Operating Systems
(1DT020 & 1TT802)

Lecture 13

I/O Systems (cont'd)
Protection and Security

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Goals for Today

- I/O systems
- Protection & Security

Note: Some slides and/or pictures in the following are adapted from slides ©2005 Silberschatz, Galvin, and Gagne, others from Kubiatowicz - CS162 ©UCB Fall 2007 (University of California at Berkeley)

I/O Systems

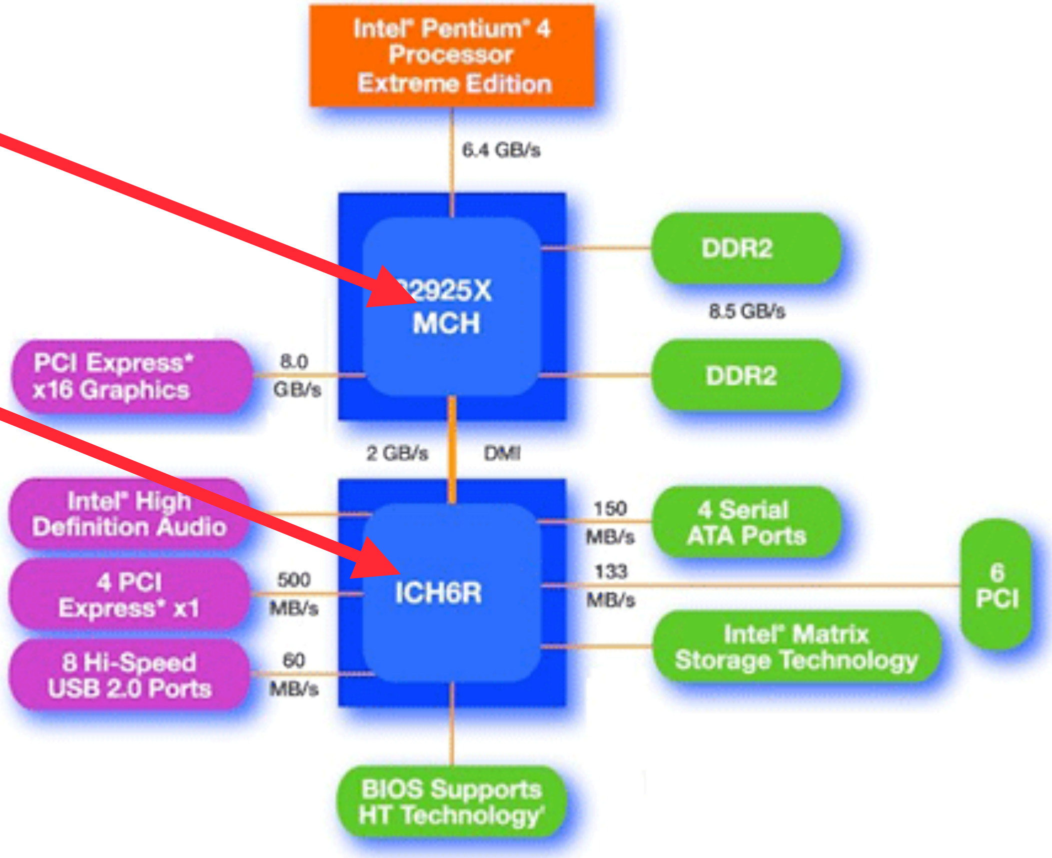
- Thousands of devices, each slightly different
  - OS should offer standard interfaces to applications
- Some operational parameters:
  - Byte/Block
    - » Some devices provide single byte at a time (*e.g.* keyboard)
    - » Others provide whole blocks (*e.g.* disks, networks, etc)
  - Also : Sequential/Random
    - » Some devices must be accessed sequentially (*e.g.* tape)
    - » Others can be accessed randomly (*e.g.* disk, cd, etc.)
- Device Rates vary over many orders of magnitude
  - OS should be able to handle this wide range
  - Better not have high overhead/byte for fast devices!
  - Better not waste time waiting for slow devices

How Does User Deal with Timing?

