

Flow and Congestion Control Recap

Activity:

- ❑ I am a sender, sending off my cards (packets) into the network
- ❑ What do you, the network and receiving hosts, need to have and do, to enforce flow control on me, the wonton sender?
- ❑ What do you need to have and do to enforce congestion control on me?
- ❑ Your resources:
 - ❖ Playing cards (packets), buffers, timers, flashcard variables

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First part of semester recap

Concept:

- ❑ A network provides the means for applications *not* directly connected to exchange messages
- ❑ Layered model
 - ❖ Computer networking is implemented in discrete, well-defined sub-tasks

Goals:

- ❑ Understand for each layer
 - ❖ Services required from layer below
 - ❖ Services offered to layer above
 - ❖ Key principles of each layer
 - ❖ Our current implementation

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Now on to Chapter 4...

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Chapter 4: Network Layer

Chapter goals:

- ❑ understand principles behind the network layer:
 - ❖ Network layer services
 - ❖ Forwarding versus routing
 - ❖ Inside a router: how a router works
 - ❖ Routing algorithms (path selection)

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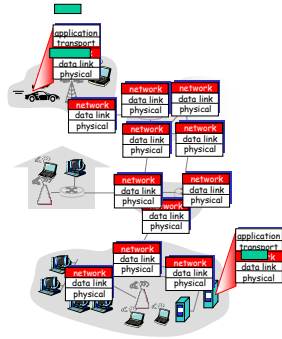
Chapter 4: Network Layer

- ❑ 4.1 Introduction
- ❑ 4.2 Virtual circuit and datagram networks
- ❑ 4.3 What's inside a router
- ❑ 4.4 IP: Internet Protocol
- ❑ 4.5 Routing algorithms
 - ❖ Link state
 - ❖ Distance Vector
 - ❖ Hierarchical routing
- ❑ 4.6 Routing in the Internet
- ❑ 4.7 Broadcast and multicast routing

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Network layer

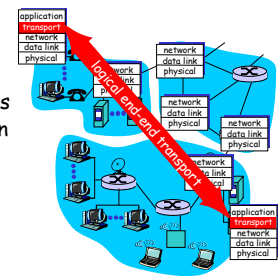
- Transport a segment from sending to receiving host
- The **sending** side encapsulates segments into datagrams
- The **receiving** side delivers segments to transport layer
- Network layer protocols run in **every host & router**
 - ❖ Router examines header fields in all IP datagrams passing through it



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... versus Transport Services

- The transport layer provides a **logical communication** between application processes running on different hosts
- Transport protocols run in end systems only



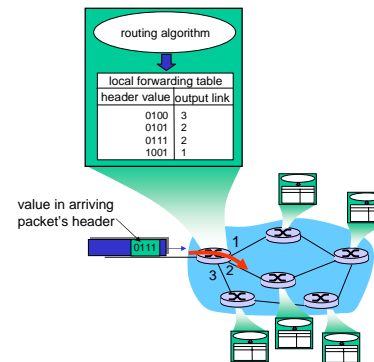
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Key Network-Layer Functions

- **1. routing:** determine route taken by packets from source to destination
 - ❖ Routing algorithms
 - **2. forwarding:** move packets from router's input to appropriate router output
- analogy:**
- **routing:** process of planning a car trip from source to destination
 - **forwarding:** process of driving through a single highway exchange or small town

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Interplay between routing and forwarding



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(Connection setup)

- 3rd important function in *some* network architectures:
- Before datagrams flow, two hosts **and intervening routers** establish virtual connection
 - ❖ Routers maintain connection state information
 - ❖ *Every* packet for given communication follows the same path through the network

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Network service model

Q: What *services* are offered by the "channel" transporting datagrams from sender to receiver?

Example services for individual datagrams:

- Guaranteed delivery
- Guaranteed minimum delay

Example services for a flow of datagrams:

- In-order datagram delivery
- Guaranteed minimum bandwidth to flow
- Restrictions on changes in inter-packet spacing

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Network Layer Services of IP?

