# COS 318: Operating Systems

# OS Structures and System Calls

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(http://www.cs.princeton.edu/courses/cos318/)

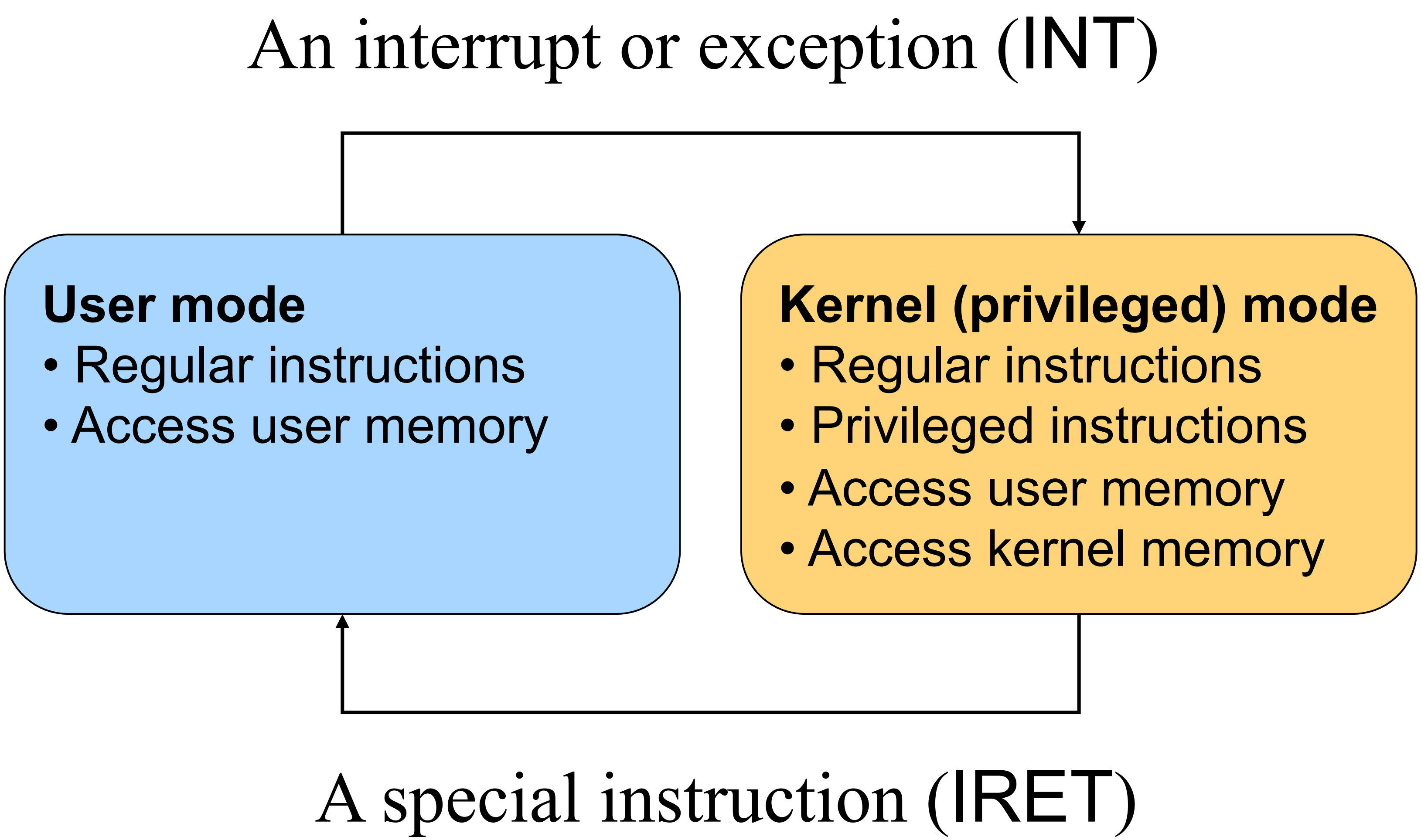
# Outline

- Protection mechanisms
  - Lead to …
- OS structures
- System and library calls

# Protection Issues

- CPU
  - Kernel has the ability to take CPU away from users to prevent a user from using the CPU forever
  - Users should not have such an ability
- Memory
  - Prevent a user from accessing others' data
  - Prevent users from modifying kernel code and data structures
- I/O
  - Prevent users from performing "illegal" I/Os
- Question
  - What's the difference between protection and security?

