

**William Stallings
Computer Organization
and Architecture
7th Edition**

**Chapter 3
System Buses**

Program Concept

- Hardwired systems are inflexible
- General purpose hardware can do different tasks, given correct control signals
- Instead of re-wiring, supply a new set of control signals

What is a program?

- A sequence of steps
- For each step, an arithmetic or logical operation is done
- For each operation, a different set of control signals is needed

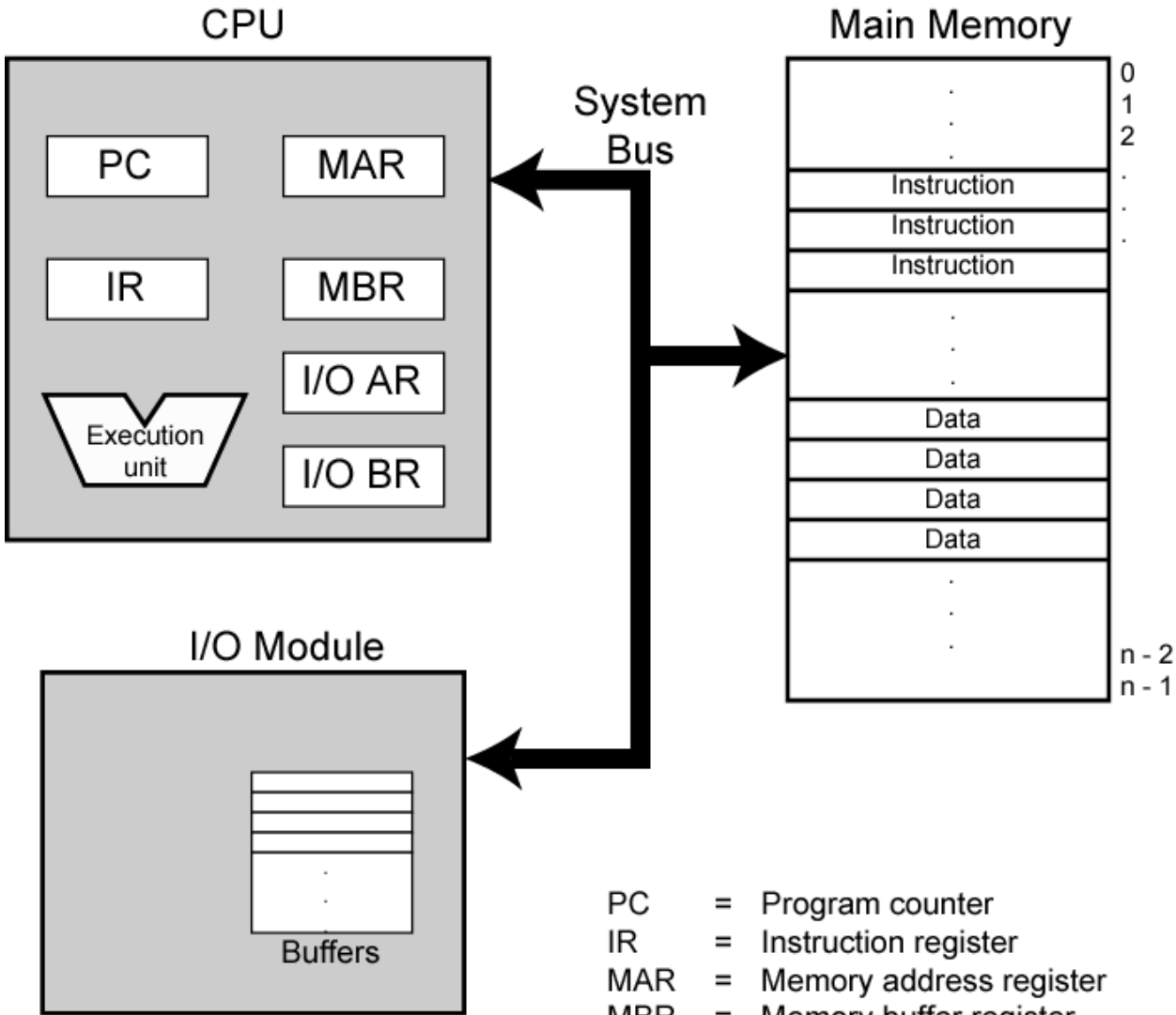
Function of Control Unit

- For each operation a unique code is provided
 - e.g. ADD, MOVE
- A hardware segment accepts the code and issues the control signals
- We have a computer!

Components

- The Control Unit and the Arithmetic and Logic Unit constitute the Central Processing Unit
- Data and instructions need to get into the system and results out
 - Input/output
- Temporary storage of code and results is needed
 - Main memory

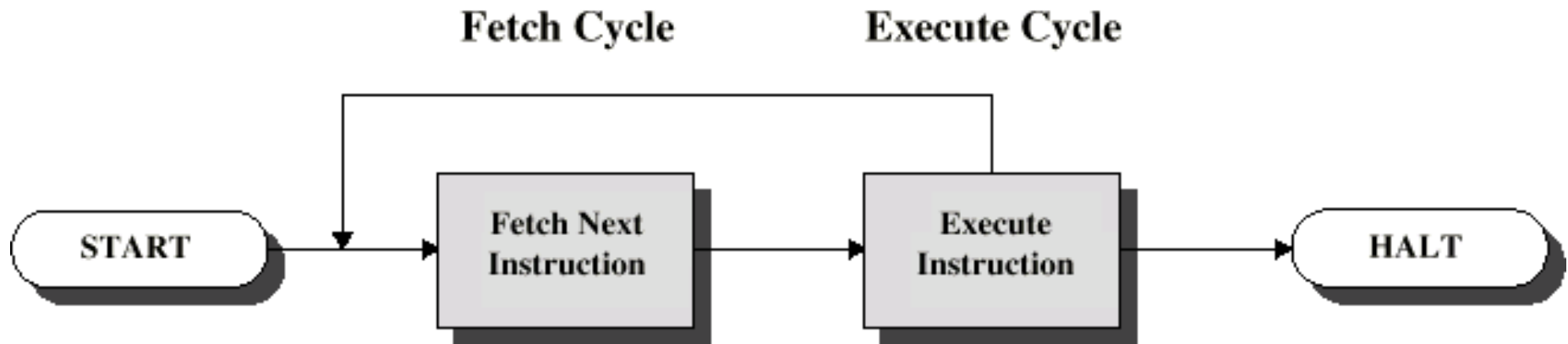
Computer Components: Top Level View



- PC = Program counter
- IR = Instruction register
- MAR = Memory address register
- MBR = Memory buffer register
- I/O AR = Input/output address register
- I/O BR = Input/output buffer register

Instruction Cycle

- Two steps:
 - Fetch
 - Execute



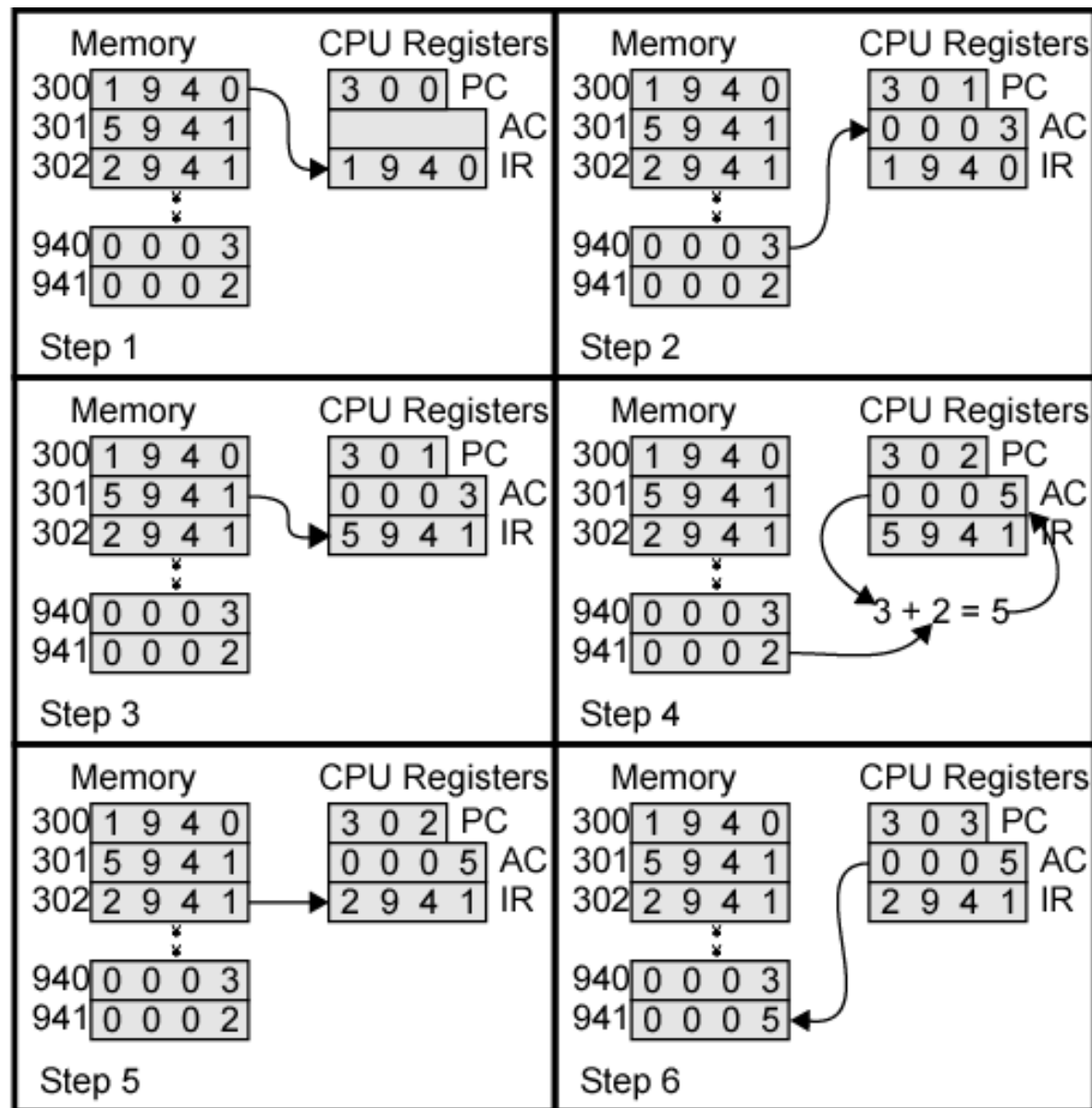
Fetch Cycle

- Program Counter (PC) holds address of next instruction to fetch
- Processor fetches instruction from memory location pointed to by PC
- Increment PC
 - Unless told otherwise
- Instruction loaded into Instruction Register (IR)
- Processor interprets instruction and performs required actions

