Architectural Support for Operating Systems

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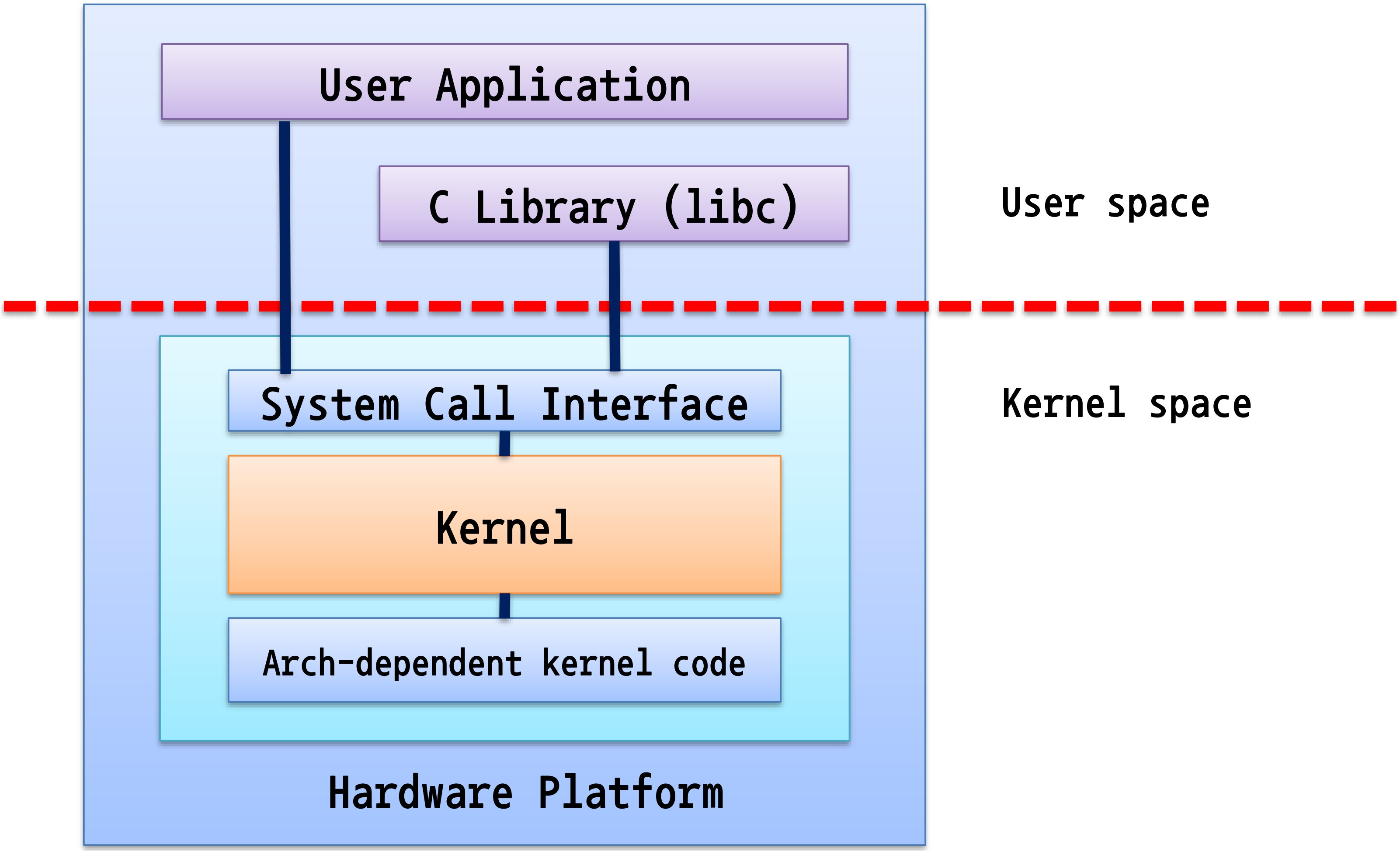
Today's Topics

