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## Random Stuff

- No tutorials or comp3891/comp9283 lecture this week
- Release the warm-up exercise tomorrow
- New weeks tutorial questions – probably tomorrow also

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# Introduction to Operating Systems

Chapter 1 – 1.3
Chapter 1.5 – 1.9

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## Learning Outcomes

- High-level understand what is an operating system and the role it plays
- A high-level understanding of the structure of operating systems, applications, and the relationship between them.
- Some knowledge of the services provided by operating systems.
- Exposure to some details of major OS concepts.

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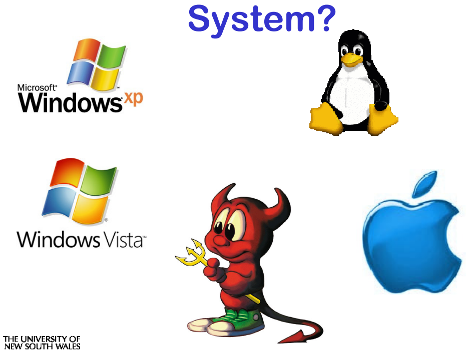
## What is an Operating System?

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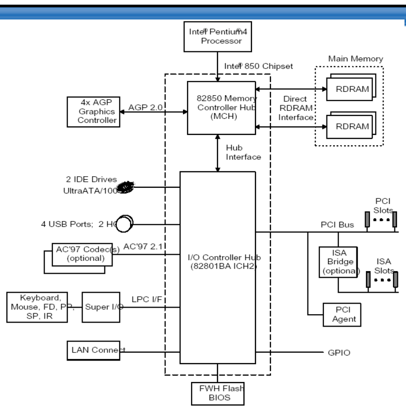


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## Viewing the Operating System as an Abstract Machine

- Extends the basic hardware with added functionality
- Provides high-level abstractions
  - More programmer friendly
  - Common core for all applications
- It hides the details of the hardware
  - Makes application code portable

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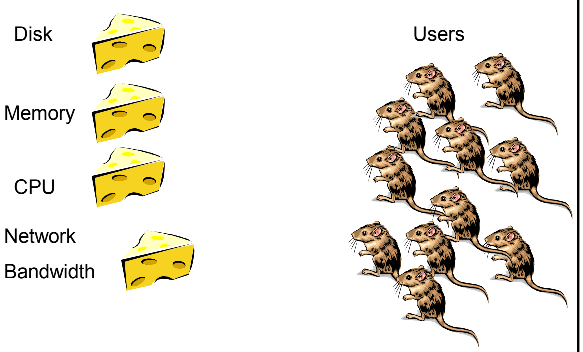






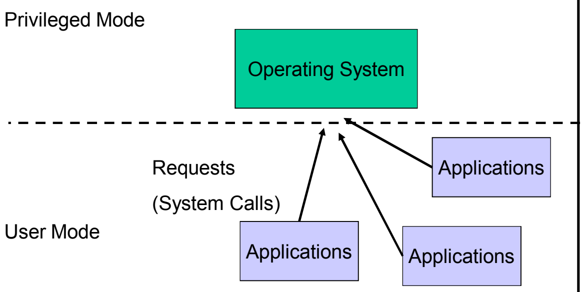

## Viewing the Operating System as a Resource Manager

- Responsible for allocating resources to users and processes
- Must ensure
  - No Starvation
  - Progress
  - Allocation is according to some desired policy
    - First-come, first-served; Fair share; Weighted fair share; limits (quotas), etc…
  - Overall, that the system is efficiently used





## Traditional View: the Operating System as the Privileged Component








## Kernel

- Portion of the operating system that is running in *privileged mode*
- Usually resident in main memory
- Contains fundamental functionality
  - Whatever is required to implement other services
  - Whatever is required to provide security
- Contains most-frequently used functions
- Also called the nucleus or supervisor





