Computer Networks
COL 334/672

Data Plane

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Slides adapted from KR

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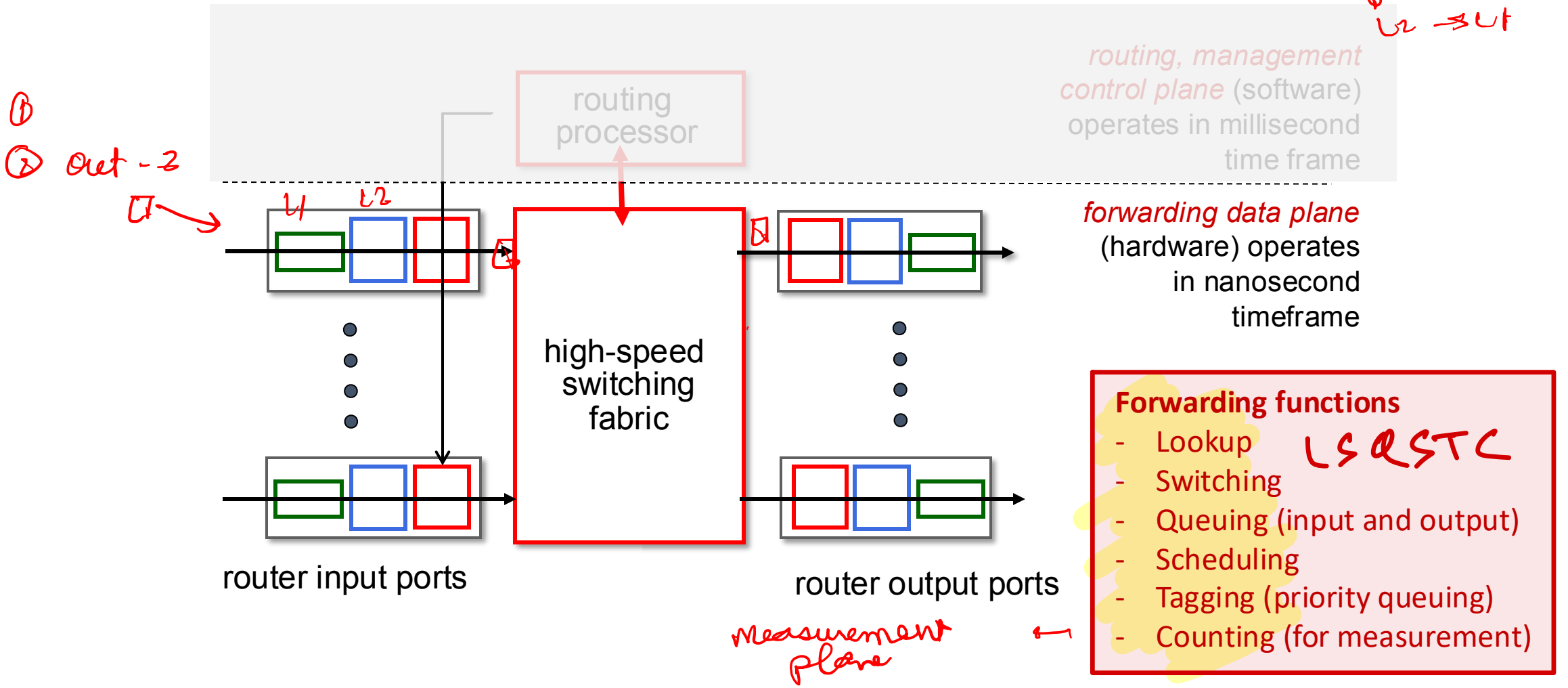
Recap

