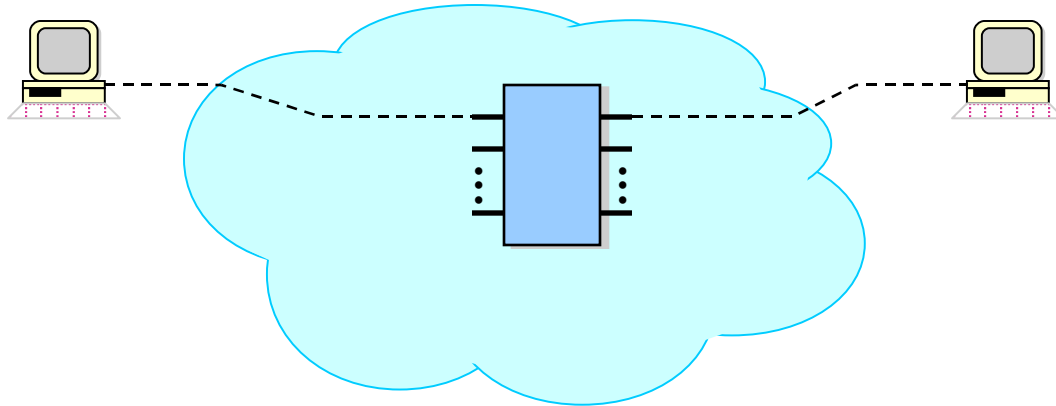


Network layer (addendum)

Slides adapted from material by
Nick McKeown and Kevin Lai

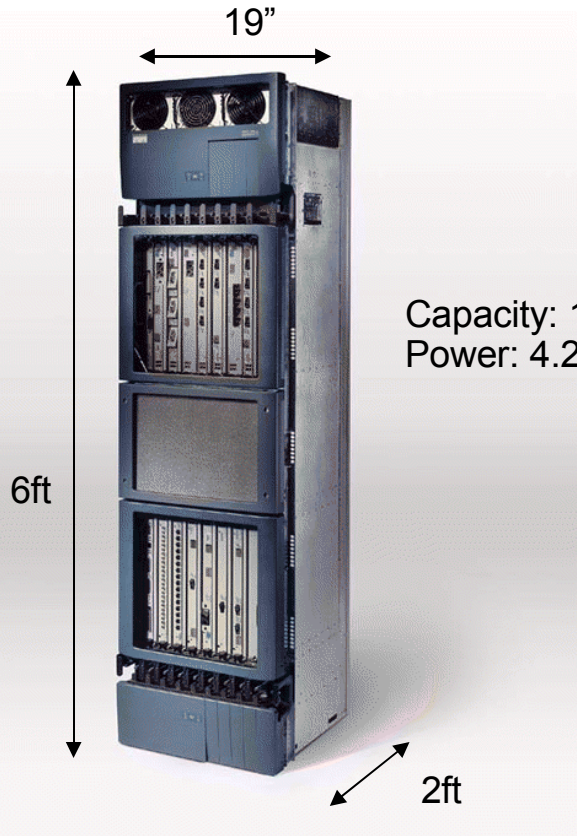
Routers



- A router consists
 - A set of input interfaces at which packets arrive
 - A set of output interfaces from which packets depart
 - Some form of interconnect connecting inputs to outputs
- Router implements two main functions
 - Forward packet to corresponding output interface
 - Manage bandwidth and buffer space resources

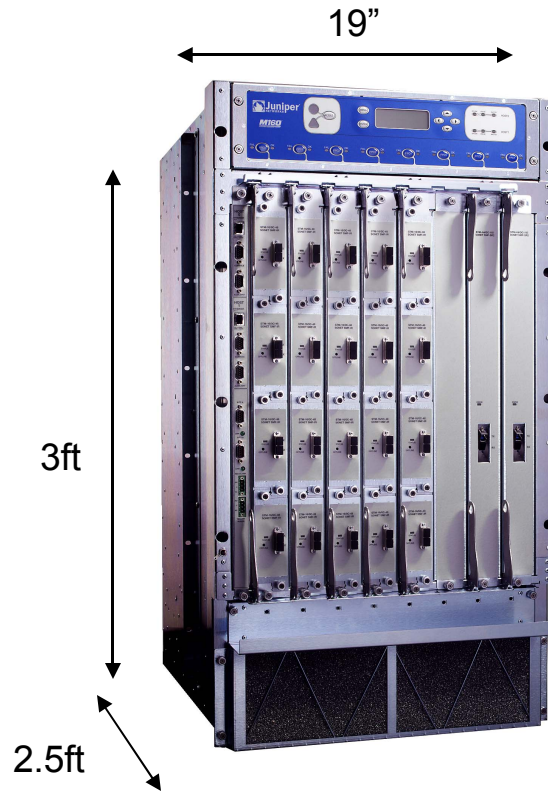
What a Router Looks Like

Cisco GSR 12416



Capacity: 160Gb/s
Power: 4.2kW

Juniper M160



Capacity: 80Gb/s
Power: 2.6kW

Why Understand Router Design

- Many companies make switches and routers
 - e.g., Cisco, Juniper, Nortel
- Many other devices have a similar structure
 - e.g., PC's internal interconnect, multi-processor interconnect
- Switch design dictates what can be done at higher layers
 - e.g., per flow state is expensive, the need to minimize per packet processing time

Why Do We Need Faster Routers?