Basic structure of OS

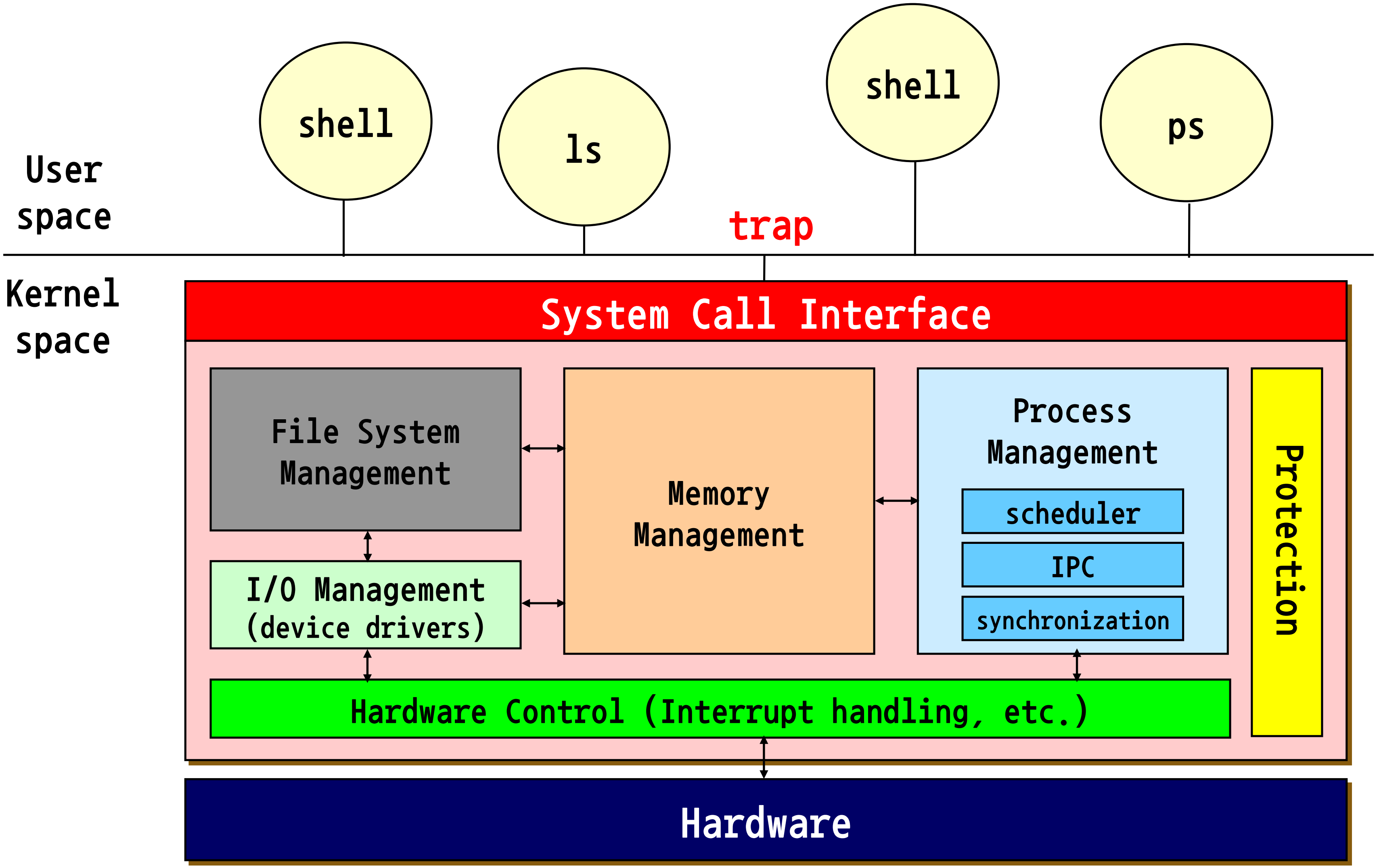
Basic computer system architecture

Architectural support for OS

OS Internals (1)

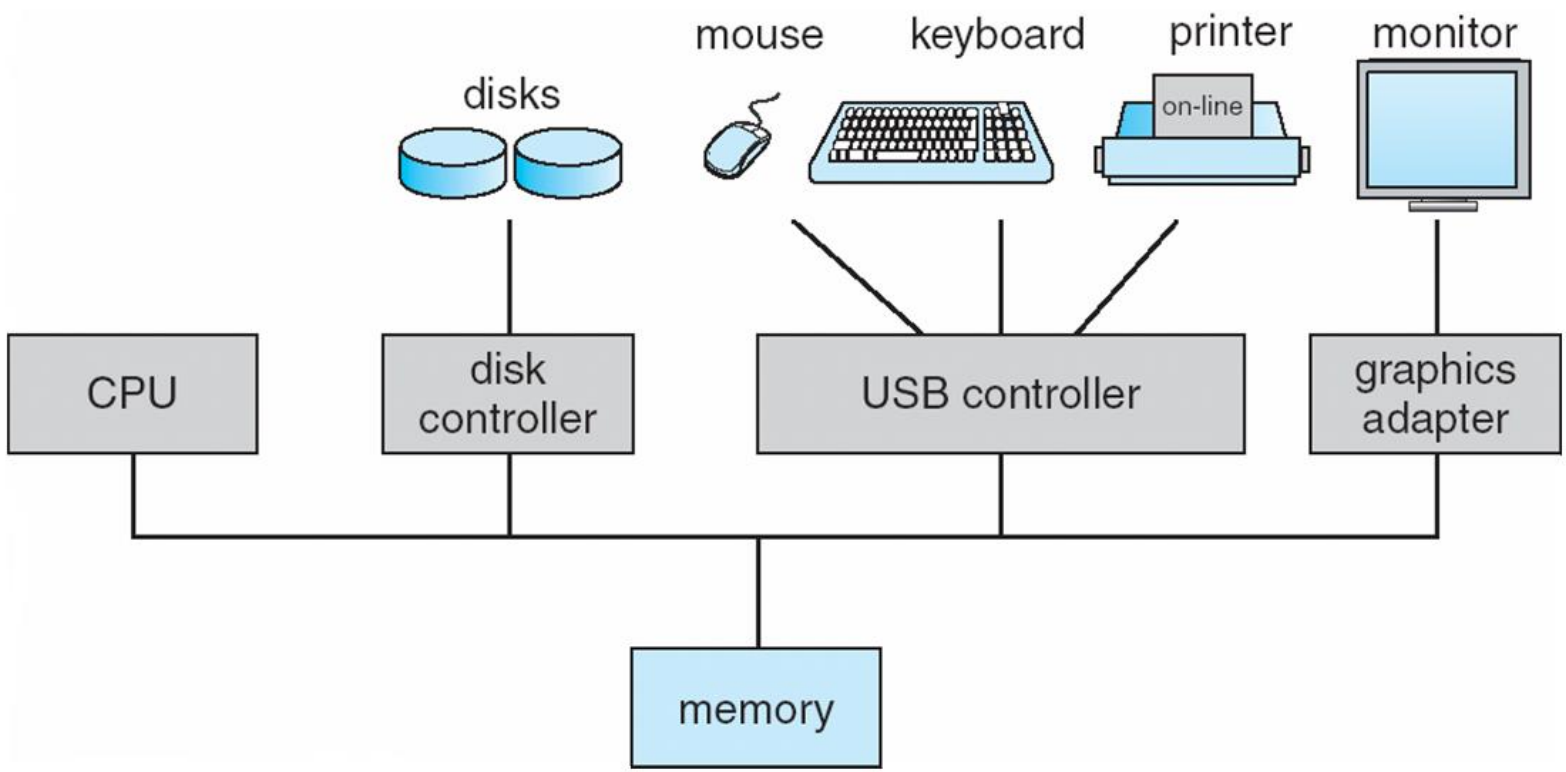


OS Internals (2)