Network Layer: Data Plane

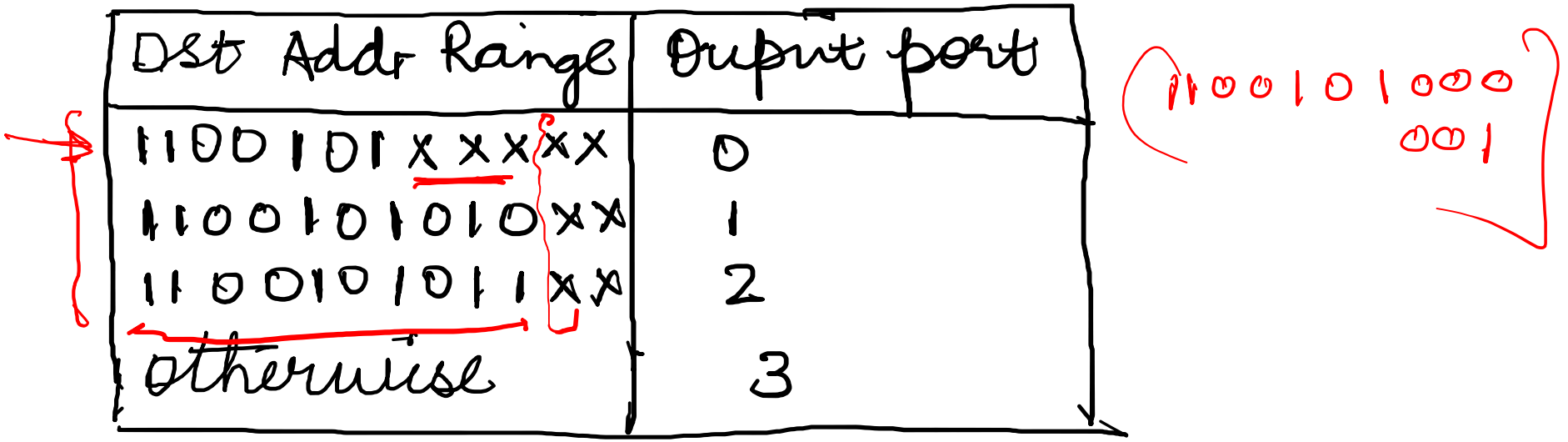


Forwarding functions

- Lookup
- Switching
- Queuing (input and output)
- Scheduling
- Tagging (priority queuing)
- Counting (for measurement)

Lookup

- **Problem statement:** Determine the output port based on destination IP lookup in the forwarding table
- How does the forwarding table look like?



How do we do destination lookup in such a table?

Lookup: when looking for forwarding table entry for given destination address, use *longest* address prefix that matches destination address called longest prefix matching

Lookup Techniques

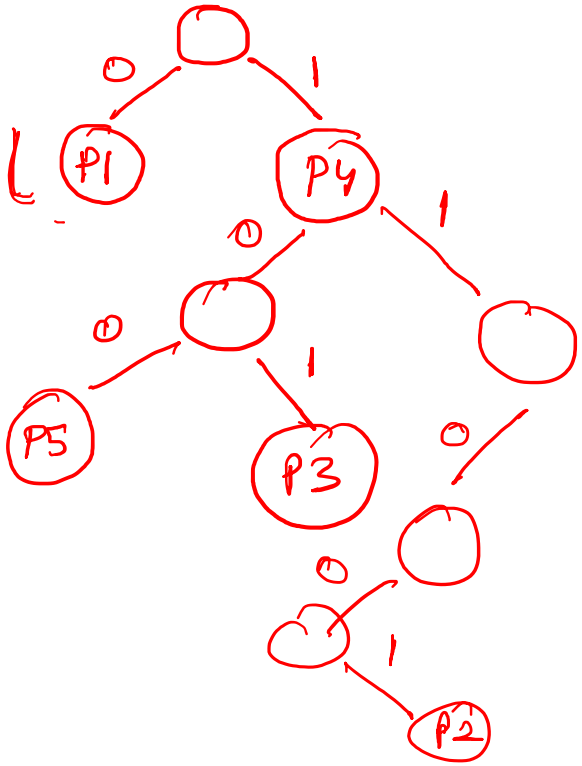
- Brute force: Search through all forwarding table entries iteratively
  - Too slow!
- Goal: Minimize the number of memory lookups
- Solution: Use Trie or Prefix tree

Example: Unibit Tries

HW:

2-bit trie →

Pref	Output
0*	P1
1*	P4
101*	P3
100*	P5
11001*	P2



How many memory lookups?

