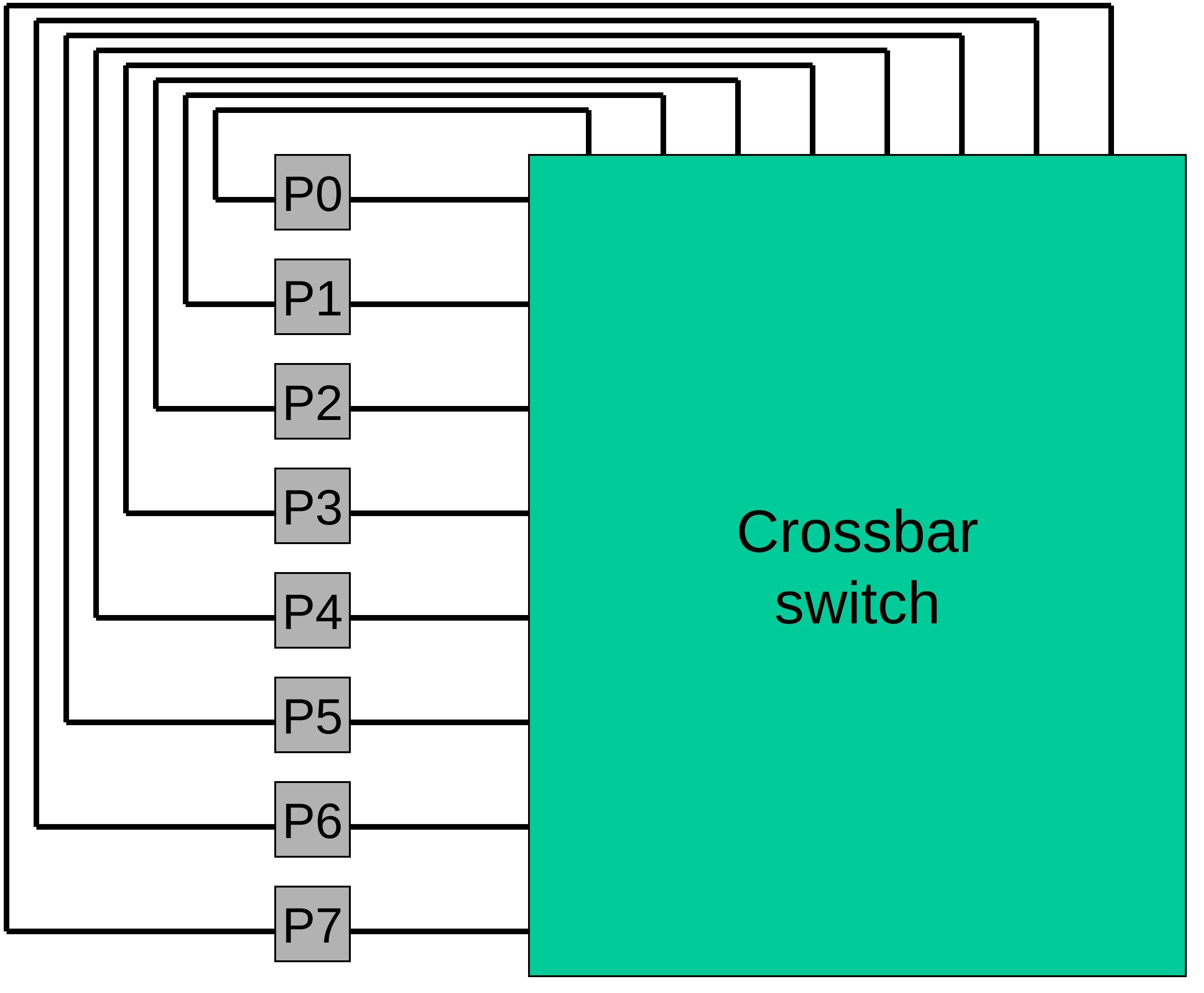
Lecture 23: Interconnection Networks

- Topics: communication latency, centralized and decentralized switches (Appendix E)

