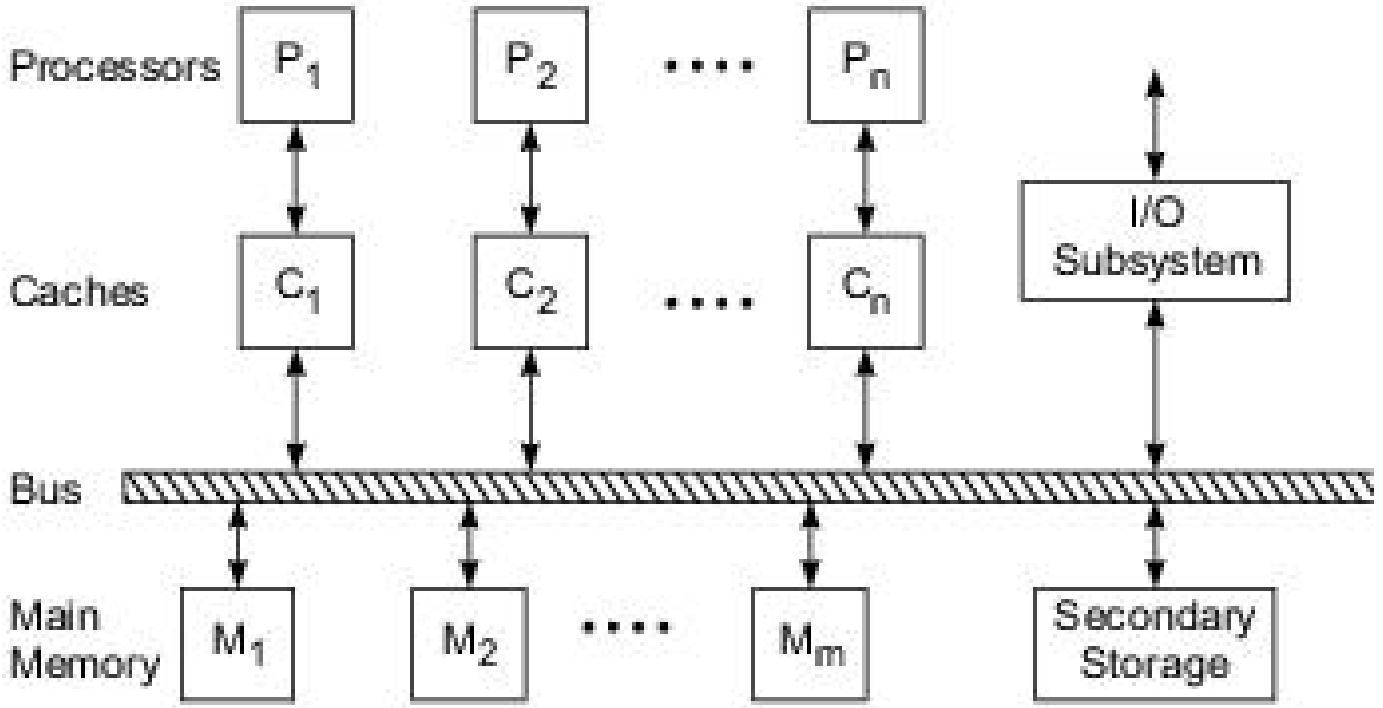
Dynamic Connection Networks

- Include bus systems, multistage interconnection networks (MIN) and crossbar switch networks
- attributed to the cost of the wires, switches, arbiters, and connectors required
- Performance is indicated by the network bandwidth, data transfer rate, network latency, and communication patterns supported
- Networks are
  - Digital buses
  - Switch Modules
  - Multistage Interconnection Network
  - Omega Network
  - Baseline Network
  - Crossbar Network

Dynamic Connection Networks (Contd…)

Digital Buses:

- Essentially a collection of wires and connectors for data transactions among processors, memory modules, and peripheral devices attached to the bus
- Bus is used for only one transaction at a time between source and destination
- In case of multiple requests, the bus arbitration logic must be able to allocate or decallocate the bus, servicing the requests one at a time
- Also called contention bus or a time-sharing bus among multiple functional modules
- Bus system has a lower cost and provides a limited bandwidth



