Open RazzmatazZ Laboratory (OrzLab)

深入淺出 Hello World – Part II

探索記憶體模型與系統呼叫

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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 feisty (development branch)
  - Linux kernel 2.6.17-9
  - gcc 4.1.2 (pre-release)
  - glibc 2.5

大綱

- 探索 Linux 記憶體模型
- 深入 syscall
- 再探動態連結

探索 Linux 記憶體模型

- Memory Section/Region
- Linux Memory Allocation
- i386 stack/register/call

Memory section (1)

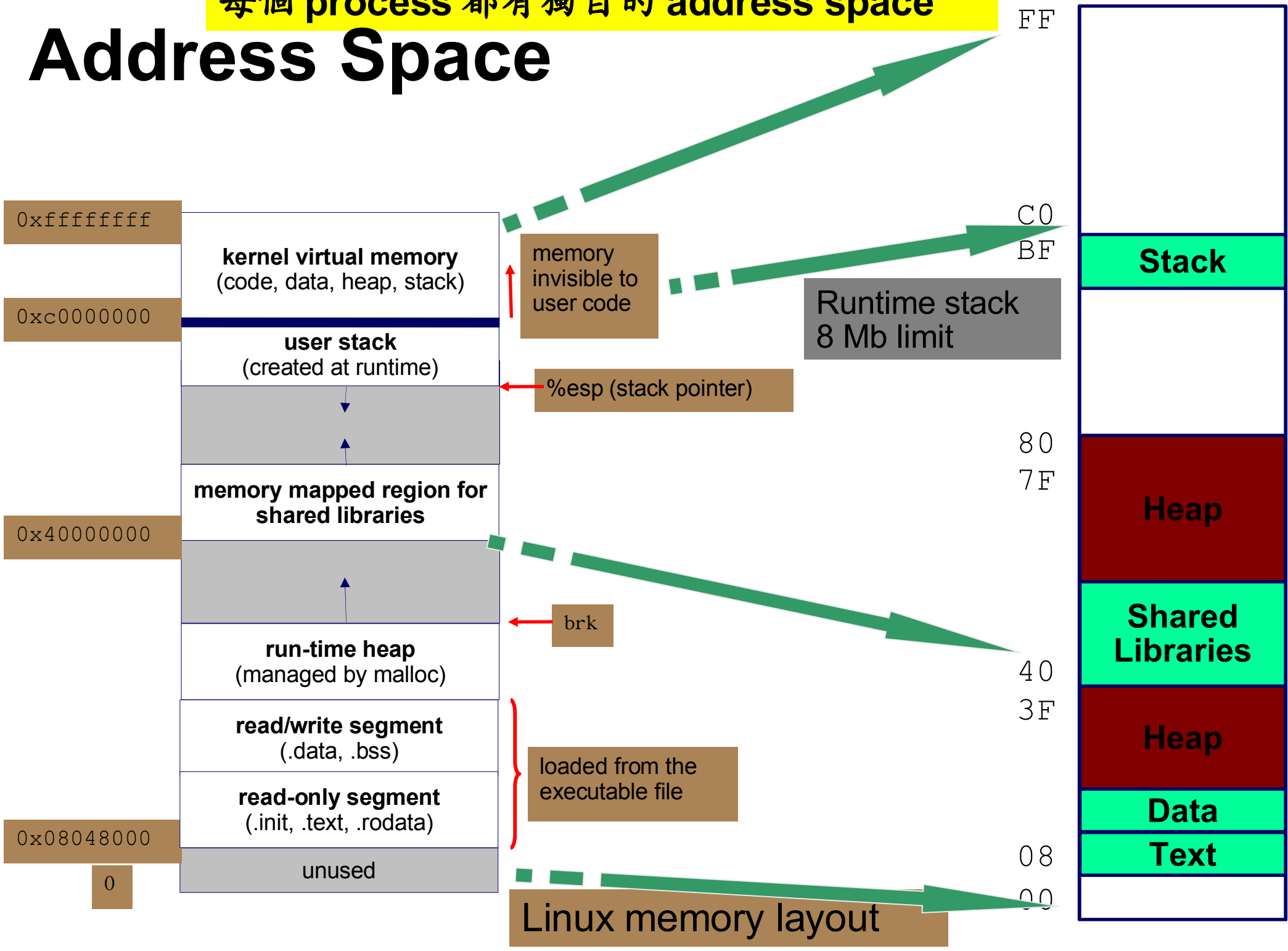
- 概念： Modular programming
- Module 就是特定 I/O 介面的黑盒子，由 re-locatable object code 組成
- Assembler 與 Linker 層面來說，程式由若干 **sections** (absolute or relocatable blocks of code or data) 集合而成
- 來自不同 module 、卻有相同名稱的 sections ，特稱爲”**partial sections**”
- Linker 的職責就是將所有 partial sections 結合爲 sections

Memory section (2)

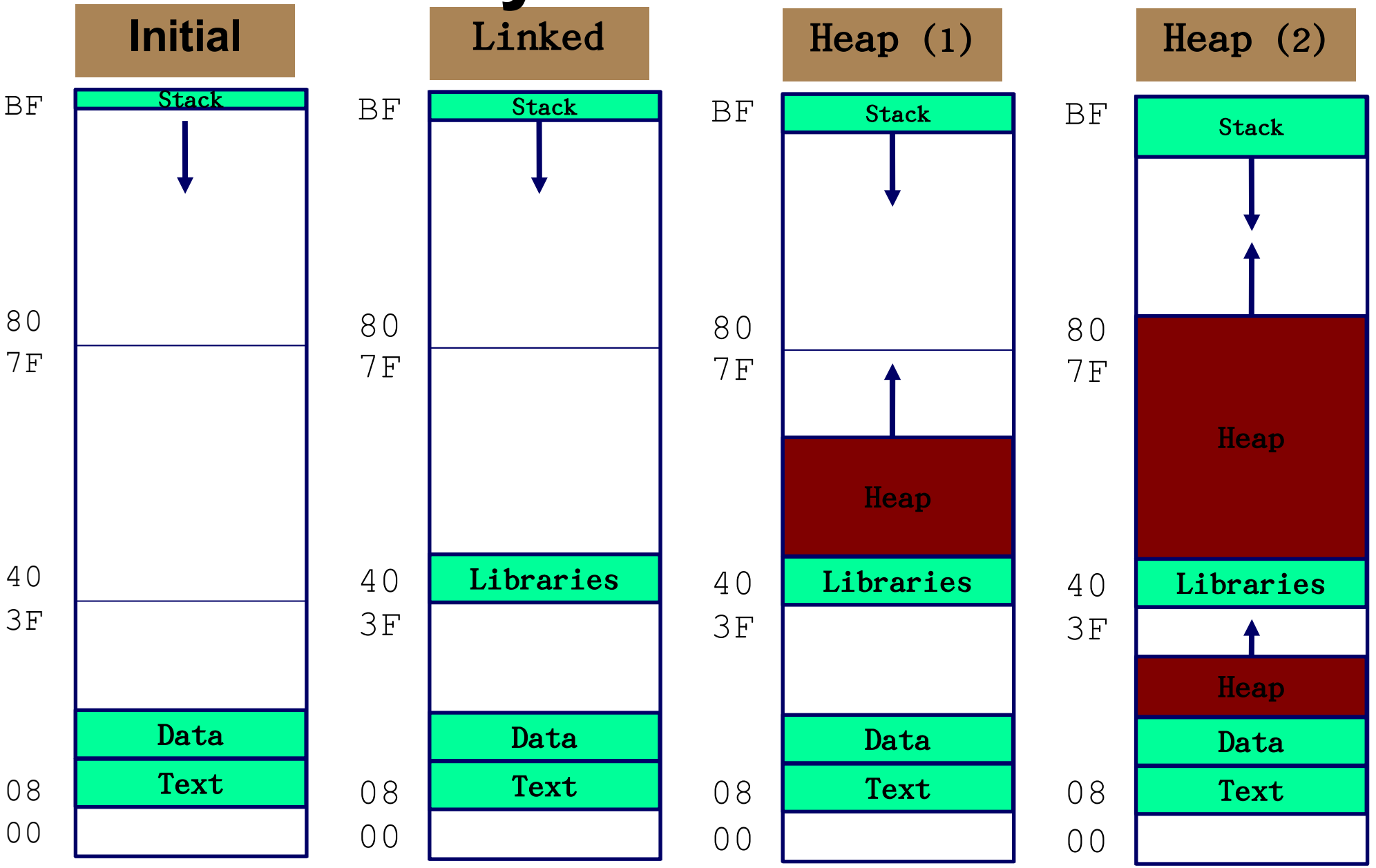
- Absolute sections
  - 需要定位於特定的 memory address
  - 不可結合到其他 section
- Module
  - 由一個或多個 code sections 所組成
- Program
  - 包含單一 absolute module ，並整合其他 absolute/relocatable section
- Linker
  - all external references to symbols in other modules are **resolved** by the linker/locator – the end product is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