Computer Systems (1)

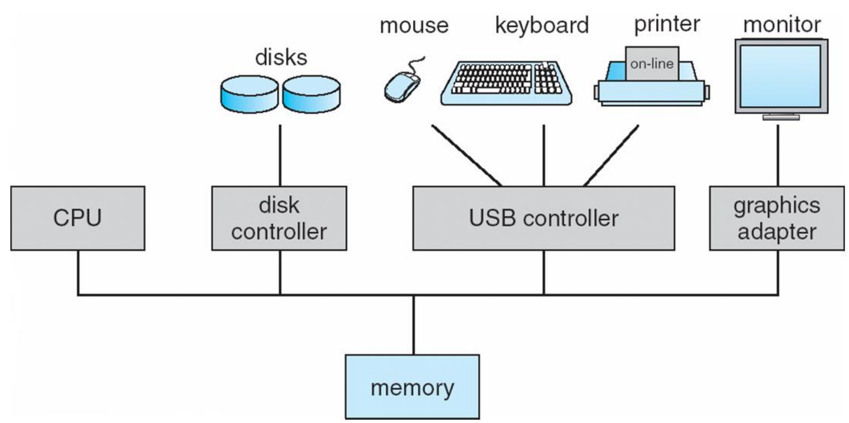
Computer system organization



Computer Systems (2)

Characteristics

- I/O devices and CPU can execute concurrently
- Each device controller is in charge of a particular device type
- Each device controller has a local buffer
- CPU moves data from/to main memory to/from local buffers
- I/O is data movements between the device to local buffer of controller
- CPU issues specific commands to I/O devices
- CPU should be able to know whether the issued command has been completed or not

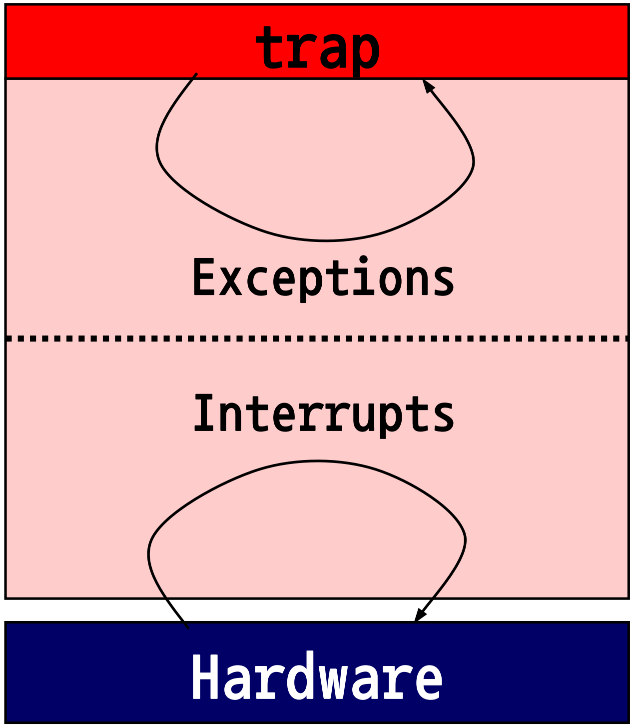


OS and Architecture

Mutual interaction

- The functionality of an OS is limited by architectural features
  - Multiprocessing on DOS/8086?
- The structure of an OS can be simplified by architectural support
  - Interrupt, DMA, synchronization, Intel-VT/AMD-V, etc.
- Most proprietary OS's were developed with the certain architecture in mind
  - SunOS/Solaris for SPARC architecture
  - IBM AIX for Power/PowerPC architecture
  - HP-UX for PA-RISC architecture
  - ...

Interrupts (1)



Interrupts

- Generated by hardware devices
  - Triggered by a signal in INTR or NMI pins (x86)
- Asynchronous

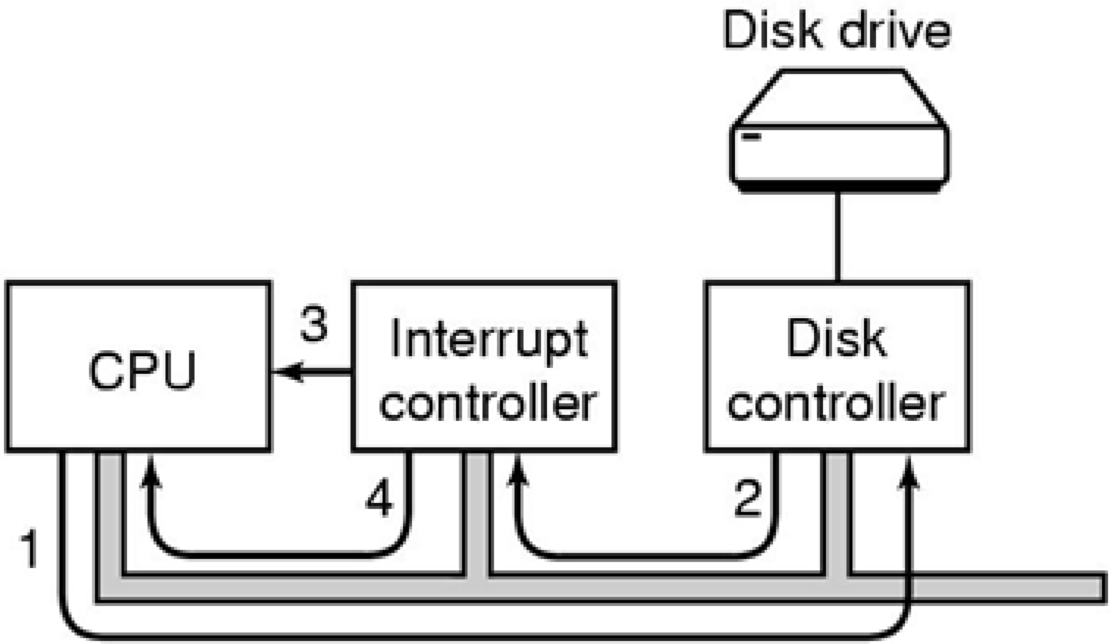
Exceptions

- Generated by software executing instructions
  - INT instruction in x86
- Synchronous
- Exception handling is same as interrupt handling

Interrupts (2)

How does the kernel notice an I/O has finished?

