操作系统课程实验

Lab1：bootloader启动

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大纲

- x86 启动顺序
- C函数调用
- gcc内联汇编（inline assembly）
- x86-32下的中断处理

- 理解x86-32平台的启动过程
- 理解x86-32的实模式、保护模式
- 理解段机制

x86启动顺序

x86启动顺序 – 寄存器初始值

Table 9-1. IA-32 Processor States Following Power-up, Reset, or INIT

Register	Pentium 4 and Intel Xeon Processor	P6 Family Processor (Including DisplayFamily = 06H)	Pentium Processor
EFLAGS[1]	00000002H	00000002H	00000002H
EIP	0000FFF0H	0000FFF0H	0000FFF0H
CR0	60000010H[2]	60000010H[2]	60000010H[2]
CR2, CR3, CR4	00000000H	00000000H	00000000H
CS	Selector = F000H Base = FFFF0000H Limit = FFFFH AR = Present, R/W, Accessed	Selector = F000H Base = FFFF0000H Limit = FFFFH AR = Present, R/W, Accessed	Selector = F000H Base = FFFF0000H Limit = FFFFH AR = Present, R/W, Accessed
SS, DS, ES, FS, GS	Selector = 0000H Base = 00000000H Limit = FFFFH AR = Present, R/W, Accessed	Selector = 0000H Base = 00000000H Limit = FFFFH AR = Present, R/W, Accessed	Selector = 0000H Base = 00000000H Limit = FFFFH AR = Present, R/W, Accessed
EDX	00000FxxH	000n06xxH[3]	000005xxH
EAX	0[4]	0[4]	0[4]
EBX, ECX, ESI, EDI, EBP, ESP	00000000H	00000000H	00000000H

摘自"IA-32 Intel体系结构软件开发者手册"

x86启动顺序 – 第一条指令

- CS = F000H, EIP = 0000FFF0H
- 实际地址是:

  Base + EIP = FFFF0000H + 0000FFF0H = FFFFFFF0H

  这是BIOS的EPROM (Erasable Programmable Read Only Memory) 所在地
- 当CS被新值加载，则地址转换规则将开始起作用
- 通常第一条指令是一条长跳转指令(这样CS和EIP都会更新)到BIOS代码中执行

x86启动顺序 – 处于实模式的段

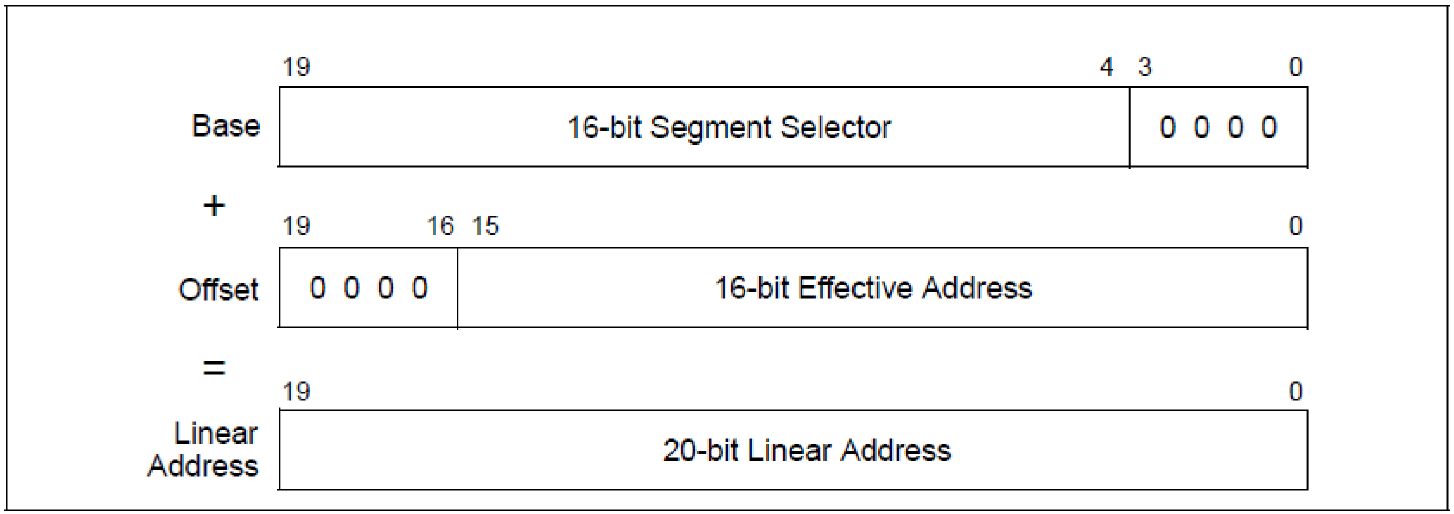


Figure 20-1. Real-Address Mode Address Translation

摘自"IA-32 Intel体系结构软件开发者手册"

- 段选择子（Segment Selector）: CS, DS, SS, …
- 偏移量（Offset）: EIP

x86启动顺序 – 从BIOS到Bootloader

- BIOS 加载存储设备（比如软盘、硬盘、光盘、USB盘）上的第一个 扇区(主引导扇区，Master Boot Record, or MBR) 的512字节到内存的 0x7c00 …
- 然后转跳到 @ 0x7c00的第一条指令开始执行

x86启动顺序 – 从bootloader到OS

- bootloader做的事情:
  - 使能保护模式（protection mode） & 段机制（segment-level protection）
  - 从硬盘上读取kernel in ELF 格式的ucore kernel (跟在MBR后面的扇区)并放到内存中固定位置
  - 跳转到ucore OS的入口点（entry point）执行，这时控制权到了ucore OS中

x86启动顺序 – 段机制

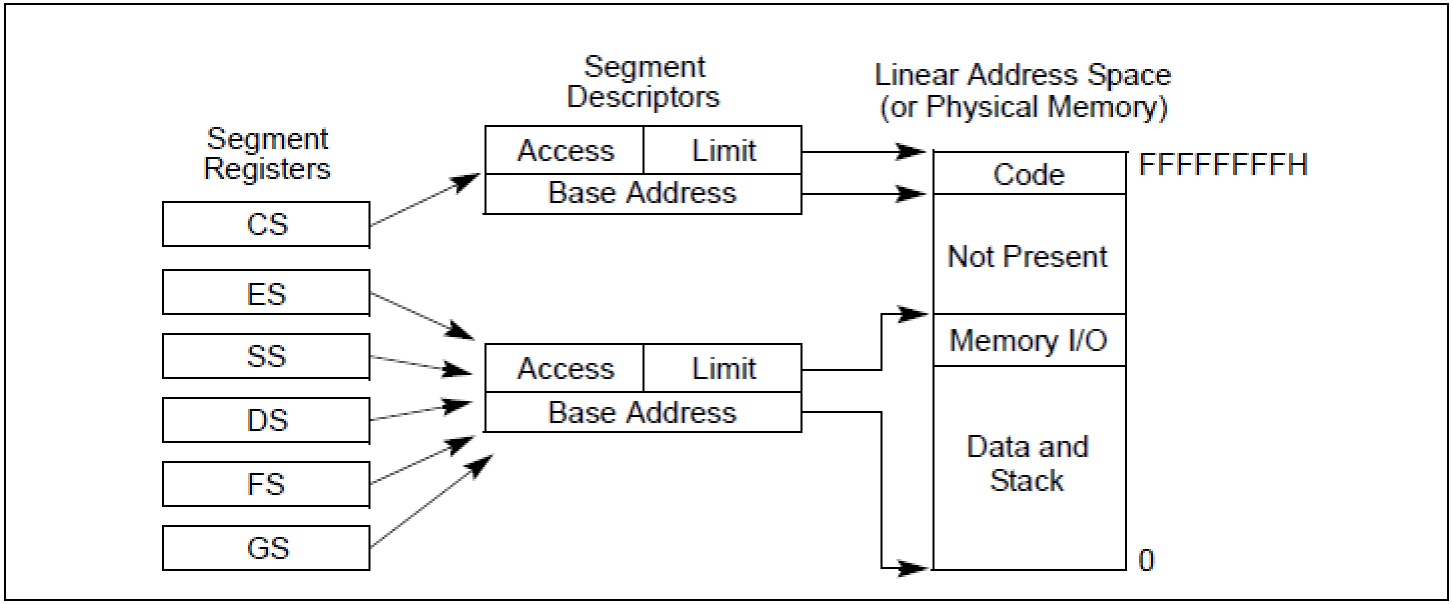


Figure 3-3. Protected Flat Model

摘自"IA-32 Intel体系结构软件开发者手册"

