COS 318: Operating Systems

OS Structures and System Calls

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

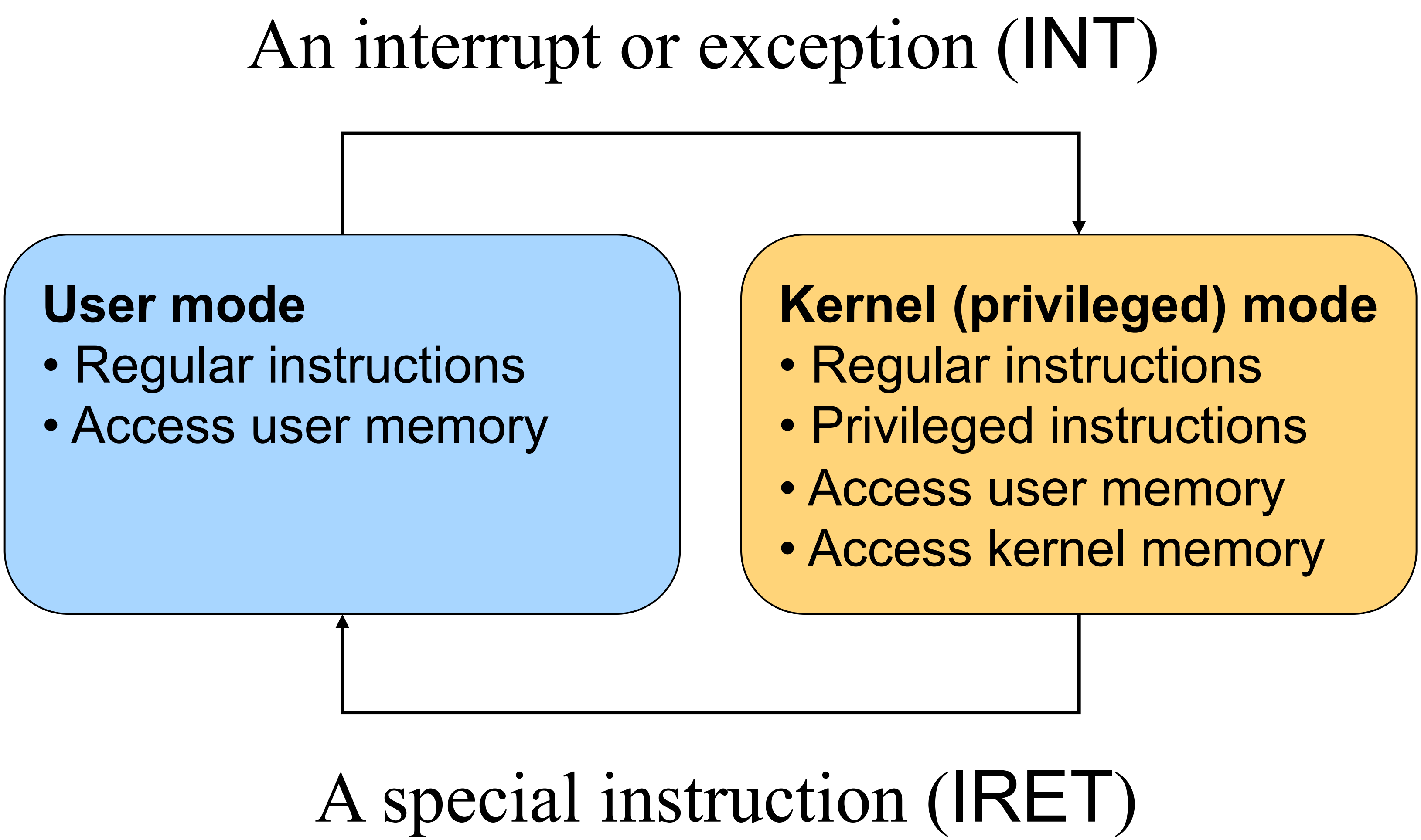
Outline

- Protection mechanisms
- 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?

