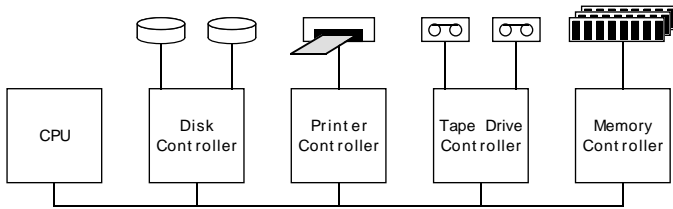


Input / Output (I/O)



- CPU and device controllers all use a common bus for communication
- Software-polling synchronous I/O
 - CPU starts an I/O operation, and continuously *polls* (checks) that device until the I/O operation finishes
 - Device controller contains registers for communication with that device
 - Input register, output register — for data
 - Control register — to tell it what to do
 - Status register — to see what it's done
 - Why not connect all I/O devices directly to CPU? Why not... memory...?

1

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Input / Output (I/O) (cont.)

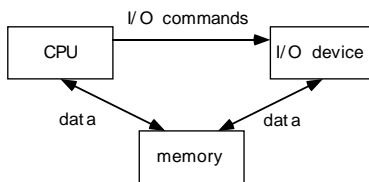
- Terminology
 - *Synchronous I/O* — CPU execution waits while I/O proceeds
 - *Asynchronous I/O* — I/O proceeds concurrently with CPU execution
- Interrupt-based asynchronous I/O
 - Device controller has its own processor, and executes asynchronously with CPU
 - Device controller puts an interrupt signal on the bus when it needs CPU's attention
 - When CPU receives an interrupt:
 1. It saves the CPU state and invokes the appropriate interrupt handler using the *interrupt vector* (addresses of OS routines to handle various events)
 2. Handler must save and restore software state (e.g., registers it will modify)
 3. CPU restores CPU state

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Input / Output (I/O) (cont.)

- Memory-mapped I/O
 - Uses direct memory access (DMA) — I/O device can transfer block of data to / from memory without going through CPU

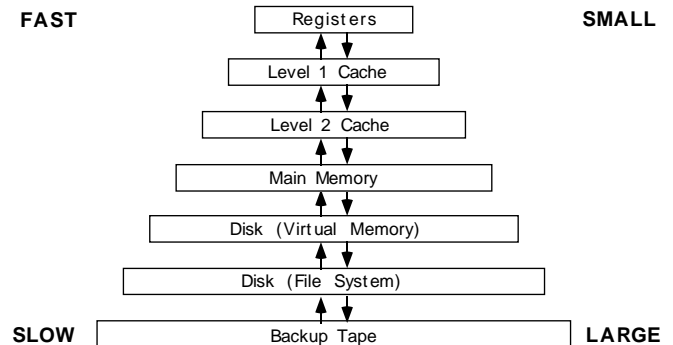


- OS allocates buffer in memory, tells I/O device to use that buffer
- I/O device operates asynchronously with CPU, interrupts CPU when finished
- Used for most high-speed I/O devices (e.g., disks, communication interfaces)

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Storage Structures



- At a given level, memory may not be as big or as fast as you'd like it be
 - Tradeoffs between size and speed
- *Principle of Locality of Reference* leads to *caching*
 - When info is needed, look on this level
 - If it's not on this level, get it from the next slower level, and save a copy here in case it's needed again sometime soon

4

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Magnetic Disks

- Provide secondary storage for system (after main memory)
- Technology
 - Covered with magnetic material
 - Read / write head “floats” just above surface of disk
 - Hierarchically organized as platters, tracks, sectors (blocks)
- Devices
 - Hard (moving-head) disk — one or more platters, head moves across tracks
 - Floppy disk — disk covered with hard surface, read / write head sits on disk, slower, smaller, removable, rugged
 - CDROM — uses laser, read-only, high-density
 - Optical —read / write

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Protection

- Multiprogramming and timesharing require that the memory and I/O of the OS and user processes be **protected** against each other
 - Note that most PCs do not support this kind of protection
- Provide protection via two modes of CPU execution: *user mode* and *kernel mode*
 - In kernel / privileged / supervisor / monitor mode, *privileged instructions* can:
 - Access I/O devices, control interrupts
 - Manipulate the state of the memory (page table, TLB, etc.)
 - Halt the machine
 - Change the mode
 - Requires architectural support:
 - Mode bit in a protected register
 - Privileged instructions, which can only be executed in kernel mode

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I/O Protection

- To prevent illegal I/O, or simultaneous I/O requests from multiple processes, perform all I/O via privileged instructions
 - User programs must make a *system call* to the OS to perform I/O
- When user process makes a system call:
 - A *trap* (software-generated interrupt) occurs, which causes:
 - The appropriate trap handler to be invoked using the trap vector
 - Kernel mode to be set
 - Trap handler:
 - Saves state
 - Performs requested I/O (if appropriate)
 - Restores state, sets user mode, and returns to calling program

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Memory Protection

- Must protect OS's memory from user programs (can't overwrite, can't access)
 - Must protect memory of one process from another process
 - Must not protect memory of user process from OS
- Simplest and most common technique:
 - *Base register* —smallest legal address
 - *Limit register* — size of address range
 - Base and limit registers are loaded by OS before running a particular process
 - CPU checks each address (instruction & data) generated in user mode
 - Any attempt to access memory outside the legal range results in a trap to the OS
- Additional hardware support is provided for virtual memory

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CPU Protection

- Use a timer to prevent CPU from being hogged by one process (either maliciously, or due to an infinite loop)
 - Set timer to interrupt OS after a specified period (small fraction of a second)
 - When interrupt occurs, control transfers to OS, which decides which process to execute for next time interval (maybe the same process, maybe another one)
- Also use timer to implement time sharing
 - At end of each time interval, OS switches to another process
 - *Context switch* = save state of that process, update Process Control Block for each of the two processes, restore state of next process

Computer Architecture & OS

- Need for OS services often drives inclusion of architectural features in CPU:

<u>OS Service</u>	<u>Hardware Support</u>
I/O	interrupts memory-mapped I/O caching
Data access	memory hierarchies file systems
Protection	system calls kernel & user mode privileged instructions interrupts & traps base & limit registers
Scheduling & Error recovery	timers