# Architecture Support: Privileged Mode

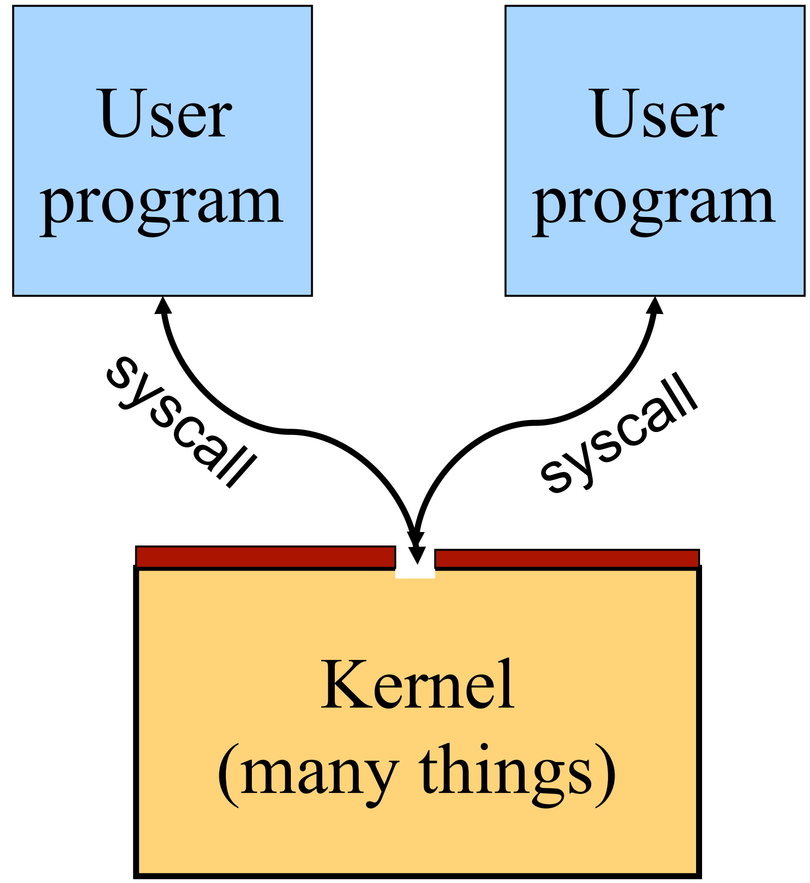


# Privileged Instruction Examples

- Memory address mapping
- Flush or invalidate data cache
- Invalidate TLB entries
- Load and read system registers
- Change processor modes from kernel to user
- Change the voltage and frequency of processor
- Halt a processor
- Reset a processor
- Perform I/O operations

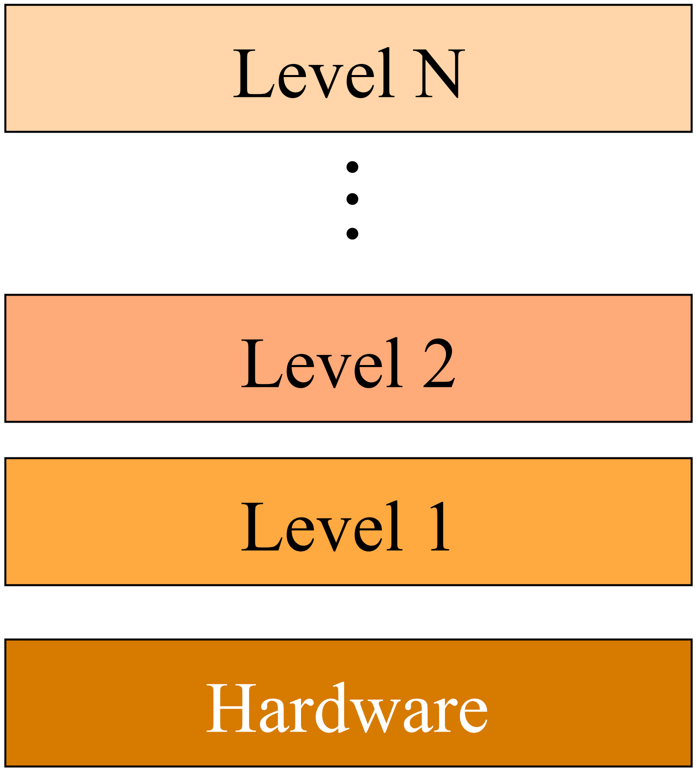
# Monolithic

- All kernel routines are together, linked in single large executable
  - Each can call any other
  - Services and utilities
- A system call interface
- Examples:
  - Linux, BSD Unix, Windows, …
- Pros
  - Shared kernel space
  - Good performance
- Cons
  - Instability: crash in any procedure brings system down
  - Inflexible / hard to maintain, extend

