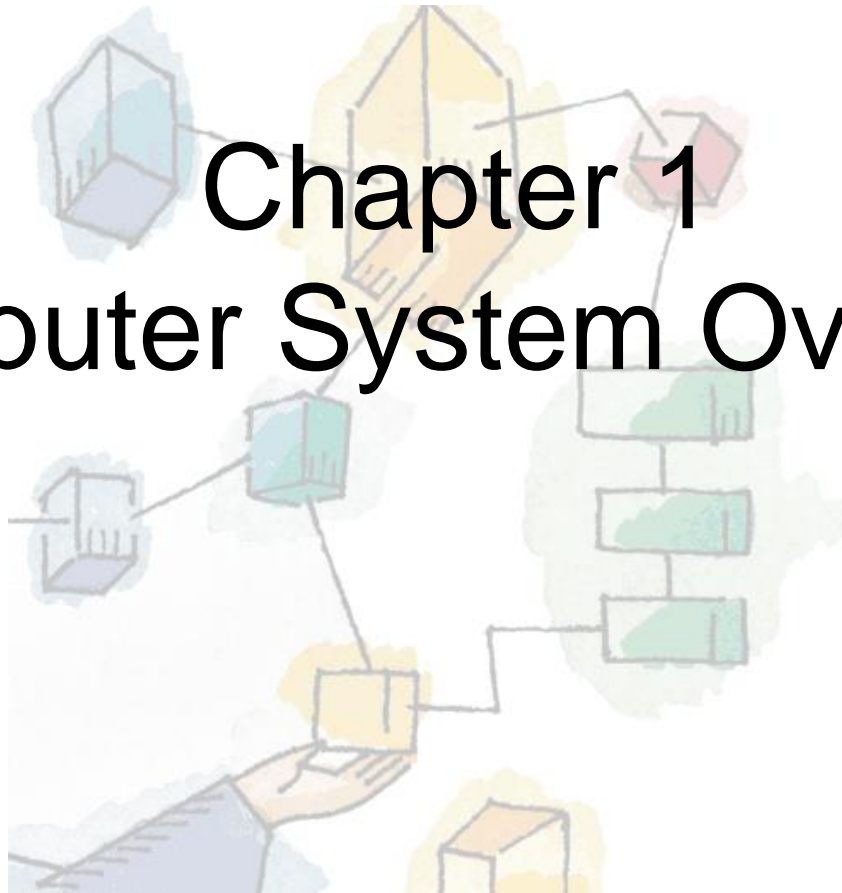


*Operating Systems:
Internals and Design Principles, 6/E*
William Stallings

Chapter 1

Computer System Overview





Roadmap



Basic Elements

- Processor Registers
- Instruction Execution
- Interrupts
- The Memory Hierarchy?
- Cache Memory
- I/O Communication Techniques





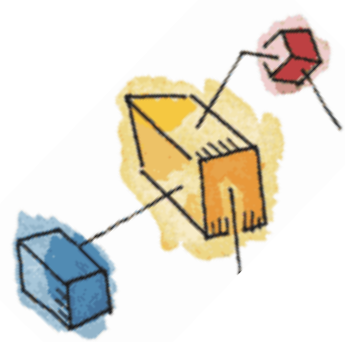
Operating System

- Exploits the hardware resources of one or more processors
- Provides a set of services to system users
- Manages secondary memory and I/O devices



A Computer's Basic Elements

- Processor CPU
- Main Memory RAM
- I/O Modules
- System Bus CB/AB/DB





①

Processor

- Controls operation, performs data processing
- Two internal registers
 - Memory address register (MAR)
 - Memory buffer register (MBR)
- I/O address register
- I/O buffer register





②

Main Memory

- **Volatile** tempo
 - Data is typically lost when power is removed
- Referred to as **real memory** or **primary memory** RAM
- **Consists of a set of locations** defined by sequentially numbers **addresses**
 - Containing **either data or instructions**



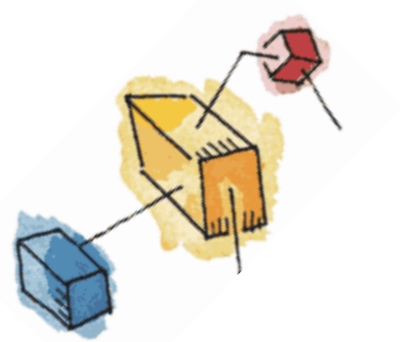


③

I/O Modules

- Moves data between the computer and the external environment such as:
 - Storage (e.g. hard drive)
 - Communications equipment
 - Terminals
- Specified by an I/O Address Register
 - (I/OAR)





④

System Bus

- Communication among processors, main memory, and I/O modules



Top-Level View

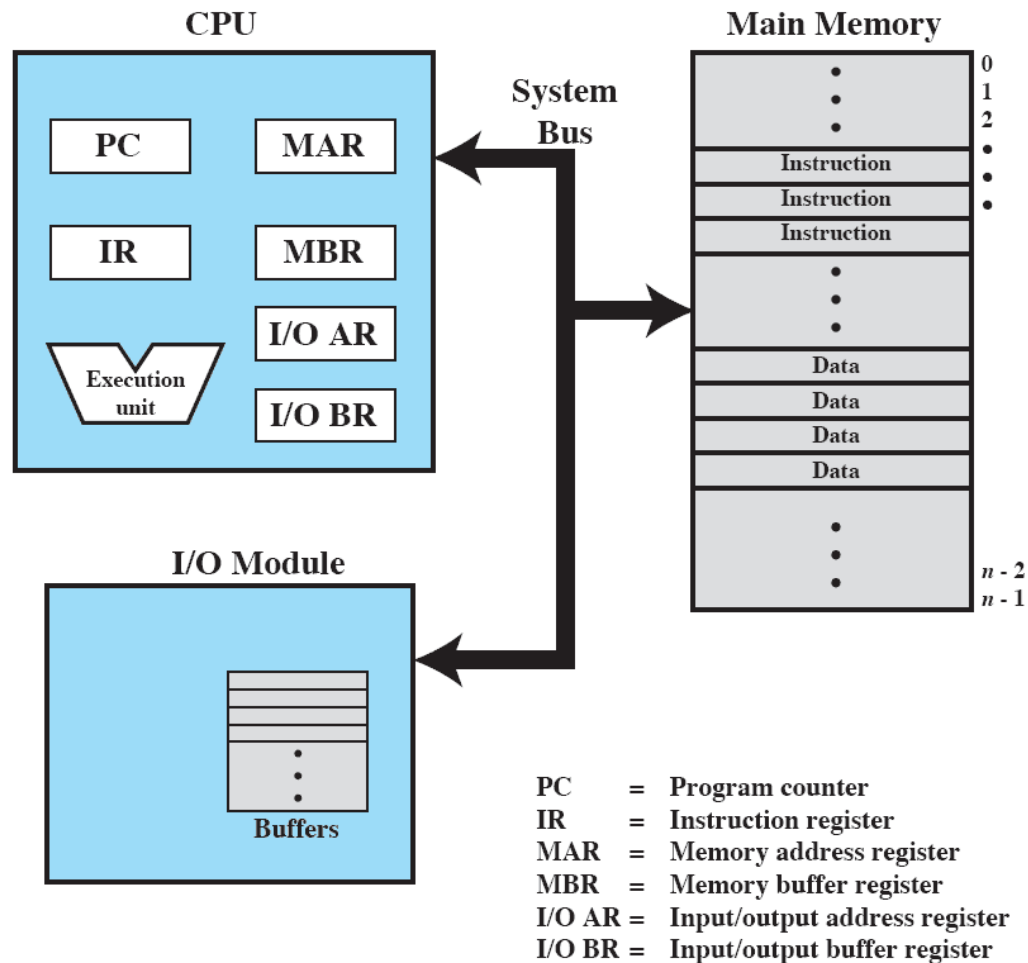


Figure 1.1 Computer Components: Top-Level View



Roadmap

- Basic Elements

→ **Processor Registers**

- Instruction Execution

- Interrupts

- The Memory Hierarchy

- Cache Memory

- I/O Communication Techniques





Processor Registers

- Faster and smaller than main memory



User-visible registers

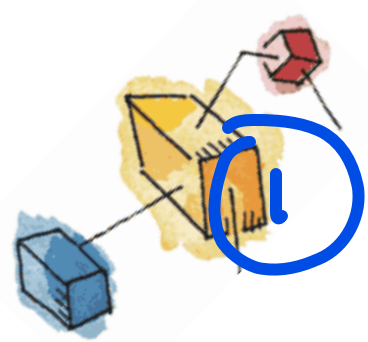
- Enable programmer to minimize main memory references by optimizing register use



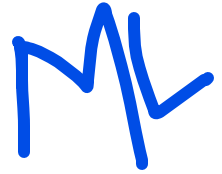
Control and status registers

- Used by processor to control operating of the processor
- Used by privileged OS routines to control the execution of programs





User-Visible Registers



- May be referenced by machine language
 - Available to all programs – application programs and system programs
- Types of registers typically available are:
 - data,
 - address,
 - condition code registers.





