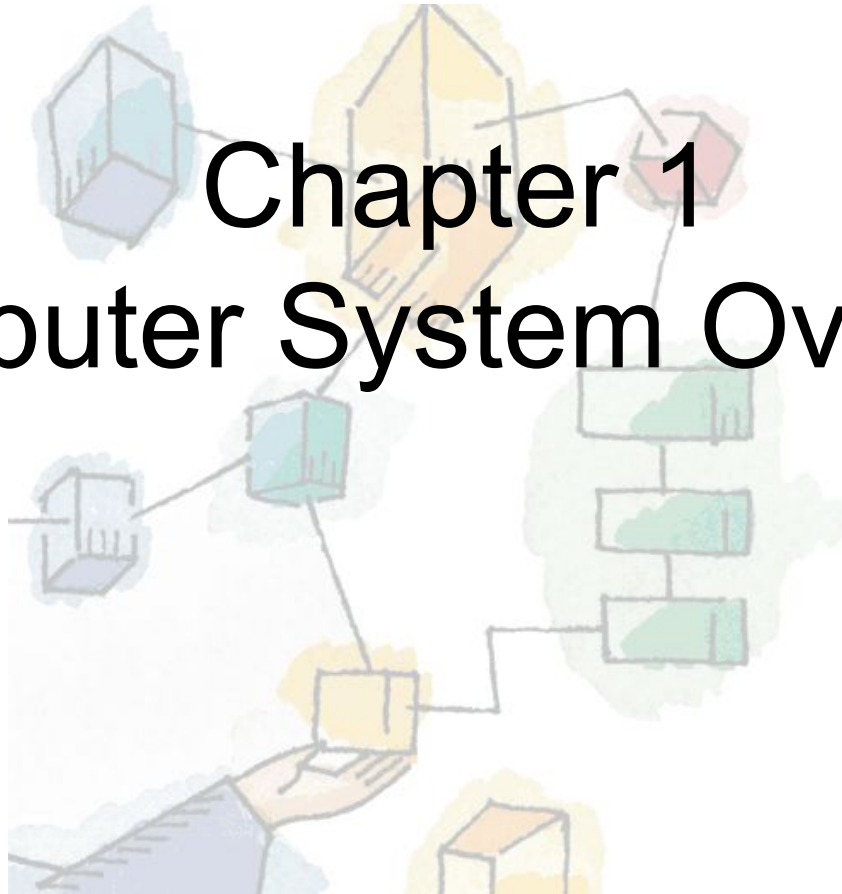


*Operating Systems:
Internals and Design Principles, 6/E*
William Stallings

Chapter 1

Computer System Overview





Roadmap



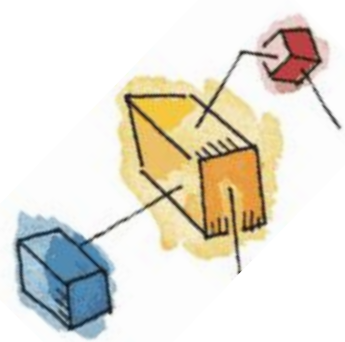
Basic Elements

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



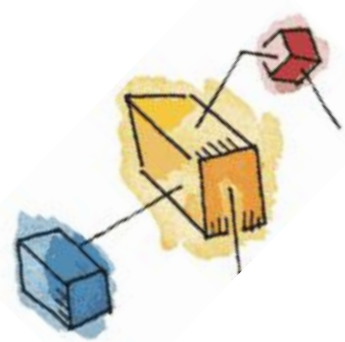
Operating System

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



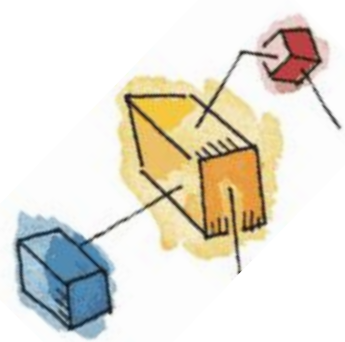
A Computer's Basic Elements

- Processor
- Main Memory
- I/O Modules
- System Bus



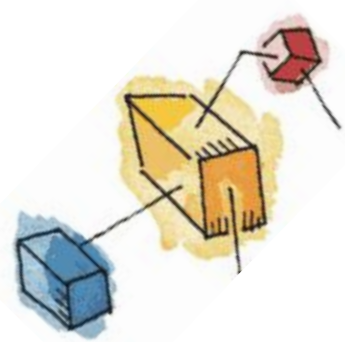
Processor

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



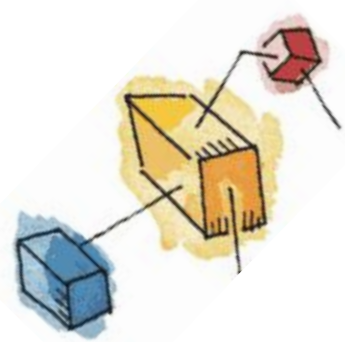
Main Memory

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



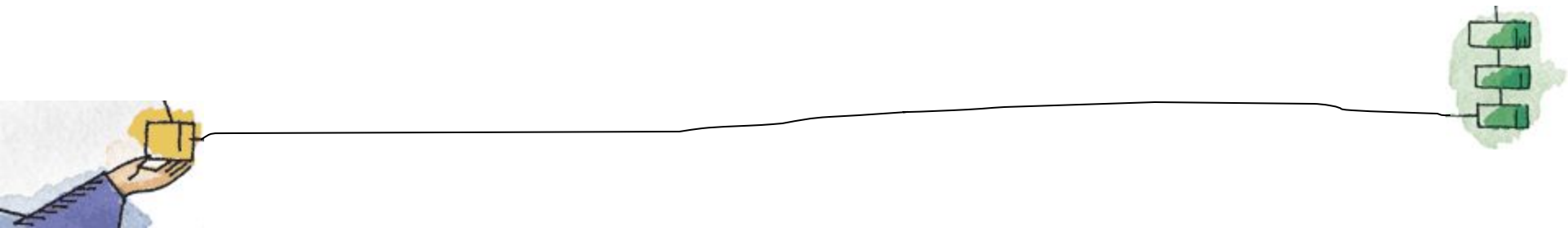
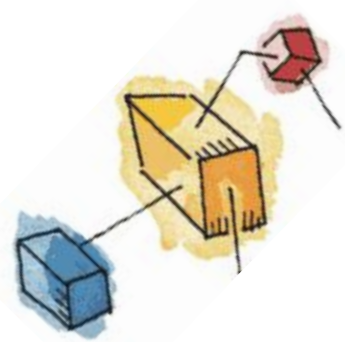
I/O Modules

- 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)



System Bus

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



Top-Level View

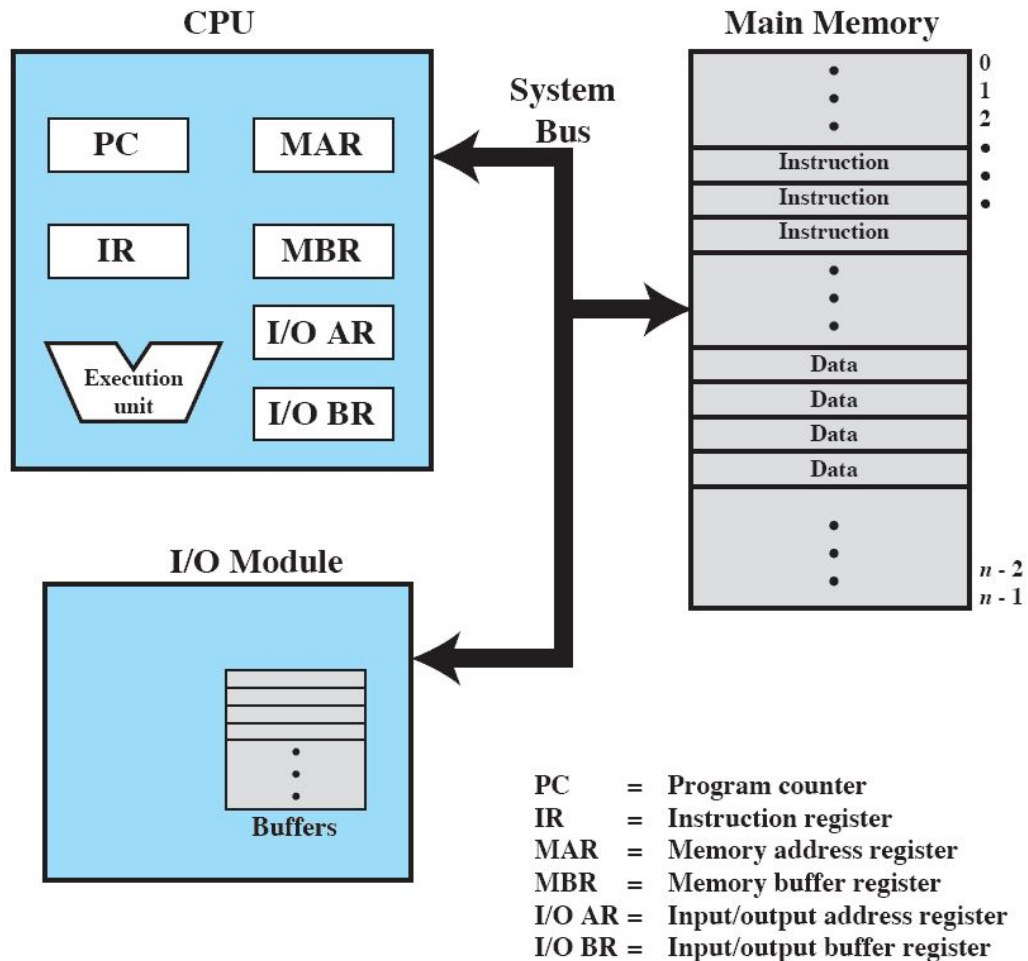


Figure 1.1 Computer Components: Top-Level View

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





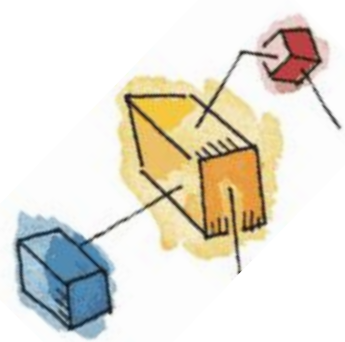
User-Visible Registers

- 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.