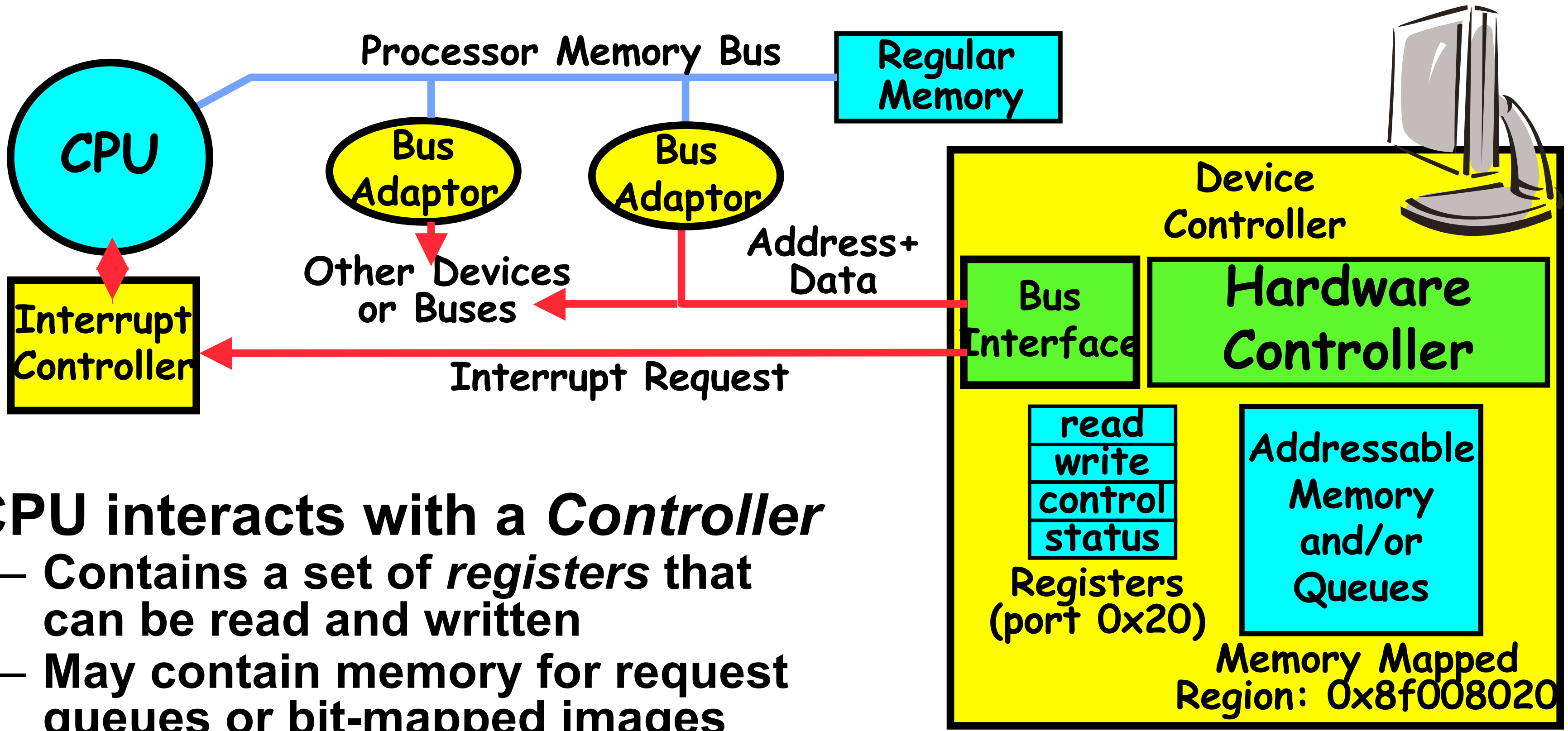
- Blocking Interface: "Wait"
  - When request data (e.g. `read()` system call), put process to sleep until data is ready
  - When write data (e.g. `write()` system call), put process to sleep until device is ready for data
- Non-blocking Interface: "Don't Wait"
  - Returns quickly from read or write request with count of bytes successfully transferred
  - Read may return nothing, write may write nothing
- Asynchronous Interface: "Tell Me Later"
  - When request data, take pointer to user's buffer, return immediately; later kernel fills buffer and notifies user
  - When send data, take pointer to user's buffer, return immediately; later kernel takes data and notifies user

Main components of Intel Chipset: Pentium 4

- **Northbridge:**
  - Handles memory
  - Graphics
- **Southbridge: I/O**
  - PCI bus
  - Disk controllers
  - USB controllers
  - Audio
  - Serial I/O
  - Interrupt controller
  - Timers