Data and Address Registers

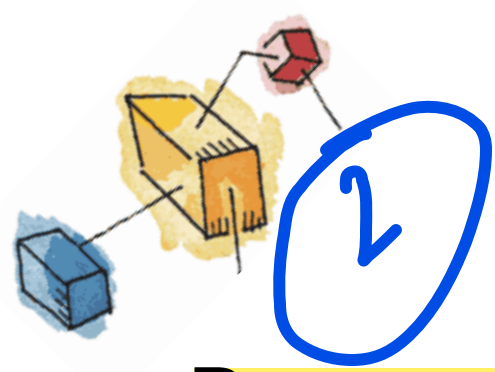
✓• Data

- Often general purpose
- But some restrictions may apply

✓✓ Address

- Index Register
- Segment pointer
- Stack pointer





Control and Status Registers

- Program counter (PC)
 - Contains the address of an instruction to be fetched
- Instruction register (IR)
 - Contains the instruction most recently fetched
- ✓ • Program status word (PSW)
 - Contains status information





Condition codes *flags*

- Usually part of the control register
 - Also called flags
- Bits set by processor hardware as a result of operations
 - Read only, intended for feedback regarding the results of instruction execution.





Roadmap

- Basic Elements
- Processor Registers
- **Instruction Execution**
- Interrupts
- The Memory Hierarchy
- Cache Memory
- I/O Communication Techniques





Instruction Execution

- A program consists of a set of instructions stored in memory
- Two steps
 - Processor reads (fetches) instructions from memory
 - Processor executes each instruction

leta hai → execute





Basic Instruction Cycle

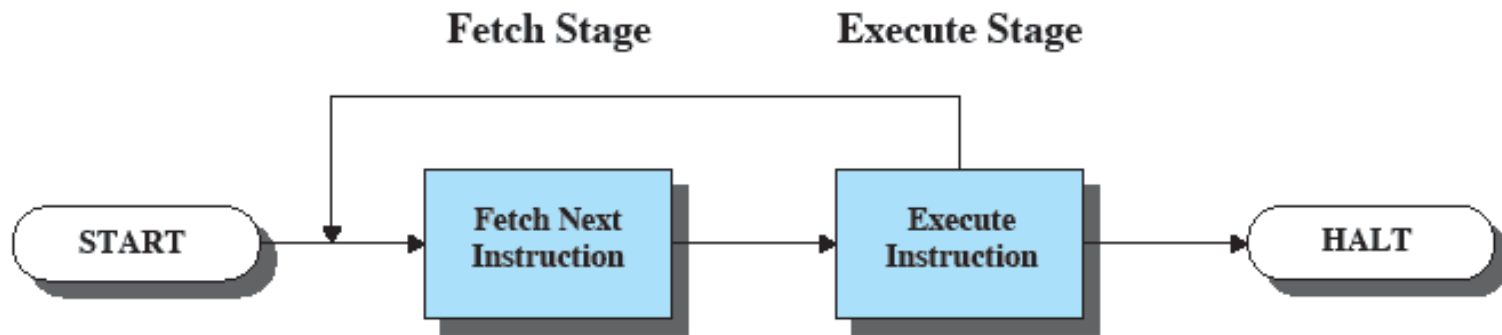
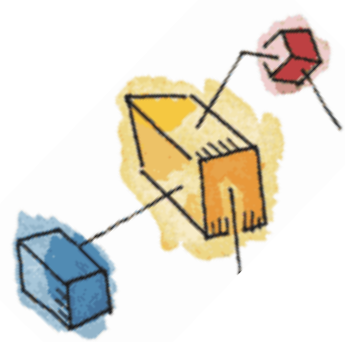


Figure 1.2 Basic Instruction Cycle



Instruction Fetch and Execute

- The processor fetches the instruction from memory
- Program counter (PC) holds address of the instruction to be fetched next
 - PC is incremented after each fetch

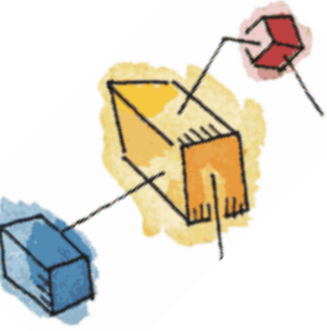




Instruction Register IR

- Fetched instruction loaded into instruction register
- Categories
 - Processor-memory,
 - processor-I/O,
 - Data processing,
 - Control

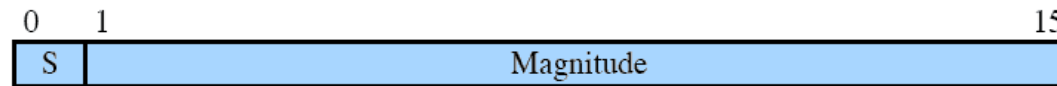




Characteristics of a Hypothetical Machine



(a) Instruction format



(b) Integer format

✓ Program counter (PC) = Address of instruction
Instruction register (IR) = Instruction being executed
Accumulator (AC) = Temporary storage

(c) Internal CPU registers

✓ 0001 = Load AC from memory
0010 = Store AC to memory
0101 = Add to AC from memory

(d) Partial list of opcodes





Figure 1.3 Characteristics of a Hypothetical Machine



Example of Program Execution

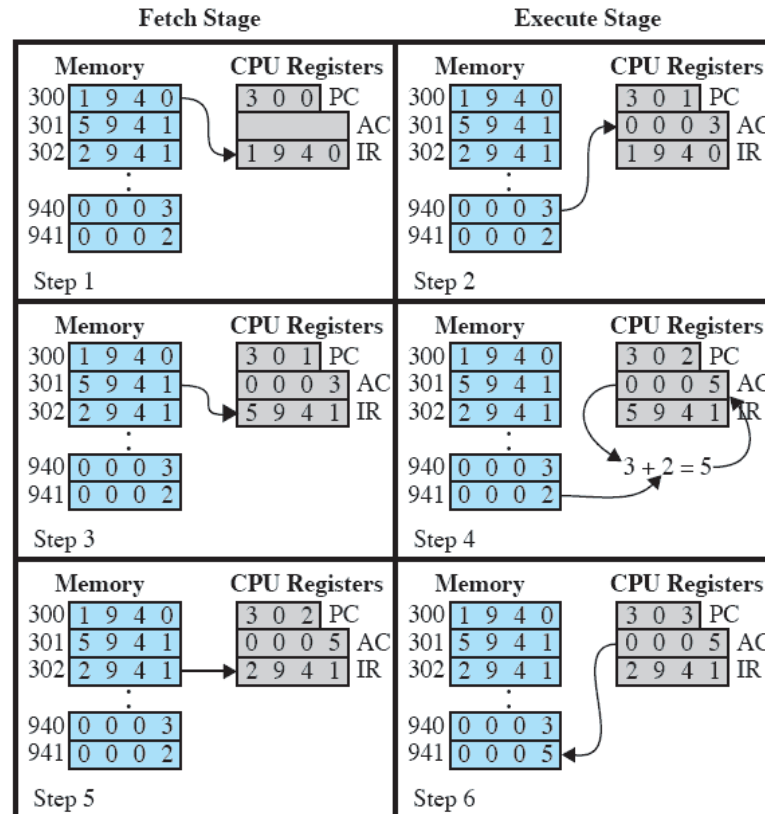


Figure 1.4 Example of Program Execution
(contents of memory and registers in hexadecimal)



Roadmap

- Basic Elements
- Processor Registers
- Instruction Execution



Interrupts

- The Memory Hierarchy
- Cache Memory
- I/O Communication Techniques





Interrupts

- Interrupt the normal sequencing of the processor
- Provided to improve processor utilization
 - Most I/O devices are slower than the processor
 - Processor must pause to wait for device





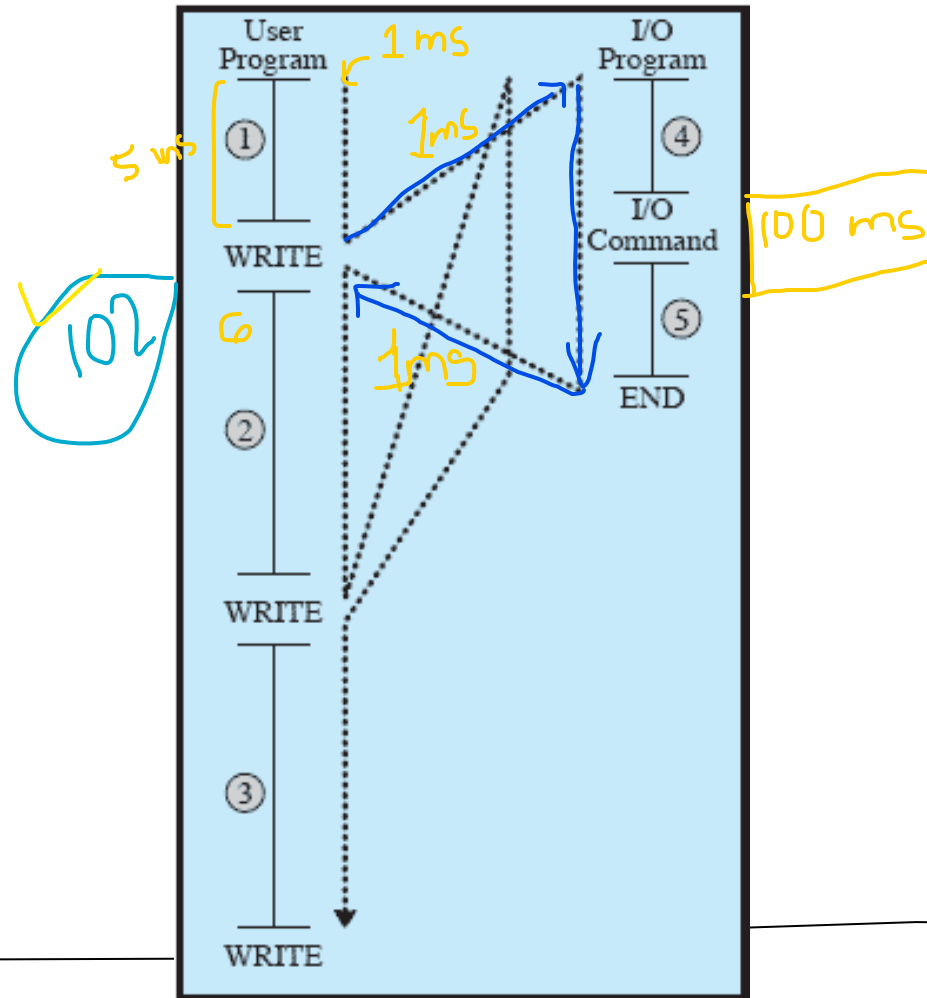
Common Classes of Interrupts

Table 1.1 **Classes of Interrupts**

✓ Program	Generated by some <u>condition that occurs as a result of an instruction execution</u> , such as arithmetic overflow, division by zero, attempt to execute an <u>illegal machine instruction</u> , and reference outside a user's allowed memory space.
✓ Timer	Generated by a <u>timer</u> within the processor. This allows the operating system to perform certain functions on a regular basis.
✓ I/O	Generated by an I/O controller, to signal normal completion of an operation or to signal a variety of error conditions.
✓ Hardware failure	Generated by a failure, such as <u>power failure</u> or <u>memory parity error</u> .

