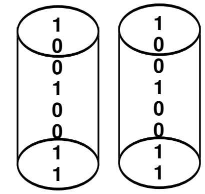
Lecture 14:
Automated Data Libraries & Networks & Interconnect—Introduction

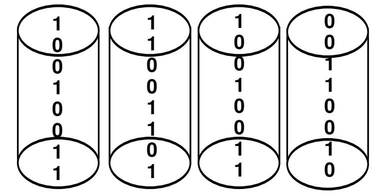
Professor David A. Patterson
Computer Science 252
Fall 1996

Review: RAID Techniques

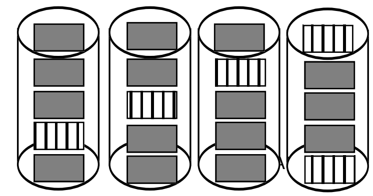
- *Disk Mirroring, Shadowing*
  - Each disk is fully duplicated onto its "shadow"
  - Logical write = two physical writes
  - 100% capacity overhead



- *Parity Data Bandwidth Array*
  - Parity computed horizontally
  - Logically a single high data bw disk



- *High I/O Rate Parity Array*
  - Interleaved parity blocks
  - Independent reads and writes
  - Logical write = 2 reads + 2 writes
  - Parity + Reed-Solomon codes



Review: RAID

RAID sales, "The Independent RAID Report" May/June 1994, p. 15 (dwilmot@crl.com, 510-938-7425)

- 1993: $3.4 billion on 214,667 arrays (≈ $15,000 / RAID)
- 1996 forecast: $11 billion
- 1997 forecast: $13 billion on 837,155 units
  - – Source: DISK/TREND, 5/94 (415-961-6209)

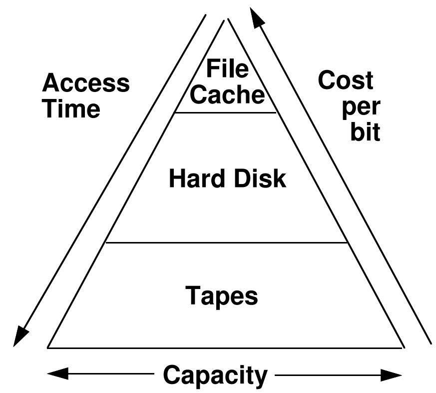
Summary: I/O Benchmarks

- Scaling to track technological change
- TPC: price performance as nomalizing configuration feature
- Auditing to ensure no foul play
- Througput with restricted response time is normal measure

Review: Storage System Issues

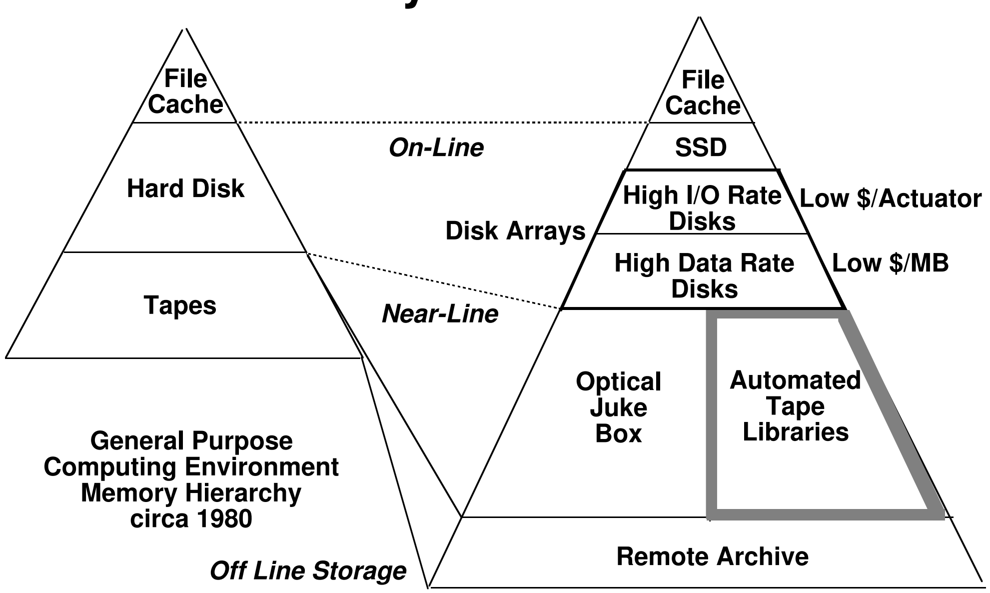
- Historical Context of Storage I/O
- Storage I/O Performance Measures
- Secondary and Tertiary Storage Devices
- A Little Queuing Theory
- Processor Interface Issues
- I/O & Memory Buses
- RAID
- ABCs of UNIX File Systems
- I/O Benchmarks
- Comparing UNIX File System Performance
- Tertiary Storage Possbilities