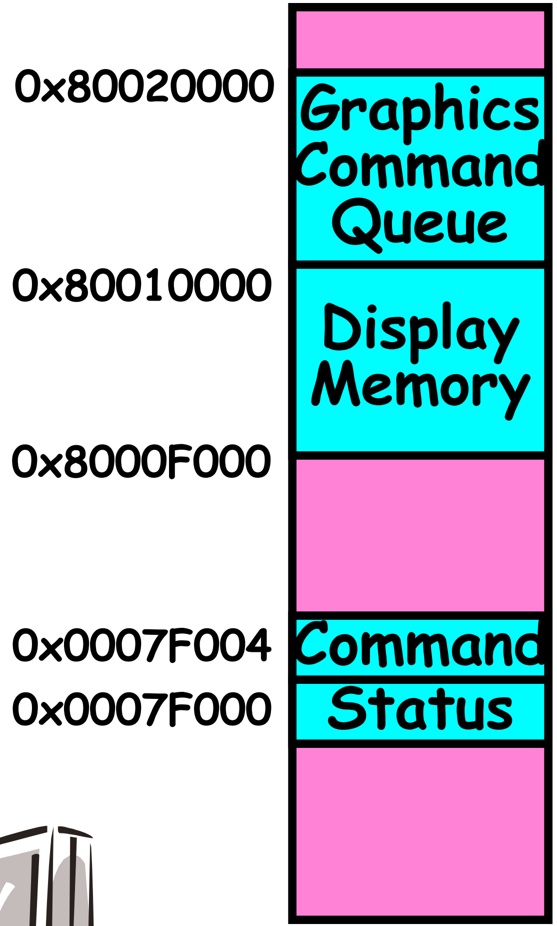
How does the processor actually talk to the device?



- CPU interacts with a *Controller*
  - Contains a set of *registers* that can be read and written
  - May contain memory for request queues or bit-mapped images
- Regardless of the complexity of the connections and buses, processor accesses registers in two ways:
  - I/O instructions: in/out instructions
    - » Example from the Intel architecture: `out 0x21,AL`
  - Memory mapped I/O: load/store instructions
    - » Registers/memory appear in physical address space
    - » I/O accomplished with load and store instructions

Example: Memory-Mapped Display Controller

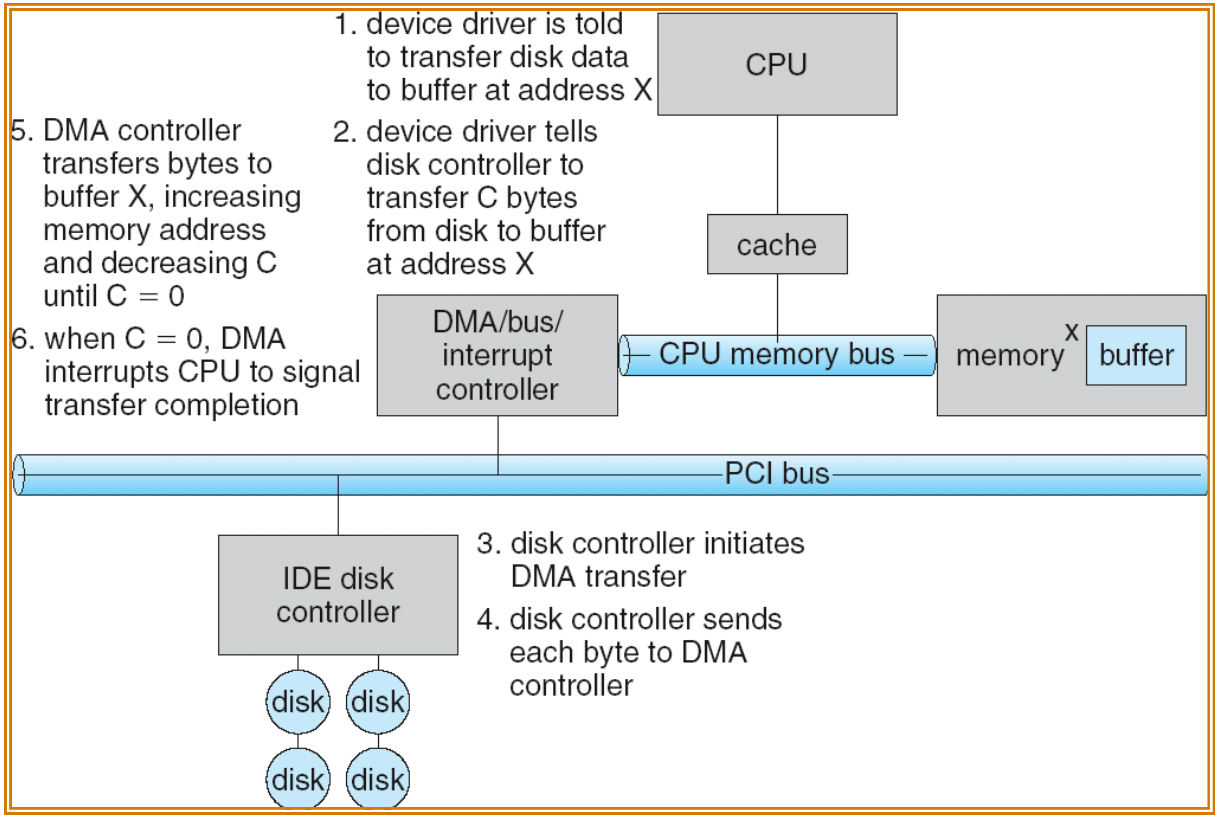
- **Memory-Mapped:**
  - Hardware maps control registers and display memory into physical address space
    - » Addresses set by hardware jumpers or programming at boot time
  - Simply writing to display memory (also called the "frame buffer") changes image on screen
    - » Addr: 0x8000F000—0x8000FFFF
  - Writing graphics description to command-queue area
    - » Say enter a set of triangles that describe some scene
    - » Addr: 0x80010000—0x8001FFFF
  - Writing to the command register may cause on-board graphics hardware to do something
    - » Say render the above scene
    - » Addr: 0x0007F004
- **Can protect with page tables**