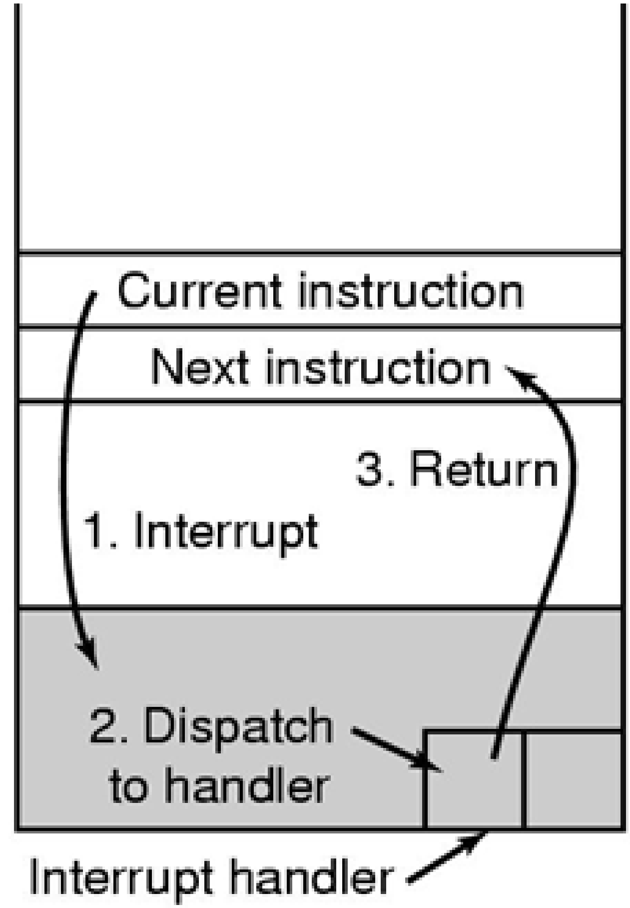
- Polling
- Hardware interrupt



Interrupts (3)

Interrupt handling

- Preserves the state of the CPU
  - In a fixed location
  - In a location indexed by the device number
  - On the system stack
- Determines the type
  - Polling
  - Vectored interrupt system
- Transfers control to the interrupt service routine (ISR) or interrupt handler



Exceptions (1)

Interrupts

- Generated by hardware devices
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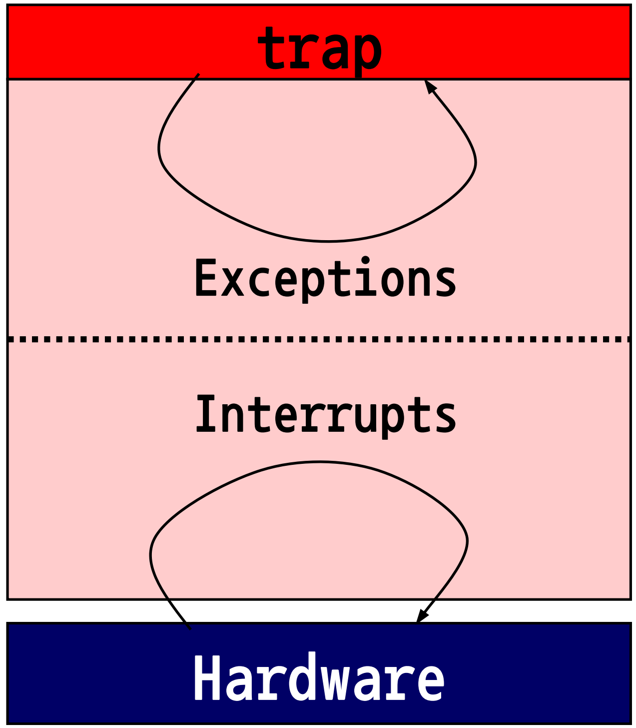
- Asynchronous



Exceptions

- Generated by software executing instructions
  - INT instruction in x86
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- Exception handling is same as interrupt handling

Exceptions (2)

