

# **William Stallings**

# **Computer Organization**

# **and Architecture**

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## **Chapter 6**

## **Input/Output**

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# Input/Output Problems

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- ⌘ 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

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- ⌘ Interface to CPU and Memory
- ⌘ Interface to one or more peripherals
- ⌘ GENERIC MODEL OF I/O DIAGRAM 6.1

# External Devices

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## ⌘ Human readable

- ☑ Screen, printer, keyboard

## ⌘ Machine readable

- ☑ Monitoring and control

## ⌘ Communication

- ☑ Modem

- ☑ Network Interface Card (NIC)

# I/O Module Function

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

# I/O Steps

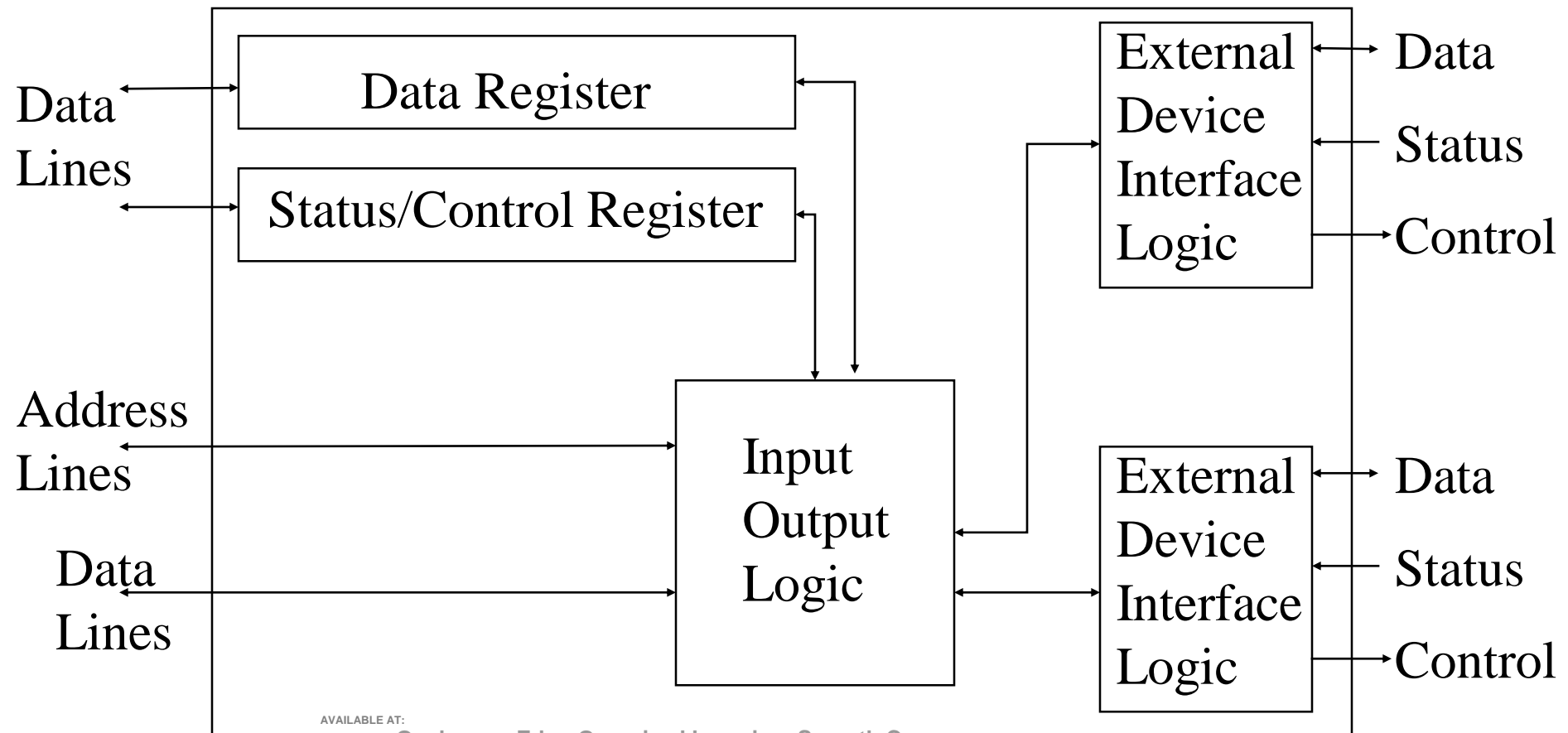
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- ⌘ CPU checks I/O module device status
- ⌘ I/O module returns status
- ⌘ If ready, CPU requests data transfer
- ⌘ I/O module gets data from device
- ⌘ I/O module transfers data to CPU
- ⌘ Variations for output, DMA, etc.

