# 深入淺出 Hello World

## 理解 Linux 上運作 Hello World 的種種機制

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# 老師說…

一分耕耘

一分收穫

# 基本想法

- 給你魚吃，也教你釣魚
- 以「實驗」觀點去理解Linux
- 處處留心皆學問、落花水面皆文章
- Geek/Hacker與一般的user/programmer的分野並不大
  - 只是專注的範疇與態度有異

# 注意

- 本議程針對x86硬體架構，至於ARM與MIPS架構，請另行聯絡以作安排
- 簡報採用創意公用授權條款(Creative Commons License: **Attribution-ShareAlike**)發行
- 議程所用之軟體，依據個別授權方式發行
- 系統平台
  - Ubuntu Edgy (development branch)
  - Linux kernel 2.6.17-4
  - gcc 4.1.2 (pre-release)
  - glibc 2.4

# Agenda

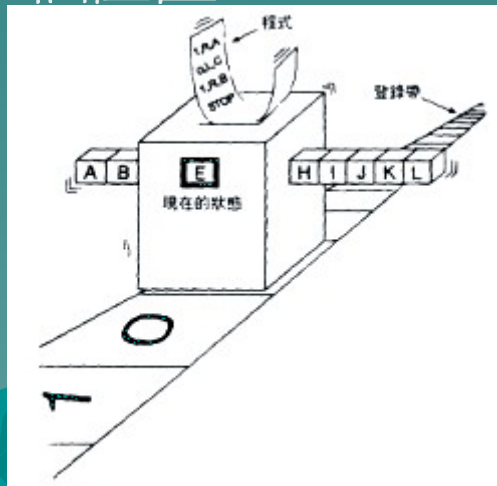
- “Hello World”人人會寫，可是又如何運作？
- "Hello World”與ELF
- 從GNU Toolchain看” Hello World“
  - 動輒上百 k 是怎麼回事？
  - 如何應用工具對 “Hello World”尋幽訪勝

# 誰不會寫 **Hello World**？

```
#include <stdio.h>

int main (int argc, char *argv[])
{
   printf (“Hello World!\n”);
   return 0;
}
```

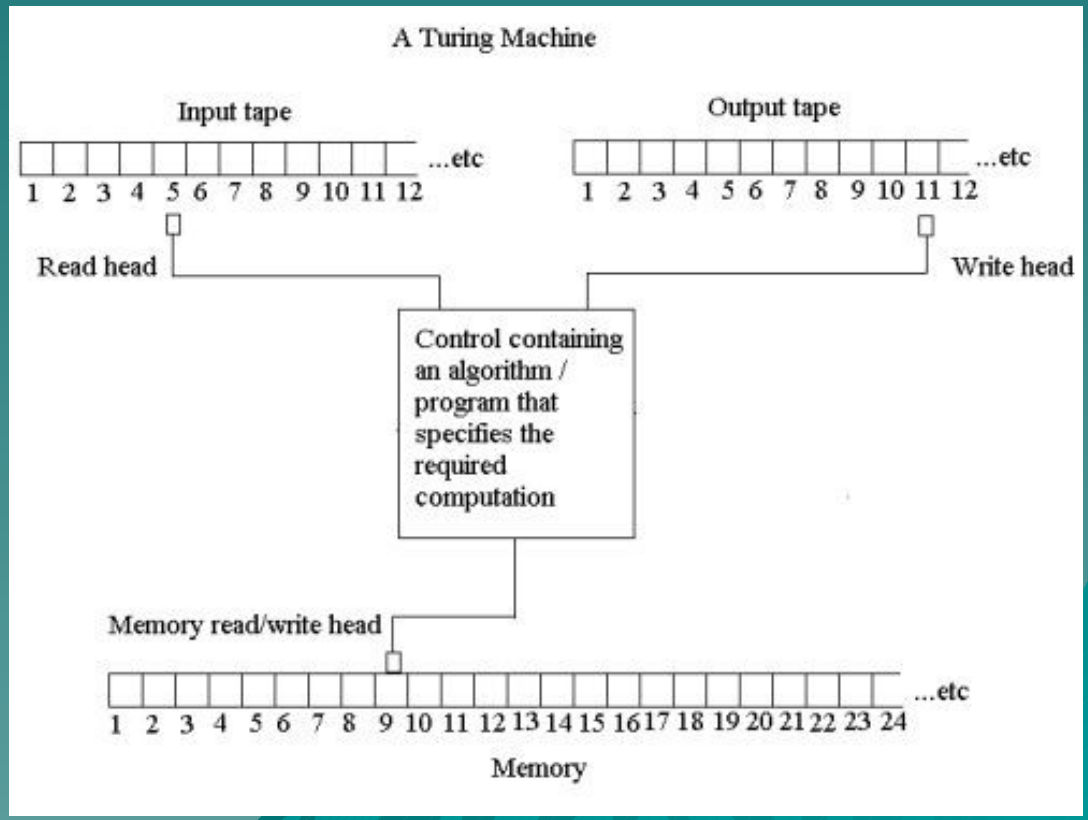
# “Hello World” 的理論基礎 (1)

- Turing Machine
  - 英國數學家Alan Turing於1936年提出的一種抽象計算模型
  - 用機器來模擬人們用紙筆進行數學運算的過程：
    - 在紙上寫上或擦除某個符號
    - 把注意力從紙的一個位置移動到另一個位置
  - 每階段要決定下一步的動作
    - 紙上某個位置的符號
    - 思維的狀態



# “Hello World” 的理論基礎 (2)

- Turing Machine
  - 每階段要決定下一步的動作
    - 紙上某個位置的符號
    - 思維的狀態



# “Hello World” as a Turing Machine

| State | Read | Write | Step | Next Step |
|---|---|---|---|---|
| 1 | Empty | H | > | 2 |
| 2 | Empty | e | > | 3 |
| 3 | Empty | l | > | 4 |
| 4 | Empty | l | > | 5 |
| 5 | Empty | o | > | 6 |
| 6 | Empty | blank | > | 7 |
| 7 | Empty | W | > | 8 |
| 8 | Empty | o | > | 9 |
| 9 | Empty | r | > | 10 |
| 10 | Empty | l | > | 11 |
| 11 | Empty | d | > | 12 |
| 12 | Empty | ! | > | STOP |

# 思考…

- 理論上，可透過任何程式語言甚至硬體機制來實現”Hello World”
- 數論中，有些猜測敘述簡單易懂，但卻難於證明
  - 費瑪最後定理與哥德巴赫猜想
  - 費瑪最後定理(1631年)

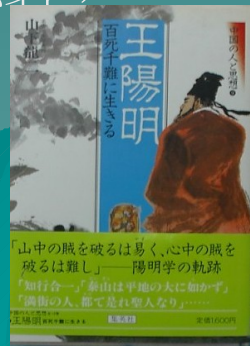
    對於 $n=3, 4, 5, \ldots$，方程式

    $$X^n + y^n = z^n$$

    沒有正整數解

> “Cubem autem in duos cubos, aut quadra-toquadratum in duos quadrato-quadratos, et generaliter nullam in infinitum ultra quadratum potestatem in duos eiusdem nominis fas est dividere cuius rei demonstrationem mirabilem sane detexi. Hanc marginis exiguitas non caperet.“
> (**Nagell** 1951, p. 252)

- 《禮記・大學》
  - 「古之欲明明德於天下者，先治其國。欲治其國者，先齊其家，欲齊其家者， 先修其身。欲修其身者，先正其心。欲正其心者，先誠其意。欲誠其意者，先致其知。致知在格物。」



# 用各種語言寫 Hello World(1)

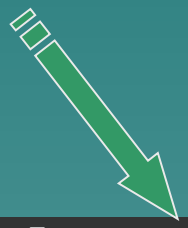
- **433 Examples in 132 (or 162*) programming languages**
  - http://www.ntecs.de/old-hp/uu9r/lang/html/lang.en.html
- 補充

```
/* Inline assembly */
#include <stdio.h>

char message[] = "Hello, world!\n";

int main(void)
{
        long _res;
        __asm__ volatile (
                "int $0x80"
                : "=a" (_res)
                : "a" ((long) 4),
                  "b" ((long) 1),
                  "c" ((long) message),
                  "d" ((long) sizeof(message)));
        return 0;
}
```

```
/* Inline BASIC */
#include "ubasic.h"
static const char program[] =
"10 GOSUB 100\n\
 20 FOR i = 1 TO 10\n\
 30     PRINT \"Hello World!\"\n\
 40 NEXT i\n\
 50 PRINT \"End\"\n\
 60 END\n\
100 RETURN\n";

int main(void)
{
        ubasic_init(program);
        do {
                ubasic_run();
        } while (!ubasic_finished());
        return 0;
}
```

# 用各種語言寫 Hello World(2)

```
\u0070\u0075\u0062\u006c\u0069\u0063\u000a\u0063\u006c\u0061
\u0073\u0073\u0020\u0055\u0067\u006c\u0079\u000a\u007b\u0070
\u0075\u0062\u006c\u0069\u0063\u000a\u0020\u0020\u0020\u0020
\u0073\u0074\u0061\u0074\u0069\u0063\u000a\u0076\u006f\u0069
\u0064\u0020\u006d\u0061\u0069\u006e\u0028\u000a\u0053\u0074
\u0072\u0069\u006e\u0067\u005b\u005d\u000a\u0020\u0020\u0020
\u0020\u0061\u0072\u0067\u0073\u0029\u007b\u000a\u0053\u0079
\u0073\u0074\u0065\u006d\u002e\u006f\u0075\u0074\u000a\u002e
\u0070\u0072\u0069\u006e\u0074\u006c\u006e\u0028\u000a\u0022
\u0048\u0065\u006c\u006c\u006f\u0020\u0057\u0022\u002b\u000a
\u0022\u006f\u0072\u006c\u0064\u0022\u0029\u003b\u007d\u007d
```



```
public class Ugly {
    public static void main(String[] args) {
        System.out.println("Hello World");
    }
}
```

```
public
class Ugly
{public
    static
void main(
String[]
    args){
System.out
.println(
"Hello W"+
"orld");}}
```

```
/* Magic Java version */
```

# 等等，這就是今天的主題？！


Orz programming 1.0



# 蘇格拉底說…

我唯一所知的

就是我一無所知

# 我們的「平台」

# 對抗無知的武器


- GNU Toolchain
  - gcc (GNU Compiler Collection)
  - binutils

$ apt-cache search binutils

**binutils** - The GNU assembler, linker and binary utilities

**binutils-dev** - The GNU binary utilities (BFD development files)


  - glibc runtime & utilities
- ELF editor
- ggcov

# Level of Software(1)

**High-level language**

(C, C++, Pascal. Fortran, Ada, …)

*compiler*

**Assembly language** (8051, Z80, 80386, ARM, …)

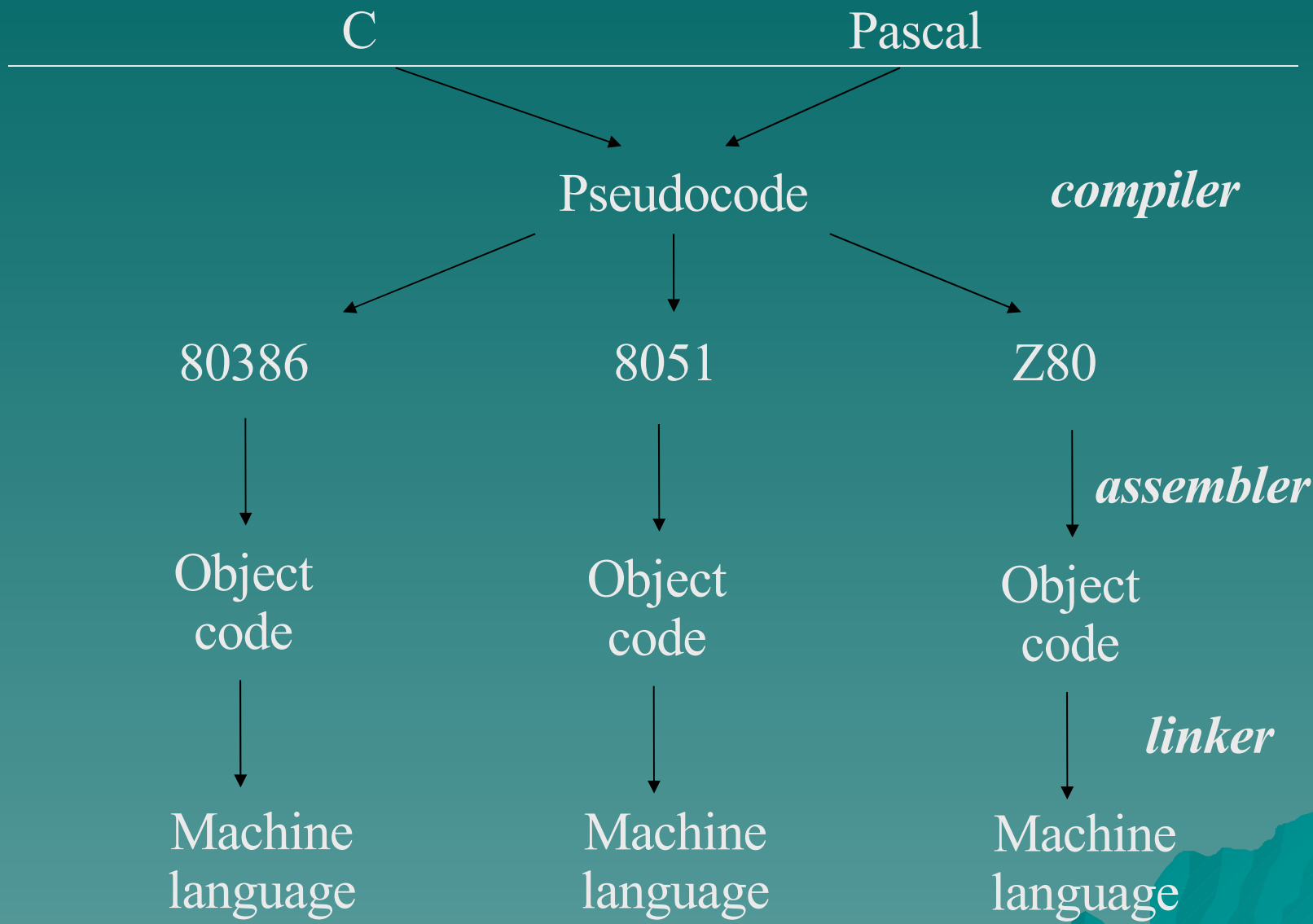
*assembler*

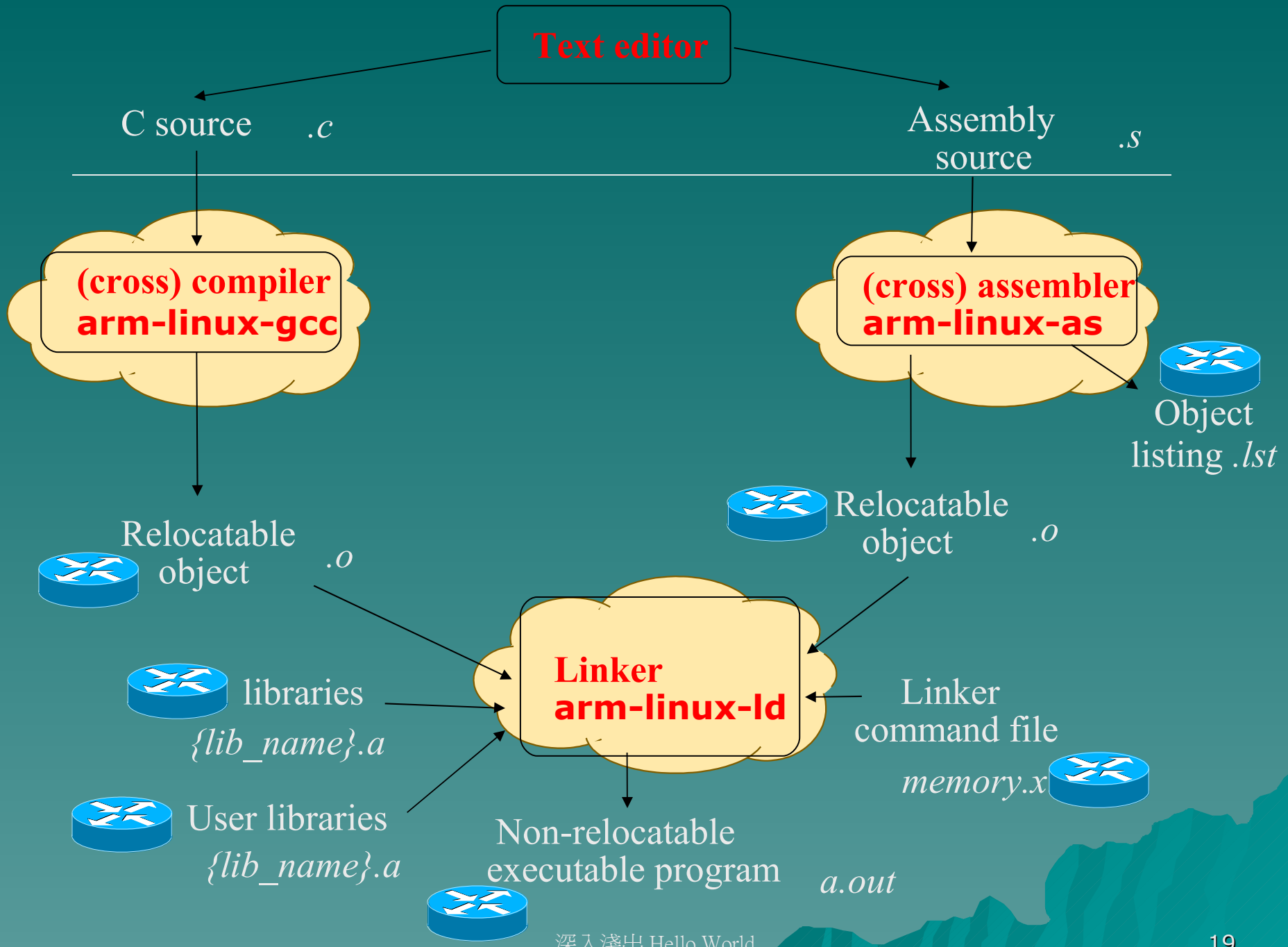
Object code

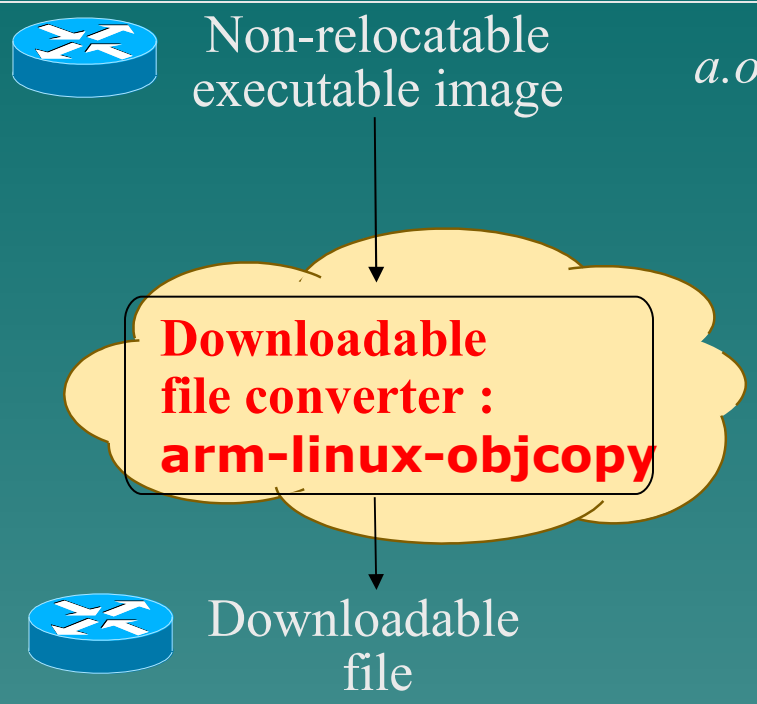
*linker*

**Machine language**

# Level of Software(2)




Text editor
C source .c
Assembly source .s
(cross) compiler arm-linux-gcc
(cross) assembler arm-linux-as
Object listing .lst
Relocatable object .o
Relocatable object .o
Linker arm-linux-ld
libraries {lib_name}.a
User libraries {lib_name}.a
Linker command file memory.x
Non-relocatable executable program a.out


Non-relocatable
executable image
a.out
Downloadable
file converter :
arm-linux-objcopy
Downloadable
file

# binutils 的常用工具

- ar
- strings
- strip
- nm
- size
- readelf
- objdump

- 建立 static library
  - Insert
  - Delete
  - List
  - Extract

- 列出 object code 中可見字元與字串

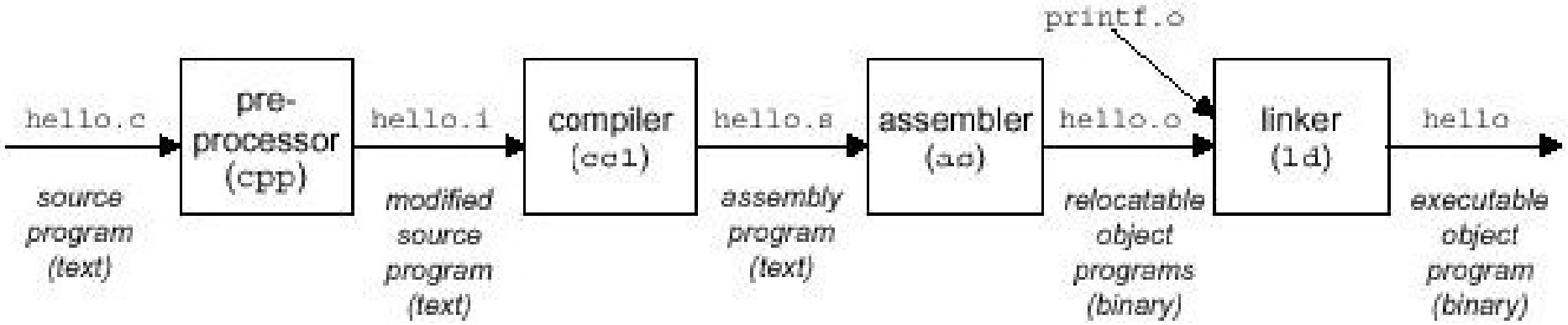
- 自 object file 中移除 symbol table information