Further classification of exceptions

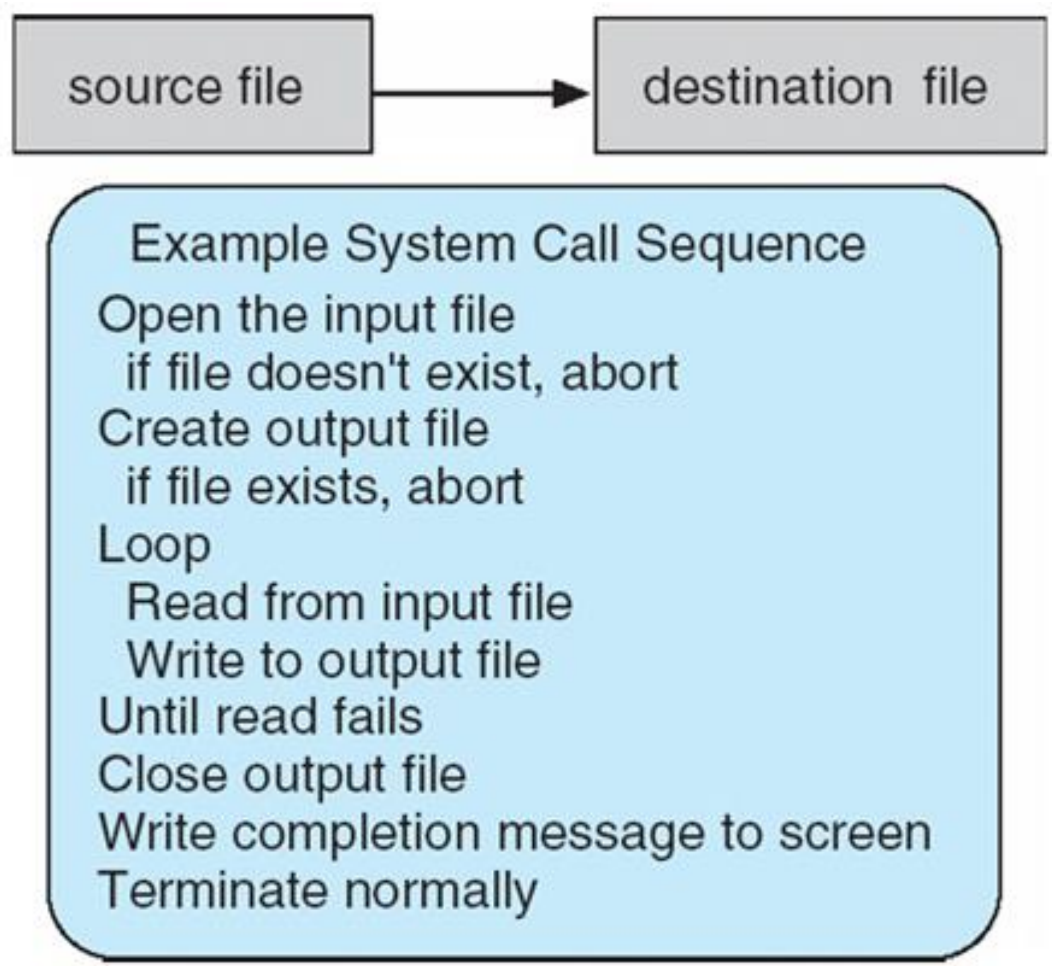
- Traps
  - Intentional
  - System calls, breakpoint traps, special instructions, ...
  - Return control to "next" instruction
- Faults
  - Unintentional but possibly recoverable
  - Page faults (recoverable), protection faults (unrecoverable), ...
  - Either re-execute faulting ("current") instruction or abort
- Aborts
  - Unintentional and unrecoverable
  - Parity error, machine check, ...
  - Abort the current program

Exceptions (3)

System calls

- Programming interface to the services provided by OS
- e.g., system call sequence to copy the contents of one file to another

cp a.txt b.txt



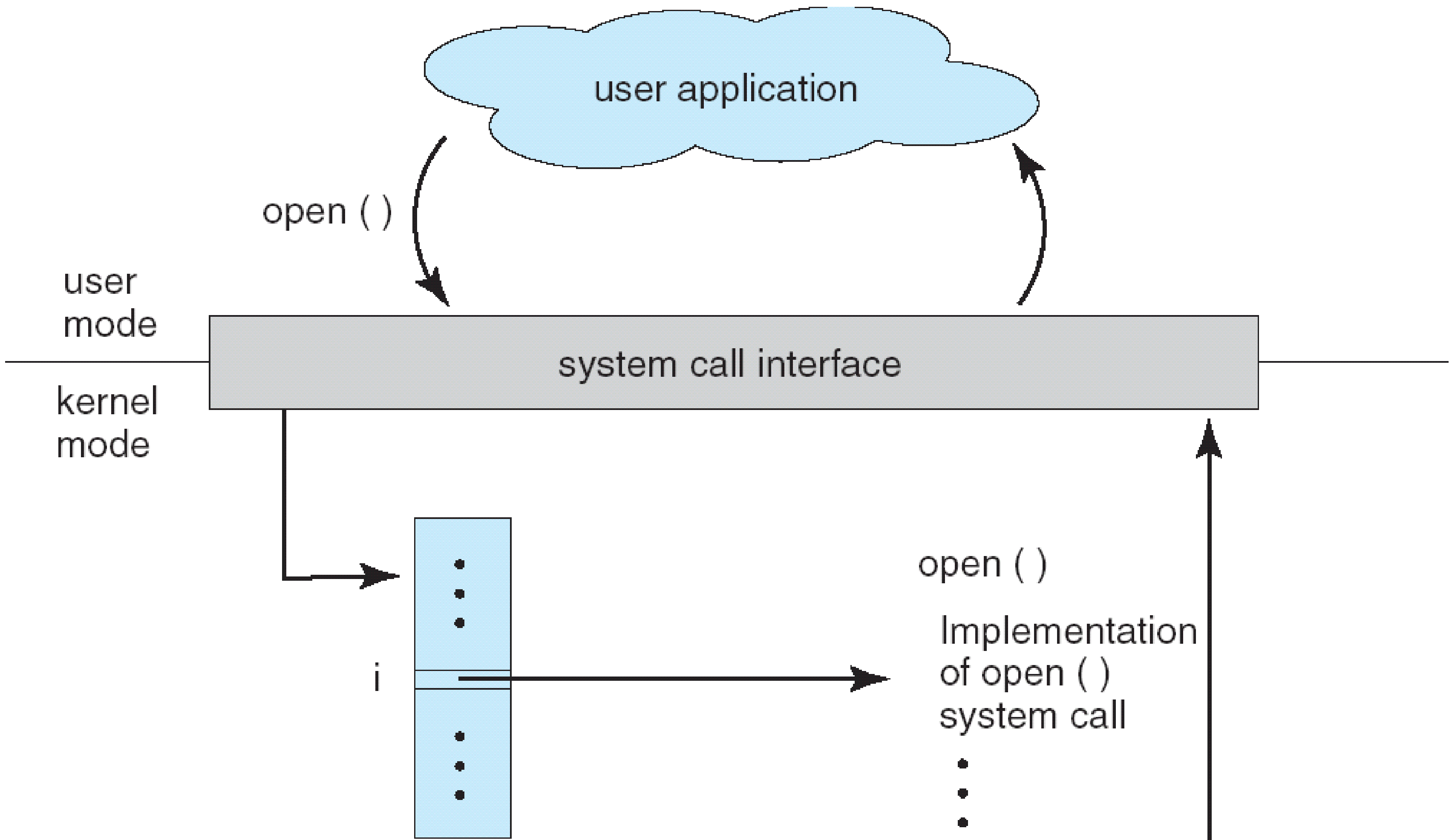
Exceptions (4)