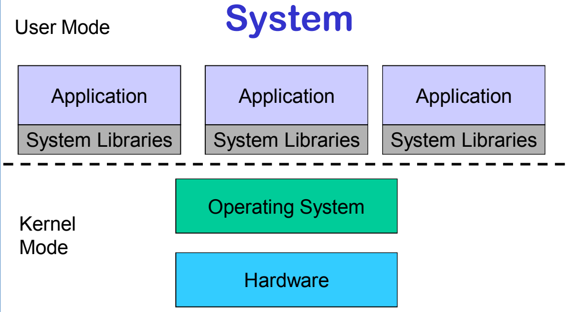
## The Operating System is Privileged

- Applications should not be able to interfere or bypass the operating system
  - OS can enforce the "extended machine"
  - OS can enforce its resource allocation policies
  - Prevent applications from interfering with each other
- Note: Some Embedded OSs have no privileged component, e.g. PalmOS
  - Can implement OS functionality, but cannot enforce it.
- Note: Some operating systems implement significant OS functionality in user-mode, e.g. User-mode Linux

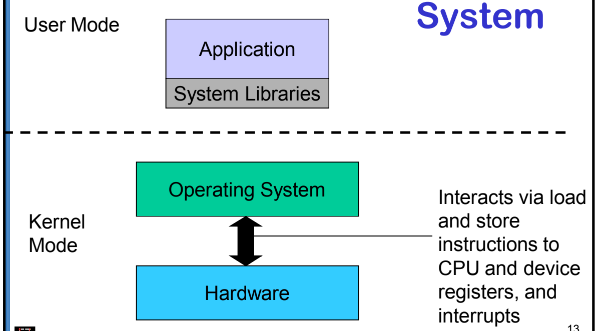




## Structure of a Computer System



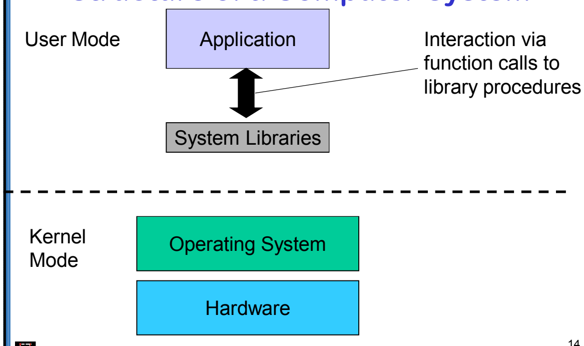
## Structure of a Computer System







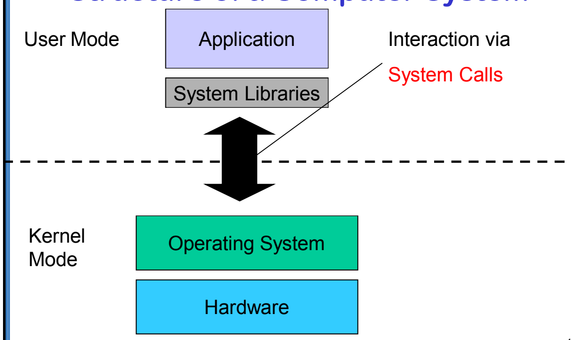

## Structure of a Computer System








## Structure of a Computer System








## A note on System Libraries

- System libraries are just that, libraries of support functions (procedures, subroutines)
  - Only a subset of library functions are actually systems calls
    - strcmp(), memcpy(), are pure library functions
    - open(), close(), read(), write() are system calls
  - System call functions are in the library for convenience





## Operating System Objectives

- Convenience
  - Make the computer more convenient to use
- Abstraction
  - Hardware-independent programming model
- Efficiency
  - Allows the computer system to be used in an efficient manner
- Ability to evolve
  - Permit effective development, testing, and introduction of new system functions without interfering with existing services
- Protection





## Services Provided by the Operating System

- Program development
  - Editors, compilers, debuggers
    - Not so much these days
- Program execution
  - Load a program and its data
- Access to I/O devices
- Controlled access to files
  - Access protection
- System access
  - User authentication

## Services Provided by the Operating System

- Error detection and response
  - internal and external hardware errors
    - memory error
    - device failure
  - software errors
    - arithmetic overflow
    - access forbidden memory locations
  - operating system cannot grant request of application





## Services Provided by the Operating System

- Accounting
  - collect statistics
  - monitor performance
  - used to anticipate future enhancements
  - used for billing users