- 列出 object file 中定義的 symbol

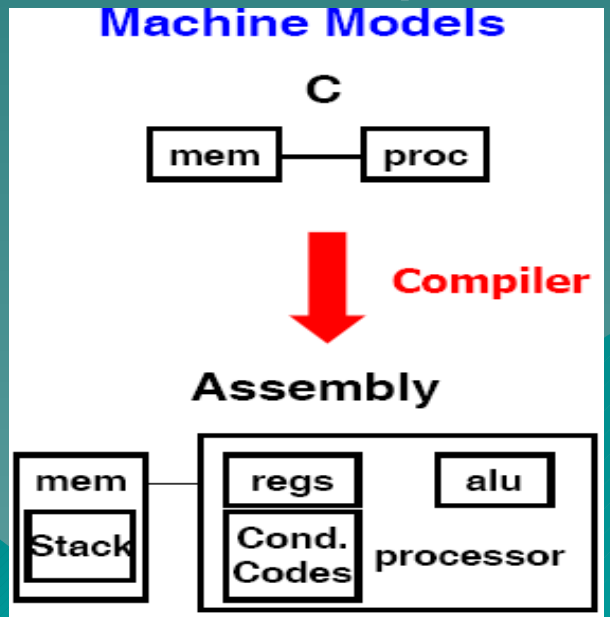
- 印列自 object file 的完整結構，包含 ELF header 中編碼的資訊

- 所有工具的源頭，可顯示 object file 中所有資訊
  - 對 **.text section** 的 dis-assembly

# “gcc -o hello hello.c”的過程




- 四大階段
  - Pre-processing
  - Compilation
  - Assembly
  - Linking
- GCC 選項（在…階段結束）
  - -E
  - -c
  - -S
  - ld



# 開始觀察 (1)

$ **gcc** -g -c hello.c

$ **file** hello

hello: **ELF 32-bit LSB executable**, **Intel 80386**, **version 1 (SYSV)**, for GNU/Linux 2.6.0, **dynamically linked** (uses shared libs), for GNU/Linux 2.6.0, **not stripped**

$ **ldd** hello

linux-gate.so.1 => (0xffffe000)

**libc.so.6** => /lib/tls/i686/cmov/libc.so.6 (0xb7e62000)

**/lib/ld-linux.so.2** (0xb7fad000)

# 開始觀察 (2)

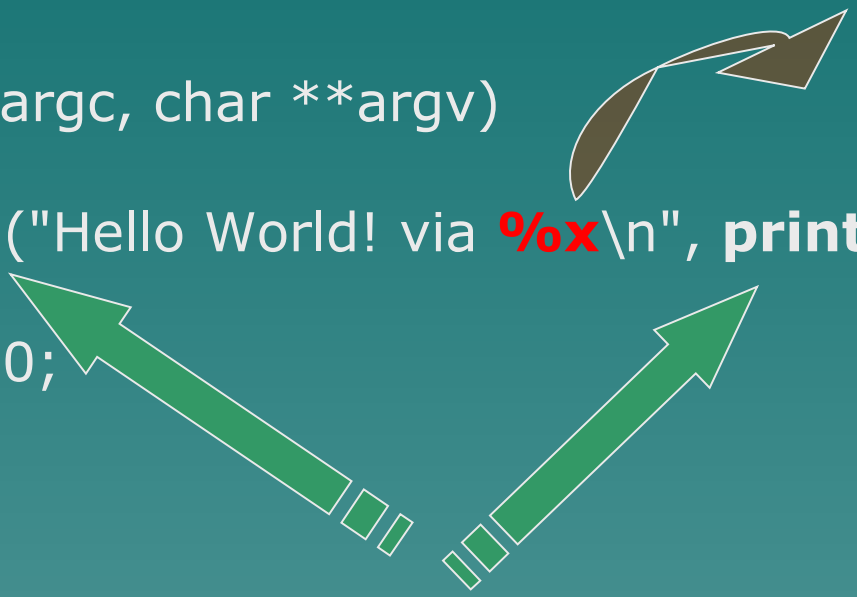
```
$ objdump -x hello
hello:     file format elf32-i386
hello
architecture: i386, flags 0x00000112:
EXEC_P, HAS_SYMS, D_PAGED
start address 0x08048870

Program Header:
    PHDR off    0x00000034 vaddr 0x08048034 paddr 0x08048034 align 2**2
         filesz 0x000000e0 memsz 0x000000e0 flags r-x
  INTERP off    0x00000114 vaddr 0x08048114 paddr 0x08048114 align 2**0
         filesz 0x00000013 memsz 0x00000013 flags r--
    LOAD off    0x00000000 vaddr 0x08048000 paddr 0x08048000 align 2**12
         filesz 0x00002120 memsz 0x00002120 flags r-x
    LOAD off    0x00002120 vaddr 0x0804b120 paddr 0x0804b120 align 2**12
         filesz 0x000001f4 memsz 0x00001280 flags rw-
 DYNAMIC off    0x0000213c vaddr 0x0804b13c paddr 0x0804b13c align 2**2
         filesz 0x000000c8 memsz 0x000000c8 flags rw-
    NOTE off    0x00000128 vaddr 0x08048128 paddr 0x08048128 align 2**2
         filesz 0x00000020 memsz 0x00000020 flags r--
...
```

# 開始觀察 (3)

```
$ objdump -d hello
hello:     file format elf32-i386

Disassembly of section .init:

08048690 <_init>:
 8048690:       55                      push   %ebp
 8048691:       89 e5                   mov    %esp,%ebp
 8048693:       83 ec 08                sub    $0x8,%esp
 8048696:       e8 f9 01 00 00          call   8048894 <call_gmon_start>
 804869b:       e8 4b 02 00 00          call   80488eb <frame_dummy>
 80486a0:       e8 1b 18 00 00          call   8049ec0 <__do_global_ctors_aux>
 80486a5:       c9                      leave
 80486a6:       c3                      ret
Disassembly of section .plt:

080486a8 <mkdir@plt-0x10>:
 80486a8:       ff 35 14 b2 04 08       pushl  0x804b214
 80486ae:       ff 25 18 b2 04 08       jmp    *0x804b218
 80486b4:       00 00                   add    %al,(%eax)
      ...
```

# 開始觀察 (4)

```
$ cat hello.c
#include <stdio.h>

int main(int argc, char **argv)
{
        printf ("Hello World! via %x\n", printf);

        return 0;
}
```



- "printf" 是 Standard C Library 的 function
- Function-symbol 在 Executable 與 Runtime 有何關聯？

# 開始觀察 (5)

- ./hello
- readelf -a hello | grep printf

```
$ make
gcc -g  -c hello.c
gcc -g  -o hello hello.o
$ ./run.sh
Launch Hello World..
Hello World! via 8048290
```

```
08049548 00000207 R_386_JUMP_SLOT   08048290   printf
    2: 08048290    57 FUNC    GLOBAL DEFAULT  UND printf@GLIBC_2.0 (2)
   73: 08048290    57 FUNC    GLOBAL DEFAULT  UND printf@@GLIBC_2.0
```

- 心中的疑惑…
  - "printf" 真如我們想像一般簡單？
  - Address 哪來的？
  - Executable 與 Memory Image 的緊密關聯
  - Object file linking 的機制

# 開始觀察 (6)

```
$ gcc -g  -S hello.c
$ cat hello.s
...
 .section        .rodata
.LC0:
        .string "Hello World! via %x\n"
        .text
.globl main
        .type   main, @function
main:
        leal    4(%esp), %ecx
        andl    $-16, %esp
        pushl   -4(%ecx)
        pushl   %ebp
        movl    %esp, %ebp
        pushl   %ecx
        subl    $20, %esp
```

```
movl    $printf, 4(%esp)
movl    $.LC0, (%esp)
call    printf
movl    $0, %eax
addl    $20, %esp
popl    %ecx
popl    %ebp
leal    -4(%ecx), %esp
ret
```

```
int main(int argc, char **argv)
{
        printf ("Hello World! via %x\n", printf);
        return 0;
}
```

# 開始觀察 (7)

$ file hello
hello: **ELF 32-bit LSB executable, Intel 80386**, version 1 (SYSV), for GNU/Linux 2.6.0, dynamically linked (uses shared libs), for GNU/Linux 2.6.0, not stripped

$ **objdump -D --disassemble-zeroes** hello
Disassembly of section .text:
…

```
08048350 <main>:
 8048350:      8d 4c 24 04                lea    0x4(%esp),%ecx
 8048354:      83 e4 f0                   and    $0xfffffff0,%esp
 8048357:      ff 71 fc                   pushl  0xfffffffc(%ecx)
 804835a:      55                         push   %ebp
 804835b:      89 e5                      mov    %esp,%ebp
 804835d:      51                         push   %ecx
 804835e:      83 ec 14                   sub    $0x14,%esp
 8048361:      c7 44 24 04 90 82 04       movl   $0x8048290,0x4(%esp)
 8048368:      08
 8048369:      c7 04 24 3c 84 04 08       movl   $0x804843c,(%esp)
 8048370:      e8 1b ff ff ff             call   8048290 <printf@plt>
 8048375:      b8 00 00 00 00             mov    $0x0,%eax
 804837a:      83 c4 14                   add    $0x14,%esp
 804837d:      59                         pop    %ecx
 804837e:      5d                         pop    %ebp
 804837f:      8d 61 fc                   lea    0xfffffffc(%ecx),%esp
 8048382:      c3                         ret
 8048383:      90                         nop
```

x86:little-endian

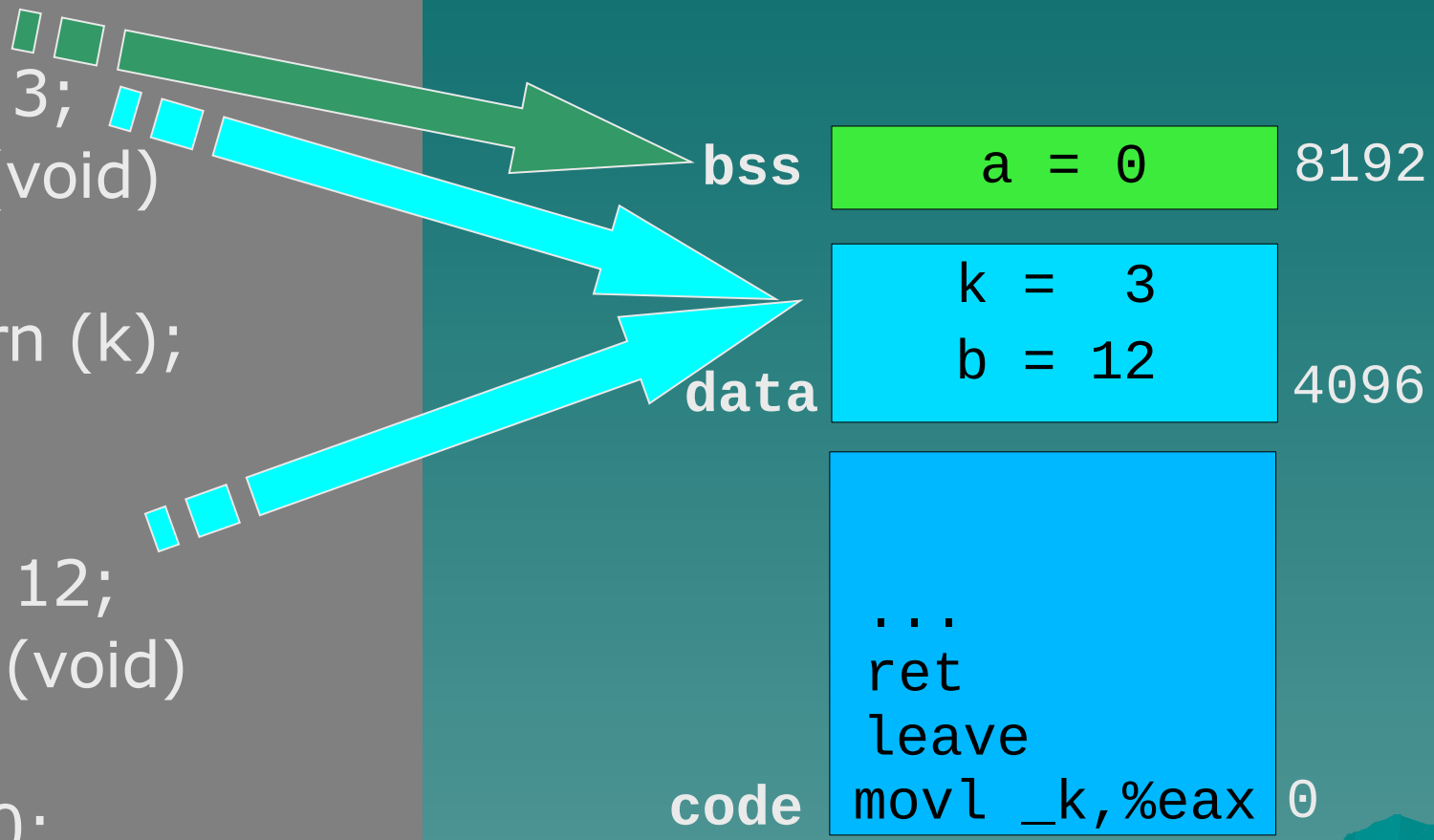
@plt ?
**PLT** (Procedure Linkage Table)

# 爲了解答上述疑惑…

# 先來奠定相關的基礎概念

# bss / data / code

```
int a;
int k = 3;
int foo(void)
{
   return (k);
}

int b = 12;
int bar (void)
{
   a = 0;
   return (a + b);
}
```



# Loader: Image File ➔ Memory Image

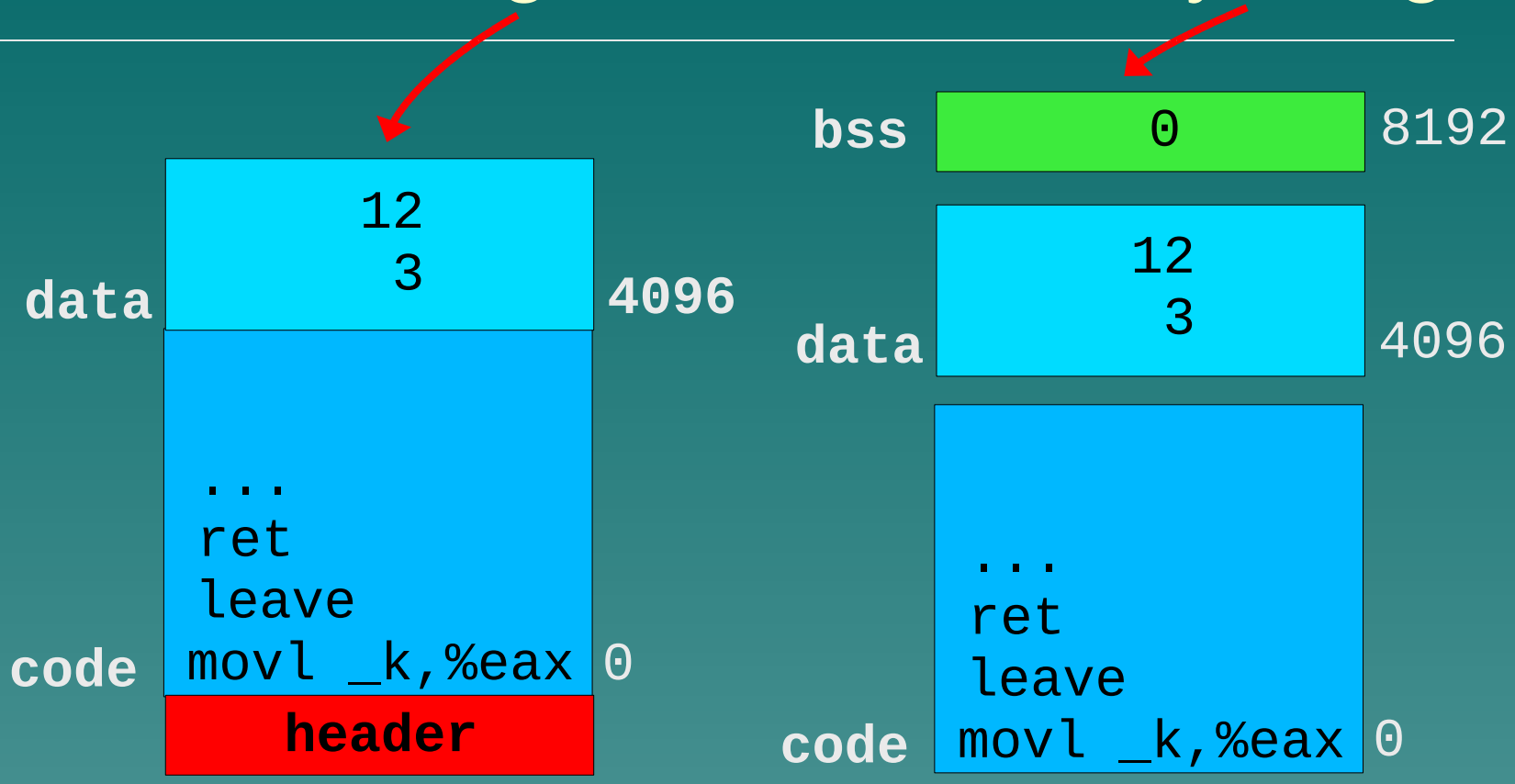



Image file 有個 header ，對 Loader 來說具有特別的意義

Memory image 多了 bss 區段

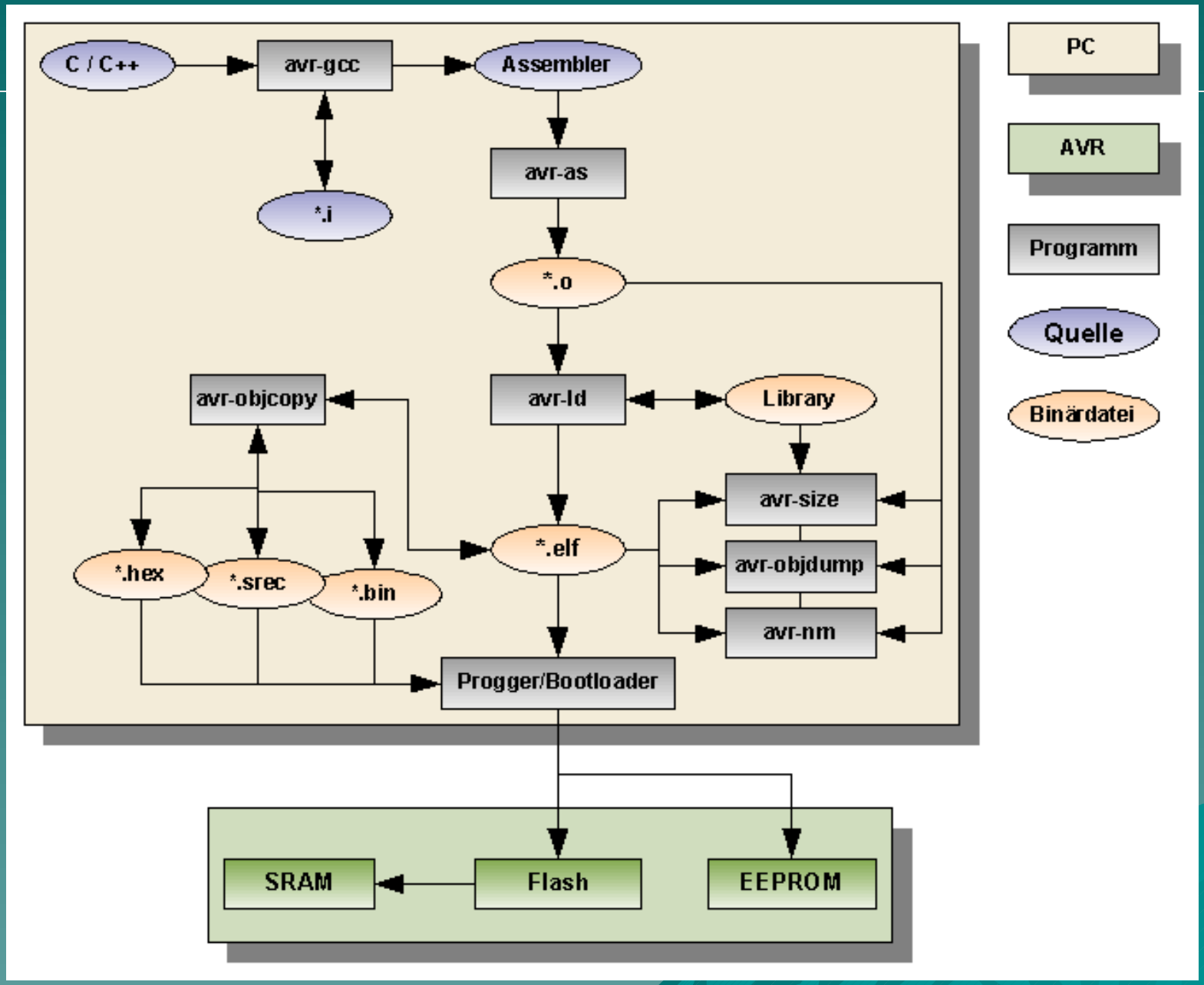
# Memory sections(1)

- 概念：Modular programming
- Module就是特定I/O介面的黑盒子，由re-locatable object code組成
- Assembler與Linker層面來說，程式由若干 **sections** (absolute or relocatable blocks of code or data) 集合而成
- 來自不同module、卻有相同名稱的sections，特稱爲”**partial sections**”
- Linker的職責就是將所有partial sections結合爲sections