- ❑ Guaranteed delivery?
- ❑ Guaranteed minimum delay?
- ❑ In-order datagram delivery?
- ❑ Guaranteed minimum bandwidth to flow?
- ❑ Restrictions on changes in inter-packet spacing?
- ❑ IP Provides? → "Best-effort service"

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Network layer connection and connection-less service

- ❑ Datagram network provides network-layer connectionless service
- ❑ Virtual Circuit, VC, network provides network-layer connection service
- ❑ Analogous to the transport-layer services, but:
 - ❖ **Service:** host-to-host
 - ❖ **No choice:** network provides one or the other
 - ❖ **Implementation:** in the core

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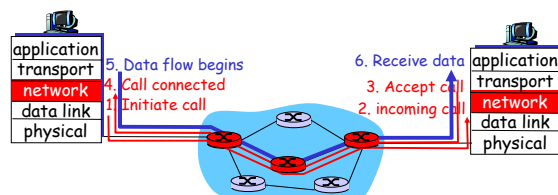
Virtual circuits

- ❑ call setup, teardown for each call *before* data can flow
- ❑ *every* router on source-dest path maintains "state" for each passing connection
- ❑ link, router resources (bandwidth, buffers) may be *allocated* to VC

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Virtual circuits: signaling protocols

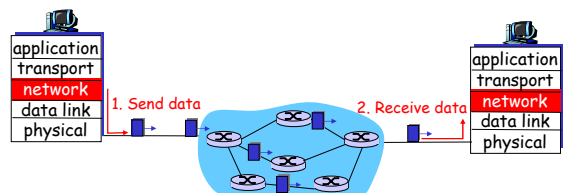
- ❑ used to setup, maintain, and teardown VC
- ❑ not used in today's Internet



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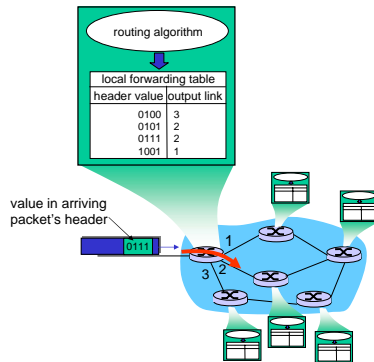
Datagram networks

- ❑ 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



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Creating and Using a Forwarding Table



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Forwarding table

4 billion possible entries

| Destination Address Range | Link Interface |
|---|----------------|
| 11001000 00010111 00010000 00000000 through 11001000 00010111 00010111 11111111 | 0 |
| 11001000 00010111 00011000 00000000 through 11001000 00010111 00011000 11111111 | 1 |
| 11001000 00010111 00011001 00000000 through 11001000 00010111 00011111 11111111 | 2 |
| otherwise | 3 |

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Longest prefix matching

| Prefix Match | 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?

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Forwarding Table "Ranges"

- What are the assumptions and implications of having large ranges of IP addresses forwarded to the same outgoing link?

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Chapter 4: Network Layer

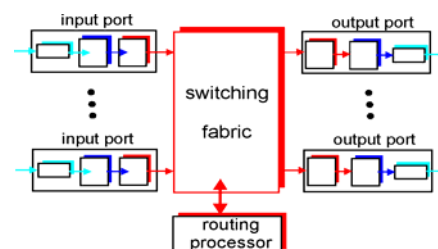
- 4.1 Introduction
- 4.2 Virtual circuit and datagram networks
- 4.3 What's inside a router
- 4.4 IP: Internet Protocol
 - Datagram format
 - IPv4 addressing
 - ICMP
 - IPv6
- 4.5 Routing algorithms
 - Link state
 - Distance Vector
 - Hierarchical routing
- 4.6 Routing in the Internet
 - RIP
 - OSPF
 - BGP
- 4.7 Broadcast and multicast routing

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Router Architecture Overview