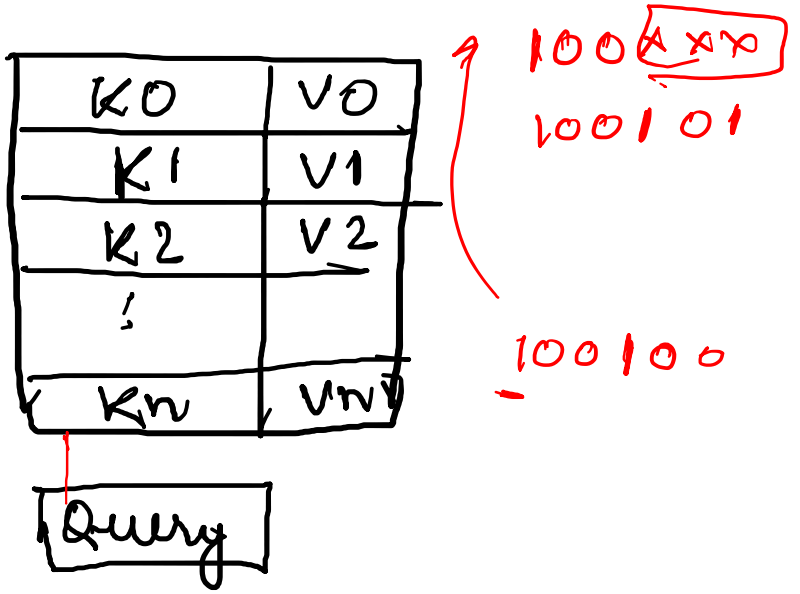
Can we do better? Multibit trie → Variable Stride trie

What is the trade-off?

Still better?

Content Addressable Memory

- Content Addressable Memory (CAM):
  - Returns address of matched data
  - O(1) lookup



- Binary CAM
  - Search words consists of only 0s and 1s
  - Would this suffice for longest prefix match?

- Ternary CAM
  - Allows a third matching state of X
  - Cisco Catalyst: ~1M routing table entries in TCAM
  - Caution: TCAM is expensive, bulkier, power hungry. Used for high-end routers

