William Stallings Computer Organization and Architecture 6th Edition

Input/Output

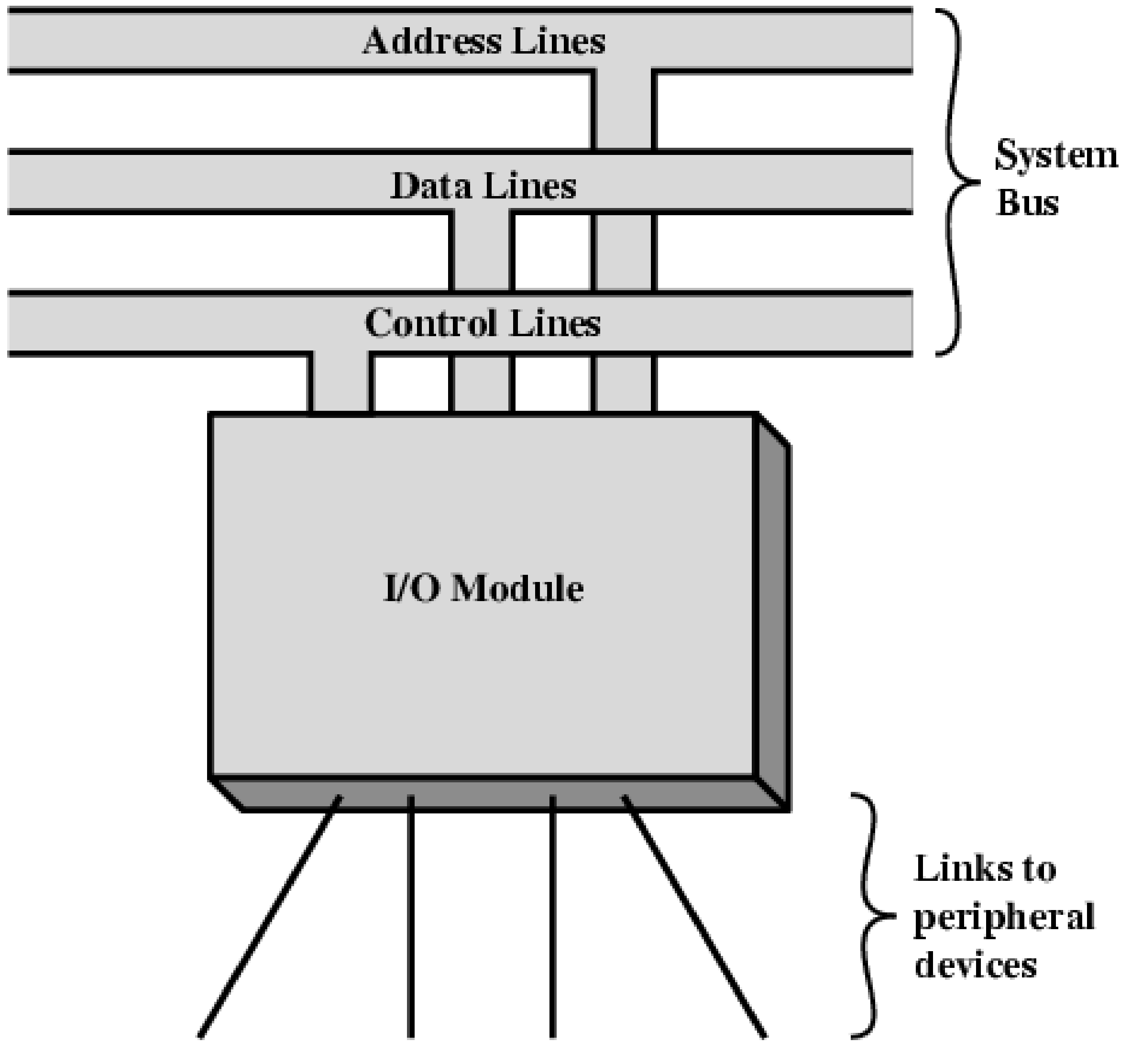
Input/Output Problems

- Wide variety of peripherals
  - Delivering different amounts of data
  - At different speeds
  - In different formats
- All slower than CPU and RAM
- Need I/O modules

