Parallel and Distributed Computing

CS3006

Lecture 4

Network Topologies

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Agenda

- A Quick Review
- Static Interconnection vs Dynamic interconnections
- Some Basic Interconnections
- Evaluating Static Interconnections

Quick Review to the Previous Lecture

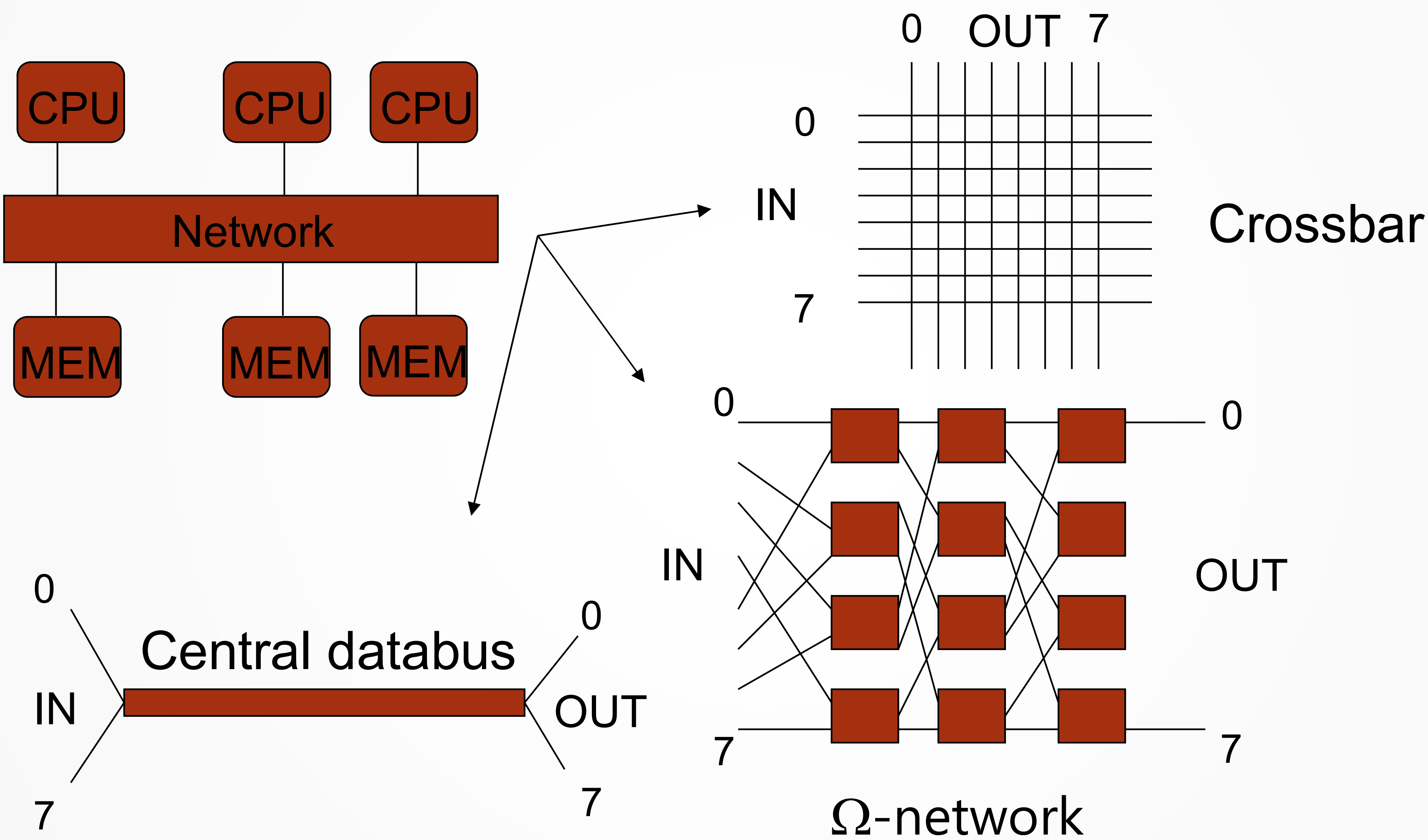
- **Flynn's Taxonomy**
  - SISD
  - MISD
  - SIMD
  - MIMD
- **PRAM Model**
  - Types
  - Arbitration protocols
- **Routing techniques and Costs**