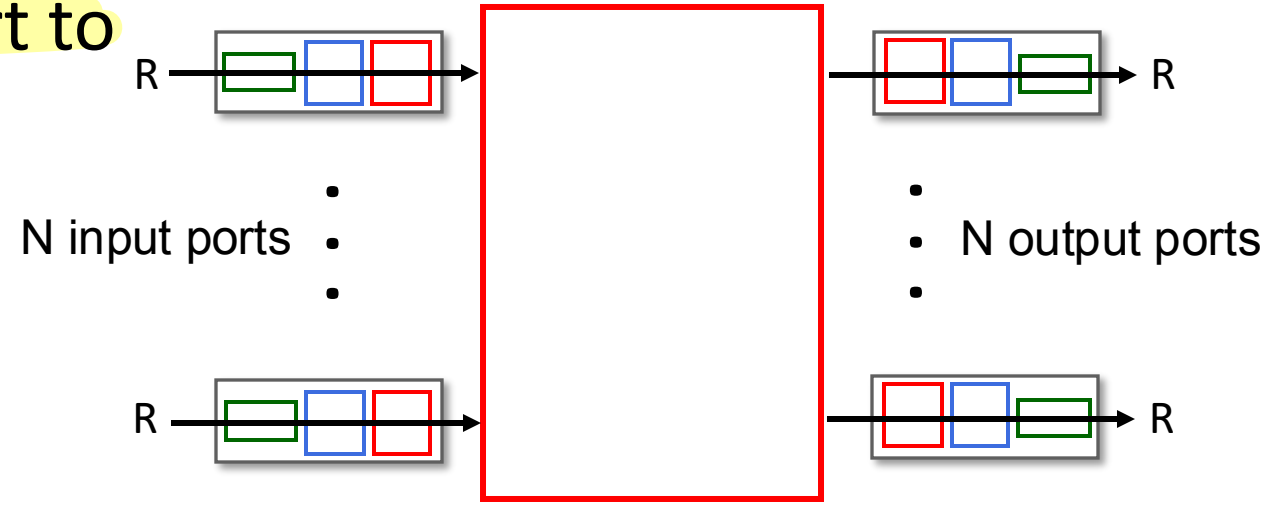
Data Plane Functions

- Prefix lookup
- **Switching**
- Queuing
- Scheduling

P S Q S

Switching

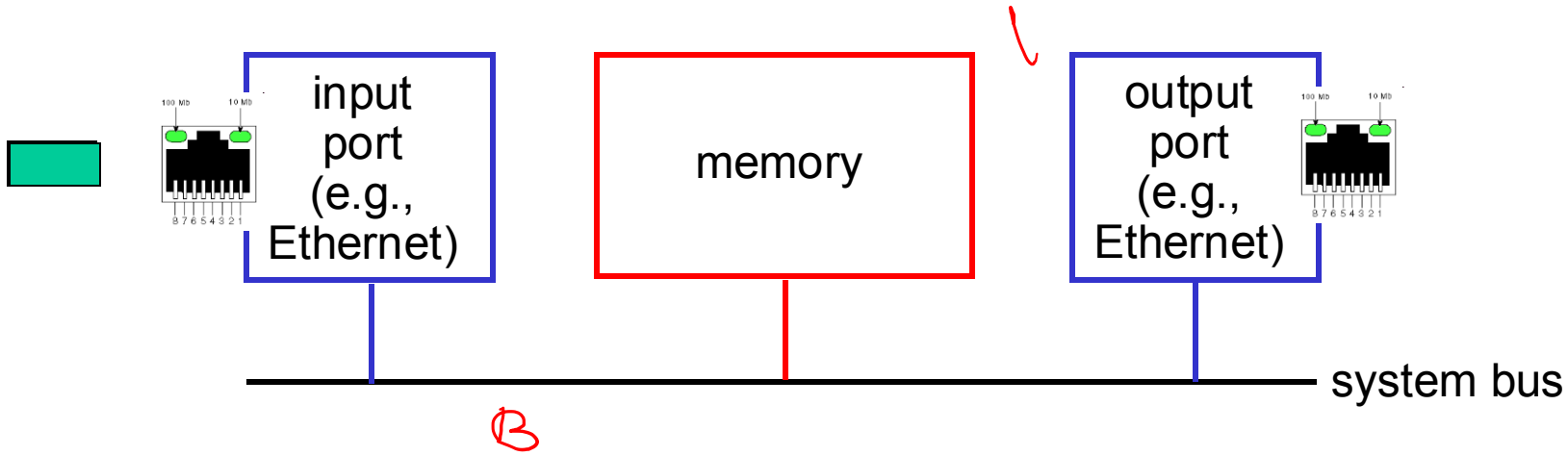
- Transfer packets from input port to appropriate output port
- Switching rate: rate at which packets can be transfer from inputs to outputs
- Often measured as multiple of input/output line rate
- What is the desired switching rate in this case?
- Switching rate depends on switching fabric and switching algorithm at the router



Switching via memory

first generation routers:

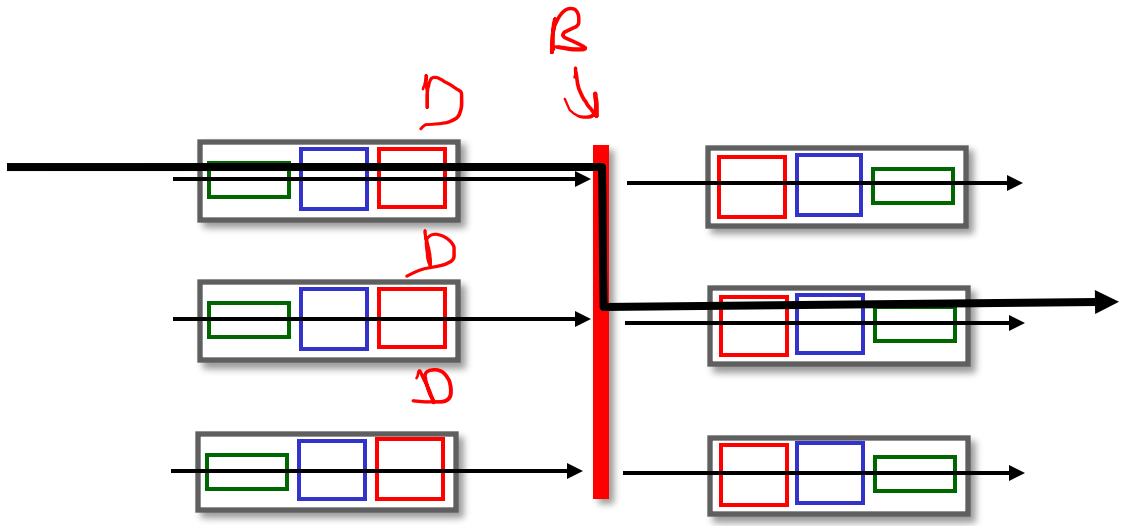
- traditional computers with switching under direct control of CPU
- packet copied to system's memory
- speed limited by memory bandwidth (2 bus crossings)
- What is the switching rate if the bus rate is B?



