Chapter 4

Computer Organization

Program Specification

Source

```
int a, b, c, d;
. . .
a = b + c;
d = a - 100;
```

Assembly Language

```
; Code for a = b + c
    load      R3,b
    load      R4,c
    add       R3,R4
    store     R3,a

; Code for d = a - 100
    load      R4,=100
    subtract  R3,R4
    store     R3,d
```

Machine Language

Assembly Language

```
; Code for a = b + c
    load      R3,b
    load      R4,c
    add       R3,R4
    store     R3,a

; Code for d = a – 100
    load      R4,=100
    subtract  R3,R4
    store     R3,d
```

Machine Language

```
10111001001100…1
10111001010000…0
10100111001100…0
10111010001100…1
10111001010000…0
10100110001100…0
10111001101100…1
```


Von Neumann Concept

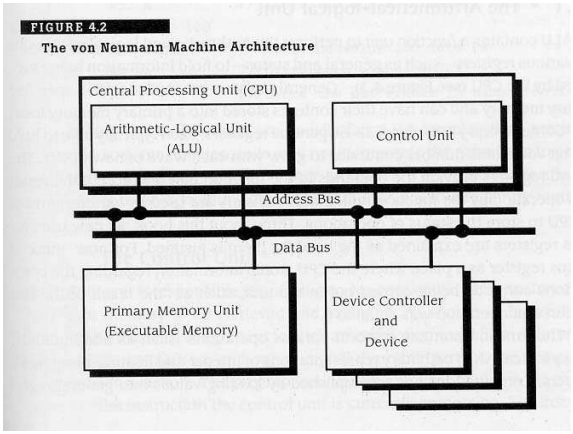
- Stored program concept
- General purpose computational device driven by internally stored program
- Data and instructions look same i.e. binary
- Operation being executed determined by HOW we look at the sequence of bits
  - Fetch
  - Decode
  - Execute

  } View bits as instruction

Data might be fetched as a result of execution

Von Neumann Architecture

- CPU
  - ALU
  - Control Unit
- I/O Buses
- Memory Unit
- Devices

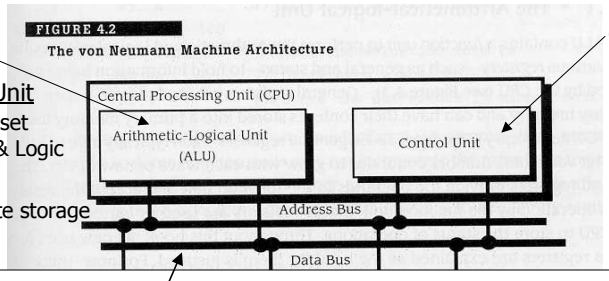


Von Neumann Machine Architecture

CPU = ALU + Cntrl Unit

ALU

- Functional Unit
  + Instruction set
  + Arithmetic & Logic
- Registers
  + Intermediate storage



Cntrl Unit

- fetch
- decode
- execute

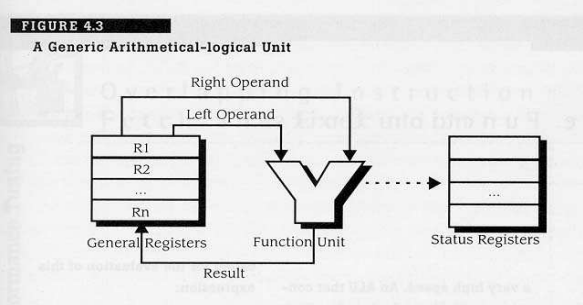
⇩ ALU

Buses

Address Bus / Data Bus wires over which Instr / data is transferred from memory to ALU

Von Neumann Bottleneck

CPU: **ALU** Component



- Assumes instruction format: OP code, LHO, RHO
  - Instruction / data fetched & placed in register
  - Instruction / data retrieved by functional unit & executed
  - Results placed back in registers
- Control Unit sequences the operations

Program Specification (revisited)