Dynamic Connection Networks (Contd…)

Switch Modules:

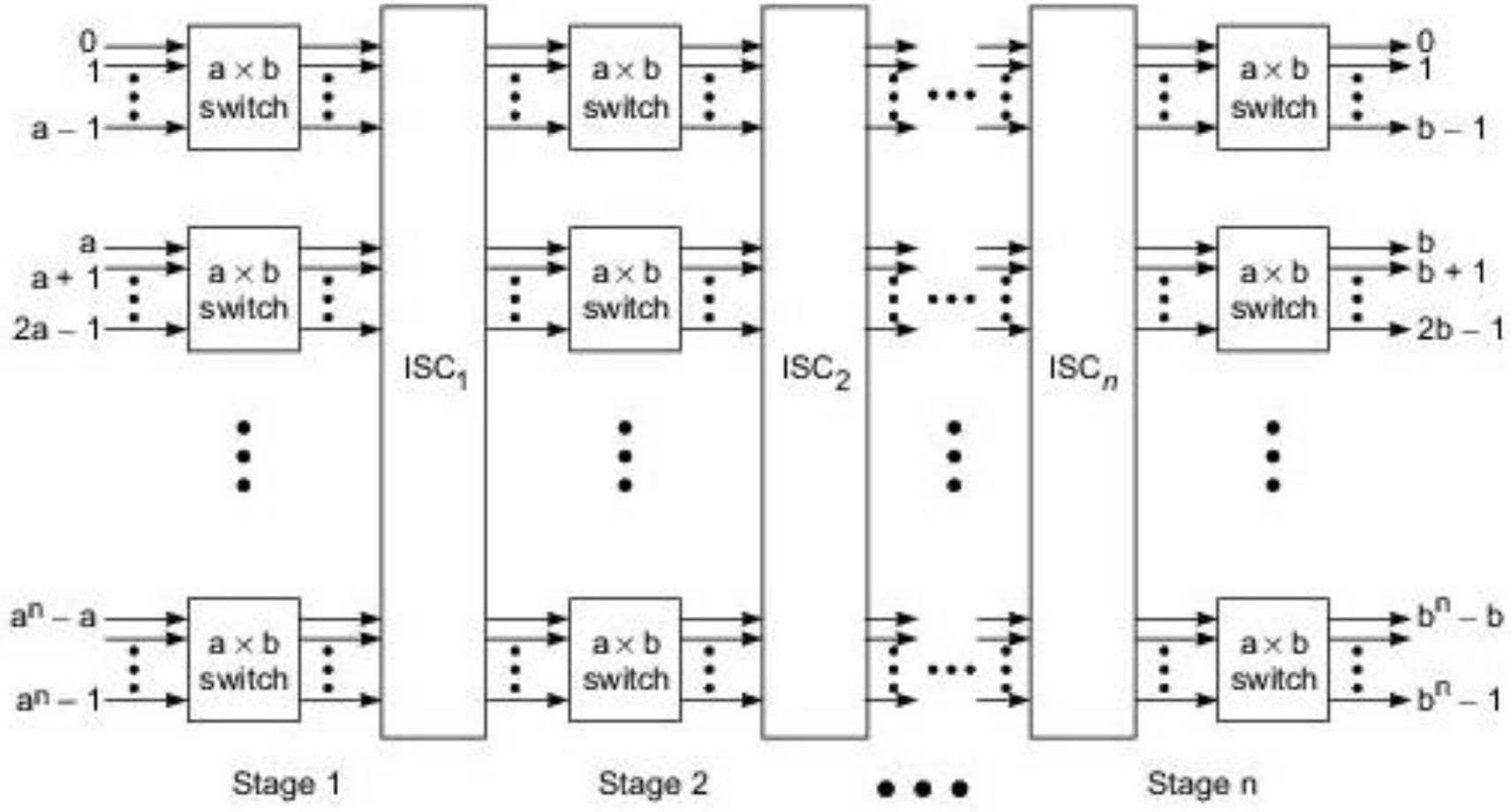
- a × b switch module has *a* inputs and *b* outputs
- A binary switch corresponds to a 2 × 2 switch module in which a = b = 2
- Theoretically, *a* and *b* do not have to be equal
- In practice, *a* and *b* are often chosen as integer powers of 2; *i.e.,* $a = b = 2^k$ for some $k \geq 1$
- Each input can be connected to one or more of the outputs
- Conflicts must be avoided at the output terminals
- One-to-one and one-to-many mappings are allowed; but many-to—one mappings are not allowed due to conflicts at the output terminal
- When only one-to-one mappings (permutations) are allowed, we call the module an n × n crossbar switch
- a 2 × 2 crossbar switch can connect two possible patterns: straight or crossover
- In general, an n × n crossbar can achieve *n!* permutations
- commonly used switch module sizes:

Module Size	*Legitimate States*	*Permutation Connections*
2×2	4	2
4×4	256	24
8×8	16,777,216	40,320
$n \times n$	n^n	$n!$

Dynamic Connection Networks (Contd…)

Multistage Interconnection Networks (MINs):

- Used in both MIMD and SIMD computers



A generalized structure of a multistage interconnection network (MIN) built with a × b switch modules and interstage connection patterns $ISC_1, ISC_2, \ldots, ISC_n$

Dynamic Connection Networks (Contd…)

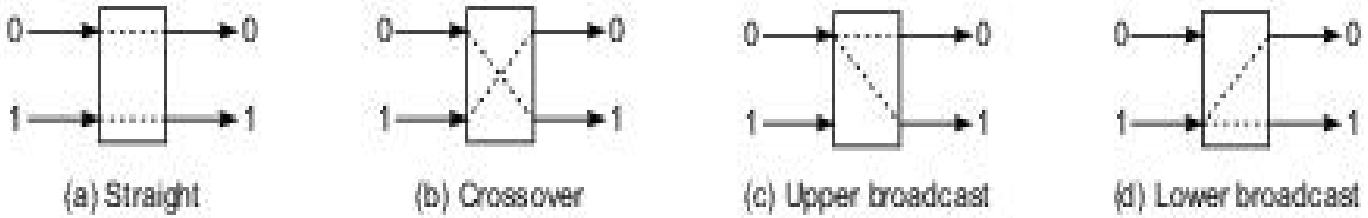
Multistage Interconnection Networks (MINs):

- Number of $a \times b$ switches are used in each stage
- Fixed inter-stage connections are used between the switches in adjacent stages
- Switches can be dynamically set to establish the desired connections between the inputs and outputs
- Different classes of MINs differ in the switch modules used as kind of interstage connection (ISC) patterns used
- Simplest switch module would be the 2×2 switches
- ISC patterns often used include *perfect shuffle*, *butterfly, multiway shuffle*, *crossbar*, *cube connection*, *etc.*