# I/O Module Diagram

Systems Bus Interface

External Device Interface



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# I/O Module Decisions

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- ⌘ 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

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

# Programmed I/O

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⌘ 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

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- ⌘ 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

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## ⌘ 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

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- ⌘ 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

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## ⌘ 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

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

# Interrupt Driven I/O

## Basic Operation

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- ⌘ 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

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- ⌘ 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

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- ⌘ 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)

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⌘ Different line for each module

- ☒ PC

- ☒ Limits number of devices

⌘ Software poll

- ☒ CPU asks each module in turn

- ☒ Slow

# Identifying Interrupting Module (2)

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## ⌘ 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

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- ⌘ 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

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

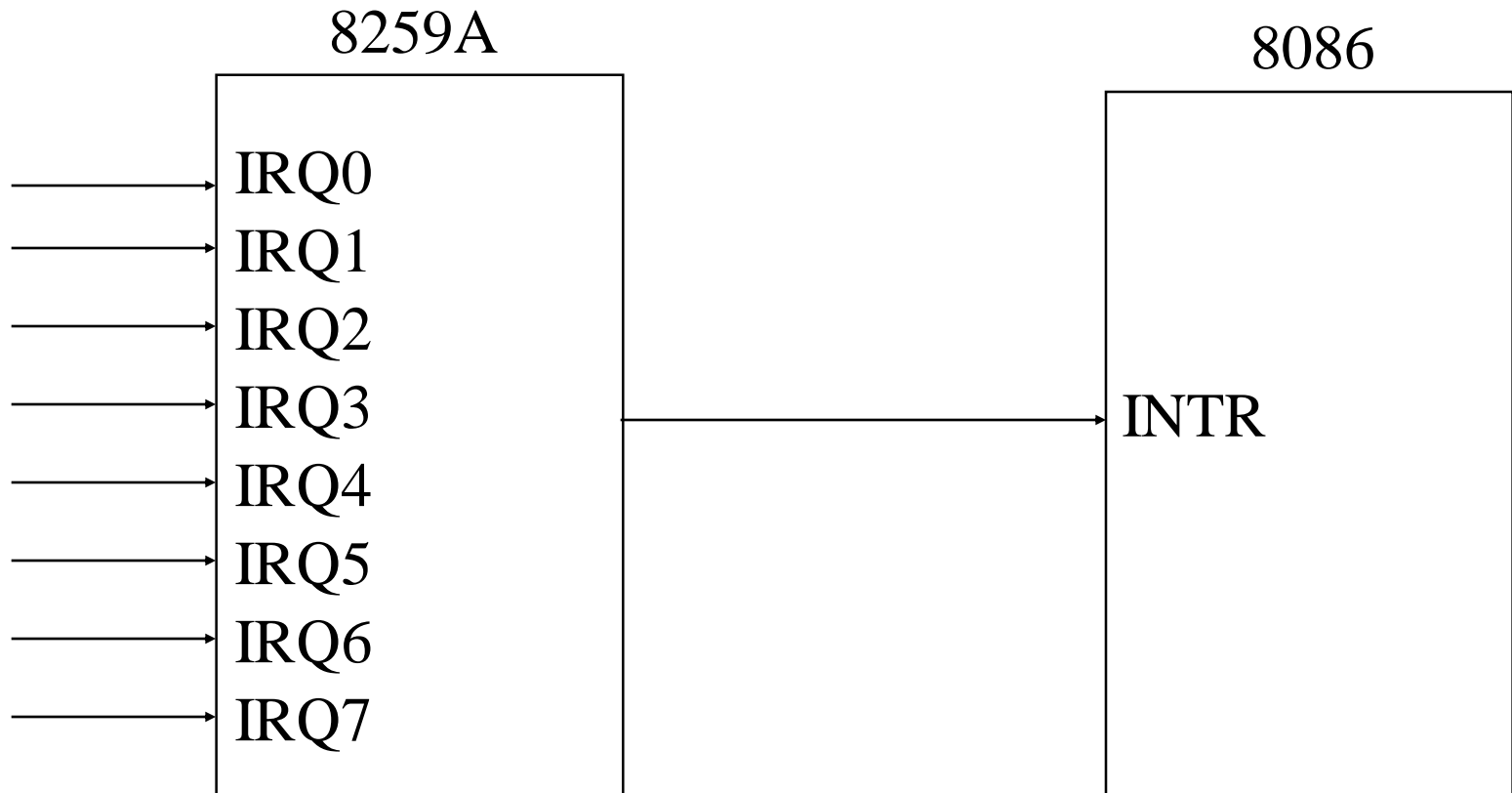
# Sequence of Events

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

# PC Interrupt Layout

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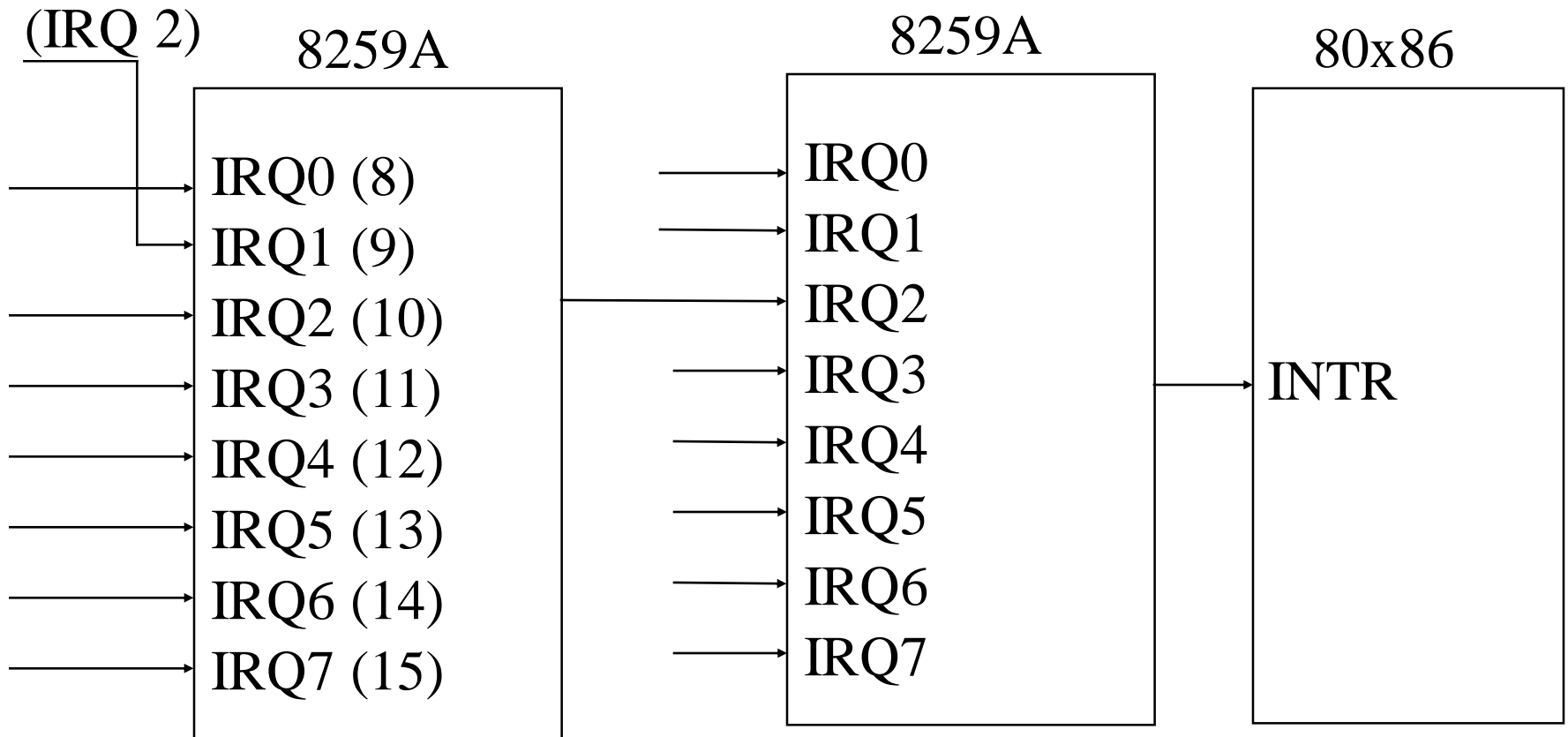
# ISA Bus Interrupt System

