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Lecture Notes on Computer Architecture

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Internal connection between processor & memory:

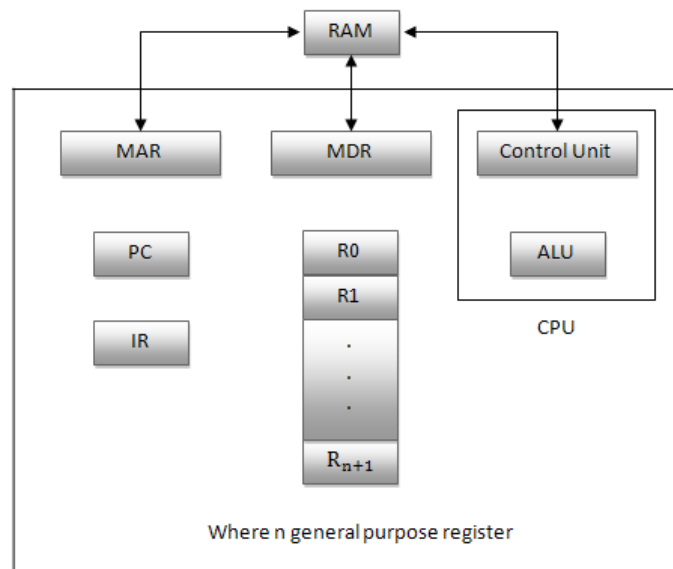


Fig: Internal Connection between Processor & Memory.

MAR:

- ✓ MAR means Memory Address Register.
- ✓ It holds the address of the main memory from where data is to be transferred.

PC:

- ✓ PC means Program Counter.
- ✓ It holds the address of the next instructions.

IR:

- ✓ IR means Instruction Register.
- ✓ It stores the instruction that is currently being executed.
- ✓ It gives the operation to the CU to generate the timing signal that controls the execution.

MDR:

- ✓ MDR means Memory Data Register / Buffer Register.
- ✓ It holds the data which write into / Read out of address location.

Register:

- ✓ n General purpose register R_0 through R_{n+1} is used for storing data.

CU:

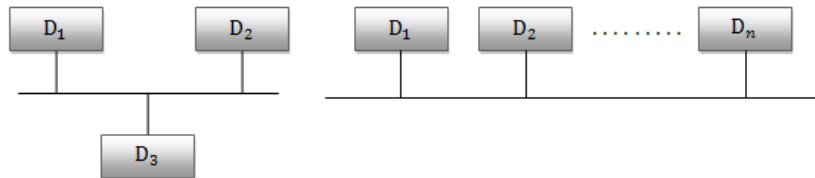
- ✓ CU means Control Unit.
- ✓ The memory, arithmetic & logic, input & output units store & process information & perform input / output operation. These operation units must be co-ordinate in same way. This is the task of the CU.
- ✓ Send control signal to other units and sense their state.

ALU:

- ✓ ALU means Arithmetic Logic Unit.
- ✓ It perform the arithmetic operation like addition, subtraction etc.

Bus:

- ✓ It is a common path way connecting two or more devices.
- ✓ It is a shared transmission medium.



- ✓ At a time only one device should be transmitted signal.

Width of Bus:

Width of Bus means at a time how many amount of data (bit) can be transferred.

Single Bus Structure:

- ✓ The system structure where all units are connected to a bus.
- ✓ The bus can be used for only one transfer at a time so that only two units can actively use the bus at any given time.



Fig: Single Bus Structure

Advantages:

- ✓ Low cost
- ✓ Flexibility
- ✓ Easy to design

Disadvantages:

- ✓ Only one data transfer at a time.
- ✓ Time consuming to any program.

Multiple Bus Structure:

- ✓ The system structure where multiple buses are used.
- ✓ Multiple buses active more concurrently in operation by allowing two or more transfers.

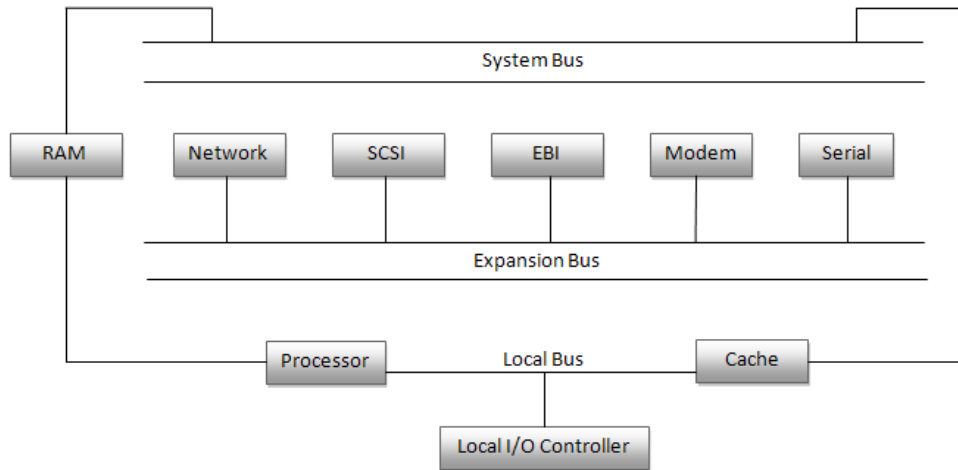


Fig: Multiple Bus structure

Advantages:

- ✓ Allows the system to support a wider variety of devices.
- ✓ More speed than single bus structure.

Disadvantage:

- ✓ Low performance due to the more devices greater the bus length propagation delays.
- ✓ The bus becomes bottleneck as the aggregate data transfer rate increases towards the capacity of the bus.

High Speed Architecture:

- ✓ High speed bus brings high devices closer to the Processor.
- ✓ High speed buses are used.
- ✓ They are independent to the processor.