Interconnection Networks

- Main problem is how to do interconnections of the CPUs to each other and to the memory

- There are three main network topologies available:
  - Crossbar (n^2 connections – data path without sharing)
  - Multi-stages network ($n \log_2 n$ connections - $\log_2 n$ switching stages and shared on a path)
  - Central databus (1 connections - n shared)

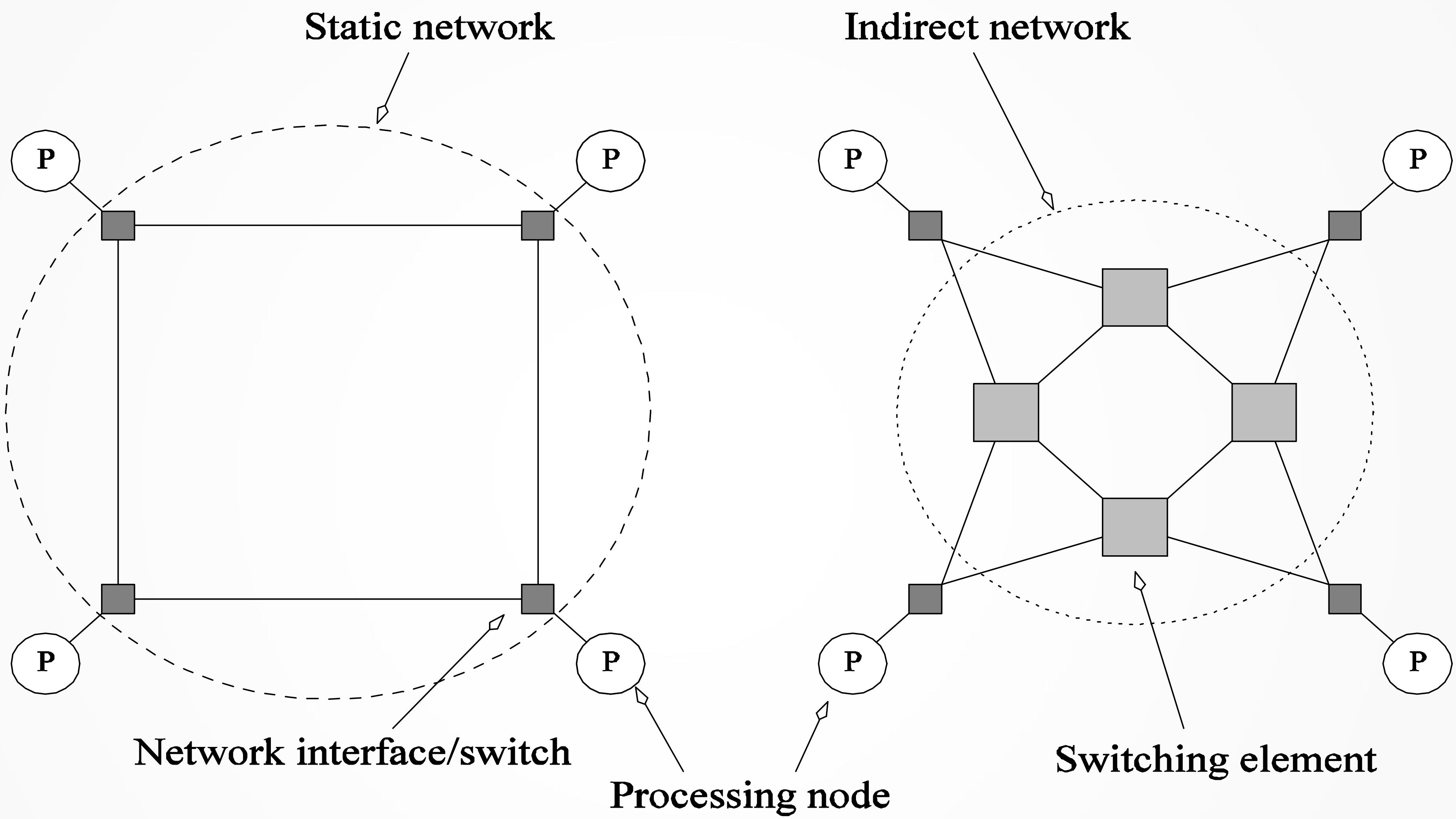
Interconnection Networks



Static vs Dynamic Interconnections

- Interconnection networks carry data between processors and to memory.
- Interconnects are made of processing elements, switches and links (wires, fiber).
- Interconnects are classified as static or dynamic.
- **Static** networks consist of point-to-point communication links among processing nodes and are also referred to as *direct* networks.
