COS 318: Operating Systems

OS Structures and System Calls

Prof. Margaret Martonosi
Computer Science Department
Princeton University

http://www.cs.princeton.edu/courses/archive/fall11/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
  - Distinctions between protection and security?

Architecture Support: Privileged Mode

An interrupt or exception (INT)

User mode

- Regular instructions
- Access user memory

Kernel (privileged) mode

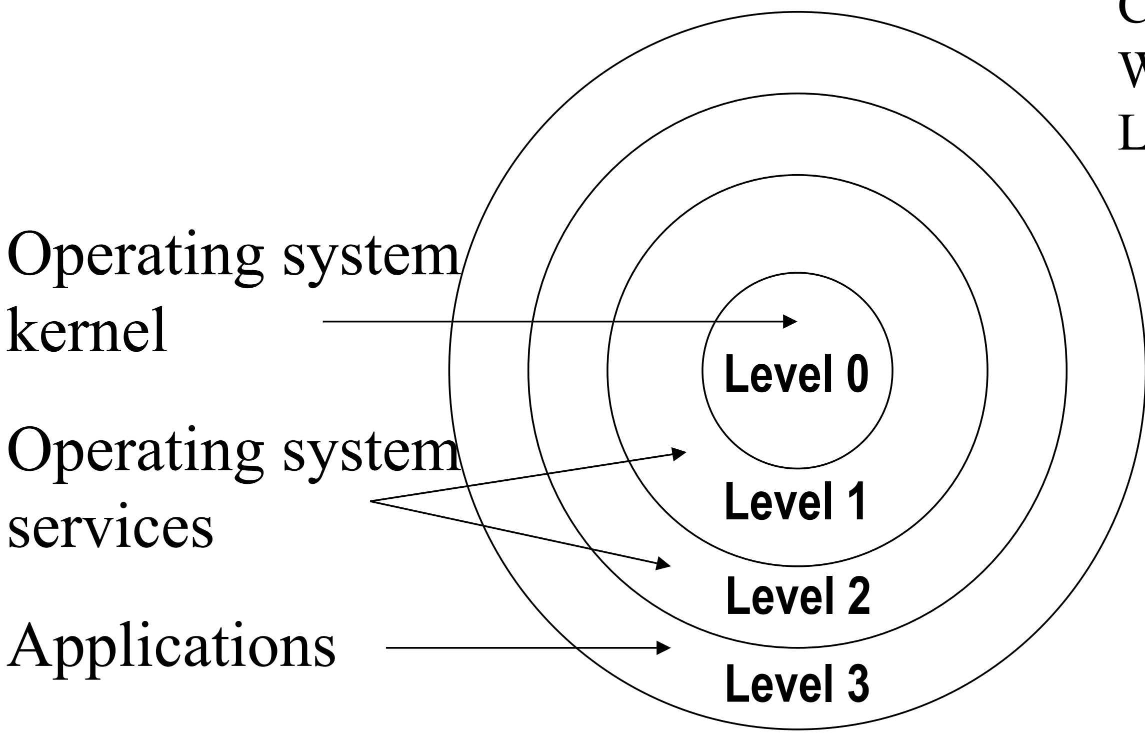
- Regular instructions
- Privileged instructions
- Access user memory
- Access kernel memory

A special instruction (IRET)