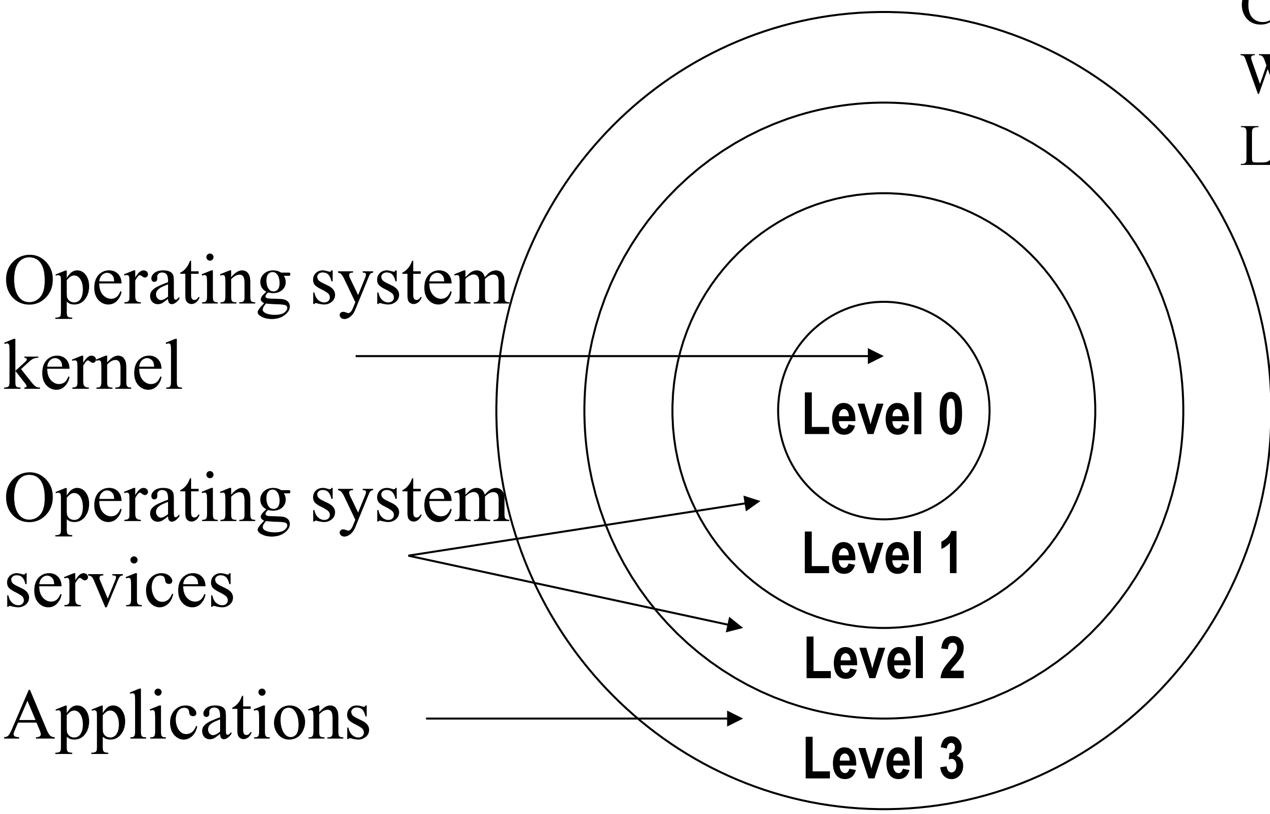
Architecture Support: Privileged Mode



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

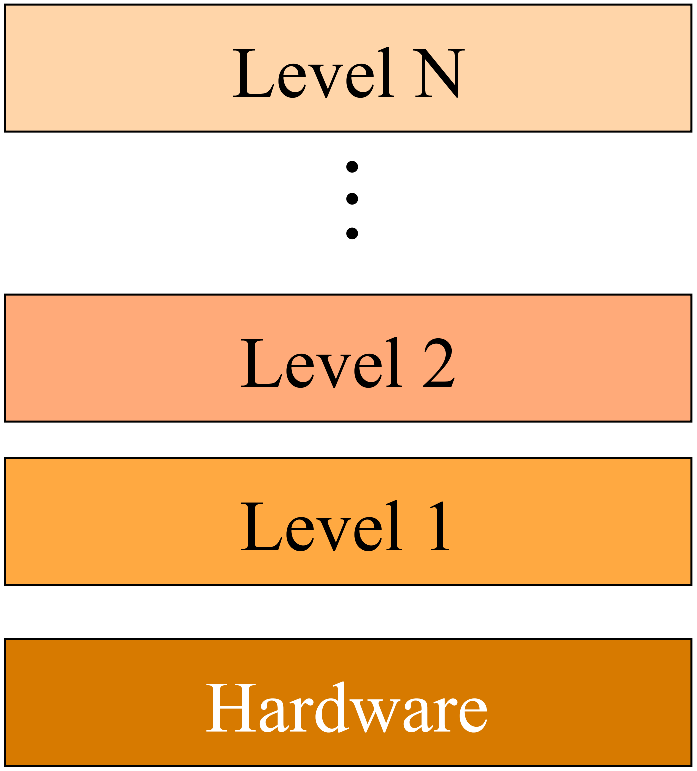
x86 Protection Rings