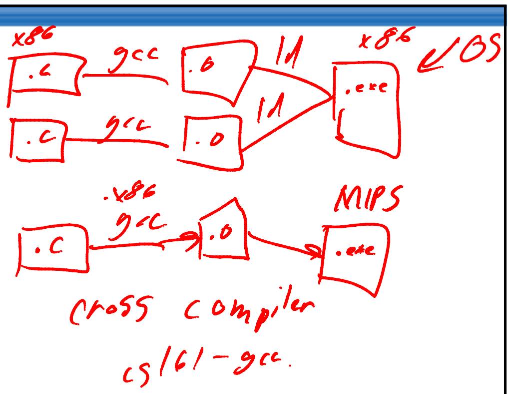


## Operating System Software

- Fundamentally, OS functions the same way as ordinary computer software
  - It is a program that is executed (just like apps)
  - It has more privileges
- Operating system relinquishes control of the processor to execute other programs
  - Reestablishes control after
    - System calls
    - Interrupts (especially timer interrupts)












## Major OS Concepts

- Processes
- Concurrency and deadlocks
- Memory management
- Files
- Information Security and Protection
- Scheduling and resource management



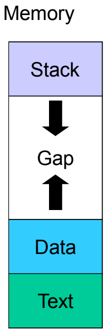


## Processes

- A program in execution
- An instance of a program running on a computer
- The entity that can be assigned to and executed on a processor
- A unit of resource ownership
- A unit of activity characterized by a single sequential thread of execution, a current state, and an associated set of system resources
  - Nowadays the execution abstraction is separated out: *Thread*
  - Single process can contain many threads

# Process

- Consist of three segments
  - Text
    - contains the code (instructions)
  - Data
    - Global variables
  - Stack
    - Activation records of procedure
    - Local variables
- Note:
  - data can dynamically grow up
  - The stack can dynamically grow down







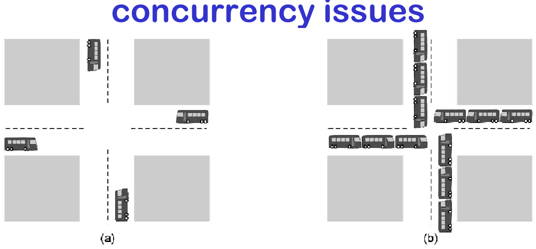

# Process

- Consists of three components
  - An executable program
    - text
  - Associated data needed by the program
    - Data and stack
  - Execution context of the program
    - All information the operating system needs to manage the process
      - Registers, program counter, stack pointer, etc…
    - A multithread program has a stack and execution context for each thread





# Multiple processes creates concurrency issues




(a) A potential deadlock. (b) an actual deadlock.





# Memory Management

- The view from thirty thousand feet
  - Process isolation
    - Prevent processes from accessing each others data
  - Automatic allocation and management
    - Don't want users to deal with physical memory directly
  - Protection and access control
    - Still want controlled sharing
  - Long-term storage
  - OS services
    - Virtual memory
    - File system





# Virtual Memory

- Allows programmers to address memory from a logical point of view
  - Gives apps the illusion of having RAM to themselves
  - Logical addresses are independent of other processes
  - Provides isolation of processes from each other
- Can overlap execution of one process while swapping in/out others.





# Virtual Memory Addressing

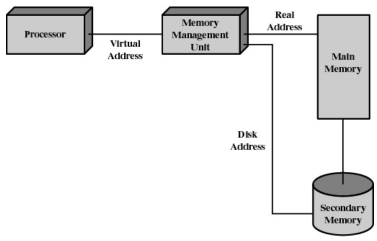


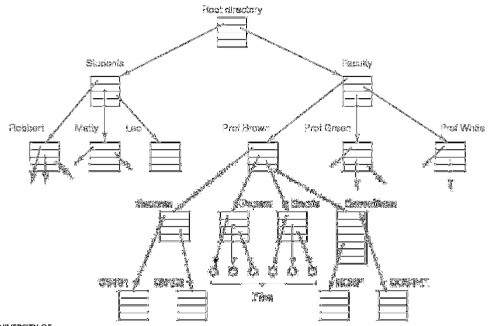

**Figure 2.10 Virtual Memory Addressing**

# File System

- Implements long-term store
- Information stored in named objects called files



# Example File System






# Information Protection and Security

- Access control
  - regulate user access to the system
  - Involves authentication
- Information flow control
  - regulate flow of data within the system and its delivery to users