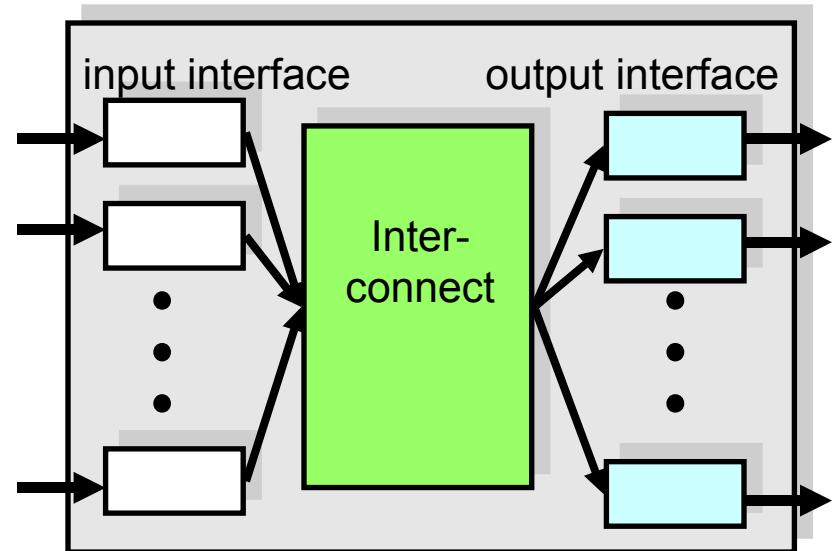
1. To prevent routers becoming the bottleneck in the Internet.
2. To increase POP capacity, and to reduce cost, size and power.

Requirements

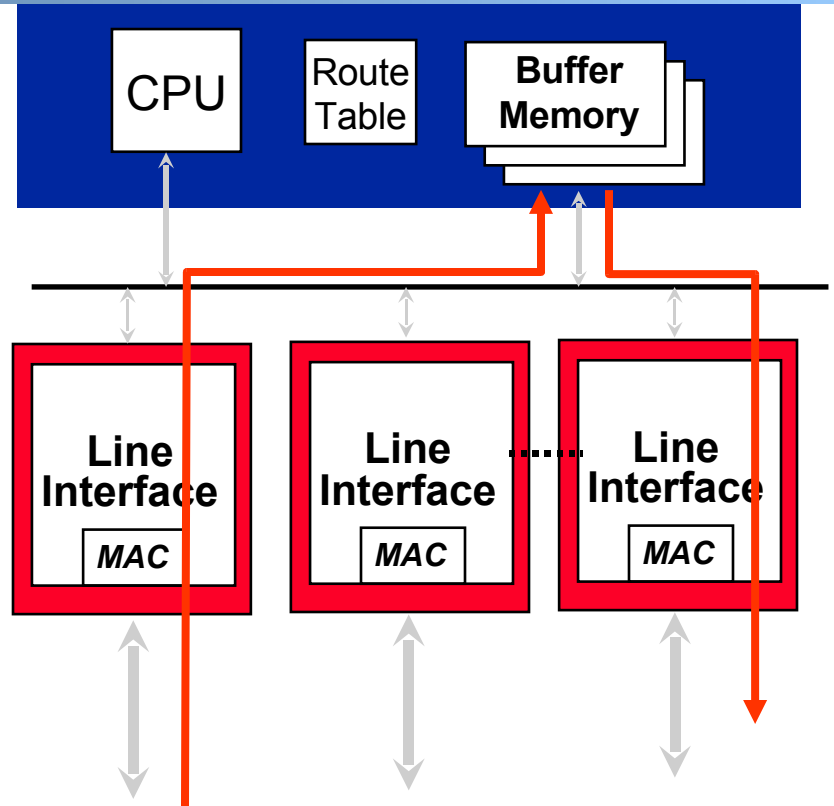
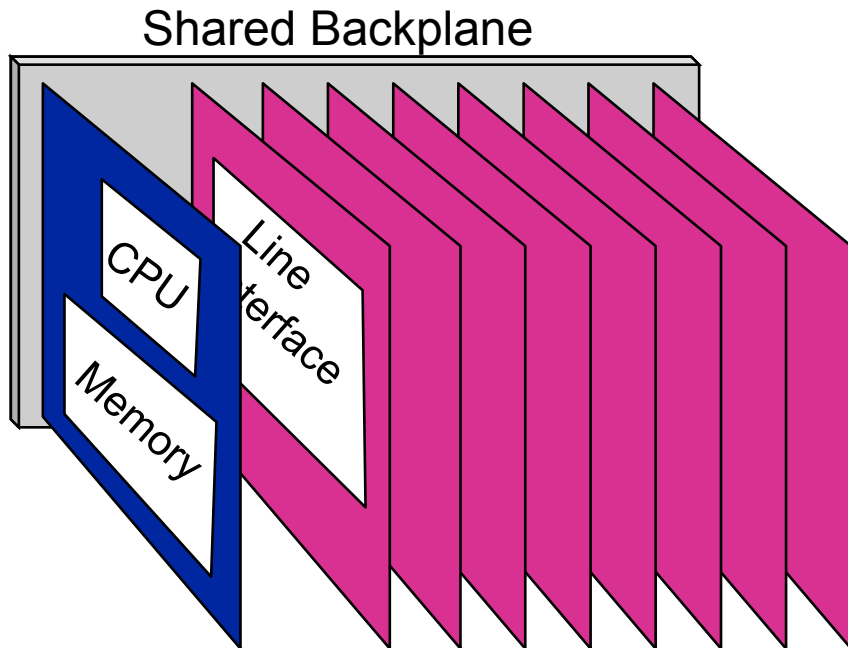
- Power
 - generates heat, costs money
 - < 5kW
- Size
 - space costs money
 - < 2m³
- Bandwidth
- Ports
 - number of external links
- Price
- Some customers want
 - Multicast
 - Quality of Service