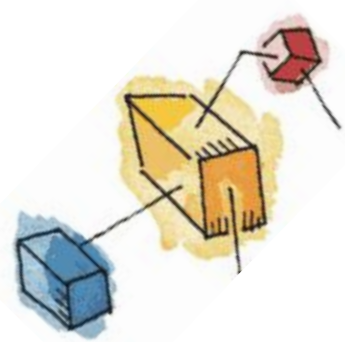
Data and Address Registers

- Data
 - Often general purpose
 - But some restrictions may apply
- Address
 - Index Register
 - Segment pointer
 - Stack pointer



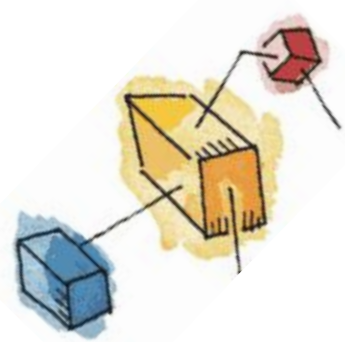
Control and Status Registers

- 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



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



Basic Instruction Cycle

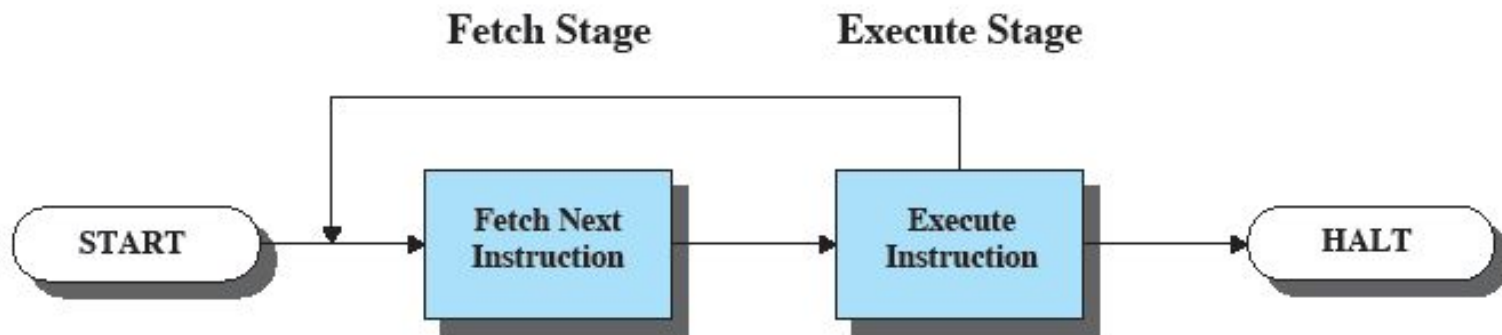
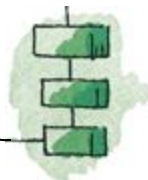
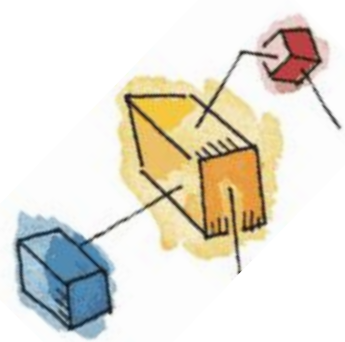


Figure 1.2 Basic Instruction Cycle



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

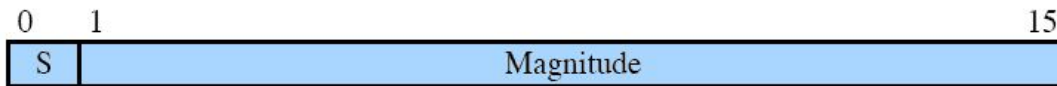
- Fetched instruction loaded into instruction register
- Categories
 - Processor-memory,
 - processor-I/O,
 - Data processing,
 - Control



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

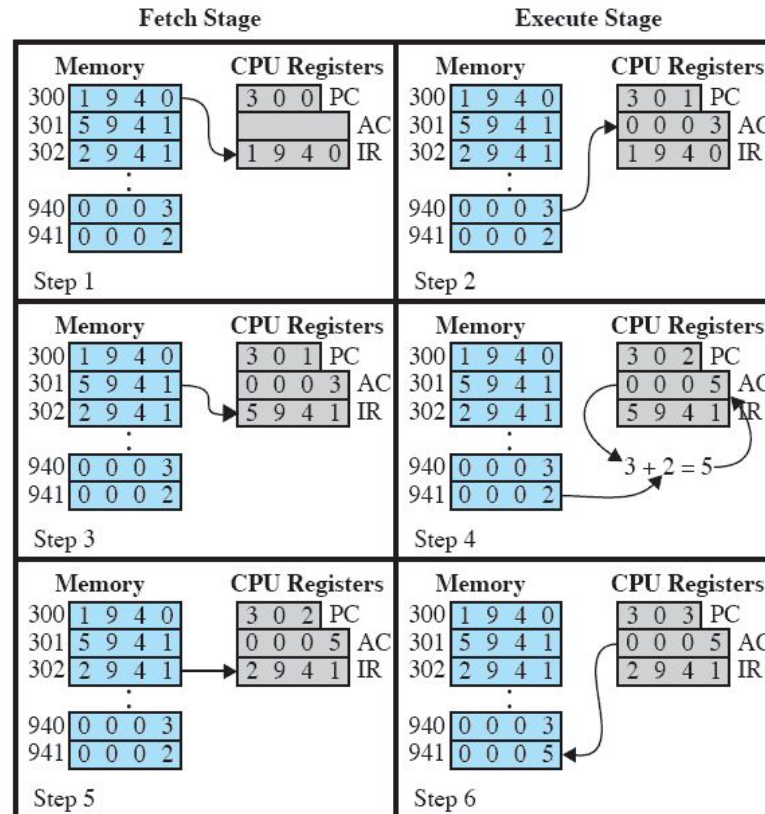


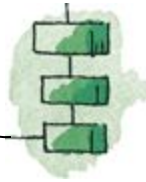
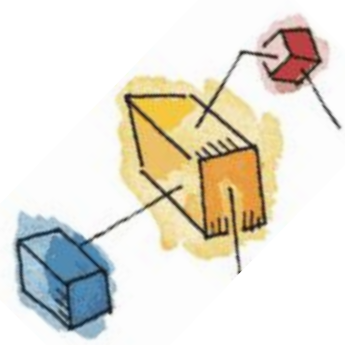
Figure 1.4 Example of Program Execution
(contents of memory and registers in hexadecimal)

Roadmap

- Basic Elements
- Processor Registers
- Instruction Execution

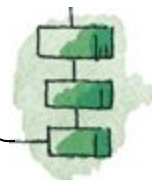
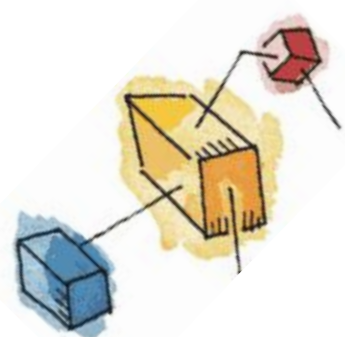
→ Interrupts

- 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



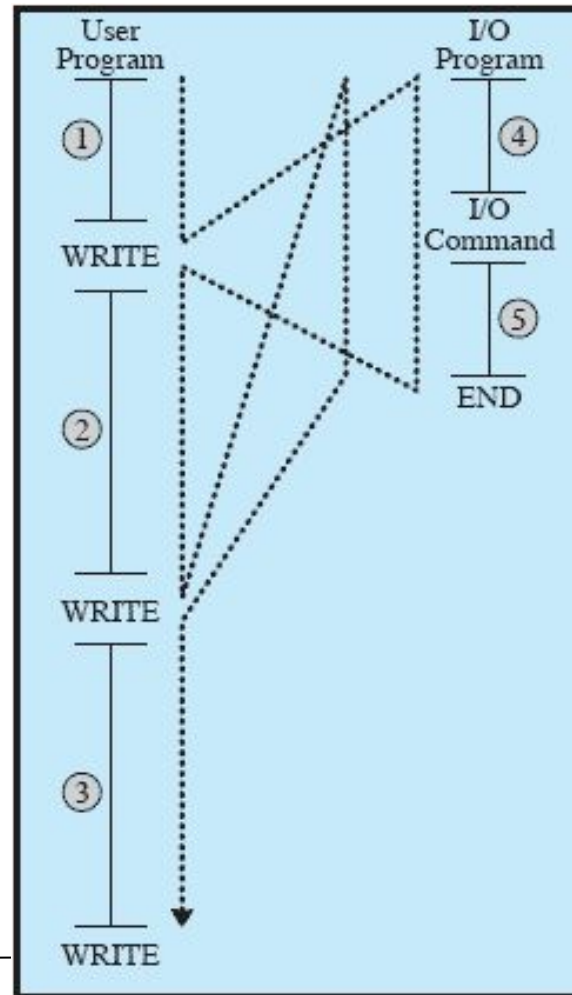
Common Classes of Interrupts

Table 1.1 Classes of Interrupts

| | |
|-------------------------|---|
| Program | Generated by some condition that occurs as a result of an instruction execution, such as arithmetic overflow, division by zero, attempt to execute an illegal machine instruction, and reference outside a user's allowed memory space. |
| Timer | Generated by a timer 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 power failure or memory parity error. |