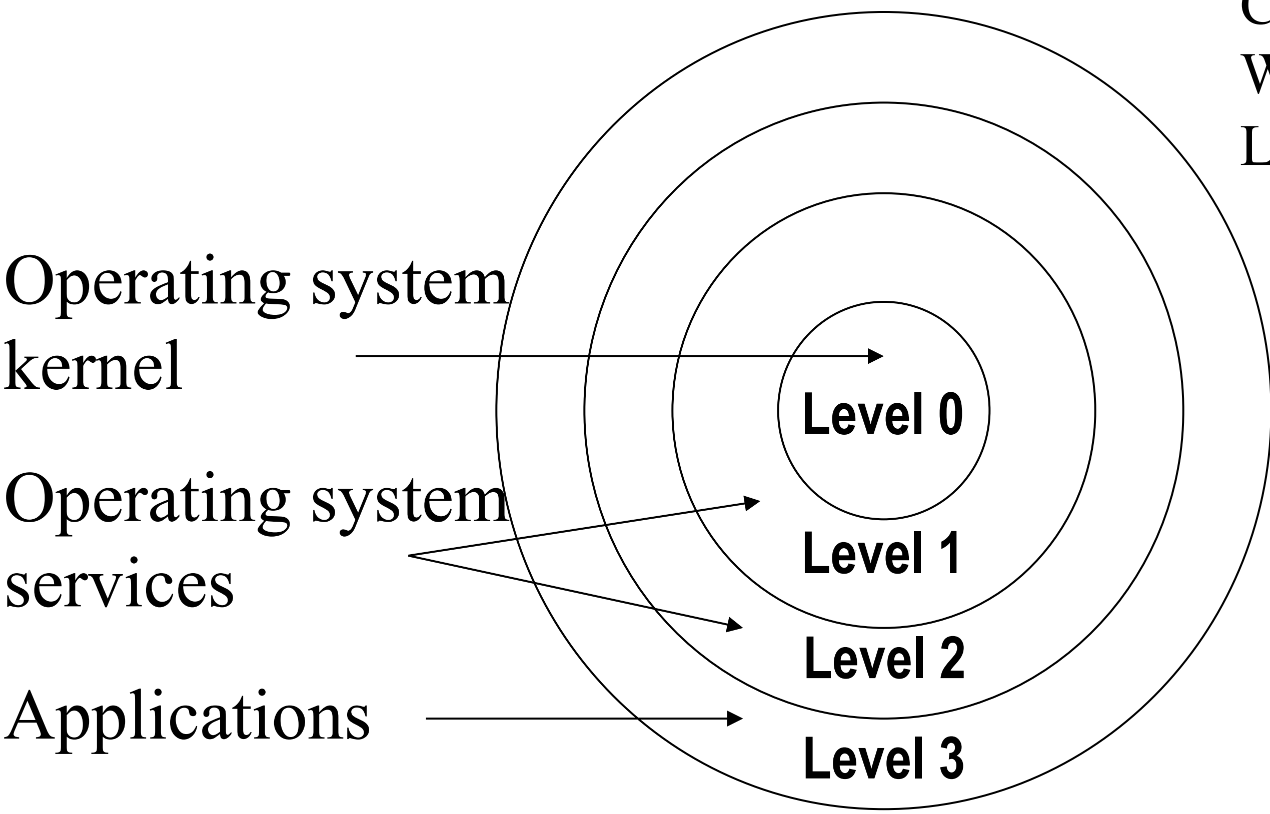


# Layered Structure

- Hiding information at each layer
- Layered dependency
- Examples
  - THE (6 layers)
    - Mostly for functionality splitting
  - MS-DOS (4 layers)
- Pros
  - Layered abstraction
- Cons
  - Inefficiency
  - Inflexible