x86启动顺序 – 段机制

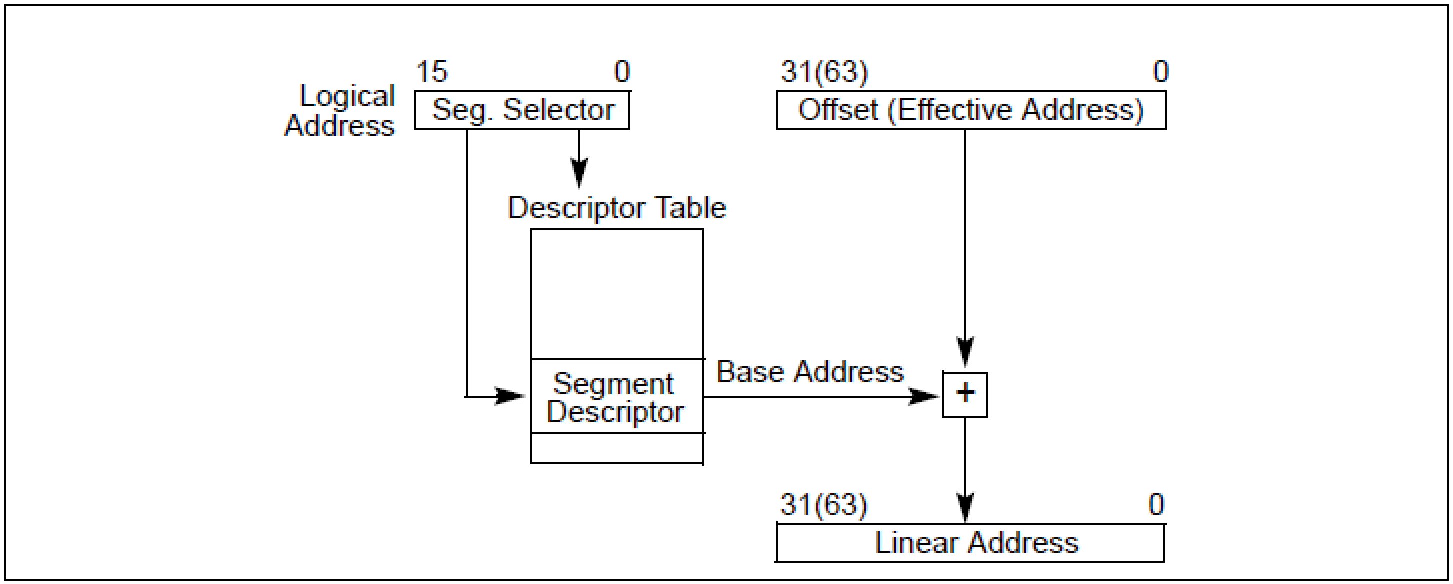


Figure 3-5. Logical Address to Linear Address Translation

摘自"IA-32 Intel体系结构软件开发者手册"

x86启动顺序 – 段机制

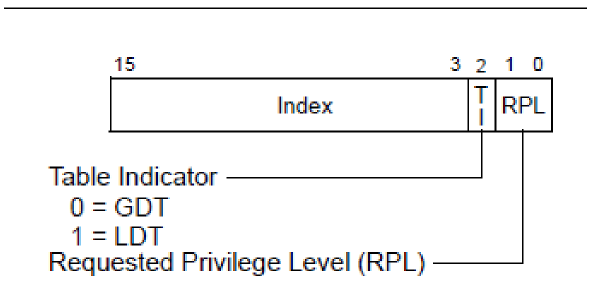


Figure 3-6. Segment Selector

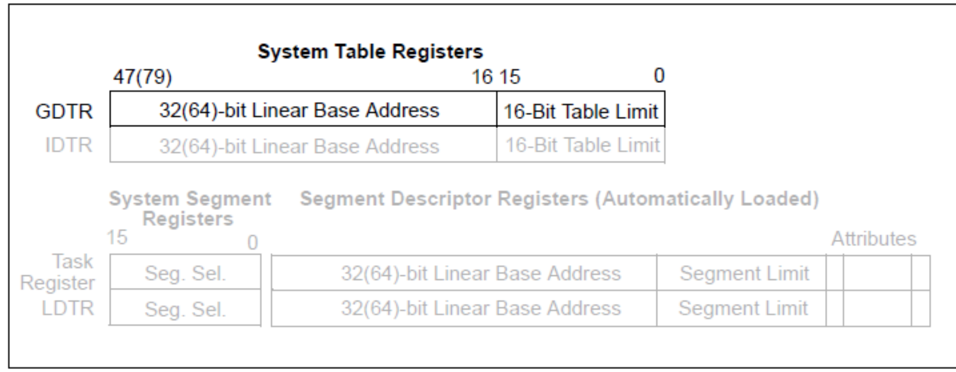


Figure 2-6. Memory Management Registers

- Loading GDT:

```
lgdt gdtdesc

gdt:
      ......

gdtdesc:
      .word 0x17
      .long gdt
```

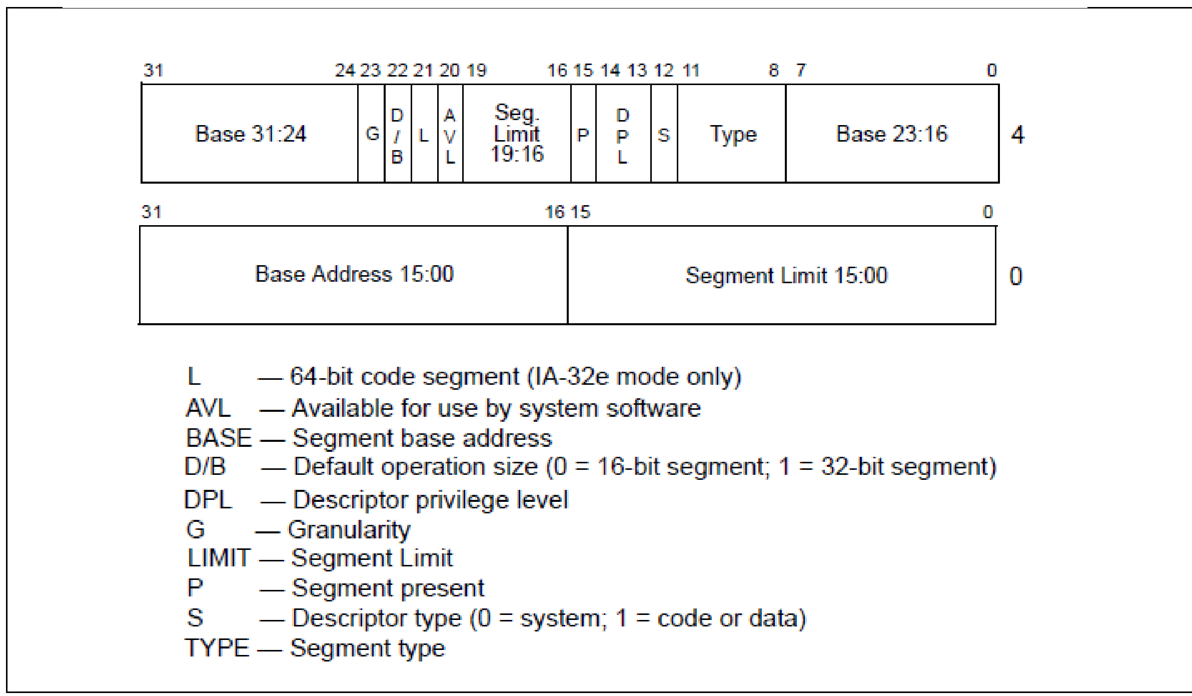


Figure 3-8. Segment Descriptor

摘自"IA-32 Intel体系结构软件开发者手册"

