# MIMD Processors

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# Introduction

- A set of general purpose processors is connected together.
- In contrast to SIMD processors, MIMD processors can execute different programs on different processors => Flexibility!
- MIMD processors works asynchronously, and don't have to synchronize with each other.
- By 90s, SIMD lost ground, since general purpose microprocessors are now very cheap and powerful.
- MIMD machines could be built from commodity (off-the-shelf) microprocessors with relatively little effort.
- MIMD architectures can be highly scalable, if an appropriate memory organization is used.

# SIMD vs MIMD

- SIMD computers require less hardware than MIMD computers (single control unit).

- However, SIMD processors are specially designed, and tend to be expensive and have long design cycles.

- Not all applications are naturally suited to SIMD processors.

- Conceptually, MIMD computers cover SIMD need.
  - Having all processors executing the same program(single program multiple data streams - SPMD).
  - SPMD avoids the complexity of general concurrent programming.

# MIMD Processor Classification(1)

- **Tightly coupled system** generally represent systems which have some degree of sharable memory through which processors can exchange information with normal load / store operations

  Ex. Multiprocessor

- **Loosely coupled systems** generally represent systems in which each processor has its own private memory and processor to processor information exchange is done via some message passing mechanism like a network interconnect or an external shared channel (FC, IB, SCSI, etc.) bus

  Ex. Multicomputer

# MIMD Processor Classification(2)

- **Centralized Memory:** Shared memory located at centralized location - consisting usually of several interleaved modules - the same distance from any processor.

  - Symmetric Multiprocessor (SMP)

  - Uniform Memory Access (UMA)

- **Distributed Memory:** Memory is distributed to each processor

  - improving scalability.

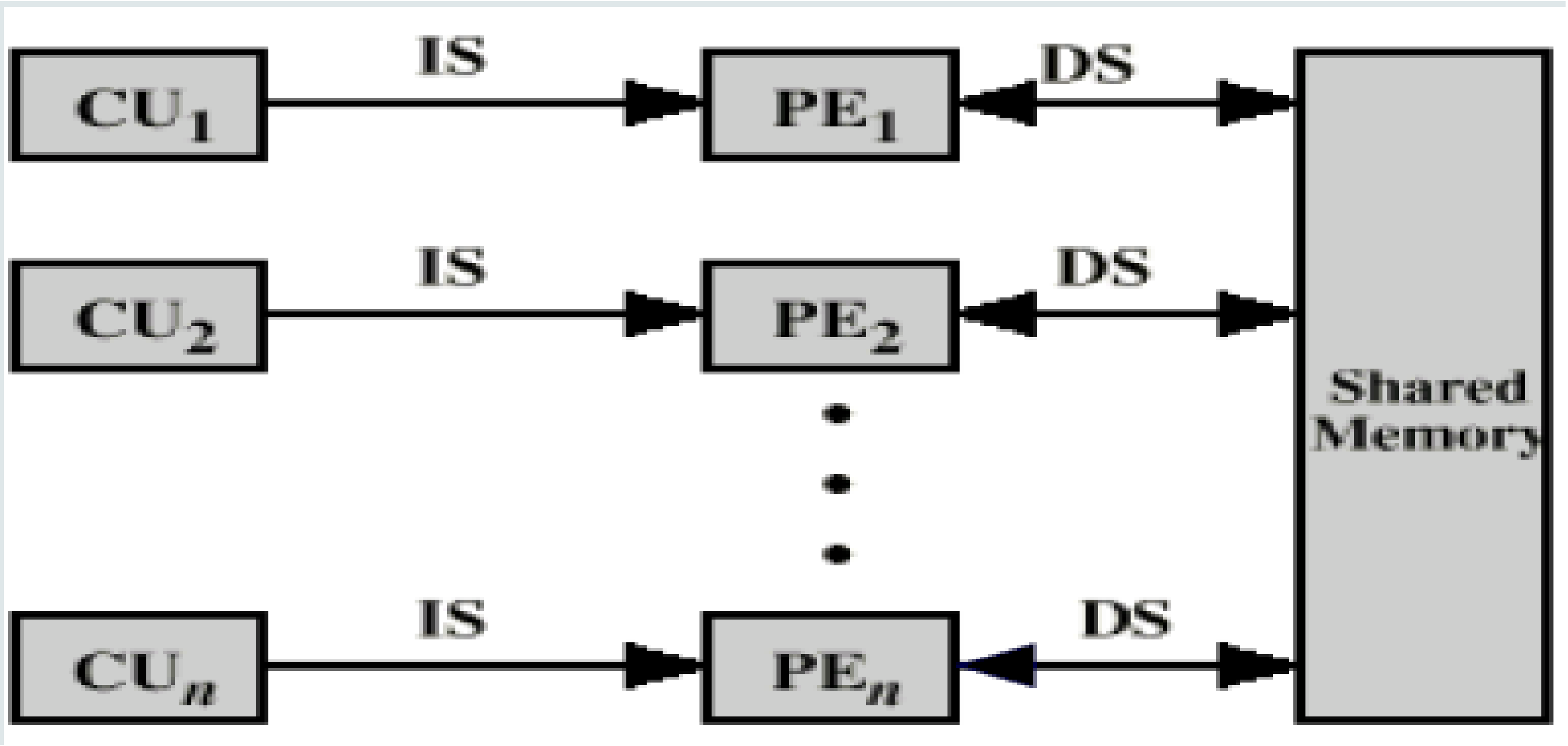
  *Message Passing Architectures:* No processor can directly access another processor's memory.

  *Hardware Distributed Shared Memory (DSM):* Memory is distributed, but the address space is shared.

  - Non-Uniform Memory Access (NUMA)

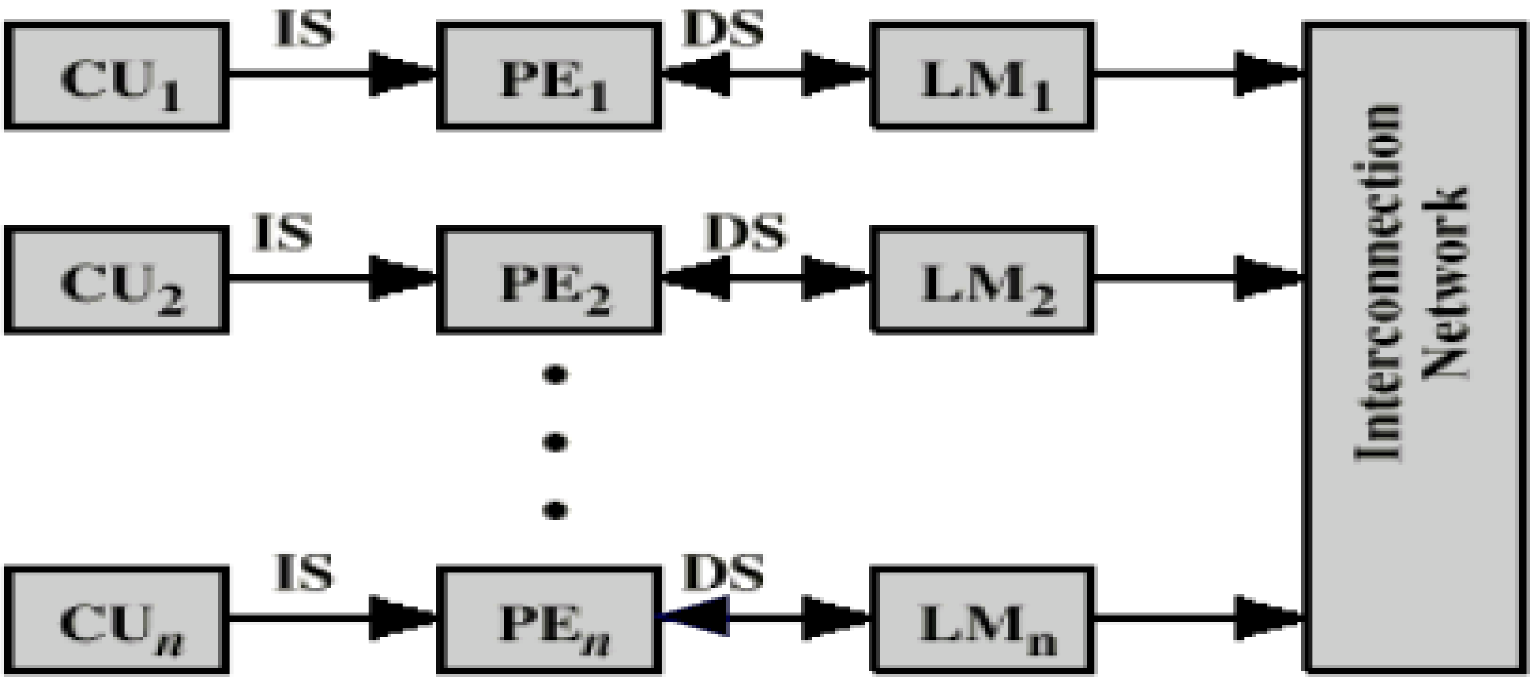
  *Software DSM:* A level of OS built on top of message passing multiprocessor to give a shared memory view to the programmer.