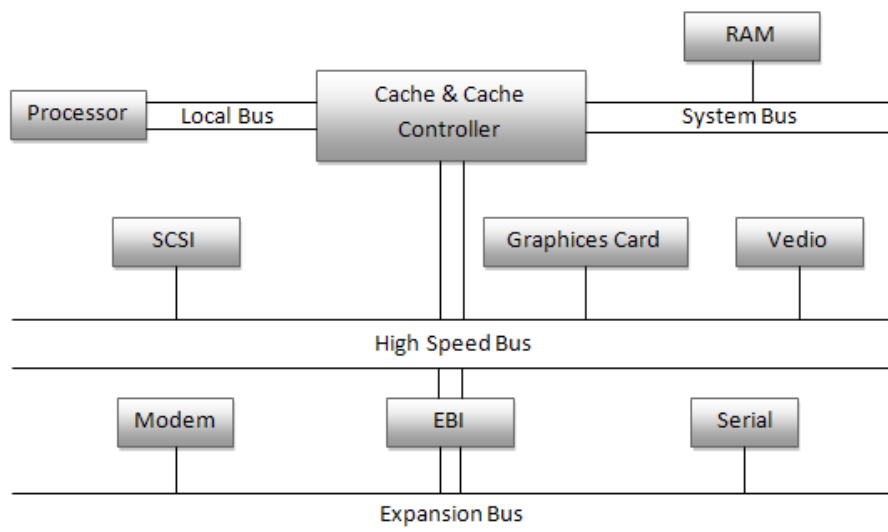


Fig: High Speed Architecture

Advantage:

- ✓ High speed

Disadvantage:

- ✓ Costly
- ✓ Implementation is very difficult

System Bus:

- ✓ A bus that connect major components (Processor, memory, I/O).
- ✓ It consists of 50 to 100 separate lines; each line is used for a particular purpose.
- ✓ 50 to 100 lines can classify into functional groups.
 - Data lines.
 - Address lines.
 - Control lines.

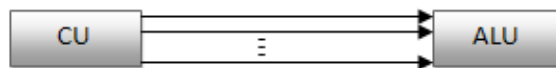


Fig: System Bus

i. Data bus:

- ✓ It transmits or transfer data between various modules.
- ✓ Data lines are collectively called data bus.

ii. Address bus:

- ✓ Address lines are collectively called address bus.
- ✓ 4-bit address bus means $2^4 = 16$ B. So, if address width is 20 bit then $2^{20} = 1$ MB.

iii. Control bus:

- ✓ Control lines are collectively called control bus.
- ✓ Used to control signals.

Bus Arbitration:

- ✓ The process of selecting bus master. That means select the device which can transmit data on the bus right now.
- ✓ Only one bus master at a time.
- ✓ Several devices may complete for the control of the bus but one gets the control.

Daisy Chaining Approach:

- ✓ Every device must be set a priority.
- ✓ If device1 priority is greater than other device then device1 is selected as a bus master.

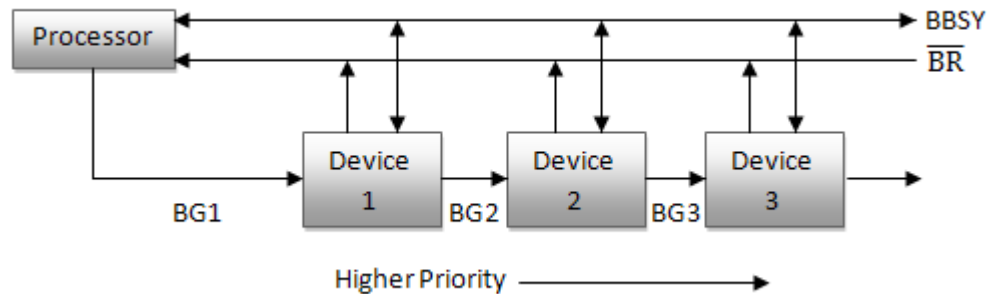


Fig: Daisy Chaining Approach

Advantage:

- ✓ Very simple concept
- ✓ Centralized, very easy to select bus master.
- ✓ Synchronizing process.

Disadvantage:

- ✓ Starvation problem (bored for waiting)
- ✓ Propagation delay
- ✓ The entire system fails if the higher priority device fails.

Distributed Arbitration:

- ✓ Distributed Arbitration means that all devices waiting to use the bus that have equal responsibility in carrying out the arbitration process, without using a central arbiter.
- ✓ Each device on the bus is assigned a 4-bit identification number.
- ✓ When one or more devices request the bus, they assert the Start – Arbitration signal and place their 4-bit ID numbers on their open collector lines, ARB0 through ARB3.

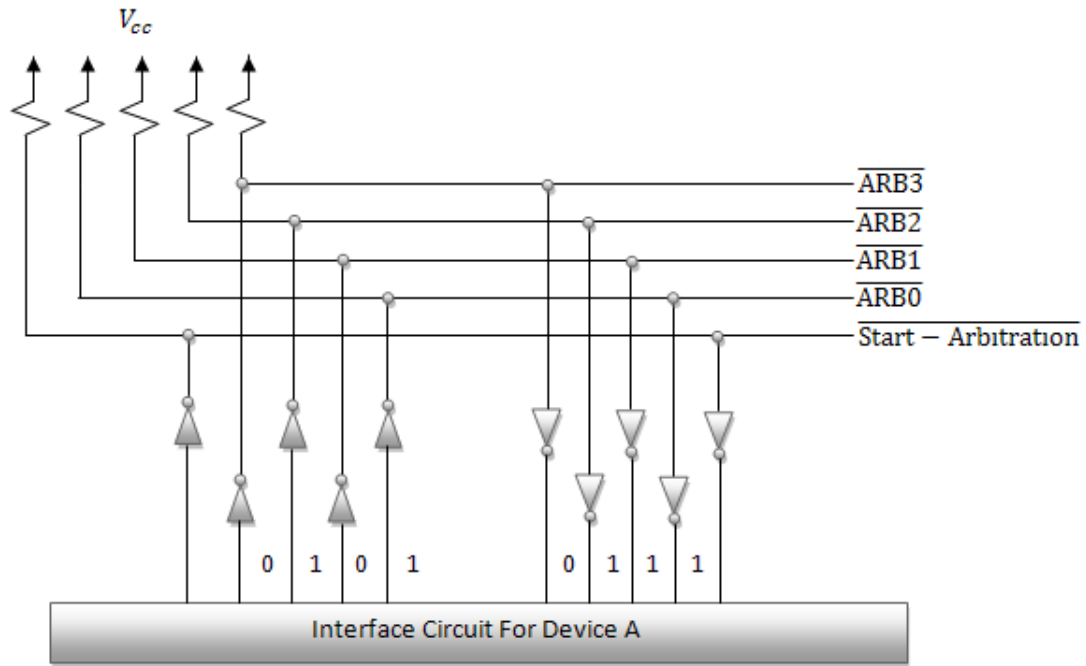


Fig: Distributed Arbitration

Advantages:

- ✓ Higher reliability due to the operation of the bus is not dependent on any single device.