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

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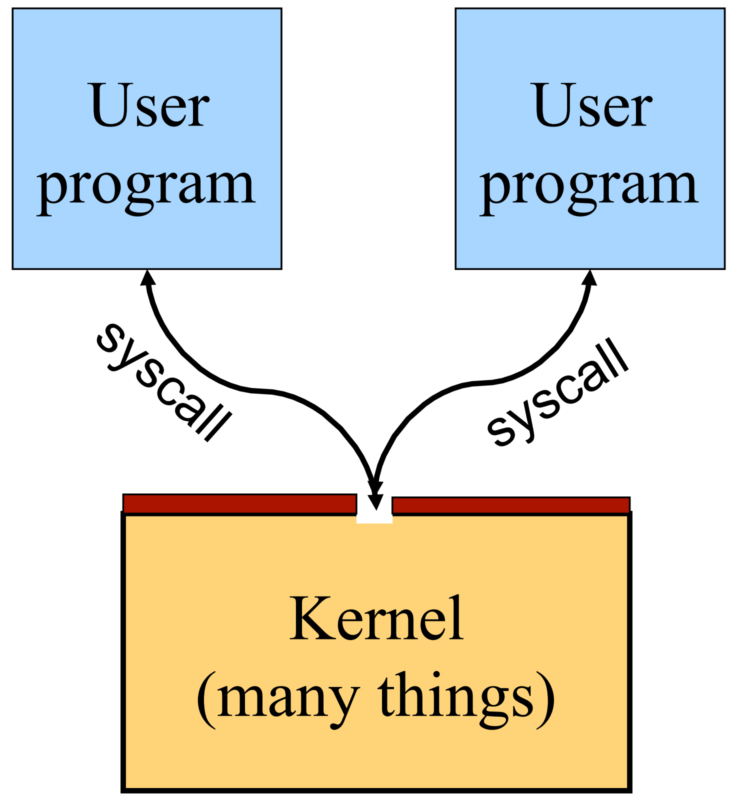
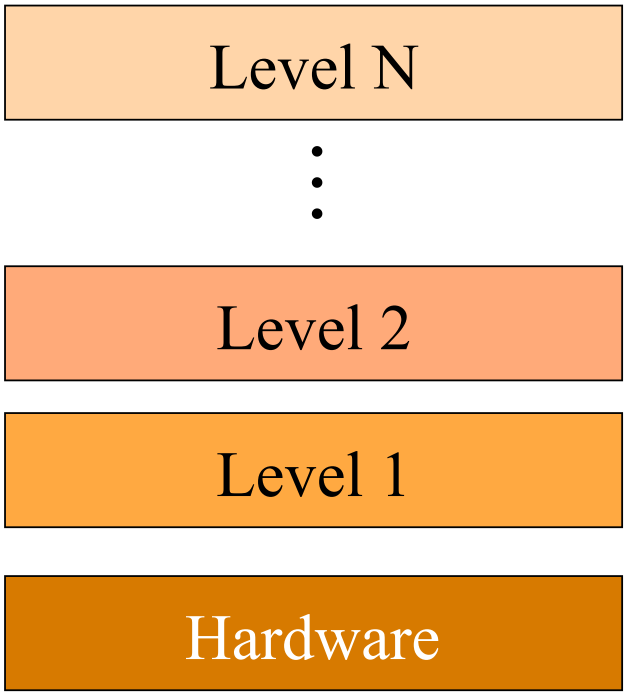
Monolithic

- All kernel routines are together, any can call any
- A system call interface
- Examples:
  - Linux, BSD Unix, Windows
- Pros
  - Shared kernel space
  - Good performance
- Cons
  - No information hiding
  - Chaotic
  - Hard to understand
  - How many bugs in 5M lines of code?



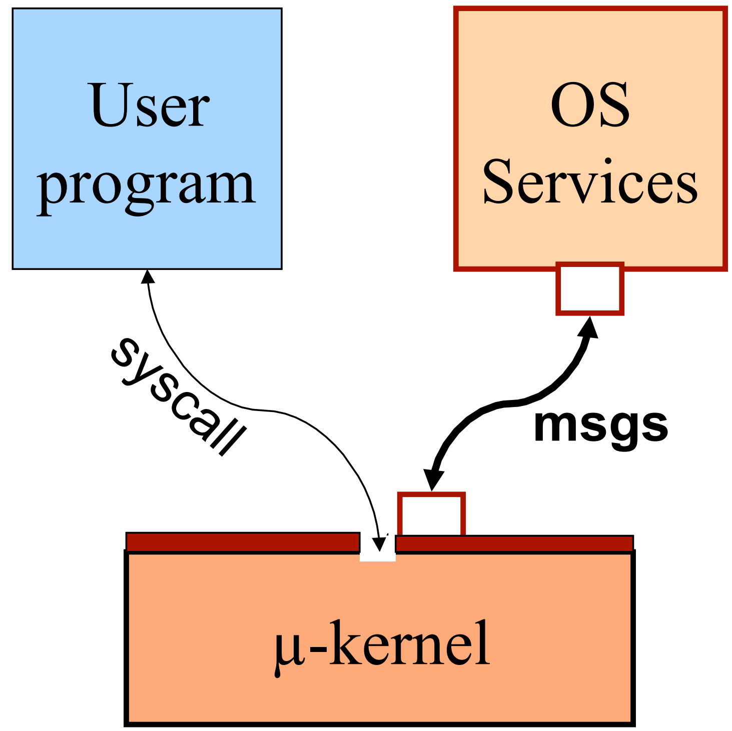
Layered Structure

- Level N constructed on N-1
- Hiding information at each layer
- Examples:
  - THE (6 layers)
  - MULTICS (8 rings)
- Pros
  - Layered abstraction
  - Separation of concerns
  - Elegance
- Cons
  - Protection boundary crossings
  - Performance
  - Inflexible