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

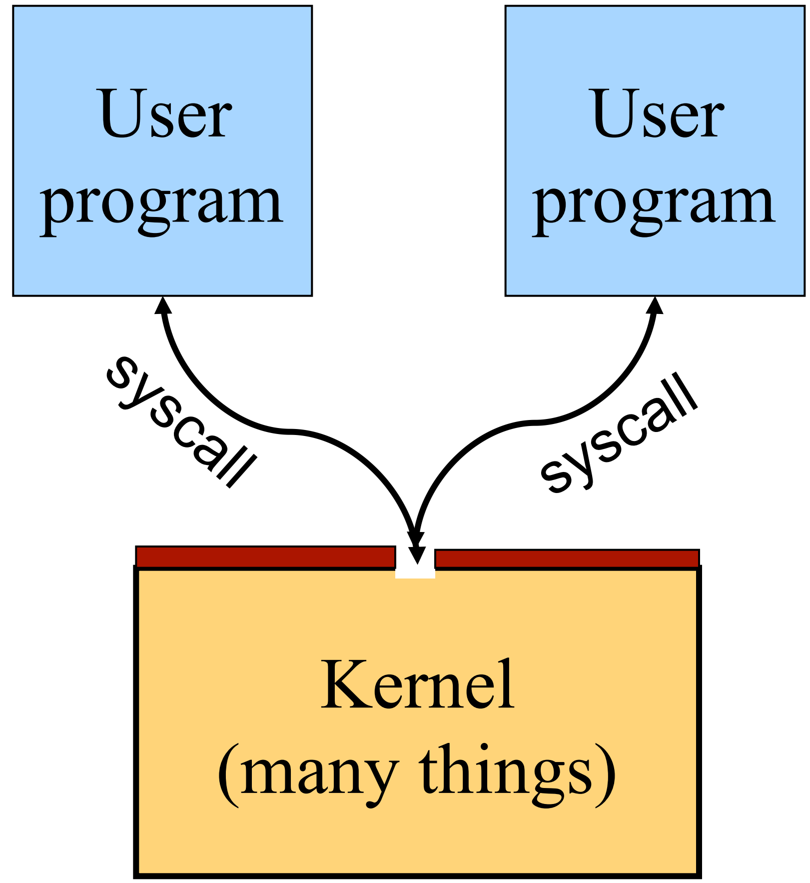
Layered Structure

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



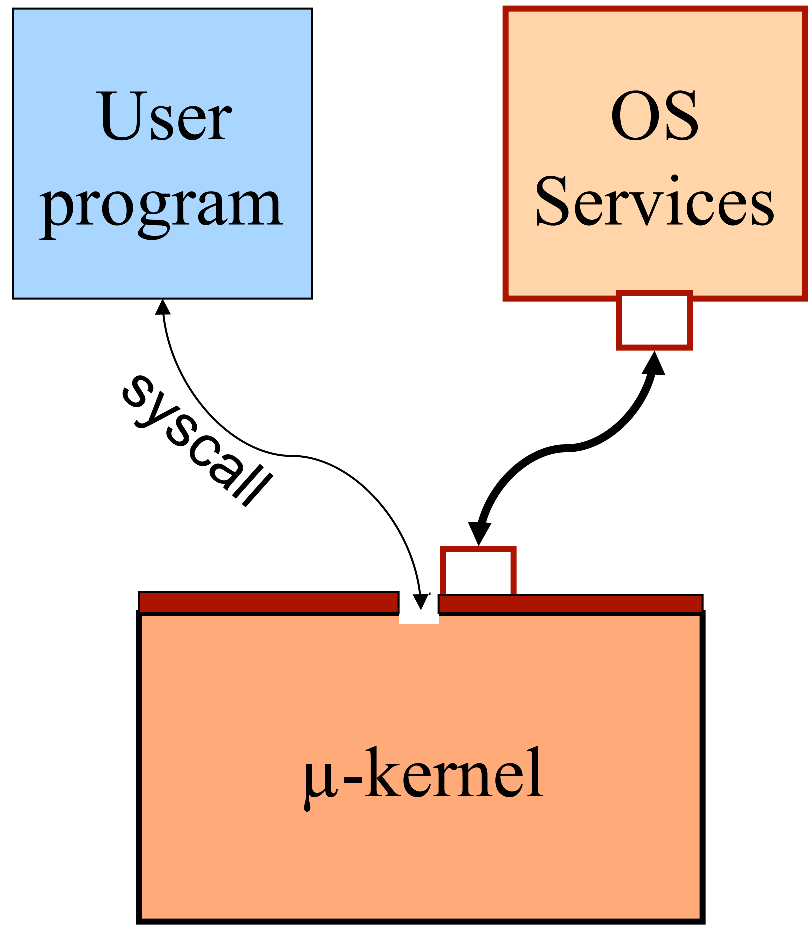
Monolithic

- All kernel routines are together
- A system call interface
- Examples:
  - Linux
  - BSD Unix
  - Windows
- Pros
  - Shared kernel space
  - Good performance
- Cons
  - Instability
  - Inflexible / hard to maintain and extend