- **Dynamic** networks are built using switches and communication links. Dynamic networks are also referred to as *indirect* networks.

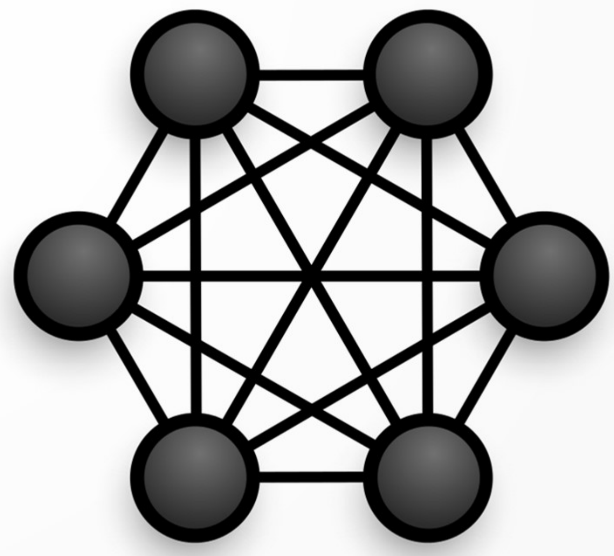
Static vs Dynamic Interconnections



Classification of interconnection networks: (a) a static network; and (b) a dynamic network.

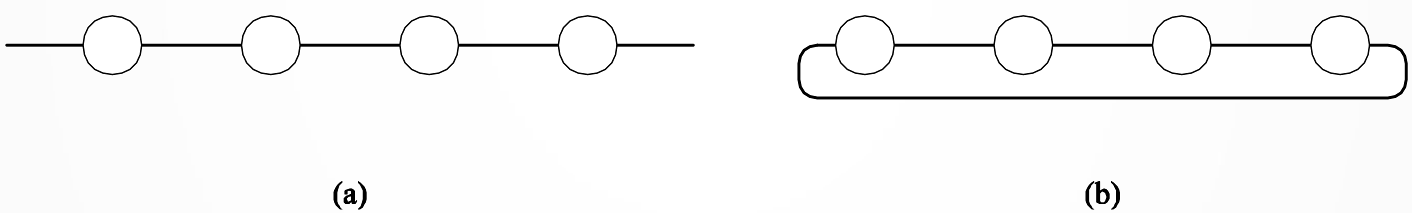
Network Topologies: Linear Arrays, Meshes, and *k-d* Meshes

- Each processor is connected to every other processor (Complete connected network).
- The number of links in the network scales as $O(p^2)$.
- While the performance scales very well, the hardware complexity is not realizable for large values of p.
- Star connected networks



Network Topologies: Linear Arrays, Meshes, and *k-d* Meshes

- In a linear array, each node has two neighbors, one to its left and one to its right.
- If the nodes at either end are connected, we refer to it as a 1-D torus or a ring.