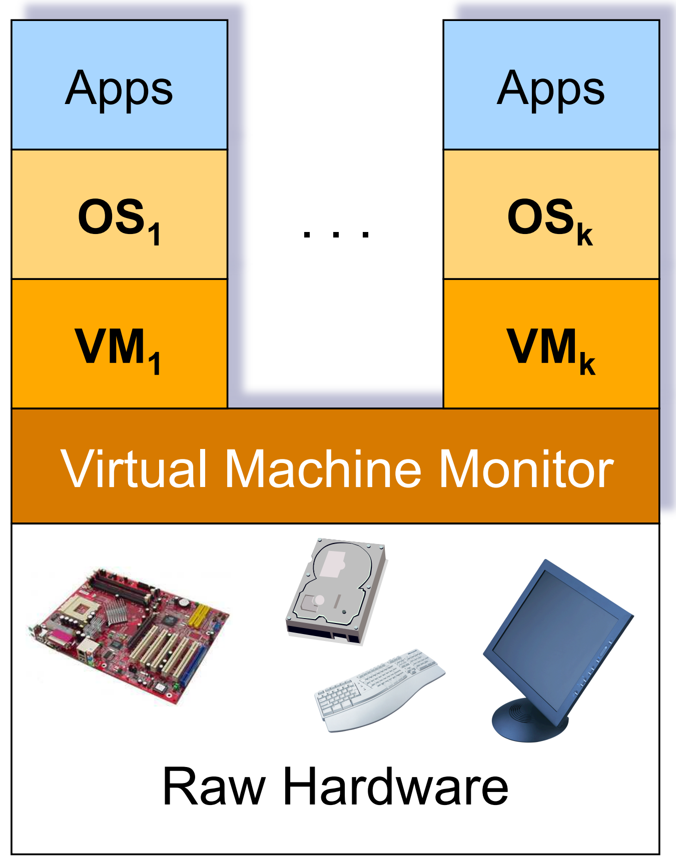
Microkernel

- Put less in kernel mode; only small part of OS
- Services are implemented as regular process
- *μ*-kernel gets svcs on for users by messaging with service processes
- Examples:
  - Mach, Taos, L4
- Pros?
  - Modularity: easier management
  - Fault isolation and reliability
- Cons?
  - Inefficient (boundary crossings)
  - Insufficient protection
  - Inconvenient to share data between kernel and services