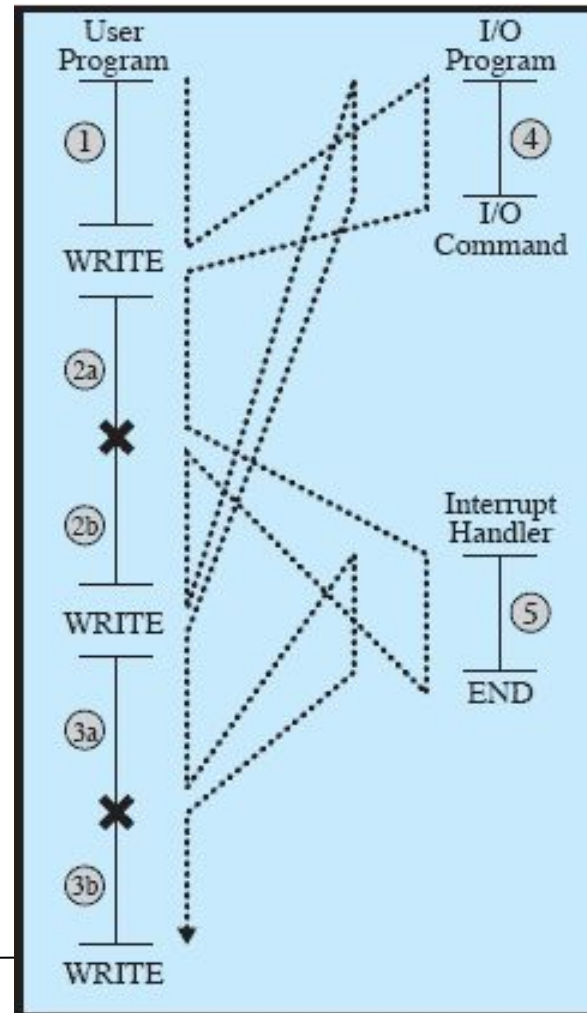


Flow of Control without Interrupts

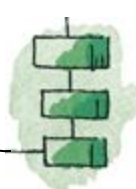
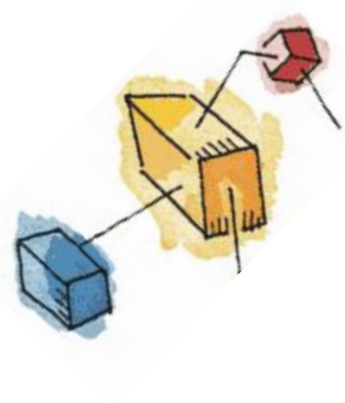


(a) No interrupts

Interrupts and the Instruction Cycle



(b) Interrupts; short I/O wait



Transfer of Control via Interrupts

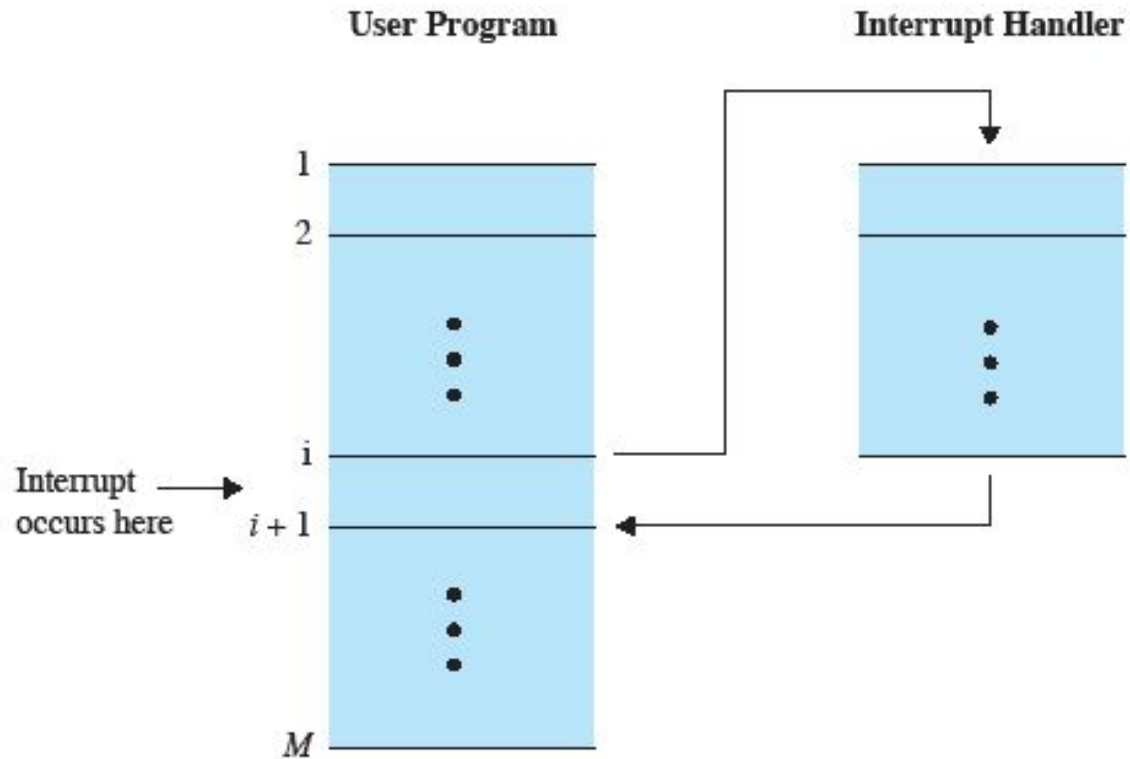


Figure 1.6 Transfer of Control via Interrupts

Instruction Cycle with Interrupts

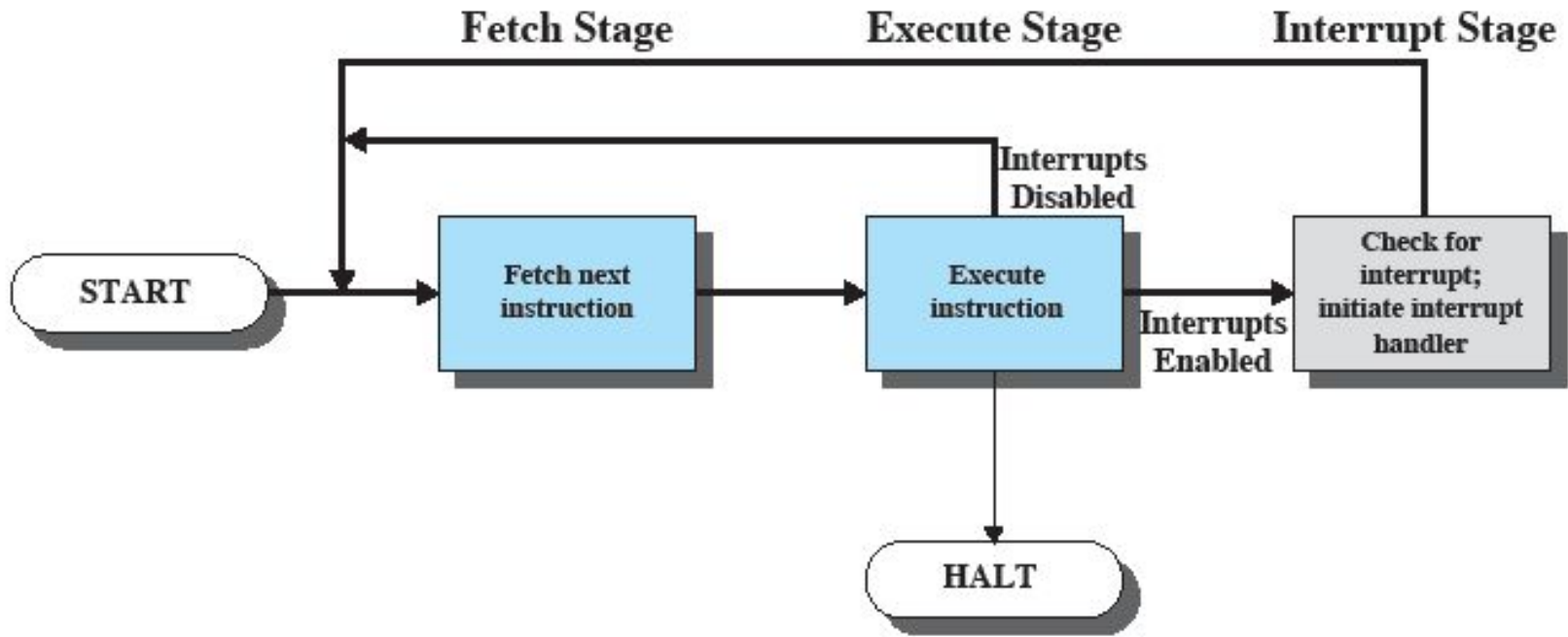
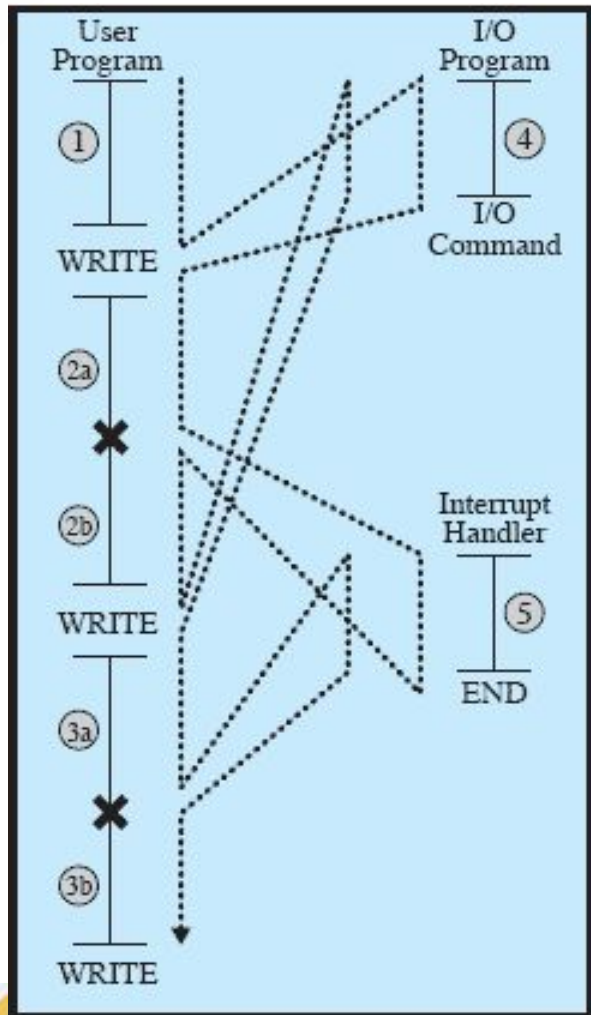
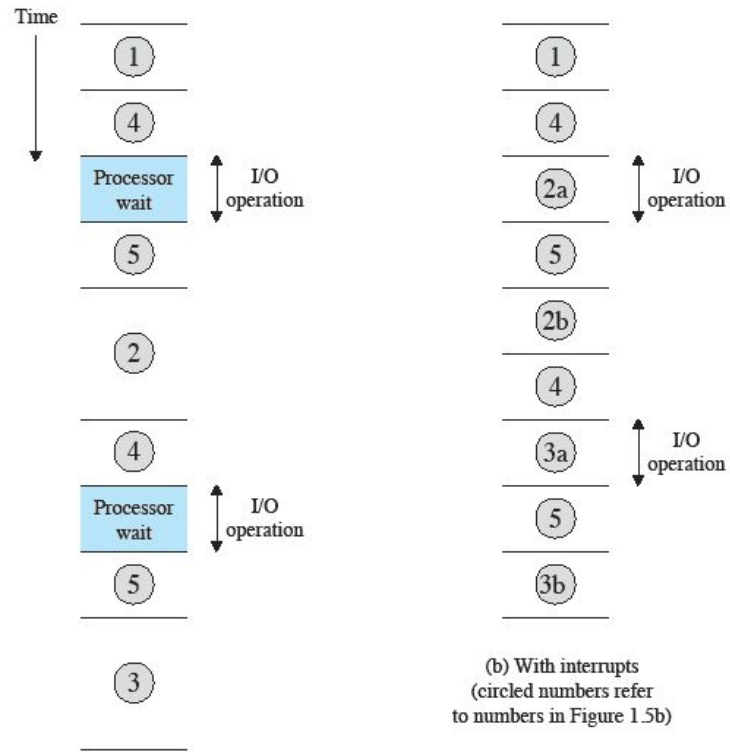