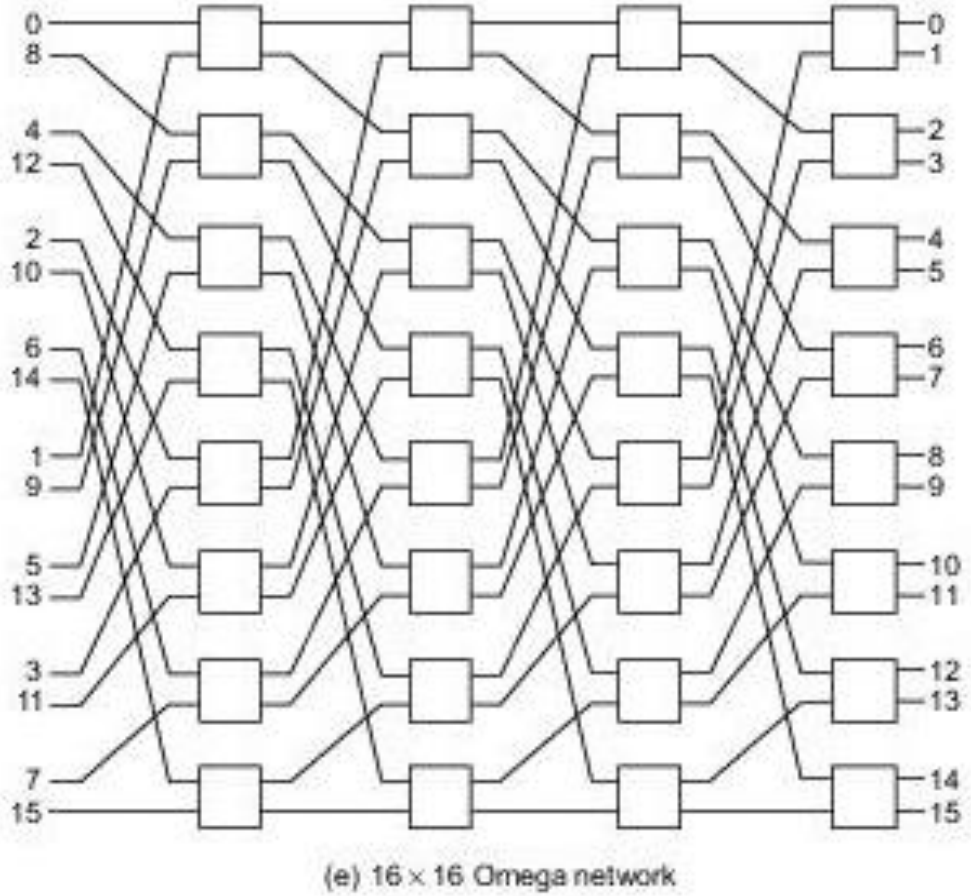
Dynamic Connection Networks (Contd…)

Omega Network:

- Four possible connections of *2 × 2* switches used in constructing the Omega network



- Four stages of 2 × *2* switches are needed
- 16 inputs on the left and 16 outputs on the right
- ISC pattern is the *perfect shuffle* over 16 objects
- an *n*-input Omega network requires $log_n 2$ stages of 2 × *2* switches
- Each stage requires $^n/_2$ switch modules
- In total, thc network uses $nlog_n 2$ switches
- Each switch module is individually controlled
- Various combinations of the switch states implement different permutations, broadcast, or other connections front the inputs to the outputs