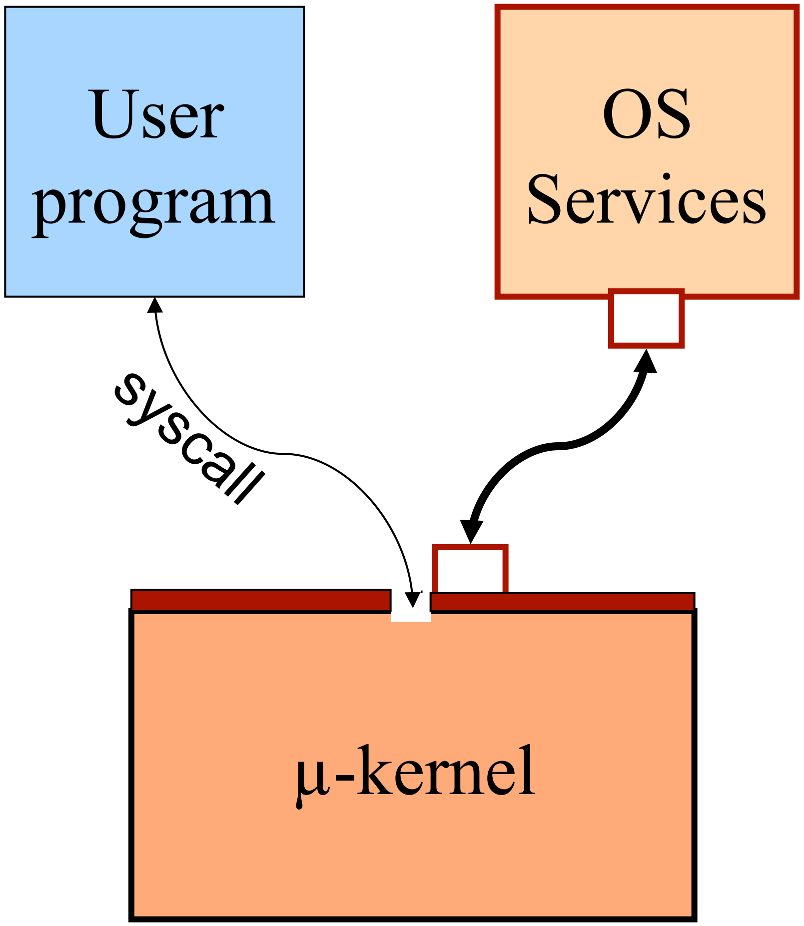
# x86 Protection Rings




Privileged instructions
Can be executed only
When current privileged
Level (CPR) is 0

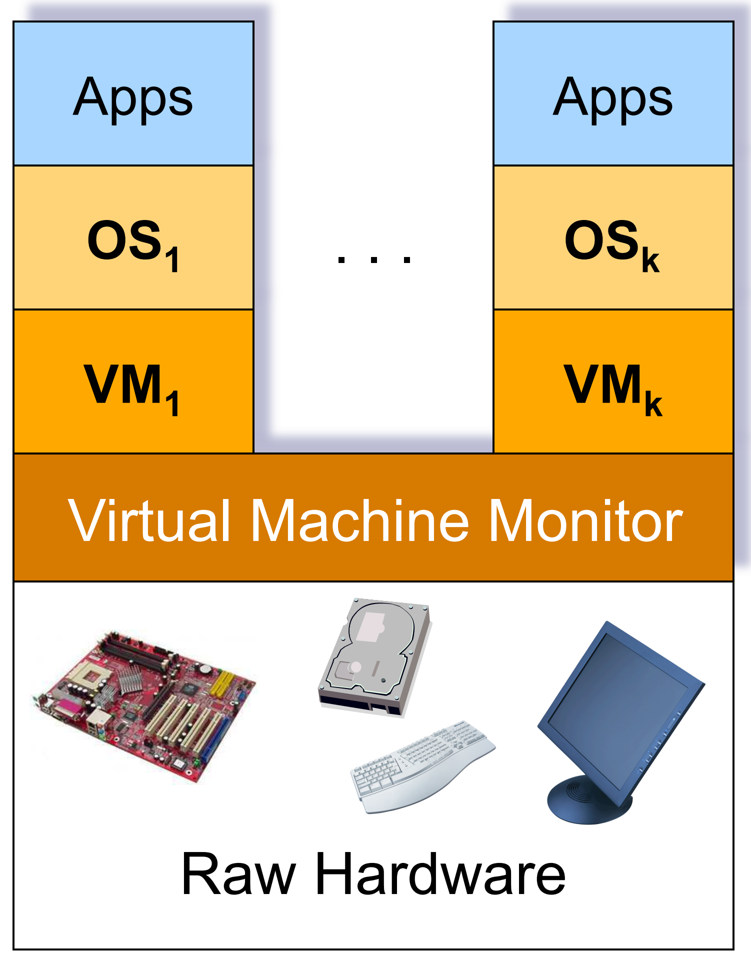
# Microkernel

- Services implemented as regular processes
- Micro-kernel obtain services for users by messaging with services
- Examples:
  - Mach, Taos, L4, OS-X
- Pros?
  - Flexibility
  - Fault isolation
- Cons?
  - Inefficient (boundary crossings)
  - Insufficient protection
  - Inconvenient to share data between kernel and services
  - Just shifts the problem?