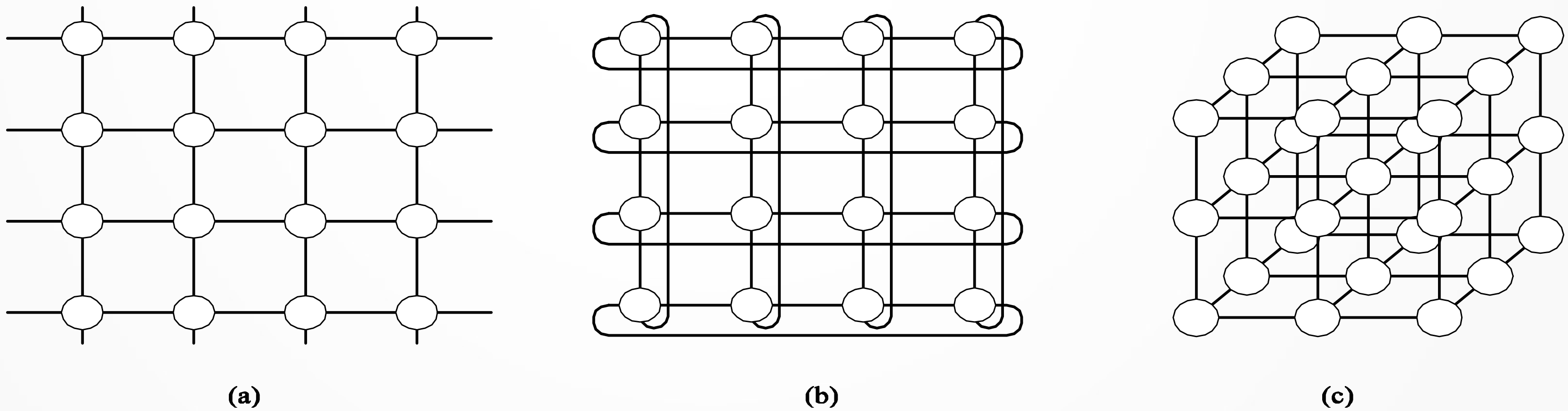


Linear arrays: (a) with no wraparound links; (b) with wraparound link.

Network Topologies: Linear Arrays, Meshes, and *k-d* Meshes

Mesh

- A generalization has nodes with 4 neighbors, to the north, south, east, and west.