Memory Hierarchies



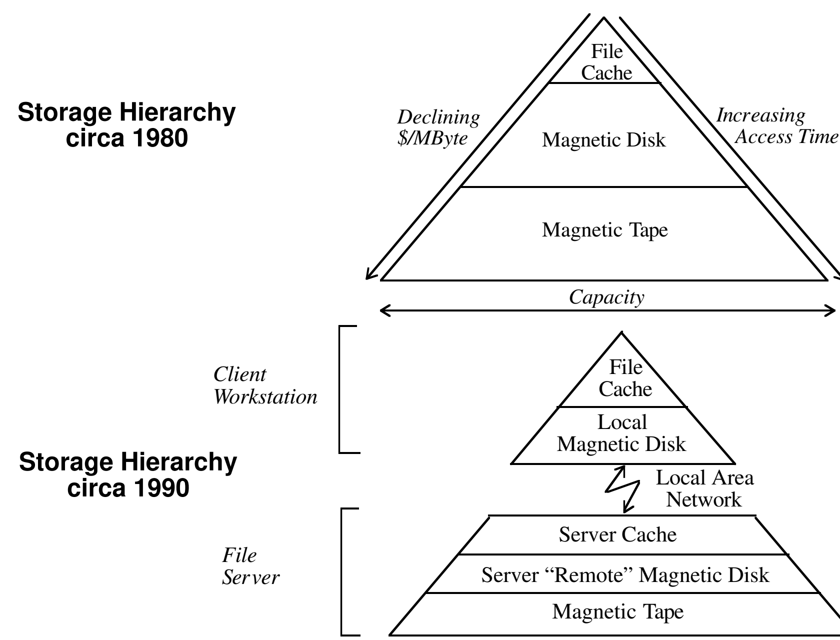
General Purpose
Computing Environment
Memory Hierarchy
circa 1980

Memory Hierarchies

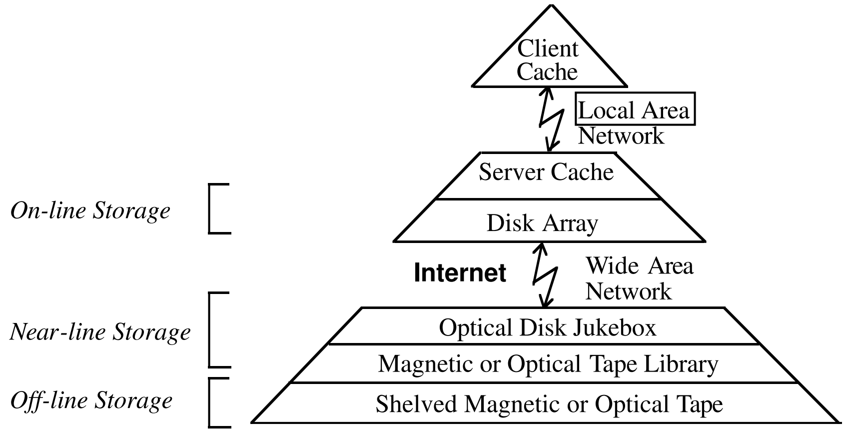


Memory Hierarchy
circa 1995

Storage Trends: Distributed Storage



Storage Trends: Wide-Area Storage



Typical Storage Hierarchy, circa 1995

Conventional disks replaced by disk arrays

Near-line storage emerges between disk and tape

What's All This About Tape?

Tape is used for:

- **Backup Storage for Hard Disk Data**

  Written once, very infrequently (hopefully never!) read

- **Software Distribution**

  Written once, read once

- **Data Interchange**

  Written once, read once

- **File Retrieval**

  Written/Rewritten, files occasionally read

  Near Line Archive

  Electronic Image Management

Relatively New Application For Tape

Alternative Data Storage Technologies

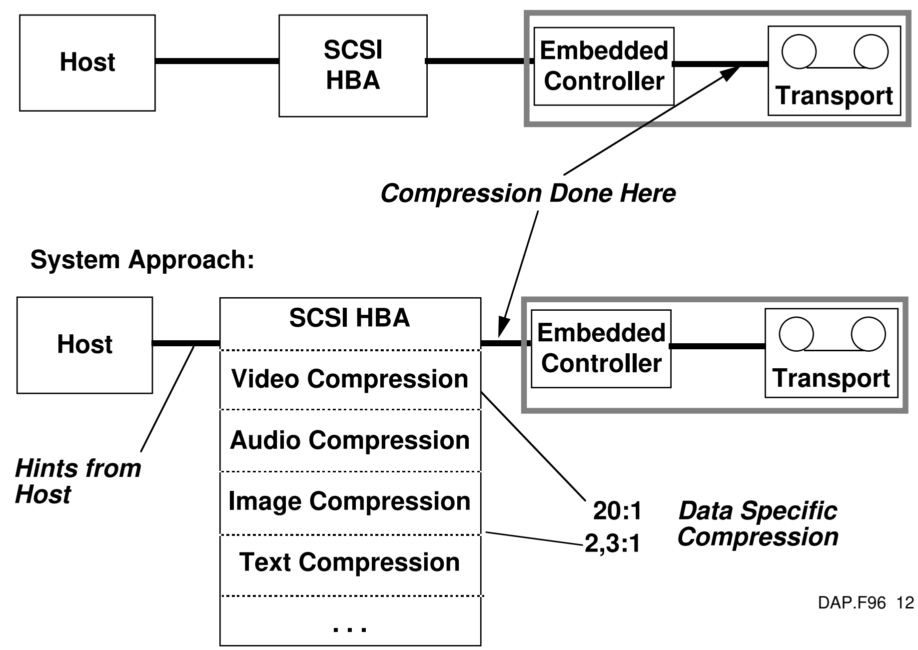
Technology	Cap (MB)	BPI	TPI	BPI*TPI (Million)	Data Xfer (KByte/s)	Access Time
Conventional Tape:						
Reel-to-Reel (.5")		140	6250	18	0.11	549 minutes
Cartridge (.25")	150	12000	104	1.25	92	minutes
Helical Scan Tape:						
VHS (.5")	2500	17435	650	11.33	120	minutes
Video (8mm)*	2300	43200	819	35.28	246	minutes
DAT (4mm)**	1300	61000	1870	114.07	183	20 seconds
Disk:						
Hard Disk (5.25")		760	30552	1667	50.94	1373 20 ms
Floppy Disk (3.5")		2	17434	135	2.35	92 1 second
CD ROM (3.5")		540	27600	15875	438.15	183 1 second

* Second Generation 8mm: 5000 MB, 500KB/s

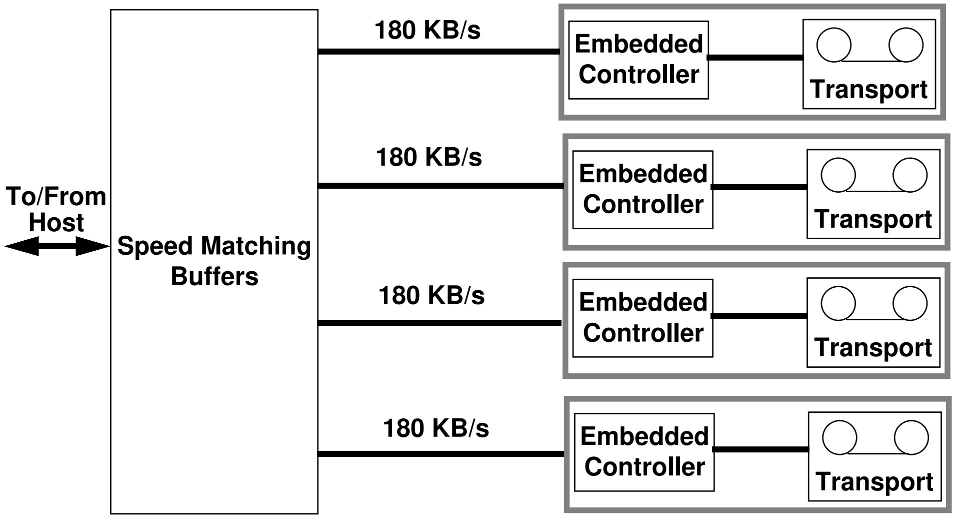
** Second Generation 4mm: 10000 GB

Data Compression Issues

Peripheral Manufacturer Approach:

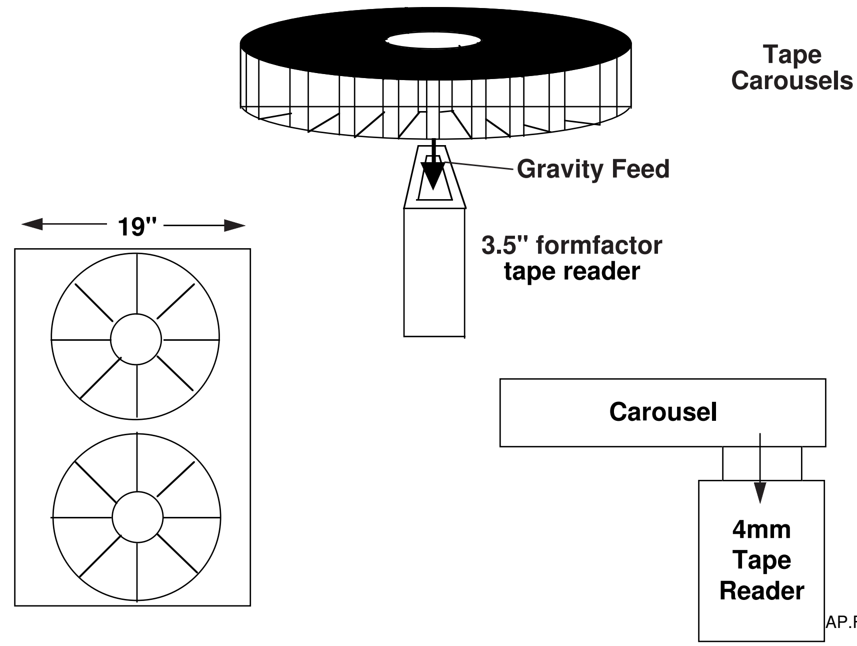


Striped Tape

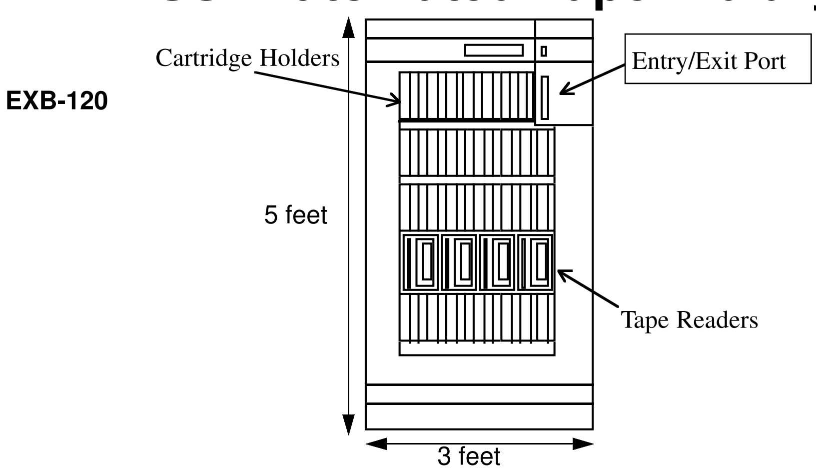


Challenges:
- Difficult to logically synchronize tape drives
- Unpredictable write times
  R after W verify, Error Correction Schemes, N Group Writing, Etc.

Automated Media Handling



MSS: Automated Tape Library



- 116 x 5 GB 8 mm tapes = 0.6 TBytes (1991)
- 4 tape readers 1991, 8 half height readers now
- 4 x .5 MByte/second = 2 MBytes/s
- $40,000 O.E.M. Price
- 1995: 3 TBytes; 2000: 9 TBytes

CS 252 Administrivia

- Homework on Chapter 6 due Monday10/21 at 5PM in 252 box, done in pairs:
  - Exercises 6.5, 6.16, 6.17
- Project Survey #2 due Wednesday 10/23 in class

Open MSS Research Issues

- Hardware/Software attack on very large storage systems
  - File system extensions to handle terabyte sized file systems
  - Storage controllers able to meet bandwidth and capacity demands
- Compression/decompression between secondary and tertiary storage
  - Hardware assist for on-the-fly compression
  - Application hints for data specific compression
  - More effective compression over large buffered data
  - DB indices over compressed data
- Striped tape: is large buffer enough?
- Applications: Where are the Terabytes going to come from?
  - Image Storage Systems
  - Personal Communications Network multimedia file server

MSS: Applications of Technology Robo-Line Library

Books/Bancroft x Pages/book x bytes/page = Bancroft
372,910 400 4000 = 0.54 TB

Full text Bancroft Near Line = 0.5 TB;