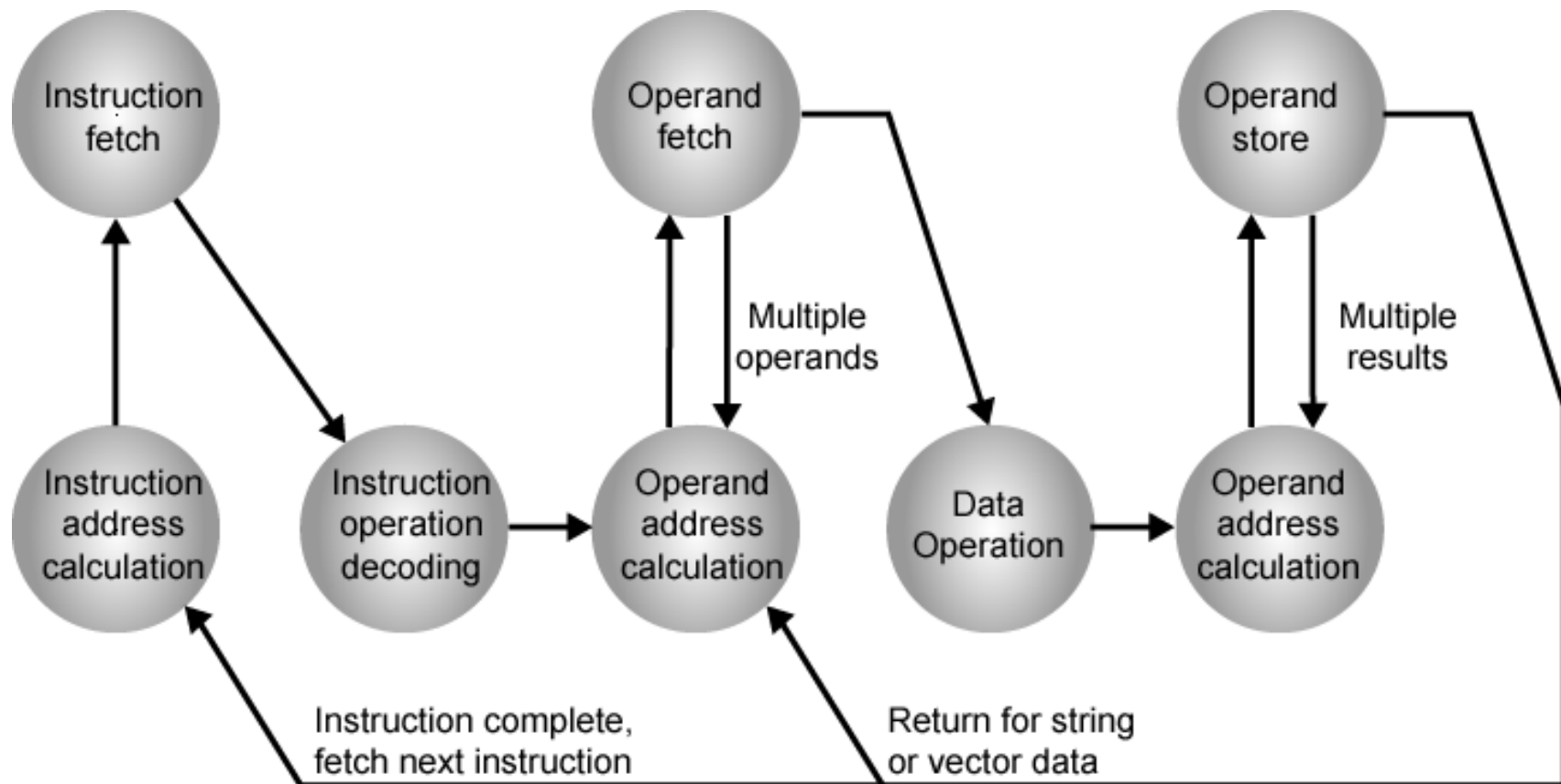
Execute Cycle

- Processor-memory
 - data transfer between CPU and main memory
- Processor I/O
 - Data transfer between CPU and I/O module
- Data processing
 - Some arithmetic or logical operation on data
- Control
 - Alteration of sequence of operations
 - e.g. jump
- Combination of above

Example of Program Execution



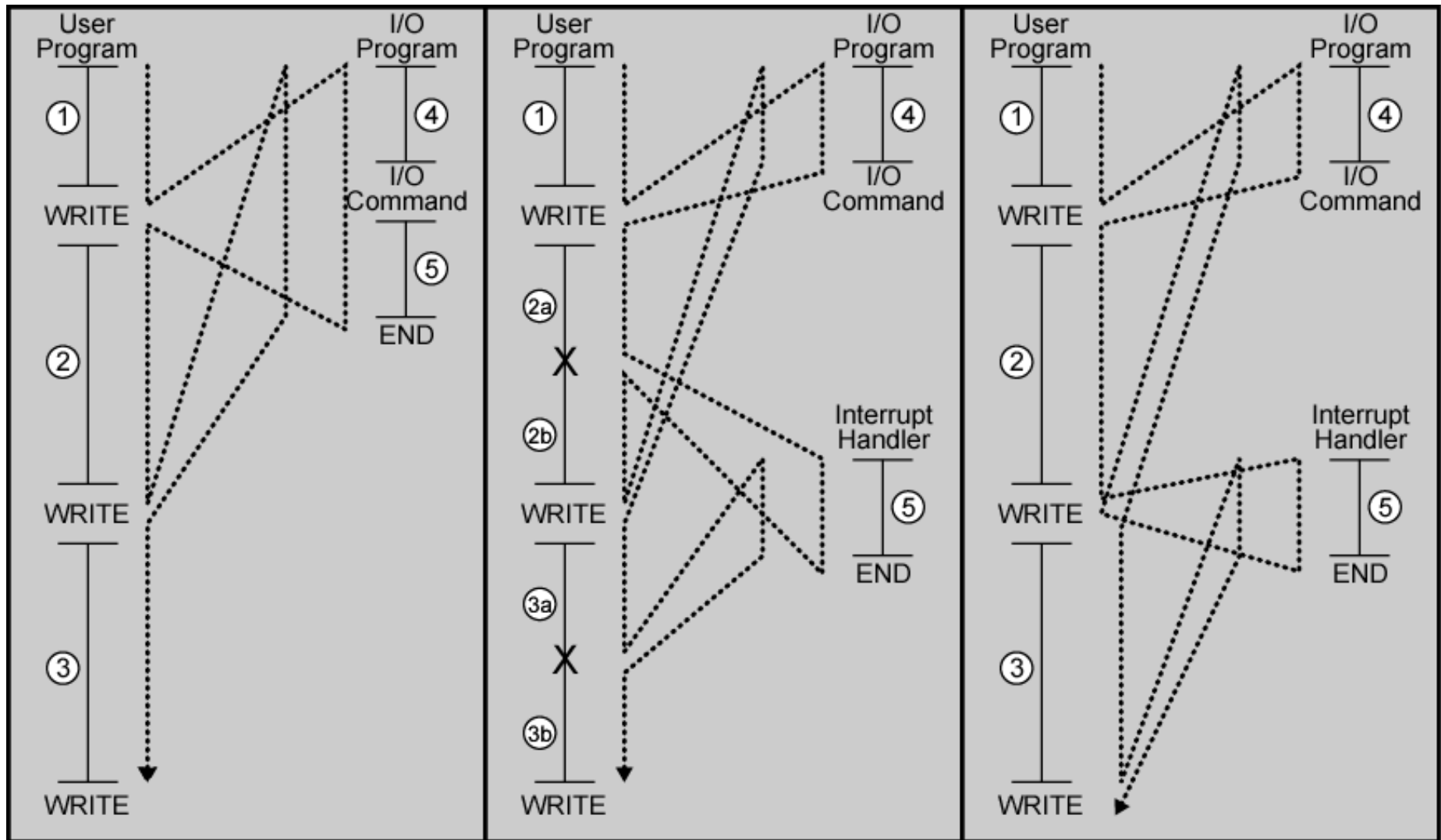
Instruction Cycle State Diagram



Interrupts

- Mechanism by which other modules (e.g. I/O) may interrupt normal sequence of processing
- Program
 - e.g. overflow, division by zero
- Timer
 - Generated by internal processor timer
 - Used in pre-emptive multi-tasking
- I/O
 - from I/O controller
- Hardware failure
 - e.g. memory parity error