每個 process 都有獨自的 address space

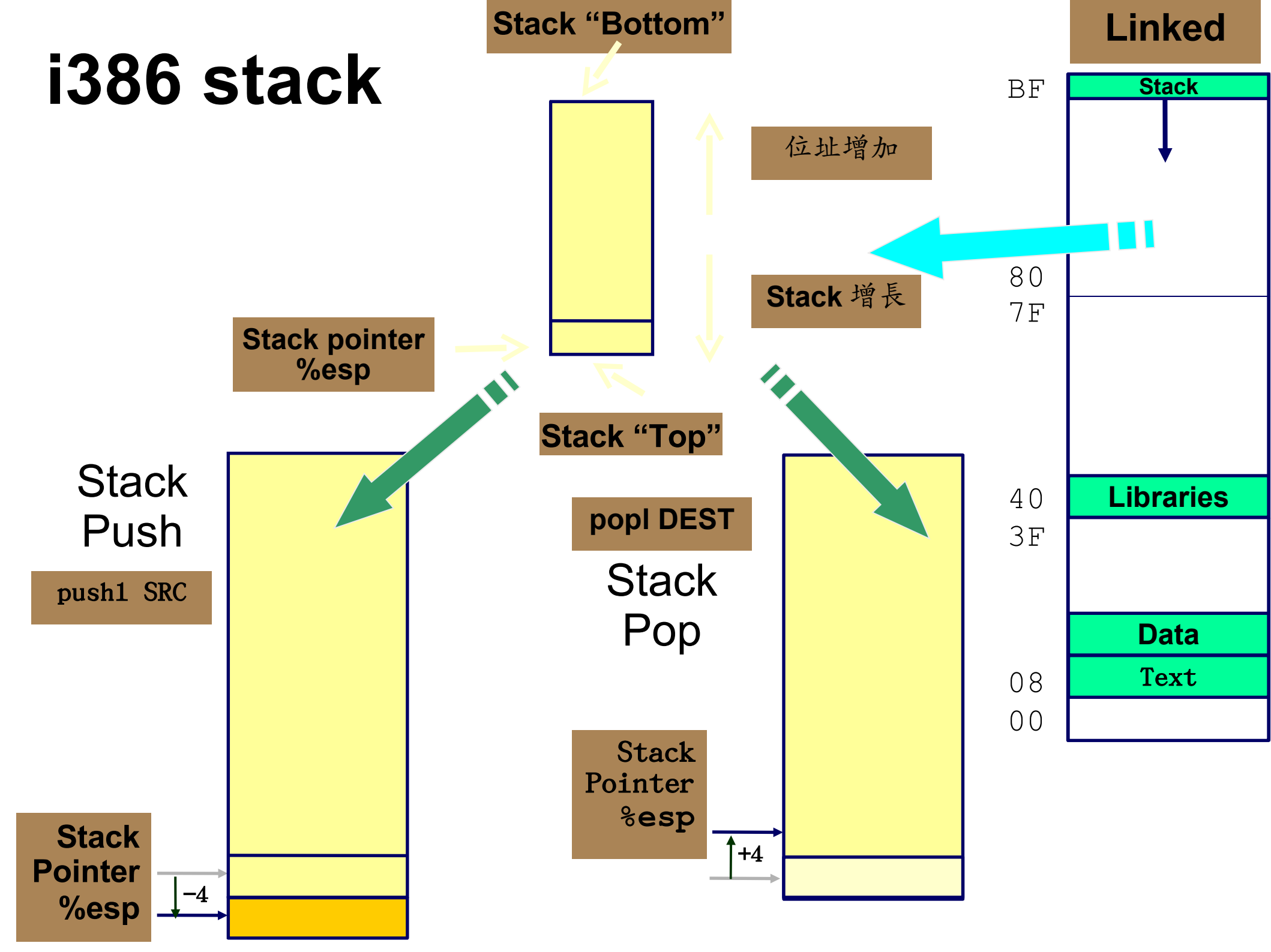
Address Space



Linux Memory Allocation



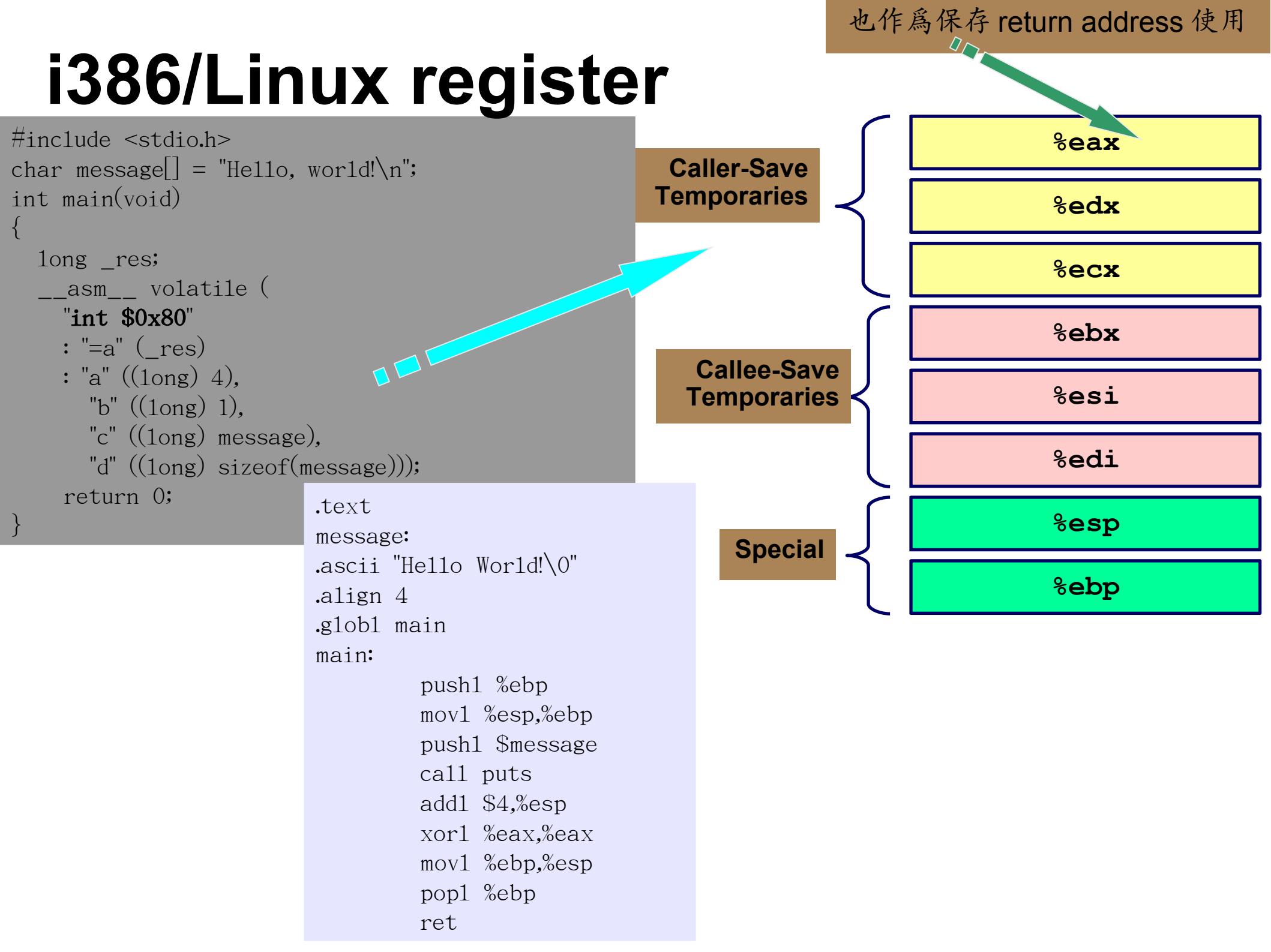
i386 stack


Stack "Bottom"
位址增加
Stack 增長
Stack pointer
%esp
Stack "Top"
Stack
Push
push1 SRC
popl DEST
Stack
Pop
Stack
Pointer
%esp
-4
+4
Linked
BF
Stack
80
7F
40
Libraries
3F
Data
Text
08
00

i386/Linux register

```
#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;
}
```

```
.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)

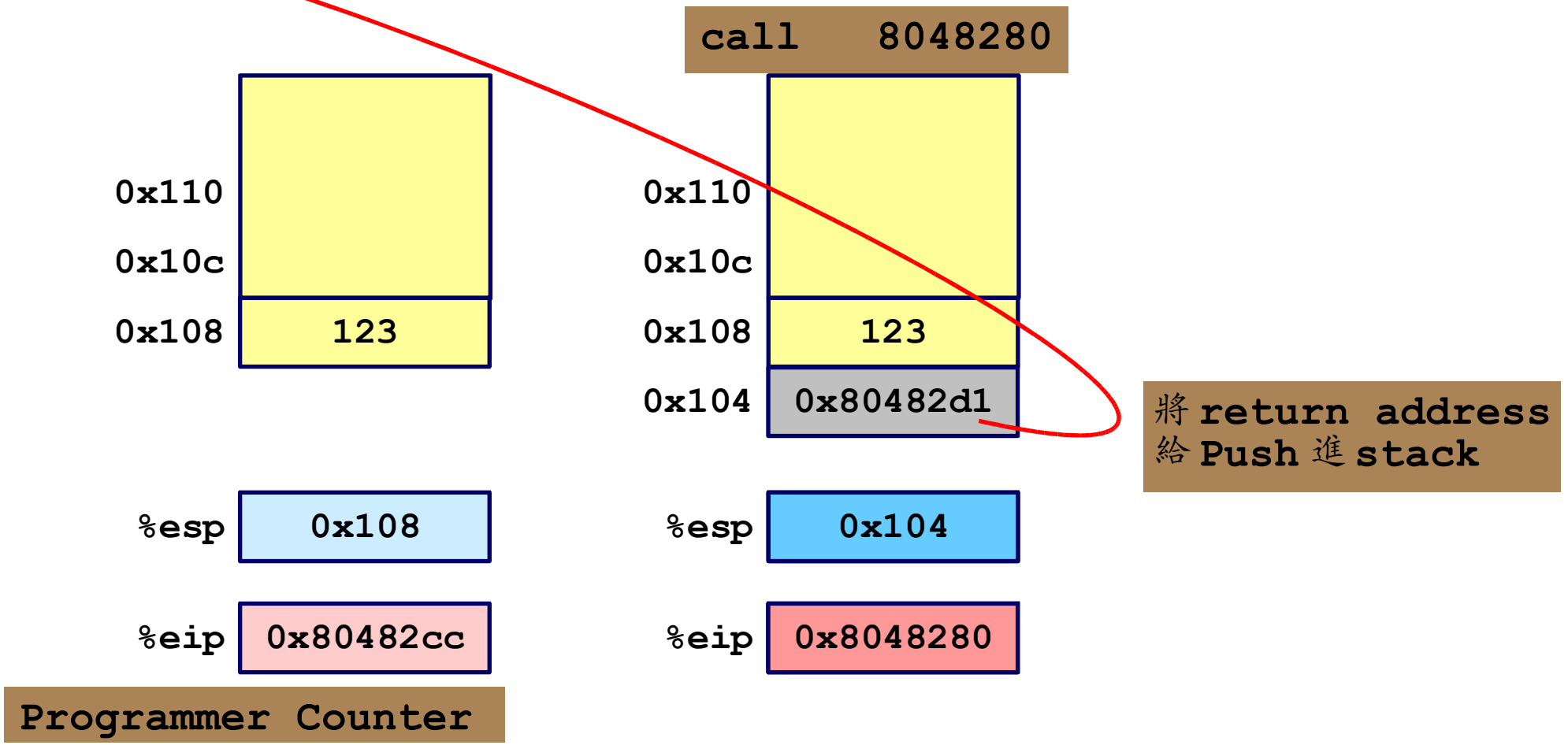
_start 爲該 Image 的 **entry point**