PCI Bus:

- ✓ PCI means Peripheral Component Interaction.
- ✓ It has high bandwidth & it is very popular.
- ✓ It is an independent bus that can function as a peripheral bus.
- ✓ It requires very few chips to implement & supports other busses connected to it.
- ✓ It used centralized arbitration scheme.
- ✓ It can be used in both signal Processor (desktop system) & multiprocessor (server system) system.

PnP:

- ✓ PnP means Plug and Play.
- ✓ The device which we insert into the computer & it automatically recognized & configured in computer is called PnP.
- ✓ Intel created the PnP standard and incorporated it into the design for PCI.

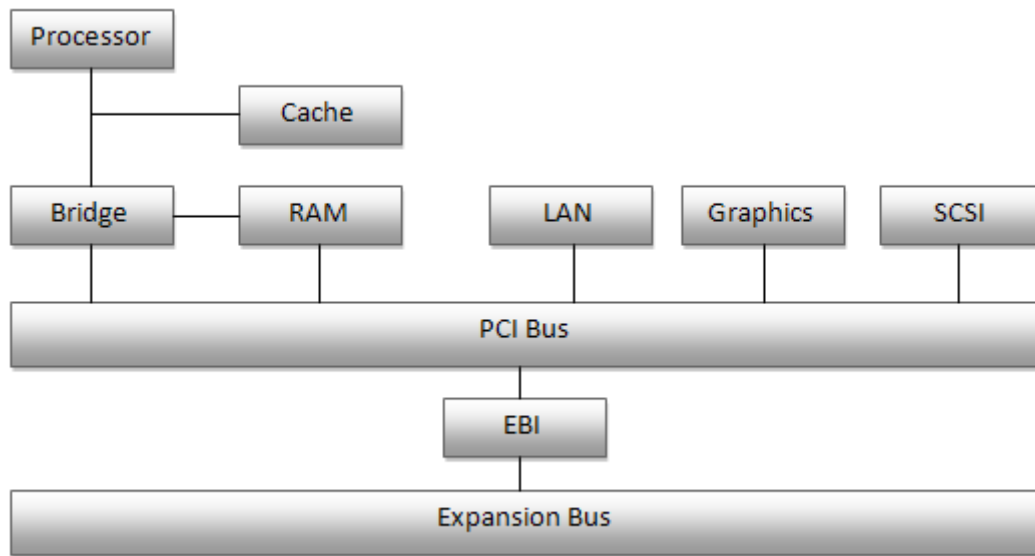


Fig: PCI Bus in Desktop System.

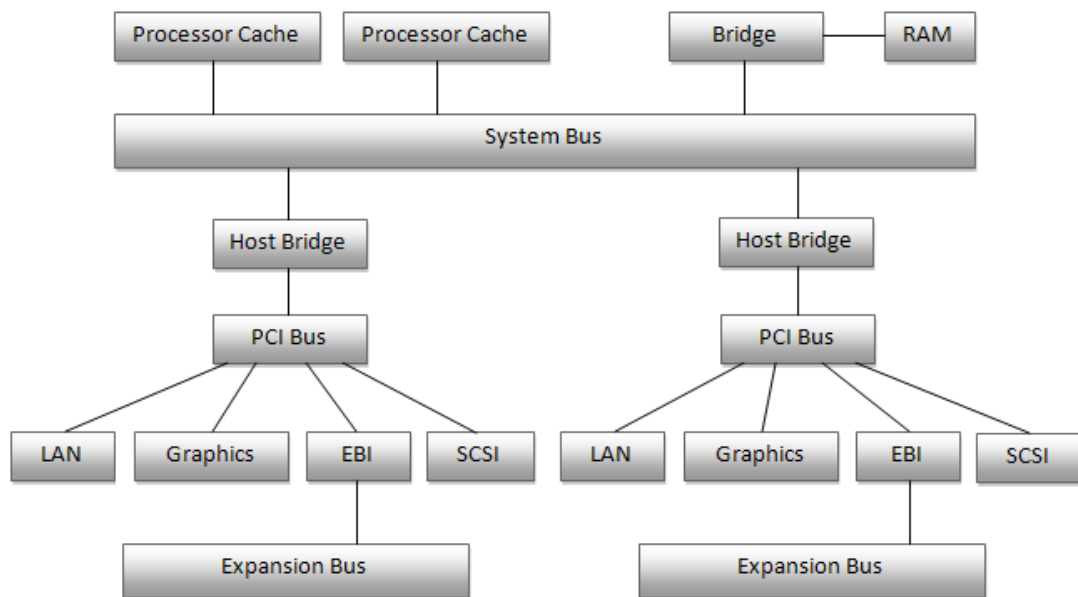


Fig: PCI Bus in Server System.

Q. What things are required to implement a PnP?

Solution:

To fully implement PnP requires three things:

➤ **PnP Bios:**

The core utility that enables PnP and detects PnP devices.

➤ **Extended System Configuration Data (ESCD):**

A file that contains information about installed PnP devices.

➤ **PnP operating system:**

Any operating system, such as Windows 95/98/ME/XP/Win7, that supports PnP. PnP handlers in the operating system complete the configuration process started by the BIOS for each PnP device.

Q. What are the key tasks for PnP automates?

Solution:

PnP automates several key tasks that were typically done either manually or with an installation utility provided by the hardware manufacturer. These tasks include the setting of:

➤ **Interrupt Request (IRQ):**

H/W interrupts to get the automation of CPU.

➤ **Direct memory access (DMA):**

The device is configured to access the system memory without consulting the CPU first.

➤ **Memory addresses:**

Many devices are assigned a section of system memory for exclusive use by that device. This ensures that the hardware will have the needed resources to operate properly.