Figure 1.7 Instruction Cycle with Interrupts

Short I/O Wait



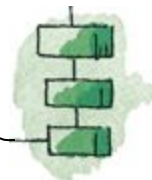
(b) Interrupts; short I/O wait



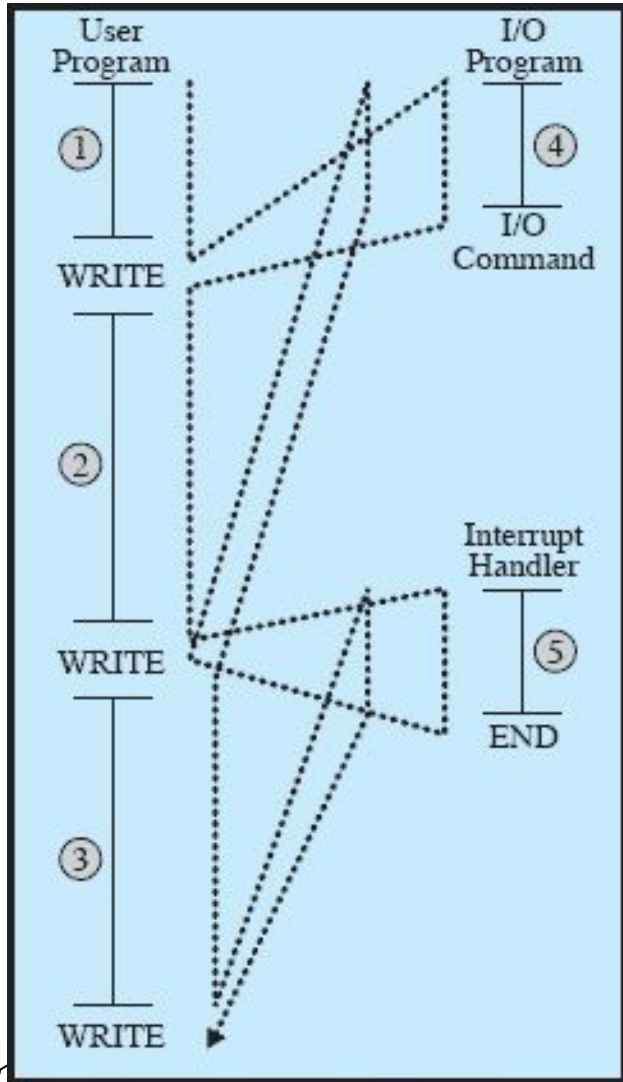
(a) Without interrupts
(circled numbers refer to numbers in Figure 1.5a)

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

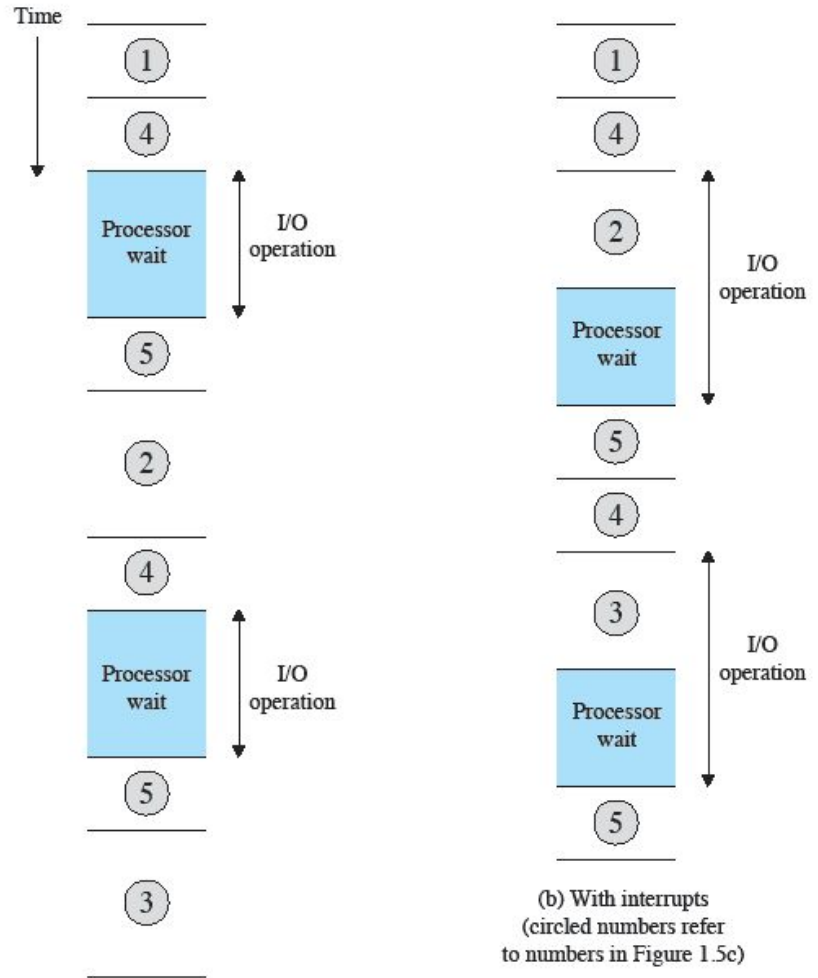
Figure 1.8 Program Timing: Short I/O Wait



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

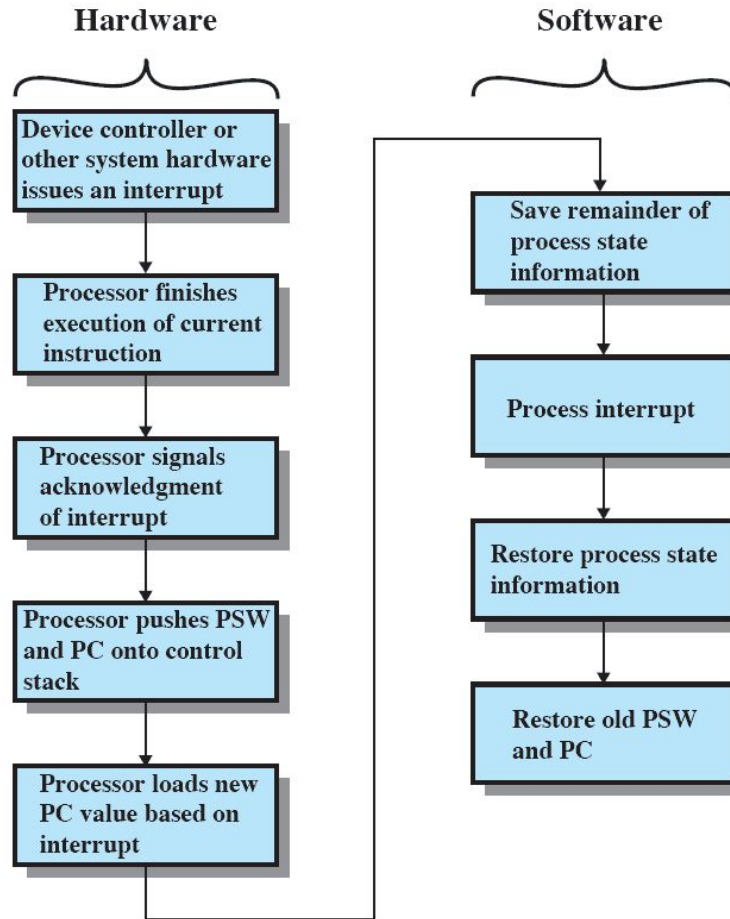
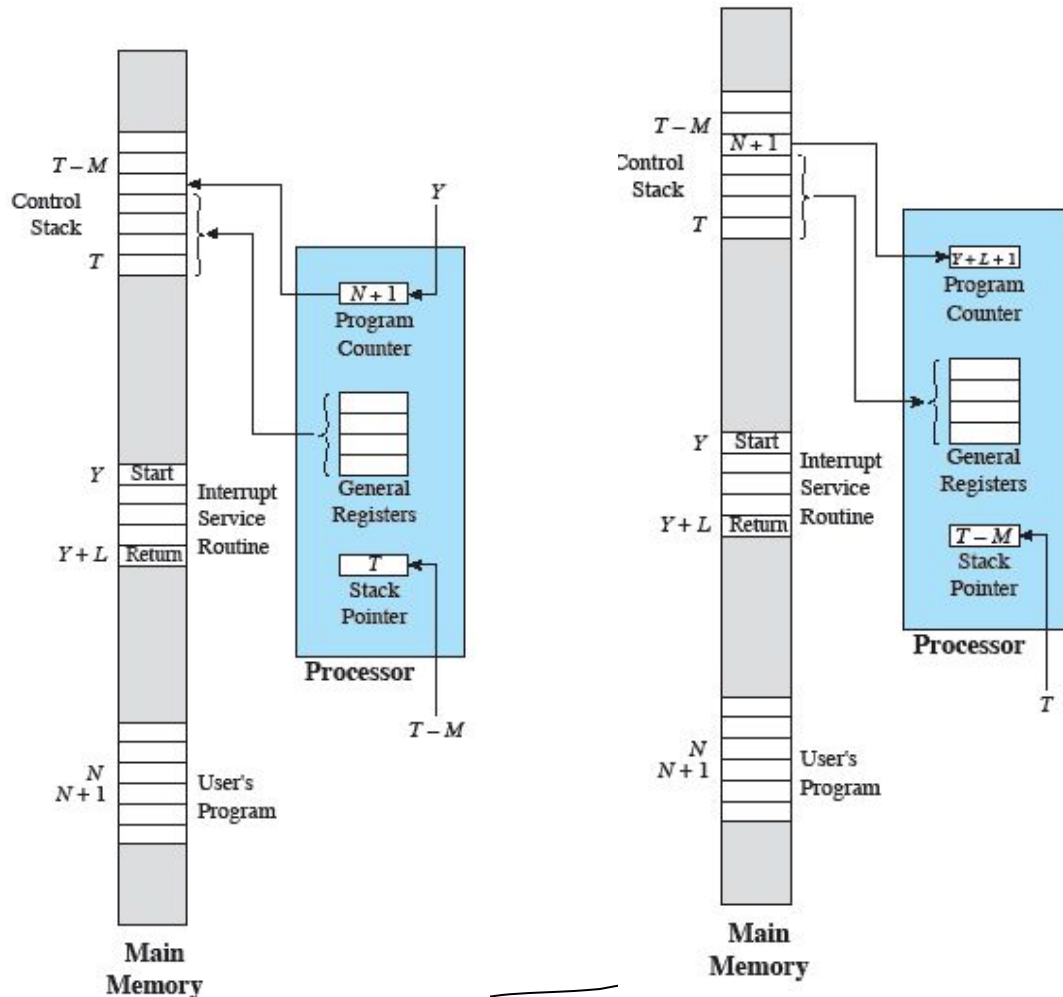