Switching via a bus

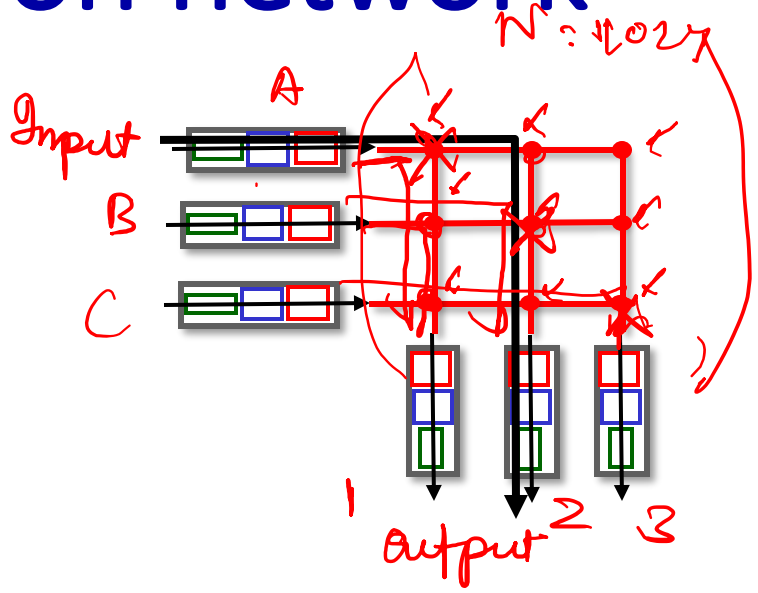
ASIC : Application Specific Integrated Circuit

- datagram from input port memory to output port memory via a shared bus
- *bus contention:* switching speed limited by bus bandwidth
- 32 Gbps bus, Cisco 5600: sufficient speed for access routers



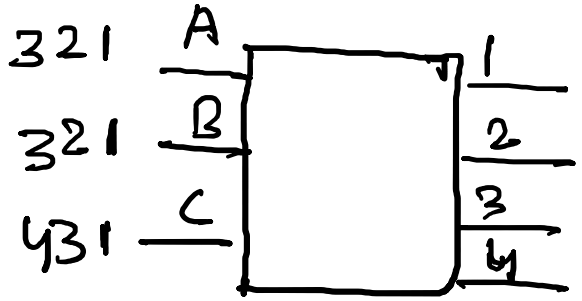
Switching via interconnection network

- Crossbar initially developed to connect processors in multiprocessor
- Need to develop efficient switching algorithms