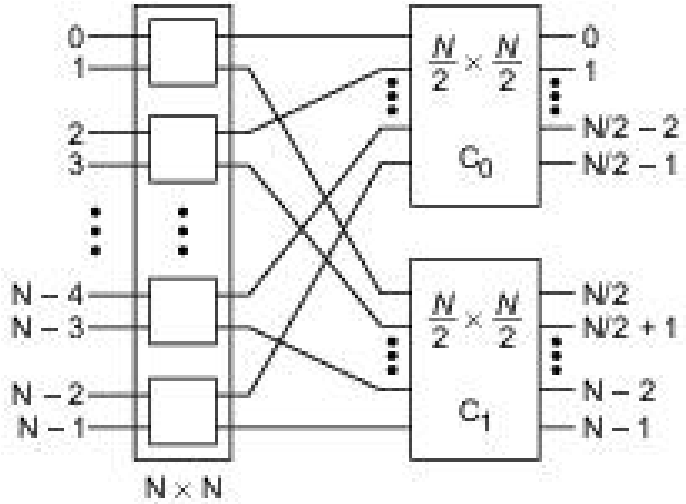


(e) 16 × 16 Omega network

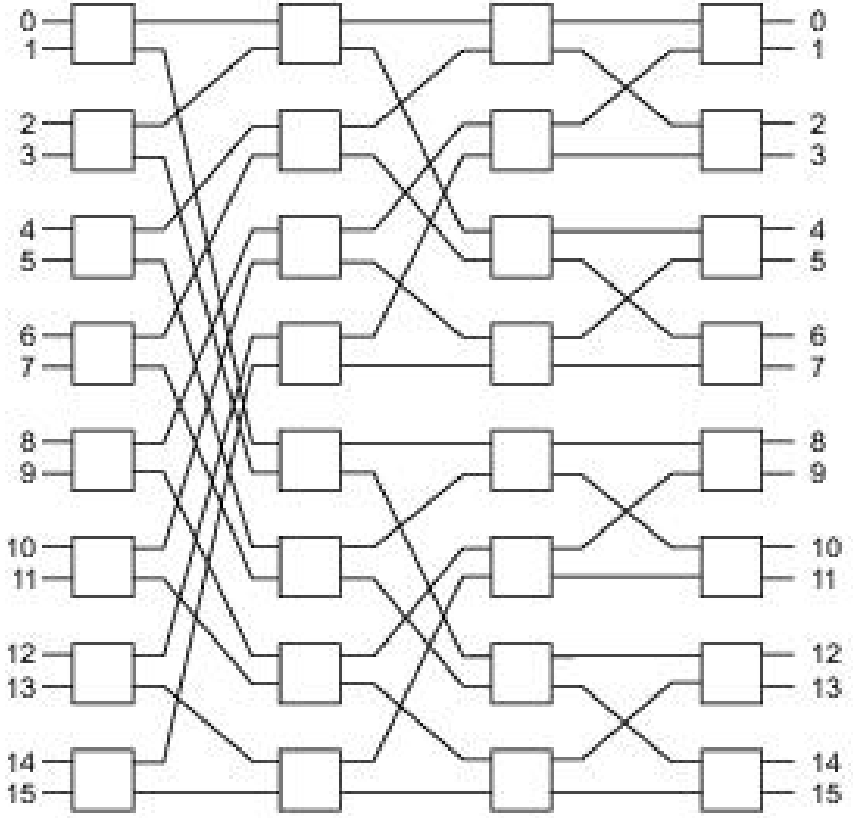
Dynamic Connection Networks (Contd…)

Baseline Network:

- A Baseline network can be generated recursively"
  - The first stage contains one $N \times N$ block, and
  - Second stage contains two $\left(\frac{N}{2}\right) \times \left(\frac{N}{2}\right)$ subblocks,labeled C_0 and C_1
  - Construction process can be recursively applied to the subblocks until $N/2$ subblocks of size 2×2 are reached
- The building blocks of subblocks are 2×2 switches; each with two states: *straight* and *crossover*



