ECE 669

Parallel Computer Architecture

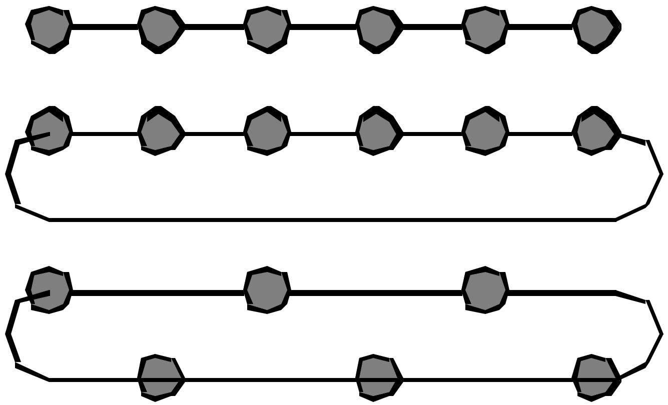
Lecture 16

Interconnection Topology

Interconnection Topologies

- **Class networks scaling with N**
- **Logical Properties:**
  - **distance, degree**
- **Physical properties**
  - **length, width**
- **Fully connected network**
  - **diameter = 1**
  - **degree = N**
  - **cost?**
    - **bus => O(N), but BW is O(1)**   **- actually worse**
    - **crossbar => $O(N^2)$ for BW O(N)**
- **VLSI technology determines switch degree**

Linear Arrays and Rings



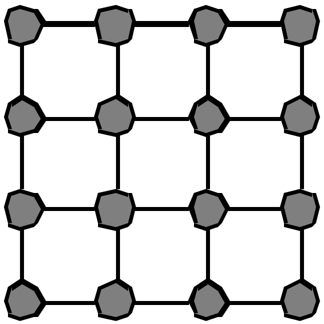
Linear Array

Torus

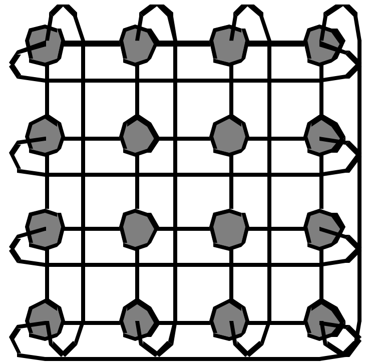
Torus arranged to use short wires

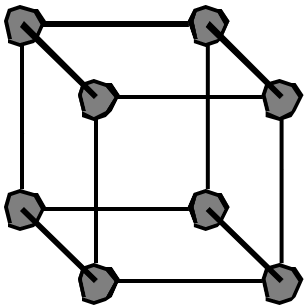
- **Linear Array**
  - **Diameter?**
  - **Average Distance?**
  - **Bisection bandwidth?**
  - **Route A -> B given by relative address R = B-A**
- **Torus?**
- **Examples: FDDI, SCI, KSR1**