Input/Output Module

- Interface to CPU and Memory
- Interface to one or more peripherals

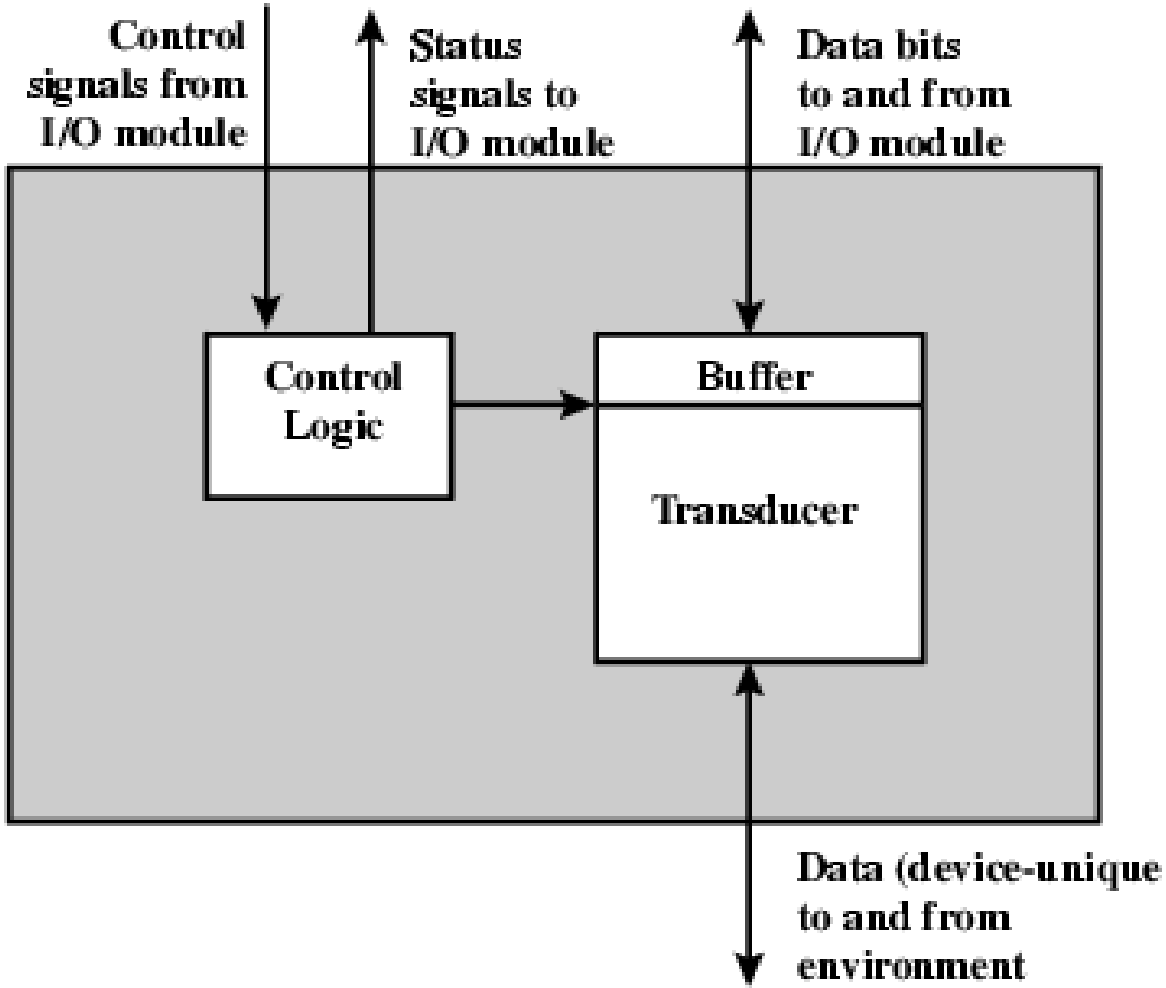
Generic Model of I/O Module



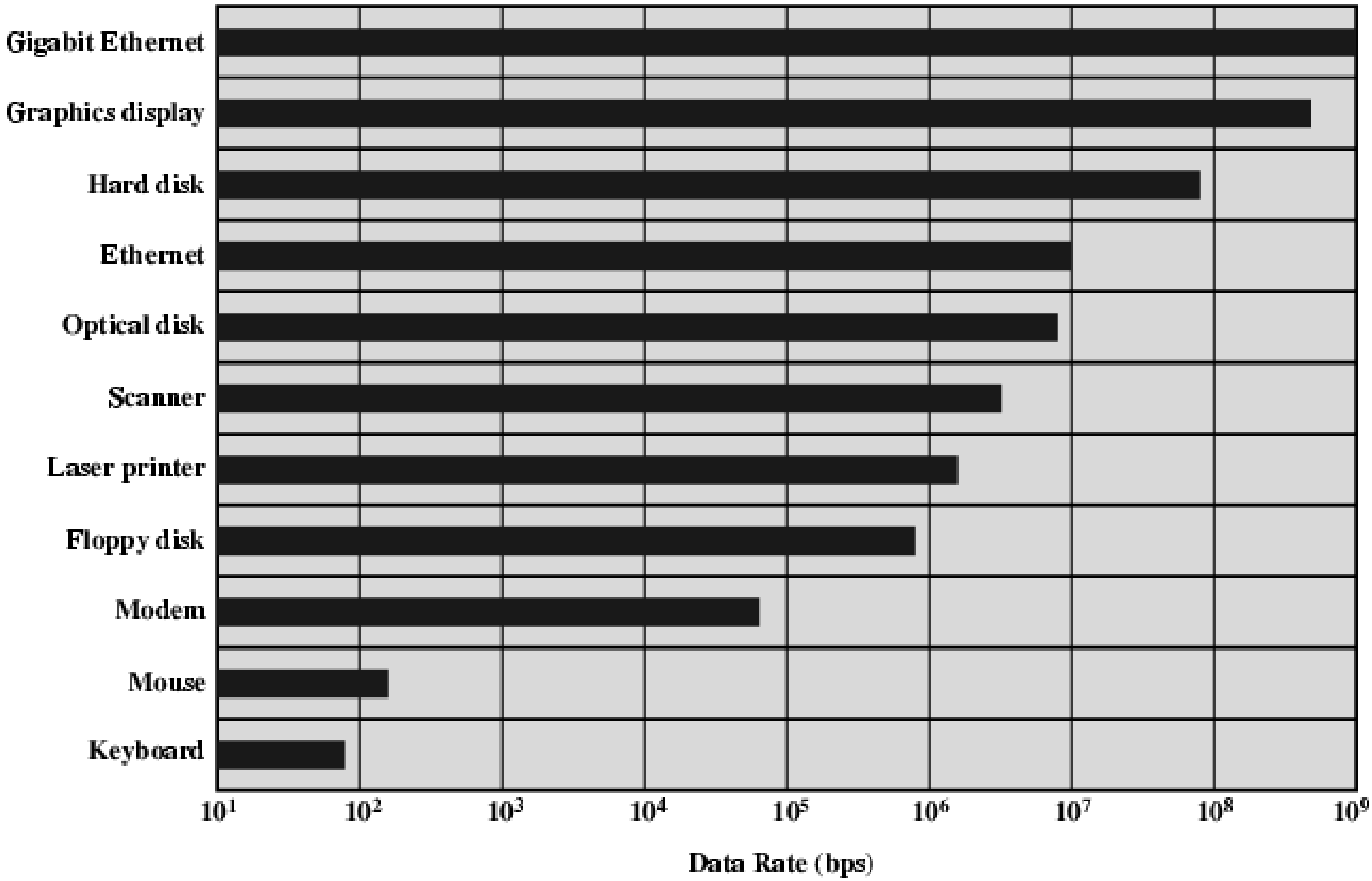
External Devices

- Human readable
  - Screen, printer, keyboard
- Machine readable
  - Monitoring and control
- Communication
  - Modem
  - Network Interface Card (NIC)

External Device Block Diagram



Typical I/O Data Rates



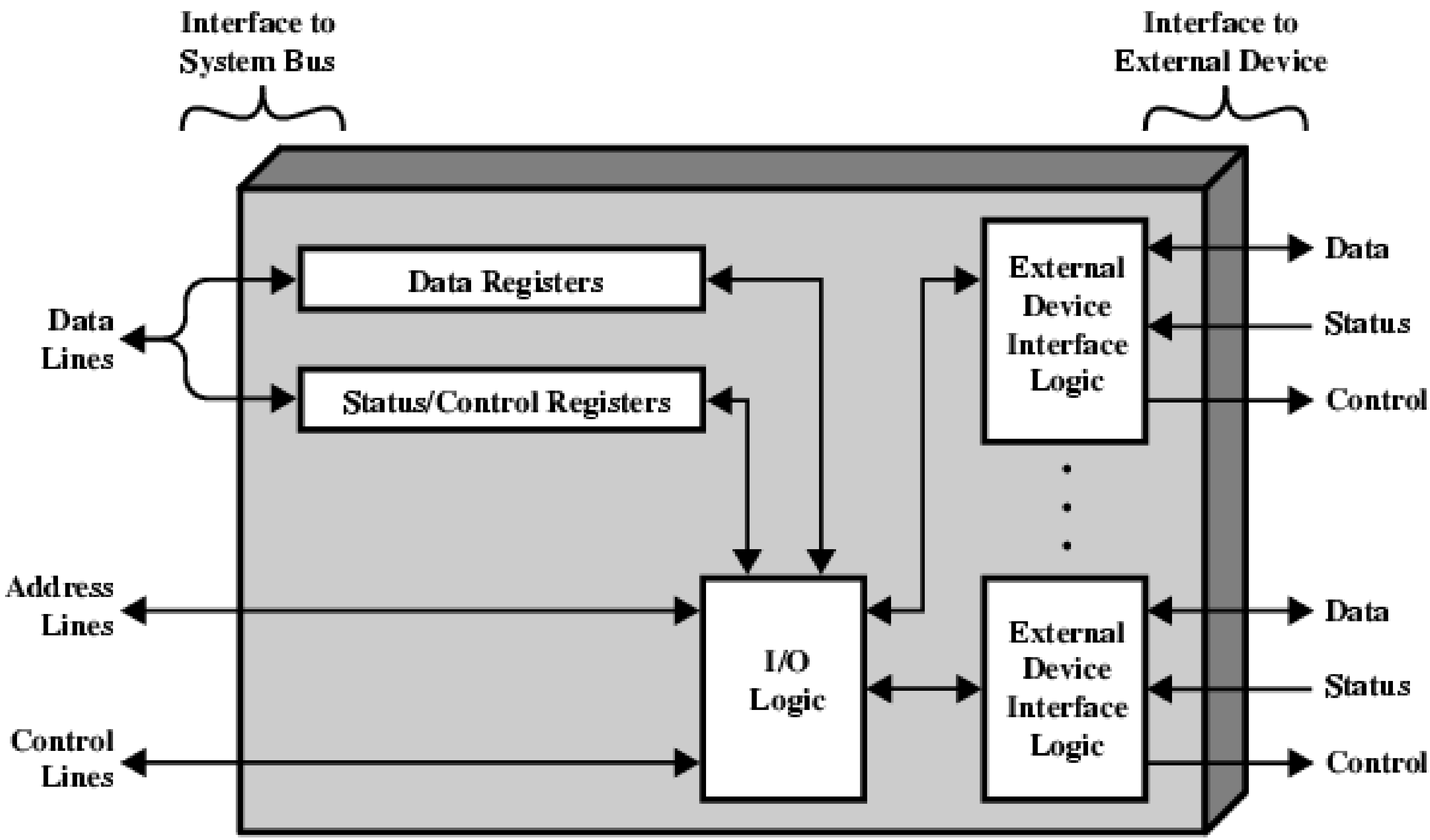
I/O Module Function

- Control & Timing
- CPU Communication
- Device Communication
- Data Buffering
- Error Detection

I/O Steps

- CPU checks I/O module device status
- I/O module returns status
- If ready, CPU requests data transfer
- I/O module gets data from device
- I/O module transfers data to CPU
- Variations for output, DMA, etc.