- A further generalization to *d* dimensions has nodes with 2*d* neighbors (i.e., 6 neighbors in case of 3d cube).



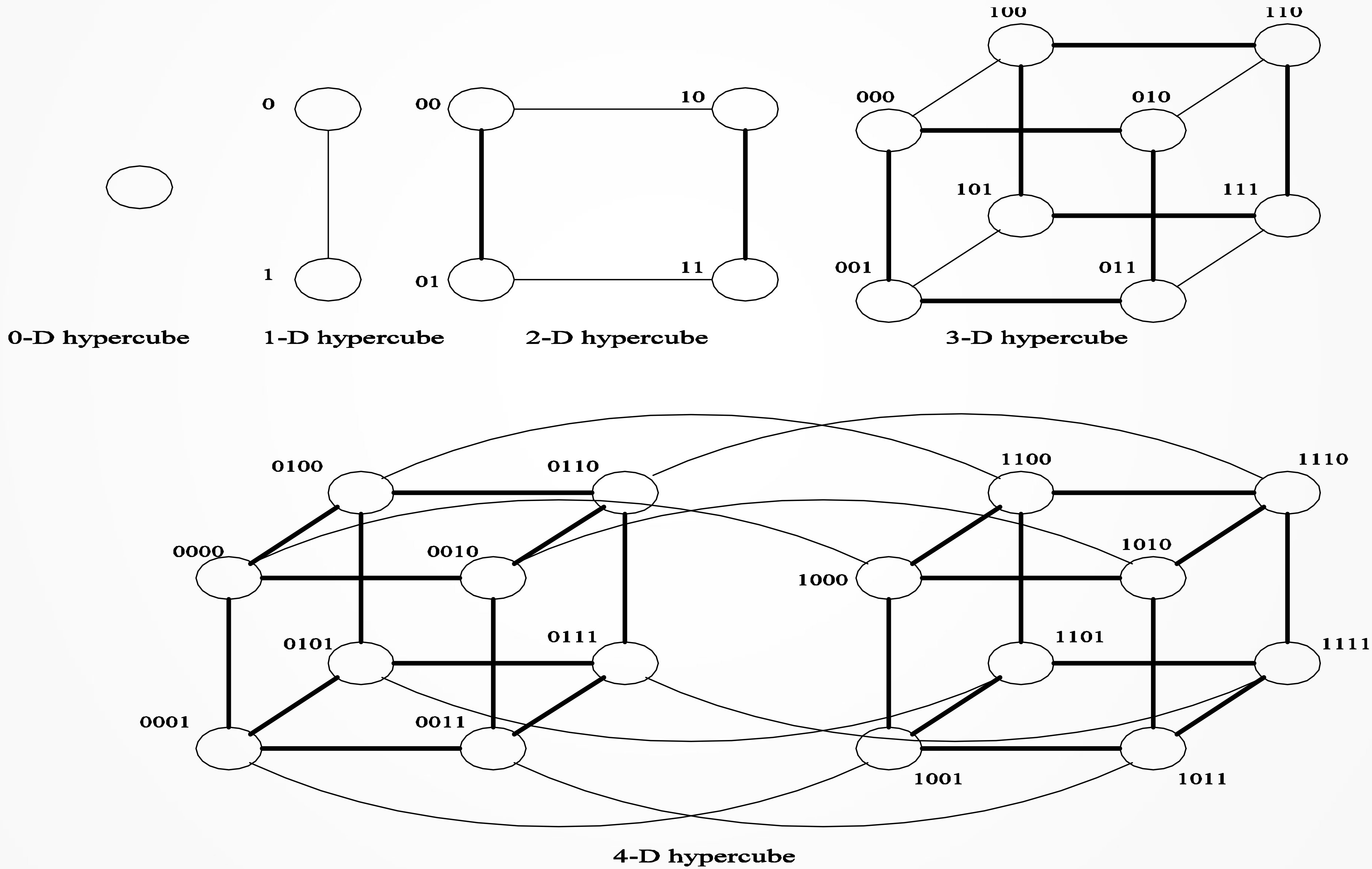
Two and three dimensional meshes: (a) 2-D mesh with no wraparound; (b) 2-D mesh with wraparound link (2-D torus); and (c) a 3-D mesh with no wraparound.