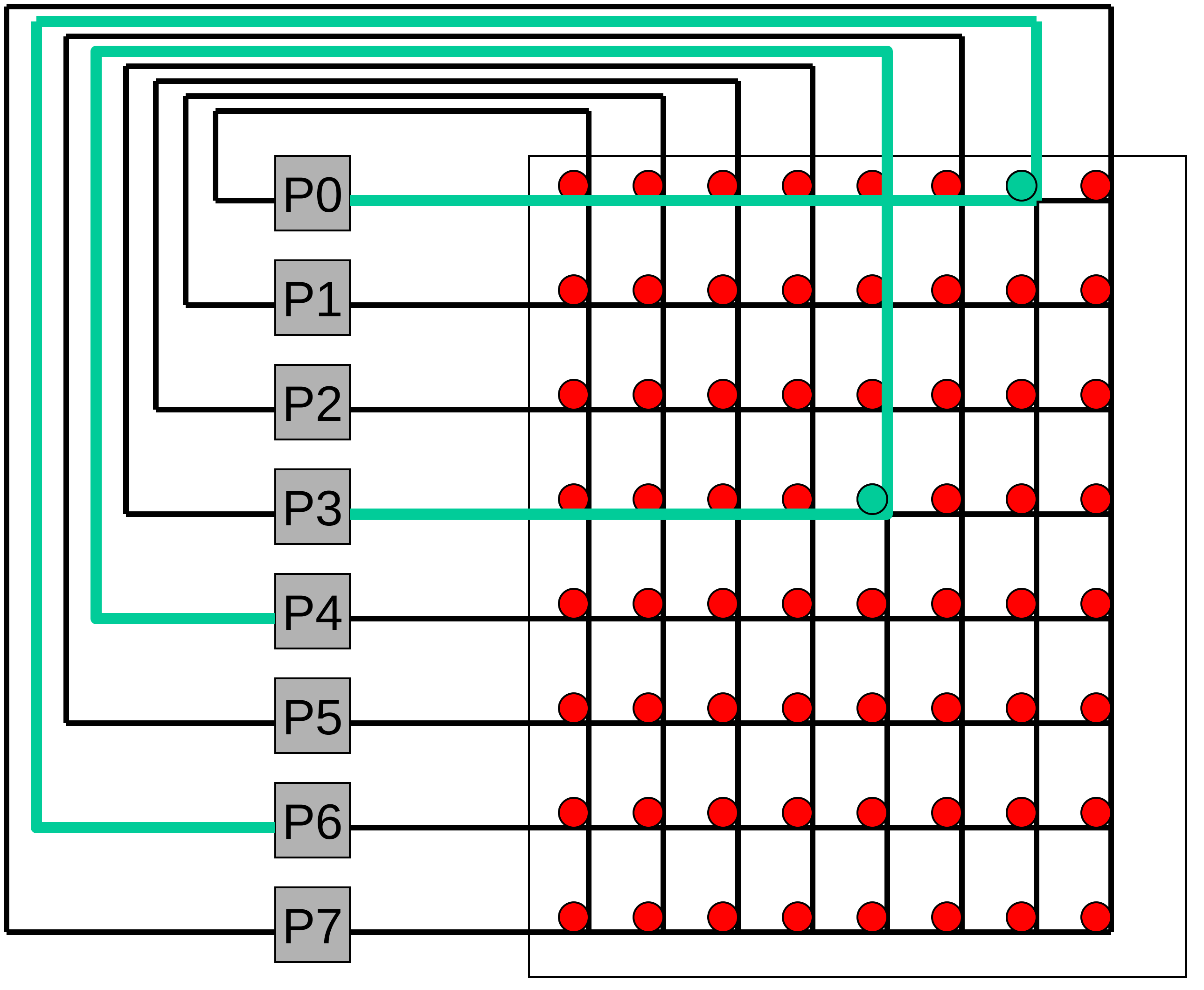
Topologies

- Internet topologies are not very regular – they grew incrementally
- Supercomputers have regular interconnect topologies and trade off cost for high bandwidth
- Nodes can be connected with
  - centralized switch: all nodes have input and output wires going to a centralized chip that internally handles all routing
  - decentralized switch: each node is connected to a switch that routes data to one of a few neighbors

