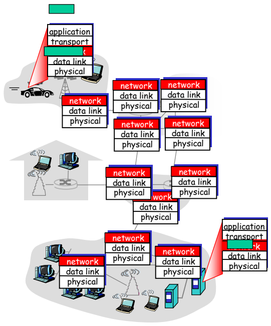
Network layer

- transport segment from sending to receiving host
- on sending side encapsulates segments into datagrams
- on rcving side, delivers segments to transport layer
- network layer in *every* host, router
- router examines header in all IP datagrams passing through it



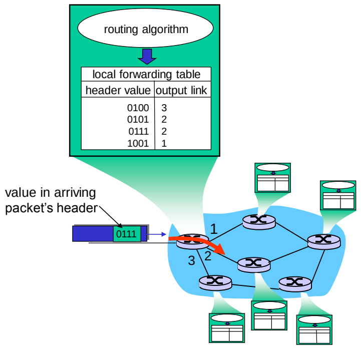
Two Key Network-Layer Functions

- *forwarding:* move packets from router's input to appropriate router output
- *routing:* determine route taken by packets from source to dest.
  - *routing algorithms*

analogy:

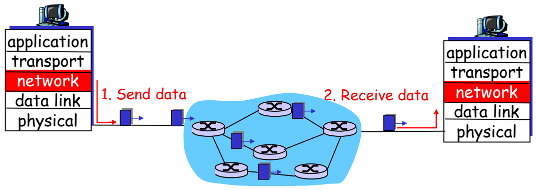
- routing: process of planning trip from source to dest
- forwarding: process of getting through single interchange

Interplay between routing and forwarding

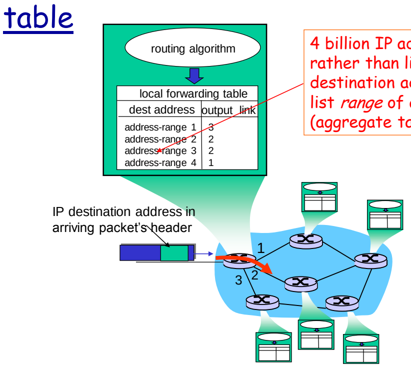


Datagram networks

- no call setup at network layer
- routers: no state about end-to-end connections
  - no network-level concept of "connection"
- packets forwarded using destination host address
  - packets between same source-dest pair may take different paths



Datagram Forwarding table



4 billion IP addresses, so rather than list individual destination address list *range* of addresses (aggregate table entries)

Longest prefix matching

Longest prefix matching

when looking for forwarding table entry for given destination address, use *longest* address prefix that matches destination address.

Destination Address Range	Link interface
11001000 00010111 00010*** *********	0
11001000 00010111 00011000 *********	1
11001000 00010111 00011*** *********	2
otherwise	3

Examples:

DA: 11001000 00010111 00010110 10100001 Which interface?

DA: 11001000 00010111 00011000 10101010 Which interface?

Chapter 4: Network Layer

4. 1 Introduction

4.2 Virtual circuit and datagram networks

4.3 What's inside a router?

4.4 IP: Internet Protocol
- Datagram format
- IPv4 addressing
- ICMP
- IPv6

4.5 Routing algorithms
- Link state
- Distance Vector
- Hierarchical routing

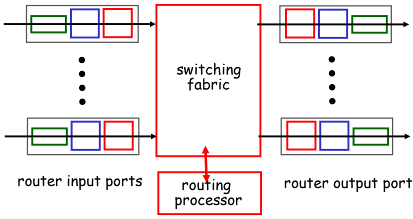
4.6 Routing in the Internet
- RIP
- OSPF
- BGP

4.7 Broadcast and multicast routing

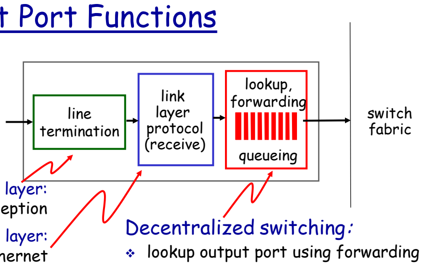
Router Architecture Overview

two key router functions:

- run routing algorithms/protocol (RIP, OSPF, BGP)
- *forwarding* datagrams from incoming to outgoing link



Input Port Functions



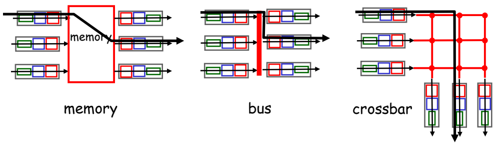
Physical layer:
bit-level reception

Data link layer:
e.g., Ethernet
see chapter 5

Decentralized switching:
- lookup output port using forwarding table in input port memory
- goal: complete input port processing at 'line speed'
- queuing: if datagrams arrive faster than forwarding rate into switch fabric

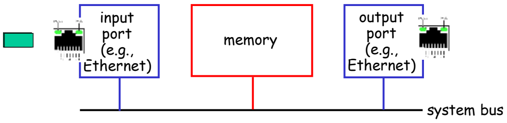
Switching fabrics

- transfer packet from input buffer to output buffer
- switching rate: rate at which packets can be transfer from inputs to outputs
  - N inputs: switching rate N times line rate desirable
- three types of switching fabrics

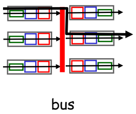


Switching Via Memory

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 per datagram)



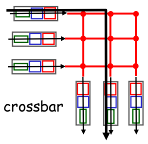
Switching Via a Bus



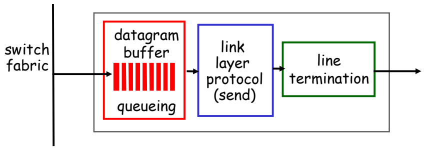
- datagram from input port memory to output port memory via a shared bus
- bus contention: switching speed limited by bus bandwidth

Switching Via An Interconnection Network

- overcome bus bandwidth limitations
- advanced design: fragmenting datagram into fixed length cells, switch cells through the fabric.

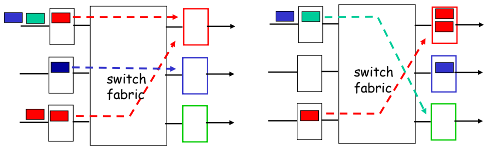


Output Ports



- *buffering* required when datagrams arrive from fabric faster than the transmission rate
- *scheduling discipline* chooses among queued datagrams for transmission

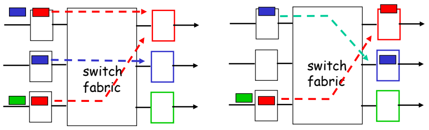
Output port queueing



- buffering when arrival rate exceeds output line speed

Input Port Queuing

- fabric slower than input ports combined -> queueing may occur at input queues
  - *queueing delay and loss due to input buffer overflow!*
- Head-of-the-Line (HOL) blocking: queued datagram at front of queue prevents others in queue from moving forward



output port contention: only one red datagram can be transferred. *lower red packet is blocked*

one packet time later: green packet experiences HOL blocking