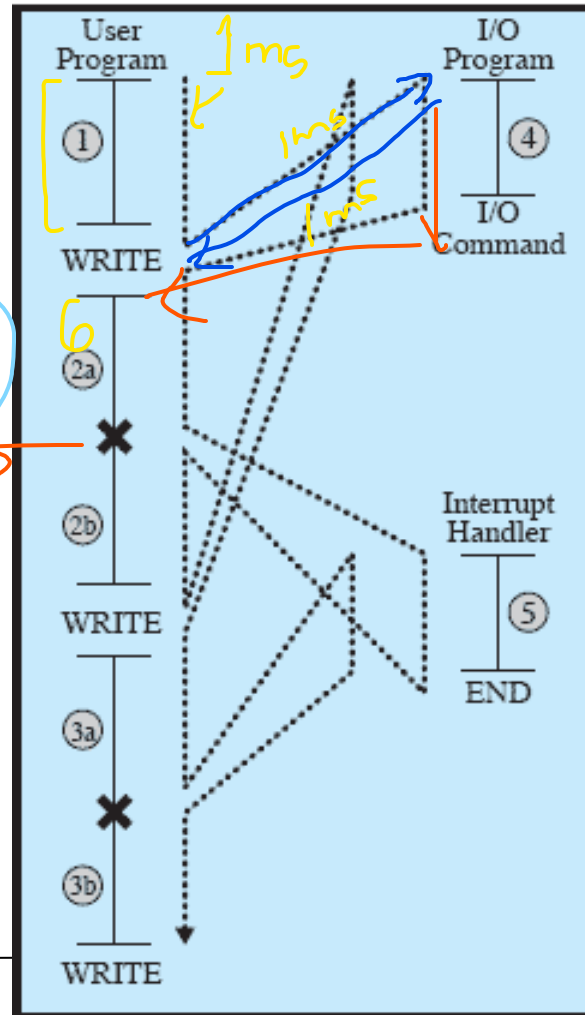


Flow of Control without Interrupts



(a) No interrupts

Interrupts and the Instruction Cycle



No Idle CPU

(b) Interrupts; short I/O wait

Transfer of Control via Interrupts

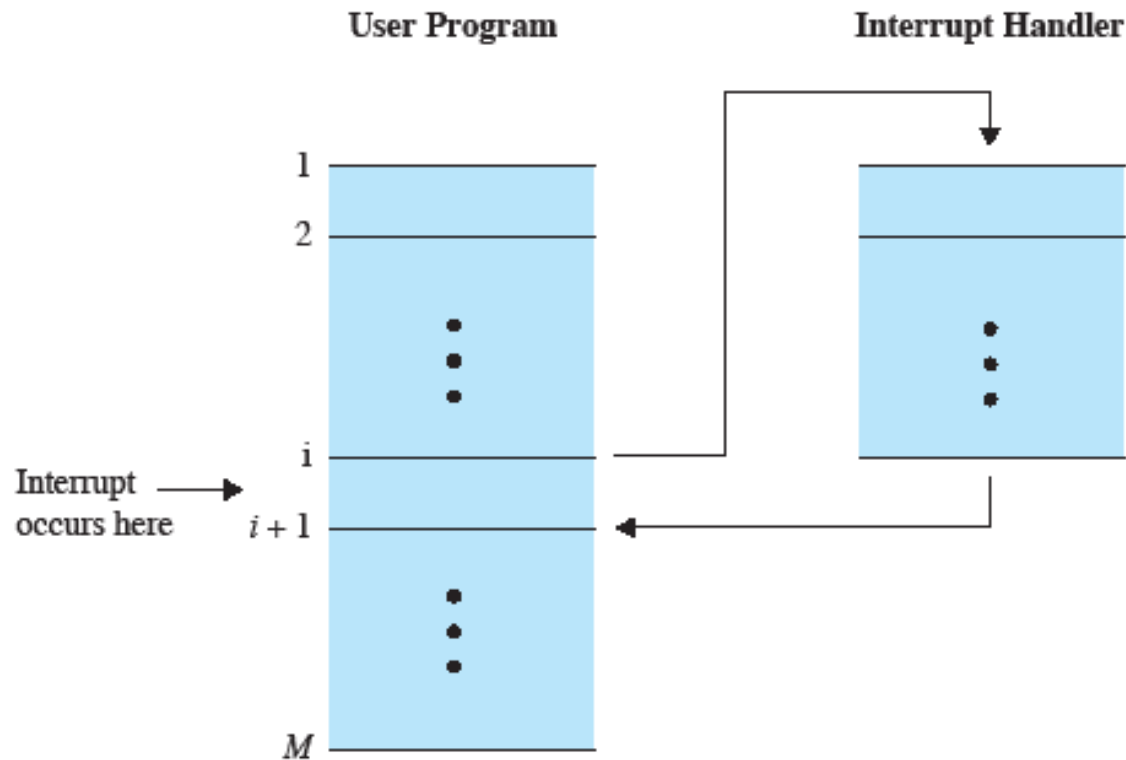


Figure 1.6 Transfer of Control via Interrupts

Instruction Cycle with Interrupts

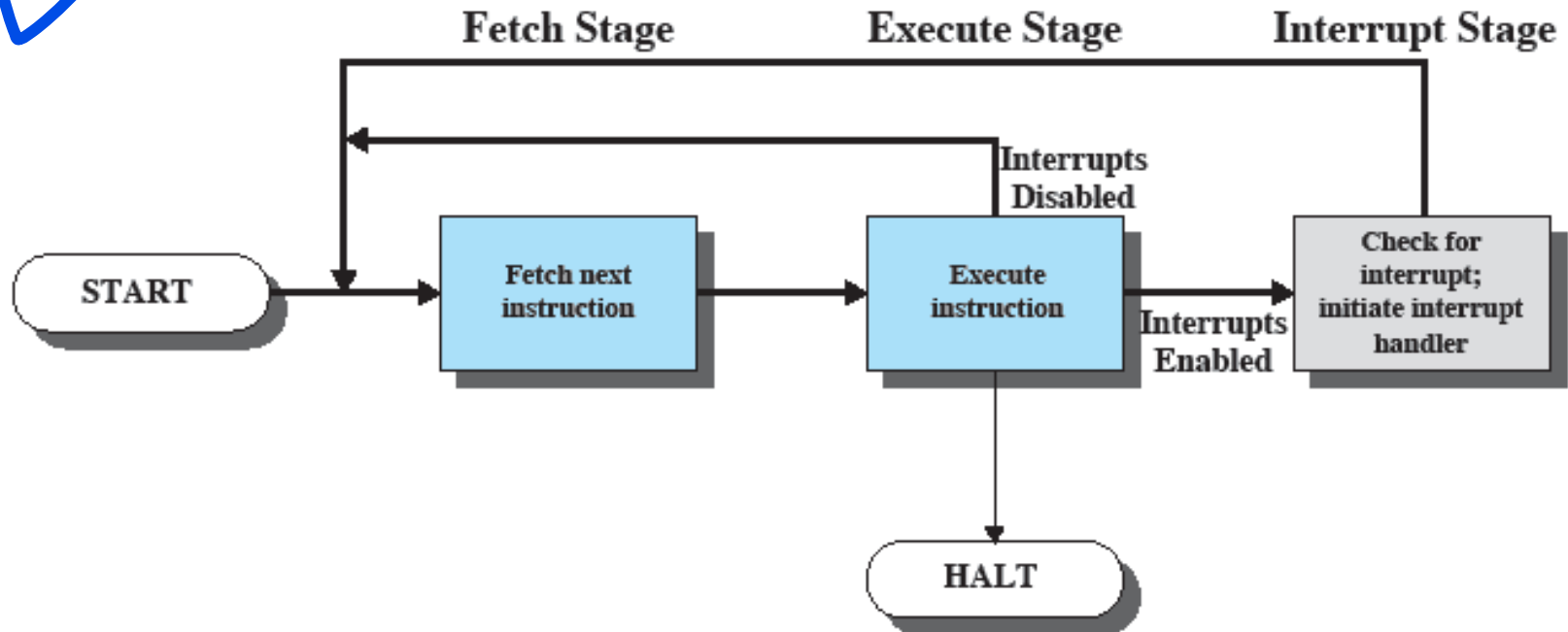
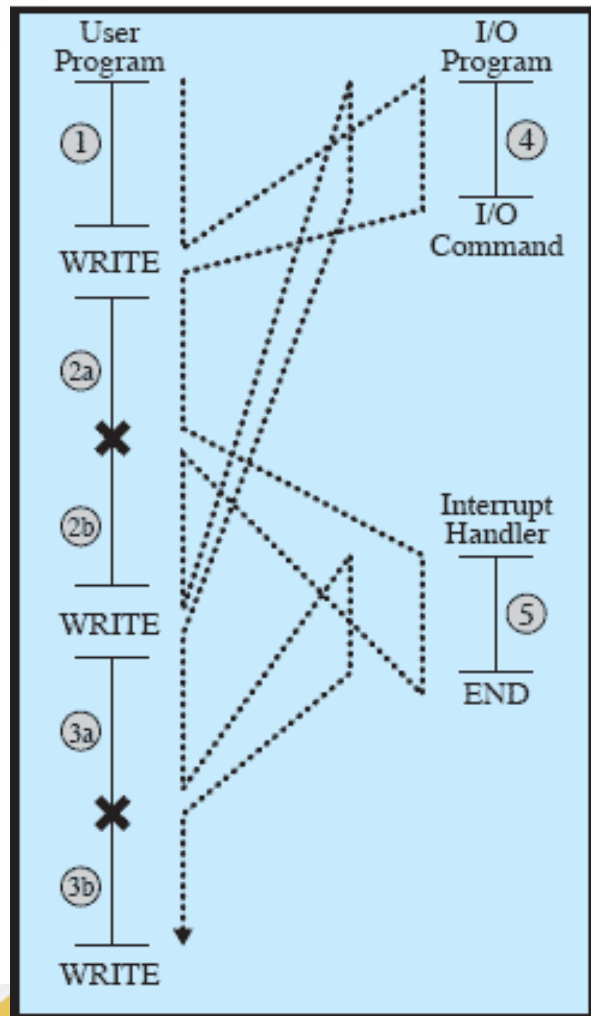
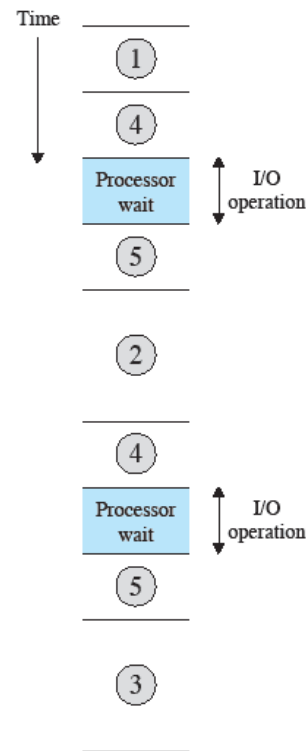


