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CS61C : Machine Structures

Lecture #26: Disks & Networks

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Andy Carle

Outline

- Buses
- Networks
- Disks

Buses in a PC: connect a few devices (2002)

CPU

Memory bus (FSB)

Memory

PCI Interface

PCI: Internal (Backplane) I/O bus

Bus - shared medium of communication that can connect to many devices. Hierarchy!!

SCSI: External I/O bus

Ethernet Interface

SCSI Interface

(1 to 15 disks)

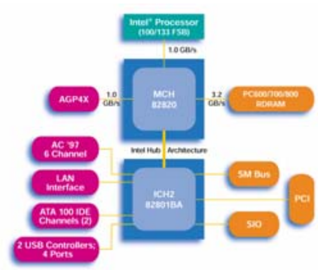
Ethernet Local Area Network

- Data rates (P4)
  - Memory: 400 MHz, 8 bytes ⇒ 3.2 GB/s (peak)
  - PCI: 100 MHz, 8 bytes wide ⇒ 0.8 GB/s (peak)
  - SCSI: "Ultra4" (160 MHz), "Wide" (2 bytes) ⇒ 0.3 GB/s (peak)

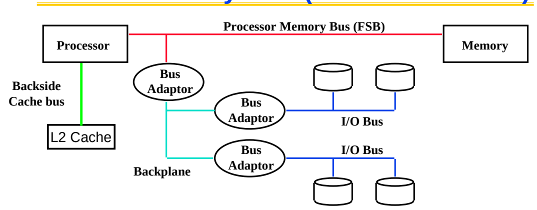
Gigabit Ethernet: ⇒ 0.125 GB/s (peak)

Main components of Intel Chipset: Pentium II/III

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



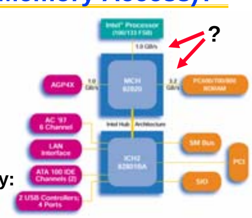
A Three-Bus System (+ backside cache)



- A small number of backplane buses tap into the processor-memory bus
  - FSB bus is only used for processor-memory traffic
  - I/O buses are connected to the backplane bus (PCI)
  - Advantage: load on the FSB is greatly reduced

What is DMA (Direct Memory Access)?

- Typical I/O devices must transfer large amounts of data to memory of processor:
  - Disk must transfer complete block
  - Large packets from network
  - Regions of frame buffer
- DMA gives external device ability to access memory directly:
  - much lower overhead than having processor request one word at a time.



- Issue: Cache coherence:
  - What if I/O devices write data that is currently in processor Cache?
    - The processor may never see new data!
  - Solutions:
    - Flush cache on every I/O operation (expensive)
    - Have hardware invalidate cache lines ("Coherence" cache misses?)

Outline

- Buses
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Why Networks?

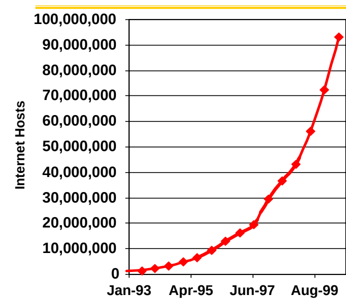
- Originally sharing I/O devices between computers
  (e.g., printers)
- Then Communicating between computers
  (e.g, file transfer protocol)
- Then Communicating between people
  (e.g., email)
- Then Communicating between networks of computers
  ⇒ p2p File sharing, WWW, …

How Big is the Network (1999)?

~30	Computers in 271 Soda
~400	in inst.cs.berkeley.edu
~4,000	in eecs&cs .berkeley.edu
~50,000	in berkeley.edu
~5,000,000	in .edu
~46,000,000	in US (.com .net .edu .mil .us .org)
~56,000,000	in the world

Source: Internet Software Consortium

Growth Rates

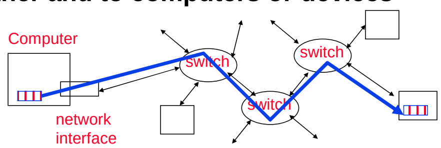


Ethernet Bandwidth	
1983	3 mb/s
1990	10 mb/s
1997	100 mb/s
1999	1000 mb/s
2004	10 Gig E

"Source: Internet Software Consortium (http://www.isc.org/)".

What makes networks work?