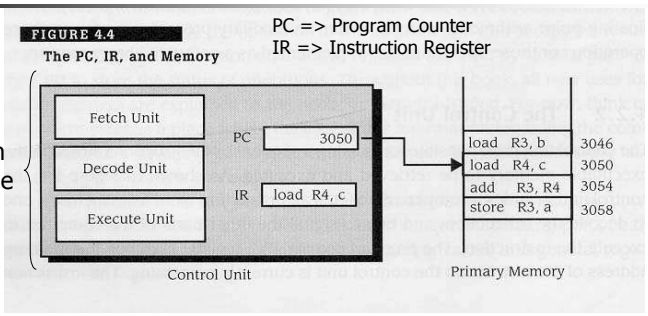
Source

```
int a, b, c, d;
. . .
a = b + c;
d = a - 100;
```

Assembly Language

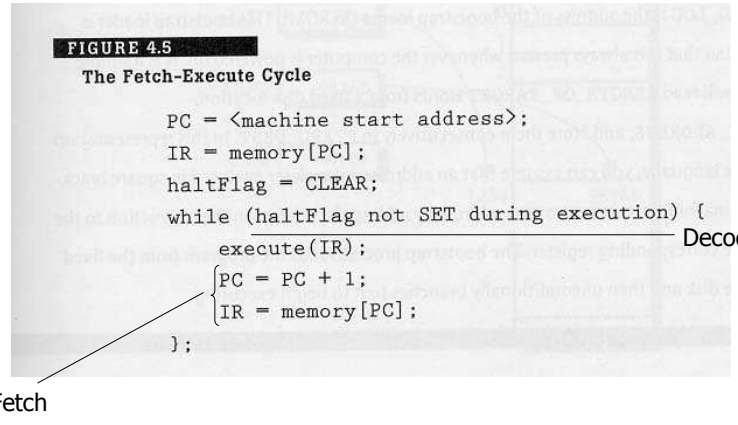
```
; Code for a = b + c
    load      R3,b
    load      R4,c
    add       R3,R4
    store     R3,a

; Code for d = a - 100
    load      R4,=100
    subtract  R3,R4
    store     R3,d
```

CPU: **Control Unit** Component



- Fetch Unit
  - Get instruction at location pointed to by PC and place in IR
- Decode Unit
  - Determine which instruction & signal hardware that implements it
- Execute Unit
  - Hardware for instruction execution (could cause more data fetches)