Figure 1.7 Instruction Cycle with Interrupts

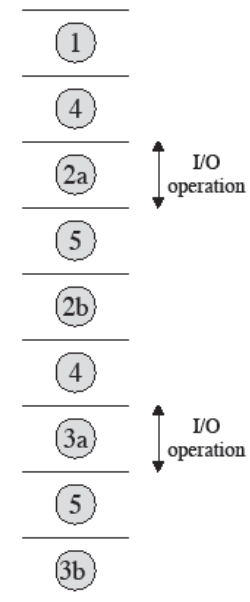
Short I/O Wait



(b) Interrupts; short I/O wait



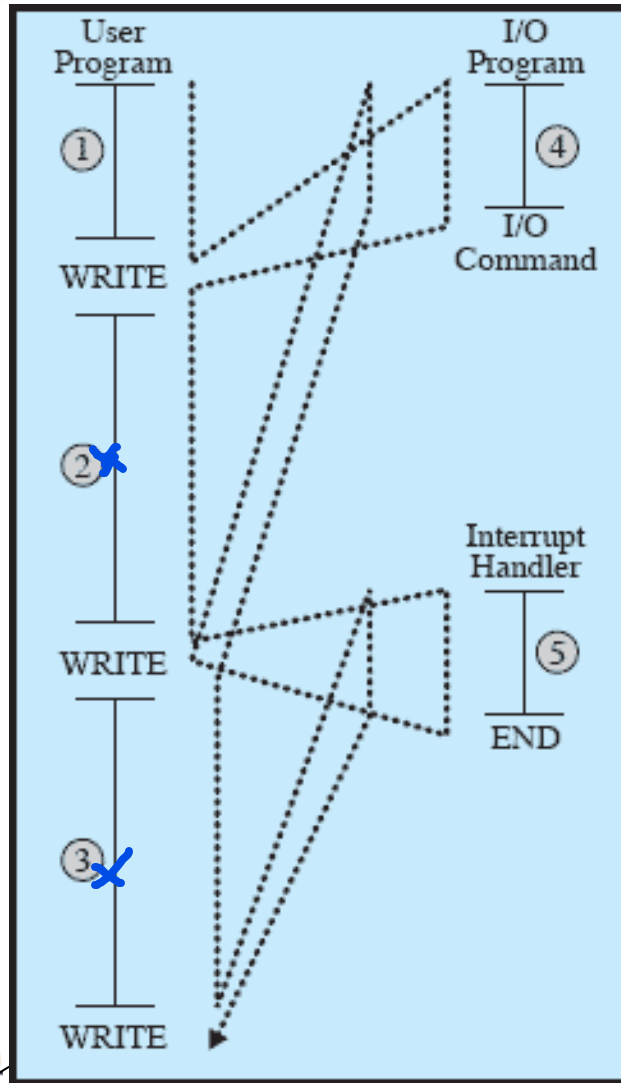
(a) Without interrupts
(circled numbers refer to numbers in Figure 1.5a)



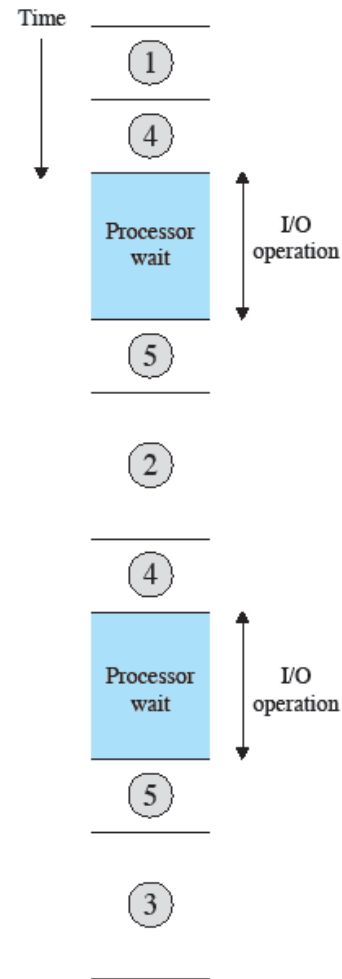
(b) With interrupts
(circled numbers refer to numbers in Figure 1.5b)

Figure 1.8 Program Timing: Short I/O Wait

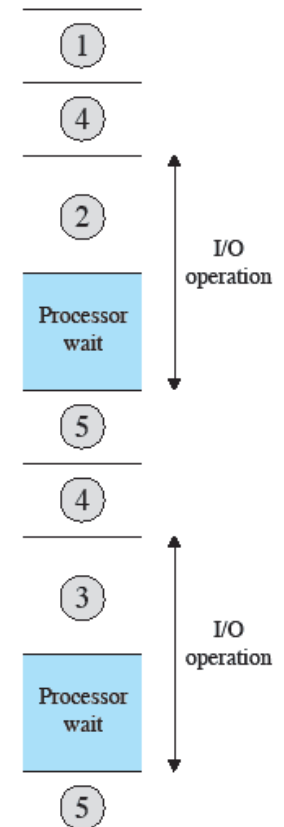
Long I/O wait



(c) Interrupts; long I/O wait



(a) Without interrupts
(circled numbers refer to numbers in Figure 1.5a)



(b) With interrupts
(circled numbers refer to numbers in Figure 1.5c)

