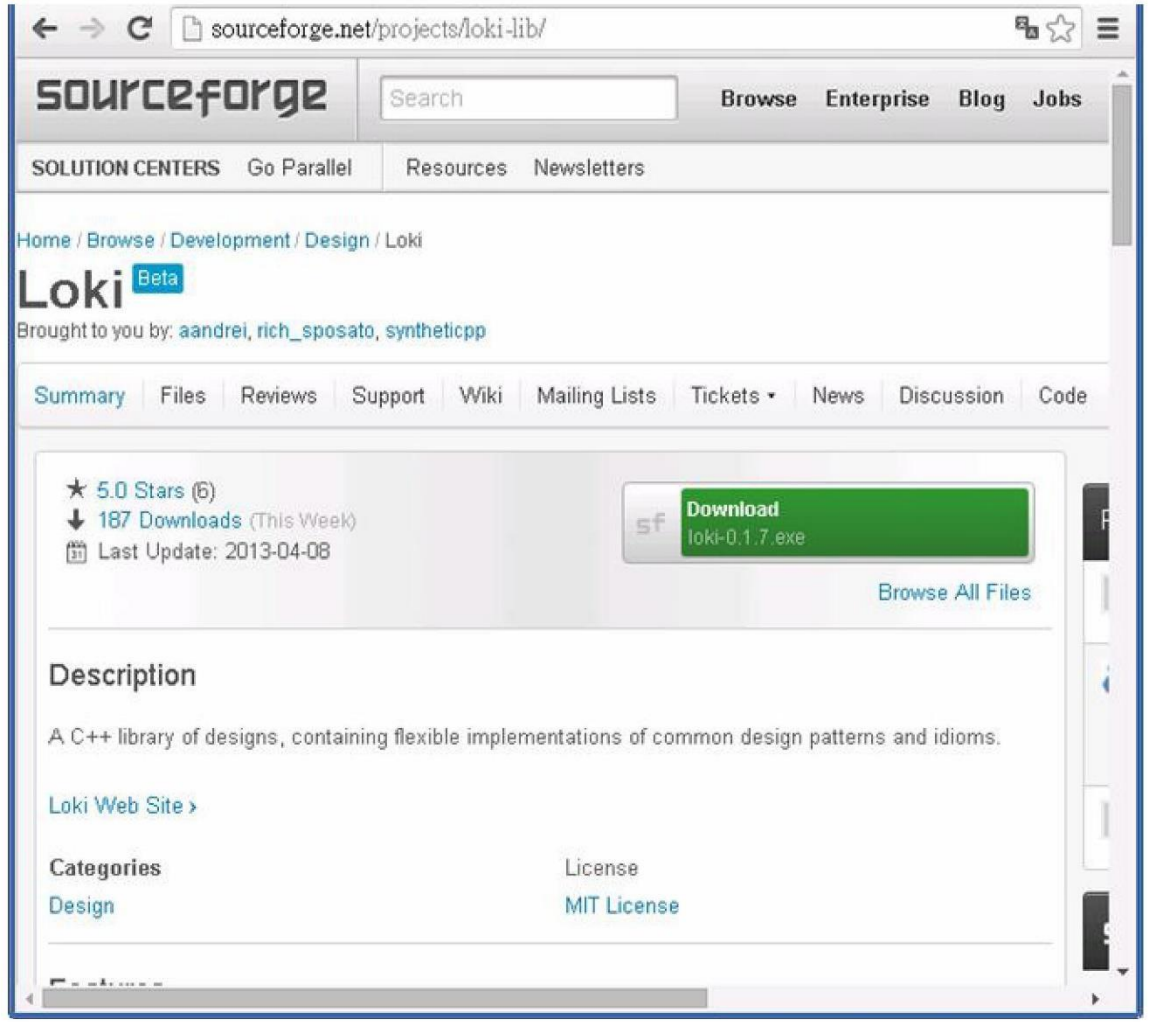
Memory Management 101

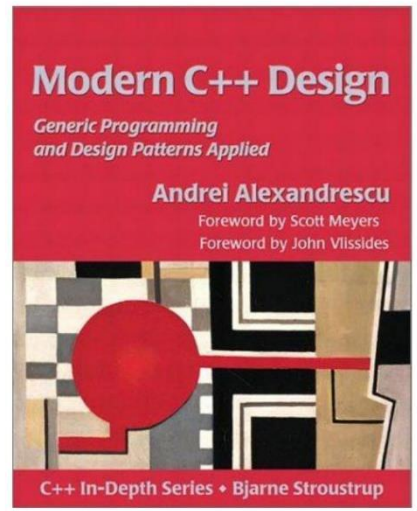
第一講 primitives
第二講 std::allocator
第三講 malloc/free
第四講 loki::allocator
第五講 other issues

侯捷

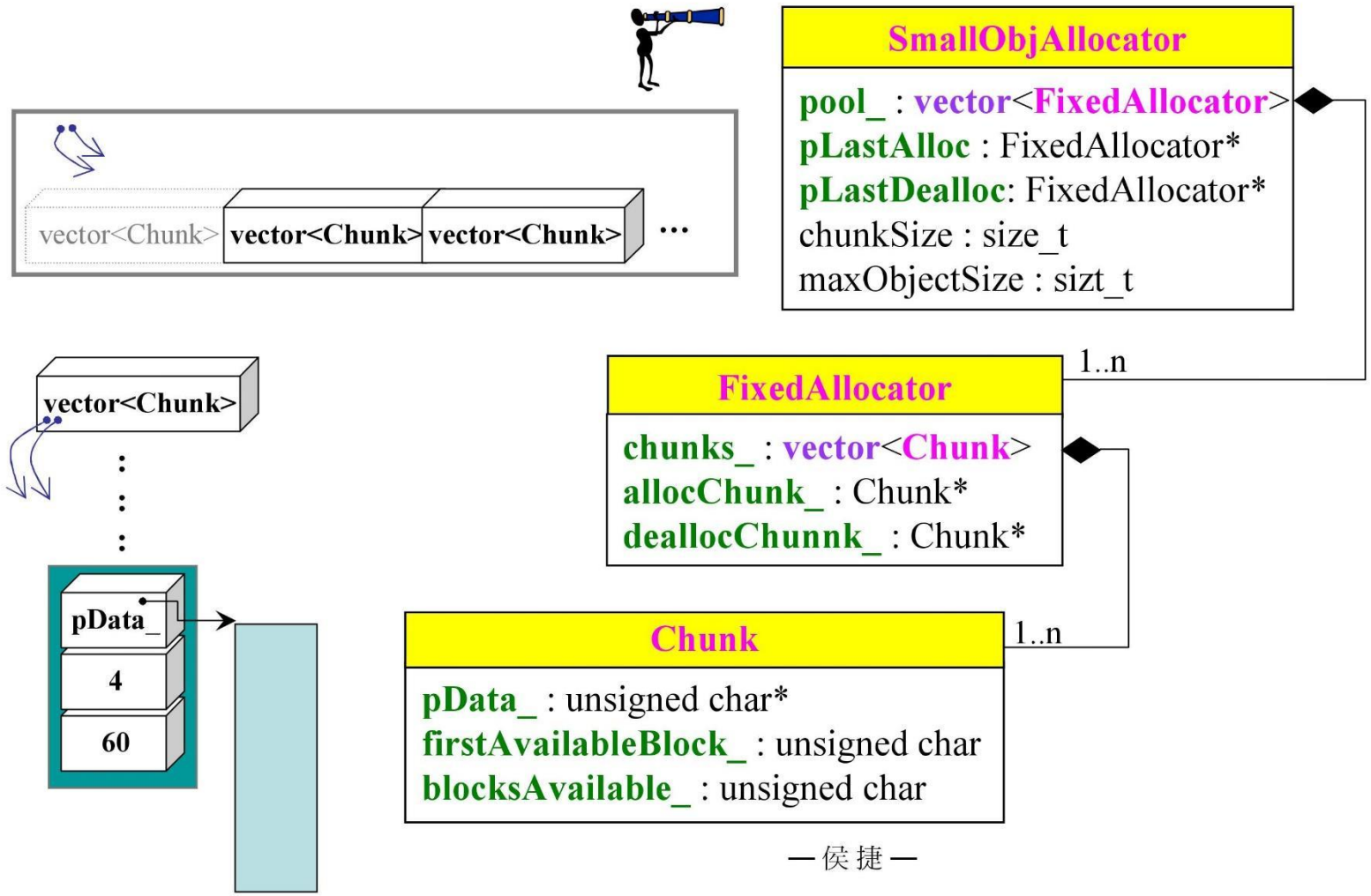
成竹在胸

Loki Library

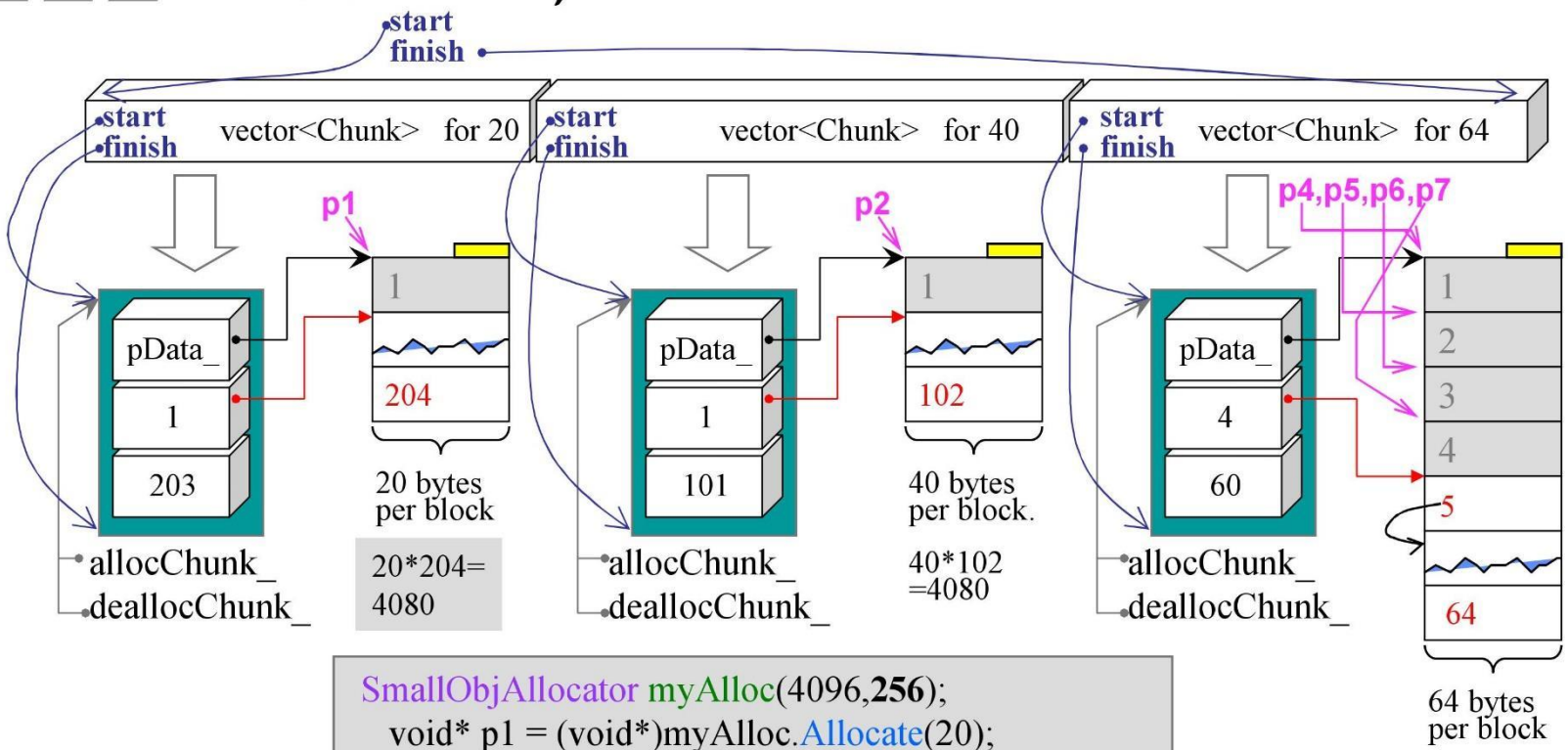




Loki allocator, 3 classes

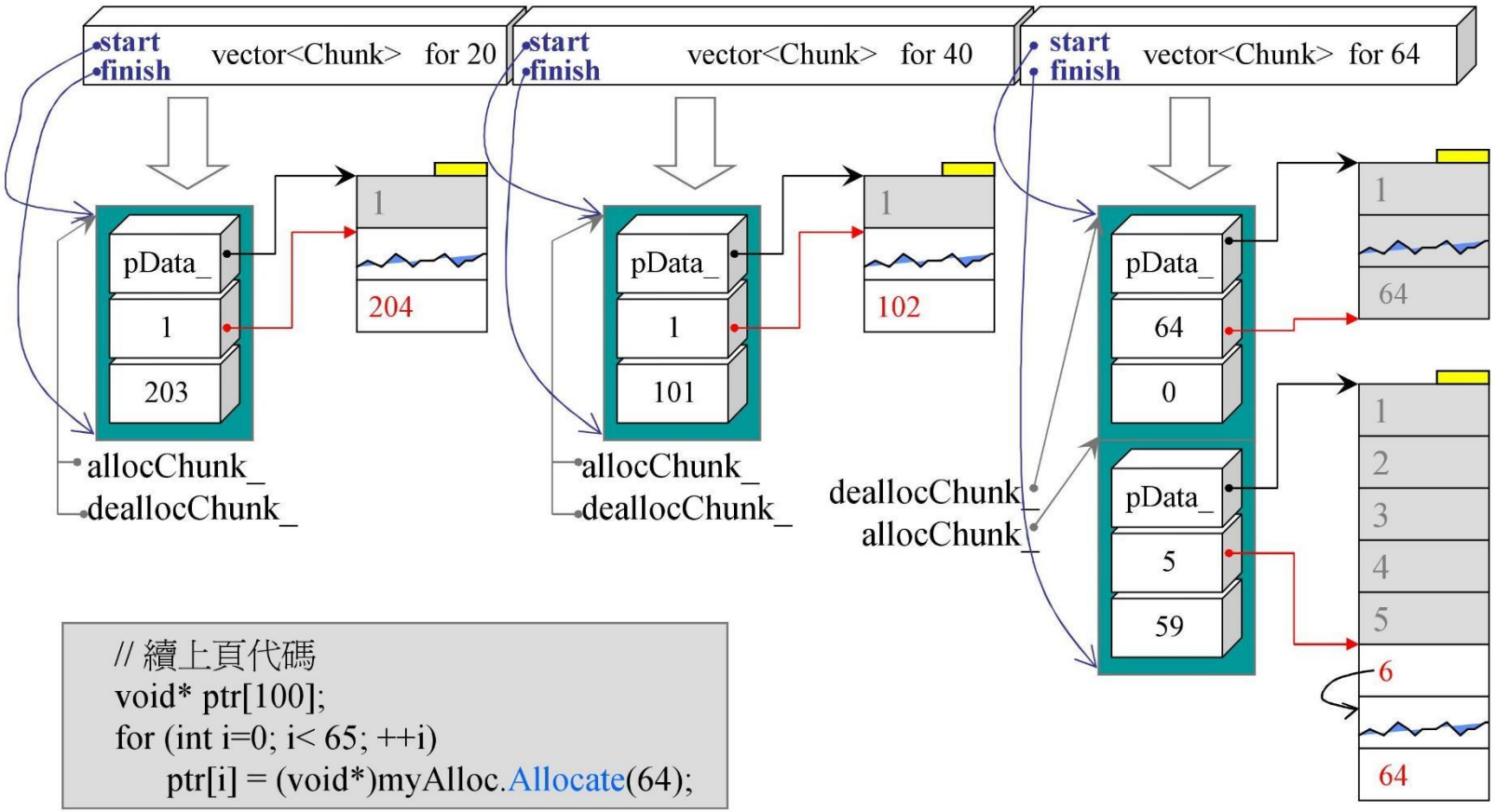


Loki allocator, 1



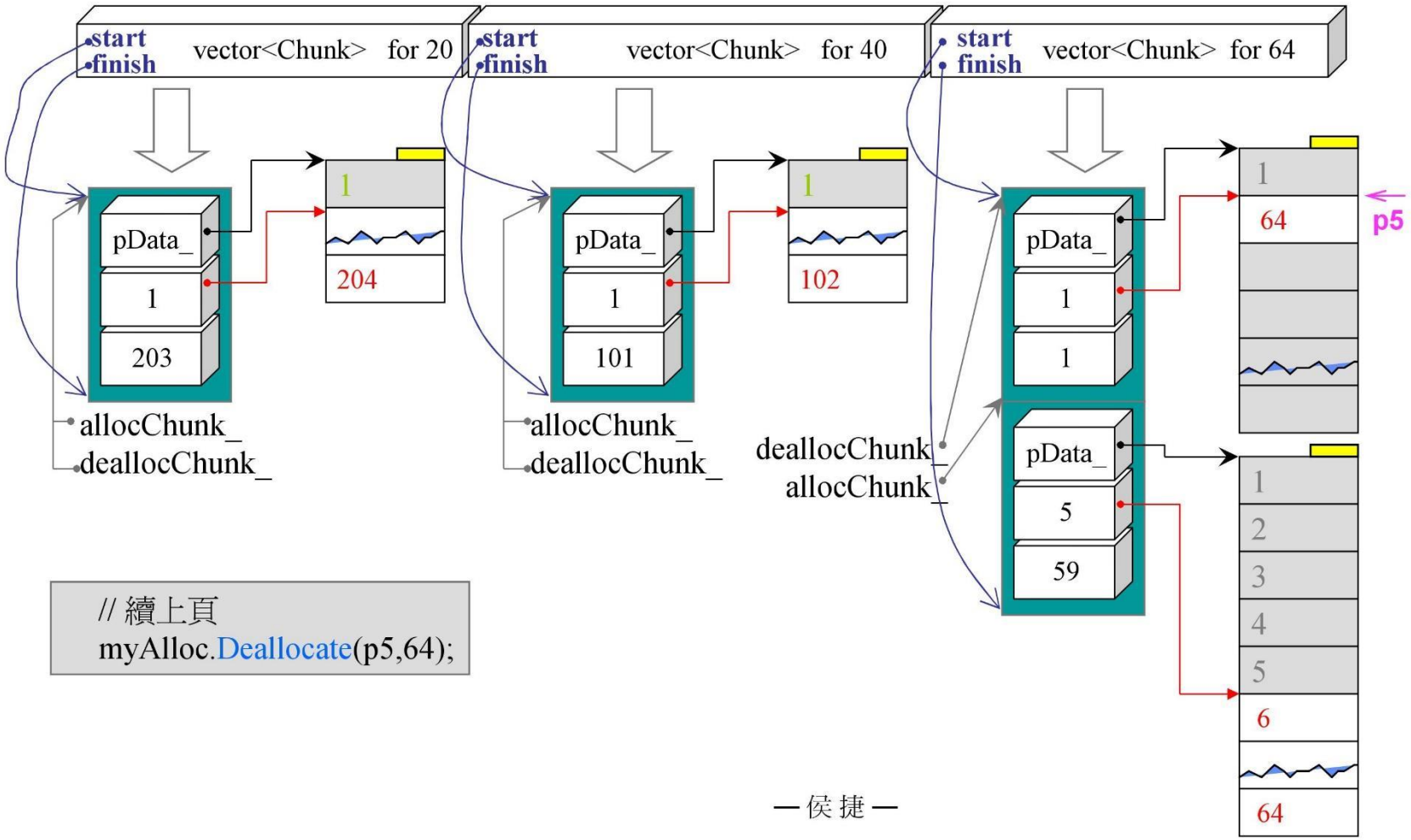

```
SmallObjAllocator myAlloc(4096,256);
  void* p1 = (void*)myAlloc.Allocate(20);
  void* p4 = (void*)myAlloc.Allocate(64);
  void* p2 = (void*)myAlloc.Allocate(40);
  void* p3 = (void*)myAlloc.Allocate(300);  // > 256
  void* p5 = (void*)myAlloc.Allocate(64);
  void* p6 = (void*)myAlloc.Allocate(64);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

Loki allocator, 2



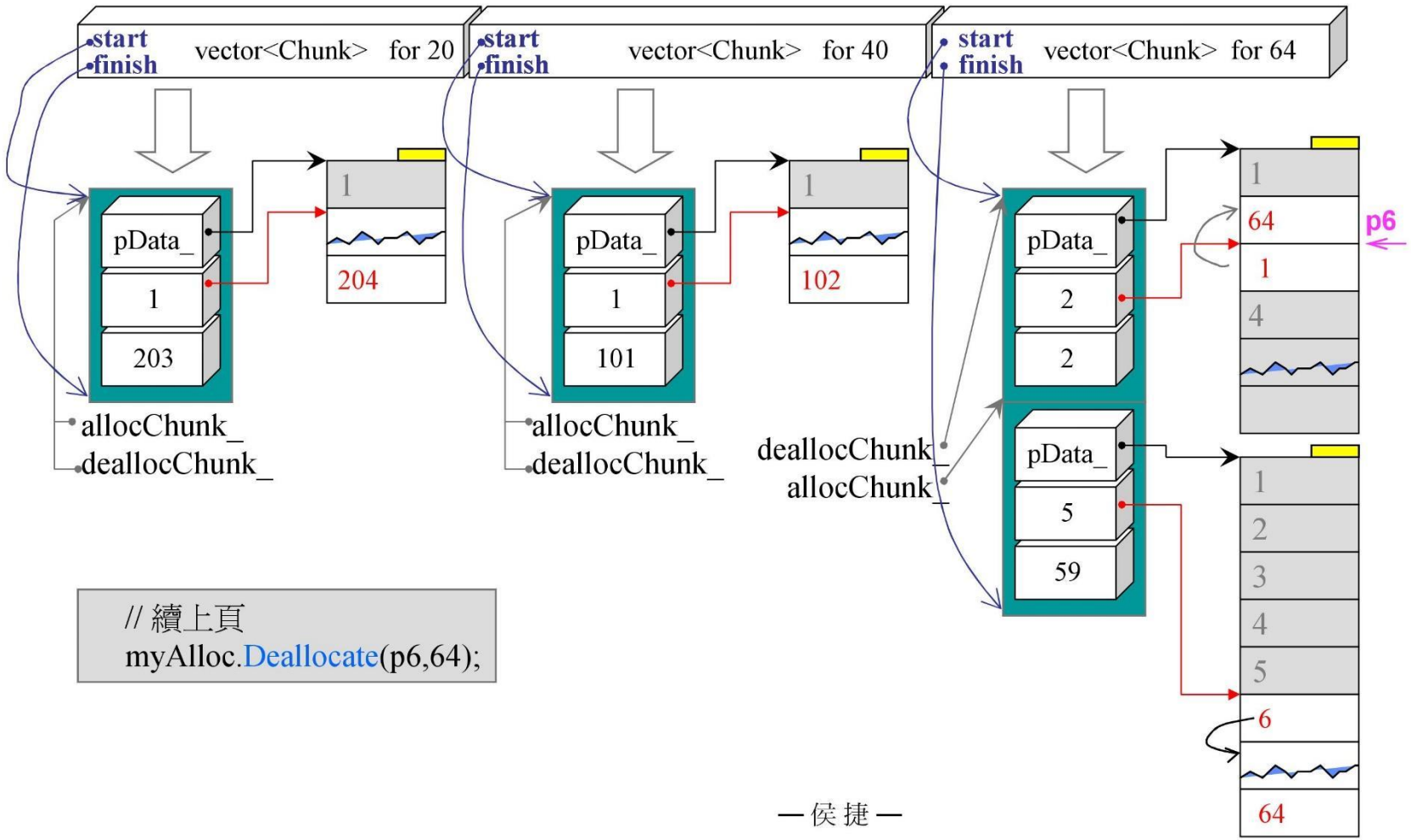

```
// 續上頁代碼
void* ptr[100];
for (int i=0; i< 65; ++i)
    ptr[i] = (void*)myAlloc.Allocate(64);
```

Loki allocator, 3



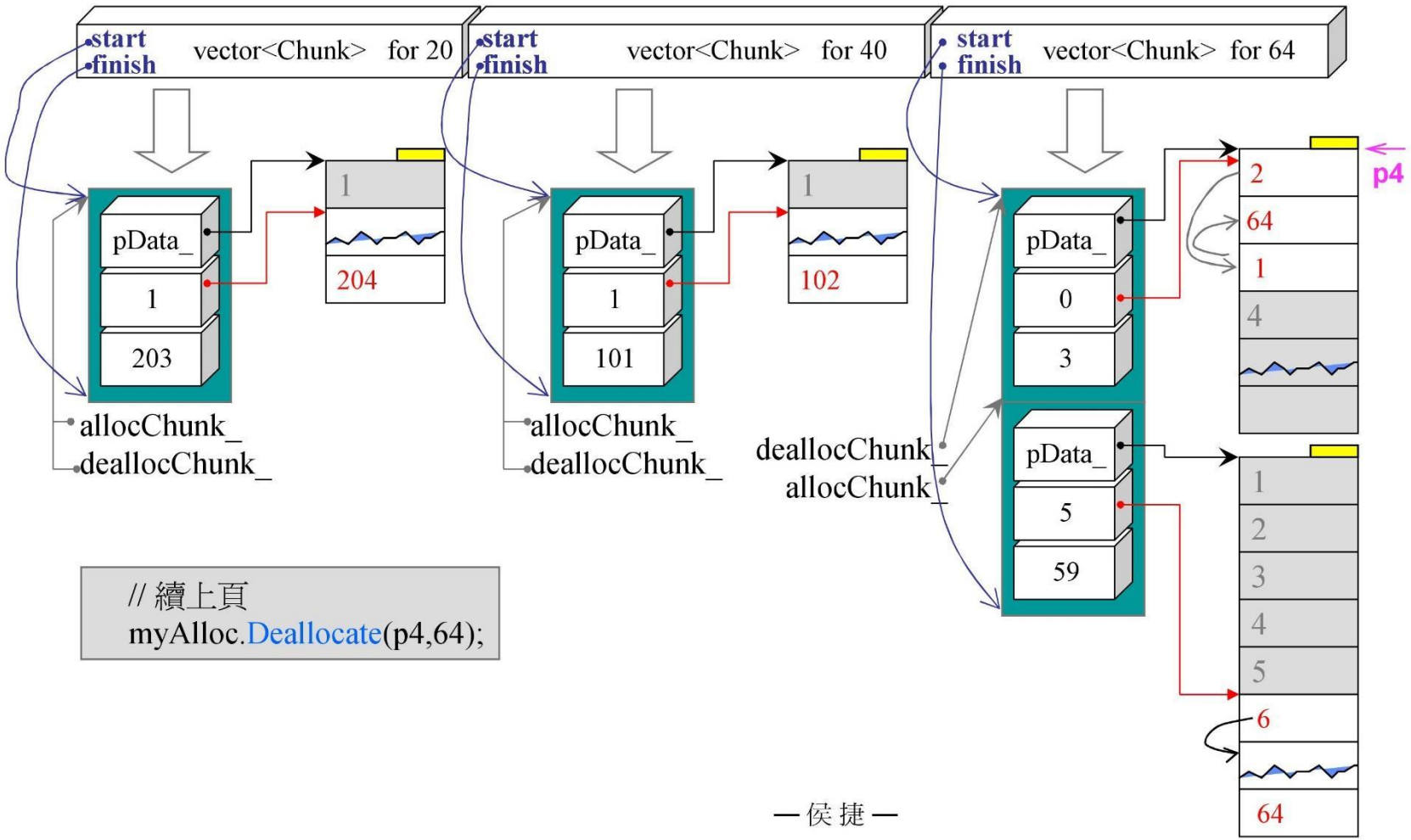

```
// 續上頁
myAlloc.Deallocate(p5,64);
```

Loki allocator, 4



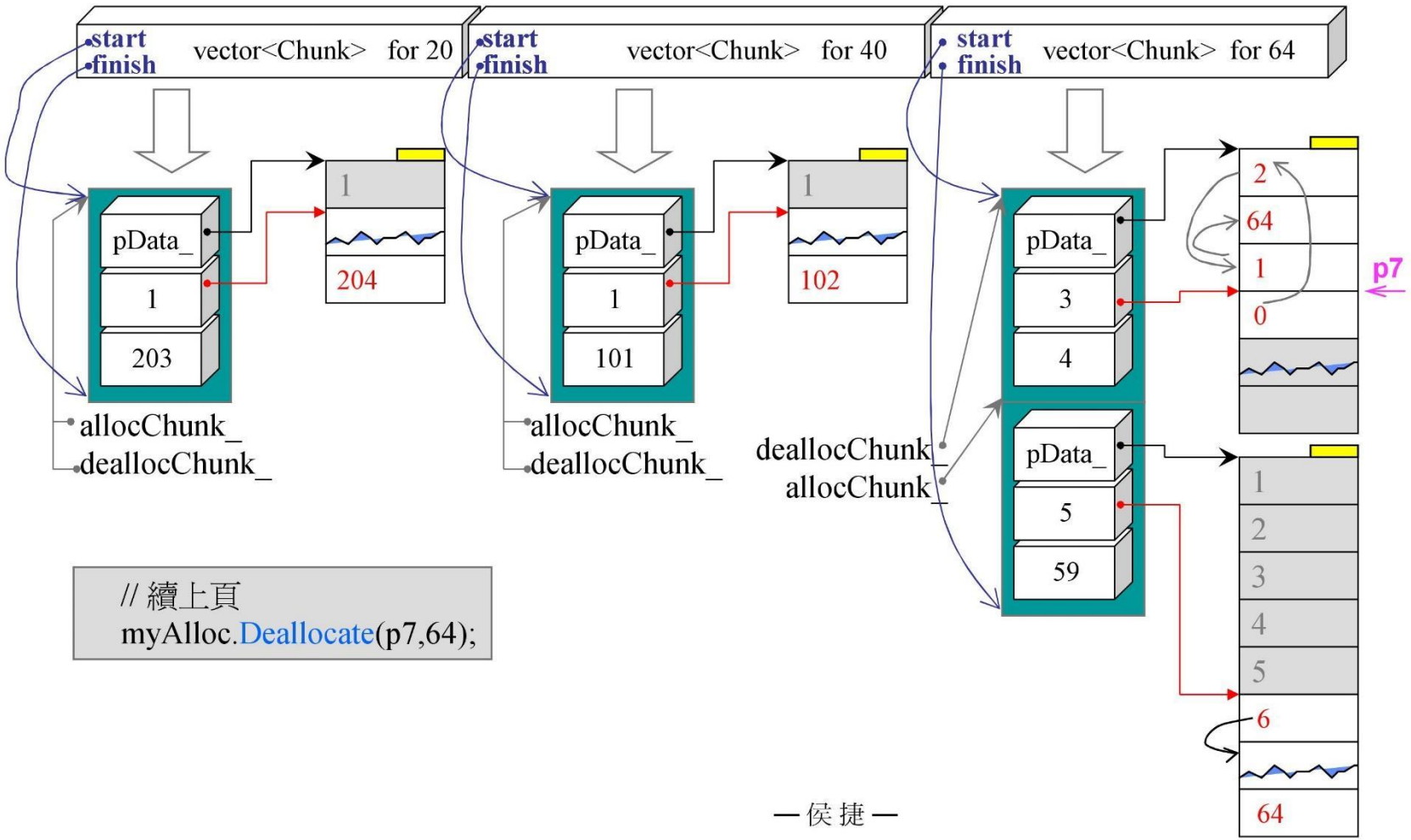