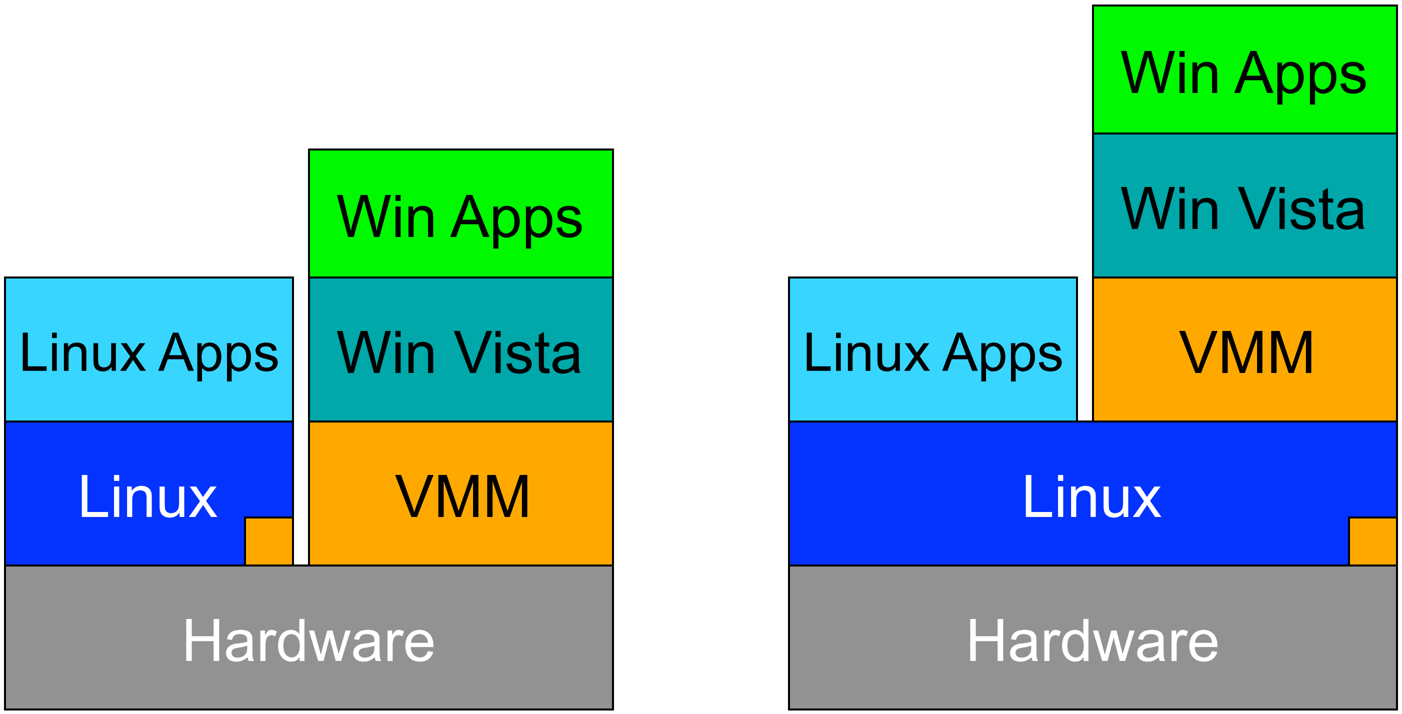
# Virtual Machine

- Virtual machine monitor
  - Virtualize hardware
  - Run several OSes
  - Examples
    - IBM VM/370
    - Java VM
    - VMWare, Xen




- What would you use virtual machine for?

# Two Popular Ways to Implement VMM

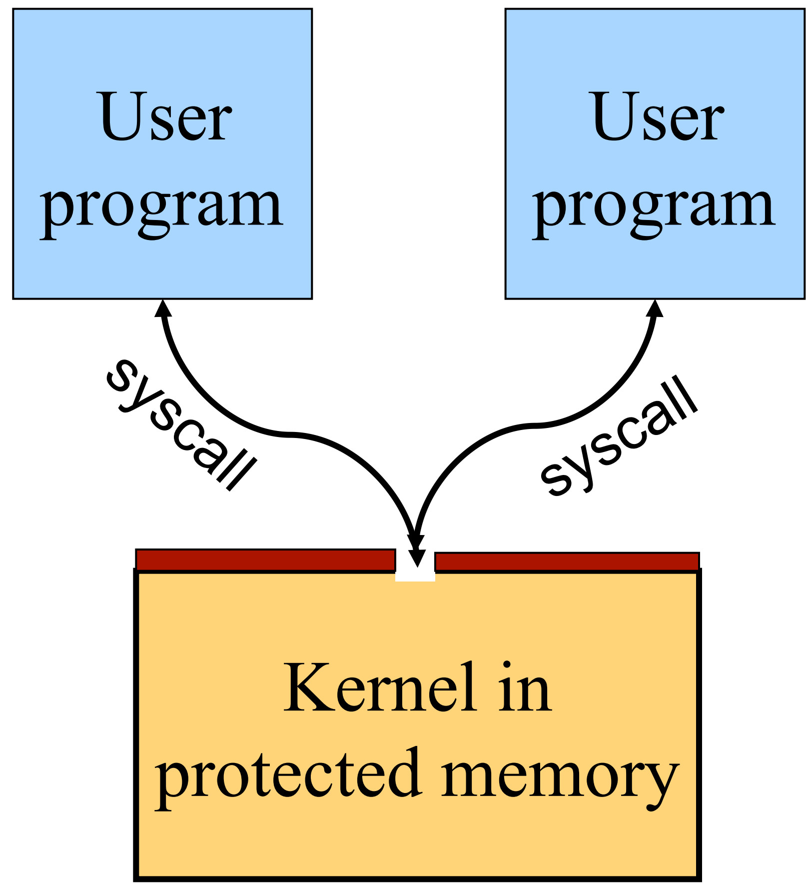



VMM runs on hardware VMM as an application

(A special lecture later in the semester)

# System Call Mechanism

- Assumptions
  - User code can be arbitrary
  - User code cannot modify kernel memory
- Design Issues
  - User makes a system call with parameters
  - The call mechanism switches code to kernel mode
  - Execute system call
  - Return with results