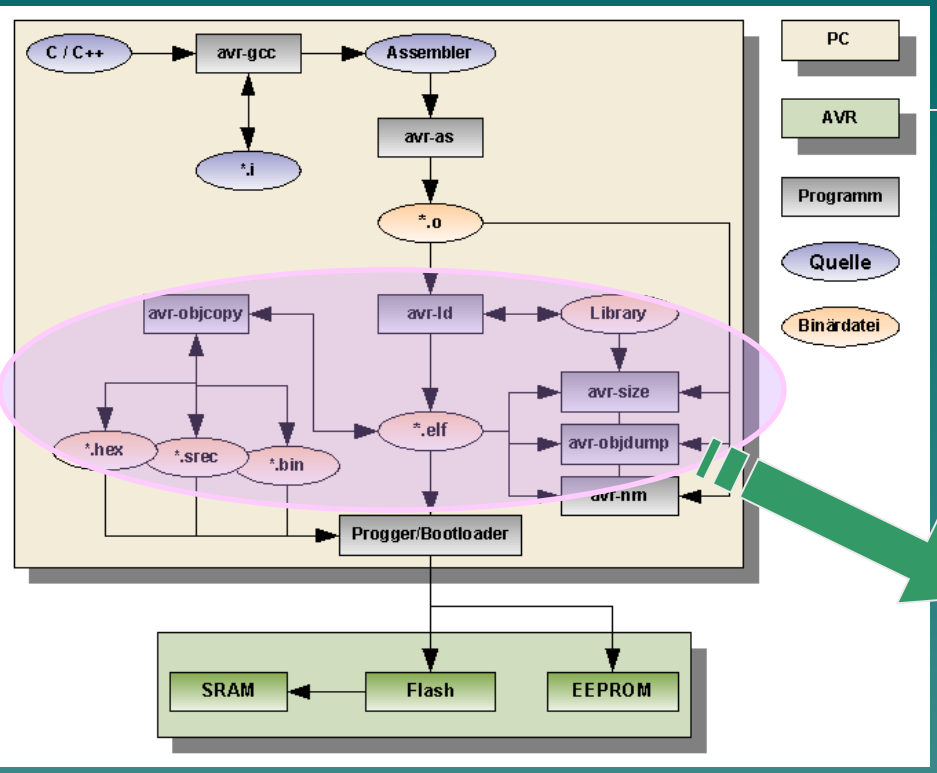
# Memory sections(2)

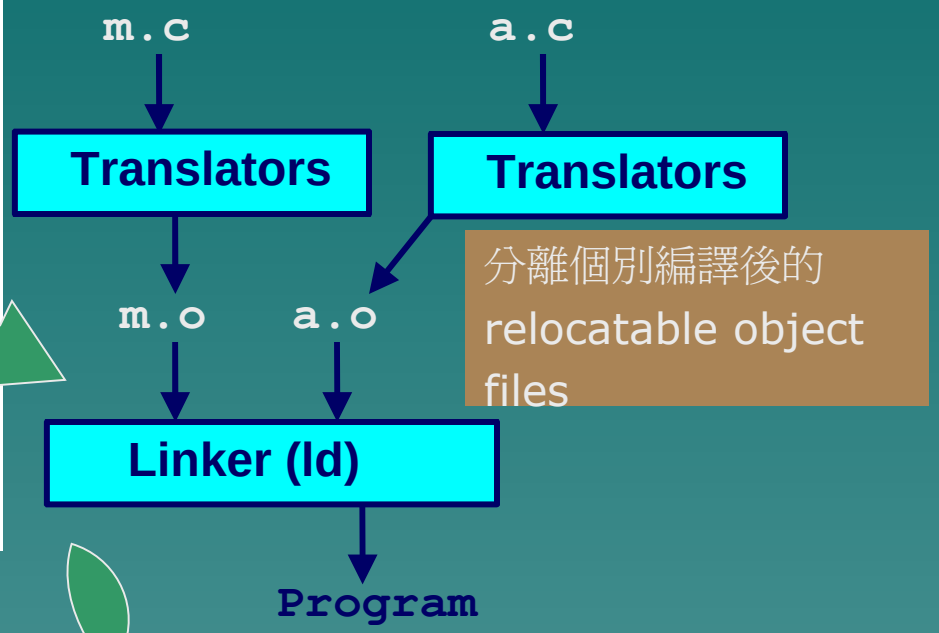
- Absolute sections
  - 需要定位於特定的memory address
  - 不可結合到其他section
- Module
  - 由一個或多個code sections所組成
- Program
  - 包含單一absolute module，並整合其他absolute/relocatable section
- Linker
  - all external references to symbols in other modules are **resolved** by the linker/locator – the end product is a single absolute object module *(the "program")*

# GNU Toolchain 運作流程



# GCC Linker - ld(1)



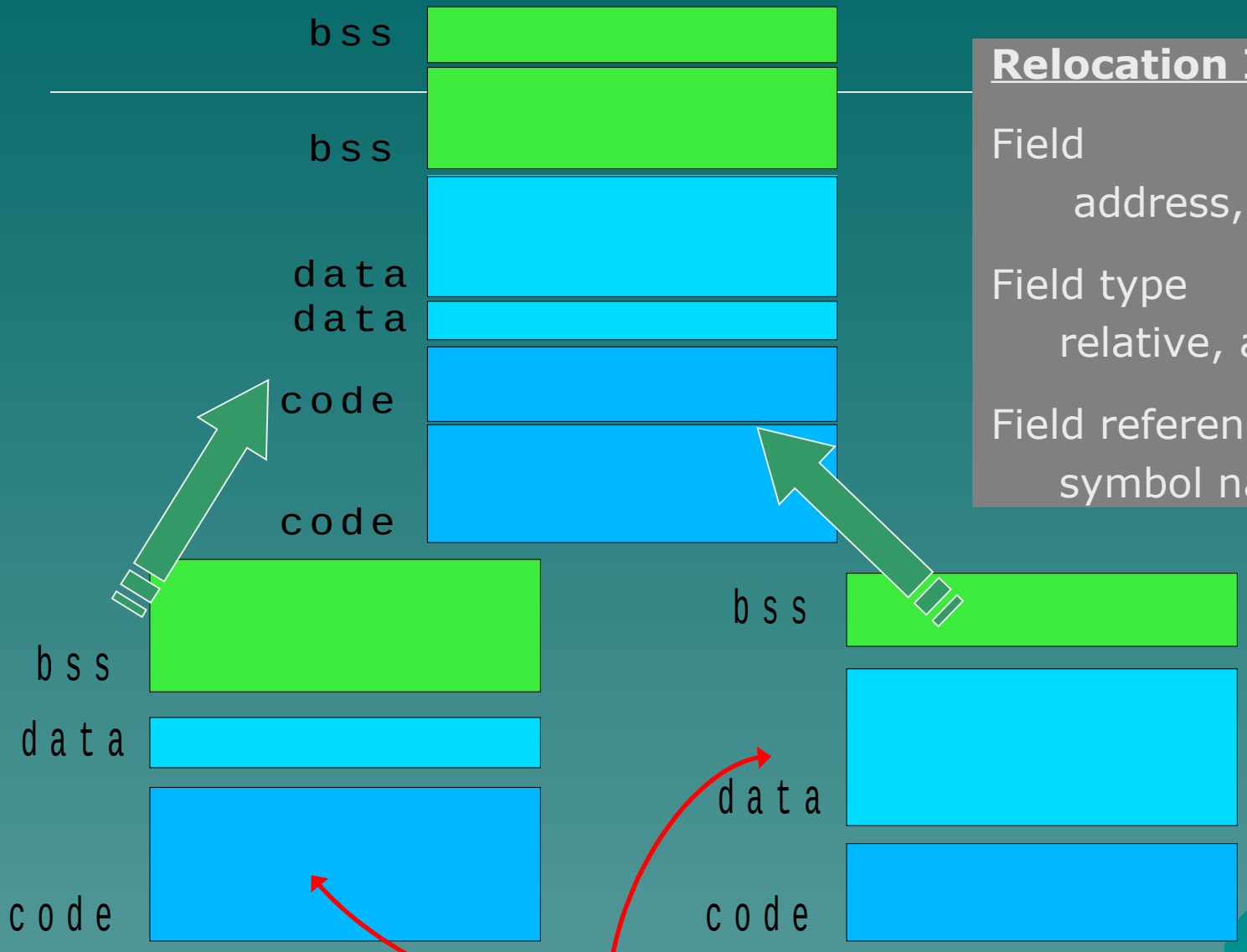




分離個別編譯後的 relocatable object files

**Executable object file**
包含所有定義於 m.c 與 a.c 的 code 與 data

- **Merge object files**
- **Resolve external reference**
- **Relocate symbols**

# GCC Linker - ld(2)



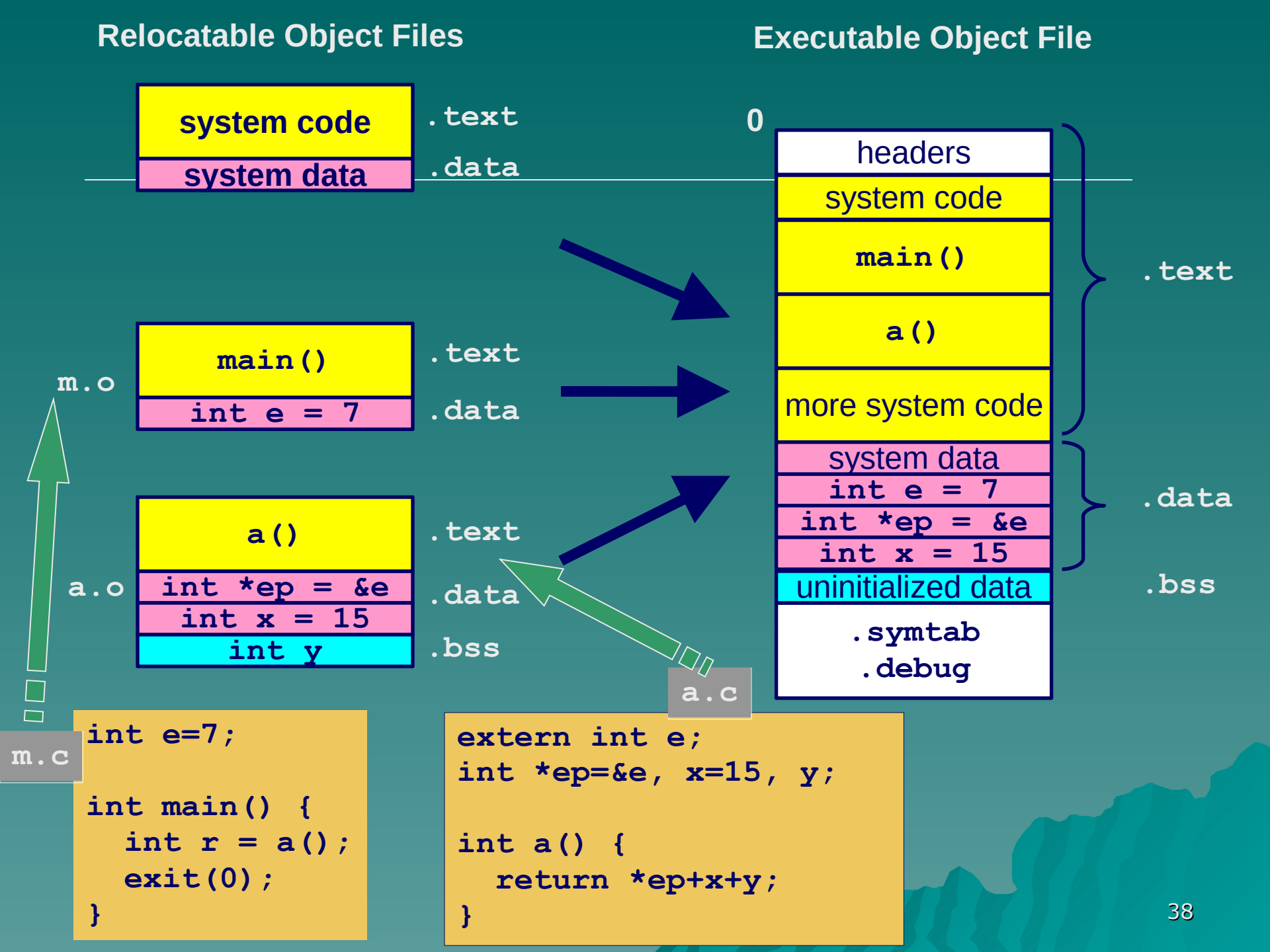

**Relocation Information**

Field
address, bit field size

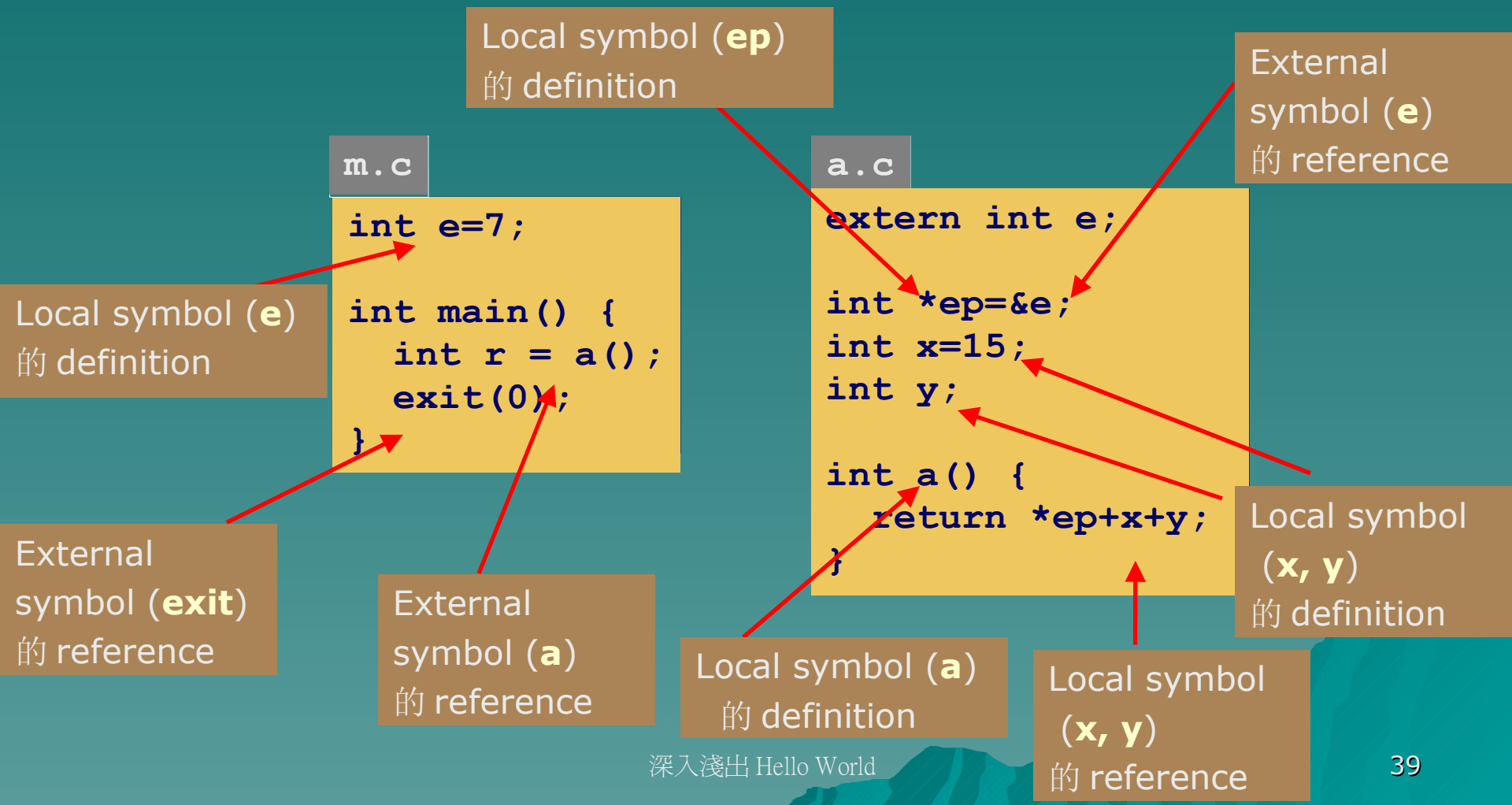
Field type
relative, absolute

Field reference
symbol name

原本每個 object file 都有相同的 address space


Relocatable Object Files
Executable Object File
system code
system data
.text
.data
0
headers
system code
main()
a()
more system code
.text
system data
int e = 7
int *ep = &e
int x = 15
.data
uninitialized data
.bss
.symtab
.debug
main()
int e = 7
m.o
a()
int *ep = &e
int x = 15
int y
a.o
m.c
a.c
int e=7;
int main() {
int r = a();
exit(0);
}
extern int e;
int *ep=&e, x=15, y;
int a() {
return *ep+x+y;
}

- 每個 symbol 都賦予一個特定值，一般來說就是 memory address
- Code ➔ symbol definitions / reference
- Reference ➔ local / external



# GCC Linker - ld(3)

m.c

```
int e=7;

int main() {
  int r = a();
  exit(0);
}
```

Relocation Info

```
Disassembly of section .text:

00000000 <main>: 00000000 <main>:
   0:   55                      pushl  %ebp
   1:   89 e5                   movl   %esp,%ebp
   3:   e8 fc ff ff ff          call   4 <main+0x4>
                                4: R_386_PC32   a
   8:   6a 00                   pushl  $0x0
   a:   e8 fc ff ff ff          call   b <main+0xb>
                                b: R_386_PC32   exit
   f:   90                      nop
```

```
Disassembly of section .data:

00000000 <e>:
   0:   07 00 00 00
```

# GCC Linker - ld(4)

a.c

```
extern int e;

int *ep=&e;
int x=15;
int y;


int a() {
  return *ep+x+y;
}
```

```
Disassembly of section .text:

00000000 <a>:
   0:   55                      pushl  %ebp
   1:   8b 15 00 00 00          movl   0x0,%edx
   6:   00
                                3: R_386_32     ep
   7:   a1 00 00 00 00          movl   0x0,%eax
                                8: R_386_32     x
   c:   89 e5                   movl   %esp,%ebp
   e:   03 02                   addl   (%edx),%eax
  10:   89 ec                   movl   %ebp,%esp
  12:   03 05 00 00 00          addl   0x0,%eax
  17:   00
                                14: R_386_32    y
  18:   5d                      popl   %ebp
  19:   c3                      ret
```

Relocation Info

```
Disassembly of section .data:

00000000 <ep>:
   0:   00 00 00 00
            0: R_386_32     e
 00000004 <x>:
   4:   0f 00 00 00
```

```
08048530 <main>:
 8048530:       55                   pushl  %ebp
 8048531:       89 e5                movl   %esp,%ebp
 8048533:       e8 08 00 00 00       call   8048540 <a>
 8048538:       6a 00                pushl  $0x0
 804853a:       e8 35 ff ff ff       call   8048474 <_init+0x94>
 804853f:       90                   nop

08048540 <a>:
 8048540:       55
 8048541:       8b 15 1c a0 04       movl   0x804a01c,%edx
 8048546:       08
 8048547:       a1 20 a0 04 08       movl   0x804a020,%eax
 804854c:       89 e5                movl   %esp,%ebp
 804854e:       03 02                addl   (%edx),%eax
 8048550:       89 ec                movl   %ebp,%esp
 8048552:       03 05 d0 a3 04       addl   0x804a3d0,%eax
 8048557:       08
                                     popl   %ebp
                                     ret
```

**Executable After Relocation and External Reference Resolution**

```
int e=7;

int main()
{
  int r = a();
  exit(0);
}
```

```
Disassembly of section .data:

0804a018 <e>:
 804a018:       07 00 00 00


0804a01c <ep>:
 804a01c:       18 a0 04 08


0804a020 <x>:
 804a020:       0f 00 00 00
```

```
extern int e;

int *ep=&e;
int x=15;
int y;

int a() {
  return *ep+x+y;
}
```

# GCC Linker - ld(5)

- Linker script
  - 描述哪些sections會出現於最終程式中
  - Compiler/Linker會有預設的linker script，讓一般的應用程式能正常完成build process
- GCC移植於多種硬體平台，並沒有定義memory model，相反地，將這些工作交付給Linker script

```
$ dpkg -L binutils | grep ldscripts
/usr/lib/ldscripts
/usr/lib/ldscripts/elf_i386.x
/usr/lib/ldscripts/elf_i386.xbn
/usr/lib/ldscripts/elf_i386.xc
/usr/lib/ldscripts/elf_i386.xd
...
```

```
$ ld –verbose
GNU ld version 2.17 Debian GNU/Linux
  Supported emulations:
   elf_i386
   i386linux
   elf_x86_64
using internal linker script:
/* Script for -z combreloc: combine and sort reloc
      sections */
OUTPUT_FORMAT("elf32-i386", "elf32-i386",
              "elf32-i386")
OUTPUT_ARCH(i386)
ENTRY(_start)
```

# GCC Linker - ld(6)

- 重要的幾個sections：

| | |
|---|---|
| **.text** | code and constants |
| **.data** | |
| **.bss** | initialized/un-initialized data |

- 其他：

| | |
|---|---|
| **.init / .fini** | to/exit entry |
| **.ctor / .dtor** | C/C++ constructor/destructor |
| **.rodata** | ROM variables |
| **.common** | shared overlayed data sections |
| **.eeprom** | EEPROMable sections |
| **.install** | startup code |
| **.vector** | interrupt vector table |
| **.debug** | debugging information |
| **.comment** | documenting comments |

# GCC Linker - ld(7)

- *gcc linker script* (簡化自 /usr/lib/ldscripts/elf_i386_x)

```
/* Default linker script, for normal executables */
OUTPUT_FORMAT("elf32-i386","elf32-i386","elf32-i386")
OUTPUT_ARCH(i386)
…
SECTIONS
{
…
 .text         :
  {
    *(.text .stub .text.* .gnu.linkonce.t.*)
    KEEP (*(.text.*personality*))
}
```

```
.data         :
  {
    *(.data .data.* .gnu.linkonce.d.*)
    KEEP (*(.gnu.linkonce.d.*personality*))
    SORT(CONSTRUCTORS)
  }

 .bss          :
  {
    *(.dynbss)
    *(.bss .bss.* .gnu.linkonce.b.*)
    *(COMMON)
}
…
}
```

**.text**
code and constants

**.data**
Initialized variables

**.bss**
Un-initialized variables

**Stored in memory block data**

# GCC Linker - ld(8)

- $ objdump /usr/lib/libc.a -xd > libc.txt

**(x) = --all-headers**
顯示所有 **header** 資訊，包含 **symbol table** 與 **relocation entries**

```
printf.o:     file format elf32-i386
rw-r--r-- 0/0    868 Jun 24 03:09 2006 printf.o
architecture: i386, flags 0x00000011:
HAS_RELOC, HAS_SYMS
start address 0x00000000

Sections:
Idx Name      Size      VMA       LMA       File off  Algn
  0 .text     00000026  00000000  00000000  00000034  2**2
              CONTENTS, ALLOC, LOAD, RELOC, READONLY, CODE
  1 .data     00000000  00000000  00000000  0000005c  2**2
              CONTENTS, ALLOC, LOAD, DATA
  2 .bss      00000000  00000000  00000000  0000005c  2**2
              ALLOC
  3 .comment  00000040  00000000  00000000
              CONTENTS, READONLY
...
```

```
SYMBOL TABLE:
00000000 l    d  .text  00000000 .text
00000000 l    d  .data  00000000 .data
00000000 l    d  .bss   00000000 .bss
00000000 l    d  .comment       00000000 .comment
00000000 l    d  .note.GNU-stack        00000000
.note.GNU-stack
00000000 g     F .text  00000026 __printf
00000000         *UND*  00000000 stdout
00000000         *UND*  00000000 vfprintf
00000000 g     F .text  00000026 printf
00000000 g     F .text  00000026 _IO_printf
```