x86启动顺序 – 使能保护模式

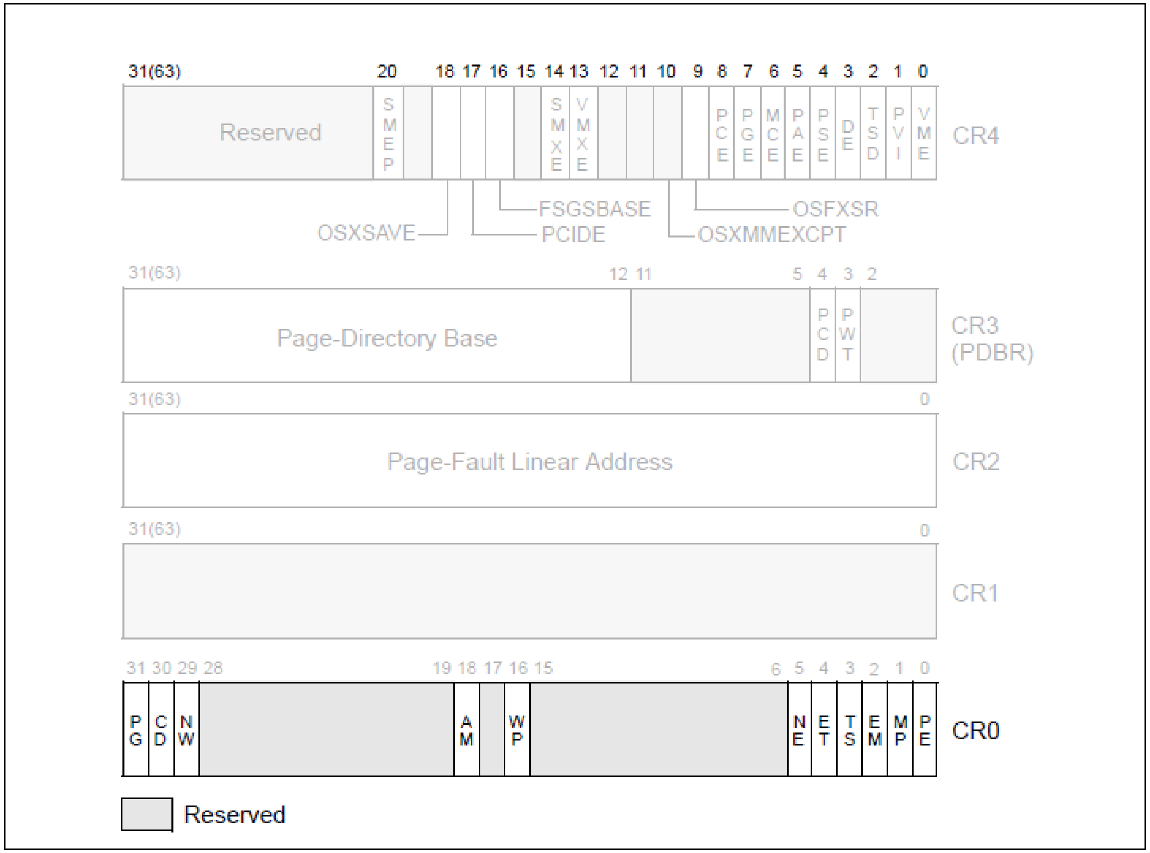


Figure 2-7. Control Registers

摘自"IA-32 Intel体系结构软件开发者手册"

- 使能保护模式（protection mode）, bootloader/OS 要设置 CR0的bit 0 (PE)
- 段机制（Segment-level protection）在保护模式下是自动使能的

x86启动顺序 – 加载 ELF格式的ucore OS kernel

```
struct elfhdr {
  uint magic;       // must equal ELF_MAGIC
  uchar elf[12];
  ushort type;
  ushort machine;
  uint version;
  uint entry;       // program entry point (in va)
  uint phoff;       // offset of the program header tables
  uint shoff;
  uint flags;
  ushort ehsize;
  ushort phentsize;
  ushort phnum;      // number of program header tables
  ushort shentsize;
  ushort shnum;
  ushort shstrndx;
};
```

x86启动顺序 – 加载 ELF格式的ucore OS kernel

```
struct proghdr {
  uint type;        // segment type
  uint offset;      // beginning of the segment in the file
  uint va;          // where this segment should be placed at
  uint pa;
  uint filesz;
  uint memsz;       // size of the segment in byte
  uint flags;
  uint align;
};
```

x86启动顺序 – 参考资料

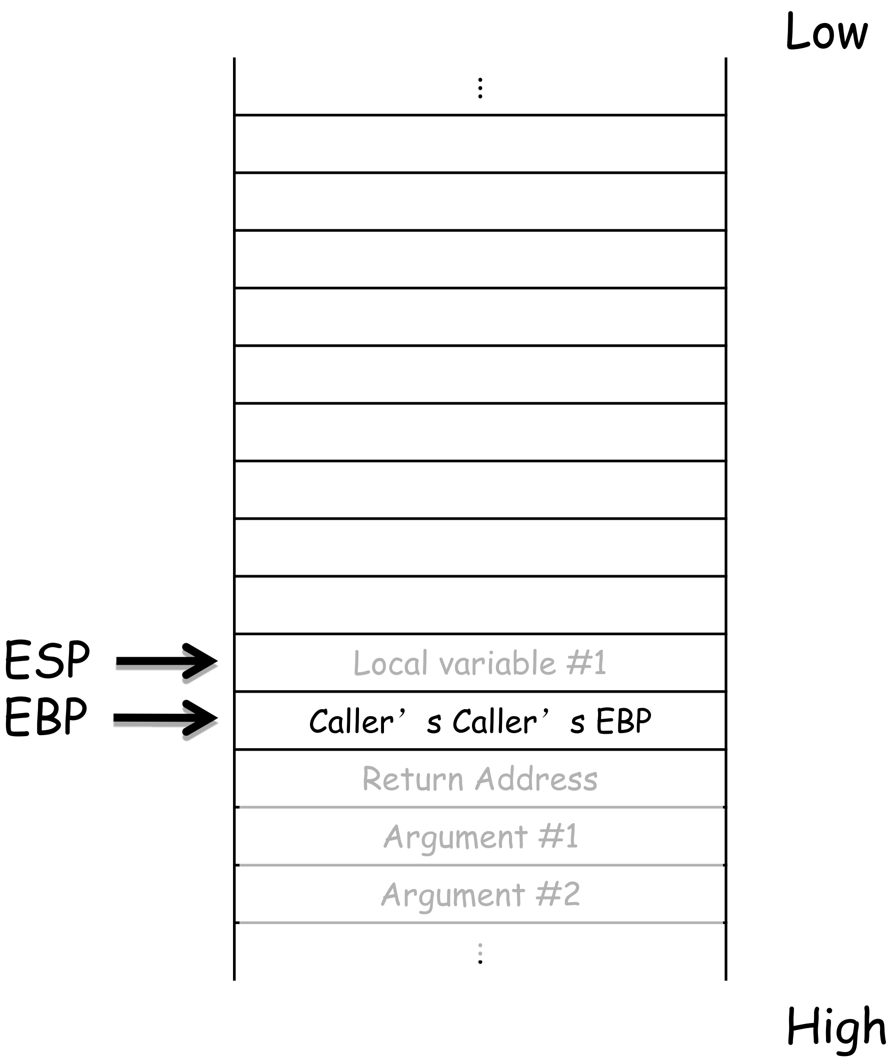
- Chap. 2.5 (Control Registers)), Vol. 3, Intel® and IA-32 Architectures Software Developer’s Manual
- Chap. 3 (Protected-Mode Memory Management), Vol. 3, Intel® and IA-32 Architectures Software Developer’s Manual
- Chap. 9.1 (Initialization Overview), Vol. 3, Intel® and IA-32 Architectures Software Developer’s Manual
- An introduction to ELF format: http://wiki.osdev.org/ELF

- 理解C函数调用在汇编级是如何实现的
- 理解如何在汇编级代码中调用C函数
- 理解基于EBP寄存器的函数调用栈

C函数调用的实现

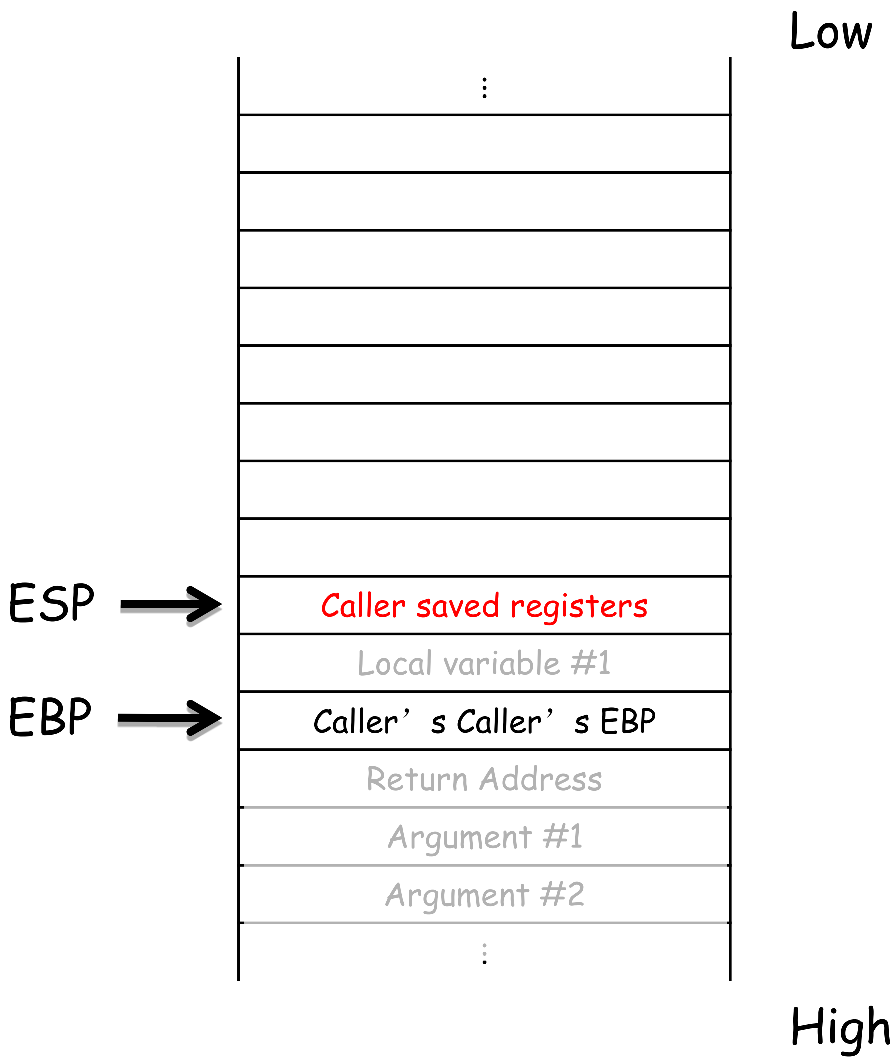
C函数调用的实现

```
    ......
    pushal
    pushl %eax
    pushl %ebx
    pushl %ecx
    call  foo
    popl  %ecx
    popl  %ebx
    popl  %eax
    popal
    ......
foo:
    pushl %ebp
    movl  %esp, %ebp
    ......
    popl  %ebp
    ret
```