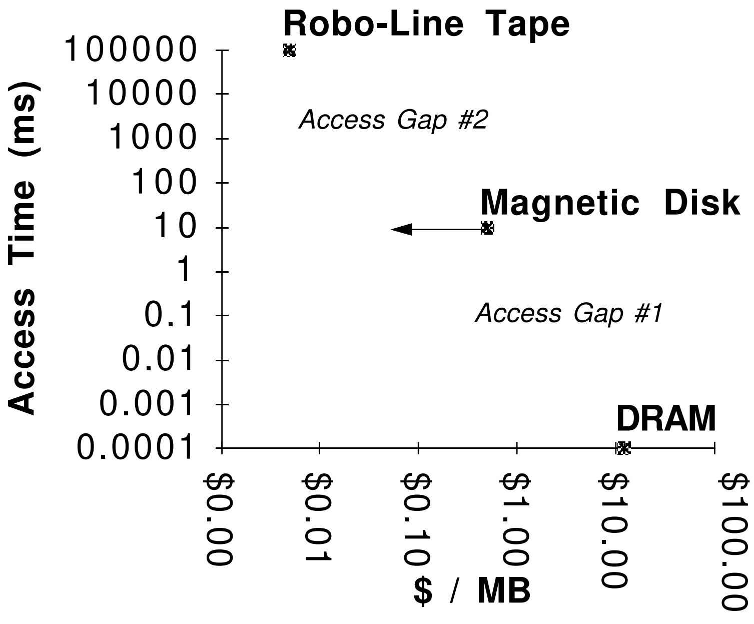
Pages images ≈ 20 TB

Predict: "RLB" (Robo-Line Bancroft) = $250,000

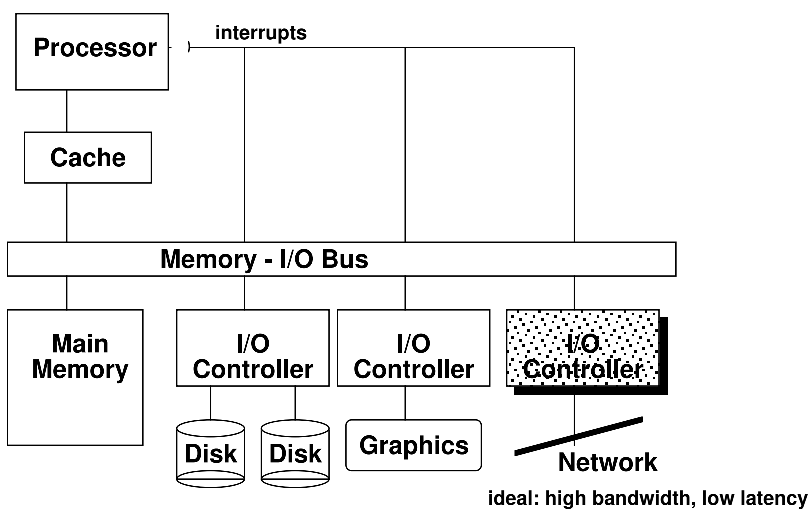
Bancroft costs:

Catalogue a book:	$20 / book
Reshelve a book:	$1/ book
% new books purchased per year never checked out:	20%

MSS: Summary



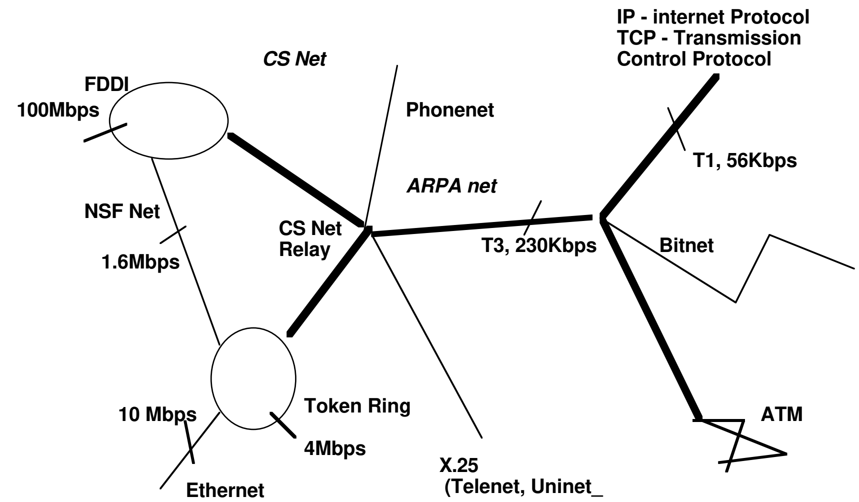
I/O to External Devices and Other Computers



Networks

- Goal: Communication between computers
- Eventual Goal: treat collection of computers as if one big computer, distributed resource sharing
- Theme: Different computers must agree on many things
  - Overriding importance of standards and protocols
- Warning: Terminology-rich environment