Multidimensional Meshes and Tori



2D Grid

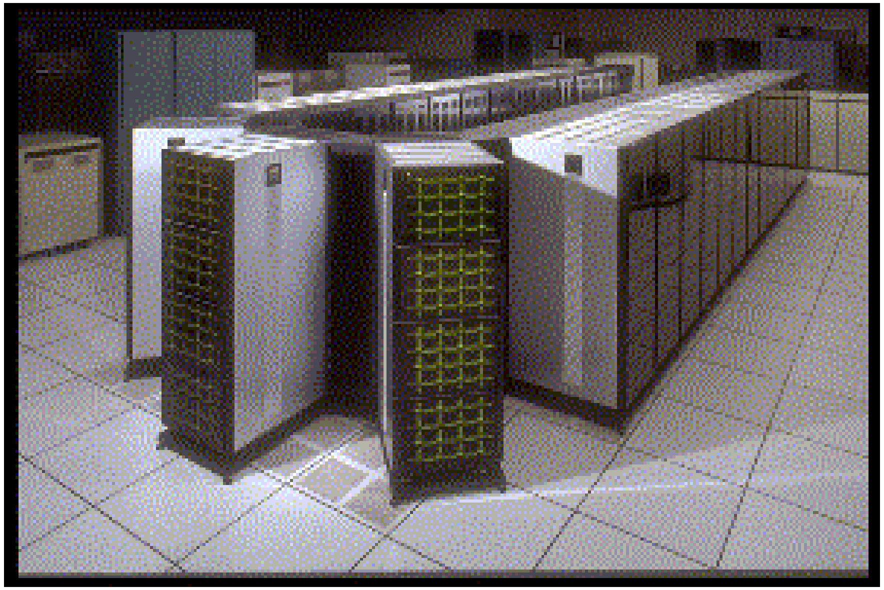




3D Cube

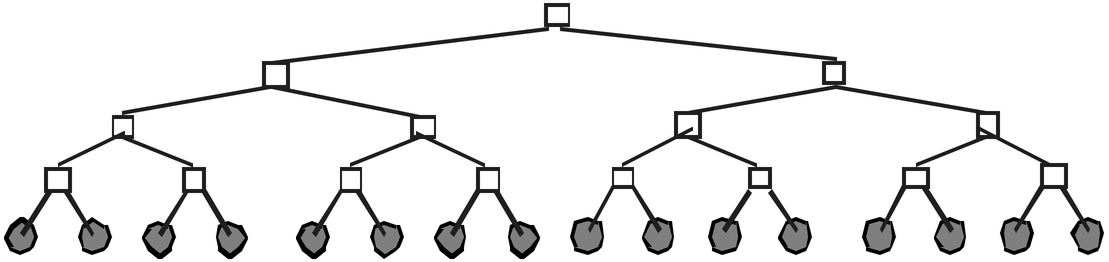
- ***n*-dimensional *k*-ary mesh: N = k^n**
  - **k = ^{n}ÖN**
  - **described by *n*-vector of radix k coordinate**
- ***n*-dimensional *k*-ary torus (or *k*-ary *n*-cube)?**

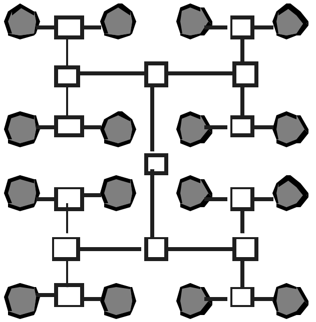
Real World 2D mesh



- 1824 node Paragon: 16 x 114 array

Trees

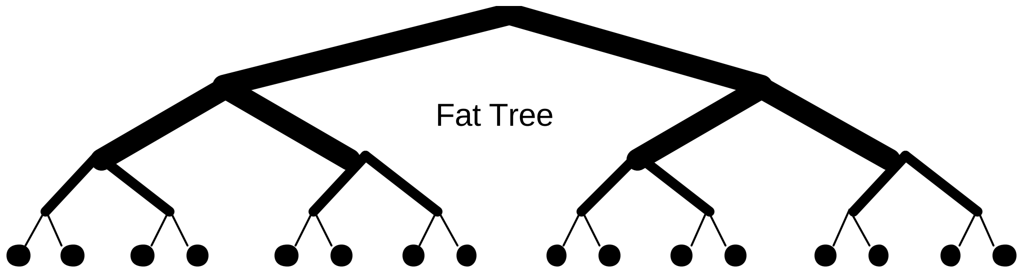


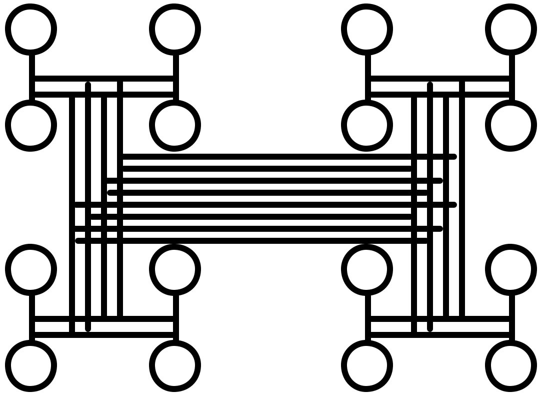


- **Diameter and ave distance logarithmic**
  - **k-ary tree, height d = $\log_k N$**
  - **address specified d-vector of radix k coordinates describing path down from root**
- **Fixed degree**
- **H-tree space is O(N) with O(ÖN) long wires**
- **Bisection BW?**