➤ **Input / Output (I/O) configuration:**

This setting defines the ports used by the device for receiving and sending information.

Q. What will be happen if a new PCI based sound card is added to a PC?

Solution:

If a new PCI based sound card is added to a PC, then it performs some tasks. Those tasks are given below:

➤ The system BIOS initiates the PnP BIOS.

➤ The PnP BIOS scans the PCI bus for hardware by sending out a signal to any device connected to the bus & asking the device who it is.

➤ The sound card responds by identifying itself. The device ID is sent back across the bus to the BIOS.

- The PnP BIOS checks the ESCD to search the configuration data for the sound card. Since the sound card was just installed, there is no existing ESCD record for it.
- The PnP BIOS assigns IRQ, DMA, memory address and I/O settings to the sound card and saves the data in the ESCD.
- Operating System boots up. It checks the ESCD and the PCI bus. The operating system detects that the sound card is a new device and displays a small window telling you that Windows has found new hardware and is determining what it is.
- If it is able to determine what the device is, it displays the name of the device and attempts to install the driver. Driver is software that enables the device to communicate with the operating system. You may be asked to insert a disk with the driver on it or tell Windows where to find the driver software.
- If Windows cannot determine what the device is, it provides a dialog window so that you can specify what type of device it is and load a driver to run it.
- Once the driver is installed, the device should be ready for use. Some devices may require that you restart the computer before you can use them.

Address Numbers:

Address Numbers refers to the number of address in an instruction.

Types of address number:

There three types of address numbers.

1. One address number
2. Two address number
3. Three address number

Q. Represent the following equation by one/two/three address number,

$$Y = (A - B)/(C + D * E) . \text{ Using three address numbers:}$$

Solution:

Using three address numbers:

<u>Instructions</u>	<u>Comments</u>
SUB Y,A,B	$Y \leftarrow A - B$
MPY T,D,E	$T \leftarrow D * E$
ADD T,T,C	$T \leftarrow T + C \leftarrow C + D * E$
DIV Y,Y,T	$Y \leftarrow \frac{Y}{T} \leftarrow (A - B)/(C + D * E)$

Using two address numbers:

<u>Instructions</u>	<u>Comments</u>
SUB A,B	$A \leftarrow A - B$
MOV Y,A	$Y \leftarrow A$
MPY D,E	$D \leftarrow D * E$
ADD D,C	$D \leftarrow D + C$
DIV Y,D	$Y \leftarrow Y/D$

Using one address number: [by using Accumulator (AC)]

<u>Instructions</u>	<u>Comments</u>
LOAD E	$AC \leftarrow E$
MPY D	$AC \leftarrow AC * D \leftarrow E * D$
ADD C	$AC \leftarrow AC + C \leftarrow E * D + C$
STORE Y	$Y \leftarrow AC$
LOAD A	$AC \leftarrow A$
SUB B	$AC \leftarrow AC - B \leftarrow A - B$
DIV Y	$AC \leftarrow AC/Y$
STORE Y	$Y \leftarrow AC$

Using one address number: [by without using Accumulator (AC)]

<u>Instructions</u>
LOAD A
SUB B
STORE A
LOAD E
MPY D
ADD C
STORE C
LOAD A
DIV C
STORE Y

Pipelining:

- ✓ It is a process in which several storages of the CPU are used to execute more than one instruction concurrently.
- ✓ It is an effective way of organizing concurrently activity in any system.
- ✓ A pipelined processor may process each instruction in four steps:

- Fetch F : Read the instruction from the memory.
- Decode D : Decode the instruction & fetch the source operand.
- Execute E : Perform the operation specified by instruction.
- Write W : Store the result in the destination location.

Example:

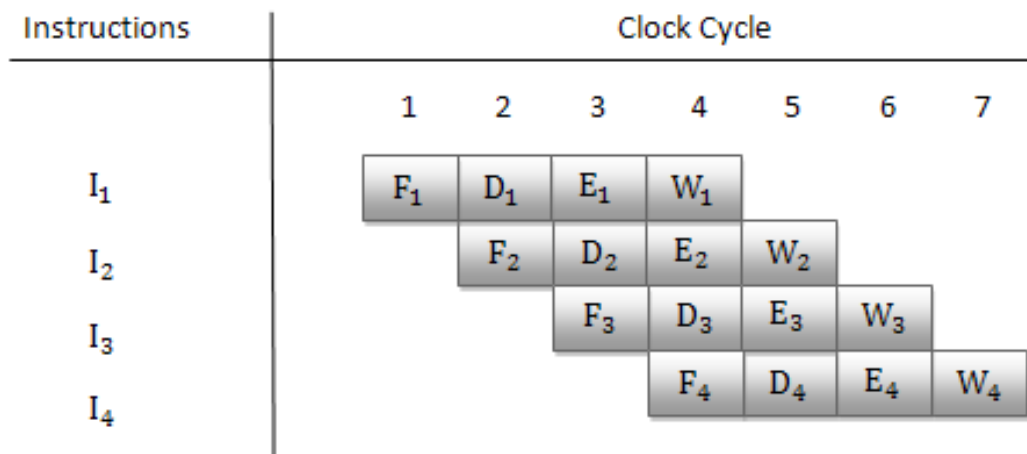


Fig: Pipelining

Normally for I_1 to I_4 instruction needs $4 \times 4 = 16$ clock cycle. But with the use of pipeline it is done with 7 clock cycle.

Super Pipelining:

- ✓ It's an alternative approach to achieve better performance.
- ✓ Many pipeline stages perform task that requires less than half of a clock cycle, so a double interval clock speed allow the performance of two tasks in one clock cycle.