# MIMD with Shared Memory




- Tightly coupled, not scalable.
- Typically called **Multi-processor.**

# MIMD with Distributed Memory



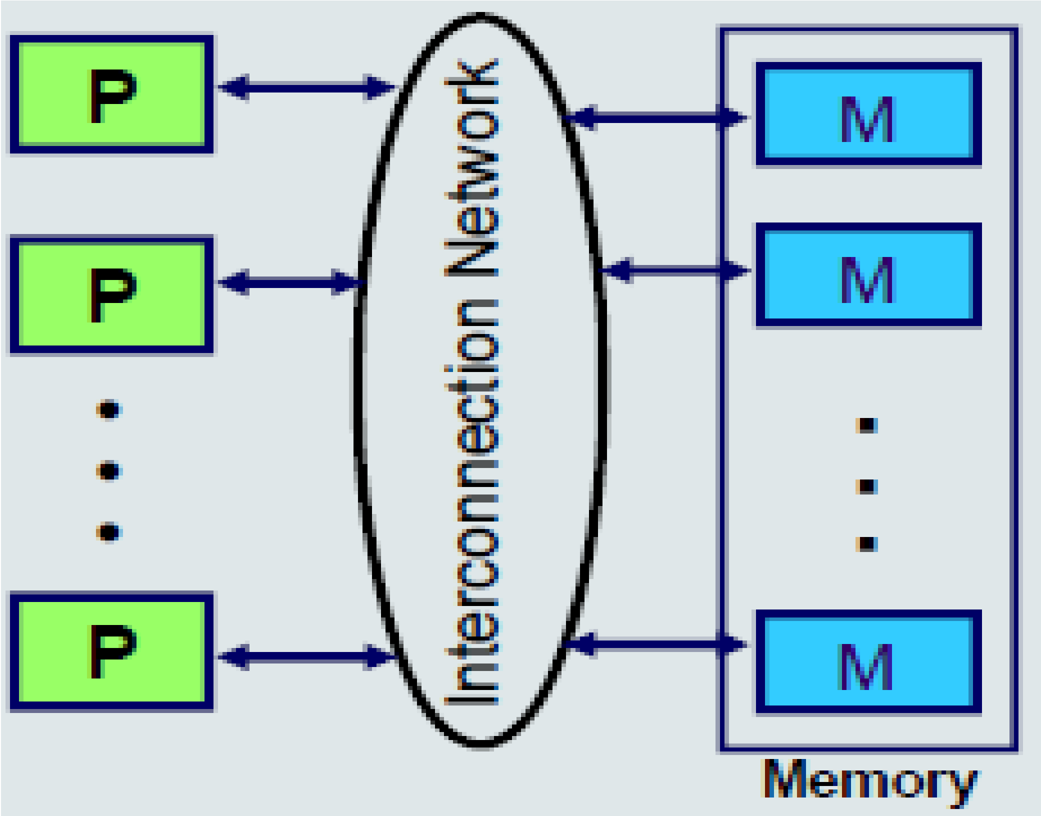

- ❑ Loosely coupled with message passing, scalable
- ❑ Typically called **Multi-computer.**

# Shared-Address-Space Platforms

- Part (or all) of the memory is accessible to all processors.
- Processors interact by modifying data objects stored in this shared-address-space.

❑ UMA (uniform memory access) = the time taken by a processor to access any memory word in the system is identical.

❑ NUMA, otherwise.



# Multi-Computer Systems(1)

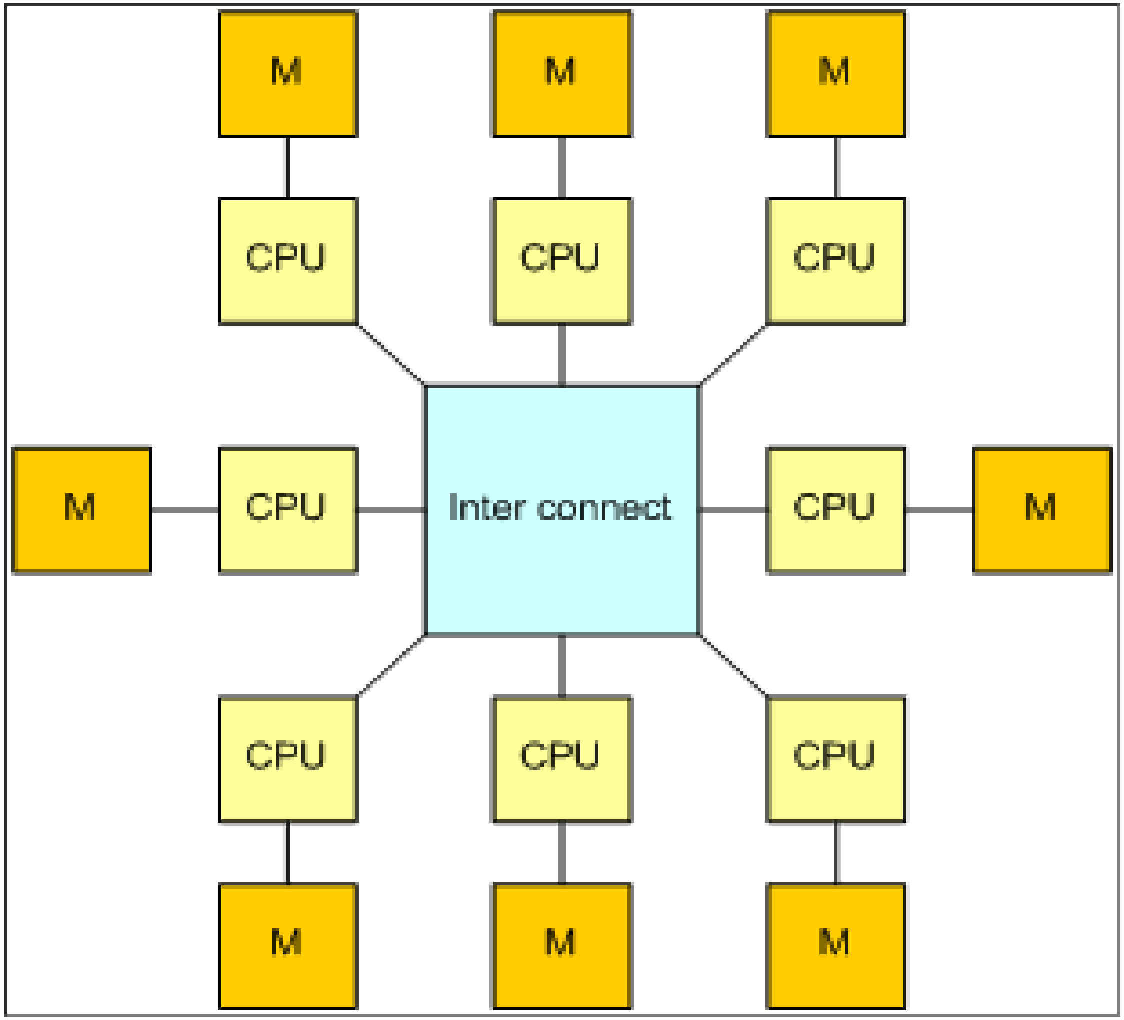
- A multi-computer system is a collection of computers interconnected by a message-passing network.
  - Clusters.

- Each processor is an autonomous computer
  - With its own local memory.
  - There is no a shared-address-space any longer.
  - They communicating with each other through the message passing network.

- Can be easily built with commodity microprocessors.

# Multi-Computer Systems(2)

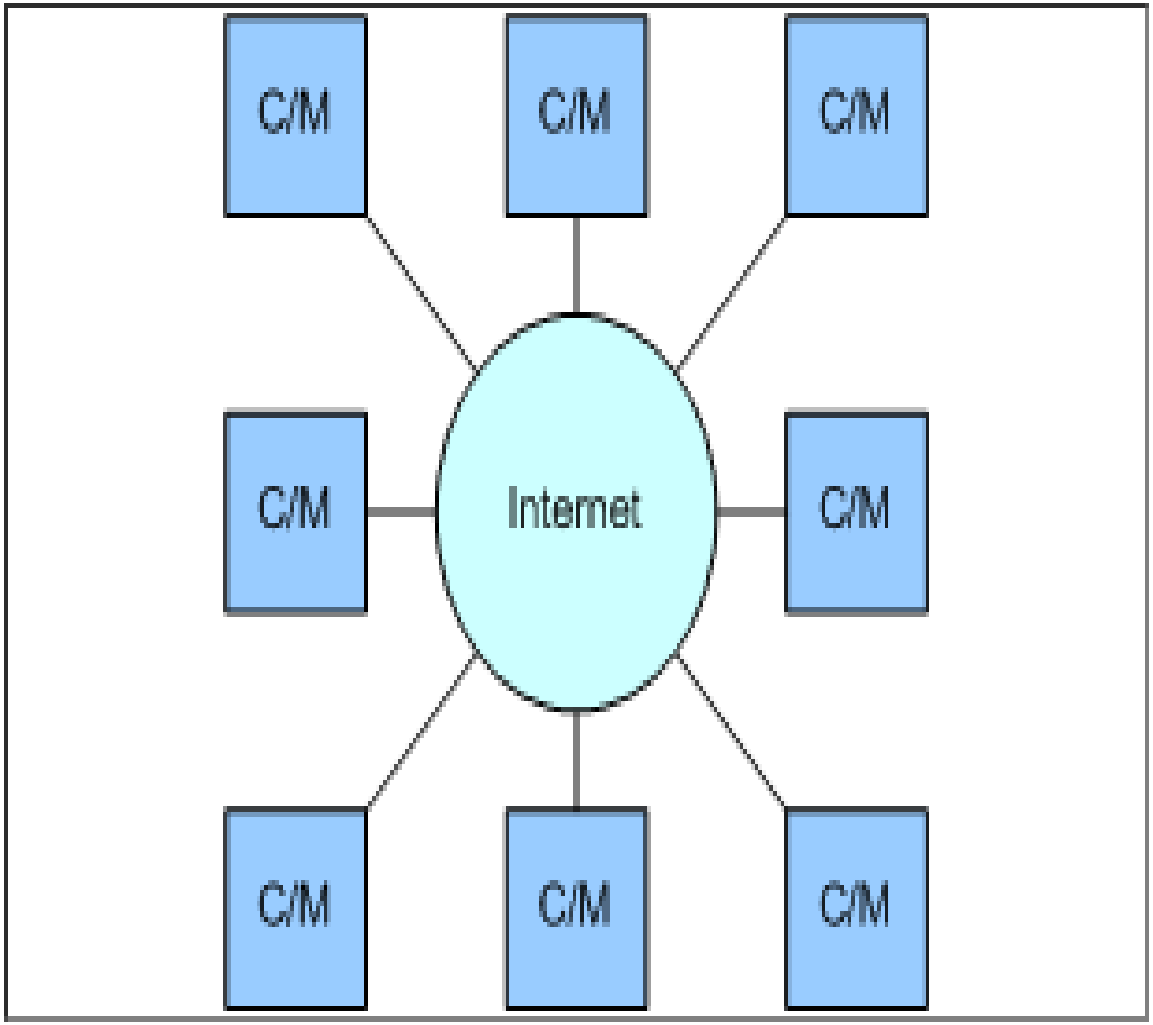
- The processor and memory pairs are connected to a fast high speed interconnect.
- The system is also called message passing multicomputer.
- Implementation is much simpler than the memory shared multiprocessor.
- Accessing a memory word takes about 10-50 μsec.



# Wide area distributed system

❑This system connects complete computer systems over a wide area network, such as Internet. It forms a distributed system. Since the accessing is rather slow the systems are loosely coupled.