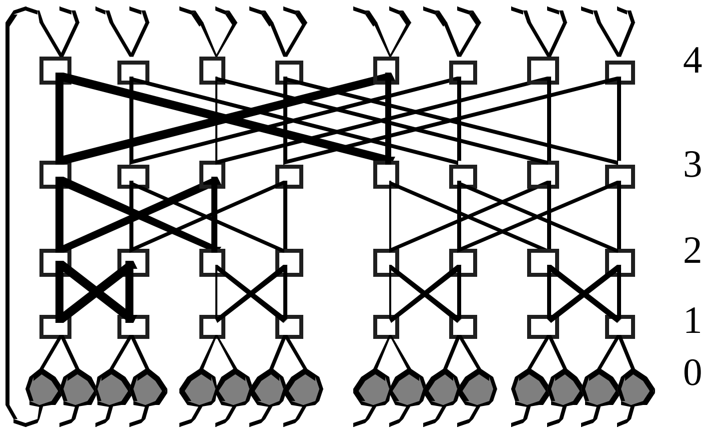
Fat-Trees

- **Fatter links (really more of them) as you go up, so bisection BW scales with N**

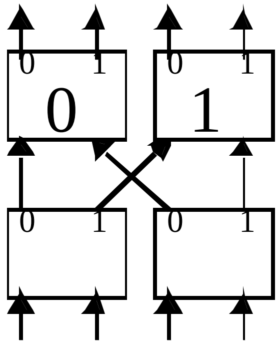




Butterflies



16 node butterfly



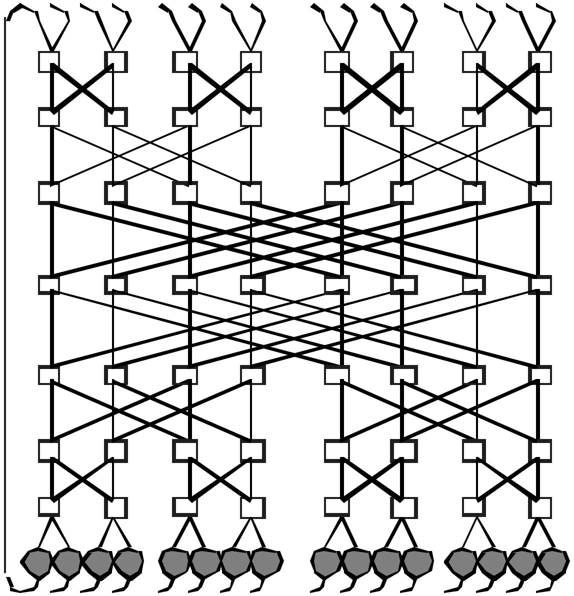
building block

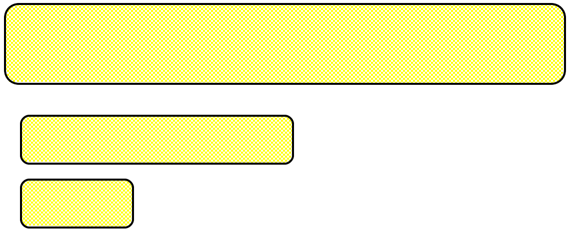
- Tree with lots of roots!
- N log N   (actually N/2 x logN)
- Exactly one route from any source to any dest
- Bisection N/2

Benes network and Fat Tree

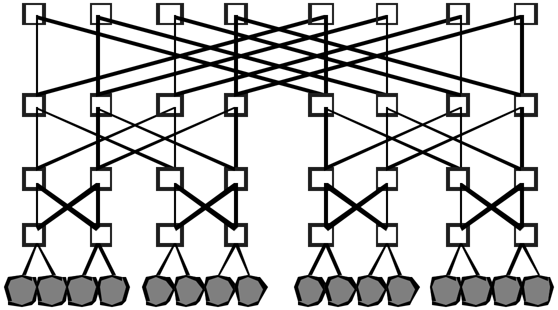
- **Back-to-back butterfly can route all permutations**
  - **off line**