.text → 0x26 = 38 bytes

# GCC Linker - ld(9)

- $ objdump /usr/lib/libc.a -xd > libc.txt

```
SYMBOL TABLE:
00000000 l    d  .text      00000000 .text
00000000 l    d  .data      00000000 .data
00000000 l    d  .bss       00000000 .bss
00000000 l    d  .comment       00000000 .comment
00000000 l    d  .note.GNU-stack        00000000 .note.GNU-stack
00000000 g     F .text      00000026 __printf
00000000         *UND*      00000000 stdout
00000000         *UND*      00000000 vfprintf
00000000 g     F .text      00000026 printf
00000000 g     F .text      00000026 _IO_printf
```

vfprintf → vfprintf.o

Symbol table 顯示： printf 依賴更大的 module – vfprintf

# GCC Linker - ld(10)

```
Disassembly of section .text:

00000000 <_IO_printf>:
   0:   55                      push   %ebp
   1:   89 e5                   mov    %esp,%ebp
   3:   83 ec 10                sub    $0x10,%esp
   6:   8d 45 0c                lea    0xc(%ebp),%eax
   9:   89 45 fc                mov    %eax,0xfffffffc(%ebp)
   c:   89 44 24 08             mov    %eax,0x8(%esp)
  10:   8b 45 08                mov    0x8(%ebp),%eax
  13:   89 44 24 04             mov    %eax,0x4(%esp)
  17:   a1 00 00 00 00          mov    0x0,%eax
                        18: R_386_32    stdout
  1c:   89 04 24                mov    %eax,(%esp)
  1f:   e8 fc ff ff ff          call   20 <_IO_printf+0x20>
                        20: R_386_PC32 vfprintf
  24:   c9                      leave
  25:   c3                      ret
```

注意 i386 的 call 指令

事實上， vfprintf 才是 printf 的實做部份

在 GNU C Library 中，" vf" 開頭的 symbol 即這一類的表現形式

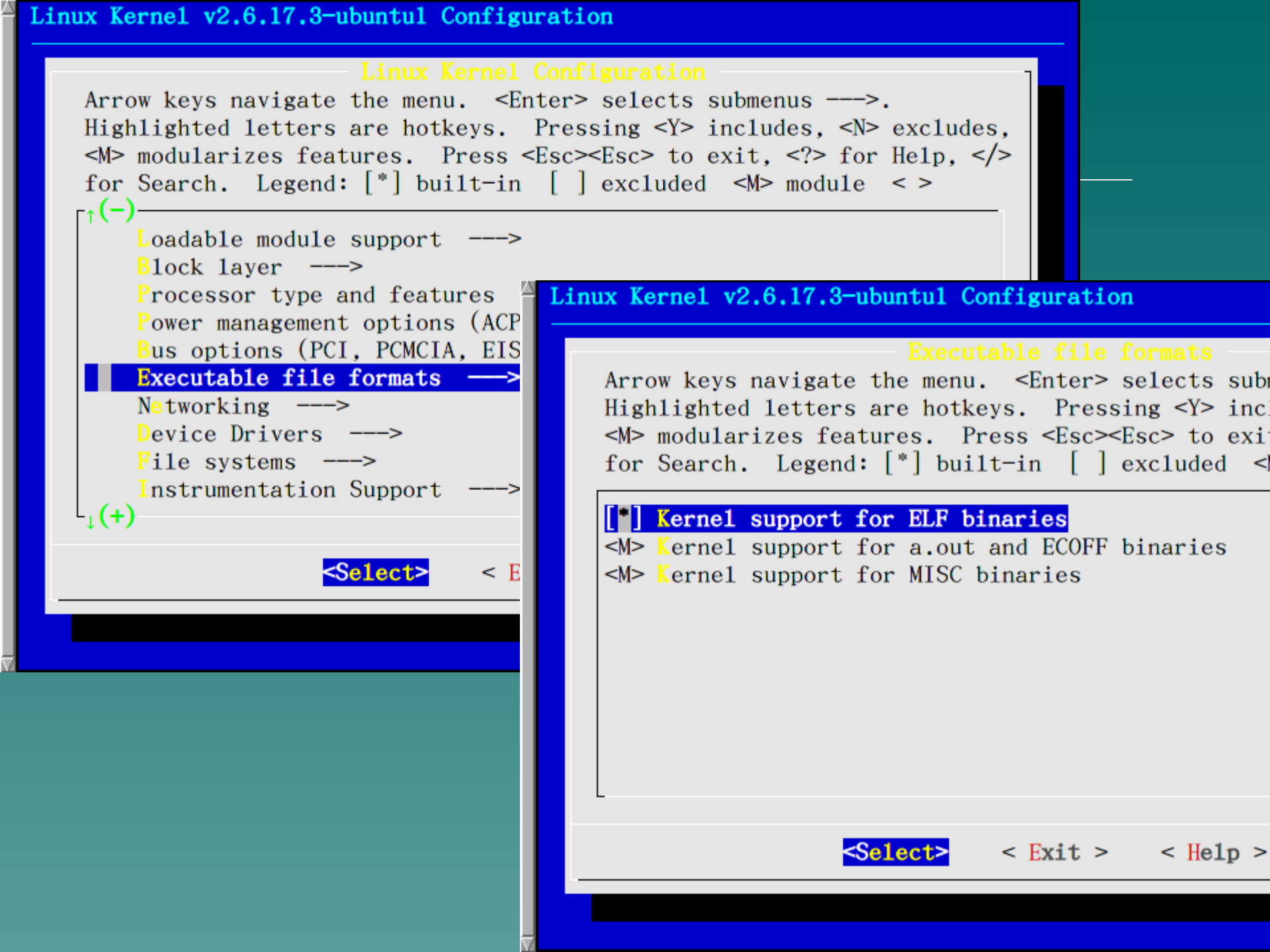
# 好朋友： ELF & DWARF

- elf
  - 小精靈、小妖精
  - 小淘氣

- dwarf
  - 矮子、侏儒
  - 矮小的動植物
  - （神話中）有魔法的小矮人

# Executable File vs. Image File

- Linked program ➔ 多個 "sections”
- Linker彙整object modules爲特定的Executable File Format
  - a.out (Assembly OUTput)
    - Unix format
  - Mach-O (Mach Object)
    - 爲Mac OS X所採用
  - ELF (Executable and Linkable Format)
    - 包含 "DWARF”


Linux Kernel v2.6.17.3-ubuntu1 Configuration
Linux Kernel Configuration
Arrow keys navigate the menu. <Enter> selects submenus --->.
Highlighted letters are hotkeys. Pressing <Y> includes, <N> excludes,
<M> modularizes features. Press <Esc><Esc> to exit, <?> for Help, </>
for Search. Legend: [*] built-in [ ] excluded <M> module < >
(-)
Loadable module support --->
Block layer --->
Processor type and features
Power management options (ACP
Bus options (PCI, PCMCIA, EIS
Executable file formats --->
Networking --->
Device Drivers --->
File systems --->
Instrumentation Support --->
(+)
<Select>
Linux Kernel v2.6.17.3-ubuntu1 Configuration
Executable file formats
Arrow keys navigate the menu. <Enter> selects sub
Highlighted letters are hotkeys. Pressing <Y> inc
<M> modularizes features. Press <Esc><Esc> to exi
for Search. Legend: [*] built-in [ ] excluded
[*] Kernel support for ELF binaries
<M> Kernel support for a.out and ECOFF binaries
<M> Kernel support for MISC binaries
<Select>
< Exit >
< Help >

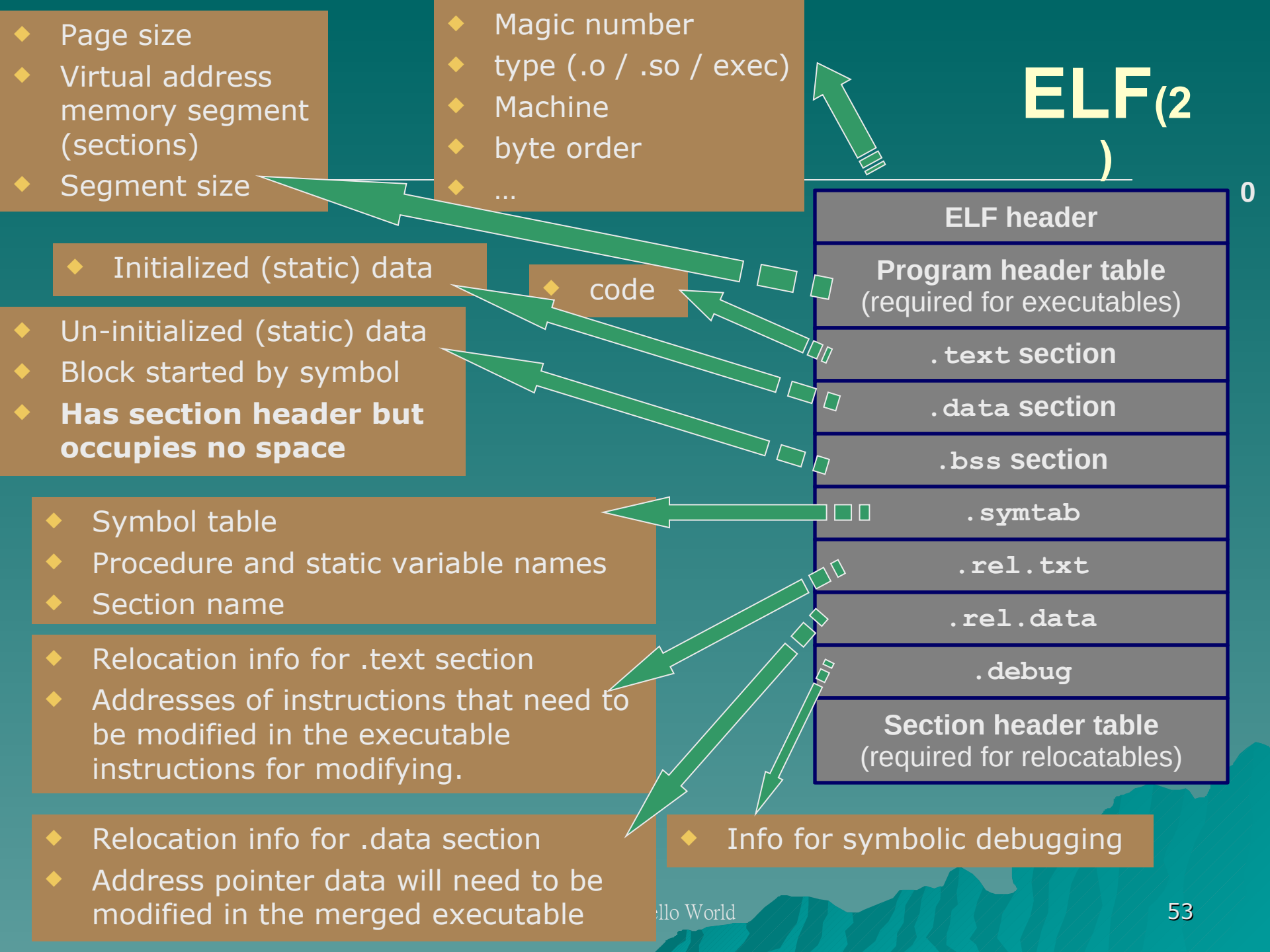
# ELF(1)

- ELF (Executable and Linkable Format)
  - 最初由UNIX System Laboratories發展，爲AT&T System V Unix所使用，稍後成爲BSD家族與GNU/Linux上object file的標準二進位格式
- COFF (Common Object File Format)
  - System V Release 3使用的二進位格式
- DWARF-1/2 (Debug Information Format)
  - 通常搭配ELF或COFF等格式

- 只要符合 DWARF 規範的 object file ，即可使用 **GNU gdb** 一類 source-level debugger
- 同時， **Machine-Independent**

```
BFD header file version 2.17

elf32-i386      (header little endian, data little endian)
coff-i386       (header little endian, data little endian)
elf32-little    (header little endian, data little endian)
elf32-big       (header big endian, data big endian)
symbolsrec      (header endianness unknown, data endianness unknown)
tekhex          (header endianness unknown, data endianness unknown)
binary          (header endianness unknown, data endianness unknown)
thex            (header endianness unknown, data endianness unknown)
```

# ELF(2)


Page size
Virtual address memory segment (sections)
Segment size
Magic number
type (.o / .so / exec)
Machine
byte order
…
0
ELF header
Program header table
(required for executables)
.text section
.data section
.bss section
.symtab
.rel.txt
.rel.data
.debug
Section header table
(required for relocatables)
Initialized (static) data
code
Un-initialized (static) data
Block started by symbol
Has section header but occupies no space
Symbol table
Procedure and static variable names
Section name
Relocation info for .text section
Addresses of instructions that need to be modified in the executable instructions for modifying.
Relocation info for .data section
Address pointer data will need to be modified in the merged executable
Info for symbolic debugging

# ELF(3)

- Page size
- Virtual address memory segment (sections)
- Segment size

- Magic number
- type (.o / .so / exec)
- Machine
- byte order
- …

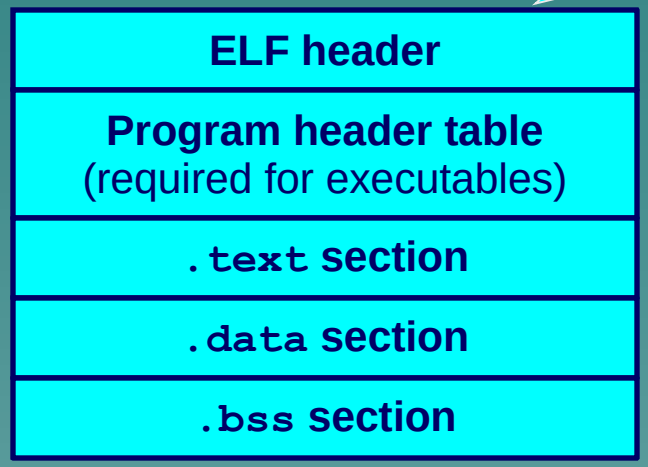
- Initialized (static) data

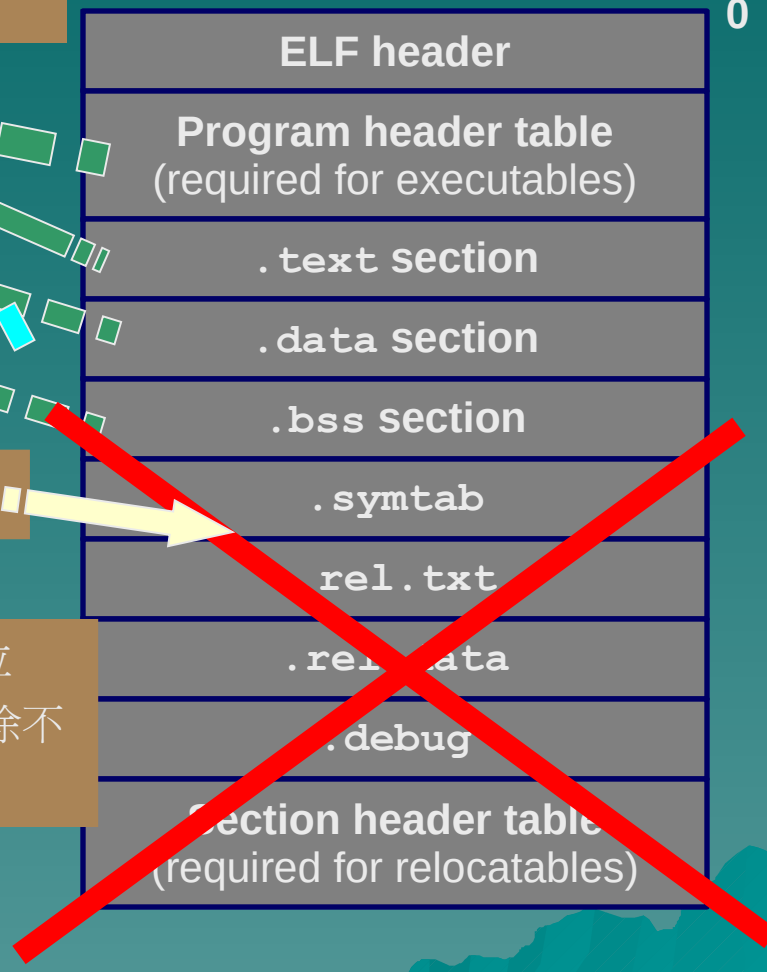
- code

- Un-initialized (static) data
- Block started by symbol
- **Has section header but occupies no space**

注意： .dynsym 還保留

Runtime 只需要左邊欄位
可透過 “**strip**” 指令去除不需要的 section



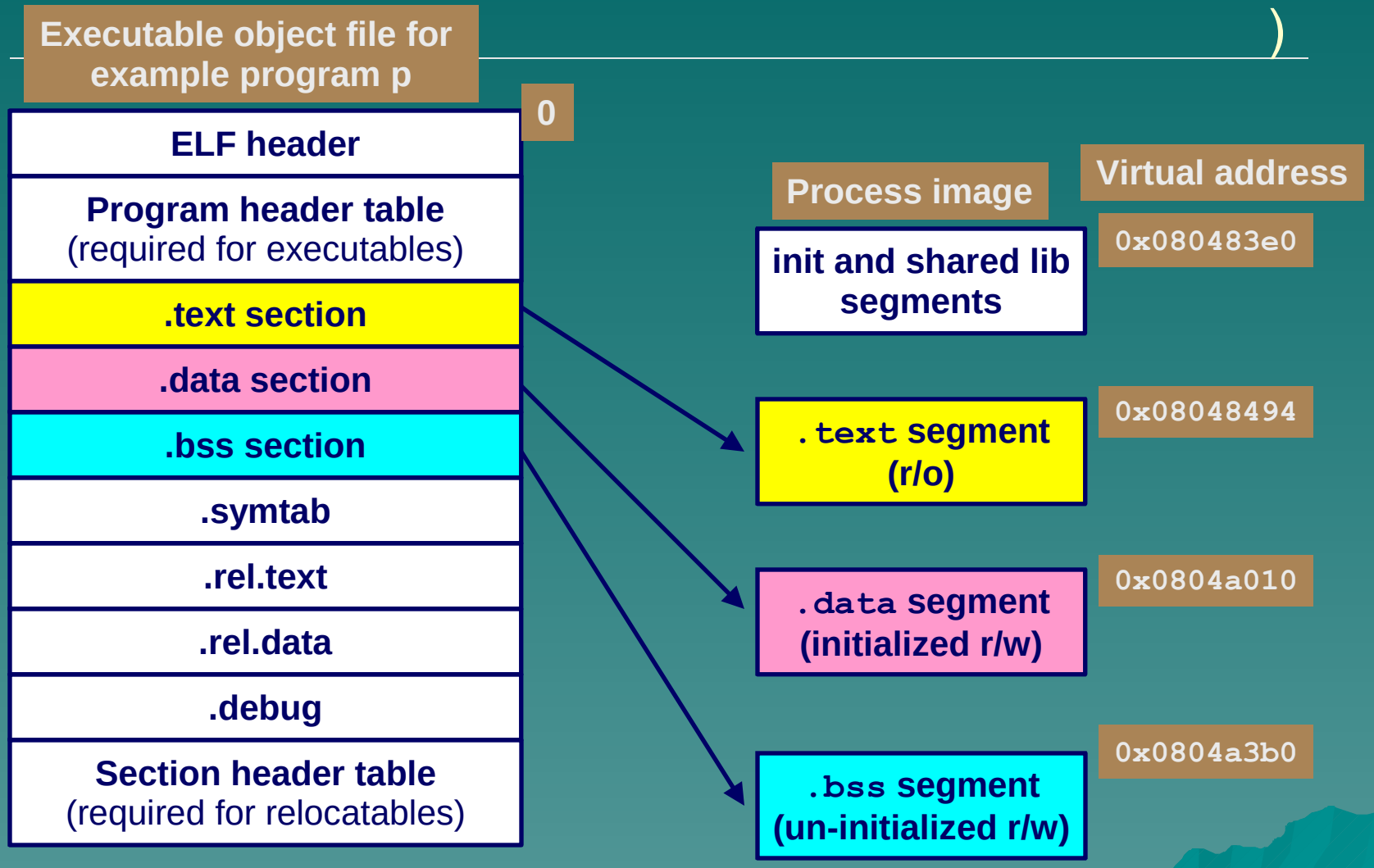
```
$ readelf -s hello

Symbol table '.dynsym' contains 5 entries:
   Num:    Value  Size Type    Bind   Vis      Ndx Name
     0: 00000000     0 NOTYPE  LOCAL  DEFAULT  UND
     1: 00000000   399 FUNC    GLOBAL DEFAULT  UND puts@GLIBC_2.0 (2)
     2: 00000000   415 FUNC    GLOBAL DEFAULT  UND
__libc_start_main@GLIBC_2.0 (2)
     3: 08048438     4 OBJECT  GLOBAL DEFAULT   14 _IO_stdin_used
     4: 00000000     0 NOTYPE  WEAK   DEFAULT  UND __gmon_start__

Symbol table '.symtab' contains 81 entries:
```

- -s|--syms|--symbols
  - Displays the entries in symbol table section of the file, if it has one.