Figure 1.10 Simple Interrupt Processing

Changes in Memory and Registers for an Interrupt



(a) Interrupt occurs after instruction at location N

(b) Return from interrupt

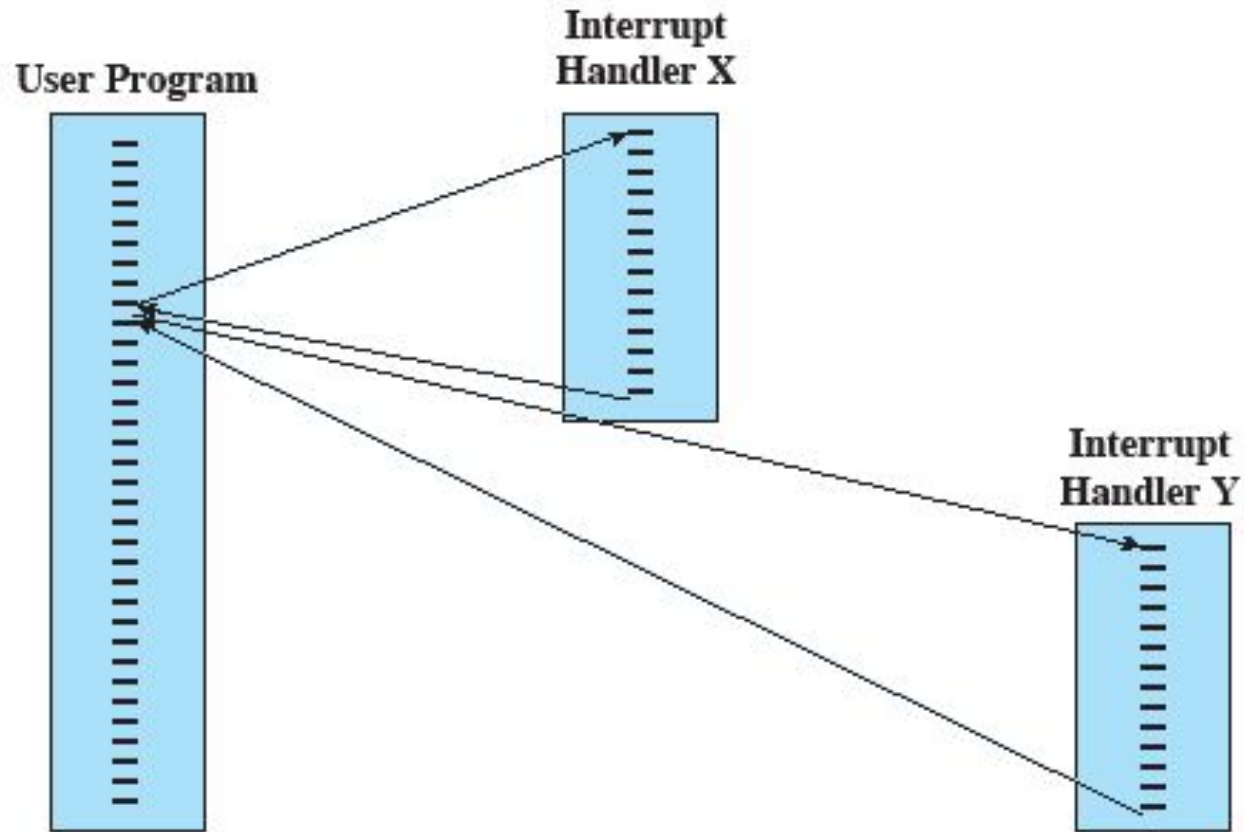


Multiple Interrupts

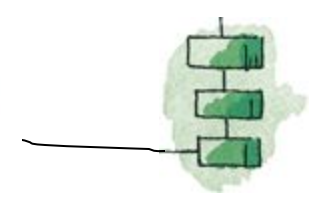
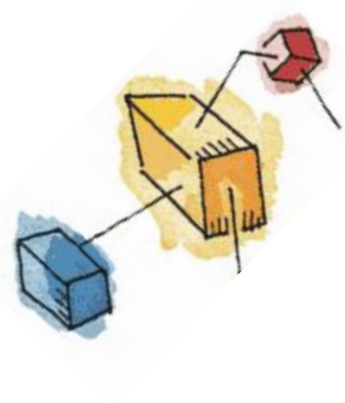
- Suppose an interrupt occurs while another interrupt is being processed.
 - E.g. printing data being received via communications line.
- Two approaches:
 - Disable interrupts during interrupt processing
 - Use a priority scheme.



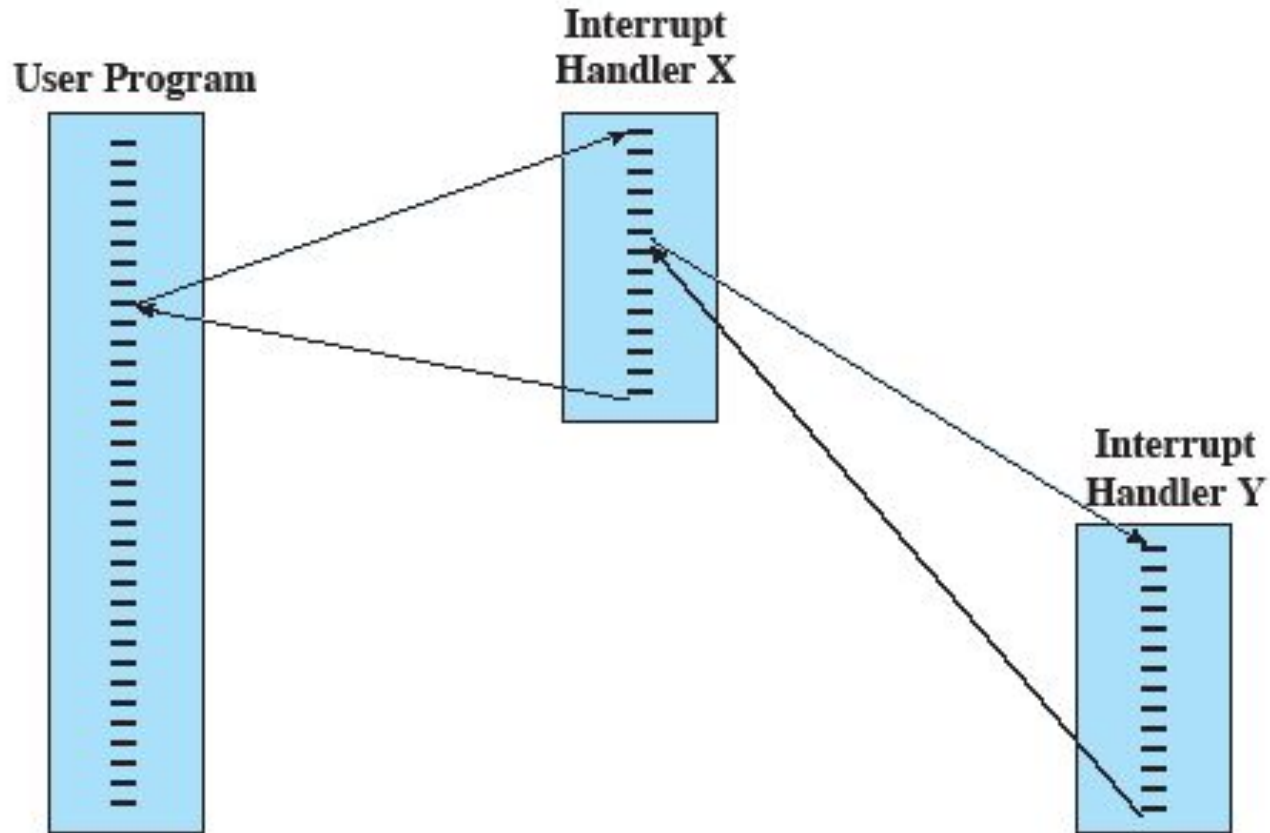
Sequential Interrupt Processing



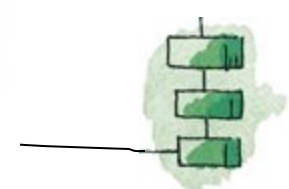
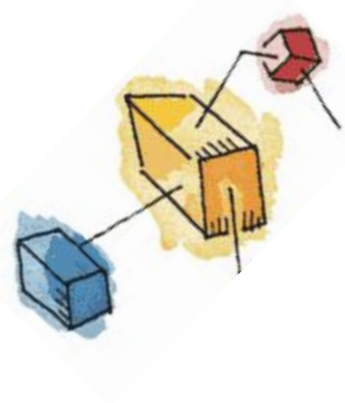
(a) Sequential interrupt processing



