Short Summery

- Classification according to memory organization
  - distributed memory
  - shared-address space
- Interconnection networks
  - dynamic networks
- crossbar, bus-based, multistage (Omega network)
Omega Network

Figure 2.10 A perfect shuffle interconnection for eight inputs and outputs.
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Figure 2.12 A complete omega network connecting eight inputs and eight outputs.
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\[
j = \begin{cases} 
2i, & 0 \leq i \leq p/2 - 1 \\
2i + 1 - p, & p/2 \leq i \leq p - 1
\end{cases}
\]
Omega network features

- There are $\log_2 p$ stages each with $p/2$ switching elements each = $p/2 \times \log_2 p$ total
  - Contrast with $\Theta(p^2)$ for the crossbar switch
- Simple routing algorithm
  - At each stage, look at the corresponding bit (starting with the msb) of the source and destination address
  - If the bits are the same, messages passes through, otherwise is crossed-over
- Omega networks are blocking networks - when routes to different memory banks share a link a message might be blocked by another
  - Contrast with nonblocking crossbar switch
Blocking in omega network

- Example of blocking: either (010 to 111) or (110 to 100) has to wait until link AB is no longer in use
Static interconnection networks

- Completely connected networks
- Star-Connected Networks
- Linear Array and Ring
- Mesh Networks
- Tree Networks
- Hypercube Network
Static Interconnection Networks I

- Completely [star] connected network is the static analogous of the crossbar [bus] interconnect
Static Interconnection Networks II

- A *n-dimensional mesh* [torus or wraparound mesh] is an extension of the linear array [ring]
- Examples: Intel Paragon (2D mesh), Cray T3D (3D torus)
Tree networks

Simple trees

Fat tree
Hypercubes

- An hypercube is a multi-dimensional mesh with exactly two processors in each dimension.
- Examples: Cosmic Cube, nCube 1, SGI Origin 2000.
4D hypercube

- 4D hypercube = two 3D hypercubes with an additional link connecting corresponding processors
Hypercube Gallery

0-D hypercube  1-D hypercube  2-D hypercube  3-D hypercube

4-D hypercube
Hypercube Property

• One node connected to $d$ others
• One bit difference in labels $\iff$ direct link
• One hyper can be partitioned in two $(d-1)$ hypers
• The Hamming distance = shortest path length
  – Hamming distance = # of bits that are different in $source$
    and $dest = # of ones in source \oplus dest$
• Each node address contains $d$ bits
  – fixing $k$ of these bits, the nodes that differ in the remaining
    $(d-k)$ form $(d-k)$ dimension subcube of $2^{(d-k)}$ nodes. There are $2^k$
    such subcubes.
Subcube example

- Subcubes of dimension 2 obtained by fixing the two most significant bits
K-ary d-cubes

- A $k$-ary $d$-cube is a $d$-dimensional mesh with $k$ elements along each dimension
  - $k$ is called the *radix*, $d$ the *dimension*
  - can be built from $k$-ary $(d-1)$-cubes by connecting the corresponding processors into a ring
- Some of the other topologies are particular instances of the $k$-ary $d$-cube:
  - A ring interconnect with $n$ nodes is a $n$-ary 1-cube
  - A two dimensional wraparound mesh of $n^2$ processors is a $n$-ary 2-cube