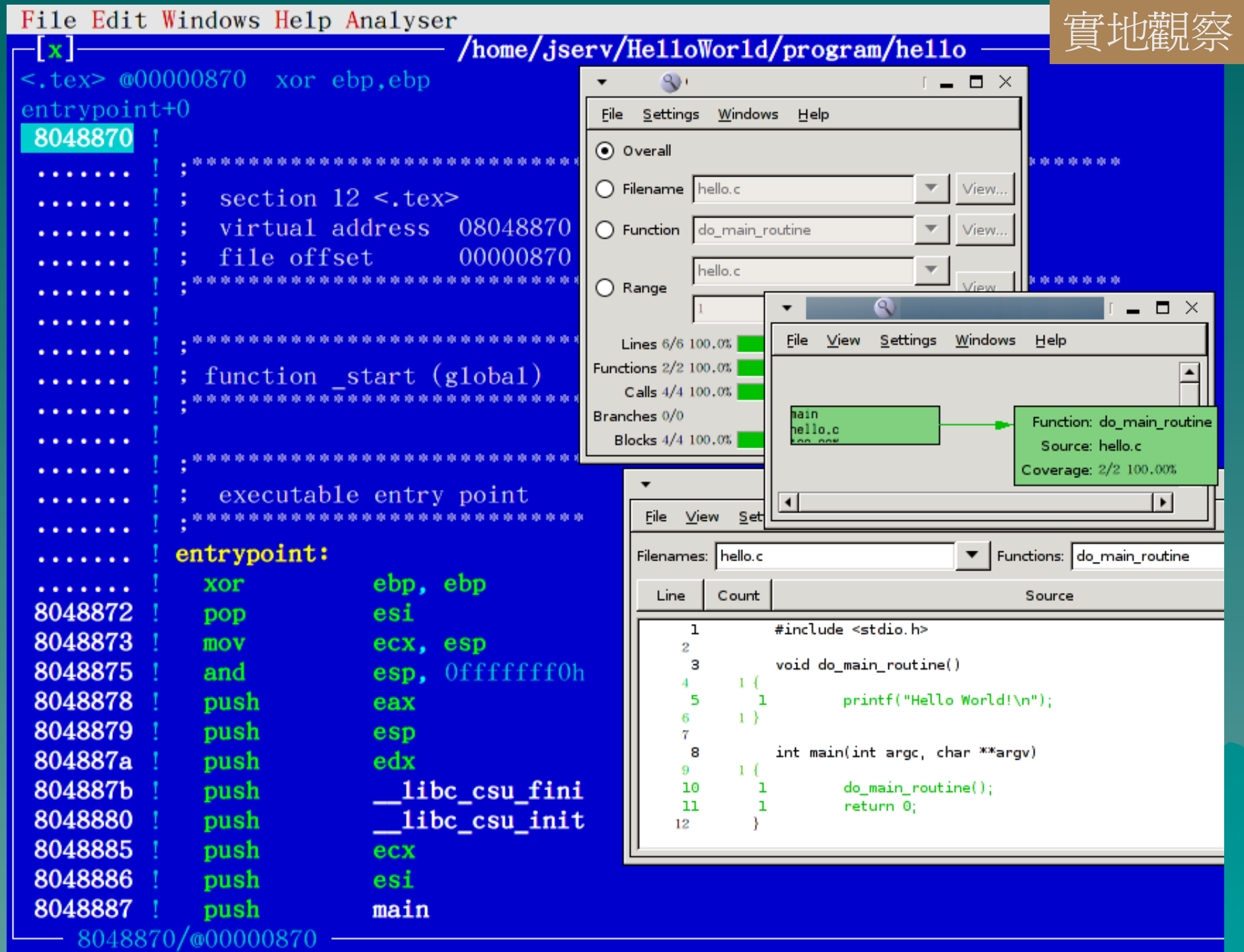
```
$ cp -f hello hello.strip
$ strip –s hello.strip
```

```
$ readelf -s hello.strip

Symbol table '.dynsym' contains 5 entries:
   Num:    Value  Size Type    Bind   Vis      Ndx Name
     0: 00000000     0 NOTYPE  LOCAL  DEFAULT  UND
     1: 00000000   399 FUNC    GLOBAL DEFAULT  UND puts@GLIBC_2.0
(2)
     2: 00000000   415 FUNC    GLOBAL DEFAULT  UND
__libc_start_main@GLIBC_2.0 (2)
     3: 08048438     4 OBJECT  GLOBAL DEFAULT   14 _IO_stdin_used
     4: 00000000     0 NOTYPE  WEAK   DEFAULT  UND __gmon_start__
```

# ELF(4)

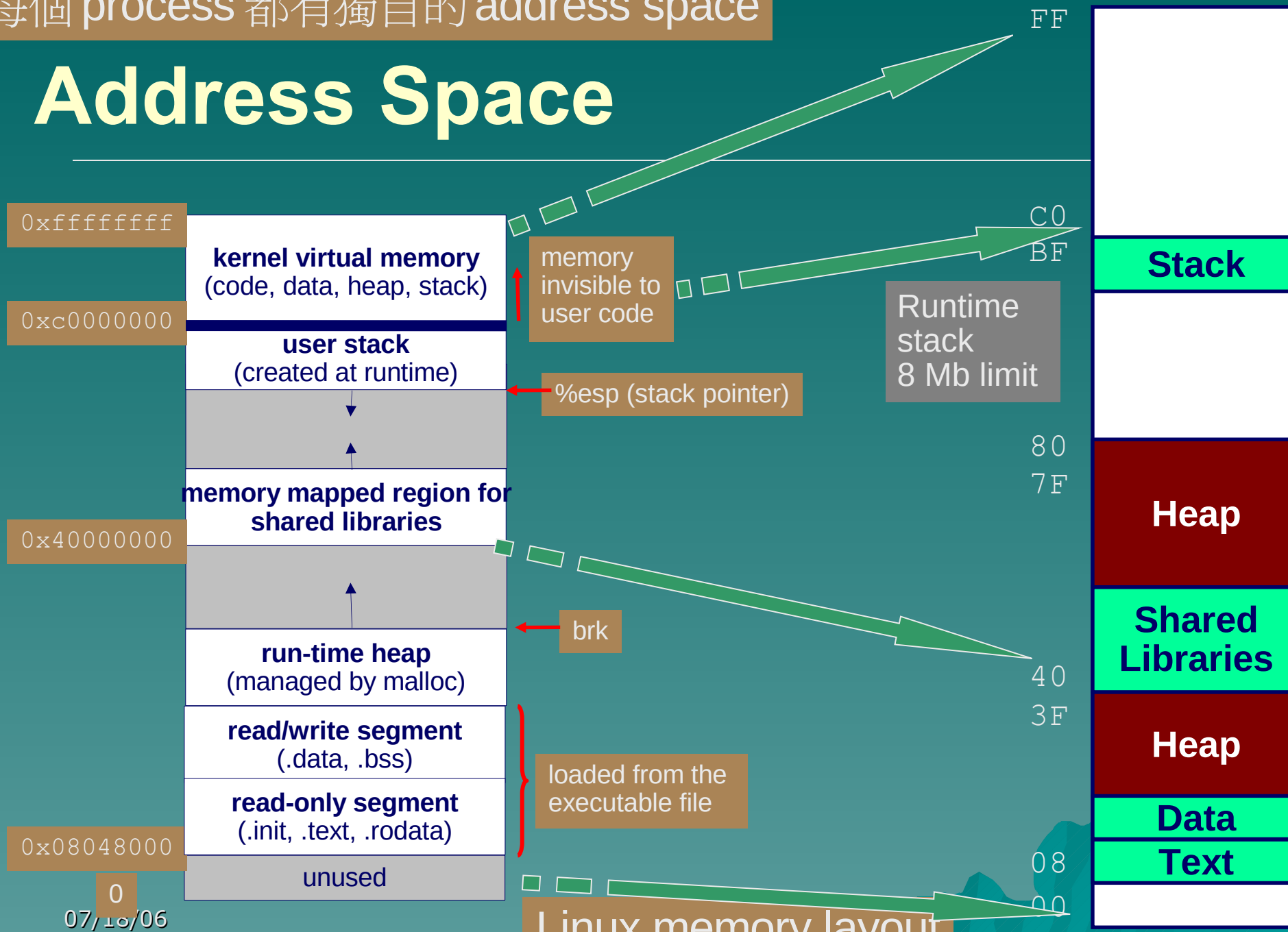



## Loading ELF Binaries…

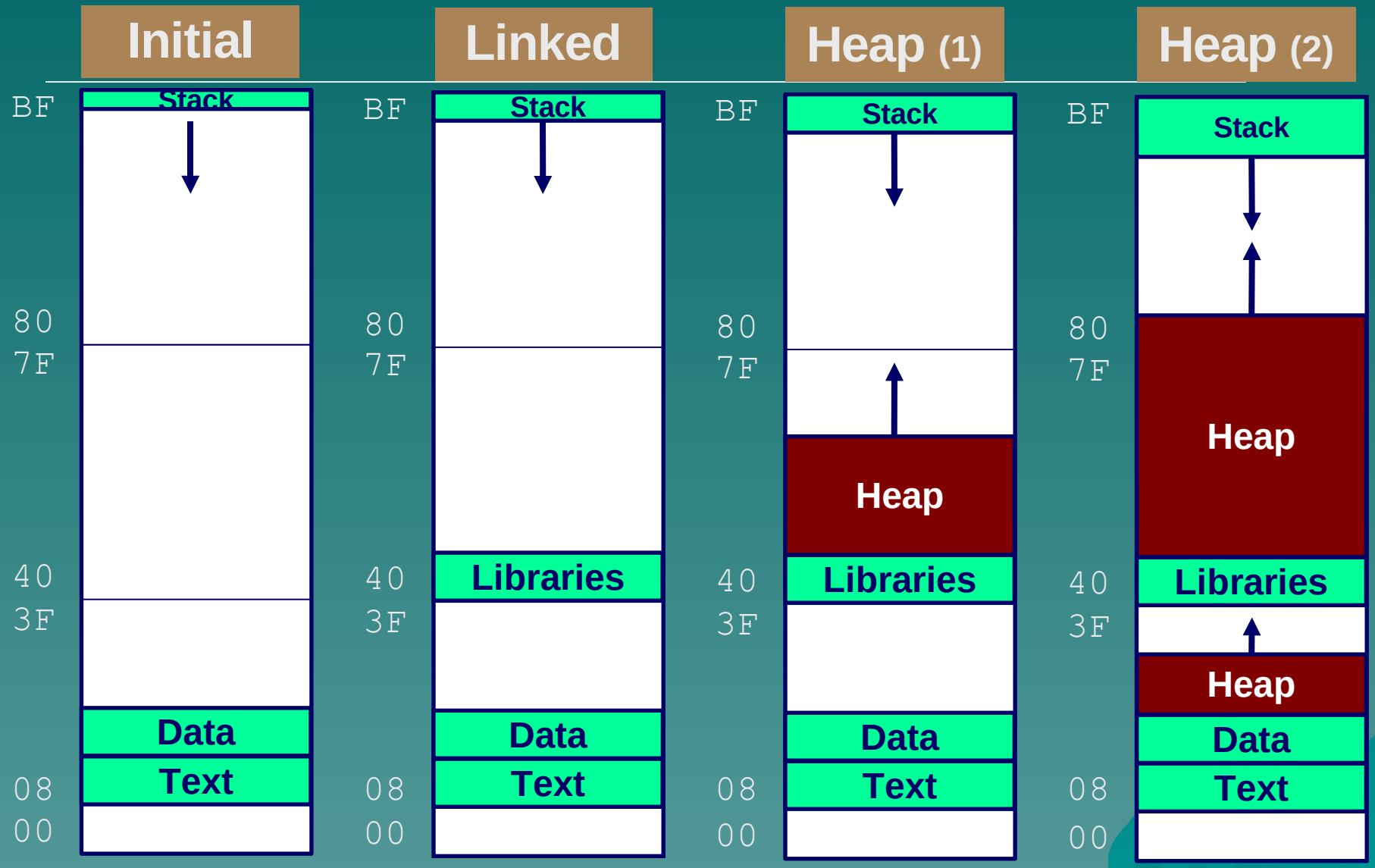

File Edit Windows Help Analyser
實地觀察
[x]
/home/jserv/HelloWorld/program/hello
<.tex> @00000870 xor ebp,ebp
entrypoint+0
8048870 !
; section 12 <.tex>
; virtual address 08048870
; file offset 00000870
; function _start (global)
; executable entry point
entrypoint:
xor ebp, ebp
8048872 ! pop esi
8048873 ! mov ecx, esp
8048875 ! and esp, 0fffffff0h
8048878 ! push eax
8048879 ! push esp
804887a ! push edx
804887b ! push __libc_csu_fini
8048880 ! push __libc_csu_init
8048885 ! push ecx
8048886 ! push esi
8048887 ! push main
8048870/@00000870
File Settings Windows Help
Overall
Filename hello.c View...
Function do_main_routine View...
Range hello.c
Lines 6/6 100.0%
Functions 2/2 100.0%
Calls 4/4 100.0%
Branches 0/0
Blocks 4/4 100.0%
File View Settings Windows Help
Function: do_main_routine
Source: hello.c
Coverage: 2/2 100.00%
File View
Filenames: hello.c
Functions: do_main_routine
Line Count Source
#include <stdio.h>
void do_main_routine()
{
printf("Hello World!\n");
}
int main(int argc, char **argv)
{
do_main_routine();
return 0;
}

每個 process 都有獨自的 address space

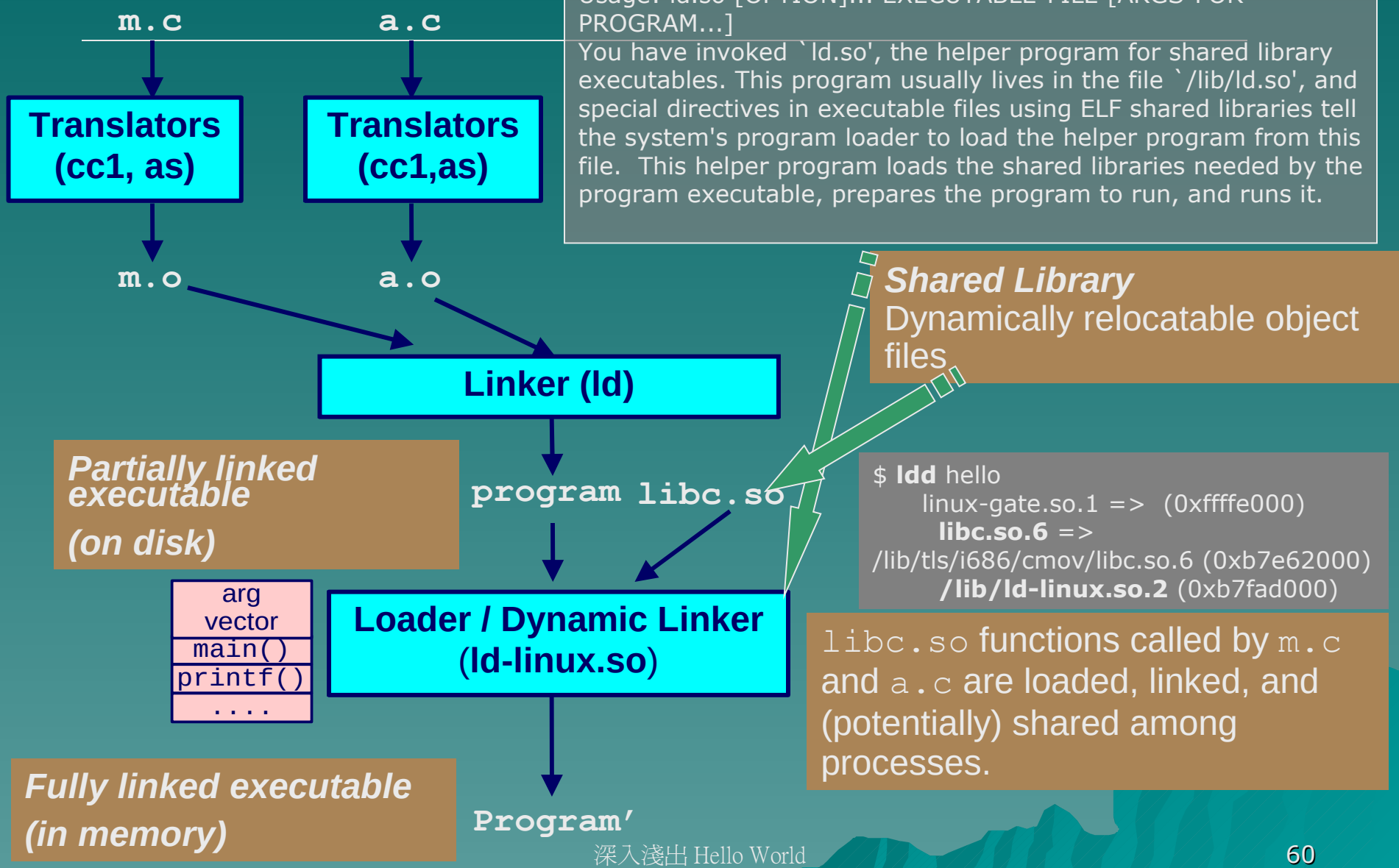
# Address Space



# Linux Memory Allocation



# Dynamically Linked Shared Libraries(1)




**$ /lib/ld-linux.so.2**

Usage: ld.so [OPTION]... EXECUTABLE-FILE [ARGS-FOR-PROGRAM...]

You have invoked `ld.so', the helper program for shared library executables. This program usually lives in the file `/lib/ld.so', and special directives in executable files using ELF shared libraries tell the system's program loader to load the helper program from this file. This helper program loads the shared libraries needed by the program executable, prepares the program to run, and runs it.

***Shared Library***

Dynamically relocatable object files

$ **ldd** hello

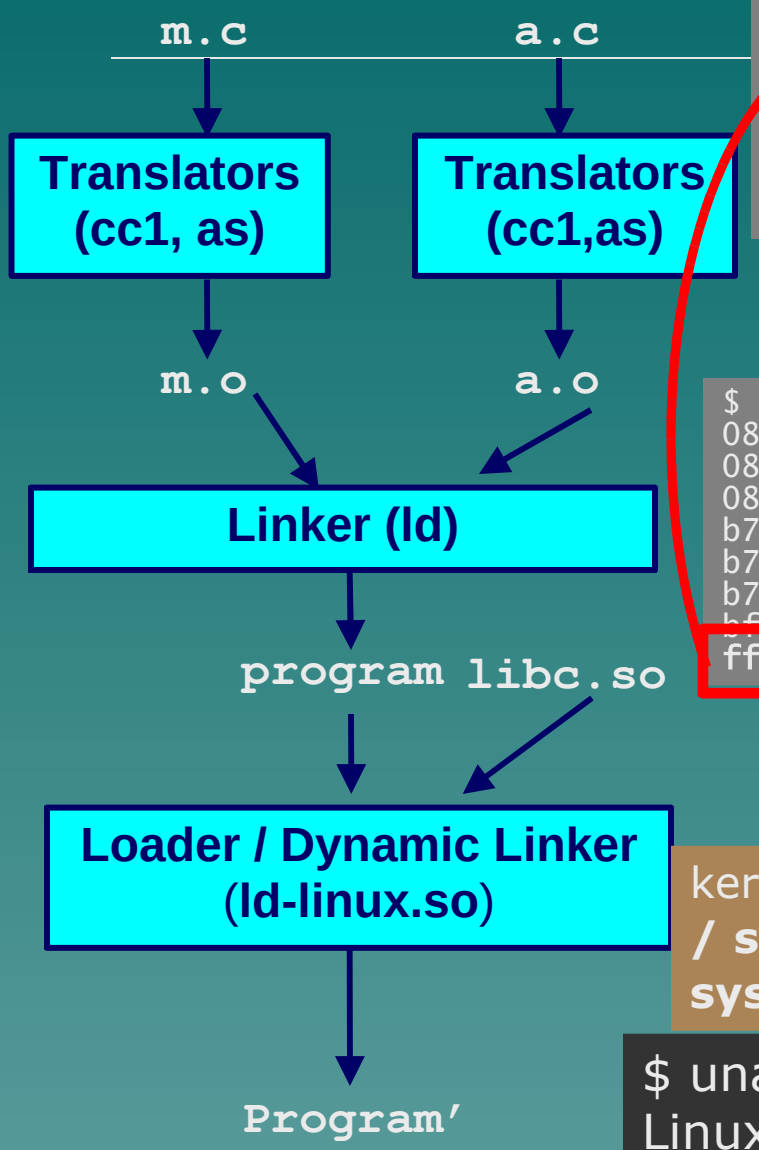
linux-gate.so.1 => (0xffffe000)

**libc.so.6** => /lib/tls/i686/cmov/libc.so.6 (0xb7e62000)

**/lib/ld-linux.so.2** (0xb7fad000)

`libc.so` functions called by `m.c` and `a.c` are loaded, linked, and (potentially) shared among processes.