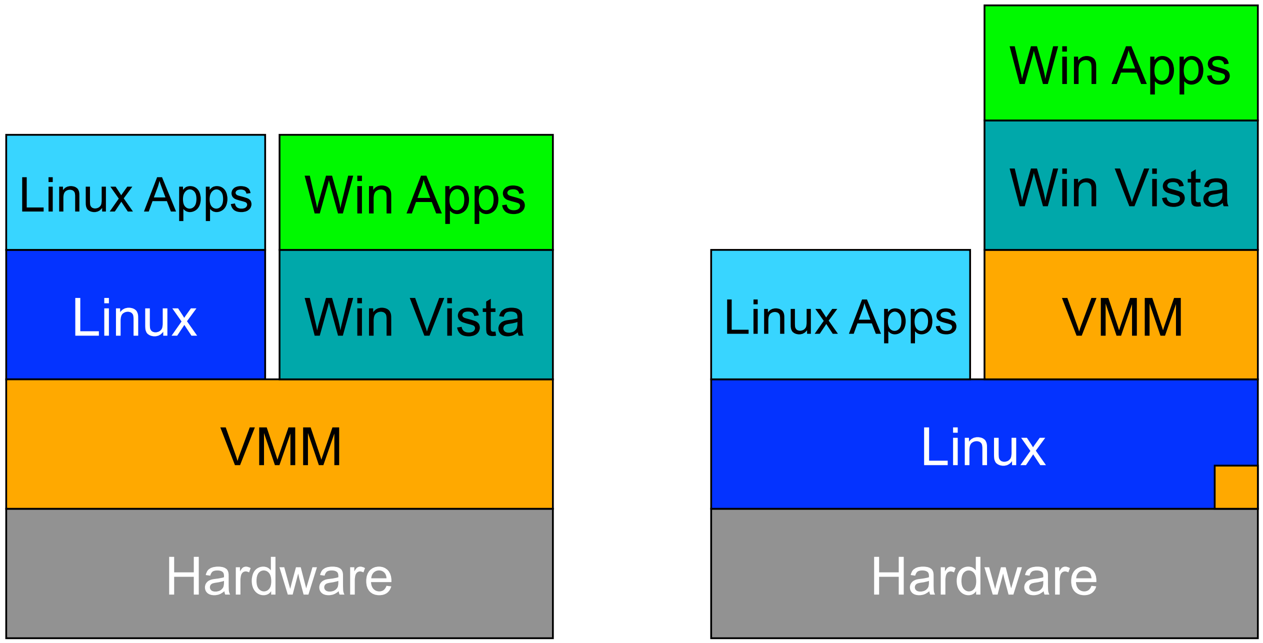


Virtual Machine

- Separate multiprogramming from abstraction; VMM provides former
- Virtual machine monitor
  - Virtualize hardware, but expose as multiple instances of “raw” HW
  - Run several OSes, one on each instance
  - Examples
    - IBM VM/370
    - Java VM
    - VMWare, Xen
- What would you use a virtual machine for?



Two Popular Ways to Implement VMM



VMM runs on hardware

VMM as an application

(A special lecture later in the semester)

Outline

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- OS structures
- System and library calls

System Calls

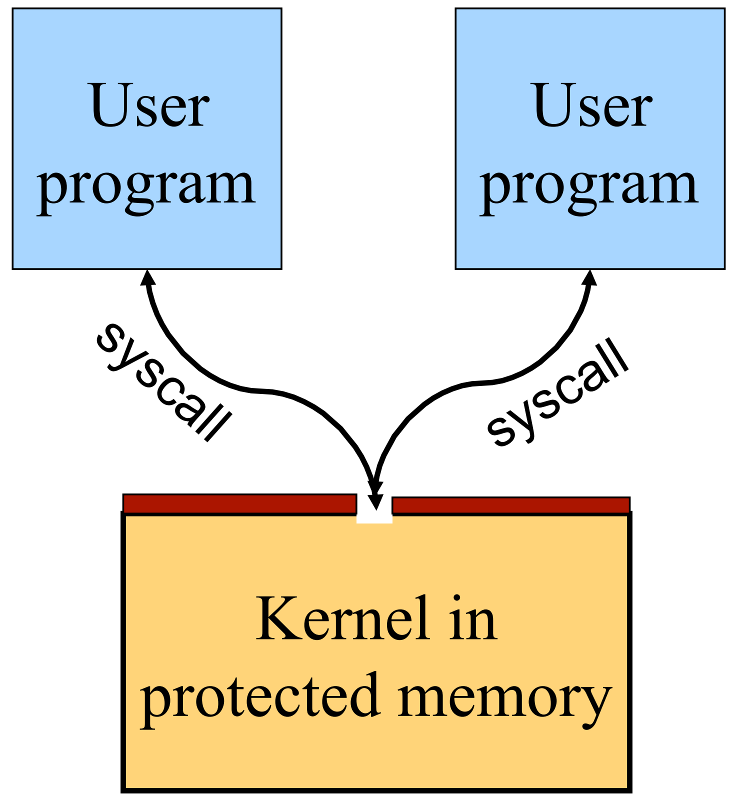
- Operating system API
  - Interface between an application and the operating system kernel
- Categories
  - Process management
  - Memory management
  - File management
  - Device management
  - Communication

How many system calls?