Network Topologies: Linear Arrays, Meshes, and *k-d* Meshes

Hypercube

- The hypercube has two nodes along each dimension except *0d* hypercube.
- *d = log p (dimensions = log(nodes))*
- The distance between any two nodes is at most *log p*.
- Each node has *log p* neighbors.
- The distance between two nodes is given by the number of bit positions at which the two nodes differ.
- Rule of thumb is: “d-dimensional hypercube can be constructed by connecting corresponding nodes of two (d-1)-dimensional hypercubes”

Network Topologies: Linear Arrays, Meshes, and *k-d* Meshes

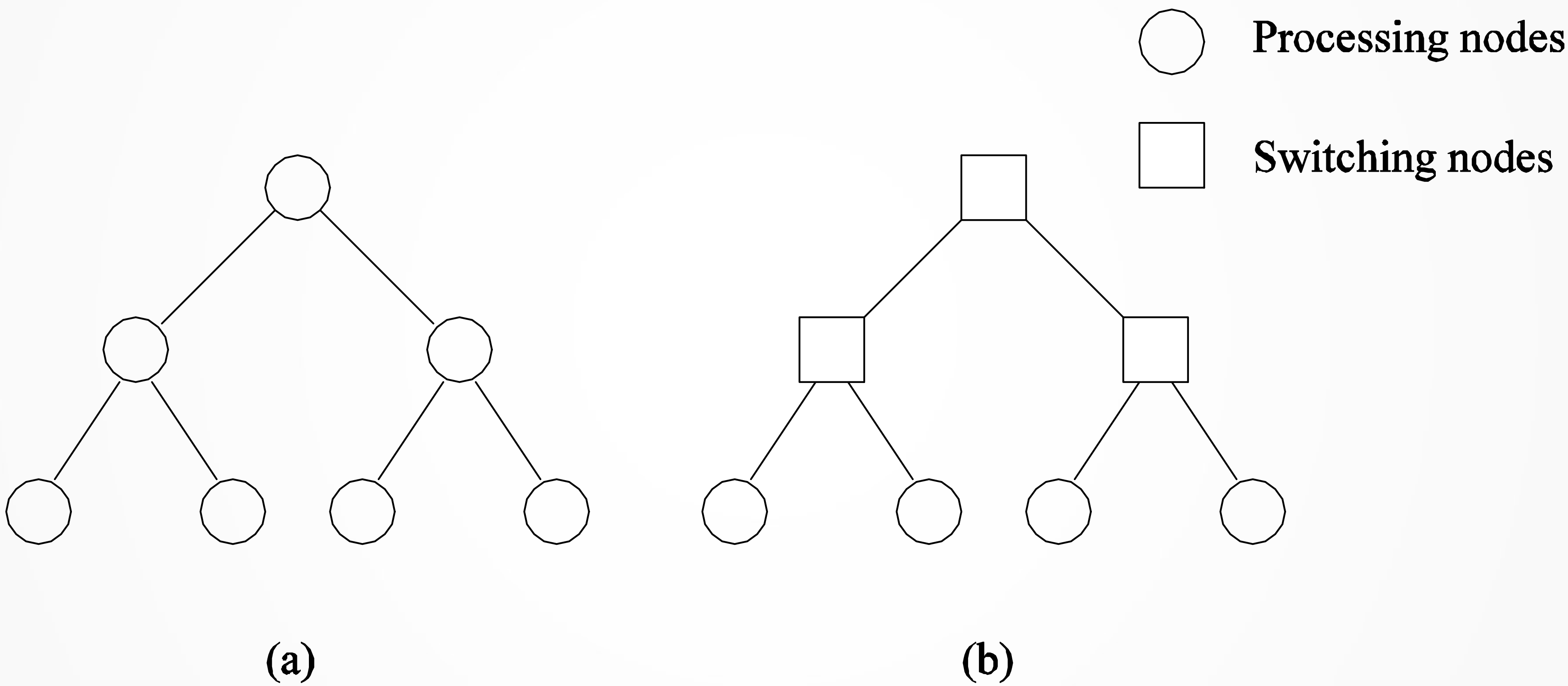


Network Topologies: Tree based Networks

- A tree network is one in which there is one path between any pair of nodes
- Linear arrays and star-connected networks are special cases of tree-based networks
- In static tree network, each node represent a processing element
- In dynamic tree network, leaf nodes represent processing element while internal nodes are switching elements.
- The source node sends the message up the tree until it reaches the node at the root of the smallest subtree containing both the source and destination nodes.

Network Topologies: Tree based Networks

Complete Binary Tree



Complete binary tree networks: (a) a static tree network; and (b) a dynamic tree network.