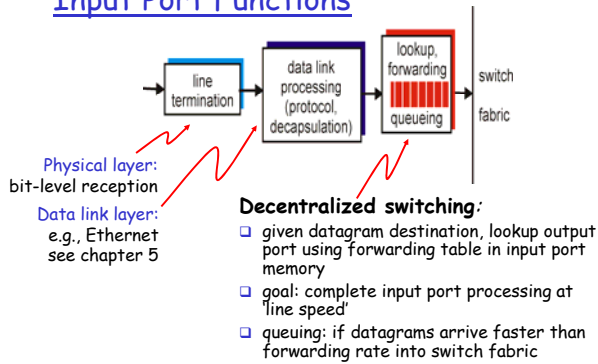
Two key router functions:

- run routing algorithms/protocol
- forwarding datagrams from incoming to outgoing link



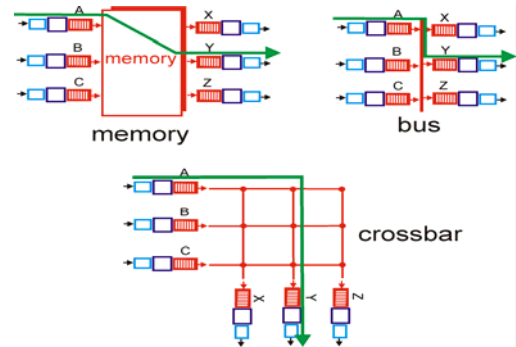
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Input Port Functions



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Three types of switching fabrics

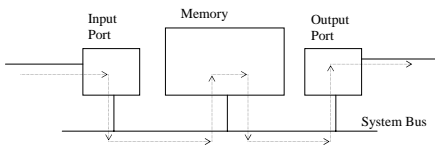


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Switching Via Memory

First generation routers:

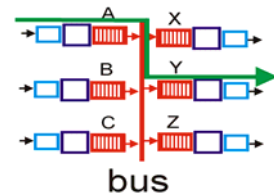
- traditional computers with switching under direct control of CPU
- packet copied to system's memory
- speed limited by memory bandwidth (2 bus crossings per datagram)



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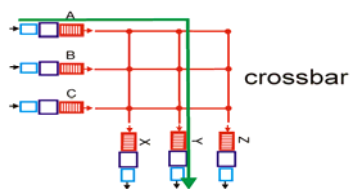
Switching Via a Bus

- 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
- Interconnection nets initially developed to connect processors in multiprocessor



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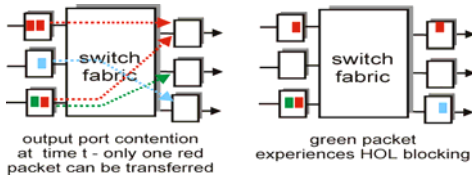
Queuing in Routers

- Where can queuing occur?
- Why does it occur?
- Packet scheduler at the output port
 - ❖ Select one queued packet for transmission
 - FCFS
 - Weighted-fair-queuing - share the outgoing link "fairly" among connections

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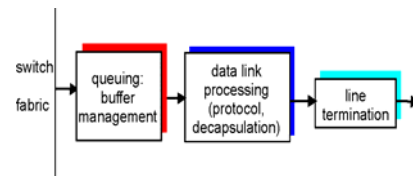
Input Port Queuing

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



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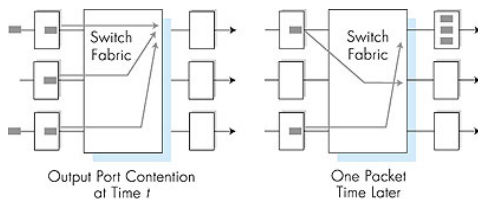
Output Ports



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

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Output port queuing



- *queuing (delay) and loss due to output port buffer overflow*

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Homework Feedback

- A number of questions were interpreted in different ways
- Problem 10
 - ❖ Non-persistent HTTP w/ & w/o parallel connections
 - ❖ Vs. persistent HTTP
- Problem 24
 - ❖ b) UDP client-server can function if the client is started first, if ... ?
 - ❖ c) Different port numbers - for client/server sockets vs. for same socket (also for problem 25)

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Summary

- There are many possible network layer services → IP provides none!
- Forwarding vs. Routing
- Inside a router
 - ❖ The internet in miniature
- A first glimpse at the network IP datagram

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