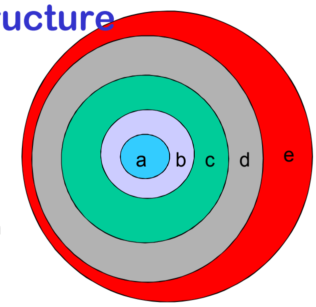
# Scheduling and Resource Management

- Fairness
  - give equal and fair access to all processes
- Differential responsiveness
  - discriminate between different classes of jobs
- Efficiency
  - maximize throughput, minimize response time, and accommodate as many uses as possible



# Operating System Structure

- The layered approach
  a) Processor allocation and multiprogramming
  b) Memory Management
  c) Devices
  d) File system
  e) Users
- Each layer depends on the inner layers






# Operating System Structure

- In practice, layering is only a guide
  - Operating Systems have many interdependencies
    - Scheduling on virtual memory
    - Virtual memory on I/O to disk
    - VM on files (page to file)
    - Files on VM (memory mapped files)
    - And many more…

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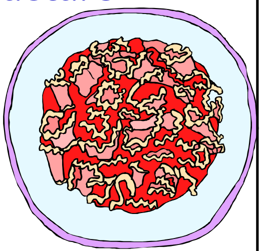
## The Monolithic Operating System Structure

- Also called the "spaghetti nest" approach
  - Everything is tangled up with everything else.
- Linux, Windows, ….



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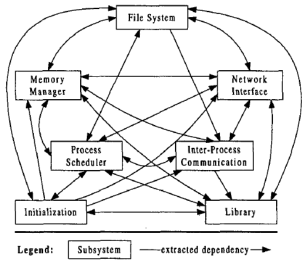
## The Monolithic Operating System Structure

- However, some reasonable structure usually prevails




Bowman, I. T., Holt, R. C., and Brewster, N. V. 1999. Linux as a case study: its extracted software architecture. In *Proceedings of the 21st international Conference on Software Engineering* (Los Angeles, California, United States, May 16 - 22, 1999). ICSE '99. ACM, New York, NY, 555-563. DOI= http://doi.acm.org/10.1145/302405.302691

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## Computer Hardware Review

Chapter 1.4

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## Learning Outcomes

- Understand the basic components of computer hardware
  - CPU, buses, memory, devices controllers, DMA, Interrupts, hard disks
- Understand the concepts of memory hierarchy and caching, and how they affect performance.

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## Operating Systems

- Exploit the hardware available
- Provide a set of high-level services that represent or are implemented by the hardware.
- Manages the hardware reliably and efficiently
- *Understanding operating systems requires a basic understanding of the underlying hardware*

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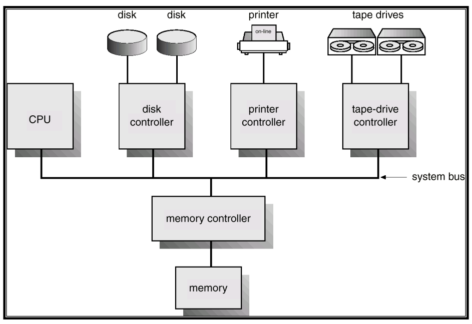
## Basic Computer Elements

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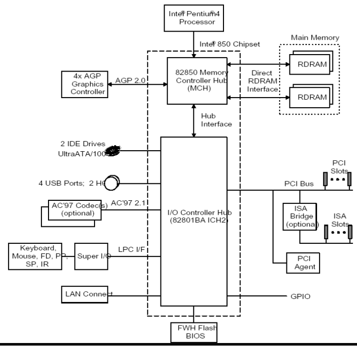
# Basic Computer Elements

- CPU
  - Performs computations
  - Load data to/from memory via system bus
- Device controllers
  - Control operation of their particular device
  - Operate in parallel with CPU
  - Can also load/store to memory (Direct Memory Access, DMA)
  - Control register appear as memory locations to CPU
    - Or I/O ports
  - Signal the CPU with "interrupts"
- Memory Controller
  - Responsible for refreshing dynamic RAM
  - Arbitrating access between different devices and CPU





# The real world is logically similar, but a little more complex








# A Simple Model of CPU Computation

- The fetch-execute cycle

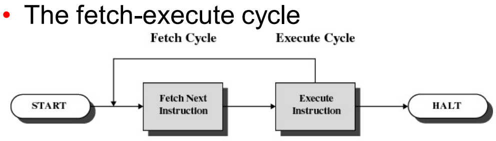



Figure 1.2 Basic Instruction Cycle





# A Simple Model of CPU Computation

- The fetch-execute cycle
  - Load memory contents from address in program counter (PC)
    - The instruction
  - Execute the instruction
  - Increment PC
  - Repeat

CPU Registers

| |
|---|
| PC: 0x0300 |
| SP: 0xcbf3 |
| Status |
| R1 |
| ↕ |
| Rn |





# A Simple Model of CPU Computation

- Stack Pointer
- Status Register
  - Condition codes
    - Positive result
    - Zero result
    - Negative result
- General Purpose Registers
  - Holds operands of most instructions
  - Enables programmers to minimise memory references.