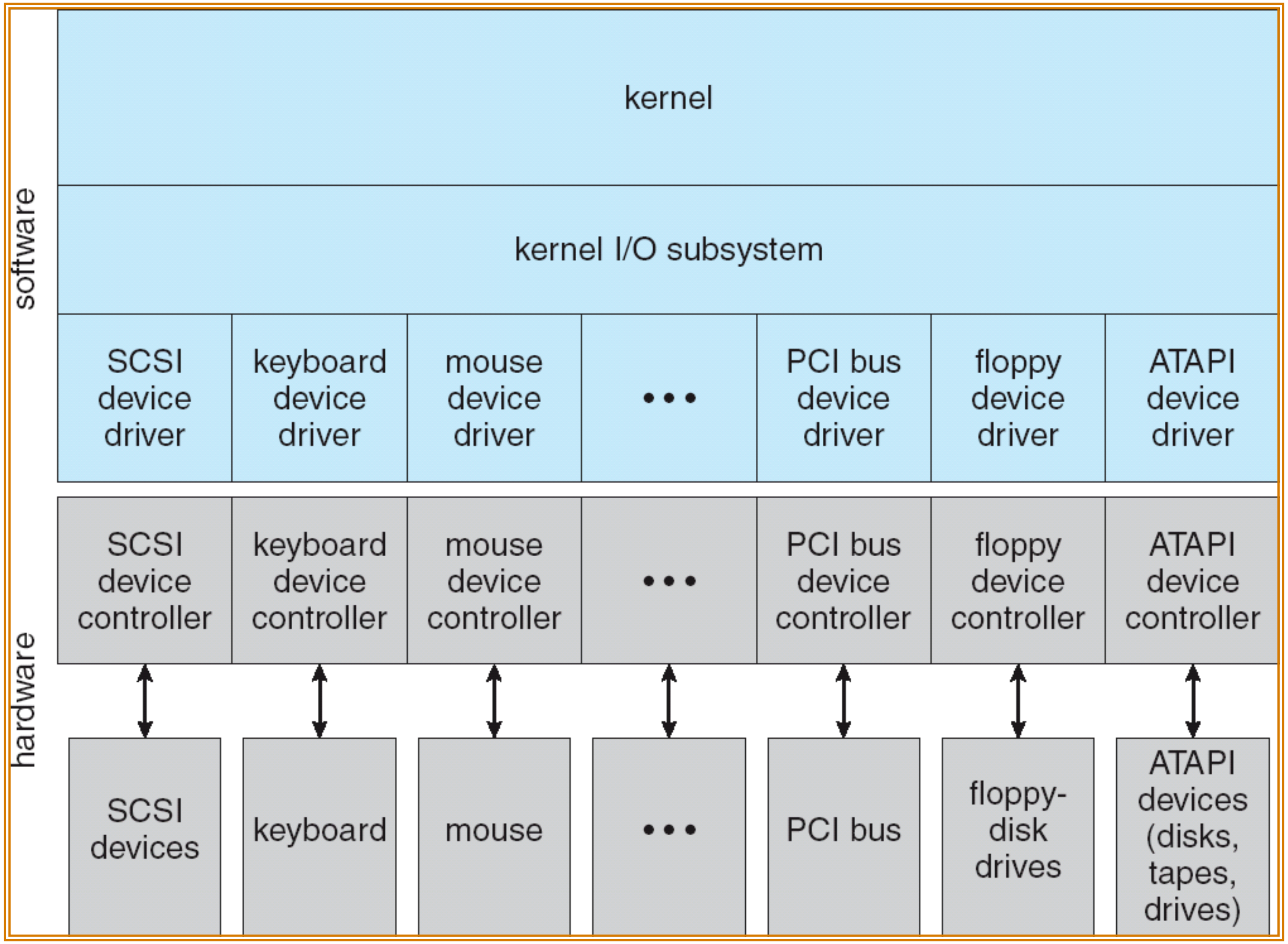
Physical Address Space

Transfering Data To/From Controller

- **Programmed I/O:**
  - **Each byte transferred via processor in/out or load/store**
  - **Pro: Simple hardware, easy to program**
  - **Con: Consumes processor cycles proportional to data size**
- **Direct Memory Access:**
  - **Give controller access to memory bus**
  - **Ask it to transfer data to/from memory directly**
- **Sample interaction with DMA controller (from book):**