I/O Module Diagram



I/O Module Decisions

- Hide or reveal device properties to CPU
- Support multiple or single device
- Control device functions or leave for CPU
- Also O/S decisions
  - e.g. Unix treats everything it can as a file

Input Output Techniques

- Programmed
- Interrupt driven
- Direct Memory Access (DMA)

Programmed I/O

- CPU has direct control over I/O
  - Sensing status
  - Read/write commands
  - Transferring data
- CPU waits for I/O module to complete operation
- Wastes CPU time

Programmed I/O - detail

- CPU requests I/O operation
- I/O module performs operation
- I/O module sets status bits
- CPU checks status bits periodically
- I/O module does not inform CPU directly
- I/O module does not interrupt CPU
- CPU may wait or come back later

I/O Commands

- CPU issues address
  - Identifies module (& device if >1 per module)
- CPU issues command
  - Control - telling module what to do
    - e.g. spin up disk
  - Test - check status
    - e.g. power? Error?
  - Read/Write
    - Module transfers data via buffer from/to device

Addressing I/O Devices

- Under programmed I/O data transfer is very like memory access (CPU viewpoint)
- Each device given unique identifier
- CPU commands contain identifier (address)

I/O Mapping

- Memory mapped I/O
  - Devices and memory share an address space
  - I/O looks just like memory read/write
  - No special commands for I/O
    - Large selection of memory access commands available
- Isolated I/O
  - Separate address spaces
  - Need I/O or memory select lines
  - Special commands for I/O
    - Limited set

Interrupt Driven I/O

- Overcomes CPU waiting
- No repeated CPU checking of device
- I/O module interrupts when ready

Interrupt Driven I/O
Basic Operation

- CPU issues read command
- I/O module gets data from peripheral whilst CPU does other work
- I/O module interrupts CPU
- CPU requests data
- I/O module transfers data

CPU Viewpoint

- Issue read command
- Do other work
- Check for interrupt at end of each instruction cycle
- If interrupted:-
  - Save context (registers)
  - Process interrupt
    - Fetch data & store
- See Operating Systems notes

Design Issues

- How do you identify the module issuing the interrupt?
- How do you deal with multiple interrupts?
  - i.e. an interrupt handler being interrupted

Identifying Interrupting Module (1)

- Different line for each module
  - PC
  - Limits number of devices
- Software poll
  - CPU asks each module in turn
  - Slow

Identifying Interrupting Module (2)

- Daisy Chain or Hardware poll
  - Interrupt Acknowledge sent down a chain
  - Module responsible places vector on bus
  - CPU uses vector to identify handler routine
- Bus Master
  - Module must claim the bus before it can raise interrupt
  - e.g. PCI & SCSI

Multiple Interrupts

- Each interrupt line has a priority
- Higher priority lines can interrupt lower priority lines
- If bus mastering only current master can interrupt

Example - PC Bus

- 80x86 has one interrupt line
- 8086 based systems use one 8259A interrupt controller
- 8259A has 8 interrupt lines

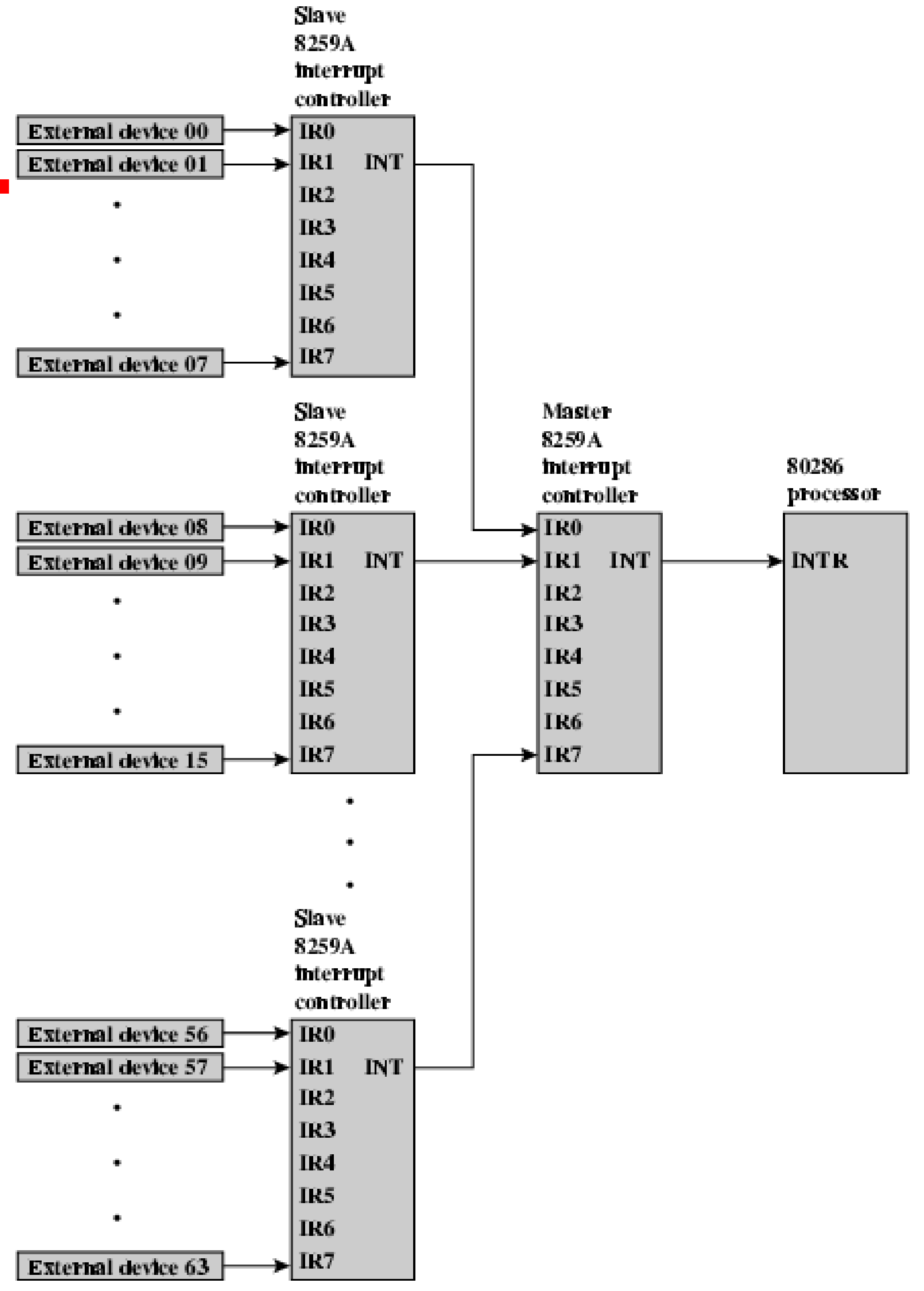
Sequence of Events

- 8259A accepts interrupts
- 8259A determines priority
- 8259A signals 8086 (raises INTR line)
- CPU Acknowledges
- 8259A puts correct vector on data bus
- CPU processes interrupt