Example:

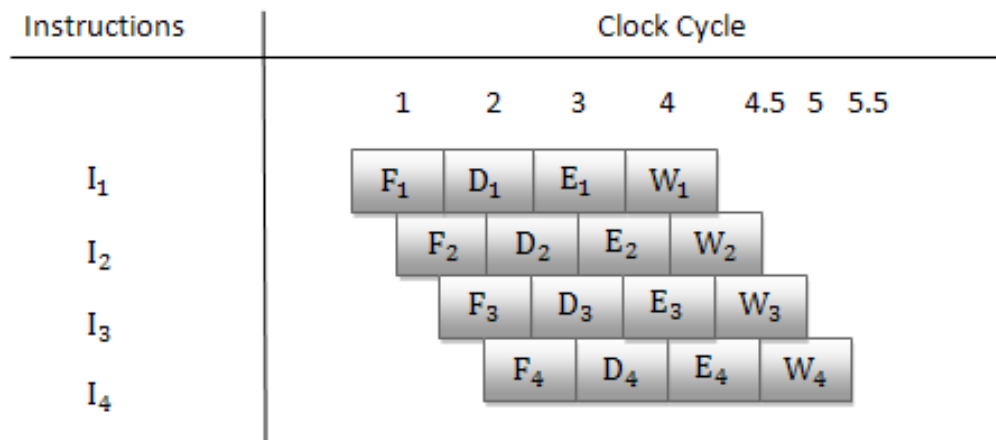


Fig: Super Pipelining

Supper Scalar:

- ✓ A Super Scalar process consists of multiple independent pipelines.
- ✓ Each pipeline consists of multiple stages, so that each one can handle multiple instructions at a time.

Example:

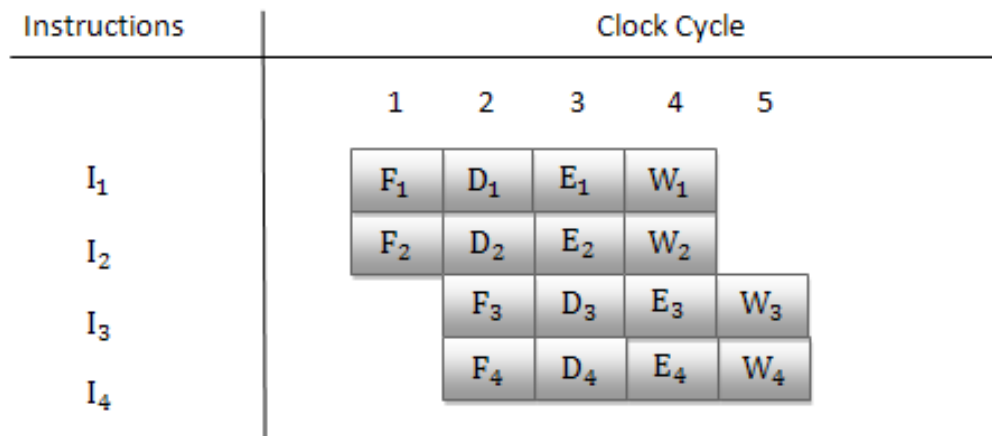


Fig: Supper Scalar

Q. Consider that, four instructions to execute I_1, I_2, I_3, I_4 and each has 4 steps (F, D, E, W). Each part/steps take 2 clock cycles to execute. Compare the performance of (i) Pipelining (ii) Super pipelining & (iii) Scalar pipelining.

Solution:

Using Pipelining:

Instructions	Clock Cycle						
	2	4	6	8	10	12	14
I_1	F ₁	D ₁	E ₁	W ₁			
I_2		F ₂	D ₂	E ₂	W ₂		
I_3			F ₃	D ₃	E ₃	W ₃	
I_4				F ₄	D ₄	E ₄	W ₄

Fig: Pipelining

Using Super Pipelining

Instructions	Clock Cycle						
	2	4	6	8	9	10	11
I_1	F ₁	D ₁	E ₁	W ₁			
I_2		F ₂	D ₂	E ₂	W ₂		
I_3			F ₃	D ₃	E ₃	W ₃	
I_4				F ₄	D ₄	E ₄	W ₄

Fig: Super Pipelining

Using Scalar Pipelining

Instructions	Clock Cycle				
	2	4	6	8	10
I_1	F_1	D_1	E_1	W_1	
I_2	F_2	D_2	E_2	W_2	
I_3		F_3	D_3	E_3	W_3
I_4		F_4	D_4	E_4	W_4

Fig: Scalar Pipelining

In the above discussion, we see that, Pipelining needs 14 clock cycles, super pipelining needs 11 clock cycles but Super Scalar needs only 10 clock cycles.

Problems of super scalar:

✓ Data dependency:

$I_1: ADD\ R_1, R_2$

$I_2: DIV\ R_3, R_1$

In this case, *DIV* of I_2 instruction depend on the I_1 results of R_1 .

✓ Procedure dependency:

✓ Resource conflict:

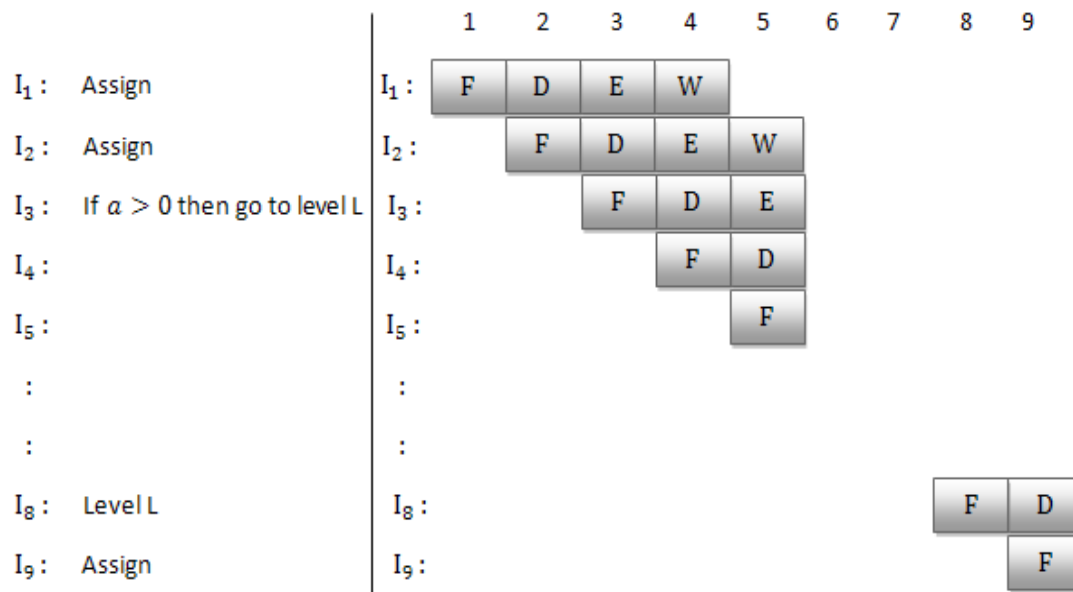
Instruction Level Parallelism:

The degree to which the instruction of a program can be executed parallel is called instruction level parallelism.