C函数调用的实现

```
    ……
    pushal
    pushl  %eax
    pushl  %ebx
    pushl  %ecx
    call   foo
    popl   %ecx
    popl   %ebx
    popl   %eax
    popal
    ……
foo:
    pushl  %ebp
    movl   %esp, %ebp
    ……
    popl   %ebp
    ret
```



C函数调用的实现

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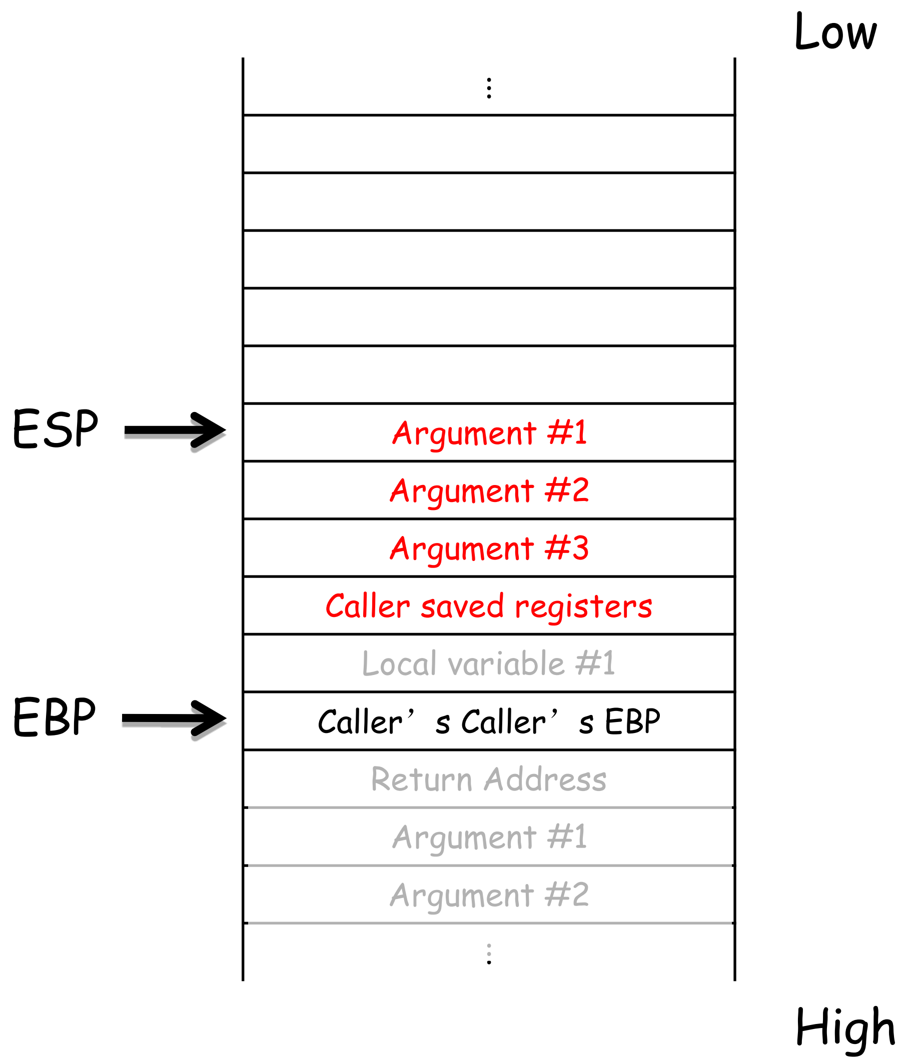
    pushl  %ebx
    pushl  %ecx
    call   foo
    popl   %ecx
    popl   %ebx
    popl   %eax
    popal
    ......
foo:
    pushl  %ebp
    movl   %esp, %ebp
    ......
    popl   %ebp
    ret
```



C函数调用的实现

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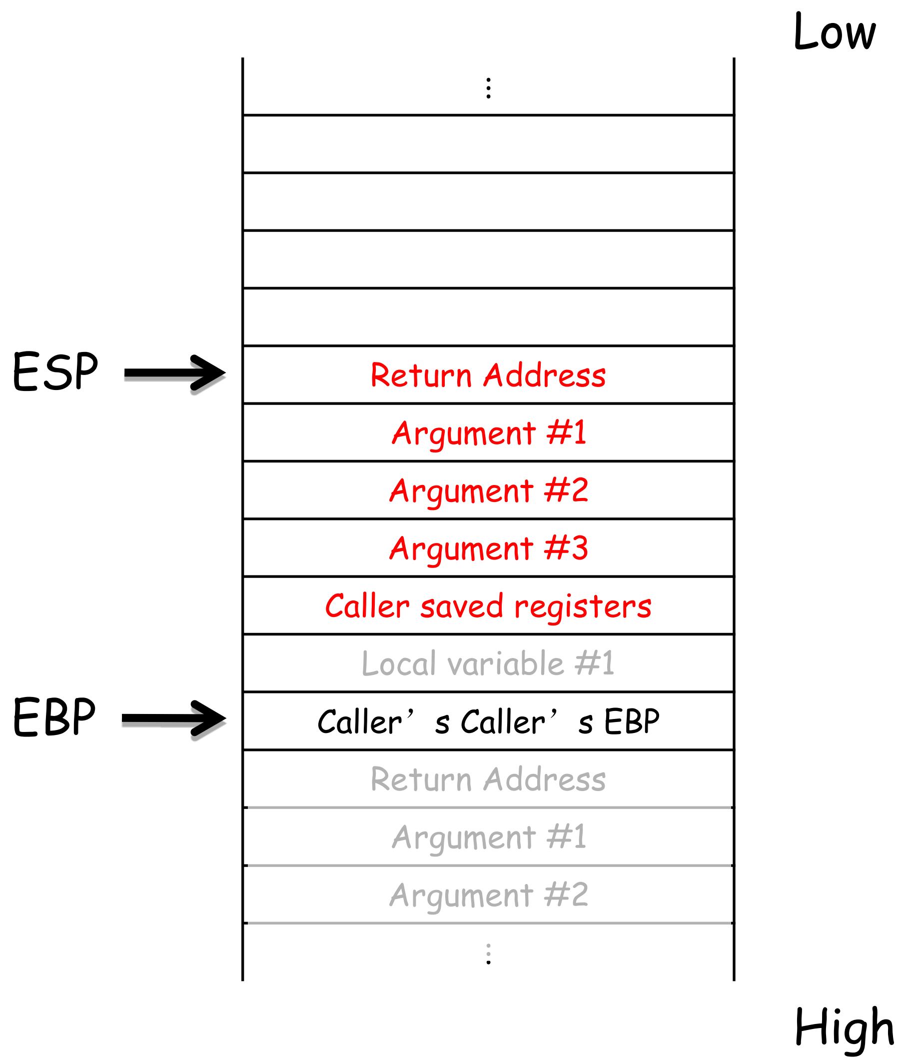
    popl   %ecx
    popl   %ebx
    popl   %eax
    popal
    ......
foo:
    pushl  %ebp
    movl   %esp, %ebp
    ......
    popl   %ebp
    ret
```