```
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

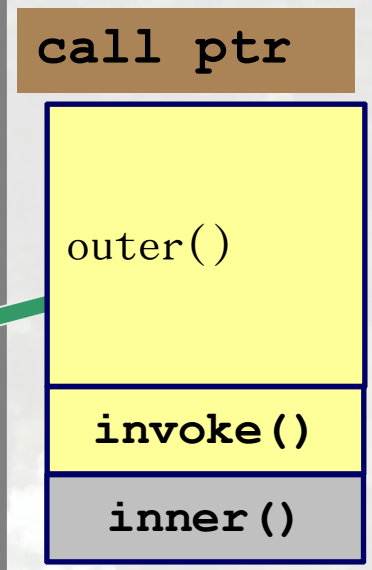
i386 call(2)

```
Disassembly of section .text:

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



GCC Inner Function

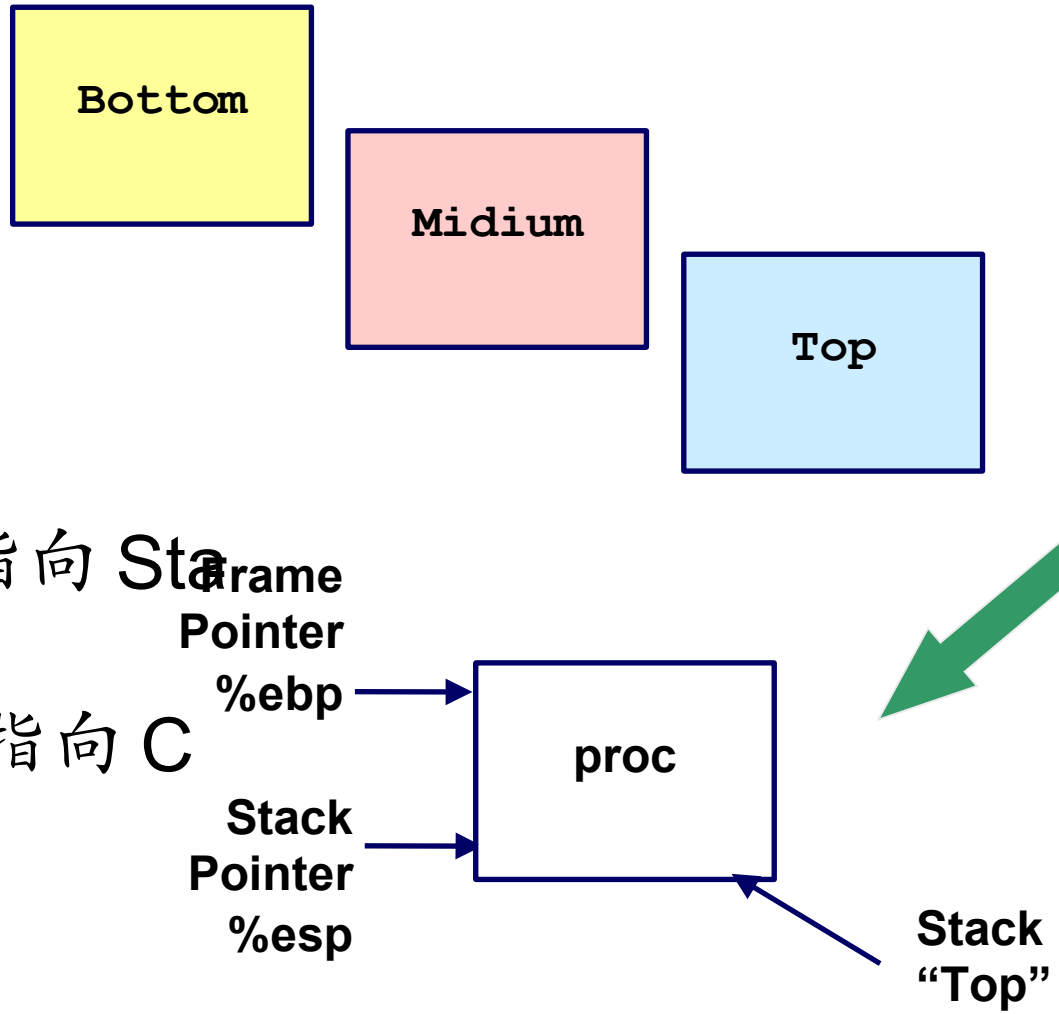
```
$ cat hello.c
#include <stdio.h>

void invoke(void (*func)()) {
    func();
}
void outer() {
    char *hello = "Hello World!\n";
    void inner() {
        printf("%s", hello);
    }
    invoke(inner);
}