Centralized Crossbar Switch



Centralized Crossbar Switch



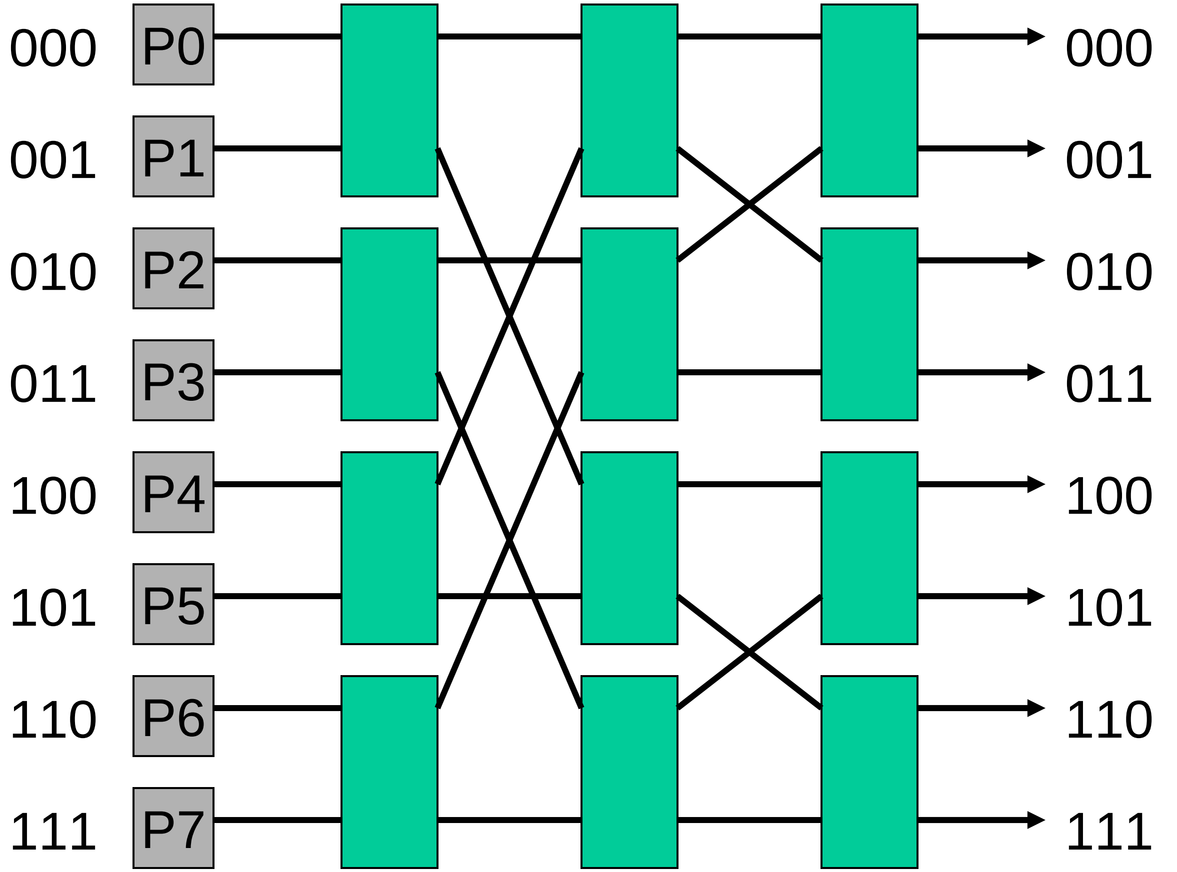
Crossbar Properties

- Assuming each node has one input and one output, a crossbar can provide maximum bandwidth: N messages can be sent as long as there are N unique sources and N unique destinations

- Maximum overhead: WN^2 internal switches, where W is data width and N is number of nodes

- To reduce overhead, use smaller switches as building blocks – trade off overhead for lower effective bandwidth