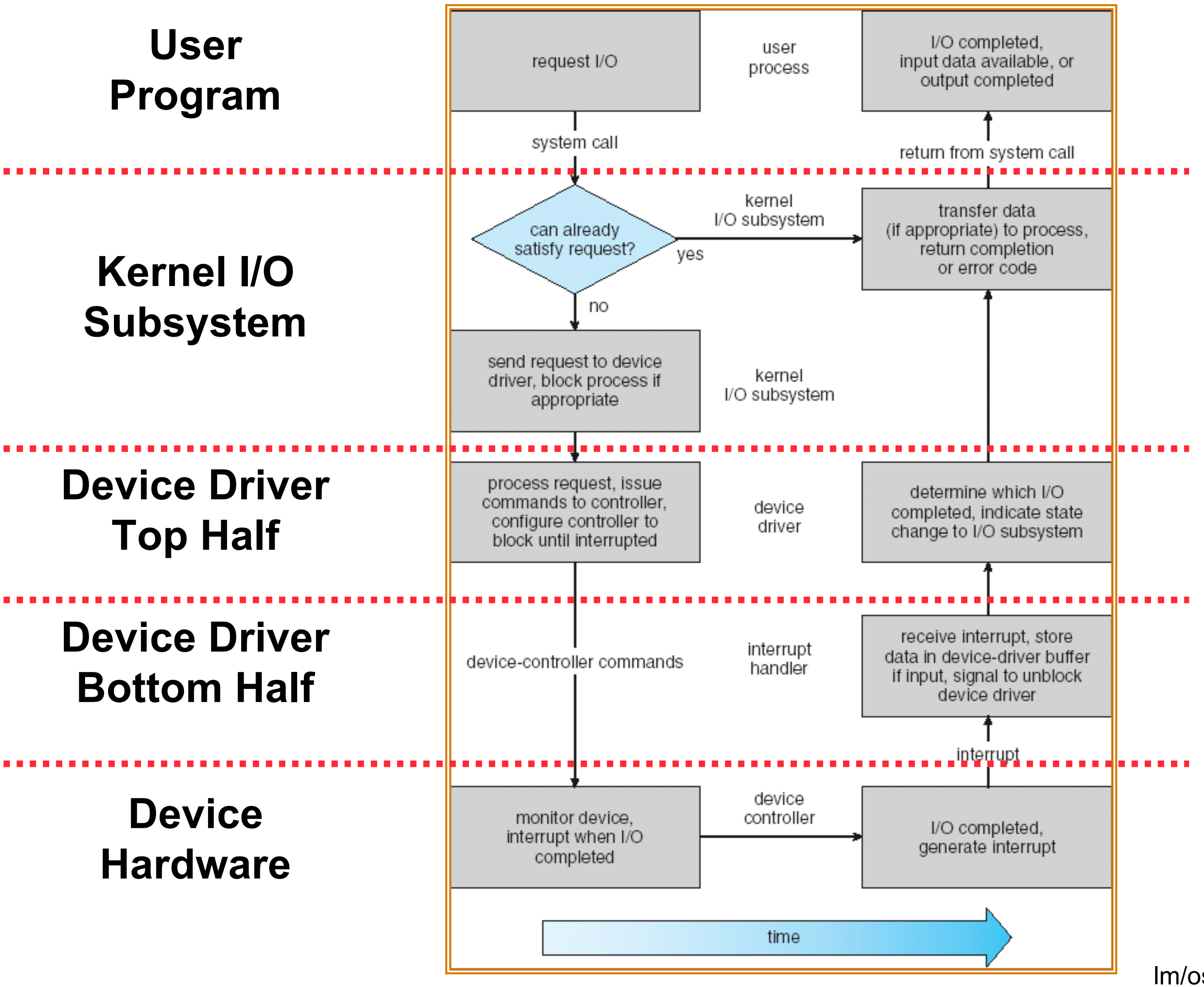
A Kernel I/O Structure



Device Drivers

- **Device Driver:** Device-specific code in the kernel that interacts directly with the device hardware
  - Supports a standard, internal interface
  - Same kernel I/O system can interact easily with different device drivers
  - Special device-specific configuration supported with the `ioctl()` system call
- Device Drivers typically divided into two pieces:
  - Top half: accessed in call path from system calls
    - » Implements a set of **standard, cross-device calls** like `open()`, `close()`, `read()`, `write()`, `ioctl()`, `strategy()`
    - » This is the kernel's interface to the device driver
    - » Top half will *start* I/O to device, may put thread to sleep until finished
  - Bottom half: run as interrupt routine
    - » Gets input or transfers next block of output
    - » May wake sleeping threads if I/O now complete