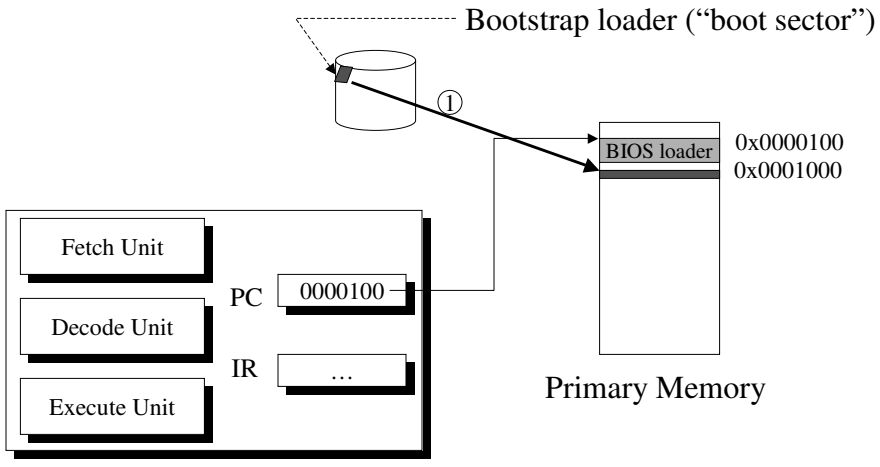
Fetch – Execute cycle



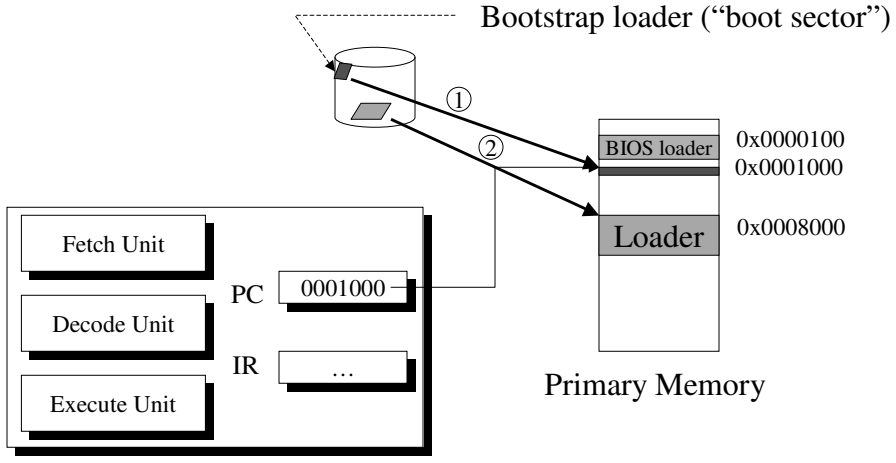
OS boot-up…

- How does the system boot up ?
  - Bootstrap loader
  - OS
  - Application

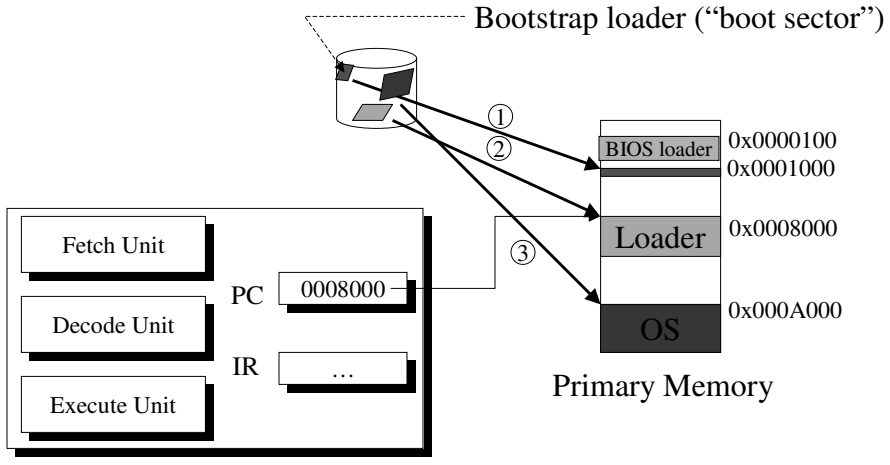
Bootstrapping



Bootstrapping



Bootstrapping



A Bootstrap Loader

The power-up sequence

```
load PC, FIXED_LOC
```

Address of BS Loader

Where FIXED_LOC addresses the bootstrap loader (in ROM).

The bootstrap loader has the form:

```
        load R1, =0
        load R2, = LENGTH_OF_TARGET
loop:   read R1, FIXED_DISK_ADDRESS
        store R1, [FIXED_DEST, R1]
        incr R1
        bleq R1, R2, loop
        br FIXED_DEST
```