Switch with Omega Network

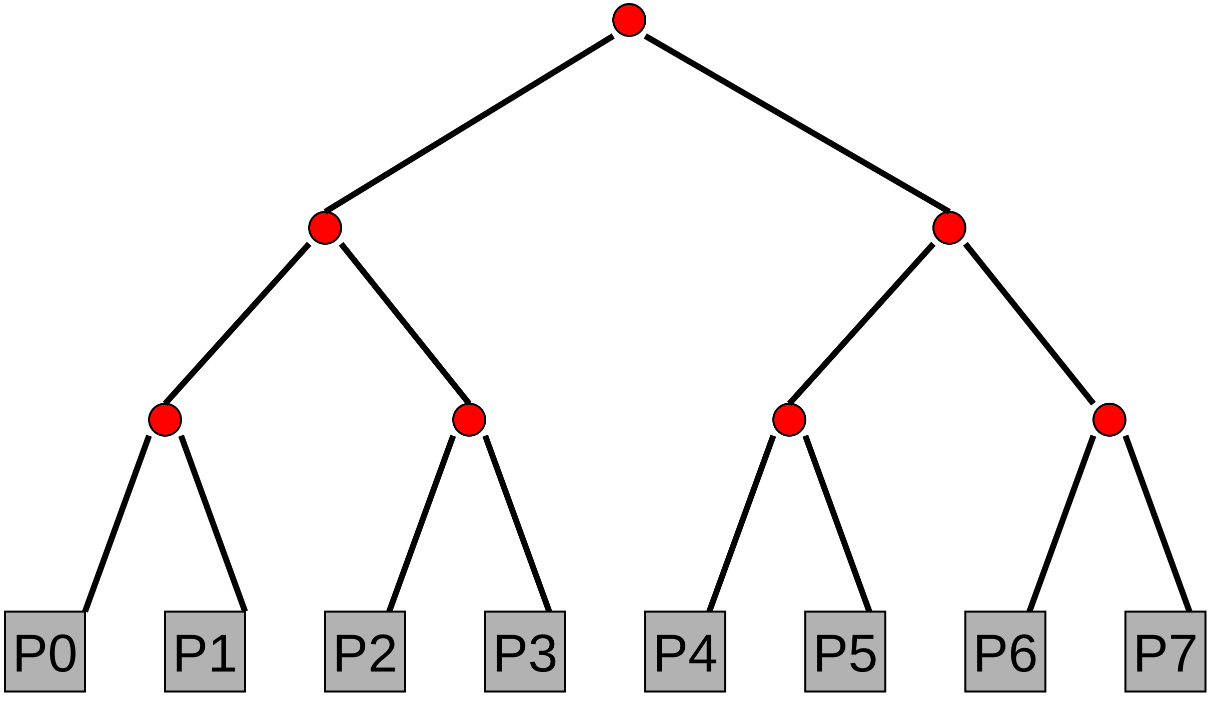


Omega Network Properties

- The switch complexity is now O(N log N)
- Contention increases: P0 → P5 and P1 → P7 cannot happen concurrently (this was possible in a crossbar)
- To deal with contention, can increase the number of levels (redundant paths) – by mirroring the network, we can route from P0 to P5 via N intermediate nodes, while increasing complexity by a factor of 2

Tree Network

- Complexity is O(N)
- Can yield low latencies when communicating with neighbors
- Can build a fat tree by having multiple incoming and outgoing links



Bisection Bandwidth

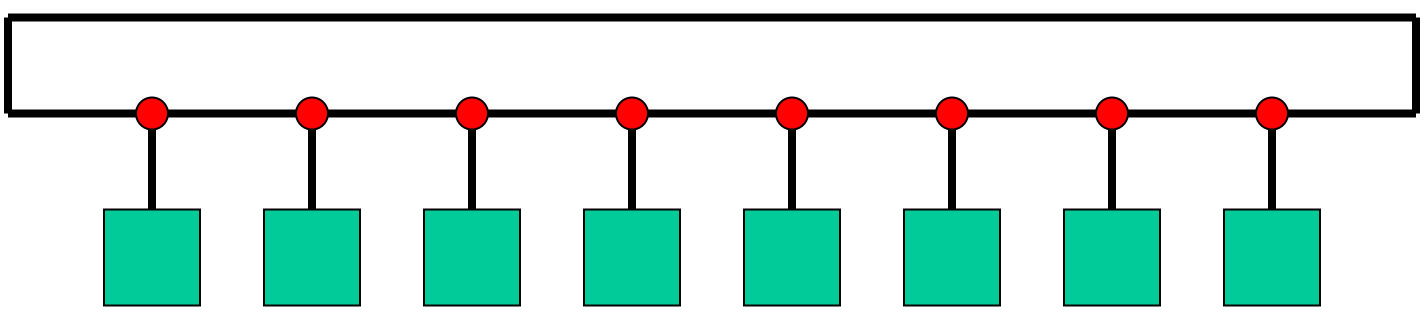
- Split N nodes into two groups of N/2 nodes such that the bandwidth between these two groups is minimum: that is the bisection bandwidth

- Why is it relevant: if traffic is completely random, the probability of a message going across the two halves is ½ – if all nodes send a message, the bisection bandwidth will have to be N/2

- The concept of bisection bandwidth confirms that the tree network is not suited for random traffic patterns, but for localized traffic patterns

Distributed Switches: Ring

- Each node is connected to a 3x3 switch that routes messages between the node and its two neighbors
- Effectively a repeated bus: multiple messages in transit
- Disadvantage: bisection bandwidth of 2 and N/2 hops on average

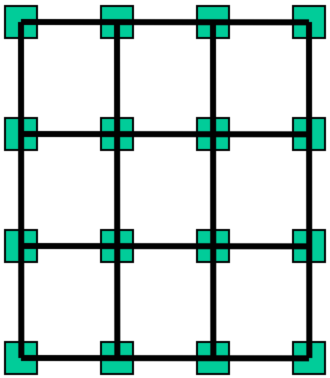


Distributed Switch Options

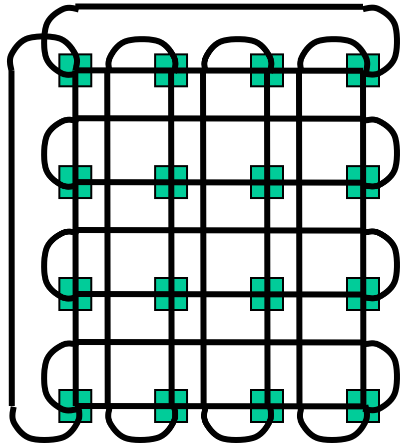
- Performance can be increased by throwing more hardware at the problem: fully-connected switches: every switch is connected to every other switch: N^2 wiring complexity, $N^2/4$ bisection bandwidth