$I_1 :$	F_1	D_1	E_1	W_1
$I_2 :$	F_2	D_2	E_2	W_2
$I_3 :$	F_3	D_3	E_3	W_3
$I_4 :$	F_4	D_4	E_4	W_4

Fig: 4th degree

Effect of branch on pipelining:



Branch Condition:

A conditional branch instruction introduces the added caused by the dependency of the branch condition on the result of a preceding instruction.

Branch Penalty:

F & D steps block the buffer until solve of the branch condition, in this situation we need some time to free this buffer. This time is called branch penalty.

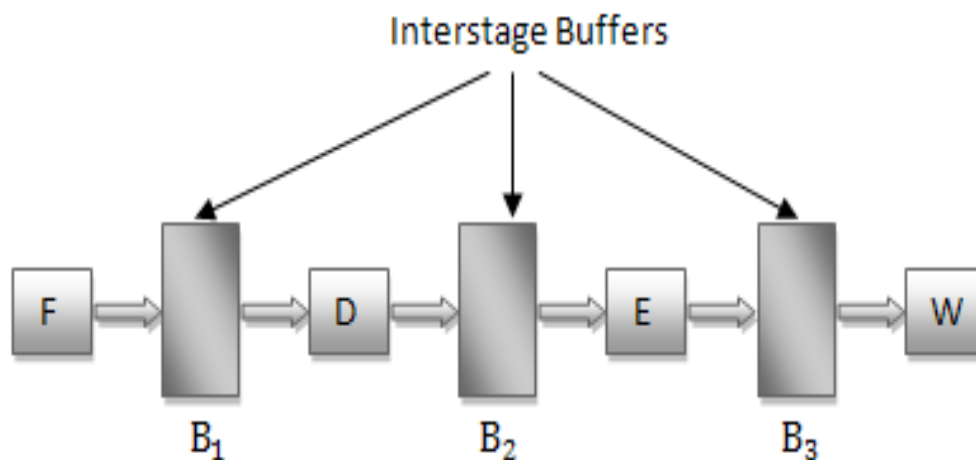


Fig: Branch Penalty.

Logic to deal with branch:

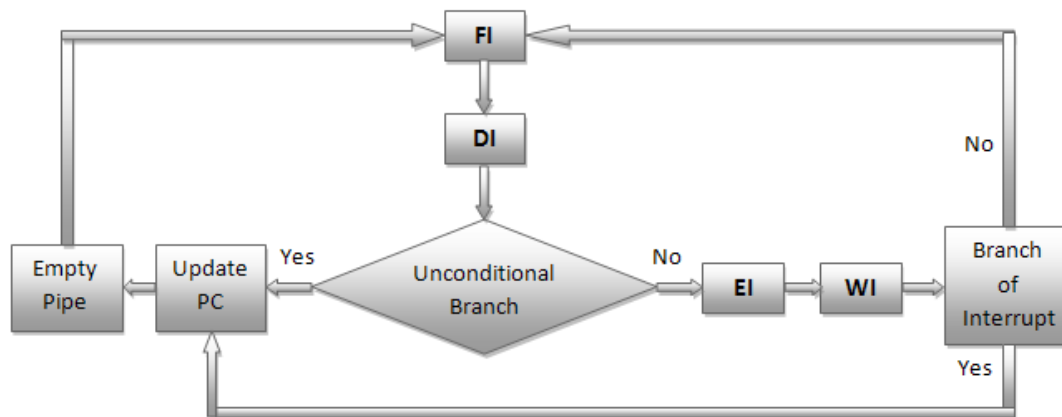


Fig: Logic to deal with branch.

Different ways of implementing a multiprocessor:

Multiprocessor System:

A machine that includes an efficient high bandwidth medium for communication among the multiple processors, memory devices or I/O devices.

There are three ways to implement a multiprocessor system:

- (i) Uniform Memory Access (UMA).
- (ii) Non-uniform memory Access (NUMA).
- (iii) Distributed Memory Access (DMA).

Uniform Memory Access (UMA):

- ✓ An interconnection network permits n processors to access k memories so that any of the processors can access any of the memories.
- ✓ The interconnection network introduces considerable delay for each memory access.
- ✓ If this delay is same for all memory access then it is an UMA system.

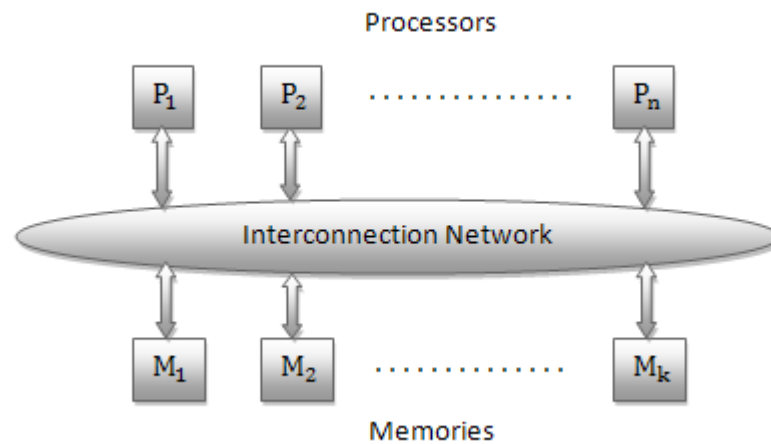


Fig: Uniform Memory Access

Non-uniform memory Access (NUMA):

- ✓ Memory modules are attached directly to the processor.
- ✓ Each processor can access its own memories (local) as well as the other processors memories via network.
- ✓ If local memory access time is T_1 and other memory access time is T_2 then $T_2 > T_1$. In this case, it is called Non-uniform memory access.