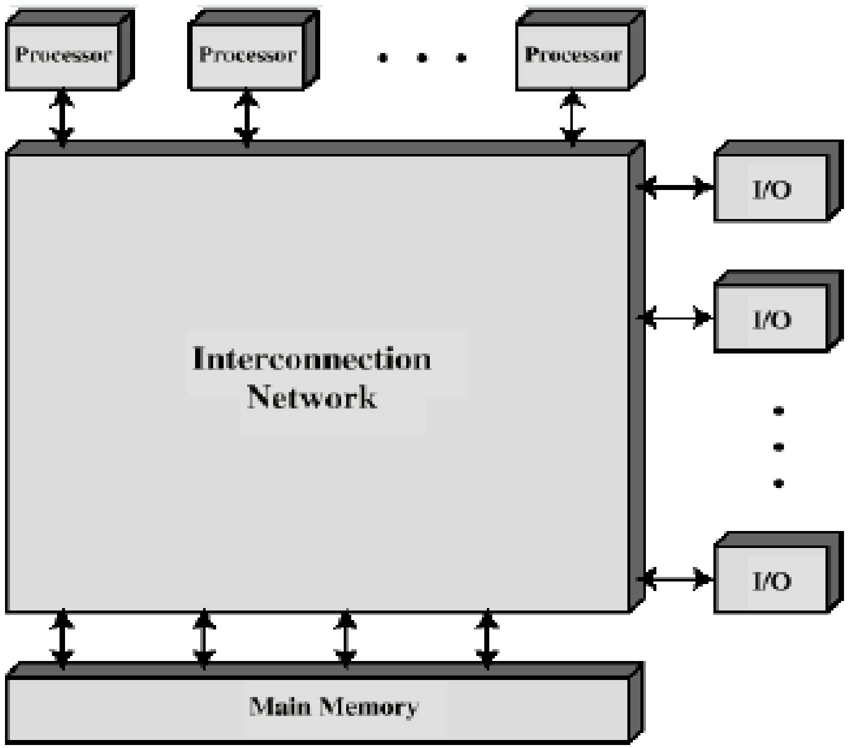
❑Accessing a memory word takes about 10'000-100'000 µsec.

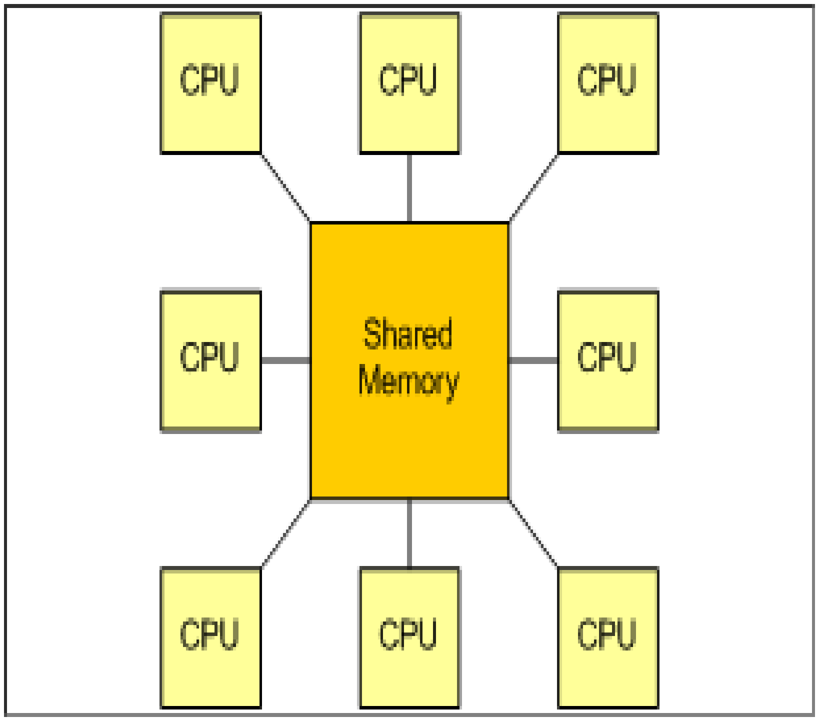


# Symmetric Multiprocessors (SMP)

- A set of similar processors of comparable capacity.
- All processors can perform the same functions (symmetric).
- Processors are connected by a bus or other internal connection.
- Processors share the same memory.
  - A single memory or a pool of memory modules
- Memory access time is (approximately) the same for each processor.
- All processors share access to I/O.
  - Either through the same channels or different channels giving paths to the same devices
- Controlled by an integrated operating system:
  - Providing interaction between processors
  - Interaction at job, task, file and data element levels

# Symmetric Multiprocessors (SMP)




- ❑Shared-memory multiprocessor.
- ❑This system is invisible to the programmer. The message passing is done under cover. The implementation is not very easy, and there are some limits as well.
- ❑Accessing a memory word takes about 0.002-0.01 µsec.

# SMP Advantages

- **High performance**
  - If similar work can be done in parallel (e.g., scientific computing).

- **Good availability**
  - Since all processors can perform the same functions, failure of a single processor does not stop the system.

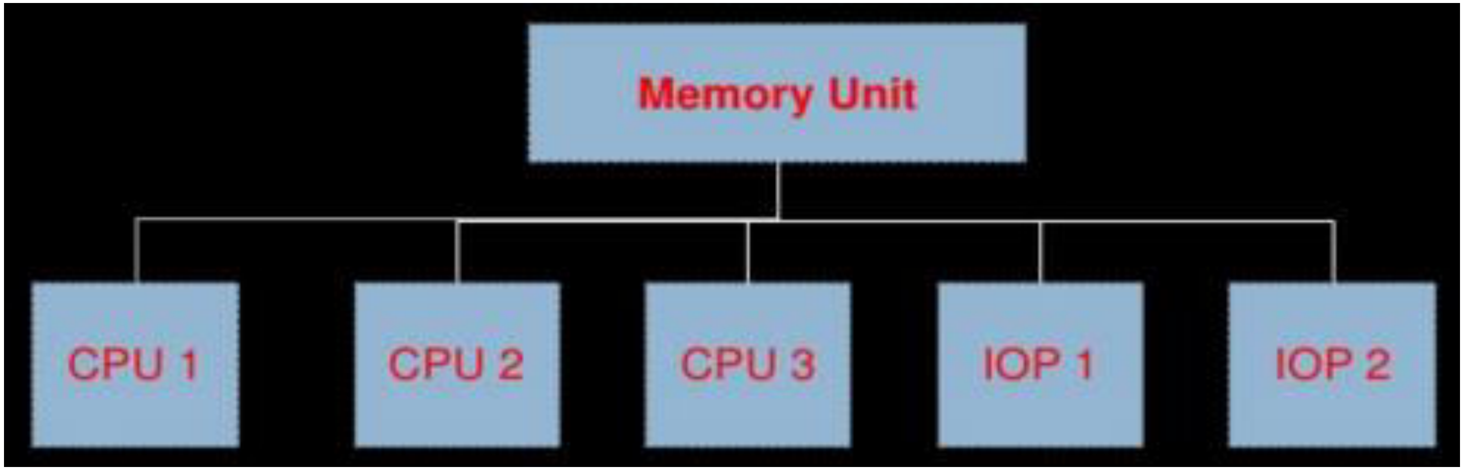
- **Support incremental growth**
  - Users can enhance performance by adding additional processors.

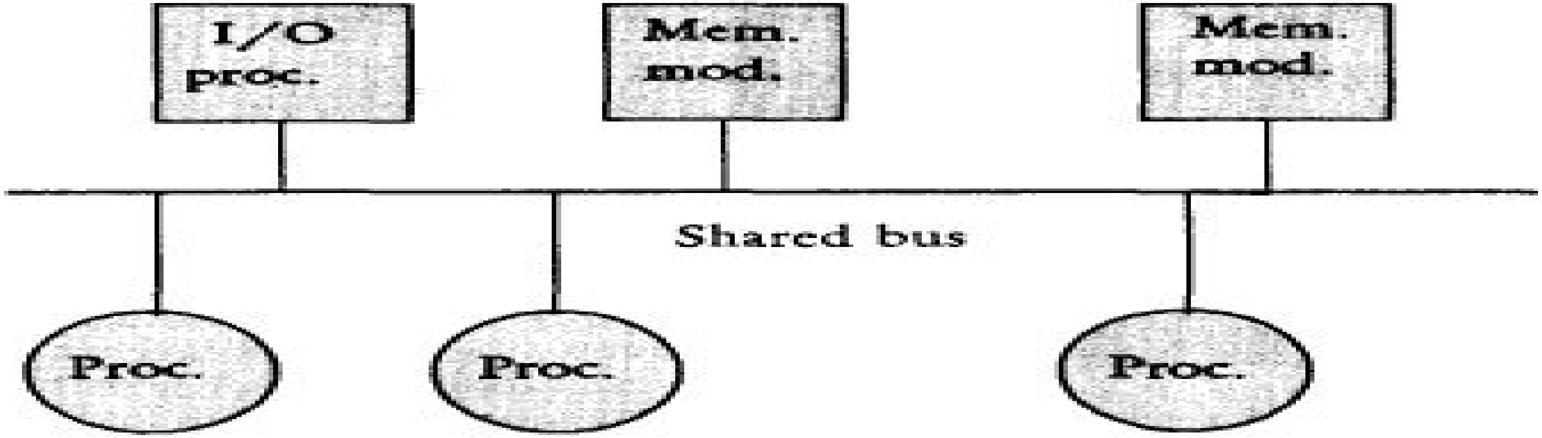
- **Scaling**
  - Vendors can offer range of products based on different number of processors.

