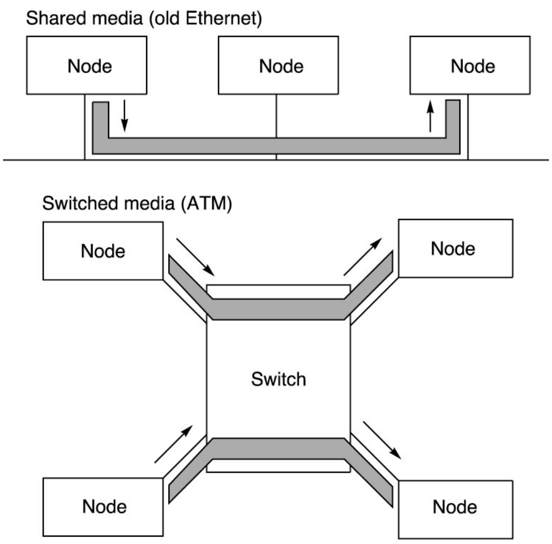
CSC 631: High-Performance Computer Architecture

Spring 2017

Lecture 12: Many-core & Interconnect

Interconnection Networks

- Classification: Shared Medium or Switched



Shared Media Networks

- Need arbitration to decide who gets to talk
- Arbitration can be centralized or distributed
- Centralized not used much for networks
  - Special arbiter device (or must elect arbiter)
  - Good performance if arbiter far away? Nah.
- Distributed arbitration
  - Check if media already used (carrier sensing)
  - If media not used now, start sending
  - Check if another also sending (collision detection)
  - If collision, wait for a while and retry
    - "For a while" is random (otherwise collisions repeat forever)
    - Exponential back-off to avoid wasting bandwidth on collisions

Switched Networks

- Need switches
  - Introduces switching overheads
- No time wasted on arbitration and collisions
- Multiple transfers can be in progress
  - If they use different links, of course
- Circuit or Packet Switching
  - Circuit switching: end-to-end connections
    - Reserves links for a connection (e.g. phone network)
  - Packet switching: each packet routed separately
    - Links used only when data transferred (e.g. Internet Protocol)

Routing

- Shared media has trivial routing (broadcast)
- In switched media we can have
  - Source-based (source specifies route)
  - Virtual circuits (end-to-end route created)
    - When connection made, set up route
    - Switches forward packets along the route
  - Destination-based (source specifies destination)
    - Switches must route packet toward destination
- Also can be classified into
  - Deterministic (one route from a source to a destination)
  - Adaptive (different routes can be used)

Routing Methods for Switches

- Store-and-Forward
  - Switch receives entire packet, then forwards it
  - If error occurs when forwarding, switch can re-send
- Wormhole routing
  - Packet consists of flits (a few bytes each)
  - First flit contains header w/ destination address
  - Switch gets header, decides where to forward
  - Other flits forwarded as they arrive
  - Looks like packet worming through network
  - If an error occurs along the way, sender must re-send
    - No switch has the entire packet to re-send it

Cut-Through Routing

- What happens when link busy?
  - Header arrives to switch, but outgoing link busy
  - What do we do with the other flits of the packet?
- Wormhole routing: stop the tail when head stops
  - Now each flit along the way blocks the a link
  - One busy link creates other busy links => traffic jam
- Cut-Through Routing
  - If outgoing link busy, receive and buffer incoming flits
  - The buffered flits stay there until link becomes free
  - When link free, the flits start worming out of the switch
  - Need packet-sized buffer space in each switch
    - Wormhole Routing switch needs to buffer only one flit

Routing: Network Latency

- Switch Delay
  - Time from incoming to outgoing link in a switch
- Switches
  - Number of switches along the way
- Transfer time
  - Time to send the packet through a link
- Store-and-Forward end-to-end transfer time
  - (Switches*SwitchDelay)+(TransferTime*(Switches+1))
- Wormhole or Cut-Through end-to-end transfer time
  - (Switches*SwitchDelay) + TransferTime
  - Much better if there are many switches along the way
  - See the example on page 811