Example Major Networks

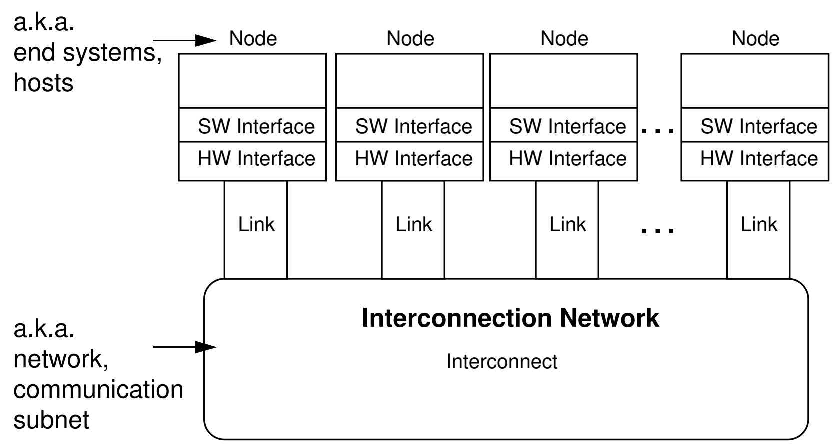


Networks

- Facets people talk a lot about:
  - direct (point-to-point) vs. indirect (multi-hop)
  - topology (e.g., bus, ring, DAG)
  - routing algorithms
  - switching (aka multiplexing)
  - wiring (e.g., choice of media, copper, coax, fiber)
- What really matters:
  - latency
  - bandwidth
  - cost
  - reliability

Interconnections (Networks)

- Examples:
  - MPP networks (SP2): 1000s nodes; ≤ 25 meters per link
  - Local Area Networks (Ethernet): 100s nodes; ≤ 1000 meters
  - Wide Area Network (ATM): 1000s nodes; ≤ 5,000,000 meters

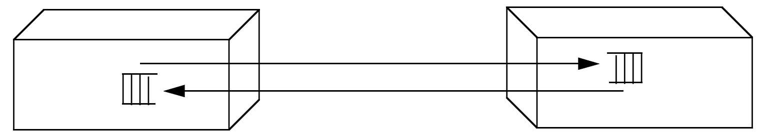


More Network Background

- Connection of 2 or more networks: Internetworking
- 3 cultures for 3 classes of networks
  - MPP: performance, latency and bandwidth
  - LAN: workstations, cost
  - WAN: telecommunications, phone call revenue
- Try for single terminology
- Motivate the complexity incrementally

ABCs of Networks

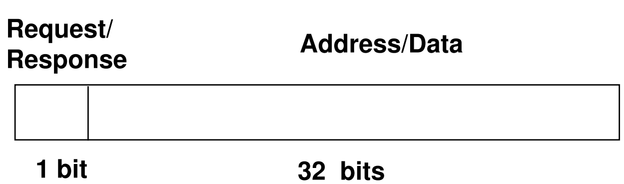
- Starting Point: Send bits between 2 computers



- Queue (FIFO) on each end
- Information sent called a message
- Can send both ways ("Full Duplex")
- Rules for communication? "protocol"
  - Inside a computer:
    - » Loads/Stores: Request (Address) & Response (Data)
    - » Need Request & Response signaling

A Simple Example

- What is the format of mesage?
  - Fixed? Number bytes?



0: Please send data from Address
1: Packet contains data corresponding to request

- Header/Trailer: information to deliver a message
- Payload: data in message (1 word above)

Questions About Simple Example

- What if more than 2 computers want to communicate?
  - Need computer address field (destination) in packet
- What if packet is garbled in transit?
  - Add error detection field in packet (e.g., CRC)
- What if packet is lost?
  - More elaborate protocols to detect loss (e.g., NAK, ARQ, time outs)
- What if multiple processes/machine?
  - Queue per process to provide protection
- Questions such as these lead to more complex protocols and packet formats

A Simple Example Revisted

- What is the format of packet?
  - Fixed? Number bytes?

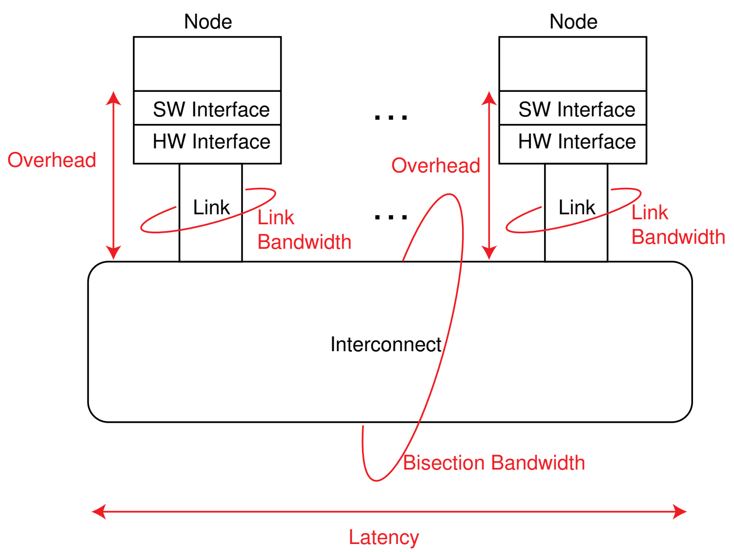
Request/ Response	Address/Data	CRC
1 bit	32 bits	4 bits