Life Cycle of An I/O Request



I/O Device Notifying the OS

- **The OS needs to know when:**
  - The I/O device has completed an operation
  - The I/O operation has encountered an error
- **I/O Interrupt:**
  - Device generates an interrupt whenever it needs service
  - Handled in bottom half of device driver
    - » Often run on special kernel-level stack
  - Pro: handles unpredictable events well
  - Con: interrupts relatively high overhead
- **Polling:**
  - OS periodically checks a device-specific status register
    - » I/O device puts completion information in status register
    - » Could use timer to invoke lower half of drivers occasionally
  - Pro: low overhead
  - Con: may waste many cycles on polling if infrequent or unpredictable I/O operations
- **Actual devices combine both polling and interrupts**
  - For instance: High-bandwidth network device:
    - » Interrupt for first incoming packet
    - » Poll for following packets until hardware empty

Protection vs Security

- **Protection:** one or more mechanisms for controlling the access of programs, processes, or users to resources
  - Page Table Mechanism
  - File Access Mechanism
- **Security:** use of protection mechanisms to prevent misuse of resources
  - Misuse defined with respect to policy
    - » E.g.: prevent exposure of certain sensitive information
    - » E.g.: prevent unauthorized modification/deletion of data
  - Requires consideration of the external environment within which the system operates
    - » Most well-constructed system cannot protect information if user accidentally reveals password

✑ **A short to introduction protection and security**

Protection : Dual-Mode Operation

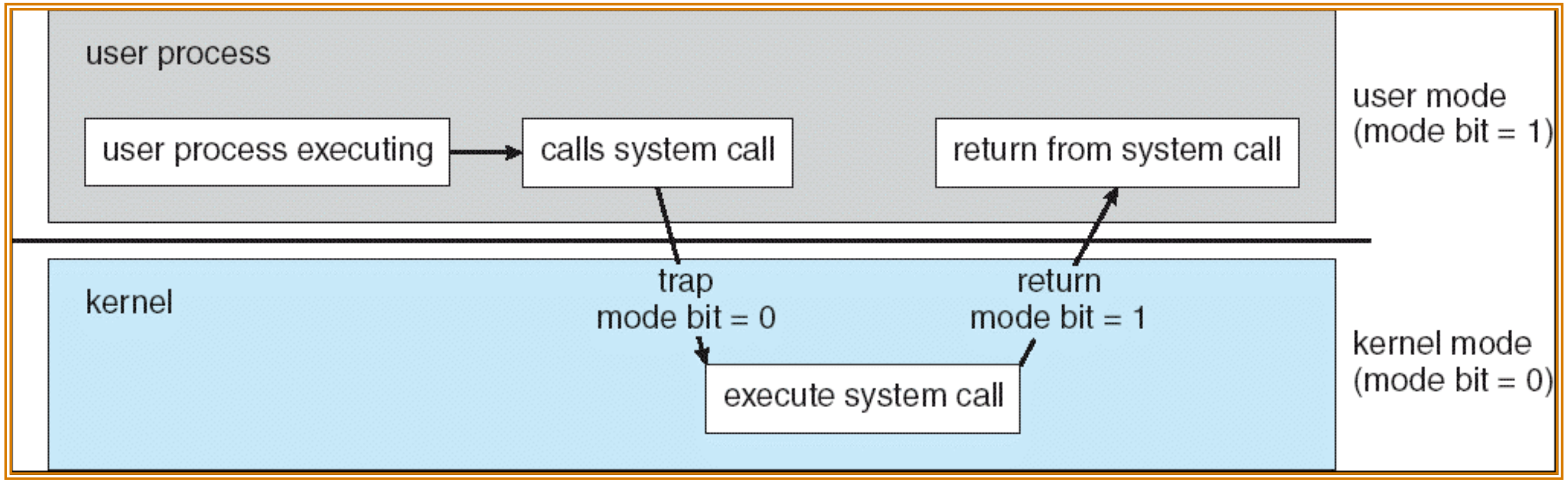
- **Multiprogramming goals**
  - Isolate processes and kernel from one another
  - Allow flexible translation that allows easy sharing between processes
  - User cannot change mode to kernel mode or modify page table mapping
  - Limited access to memory: cannot adversely effect other processes
    - » Side-effect: Limited access to memory-mapped I/O operations
  - Limited access to interrupt controller
  - What else needs to be protected?
- **To Assist with Protection, Hardware provides at least two modes:** "Kernel" mode (o "protected") and "User" mode
  - Mode set with bits in control register only accessible in kernel-mode
  - Some instructions only available in kernel mode (Privileged instructions)
- **Intel processor actually has four "rings" of protection:**
  - PL (Priviledge Level) from 0 – 3 (PL0 has full access, PL3 has least)
  - Privilege Level set in code segment descriptor (CS)
  - Mirrored "IOPL" bits in condition register gives permission to programs to use the I/O instructions
  - Typical OS kernels on Intel only use PL0 ("kernel") and PL3 ("user")
- **A couple of issues :**
  - How to share CPU between kernel and user programs?
  - How do programs interact?
  - How does one switch between kernel and user modes?