Generic Router Architecture

- Input and output interfaces are connected through an interconnect
- A interconnect can be implemented by
 - Shared memory
 - low capacity routers (e.g., PC-based routers)
 - Shared bus
 - Medium capacity routers
 - Point-to-point (switched) bus
 - High capacity routers

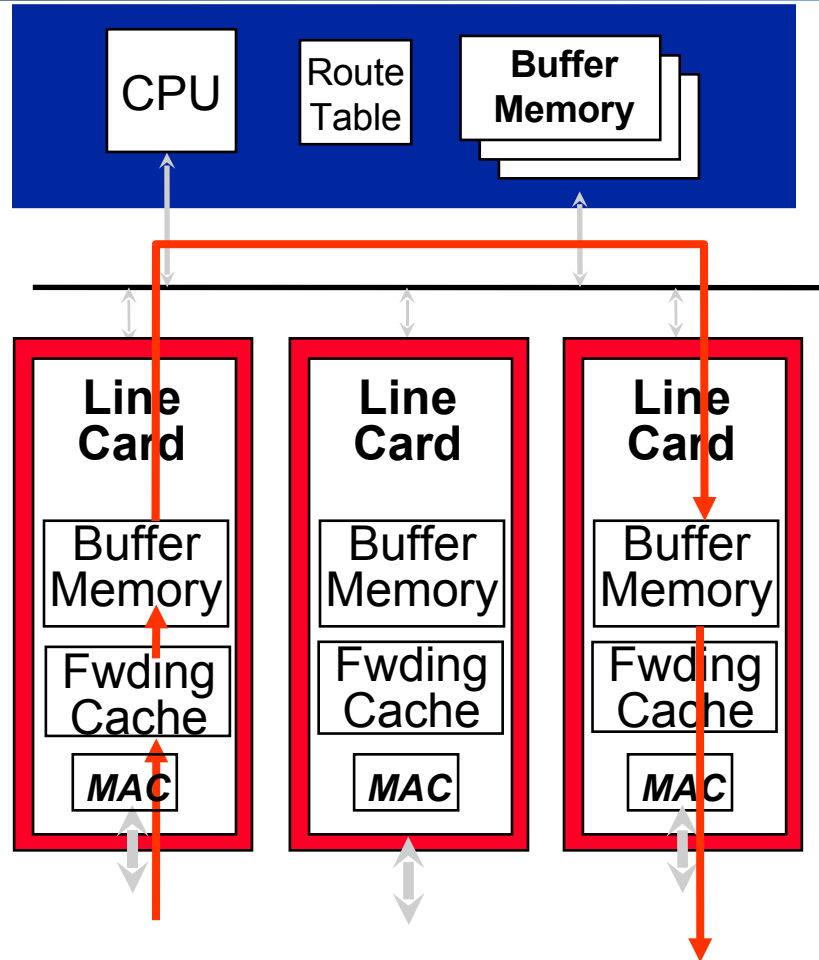


First Generation Routers



Typically <math><0.5\text{Gb/s}</math> aggregate capacity

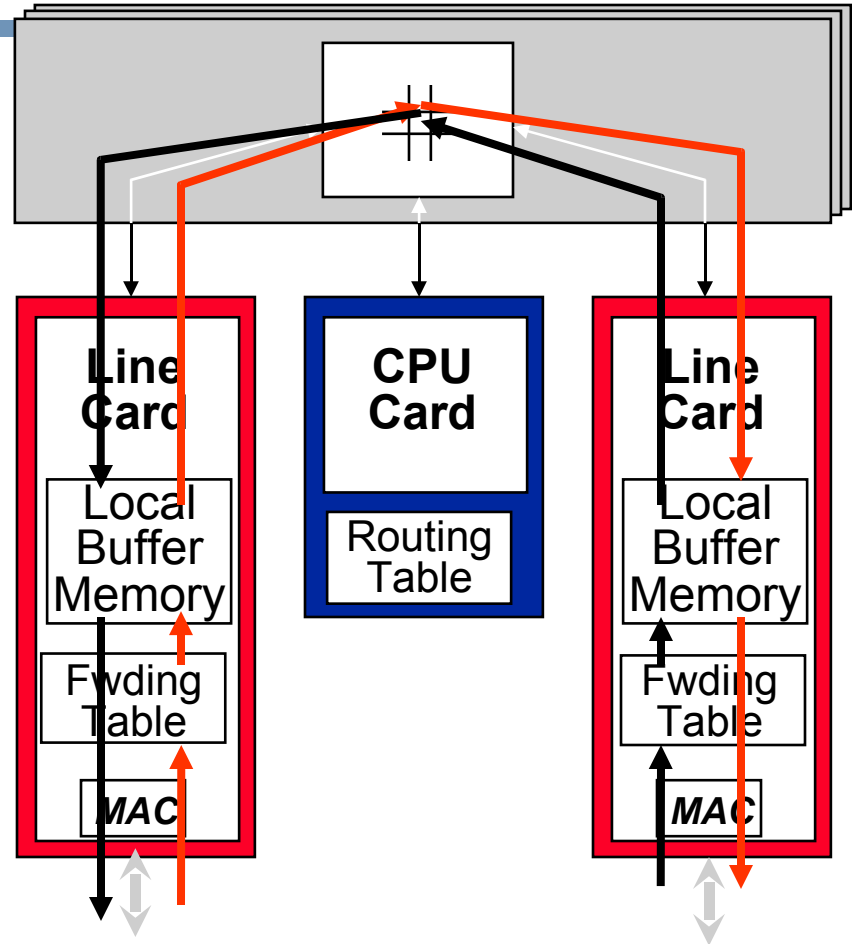
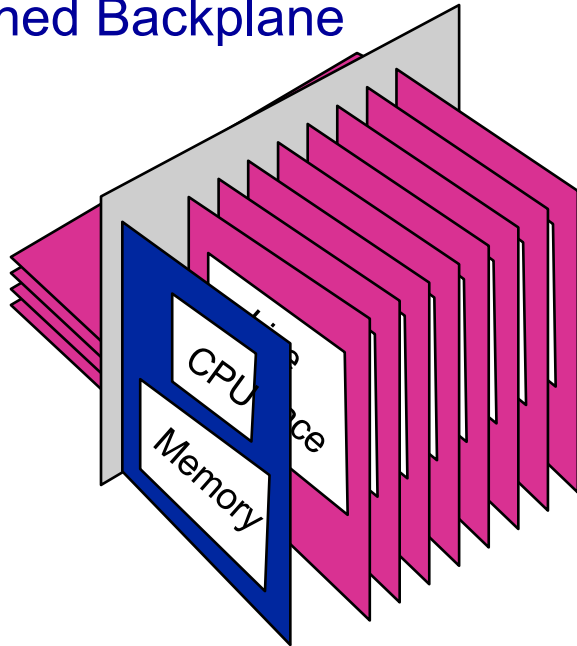