00: Request—Please send data from Address
01: Reply—Packet contains data corresponding to request
10: Acknowledge request
11: Acknowledge reply

Software 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, is matches send ACK; if not, deletes message (sender resends when timer expires)
  - 1: If OK, OS copies data to user address space and signals application to continue
- Sequence of steps for SW: protocol
  - Example similar to UDP/IP protocol in UNIX

Network Performance Measures

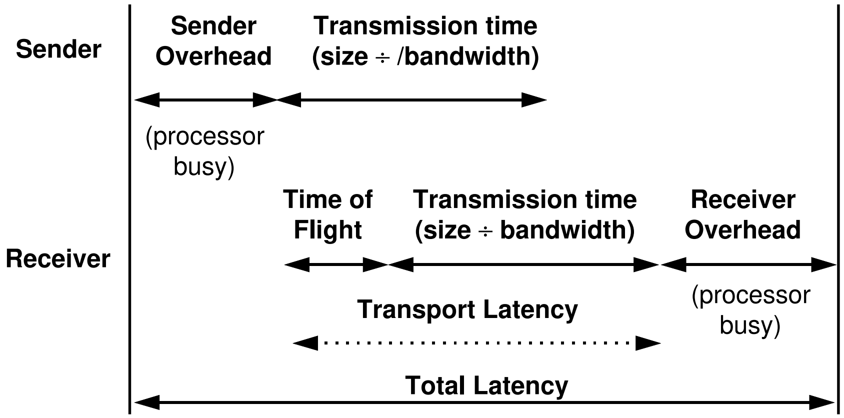


- Overhead: latency of interface vs. Latency: network

Example Performance Measures

Interconnect	*MPP*	*LAN*	*WAN*
Example	CM-5	Ethernet	ATM
Bisection BW	N x 5 MB/s	1.125 MB/s	N x 10 MB/s
Int./Link BW	20 MB/s	1.125 MB/s	10 MB/s
Latency	5 µsec	15 µsec	50 to 10,000 µs
HW Overhead to/from	0.5/0.5 µs	6/6 µs	6/6 µs
SW Overhead to/from	1.6/12.4 µs	200/241 µs	207/360 µs
		(TCP/IP on LAN/WAN)	

Performance Metrics



Total Latency = Sender Overhead + Time of Flight +
Message Size ÷ BW + Receiver Overhead

Total Latency Example

- **10 Mbit/sec., sending overhead of 230 μsec & receiving overhead of 270 μsec.**
- **a 1000 byte message (including the header), allows 1000 bytes in a single message.**
- **2 situations: distance 100 m vs. 1000 km**
- **Speed of light = 299,792.5 km/sec**
- **Latency$_{100m}$ =**
- **Latency$_{1000km}$ =**
- **Long time of flight => complex WAN protocol**

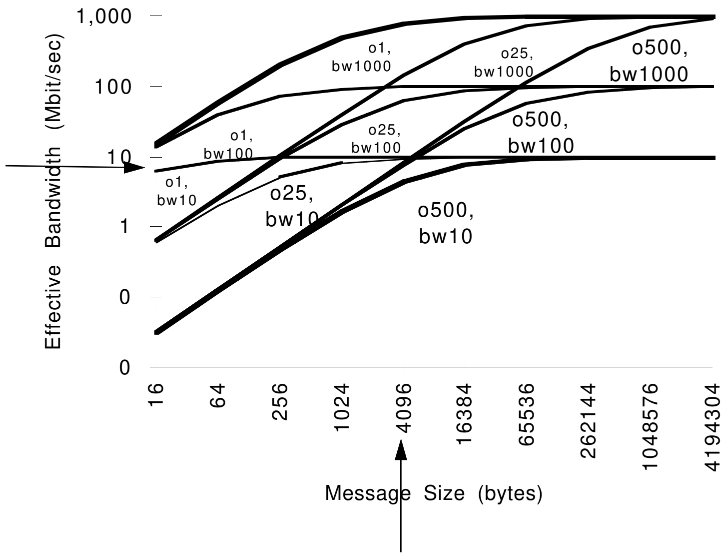
5 minute Class Break

- **Lecture Format:**
  - ≈ 1 minute: review last time & motivate this lecture
  - ≈ 20 minute lecture
  - ≈ 3 minutes: discuss class manangement
  - ≈ 25 minutes: lecture
  - 5 minutes: break
  - ≈25 minutes: lecture
  - ≈1 minute: summary of today's important topics