How to get from Kernel→User

- What does the kernel do to create a new user process?
  - Allocate and initialize address-space control block
  - Read program off disk and store in memory
  - Allocate and initialize translation table
    - » Point at code in memory so program can execute
    - » Possibly point at statically initialized data
  - Run Program:
    - » Set machine registers
    - » Set hardware pointer to translation table
    - » Set processor status word for user mode
    - » Jump to start of program
- How does kernel switch between processes?
  - Same saving/restoring of registers as before
  - Save/restore hardware pointer to translation table

User→Kernel (System Call)

- How does the user program get back into kernel?



- System call: **Voluntary procedure call into kernel**
  - Hardware for controlled User→Kernel transition
  - Can any kernel routine be called?
    - » No! Only specific ones.
  - System call ID encoded into system call instruction
    - » Index forces well-defined interface with kernel

System Call Continued

- What are some system calls?
  - I/O: open, close, read, write, lseek
  - Files: delete, mkdir, rmdir, truncate, chown, chgrp, ..
  - Process: fork, exit, wait
  - Network: socket create, set options
  - Operations on shared memory segments, semaphores, other IPC
- Are system calls constant across operating systems?
  - Not entirely, but there are lots of commonalities
  - Also some standardization attempts (POSIX)
- What happens at beginning of system call?
  - » On entry to kernel, sets system to kernel mode
  - » Handler address fetched from table/Handler started
- System Call argument passing:
  - In registers (not very much can be passed)
  - Write into user memory, kernel copies into kernel memory
    - » User addresses must be translated!
    - » Kernel has different view of memory than user
  - Every argument must be explicitly checked!

User→Kernel (Exceptions: Traps and Interrupts)

- A system call instruction causes a synchronous exception (or "trap")
  - In fact, often called a software "trap" instruction
- Other sources of *Synchronous Exceptions:*
  - Divide by zero, Illegal instruction, undefined instruction, Bus error (bad address, e.g. unaligned access)
  - Segmentation Fault (address out of range)
  - Page Fault (for illusion of infinite-sized memory)
- Interrupts are *Asynchronous Exceptions*
  - Examples: timer, disk ready, network, etc….
  - Interrupts can be disabled, traps cannot!
- On system call, exception, or interrupt:
  - Hardware enters kernel mode with interrupts disabled
  - Saves PC, then jumps to appropriate handler in kernel
  - For some processors (x86), processor also saves registers, changes stack, etc.
- Actual handler typically saves registers, other CPU state, and switches to kernel stack

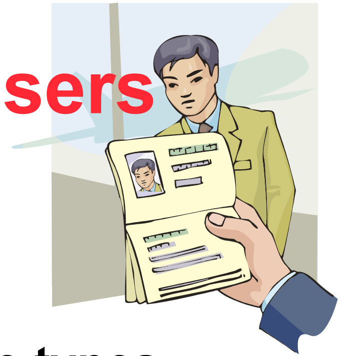
Communication

- **Now that we have isolated processes, how can they communicate?**
  - **Shared memory: common mapping to physical page**
    - » **As long as they place objects in shared memory address range, threads from each process can communicate**
    - » **Note that processes A and B can talk to shared memory through different addresses**
    - » **In some sense, this violates the whole notion of protection that we have been developing**
  - **If address spaces don't share memory, all inter-address space communication must go through kernel (via system calls)**
    - » **Byte stream producer/consumer (put/get): Example, communicate through pipes connecting `stdin/stdout`**
    - » **Message passing (send/receive): another kind of process communication and synchronization tool**
      - **Blocking vs non blocking send**
      - **Blocking vs non blocking receive**
      - **Naming : the other process, a mail box (which can be shared), a private channel**
    - » **File System (read/write): File system is shared state!**

Security: Preventing Misuse

- **Types of Misuse:**
  - Accidental:
    - » If I delete shell, can't log in to fix it!
    - » Could make it more difficult by asking: "do you really want to delete the shell?"
  - Intentional:
    - » Doesn't help to ask if user wants perform action
- **Three Pieces to Security**
  - **Authentication:** who the user actually is
  - **Authorization:** who is allowed to do what
  - **Enforcement:** make sure people do only what they are supposed to do
- **Loopholes in any carefully constructed system:**
  - Log in as super-user and you've circumvented authentication
  - Log in as self and can do anything with your resources; for instance: run program that erases all of your files
  - Can you trust software to correctly enforce Authentication and Authorization?