int main() {
    outer();
}
$ ./hello
Hello World!
```



將 return address
給 Push 進 stack

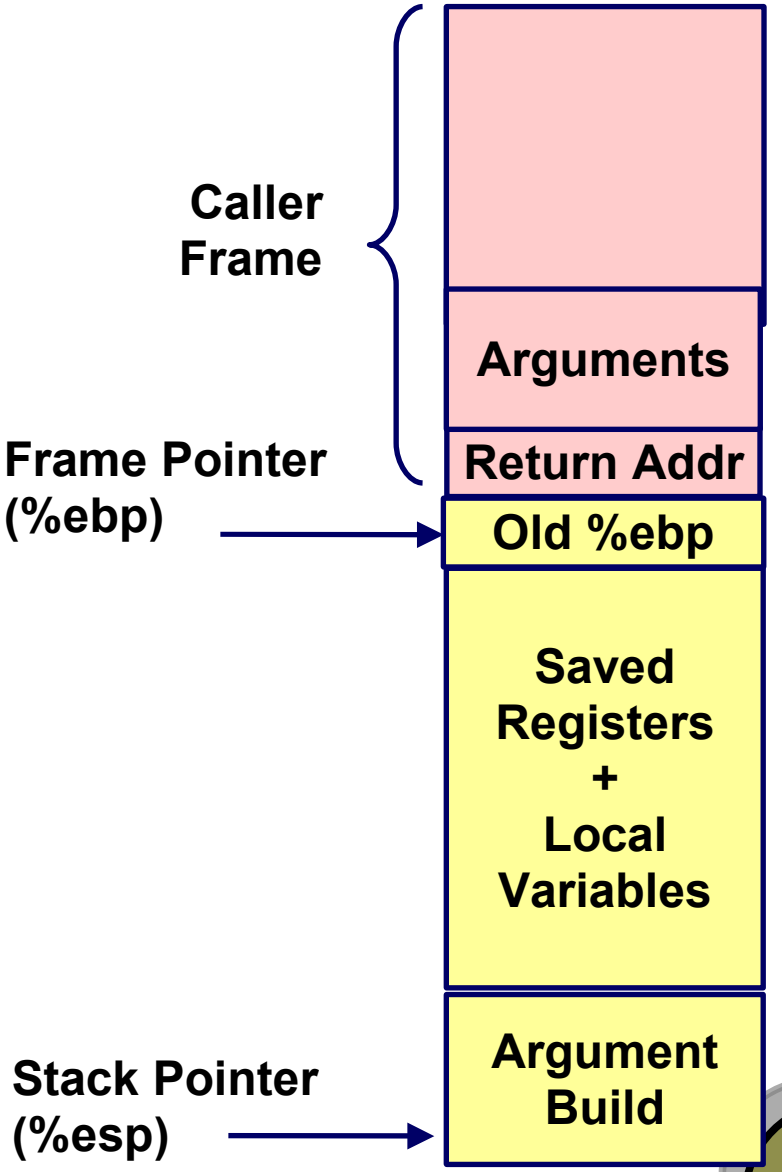
Stack Frame

- 要素
  - Local variables
  - Return information
  - Temporary space
- Pointers
  - Stack Pointer %esp 指向 Stack 的頂端
  - Frame pointer %ebp 指向 Current Frame 的開端



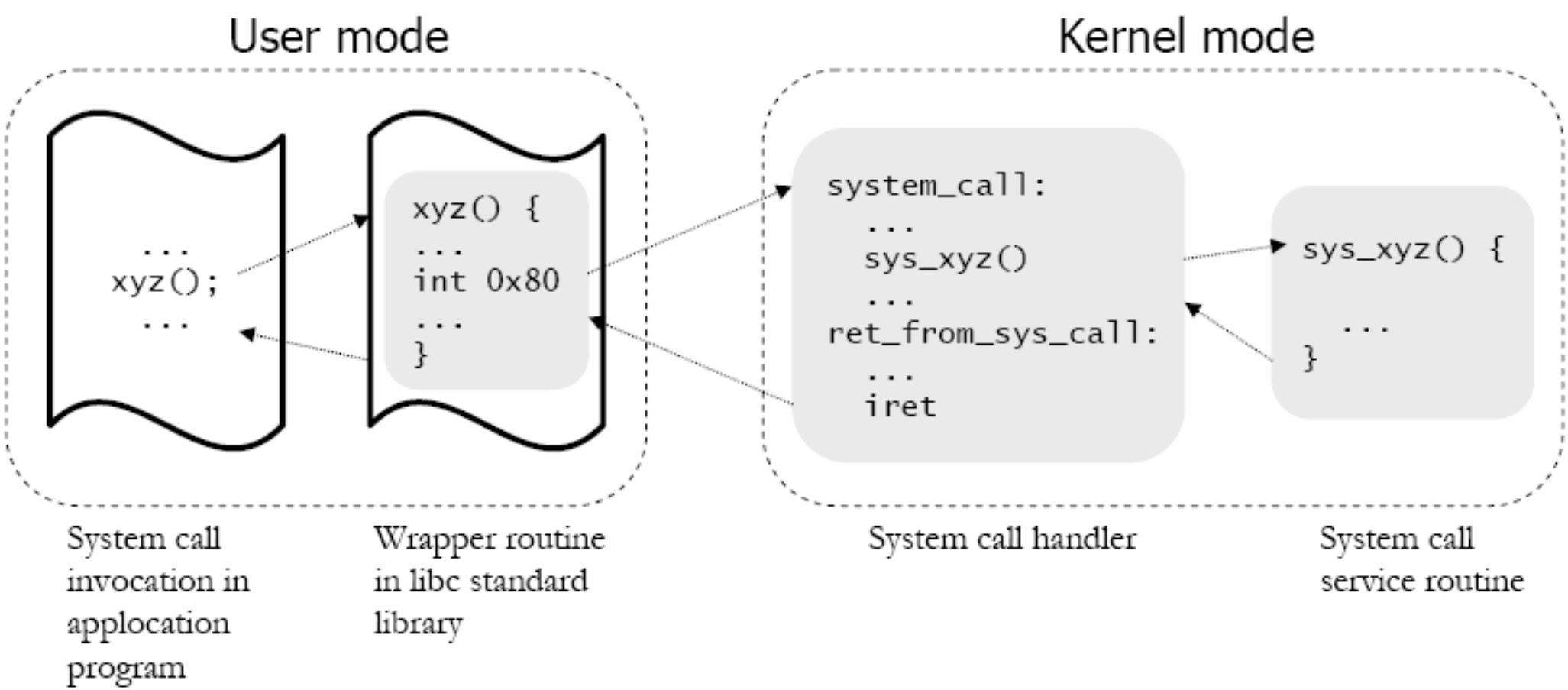
Stack Frame - IA32/Linux

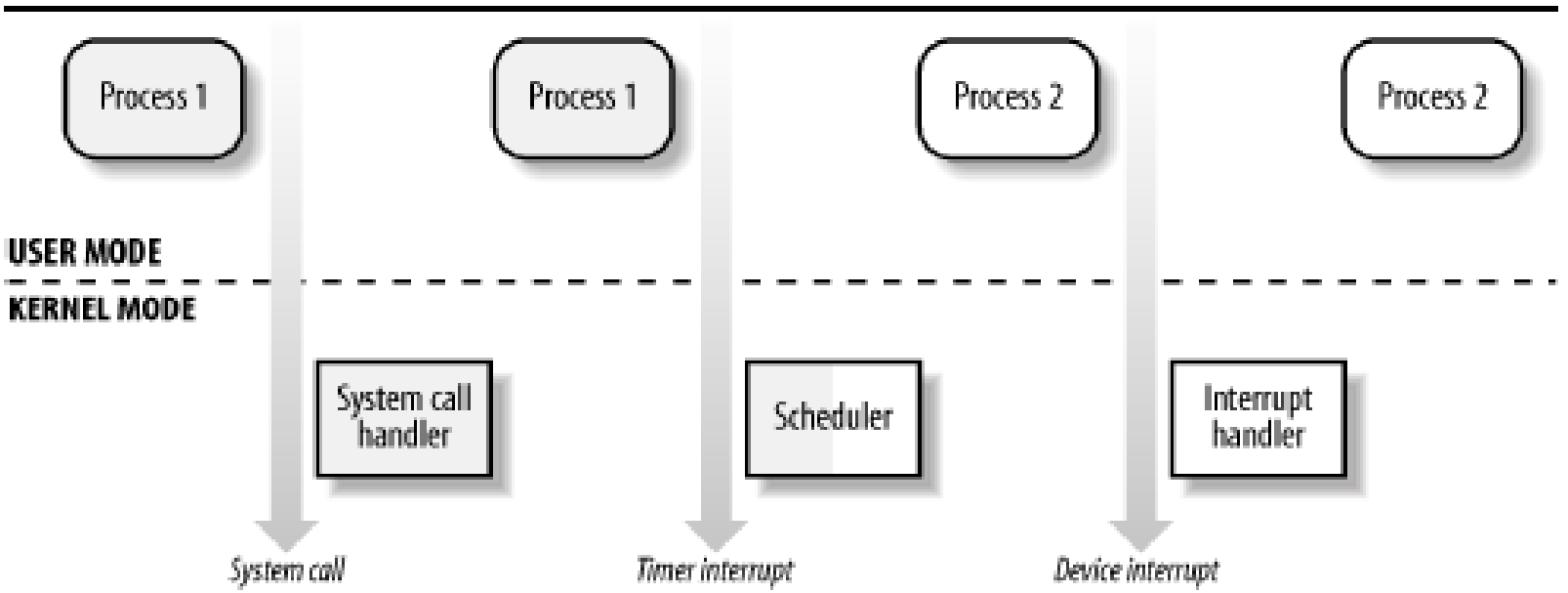
- Current Stack Frame
  - Arugment Build
    - Parameters for function about to call
  - Local variables
  - Saved register context
  - Old frame pointer
- Caller Stack Frame
  - Return address
    - Pushed by **call** instruction
  - Arguments for this call



深入 syscall

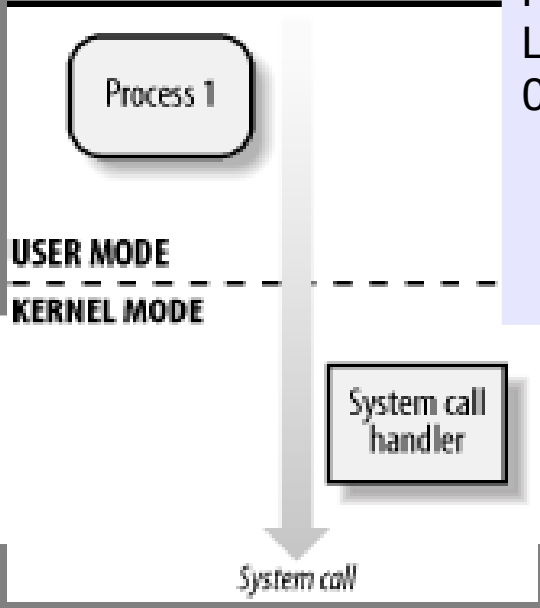
- syscall = system call
- 機制
  - libc wrapper
  - direct syscall
  - syscall function
- Linux kernel 2.6 的 virtual syscall


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

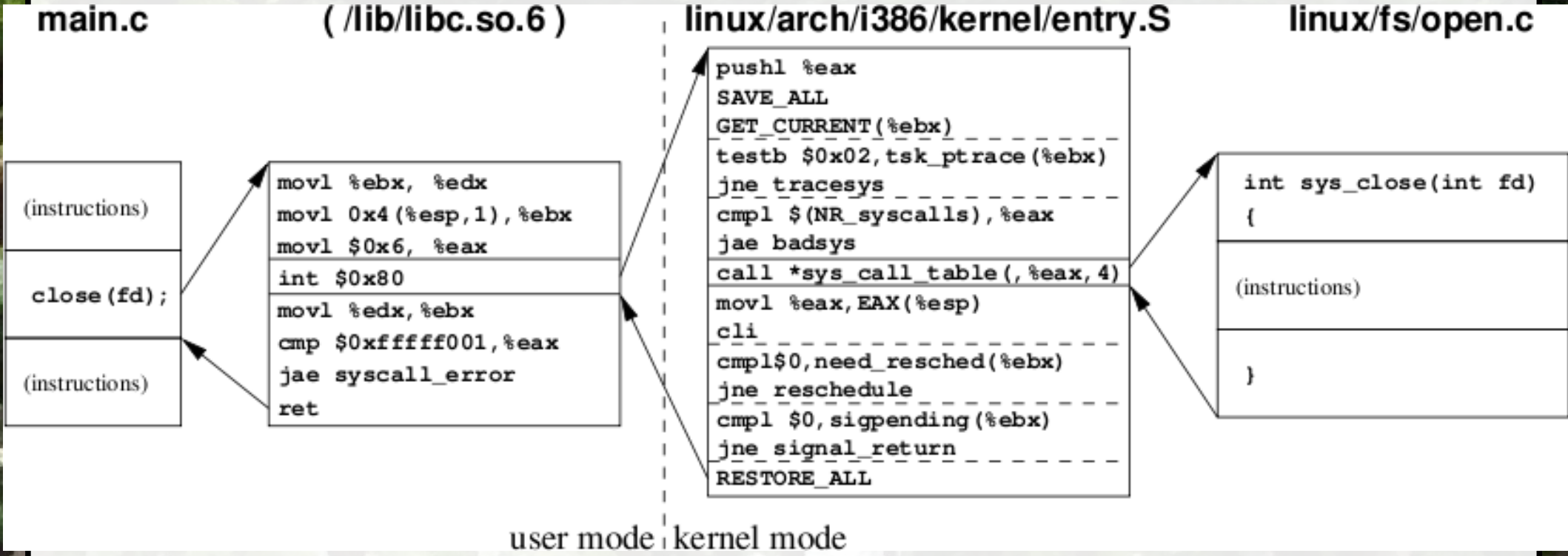
```
$ cat hello-loop.c
#include <stdio.h>
#include <unistd.h>
int main(int argc, char **argv)
{
        printf("Hello World!\n");
        while (1) {
                usleep(10000);
        }
        return 0;
}
$ ./hello-loop
Hello World!
```

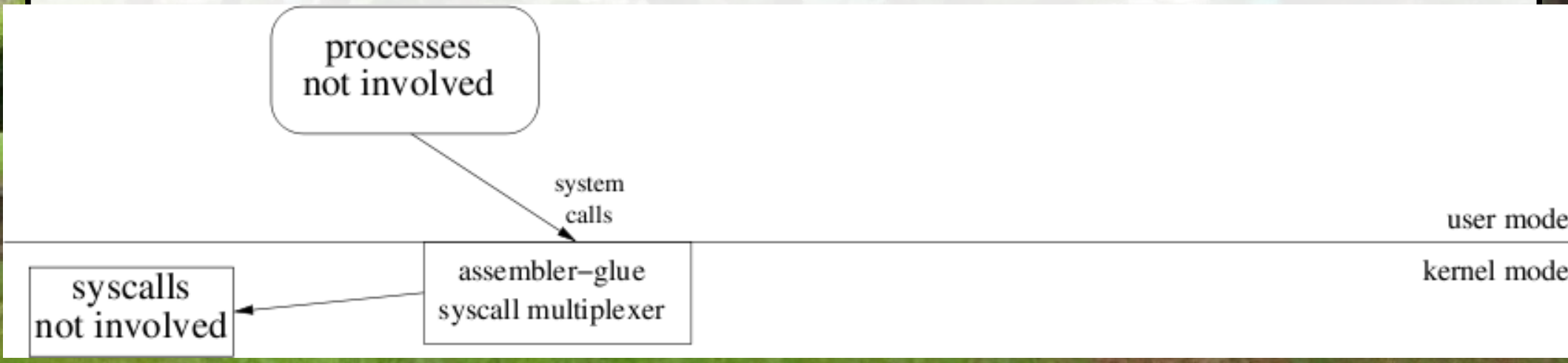
```
$ pidof hello-loop
6987
$ gdb
(gdb) attach 6987
Attaching to process 6987
Reading symbols from
/home/jserv/HelloWorld/samples/hello-loop...done.
Using host libthread_db library
"/lib/tls/i686/cmov/libthread_db.so.1".
Reading symbols from
/lib/tls/i686/cmov/libc.so.6...done.
Loaded symbols for /lib/tls/i686/cmov/libc.so.6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