- links connecting switches to each other and to computers or devices



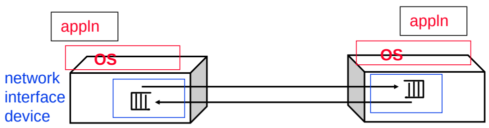
- ability to name the components and to route packets of information - messages - from a source to a destination
- Layering, protocols, and encapsulation as means of abstraction (61C big idea)

Typical Types of Networks

- Local Area Network (Ethernet)
  - Inside a building: Up to 1 km
  - (peak) Data Rate: 10 Mbits/sec, 100 Mbits /sec,10Gbits/sec (1.25, 12.5, 1250 MBytes/s)
  - Run, installed by network administrators
- Wide Area Network
  - Across a continent (10km to 10000 km)
  - (peak) Data Rate: 1.5 Mb/s to >10000 Mb/s
  - Run, installed by telecommunications companies (Sprint, UUNet[MCI], AT&T)
- Wireless Networks

ABCs of Networks: 2 Computers

- **Starting Point: Send bits between 2 computers**



- **Queue (First In First Out) on each end**
- **Can send both ways ("Full Duplex")**
- **Information sent called a "message"**
  - **Note: Messages also called packets**

A Simple Example: 2 Computers

- **What is Message Format?**
  - **Similar idea to Instruction Format**
  - **Fixed size? Number bits?**

Length	Data
8 bit	**32 x Length bits**

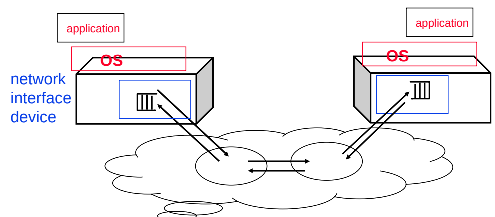
- **Header(Trailer): information to deliver message**
- **Payload: data in message**
- **What can be in the data?**
  - **anything that you can represent as bits**
  - **values, chars, commands, addresses...**

Questions About Simple Example

- **What if more than 2 computers want to communicate?**
  - **Need computer "address field" in packet to know which computer should receive it (destination), and to which computer it came from for reply (source) [just like envelopes!]**

Dest.	Source	Len	
Net ID	Net ID		CMD/ Address /Data
8 bits	8 bits	8 bits	32xn bits
Header			Payload

ABCs: many computers



- **switches and routers interpret the header in order to deliver the packet**
- **source encodes and destination decodes content of the payload**

Questions About Simple Example

- **What if message is garbled in transit?**
- **Add redundant information that is checked when message arrives to be sure it is OK**
- **8-bit sum of other bytes: called "Check sum"; upon arrival compare check sum to sum of rest of information in message**

				Checksum
Net ID	Net ID	Len	CMD/ Address /Data	
Header			Payload	Trailer

Math 55 talks about what a Check sum is…

Questions About Simple Example

- **What if message never arrives?**
- **Receiver tells sender when it arrives (ack) [ala registered mail], sender retries if waits too long**
- **Don't discard message until get "ACK" (for ACKnowledgment); Also, if check sum fails, don't send ACK**

					Checksum
Net ID	Net ID	Len	ACK INFO	CMD/ Address /Data	
Header				Payload	Trailer

Observations About Simple Example

- Simple questions such as those above lead to more complex procedures to send/receive message and more complex message formats
- Protocol: algorithm for properly sending and receiving messages (packets)

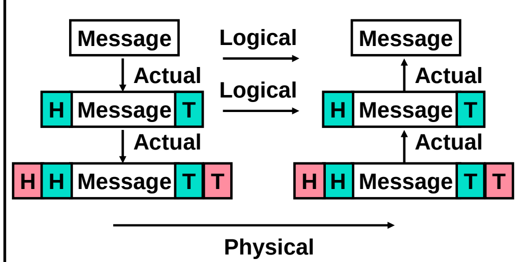
Software Protocol to Send and Receive

- SW Send steps
  - 1: Application copies data to OS buffer
  - 2: OS calculates checksum, starts timer
  - 3: OS sends data to network interface HW and says start
- SW Receive steps
  - 3: OS copies data from network interface HW to OS buffer
  - 2: OS calculates checksum, if OK, send ACK; if not, delete message (sender resends when timer expires)
  - 1: If OK, OS copies data to user address space, & signals application to continue

Protocol for Networks of Networks?