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- ⌘ 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

# ISA Interrupt Layout

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# Foreground Reading

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⌘ <http://www.pcguide.com/ref/mbsys/res/irq/func.htm>

⌘ In fact look at <http://www.pcguide.com/>

# Direct Memory Access

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

# DMA Function

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

# DMA Operation

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⌘ 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

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- ⌘ 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

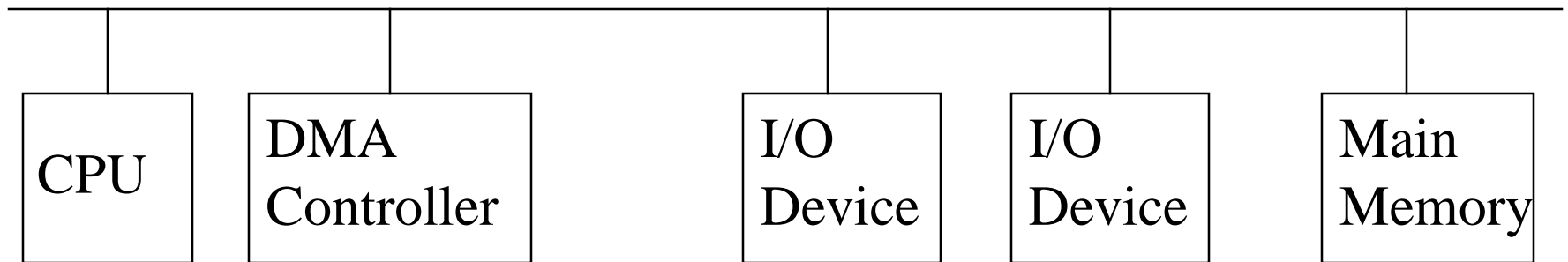
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- ⌘ What effect does caching memory have on DMA?
- ⌘ Hint: how much are the system buses available?



# DMA Configurations (1)

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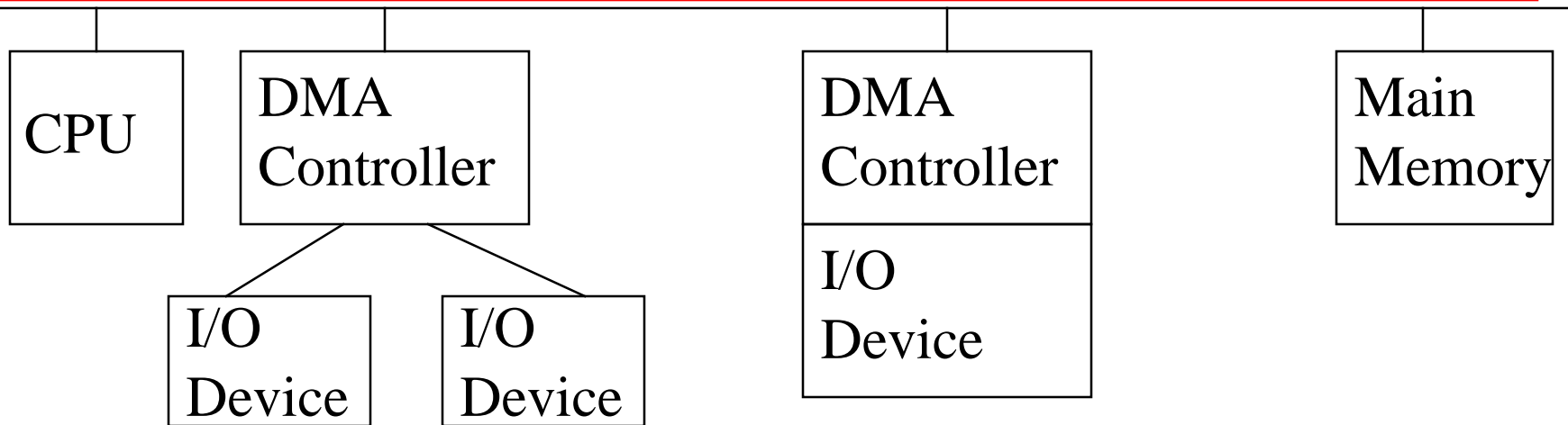
- ⌘ Single Bus, Detached DMA controller
- ⌘ Each transfer uses bus twice
  - ☑ I/O to DMA then DMA to memory
- ⌘ CPU is suspended twice