典型系統呼叫 (1)


main.c
(/lib/libc.so.6)
linux/arch/i386/kernel/entry.S
linux/fs/open.c
(instructions)
close(fd);
(instructions)
movl %ebx, %edx
movl 0x4(%esp,1),%ebx
movl $0x6, %eax
int $0x80
movl %edx,%ebx
cmp $0xfffff001,%eax
jae syscall_error
ret
pushl %eax
SAVE_ALL
GET_CURRENT(%ebx)
testb $0x02,tsk_ptrace(%ebx)
jne tracesys
cmpl $(NR_syscalls),%eax
jae badsys
call *sys_call_table(,%eax,4)
movl %eax,EAX(%esp)
cli
cmpl$0,need_resched(%ebx)
jne reschedule
cmpl $0,sigpending(%ebx)
jne signal_return
RESTORE_ALL
int sys_close(int fd)
{
(instructions)
}
user mode
kernel mode


processes
not involved
system
calls
user mode
kernel mode
assembler–glue
syscall multiplexer
syscalls
not involved

典型系統呼叫 (2)

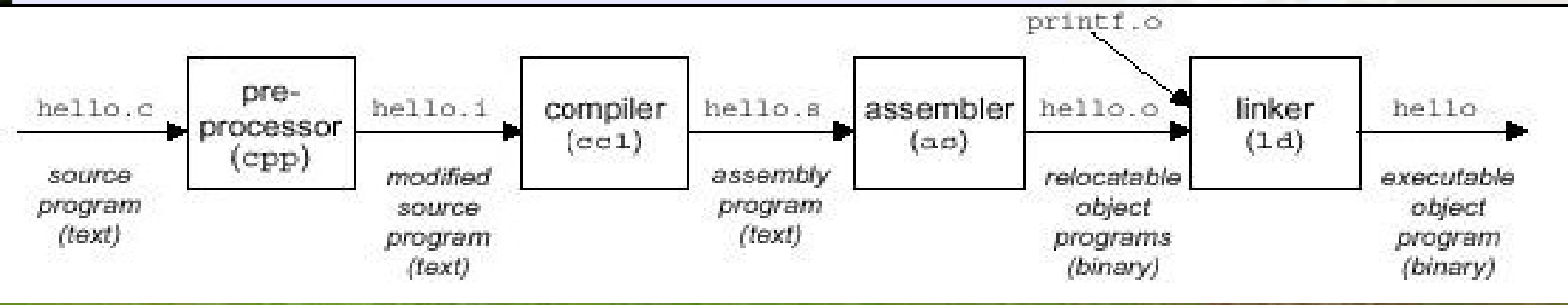
- 在 x86 保護模式，處理 int 中斷指令時， CPU 需要作繁複的查表與確認動作，才得以切換執行權，當 Kernel 執行系統呼叫完畢後，以 iret 返回，該指令恢復目前的 stack ， 並回到原本的執行
  - CPL <= DPL
- 由 Ring3 進入 Ring0 的過程浪費許多 CPU 週期

回頭看 hello.c 的編譯過程

```
$ gcc -v -o hello hello.c
Using built-in specs.
Target: i486-linux-gnu
...
 /usr/lib/gcc/i486-linux-gnu/4.1.2/collect2 --eh-frame-hdr
-m elf_i386 -dynamic-linker /lib/ld-linux.so.2 -o hello
/usr/lib/gcc/i486-linux-gnu/4.1.2/../../../../lib/crt1.o
/usr/lib/gcc/i486-linux-gnu/4.1.2/../../../../lib/crti.o
/usr/lib/gcc/i486-linux-gnu/4.1.2/crtbegin.o -L
/usr/lib/gcc/i486-linux-gnu/4.1.2 -L/usr/lib/gcc/i486-
linux-gnu/4.1.2 -L/usr/lib/gcc/i486-linux-
gnu/4.1.2/../../../../lib -L/lib/../lib -L/usr/lib/../lib
/tmp/ccyj1YoV.o -lgcc --as-needed -lgcc_s --no-as-
needed -lc -lgcc --as-needed -lgcc_s --no-as-needed
/usr/lib/gcc/i486-linux-gnu/4.1.2/crtend.o
/usr/lib/gcc/i486-linux-gnu/4.1.2/../../../../lib/crtn.o
$ wc -c hello
6749 hello
```

crt*.o
C Runtime object files

```
$ cat hello.c
int main() {
   printf("Hello World\n");
   return 0;
}
$ strace ./hello
...

write(1, "Hello World\n", 12Hello World.) = 12
exit_group(0)                           = ?
Process 14211 detached
```



系統呼叫 (1)

```
$ cat hello-write.c
#include <unistd.h>
int main()
{
    write(1, "Hello World\n", 12);
    return 0;
}
$ ./hello-write
Hello World
```

- 改用 POSIX 之 write 系統呼叫
- 但還不是最「直接」的使用系統呼叫
- 透過 libc wrapper 實現

```
/* Write N bytes of BUF to FD.  Return the number written, or -1.

   This function is a cancellation point and therefore not marked with
   __THROW.  */
extern ssize_t write (int __fd, __const void *__buf, size_t __n) __wur;
```

(/usr/include/unistd.h)

系統呼叫 (2)

```
$ cat hello-syscall.c
#include <asm/unistd.h>

static int errno;
_syscall1(int, exit, int, status);
_syscall3(int, write,
          int, fd,
          const void*, buf,
          unsigned long, count);

int main()
{
    write(1, "Hello World\n", 12);
    exit(0);
}
$ ./hello-syscall
Hello World
```

- linux-2.6.17/include/asm-i386/unistd.h
- gcc -o hello-syscall \
  -D__KERNEL__ \
  -fno-builtin \
  -fomit-frame-pointer \
  -I/lib/modules/`uname -r`/build/include \
  hello-syscall.c

```
#define _syscall1(type,name,type1,arg1) \
type name(type1 arg1) \
{ \
long __res; \
__asm__ volatile ("push %%ebx ; movl %2,%%ebx ; int
          $0x80 ; pop %%ebx" \
        : "=a" (__res) \
        : "0" (__NR_##name),"ri" ((long)(arg1)) : "memory"); \
__syscall_return(type,__res); \
}
```

```
extern ssize_t write (int __fd, __const void *__buf, size_t __n) __wur;
```

(/usr/include/unistd.h)

系統呼叫 (3)

```
$ cat hello-syscall2.c
#include <asm/unistd.h>

static int errno;
_syscall1(int, exit, int, status);
_syscall3(int, write,
    int, fd, const void*, buf,
    unsigned long, count);

void hello()
{
      write(1, "Hello World\n", 12);
      exit(0);
}
```

```
$ gcc -c -Os -D__KERNEL__ \
          -fno-builtin -fomit-frame-pointer \
          -I/lib/modules/`uname -r`/build/include \
          hello-syscall2.c
$ ld -o hello-syscall2 \
          -e hello \
          hello-syscall2.o
$ wc -c hello-syscall2
977 hello-syscall2
```

```
#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;
}
```

```
$ gcc -c -E  -Os -D__KERNEL__ -fno-builtin -fomit-fram  pointer \
-I/lib/modules/`uname -r`/build/include hello-sysc l2.c
...
int write(int fd,const void* buf,unsigned long count) { long __res; __asm__ volatile
("push %%ebx ; movl %2,%%ebx ; int $0x80 ; pop %%ebx" : "=a" (__res) : "0"
(4),"ri" ((long)(fd)),"c" ((long)(buf)), "d" ((long)(count)) : "memory"); do { if
((unsigned long)(__res) >= (unsigned long)(-(128 + 1))) { errno = -(__res); __res =
-1; } return (int) (__res); } while (0); };
...
```

系統呼叫 (4)

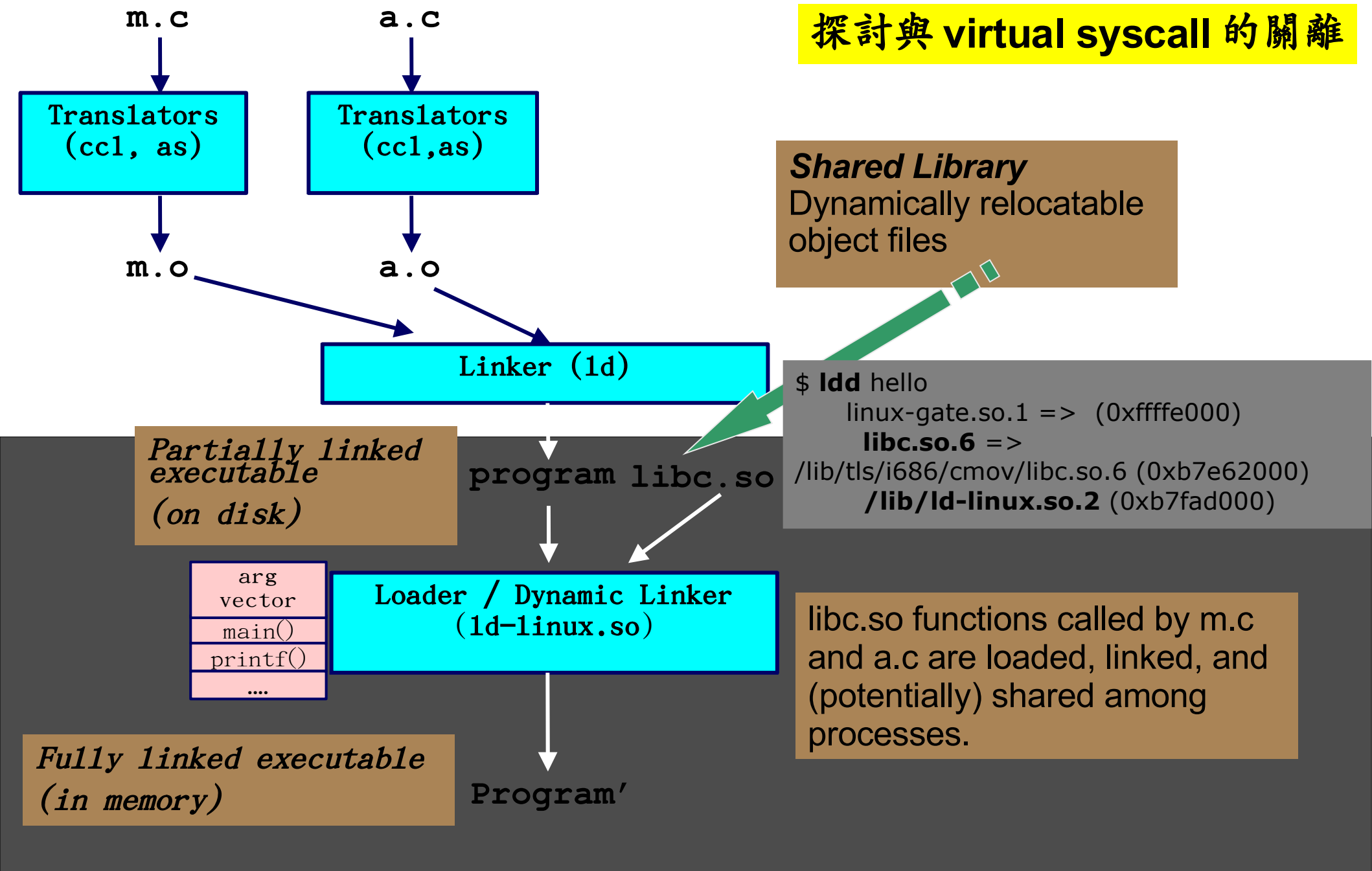
```
$ cat hello-syscall3.c
#include <stdio.h>
#include <sys/syscall.h>
#include <unistd.h>

int main()
{
        int ret;
        ret = syscall(__NR_write, 1, "Hello World\n", 12);
        return 0;
}
$ ./hello-syscall3
Hello World
```

```
#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;
}
```

