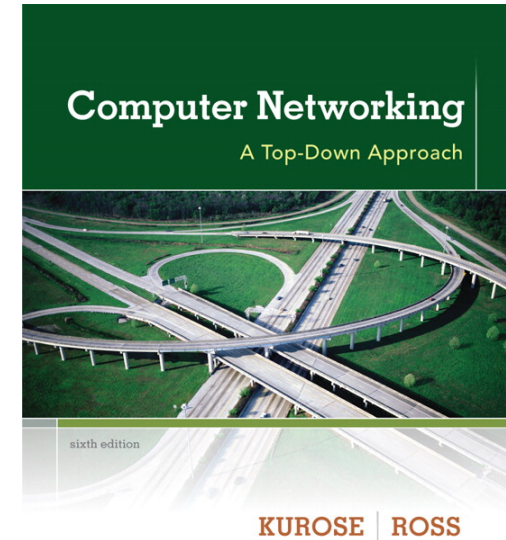


Chapter 4

Network Layer



*Computer
Networking: A Top
Down Approach*
6th edition
Jim Kurose, Keith Ross
Addison-Wesley
March 2012

Slides based on materials developed by Kurose and Ross.

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Chapter 4: outline

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

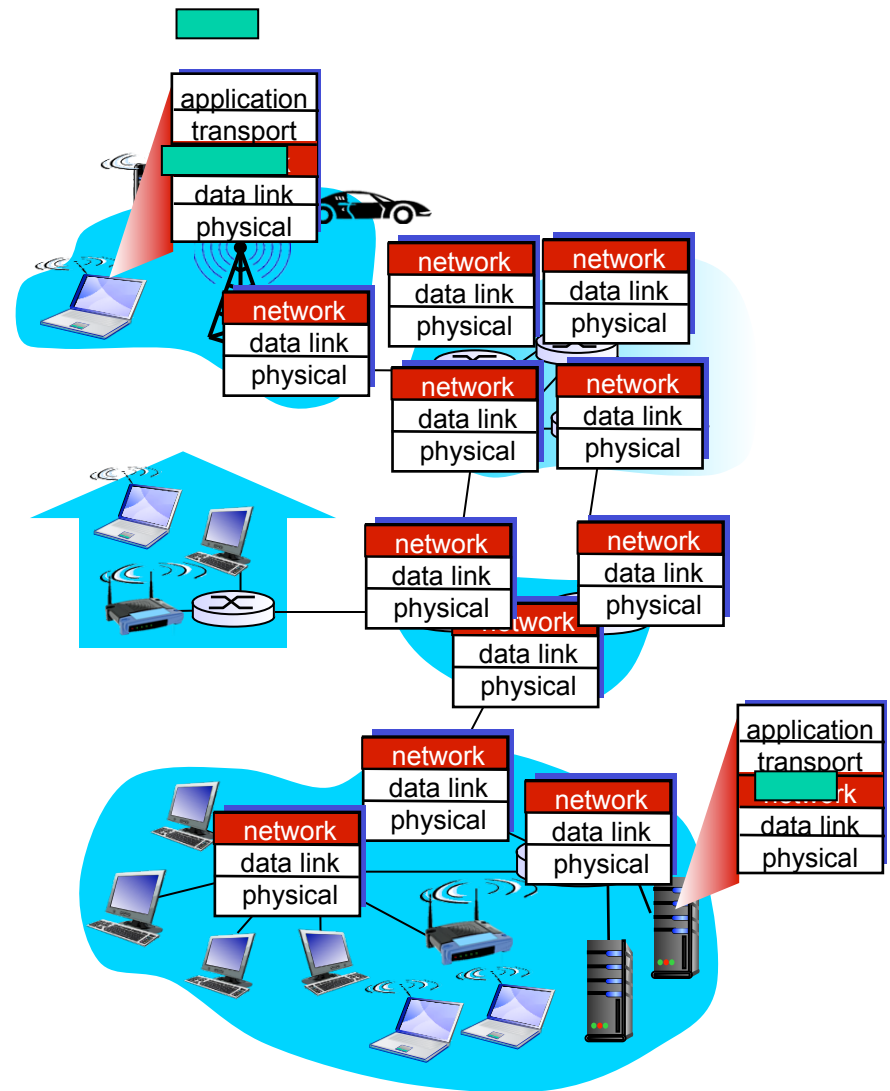
4.6 routing in the Internet

- RIP
- OSPF
- BGP

4.7 broadcast and multicast routing

Network layer

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



Two key network-layer functions

- ❖ *routing*: determine route taken by packets from source to dest.