Important system calls (POSIX & Win32)

Process Management	fork	CreateProcess	Create a new process
	waitpid	WaitForSingleObject	Wait for a process to exit
	execve	(none)	CreateProcess = fork + execve
	exit	ExitProcess	Terminate execution
	kill	(none)	Send a signal
File Management	open	CreateFile	Create a file or open an existing file
	close	CloseHandle	Close a file
	read	ReadFile	Read data from a file
	write	WriteFile	Write data to a file
	lseek	SetFilePointer	Move the file pointer
	stat	GetFileAttributesEx	Get various file attributes
	chmod	(none)	Change the file access permission
File System Management	mkdir	CreateDirectory	Create a new directory
	rmdir	RemoveDirectory	Remove an empty directory
	link	(none)	Make a link to a file
	unlink	DeleteFile	Destroy an existing file
	mount	(none)	Mount a file system
	umount	(none)	Unmount a file system
	chdir	SetCurrentDirectory	Change the curent working directory

Exceptions (5)

Implementing system calls

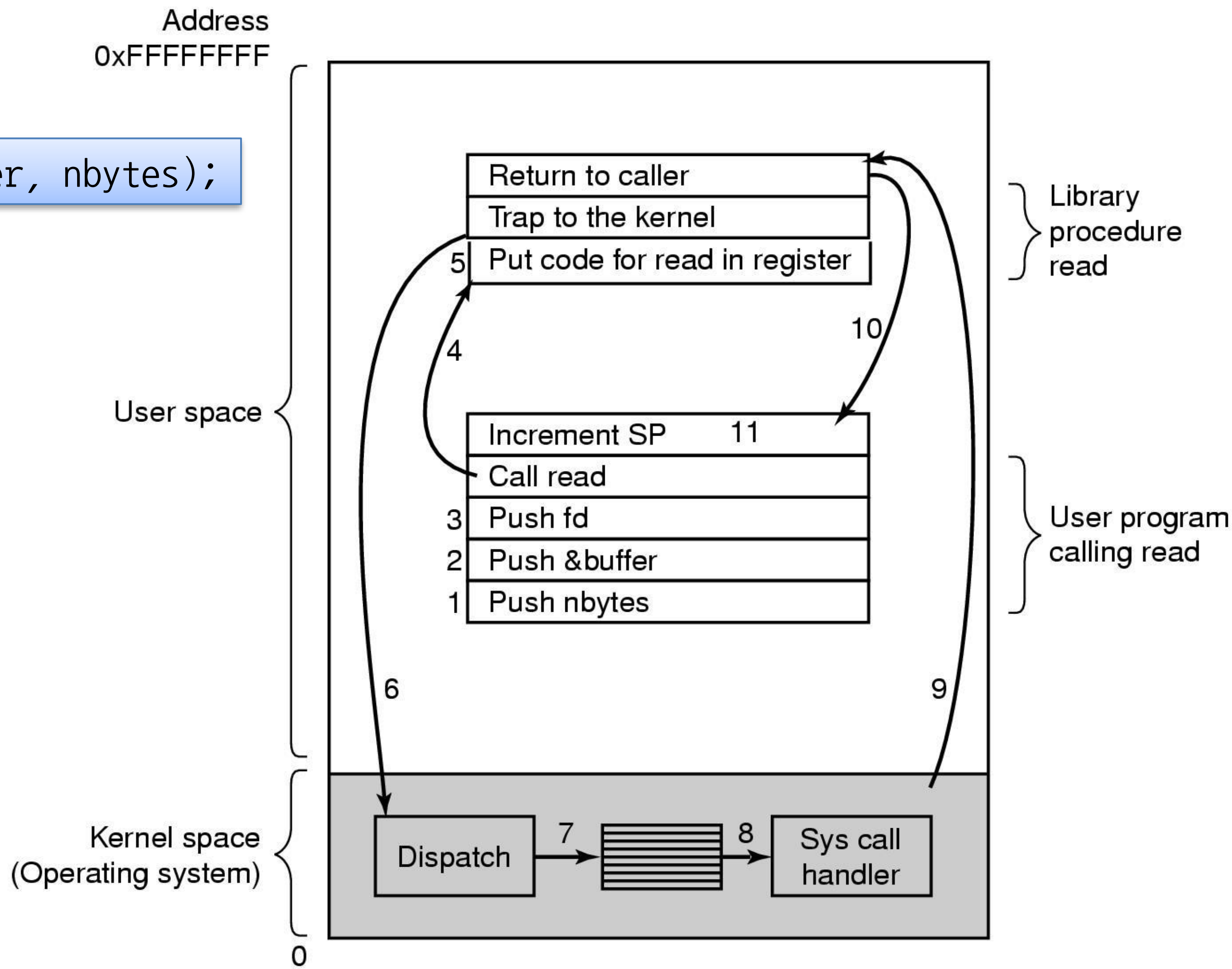


System call table

Exceptions (6)