```
// 續上頁
myAlloc.Deallocate(p6,64);
```

Loki allocator, 5



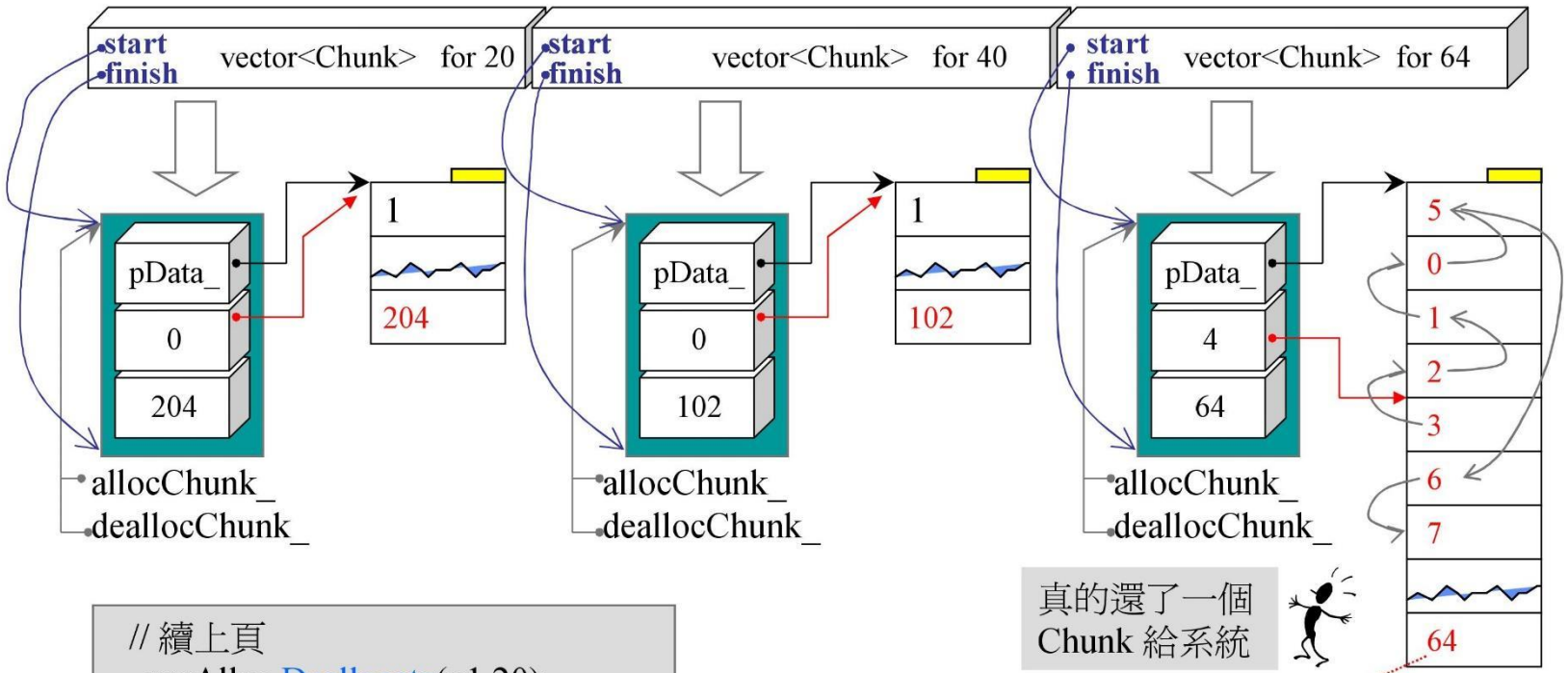

```
// 續上頁
myAlloc.Deallocate(p4,64);
```

Loki allocator, 6




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

Loki allocator, 7



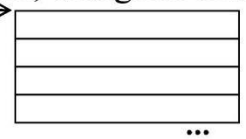
真的還了一個 Chunk 給系統


```
// 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)

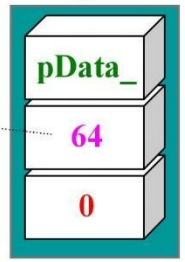
Loki allocator, Chunk

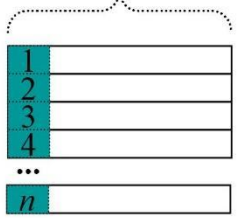
```
void FixedAllocator::Chunk::Init(std::size_t blockSize, unsigned char blocks)
{
   pData_ = new unsigned char[blockSize * blocks];
   Reset(blockSize, blocks);
}
```



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

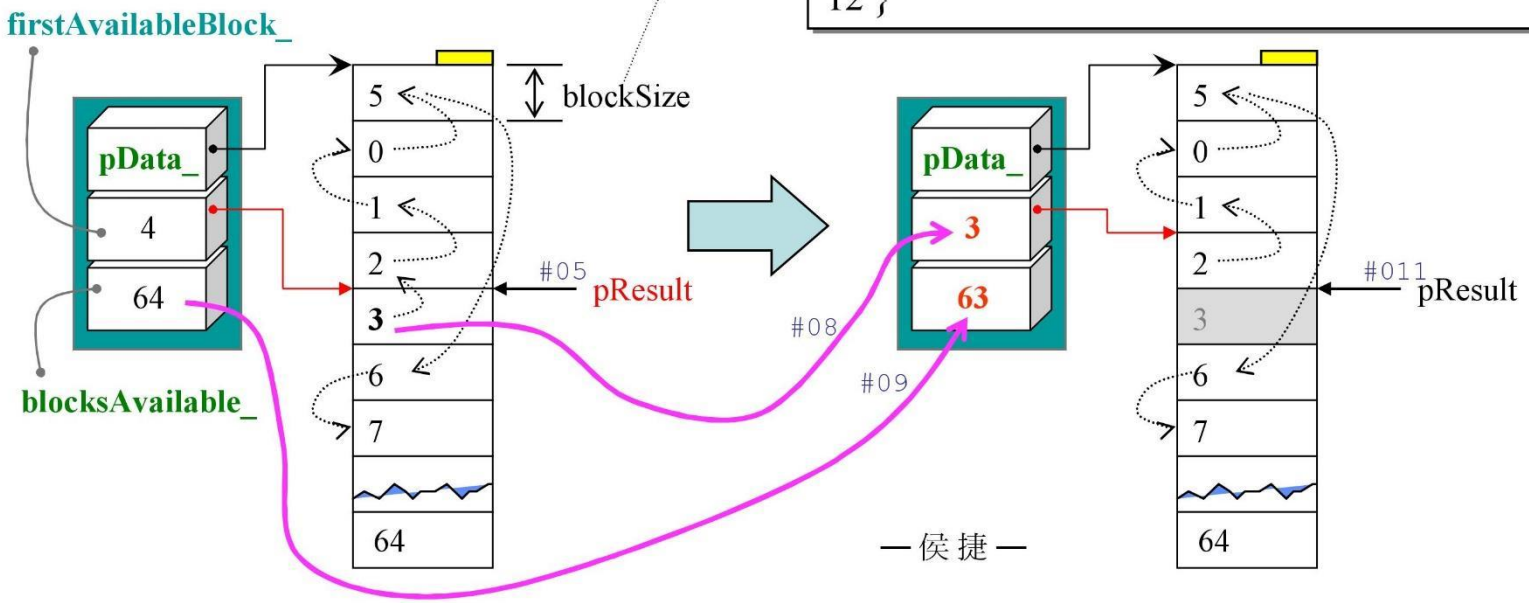
```
void FixedAllocator::Chunk::Reset(std::size_t blockSize,
                                  unsigned char blocks)
{
   firstAvailableBlock_ = 0;
   blocksAvailable_ = blocks;

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





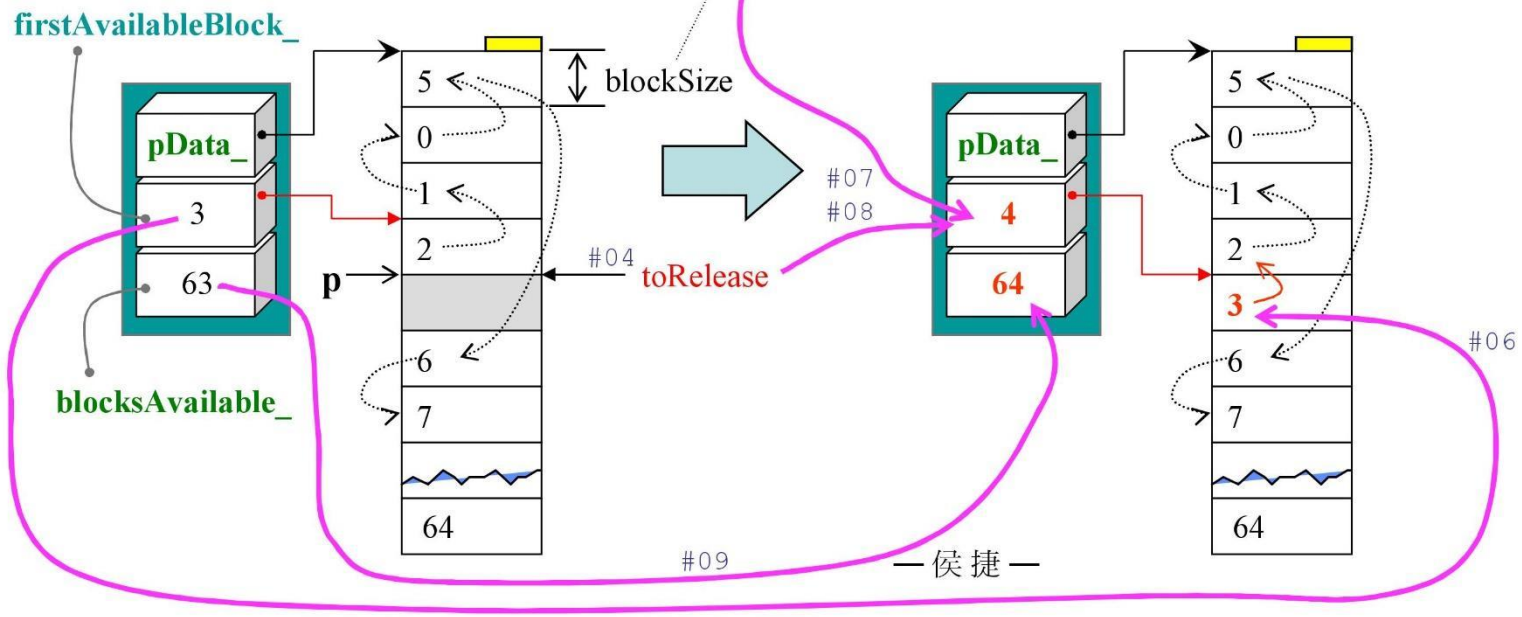
Chunk::Allocate()

```
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 }
```



```
#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

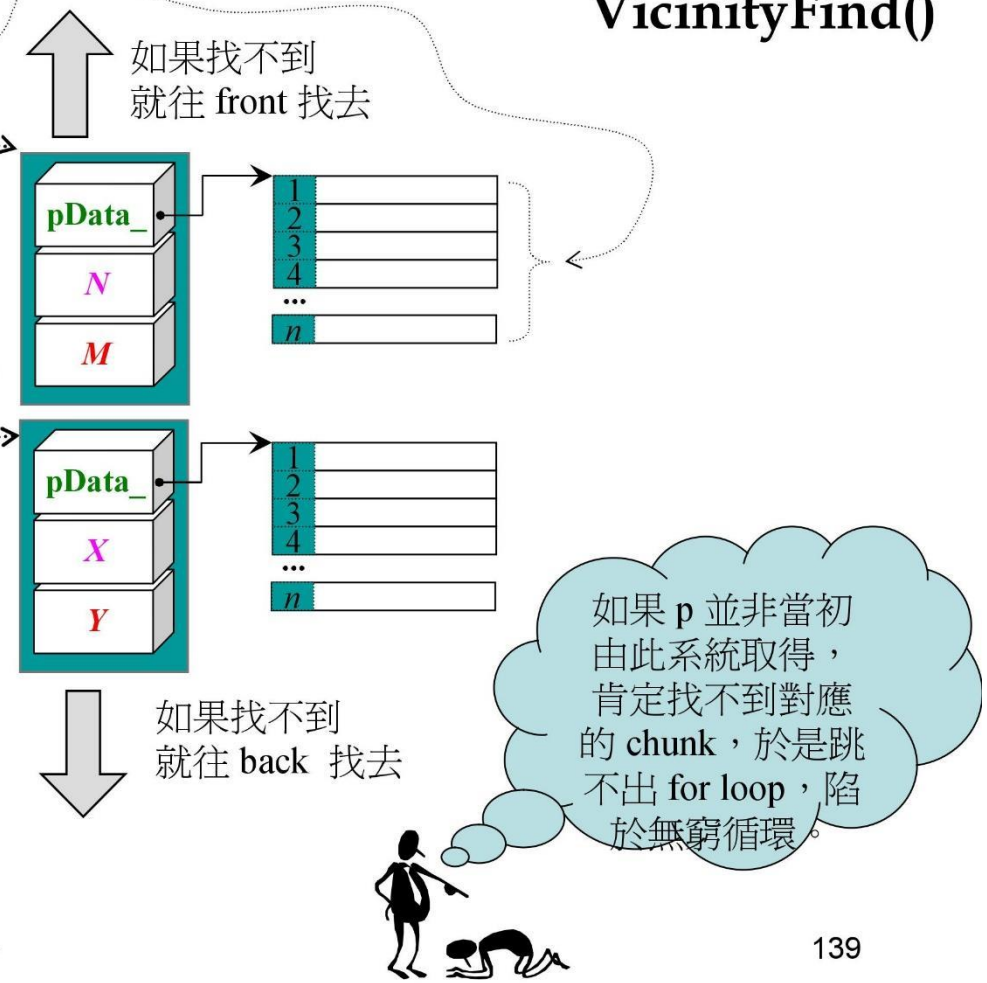
FixedAllocator::Allocate()

FixedAllocator::Deallocate()

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

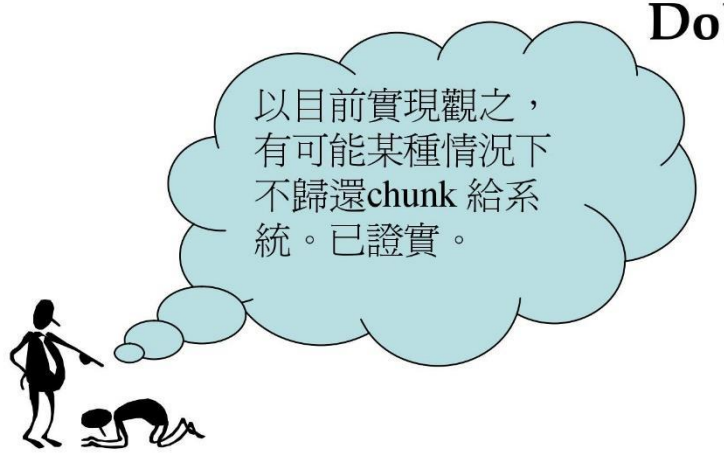
FixedAllocator::VicinityFind()

```
#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？

内存管理

從平地到萬丈高樓

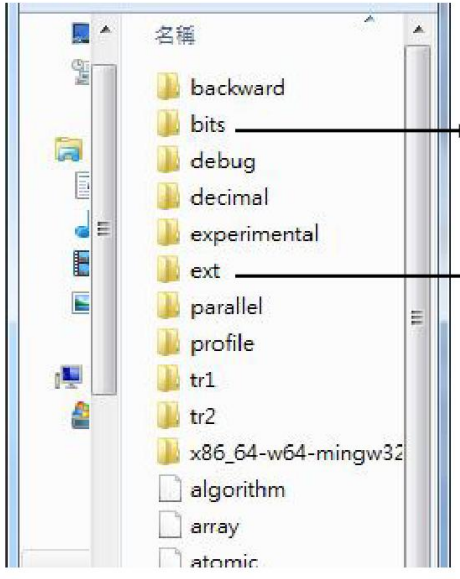
Memory Management 101

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

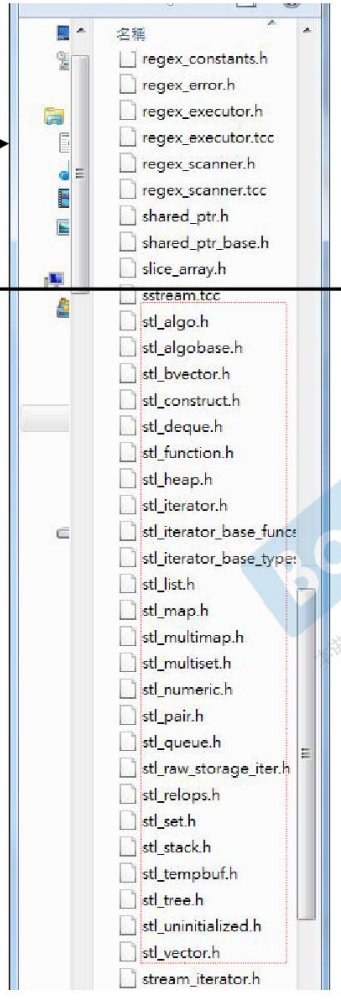
侯捷

GNU C++

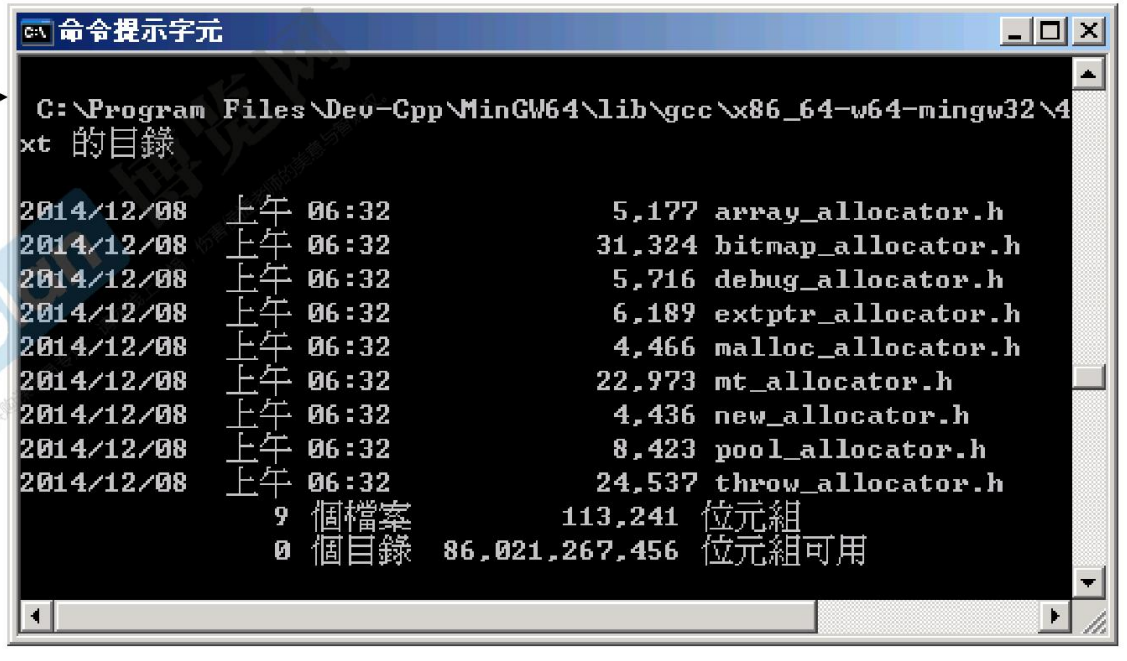
…\4.9.2\include\c++



…\include\c++\bits



…\include\c++\ext



GNU C++ 對於 Allocator 的描述

當你將元素加入容器中，容器必須分配更多內存以保存這些元素，於是它們向其模板參數 **Allocator** 發出申請，該模板參數往往被另名為 (*aliased to*) allocator_type。甚至你將 chars 添加到 string class 也是如此，因為 string 也算是一個正規的 STL 容器。

每個元素類型為 T 的容器 (container-of-T) 的 Allocator 模板實參默認為 **allocator<T>.**。其接口只有大約 20 個 public 聲明，包括嵌套的 (nested) typedefs 和成員函數。最重要的兩個成員函數是：

T* **allocate** (size_type n, const void* hint = 0);
void **deallocate** (T* p, size_type n);

n 指的是客戶申請的元素個數，不是指空間總量。

這些空間是通過調用 ::operator new 獲得，但何時調用以及多麼頻繁調用，並無具體指定。

```
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;
```

GNU C++ 對於 Allocator 的描述

最容易滿足需求的作法就是每當容器需要內存就調用 operator new，每當容器釋放內存就調用 operator delete。這種作法比起分配大塊內存並緩存 (caching) 然後徐徐小塊使用當然較慢，優勢則是可以在極大範圍的硬件和操作系統上有效運作。

- **__gnu_cxx::new_allocator**

  實現出簡樸的 operator new 和 operator delete 語意。

```
template<typename _Tp>
class new_allocator
{
  .....
  pointer allocate(size_type __n, const void* = 0) {
    ……
    return static_cast<_Tp*>
        (::operator new(__n * sizeof(_Tp)));
  }
  void deallocate(pointer __p, size_type)
  { ::operator delete(__p); }
};
```

- **__gnu_cxx::malloc_allocator**

  其實現與上例唯一不同的是，
  它使用 C 函數 std::malloc 和 std::free。

```
template<typename _Tp>
class malloc_allocator
{
   pointer allocate(size_type __n, const void* = 0)   {
        ……
      pointer __ret = ……(std::malloc(__n * sizeof(_Tp)));
   }
   void deallocate(pointer __p, size_type)  {
      std::free(……(__p)); }
};
```

— 侯 捷

GNU C++ 對於 Allocator 的描述

另一種作法就是使用**智能型** allocator，將分配所得的內存加以緩存 (*cache*)。這種額外機制可以數種形式呈現：

- 可以是個 bitmap index，用以索引至一個以 2 的指數倍成長的籃子 (exponentially increasing power-of-two-sized buckets)

- 也可以是個相較之下比較簡易的 fixed-size pooling cache.

這裡所說的 cache 被程序內的所有容器共享，而 operators new 和 operator delete 不經常被調用，這可帶來速度上的優勢。使用這類技巧的 allocators 包括：

?!

不需要cookie

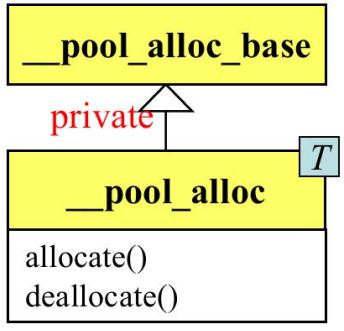
- **__gnu_cxx::bitmap_allocator**
  一個高效能 allocator, 使用 bit-map 追蹤被使用和未被使用 (used and unused) 的內存塊。

- **__gnu_cxx::pool_allocator**

- **__gnu_cxx::__mt_alloc**

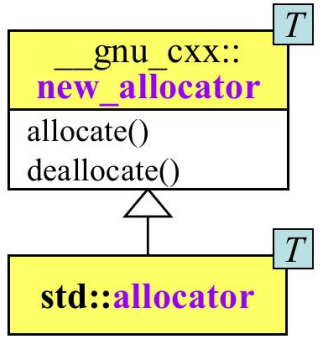
GNU C++ 對於 Allocator 的描述

Class allocator 只擁有 typedef, constructor, 和 rebind 等成員。它繼承自一個_high-speed extension allocators。也因此，所有分配和歸還 (allocation and deallocation) 都取決於該 base class，而這個 base class 也許是終端用戶無法碰觸和操控的 (user-configurable).



很難挑選出某個分配策略說它**能提供最大共同利益而不至於令某些行為過度劣勢**。事實上，就算要挑選何種典型動作以量測速度，都是一種困難。

GNU C++ 提供三項綜合測試 (three synthetic benchmarks) 用以完成 C++ allocators 之間的速度評比：



- Insertion. 經過多次 iterations 後各種 STL 容器將擁有某些極大量。分別測試循序式 (sequence) 和關聯式 (associative) 容器。

- 多線程環境中的 insertion and erasure. 這個測試展示 allocator 歸還內存的能力, 以及量測線程之間對內存的競爭。

- A threaded producer/consumer model. 分別測試循序式 (sequence) 和關聯式 (associative) 容器。

GNU C++ 對於 Allocator 的描述

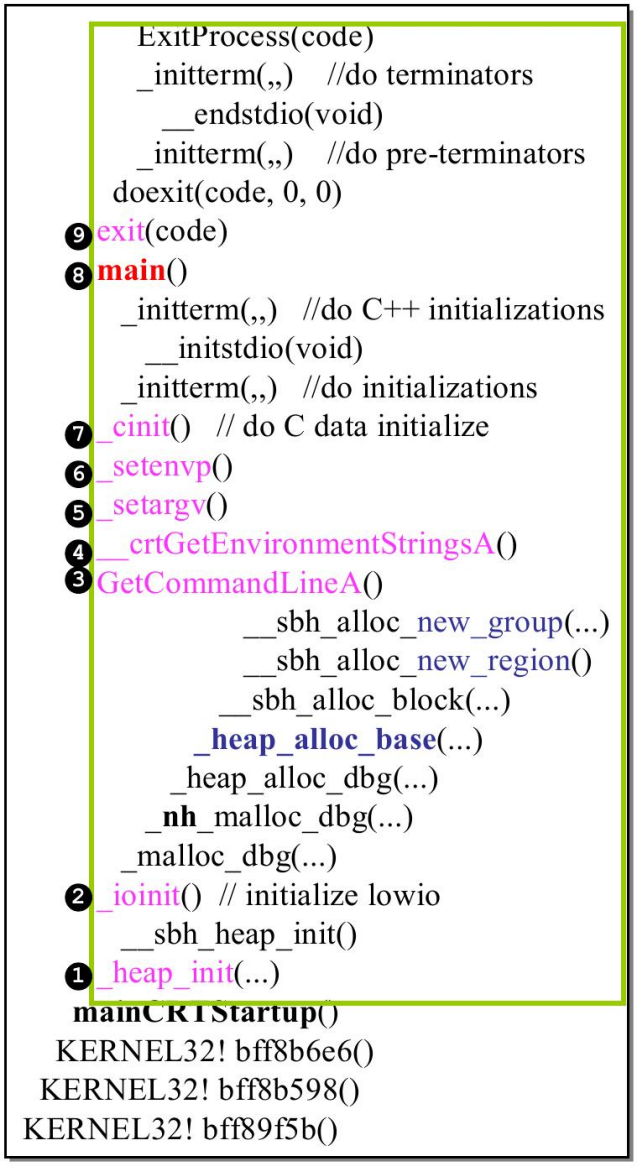
另兩個**智能型** allocator：

- **__gnu_cxx::debug_allocator**

這是一個外覆器 (wrapper)，可包覆於任何 allocator 之上。它把客戶的申請量添加一些，然後由 allocator 回應，並以那一小塊額外內存放置_size 信息。一旦 deallocate() 收到一個 pointer，就會檢查 size 並以 assert() 保證吻合。

- **__gnu_cxx::array_allocator**

允許分配一已知且固定大小 (known and fixed size) 的內存塊，內存來自 std::array objects。用上這個 allocator，大小固定的容器 (包括 std::string) 就無需再調用 ::operator new 和 ::operator delete。這就允許我們使用 STL abstractions 而無需在運行期添亂、增加開銷。甚至在 program startup 情況下也可使用。



VS2013 標準分配器 與 new_allocator

《…\xmemory0》

```
template<class _Ty>
class allocator
  : public _Allocator_base<_Ty>
{  // generic allocator for objects of class _Ty
public:
   typedef value_type *pointer;
   typedef size_t size_type;

   void deallocate(pointer _Ptr, size_type)
   {          // deallocate object at _Ptr, ignore size
      ::operator delete(_Ptr);
   }
   pointer allocate(size_type _Count)
   {          // allocate array of _Count elements
      return (_Allocate(_Count, (pointer)0));
   }
   pointer allocate(size_type _Count, const void *)
   {// allocate array of _Count elements, ignore hint
      return (allocate(_Count));
   }
…
};
```

《…\memory》

```
…
#include <xmemory>
```

《…\xmemory》

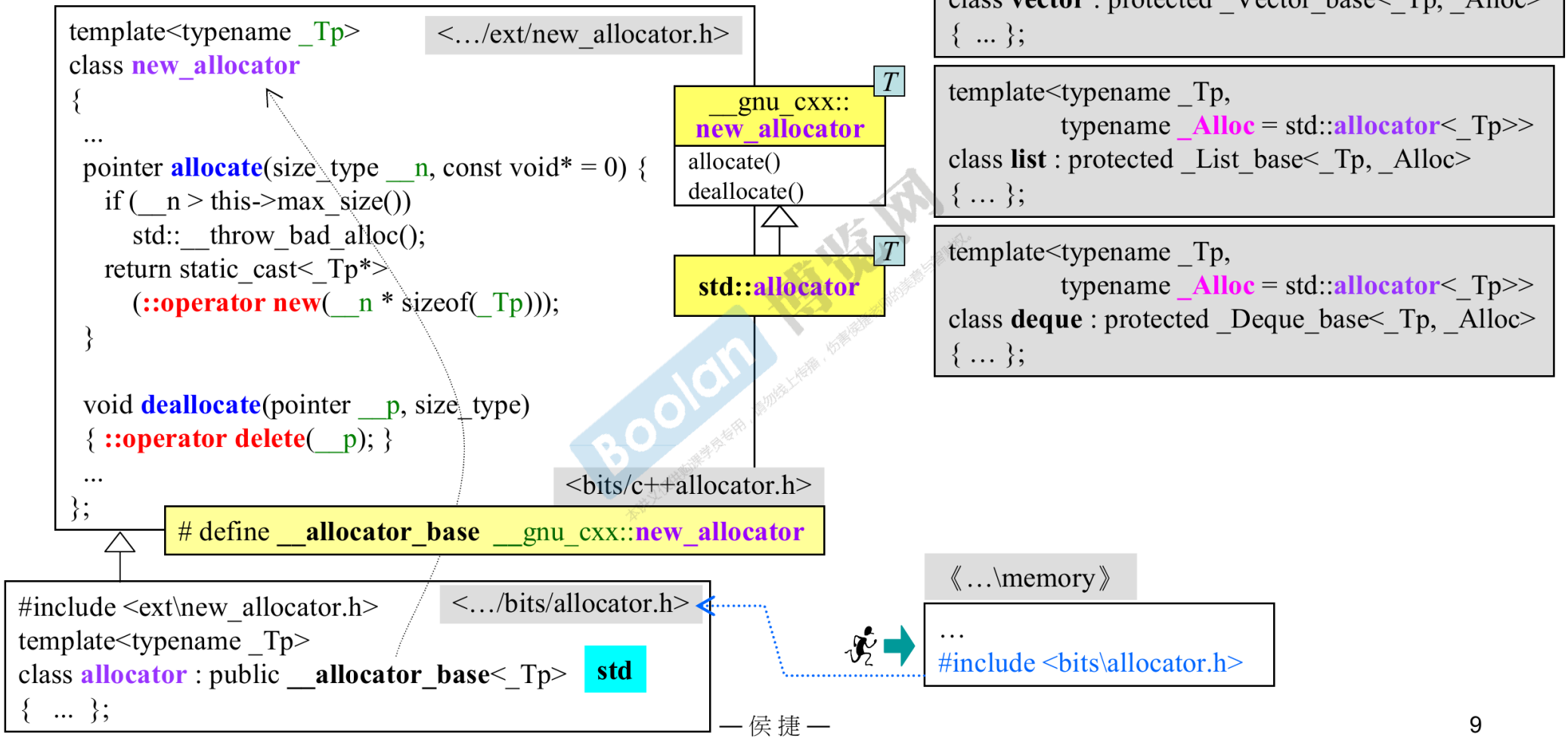
```
…
#include
<xmemory0>
```

<…/list>

```
template<class _Ty,
    class _Alloc = allocator<_Ty>>
class list
   : public _List_buy<_Ty, _Alloc>
{       // bidirectional linked list
   …
};
```