# Interconnection Network

- Time-shared common bus
- Multiport Memory
- Crossbar Switch
- Multi-stage Switching Network
- Hypercube System

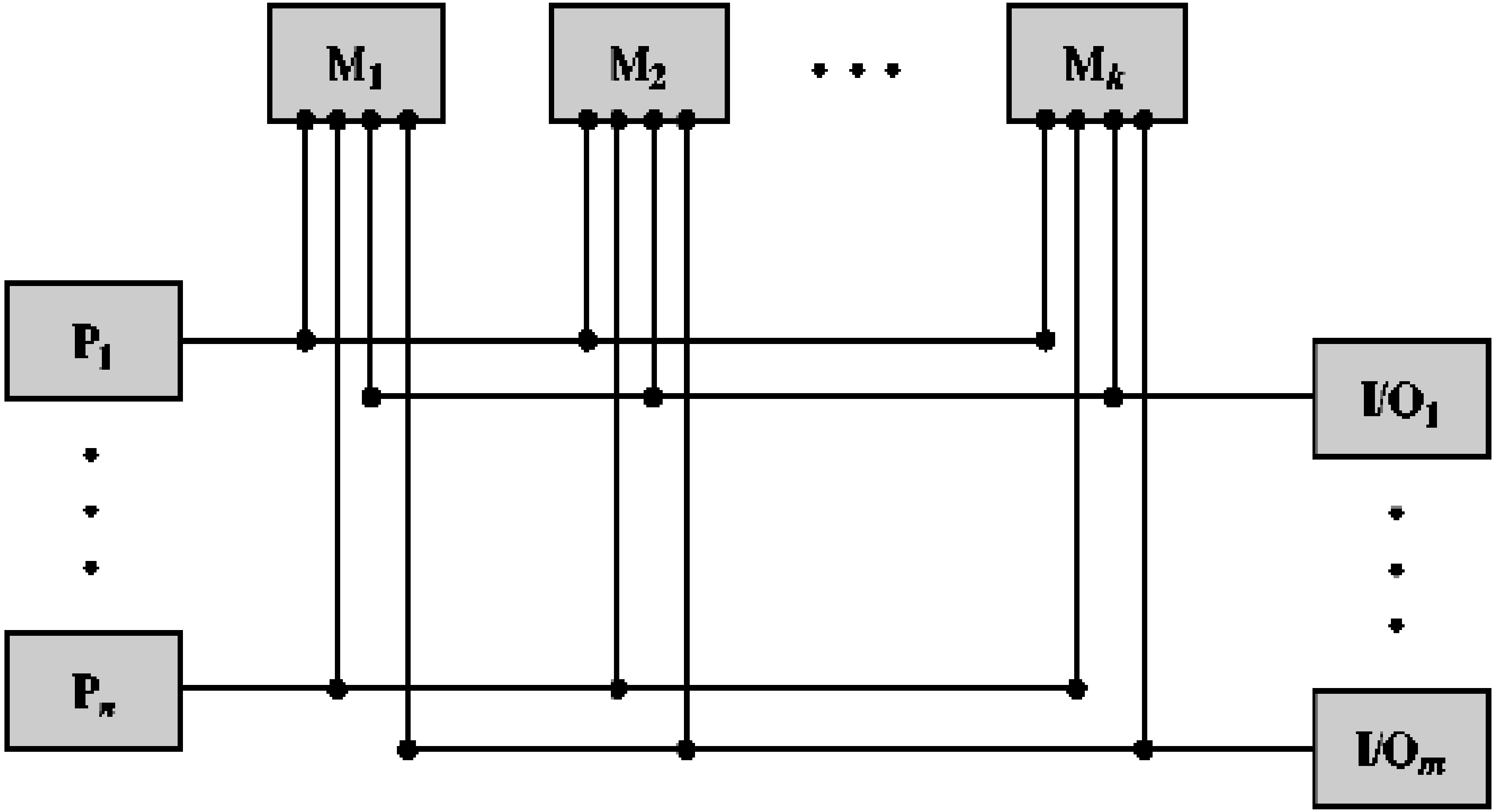
# Time-shared Common Bus




Common bus is used for interconnection.

# Multiport Memory




**Separate buses between each memory module & each processor**

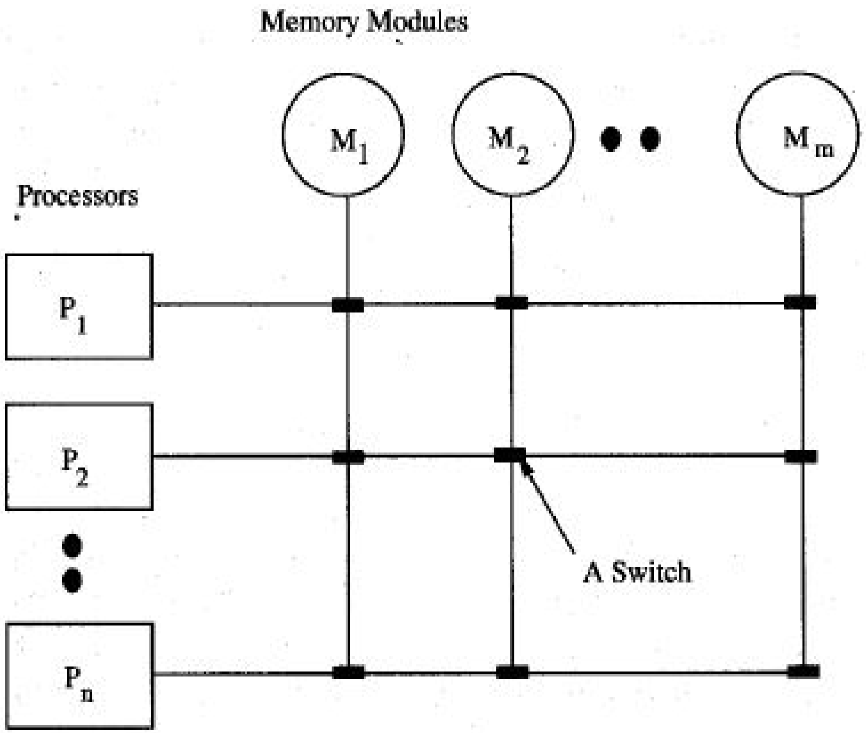
# Crossbar Switch(1)

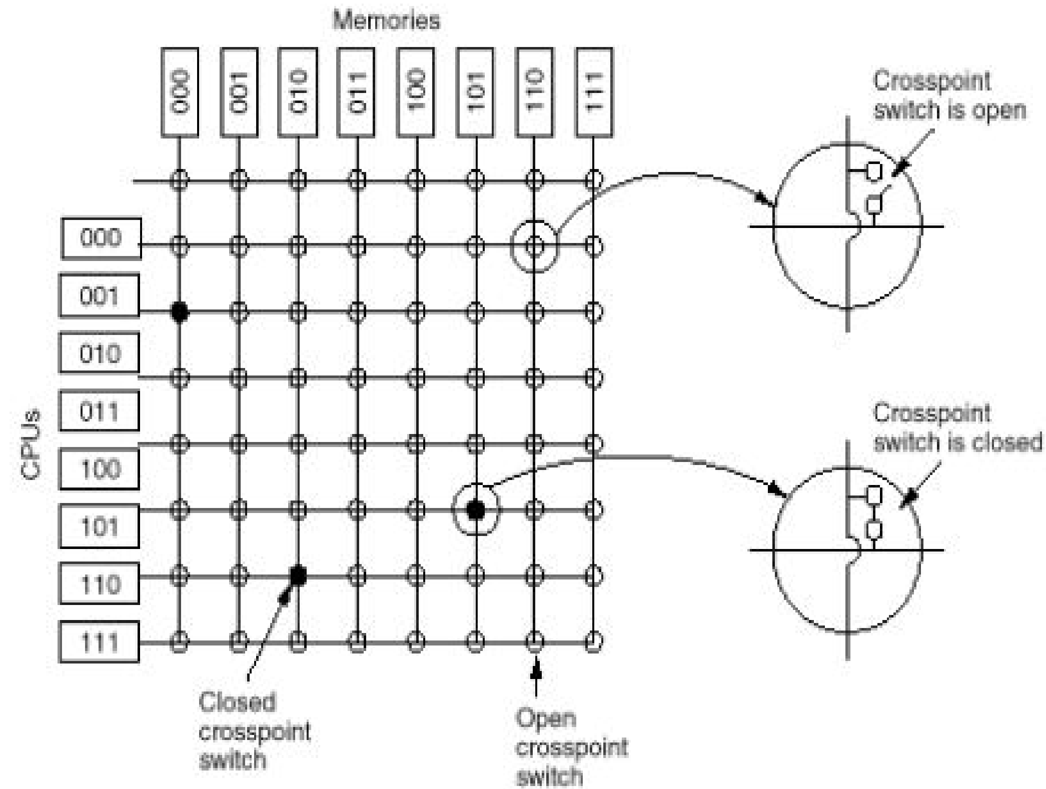
- The simplest circuit for connecting n CPUs to k memories is the crossbar switch. Crossbar switches have long been used in telephone switches.

- At each intersection is a cross-point - a switch that can be opened or closed.

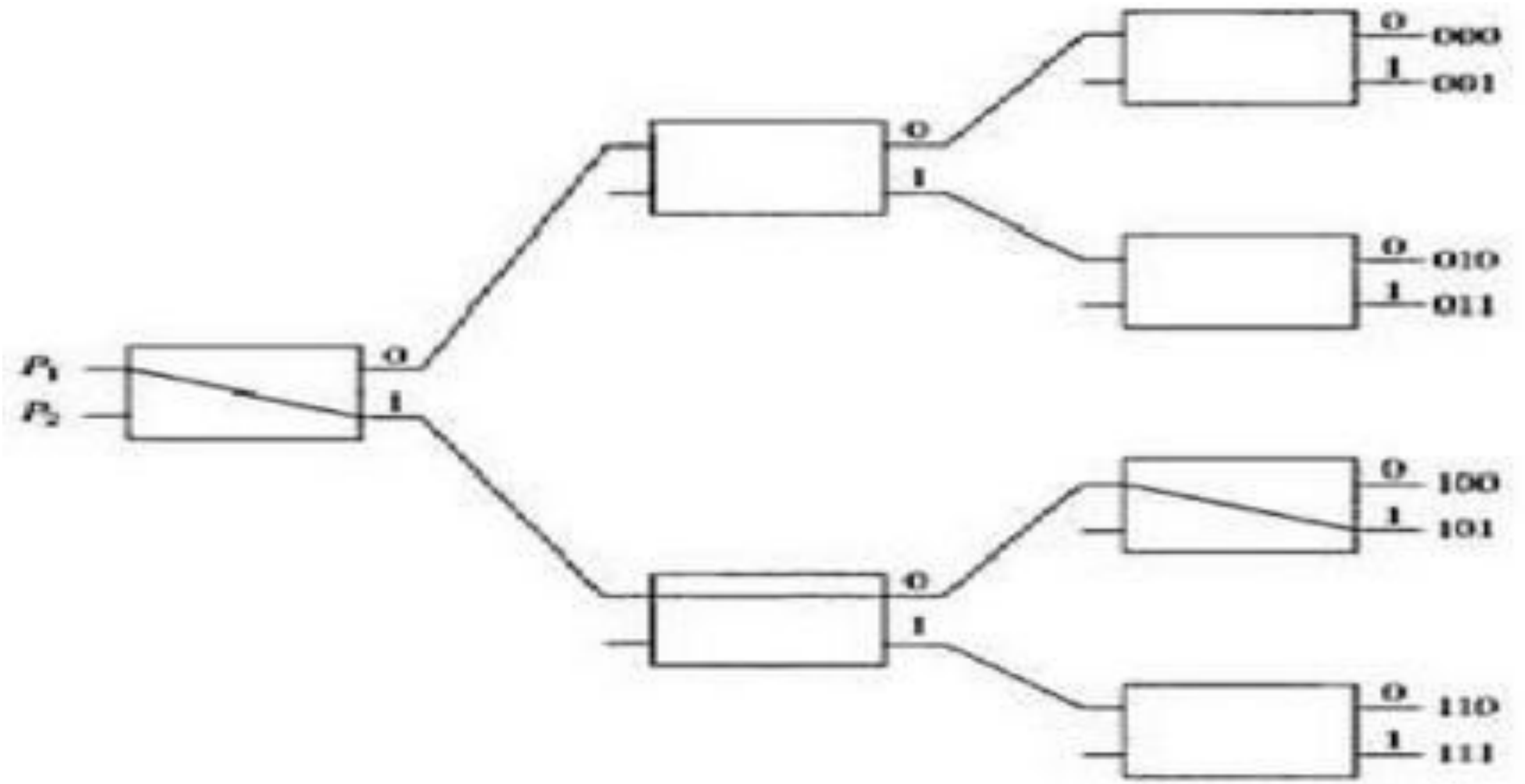
- The crossbar is a non-blocking network