Implementing system calls (cont'd)

```
count = read (fd, buffer, nbytes);
```



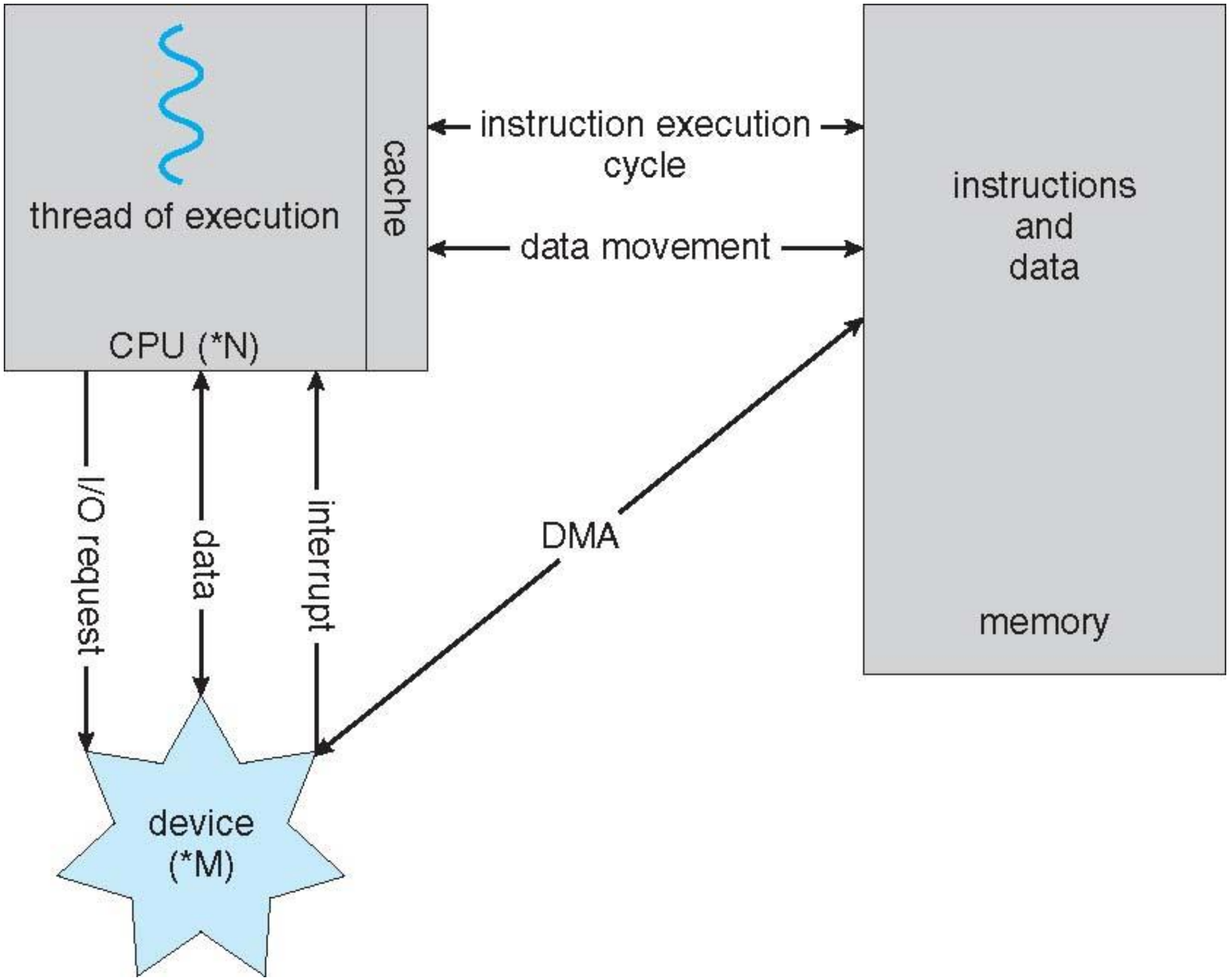
DMA (1)

Data transfer modes in I/O

- Programmed I/O (PIO)
  - CPU is involved in moving data between I/O devices and memory
  - By special I/O instructions vs. by memory-mapped I/O
- DMA (Direct Memory Access)
  - Used for high-speed I/O devices able to transmit information at close to memory speeds
  - Device controller transfers blocks of data from buffer storage directly to main memory
    - Without CPU intervention
  - Only an interrupt is generated per block

DMA (2)

Processing I/O requests



Timers

How does the OS take control of CPU from the running programs?

- Use a hardware timer that generates a periodic interrupt
- The timer interrupt transfers control back to OS
- The OS preloads the timer with a time to interrupt
  - 10ms for Linux 2.4, 1ms for Linux 2.6
  - Dynamic changing for current Linux
  - (cf.) time slice
- The timer is privileged
  - Only the OS can load it

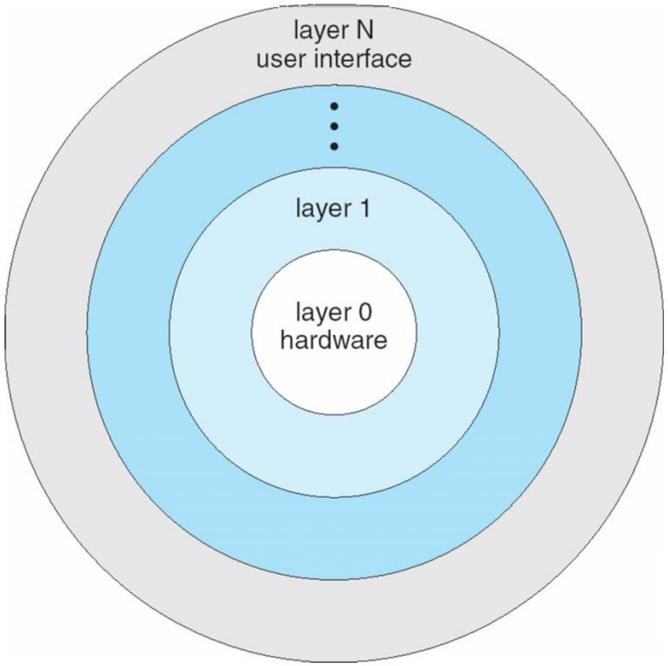
Protected Instructions

Protected or privileged instructions

- Direct I/O access
  - Use privileged instructions or memory-mapping
- Memory state management
  - Page table updates, page table pointers
  - TLB loads, etc.
- Setting special "mode bits"

OS Protection (1)

How does the processor know if a protected instruction should be executed?