```
// TEMPLATE FUNCTION _Allocate
template<class _Ty> inline
_Ty *_Allocate(size_t _Count, _Ty *)
{    // allocate storage for _Count elements of type _Ty
   void *_Ptr = 0;
   if (_Count == 0);
   else if ((( )(-1) / sizeof (_Ty) < _Count)
            || (_Ptr = ::operator new(_Count * sizeof (_Ty))) == 0)
      _Xbad_alloc();    // report no memory
   return ((_Ty *)_Ptr);
}
```

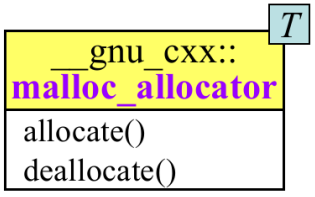
G4.9 標準分配器 與 new_allocator



G4.9 malloc_allocator

<…/ext/malloc_allocator.h>

```
template<typename _Tp>
  class malloc_allocator
  {
    // NB: __n is permitted to be 0.  The C++ standard says nothing
    // about what the return value is when __n == 0.
    pointer
    allocate(size_type __n, const void* = 0)
    {
          if (__n > this->max_size())
            std::__throw_bad_alloc();

          pointer __ret = static_cast<_Tp*>(std::malloc(__n * sizeof(_Tp)));
          if (!__ret)
            std::__throw_bad_alloc();
          return __ret;
    }

    // __p is not permitted to be a null pointer.
    void
    deallocate(pointer __p, size_type)
    { std::free(static_cast<void*>(__p)); }

    size_type
    max_size() const _GLIBCXX_USE_NOEXCEPT
    { return size_t(-1) / sizeof(_Tp); }
……
};
```

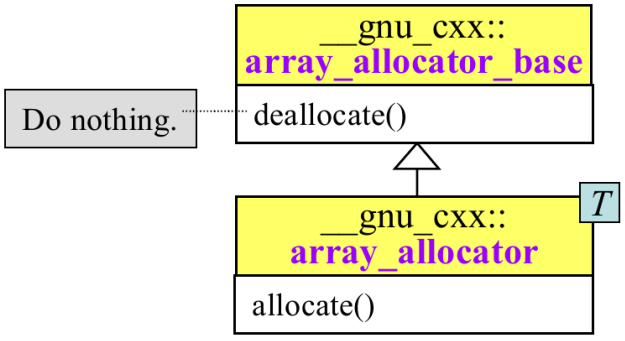


G4.9 array_allocator

<…/ext/array_allocator.h>

```
template<typename _Tp, typename _Array = std::tr1::array<_Tp, 1>>
  class array_allocator : public array_allocator_base<_Tp>
  {
  public:
    typedef size_t      size_type;
    typedef _Tp         value_type;
    typedef _Array      array_type;
    ……
  private:
    array_type* _M_array;
    size_type   _M_used;

  public:
    array_allocator(array_type* __array = NULL) throw()
    : _M_array(__array), _M_used(size_type()) { }

    ……
```

```
pointer
allocate(size_type __n, const void* = 0)
{
    if (_M_array == 0 || _M_used + __n > _M_array->size())
        std::__throw_bad_alloc();
    pointer __ret = _M_array->begin() + _M_used;
    _M_used += __n;
    return __ret;
}
};
```



G4.9 array_allocator

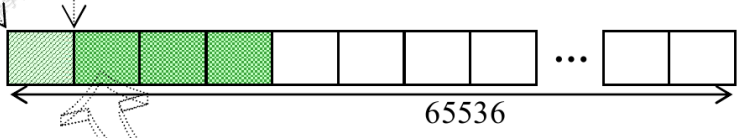
```
using namespace std;
using namespace std::tr1;
using namespace __gnu_cxx;

typedef ARRAY  std::array<int, 65536>;

ARRAY* pa = new ARRAY;

array_allocator<int, ARRAY> myalloc(pa);

int* p1 = myalloc.allocate(1);

int* p2 = myalloc.allocate(3);
myalloc.deallocate(p1);       //no-op
myalloc.deallocate(p2);       //no-op

delete pa;
```

使用 std::tr1::array 或 std::array 均可.

這種 array object
其內部將有 int _M_instance[65536];

```
pointer allocate(size_type __n, const void* = 0)
{
   if (_M_array == 0 || _M_used + __n > _M_array->size())
      std::__throw_bad_alloc();
   pointer __ret = _M_array->begin() + _M_used;
   _M_used += __n;
   return __ret;
}
```

```
template<typename _Tp, std::size_t _Nm>
   struct array
   {……
    value_type _M_instance[_Nm ? _Nm : 1];

    iterator  begin()
    { return iterator(&_M_instance[0]); }
    size_type size() const { return _Nm; }
    ……
   };
```



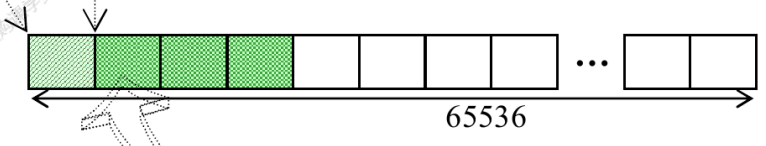
array_allocator 並不會
回收已給出的內存空間

G4.9 array_allocator

```
using namespace std;
using namespace std::tr1;
using namespace __gnu_cxx;

int my[65536];

array_allocator<int, array<int,65536>>
myalloc(&my);

int* p1 = myalloc.allocate(1);

int* p2 = myalloc.allocate(3);
myalloc.deallocate(p1);      //no-op
myalloc.deallocate(p2);      //no-op
```

使用 std::tr1::array 或 std::array 均可.

這種 array object
其內部將有 int _M_instance[65536];



array_allocator 並不會
回收已給出的內存空間

G4.9 debug_allocator

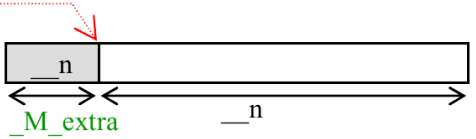
<…/ext/debug_allocator.h>

```
template<typename _Alloc>
  class debug_allocator
  {
  ……

  private:
    size_type _M_extra;  //通常是個 size_t;
    _Alloc _M_allocator;

    size_type _S_extra()  {
      const size_t __obj_size = sizeof(value_type);
      return (sizeof(size_type) + __obj_size - 1) / __obj_size;
    }

  public:
    debug_allocator(const _Alloc& __a)
      : _M_allocator(__a), _M_extra(_S_extra()) { }
```

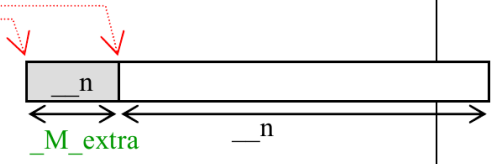
計算 extra (bytes) 相當於幾個元素

Alloc

__gnu_cxx::
debug_allocator
allocate()
deallocate()




```
pointer  allocate(size_type __n)  {
  pointer __res = _M_allocator.allocate(__n + _M_extra);
  size_type* __ps = reinterpret_cast<size_type*>(__res);
  *__ps = __n;
  return __res + _M_extra;
}

void  deallocate(pointer __p, size_type __n)  {
  using std::__throw_runtime_error;
  if (__p)  {
      pointer __real_p = __p - _M_extra;
      if (*reinterpret_cast<size_type*>(__real_p) != __n)
          __throw_runtime_error
            ("debug_allocator::deallocate wrong size");
      _M_allocator.deallocate(__real_p, __n + _M_extra);
  }
  else
      __throw_runtime_error
        ("debug_allocator::deallocate null pointer");
}
……
```



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

SGI style

```
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 → __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.

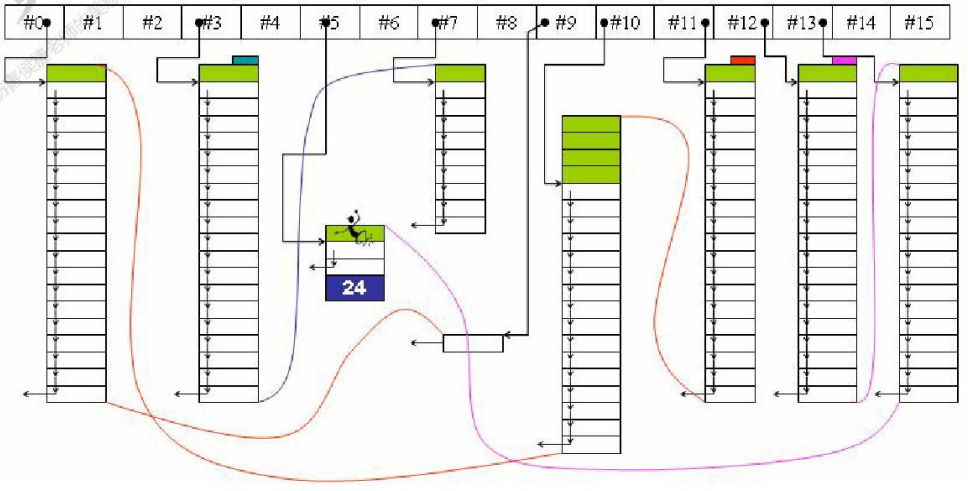
<…/ext/pool_allocator.h> **G4.9**

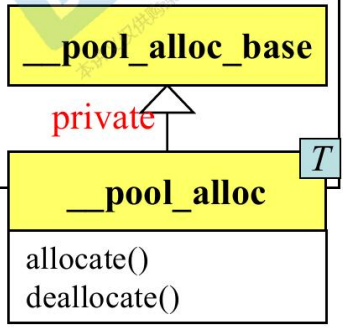
```
class __pool_alloc_base
{
protected:
  enum { _S_align = 8 };
  enum { _S_max_bytes = 128 };
  enum { _S_free_list_size = (size_t)_S_max_bytes / (size_t)_S_align };

  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;
  ...
```

STD style

用例：

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






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

G4.9 __pool_alloc 用例

```
//欲使用 std::allocator 以外的 allocator, 必須自行 #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);
```

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

相距 sizeof(double), 表示不帶 cookie

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

相距 > sizeof(double), 並不表示就帶著 cookie.

```
cout << sizeof(std::allocator<int>) << endl;   //1
vector<int, std::allocator<int>> vec;
cookie_test(std::allocator<double>(), 1);
```

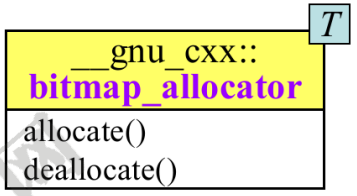
```
p1= 0x3e4098   p2= 0x3e4088   p3= 0x3e4078
```

相距(總是) == sizeof(double)=8, 可斷定帶著 cookie.

G4.9 bitmap_allocator

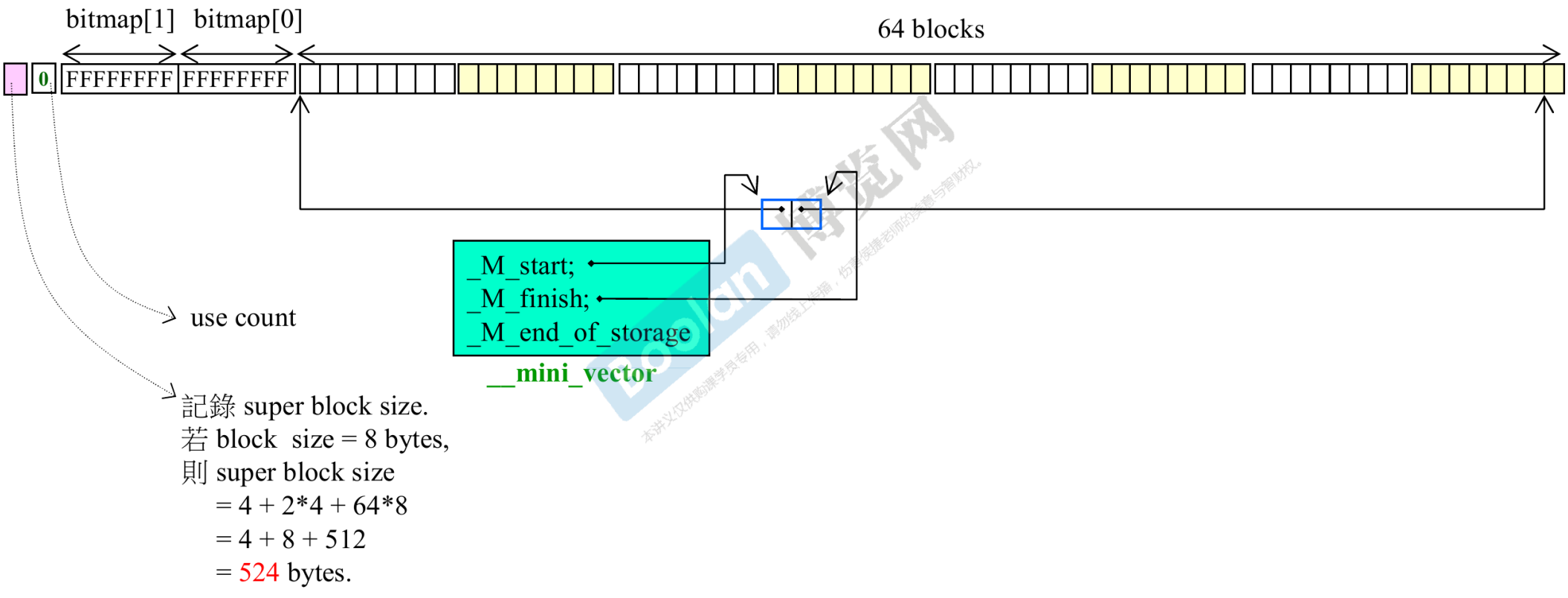
<…/ext/bitmap_allocator.h>

```
template<typename _Tp>
class bitmap_allocator : private free_list  {
…
   public:
     pointer allocate(size_type __n)   {
              if (__n > this->max_size())
                 std::__throw_bad_alloc();
              if (__builtin_expect(__n == 1, true))
                  return this->_M_allocate_single_object();
              else {
                  const size_type __b = __n * sizeof(value_type);
                  return reinterpret_cast<pointer>(::operator new(__b));
              }
     }
     void deallocate(pointer __p, size_type __n) throw()  {
              if (__builtin_expect(__p != 0, true)) {
                 if (__builtin_expect(__n == 1, true))
                    this->_M_deallocate_single_object(__p);
                 else
                    ::operator delete(__p);
              }
     }
```



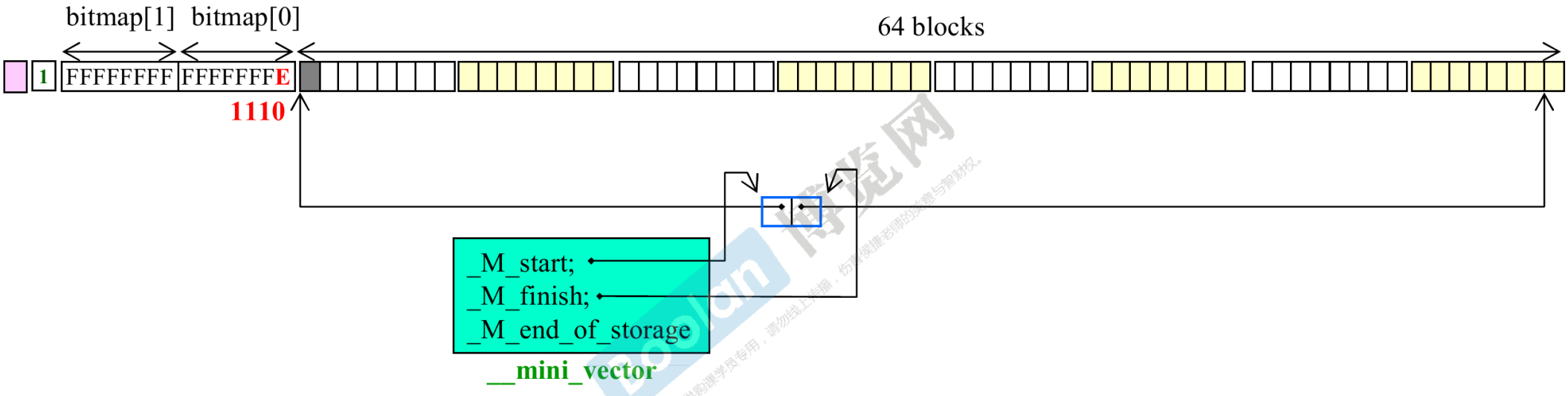
G4.9 bitmap_allocator,

關於 blocks, super-blocks, bitmap, mini-vector



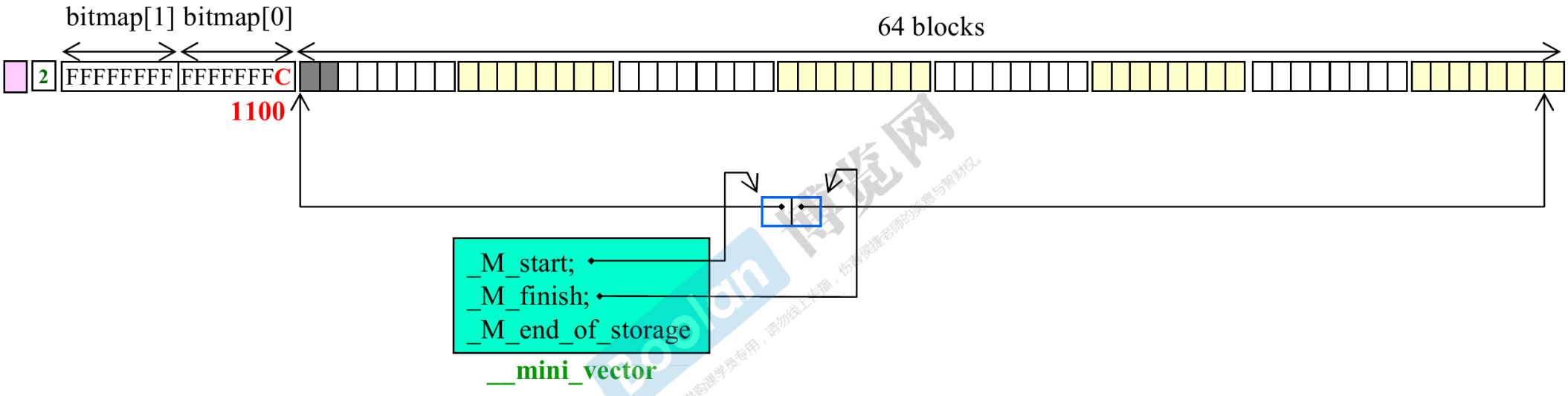
G4.9 bitmap_allocator,

關於 blocks, super-blocks, bitmap, mini-vector



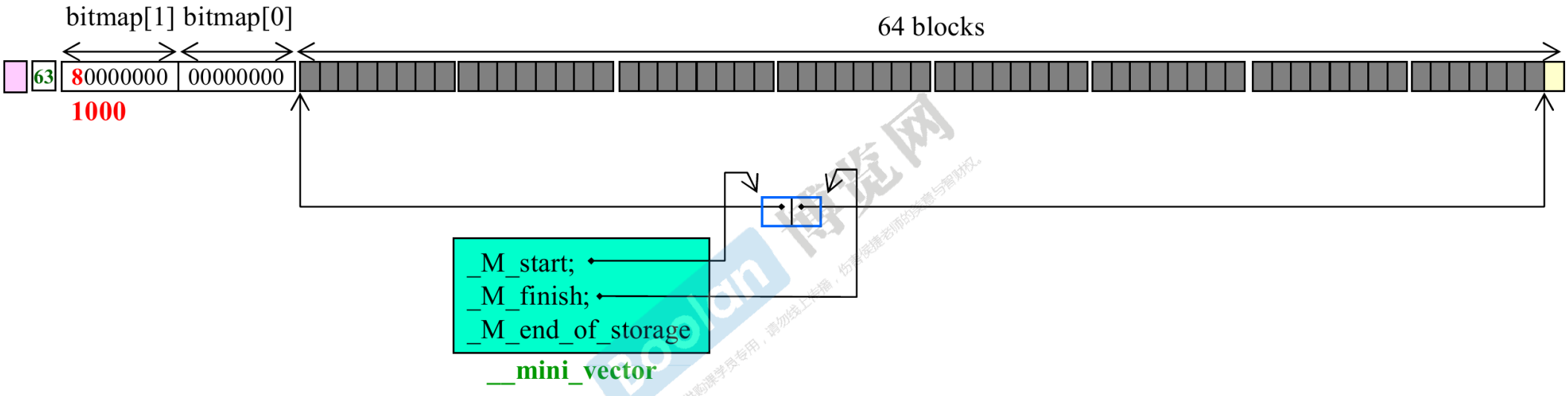
G4.9 bitmap_allocator,

關於 blocks, super-blocks, bitmap, mini-vector



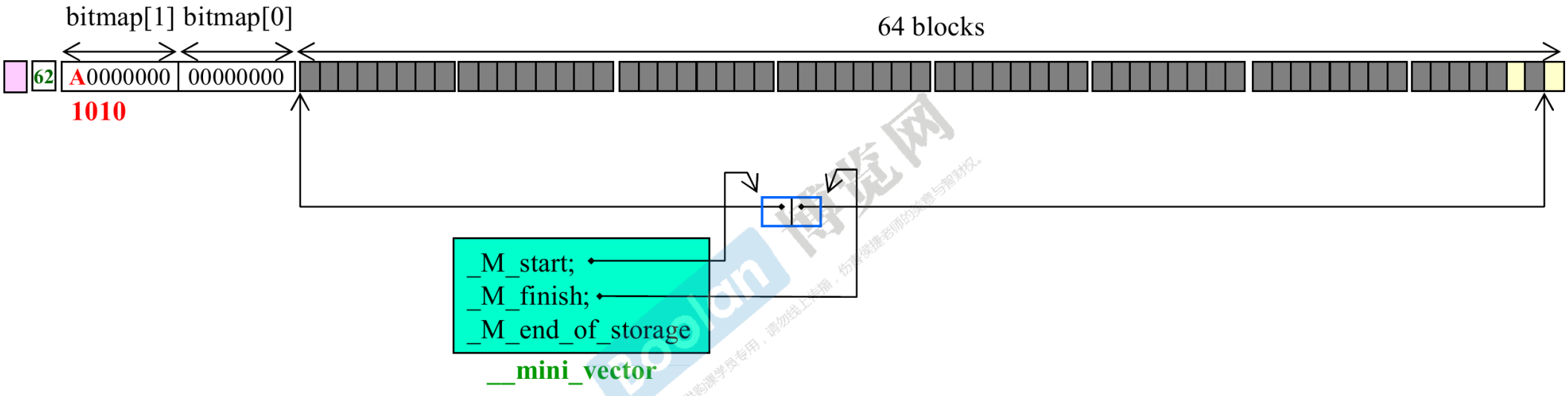
G4.9 bitmap_allocator,

關於 blocks, super-blocks, bitmap, mini-vector



G4.9 bitmap_allocator,

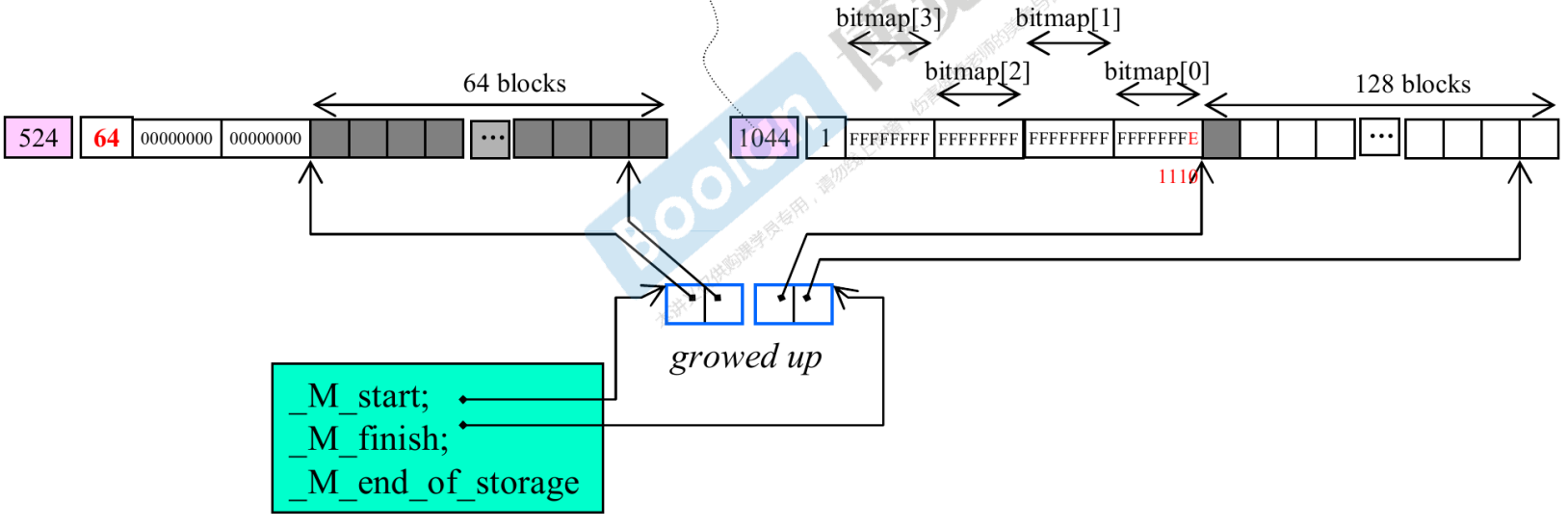
關於 blocks, super-blocks, bitmap, mini-vector



G4.9 bitmap_allocator,

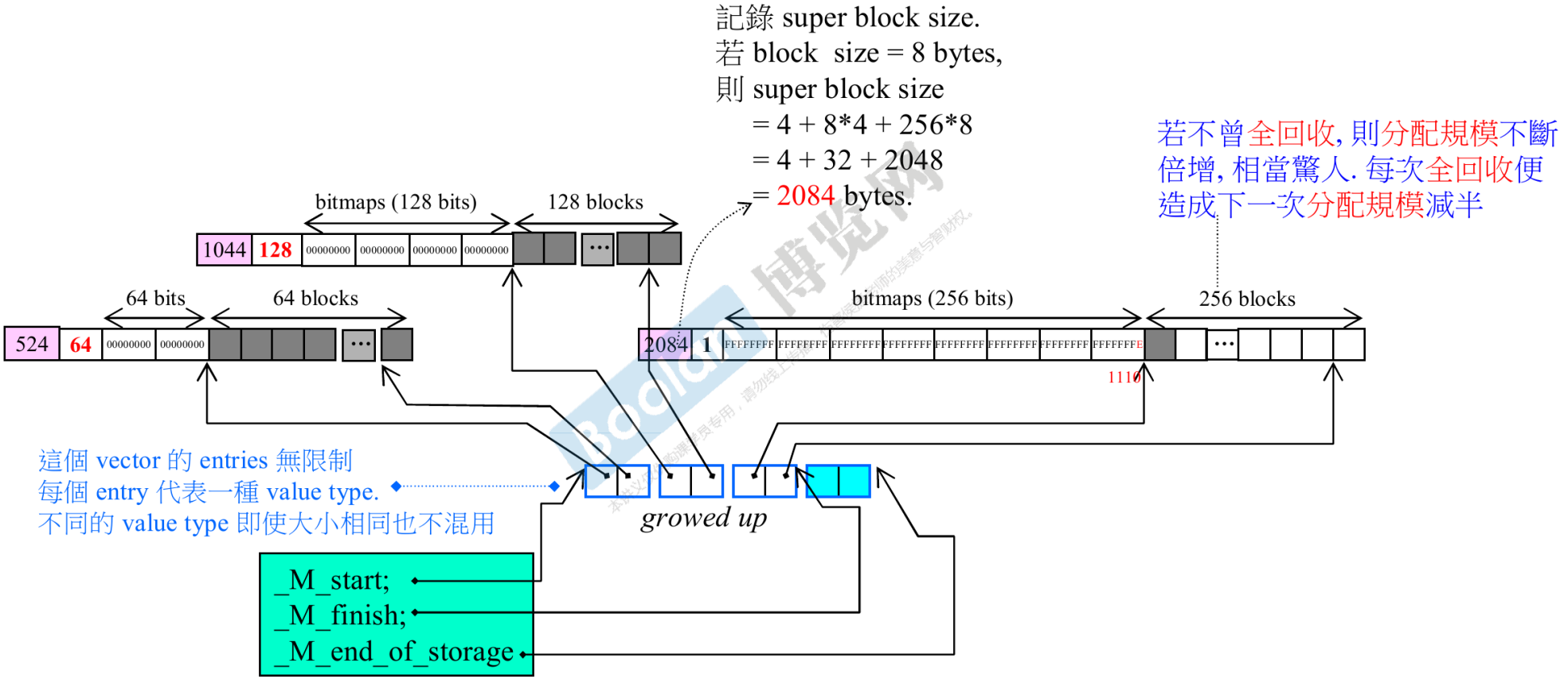
1st super-block 用罄, 啟動 2nd super-block

記錄 super block size.
若 block size = 8 bytes,
則 super block size
= 4 + 4*4 + 128*8
= 4 + 16 + 1024
= 1044 bytes.