- Internetworking: allows computers on independent and incompatible networks to communicate reliably and efficiently;
  - Enabling technologies: SW standards that allow reliable communications without reliable networks
  - Hierarchy of SW layers, giving each layer responsibility for portion of overall communications task, called protocol families or protocol suites
- Abstraction to cope with complexity of communication vs. Abstraction for complexity of computation

Protocol Family Concept



Protocol Family Concept

- Key to protocol families is that communication occurs logically at the same level of the protocol, called peer-to-peer…

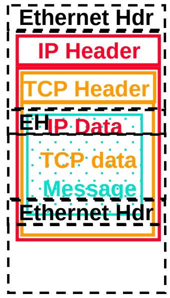
  …but is implemented via services at the next lower level
- Encapsulation: carry higher level information within lower level "envelope"
- Fragmentation: break packet into multiple smaller packets and reassemble

Protocol for Network of Networks

- Transmission Control Protocol/Internet Protocol (TCP/IP)
  - This protocol family is the basis of the Internet, a WAN protocol
  - IP makes best effort to deliver
  - TCP guarantees delivery
  - TCP/IP so popular it is used even when communicating locally: even across homogeneous LAN

TCP/IP packet, Ethernet packet, protocols

- Application sends message
- TCP breaks into 64KB segments, adds 20B header
- IP adds 20B header, sends to network
- If Ethernet, broken into 1500B packets with headers, trailers (24B)
- All Headers, trailers have length field, destination, ...

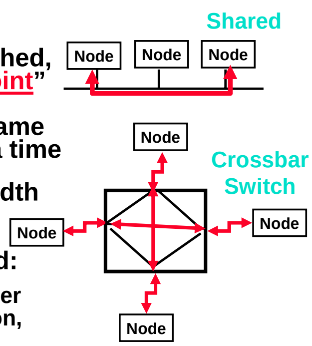


Overhead vs. Bandwidth

- Networks are typically advertised using peak bandwidth of network link: e.g., 100 Mbits/sec Ethernet ("100 base T")
- Software overhead to put message into network or get message out of network often limits useful bandwidth
- Assume overhead to send and receive = 320 microseconds (μs), want to send 1000 Bytes over "100 Mbit/s" Ethernet
  - Network transmission time: 1000Bx8b/B /100Mb/s = 8000b / (100b/μs) = 80 μs
  - Effective bandwidth: 8000b/(320+80)μs = 20 Mb/s

Shared vs. Switched Based Networks

- Shared Media vs. Switched: in switched, pairs ("point-to-point" connections) communicate at same time; shared 1 at a time
- Aggregate bandwidth (BW) in switched network is many times shared:
  - point-to-point faster since no arbitration, simpler interface



Network Summary

- Protocol suites allow heterogeneous networking
  - Another form of principle of abstraction
  - Protocols $\Rightarrow$ operation in presence of failures
  - Standardization key for LAN, WAN
- Integrated circuit ("Moore's Law") revolutionizing network switches as well as processors
  - Switch just a specialized computer
- Trend from shared to switched networks to get faster links and scalable bandwidth

Outline

- Buses
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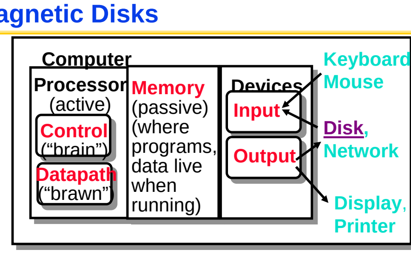
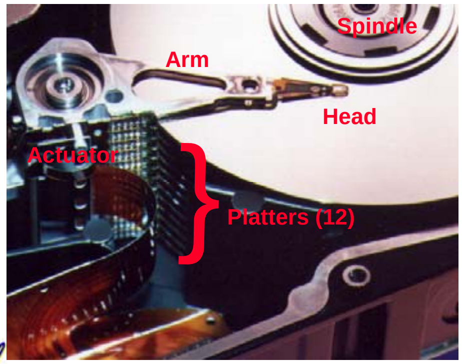
- Disks

Magnetic Disks

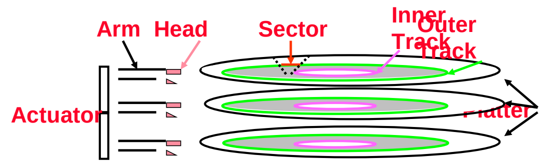


- Purpose:
  - Long-term, nonvolatile, inexpensive storage for files
  - Large, inexpensive, slow level in the memory hierarchy (discuss later)

Photo of Disk Head, Arm, Actuator

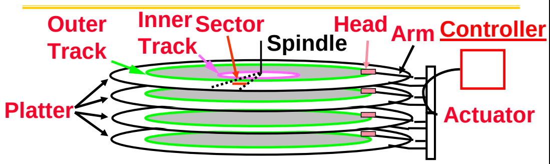


Disk Device Terminology



- Several platters, with information recorded magnetically on both surfaces (usually)
- Bits recorded in tracks, which in turn divided into sectors (e.g., 512 Bytes)
- Actuator moves head (end of arm) over track ("seek"), wait for sector rotate under head, then read or write