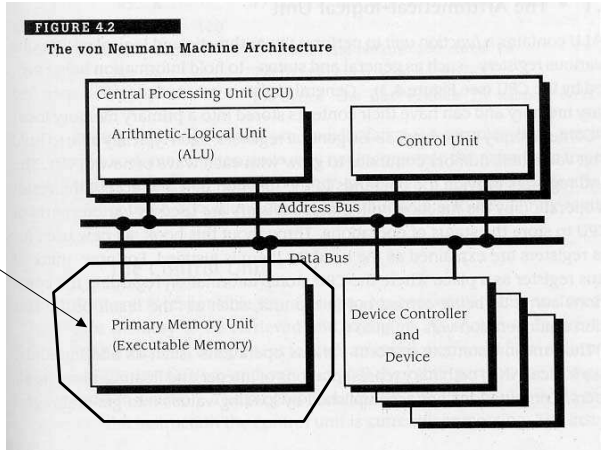
Reads OS in

Fetch
Decode
Execute

Branches to OS

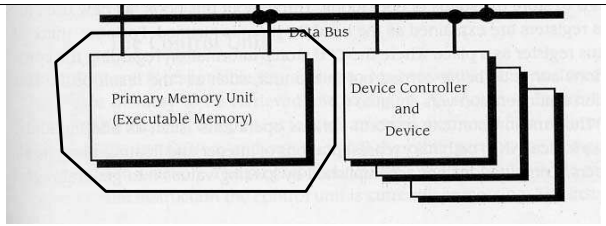
Memory Unit

Memory Unit



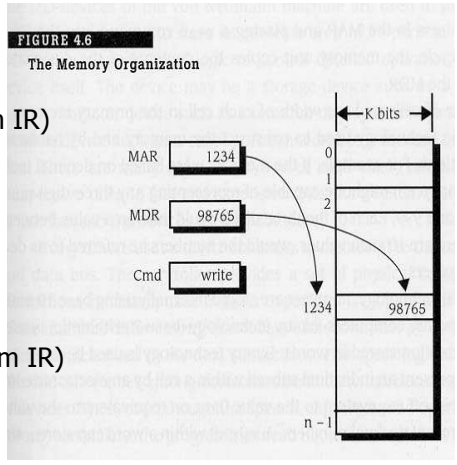
Memory Unit

- Memory Unit contains
  - Memory
    - Instructions & Data
  - MAR (Memory Address Register)
  - MDR (Memory Data register)
  - CMD (Command Register)
  - Get instruction at location pointed to by PC and place in IR

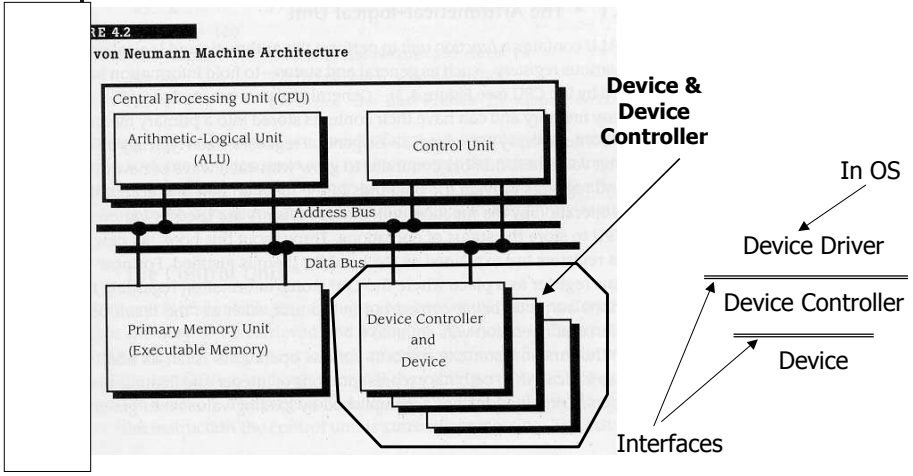


Memory Access

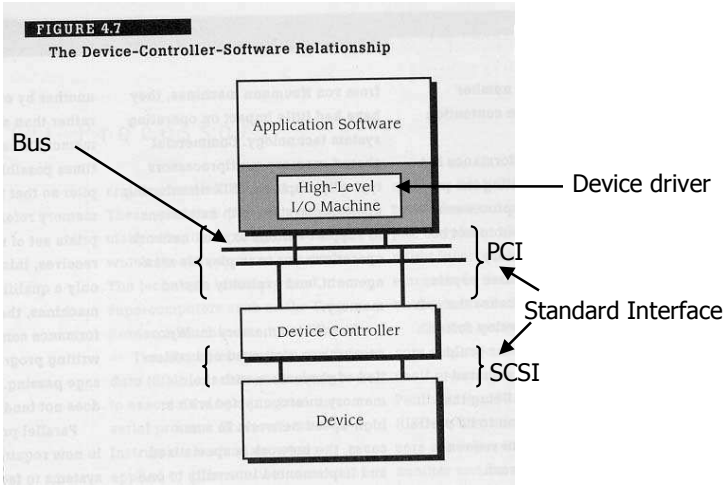
- Read from Memory
  - `MAR ← MemAddr`
  - `CMD ← 'Read OP'` (from IR)
  - Execute
    `MDR ← Mem[ MAR ]`
- Write to Memory
  - `MAR ← MemAddr`
  - `CMD ← 'Write OP'` (from IR)
  - Execute
    `Mem[ MAR ] ← MDR`