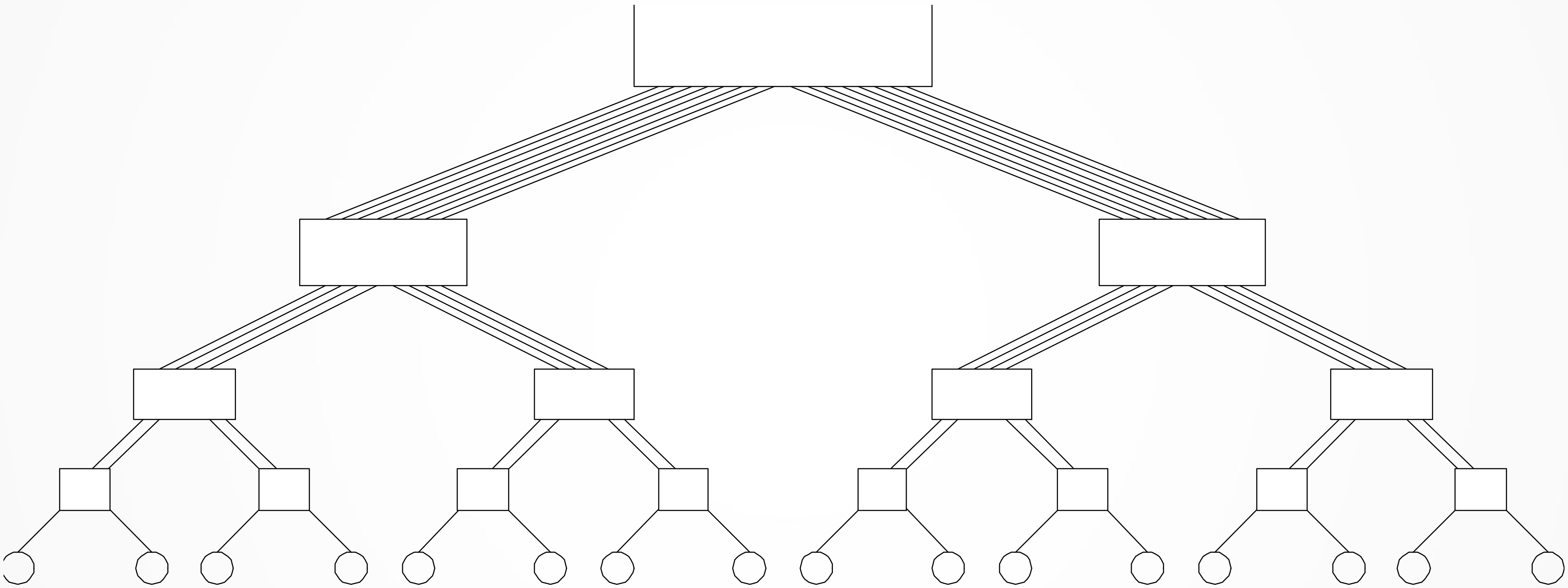
Network Topologies: Tree based Networks

Properties of Complete Binary Tree Network

- The distance between any two nodes is no more than $2\log p$.
- Links higher up the tree potentially carry more traffic than those at the lower levels.
- For this reason, a variant called a fat-tree, fattens the links as we go up the tree.
- Trees can be laid out in 2D with no wire crossings. This is an attractive property of trees.

Network Topologies: Tree based Networks

Properties of Complete Binary Tree Network



A fat tree network of 16 processing nodes.

Evaluating Static Interconnections

The parameters to evaluate a static interconnection:-

- ***Cost:*** Usually depends on number of links for communication. E.g., cost for linear array is $p-1$.
  - *Lower values are favorable*
- ***Diameter:*** The shortest distance between the farthest two nodes in the network. The diameter of a linear array is $p - 1$.
  - *Lower values are favorable*
- ***Bisection Width:*** The minimum number of wires you must cut to divide the network into two equal parts. The bisection width of a linear array is 1.
  - What it tells about performance of a topology?

Evaluating Static Interconnections

The parameters to evaluate a static interconnection:-

- ***Arc-connectivity:*** *The minimum number of arcs or links that must be removed from the network, to break the network into two disconnected networks*
  - *Higher value are desirable*
  - It is minimum number of the links that must be cut to separate the single node from the network
  - Higher values means, that incase of link failure there are multiple other routes to the node.
  - Arc-connectivity of linear array is *1* and 2 for ring.

Evaluating Static Interconnections

Network	Diameter	Bisection Width	Arc Connectivity	Cost (No. of links)
Completely-connected	1	$p^2/4$	$p-1$	$p(p-1)/2$
Star	2	1	1	$p-1$
Complete binary tree	$2\log((p+1)/2)$	1	1	$p-1$
Linear array	$p-1$	1	1	$p-1$
2-D mesh, no wraparound	$2(\sqrt{p}-1)$	$\sqrt{p}$	2	$2(p-\sqrt{p})$
2-D wraparound mesh	$2\lfloor\sqrt{p}/2\rfloor$	$2\sqrt{p}$	4	$2p$
Hypercube	$\log p$	$p/2$	$\log p$	$(p\log p)/2$

Questions

References

1. Flynn, M., “Some Computer Organizations and Their Effectiveness,” IEEE Transactions on Computers, Vol. C-21, No. 9, September 1972.
2. Kumar, V., Grama, A., Gupta, A., & Karypis, G. (1994). *Introduction to parallel computing* (Vol. 110). Redwood City, CA: Benjamin/Cummings.
3. Quinn, M. J. Parallel Programming in C with MPI and OpenMP,(2003).

Cache Coherence and snooping

- In a snooping system, all caches on the bus monitor (or snoop) the bus to determine if they have a copy of the block of data that is requested on the bus.
- Every cache has a copy of the sharing status of every block of physical memory it has.

Snooping Protocol Types

- Write-invalidate (mostly used)
  - The processor that is writing data causes copies in the caches of all other processors in the system to be rendered **invalid** before it changes its local copy.
- Write-update
  - The processor that is writing the data broadcasts the new data over the bus
  - All caches that contain copies of the data are then updated