Switch Technology

- What do we want in a switch
  - Many input and output links
    - Usually number of input and output links the same
  - Low contention inside the switch
    - Best if there is none (only external links cause contention)
  - Short switching delay
- Crossbar
  - Very low switching delay, no internal contention
  - Complexity grows as square of number of links
    - Can not have too many links (e.g. up to 64 in and 64 out)

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  - Complexity grows as square of number of links
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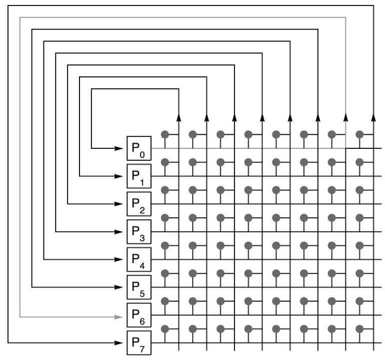
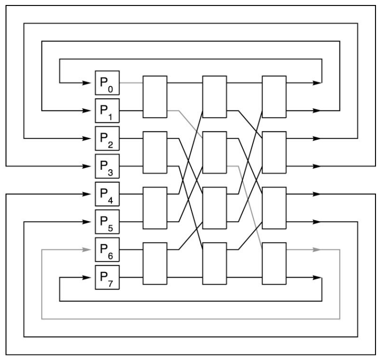
- Omega Network
  - Build switches with more ports using small crossbars
  - Lower complexity per link, but longer delay and more contention

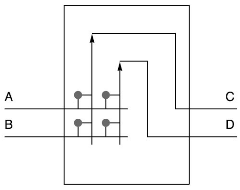
Switch Technology



a. Crossbar

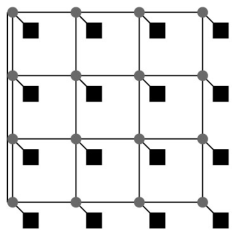


b. Omega network

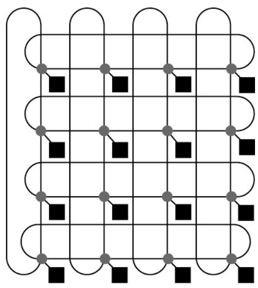


c. Omega network switch box

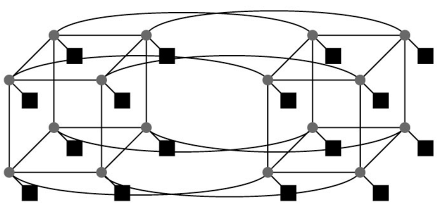
Network Topology



a. 2D grid or mesh of 16 nodes



b. 2D torus of 16 nodes



c. Hypercube tree of 16 nodes (16 = 2^4 so = 4)

Network Topology

- What do we want in a network topology
  - Many nodes, high bandwidth, low contention, low latency
  - Low latency: few switches along any route
    - For each (src, dest) pair, we choose shortest route
    - Longest such route over all (src,dst) pairs: *network diameter*
    - We want networks with small diameter!
  - Low contention: high aggregate bandwidth
    - Divide network into two groups, each with half the nodes
    - Total bandwidth between groups is *bisection bandwidth*
    - Actually, we use the minimum over all such bisections

On-Chip Networks

- We'll have many cores on-chip
  - Need switched network to provide bandwidth
- Need to map well onto chip surface
  - E.g. hypercube is not great
- Mesh or grid should work well, torus OK too
  - Limited ports per switch (CPU & 4 neighbors)
  - All links short (going to neighbors)
  - Many parallel algorithms map well onto grids
    - Matrices, grids, etc.

Trouble with shared caches

- Private caches OK
  - Each placed with its own processor
- We want a shared cache, too
  - Fits more data than if broken into private caches
    - Private caches replicate data
  - Dynamically shared
    - Threads that need more space get more space
- But how do we make a shared cache fast