Program Flow Control



(a) No interrupts

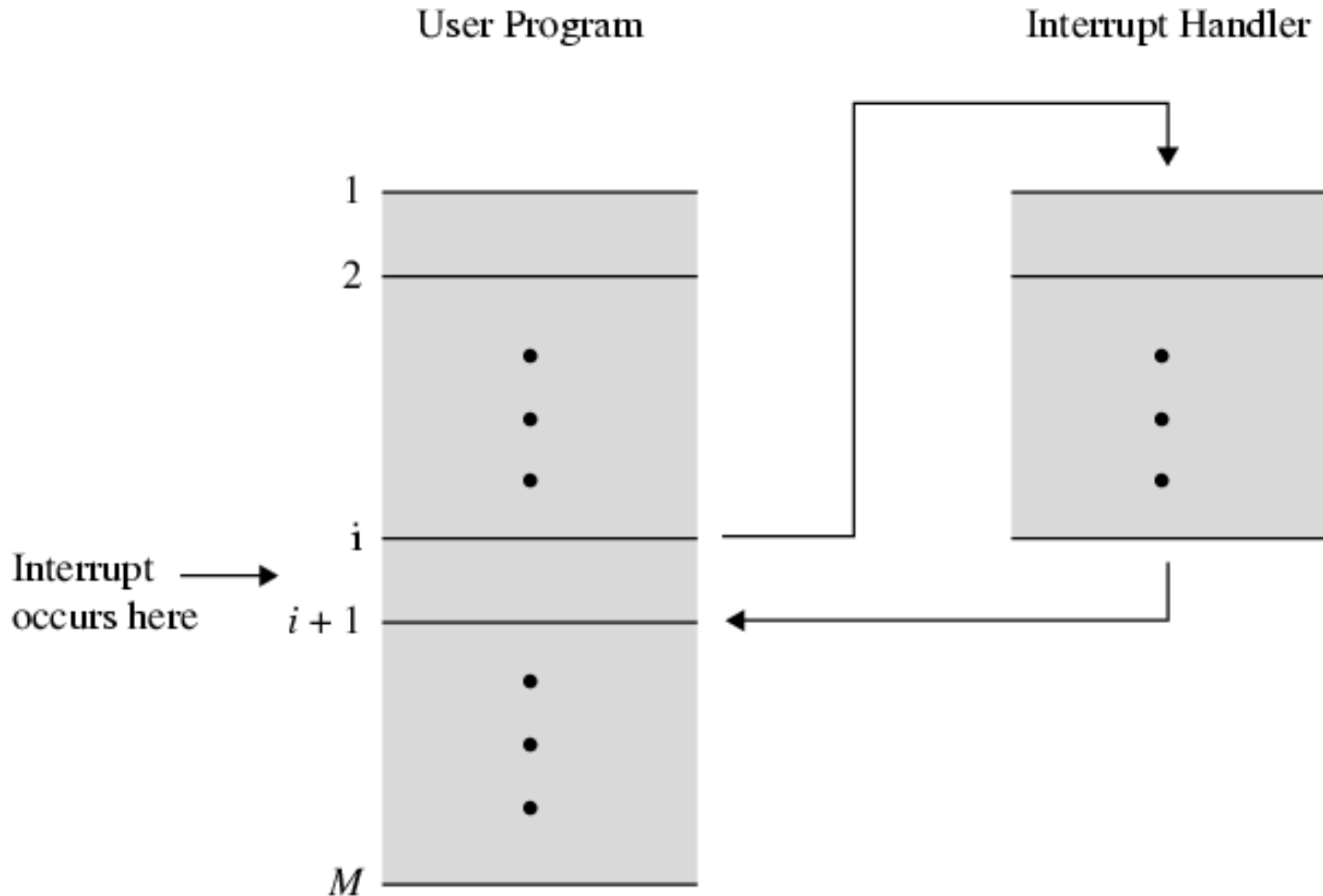
(b) Interrupts; short I/O wait

(c) Interrupts; long I/O wait

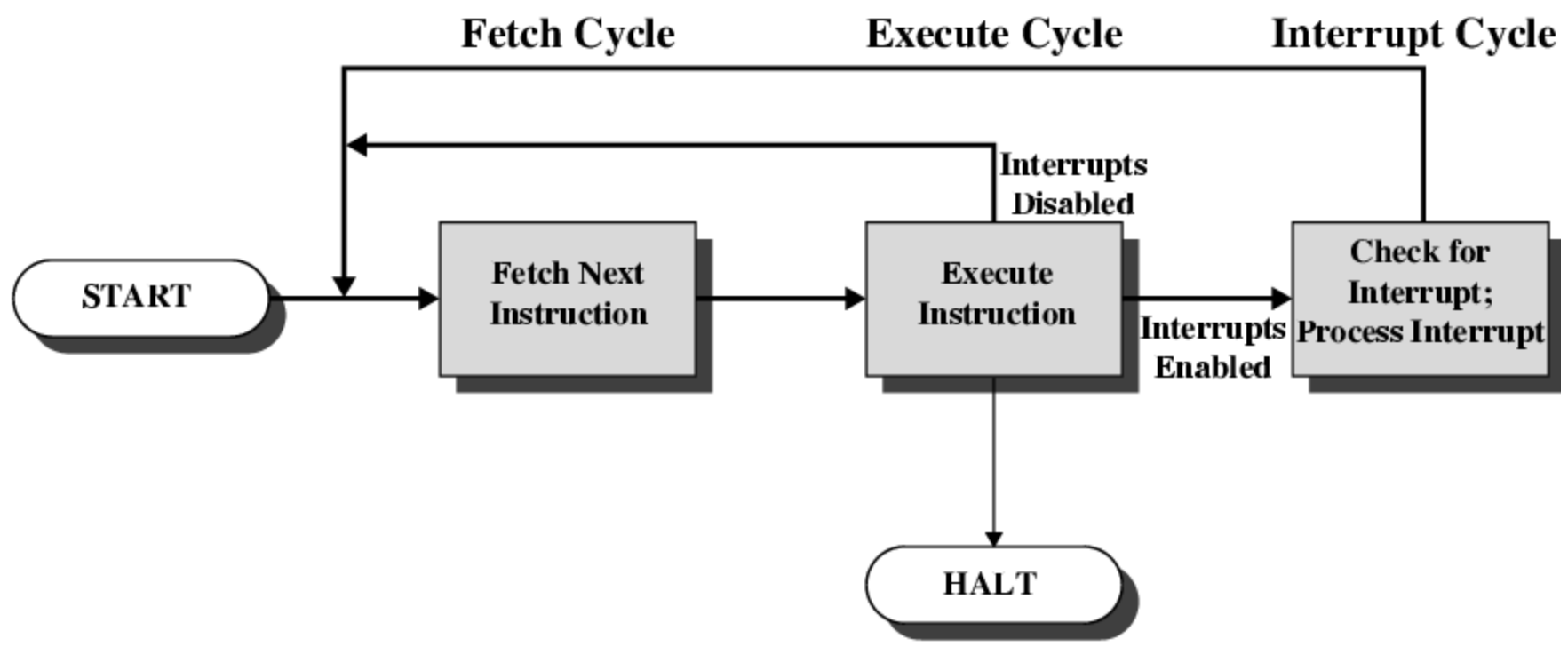
Interrupt Cycle

- Added to instruction cycle
- Processor checks for interrupt
 - Indicated by an interrupt signal
- If no interrupt, fetch next instruction
- If interrupt pending:
 - Suspend execution of current program
 - Save context
 - Set PC to start address of interrupt handler routine
 - Process interrupt
 - Restore context and continue interrupted program