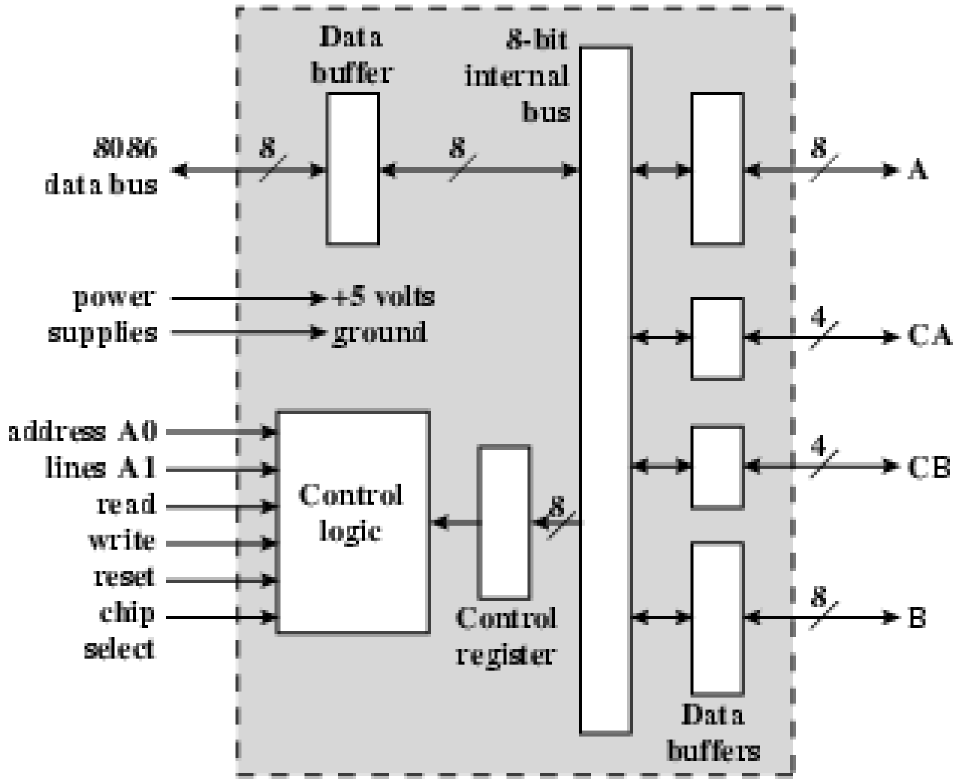
ISA Bus Interrupt System

- ISA bus chains two 8259As together
- Link is via interrupt 2
- Gives 15 lines
  - 16 lines less one for link
- IRQ 9 is used to re-route anything trying to use IRQ 2
  - Backwards compatibility
- Incorporated in chip set