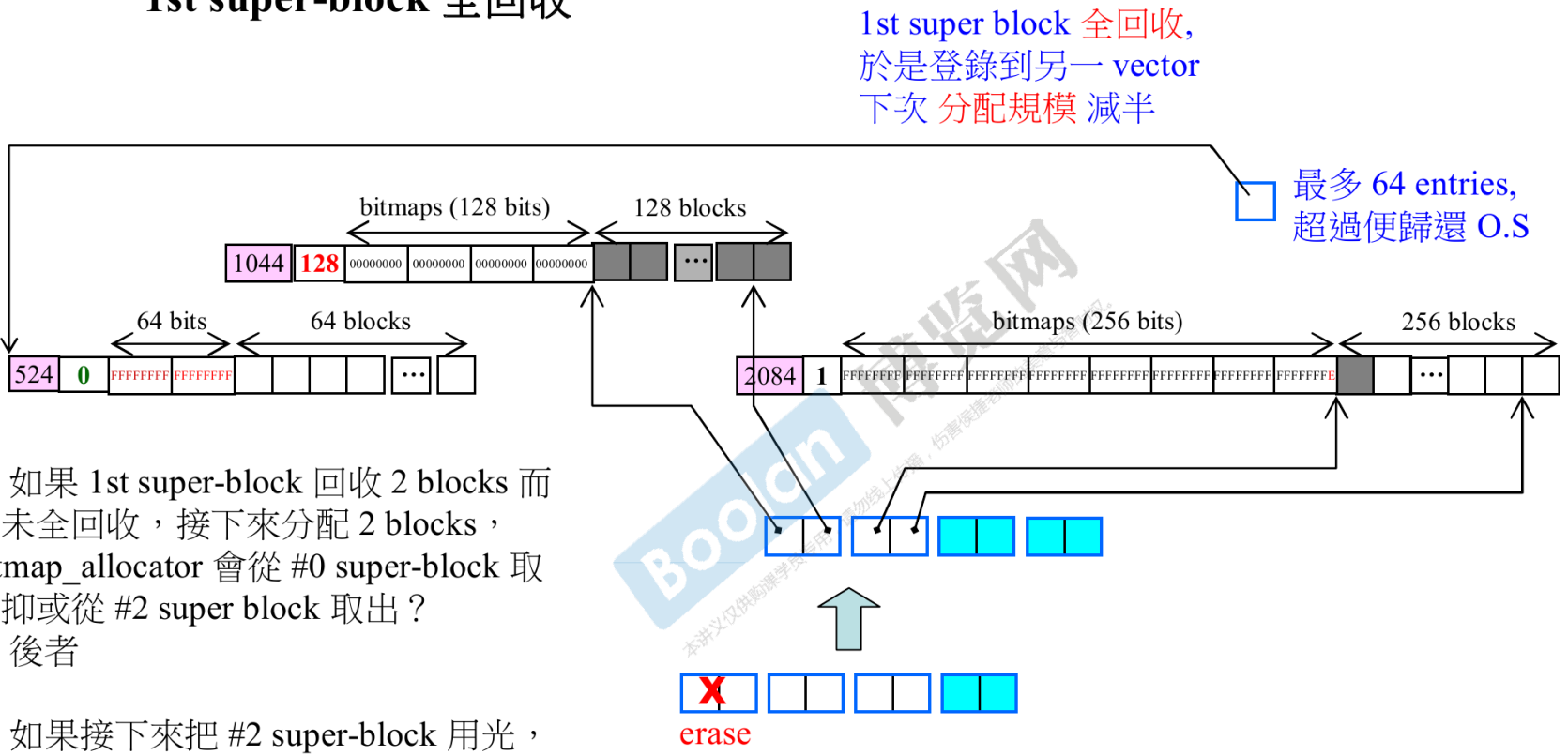
G4.9 bitmap_allocator,

2nd super-block 用罄, 啟動 3rd super-block



G4.9 bitmap_allocator,

1st super-block 全回收



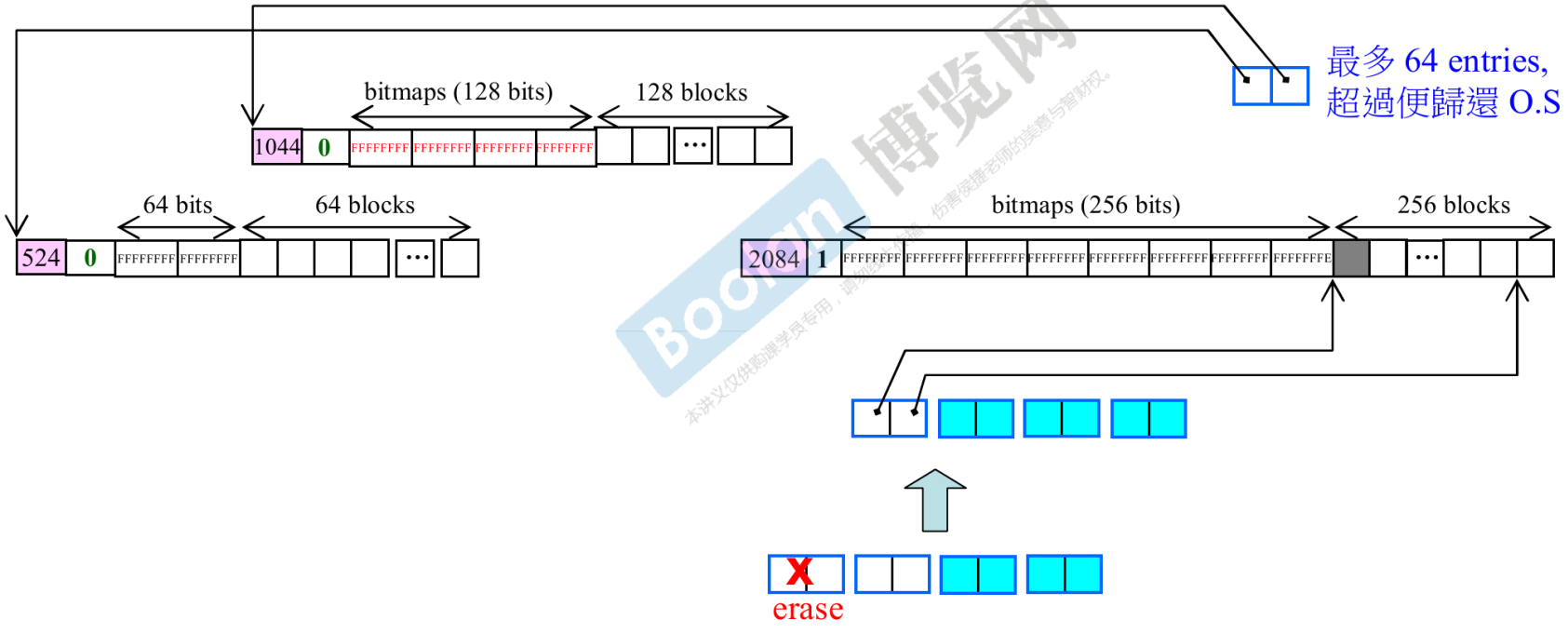
Q: 如果 1st super-block 回收 2 blocks 而尚未全回收，接下來分配 2 blocks，bitmap_allocator 會從 #0 super-block 取出抑或從 #2 super block 取出？
A: 後者

Q; 如果接下來把 #2 super-block 用光，然後分配 2 blocks，bitmap_allocator 會從 #0 super-block 取出抑或新建一個 #3 super block 並從中取出？
A: 前者

G4.9 bitmap_allocator,

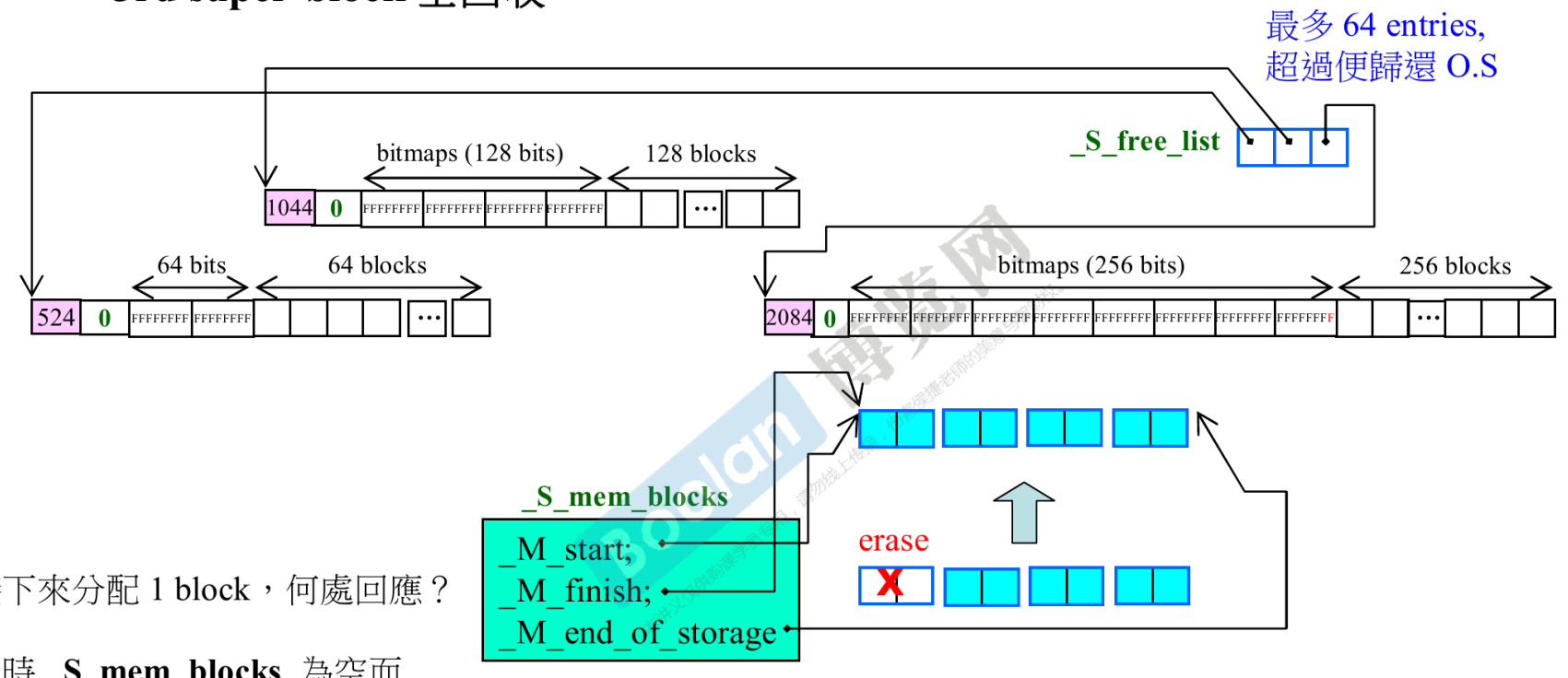
2nd super-block 全回收

這個 vector 的元素排列將以 super block size 為依據. 因此當觸及 threshold (64)，新進者若大於最末者便直接 delete 新進者, 否則 delete 最末者然後再 insert 新進者. 若未觸及 64 則無條件 insert 至適當位置.



G4.9 bitmap_allocator,

3rd super-block 全回收



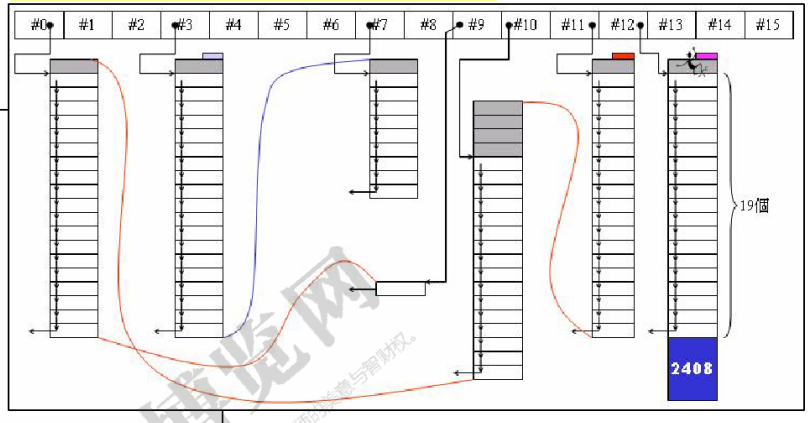
Q: 接下來分配 1 block，何處回應？

A: 此時 **_S_mem_blocks** 為空而 **_S_free_list** 有三個 super-blocks，於是取一個放進 **_S_mem_blocks**，然後遵循先前法則完成分配。

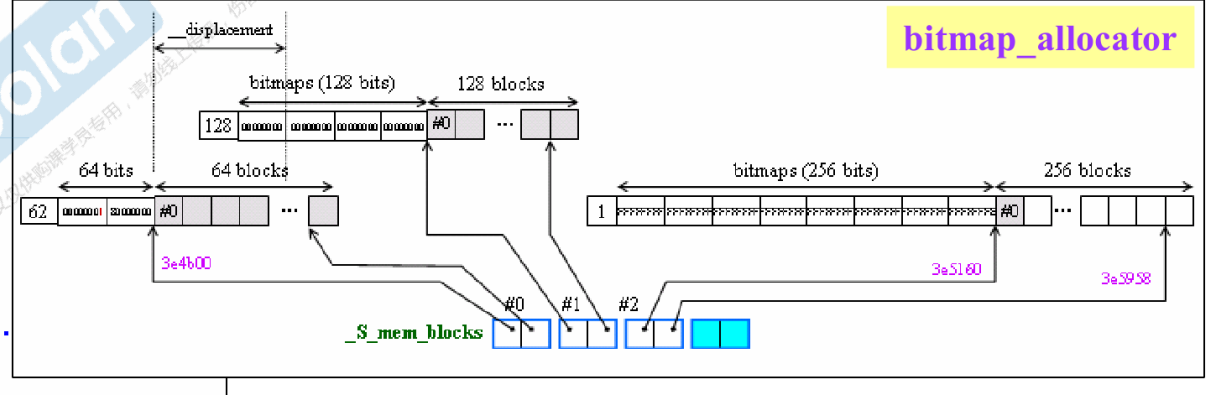
使用 G4.9 分配器

```
916  #include <list>
917  #include <stdexcept>
918  #include <string>
919  #include <cstdlib>      //abort()
920  #include <cstdio>       //snprintf()
921  #include <algorithm>    //find()
922  #include <iostream>
923  #include <ctime>
924
925  #include <cstddef>
926  #include <memory>       //內含 std::allocator
927      //欲使用 std::allocator 以外的 allocator, 得自行 #include <ext\...>
928  #include <ext\array_allocator.h>
929  #include <ext\mt_allocator.h>
930  #include <ext\debug_allocator.h>
931  #include <ext\pool_allocator.h>
932  #include <ext\bitmap_allocator.h>
933  #include <ext\malloc_allocator.h>
934  #include <ext\new_allocator.h>
935  namespace jj20
936  {
937  void test_list_with_special_allocator()
938  {
939      cout << "\ntest_list_with_special_allocator().....
940
941      list<string, allocator<string>> c1;
942      list<string, __gnu_cxx::malloc_allocator<string>> c2;
943      list<string, __gnu_cxx::new_allocator<string>> c3;
944      list<string, __gnu_cxx::__pool_alloc<string>> c4;
945      list<string, __gnu_cxx::__mt_alloc<string>> c5;
946      list<string, __gnu_cxx::bitmap_allocator<string>> c6;
```

__pool_alloc (pool allocator)



bitmap_allocator



使用 G4.9 分配器

```
948  int choice;
949  long value;
950
951      cout << "select: ";
952      cin >> choice;
953      if ( choice != 0 ) {
954          cout << "how many elements: ";
955          cin >> value;
956      }
957
958  char buf[10];
959  clock_t timeStart = clock();
960      for(long i=0; i< value; ++i)
961      {
962          try {
963              snprintf(buf, 10, "%d", i);
964              switch (choice)
965              {
966                  case 1 :    c1.push_back(string(buf));
967                              break;
968                  case 2 :    c2.push_back(string(buf));
969                              break;
970                  case 3 :    c3.push_back(string(buf));
971                              break;
972                  case 4 :    c4.push_back(string(buf));
973                              break;
974                  case 5 :    c5.push_back(string(buf));
975                              break;
976                  case 6 :    c6.push_back(string(buf));
977                              break;
978                  default:
979                      break;
980              }
981          }
982          catch(exception& p) {
983              cout << "i=" << i << " " << p.what() << en
984              abort();
985          }
986      }
987      cout << "a lot of push_back(), milli-seconds : "
988           << (clock()-timeStart) << endl;
```

```
989
990
991      //test all allocators' allocate() & deallocate();
992      int* p;
993      allocator<int> alloc1;
994      p = alloc1.allocate(1);
995      alloc1.deallocate(p,1);
996
997      __gnu_cxx::malloc_allocator<int> alloc2;
998      p = alloc2.allocate(1);
999      alloc2.deallocate(p,1);
1000
1001     __gnu_cxx::new_allocator<int> alloc3;
1002     p = alloc3.allocate(1);
1003     alloc3.deallocate(p,1);
1004
1005     __gnu_cxx::__pool_alloc<int> alloc4;
1006     p = alloc4.allocate(2);
1007     alloc4.deallocate(p,2);
1008
1009     __gnu_cxx::__mt_alloc<int> alloc5;
1010     p = alloc5.allocate(1);
1011     alloc5.deallocate(p,1);
1012
1013     __gnu_cxx::bitmap_allocator<int> alloc6;
1014     p = alloc6.allocate(3);
1015     alloc6.deallocate(p,3);
1016 }
1017 }
```

The End

侯捷 C++Startup揭密：C++程序的生前和死后

1. 前言，如何自定Startup code

- C++進入點是 main() 嗎？
- 什麼代碼比 main() 更早被執行？
- 什麼代碼在 main() 結束後才被執行？
- 為什麼上述代碼可以如此行為？
- Heap 的結構如何？
- I/O 的結構如何？

我們的目標

- 徹底解決上頁所提的每一項疑問

你應具備的基礎

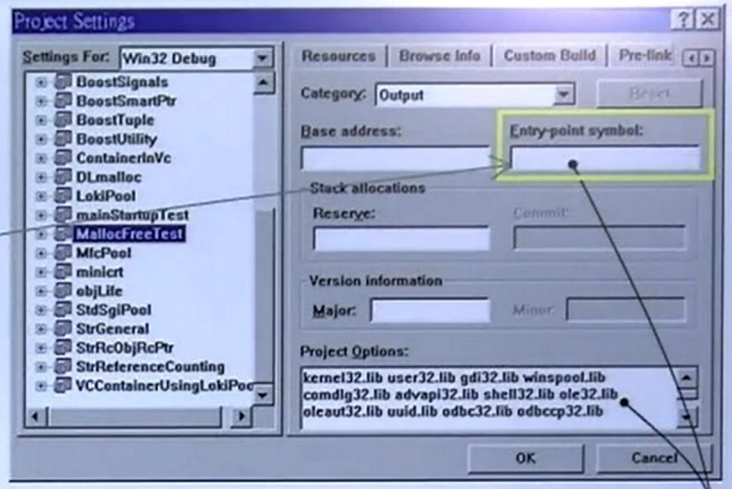
- 是個 C++ programmer

我們所觀察的代碼

VC6, VC10

源碼之前了無秘密

自定 Startup code (Entry-Point Symbol)



/ENTRY (Entry-Point Symbol)

The Entry-Point Symbol (/ENTRY:*function*) option sets the **starting address** for an .EXE file or DLL. (To find this option in the development environment, click **Settings** on the **Project** menu. Then click the **Link** tab, and click **Output** in the **Category** box.)

Type a function name in the **Entry-Point Symbol** text box (or in the *function* argument on the command line). The function must be defined with the **__stdcall** calling convention. The parameters and return value must be defined as documented in the Win32 API for **WinMain** (for an .EXE file) or **DllEntryPoint** (for a DLL). It is recommended that you let the linker set the entry point so that the C run-time library is initialized correctly, and C++ constructors for static objects are executed.

CRT　　這兩件就是 startup code 的主要用途

By default, the starting address is a function name from the C run-time library. The linker selects it according to the attributes of the program, as shown in the following table.

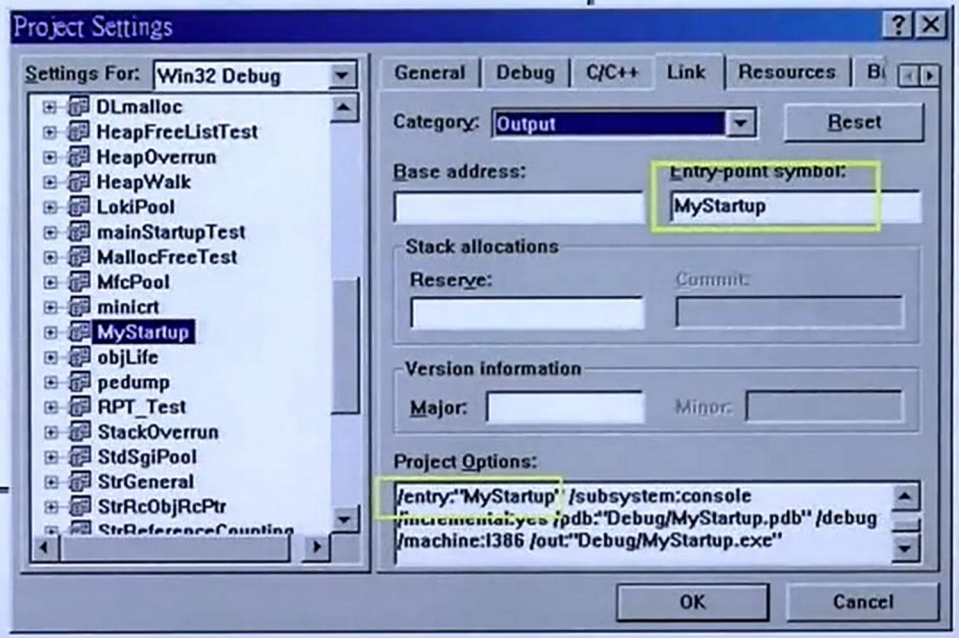
	Function name	Default for
1	**mainCRTStartup** (or **wmainCRTStartup**)	An application using /SUBSYSTEM:**CONSOLE**; calls **main** (or **wmain**)
2	**WinMainCRTStartup** (or **wWinMainCRTStartup**)	An application using /SUBSYSTEM:**WINDOWS**; calls **WinMain** (or **wWinMain**), which must be defined with **__stdcall**
3	**_DllMainCRTStartup**	A DLL; calls **DllMain**, which must be defined with **__stdcall**, if it exists

Startup code 的三個可能形式 (函數名稱)

完成之後 Project Options 會多出 **/entry:"*MyStartup*"**

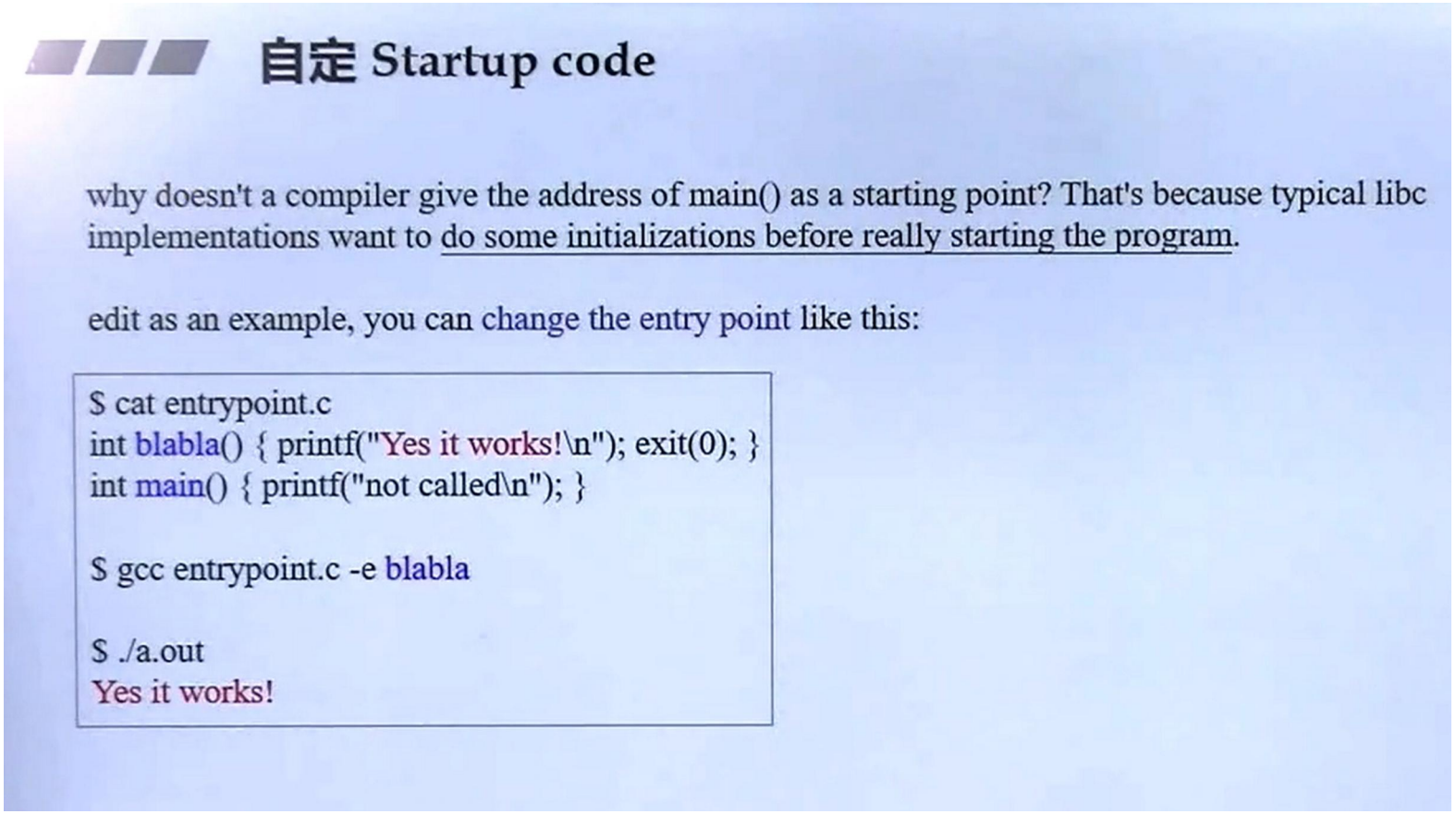
自定 Startup code

```
#include <windows.h>
int MyStartup( void )
{
 int a=10;
 HANDLE crtHeap=HeapCreate(HEAP_NO_SERIALIZE, 0x010, 4000*1024);
 int *p=(int*)HeapAlloc(crtHeap, HEAP_ZERO_MEMORY, 0x010);
 int i,j;

 for(i=0; i<100; i++)
 {
     //int j;
     for(j=0; j<100; j++,p++)
     {
        *p = i*100 + (j+1);
     }
 }

 MessageBoxA(NULL,p,"abcd",MB_OK);
 return 0;
}
```



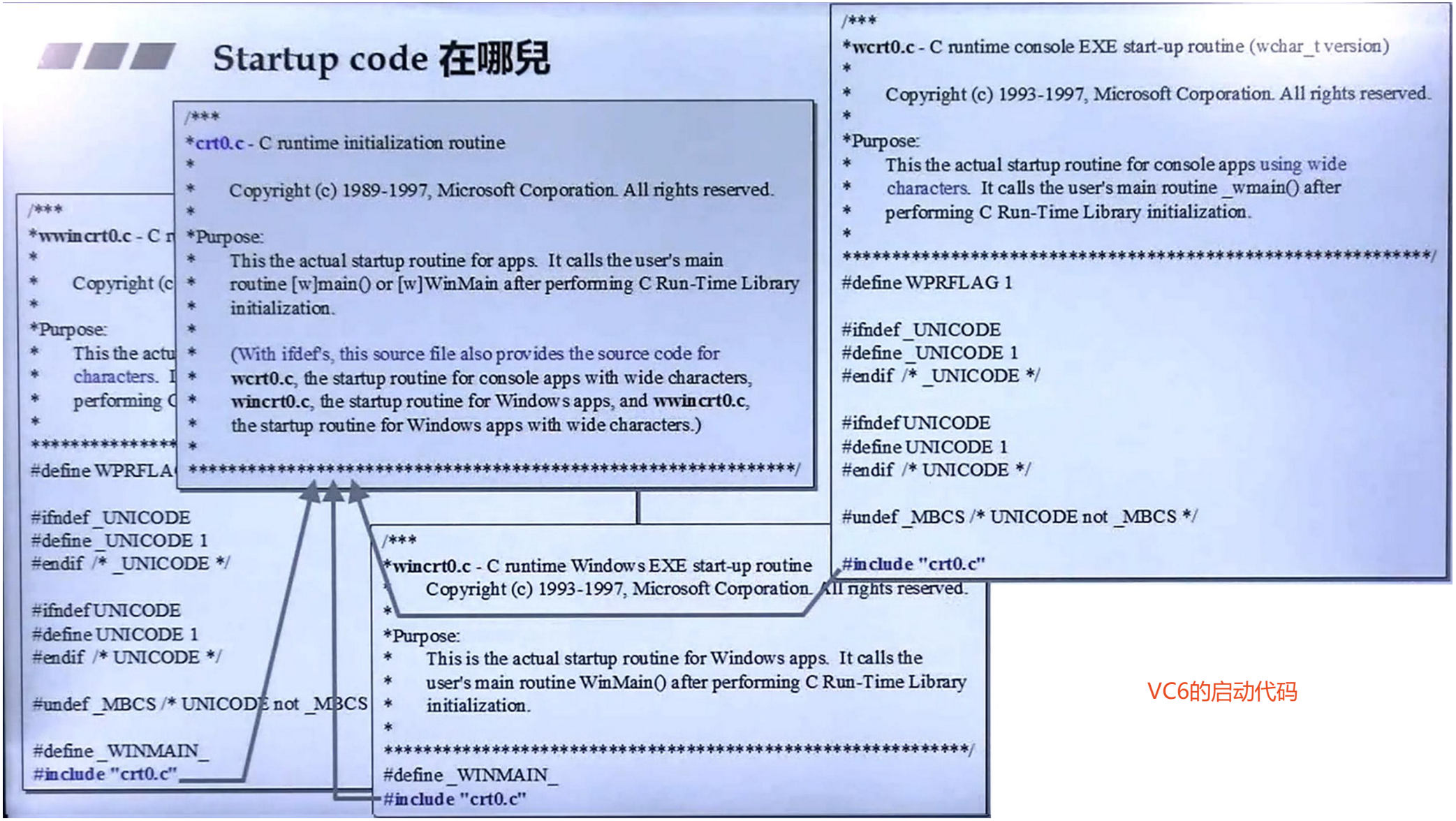
main由Startup code调用

main前调用startup code

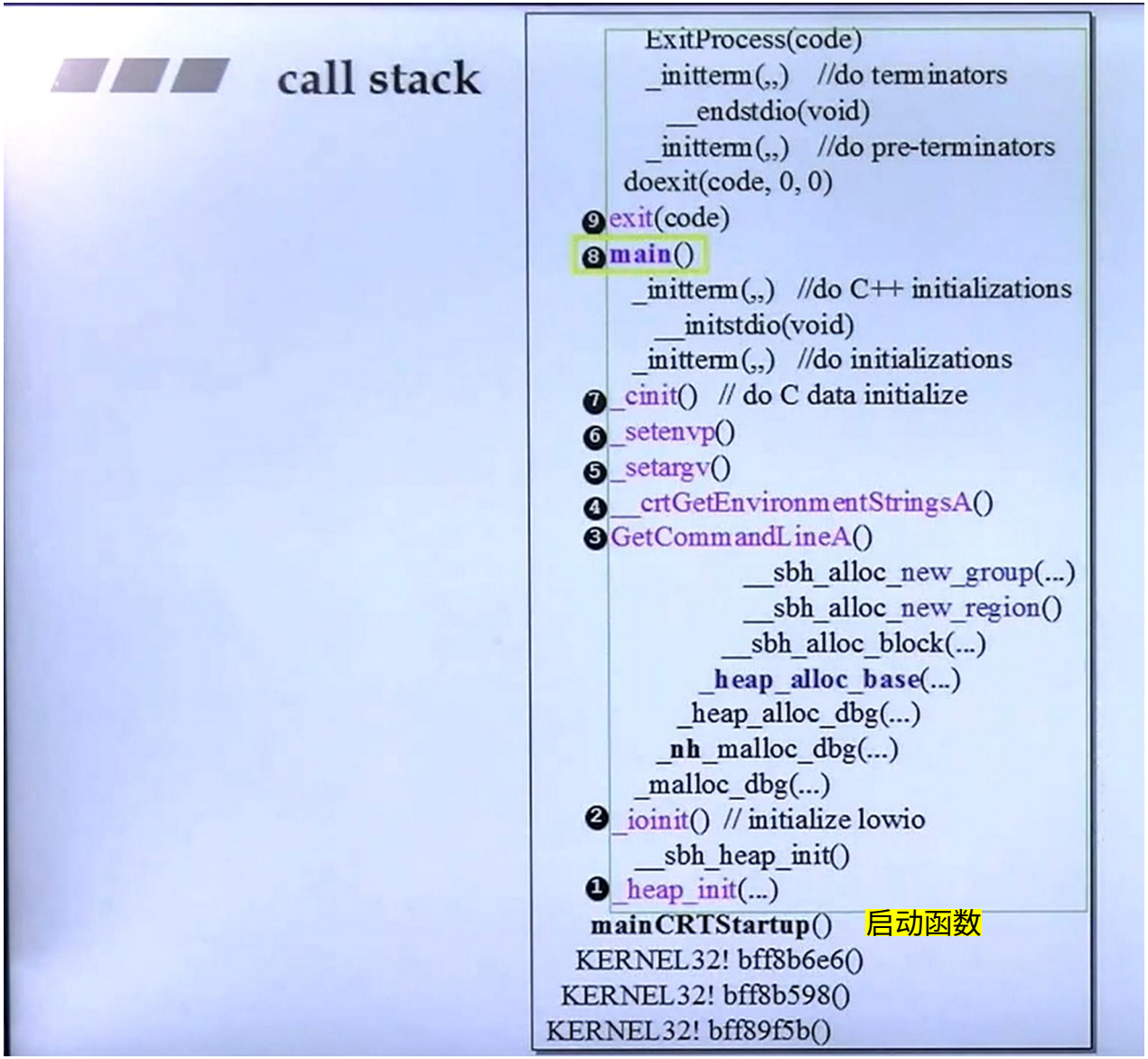


2. 默认的Startup code在哪儿

Startup code 在哪兒



VC6的启动代码



启动函数

从下往上

3. Startup code代码摘要

mainCRTStartup()