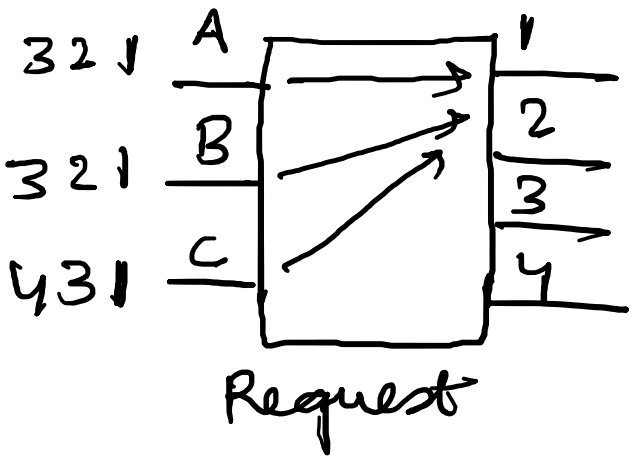


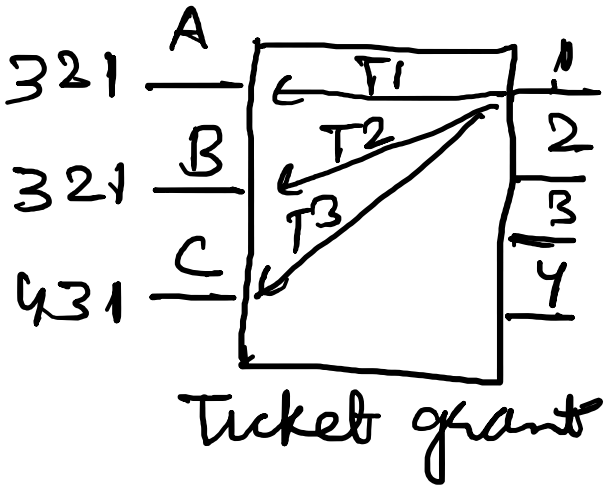
Switching algorithm

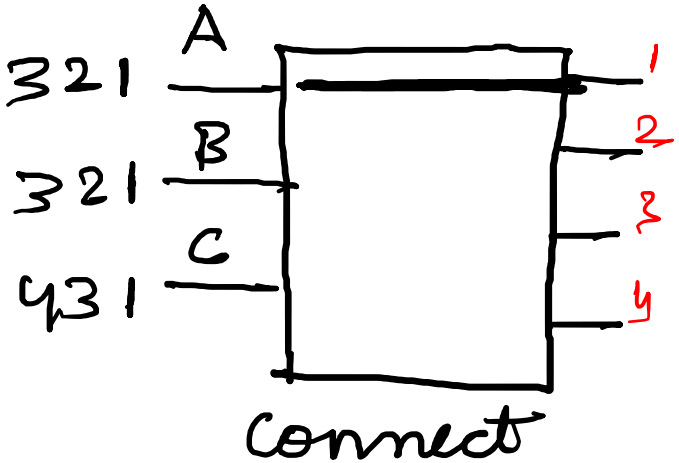
- Take a ticket mechanism: Use a simple ticket number mechanism for scheduling packets waiting at input port