# Dynamically Linked Shared Libraries(2)




```
$ ldd hello
        linux-gate.so.1 =>  (0xffffe000)
        libc.so.6 =>
/lib/tls/i686/cmov/libc.so.6 (0xb7e62000)
        /lib/ld-linux.so.2 (0xb7fad000)
```

***/proc/self/maps***
***Memory map***

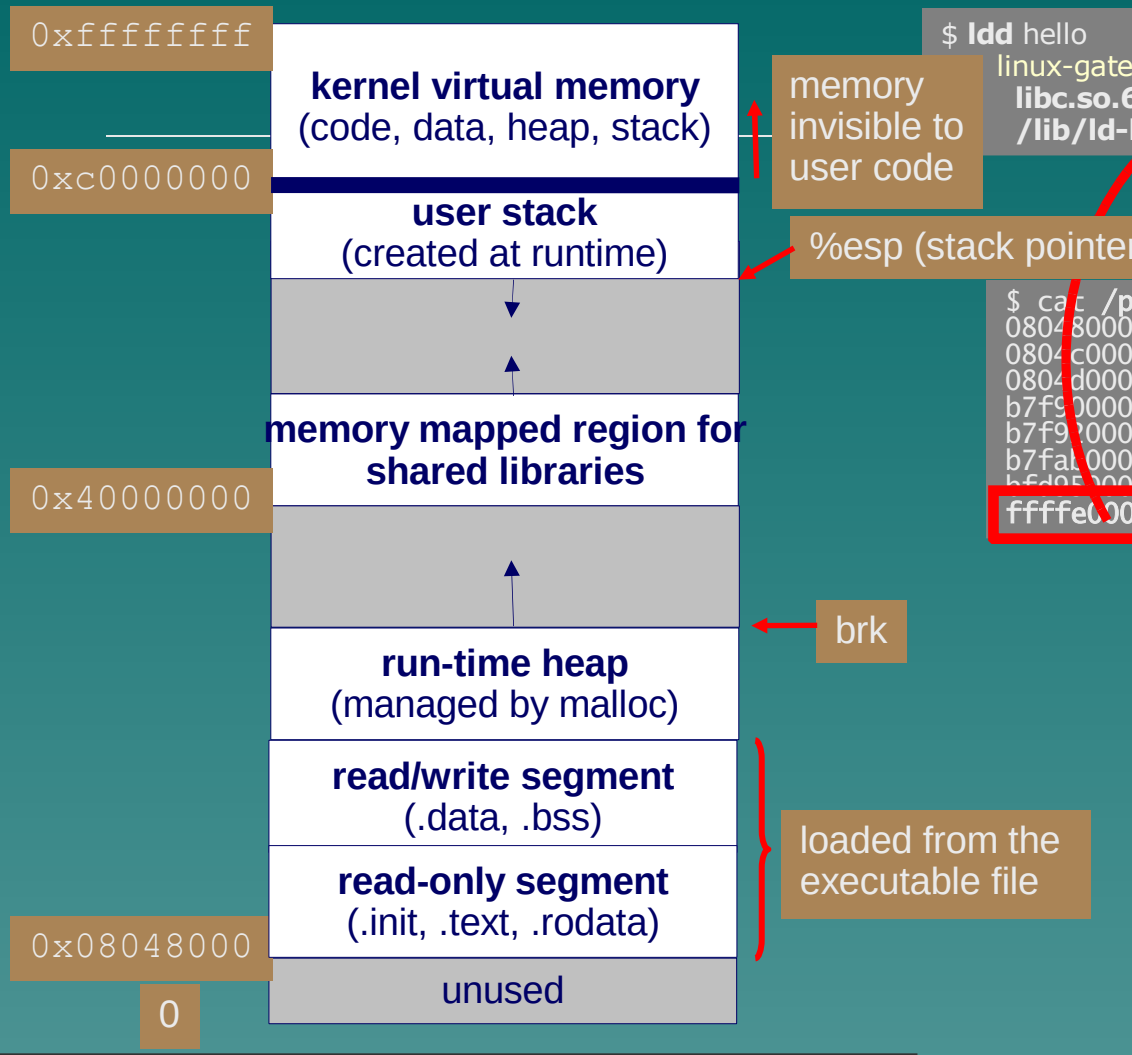
```
$ cat /proc/self/maps
08048000-0804c000 r-xp 00000000 31222    /bin/cat
0804c000-0804d000 rw-p 00003000 31222    /bin/cat
0804d000-0806e000 rw-p 0804d000 0          [heap]
b7f90000-b7f92000 rw-p b7f90000 0
b7f92000-b7fab000 r-xp 00000000 295771   /lib/ld-2.4.so
b7fab000-b7fad000 rw-p 00018000 295771   /lib/ld-2.4.so
bfd95000-bfdab000 rw-p bfd95000 0          [stack]
ffffe000-fffff000 ---p 00000000 0          [vdso]
```

***vdso ➔ Virtual DSO***

kernel 2.6 支援 Pentium III+ 的快速系統呼叫 **sysenter / sysexit** 機制。核心提供原先的 int 0x80 ，與新的 **sysenter** 雙介面，並虛擬印射了 **linux-gate.so.1** 來實作

```
$ uname -a
Linux venux 2.6.15-23-686 #1 SMP PREEMPT
Tue May 23 14:03:07 UTC 2006 i686 GNU/Linux
```

# Dynamically Linked Shared Libraries(3)




```
$ ldd hello
    linux-gate.so.1 =>  (0xffffe000)
    libc.so.6 => /lib/tls/i686/cmov/libc.so.6 (0xb7e62000)
    /lib/ld-linux.so.2 (0xb7fad000)
```

***/proc/self/maps***
***Memory map***

```
$ cat /proc/self/maps
08048000-0804c000 r-xp 00000000 31222     /bin/cat
0804c000-0804d000 rw-p 00003000 31222   /bin/cat
0804d000-0806e000 rw-p 0804d000 0           [heap]
b7f90000-b7f92000 rw-p b7f90000 0
b7f92000-b7fab000  r-xp 00000000 295771  /lib/ld-2.4.so
b7fad000-b7fad000 rw-p 00018000 295771  /lib/ld-2.4.so
bfd85000-bfdab000 rw-p bfd85000 0           [stack]
ffffe000-fffff000 ---p 00000000  0          [vdso]
```

***vdso ➔ Virtual DSO***

auxiliary vector (auxv)

**argv ➔** program arguments

**envp ➔** environment variables

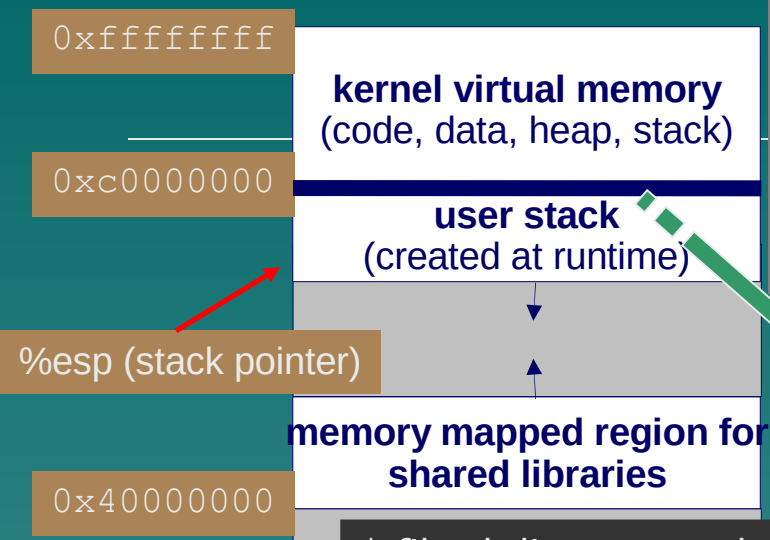
適用新建立的 Process

```
$ gdb -c core -q
Core was generated by `hello'.
Program terminated with signal 11, Segmentation fault.
#0  0xffffe777 in ?? ()
(gdb) bt
#0  0xffffe777 in ?? ()
```

**VA stack exploit**
Ref: Exploiting with linux-gate.so.1 . by Izik

```
# JMP *%ESP @ linux-gate.so.1jmp    = "\x77\xe7\xff\xff"
```

# Dynamically Linked Shared Libraries(4)




```
$ dd if=/proc/self/mem \
     of=linux-gate.dso bs=4096 \
     skip=1048574 count=1
1+0 records in
1+0 records out
```

*/proc/self/mem*
*Memory snapshot*

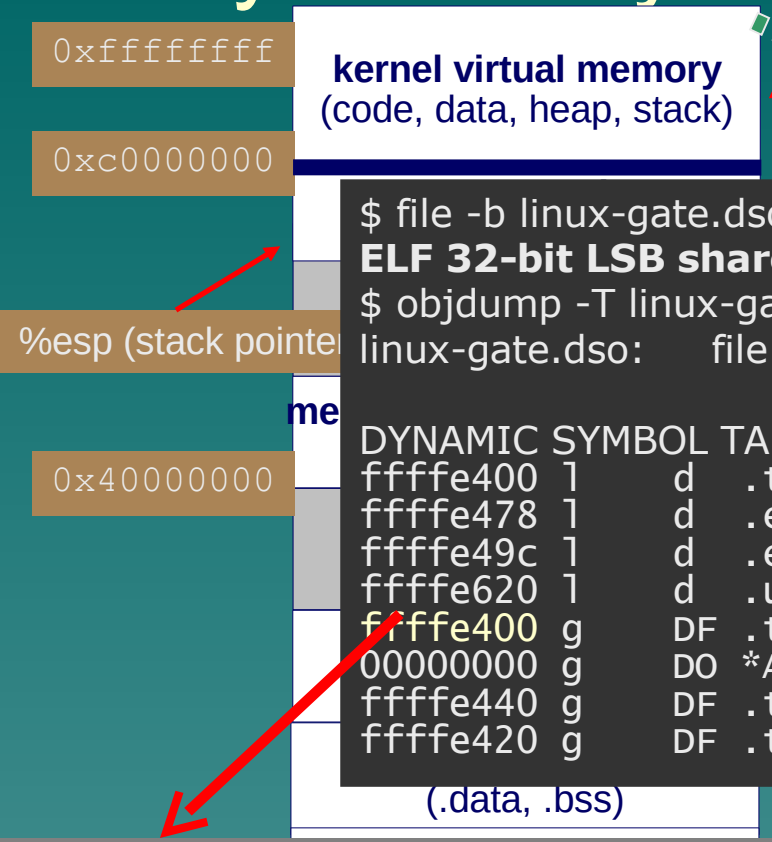
$2^{20} = 1048576$

virtual system call

```
$ file -b linux-gate.dso
ELF 32-bit LSB shared object, Intel 80386, version 1 (SYSV), stripped
$ objdump -T linux-gate.dso
linux-gate.dso:     file format elf32-i386

DYNAMIC SYMBOL TABLE:
ffffe400 l    d  .text  00000000              .text
ffffe478 l    d  .eh_frame_hdr  00000000              .eh_frame_hdr
ffffe49c l    d  .eh_frame      00000000              .eh_frame
ffffe620 l    d  .useless       00000000              .useless
ffffe400 g    DF .text  00000014  LINUX_2.5   __kernel_vsyscall
00000000 g    DO *ABS*  00000000  LINUX_2.5   LINUX_2.5
ffffe440 g    DF .text  00000007  LINUX_2.5   __kernel_rt_sigreturn
ffffe420 g    DF .text  00000008  LINUX_2.5   __kernel_sigreturn
```

```
$ LD_TRACE_LOADED_OBJECTS=1 ./hello
        linux-gate.so.1 =>  (0xffffe000)
        libc.so.6 => /lib/tls/i686/cmov/libc.so.6 (0xb7e9b000)
        /lib/ld-linux.so.2 (0xb7fe6000)
```

# Dynamically Linked Shared Libraries(5)

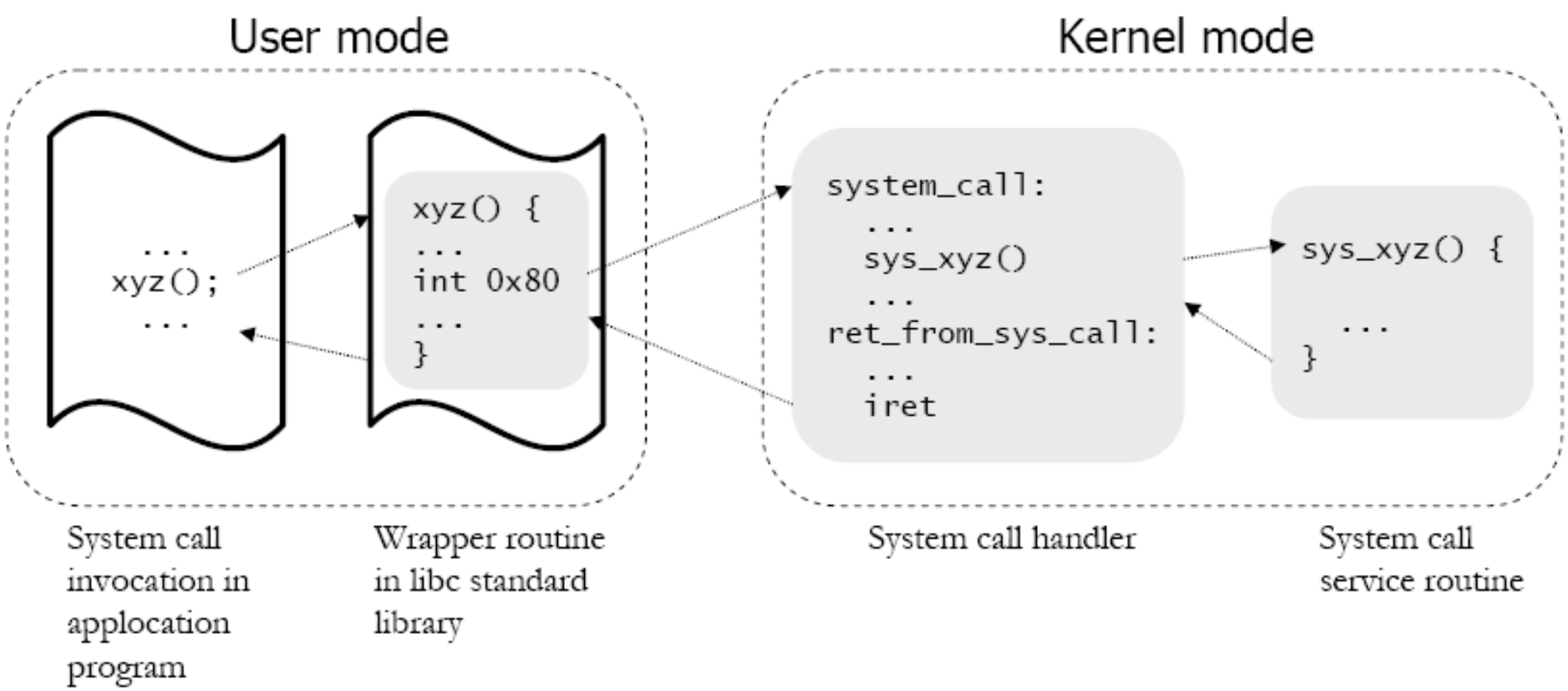


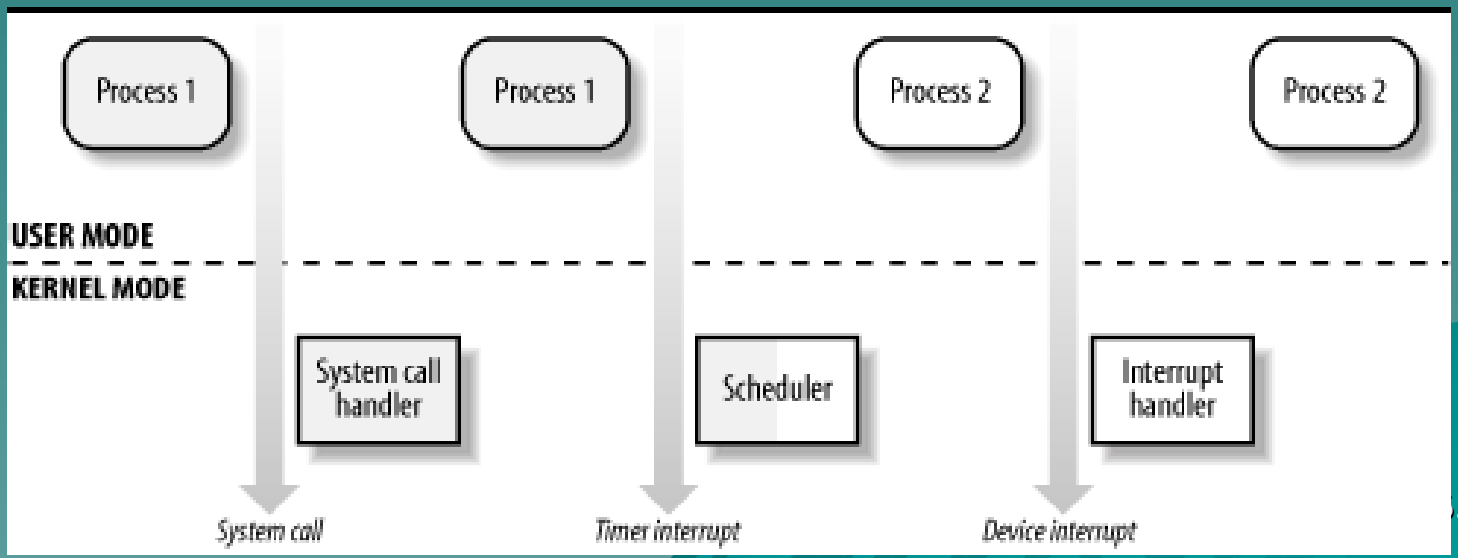

virtual system call

```
$ file -b linux-gate.dso
ELF 32-bit LSB shared object, Intel 80386, version 1 (SYSV), stripped
$ objdump -T linux-gate.dso
linux-gate.dso:     file format elf32-i386

DYNAMIC SYMBOL TABLE:
ffffe400 l    d  .text  00000000              .text
ffffe478 l    d  .eh_frame_hdr  00000000              .eh_frame_hdr
ffffe49c l    d  .eh_frame      00000000              .eh_frame
ffffe620 l    d  .useless       00000000              .useless
ffffe400 g    DF .text  00000014  LINUX_2.5   __kernel_vsyscall
00000000 g    DO *ABS*  00000000  LINUX_2.5   LINUX_2.5
ffffe440 g    DF .text  00000007  LINUX_2.5   __kernel_rt_sigreturn
ffffe420 g    DF .text  00000008  LINUX_2.5   __kernel_sigreturn
```

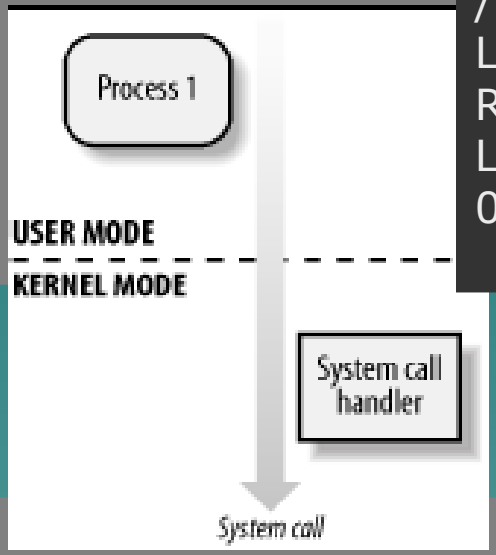
```
$ objdump -d --start-address=0xffffe400 \
--stop-address=0xffffe414 linux-gate.dso

linux-gate.dso:     file format elf32-i386
Disassembly of section .text:

ffffe400 <__kernel_vsyscall>:
ffffe400:       51              push   %ecx
ffffe401:       52              push   %edx
ffffe402:       55              push   %ebp
ffffe403:       89 e5           mov    %esp,%ebp
ffffe405:       0f 34           sysenter
```

```
ffffe407:       90              nop
ffffe408:       90              nop
ffffe409:       90              nop
ffffe40a:       90              nop
ffffe40b:       90              nop
ffffe40c:       90              nop
ffffe40d:       90              nop
ffffe40e:       eb f3           jmp    ffffe403 <__kernel_vsyscall+0x3>
ffffe410:       5d              pop    %ebp
ffffe411:       5a              pop    %edx
ffffe412:       59              pop    %ecx
ffffe413:       c3              ret
```


User mode
Kernel mode
...
xyz();
...
xyz() {
...
int 0x80
...
}
system_call:
...
sys_xyz()
...
ret_from_sys_call:
...
iret
sys_xyz() {
...
}
System call invocation in applocation program
Wrapper routine in libc standard library
System call handler
System call service routine

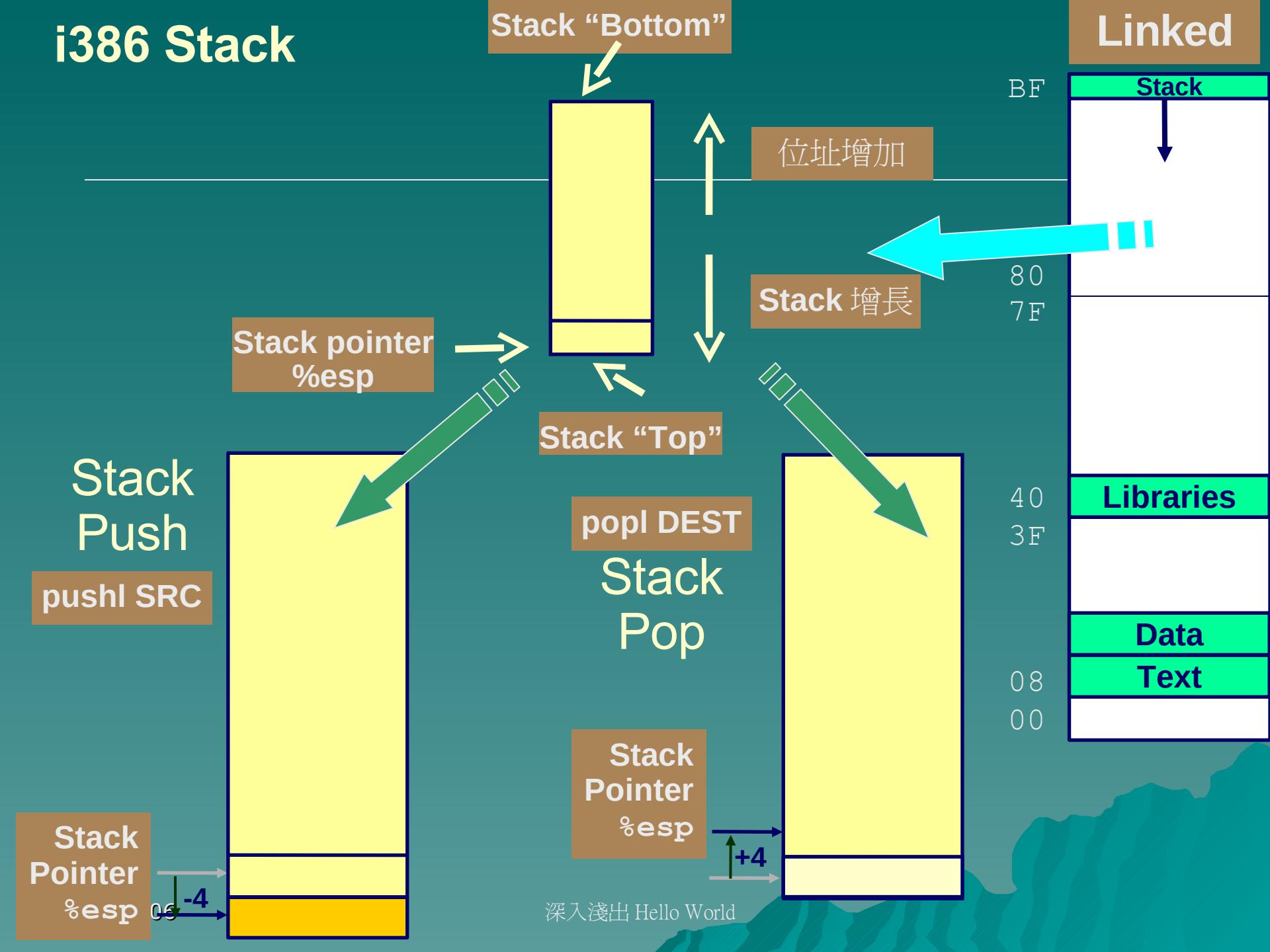

Process 1
Process 1
Process 2
Process 2
USER MODE
KERNEL MODE
System call handler
Scheduler
Interrupt handler
System call
Timer interrupt
Device interrupt

```
$ cat hello-loop.c
#include <stdio.h>
#include <unistd.h>
int main(int argc, char **argv)
{
        printf("Hello World!\n");
        while (1) {
                usleep(10000);
        }
        return 0;
}
$ ./hello-loop
Hello World!
```




```
$ pidof hello-loop
6987
$ gdb
(gdb) attach 6987
Attaching to process 6987
Reading symbols from
/home/jserv/HelloWorld/samples/hello-
loop...done.
Using host libthread_db library
"/lib/tls/i686/cmov/libthread_db.so.1".
Reading symbols from
/lib/tls/i686/cmov/libc.so.6...done.
Loaded symbols for /lib/tls/i686/cmov/libc.so.6
Reading symbols from /lib/ld-linux.so.2...done.
Loaded symbols for /lib/ld-linux.so.2
0xffffe410 in __kernel_vsyscall ()
```

```
(gdb) bt
#0  0xffffe410 in __kernel_vsyscall ()
#1  0xb7e37ef0 in nanosleep () from /lib/tls/i686/cmov/libc.so.6
#2  0xb7e6f93a in usleep () from /lib/tls/i686/cmov/libc.so.6
#3  0x080483ad in main () at hello-loop.c:7
```


i386 Stack
Stack "Bottom"
Linked
BF
Stack
位址增加
Stack 增長
80
7F
Stack pointer
%esp
Stack "Top"
Stack
Push
pushl SRC
popl DEST
Stack
Pop
40
3F
Libraries
Data
Text
08
00
Stack
Pointer
%esp
-4
Stack
Pointer
%esp
+4
深入淺出 Hello World