Transfer of Control via Interrupts

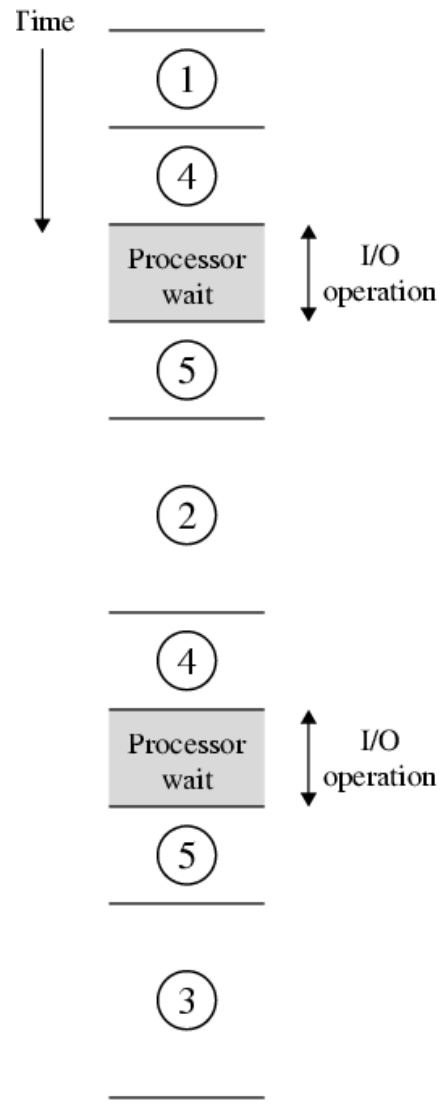


Instruction Cycle with Interrupts

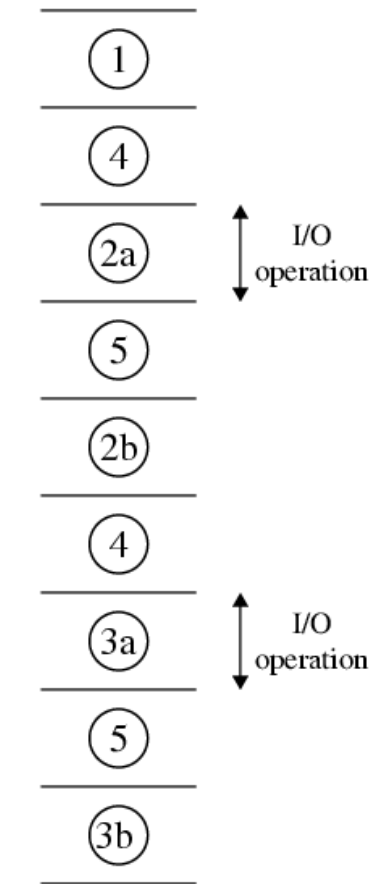


Program Timing

Short I/O Wait



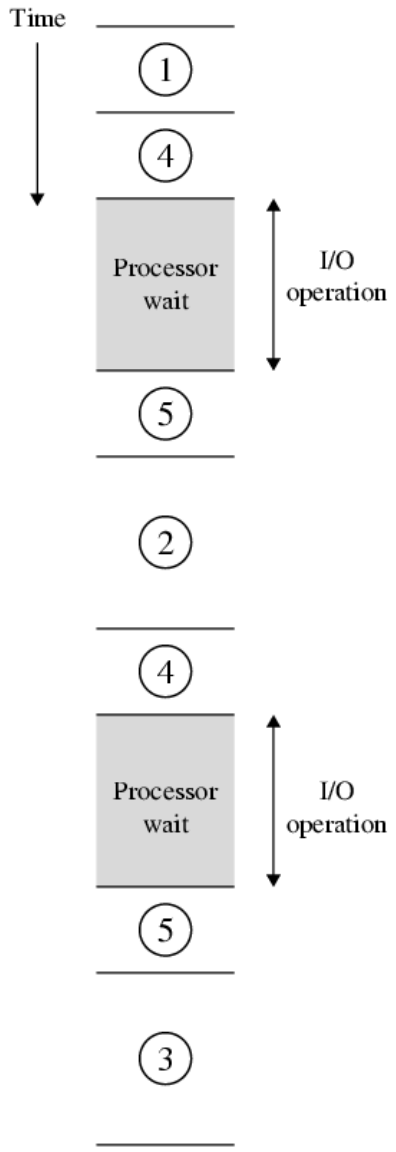
(a) Without interrupts



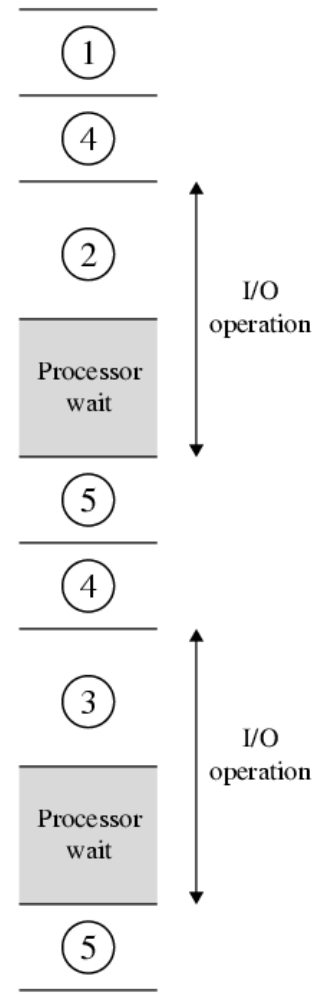
(b) With interrupts

Program Timing

Long I/O Wait

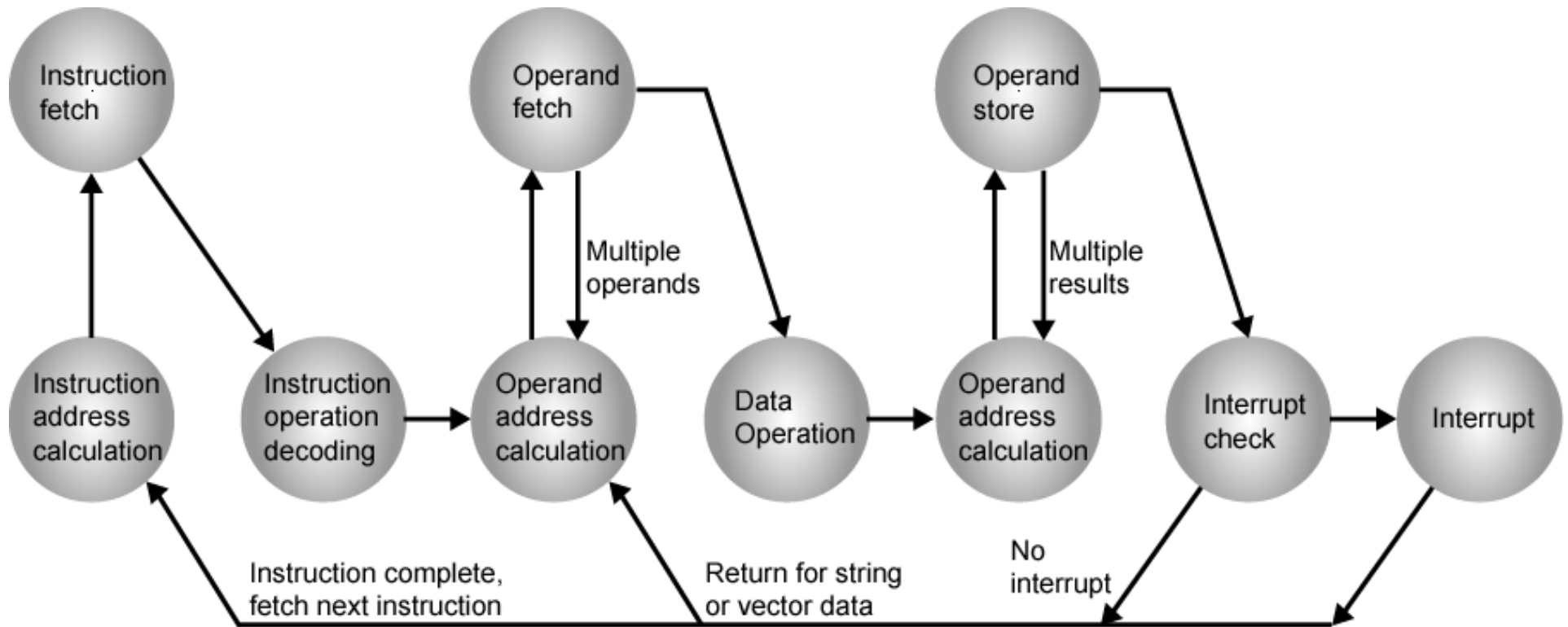


(a) Without interrupts



(b) With interrupts

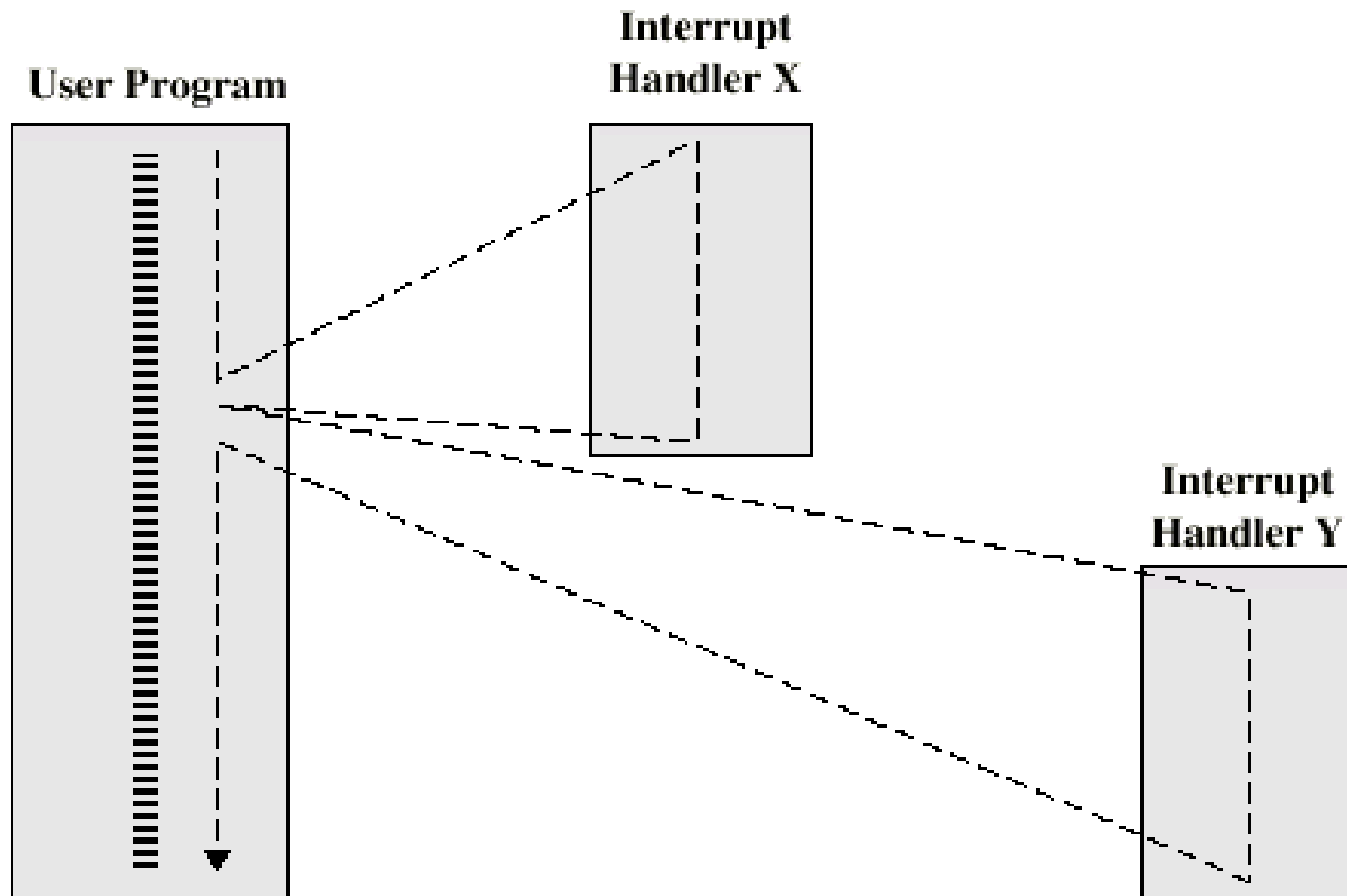
Instruction Cycle (with Interrupts) - State Diagram



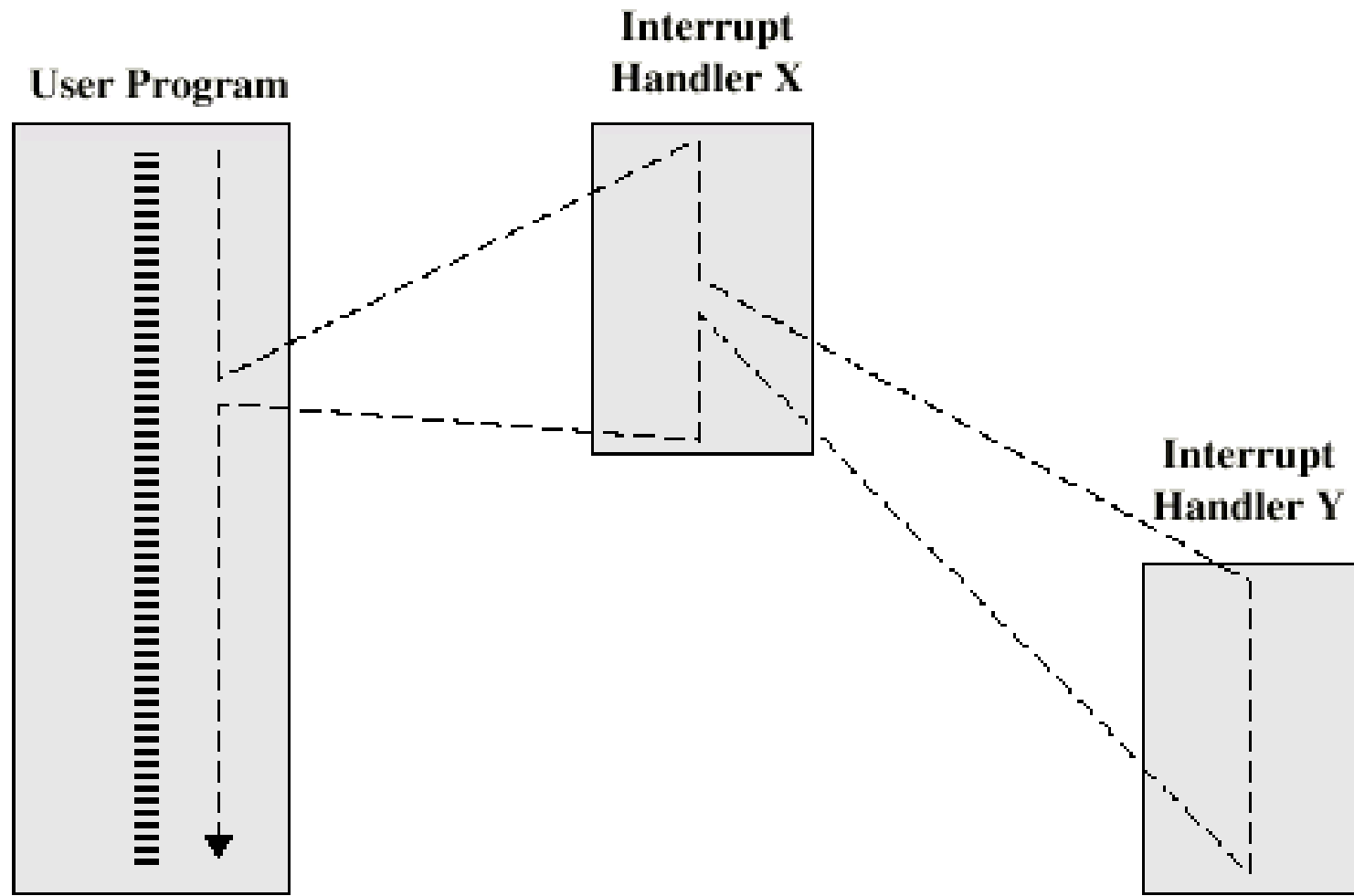
Multiple Interrupts

- **Disable interrupts**
 - Processor will ignore further interrupts whilst processing one interrupt
 - Interrupts remain pending and are checked after first interrupt has been processed
 - Interrupts handled in sequence as they occur
- **Define priorities**
 - Low priority interrupts can be interrupted by higher priority interrupts
 - When higher priority interrupt has been processed, processor returns to previous interrupt