Second Generation Routers



Typically <5Gb/s aggregate capacity

Third Generation Routers

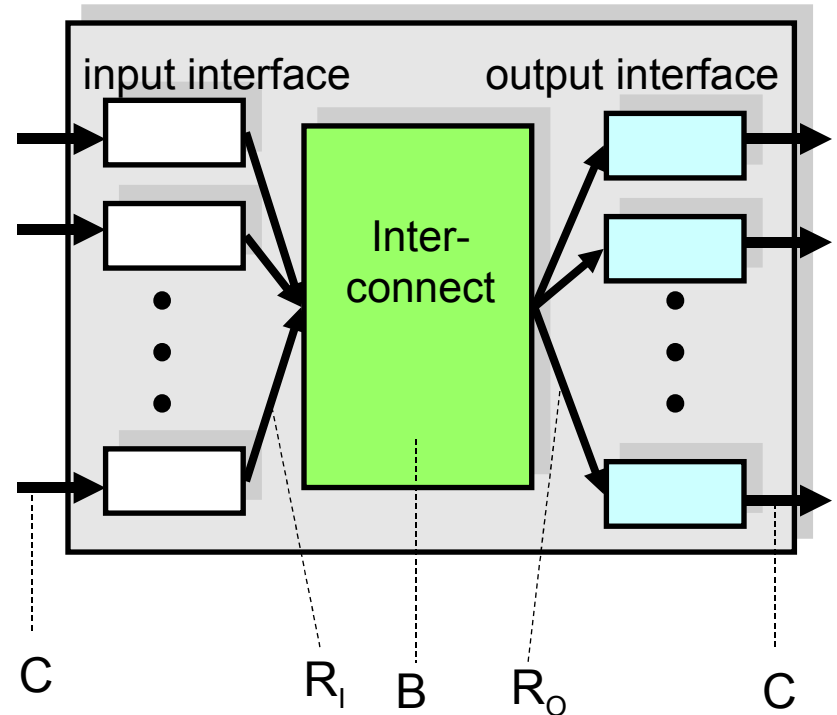
Switched Backplane



Typically <50Gb/s aggregate capacity

Speedup

- C – input/output link capacity
- R_I – maximum rate at which an input interface can send data into interconnect
- R_O – maximum rate at which an output can read data from interconnect
- B – maximum aggregate interconnect transfer rate
- Interconnect speedup: B/C
- Input speedup: R_I/C
- Output speedup: R_O/C