# i386/Linux Register

也作爲保存 return address 使用

```
#include <stdio.h>
char message[] = "Hello, world!\n";
int main(void)
{
  long _res;
  __asm__ volatile (
    "int $0x80"
    : "=a" (_res)
    : "a" ((long) 4),
      "b" ((long) 1),
      "c" ((long) message),
      "d" ((long) sizeof(message)));
    return 0;
}
```

**Caller-Save Temporaries**

- %eax
- %edx
- %ecx

**Callee-Save Temporaries**

- %ebx
- %esi
- %edi

**Special**

- %esp
- %ebp

```
.text
message:
.ascii "Hello World!\0"
.align 4
.globl main
main:
        pushl %ebp
        movl %esp,%ebp
        pushl $message
        call puts
        addl $4,%esp
        xorl %eax,%eax
        movl %ebp,%esp
        popl %ebp
        ret
```

# i386 call (1)

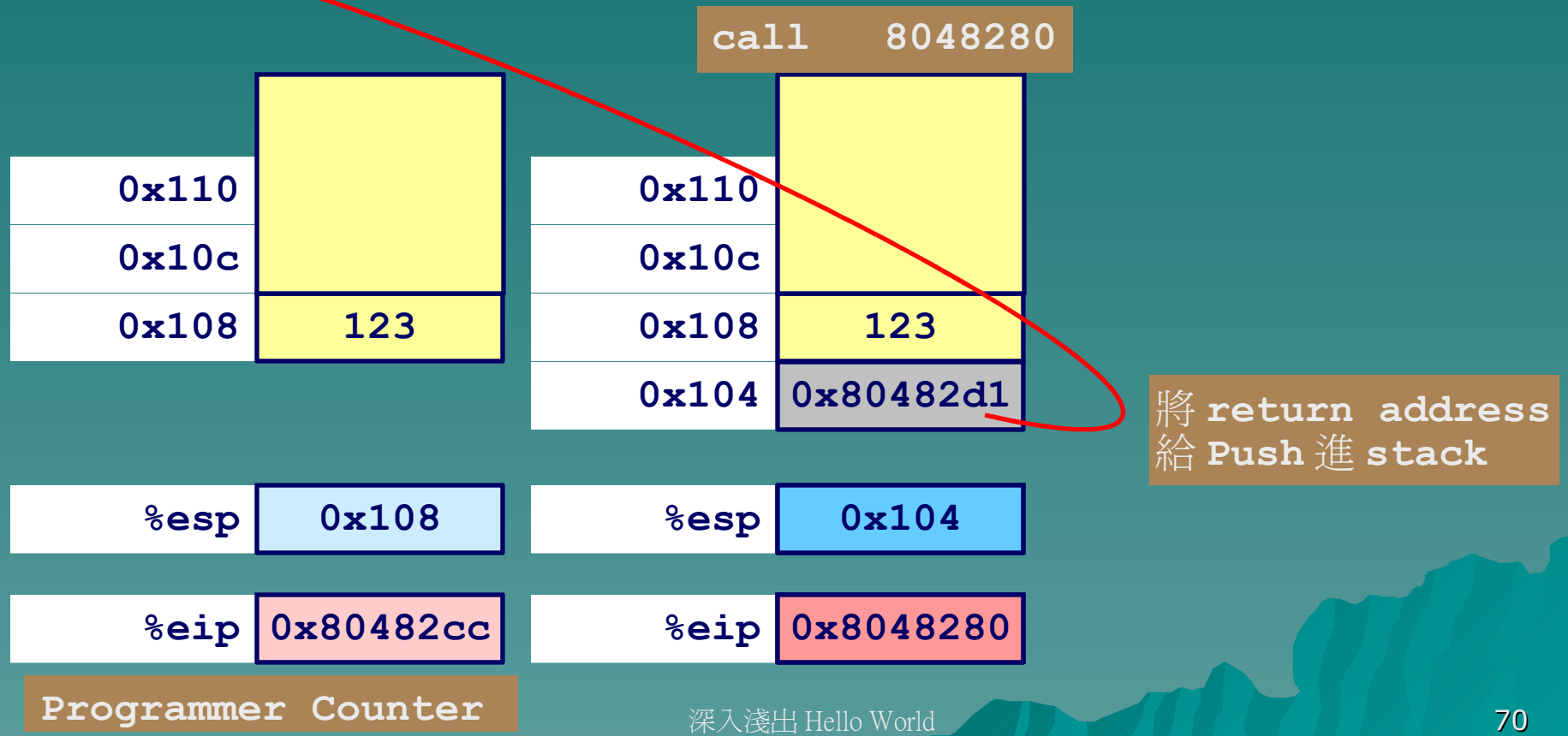
_start 爲該 Image 的 entry point

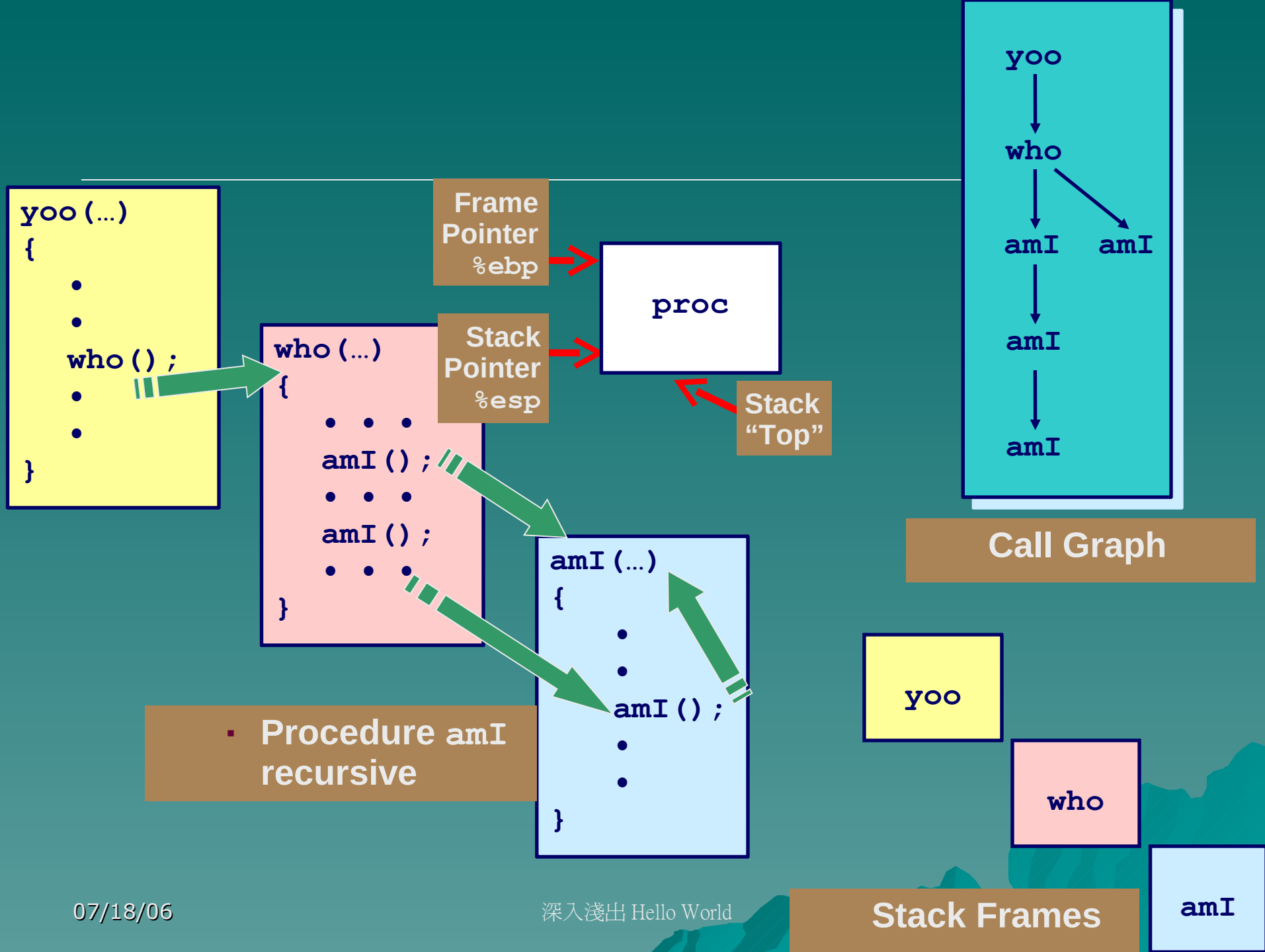
```
Disassembly of section .text:

080482b0 <_start>:
 80482b0:      31 ed                   xor    %ebp,%ebp
 80482b2:      5e                      pop    %esi
 80482b3:      89 e1                   mov    %esp,%ecx
 80482b5:      83 e4 f0                and    $0xfffffff0,%esp
 80482b8:      50                      push   %eax
 80482b9:      54                      push   %esp
 80482ba:      52                      push   %edx
 80482bb:      68 84 83 04 08          push   $0x8048384
 80482c0:      68 89 83 04 08          push   $0x8048389
 80482c5:      51                      push   %ecx
 80482c6:      56                      push   %esi
 80482c7:      68 50 83 04 08          push   $0x8048350
 80482cc:      e8 af ff ff ff          call   8048280 <__libc_start_main@plt>
 80482d1:      f4                      hlt
 80482d2:      90                      nop
 80482d3:      90                      nop

08048280 <__libc_start_main@plt>:
 8048280:      ff 25 44 95 04 08 jmp    *0x8049544
 8048286:      68 00 00 00 00    push   $0x0
 804828b:      e9 e0 ff ff ff    jmp    8048270 <_init+0x18>
```

- call LABLE
  - 使用 stack 來實現 procedure call
  - 先 PUSH 返回位址，然後 JUMP 到 LABLE

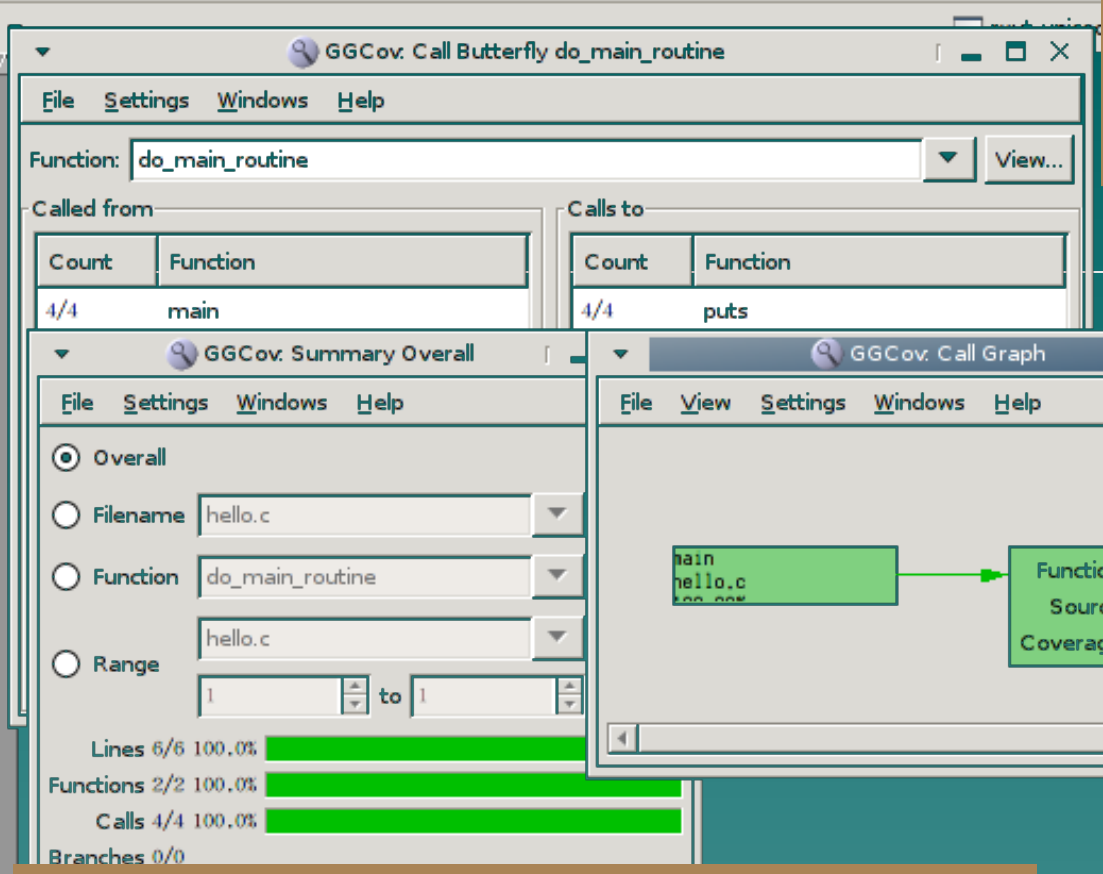
# i386 call (2)

```
Disassembly of section .text:

080482b0 <_start>:
...
80482cc:    e8 af ff ff ff      call   8048280 <__libc_start_main@plt>
80482d1:    f4                  hlt
```




yoo(...)
{
•
•
who();
•
•
}
who(...)
{
• • •
amI();
• • •
amI();
• • •
}
amI(...)
{
•
•
amI();
•
•
}
Frame Pointer %ebp
Stack Pointer %esp
proc
Stack "Top"
yoo
who
amI
amI
amI
amI
Call Graph
yoo
who
amI
Stack Frames
Procedure amI recursive

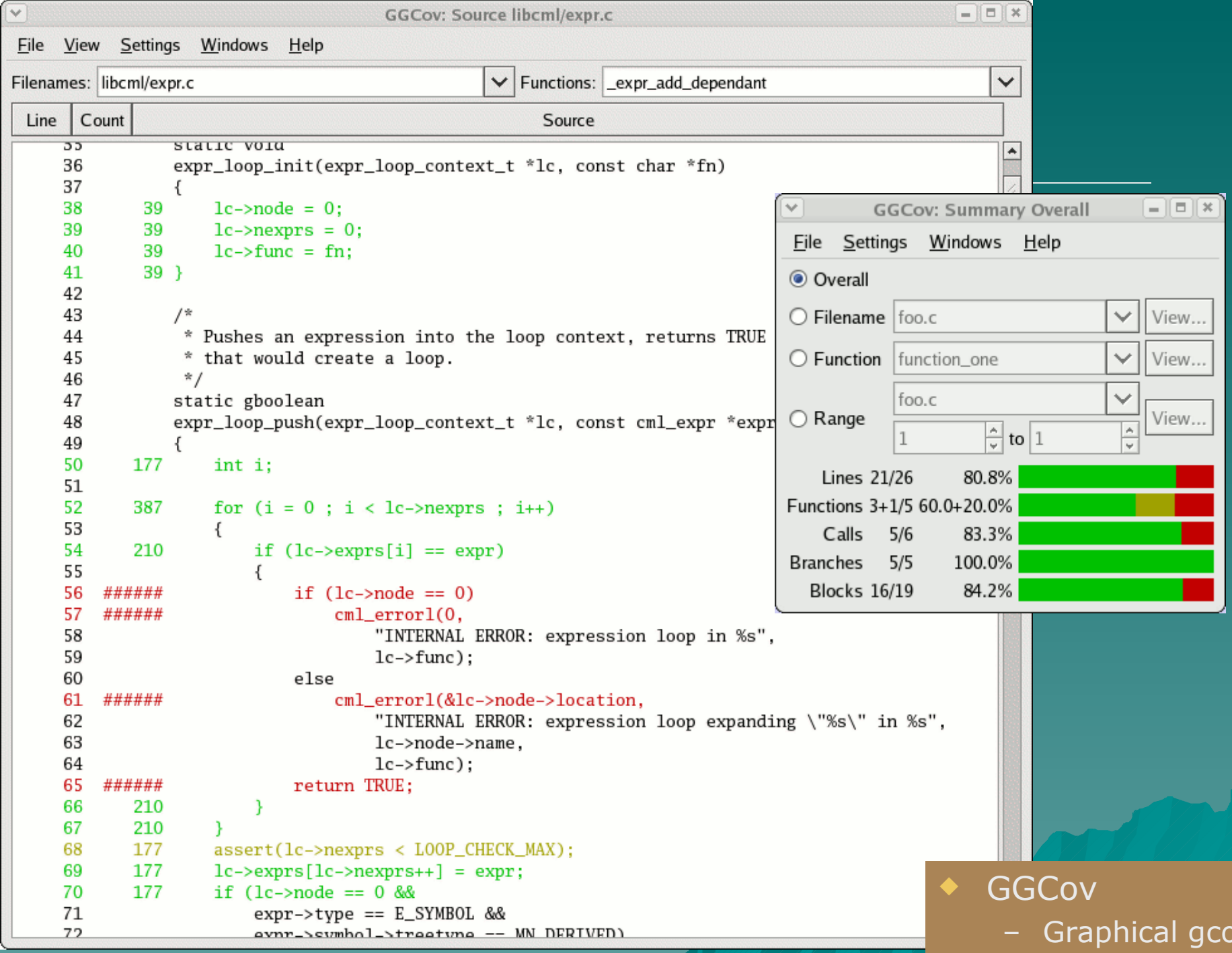
# 用工具來建構 Call Graph 並分析 Runtime 數據



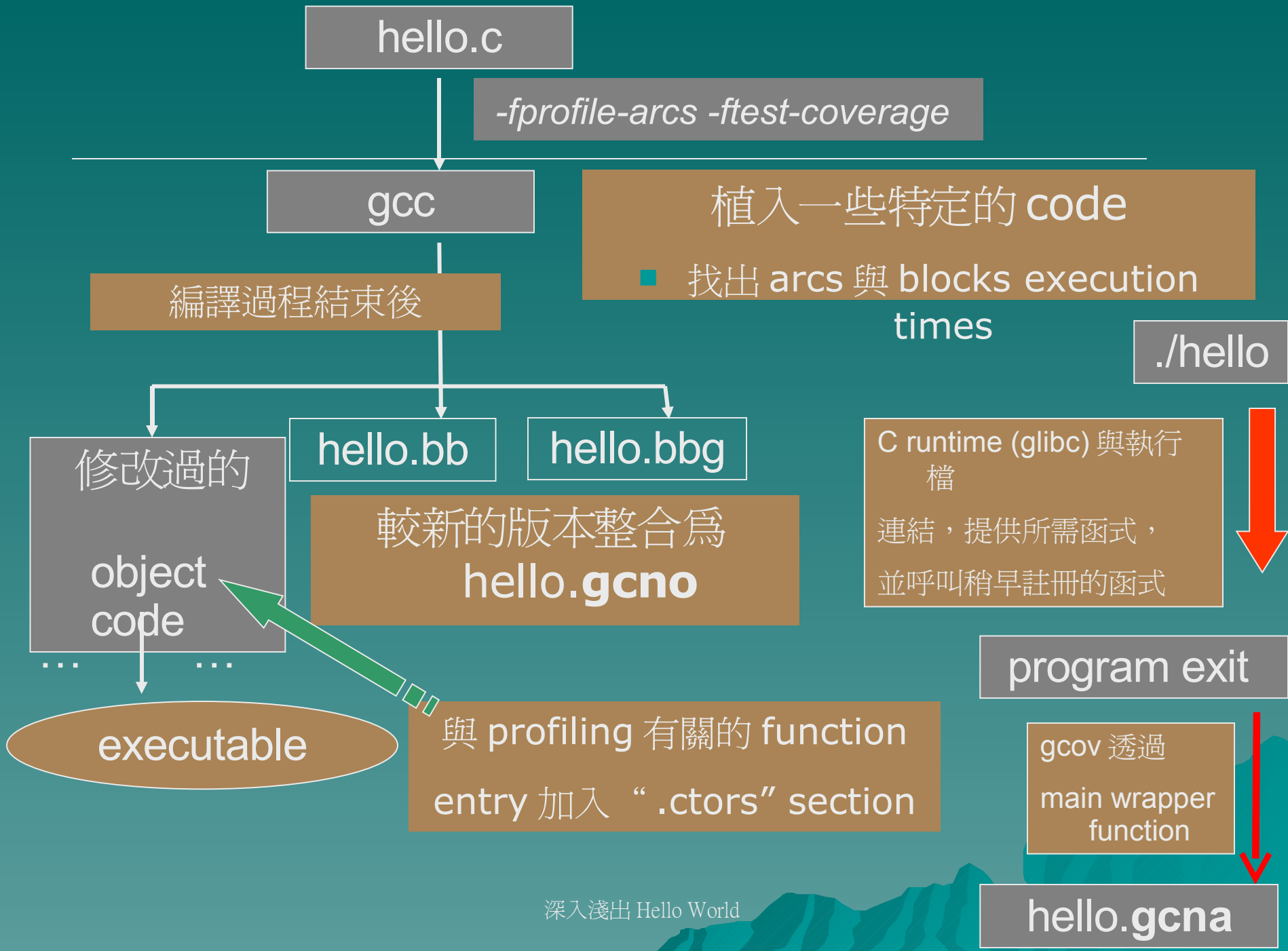

```
#include <stdio.h>

void do_myroutine(void) {
    puts("Hello World!\n");
}

int main(int argc, char *argv[])
{
    do_myroutine();
    return;
}
```

```
$ gcc -fprofile-arcs -ftest-coverage
hello.c –o hello
$ ./hello
```