C函数调用的实现

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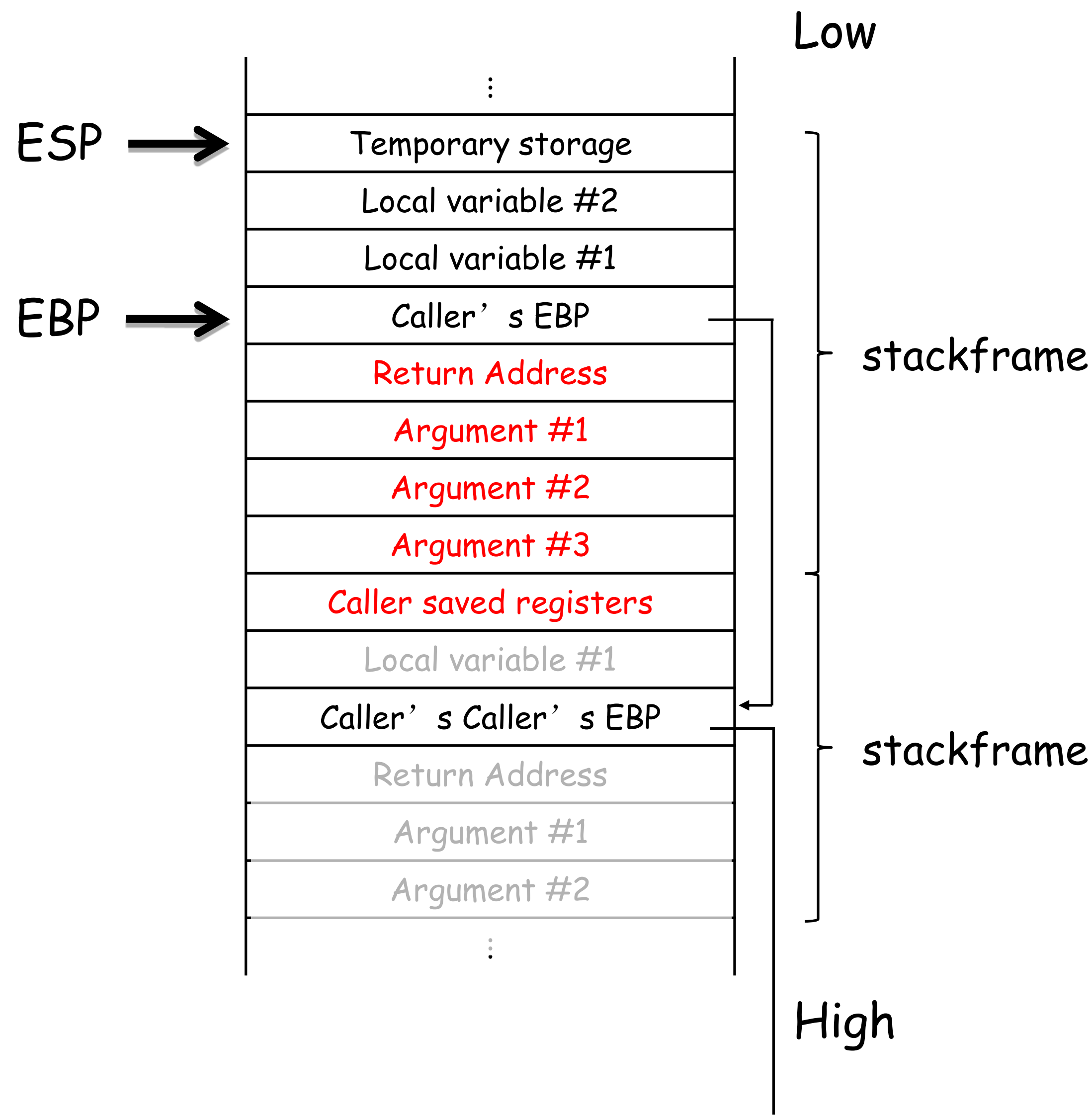
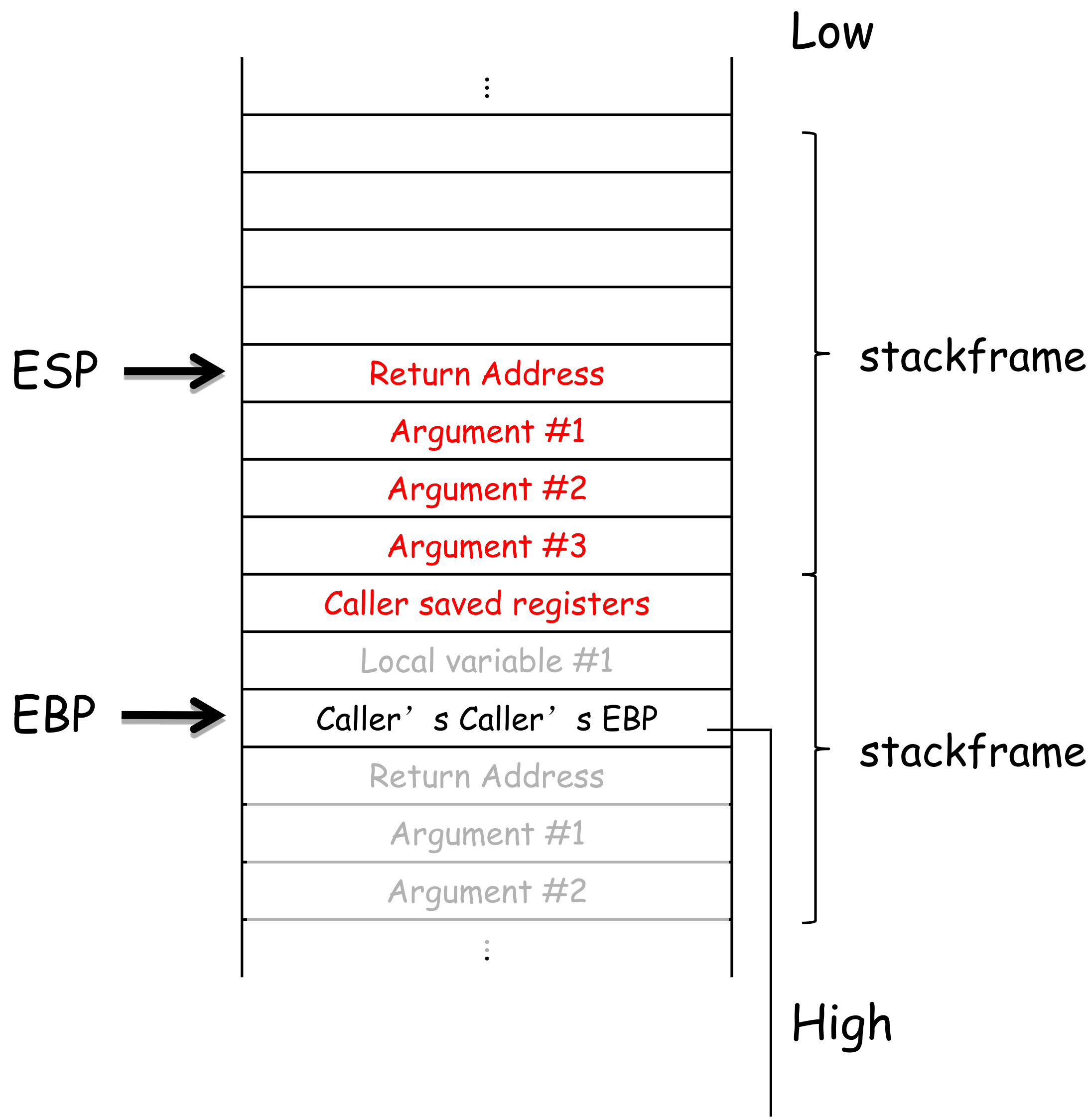
    pushl  %ebx
    pushl  %ecx
    call   foo
    popl   %ecx
    popl   %ebx
    popl   %eax
    popal
    ......
foo:
    pushl  %ebp
    movl   %esp, %ebp
    ......
    popl   %ebp
    ret
```



C函数调用的实现

```
    ......
    pushal
    pushl  %eax
    pushl  %ebx
    pushl  %ecx
    call   foo
    popl   %ecx
    popl   %ebx
    popl   %eax
    popal
    ......
foo:
    pushl  %ebp
    movl   %esp, %ebp
    ......
    popl   %ebp
    ret
```



C函数调用的实现

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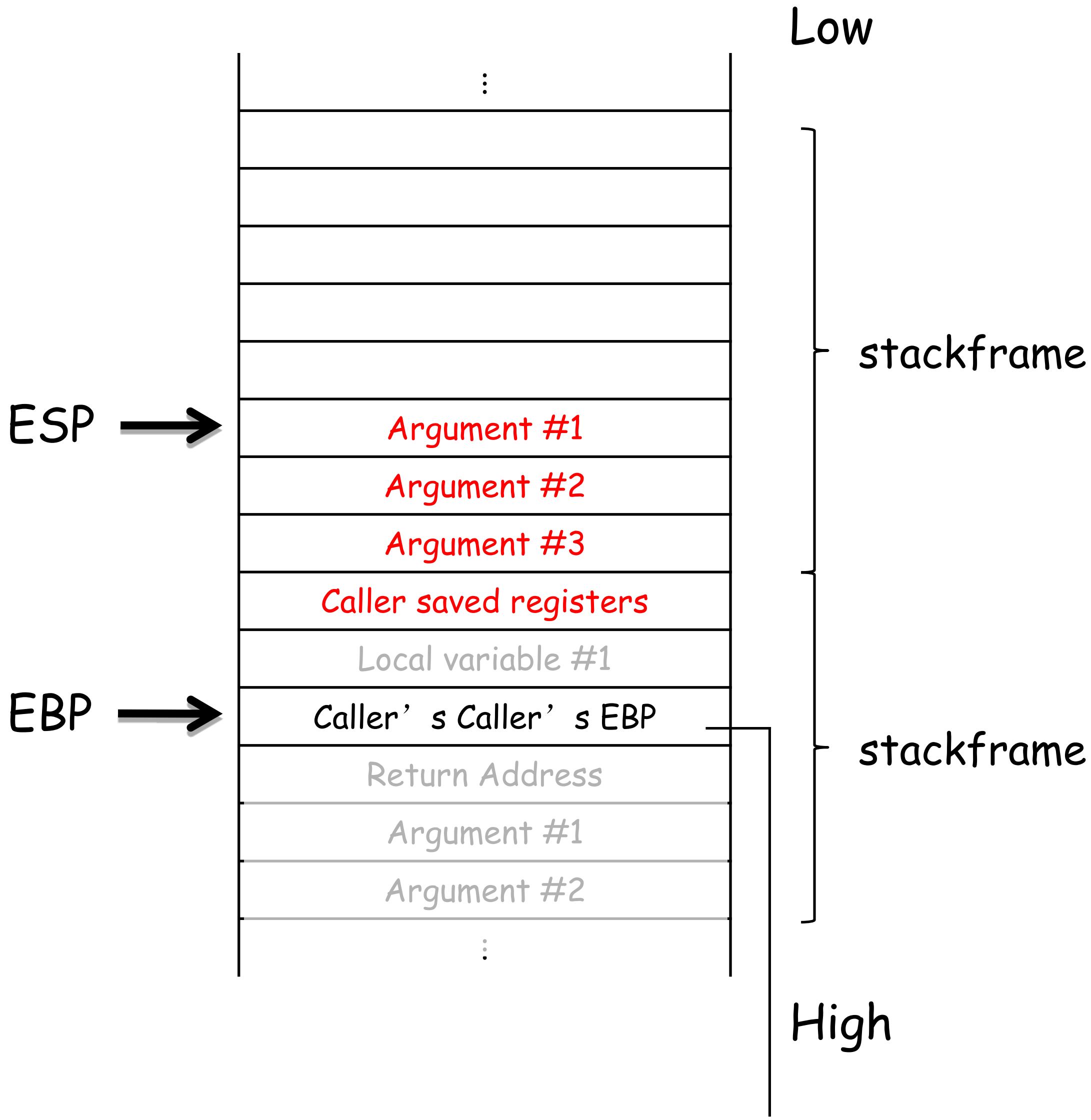
    pushal
    pushl  %eax
    pushl  %ebx
    pushl  %ecx
    call   foo
    popl   %ecx
    popl   %ebx
    popl   %eax
    popal
    ......
foo:
    pushl  %ebp
    movl   %esp, %ebp
    ......
    popl   %ebp
    ret
```