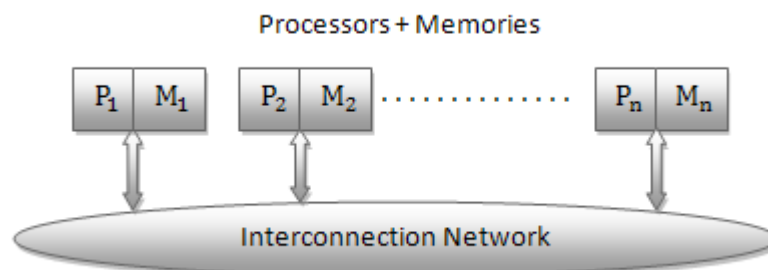


Fig: Non-uniform memory Access

Distributed Memory Access (DMA):

- ✓ All memory modules are private to their corresponding processor.
- ✓ A processor can not access a remote memory without the cooperation of the remote processor. Ex. Processor P_1 can't access the memory of P_2 until P_2 permit.
- ✓ Permission procedure is implementing by message exchanged via the network.

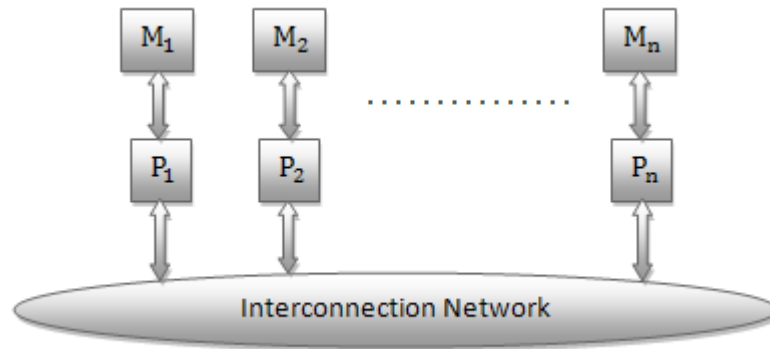


Fig: Distributed Memory Access

Q. What is RISC & CISC?

Solution:

RISC:

- ✓ RISC means “Reduced instruction Set Computer”.
- ✓ It has large number of general purpose register (32).
- ✓ Limited & simple instruction set (24).
- ✓ Optimized instruction pipelining.

Example:

$LOAD\ A, [address]$
 $LOAD\ B, [address]$
 $MPY\ A, B$
 $STORE\ [address], A$

Advantage:

- ✓ For pipelining it has fast execution rate.
- ✓ Uses VLSI technology.

Disadvantages:

- ✓ Needed more instruction than CISC to perform the same task. So, it is less effective than CISC.

CISC:

- ✓ CISC means “Complex Instruction Set Computer”.
- ✓ Small number of general purpose registers (8).
- ✓ Complex and huge number of instruction set (215).

Example:

MPY [address1], [address2]

Advantage:

- ✓ Program size or length smaller.
- ✓ Consume less memory for storing a program.
- ✓ Low page fault due to smaller program.

Disadvantage:

- ✓ Instructions are so complex, so, can't optimize easily.
- ✓ Cost is higher than RISC.

Q. What are SISD, SIMD, MISD, and MIMD?**Solution:****SISD:**

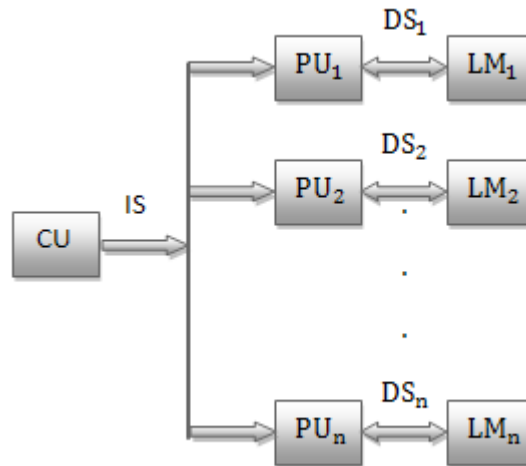
- ✓ SISD means “Single Instruction Single Data”.
- ✓ A single processor can execute a single instruction stream to operate on data stored in a single memory.
- ✓ Central unit send single instruction to processing unit then processing unit execute and store this data to memory unit.



Example: Uniprocessor.

SIMD:

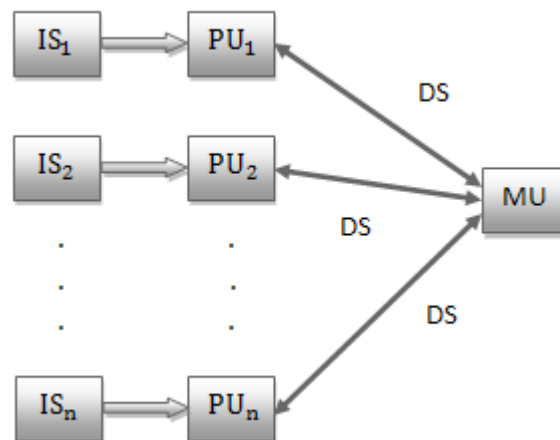
- ✓ SIMD means “Single Instruction Multiple Data”.
- ✓ A single instruction stream is executed by multiple processing elements.
- ✓ Each processing element has an associate memory so that each instruction is executed on a different set of data by the processors.



Example: Vector Processor, Array Processor.

MISD:

- ✓ MISD means “Multiple Instruction Single Data”.
- ✓ A sequence of instructions stream are executed by a number of processors by using data from a single memory.



Example: Systolic Array.

MIMD:

- ✓ MIMD means “Multiple Instruction Multiple Data”.
- ✓ A set of processors simultaneously execute different instruction stream by using different data sets.
- ✓ There are two types, such as Shared memory system & Distributed memory system.

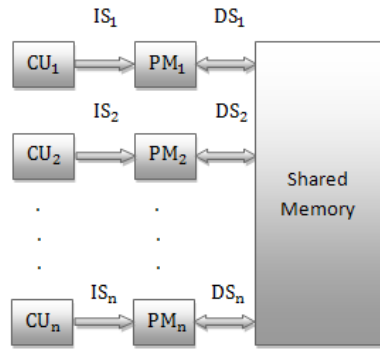


Fig: Shared Memory Schema.