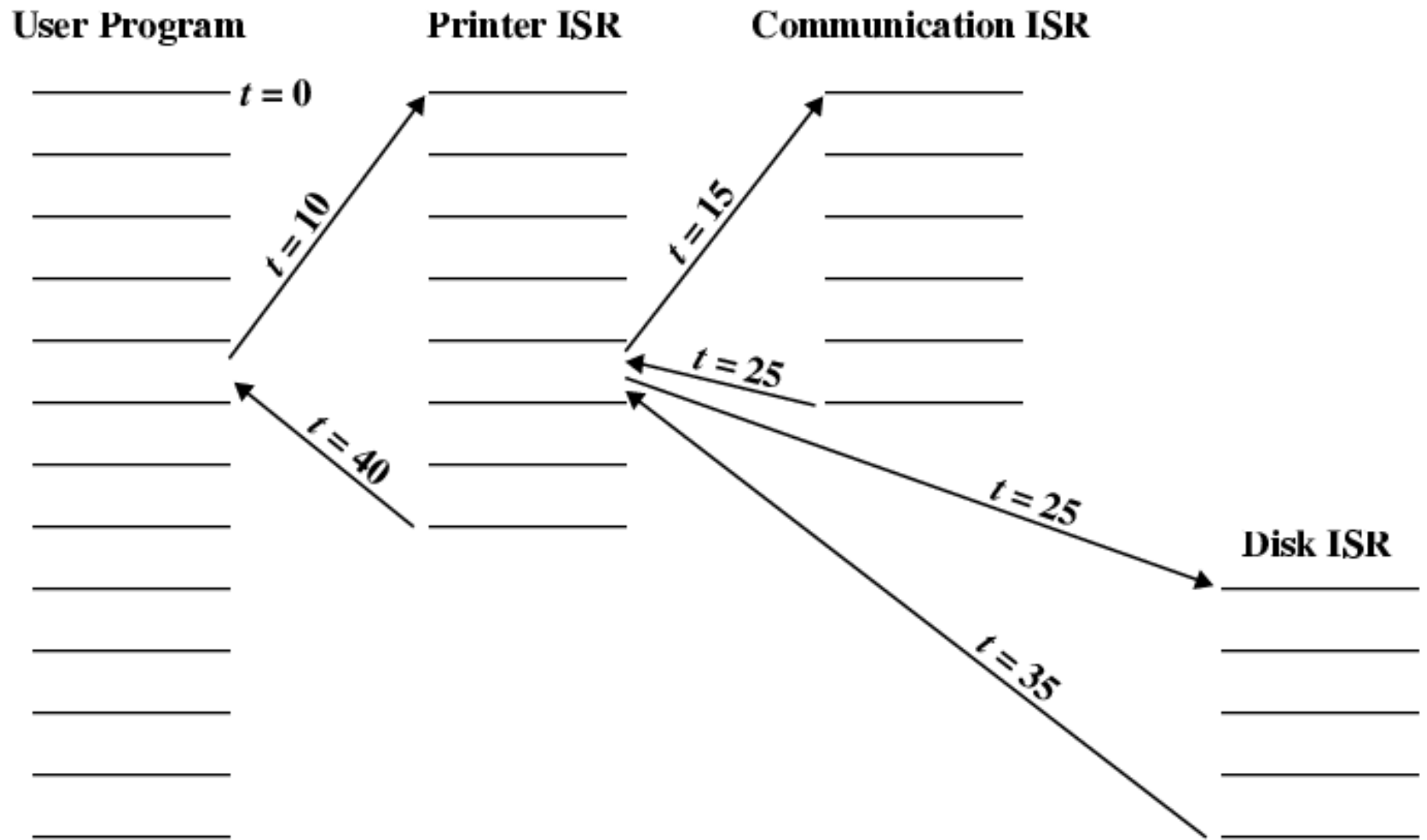
Multiple Interrupts - Sequential



Multiple Interrupts - Nested



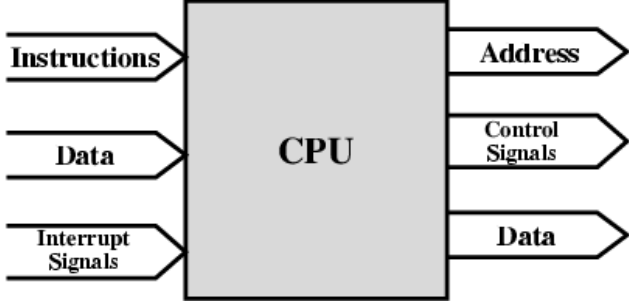
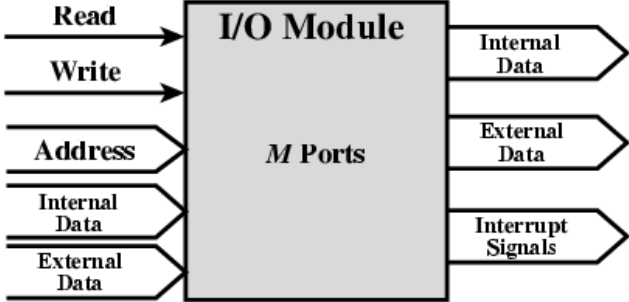
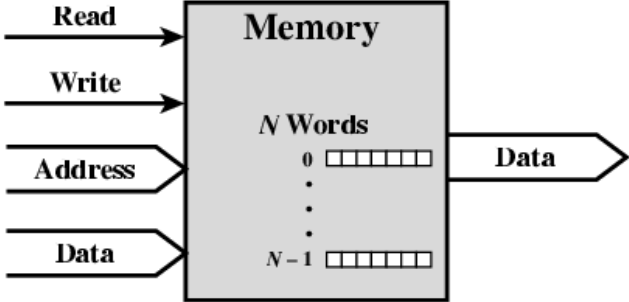
Time Sequence of Multiple Interrupts



Connecting

- All the units must be connected
- Different type of connection for different type of unit
 - Memory
 - Input/Output
 - CPU

Computer Modules



Memory Connection

- Receives and sends data
- Receives addresses (of locations)
- Receives control signals
 - Read
 - Write
 - Timing

Input/Output Connection(1)

- Similar to memory from computer's viewpoint
- Output
 - Receive data from computer
 - Send data to peripheral
- Input
 - Receive data from peripheral
 - Send data to computer

Input/Output Connection(2)

- Receive control signals from computer
- Send control signals to peripherals
 - e.g. spin disk
- Receive addresses from computer
 - e.g. port number to identify peripheral
- Send interrupt signals (control)

CPU Connection

- Reads instruction and data
- Writes out data (after processing)
- Sends control signals to other units
- Receives (& acts on) interrupts

Buses

- There are a number of possible interconnection systems
- Single and multiple BUS structures are most common
- e.g. Control/Address/Data bus (PC)
- e.g. Unibus (DEC-PDP)

What is a Bus?

- A communication pathway connecting two or more devices
- Usually broadcast
- Often grouped
 - A number of channels in one bus
 - e.g. 32 bit data bus is 32 separate single bit channels
- Power lines may not be shown

Data Bus

- Carries data
 - Remember that there is no difference between “data” and “instruction” at this level
- Width is a key determinant of performance
 - 8, 16, 32, 64 bit

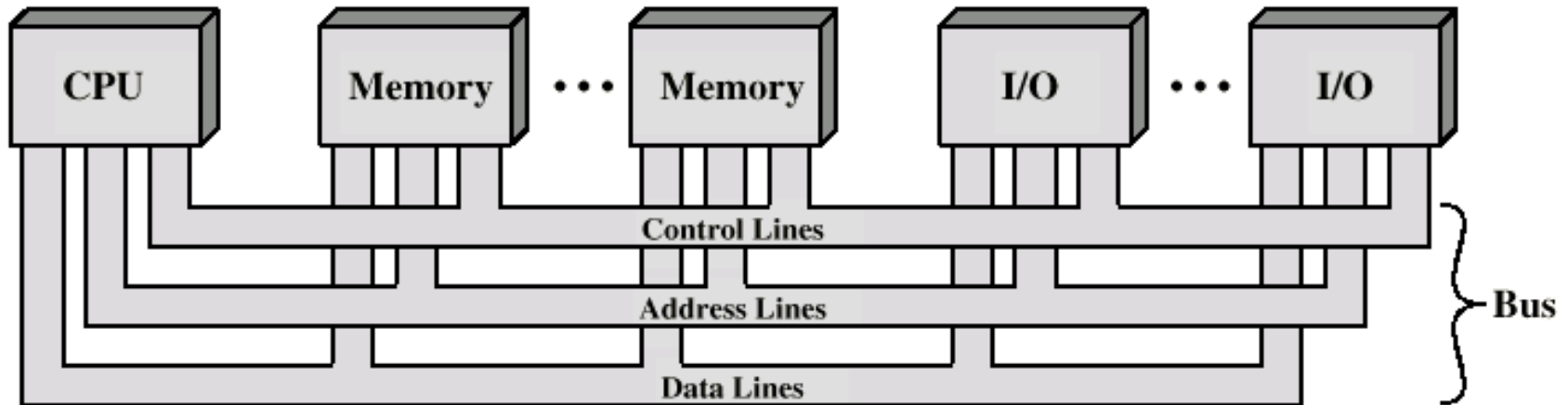
Address bus

- Identify the source or destination of data
- e.g. CPU needs to read an instruction (data) from a given location in memory
- Bus width determines maximum memory capacity of system
 - e.g. 8080 has 16 bit address bus giving 64k address space

Control Bus

- Control and timing information
 - Memory read/write signal
 - Interrupt request
 - Clock signals

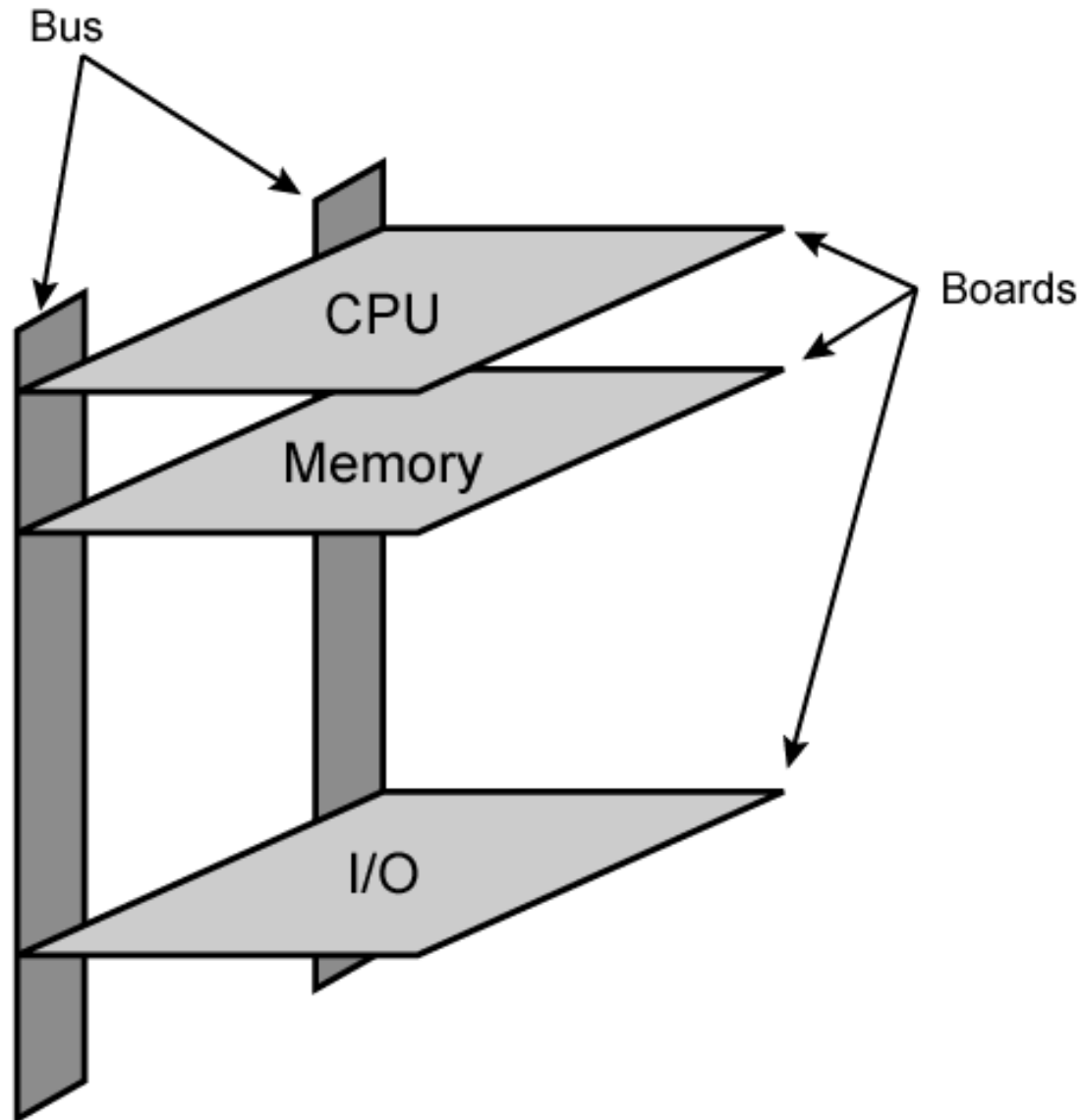
Bus Interconnection Scheme



Big and Yellow?