Figure 1.9 Program Timing: Long I/O Wait

Simple Interrupt Processing

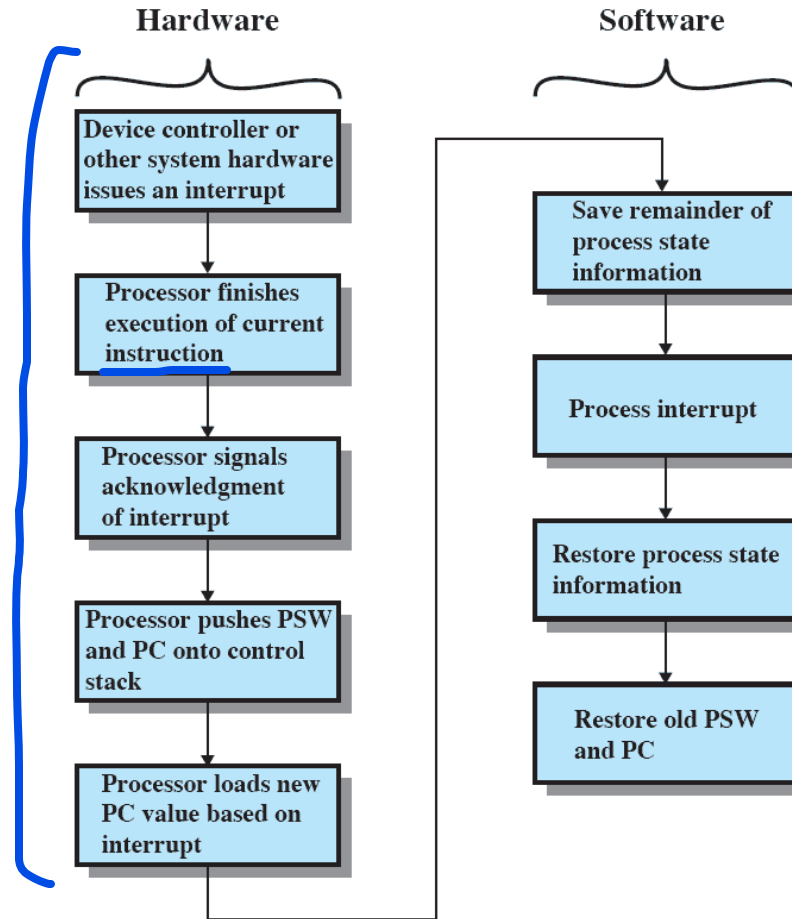
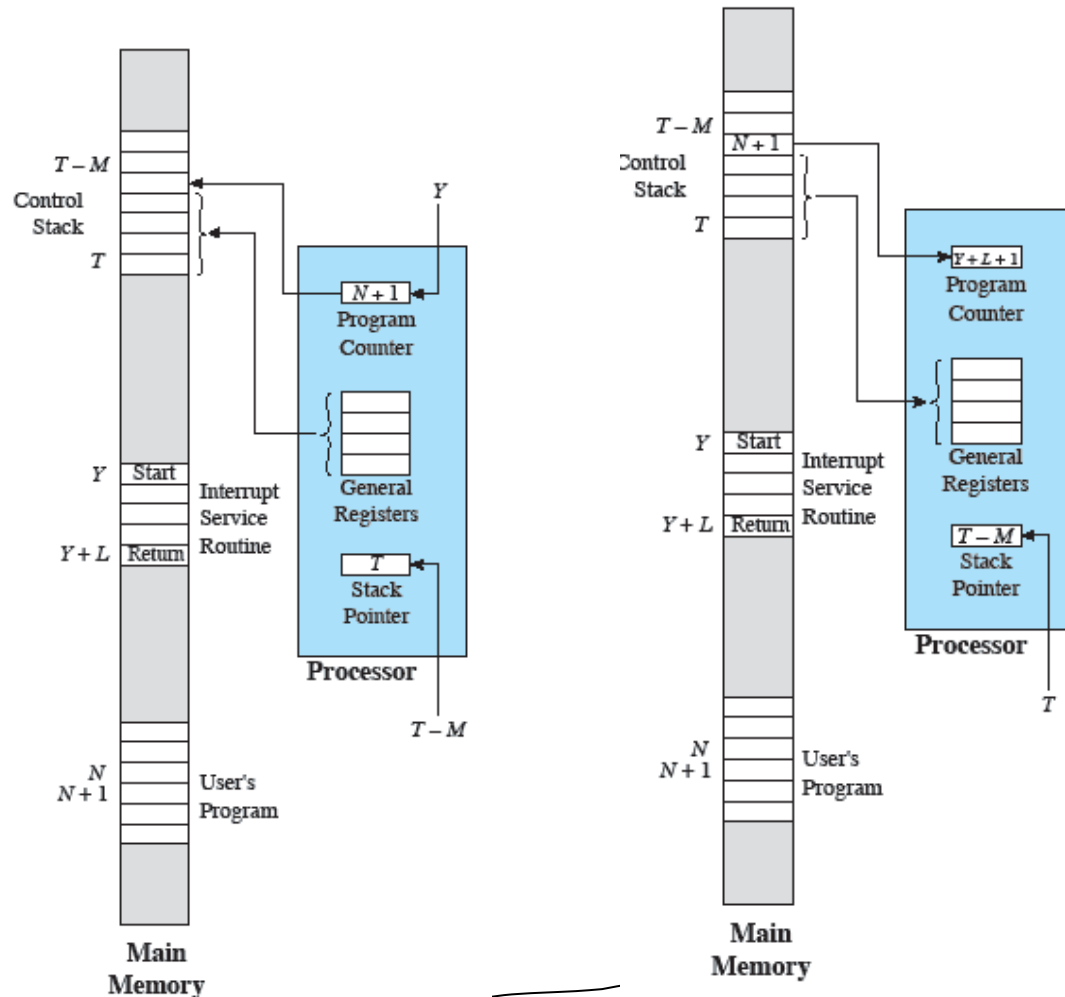


Figure 1.10 Simple Interrupt Processing

Changes in Memory and Registers for an Interrupt



(a) Interrupt occurs after instruction at location N

(b) Return from interrupt

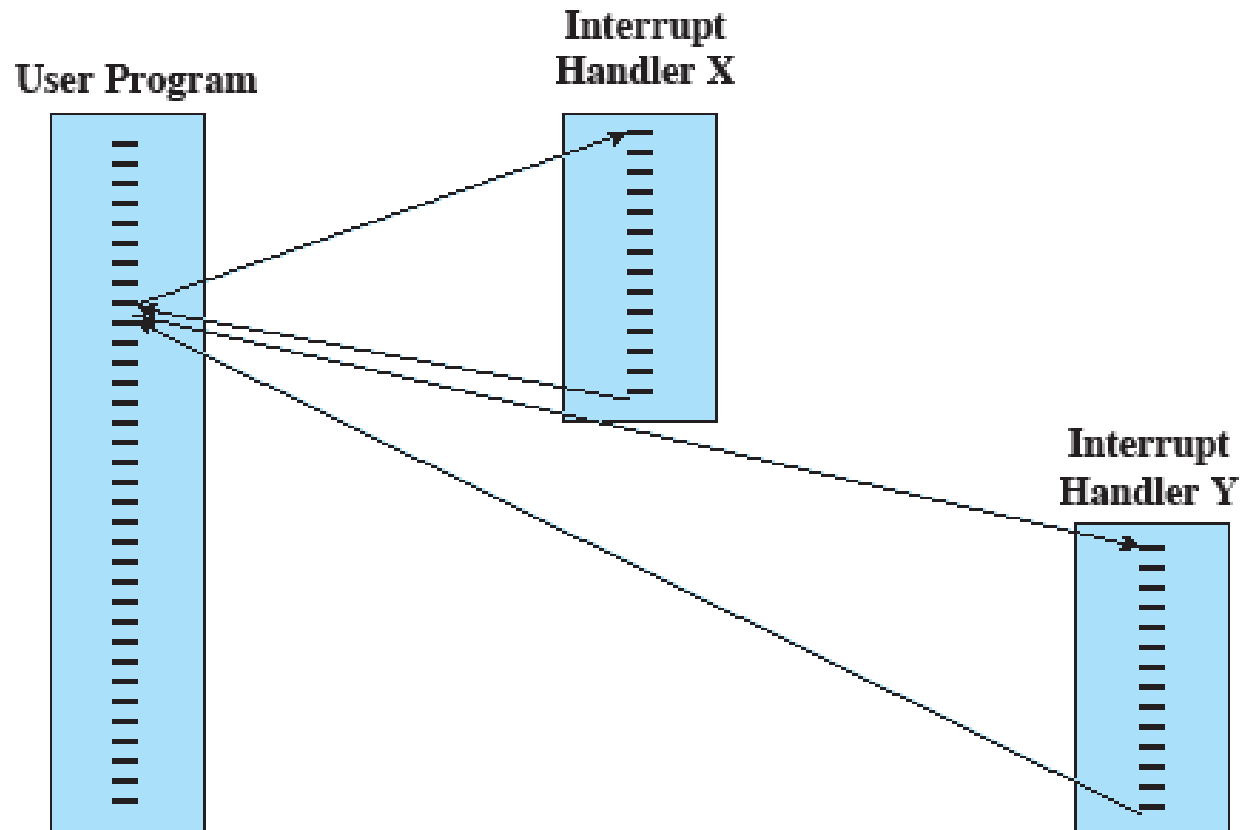


Multiple Interrupts

- Suppose an interrupt occurs while another interrupt is being processed.
 - E.g. printing data being received via communications line.
- Two approaches:
 - Disable interrupts during interrupt processing
 - Use a priority scheme.