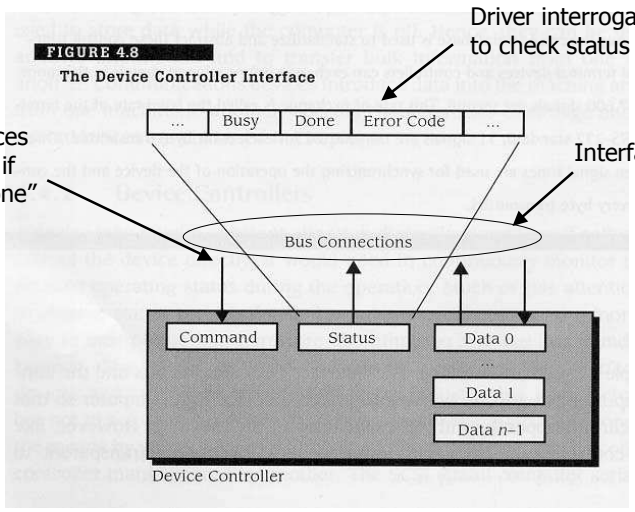
Device & Device Controller



Device Controller-Software Relationship

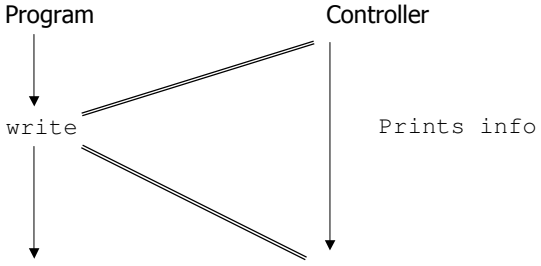


Device Controller Interface

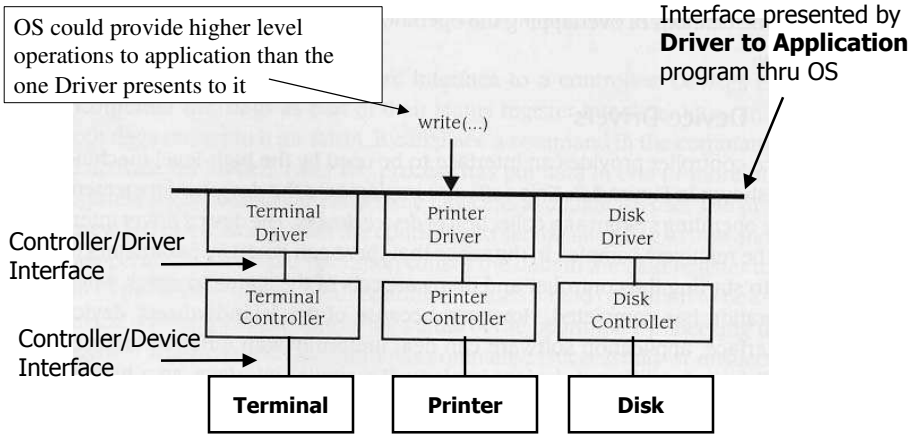


Device Controller

- Device controller is a processor and allows 2 parts of the process to proceed concurrently



Device Driver Interface



How do interrupts factor in ?

- Scenario (1)
  - Program:

```
while device_flag busy {}
```

  => Busy wait - consumes CPU cycles

- Scenario (2)
  - Program:

```
while (Flag != write) {
  sleep( X )
}
```

  =>If write available while program sleeping - inefficient

How do interrupts factor in ? …

- Scenario (3)
  - Program:

    `issues "write"`

Driver:

- Suspend program until write is completed,

  then program is unsuspended

This is Interrupt-driven

Interrupts Driven Service Request

- Process is suspended only if driver/controller/device cannot service request
- If a process is suspended, then, when the suspended process' service request can be honored
  - Device interrupts CPU
  - OS takes over
  - OS examines interrupts
  - OS un-suspends the process
- Interrupts
  - Eliminate busy wait
  - Minimizes idle time

Interrupts …

Interrupt Handler in OS:

```
disables interrupts
        :
        :   Interrupt processed
        :
        :
enables interrupts
```

What if multiple devices (or 2nd device) sends interrupt while the OS is handling prior interrupt ?