CPU Registers

| |
|---|
| PC: 0x0300 |
| SP: 0xcbf3 |
| Status |
| R1 |
| ↕ |
| Rn |





# Privileged-mode Operation

- To protect operating system execution, two or more CPU modes of operation exist
  - Privileged mode (system-, kernel-mode)
    - All instructions and registers are available
  - User-mode
    - Uses 'safe' subset of the instruction set
      - E.g. no disable interrupts instruction
    - Only 'safe' registers are accessible

CPU Registers

| |
|---|
| Interrupt Mask |
| Exception Type |
| MMU regs |
| Others |
| PC: 0x0300 |
| SP: 0xcbf3 |
| Status |
| R1 |
| ↕ |
| Rn |

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## ‘Safe’ registers and instructions

- Registers and instructions are safe if
  - Only affect the state of the application itself
  - They cannot be used to uncontrollably interfere with
    - The operating system
    - Other applications
  - They cannot be used to violate a correctly implemented operating system policy.



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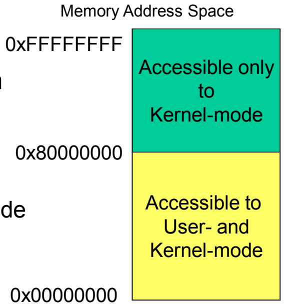
## Privileged-mode Operation

- The accessibility of addresses within an address space changes depending on operating mode
  - To protect kernel code and data



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## I/O and Interrupts

- I/O events (keyboard, mouse, incoming network packets) happen at unpredictable times
- How does the CPU know when to service an I/O event?



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## Interrupts

- An interruption of the normal sequence of execution
- A suspension of processing caused by an event external to that processing, and performed in such a way that the processing can be resumed.
- Improves processing efficiency
  - Allows the processor to execute other instructions while an I/O operation is in progress
  - Avoids unnecessary completion checking (polling)



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## Interrupt Cycle

- Processor checks for interrupts
- If no interrupts, fetch the next instruction
- If an interrupt is pending, divert to the interrupt handler

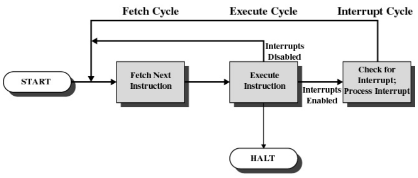


Figure 1.7 Instruction Cycle with Interrupts



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## Classes of Interrupts

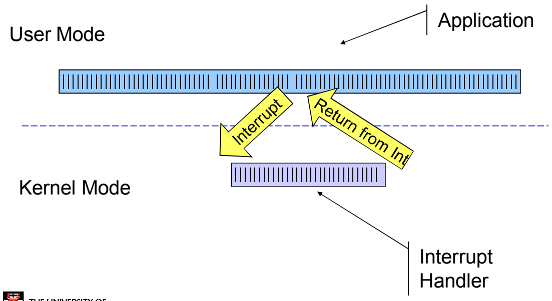
- Program exceptions
  (also called *synchronous interrupts*)
  - Arithmetic overflow
  - Division by zero
  - Executing an illegal/privileged instruction
  - Reference outside user’s memory space.
- Asynchronous (external) events
  - Timer
  - I/O
  - Hardware or power failure

# Interrupt Handler

- A software routine that determines the nature of the interrupt and performs whatever actions are needed.
- Control is transferred to the handler by *hardware*.
- The handler is generally part of the operating system.



# Simple Interrupt






# Memory Hierarchy

- Going down the hierarchy
  - Decreasing cost per bit
  - Increasing capacity
  - Increasing access time
  - Decreasing frequency of access to the memory by the processor
    - Hopefully
    - Principle of locality!!!!!