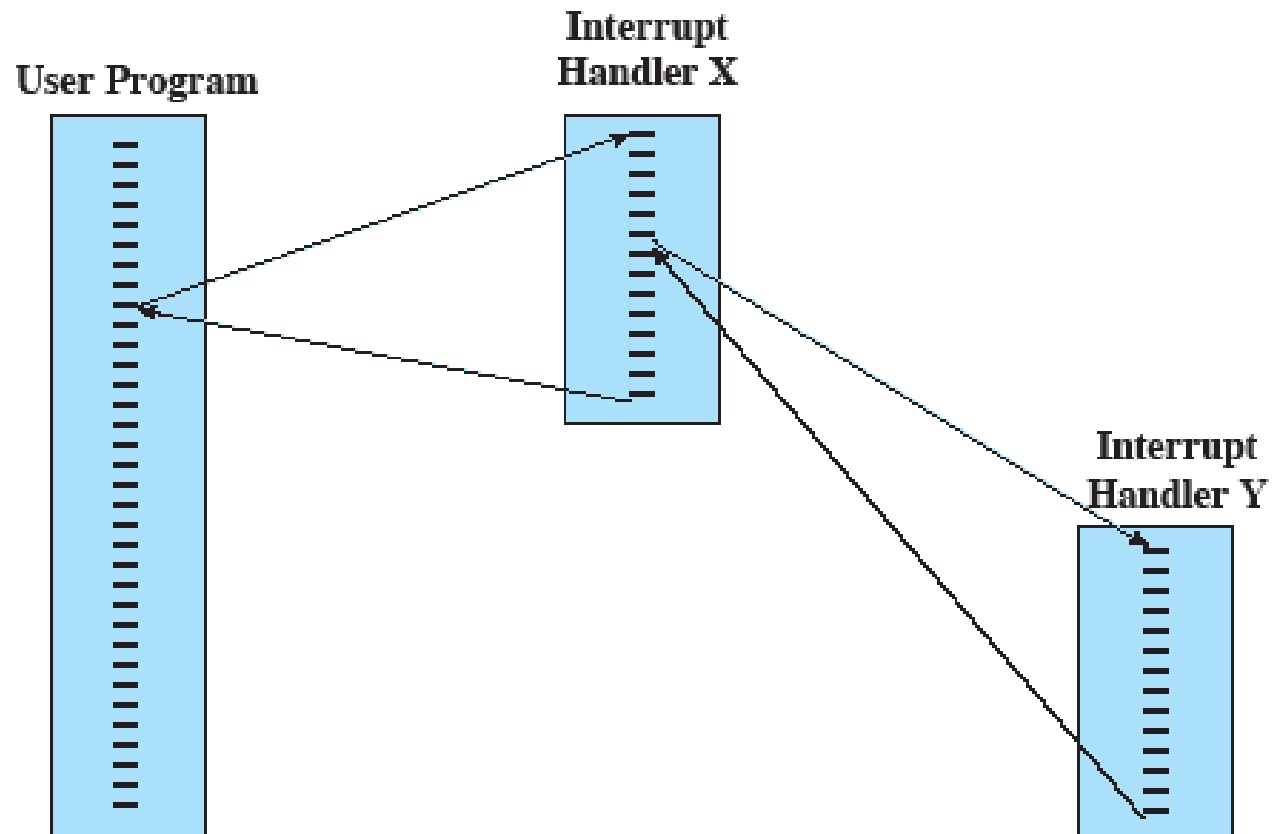


Sequential Interrupt Processing



(a) Sequential interrupt processing

Nested Interrupt Processing



(b) Nested interrupt processing

Example of Nested Interrupts

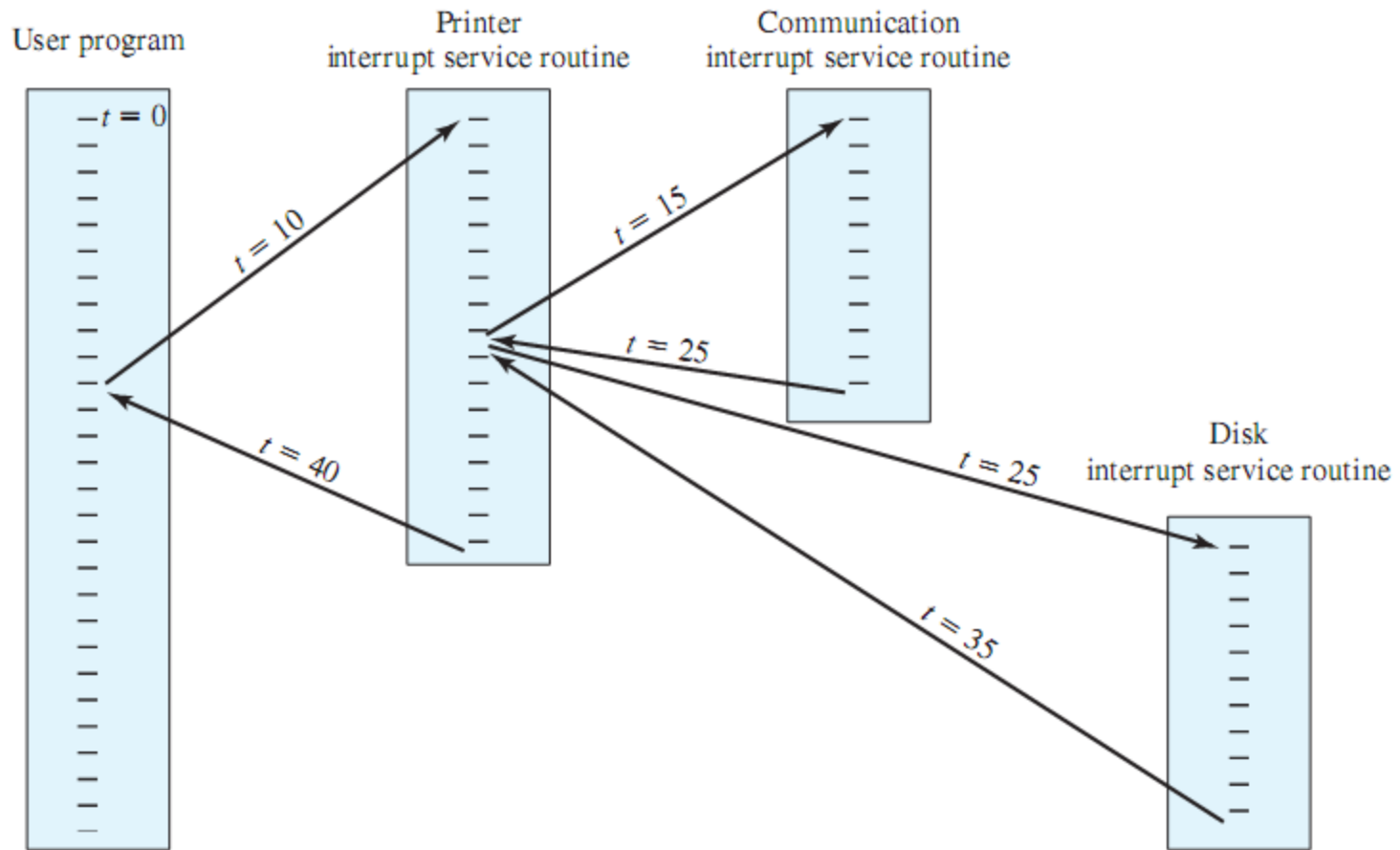


Figure 1.13 Example Time Sequence of Multiple Interrupts



Multiprogramming

- Processor has more than one program to execute
- The sequence the programs are executed depend on their relative priority and whether they are waiting for I/O
- After an interrupt handler completes, control may not return to the program that was executing at the time of the interrupt





Roadmap

- Basic Elements
- Processor Registers
- Instruction Execution
- Interrupts



The Memory Hierarchy

- Cache Memory
- I/O Communication Techniques





Memory Hierarchy

- Major constraints in memory
 - Amount
 - Speed
 - Expense *Cost*
- Faster access time, greater cost per bit
- Greater capacity, smaller cost per bit
- Greater capacity, slower access speed





The Memory Hierarchy

- Going **down** the hierarchy
 - Decreasing cost per bit
 - Increasing capacity
 - **Increasing access time**
 - **Decreasing frequency of access to the memory by the processor**

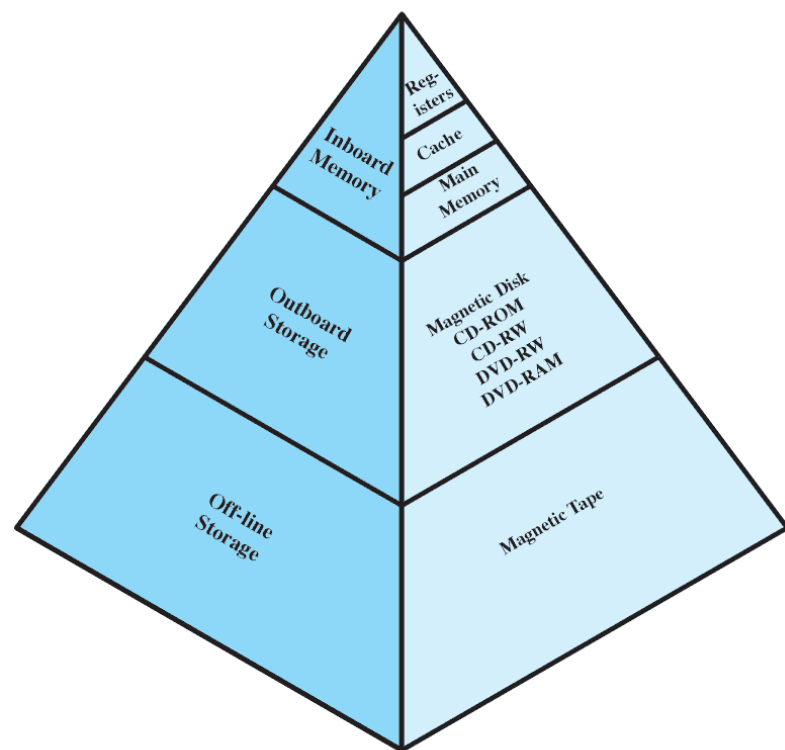
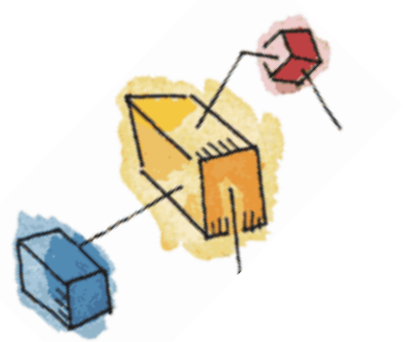


Figure 1.14 The Memory Hierarchy





Secondary Memory

- Auxiliary memory
- External
- Nonvolatile
- Used to store program and data files





Roadmap

- Basic Elements
- Processor Registers
- Instruction Execution
- Interrupts
- The Memory Hierarchy



Cache Memory

- I/O Communication Techniques





Cache Memory

- ✓ • Invisible to the OS
 - Interacts with other memory management hardware
- Processor must access memory at least once per instruction cycle
 - Processor speed faster than memory access speed
- Exploit the principle of locality with a small fast memory





Principal of Locality

- More details later but in short ...
- Data which is required soon is often close to the current data
 - If data is referenced, then it's neighbour might be needed soon.