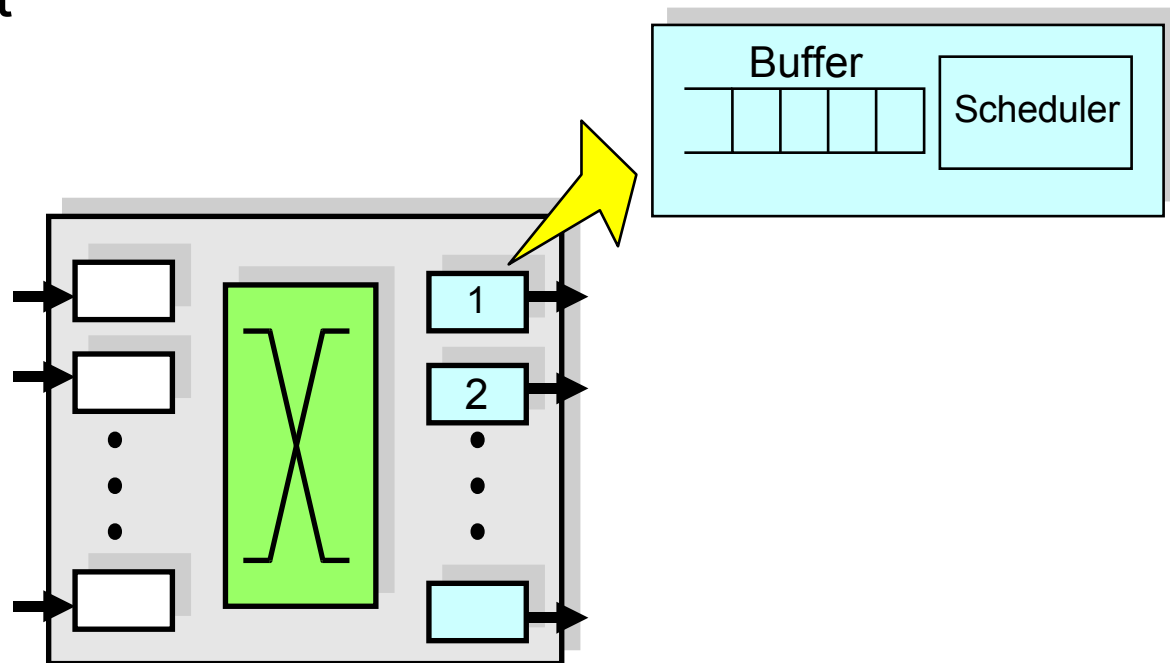


Typical Functions Performed by Input Interface on Data Path

- **Packet forwarding:** decide to which output interface to forward each packet based on the information in packet header
 - examine packet header
 - lookup in forwarding table
 - update packet header

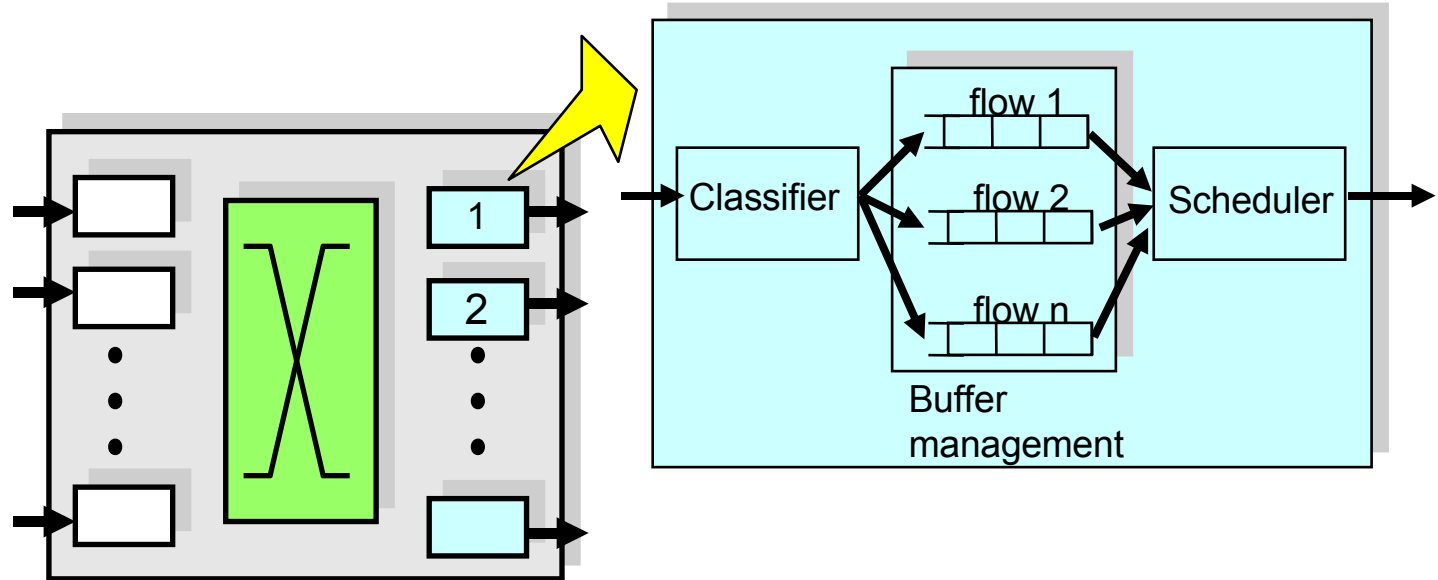
Typical Functions Performed by Output Interface