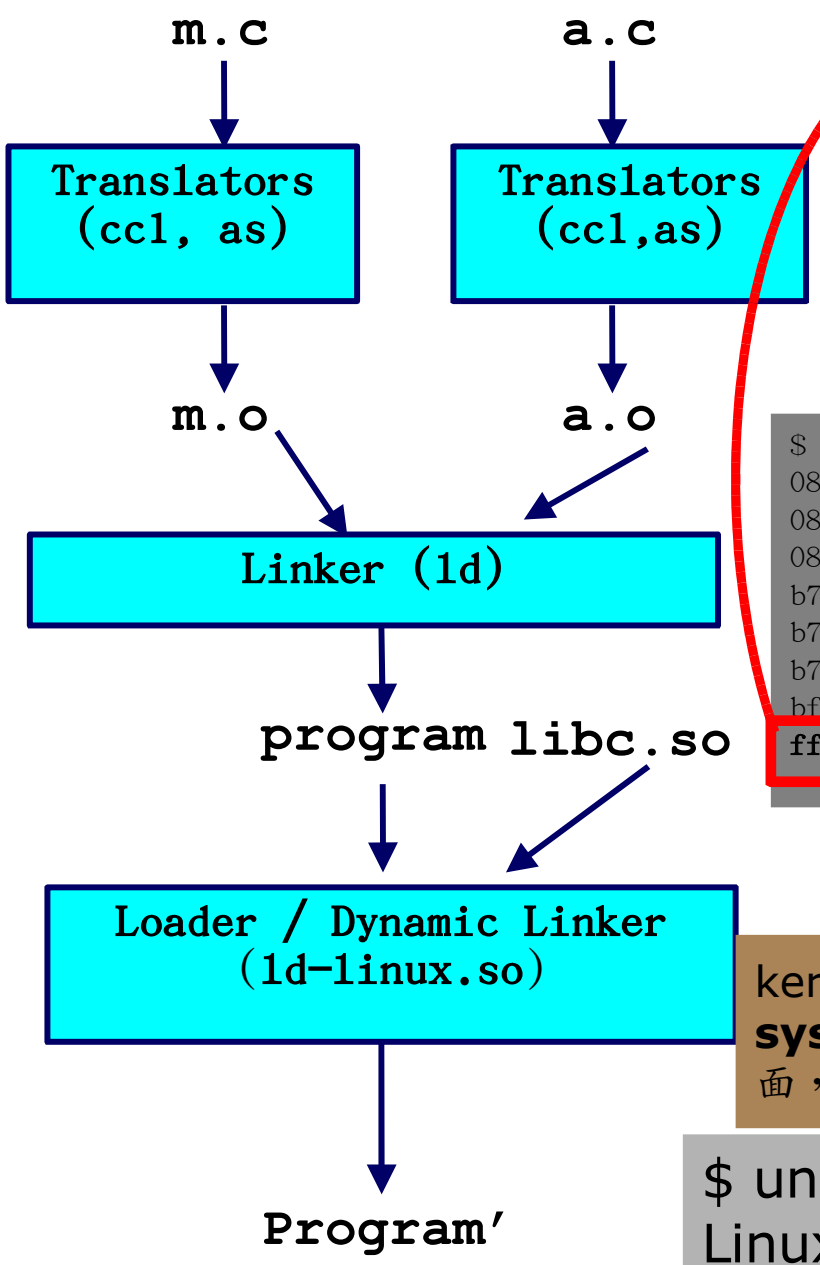
```
$ head /usr/include/bits/syscall.h
/* Generated at libc build time from kernel syscall list.  */

#ifndef _SYSCALL_H
# error "Never use <bits/syscall.h> directly; include <sys/syscall.h> instead."
#endif

#define SYS__llseek __NR__llseek
#define SYS__newselect __NR__newselect
#define SYS__sysctl __NR__sysctl
#define SYS_access __NR_access
```

```
$ head -n 12 /usr/include/asm-i386/unistd.h
#ifndef _ASM_I386_UNISTD_H_
#define _ASM_I386_UNISTD_H_

/*
 * This file contains the system call numbers.
 */

#define __NR_restart_syscall      0
#define __NR_exit                 1
#define __NR_fork                 2
#define __NR_read                 3
#define __NR_write                4
```

Dynamically Linked Shared Libraries(1)



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

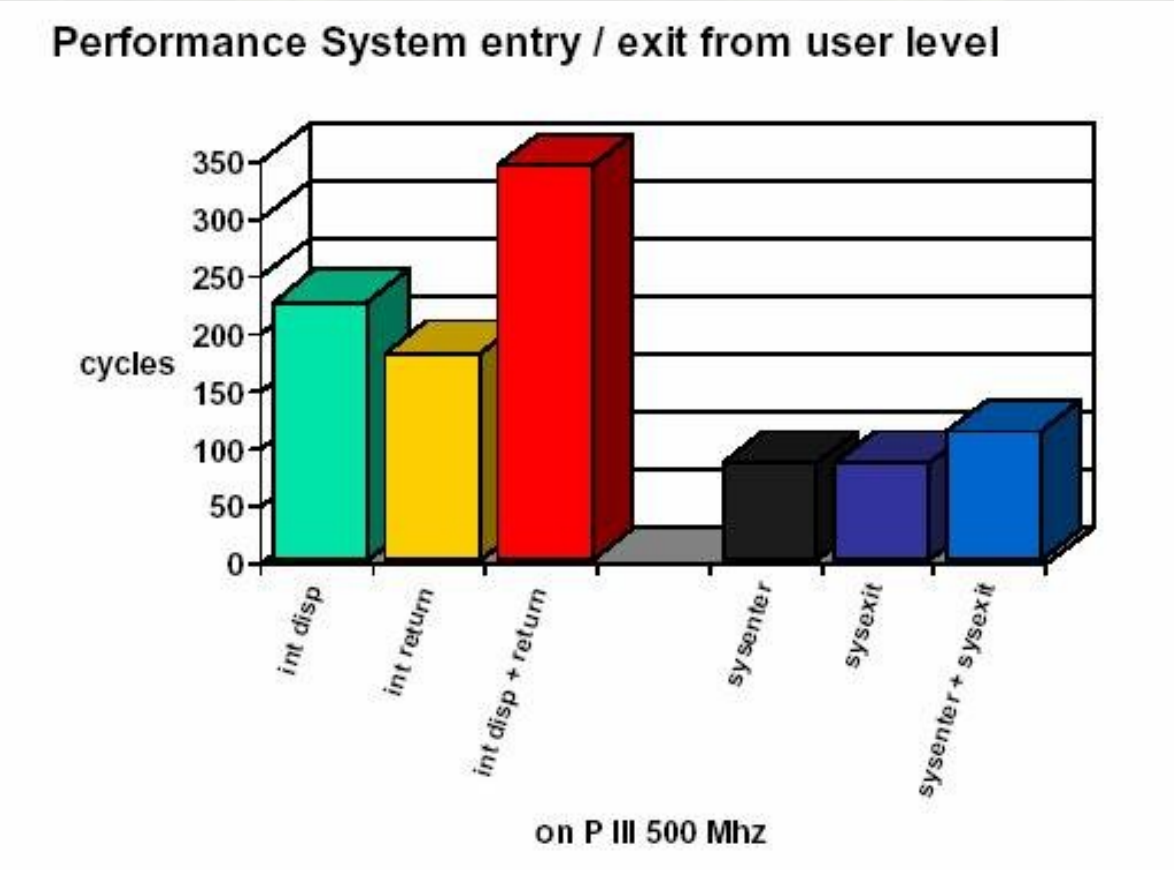
kernel 2.6 支援 Pentium III+ 的快速系統呼叫 **sysenter / sysexit** 機制。核心提供原先的 int 0x80 ，與新的 **sysenter** 雙介面，並虛擬印射了 **linux-gate.so.1** 來實作

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

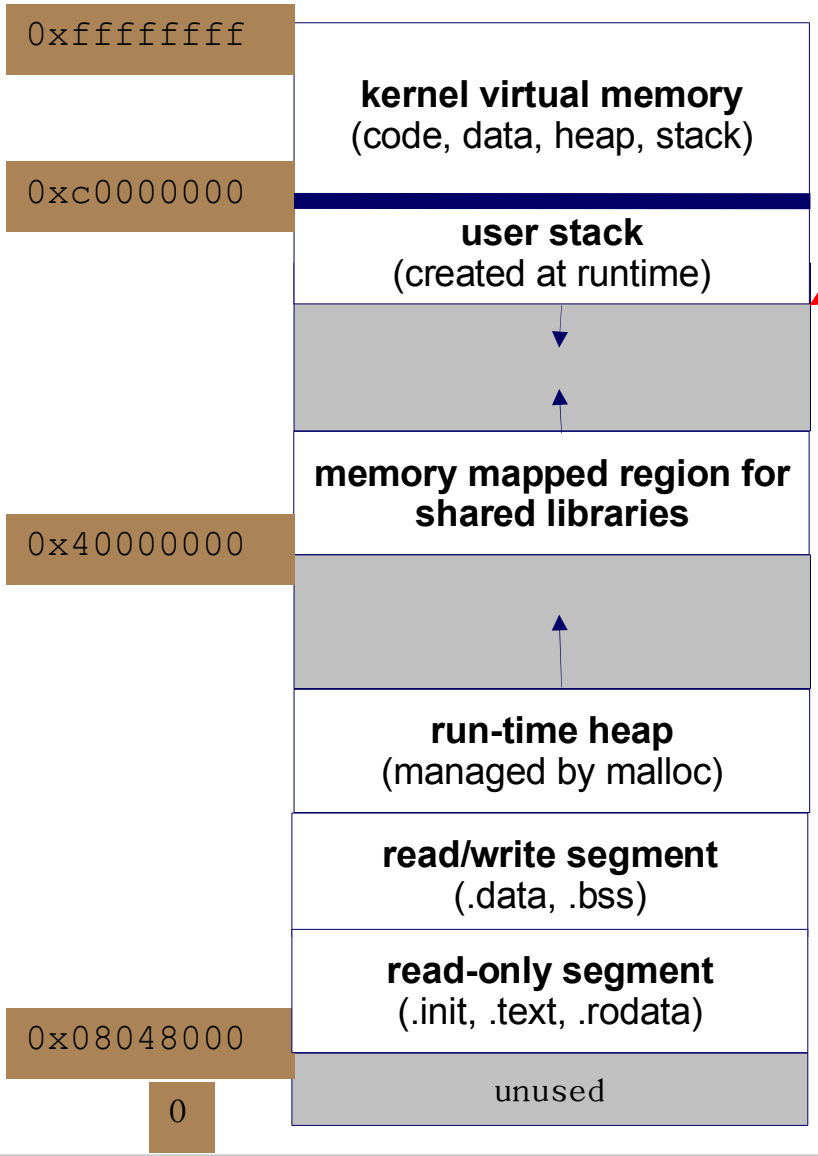
int80 vs. sysenter/sysexit

耗費時間	User-Mode	Kernel-Mode
以 **int80** 為基礎的系統呼叫	17.500ms	7.00ms
以 **systenter/ sysexit** 為基礎	**9.833ms**	**6.833ms**