Disk Device Performance



- Disk Latency = Seek Time + Rotation Time + Transfer Time + Controller Overhead
  - Seek Time? depends no. tracks move arm, seek speed of disk
  - Rotation Time? depends on speed disk rotates, how far sector is from head
  - Transfer Time? depends on data rate (bandwidth) of disk (bit density), size of request

Data Rate: Inner vs. Outer Tracks

- To keep things simple, originally same # of sectors/track
  - Since outer track longer, lower bits per inch
- Competition decided to keep bits/inch (BPI) high for all tracks ("constant bit density")
  - More capacity per disk
  - More sectors per track towards edge
  - Since disk spins at constant speed, outer tracks have faster data rate
- Bandwidth outer track 1.7X inner track!

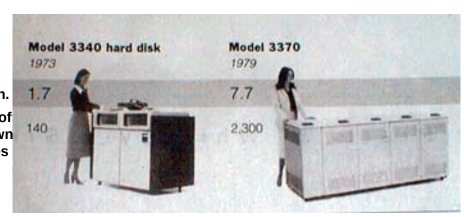
Disk Performance Model /Trends

- Capacity : + 100% / year (2X / 1.0 yrs)
  Over time, grown so fast that # of platters has reduced (some even use only 1 now!)
- Transfer rate (BW) : + 40%/yr (2X / 2 yrs)
- Rotation+Seek time : – 8%/yr (1/2 in 10 yrs)
- Areal Density
  - Bits recorded along a track: Bits/Inch (BPI)
  - # of tracks per surface: Tracks/Inch (TPI)
  - We care about bit density per unit area Bits/Inch^2
  - Called Areal Density = BPI x TPI
- MB/$: > 100%/year (2X / 1.0 yrs)
  - Fewer chips + areal density

Disk History (IBM)

Data density Mbit/sq. in.

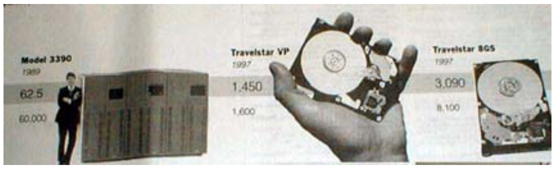
Capacity of Unit Shown Megabytes



1973:	1979:
1. 7 Mbit/sq. in	7. 7 Mbit/sq. in
0.14 GBytes	2.3 GBytes

source: New York Times, 2/23/98, page C3, "Makers of disk drives crowd even more data into even smaller spaces"

Disk History



1989:
63 Mbit/sq. in
60 GBytes

1997:
1450 Mbit/sq. in
2.3 GBytes

1997:
3090 Mbit/sq. in
8.1 GBytes

source: New York Times, 2/23/98, page C3, "Makers of disk drives crowd even more data into even smaller spaces"

Modern Disks: Barracuda 7200.7 (2004)

- 200 GB, 3.5-inch disk
- 7200 RPM; Serial ATA
- 2 platters, 4 surfaces
- 8 watts (idle)
- 8.5 ms avg. seek
- 32 to 58 MB/s Xfer rate
- $125 = $0.625 / GB

source: www.seagate.com;

Modern Disks: Mini Disks

- 2004 Toshiba Minidrive:
  - 2.1" x 3.1" x 0.3"
  - 40 GB, 4200 RPM, 31 MB/s, 12 ms seek
  - 20GB/inch^3 !!
  - Mp3 Players

Modern Disks: 1 inch disk drive!

- 2004 Hitachi Microdrive:
  - 1.7" x 1.4" x 0.2"
  - 4 GB, 3600 RPM, 4-7 MB/s, 12 ms seek
  - 8.4 GB/inch^3
  - Digital cameras, PalmPC
- 2006 MicroDrive?
  - 16 GB, 10 MB/s!
  - Assuming past trends continue

Modern Disks: << 1 inch disk drive!

- Not magnetic but …
- 1gig Secure digital
  - Solid State NAND Flash
  - 1.2" x 0.9" x 0.08" (!!)
  - 11.6 GB/inch^3

Magnetic Disk Summary

- Magnetic Disks continue rapid advance: 60%/yr capacity, 40%/yr bandwidth, slow on seek, rotation improvements, MB/$ improving 100%/yr?
  - Designs to fit high volume form factor
- RAID
  - Higher performance with more disk arms per $
  - Adds option for small # of extra disks
  - Today RAID is > $27 billion dollar industry, 80% nonPC disks sold in RAIDs; started at Cal