C函数调用的实现

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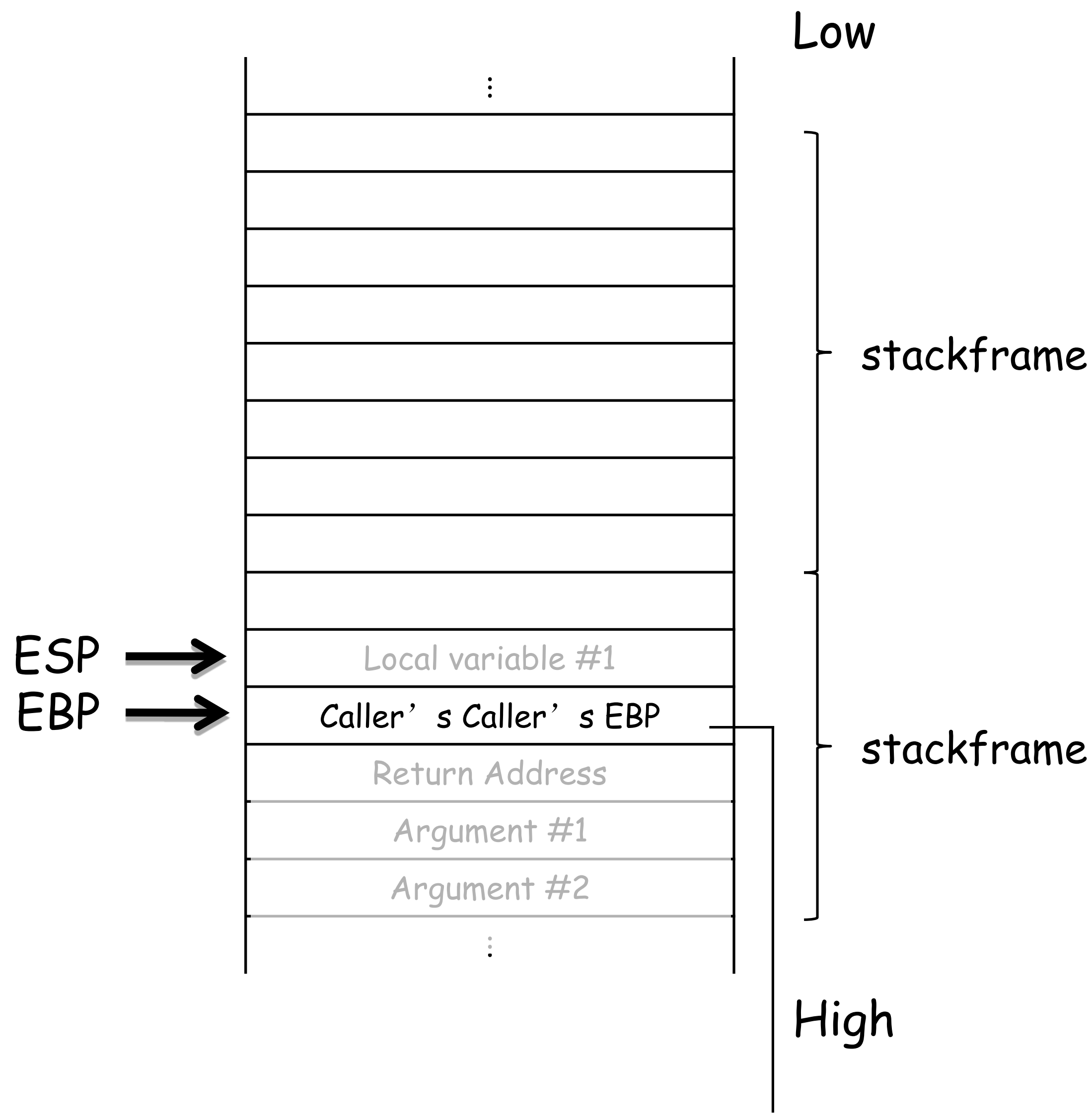
    pushal
    pushl  %eax
    pushl  %ebx
    pushl  %ecx
    call   foo
    popl   %ecx
    popl   %ebx
    popl   %eax
    popal
    ......
foo:
    pushl  %ebp
    movl   %esp, %ebp
    ......
    popl   %ebp
    ret
```



C函数调用的实现

- 其他需要注意的事项
  - 参数（parameters） & 函数返回值（return values）可通过寄存器或位于内存中的栈来传递
  - 不需要保存/恢复(save/restore)所有寄存器

C函数调用的实现 – 参考资料

- Understanding the Stack: http://www.cs.umd.edu/class/sum2003/cmsc311/Notes/Mips/stack.html

- 能过阅读理解内联汇编（inline assembly instructions）

GCC内联汇编 INLINE ASSEMBLY

CC内联汇编

- 什么是内联汇编(Inline assembly)?
  - 这是GCC对C语言的扩张
  - 可直接在C语句中插入汇编指令
- 有何用处?
  - 调用C语言不支持的指令
  - 用汇编在C语言中手动优化
- 如何工作?
  - 用给定的模板和约束来生成汇编指令
  - 在C函数内形成汇编源码

CC内联汇编 – Example 1

Assembly (*.S):

```
movl $0xffff, %eax
```

⇩

Inline assembly (*.c):

```
asm ("movl $0xffff, %%eax\n")
```

CC内联汇编 - Syntax

```
asm ( assembler template
    : output operands     (optional)
    : input operands      (optional)
    : clobbers            (optional, you may skip this for now)
    );
```

CC内联汇编 – Example 2

Inline assembly (*.c):

```
uint32_t cr0;
asm volatile ("movl %%cr0, %0\n" :"=r"(cr0));
cr0 |= 0x80000000;
asm volatile ("movl %0, %%cr0\n" ::"r"(cr0));
```

⇩

Generated asssembly code (*.s):

```
movl %cr0, %ebx
movl %ebx, 12(%esp)
orl  $-2147483648, 12(%esp)
movl 12(%esp), %eax
movl %eax, %cr0
```

CC内联汇编– Example 2

Inline assembly (*.c):

```
uint32_t cr0;
asm volatile ("movl %%cr0, %0\n" :"=r"(cr0));
cr0 |= 0x80000000;
asm volatile ("movl %0, %%cr0\n" ::"r"(cr0));
```

- **`volatile`**
  No reordering; No elimination
- **`%0`**
  The first constraint following
- **`r`**
  A constraint; GCC is free to use any register

CC内联汇编 – Example 3

```
long __res, arg1 = 2, arg2 = 22, arg3 = 222, arg4 = 233;
__asm__ volatile ("int $0x80"
    : "=a" (__res)
    : "0" (11),"b" (arg1),"c" (arg2),"d" (arg3),"S" (arg4));
```

⇩