- Most commercial designs adopt a point between the two extremes (ring and fully-connected):
  - Grid: each node connects with its N, E, W, S neighbors
  - Torus: connections wrap around
  - Hypercube: links between nodes whose binary names differ in a single bit

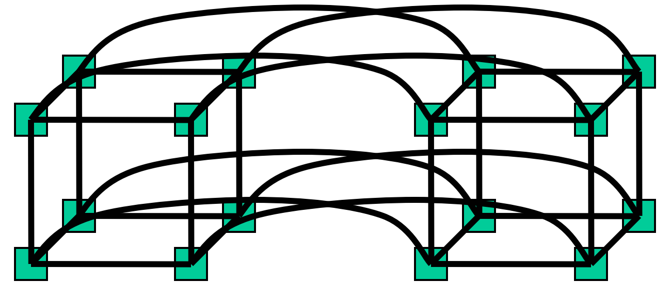
Topology Examples



Grid



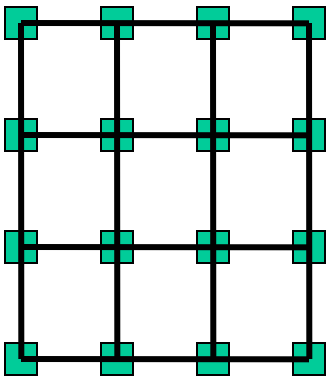
Torus



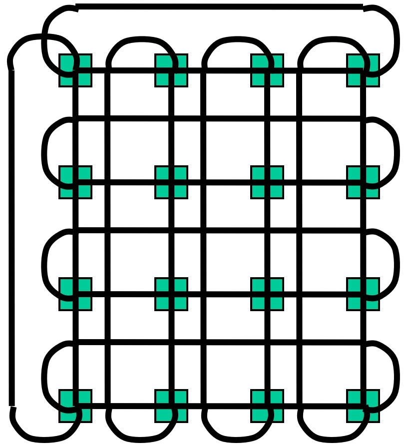
Hypercube

Criteria	Bus	Ring	2Dtorus	6-cube	Fully connected
Performance Bisection bandwidth					
Cost Ports/switch Total links					

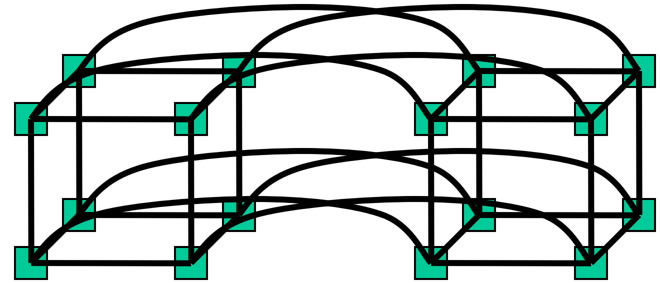
Topology Examples



Grid



Torus



Hypercube

Criteria	Bus	Ring	2Dtorus	6-cube	Fully connected
Performance					
Bisection bandwidth	1	2	16	32	1024
Cost					
Ports/switch		3	5	7	64
Total links	1	128	192	256	2080

k-ary d-cube

- Consider a k-ary d-cube: a d-dimension array with k elements in each dimension, there are links between elements that differ in one dimension by 1 (mod k)

- Number of nodes $N = k^d$

Number of switches :
Switch degree :
Number of links :
Pins per node :

Avg. routing distance:
Diameter :
Bisection bandwidth :
Switch complexity :

Should we minimize or maximize dimension?

k-ary d-Cube

- Consider a k-ary d-cube: a d-dimension array with k elements in each dimension, there are links between elements that differ in one dimension by 1 (mod k)

- Number of nodes $N = k^d$

(with no wraparound)

Number of switches	N	Avg. routing distance	d(k-1)/2
Switch degree	2d + 1	Diameter	d(k-1)
Number of links	Nd	Bisection bandwidth	$2wk^{d-1}$
Pins per node	2wd	Switch complexity	$(2d + 1)^2$

Should we minimize or maximize dimension?

Title

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