- What do buses look like?
 - Parallel lines on circuit boards
 - Ribbon cables
 - Strip connectors on mother boards
 - e.g. PCI
 - Sets of wires

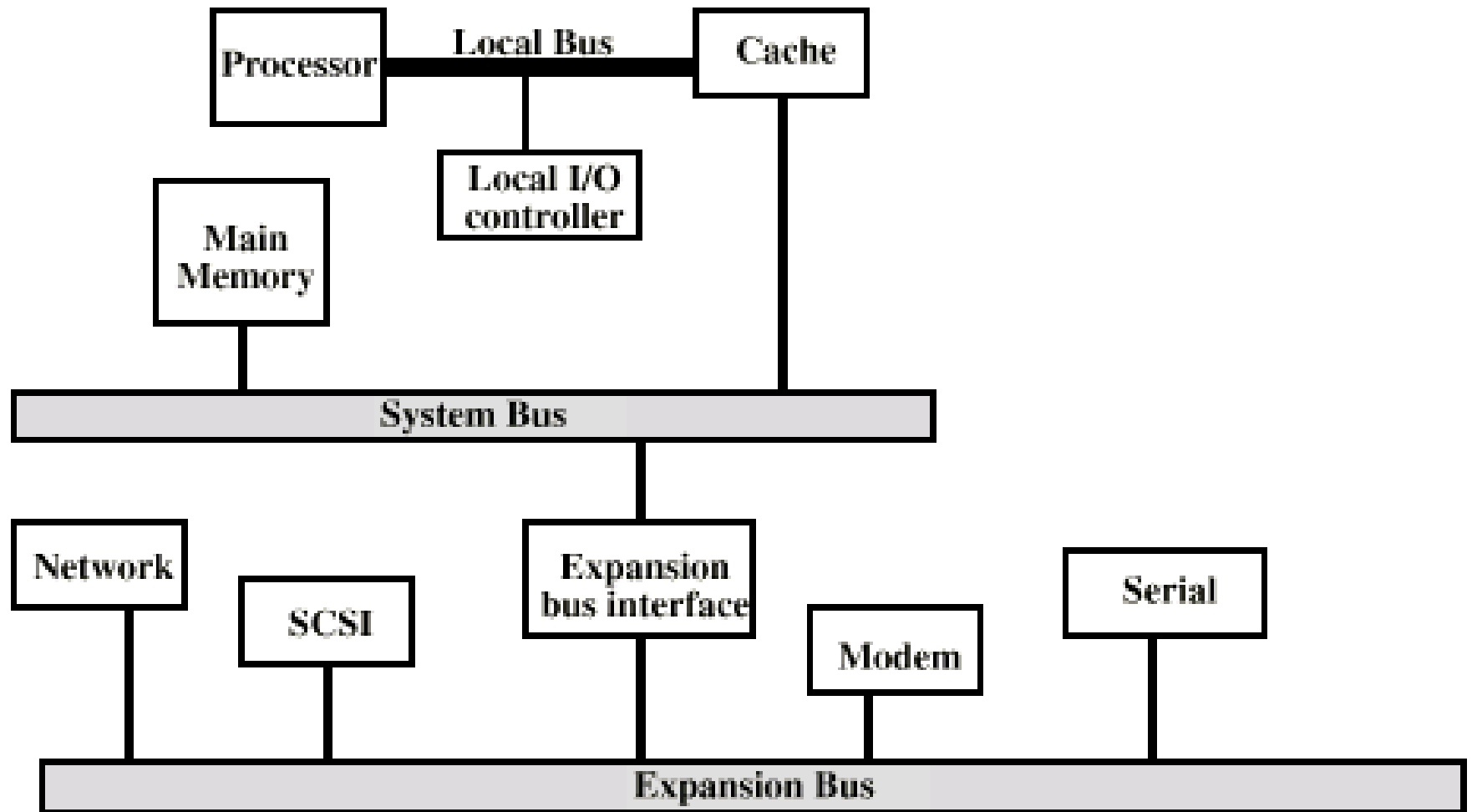
Physical Realization of Bus Architecture



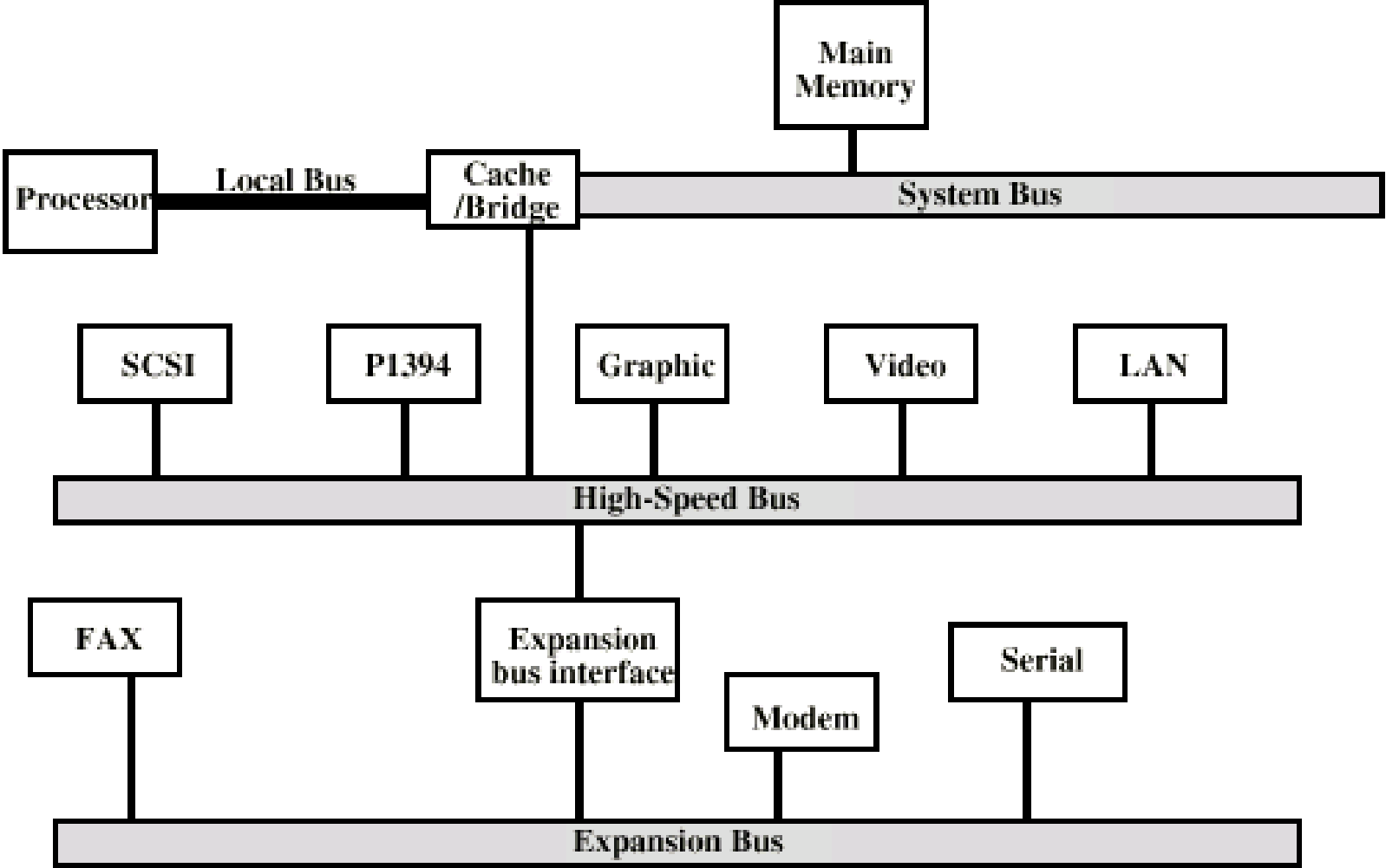
Single Bus Problems

- **Lots of devices on one bus leads to:**
 - **Propagation delays**
 - Long data paths mean that co-ordination of bus use can adversely affect performance
 - If aggregate data transfer approaches bus capacity
- **Most systems use multiple buses to overcome these problems**

Traditional (ISA) (with cache)



High Performance Bus



Bus Types

- **Dedicated**
 - Separate data & address lines
- **Multiplexed**
 - Shared lines
 - Address valid or data valid control line
 - Advantage - fewer lines
 - Disadvantages
 - More complex control
 - Ultimate performance

Bus Arbitration

- More than one module controlling the bus
- e.g. CPU and DMA controller
- Only one module may control bus at one time
- Arbitration may be centralised or distributed