- The architecture must support at least two modes of operation: kernel and user mode
  - 4 privilege levels in IA-32: Ring 0 > 1 > 2 > 3
- Mode is set by a status bit in a protected processor register
  - User programs in user mode, OS in kernel mode
  - Current Privilege Level (CPL) in IA-32: CS register
- Protected instructions can only be executed in the kernel mode

OS Protection (2)

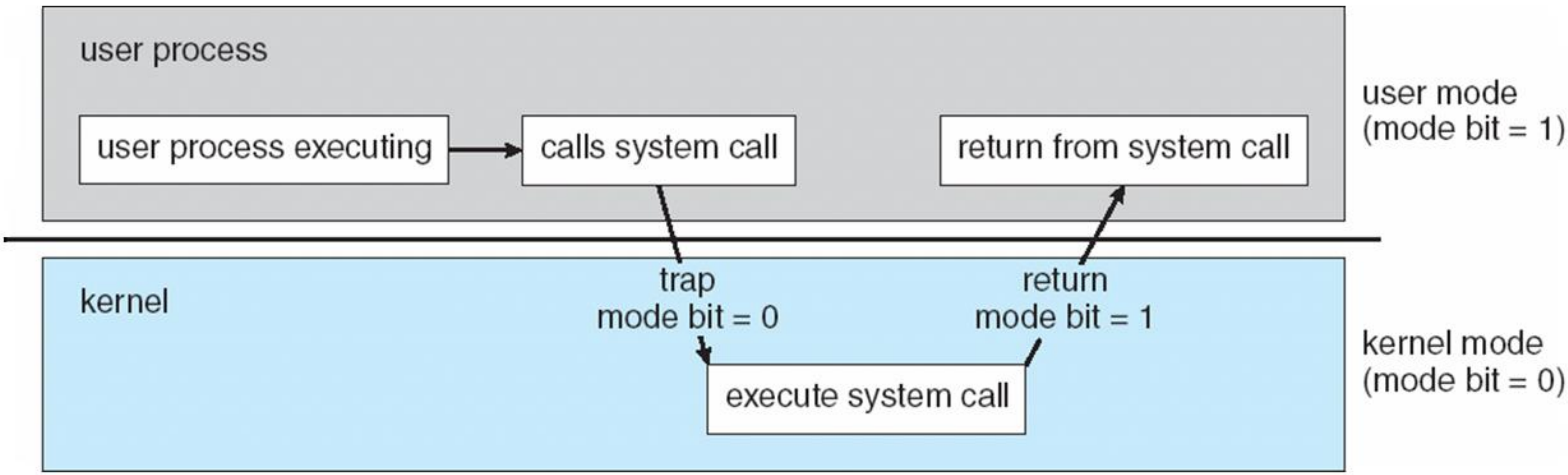
Crossing protection boundaries

- User programs must call an OS to do something privileged
  - OS defines a sequence of system calls (system call table)
- There must be a system call instruction that:
  - Causes an exception, which invokes a kernel handler
  - Passes a parameter indicating which system call to invoke
  - Saves caller's state (registers, mode bits) so they can be restored
  - OS must verify caller's parameters (e.g. pointers)
  - Must provide a way to return to user mode when done

OS Protection (3)

Making a system call

- System call changes mode to kernel
- Return from system call resets it to user



Memory Protection (1)

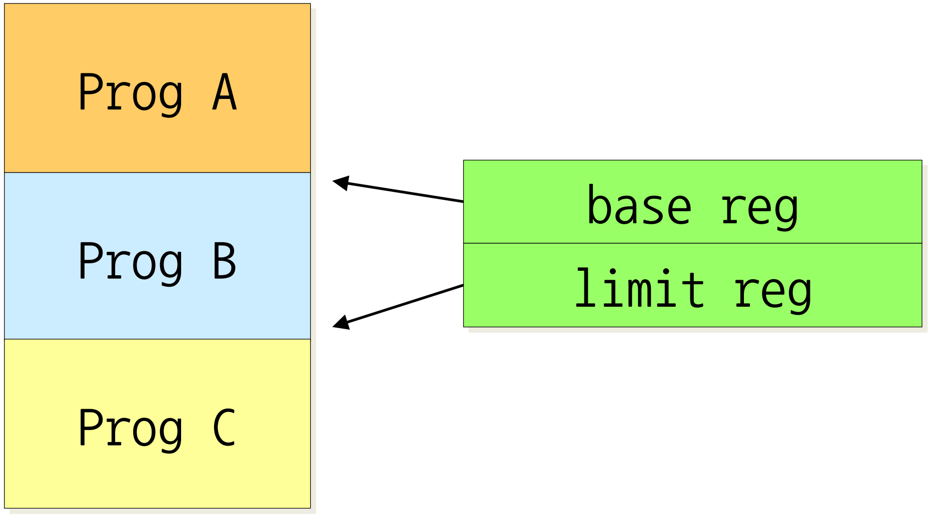
Requirements

- OS must protect user programs from each other
  - Malicious users
- OS must also protect itself from user programs
  - Integrity and security

Memory Protection (2)

Simplest scheme

- Use base and limit registers
- Base and limit registers are loaded by OS before starting a program



Memory Protection (3)

MMU (Memory Management Unit)

- Memory management hardware provides more sophisticated memory protection mechanisms
  - Base and limit registers
  - Page table pointers, page protection, TLBs
  - Virtual memory
  - Segmentation
- Manipulation of memory management hardware are protected (privileged) operations

Synchronization

Problems

- Interrupt can occur at any time and may interfere with the interrupted code
- OS must be able to synchronize concurrent processes

Synchronization

- Turn off/on interrupts
- Use a special atomic instructions
  - read-modify-write (e.g., INC, DEC)
  - test-and-set
  - LOCK prefix in IA32
  - LL (Load Locked) & SC (Store Conditional) in MIPS