VC6

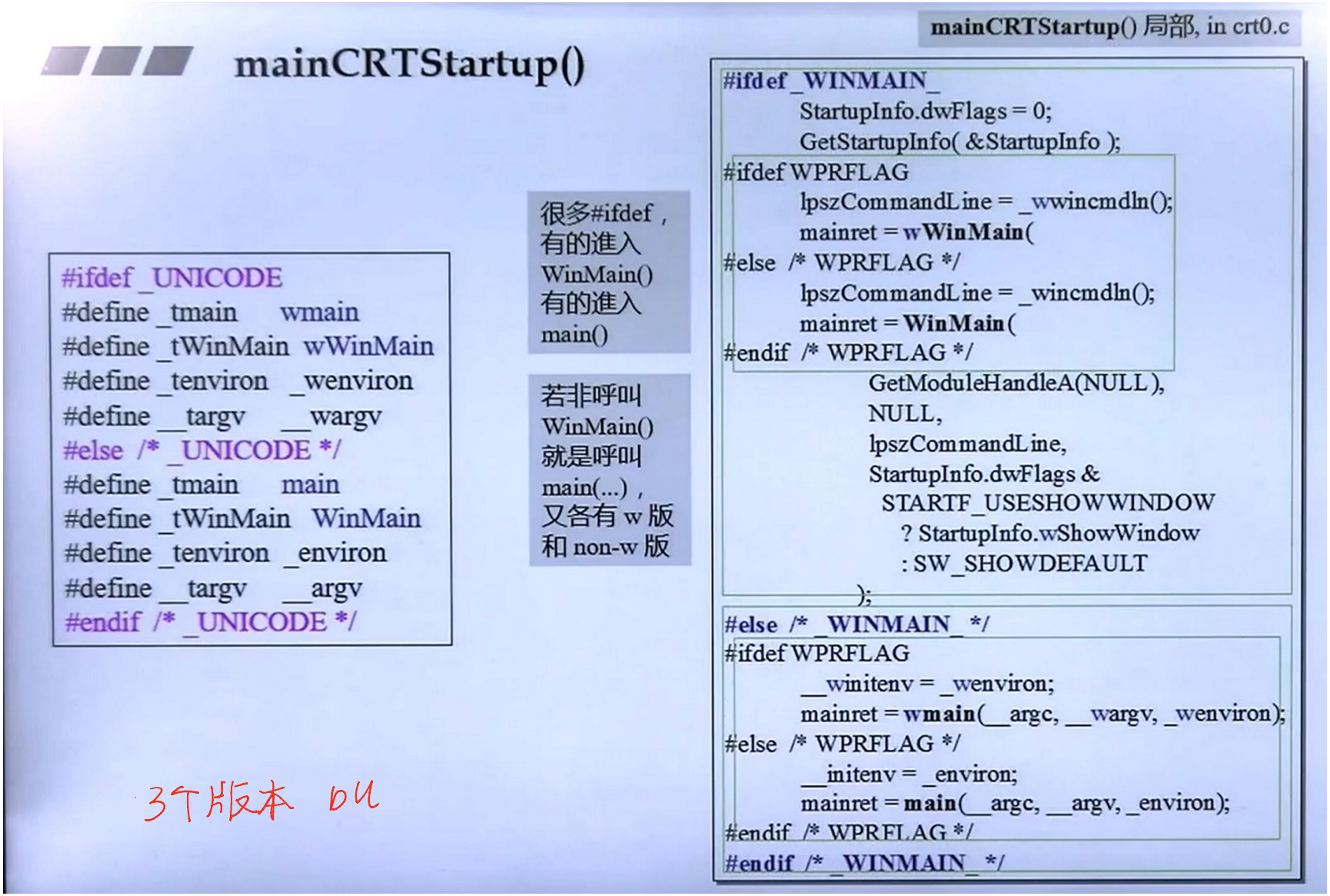
mainCRTStartup() in crt0.c

```
01 void mainCRTStartup(void)
02 {
03     int mainret;
04     // Get the full Win32 version
05     _osver = GetVersion();
06     _winminor = (_osver >> 8) & 0x00FF ;
07     _winmajor = _osver & 0x00FF ;
08     _winver = (_winmajor << 8) + _winminor;
09     _osver = (_osver >> 16) & 0x00FFFF ;
10
11  1  if ( !_heap_init(0) )          /* initialize heap */
12         fast_error_exit(_RT_HEAPINIT);  /* write message and die */
13
```

這是整理後的結果。實際上有很多#ifdef，有的進入 WinMain() 有的進入 main()

heap初始化

```
14     /*
15      * Guard the remainder of the initialization code and the call
16      * to user's main, or WinMain, function in a __try/__except
17      * statement.
18      */
19     __try {                    IO初始化
20  2  _ioinit();                 /* initialize lowio */
21     /* get cmd line info */
22  3  _acmdln = (char *)GetCommandLineA();
23     /* get environ info */
24  4  _aenvptr = (char *)__crtGetEnvironmentStringsA();
25  5  _setargv();                字符串处理
26  6  _setenvp();
27  7  _cinit();      /* do C data initialize */
28  8  __initenv = _environ;
29  9  mainret = main(__argc, __argv, _environ);
30     exit(mainret);                  ^——>注意 calling convention
31     }
32     __except ( _XcptFilter(GetExceptionCode(),
33                            GetExceptionInformation()) )
34     {
35        // Should never reach here
36        _exit( GetExceptionCode() );
37     } /* end of try - except */
38 }
```



4. Heap_init() - Startup的首要工程

VC6 _heap_init()

我的《C++內存管理機制》(全五講) 中的第三講 malloc/free 對於 CRT 的 SBH 設計和運行有極詳細的說明。本課程此處之 _heap_init() 及其引發的 memory 分配與管理, 是屬相同主題。

本處之特別：

1, 藉 Startup code 處理字符串 (包括命令行參數, 環境變數) 過程中的詳細數據觀察，釐清、確認和加強所有環節。

2, 增加說明 Windows Heap (操作系統層) 的結構和管理。(當 CRT's SBH 不再存在時)

```
    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()
```

小区块管理

SBH: Small Block Heap

何謂 small ?

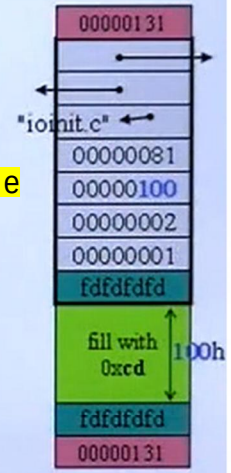
内存塊
1, 從何處來 ?
2, 大小幾何 ?
3, 回收至何處 ?

调用至此时还没有加cookie
所以1024-8 = 1016

门槛

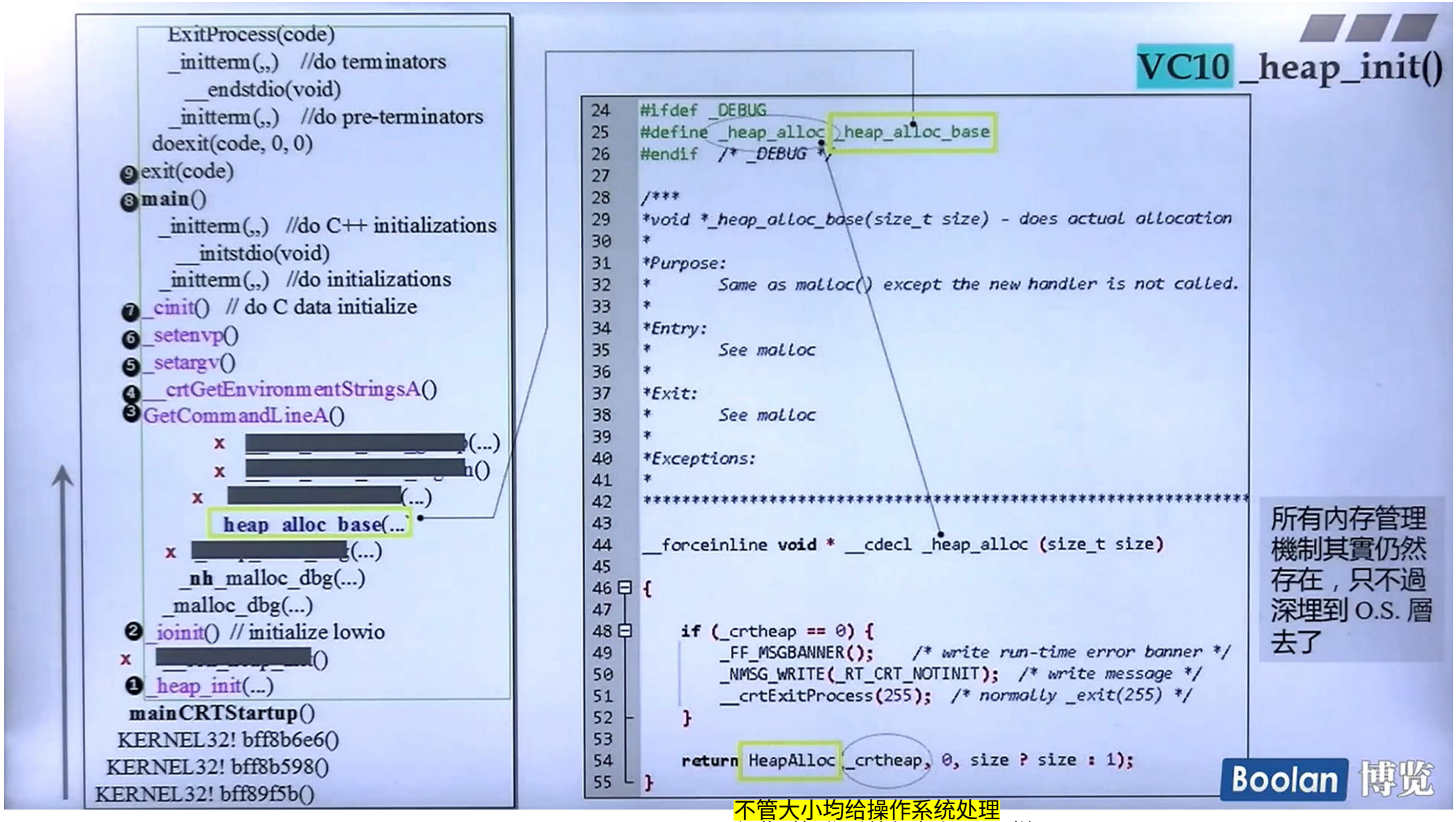
```
if (size <= __sbh_threshold) {    //3F8, i.e. 1016
    pvReturn = __sbh_alloc_block(size);
    if (pvReturn)  return pvReturn;
}
if (size == 0)  size = 1;
size = (size + ...) & ~(...);
return HeapAlloc(_crtheap, 0, size);
```

大于1K的让操作系统处理



_ioinit()包装(Debug模式下)
包装完后加cookie表边界
最后再调整为16的倍数

VC10 _heap_init()



不管大小均给操作系统处理
但此时操作系统行为和VC6一样

SBH 之始 – _heap_init() 和 __sbh_heap_init()

CRT 會先為自己建立一個 _crtheap，然後從中分配 SBH 所需的 headers, regions 做為管理之用。App. 動態分配時若 size > threshold 就調用 HeapAlloc() 從 _crtheap 取。若 size <= threshold 就徑自從 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;
}
```

建立一个池塘pool
从池塘中挖出16个Headers

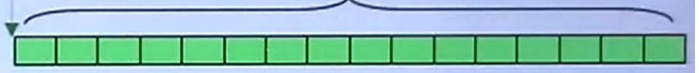
4096

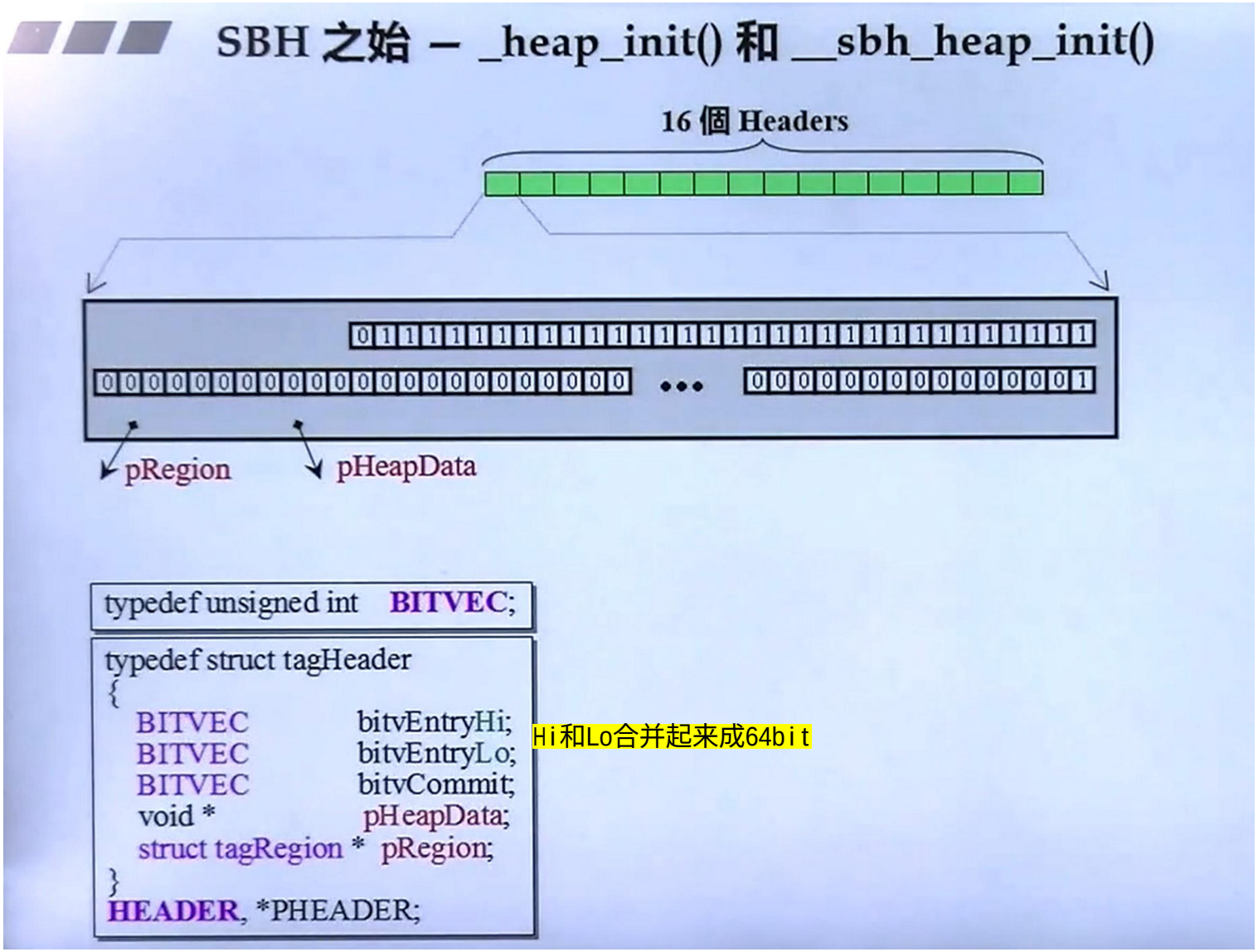
不論 big-block heap or small-block heap，只要失敗就 return 0，別玩了。

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;
}
```

16 個 Headers



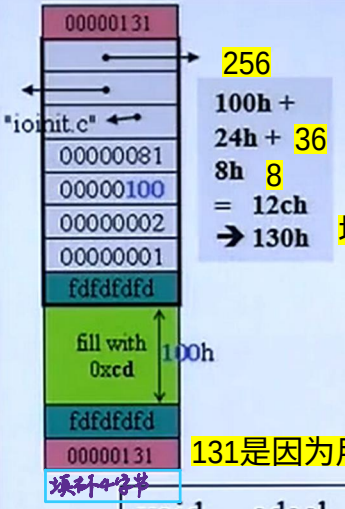

SBH 之始 – _heap_init() 和 __sbh_heap_init()
16 個 Headers
pRegion
pHeapData
typedef unsigned int BITVEC;
typedef struct tagHeader
{
BITVEC bitvEntryHi;
BITVEC bitvEntryLo;
BITVEC bitvCommit;
void * pHeapData;
struct tagRegion * pRegion;
}
HEADER, *PHEADER;
Hi和Lo合并起来成64bit

5. 内存分配精解1

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
```



256
100h + 24h + 36
8h 8
= 12ch
➔ 130h

填补为16倍数

```
#ifndef _DEBUG
#define _malloc_crt   malloc
...
#else  /* _DEBUG */
#define _THISFILE     __FILE__
#define _malloc_crt(s)   _malloc_dbg
                           (s, _CRT_BLOCK,
                            _THISFILE, __LINE__)
...
#endif  /* _DEBUG */
```

登记文件中第几行

131是因为用最后一个bit登记状态

```
typedef struct {
    long osfhnd;
    char osfile;
    char pipech;
} ioinfo;
```

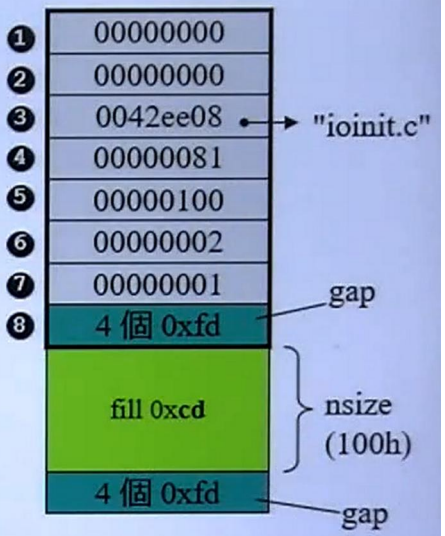
```
void __cdecl _ioinit (void)
{
...
line81  if ( (pio = _malloc_crt( IOINFO_ARRAY_ELTS * sizeof(ioinfo) ))
                                                          32        8
            == NULL )
...
}
```

第1次分配内存大小256

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;   ➔ 調整大小
…
pHead = (_CrtMemBlockHeader *)_heap_alloc_base(blockSize);   ➔ 從 SBH 擷取一內存塊
… (續下頁)   ➔ 設妥 Debug Heap
```

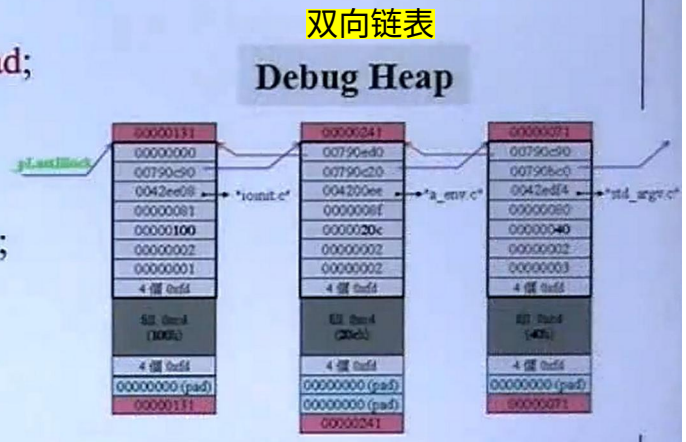
VC6 内存分配

每个Debug模式下的区块都会被串起来(即使已经分配给了客户

```
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()
```

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

pHead->pBlockHeaderNext =  _pFirstBlock;
pHead->pBlockHeaderPrev = NULL;
pHead->szFileName = (char*)szFileName;
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);
```

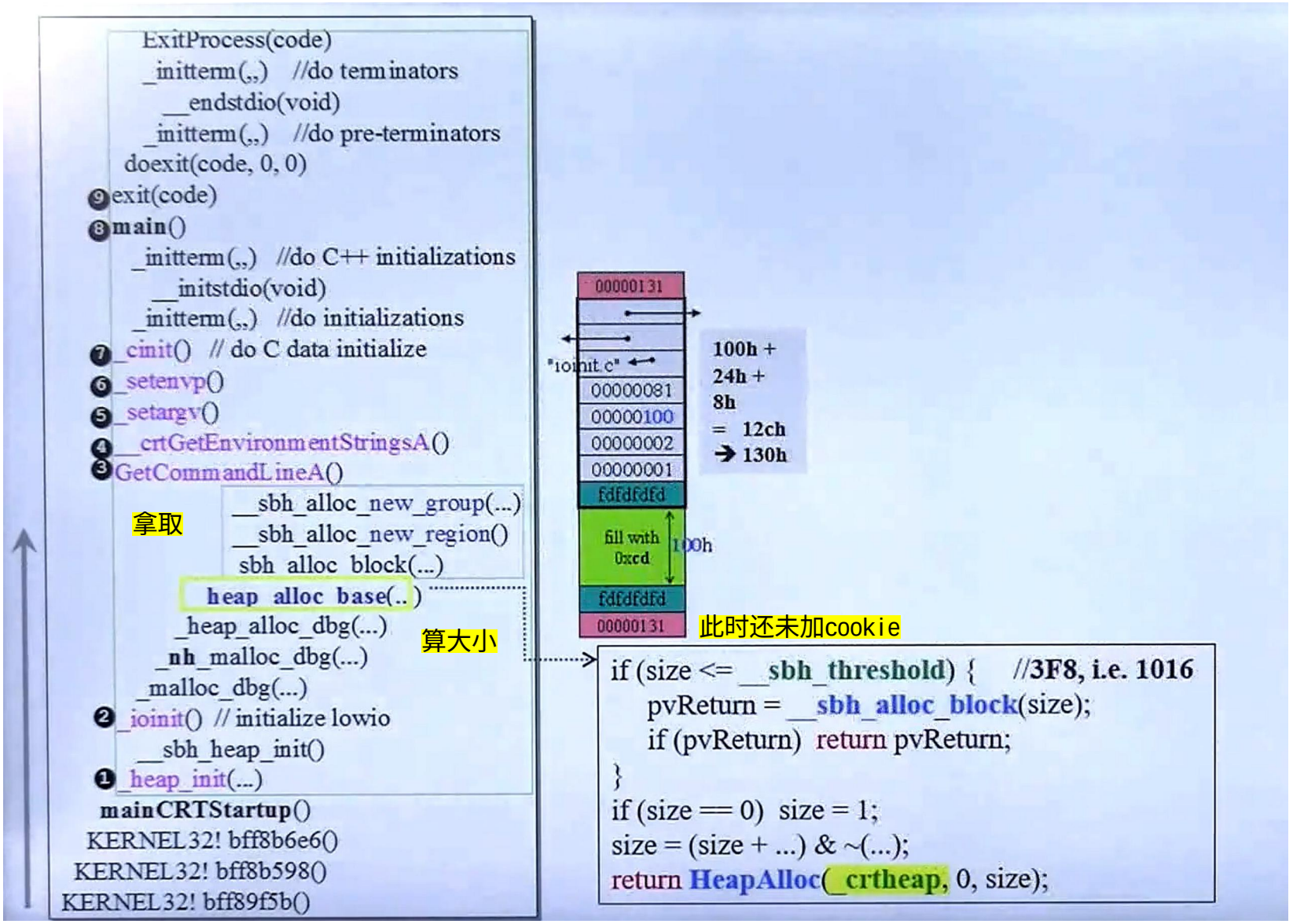
双向链表



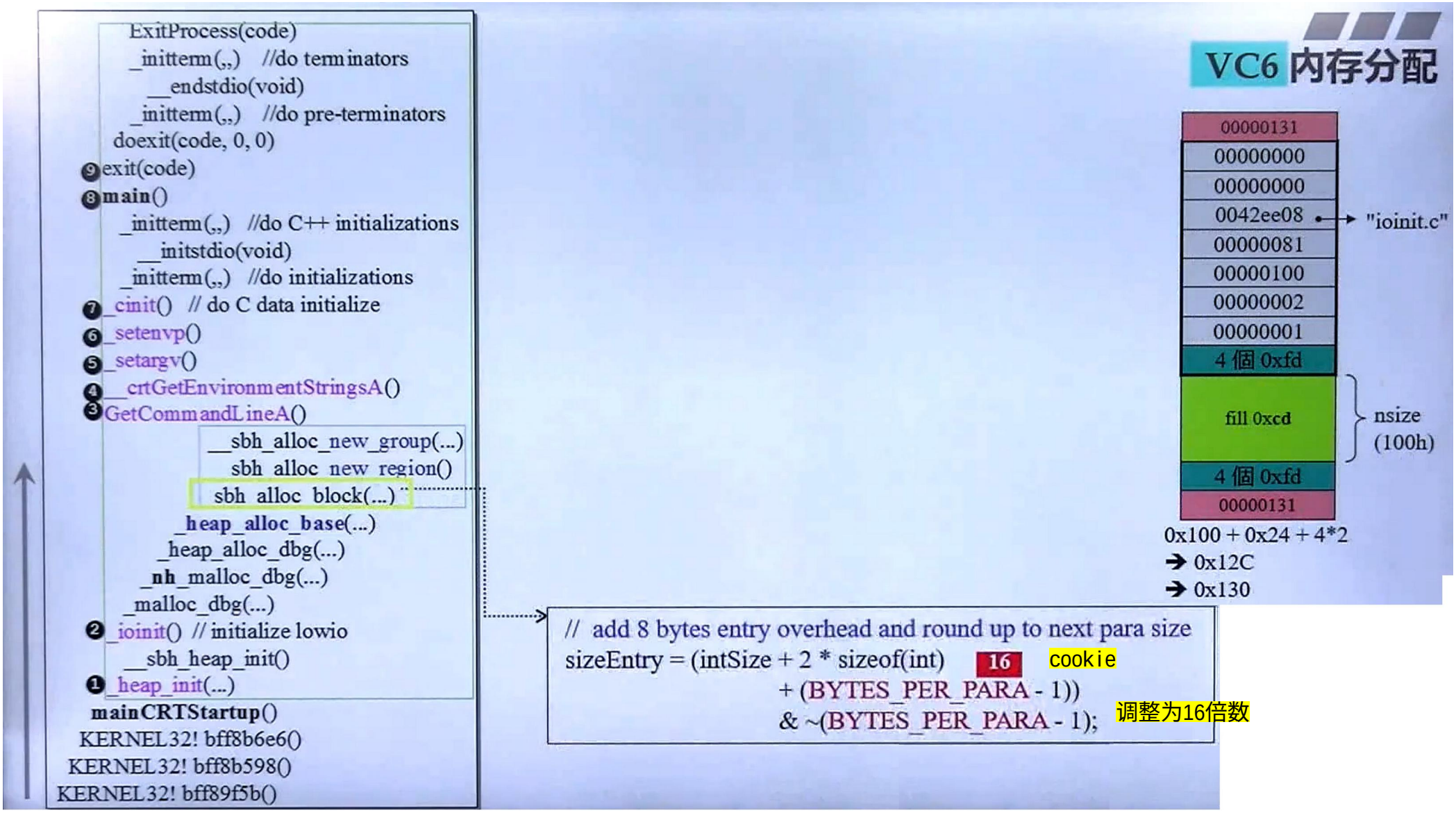
设定的初值

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

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

Boolan 博览

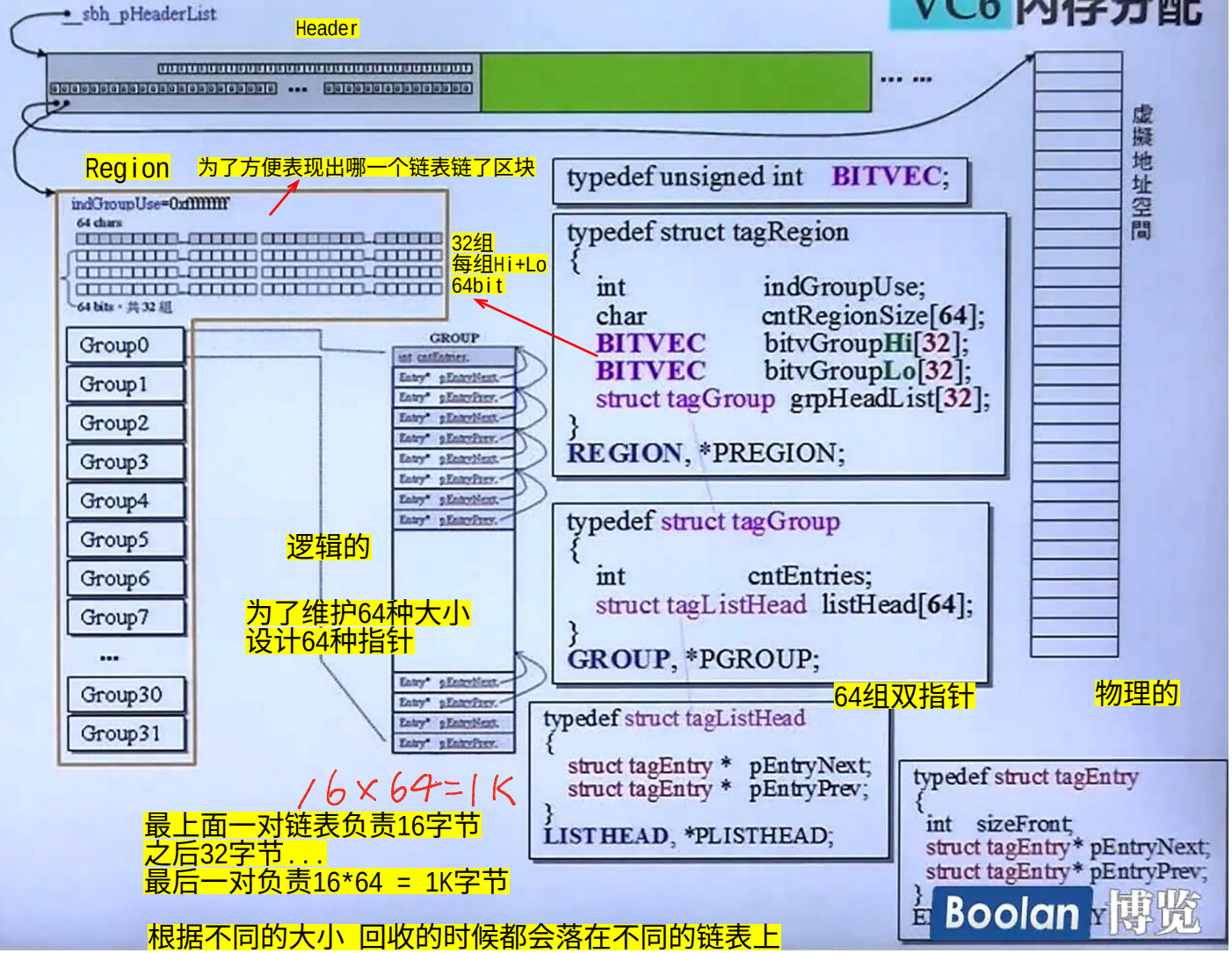

ExitProcess(code)
_initterm(,,) //do terminators
__endstdio(void)
_initterm(,,) //do pre-terminators
doexit(code, 0, 0)
9 exit(code)
8 main()
_initterm(,,) //do C++ initializations
__initstdio(void)
_initterm(,,) //do initializations
7 _cinit() // do C data initialize
6 _setenvp()
5 _setargv()
4 __crtGetEnvironmentStringsA()
3 GetCommandLineA()
拿取
__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()
算大小
00000131
"ioinit.c"
00000081
00000100
00000002
00000001
fdfdfdfd
fill with 0xcd
100h
fdfdfdfd
00000131
100h +
24h +
8h
= 12ch
➔ 130h
此时还未加cookie
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);

6. 内存分配精解2


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()
// add 8 bytes entry overhead and round up to next para size
sizeEntry = (intSize + 2 * sizeof(int) 16 cookie
+ (BYTES_PER_PARA - 1))
& ~(BYTES_PER_PARA - 1); 调整为16倍数
VC6 内存分配
00000131
00000000
00000000
0042ee08
"ioinit.c"
00000081
00000100
00000002
00000001
4 個 0xfd
fill 0xcd
nsize
(100h)
4 個 0xfd
00000131
0x100 + 0x24 + 4*2
0x12C
0x130

VC6 内存分配

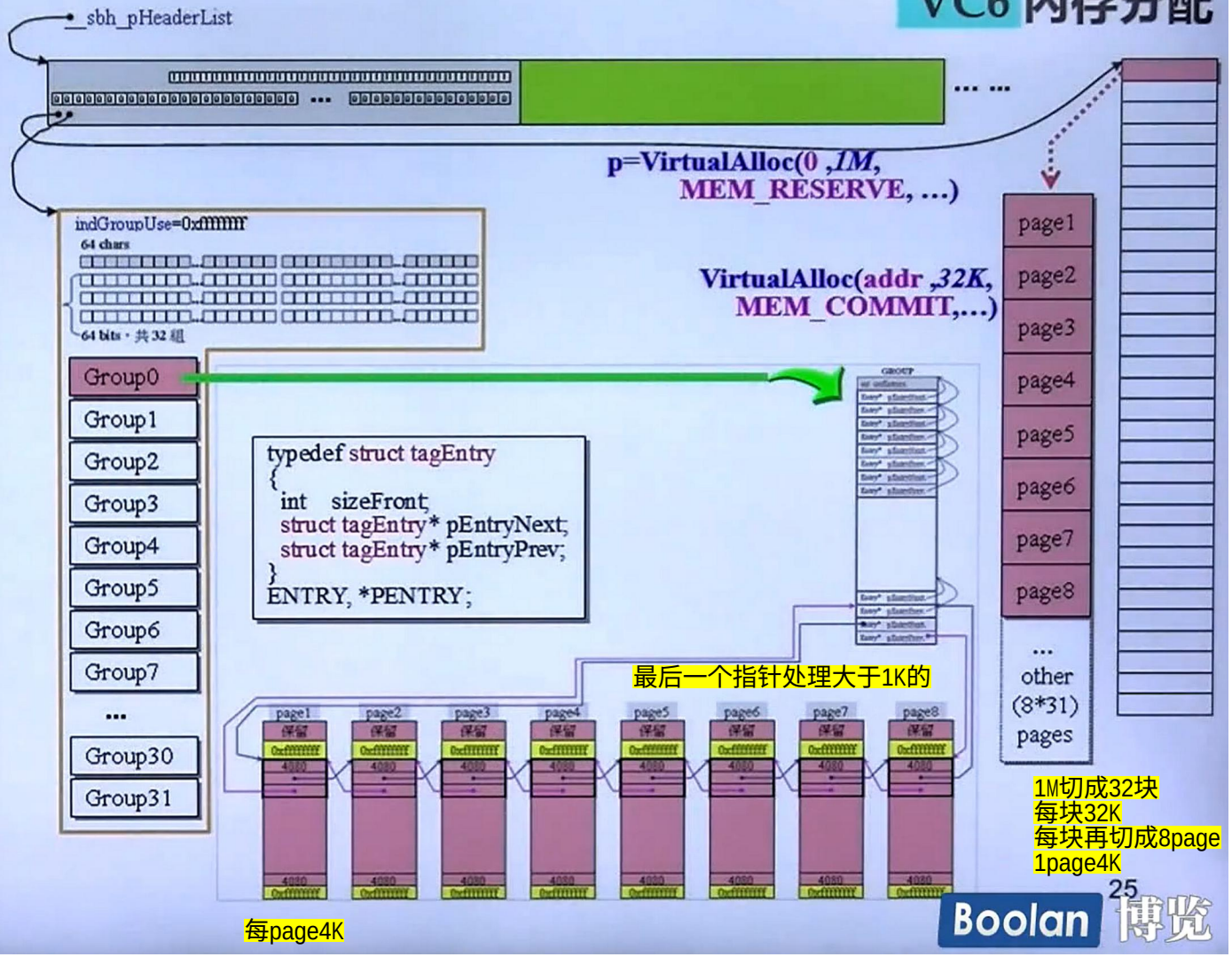
```
ExitProcess(code)
  _initterm(,,)   //do terminators
    __endstdio(void)
  _initterm(,,)   //do pre-terminators
doexit(code, 0, 0)
9 exit(code)
8 main()
  _initterm(,,)   //do C++ initializations
    __initstdio(void)
  _initterm(,,)   //do initializations
7 _cinit()  // do C data initialize
6 _setenvp()
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()
```

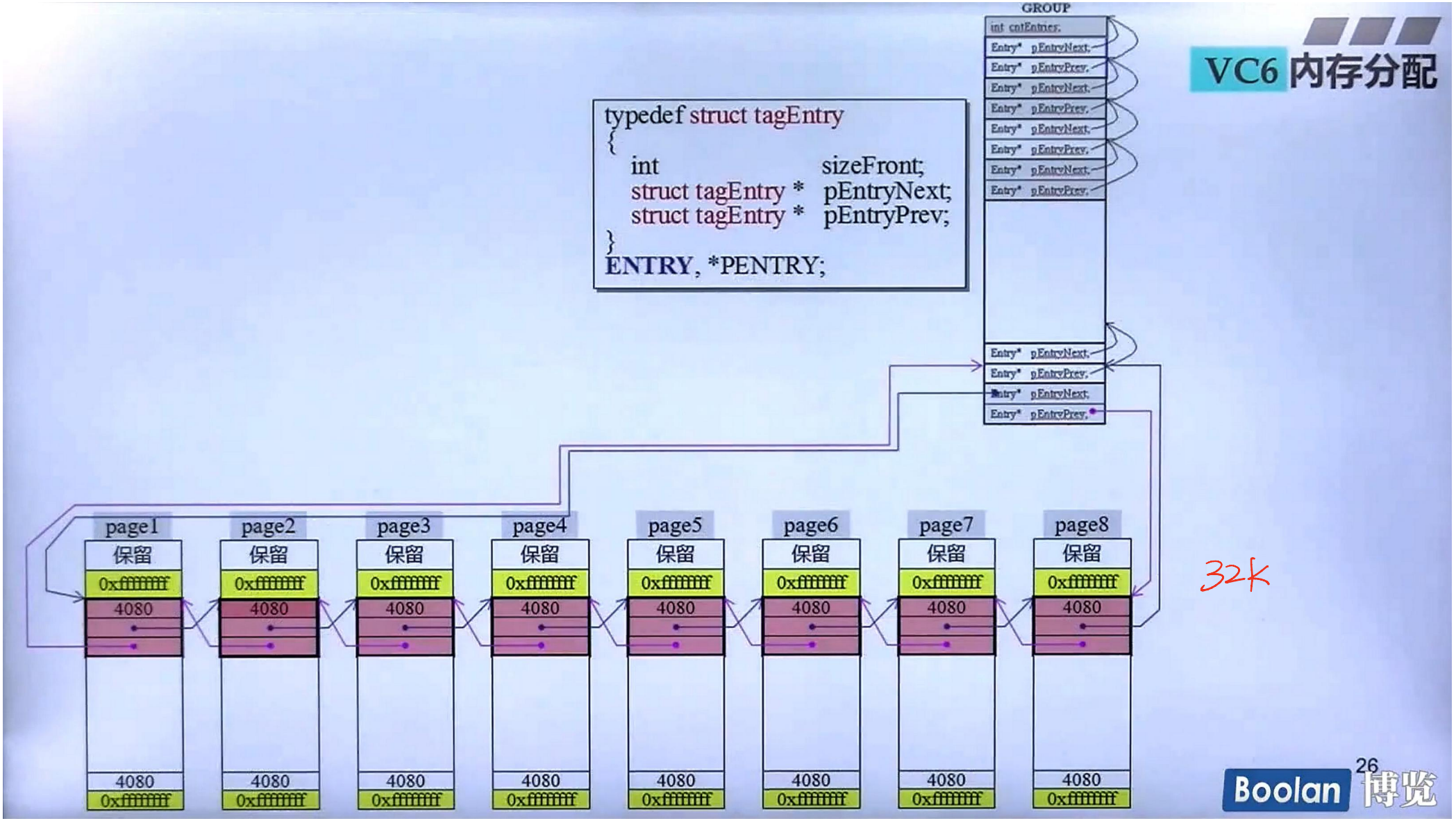