```
……
movl   $11, %eax
movl   -28(%ebp), %ebx
movl   -24(%ebp), %ecx
movl   -20(%ebp), %edx
movl   -16(%ebp), %esi
int    $0x80
movl   %edi, -12(%ebp)
```

- Constraints
  a = %eax
  b = %ebx
  c = %ecx
  d = %edx
  S = %esi
  D = %edi
  0 = same as the first

CC内联汇编- 参考资料

- GCC Manual 6.41 – 6.43
- Inline assembly for x86 in Linux: http://www.ibm.com/developerworks/library/l-ia/index.html

- 了解x86中的中断源
- 了解CPU与操作系统如何处理中断
- 能够对中断向量表(中断描述符表，简称IDT)进行初始化

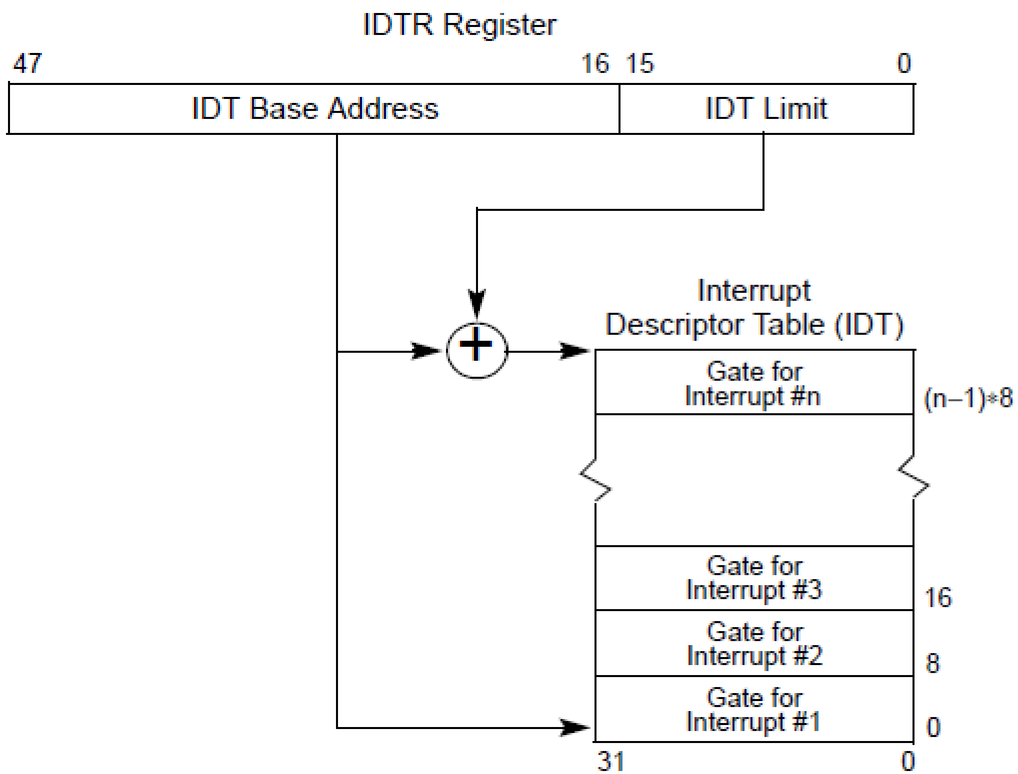
X86中的中断处理

X86中的中断处理 – 中断源

- 中断 Interrupts
  - 外部中断 External (hardware generated) interrupts
    串口、硬盘、网卡、时钟、…
  - 软件产生的中断 Software generated interrupts
    The **INT** *n* 指令，通常用于系统调用
- 异常 Exceptions
  - 程序错误
  - 软件产生的异常 Software generated exceptions
    INTO, **INT** 3 and **BOUND**
  - 机器检查出的异常S

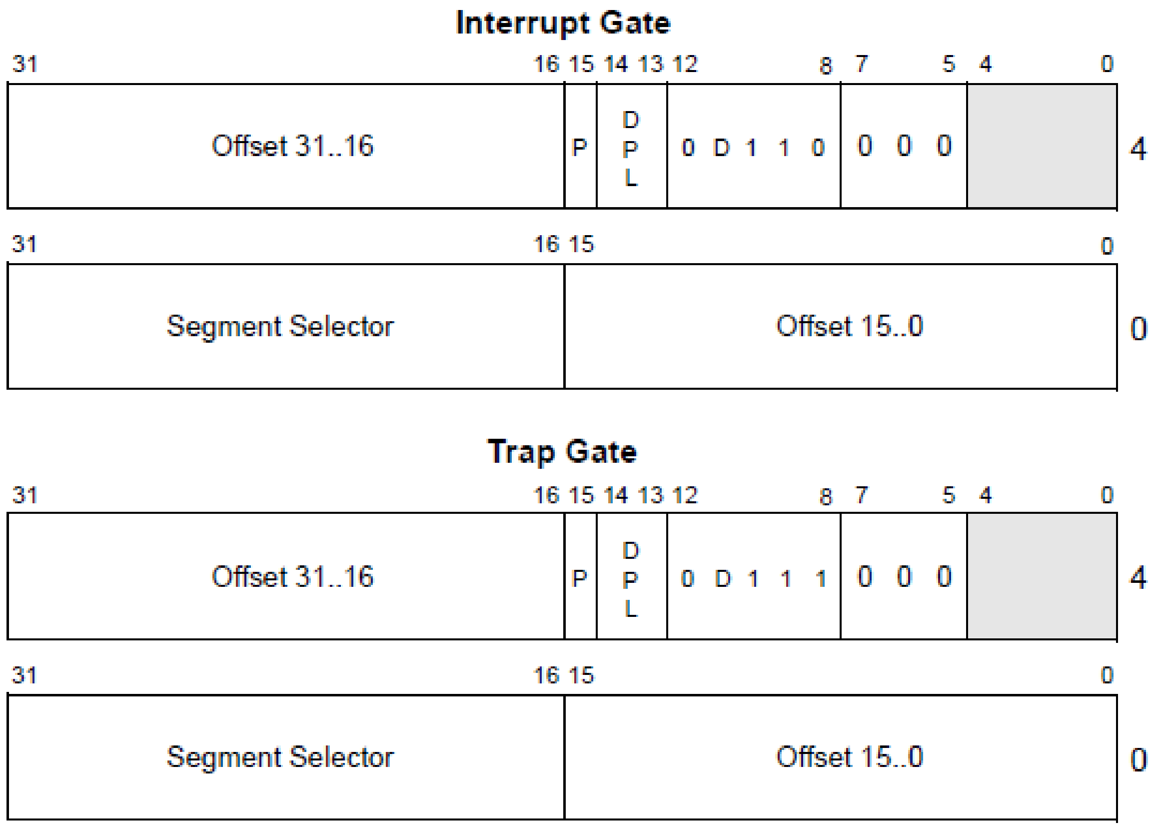
X86中的中断处理– 确定中断服务例程(ISR)

- 每个中断或异常与一个中断服务例程（ Interrupt Service Routine ， 简称ISR）关联，其关联关系存储在中断描述符表（ Interrupt Descriptor Table，简称IDT）。