16-node Benes Network (Unidirectional)





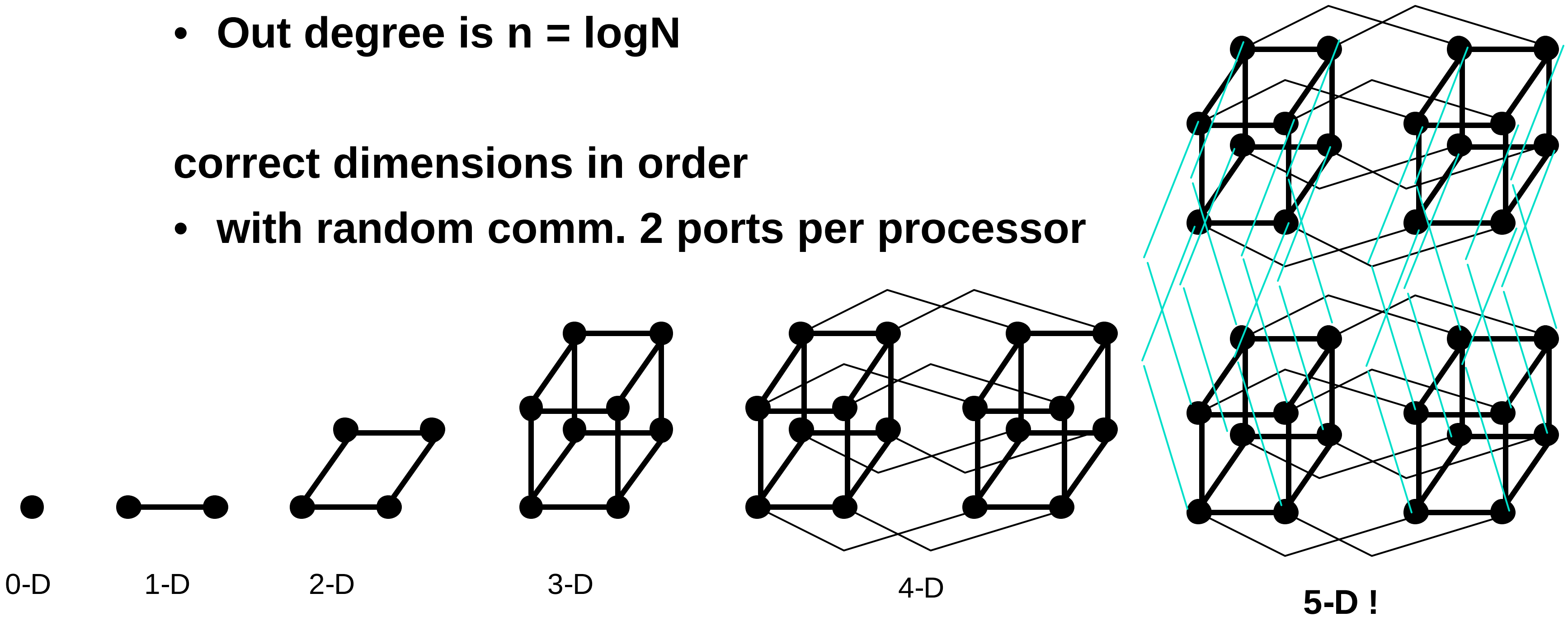
16-node 2-ary Fat-Tree (Bidirectional)