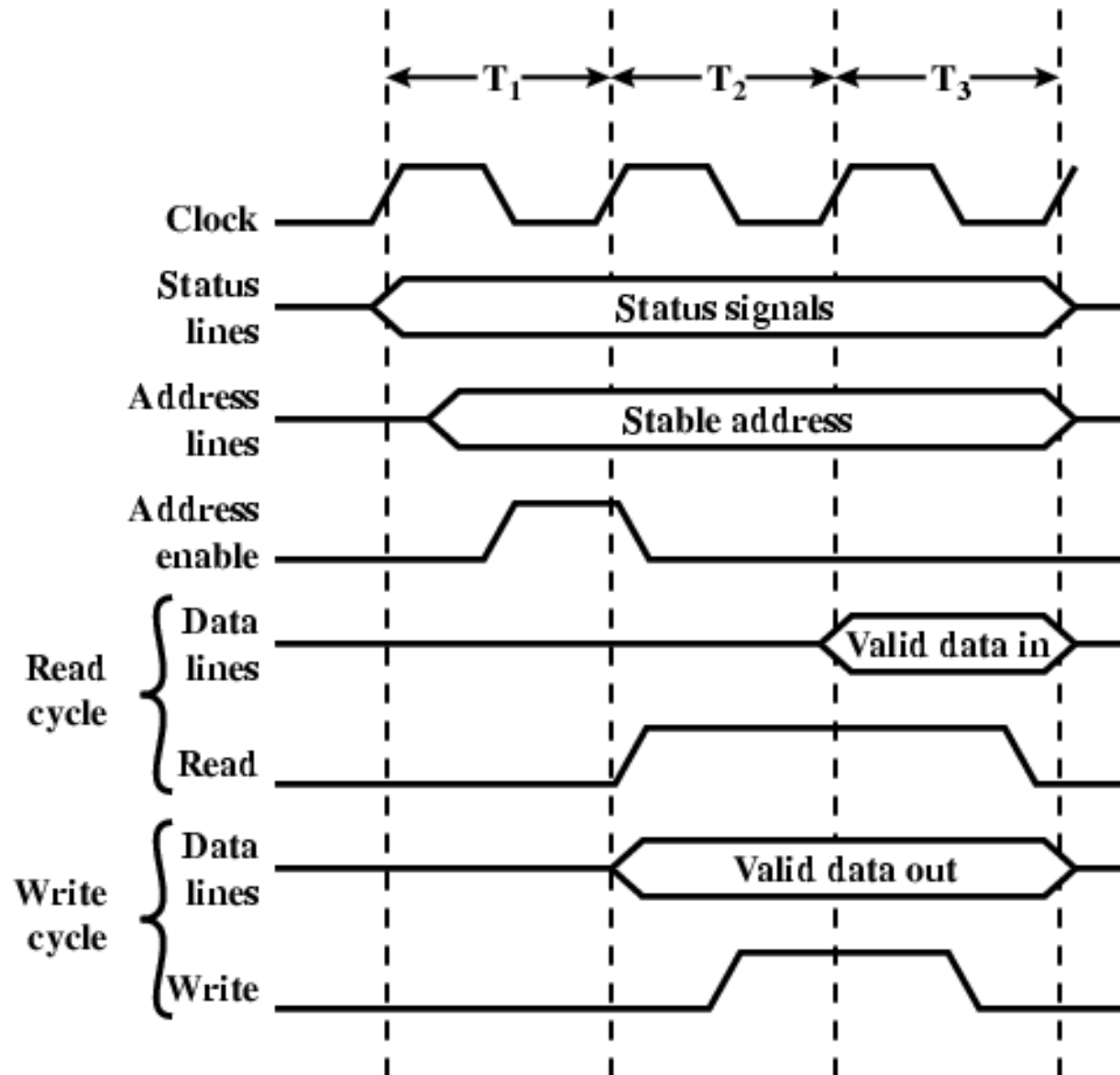
Centralised or Distributed Arbitration

- **Centralised**
 - Single hardware device controlling bus access
 - Bus Controller
 - Arbiter
 - May be part of CPU or separate
- **Distributed**
 - Each module may claim the bus
 - Control logic on all modules

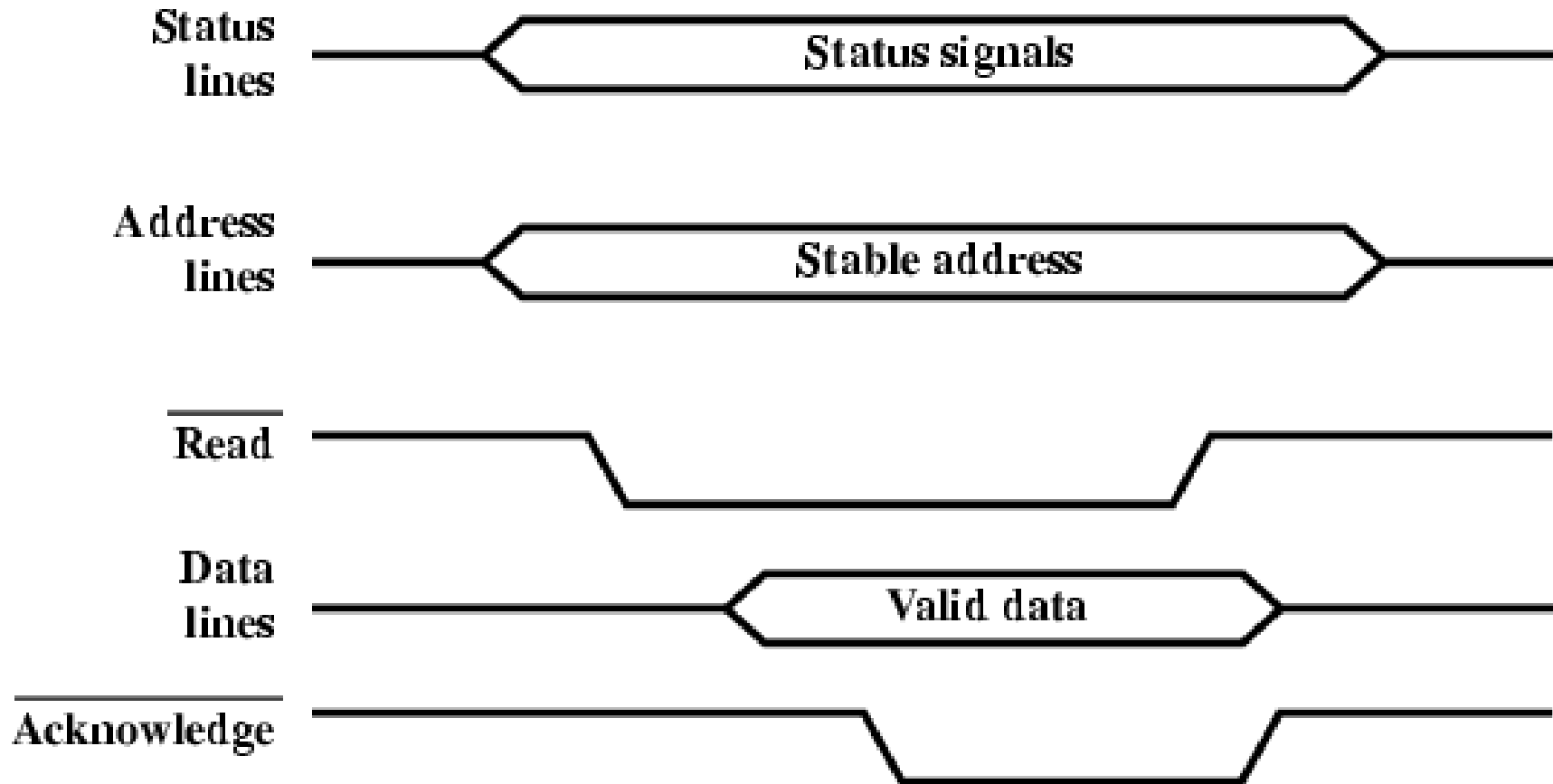
Timing

- Co-ordination of events on bus
- Synchronous
 - Events determined by clock signals
 - Control Bus includes clock line
 - A single 1-0 is a bus cycle
 - All devices can read clock line
 - Usually sync on leading edge
 - Usually a single cycle for an event

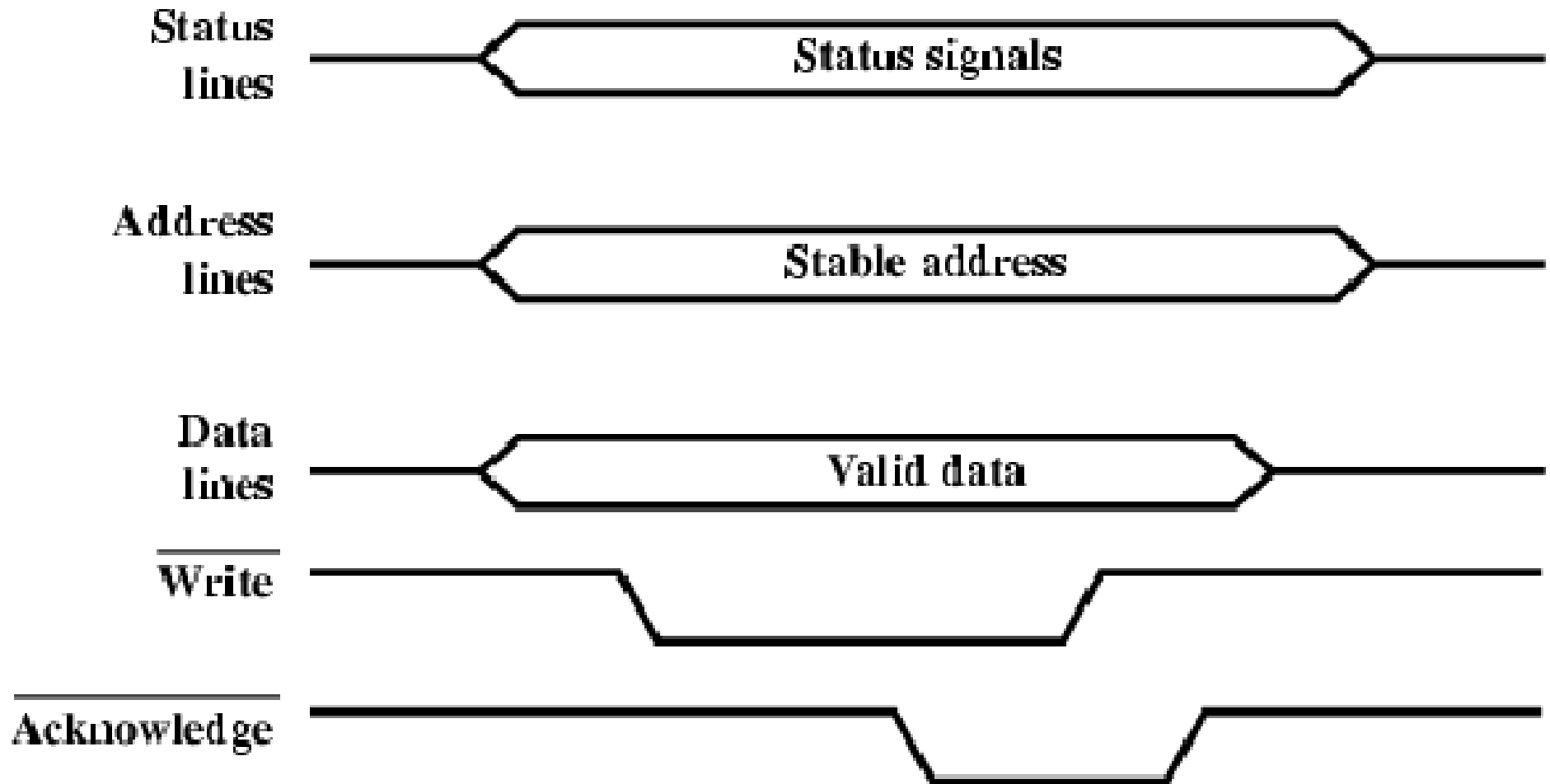
Synchronous Timing Diagram



Asynchronous Timing - Read Diagram



Asynchronous Timing - Write Diagram



PCI Bus

- Peripheral Component Interconnection
- Intel released to public domain
- 32 or 64 bit
- 50 lines