Nested Interrupt Processing



(b) Nested interrupt processing



Example of Nested Interrupts

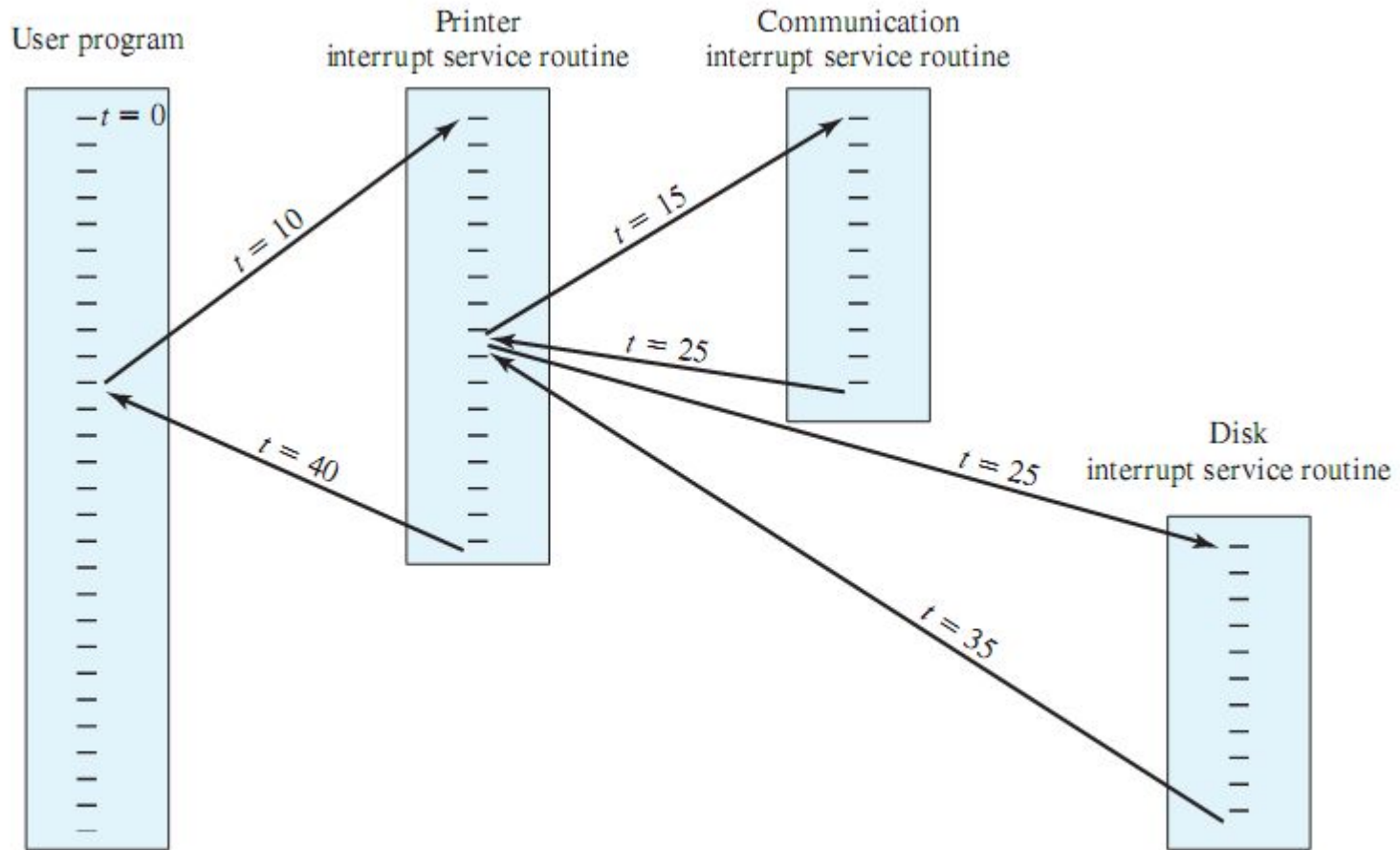


Figure 1.13 Example Time Sequence of Multiple Interrupts



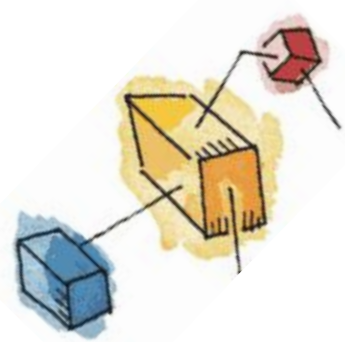
Multiprogramming

- 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
- 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

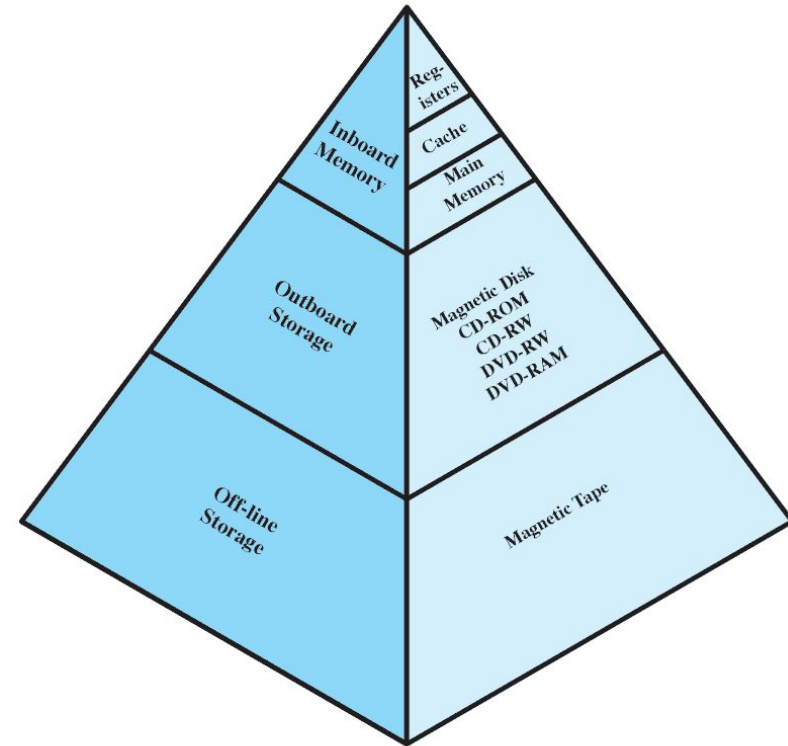
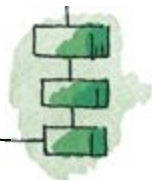
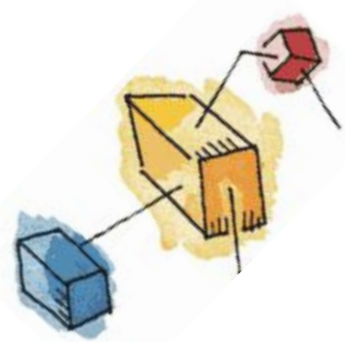


Figure 1.14 The Memory Hierarchy

Secondary Memory

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





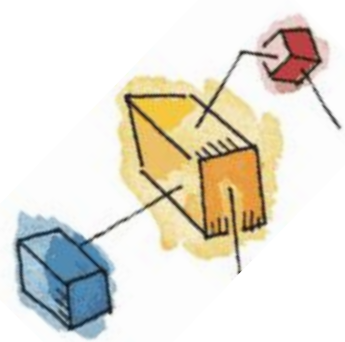
Roadmap

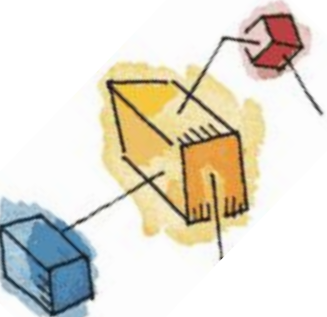
- Basic Elements
- Processor Registers
- Instruction Execution
- Interrupts
- The Memory Hierarchy
- **Cache Memory**
- I/O Communication Techniques