# Exceptions

- Sources
  - Hardware (by external devices)
  - Software: INT n
- Exceptions
  - Normal: faults, traps, aborts, and interrupts
  - Special software generated: INT 3
  - Machine-check exceptions
- See Intel document volume 3 for details

# Interrupt and Exceptions (1)

| Vector # | Mnemonic | Description | Type |
| --- | --- | --- | --- |
| 0 | #DE | Divide error (by zero) | Fault |
| 1 | #DB | Debug | Fault/trap |
| 2 | | NMI interrupt | Interrupt |
| 3 | #BP | Breakpoint | Trap |
| 4 | #OF | Overflow | Trap |
| 5 | #BR | BOUND range exceeded | Trap |
| 6 | #UD | Invalid opcode | Fault |
| 7 | #NM | Device not available | Fault |
| 8 | #DF | Double fault | Abort |
| 9 | | Coprocessor segment overrun | Fault |
| 10 | #TS | Invalid TSS | |

# Interrupt and Exceptions (2)

| Vector # | Mnemonic | Description | Type |
|---|---|---|---|
| 11 | #NP | Segment not present | Fault |
| 12 | #SS | Stack-segment fault | Fault |
| 13 | #GP | General protection | Fault |
| 14 | #PF | Page fault | Fault |
| 15 | | Reserved | Fault |
| 16 | #MF | Floating-point error (math fault) | Fault |
| 17 | #AC | Alignment check | Fault |
| 18 | #MC | Machine check | Abort |
| 19-31 | | Reserved | |
| 32-255 | | User defined | Interrupt |

# System Calls

- Operating system API
  - Interface between an application and the operating system kernel
- Categories
  - Process management
  - Memory management
  - File management
  - Device management
  - Communication

# How many system calls?

| | | |
|---|---|---|
| ◆ 6th Edition Unix: | ~45 | |
| ◆ POSIX: | ~130 | |
| ◆ FreeBSD: | ~130 | |
| ◆ Linux: | ~250 | ("fewer than most") |
| ◆ Windows 7: | ? | |