Intel® Pentium® III CPU, 450 MHzProcessor Family: 6 Model: 7 Stepping: 2



Dynamically Linked Shared Libraries(3)



memory invisible to user code

%esp (stack pointer)

brk

loaded from the executable file

```
$ 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

auxiliary vector (auxv)

argv ➔ program arguments

envp ➔ environment variables

適用新建立的 Process

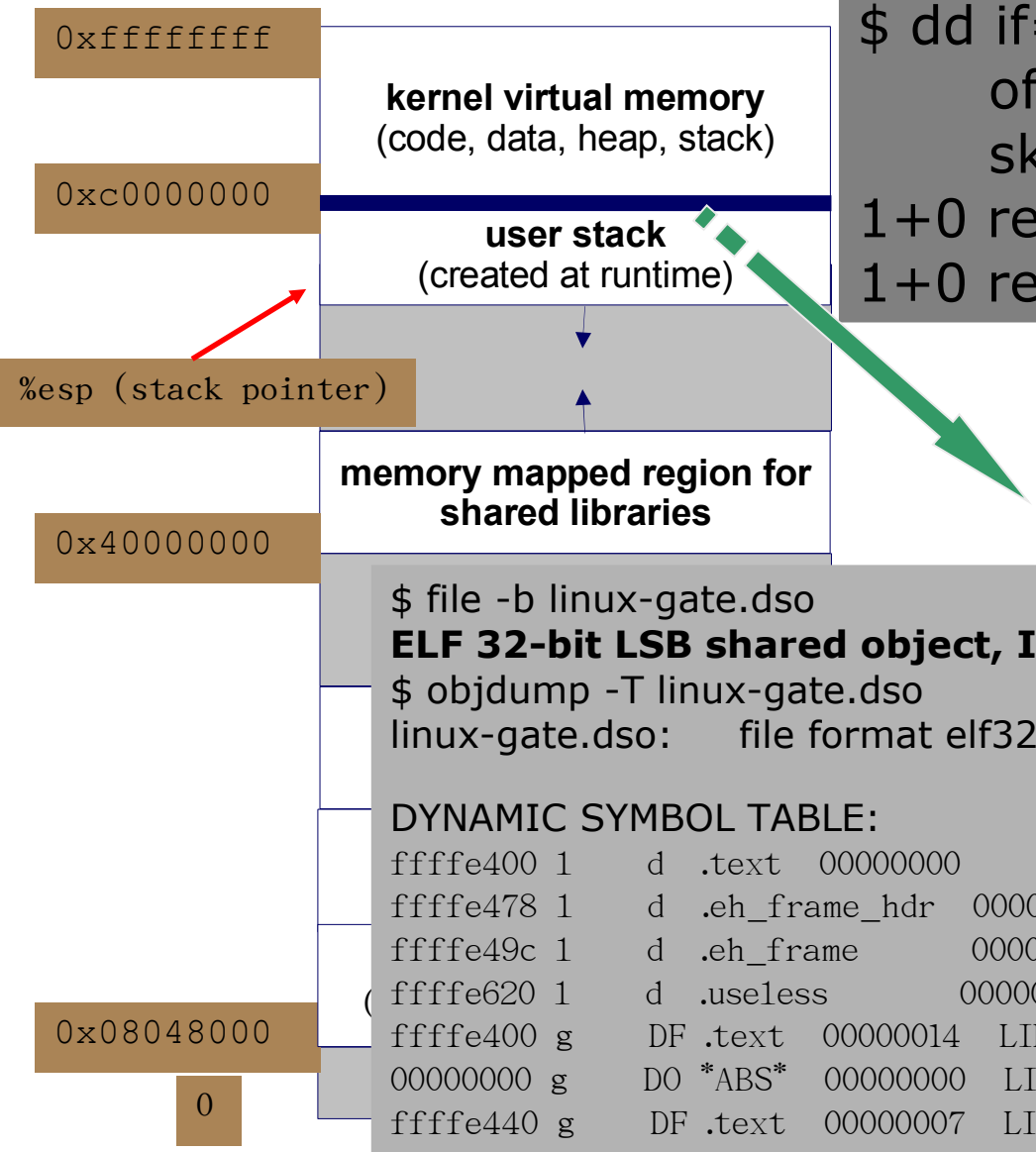
```
$ gdb -c core -q
Core was generated by `hello'.
Program terminated with signal 11, Segmentation fault.
#0  0xffffe777 in ?? ()
(gdb) bt
#0  0xffffe777 in ?? ()
```

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)



/proc/self/mem
Memory snapshot

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

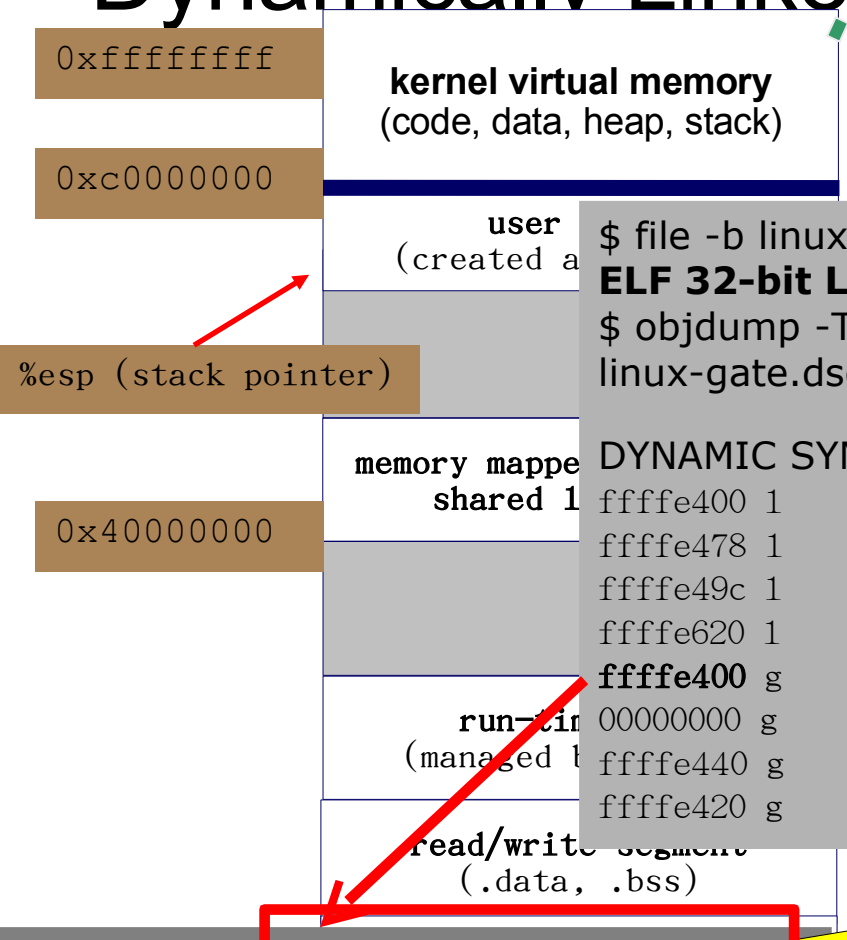
2^{20} = **1048576**

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
```

__kernel_vsyscall 進入點

```
$ 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
```

```
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
```