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

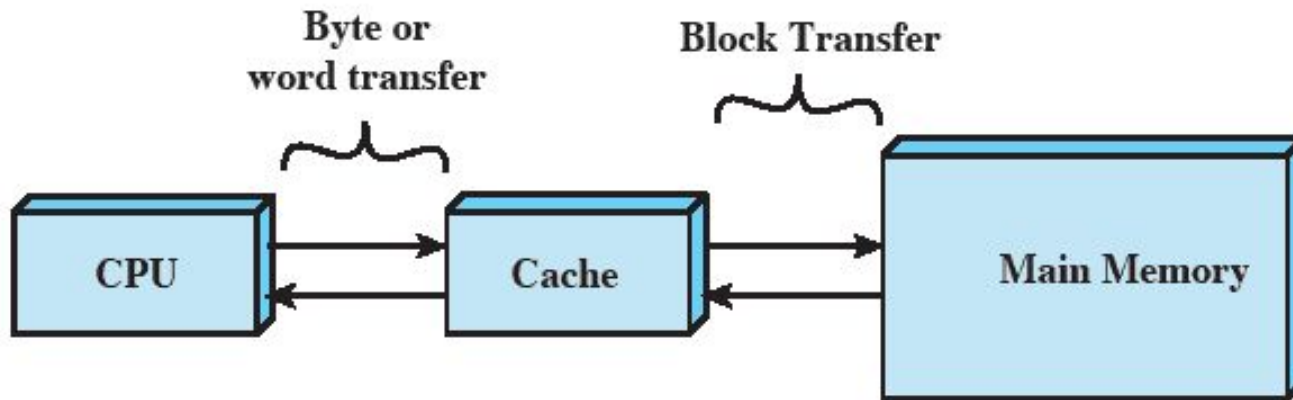
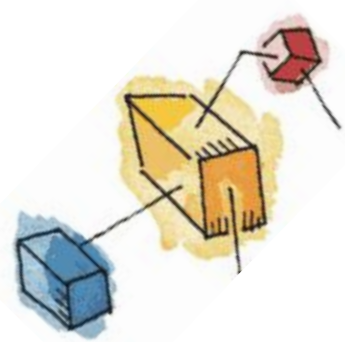


Figure 1.16 Cache and Main Memory



Cache Principles

- 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

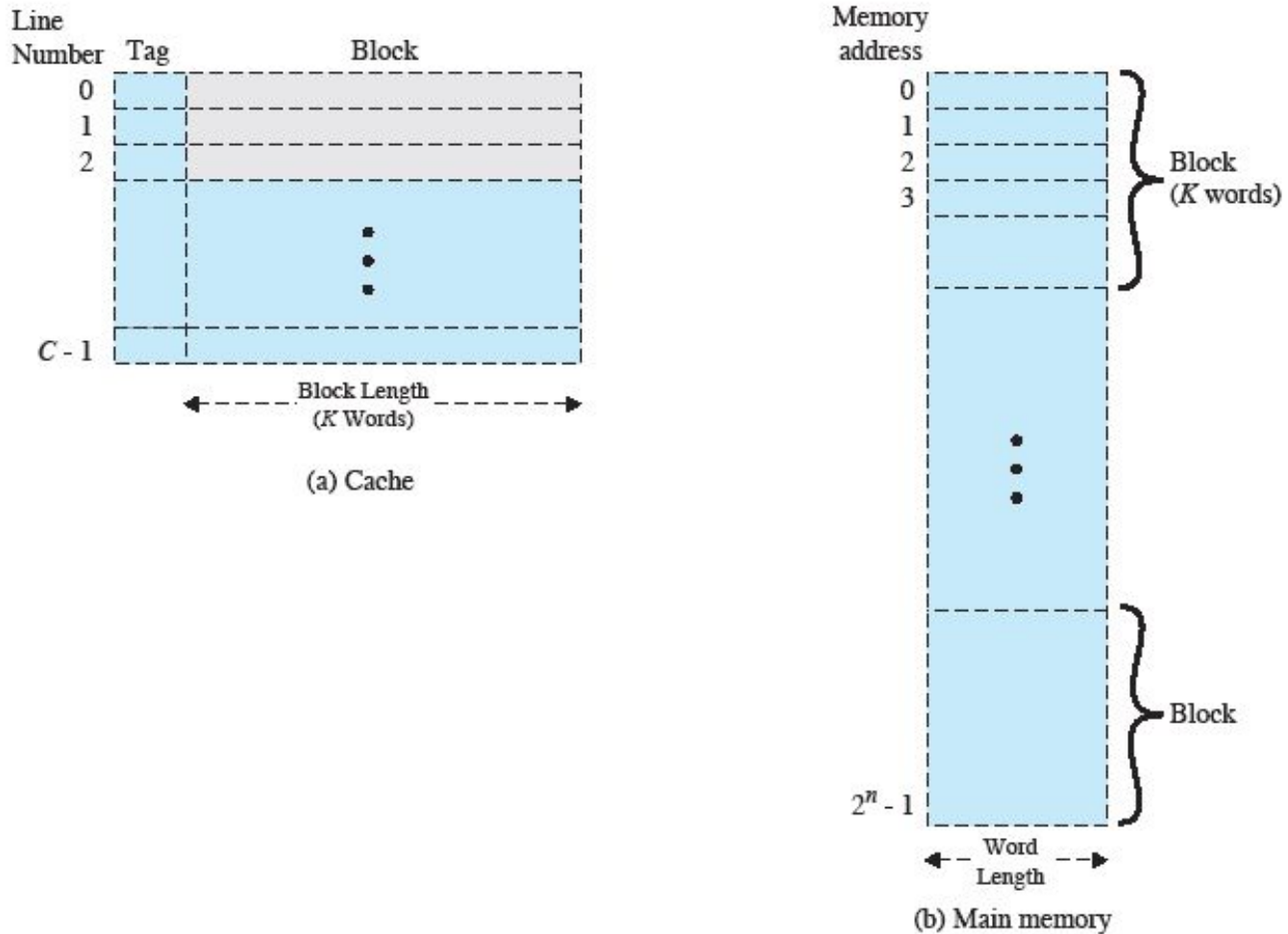


Figure 1.17 Cache/Main-Memory Structure

Cache Read Operation

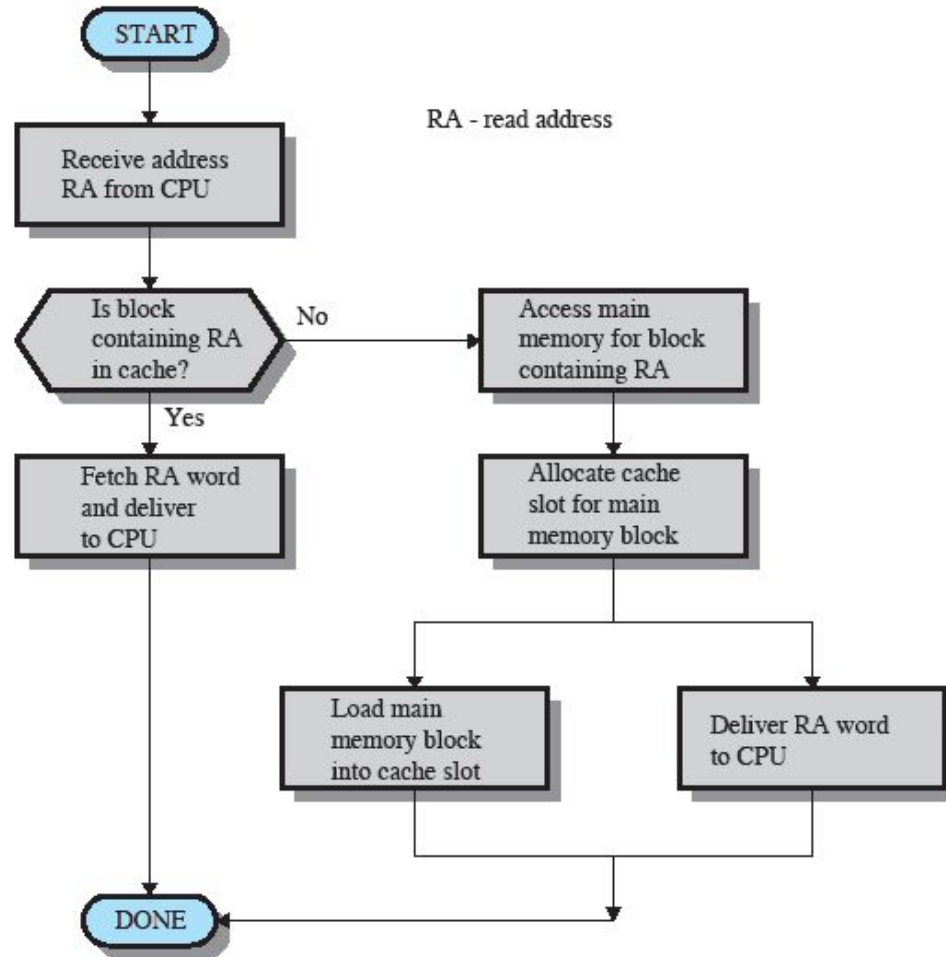
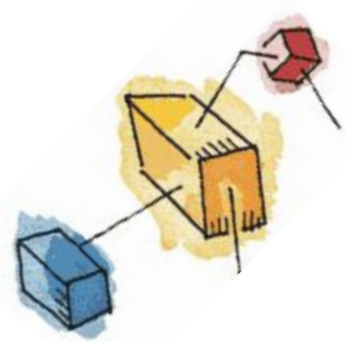


Figure 1.18 Cache Read Operation



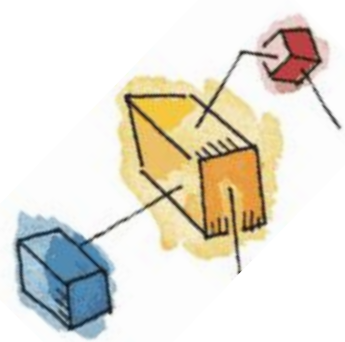
Cache Design Issues

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



Size issues

- Cache size
 - Small caches have significant impact on performance
- 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.