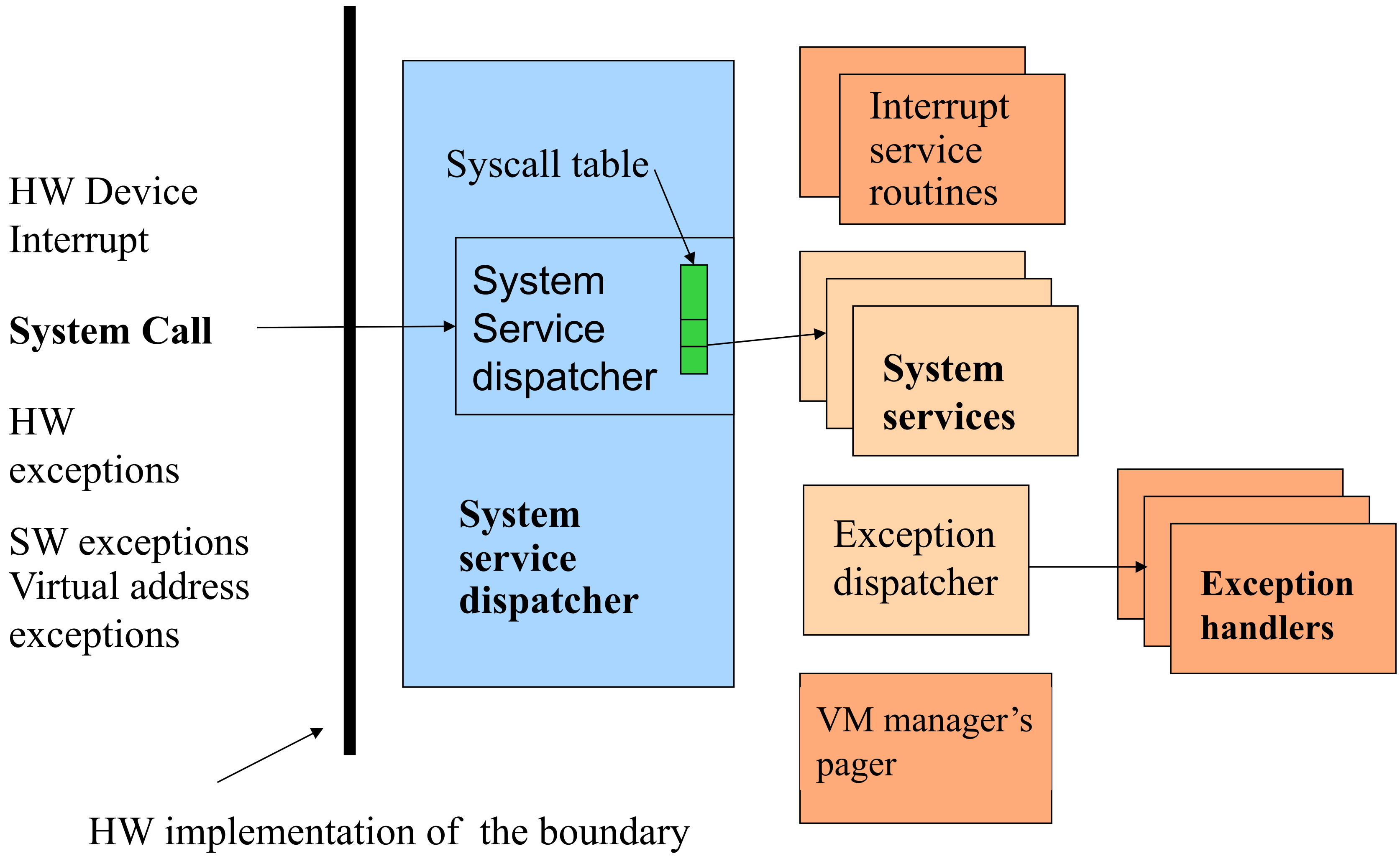
- 6th Edition Unix: ~45
- POSIX: ~130
- FreeBSD: ~130
- Linux: ~250
- Windows: 400? 1000? 1M?

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
  - (Like a procedure call, just crosses kernel boundary)