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# DMA Configurations (2)

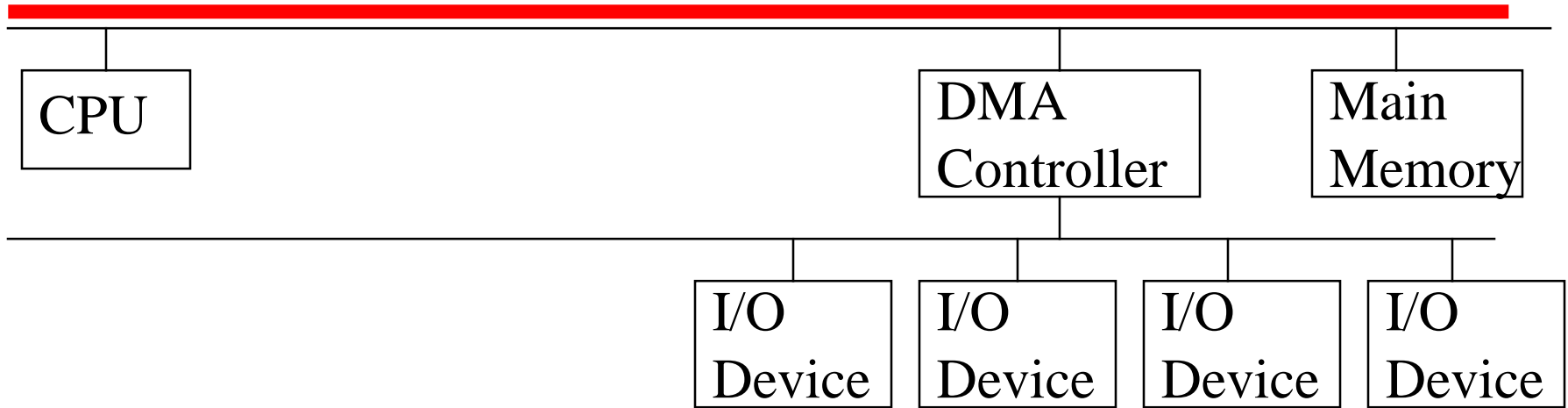


- ⌘ Single Bus, Integrated DMA controller
- ⌘ Controller may support >1 device
- ⌘ Each transfer uses bus once
  - ☑ DMA to memory
- ⌘ CPU is suspended once

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# DMA Configurations (3)



- ⌘ 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

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- ⌘ 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

# Interfacing

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

# Small Computer Systems Interface (SCSI)

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- ⌘ Parallel interface
- ⌘ 8, 16, 32 bit data lines
- ⌘ Daisy chained
- ⌘ Devices are independent
- ⌘ Devices can communicate with each other as well as host

# SCSI - 1

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- ⌘ Early 1980s
- ⌘ 8 bit
- ⌘ 5MHz
- ⌘ Data rate 5MBytes.s<sup>-1</sup>
- ⌘ Seven devices
  - ☑ Eight including host interface

# SCSI - 2

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- ⌘ 1991
- ⌘ 16 and 32 bit
- ⌘ 10MHz
- ⌘ Data rate 20 or 40 Mbytes.s<sup>-1</sup>
- ⌘ (Check out Ultra/Wide SCSI)



# SCSI Signaling (1)

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- ⌘ Between initiator and target