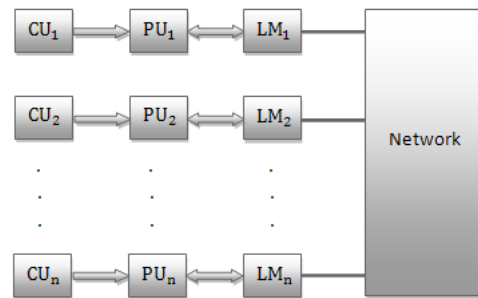


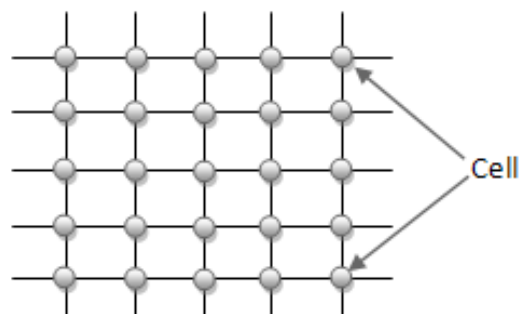
Fig: Distributed Memory System.

Q. Describe about ROM, PROM, EPROM, EEPROM & Flash memory.

Solution:

ROM:

- ✓ ROM means “Read Only Memory”.
- ✓ It is an IC programmed with data when manufactured.
- ✓ It is used not only computer but also in electrical devices like toys.
- ✓ It contains grid of columns and rows where the columns & rows intersect.
- ✓ A ROM chip needs programming of perfect and complicated data during manufactured.
- ✓ There is a cell. If we send a current with high voltage above then forward break over, the appropriate column with the selective row will selected.
- ✓ If any error is found then the chip thrown away & again we need manufactured.



Advantages:

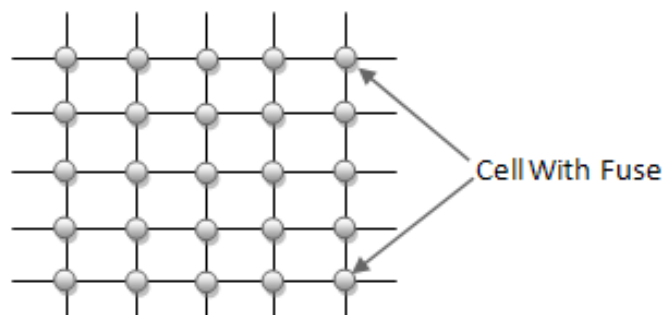
- ✓ Low power consumption.
- ✓ Cost effective.
- ✓ Extremely reliable.

Disadvantages:

- ✓ It is one time device.
- ✓ If any error then it is not usable.

PROM:

- ✓ PROM means “Programmable Read Only Memory”.
- ✓ Creating ROM chip is time consuming & expensive. So, we need to think another device like PROM.
- ✓ PROM inexpensive & can be programmed with a tool called programmer.
- ✓ Like ROM it has grids of columns & rows but the difference is in every intersection between rows and columns there is a fuse.
- ✓ Fuse is connected to logical 1 [+5V to +10V]. So, at the initial state, all cells contain logical 1. To change the value of a cell 1 to 0 the programmer is used to set a specific amount current to the cell. The higher voltage breaks the connection between rows and columns by burning out the fuse that means burning out the PROM.
- ✓ If we want bring logical 1 to 0 then apply fixed amount of current then it goes 1 to 0 and fuse is burn.



Advantage:

- ✓ After manufacture can be programmed but only once.

Disadvantage:

- ✓ PROM is expensive than other device.
- ✓ It can't program more than one.

EPRM:

- ✓ EPROM means "Erasable Programmable Read Only Memory".
- ✓ It can be overwritten many times.
- ✓ It special type memory device that retrain its content until the ultraviolet (UV) light is exposed, the UV light clear it contents making it possible to reprogram the memory.
- ✓ To write and erase an EPROM you need a tool called EPROM programmer.
- ✓ Each cell contain two transmitter separated by an oxide layer. One of them is known as floating point gate & another is known as control gate.
- ✓ The floating point gate is connected to the row via the control gate. There is a link between them. As long as link is in place the cell contains 1.
- ✓ To change 1 to 0 require a process called Fowler Northeim Tunneling. It changes the position of electron in the floating gate.
- ✓ An electron charge (10V to 30V) is applied to the floating gate. This change causes the floating point gate act as electron gun. It's the barrier between floating point gate & control gate.

Advantages:

- ✓ Easy to program.
- ✓ Rewritten many times.

Disadvantages:

- ✓ To erase data from EPROM needs UV light.

EEPROM:

- ✓ EEPROM means "Electrically Erasable Programmable Read Only Memory".
- ✓ The entire chip does not have to completely erase to change a specific portion.

- ✓ Changing the content does not need additional requirement instead of UV light, the electron are return to the normal position by applying electric field to each cell. This erases the target cell of the EEPROM.
- ✓ EEPROM sort by hybrid between a static RAM and EPROM So that data can be changed easily.

Advantages:

- ✓ A single portion can be updated, need not change whole portion.

Disadvantage:

- ✓ At a time more than one byte can't be changed.
- ✓ It's much slower.
- ✓ After 10000 to 40000 writes the chip will be completely dead.

Flash Memory:

- ✓ A flash cell is based on a single transistor controlled by trapped charge, just like an EEPROM cell.
- ✓ There are some differences between flash and EEPROM. In EEPROM it is possible to read and write the contents of a single cell. In a flash device it is possible to read the contents of a single cell, but it is only possible to write an entire block of cells. Prior to writing, the previous contents of the block are erased.

Advantages:

- ✓ Flash devices have greater density, which leads to higher capacity and a lower cost per bit.
- ✓ They require a single power supply voltage and consume less power in their operation.

Q. What are the differences between RAM & ROM?

Solution:

The differences between RAM & ROM are given below:

- ✓ Both RAM & ROM provide the user random access to stored data.
- ✓ RAM provide only short term memory since data stored in RAM is lost when power is turned off, but ROM provide long term storage since data is permanently store here.
- ✓ RAM's data frequently & speedy be altered & changed, but ROM can not be reconfigured.