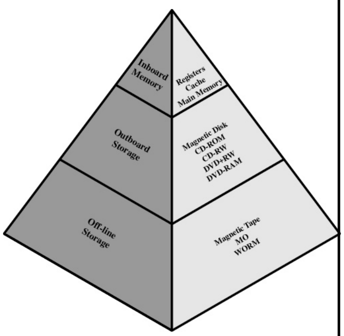



Figure 1.14 The Memory Hierarchy

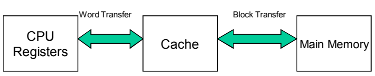
# Memory Hierarchy

- Rough approximation of memory hierarchy

| Typical access time | | Typical capacity |
|---|---|---|
| 1 nsec | Registers | <1 KB |
| 2 nsec | Cache | 1 MB |
| 10 nsec | Main memory | 64-512 MB |
| 10 msec | Magnetic disk | 5-50 GB |
| 100 sec | Magnetic tape | 20-100 GB |



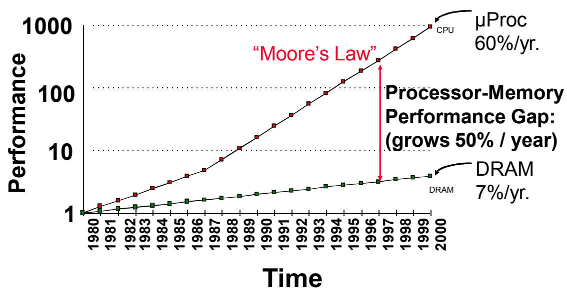
# Cache




- Cache is fast memory placed between the CPU and main memory
  - 1 to a few cycles access time compared to RAM access time of tens – hundreds of cycles
- Holds recently used data or instructions to save memory accesses.
- Matches slow RAM access time to CPU speed if high hit rate
- Is hardware maintained and (mostly) transparent to software
- Sizes range from few kB to several MB.
- Usually a hierarchy of caches (2–5 levels), on- and off-chip.
- Block transfers can achieve higher transfer bandwidth than single words.
  - Also assumes probability of using newly fetch data is higher than the probability of reuse ejected data.



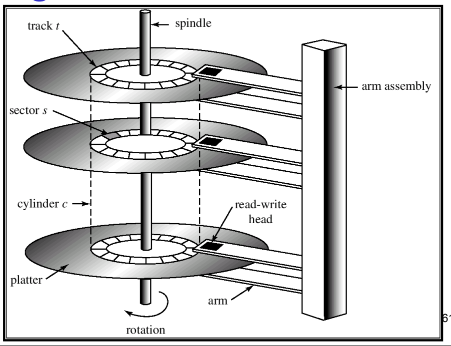
# Processor-DRAM Gap (latency)






Slide originally from Dave Patterson, Parcon 98

## Moving-Head Disk Mechanism






## Example Disk Access Times

- Disk can read/write data relatively fast
  - 15,000 rpm drive - 80 MB/sec
  - 1 KB block is read in 12 microseconds
- Access time dominated by time to locate the head over data
  - Rotational latency
    - Half one rotation is 2 milliseconds
  - Seek time
    - Full inside to outside is 8 milliseconds
    - Track to track .5 milliseconds
- 2 milliseconds is 164KB in "lost bandwidth"



## A Strategy: Avoid Waiting for Disk Access

- Keep a subset of the disk's data in memory

⇒ Main memory acts as a *cache* of disk contents



## Two-level Memories and Hit Rates

- Given a two-level memory,
  - cache memory and main memory (RAM)
  - main memory and disk

what is the effective access time?

- Answer: It depends on the hit rate in the first level.



## Effective Access Time

$$
\begin{aligned}
T_{eff} &= H \times T_1 + (1 - H) \times (T_1 + T_2) \\
T_1 &= \text{access time of memory 1} \\
T_2 &= \text{access time of memory 2} \\
H &= \text{hit rate in memory 1} \\
T_{eff} &= \text{effective access time of system}
\end{aligned}
$$



## Example

- Cache memory access time 1ns
- Main memory access time 10ns
- Hit rate of 95%

$$
\begin{aligned}
T_{eff} &= 0.95 \times 1 \times 10^{-9} + \\
&\quad 0.05 \times (1 \times 10^{-9} + 10 \times 10^{-9}) \\
&= 1.5 \times 10^{-9}
\end{aligned}
$$