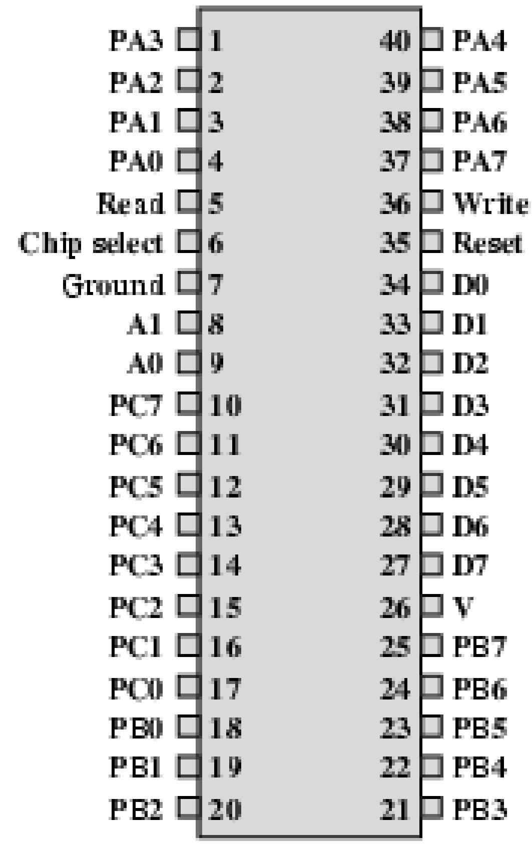
82C59A Interrupt Controller



Intel 82C55A Programmable Peripheral Interface

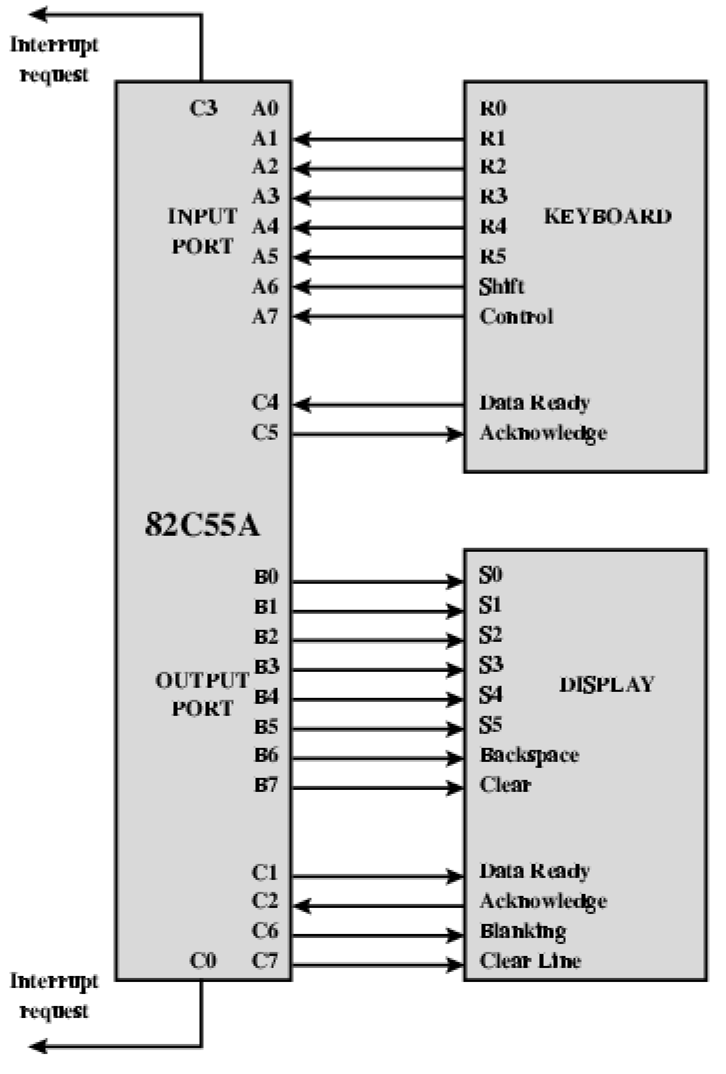


(a) Block diagram



(b) Pin layout

Using 82C55A To Control Keyboard/Display



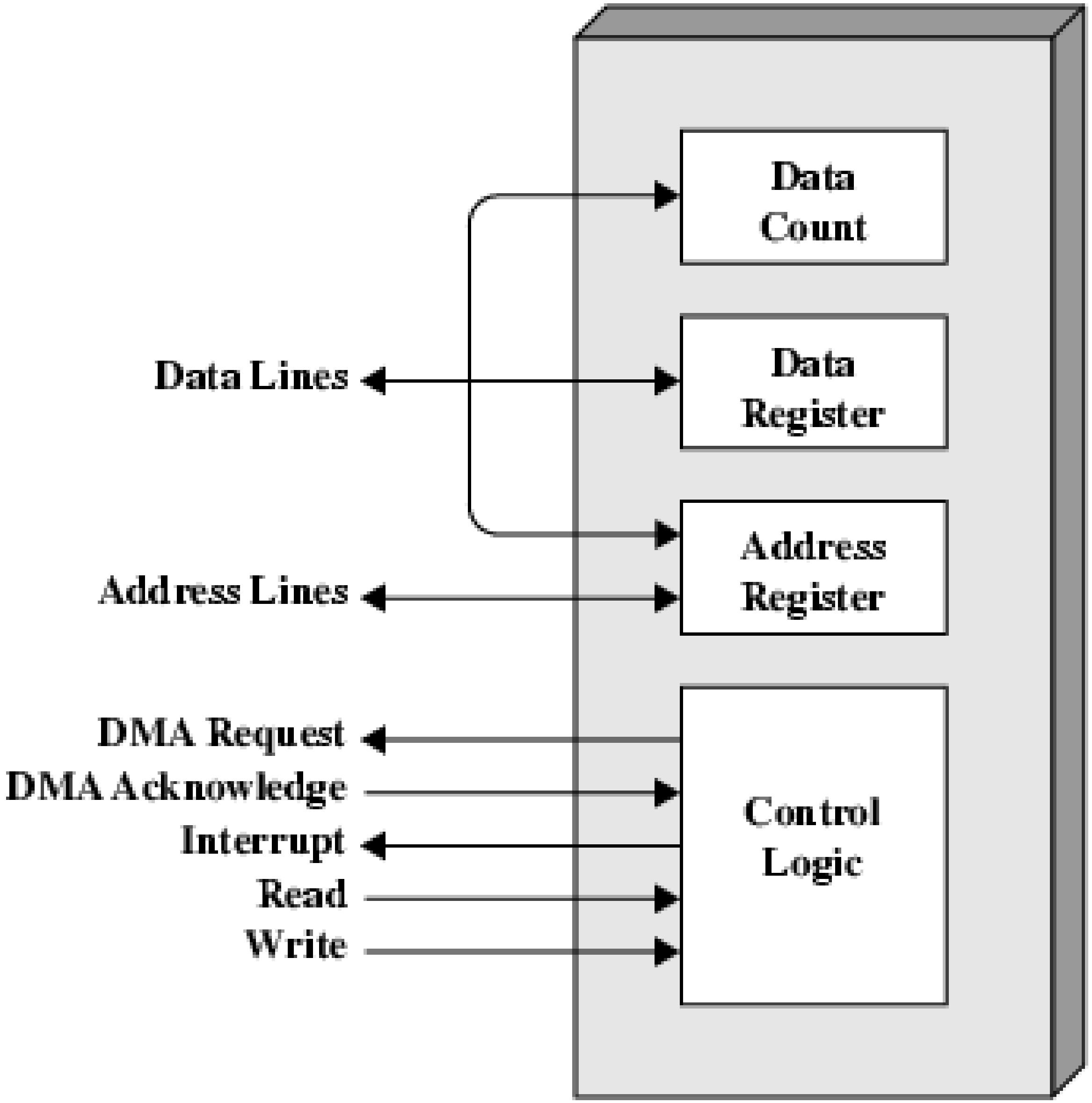
Direct Memory Access

- Interrupt driven and programmed I/O require active CPU intervention
  - Transfer rate is limited
  - CPU is tied up
- DMA is the answer

DMA Function

- Additional Module (hardware) on bus
- DMA controller takes over from CPU for I/O

DMA Module Diagram



DMA Operation

- CPU tells DMA controller:-
  - Read/Write
  - Device address
  - Starting address of memory block for data
  - Amount of data to be transferred
- CPU carries on with other work
- DMA controller deals with transfer
- DMA controller sends interrupt when finished

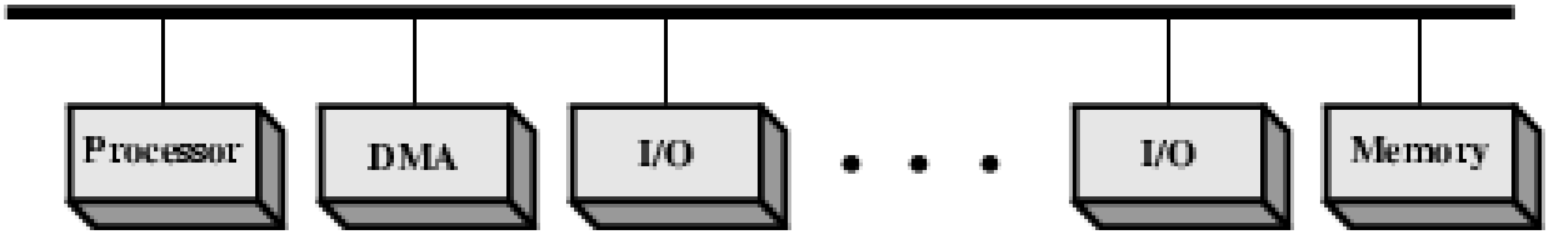
DMA Transfer
Cycle Stealing

- DMA controller takes over bus for a cycle
- Transfer of one word of data
- Not an interrupt
  - CPU does not switch context
- CPU suspended just before it accesses bus
  - i.e. before an operand or data fetch or a data write
- Slows down CPU but not as much as CPU doing transfer

Aside

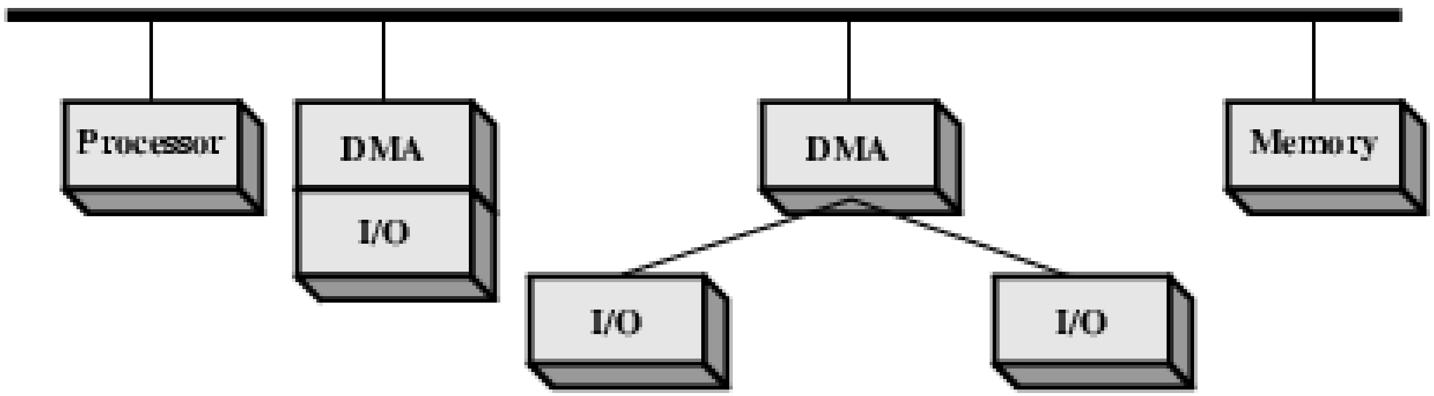
- What effect does caching memory have on DMA?
- Hint: how much are the system buses available?

DMA Configurations (1)



- Single Bus, Detached DMA controller
- Each transfer uses bus twice
    - —I/O to DMA then DMA to memory
- CPU is suspended twice

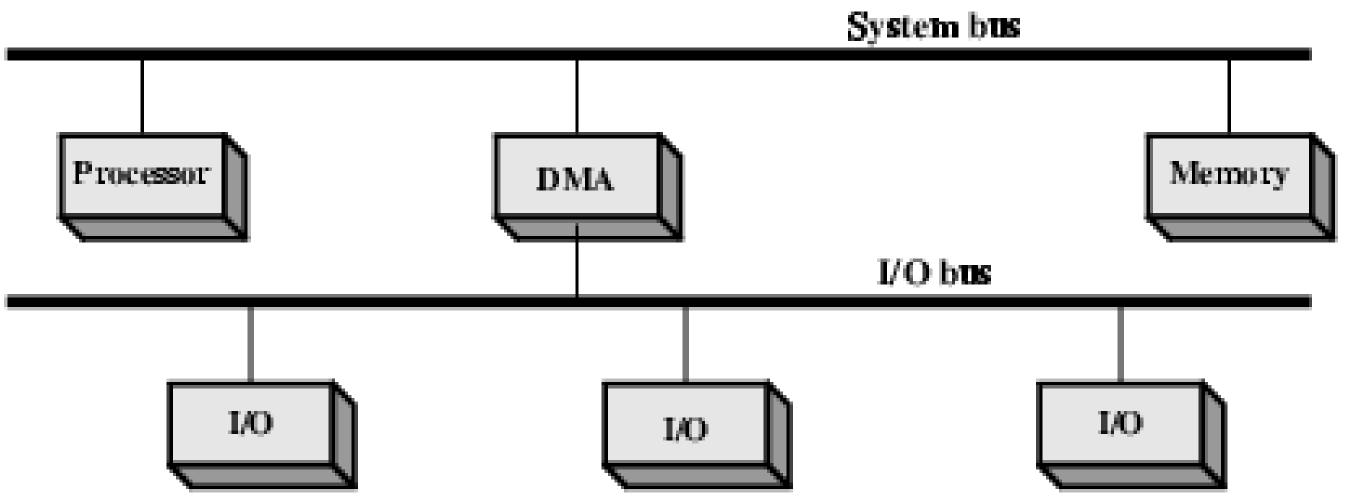
DMA Configurations (2)