# Crossbar Switch(2)



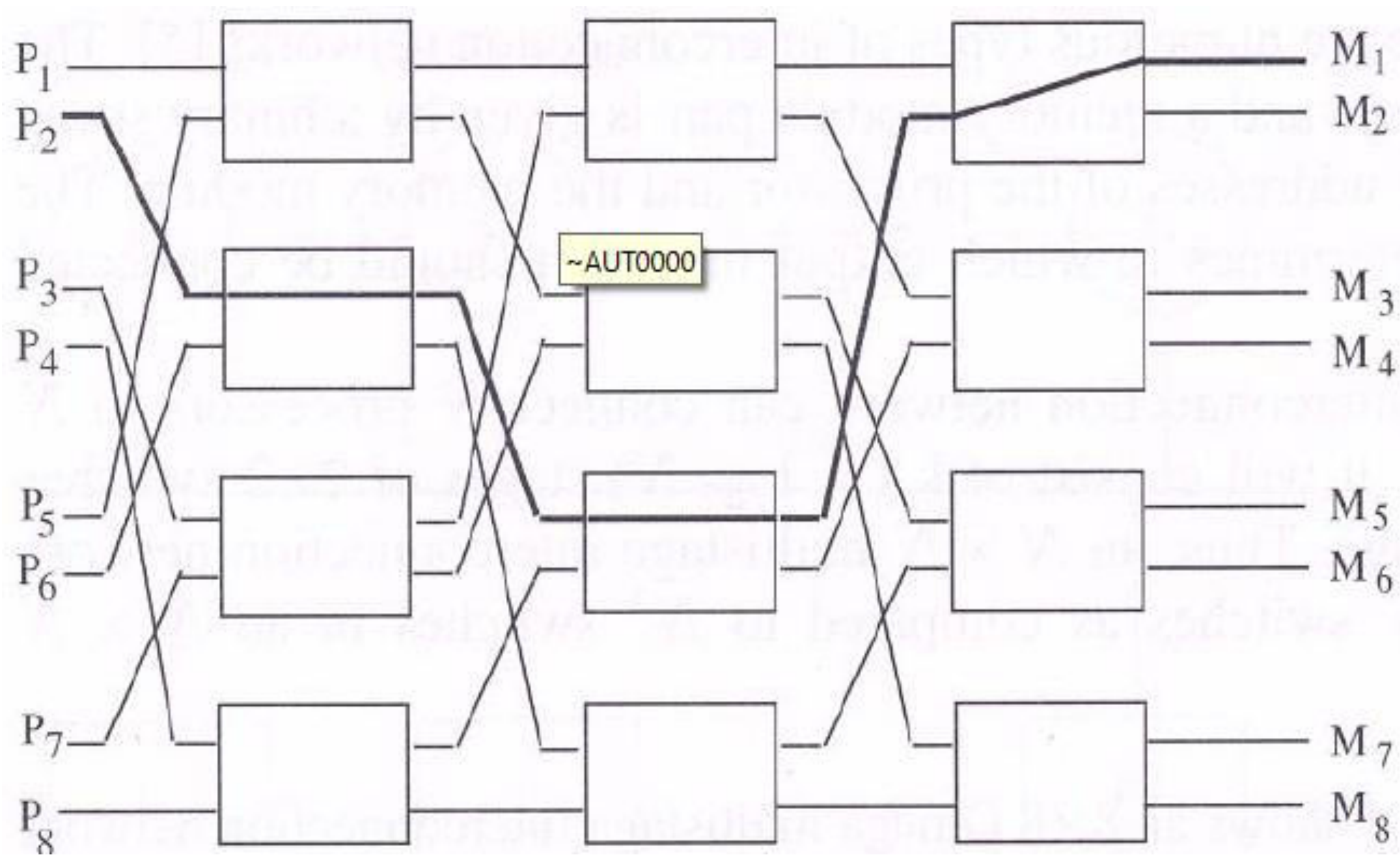



# Multi-stage Switching Network(1)



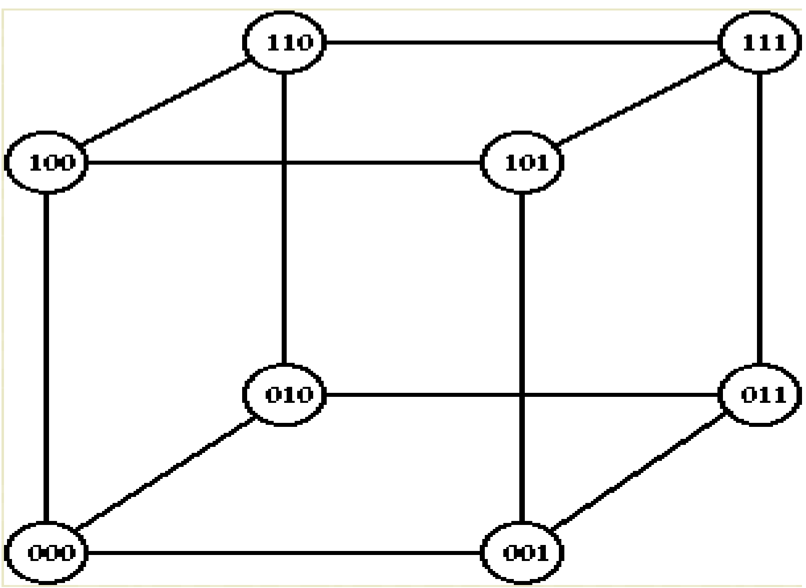

Use of 2 i/p and 2 o/p interchange switch(2x2 crossbar)

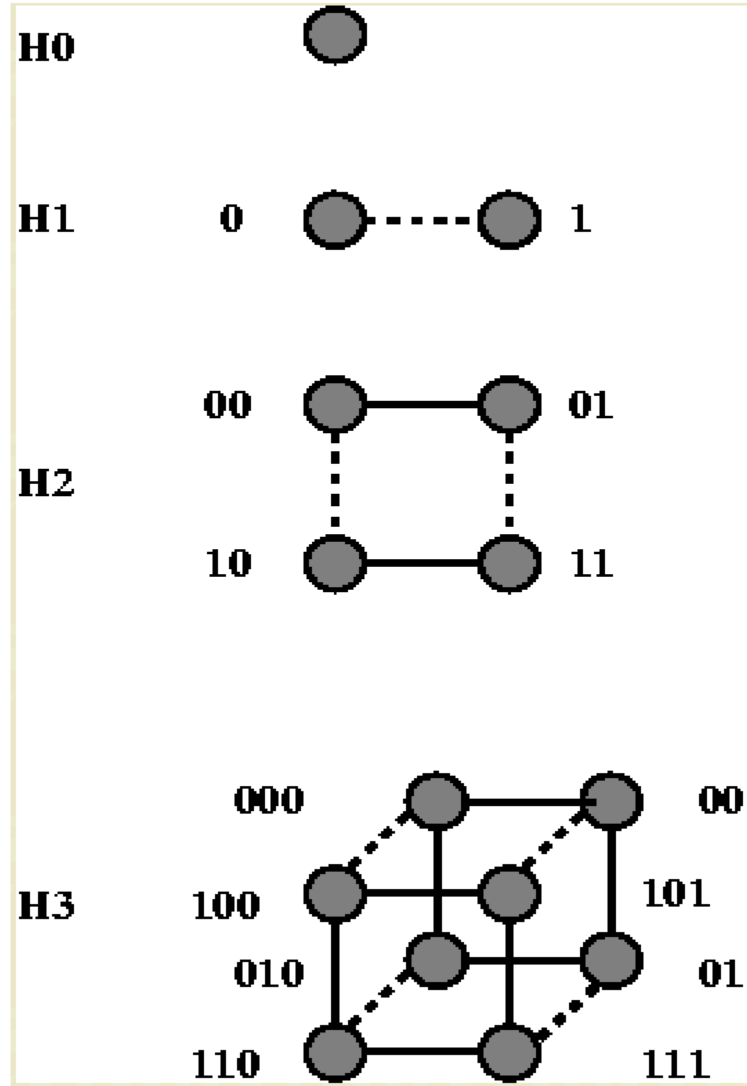
# Multi-stage Switching Network(2)