Authentication: Identifying Users



- **How to identify users to the system?**
  - Passwords
    - » Shared secret between two parties
    - » Since only user knows password, someone types correct password ⇒ must be user typing it
    - » Very common technique
      - Encrypt passwords to help hid them
      - Force them to be longer/not amenable to dictionary attack
      - Use one-time passwords

  - Smart Cards
    - » Electronics embedded in card capable of providing long passwords or satisfying challenge → response queries
    - » May have display to allow reading of password
    - » Or can be plugged in directly; several credit cards now in this category

  - Biometrics
    - » Use of one or more intrinsic physical or behavioral traits to identify someone
    - » Examples: fingerprint reader, palm reader, retinal scan
    - » Becoming quite a bit more common

Authorization: Who Can Do What?

- **How do we decide who is authorized to do actions in the system?**
- **Access Control Matrix: contains all permissions in the system**
  - Resources across top
    - » Files, Devices, etc…
  - Domains in columns
    - » A domain might be a user or a group of permissions
    - » E.g. opposite : User D3 can read F2 or execute F3
  - In practice, table would be huge and sparse!

domain \ object	F_1	F_2	F_3	printer
D_1	read		read	
D_2				print
D_3		read	execute	
D_4	read write		read write	

- **Important issues :**
  - When are access rights checked ?
  - How (and when) to revoke authorization ?
    - » List of revocation attached to objects or processes?
    - » Expiration dates? Epoch numbers?

Authorization: Implementation Choices

- **Access Control Lists:** store permissions with object
  - Still might be lots of users!
  - UNIX limits each file to: r,w,x for owner, group, world
  - More recent systems allow definition of groups of users and permissions for each group
  - ACLs allow easy changing of an object's permissions
    - » Example: add Users C, D, and F with rw permissions
- **Capability List:** each process tracks which objects has permission to touch
  - Popular in the past, idea out of favor today
  - Consider page table: Each process has list of pages it has access to, not each page has list of processes …
  - Capability lists allow easy changing of a domain's permissions
    - » Example: you are promoted to system administrator and should be given access to all system files
- **A combination approach: Users have capabilities (groups or roles), Objects have ACLs**
  - ACLs refer to users or groups
  - Change object permission by modifying ACL
  - Change broader user permission via change in group membership

Authorization Continued

- **Principle of least privilege:** programs, users, and systems should get only enough privileges to perform their tasks
  - Very hard to do in practice
    - » How do you figure out what the minimum set of privileges is needed to run your programs?
  - People often run at higher privilege then necessary
    - » Such as the "administrator" privilege under windows
- One solution: Signed Software
  - Only use software from sources that you trust, thereby dealing with the problem by means of authentication
  - Fine for big, established firms such as Microsoft, since they can make their signing keys well known and people trust them
    - » Actually, not always fine: recently, one of Microsoft's signing keys was compromised, leading to malicious software that looked valid
  - What about new startups?
    - » Who "validates" them?
    - » How easy is it to fool them?

Summary (I/O systems)

- **I/O Devices Types:**
  - **Many different speeds (0.1 bytes/sec to GBytes/sec)**
  - **Different Access Patterns: block, char, net devices**
  - **Different Access Timing: Non-/Blocking, Asynchronous**
- **I/O Controllers: Hardware that controls actual device**
  - **CPU accesses through I/O insts, ld/st to special phy memory**
  - **Report results through interrupts or a status register polling**
- **Device Driver: Device-specific code in kernel**

Summary (Protection & Security)

- **Protection: Prevent unauthorized Sharing of resources**
  - Address space protected using translation of addresses through Memory Management Unit (MMU)
    - » Every Access translated through page table
    - » Changing of page tables only available to kernel
  - Dual-Mode
    - » Kernel/User distinction: User restricted
    - » User→Kernel: System calls, Traps, or Interrupts
    - » Inter-process communication: shared memory, or through kernel (system calls)
- **Security : prevent misuse**
  - User Identification
    - » Passwords/Smart Cards/Biometrics
    - » Encrypt password to help hid them
    - » Force passwords to be longer/not amenable to dictionary attack
  - Authorization
    - » Access Matrix
      - Access lists
      - Capabilities