Cache and Main Memory

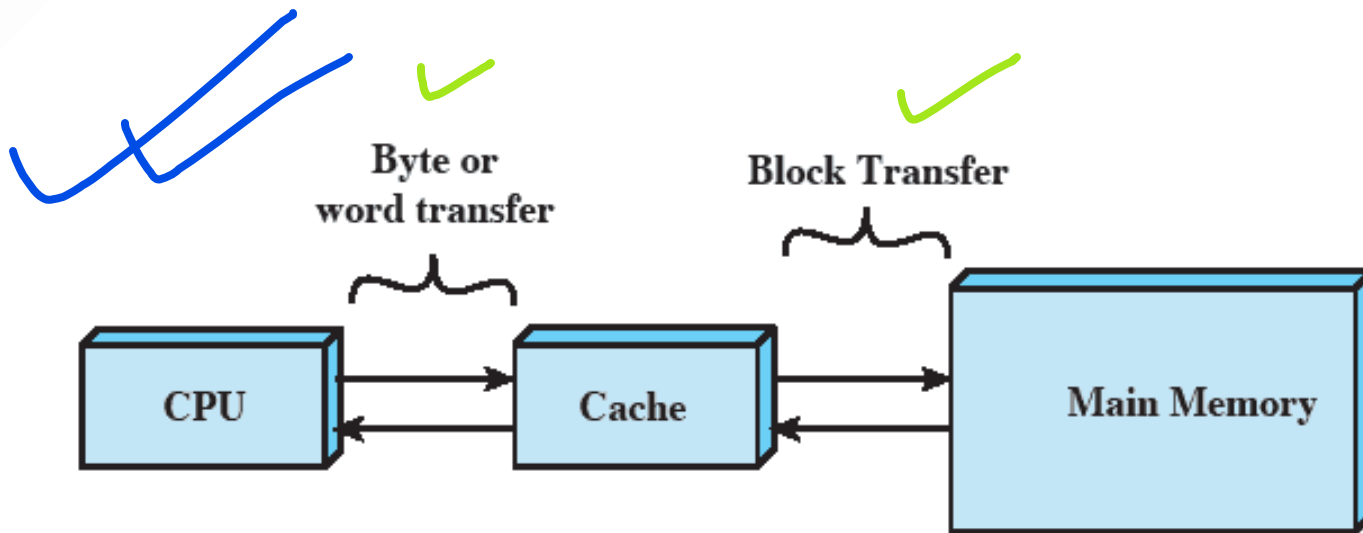


Figure 1.16 Cache and Main Memory



Cache Principles

A diagram in the top-left corner shows a blue cube (cache) connected by lines to a larger orange cube (main memory) and a small red cube (processor). The orange cube is partially enclosed by a yellow cloud-like shape.

- Contains copy of a portion of main memory
- Processor first checks cache
 - If not found, block of memory read into cache
- Because of locality of reference, likely future memory references are in that block



Cache/Main-Memory Structure

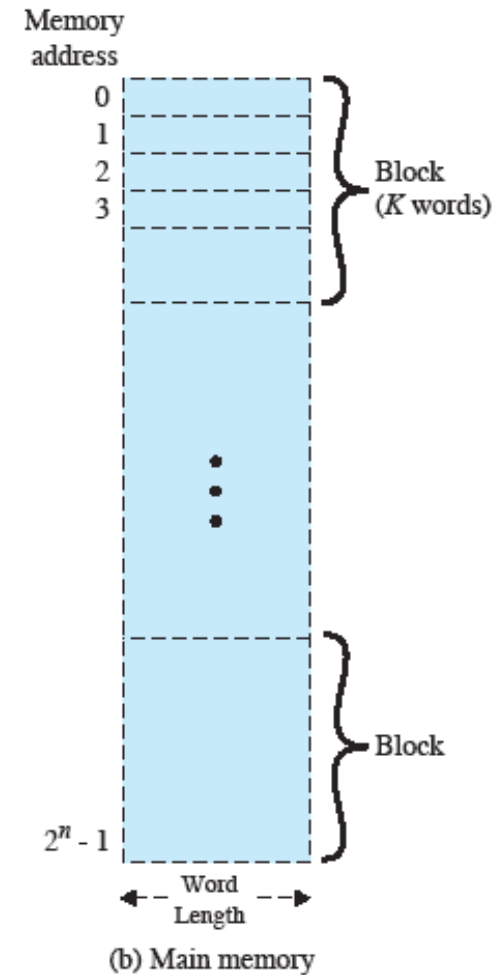
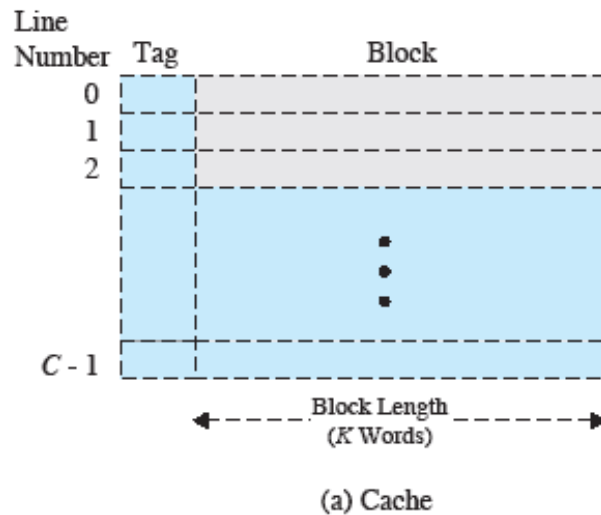


Figure 1.17 Cache/Main-Memory Structure

Cache Read Operation

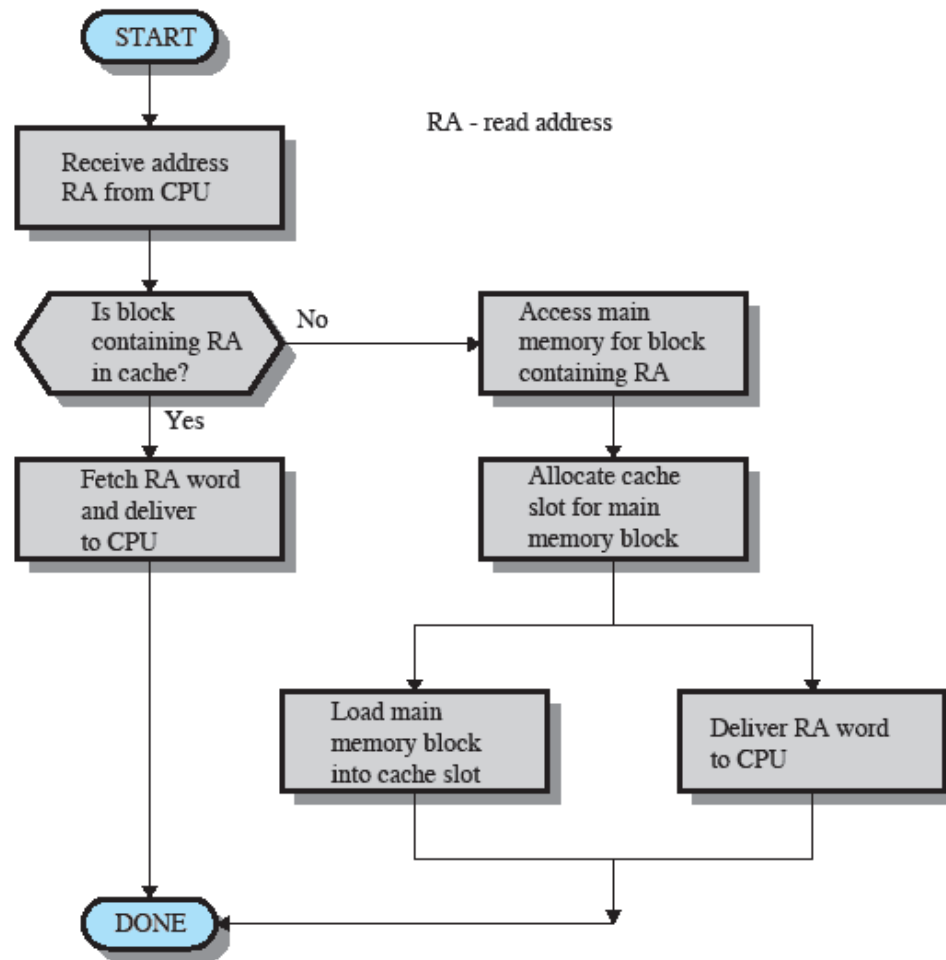


Figure 1.18 Cache Read Operation



Cache Design Issues

- Main categories are:
 - Cache size
 - Block size
 - Mapping function
 - Replacement algorithm
 - Write policy





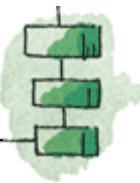
Size issues

① • Cache size

- Small caches have significant impact on performance

② • Block size

- The unit of data exchanged between cache and main memory
- Larger block size means more hits
- But too large reduces chance of reuse.





Mapping function

- Determines which cache location the block will occupy
- Two constraints:
 - When one block read in, another may need replaced
 - Complexity of mapping function increases circuitry costs for searching.