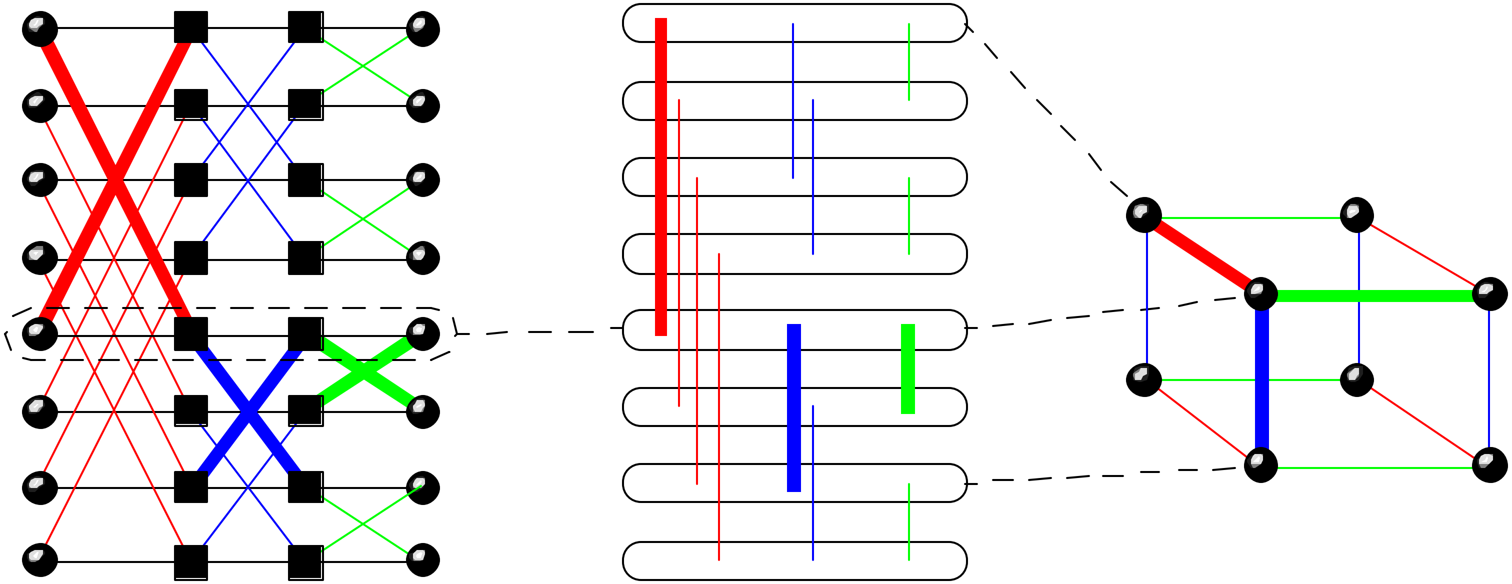
Hypercubes

- Also called binary n-cubes.   # of nodes = N = 2^n.
- O(logN) Hops
- Good bisection BW
- Complexity
  - Out degree is n = logN

  correct dimensions in order
  - with random comm. 2 ports per processor



Relationship: ButterFlies to Hypercubes



- **Wiring is isomorphic**
- **Except that Butterfly always takes log n steps**

Toplology Summary

Topology	Degree	Diameter	Ave Dist	Bisection	D (D ave) @ P=1024	
1D Array	2	N-1	N / 3	1	huge	
1D Ring	2	N/2	N/4	2		
2D Mesh	4	2 ($N^{1/2}$ - 1)	2/3 $N^{1/2}$	$N^{1/2}$	63 (21)	
2D Torus	4	$N^{1/2}$	1/2 $N^{1/2}$	$2N^{1/2}$	32 (16)	
k-ary n-cube	2n	nk/2	nk/4	nk/4	15 (7.5)	@n=3
Hypercube	n =log N		n	n/2	N/2	10 (5)

- **All have some "bad permutations"**
  - **many popular permutations are very bad for meshs (transpose)**
  - **ramdomness in wiring or routing makes it hard to find a bad one!**

Real Machines

Machine	Topology	Cycle Time (ns)	Channel Width (bits)	Routing Delay (cycles)	Flit (data bits)
nCUBE/2	Hypercube	25	1	40	32
TMC CM-5	Fat-Tree	25	4	10	4
IBM SP-2	Banyan	25	8	5	16
Intel Paragon	2D Mesh	11.5	16	2	16
Meiko CS-2	Fat-Tree	20	8	7	8
CRAY T3D	3D Torus	6.67	16	2	16
DASH	Torus	30	16	2	16
J-Machine	3D Mesh	31	8	2	8
Monsoon	Butterfly	20	16	2	16
SGI Origin	Hypercube	2.5	20	16	160
Myricom	Arbitrary	6.25	16	50	16

- **Wide links, smaller routing delay**
- **Tremendous variation**