```
typedef unsigned int    BITVEC;

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;

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

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()
```



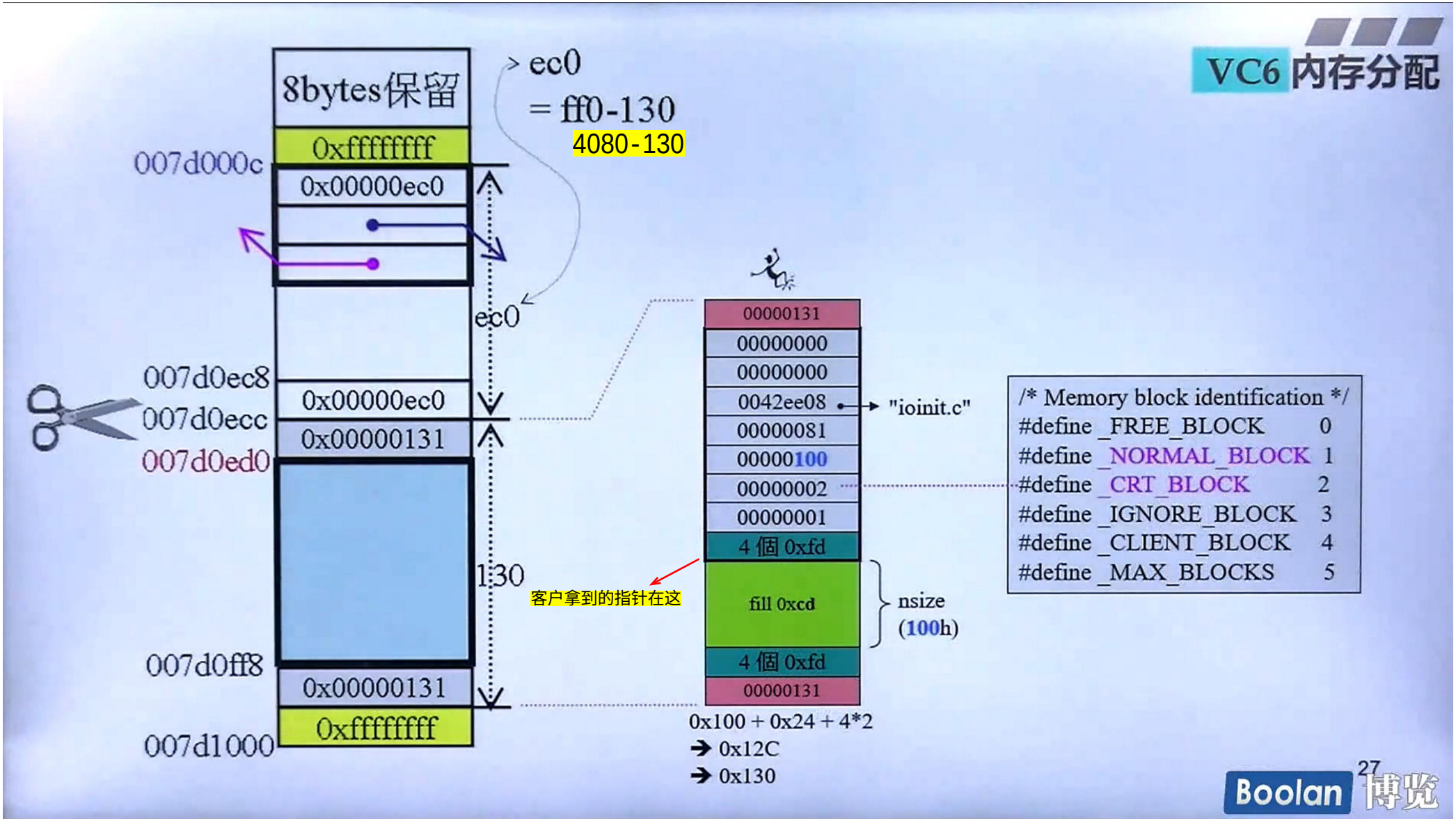


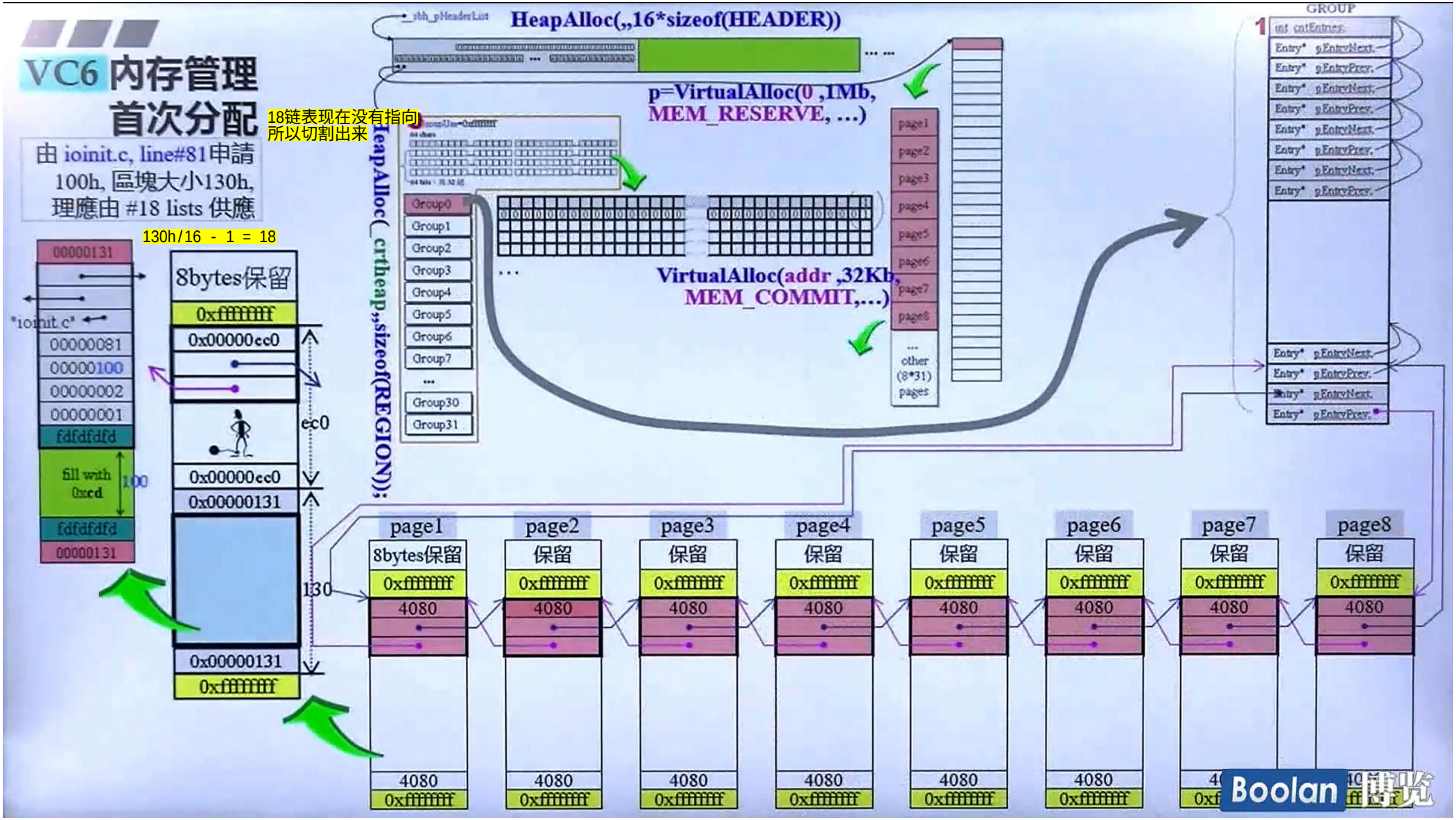
物理上是连续的
切成了8块
还要加上分隔
4096-8=4088 变成16的倍数 4080

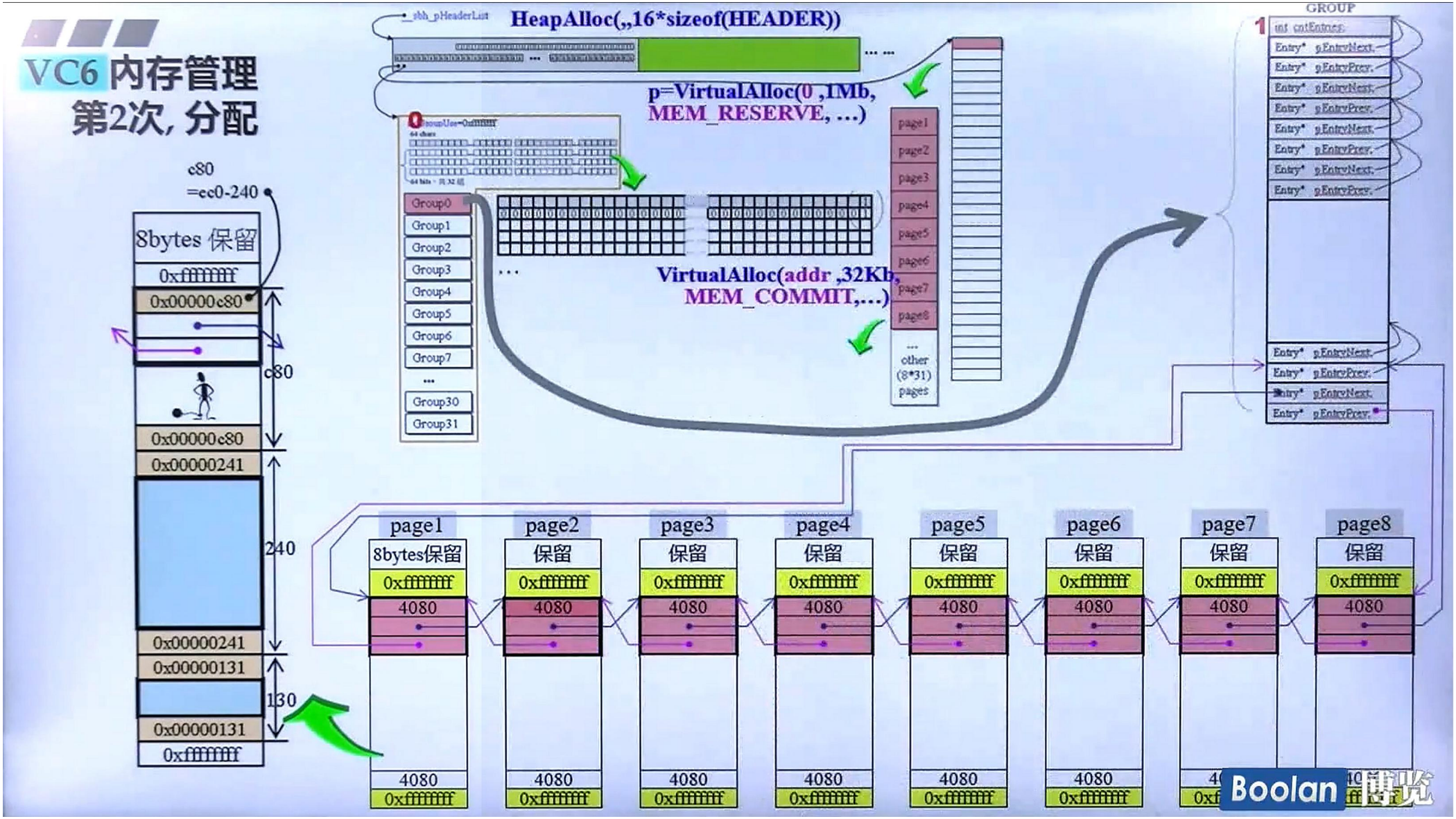
每个page可用的即为4080

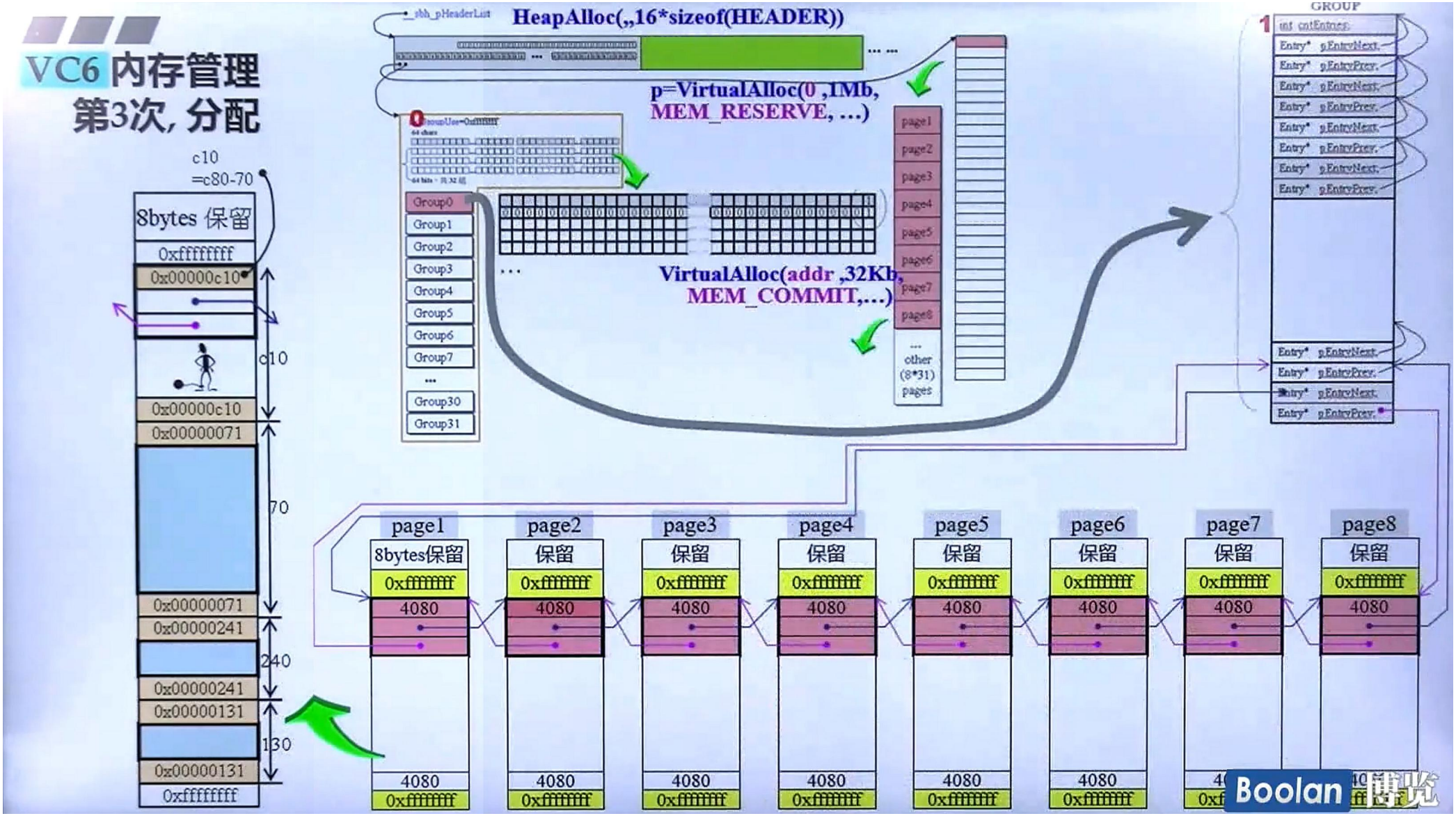
7. 内存分配精解3

怎么切

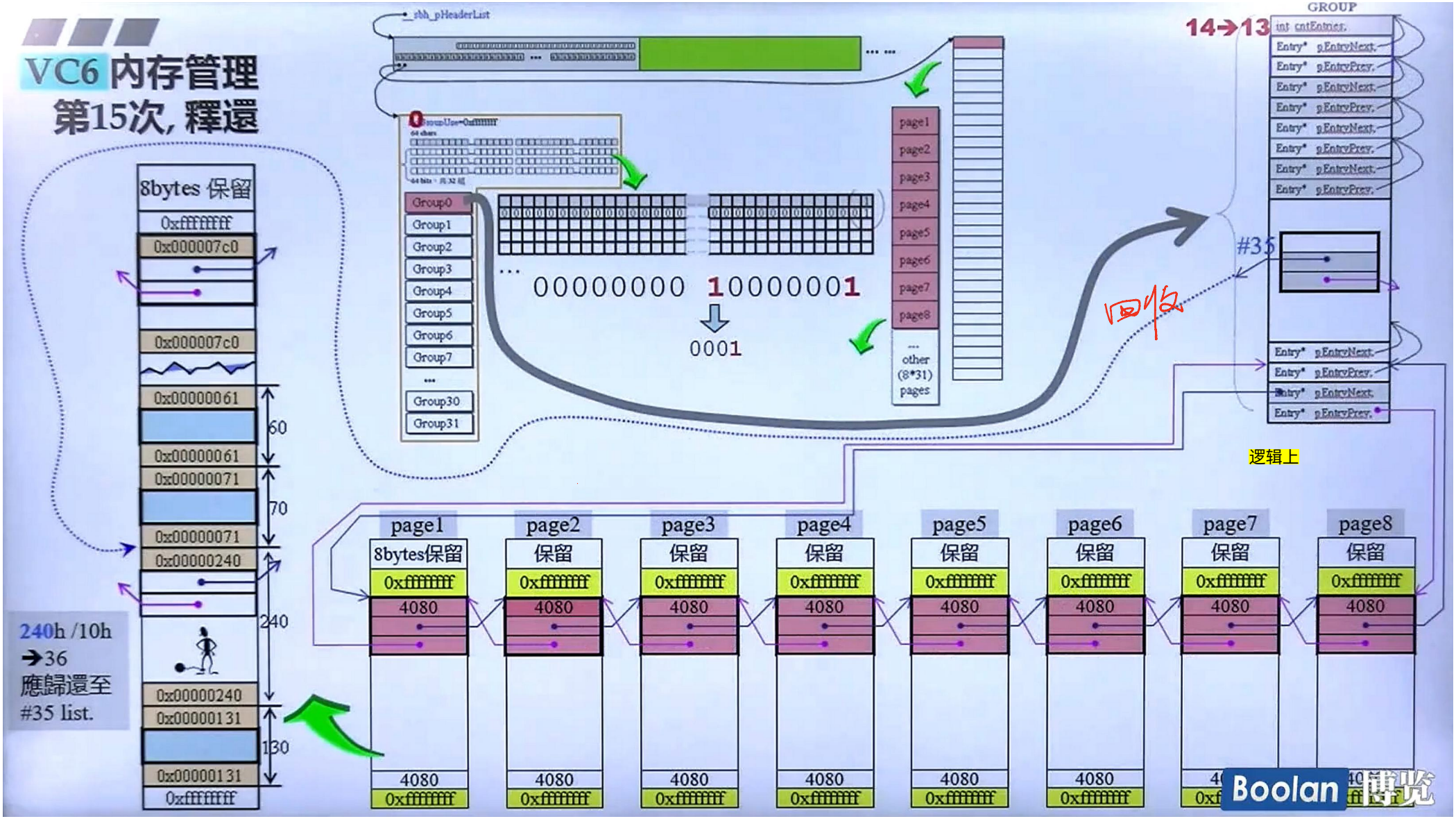

VC6 内存分配
8bytes保留
0xffffffff
007d000c
0x00000ec0
ec0
= ff0-130
4080-130
ec0
007d0ec8
0x00000ec0
007d0ecc
0x00000131
007d0ed0
130
007d0ff8
0x00000131
0xffffffff
007d1000
客户拿到的指针在这
00000131
00000000
00000000
0042ee08
"ioinit.c"
00000081
00000100
00000002
00000001
4 個 0xfd
fill 0xcd
nsize
(100h)
4 個 0xfd
00000131
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
27
Boolan 博览


VC6 内存管理
首次分配
由 ioinit.c, line#81申請
100h, 區塊大小130h,
理應由 #18 lists 供應
18链表现在没有指向
所以切割出来
130h/16 - 1 = 18
HeapAlloc(,,16*sizeof(HEADER))
p=VirtualAlloc(0 ,1Mb,
MEM_RESERVE, ...)
VirtualAlloc(addr ,32Kb,
MEM_COMMIT,...)
HeapAlloc(crtheap,,sizeof(REGION));
GROUP
8bytes保留
0xffffffff
0x00000ec0
0x00000131
ec0
130
100
fill with 0xcd
page1
page2
page3
page4
page5
page6
page7
page8
保留
4080
Group0
Group1
Group2
Group3
Group4
Group5
Group6
Group7
Group30
Group31
other (8*31) pages
Boolan 博览

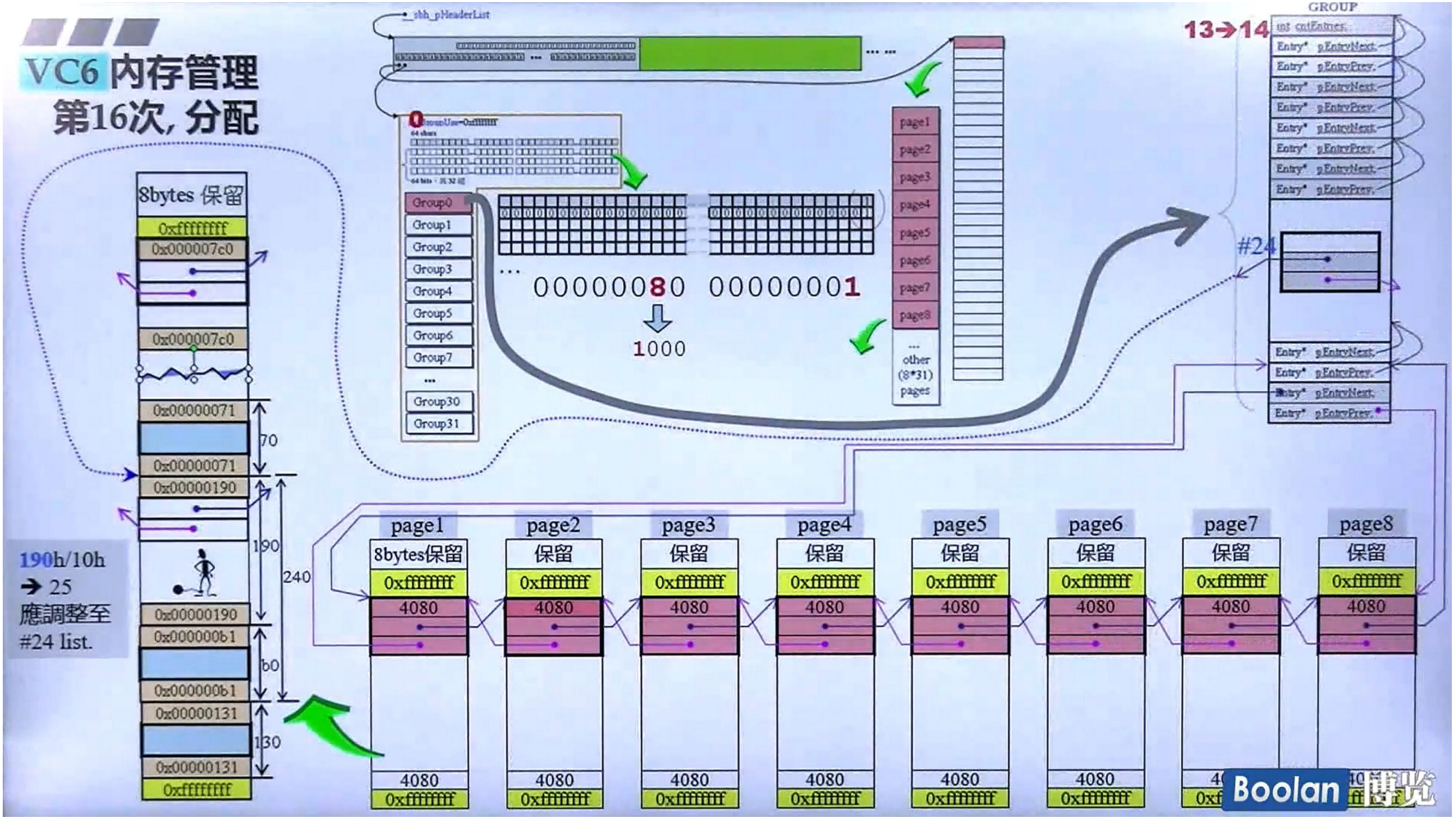

VC6 内存管理
第2次, 分配
c80
=ec0-240
8bytes 保留
0xffffffff
0x00000c80
c80
0x00000c80
0x00000241
240
0x00000241
0x00000131
130
0x00000131
0xffffffff
HeapAlloc(,,16*sizeof(HEADER))
p=VirtualAlloc(0 ,1Mb,
MEM_RESERVE, ...)
VirtualAlloc(addr ,32Kb,
MEM_COMMIT,...)
Group0
Group1
Group2
Group3
Group4
Group5
Group6
Group7
Group30
Group31
page1
page2
page3
page4
page5
page6
page7
page8
other
(8*31)
pages
GROUP
Entry* pEntryNext;
Entry* pEntryPrev;
page1
page2
page3
page4
page5
page6
page7
page8
8bytes保留
保留
0xffffffff
4080
Boolan 博览



-1 防止不同page合并

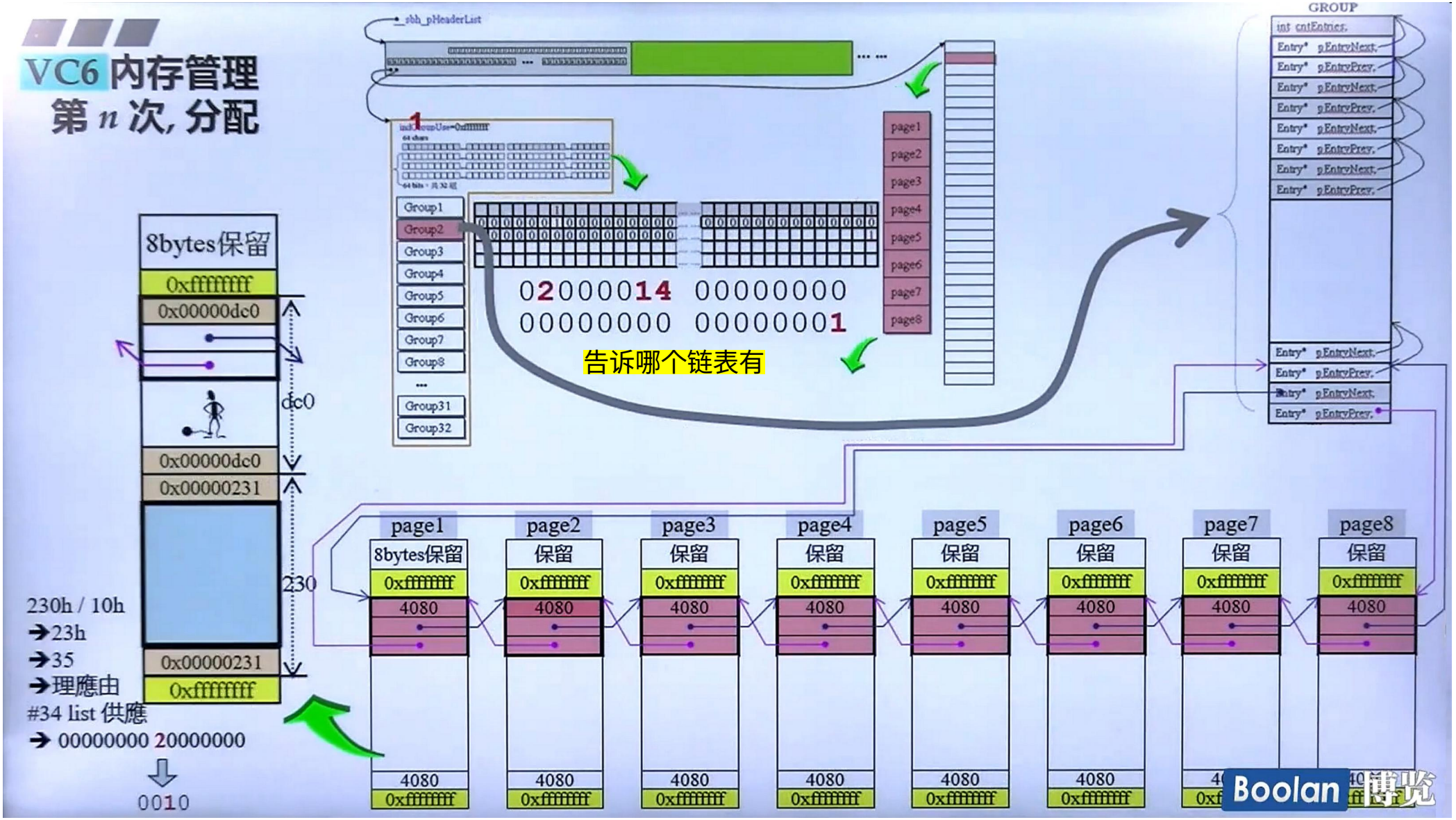


回收后下一次若还要相同大小的区块
则直接由链表指出
不用重新切割之类的操作



取最靠近需求的去切割
所以直接取上一个回收的240切

链表不断在调整


VC6 内存管理
第 n 次, 分配
8bytes保留
0xffffffff
0x00000dc0
dc0
0x00000dc0
0x00000231
230
0x00000231
0xffffffff
230h / 10h
➔23h
➔35
➔理應由
#34 list 供應
➔ 00000000 20000000
0010
Group1
Group2
Group3
Group4
Group5
Group6
Group7
Group8
Group31
Group32
page1
page2
page3
page4
page5
page6
page7
page8
02000014 00000000
00000000 00000001
告诉哪个链表有
GROUP
int cntEntries;
Entry* pEntryNext;
Entry* pEntryPrev;
保留
4080
Boolan 博览

8. 内存分配精解4

VC6 内存管理

區塊之合併

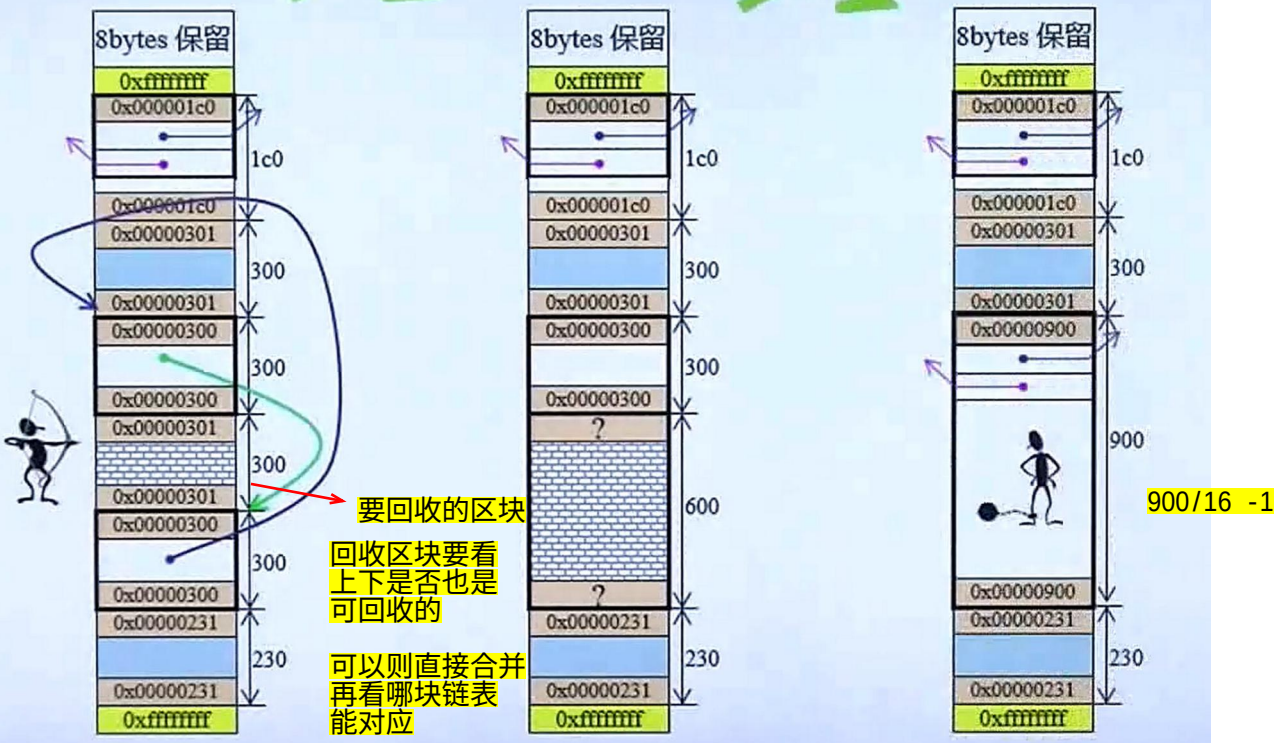
上 cookie
與
下 cookie
的作用

下方區塊若為 free，
合併之
（unlink 下方區塊）

上方區塊若為 free，
合併之
（unlink 上方區塊）

和上面合并

注意：腦袋裡要有兩張畫面 (兩個意象)，一是 memory block 處於線性空間 (物理意象)，一是 memory block 處於自由鏈表 (邏輯意象)。

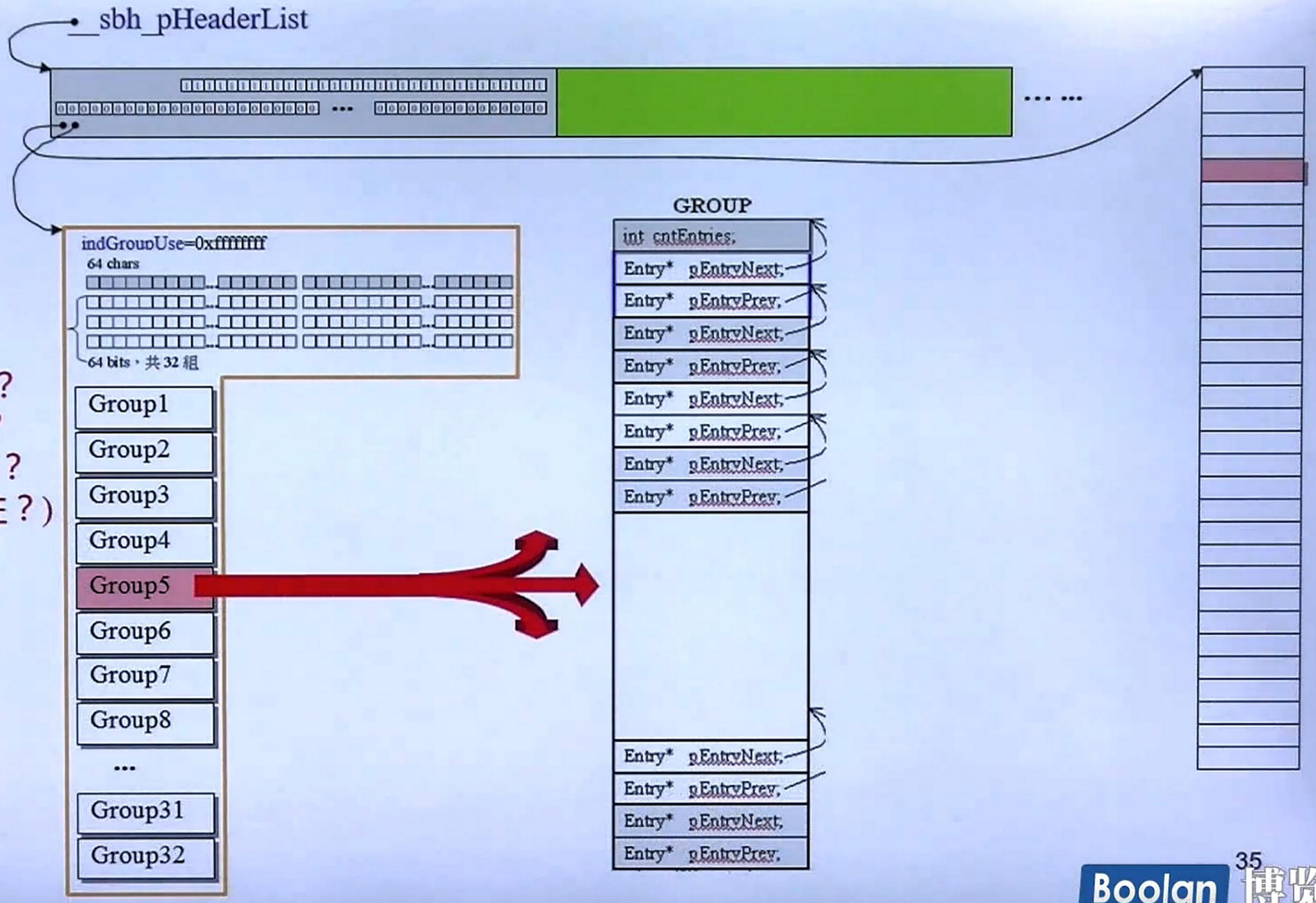


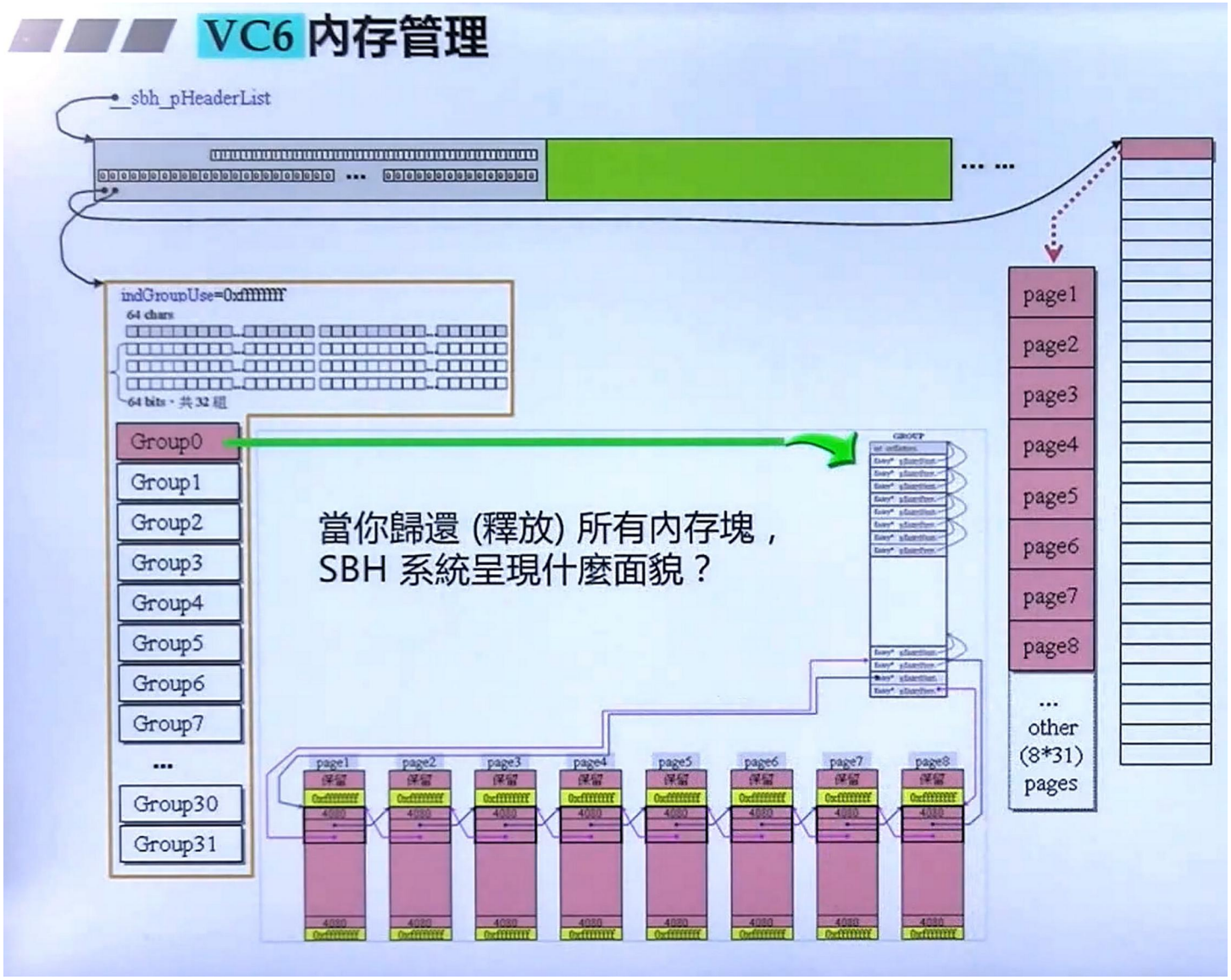
VC6 內存管理

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？)

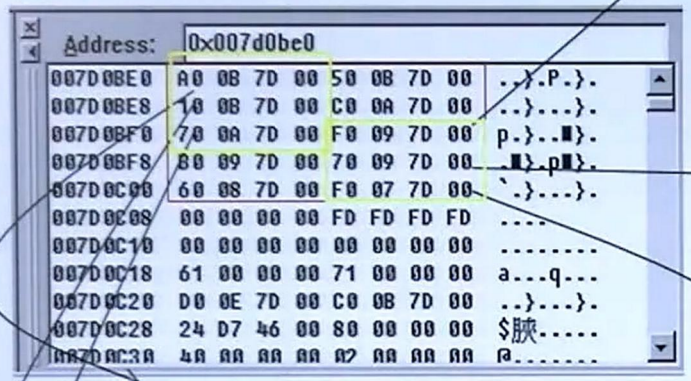




9. Main()生前所有内存分配之实例观察与解释

_environ 是 **pointer to pointer table**, table 中的每個 entry 都是 pointer to string which represents an environment variable.

_environ : 0x007d0be0



0