(b) Single-bus, Integrated DMA-I/O

- Single Bus, Integrated DMA controller
- Controller may support >1 device
- Each transfer uses bus once
  - —DMA to memory
- CPU is suspended once

DMA Configurations (3)



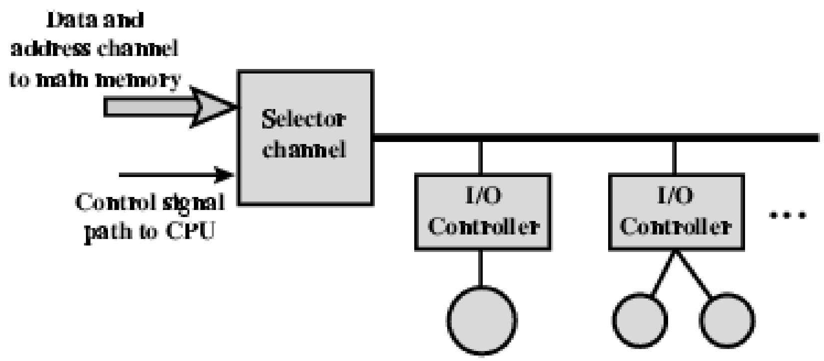
(c) I/O bus

- Separate I/O Bus
- Bus supports all DMA enabled devices
- Each transfer uses bus once
    - —DMA to memory
- CPU is suspended once

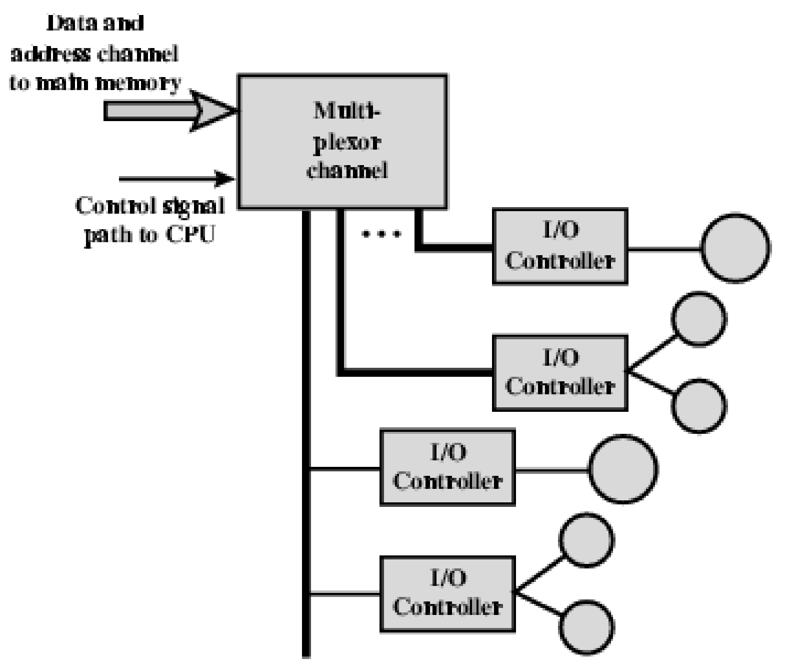
I/O Channels

- I/O devices getting more sophisticated
- e.g. 3D graphics cards
- CPU instructs I/O controller to do transfer
- I/O controller does entire transfer
- Improves speed
  - Takes load off CPU
  - Dedicated processor is faster

I/O Channel Architecture



(a) Selector



(b) Multiplexor

Interfacing

- Connecting devices together
- Bit of wire?
- Dedicated processor/memory/buses?
- E.g. FireWire, InfiniBand

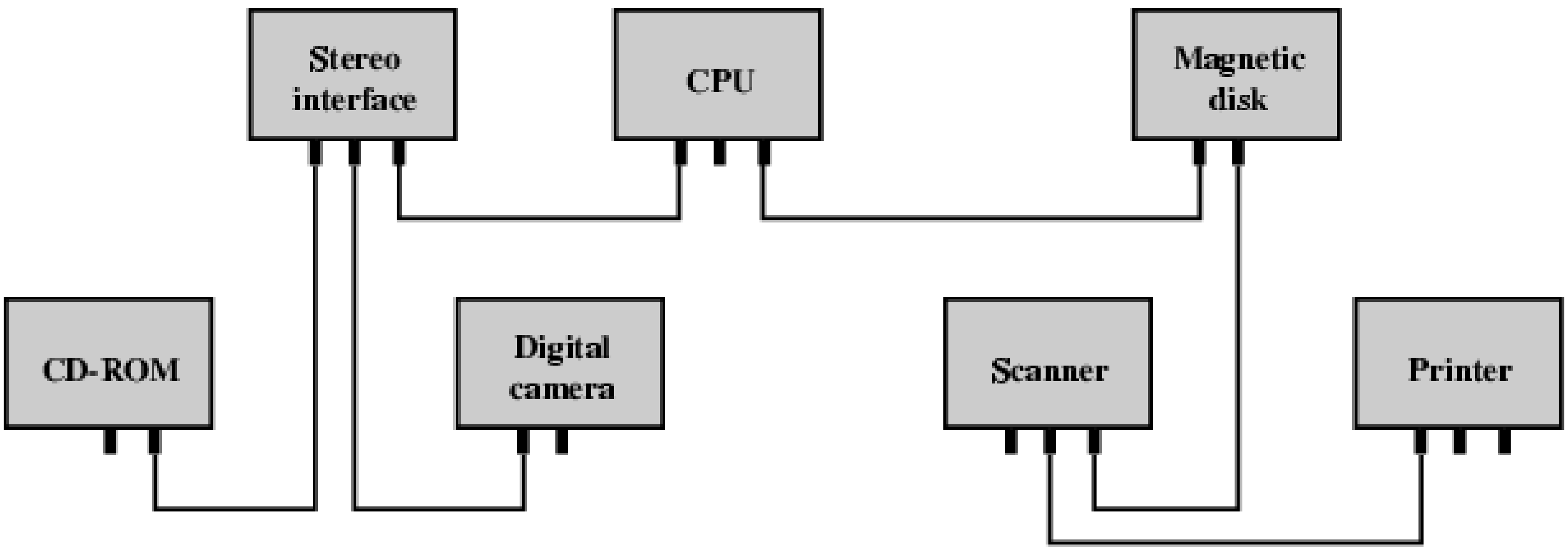
IEEE 1394 FireWire

- High performance serial bus
- Fast
- Low cost
- Easy to implement
- Also being used in digital cameras, VCRs and TV

FireWire Configuration

- Daisy chain
- Up to 63 devices on single port
    - Really 64 of which one is the interface itself
- Up to 1022 buses can be connected with bridges
- Automatic configuration
- No bus terminators
- May be tree structure