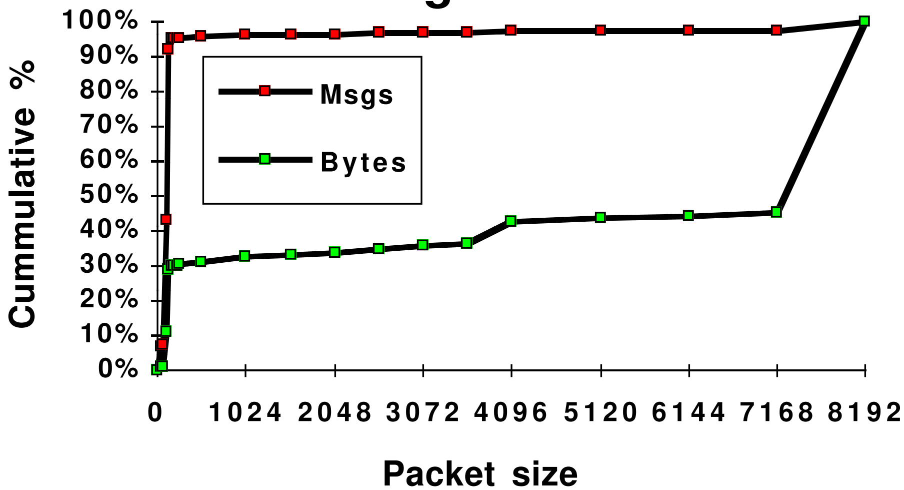
Simplified Latency Model

- **Total Latency ≈ Overhead + Message Size ÷ BW**
- **Overhead = Sender Overhead + Time of Flight + Receiver Overhead**
- **Example: show what happens as vary**
  - Overhead: 1, 25, 500 μsec
  - BW:10,100, 1000 Mbit/sec
  - Message Size: 16 Bytes to 4 MB
- **If overhead 500 μsec, how big a message > 10 Mb/s?**
- **How big are messages?**

Overhead, BW, Size

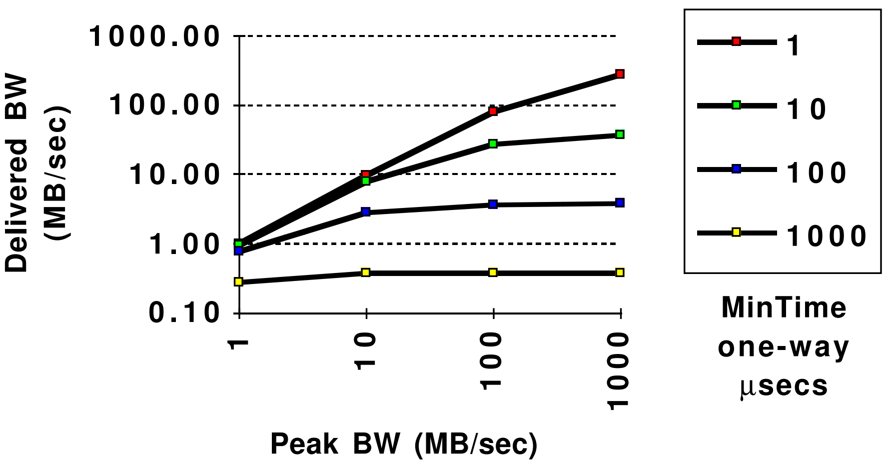


Measurement: Sizes of Message for NFS



- 95% Msgs, 30% bytes for packets ≤ 200 bytes
- > 50% data transfered in packets = 8KB

Impact of Overhead on Delivered BW



- BW model: Time = overhead + msg size/peak BW
- > 50% data transfered in packets = 8KB

Interconnect Issues

- Performance Measures
- Implementation Issues
- Architectual Issues
- Practical Issues

Implementation Issues

Interconnect	*MPP*	*LAN*	*WAN*
Example	CM-5	Ethernet	ATM
Maximum length between nodes	25 m	500 m; ≤5 repeaters	copper: 100 m optical: 2 km—25 km
Number data lines	4	1	1
Clock Rate	40 MHz	10 MHz	≥ 155.5 MHz
Shared vs. Switch	Switch	Shared	Switch
Maximum number of nodes	2048	254	> 10,000
Media Material	Copper	Twisted pair copper wire or Coaxial cable	Twisted pair copper wire or optical fiber

Summary: Interconnections

- Communication between computers
- Packets for standards, protocols to cover normal and abnormal events
- Performance issues: HW & SW overhead, interconnect latency, bisection BW
- Implementation issues: length, width, media