# From http://minnie.tuhs.org/UnixTree/V6

## V6/usr/sys/ken/sysent.c

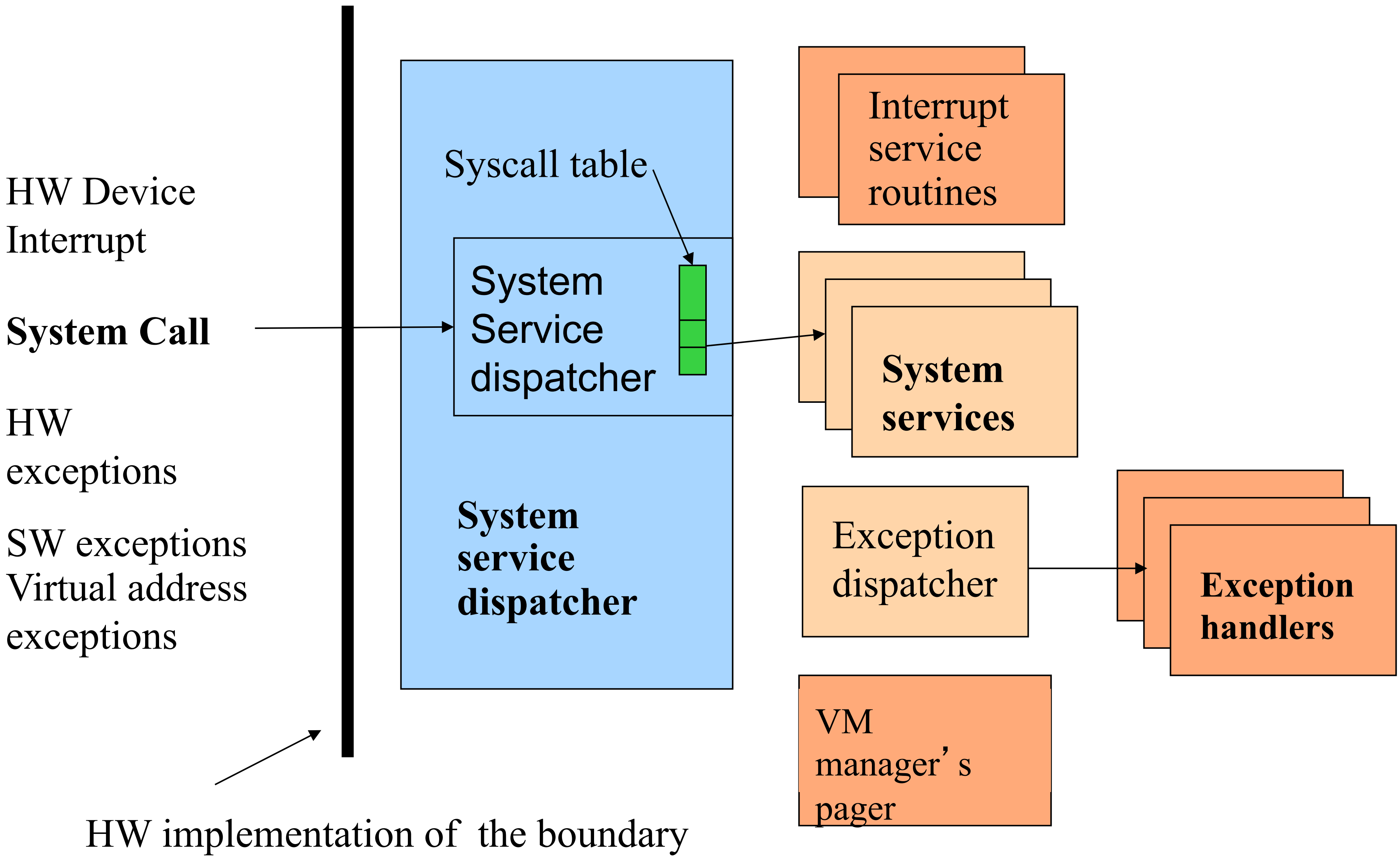
Find at most 5 related files. Search

☐ including files from this version of Unix.

```
#
/*
 */

/*
 * This table is the switch used to transfer
 * to the appropriate routine for processing a system call.
 * Each row contains the number of arguments expected
 * and a pointer to the routine.
 */
int     sysent[]
{
        0, &nullsys,                    /*  0 = indir */
        0, &rexit,                      /*  1 = exit */
        0, &fork,                       /*  2 = fork */
        2, &read,                       /*  3 = read */
        2, &write,                      /*  4 = write */
        2, &open,                       /*  5 = open */
        0, &close,                      /*  6 = close */
        0, &wait,                       /*  7 = wait */
        2, &creat,                      /*  8 = creat */
        2, &link,                       /*  9 = link */
        1, &unlink,                     /* 10 = unlink */
        2, &exec,                       /* 11 = exec */
        1, &chdir,                      /* 12 = chdir */
        0, &gtime,                      /* 13 = time */
        3, &mknod,                      /* 14 = mknod */
        2, &chmod,                      /* 15 = chmod */
        2, &chown,                      /* 16 = chown */
        1, &sbreak,                     /* 17 = break */
        2, &stat,                       /* 18 = stat */
        2, &seek,                       /* 19 = seek */
        0, &getpid,                     /* 20 = getpid */
        3, &smount,                     /* 21 = mount */
        1, &sumount,                    /* 22 = umount */
        0, &setuid,                     /* 23 = setuid */
        0, &getuid,                     /* 24 = getuid */
        0, &stime,                      /* 25 = stime */
        3, &ptrace,                     /* 26 = ptrace */
        0, &nosys,                      /* 27 = x */
        1, &fstat,                      /* 28 = fstat */
        0, &nosys,                      /* 29 = x */
        1, &nullsys,                    /* 30 = smdate; inoperative */
        1, &stty,                       /* 31 = stty */
        1, &gtty,                       /* 32 = gtty */
        0, &nosys,                      /* 33 = x */
        0, &nice,                       /* 34 = nice */
        0, &sslep,                      /* 35 = sleep */
        0, &sync,                       /* 36 = sync */
        1, &kill,                       /* 37 = kill */
        0, &getswit,                    /* 38 = switch */
        0, &nosys,                      /* 39 = x */
        0, &nosys,                      /* 40 = x */
        0, &dup,                        /* 41 = dup */
        0, &pipe,                       /* 42 = pipe */
        1, &times,                      /* 43 = times */
        4, &profil,                     /* 44 = prof */
        0, &nosys,                      /* 45 = tiu */
        0, &setgid,                     /* 46 = setgid */
        0, &getgid,                     /* 47 = getgid */
        2, &ssig,                       /* 48 = sig */
```

# OS Kernel: Trap Handler



# Passing Parameters

- Pass by registers
  - # of registers
  - # of usable registers
  - # of parameters in system call
  - Spill/fill code in compiler
- Pass by a memory vector (list)
  - Single register for starting address
  - Vector in user's memory
- Pass by stack
  - Similar to the memory vector
  - Procedure call convention

# Library Stubs for System Calls

- Example:

int read( int fd, char * buf, int size)