- **Buffer management:** decide when and which packet to drop
- **Scheduler:** decide when and which packet to transmit



Typical Functions Performed by Output Interface (cont'd)

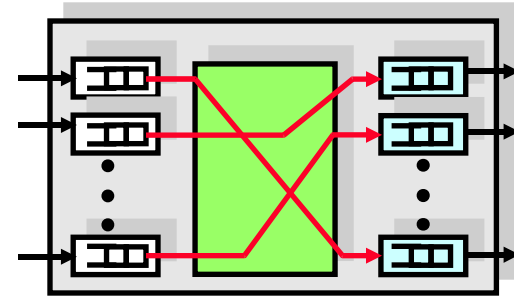
- **Packet classification:** map each packet to a predefined flow/connection (for datagram forwarding)
 - use to implement more sophisticated services (e.g., QoS)



- Flow: a subset of packets between any two endpoints in the network

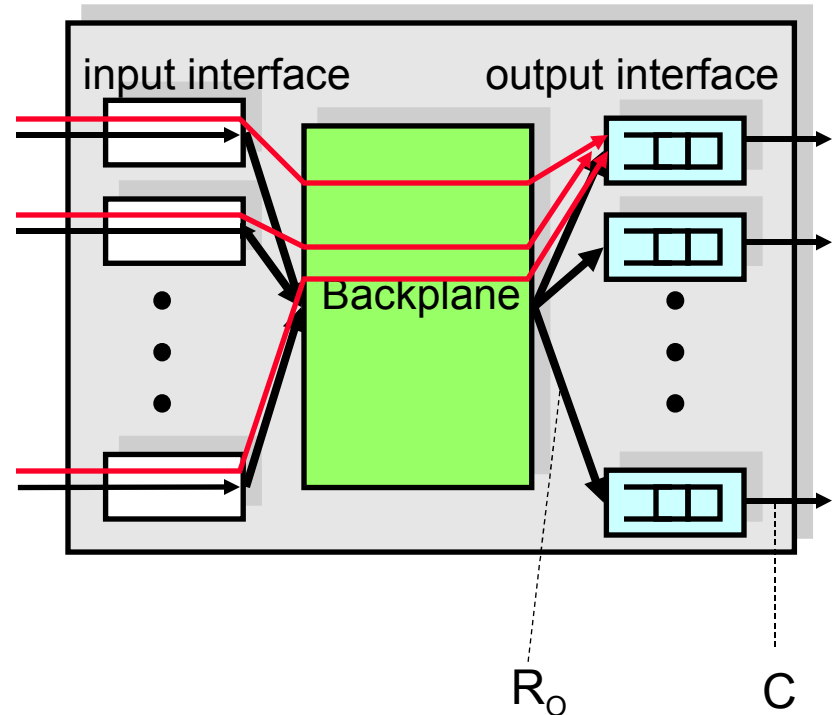
Interconnect

- Point-to-point switch allows to **simultaneously** transfer a packet between any two disjoint pairs of input-output interfaces
- Goal: come-up with a schedule that
 - Provide Quality of Service
 - Maximize router throughput
- Challenges:
 - Address head-of-line blocking at inputs
 - Resolve input/output speedups contention
 - Avoid packet dropping at output if possible
- Note: packets are fragmented in fix sized **cells** at inputs and reassembled at outputs