  - ☒ Usually host & device

- ⌘ Bus free? (c.f. Ethernet)

- ⌘ Arbitration - take control of bus (c.f. PCI)

- ⌘ Select target

- ⌘ Reselection

  - ☒ Allows reconnection after suspension

  - ☒ e.g. if request takes time to execute, bus can be released

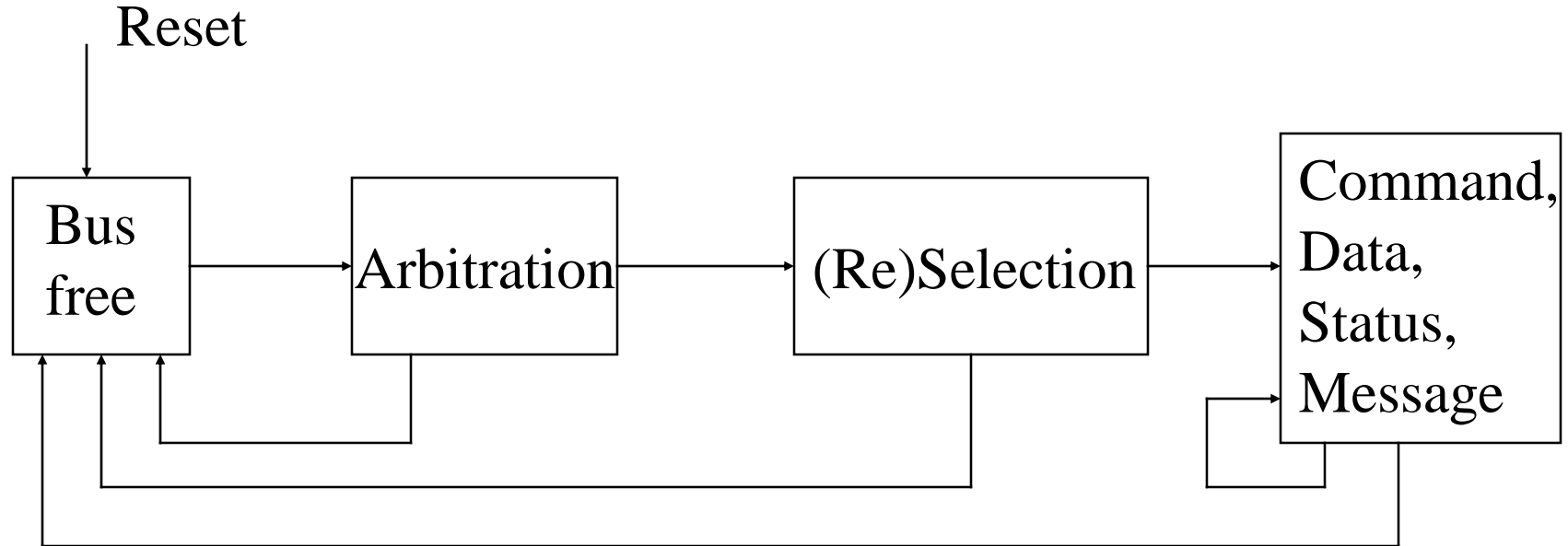
# SCSI Signaling (2)

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- ⌘ Command - target requesting from initiator
- ⌘ Data request
- ⌘ Status request
- ⌘ Message request (both ways)

# SCSI Bus Phases

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# Configuring SCSI

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⌘ Bus must be terminated at each end

- ☑ Usually one end is host adapter

- ☑ Plug in terminator or switch(es)

⌘ SCSI Id must be set

- ☑ Jumpers or switches

- ☑ Unique on chain

- ☑ 0 (zero) for boot device

- ☑ Higher number is higher priority in arbitration

# IEEE 1394 FireWire

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

# FireWire Configuration

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- ⌘ 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

# FireWire v SCSI

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# FireWire 3 Layer Stack

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## ⌘ Physical

- ☑ Transmission medium, electrical and signaling characteristics

## ⌘ Link

- ☑ Transmission of data in packets

## ⌘ Transaction

- ☑ Request-response protocol

# FireWire - Physical Layer

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⌘ 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

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## ⌘ 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

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# Foreground Reading

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