```
007D0BA0  54 4D 50 3D 43 3A 5C 57  TMP=C:\W
007D0BA8  49 4E 44 4F 57 53 5C 54  INDOWS\T
007D0BB0  45 4D 50 00 FD FD FD FD  EMP.
```

長度 20

1

```
007D0B50  54 45 4D 50 3D 43 3A 5C  TEMP=C:\
007D0B58  57 49 4E 44 4F 57 53 5C  WINDOWS\
007D0B60  54 45 4D 50 00 FD FD FD  TEMP
```

長度21

2

```
007D0B10  50 52 4F 4D 50 54 3D 24  PROMPT=$
007D0B18  70 24 67 00 FD FD FD FD  p$g.
```

長度12

3

```
007D0AC0  77 69 6E 62 6F 6F 74 64  winbootd
007D0AC8  69 72 3D 43 3A 5C 57 49  ir=C:\WI
007D0AD0  4E 44 4F 57 53 00 FD FD  NDOWS.
007D0AD8  FD FD 00 00 00 00 00 00  ....
```

長度22

4

```
007D0A70  43 4F 4D 53 50 45 43 3D  COMSPEC=
007D0A78  43 3A 5C 57 49 4E 44 4F  C:\WINDO
007D0A80  57 53 5C 43 4F 4D 4D 41  WS\COMMA
007D0A88  4E 44 2E 43 4F 4D 00 FD  ND.COM.
007D0A90  FD FD FD 00 00 00 00 00  .....
```

長度31

5

```
007D09F0  50 41 54 48 3D 43 3A 5C  PATH=C:\
007D09F8  57 49 4E 44 4F 57 53 3B  WINDOWS;
007D0A00  43 3A 5C 57 49 4E 44 4F  C:\WINDO
007D0A08  57 53 5C 43 4F 4D 4D 41  WS\COMMA
007D0A10  4E 44 3B 45 3A 5C 55 54  ND;E:\UT
007D0A18  49 4C 49 54 59 3B 43 3A  ILITY;C:
007D0A20  5C 50 52 4F 47 52 41 7E  \PROGRA~
007D0A28  31 5C 43 4F 4D 4D 4F 4E  1\COMMON
007D0A30  7E 31 5C 4D 55 56 45 45  ~1\MUVEE
007D0A38  54 7E 31 5C 30 33 30 36  T~1\0306
007D0A40  32 35 00 FD FD FD FD 00  25.
```

長度83

6

```
007D09B0  43 4D 44 4C 49 4E 45 3D  CMDLINE=
007D09B8  57 49 4E 00 FD FD FD FD  WIN.
```

長度12

7

```
007D0970  77 69 6E 64 69 72 3D 43  windir=C
007D0978  3A 5C 57 49 4E 44 4F 57  :\WINDOW
007D0980  53 00 FD FD FD FD 00 00  S.
```

長度18

8

```
007D0860  5F 41 43 50 5F 50 41 54  _ACP_PAT
007D0868  48 3D 43 3A 5C 4D 53 44  H=C:\MSD
007D0870  45 56 5C 43 4F 4D 4D 4F  EV\COMMO
007D0878  4E 5C 4D 53 44 45 56 39  N\MSDEV9
007D0880  38 5C 42 49 4E 3B 43 3A  8\BIN;C:
007D0888  5C 6D 73 64 65 76 5C 56  \msdev\V
007D0890  43 39 38 5C 42 49 4E 3B  C98\BIN;
007D0898  43 3A 5C 4D 53 44 45 56  C:\MSDEV
007D08A0  5C 43 4F 4D 4D 4F 4E 5C  \COMMON\
007D08A8  54 4F 4F 4C 53 3B 43 3A  TOOLS;C:
```

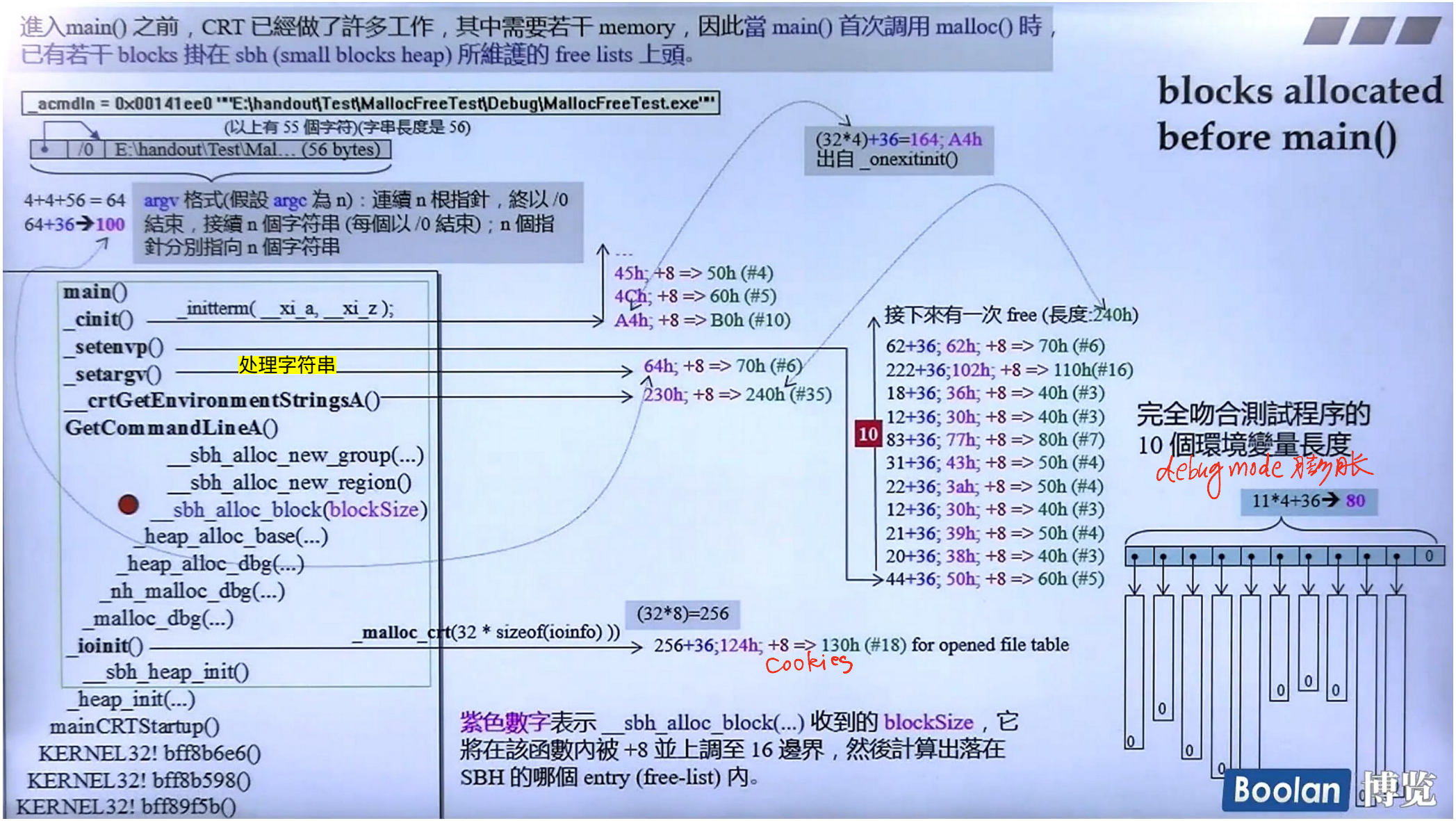
長度??

9