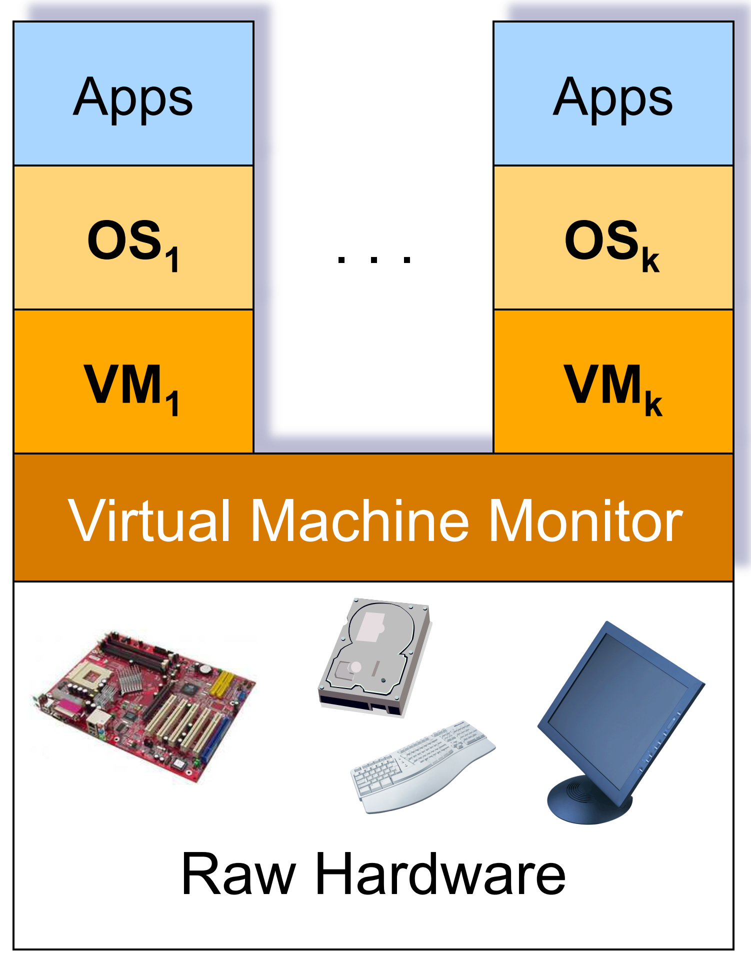
Microkernel

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



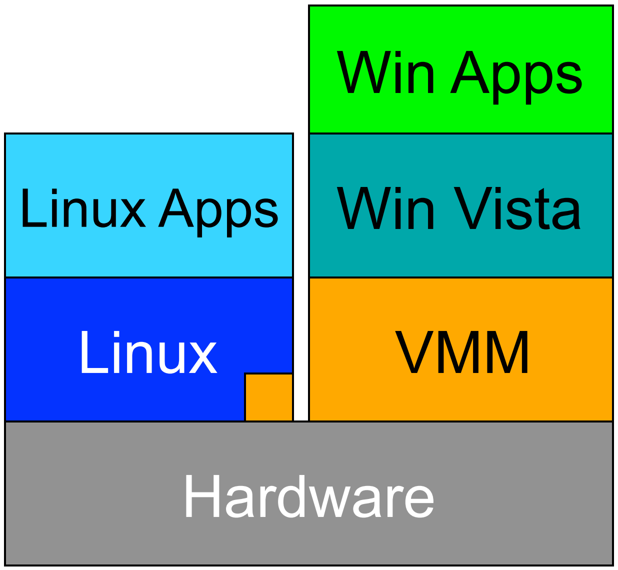
Virtual Machine

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

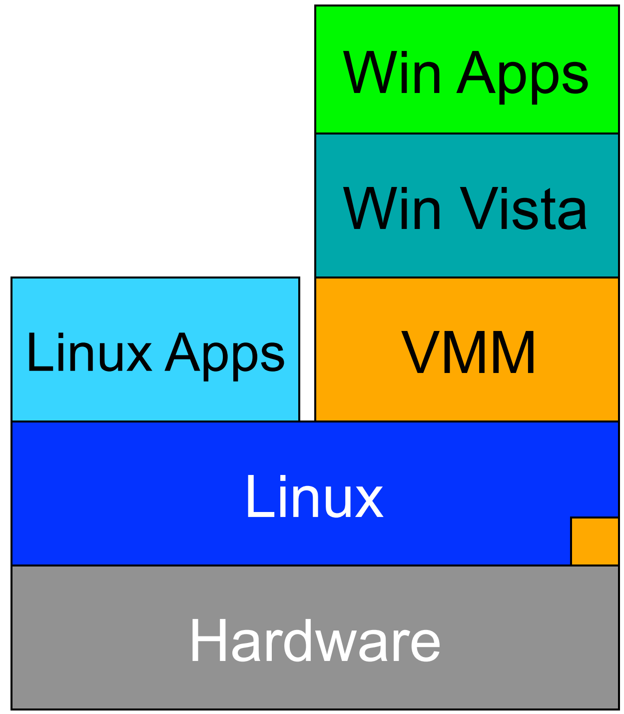


- What would you use virtual machine for?