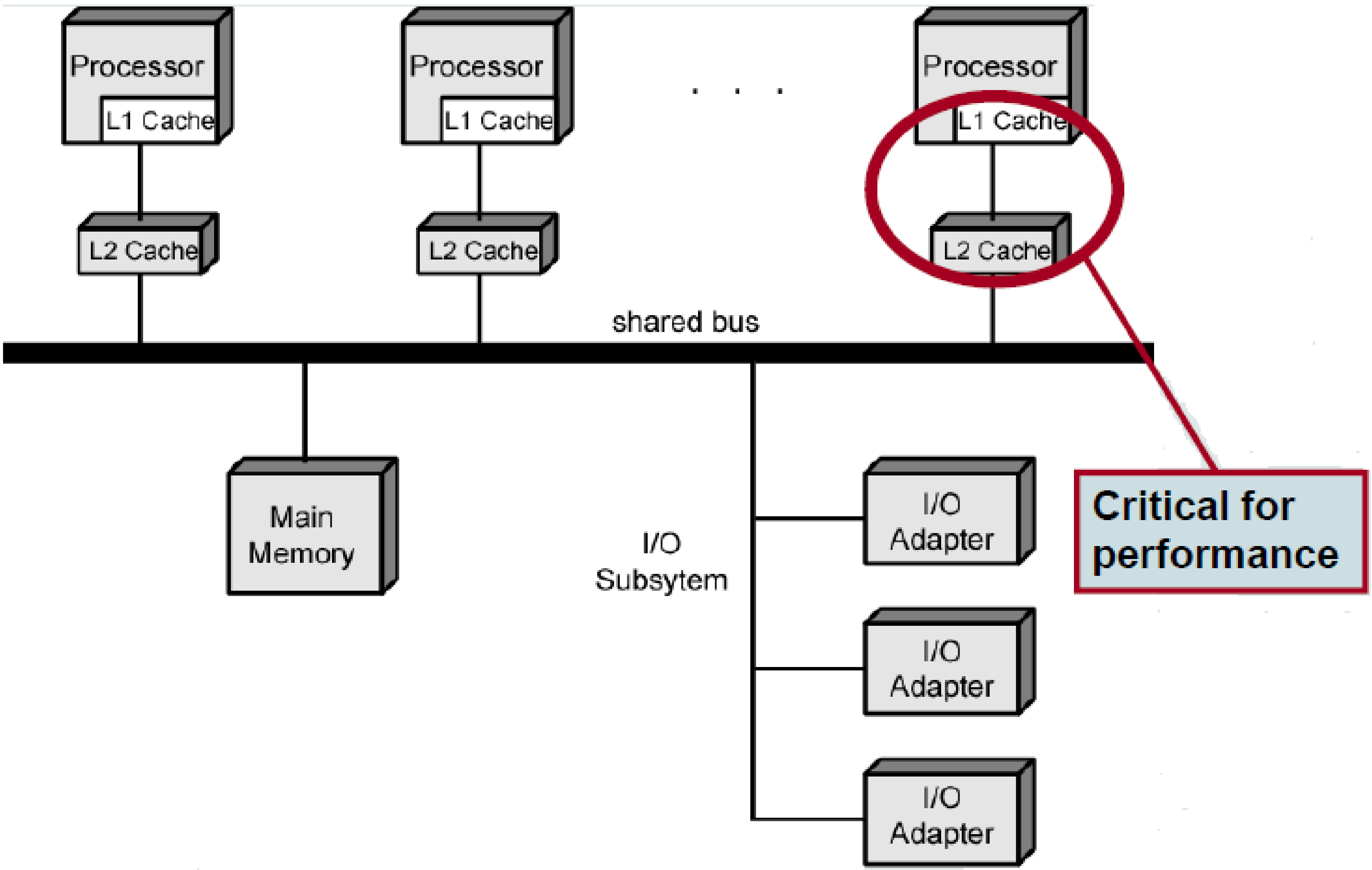
# Hypercube System

- A *k*-dimensional hypercube contains $2^k$ processors (nodes).
- Each processing node contains a switch.
- Mostly in Multicomputer System



# SMP based on Shared Bus



# Shared Bus – Pros and Cons

- **Advantages:**
  - Simplicity.
  - Flexibility - Easy to expand the system by attaching more processors.

- **Disadvantages:**
  - Performance limited by bus bandwidth.
  - Each processor should have local cache
    - To reduce number of bus accesses
    - Can lead to problems with cache coherence
      - Should be solved in hardware (to be discussed later).

# Operating System Issues

- An SMP OS manages processor resources so that the user perceives a single system.
- It should appear as a single-processor multiprogramming system.
- In both SMP and uniprocessor, multiple processes may be active at one time.

  - OS is responsible for scheduling their execution and allocating resources.
- A user may construct applications that use multiple processes without regard to whether a single processor or multiple processors will be available.
- OS supports reliability and fault tolerance.

  - Graceful degradation.

# MIMD Design Issues

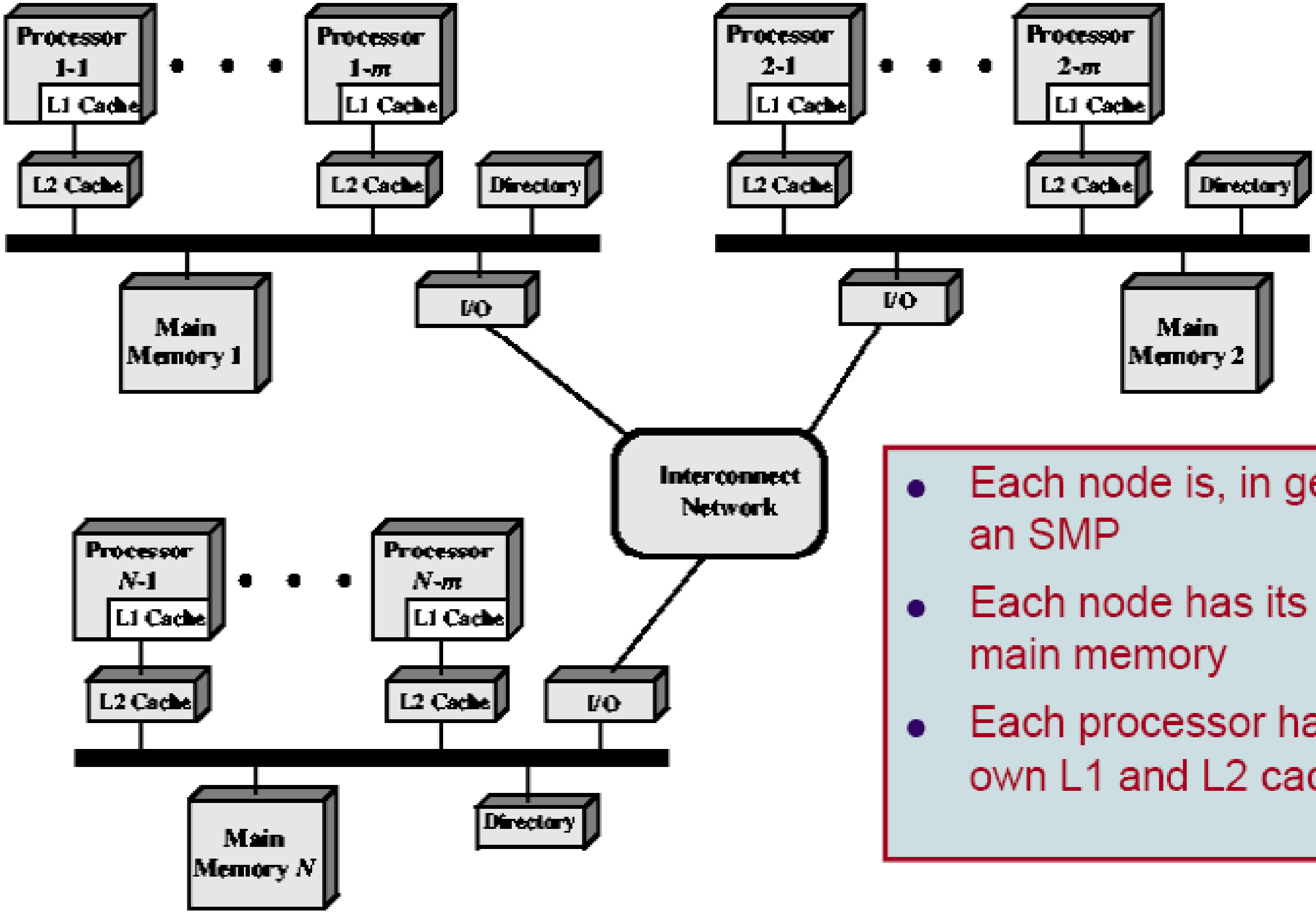
- Design issues related to an MIMD machine are very complex, since it involves both architecture and software issues.
- The most important issues include:
    - Processor design
    - Physical organization
    - Interconnection structure
    - Inter-processor communication protocols
    - Memory hierarchy
    - Cache organization and coherency
    - Operating system design
    - Parallel programming languages
    - Application software techniques

# Memory Access Issues

- **Uniform memory access (UMA), as in SMP:**
  - All processors have access to all parts of memory.
  - Access time to all regions of memory is the same.
  - Access time for different processors is the same.
- **Non-uniform memory access (NUMA)**
  - All processors have access to all parts of memory.
  - Access time of processor differs depending on region of memory.
  - Different processors access different regions of memory at different speeds.
- **No Remote Access or NORMA systems**
  - Distributed systems