(a) Recursive construction

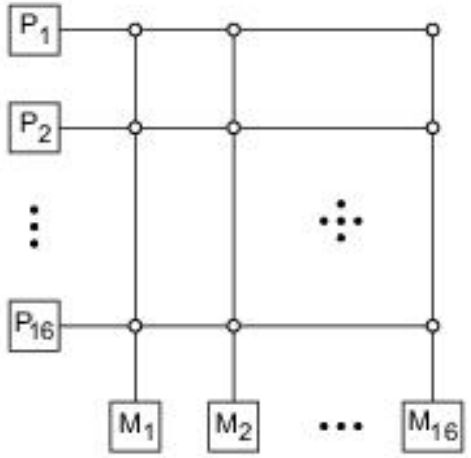


(b) A 16 × 16 Baseline network

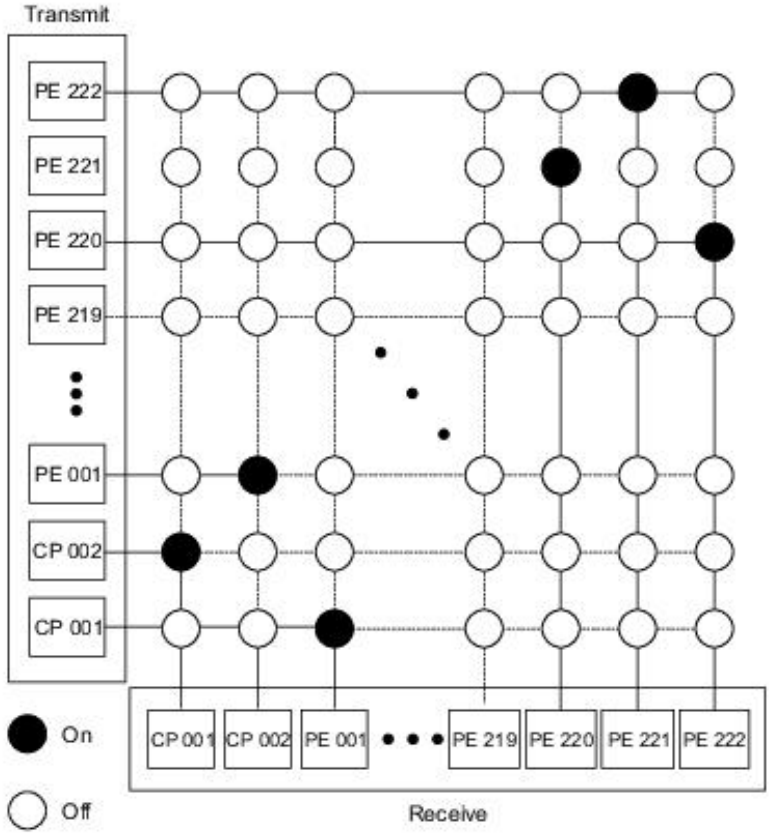
Dynamic Connection Networks (Contd…)

Crossbar Network:

- Highest bandwidth and interconnection and routing capability
- visualized as a single-stage switch network
- Like a telephone switchboard, the cross-point switches dynamic connections between source, destination pairs
- Provides a dedicated connection path between a pair
- Switch can be set ON or OFF dynamically upon program demand



(a) Interprocessor-memory crossbar network built in the C.mmp multiprocessor at Carnegie-Mellon University (1972)



(b) The interprocessor crossbar network built in the Fujitsu VPP500 vector parallel processor (1992)

Dynamic Connection Networks (Contd…)

Crossbar Network:

- To build a shared-memory multiprocessor, one can use a crossbar network between the processors and memory modules
- Essentially a memory-access network
- Each memory module can satisfy only one processor request at a time
- When multiple requests arrive at the some memory module simultaneously, the crossbar must resolve the conflicts
- Behaviour of crossbar is similar to that of a bus
- Processor can generate a sequence of addresses to access multiple memory modules simultaneously, only one crosspoint switch can be set on in each column
- Several crosspoint switches can be set on simultaneously in order to support parallel (or interleaved] memory accesses
- Large crossbar [224 × 224) was actually built in a vector parallel processor (VPP500) by Fujitsu Inc. (1992)
- PEs are processors with attached memory
- CPs stand for control processors which are used to supervise the entire system operation, including the crossbar networks
- At one time only one crosspoint switch can be set on in each row and each column
- Interprocessor crossbar provides permutation connections among the processors
- Only one-to-one connections are provided
- The $n \times n$ crossbar connects at most n source, destination pairs at a time
- Crossbar switch is the most expensive one to build, due to the fact that its hardware complexity increascs to n^2
- For a small network size, it is the desired choice

Summary of Dynamic Connection Networks

Network Characteristics	*Bus System*	*Multistage Network*	*Crossbar Switch*
Minimum latency for unit data transfer	Constant	$O(\log_k n)$	Constant
Bandwidth per processor	$O(w/n)$ to $O(w)$	$O(w)$ to $O(nw)$	$O(w)$ to $O(nw)$
Wiring Complexity	$O(w)$	$O(nw \log_k n)$	$O(n^2 w)$
Switching Complexity	$O(n)$	$O(n \log_k n)$	$O(n^2)$
Connectivity and routing capability	Only one to one at a time.	Some permutations and broadcast, if network unblocked	All permutations, one at a time.
Early representative computers	Symmetry S-1, Encore Multimax	BBN TC-2000, IBM RP3	Cray Y-MP/816, Fujitsu VPP500
Remarks	Assume n processors on the bus; bus width is w bits.	$n \times n$ MIN using $k \times k$ switches with line width of w bits.	Assume $n \times n$ crossbar with line width of w bits.