- IDT的起始地址和大小保存在中断描述符表寄存器IDTR中



摘自"IA-32 Intel体系结构软件开发者手册"

X86中的中断处理–确定中断服务例程（ISR）



DPL	Descriptor Privilege Level
Offset	Offset to procedure entry point
P	Segment Present flag
Selector	Segment Selector for destination code segment
D	Size of gate: 1 = 32 bits; 0 = 16 bits

Reserved

摘自"IA-32 Intel体系结构软件开发者手册"

X86中的中断处理–确定中断服务例程（ISR）

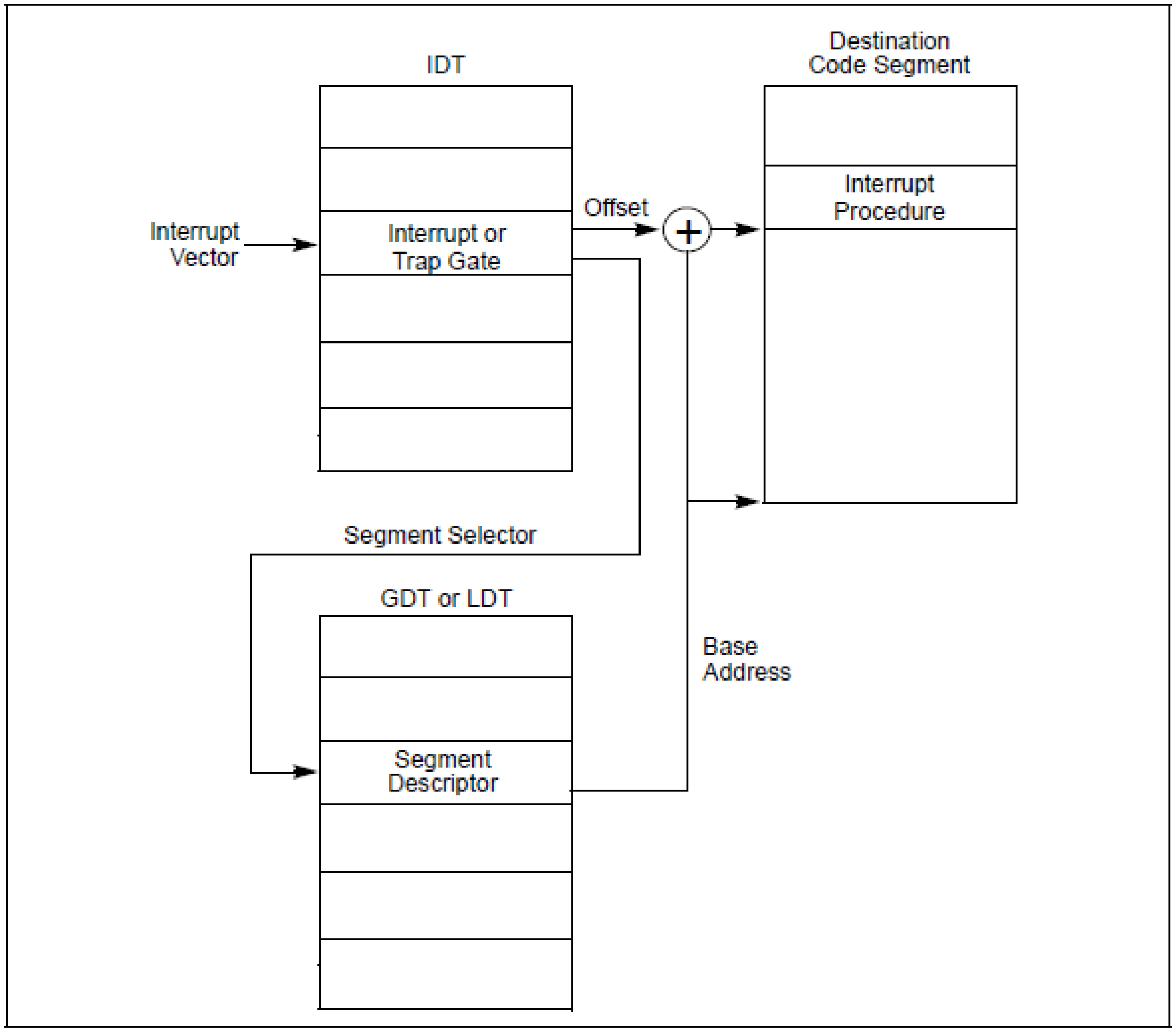
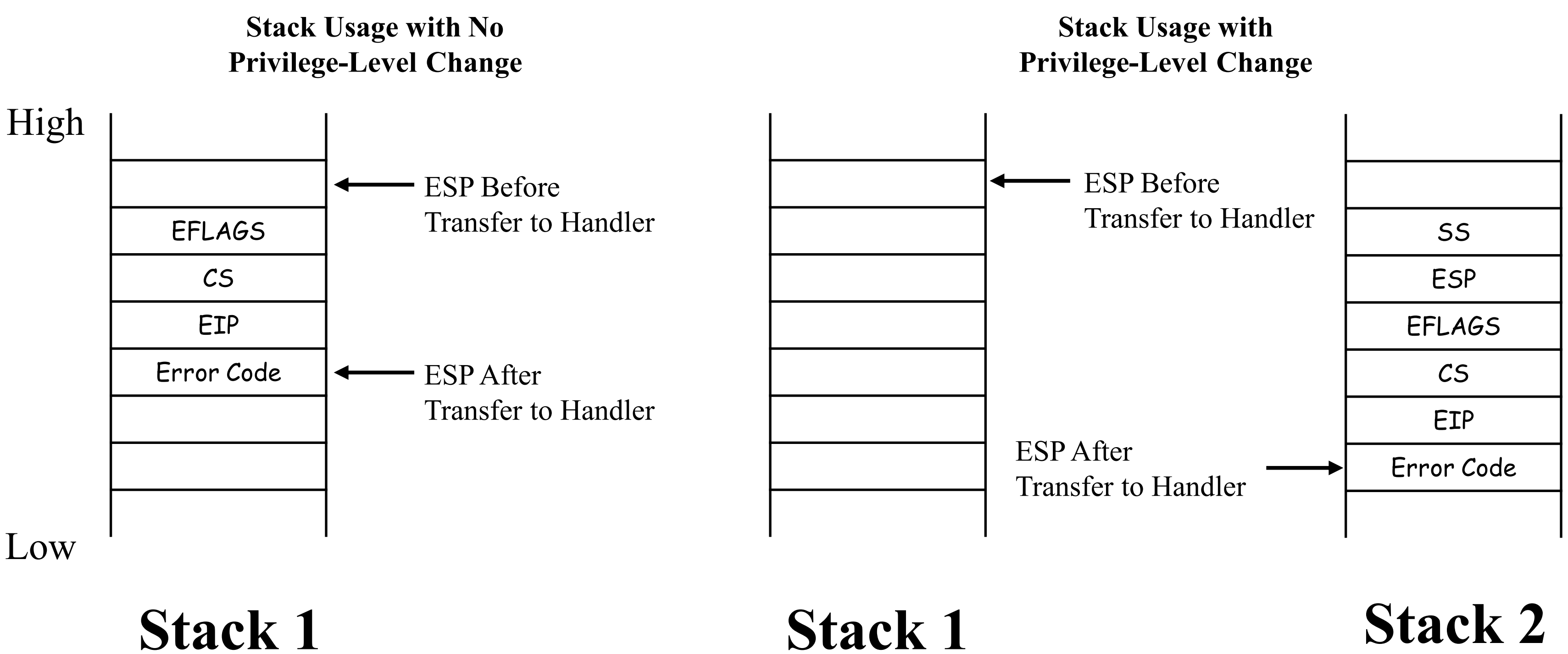


Figure 6-3. Interrupt Procedure Call

摘自"IA-32 Intel体系结构软件开发者手册"

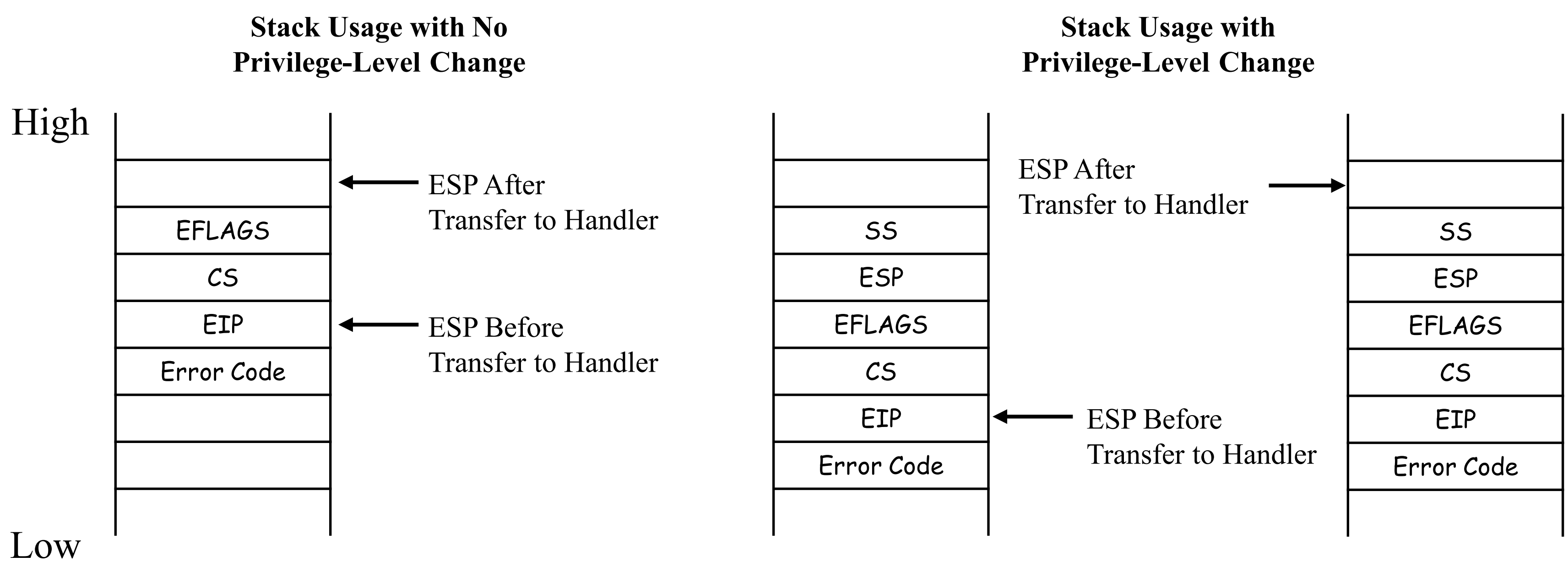
X86中的中断处理 - 切换到中断服务例程（ISR）

- 不同特权级的中断切换对堆栈的影响



X86中的中断处理 – 从中断服务例程（ISR）返回

- **iret** vs. **ret vs. retf** : iret 弹出 EFLAGS 和 SS/ESP(根据是否改变特权级)，但 ret弹出EIP， retf弹出CS和EIP



X86中的中断处理 – 系统调用

- 用户程序通过系统调用访问OS内核服务。
- 如何实现
  - 需要指定中断号
  - 使用Trap，也称Software generated interrupt
  - 或使用特殊指令 (**SYSENTER/SYSEXIT**)

X86中的中断处理 – 参考资料

- Chap. 6, Vol. 3, Intel® and IA-32 Architectures Software Developer’s Manual