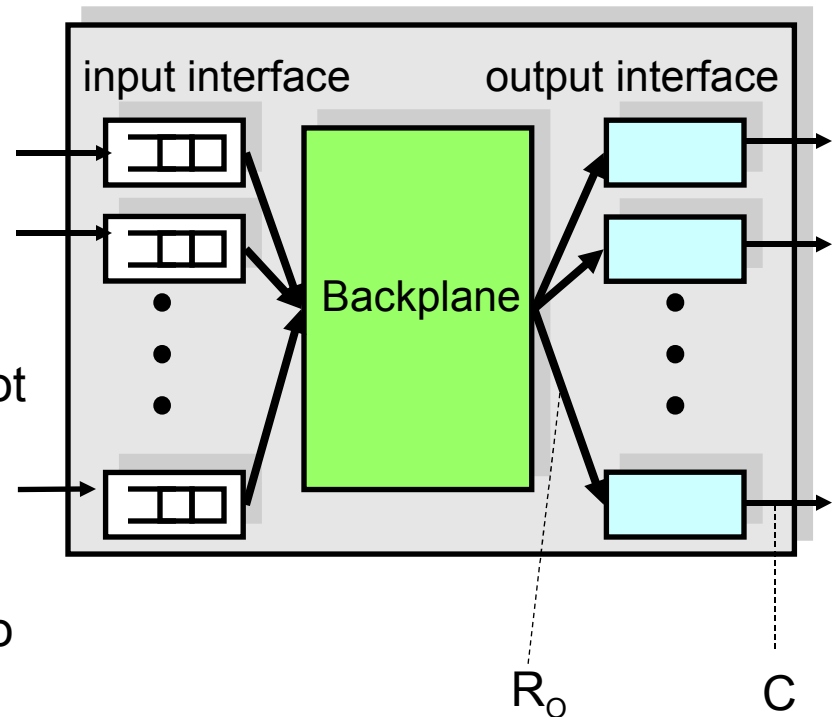
Output Queued (OQ) Routers

- Only output interfaces store packets
- Advantages
 - Easy to design algorithms: only one congestion point
- Disadvantages
 - Requires an output speedup of N , where N is the number of interfaces \rightarrow not feasible



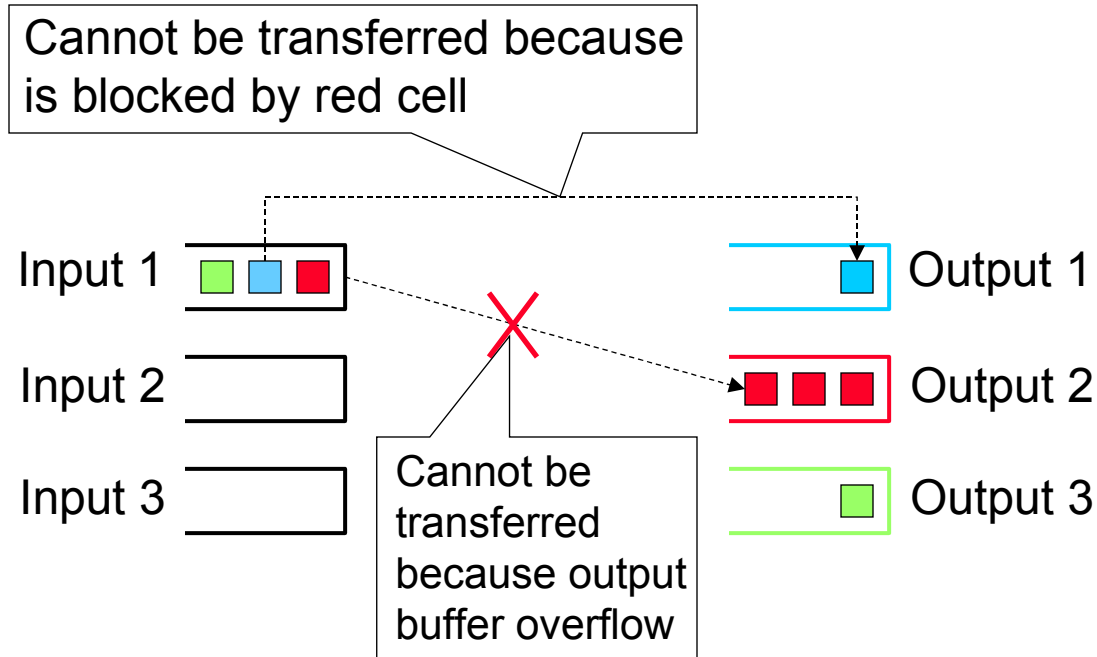
Input Queueing (IQ) Routers

- Only input interfaces store packets
- Advantages
 - Easy to built
 - Store packets at inputs if contention at outputs
 - Relatively easy to design algorithms
 - Only one congestion point, but not output...
 - need to implement backpressure
- Disadvantages
 - Hard to achieve utilization $\rightarrow 1$ (due to output contention, head-of-line blocking)
 - However, theoretical and simulation results show that for **realistic** traffic an input/output speedup of 2 is enough to achieve utilizations close to 1