虛擬系統呼叫

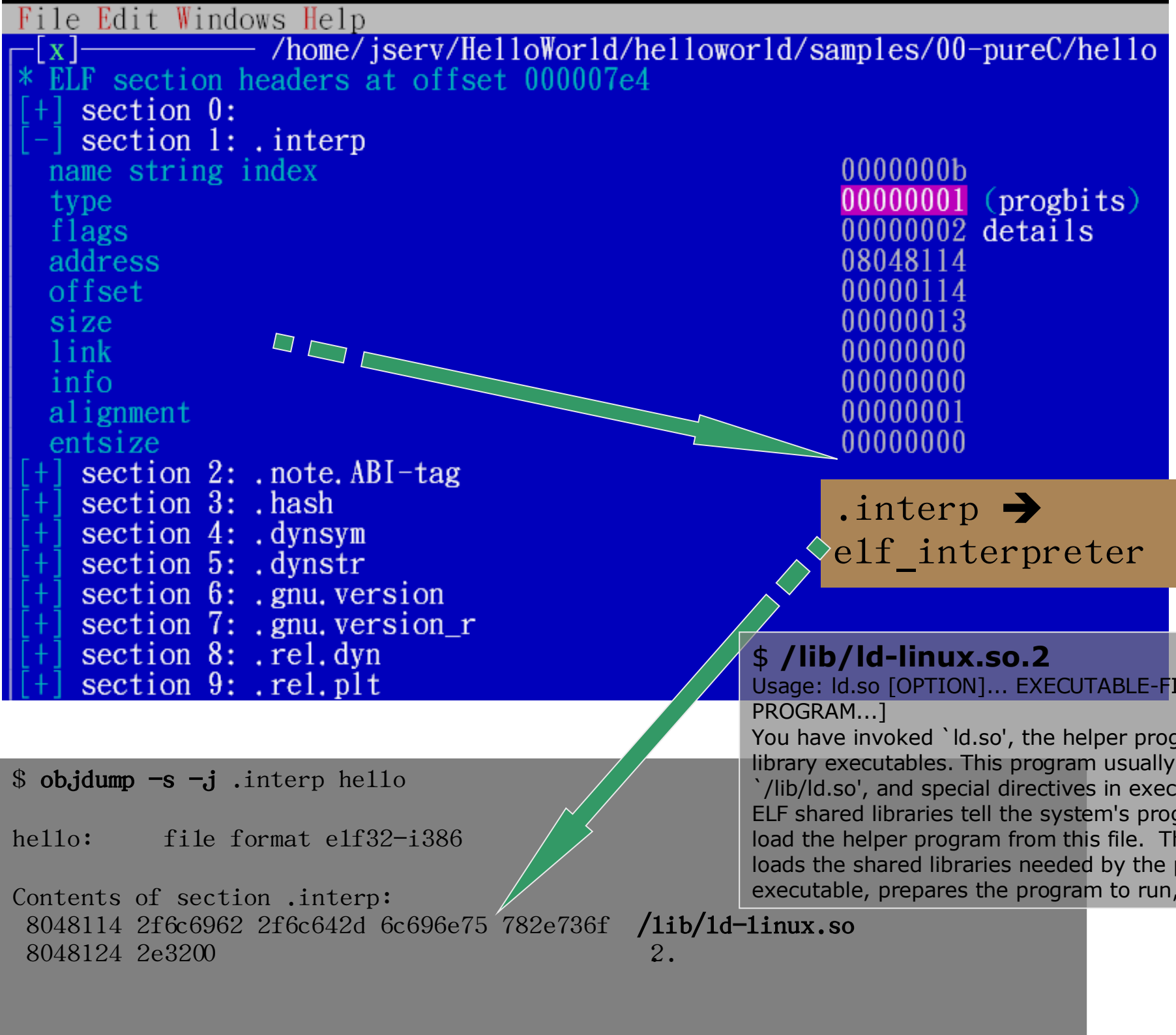
```
$ cat hello.c
#include <stdio.h>
#include <sys/syscall.h>
#include <unistd.h>
int main() {
        int ret;
        char message[] = "Hello, world!\n";
        __asm__ volatile (
                "call *%2"
                : "=a" (ret)
                : "a" (__NR_write),
                  "S" (0xffffe400),
                  "b" ((long) 1),
                  "c" ((long) message),
                  "d" ((long) sizeof(message)));
        return 0;
}
$ ./hello
Hello, world!
```

```
$ 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
```

以 **procedure call** 的形式呼叫了 **system call**

再探動態連結

- 執行時期的系統呼叫
- glibc 的 HWCAP 機制
- Rundll32.exe on Linux


File Edit Windows Help
[x] /home/jserv/HelloWorld/helloworld/samples/00-pureC/hello
* ELF section headers at offset 000007e4
[+] section 0:
[-] section 1: .interp
name string index 0000000b
type 00000001 (progbits)
flags 00000002 details
address 08048114
offset 00000114
size 00000013
link 00000000
info 00000000
alignment 00000001
entsize 00000000
[+] section 2: .note.ABI-tag
[+] section 3: .hash
[+] section 4: .dynsym
[+] section 5: .dynstr
[+] section 6: .gnu.version
[+] section 7: .gnu.version_r
[+] section 8: .rel.dyn
[+] section 9: .rel.plt
.interp ➔
elf_interpreter
$ /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.
$ objdump -s -j .interp hello
hello: file format elf32-i386
Contents of section .interp:
8048114 2f6c6962 2f6c642d 6c696e75 782e736f /lib/ld-linux.so
8048124 2e3200 2.

執行時期的系統呼叫 (1)

- glibc 的實做 sysdeps/unix/sysv/linux/i386/sysdep.h

```
# define INTERNAL_SYSCALL(name, err, nr, args...) \
({    \
   register unsigned int resultvar; \
   EXTRAVAR_##nr     \
   asm volatile ( \
      LOADARGS_##nr \
      "movl %1, %%eax\n\t"     \
      "int $0x80\n\t"     \
      RESTOREARGS_##nr     \
      : "=a" (resultvar) \
      : "i" (__NR_##name) \
            ASMFMT_##nr(args)
      : "memory", "cc"); \
   ( int) resultvar; })
```

```
#define INLINE_SYSCALL(name, nr, args...) \
({   \
    unsigned int resultvar = INTERNAL_SYSCALL
   (name, , nr, args); \
    if (__builtin_expect
   (INTERNAL_SYSCALL_ERROR_P (resultvar, ), 0))
    { \
        __set_errno (INTERNAL_SYSCALL_ERRNO
   (resultvar, )); \
        resultvar = 0xffffffff; \
    } \
} \
(int) resultvar; })
```

執行時期的系統呼叫 (2)

- 程式載入器或 shell 會有類似的操作
  - execve syscall
- Linux Kernel
  - arch/i386/kernel/traps.c

```
mov1 <envp>, %edx
mov1 <argv>, %ecx
mov1 <file>, %ebx
mov1 $11, %eax                ; execve
int $0x80
```

```
void __init trap_init(void)
{
    ...
  set_system_gate(SYSCALL_VECTOR,
                  &system_call);
}
```

將於 Part III 中透過 User-Mode-Linux 與 qemu 分析其原理

glibc 的 HWCAP 機制 (1)

- $ COLUMNS=200 dpkg -l | grep libc6
  - ii **libc6** 2.5-0ubuntu2 GNU C Library: Shared libraries
  - ii libc6-dev 2.5-0ubuntu2 GNU C Library: Development Libraries and Header Files
  - ii **libc6-i686** 2.5-0ubuntu2 GNU C Library: Shared libraries [**i686 optimized**]
- 一般 i386 與 i686 最佳化的 glibc 如何共存?
- 特定之函數，如數學運算，如何在執行時期針對硬體挑選最佳的實做?
- 引入 HWCAP (Hardware Capacities) 的機制
  - LD_SHOW_AUXV (AUXiliary Vector)

glibc 的 HWCAP 機制 (2)

```
$ ldd hello
        linux-gate.so.1 =>  (0xffffe000)
        libc.so.6 => /lib/tls/i686/cmov/libc.so.6 (0xb7e8d000)
        /lib/ld-linux.so.2 (0xb7fe5000)
$ realpath /lib/libc.so.6
/lib/libc-2.5.so
$ strace -f ./hello
execve("./hello", ["./hello"], [/* 28 vars */]) = 0
...
access("/etc/ld.so.nohwcap", F_OK)      = -1 ENOENT (No such file or
directory)
open("/lib/tls/i686/cmov/libc.so.6", O_RDONLY) = 3
read(3, "\177ELF\1\1\1\0\0\0\0\0\0\0\0\0\3\0\3\0\1\0\0\0`\1\000"..., 512) = 512
fstat64(3, {st_mode=S_IFREG|0644, st_size=1311200, ...}) = 0
...
```

cmov = Pentium4 SSE2 Conditional MOVe

glibc 的 HWCAP 機制 (3)

```
$ LD_SHOW_AUXV=1 ./hello
AT_SYSINFO:      0xffffe400
AT_SYSINFO_EHDR: 0xffffe000
AT_HWCAP:    fpu vme de pse tsc msr mce cx8 sep mtrr pge mca cmov pat
clflush dts acpi mmx fxsr sse sse2 tm pbe
AT_PAGESZ:       4096
AT_CLKTCK:       100
AT_PHDR:         0x8048034
AT_PHENT:        32
AT_PHNUM:        7
AT_BASE:         0xb7fca000
AT_FLAGS:        0x0
AT_ENTRY:        0x80482b0
AT_UID:          1000
AT_EUID:         1000
AT_GID:          1000
AT_EGID:         1000
AT_SECURE:       0
AT_PLATFORM:     i686
Hello World!
```

Rundll32.exe on Linux(1)

- MS-Windows Rundll.exe 允許透過命令列載入 DLL 並呼叫其中的 function
  - Rundll32.exe DllFileName FuncName
- izik(http://www.tty64.org) 針對 x86/Linux 撰寫 Runlib32
  - ./runlib libc.so.6,puts \""Hello World"\"

```
$ ./runlib -v -x printf-out libc.so.6,puts \""Hello World"\"
puts[<0xb7ed8610>]@libc.so.6[]
------------------------------------------------------
* Stack Generated (1 parameters, 4 bytes)
--------------------------------------
Generated Assembly
-----------------
 * pushl $0xbfce7c9a
 * call 0xb7ed8610
```

```
Streams Buffers
---------------
 * Standart Output (STDOUT) : 15 bytes
 * Standart Error  (STDERR) : 0 bytes

Function Result
---------------
 * Pointer: No
 * Value: 12
$ cat printf-out
Hello World
```

Rundll32.exe on Linux(2)

src/lib.c

```
/*
 * Manually pushing the function arguments to
* the stack
 */

if (ptr->stack) {
        for (j = 0; j < ptr->stack->stack_items; j++) {
                __asm__ __volatile__ (\
                        "pushl %0 \n" \
                        : /* no output */ \
                        : "r" (ptr->stack->stack[j]) \
                        : "%eax" \
                        );
        }
}
```

```
/*
 * Make the CALL!
 */
ret = (unsigned long) ptr->fcn_handler();

/*
 * Be polite, let's clean the stack afterward
 */
if (ptr->stack) {
        ptr->stack->stack_items *= sizeof(long);
        __asm__ __volatile__ (\
                "addl %0, %%esp \n" \
                : /* no output */ \
                : "r" (ptr->stack->stack_items) \
                : "%esp" );
        ptr->stack->stack_items /= sizeof(long);
}

s_errno = errno;
signal(SIGSEGV, SIG_DFL);
```

Rundll32.exe on Linux(3)

- Trampoline (Assembly/Machine_code-C interfacing)
- 類似技術廣泛應用於:
  - ffcall (GNUstep/Objective-C)
  - libffi (GNU GCC)
  - JIT compiler (Kaffe, Hotspot, ...)
  - Boot-straping code in dynamic programming language engine

參考資料

- 《Binary Hacks》， O'Reilly Japan
- Linkers and Loaders
  - http://www.iecc.com/linker/
- Startup state of a Linux/i386 ELF binary
  - http://asm.sourceforge.net/articles/startup.html
- IA32 上 Linux 內核中斷機制分析
  - http://www.whitecell.org/list.php?id=23
- FFCALL
  - http://www.haible.de/bruno/packages-ffcall.html
- Linux 2.6 對新型 CPU 快速系統調用的支持
  - http://www-128.ibm.com/developerworks/cn/linux/kernel/l-k26ncpu/

Incoming Part III

- 以 User-Mode-Linux 與 qemu 分析系統呼叫
- 探索 Linux Kernel 之 Program Loader
- User-space 與 Kernel-space 的互動
- 效能與記憶體窺探