Two Popular Ways to Implement VMM



VMM runs on hardware

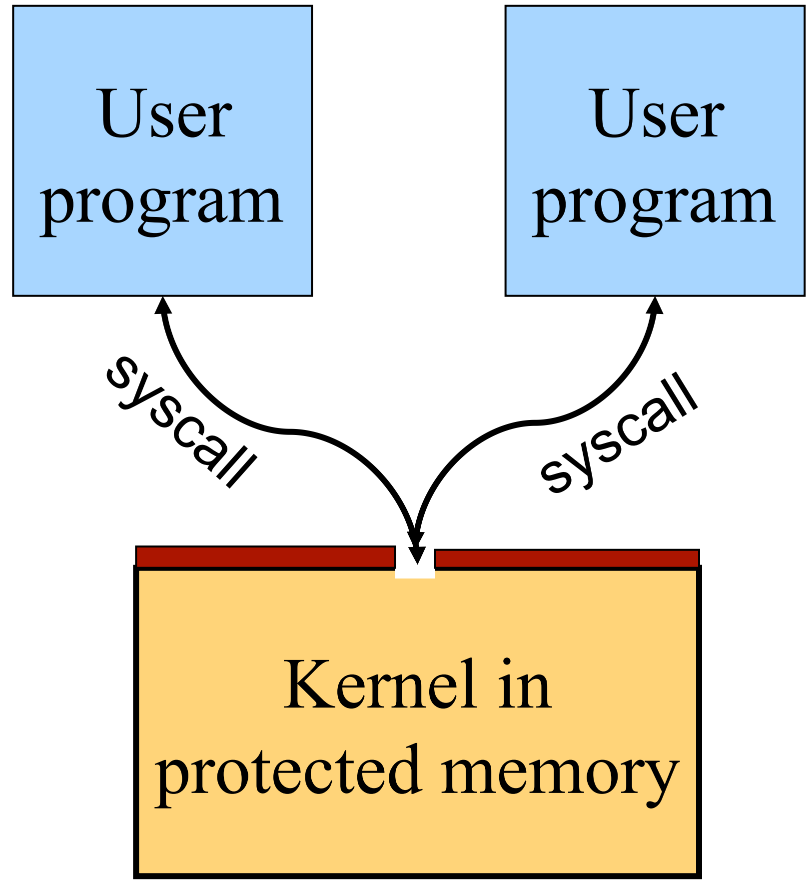


VMM as an application

(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

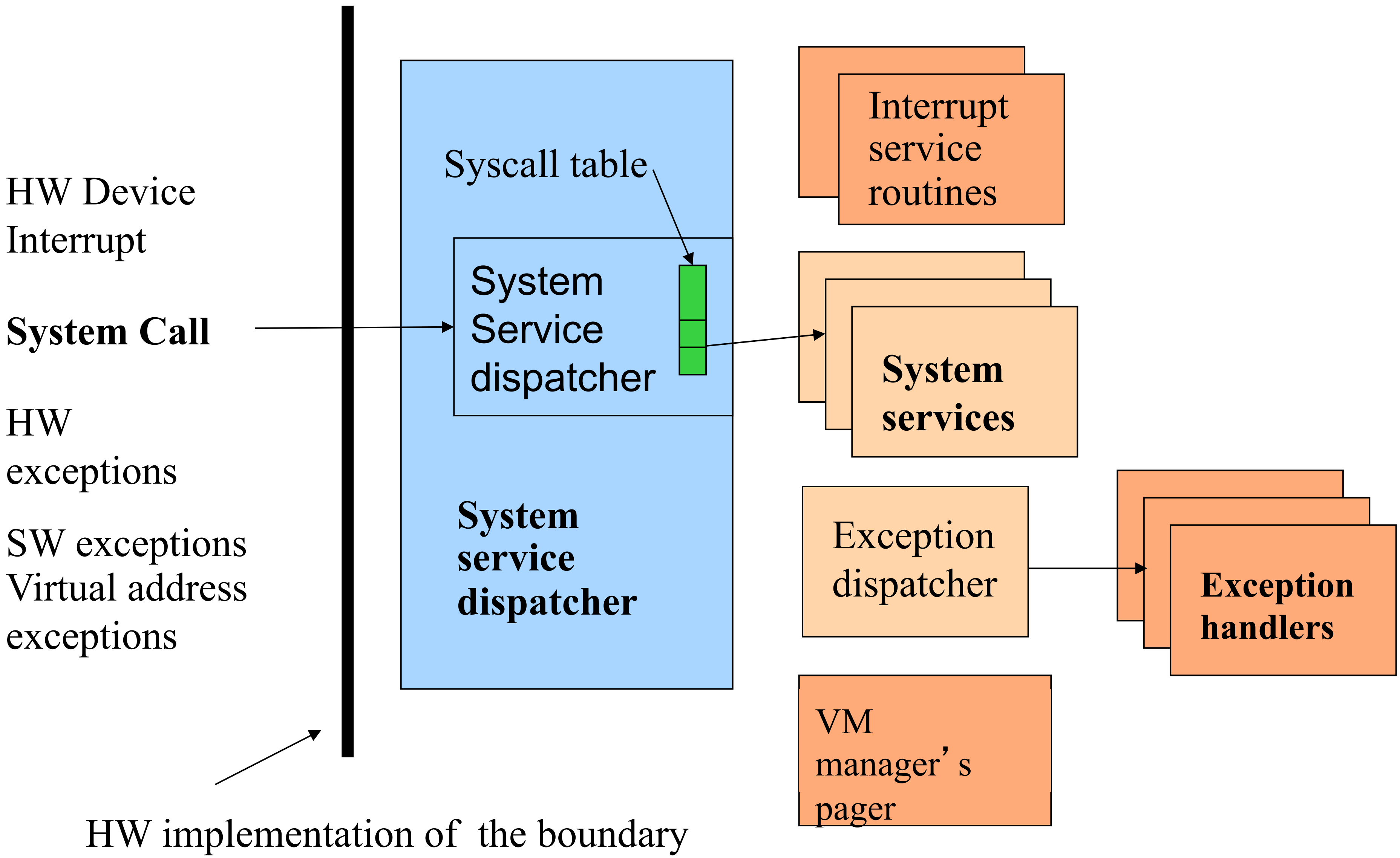
Find at most 5 related files. Search

☐ 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