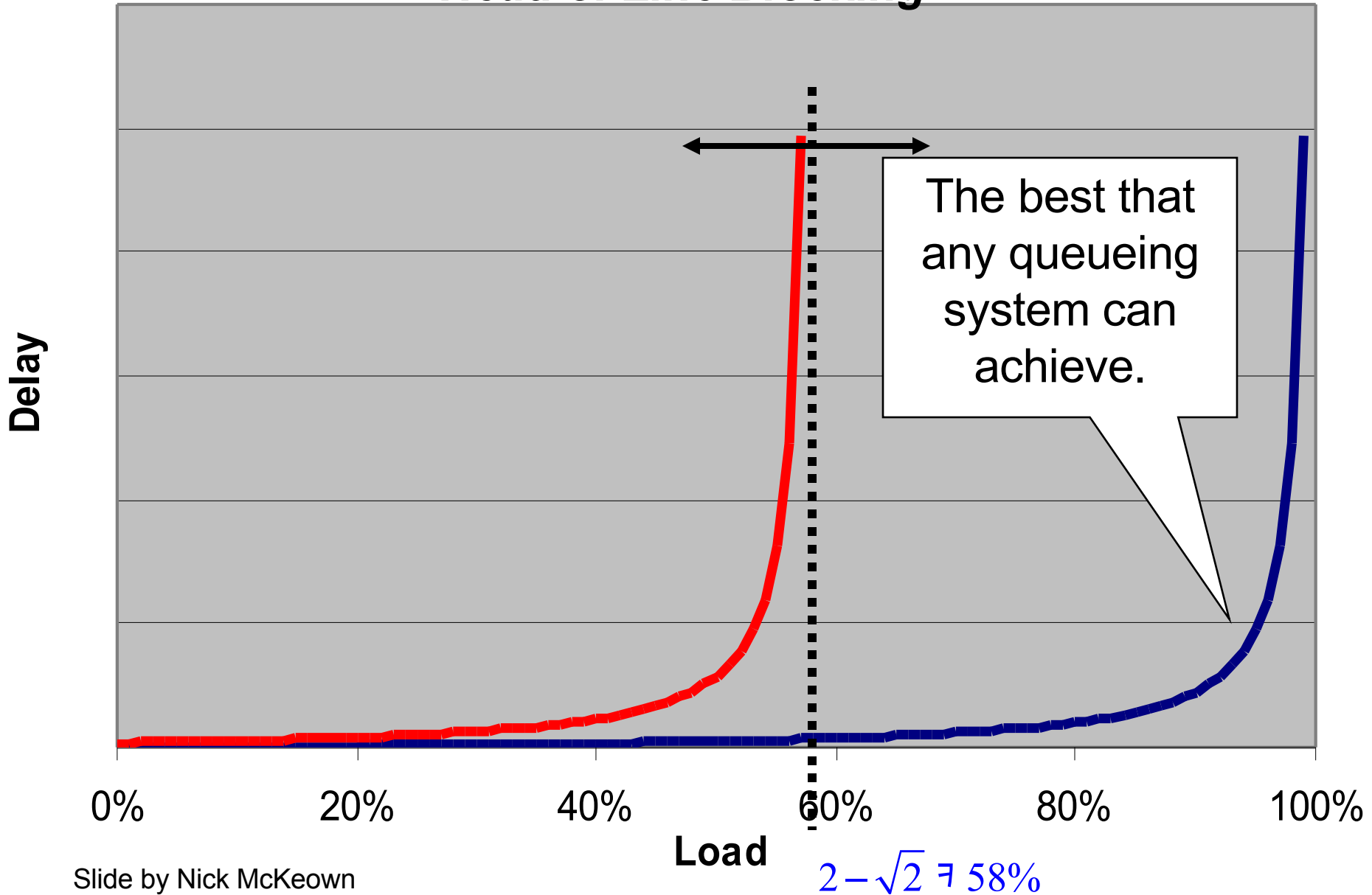
Head-of-line Blocking

- The cell at the head of an input queue cannot be transferred, thus blocking the following cells



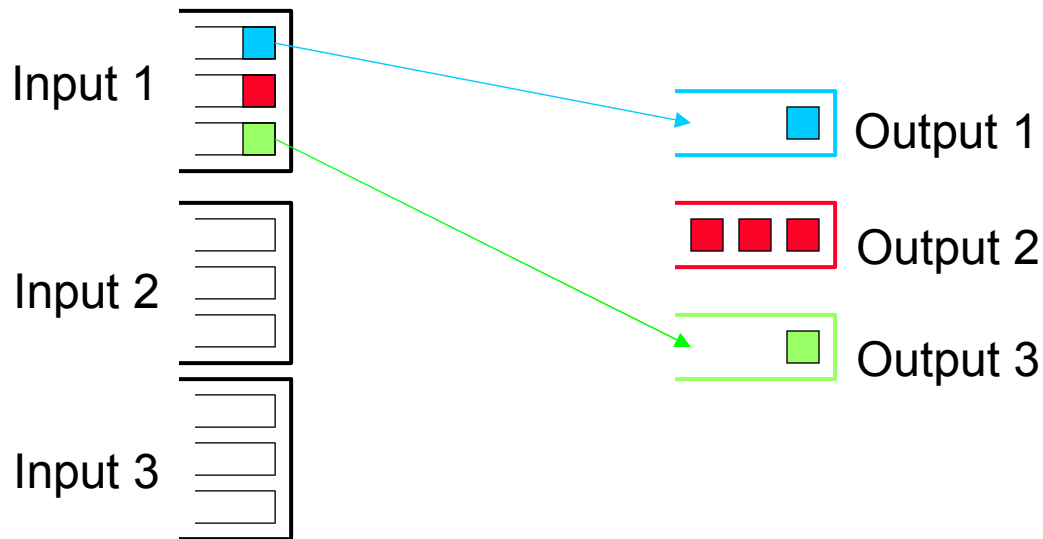
A Router with Input Queues

Head of Line Blocking



Solution to Avoid Head-of-line Blocking

- Maintain at each input N virtual queues, i.e., one per output



Combined Input-Output Queueing (CIOQ) Routers

- Both input and output interfaces store packets
- Advantages
 - Easy to built
 - Utilization 1 can be achieved with limited input/output speedup (≤ 2)
- Disadvantages
 - Harder to design algorithms
 - Two congestion points
 - Need to design flow control