{

move fd, buf, size to $R_1$, $R_2$, $R_3$

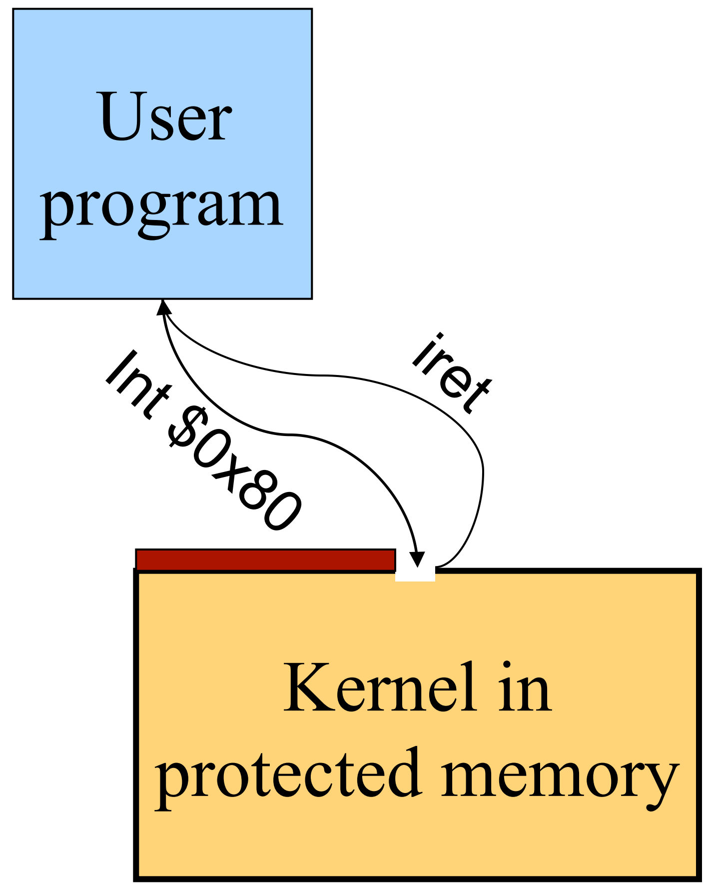
move READ to $R_0$

int $0x80

move result to $R_{result}$

}

Linux: 80
NT: 2E



# System Call Entry Point

**EntryPoint**:

switch to kernel stack

save context

check $R_0$

call the real code pointed by $R_0$

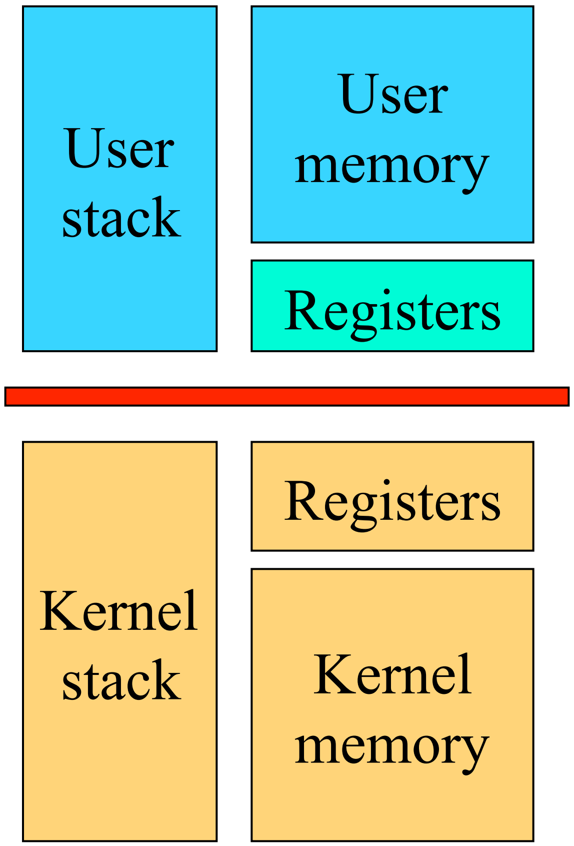
place result in $R_{result}$

restore context

switch to user stack

iret (change to user mode and return)

(Assume passing parameters in registers)



# Design Issues

- System calls
  - There is one result register; what about more results?
  - How do we pass errors back to the caller?
  - Can user code lie?
- System calls vs. library calls
  - What should be system calls?
  - What should be library calls?

# Backwards compatibility...

The Open Group Base Specifications Issue 6
IEEE Std 1003.1, 2004 Edition


## *NAME*

open - open a file

## *SYNOPSIS*

```
[OH] #include <sys/stat.h>

#include <fcntl.h>

int open(const char *path, int oflag, ... );
```

The use of *open*() to create a regular file is preferable to the use of *creat()*, because the latter is redundant and included only for historical reasons.

# Division of Labor (or Separation Of Concerns)

Memory management example

- Kernel
  - Allocates "pages" with hardware protection
  - Allocates a big chunk (many pages) to library
  - Does not care about small allocs
- Library
  - Provides malloc/free for allocation and deallocation
  - Application use these calls to manage memory at fine granularity
  - When reaching the end, library asks the kernel for more

# Summary

- Protection mechanism
  - Architecture support: two modes
  - Software traps (exceptions)
- OS structures
  - Monolithic, layered, microkernel and virtual machine
- System calls
  - Implementation
  - Design issues
  - Tradeoffs with library calls