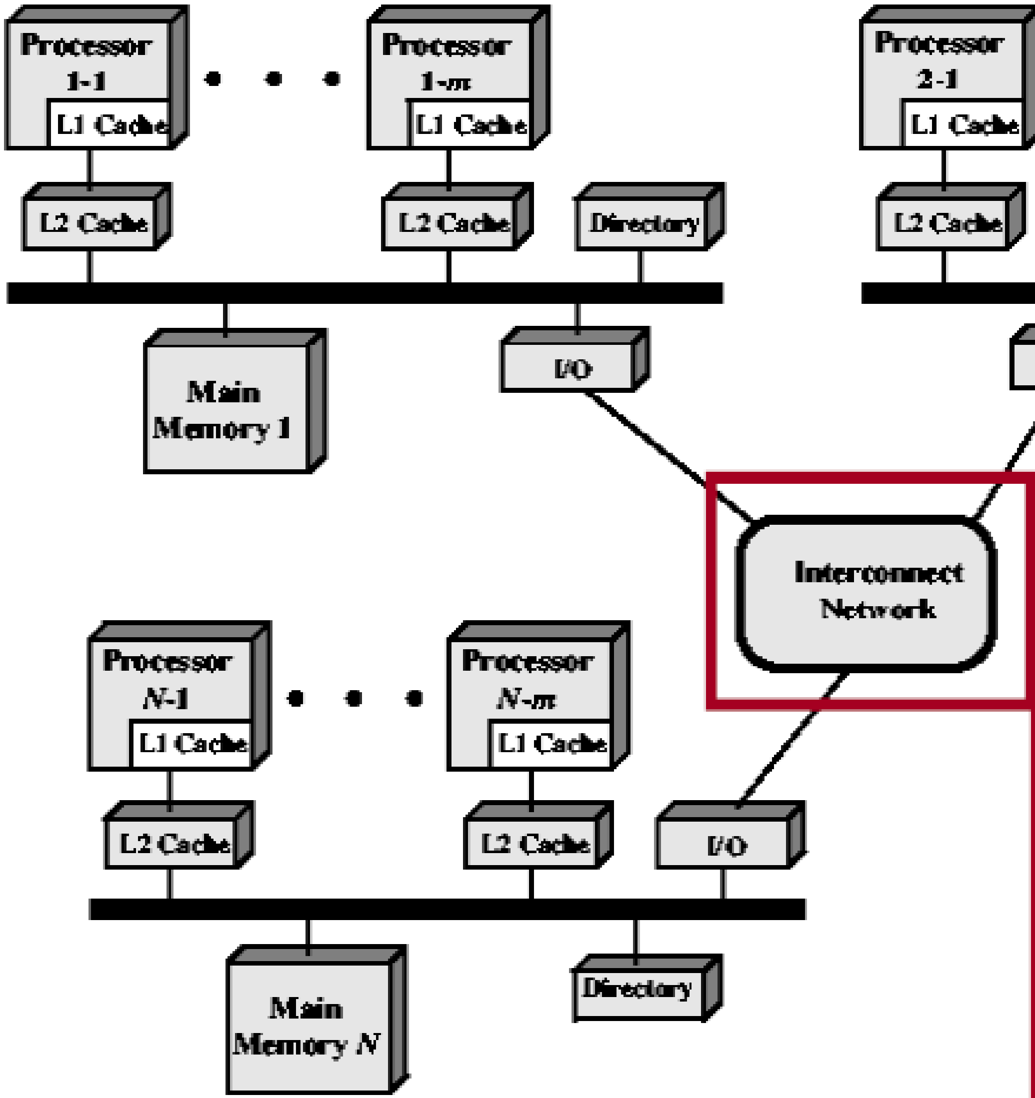
*Ref: Karsuk*

# A Typical NUMA Organization(1)



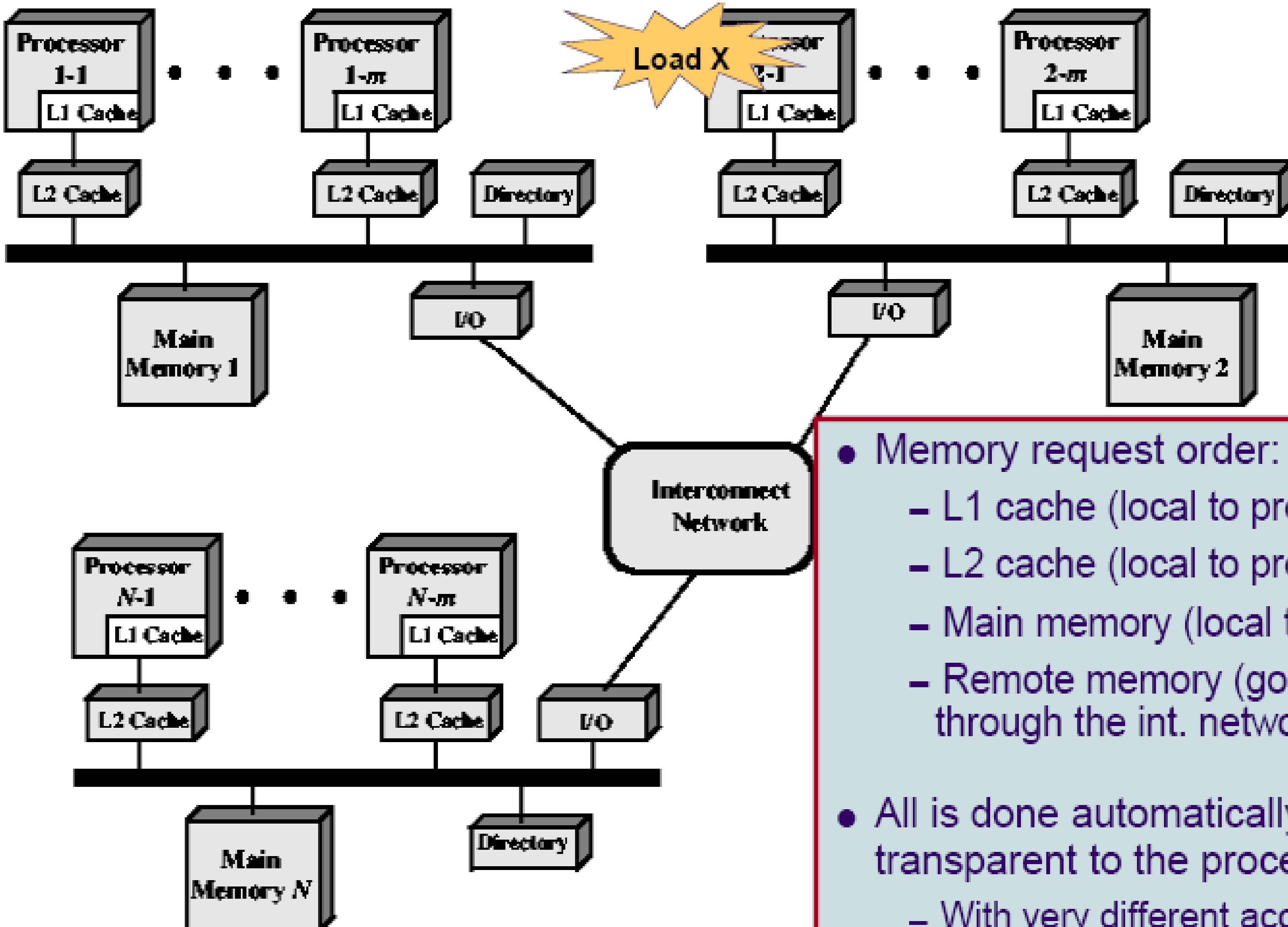

- Each node is, in general, an SMP
- Each node has its own main memory
- Each processor has its own L1 and L2 cache

# A Typical NUMA Organization(2)




- Nodes are connected by some networking facility
- Each processor sees a single addressable memory space
  - Each location has a unique system-wide address

# A Typical NUMA Organization(3)




- Memory request order:
  - L1 cache (local to processor)
  - L2 cache (local to processor)
  - Main memory (local to node)
  - Remote memory (going through the int. network)
- All is done automatically and transparent to the processor.
  - With very different access time!

# NUMA-Pros and Cons

- Effective performance at higher levels of parallelism than SMP.

- However, performance can break down if too much access to remote memory. This can be avoided by:
  - Designing better L1 and L2 caches to reduce memory access.
    - Need also good temporal locality of software.
  - If software has good spatial locality, data needed for an application will reside on a small number of frequently used pages.
    - They can be initially loaded into the local memory.
  - Enhancing VM by including in OS a page migration mechanism to move a VM page to a node that is frequently using it.

- NUMA does not transparently look like a SMP.
  - Software changes needed to move OS and applications from SMP to NUMA.
  - Page allocation, process allocation and load balancing are needed.

# Loosely Coupled MIMD - Clusters

**Cluster:** A set of computers connected over a high-bandwidth local area network, and used as a parallel computer.

- A group of interconnected stand-alone computers
- Work together as a unified resource
- Give illusion of being one machine
- Each computer called a node
- A node can also be a multiprocessor itself, such as an SMP.
- Message passing for communication between nodes
- **NOW:** Network of Workstations, homogeneous cluster.
- **Grid:** Computers connected over a wide area network.

# Cluster Benefits

- Absolute scalability
  - Cluster with a very large number of nodes is possible.
- Incremental scalability
  - A user can start with a small system and expand it as needed, without having to go through a major upgrade.
- High availability
  - Fault tolerance by nature.
- Superior price/performance
  - Can be built with cheap commodity nodes.
- Supercomputing-class commodity components are available
- The promise of supercomputing to the average PC User?

# Cluster Configurations(1)

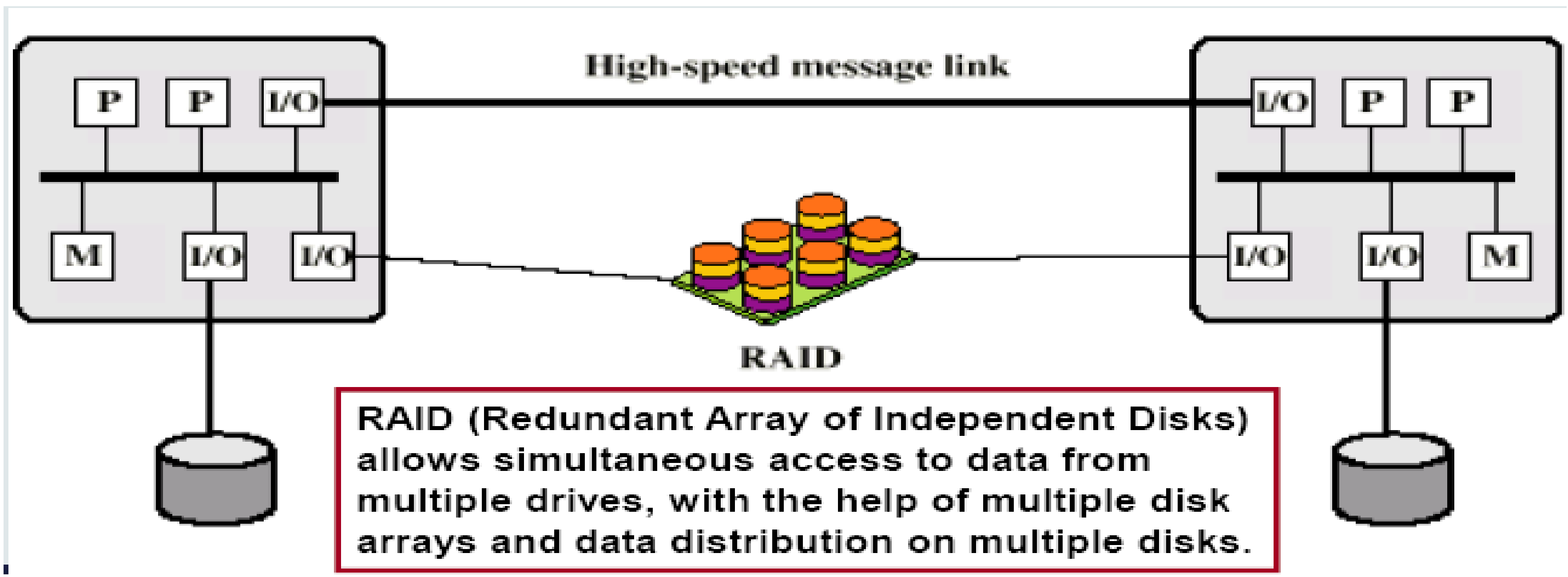
- The simplest classification of clusters is based on whether the nodes share access to disks.
- Cluster with no shared disk.

    - Interconnection is by high-speed link

        - LAN may be shared with other non-cluster computers
        - Dedicated interconnection facility

# Cluster Configurations(2)

- Shared-disk cluster
  - Still connected by a message link
  - Disk subsystem directly linked to multiple computers
  - Disks should be made fault-tolerant
- To avoid single point of failure in the system.