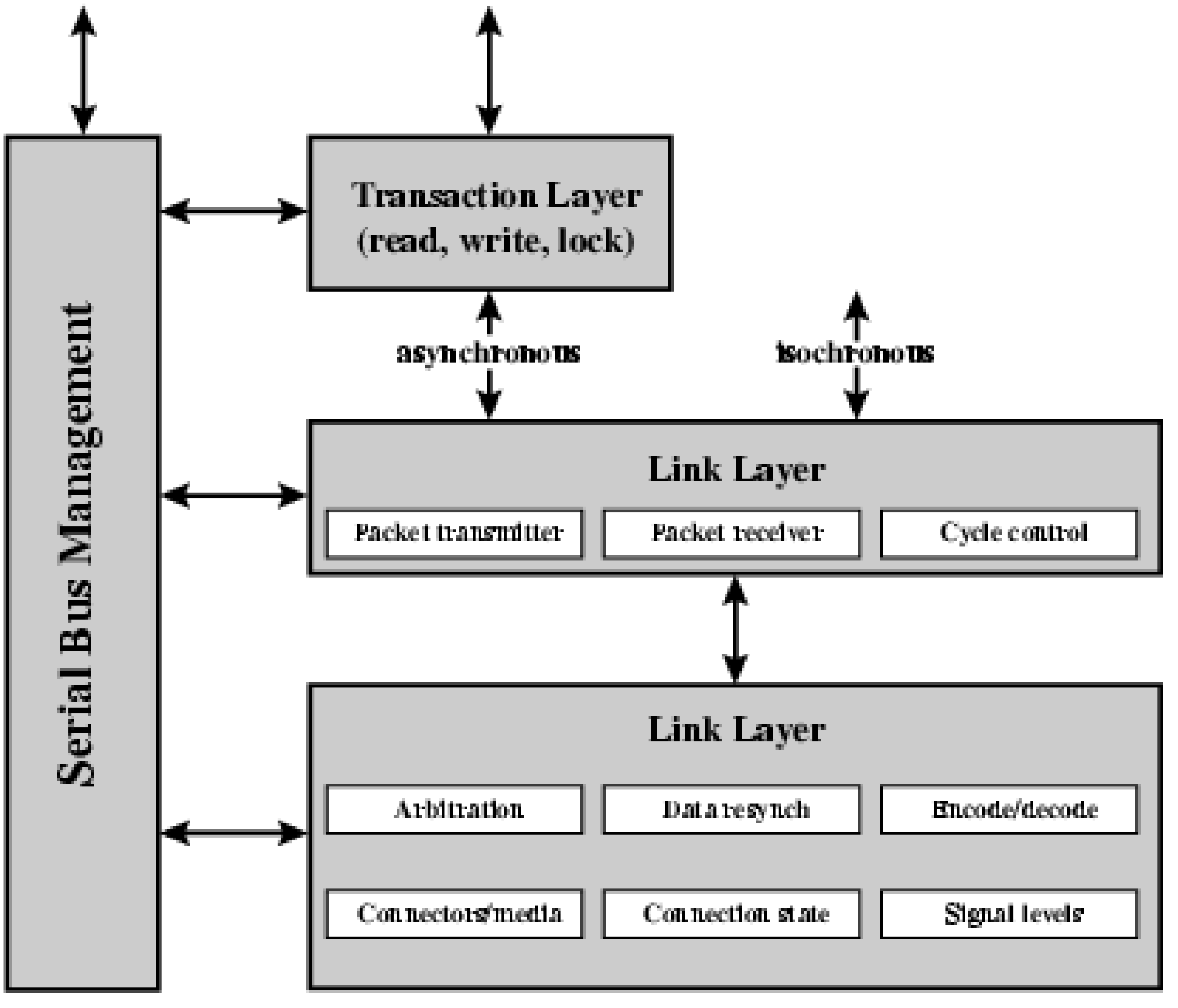
Simple FireWire Configuration



FireWire 3 Layer Stack

- Physical
  - Transmission medium, electrical and signaling characteristics
- Link
  - Transmission of data in packets
- Transaction
  - Request-response protocol

FireWire Protocol Stack



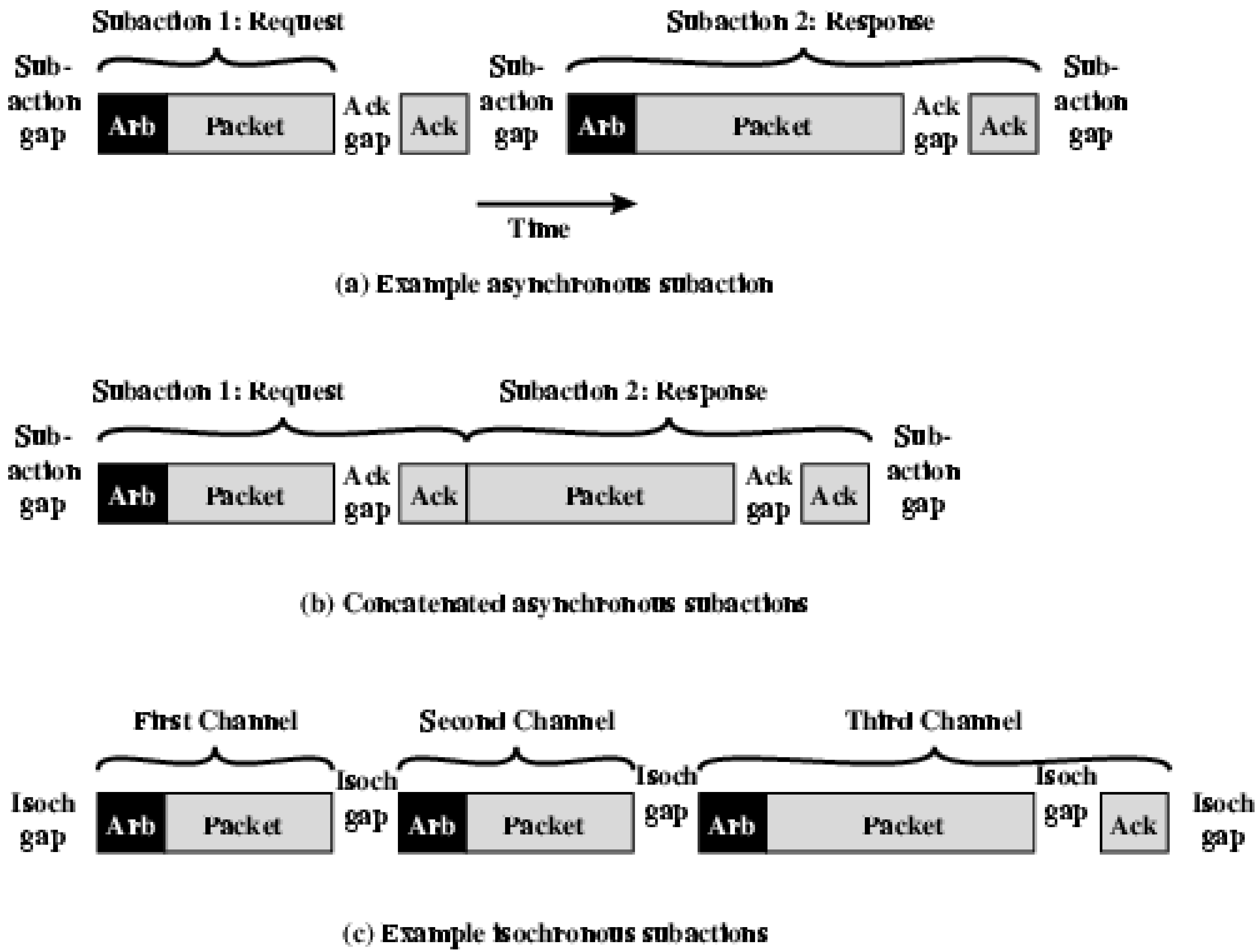
FireWire - Physical Layer

- Data rates from 25 to 400Mbps
- Two forms of arbitration
  - Based on tree structure
  - Root acts as arbiter
  - First come first served
  - Natural priority controls simultaneous requests
    - i.e. who is nearest to root
  - Fair arbitration
  - Urgent arbitration

FireWire - Link Layer

- Two transmission types
  - Asynchronous
    - Variable amount of data and several bytes of transaction data transferred as a packet
    - To explicit address
    - Acknowledgement returned
  - Isochronous
    - Variable amount of data in sequence of fixed size packets at regular intervals
    - Simplified addressing
    - No acknowledgement