OS Kernel: Trap Handler



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 */
```

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

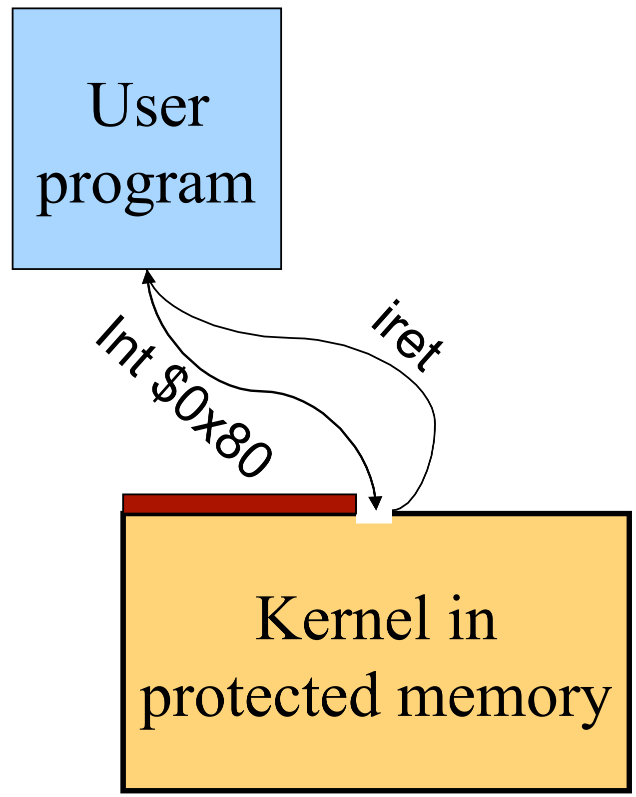
  move result from R_{result}

  }

Linux: 80
NT: 2E

Assembly instructions to marshall args, invoke interrupt, And then put result in right place

int vs. int !!!



System Call Entry Point

EntryPoint:

save context

switch to kernel stack

check R_0

call the real code pointed by R_0

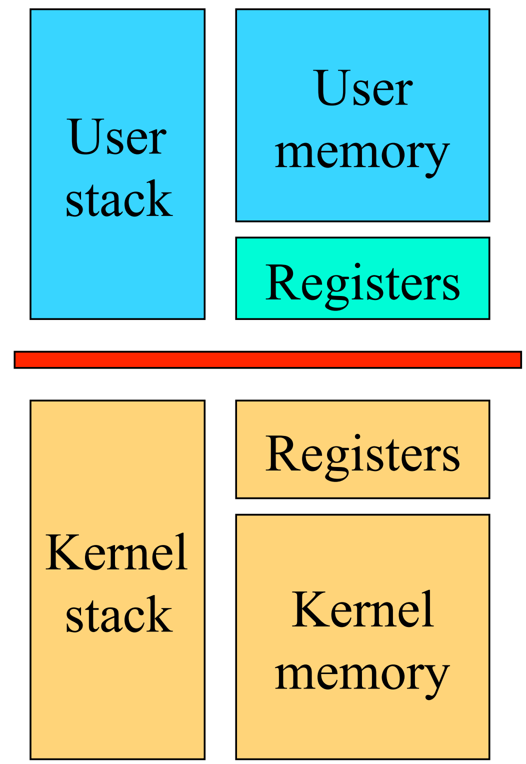
place result in R_{result}

switch to user stack

restore context

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?
- System calls vs. library calls
  - What should go in system calls?
  - What should go in 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.

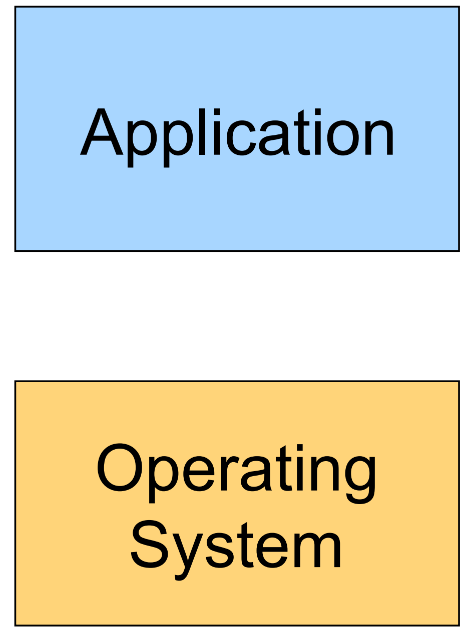
Division of Labors

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?



Interrupts and Exceptions

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

Interrupts 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	

Interrupts 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

Example: Divide error

- What happens when your program divides by zero?
  - Processor exception
    - Defined by x86 architecture as INT 0
  - Jump to kernel, execute handler 0 in interrupt vector
  - Handler 0 sends SIGFPE to process
  - Kernel returns control to process
  - Process has outstanding signal
  - Did process register SIGFPE handler?
    - Yes:
      - Execute SIGFPE handler
      - When handler returns, resume program and redo divide
    - No: kills process

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