- **gcov** is a **test coverage** program, which helps discover where your optimization efforts will best affect your code. Using gcov one can find out some basic performance statistics on a per source file level such as:
  - how often each line of code executes
  - what lines of code are actually executed




- GGCov
  - Graphical gcov


hello.c
-fprofile-arcs -ftest-coverage
gcc
植入一些特定的 code
找出 arcs 與 blocks execution times
編譯過程結束後
./hello
hello.bb
hello.bbg
修改過的
object code
較新的版本整合爲
hello.gcno
C runtime (glibc) 與執行檔
連結，提供所需函式，
並呼叫稍早註冊的函式
program exit
executable
與 profiling 有關的 function
entry 加入 “ .ctors” section
gcov 透過
main wrapper function
hello.gcna

# 邁入新紀元…


Orz programming 2.0



# 01-preload

```
$ cat hello.c
#include <stdio.h>

char message[128] =
        "Hello World!\n";
int main(int argc, char **argv)
{
        puts(message);
        return 0;
}
```

```
gcc -o hack.so -shared hack.c -ldl
```

```
LD_PRELOAD=./hack.so ./hello
```

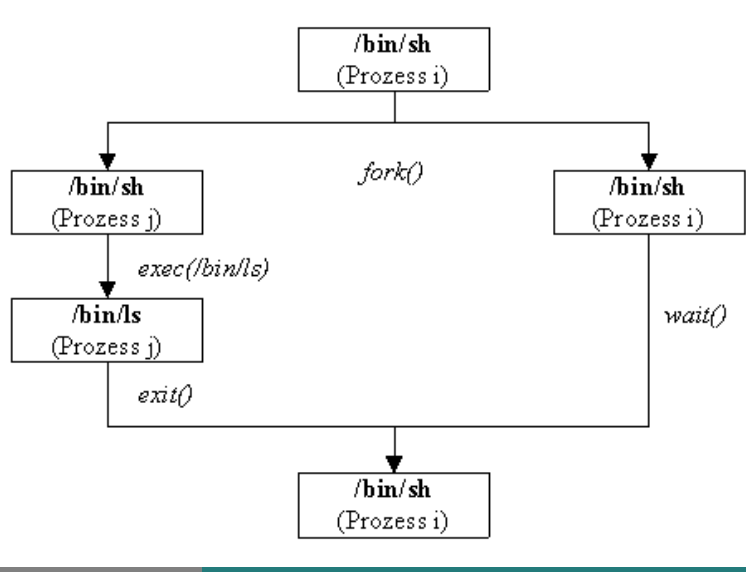
```
$ LD_PRELOAD=./hack.so
LD_TRACE_LOADED_OBJECTS=1 ./hello
        linux-gate.so.1 =>  (0xffffe000)
        ./hack.so (0xb7f21000)
        libc.so.6 => /lib/tls/i686/cmov/libc.so.6
(0xb7dd8000)
        libdl.so.2 => /lib/tls/i686/cmov/libdl.so.2
(0xb7dd3000)
        /lib/ld-linux.so.2 (0xb7f25000)
```

```
$ cat hack.c
#include <string.h>
#include <stdlib.h>
#include <unistd.h>

int puts (char * s)
{
  char *t = s;
  while (*s) {
    if (*s == 'H')
      *s = 'K';
    else
      *s = toupper( *s );
    s++;
  }
  return (int)
    write(0, t, strlen(t));
}
```

# 02-avoid-preload(1)

```
#include <stdio.h>
#include <unistd.h>

#define FORKED_ENV "HELLO_BEEN_FORKED"
static int been_forked = 0;

static char message[128] = "Hello World!";

int main(int argc, char **argv)
{
        int pid = fork();

        if (getenv(FORKED_ENV)) {
                been_forked = 1;
        }
```

```
LD_PRELOAD=./hack.so ./hello
```




```
        /* in child process */
        if (! pid) {
                if (! been_forked) {
                        setenv(FORKED_ENV, "1", 1);
                        execvp(argv[0], argv);
                }
        }

        /* in parent process */
        if (pid) {
                puts(message);
                waitpid (pid, NULL, 0);
        }

        return 0;
}
```

# 02-avoid-preload(2)

```
#include <stdio.h>
#include <unistd.h>

#define FORKED_ENV "HELLO_BEEN_FORKED"
static int been_forked = 0;

void __attribute__((constructor)) unset_ld_preload()
{
        printf("Performing %s...\n", __FUNCTION__);
        unsetenv("LD_PRELOAD");
        if (getenv(FORKED_ENV)) {
                been_forked = 1;
        }
}

static char message[128] = "Hello World!";

int main(int argc, char **argv)
{
        int pid = fork();
```

.ctor section

GCC Extension:
constructor attribute

```
/* in child process */
if (! pid) {
        if (! been_forked) {
                setenv(FORKED_ENV, "1", 1);
                execvp(argv[0], argv);
        }
}

/* in parent process */
if (pid) {
        puts(message);
        waitpid (pid, NULL, 0);
}

return 0;
}
```

LD_PRELOAD=./hack.so ./hello

# 03-dynamic loading(1)

```
$ cat hello.c
#include <stdio.h>
#include <stdlib.h>
#include <dlfcn.h>
int main(int argc, char **argv)
{
  void *handle;
  void (*func)(void);
  const char *error;

  /* shared object */
  handle = dlopen ("./shared.so",
                   RTLD_NOW);
  if (! handle) {
    fputs(dlerror(), stderr);
    exit(1);
  }
  func = dlsym (handle, "hello");
  if ((error = dlerror()) != NULL) {
    fputs(error, stderr); exit(1);
  }
  (*func)();
  dlclose(handle);
}
```

```
$cat share.c
#include <stdio.h>
#include <stdlib.h>

/* GCC __attribute__ */
void __attribute__((constructor))
Hello_init()
{
  printf("_init invoked
}
void __attribute__((destructor))
Hello_fini()
{
  printf("_fini invoked
}

/* Customized routines here */
void hello()
{
  printf("Hell World!\n");
}
```

可替代爲 **init**

可替代爲 **fini**

# 03-dynamic loading(2)

```
$ cat Makefile
LIBS= -ldl
SRCS=main.c
OBJECTS=$(SRCS:.c=.o)
CFLAGS=-g -rdynamic -fPIC
CC=gcc

all: hello shared.so

hello: $(OBJECTS)
	$(CC) $(CFLAGS) -o $@ $(OBJECTS) $(LIBS)

# Shared Objects here
shared.so: shared.o
	gcc -shared shared.o -o shared.so -g
```

**PIC → Position-Independent Code**

- shared libraries→ 可在任何位址載入與執行，而不需要 Linker 在執行時期介入
- 然而， PIC 會帶來效能衝擊

LD_DEBUG=libs ./hello

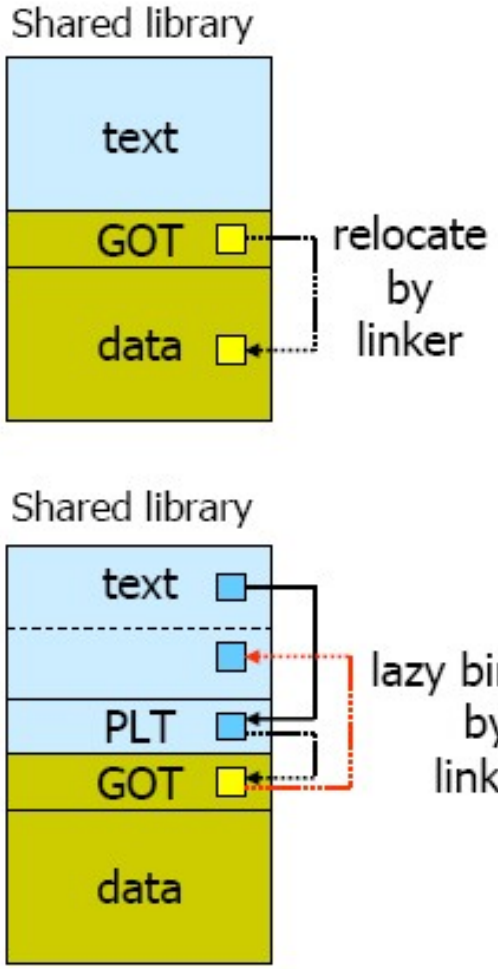
```
      7043:     find library=libdl.so.2 [0];
searching
      7043:      search cache=/etc/ld.so.cache
      7043:       trying
file=/lib/tls/i686/cmov/libdl.so.2
      7043:
      7043:     find library=libc.so.6 [0]; searching
      7043:      search cache=/etc/ld.so.cache
      7043:       trying
file=/lib/tls/i686/cmov/libc.so.6
      7043:
      7043:
      7043:     calling init:
/lib/tls/i686/cmov/libc.so.6
      7043:
      7043:
      7043:     calling init:
/lib/tls/i686/cmov/libdl.so.2
      7043:
      7043:
      7043:     initialize program: ./hello
      7043:
      7043:
      7043:     transferring control: ./hello
      7043:
I am about to load Hello World module..ok
```

```
7043:
      7043:     calling init: ./shared.so
      7043:
_init invoked!
Hell World!
Execution Finished.ok
      7043:
      7043:     calling fini: ./shared.so [0]
      7043:
_fini invoked!
      7043:
```

# 03-dynamic loading(3)

```
// global data reference

    call L1
L1: popl %ebx
    addl $GOTENTRY, %ebx
    movl (%ebx), %eax
    movl (%eax), %eax
```

```
// global procedure reference

    call $PLTENTRY
    …
-----------------------------------------
PLT[0]:   pushl (GOT[1])     // special id
          jmp  *(GOT[2])     // dyn linker
          …
PLTENTRY: jmp  *($GOTENTRY)
PLTLAZY:  pushl $func_id
          jmp  PLT[0]
-----------------------------------------
GOT[1]  : (special id for dyn linker)
GOT[2]  : (entry point in dynamic linker)
          …
GOTENTRY: $PLTLAZY           // changed by
          real entry point   // lazy binding
```




實做方式：

- GOT (global offset table) ：位於 data segment
- PLT (procedure linkage table) ：位於 code segment

# 04-PIE (Position-Independent

```
$ cat hello.c
#include <stdio.h>
void hello() {
    printf("Hello World!\n");
}

int main(void) {
    hello();
    return 0;
}
```

```
gcc -c hello.c
gcc -o hello hello.o
```

```
gcc -c hello.c -fPIE
gcc -o hello-pie -pie hello.o
```

```
objdump -d hello | grep main -A3
```

```
08048360 <main>:
 8048360:       8d 4c 24 04             lea    0x4(%esp),%ecx
 8048364:       83 e4 f0                and    $0xfffffff0,%esp
 8048367:       ff 71 fc                pushl  0xfffffffc(%ecx)
```

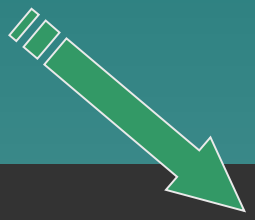
```
0000060e <main>:
 60e:   8d 4c 24 04             lea    0x4(%esp),%ecx
 612:   83 e4 f0                and    $0xfffffff0,%esp
 615:   ff 71 fc                pushl  0xfffffffc(%ecx)
```

Position-Independent Execution

# 04-PIE (Position-Independent Execution)

```
$ cat say.c
#include <stdio.h>
#include <stdlib.h>
#include <dlfcn.h>
#include <assert.h>
typedef void (*hello_t)(void);

int main(void)
{
    hello_t hello;
    void *handle = dlopen (
        "./hello-impl",
        RTLD_LAZY);
    assert(handle);
    hello = dlsym(handle, "hello");
    hello();
    dlclose(handle);
    return 0;
}
```

```
$ cat hello.c
#include <stdio.h>
void hello() {
    printf("Hello World!\n");
}

int main(void) {
    hello();
    return 0;
}
```



```
build_say:
        gcc -c hello.c -fPIE -o hello-impl.o
        gcc -o hello-impl -pie -rdynamic
hello-impl.o
        gcc -g -o say say.c -ldl
```

# 05-printf-vs-puts(1)

- C語言真的是WYSIWYG (What You See Is What You Get) 嗎？

```
$ cat Makefile
all: PrepareSourceCode Normal NoBuiltIns

PrepareSourceCode:
	echo "int main() { printf(\"Hello World\\\\\"); return 0; }" >  hello.c

Normal:
	gcc -o hello hello.c
	readelf -a hello | egrep 'printf|puts'

NoBuiltIns:
	gcc -o hello_opt_nobuiltins -fno-builtin hello.c
	readelf -a hello_opt_nobuiltins | egrep 'printf|puts'
```

# 05-printf-vs-puts(2)

int main() { printf("Hello World\n"); return 0; }

```
$ make
echo "int main() { printf(\"Hello World\"); return 0; }" >
hello.c
gcc -o hello hello.c
hello.c: In function 'main':
hello.c:1: warning: incompatible implicit declaration of
built-in function 'printf'
readelf -a hello | egrep 'printf|puts'
08049528  00000107 R_386_JUMP_SLOT   00000000   puts
     1: 00000000   399 FUNC    GLOBAL DEFAULT  UND puts@GLIBC_2.0 (2)
    64: 00000000   399 FUNC    GLOBAL DEFAULT  UND puts@@GLIBC_2.0
gcc -o hello_opt_nobuiltins -fno-builtin hello.c

readelf -a hello_opt_nobuiltins | egrep 'printf|puts'
08049538  00000207 R_386_JUMP_SLOT   00000000   printf
     2: 00000000    57 FUNC    GLOBAL DEFAULT  UND printf@GLIBC_2.0
(2)
    71: 00000000    57 FUNC    GLOBAL DEFAULT  UND printf@@GLIBC_2.0
```

-fno-builtin

Hint: 如果將" \n"自字串中移除，又會如何？

# 06-backtrace

Binary File Descriptor
libbfd 爲 binutils-dev 所提供

```
#include <assert.h>
#include <bfd.h>
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <libgen.h>
static bfd *abfd;
static asymbol **symbols;
static int nsymbols;

void show_debug_info (void *address) {
    asection *section =
        bfd_get_section_by_name(
            abfd, ".debug_info");
    assert(section != NULL);

    const char *file_name;
    const char *function_name;
    int lineno;
    int found = bfd_find_nearest_line(
      abfd, section, symbols, (long)address,
      &file_name, &function_name, &lineno);
    if (found && file_name != NULL &&
        function_name != NULL) {
        char tmp[strlen(file_name)];
        strcpy(tmp, file_name);
        printf("%s:%s:%d\n",
            basename(tmp),
            function_name, lineno);
    }
}
```

```
void hello ()
{
   printf("Hello World!\n");
   show_debug_info(
      __builtin_return_address(0) - 1);
}

void __attribute__((constructor))
init_bfd_stuff ()  {
   abfd = bfd_openr(
      "/proc/self/exe", NULL);
   assert(abfd != NULL);
   bfd_check_format(abfd, bfd_object);

   int size =
     bfd_get_symtab_upper_bound(abfd);
   assert(size > 0);
   symbols = malloc(size);
   assert(symbols != NULL);
   nsymbols = bfd_canonicalize_symtab(
      abfd, symbols);
}

int main () {
   hello();
   return 0;
}
```

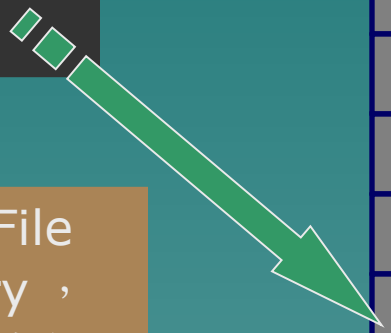
```
$ ls -l /proc/self/exe
lrwxrwxrwx 1 jserv jserv 0 Jul 10 16:02 /proc/self/exe
-> /bin/ls
$ realpath /proc/self/exe
/usr/bin/realpath
```

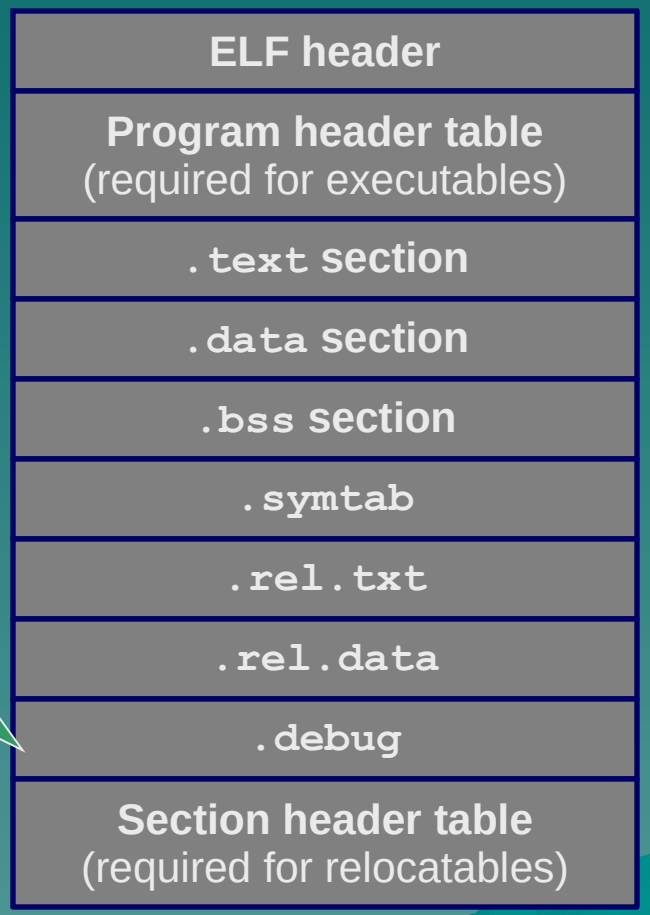
# ELF

```
$ gcc -o hello hello.c -lbfd
$ ./hello
Hello World!
```

```
$ gcc -o hello_g hello.c -g -lbfd
$ ./hello_g
Hello World!
hello.c:main:54
```

透過 BFD (Binary File Descriptor) Library，得到 Runtime 擷取資訊並改變流程的新途徑





# 07-SegFault(1)

```
$ ./hello
Floating point exception
```

```
$ cat hello.c
#include <stdio.h>

int magic_num()
{
  return (0 / 0);
}

void hello()
{
  printf("Hello World! A special num: %d\n",
    magic_num());
}

int main(int argc, char **argv)
{
  hello();
  return 0;
}
```

```
$ gdb ./hello
(gdb) run
Starting program: ./hello

Program received signal SIGFPE, Arithmetic exception.
0x08048365 in magic_num () at hello.c:5
5               return (0 / 0);
(gdb) bt
#0  0x08048365 in magic_num () at hello.c:5
#1  0x0804837b in hello () at hello.c:10
#2  0x080483a3 in main () at hello.c:15
```

```
$ make
gcc -o hello -g hello.c
hello.c: In function 'magic_num':
hello.c:5: warning: division by zero
```

# 07-SegFault(2)

```
$ ./hello
Floating point exception
```

```
$ cat hello.c
#include <stdio.h>

int magic_num()
{
  return (0 / 0);
}

void hello()
{
  printf("Hello World! A special num: %d\n",
    magic_num());
}

int main(int argc, char **argv)
{
  hello();
  return 0;
}
```

```
$ cat hello-backtrace.c
#include <stdio.h>
#include <stdlib.h>
#include <execinfo.h>
#include <signal.h>
static void stacktrace(int signal) {
  void *trace[128];
  int n = backtrace(trace,
     sizeof(trace) / sizeof(trace[0]));
  backtrace_symbols_fd(trace, n, 1);
}

int magic_num() { }
void hello() { }

int main(int argc, char **argv) {
  struct sigaction sa;
  memset(&sa, 0, sizeof(sa));
  sa.sa_handler = stacktrace;
  sa.sa_flags = SA_ONESHOT;
  sigaction(SIGFPE, &sa, NULL);
  hello();
  return 0;
}
```

```
$ ./hello-backtrace
./hello-backtrace[0x8048663]
[0xffffe420]
./hello-backtrace(hello+0xb)[0x80486b0]
./hello-backtrace(main+0x69)[0x804872b]
/lib/tls/i686/cmov/libc.so.6(__libc_start_main+0xd
]
./hello-backtrace[0x80485c5]
Floating point exception
```

# 07-SegFault(3)

```
$ ./hello
Floating point exception
```

```
$ cat hello.c
#include <stdio.h>

int magic_num()
{
  return (0 / 0);
}

void hello()
{
  printf("Hello World! A s
    magic_num());
}

int main(int argc, char **
{
  hello();
  return 0;
}
```

```
$ SEGFAULT_SIGNALS=all
LD_PRELOAD=/lib/libSegFault.so ./hello
*** Floating point exception
Register dump:

 EAX: 00000000  EBX: b7f14ff4  ECX: bff18a70  EDX: 00000000
 ESI: b7f4cce0  EDI: 00000000  EBP: bff18a38  ESP: bff18a34

 EIP: 08048365  EFLAGS: 00210282

 CS: 0073  DS: 007b  ES: 007b  FS: 0000  GS: 0033  SS: 007b

 Trap: 00000000  Error: 00000000  OldMask: 00000000
 ESP/signal: bff18a34  CR2: 00000000

Backtrace:
/lib/libSegFault.so[0xb7f2e1e9]
[0xffffe420]
./hello[0x804837b]
./hello[0x80483a3]
/lib/tls/i686/cmov/libc.so.6(__libc_start_main+0xd8)[0xb7df88b8]
./hello[0x80482d1]

Memory map:
...
```

**SEGFAULT_SIGNALS=all**

LD_PRELOAD=/lib/libSegFault.so

# 參考資料

- GNU Binary Utilities, *Free Software Foundation*

  http://www.gnu.org/software/binutils/manual/html_chapter/binutils.html
- ELF/DWARF, *Free Standards Group – Reference Specifications*
  *http://www.freestandards.org/spec/refspecs/*
- The GCC Project, *Free Software Foundation*

  http://gcc.gnu.org/
- O'Reilly Understanding the Linux Kernel

  http://www.oreilly.com/catalog/linuxkernel/