If **priority** of 2nd interrupt higher than 1st then 1st interrupt suspended ⇨ 2nd interrupt handled ⇨ Resumption of handling 1st interrupt

Control Unit with Interrupt (H/W)

```
PC = <machine start address>;
IR = memory[PC];
haltFlag = CLEAR;
while(haltFlag not SET) {
    execute(IR);
    PC = PC + sizeof(INSTRUCT);
    IR = memory[PC];
    if(InterruptRequest) {
        memory[0] = PC;
        PC = memory[1]
};
```

memory[1] contains the address of the interrupt handler

Interrupt Handler (Software)

```
interruptHandler() {
    saveProcessorState();
    for(i=0; i<NumberOfDevices; i++)
        if(device[i].done) goto deviceHandler(i);
    /* something wrong if we get to here … */


deviceHandler(int i) {
    finishOperation();
    returnToScheduler();
}
```


A Race Condition

```
saveProcessorState() {
    for(i=0; i<NumberOfRegisters; i++)
        memory[K+i] = R[i];
    for(i=0; i<NumberOfStatusRegisters; i++)
        memory[K+NumberOfRegisters+i] = StatusRegister[i];
}
```

```
PC = <machine start address>;
IR = memory[PC];
haltFlag = CLEAR;
while(haltFlag not SET) {
    execute(IR);
    PC = PC + sizeof(INSTRUCT);
    IR = memory[PC];
    if(InterruptRequest && InterruptEnabled) {
        disableInterupts();
        memory[0] = PC;
        PC = memory[1]
};
```

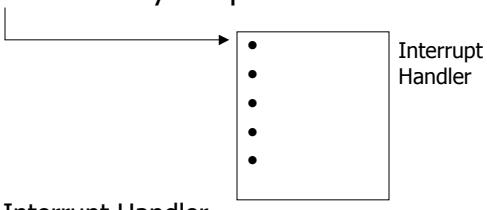
Revisiting the `trap` Instruction (H/W)

```
executeTrap(argument) {
    setMode(supervisor);
    switch(argument) {
    case 1: PC = memory[1001];  // Trap handler 1
    case 2: PC = memory[1002];  // Trap handler 2
    . . .
    case n: PC = memory[1000+n];// Trap handler n
};
```

- The trap instruction dispatches a trap handler routine atomically
- Trap handler performs desired processing
- "A trap is a software interrupt"

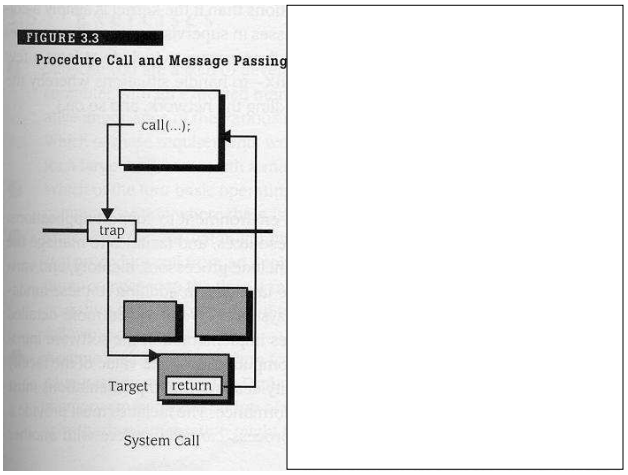
Requesting Service from OS

- Kernel functions are invoked by "trap"



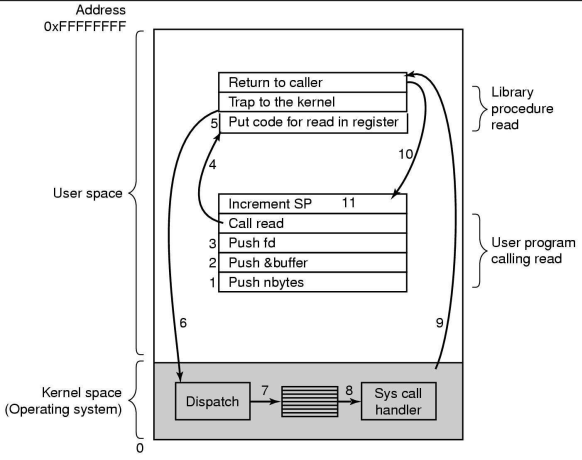
- System call
  - Process traps to OS Interrupt Handler
  - Supervisor mode set
  - Desired function executed
  - User mode set
  - Returns to application

Requesting Svc: System Call



Steps in making a system call

Taken from Modern Operating Systems, 2nd Ed, Tanenbaum, 2001



There are 11 steps in making the system call read (fd, buffer, nbytes)