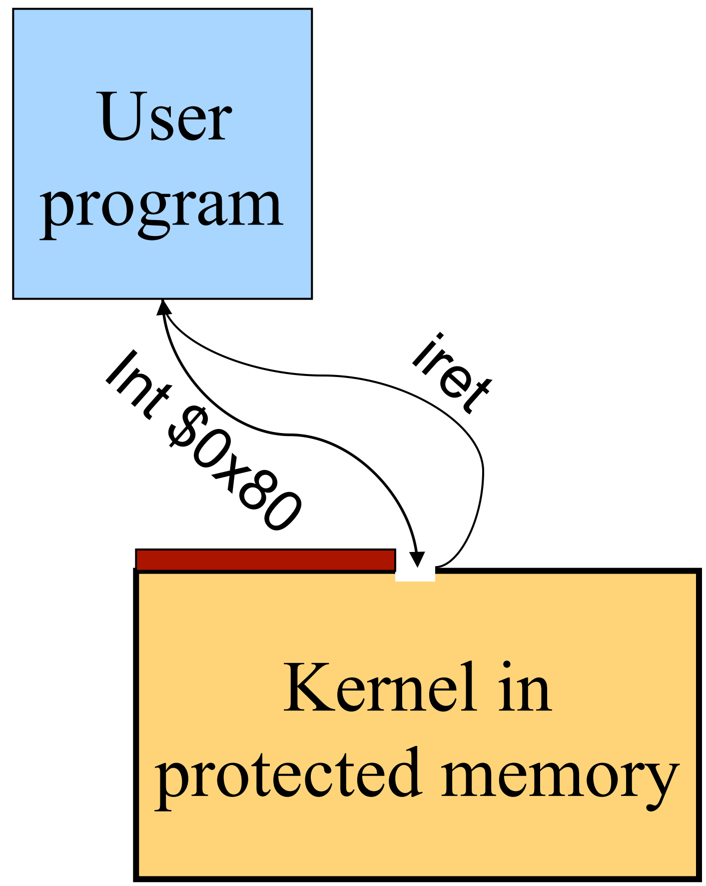
move READ to R_0

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

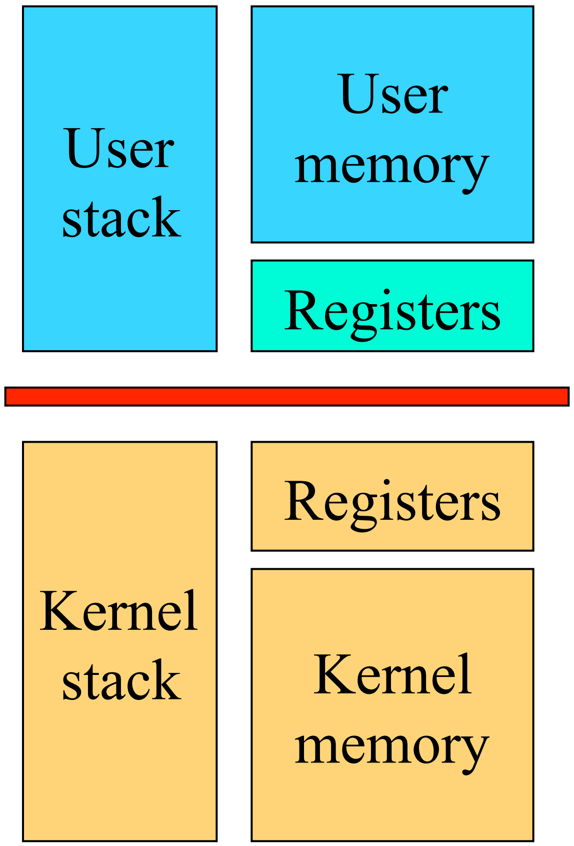
call the real code pointed by R_0
place result in R_{result}

restore context

switch to user stack

iret (change to user mode and return)