FireWire Subactions



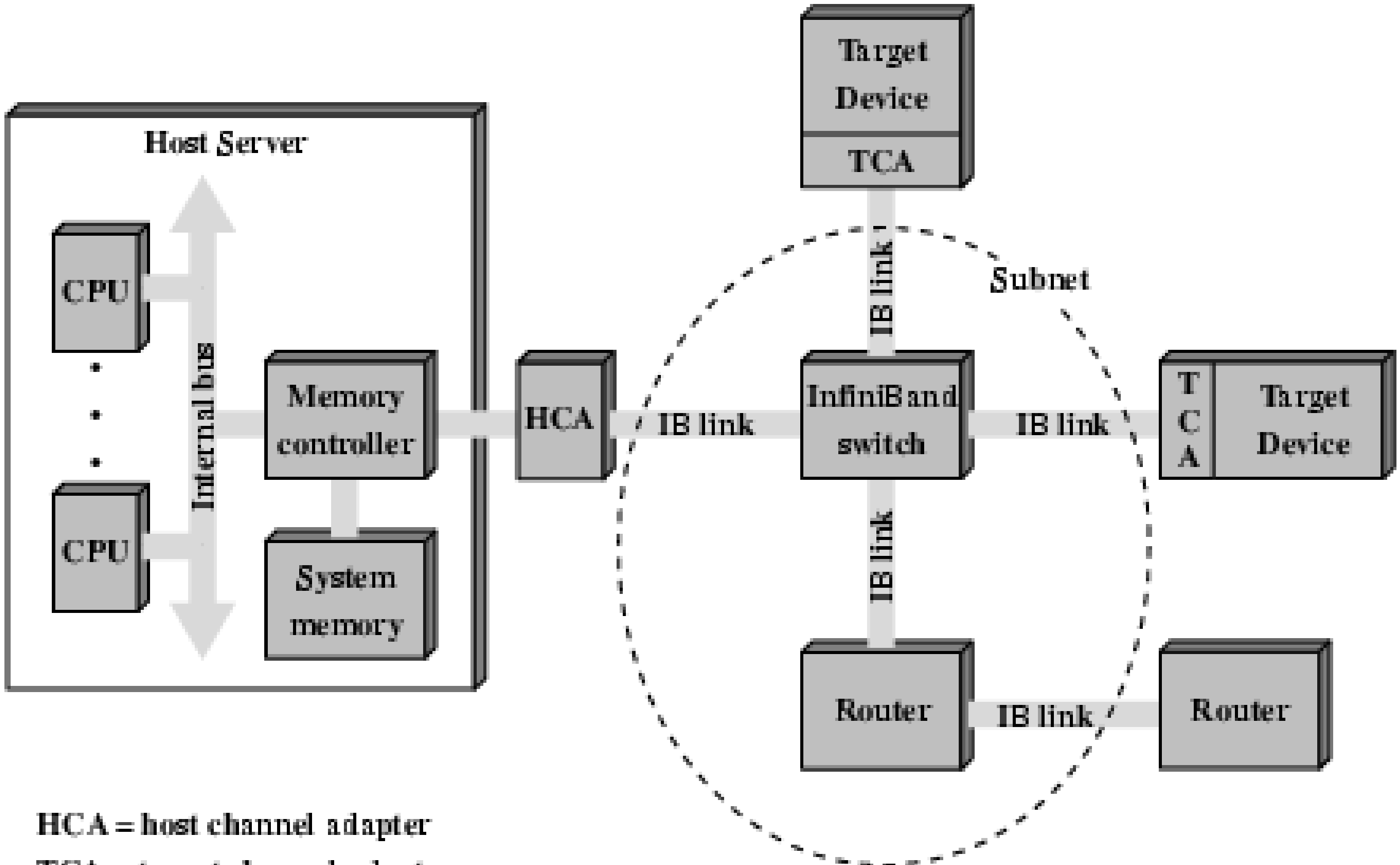
InfiniBand

- I/O specification aimed at high end servers
  - Merger of Future I/O (Cisco, HP, Compaq, IBM) and Next Generation I/O (Intel)
- Version 1 released early 2001
- Architecture and spec. for data flow between processor and intelligent I/O devices
- Intended to replace PCI in servers
- Increased capacity, expandability, flexibility

InfiniBand Architecture

- Remote storage, networking and connection between servers
- Attach servers, remote storage, network devices to central fabric of switches and links
- Greater server density
- Scalable data centre
- Independent nodes added as required
- I/O distance from server up to
  - 17m using copper
  - 300m multimode fibre optic
  - 10km single mode fibre
- Up to 30Gbps

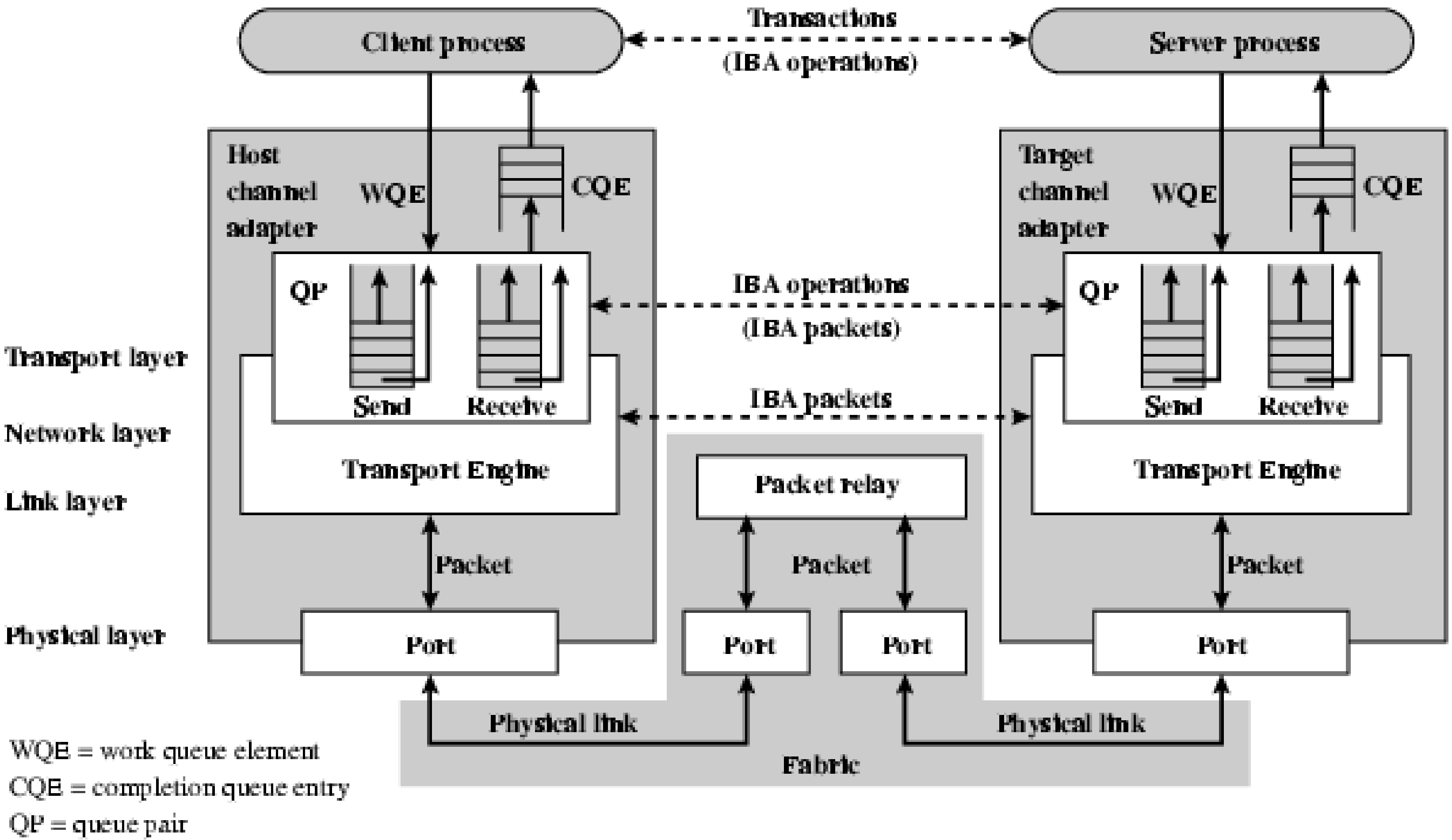
InfiniBand Switch Fabric



InfiniBand Operation

- 16 logical channels (virtual lanes) per physical link
- One lane for management, rest for data
- Data in stream of packets
- Virtual lane dedicated temporarily to end to end transfer
- Switch maps traffic from incoming to outgoing lane

InfiniBand Protocol Stack



Foreground Reading

- Check out Universal Serial Bus (USB)
- Compare with other communication standards e.g. Ethernet