PCI Bus Lines (required)

- **Systems lines**
 - Including clock and reset
- **Address & Data**
 - 32 time mux lines for address/data
 - Interrupt & validate lines
- **Interface Control**
- **Arbitration**
 - Not shared
 - Direct connection to PCI bus arbiter
- **Error lines**

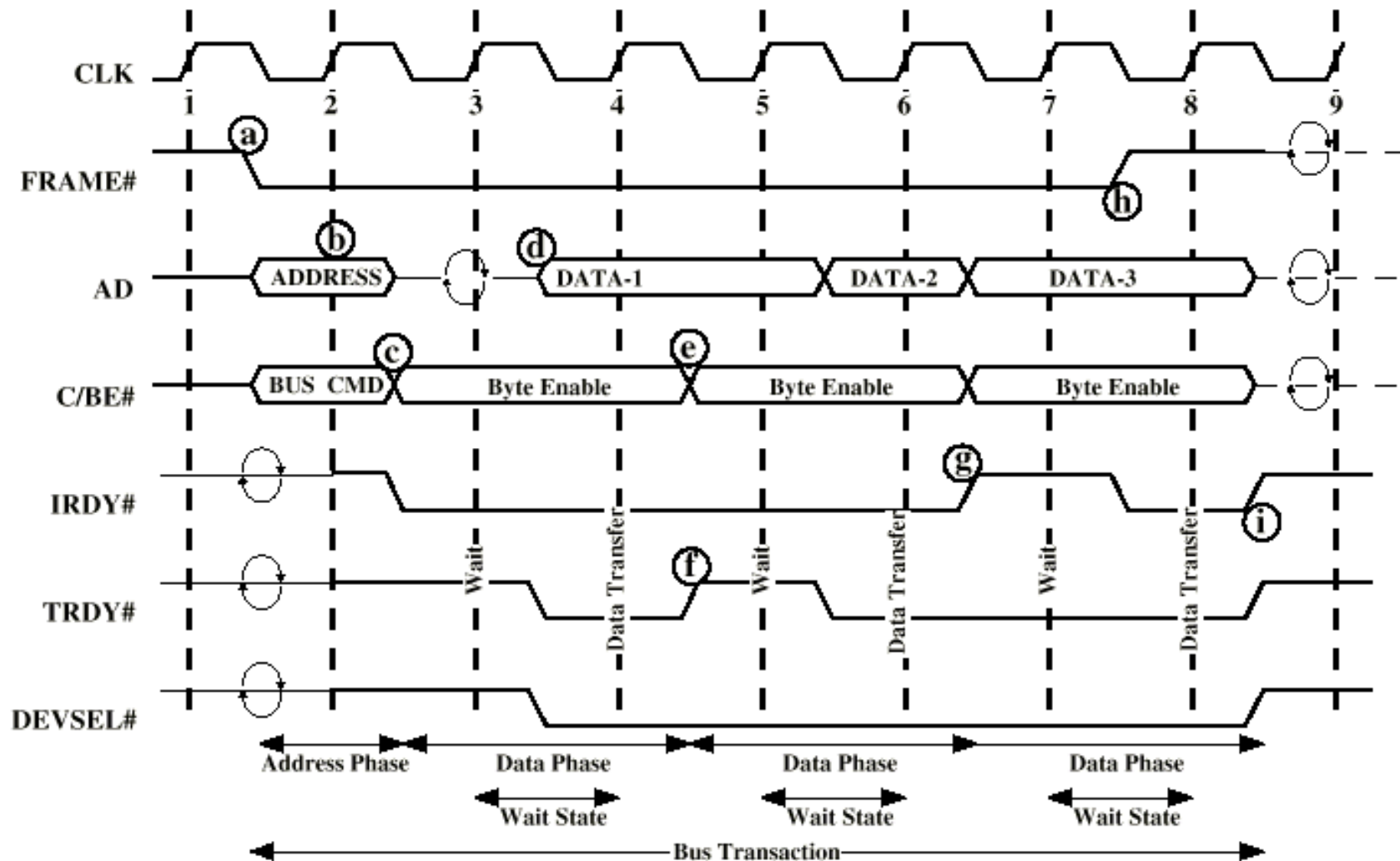
PCI Bus Lines (Optional)

- **Interrupt lines**
 - Not shared
- **Cache support**
- **64-bit Bus Extension**
 - Additional 32 lines
 - Time multiplexed
 - 2 lines to enable devices to agree to use 64-bit transfer
- **JTAG/Boundary Scan**
 - For testing procedures

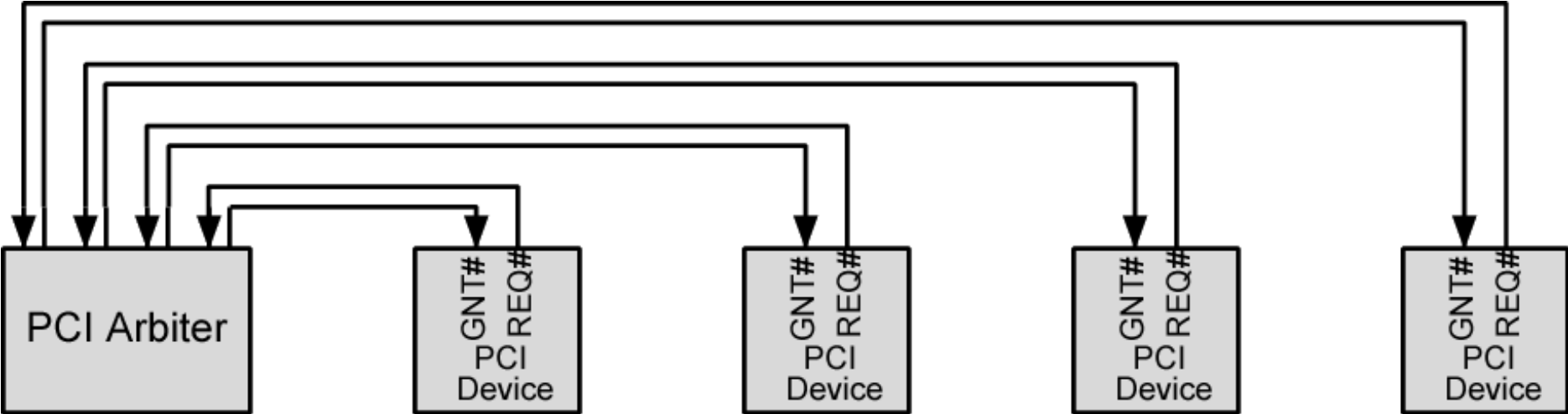
PCI Commands

- Transaction between initiator (master) and target
- Master claims bus
- Determine type of transaction
 - e.g. I/O read/write
- Address phase
- One or more data phases

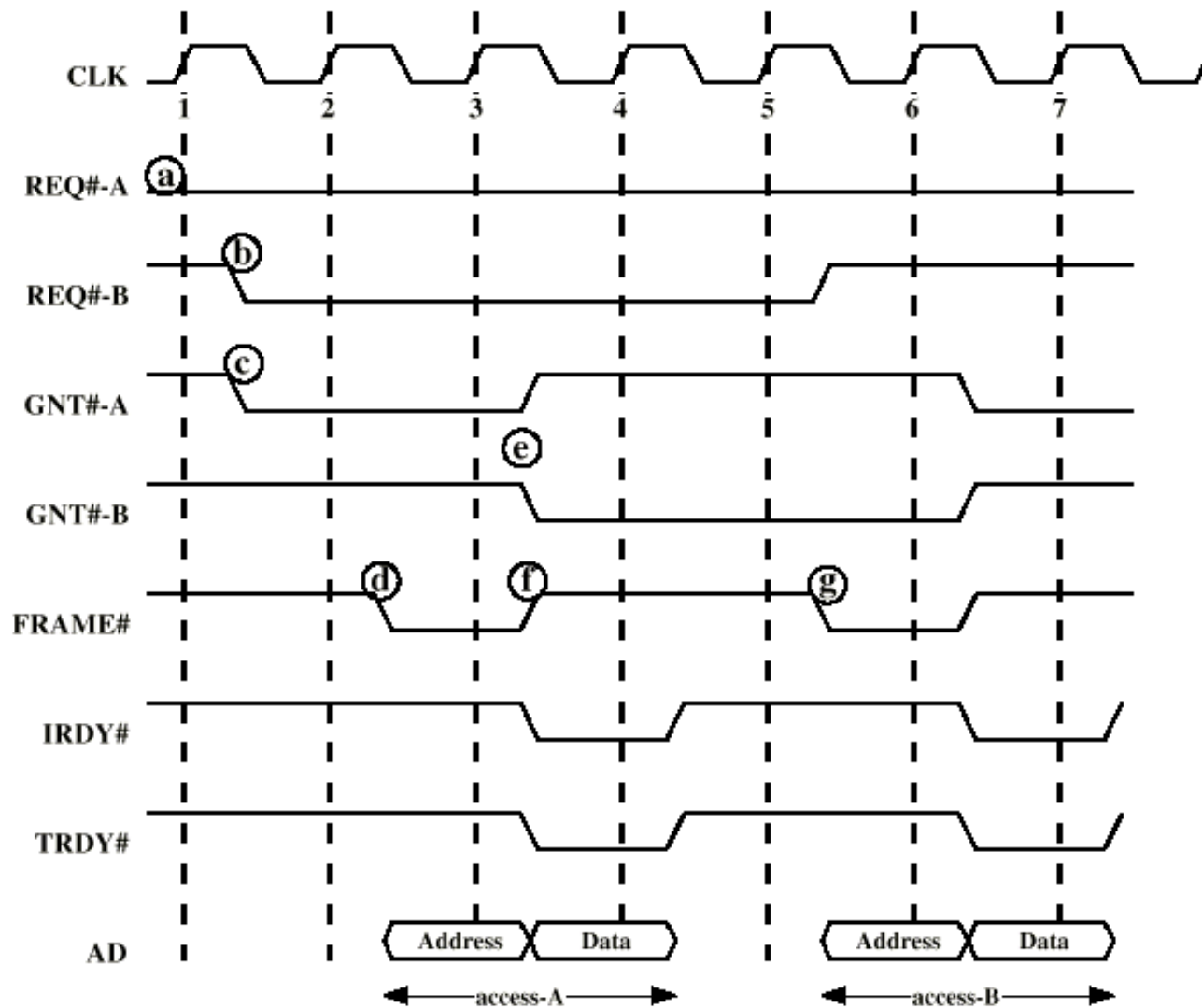
PCI Read Timing Diagram



PCI Bus Arbiter



PCI Bus Arbitration



Foreground Reading

- Stallings, chapter 3 (all of it)
- www.pcguide.com/ref/mbsys/buses/

- In fact, read the whole site!
- www.pcguide.com/