```
007D07F0  5F 41 43 50 5F 4C 49 42  _ACP_LIB
007D07F8  3D 43 3A 5C 6D 73 64 65  =C:\msde
007D0800  76 5C 56 43 39 38 5C 4C  v\VC98\L
007D0808  49 42 3B 43 3A 5C 6D 73  IB;C:\ms
007D0810  64 65 76 5C 56 43 39 38  dev\VC98
007D0818  5C 4D 46 43 5C 4C 49 42  \MFC\LIB
007D0820  3B 63 3A 5C 62 6F 6F 73  ;c:\boos
007D0828  74 5C 6C 69 62 00 FD FD  t\lib.
007D0830  FD FD 00 00 00 00 00 00  ......
```

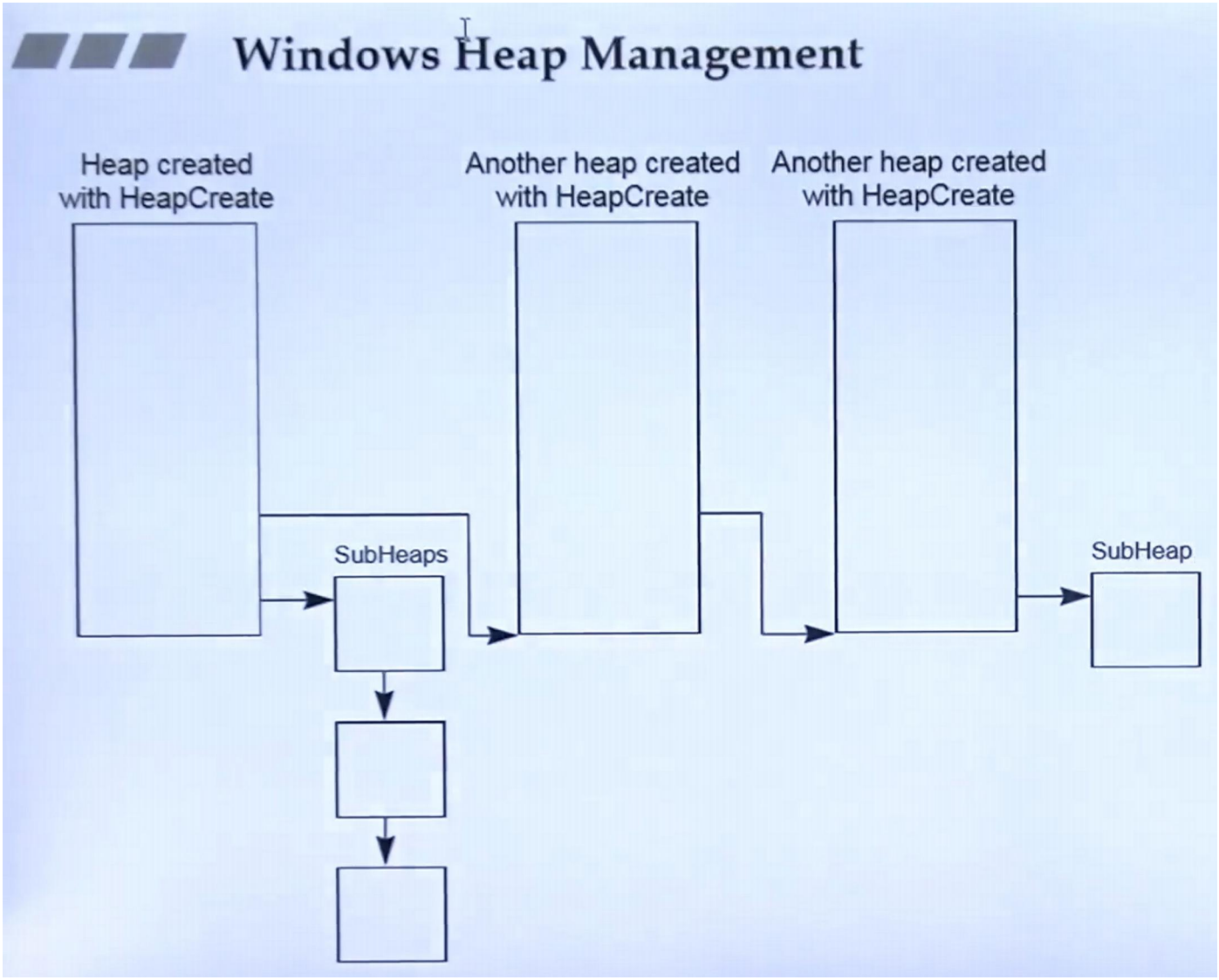
長度62

blocks allocated before main()

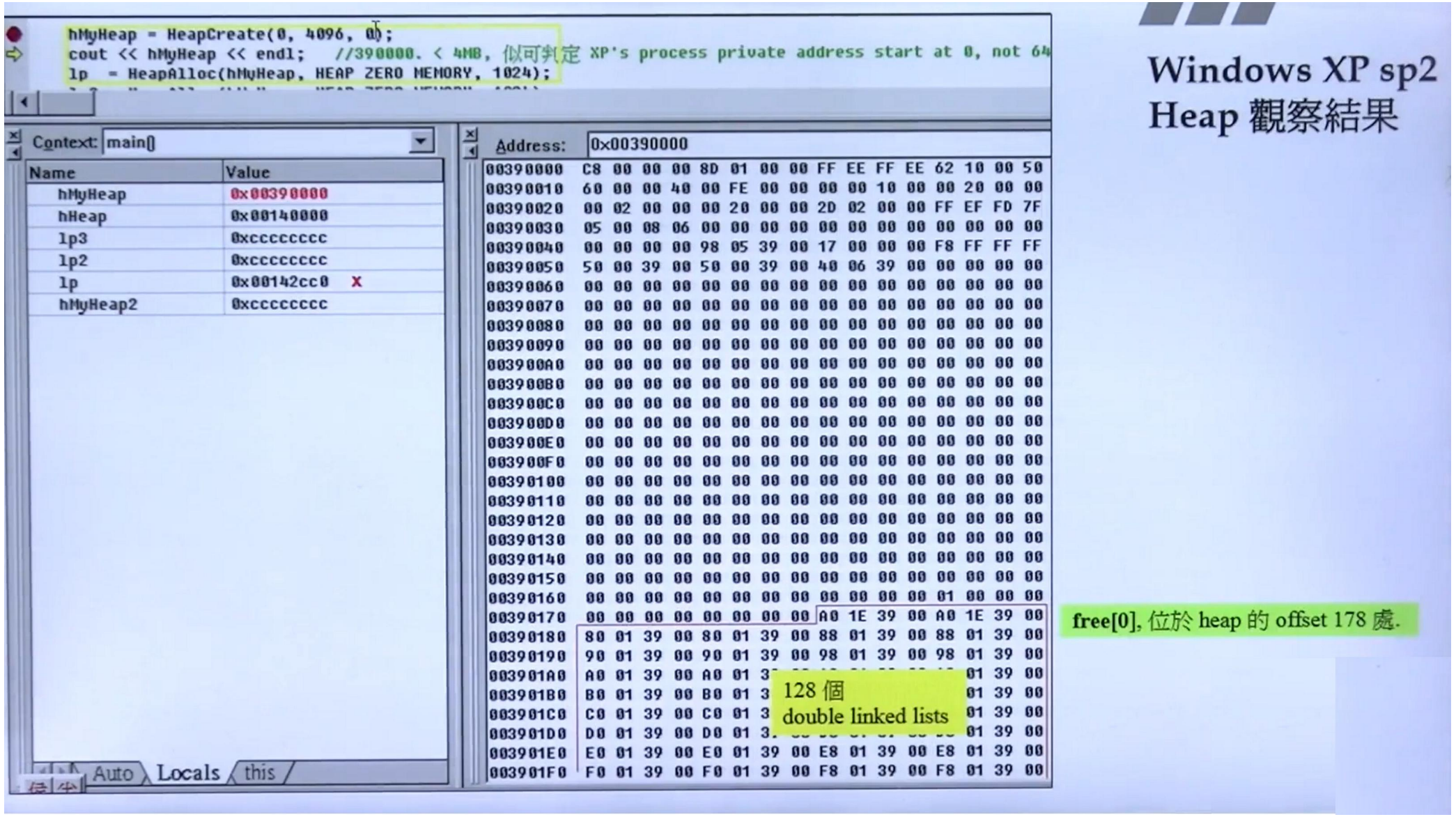


10. HeapAlloc()角色与影响

Windows Heap Management

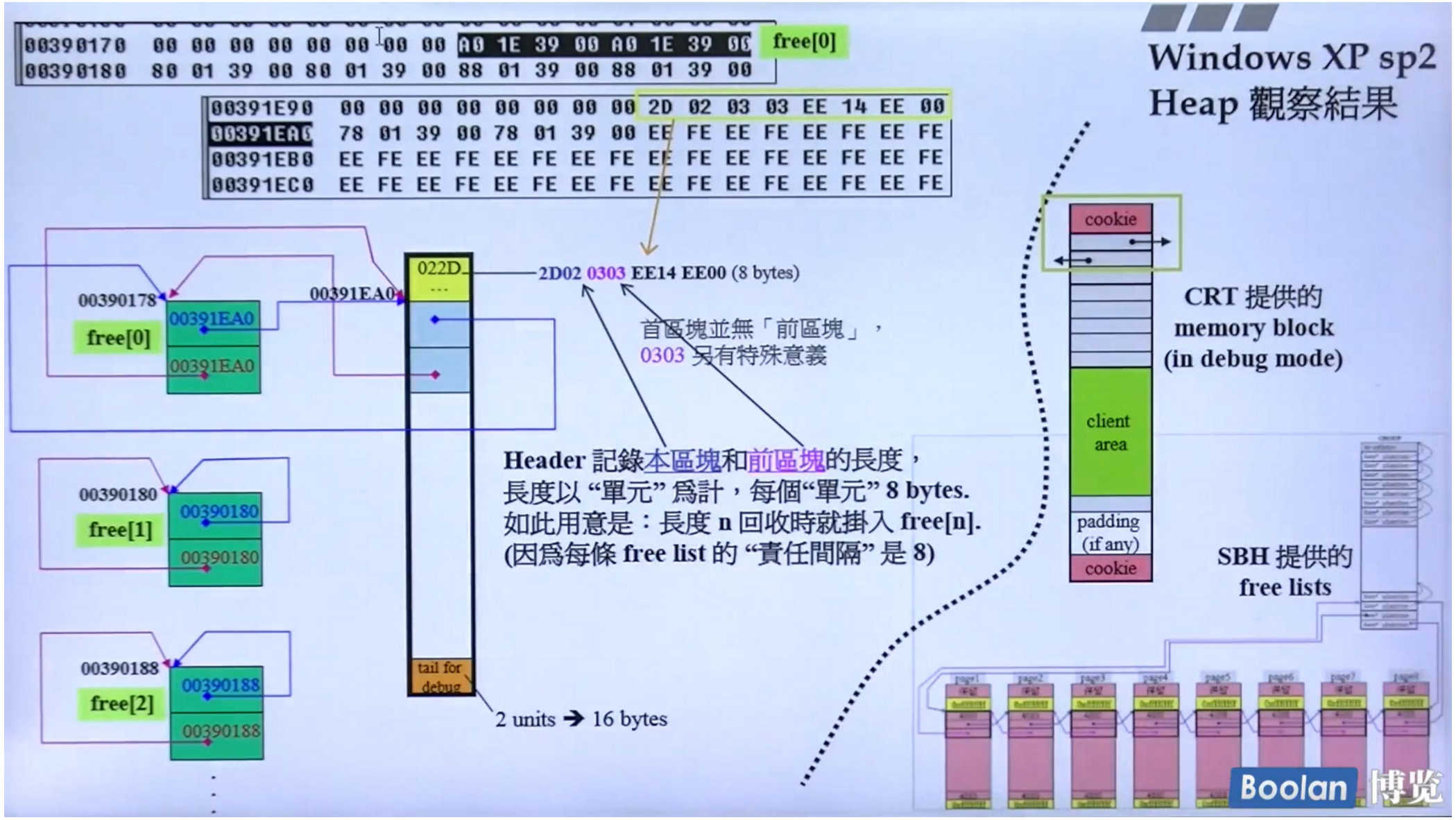


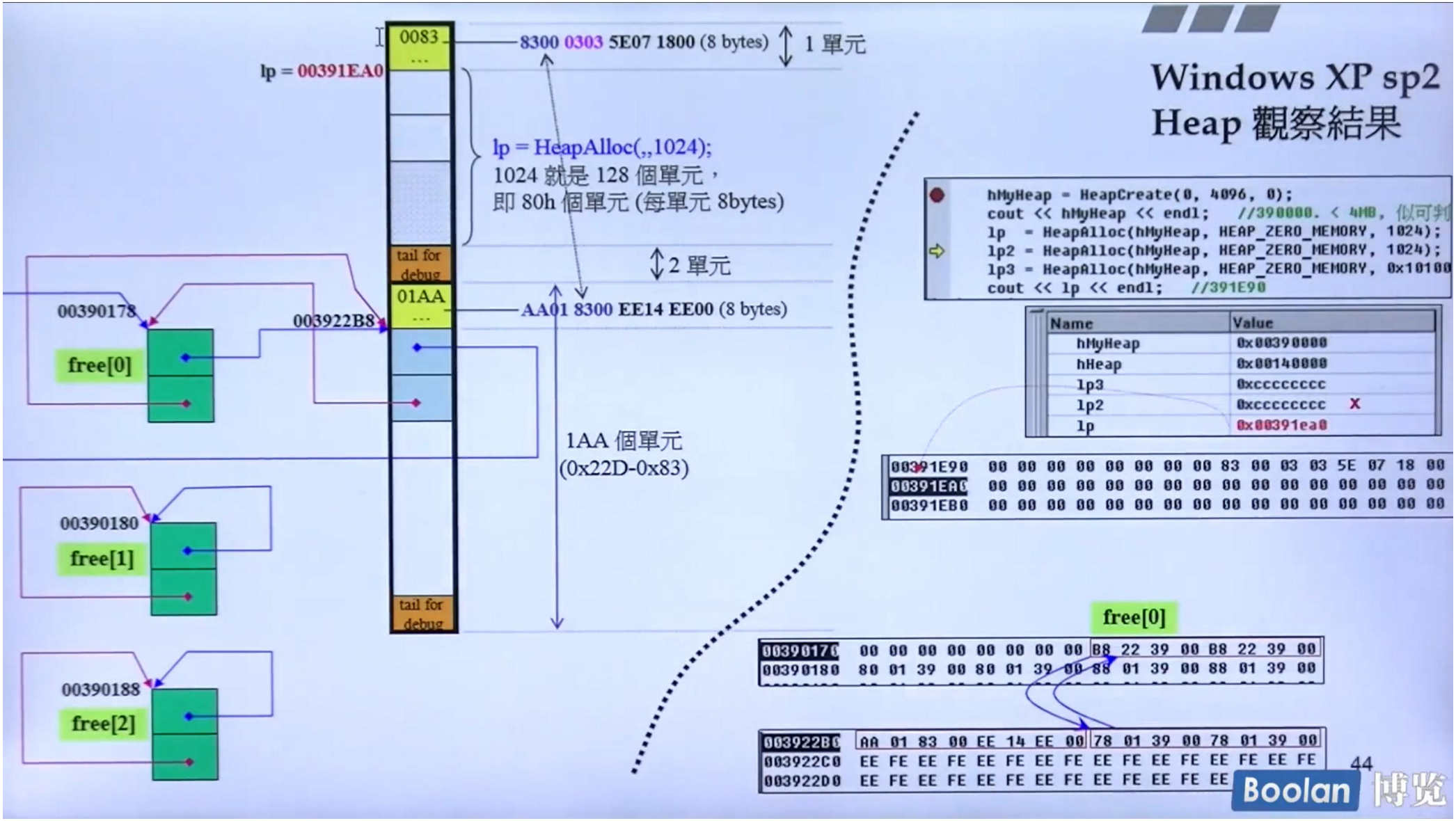
Windows XP sp2 Heap 觀察結果



free[0], 位於 heap 的 offset 178 處.


free[0], 位於 heap 的 offset 178 處.
Windows XP sp2
Heap 觀察結果
size: 022D
free[127]
128 個 free lists，
也就是 128 對指針，
0x390178 + 128 * 8
= 0x390578
42
Boolan 博


00390170 00 00 00 00 00 00 00 00 A0 1E 39 00 A0 1E 39 00
00390180 80 01 39 00 80 01 39 00 88 01 39 00 88 01 39 00
free[0]
00391E90 00 00 00 00 00 00 00 00 2D 02 03 03 EE 14 EE 00
00391EA0 78 01 39 00 78 01 39 00 EE FE EE FE EE FE EE FE
00391EB0 EE FE EE FE EE FE EE FE EE FE EE FE EE FE EE FE
00391EC0 EE FE EE FE EE FE EE FE EE FE EE FE EE FE EE FE
Windows XP sp2
Heap 觀察結果
00390178
free[0]
00391EA0
00391EA0
00391EA0
022D
...
2D02 0303 EE14 EE00 (8 bytes)
首區塊並無「前區塊」，
0303 只有特殊意義
00390180
free[1]
00390180
00390180
00390188
free[2]
00390188
00390188
tail for debug
2 units → 16 bytes
Header 記錄本區塊和前區塊的長度，
長度以 “單元” 爲計，每個“單元” 8 bytes.
如此用意是：長度 n 回收時就掛入 free[n].
(因爲每條 free list 的 “責任間隔” 是 8)
cookie
client area
padding (if any)
cookie
CRT 提供的
memory block
(in debug mode)
SBH 提供的
free lists
Boolan 博览



11. Io_init() - startup 的第二项大工程

_io_init()

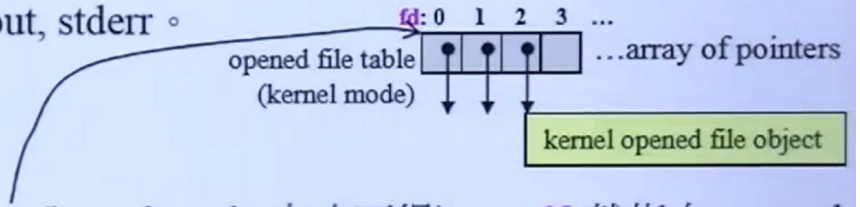
I/O 泛指程序和外界的各種交互作用，包括 file, pipe, network, console, semaphore 等等，或泛指能被 OS 理解爲 file 的任何事務 — file 在此是一個廣義概念。

```
FILE* fp = fopen("xxx.dat", "wb");
```

```
struct _iobuf { … };
typedef struct _iobuf FILE;
```

C 通過一個 pointer to **FILE** 來進行 file 操作。在 OS 層面，Linux 對應於 **FILE** 的是 File Descriptor (**fd**)，Windows 對應的則是 **file handle**. 二者都用來映射 kernel file object。

fd 具體是個 index of **opened file table** —process 個別擁有的這個 table 是個 array of pointers，每個 pointer 指向一個 kernel opened object。當 client 開啓一個 file，OS 會建立一個 (kernel) **opened file object** 並找到上述 table 中的一個 idle entry 指向之，然後以該 entry 的 index 做爲 **fd**。此 table 位於 kernel mode，因此 client 即使擁有 **fd** 亦無法獲得 table address. Linux 的 **fd** 0,1,2 分別代表 stdin, stdout, stderr。



C 的 **FILE** 與 Linux 的 **fd** 必有一對一關係。只要有 table address p (kernel mode 中才可得)，p+**fd** 就指向 opened file table 的某個 entry，從而可得 kernel file object。

Windows 的 **file handle** 和 Linux 的 **fd** 大同小異，但 **handle** 不是 index，而是 index 經某種變換後的結果。

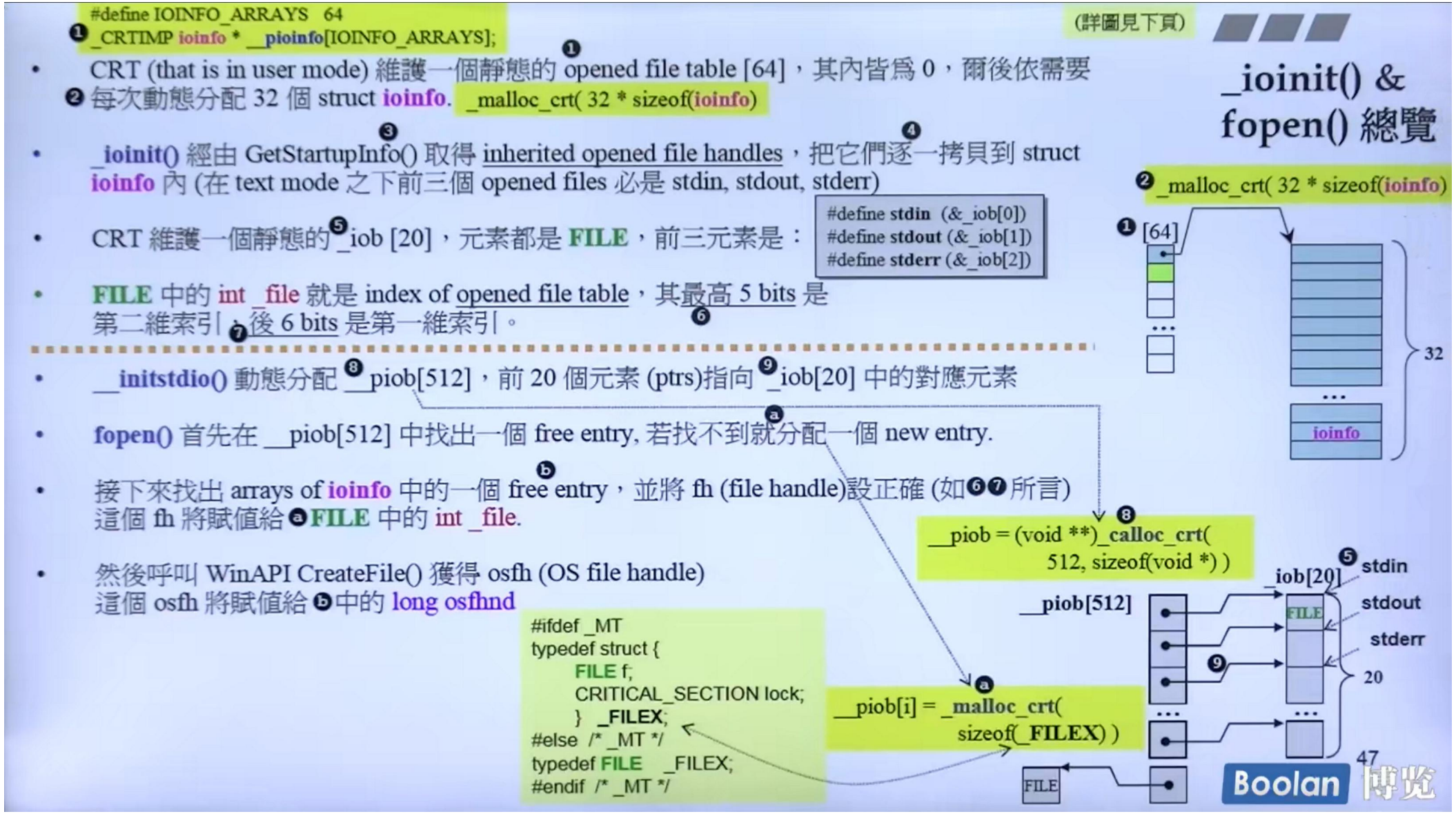
I/O initialization 就是要在 **client space** 中建立起 stdin, stdout, stderr 及其對應的 **FILE**s，使程式進入 main() 之後立即可用 printf(), scanf() 等函式。

_io_init()

```
    ExitProcess(code)
    _initterm(,,)   //do terminators
      __endstdio(void)
    _initterm(,,)   //do pre-terminators
  doexit(code, 0, 0)
exit(code)
main()
  _initterm(,,) //do C++ initializations
    __initstdio(void)
  _initterm(,,) //do initializations
_cinit()
_setenvp()
_setargv()
__crtGetEnvironmentStringsA()
GetCommandLineA()
            __sbh_alloc_new_group(...)
            __sbh_alloc_new_region()
          __sbh_alloc_block(...)
        _heap_alloc_base(...) //size:292
      _heap_alloc_dbg(...)
    _nh_malloc_dbg(...)
  _malloc_dbg(...) //size:256
_ioinit()
  __sbh_heap_init()
_heap_init(...)
mainCRTStartup()
```

ioinit.c

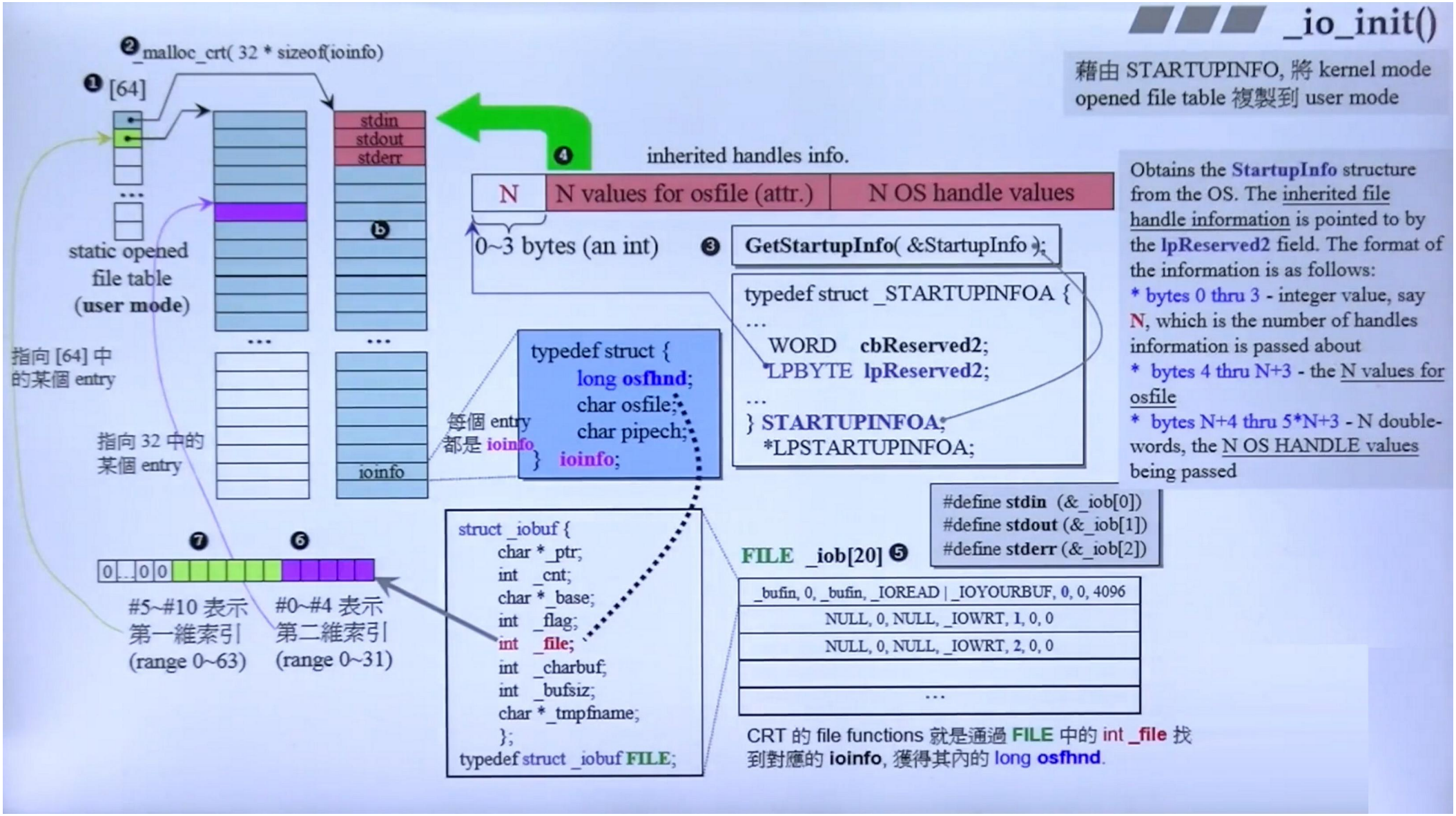
```
/***
*Purpose:
*       Allocates and initializes initial array(s) of ioinfo structs. Then,
*       obtains and processes information on inherited file handles from the
*       parent process (e.g., cmd.exe).
*
*       Obtains the StartupInfo structure from the OS. The inherited file
*       handle information is pointed to by the lpReserved2 field. The format
*       of the information is as follows:
*           bytes 0 thru 3 - integer value, say N, which is the
*                            number of handles information is passed about
*           bytes 4 thru N+3   - the N values for osfile
*           bytes N+4 thru 5*N+3  - N double-words, the N OS HANDLE values
*                            being passed
*       Next, osfhnd and osfile for the first three ioinfo structs,
*       corrsponding to handles 0, 1 and 2, are initialized as follows:
*           If the value in osfhnd is INVALID_HANDLE_VALUE, then try to
*           obtain a HANDLE by calling GetStdHandle, and call GetFileType to
*           help set osfile. Otherwise, assume _osfhndl and _osfile are
*           valid, but force it to text mode (standard input/output/error
*           are to always start out in text mode).
*       Notes:
*           1. In general, not all of the passed info from the parent process
*              will describe open handles! If, for example, only C handle 1
*              (STDOUT) and C handle 6 are open in the parent, info for C
*              handles 0 thru 6 is passed to the the child.
*           2. Care is taken not to 'overflow' the arrays of ioinfo structs.
*           3. See exec\dospawn.c for the encoding of the file handle info
*              to be passed to a child process.
*Entry:
*       No parameters: reads the STARTUPINFO structure.
*Exit:
*       No return value.
*Exceptions:
*******************************************************************************/
```



12. C_init() startup的第三大工程

_io_init()

藉由 STARTUPINFO, 將 kernel mode opened file table 複製到 user mode

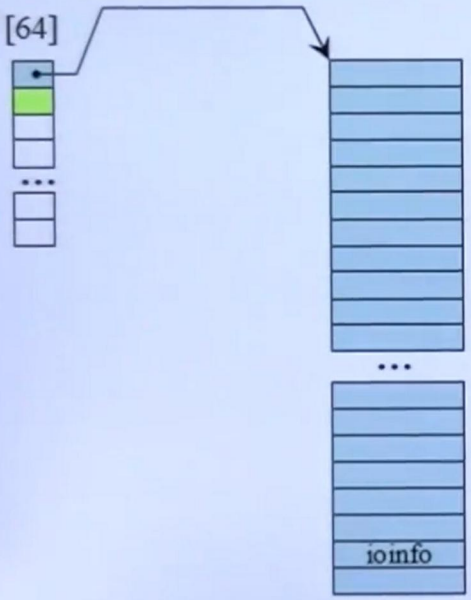


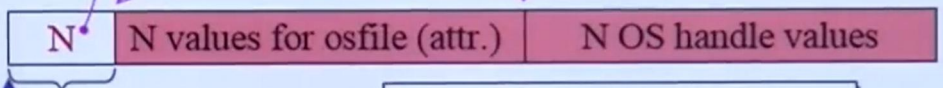
```
#0080    /* * Process inherited file handle information, if any  */
#0081    GetStartupInfo( &StartupInfo );
#0082    if ( (StartupInfo.cbReserved2 != 0) &&
#0083         (StartupInfo.lpReserved2 != NULL) )
#0084    {
#0085        /* * Get the number of handles inherited. */
#0086        cfi_len = *(UNALIGNED int *)(StartupInfo.lpReserved2);

#0087        /* * Set pointers to the start of the passed file info and OS
#0088         * HANDLE values.  */
#0089        posfile = (char *)(StartupInfo.lpReserved2) + sizeof( int );
#0090        posfhnd = (UNALIGNED long *)(posfile + cfi_len);
```

```
#define IOINFO_ARRAYS   64
_CRTIMP ioinfo * __pioinfo[IOINFO_ARRAYS];
```

❷ _malloc_crt(32 * sizeof(ioinfo)

❶ [64]





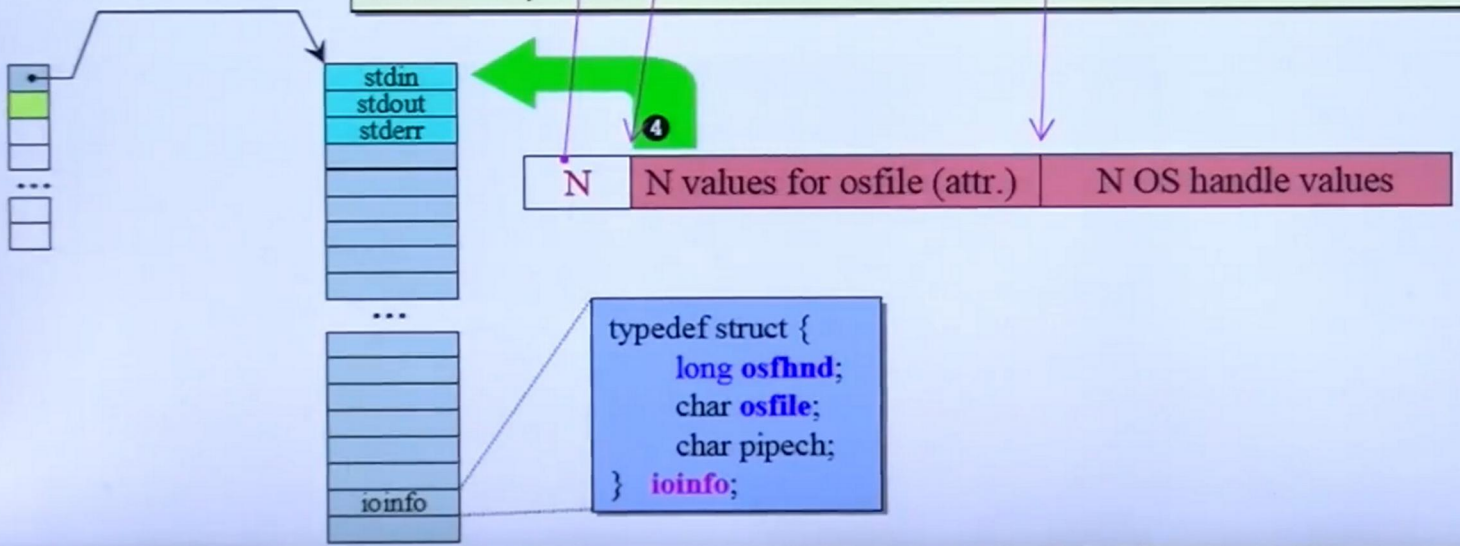
0~3 bytes (an int)

❸ **GetStartupInfo**(&StartupInfo);

```
typedef struct _STARTUPINFOA {
…
    WORD    cbReserved2;
    LPBYTE  lpReserved2;
…
} STARTUPINFOA;
  *LPSTARTUPINFOA;
```

_io_init()

```
#0119        for ( fh = 0 ; fh < cfi_len ; fh++, posfile++, posfhnd++ ) {
#0120          /*
                ...
#0127           */
#0128          if ( (*posfhnd != (long)INVALID_HANDLE_VALUE) &&
#0129              (*posfile & FOPEN) &&
#0130              ((*posfile & FPIPE) ||
#0131               (GetFileType( (HANDLE)*posfhnd ) != FILE_TYPE_UNKNOWN)) )
#0132          {
#0133            pio = _pioinfo( fh );
#0134            pio->osfhnd = *posfhnd;
#0135            pio->osfile = *posfile;
#0136          }
#0137        }
#0138      }
```



file test

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

int main()
{
  cout << stdin << endl;          //00414538
  cout << stdin->_file << endl;   //0
  cout << stdout << endl;         //00414558
  cout << stdout->_file << endl;  //1
  cout << stderr << endl;         //00414578
  cout << stderr->_file << endl;  //2

  FILE* fp = fopen("xxx.dat", "wb");
  if (fp == NULL) return -1;
  cout << fp << endl;             //00414598
  cout << fp->_file << endl;      //3

  fwrite("abcde", 5, 1, fp);
  fclose(fp);
  cout << fp << endl;             //00414598
  cout << fp->_file << endl;      //3
```

fclose() 會歸還 file handle!

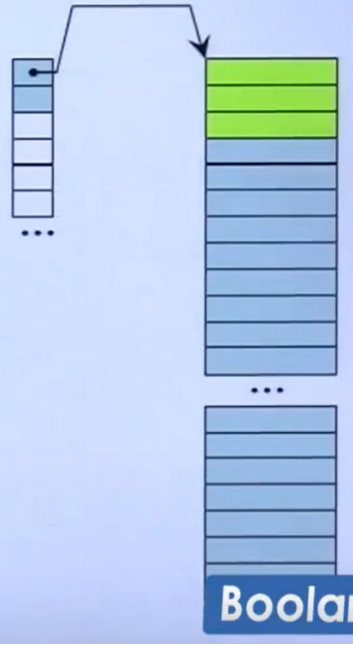
```
#define stdin  (&_iob[0])
#define stdout (&_iob[1])
#define stderr (&_iob[2])
```

sizeof(FILE): 0x20
所以 stdin, stdout, stderr (都是指針) 相差 0x20

```
  fp = fopen("yyy.dat", "wb");
  if (fp == NULL) return -1;
  cout << fp << endl;             //00414598
  cout << fp->_file << endl;      //3
```

```
  fwrite("fghij", 5, 1, fp);
  fclose(fp);
  cout << fp << endl;             //00414598
  cout << fp->_file << endl;      //3

  int i;
  FILE* f[60];
  char buffer[20];
  for (i=0; i< 60; ++i) {
     f[i] = fopen(_itoa(i,buffer,10), "wb");
     cout << f[i]->_file << endl;      //3 4 5 6 ... 62
  }
  return 0;
}
```

本例先檢驗 std I/O 的 handle 分別爲 0,1,2. 然後 open/close 二次。然後 open 60 次。故總共佔用 3+60 = 63 個 handles。



_cinit()

```
    ExitProcess(code)
    _initterm(,,)   //do terminators
      __endstdio(void)
    _initterm(,,)   //do pre-terminators
  doexit(code, 0, 0)
exit(code)
main()
  _initterm(,,) //do C++ initializations
    __initstdio(void)
  _initterm(,,) //do initializations
  _cinit()
_setenvp()
_setargv()
__crtGetEnvironmentStringsA()
GetCommandLineA()
            __sbh_alloc_new_group(...)
            __sbh_alloc_new_region()
          __sbh_alloc_block(...)
        _heap_alloc_base(...)
      _heap_alloc_dbg(...)
    _nh_malloc_dbg(...)
  _malloc_dbg(...)
_ioinit()
  __sbh_heap_init()
_heap_init(...)
mainCRTStartup()
```

```
/***
*_cinit - C initialization
*
*Purpose:
*       This routine performs the shared DOS and Windows initialization.
*       The following order of initialization must be preserved -
*
*       1.  Check for devices for file handles 0 - 2
*       2.  Integer divide interrupt vector setup
*       3.  General C initializer routines
*
*Entry:
*       No parameters: Called from __crtstart and assumes data
*       set up correctly there.
*
*Exit:
*       Initializes C runtime data.
*
*Exceptions:
*
*******************************************************/
```