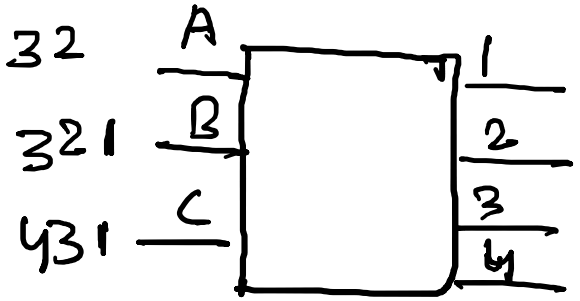
Round 1

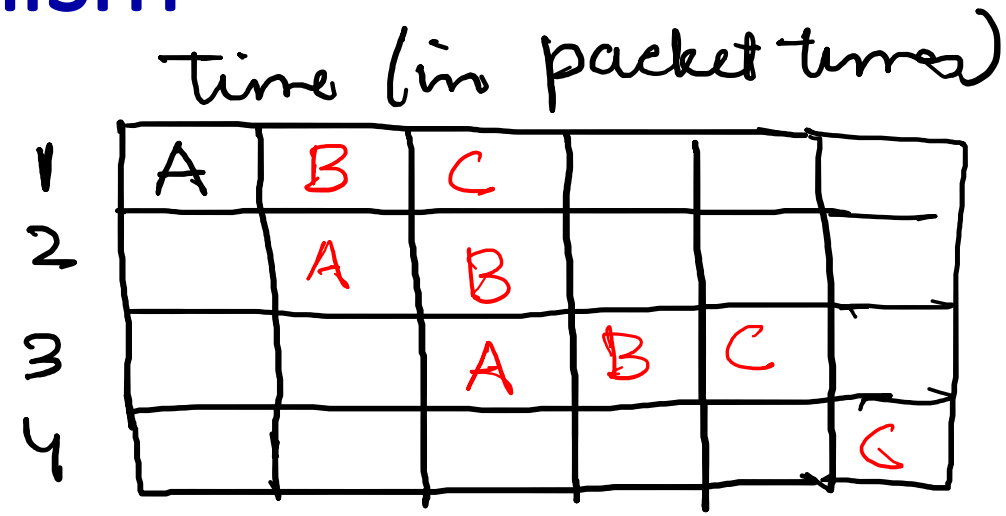




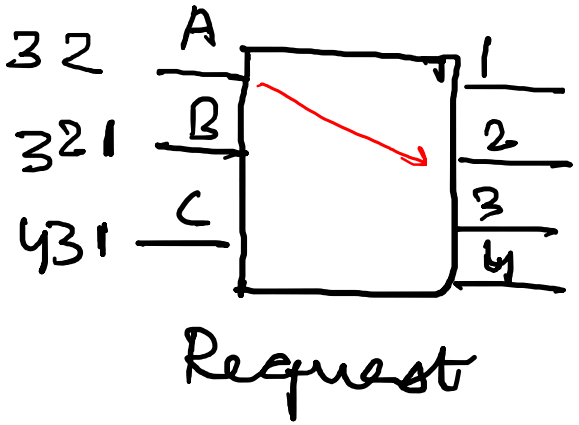


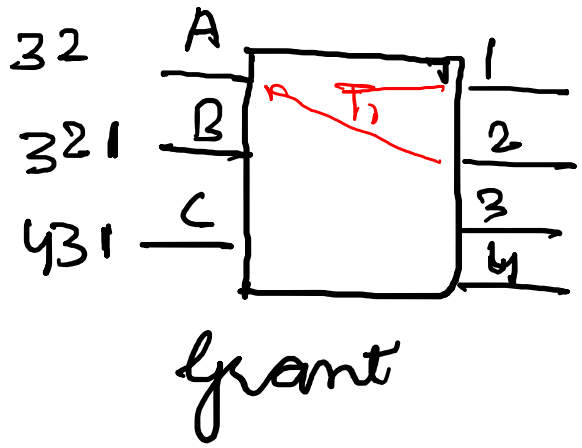
Take a Ticket Mechanism

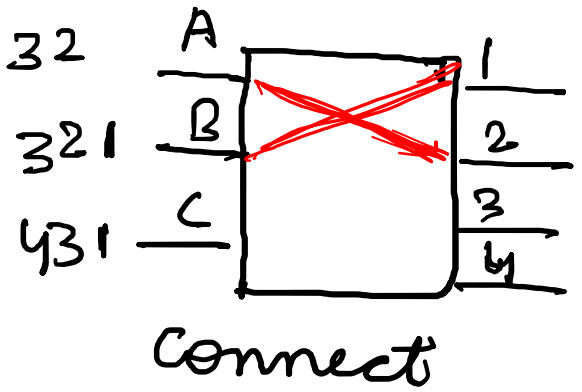




Round 2



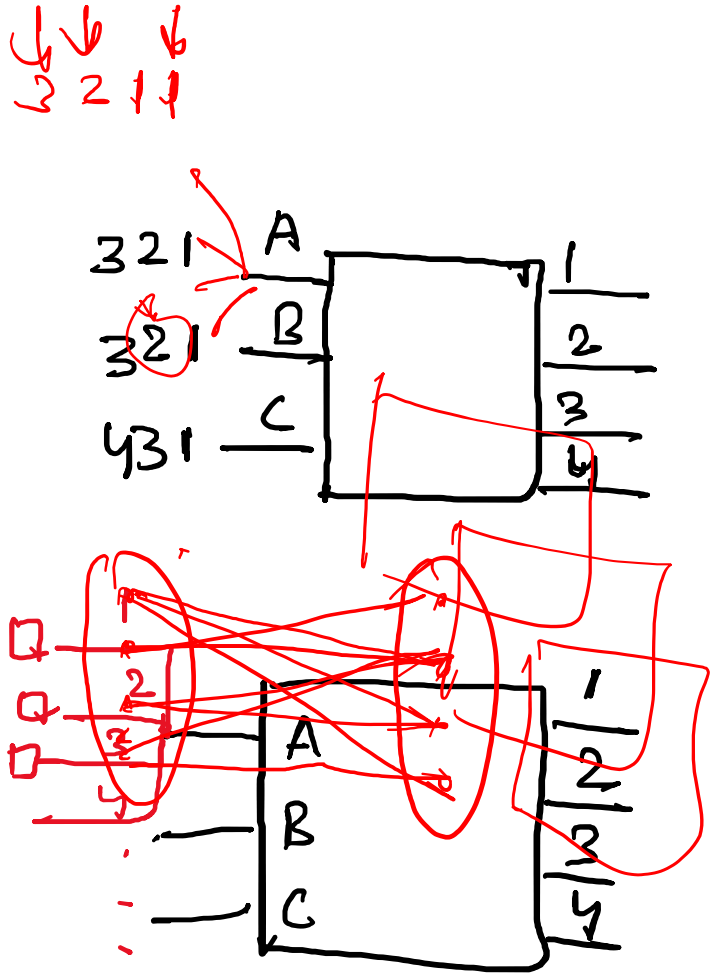




Can we do better?

Input port queuing

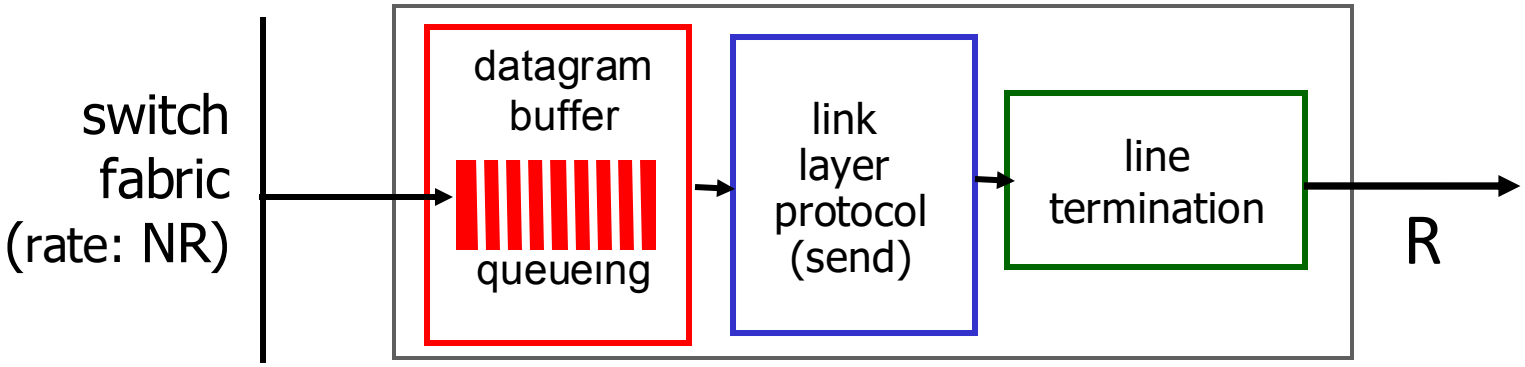
- Head-of-the-Line (HOL) blocking: queued datagram at front of queue prevents others in queue from moving forward
- Use virtual output queuing
- This reduces to maximal bipartite matching problem
- Known algorithms to solve it optimally
  - However, too slow!
  - Approximation algorithms: E.g., Parallel Iterative Match, iSLIP
- Can we still do better?
  - Hardware optimization: use multiple switching planes in parallel



Data Plane Functions

- Prefix lookup
- Switching
- **Queuing**
- Scheduling

Output port queuing



- *Buffering* required when datagrams arrive from fabric faster than link transmission rate, otherwise datagrams will get lost

How much buffering?

- RFC 3439 rule of thumb: average buffering equal to "typical" RTT (say 250 msec) times link capacity C
  - e.g., C = 10 Gbps link: 2.5 Gbit buffer
- more recent recommendation: with *N* flows, buffering equal to

$$\frac{RTT \cdot C}{\sqrt{N}}$$

- Why not simply use large buffers?
- but *too* much buffering can increase delays (particularly in home routers)
  - long RTTs: poor performance for real-time apps, sluggish TCP response