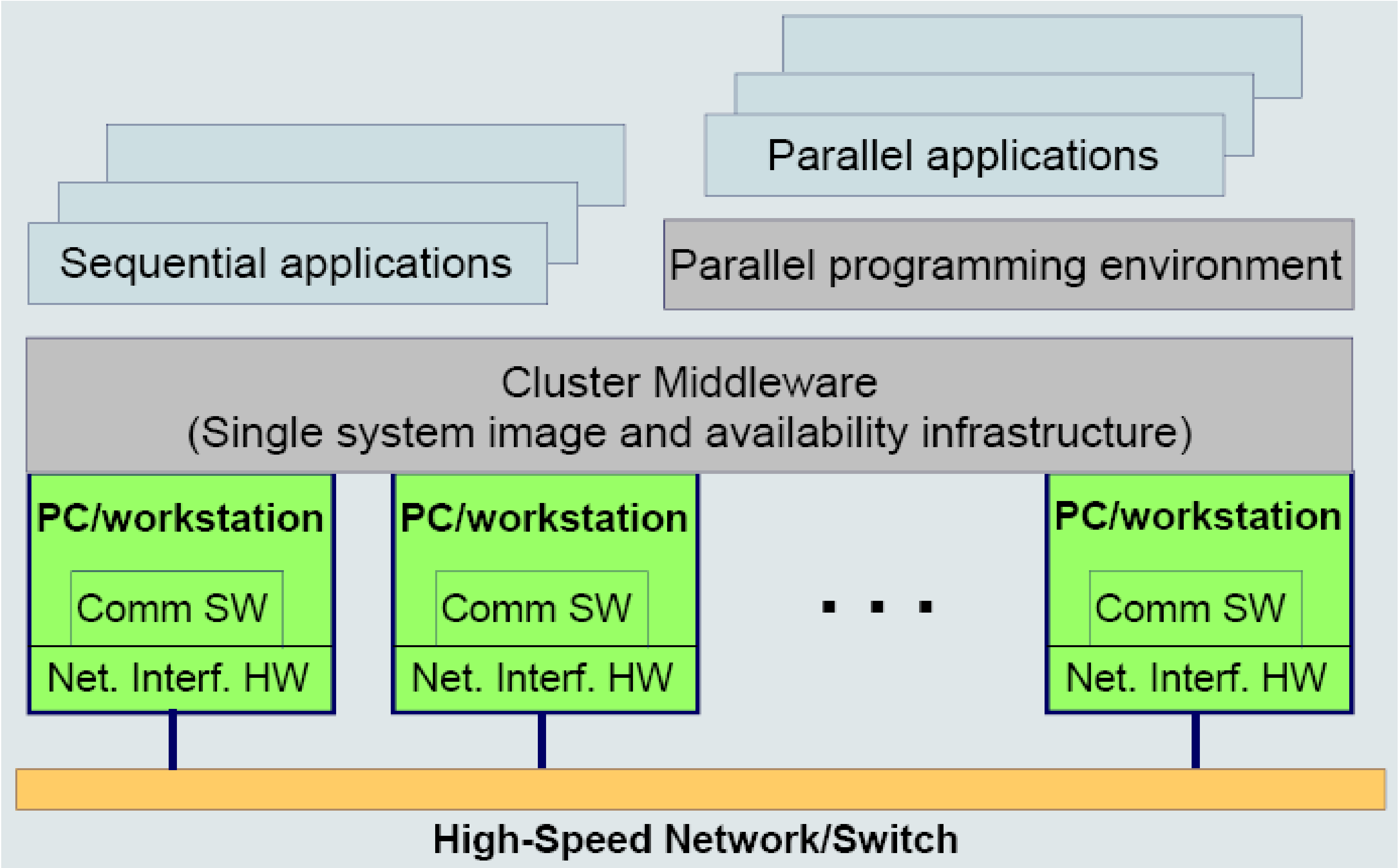

RAID (Redundant Array of Independent Disks) allows simultaneous access to data from multiple drives, with the help of multiple disk arrays and data distribution on multiple disks.

# Parallelizing Computation

**How to make a single application executing in parallel on a cluster:**

- *Paralleling complier*
  - Determines at compile time which parts can be executed in parallel.
- *Parallelized application*
  - Application written from scratch to be parallel.
  - Message passing to move data between nodes.
  - Hard to program.
  - Best end results.
- *Parametric computing*
  - If a problem is repeated execution of algorithm on different sets of data.
    - e.g. simulation using different scenarios.
  - Needs effective tools to organize and run.

# Cluster Computer Architecture



# Cluster vs. SMP

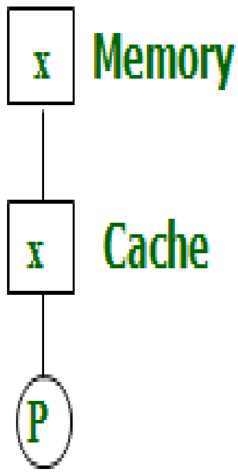
- Both provide multiprocessor support to high demand applications.
- Both available commercially
  - SMP for longer time
- **SMP:**
  - Easier to manage and control
  - Closer to single processor systems
    - Scheduling is the main difference
    - Less physical space
    - Lower power consumption
- **Clustering:**
  - Superior incremental and absolute scalability
  - Superior availability
    - High degree of redundancy

# Cache coherence(1)

- **Single Processor caching**

Hit: data in the cache

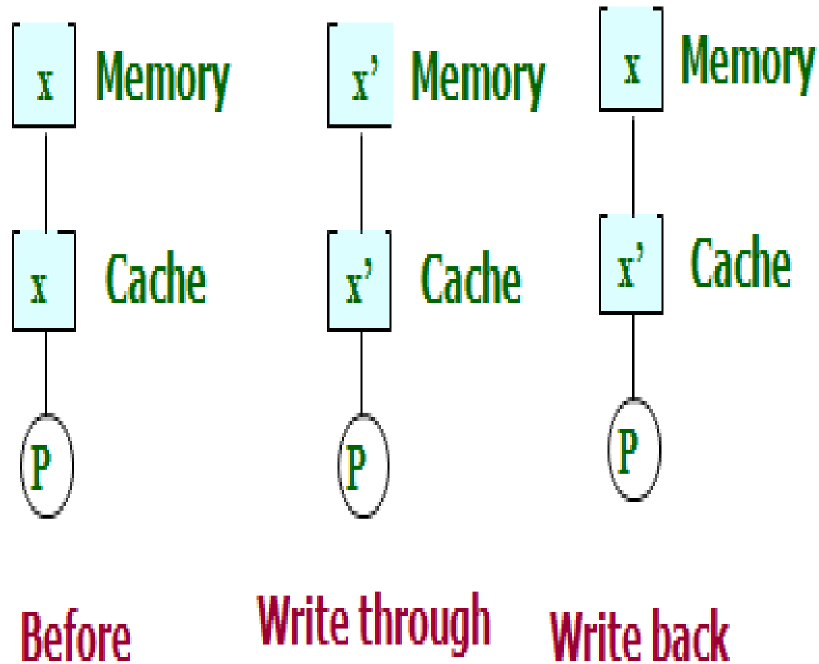
Miss: data is not in the cache



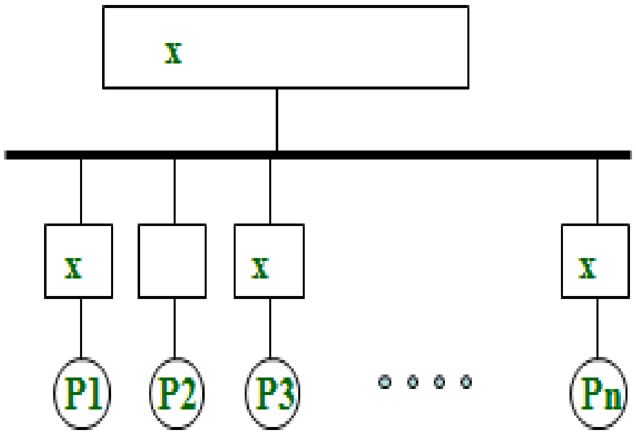

Hit rate: h

Miss rate: m = (1-h)

- **Cache Coherence Policies**

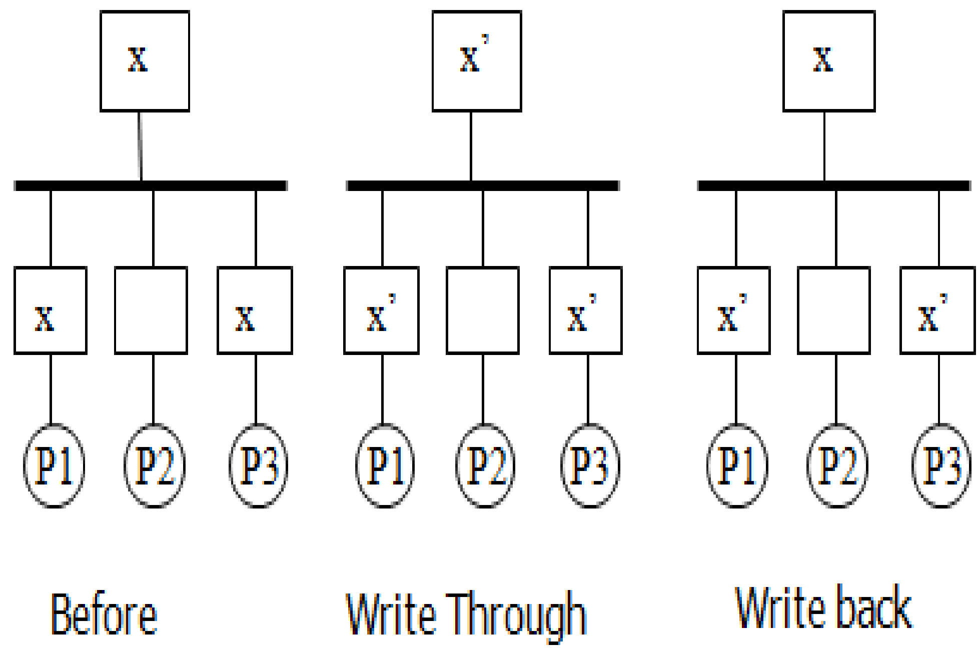


# Cache coherence(2)




-Multiple copies of x

-What if P1 updates x?



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2. Advanced Computer Architecture –Karsuk
3. Computer System Architecture - Mano