(Assume passing parameters in registers)



A simple system call (6th Edition chdir)

- "call the real code pointed by R_0 place result in R_{result}"

```
chdir()
{
        register *ip;
        extern uchar;

        ip = namei(&uchar, 0);
        if(ip == NULL)
                return;
        if((ip->i_mode&IFMT) != IFDIR) {
                u.u_error = ENOTDIR;
        bad:
                iput(ip);
                return;
        }
        if(access(ip, IEXEC))
                goto bad;
        iput(u.u_cdir);
        u.u_cdir = ip;
        prele(ip);
}
```

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?

Syscall or library?

```
/*
 * open system call
 */
open()
{
        register *ip;
        extern uchar;

        ip = namei(&uchar, 0);
        if(ip == NULL)
                return;
        u.u_arg[1]++;
        open1(ip, u.u_arg[1], 0);
}

/*
 * creat system call
 */
creat()
{
        register *ip;
        extern uchar;

        ip = namei(&uchar, 1);
        if(ip == NULL) {
                if(u.u_error)
                        return;
                ip = maknode(u.u_arg[1]&07777&(~ISVTX));
                if (ip==NULL)
                        return;
                open1(ip, FWRITE, 2);
        } else
                open1(ip, FWRITE, 1);
}
```

```
/*
 * common code for open and creat.
 * Check permissions, allocate an open file structure,
 * and call the device open routine if any.
 */
open1(ip, mode, trf)
int *ip;
{
        register struct file *fp;
        register *rip, m;
        int i;

        rip = ip;
        m = mode;
        if(trf != 2) {
                if(m&FREAD)
                        access(rip, IREAD);
                if(m&FWRITE) {
                        access(rip, IWRITE);
                        if((rip->i_mode&IFMT) == IFDIR)
                                u.u_error = EISDIR;
                }
        }
        if(u.u_error)
                goto out;
        if(trf)
                itrunc(rip);
        prele(rip);
        if ((fp = falloc()) == NULL)
                goto out;
        fp->f_flag = m&(FREAD|FWRITE);
        fp->f_inode = rip;
        i = u.u_ar0[R0];
        openi(rip, m&FWRITE);
        if(u.u_error == 0)
                return;
        u.u_ofile[i] = NULL;
        fp->f_count--;

out:
        iput(rip);
}
```

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.

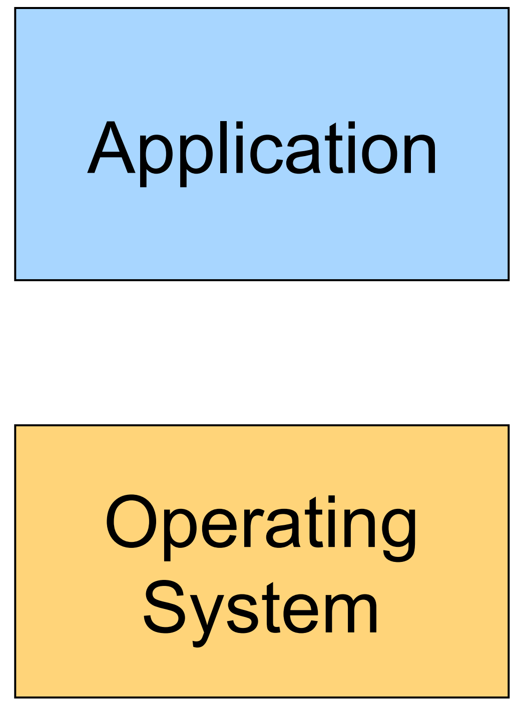
Division of Labor (or Separation Of Concerns)

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

Feedback To The Program

- Applications view system calls and library calls as procedure calls
- What about OS to apps?
  - Various exceptional conditions
  - General information, like screen resize
- What mechanism would OS use for this?



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