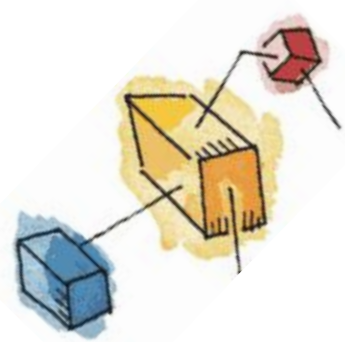




Mapping function

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





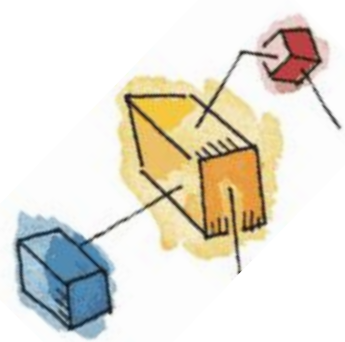
Replacement Algorithm

- 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





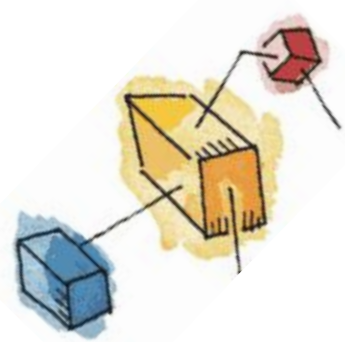
Roadmap

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



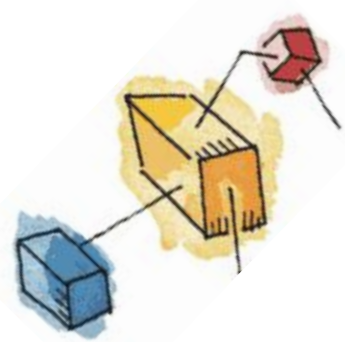
I/O Techniques

- 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)



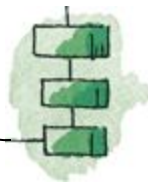
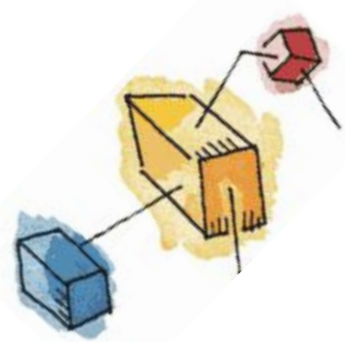
Programmed I/O

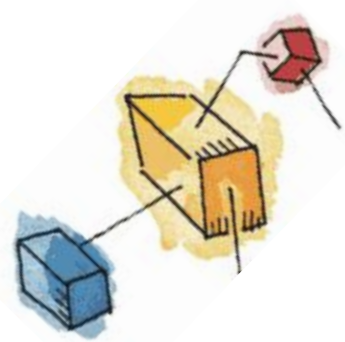
- The I/O module performs the requested action
 - then sets the appropriate bits in the I/O status register
 - but takes no further action to alert the processor.
- As there are no interrupts, the processor must determine when the instruction is complete



Programmed I/O Instruction Set

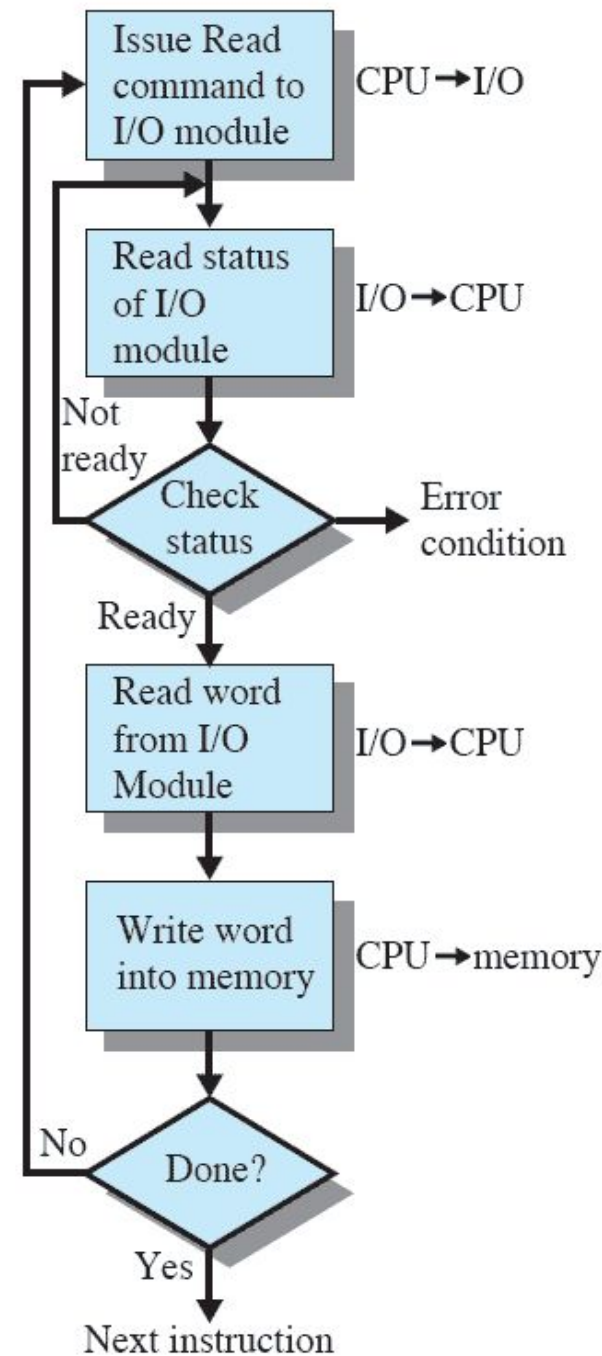
- Control
 - Used to activate and instruct device
- Status
 - Tests status conditions
- Transfer
 - Read/write between process register and device





Programmed I/O Example

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



(a) Programmed I/O

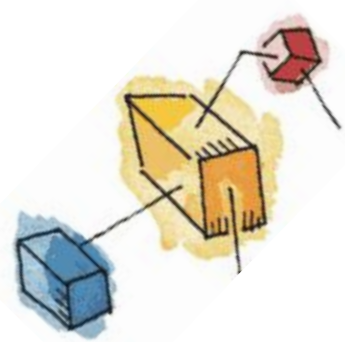




Interrupt-Driven I/O

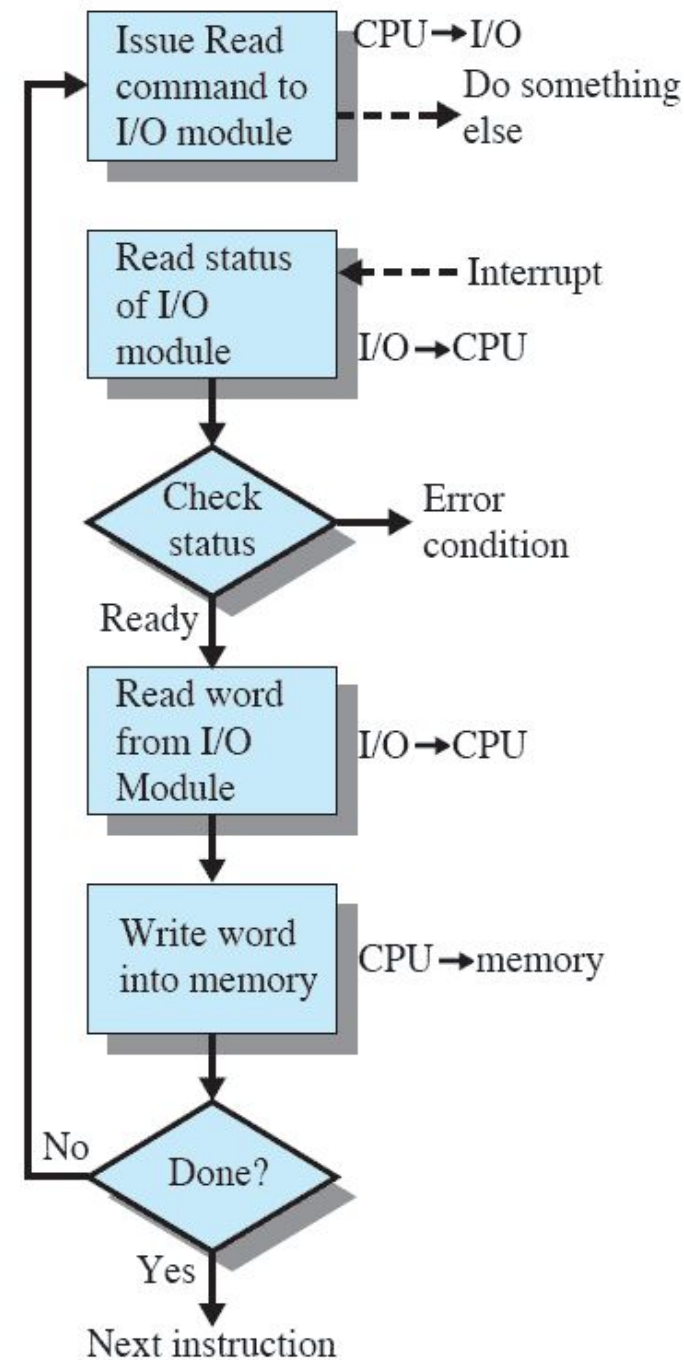
- Processor issues an I/O command to a module
 - and then goes on to do some other useful work.
- The I/O module will then interrupt the processor to request service when it is ready to exchange data with the processor.





Interrupt-Driven I/O

- Eliminates needless waiting
 - But everything passes through processor.



(b) Interrupt-driven I/O





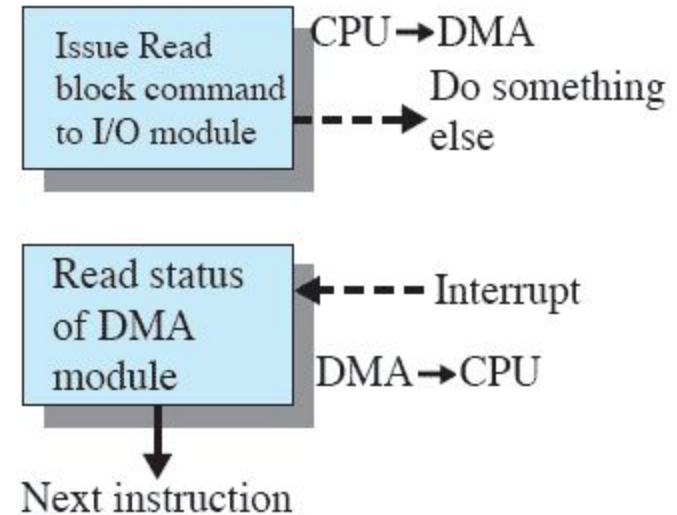
Direct Memory Access

- 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