Replacement Algorithm

- Chooses which block to replace when a new block is to be loaded into the cache.
- Ideally replacing a block that isn't likely to be needed again
 - Impossible to guarantee
- Effective strategy is to replace a block that has been used less than others
 - Least Recently Used (LRU)





Write policy

- Dictates when the memory write operation takes place
- Can occur every time the block is updated
- Can occur when the block is replaced
 - Minimize write operations
 - Leave main memory in an obsolete state





Roadmap

- Basic Elements
- Processor Registers
- Instruction Execution
- Interrupts
- The Memory Hierarchy
- Cache Memory

→ I/O Communication Techniques





I/O Techniques

- When the processor encounters an instruction relating to I/O,
 - it executes that instruction by issuing a command to the appropriate I/O module.
- Three techniques are possible for I/O operations:
 - Programmed I/O
 - Interrupt-driven I/O
 - Direct memory access (DMA)





① Programmed I/O

- The I/O module performs the requested action
 - then sets the appropriate bits in the I/O status register
 - but takes no further action to alert the processor.
- As there are no interrupts, the processor must determine when the instruction is complete





Programmed I/O Instruction Set

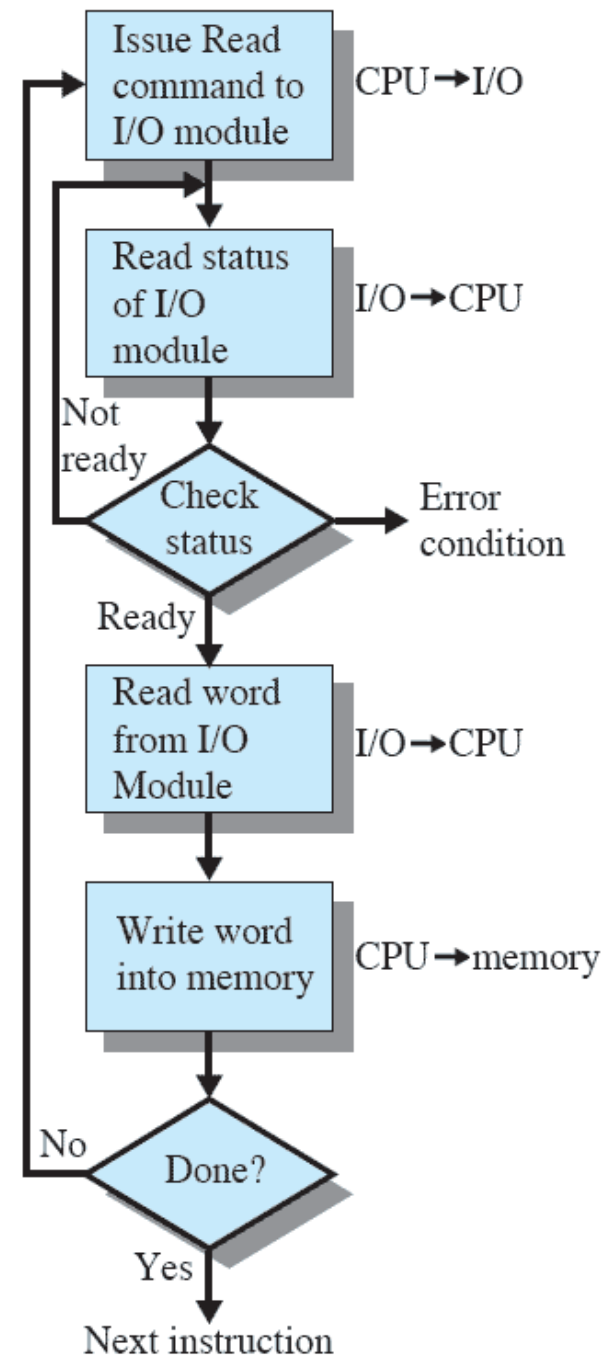
- **Control**
 - Used to activate and instruct device
- **Status**
 - Tests status conditions
- **Transfer**
 - Read/write between process register and device



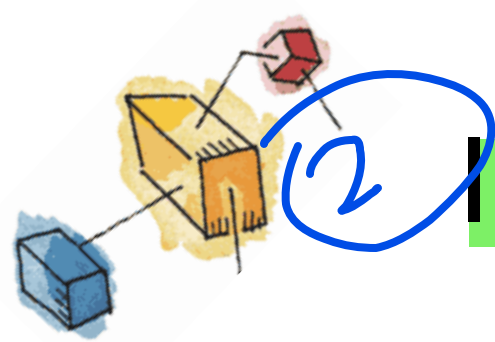


Programmed I/O Example

- Data read in a word at a time
 - Processor remains in status-checking loop while reading

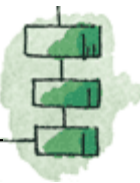


(a) Programmed I/O



Interrupt-Driven I/O

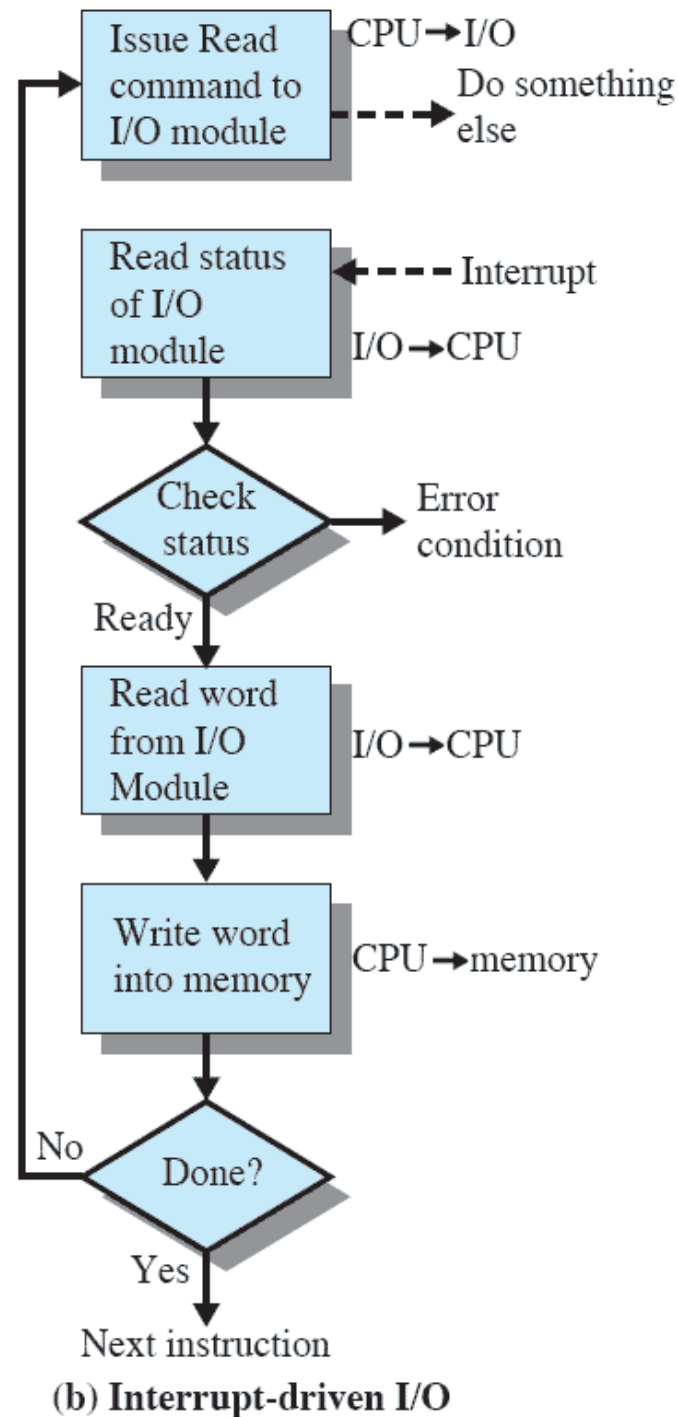
- Processor issues an I/O command to a module
 - and then goes on to do some other useful work.
- The I/O module will then interrupt the processor to request service when it is ready to exchange data with the processor.

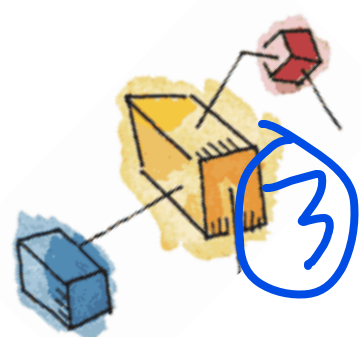




Interrupt-Driven I/O

- Eliminates needless waiting
 - But everything passes through processor.





Direct Memory Access

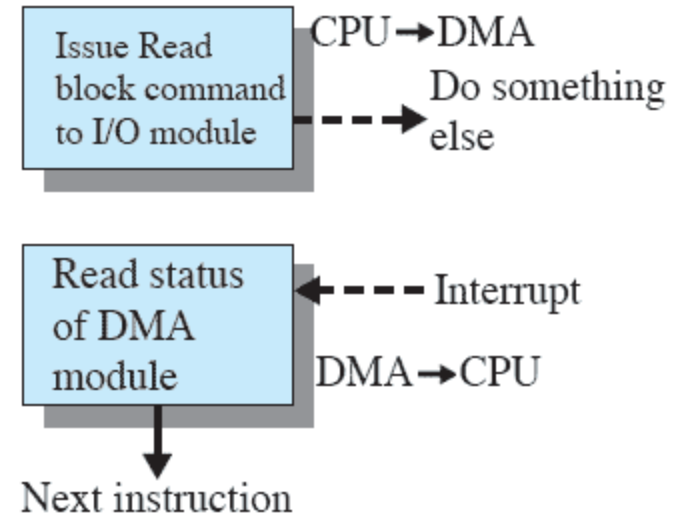
- Performed by a separate module on the system
- When needing to read/write processor issues a command to DMA module with:
 - Whether a read or write is requested
 - The address of the I/O device involved
 - The starting location in memory to read/write
 - The number of words to be read/written





Direct Memory Access

- I/O operation delegated to DMA module
- Processor only involved when beginning and ending transfer.
- Much more efficient.



(c) Direct memory access