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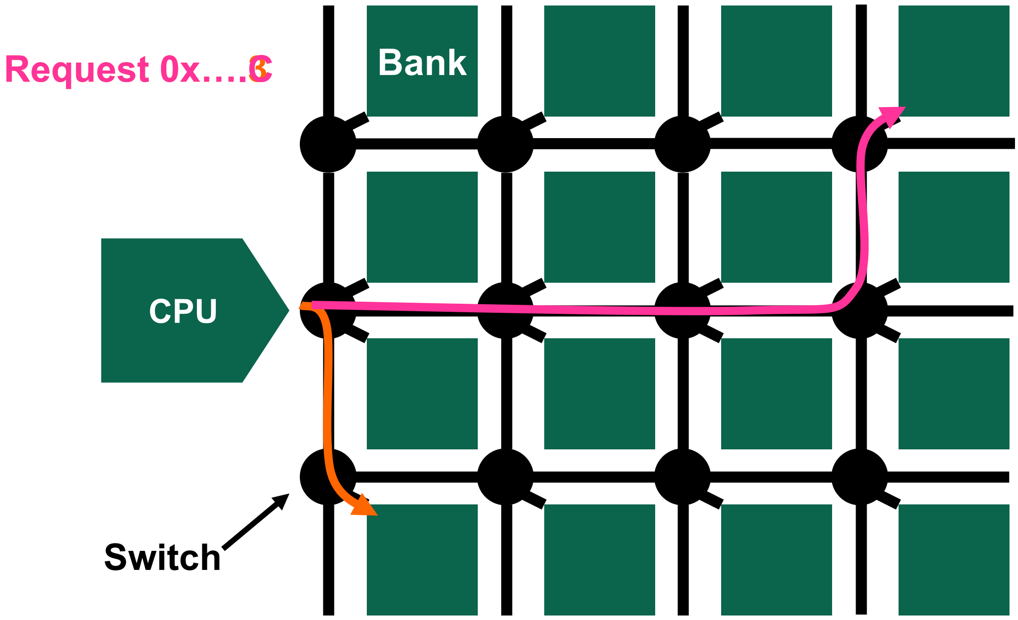
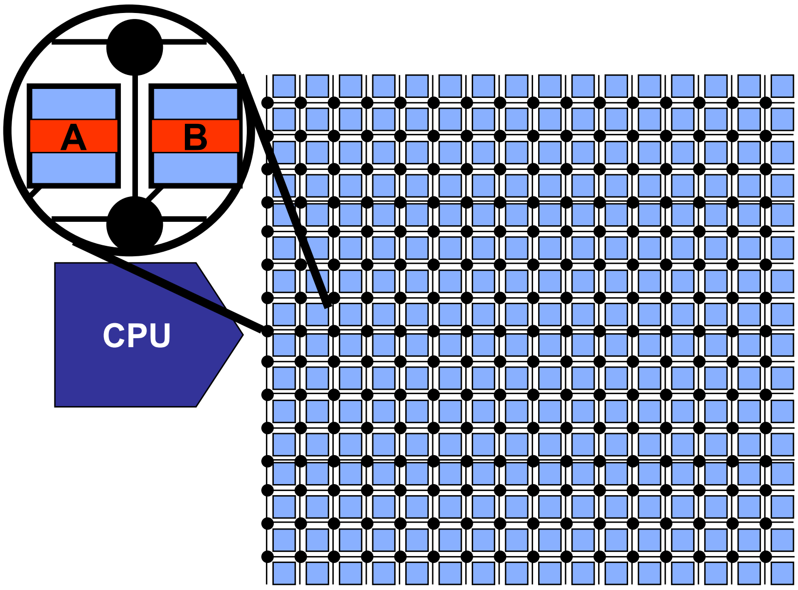
Non-uniform Cache Arch. (NUCA)



S-NUCA Perormance

- Fast access to nearby banks
- Slow access to far-away banks
- Average better than worst-case

D-NUCA Solution



D-NUCA Perormance

- Fast access to nearby banks
- Slow access to far-away banks
- Average much better than worst-case
- But we keep moving blocks
  - Lots of power-hungry activity
- Need smart policies for block migration
  - Move blocks less frequently
  - But get most of the benefit of being able to move

D-NUCA Issues

- Blocks keep moving, how do we find them?
- One solution: Use an on-chip directory!
  - Use direct mapping to assign a home bank
  - If we don't know where the block is,
    ask the home bank
  - If we move the block, tell the home bank
  - If we think we know where the block is,
    look there. If it's been moved, ask home bank