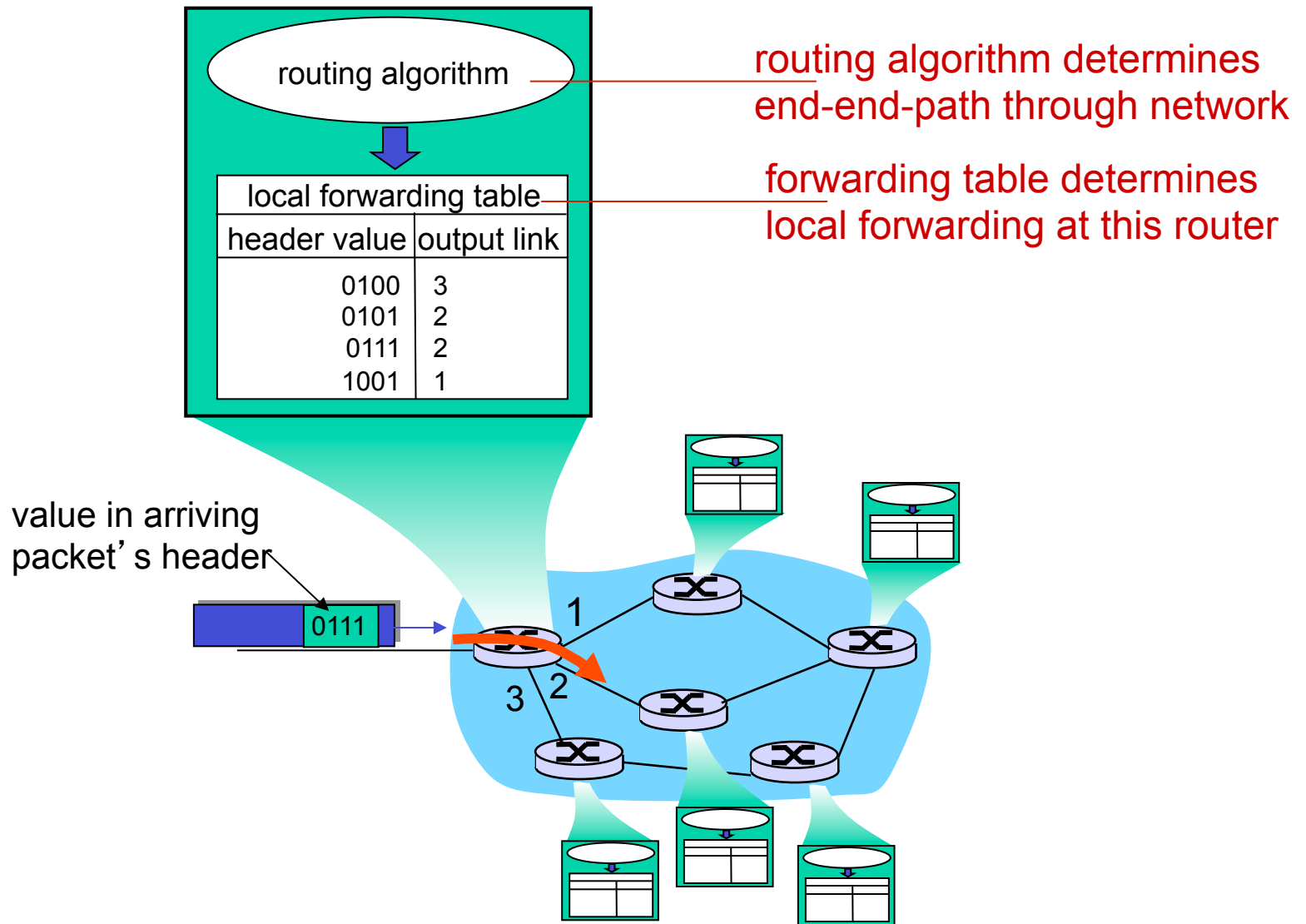
- *routing algorithms*

- ❖ *forwarding*: move packets from router's input to appropriate router output

analogy:

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

Interplay between routing and forwarding



Network service model

Q: What *service model* for transporting datagrams from sender to receiver?

example services for individual datagrams:

- ❖ guaranteed delivery
- ❖ guaranteed delivery with less than 40 msec delay

example services for a flow of datagrams:

- ❖ in-order datagram delivery
- ❖ guaranteed minimum bandwidth to flow
- ❖ restrictions on changes in inter-packet spacing

Network layer service models:

Network Architecture	Service Model	Guarantees ?				Congestion feedback
		Bandwidth	Loss	Order	Timing	
Internet	"best effort"	none	no	no	no	no (inferred via loss)
ATM	CBR	constant rate	yes	yes	yes	no congestion
ATM	VBR	guaranteed rate	yes	yes	yes	no congestion
ATM	ABR	guaranteed minimum	no	yes	no	yes
ATM	UBR	none	no	yes	no	no

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Connection, connection-less service

- ❖ *datagram* network provides network-layer *connectionless* service
- ❖ *virtual-circuit* network provides network-layer *connection* service
- ❖ analogous to TCP/UDP connection-oriented / connectionless transport-layer services, but:
 - *service*: host-to-host
 - *no choice*: network provides one or the other
 - *implementation*: in network core
- ❖ (Basically circuit switching of Chapter 1)

[Virtual circuits]

“source-to-dest path behaves much like telephone circuit”

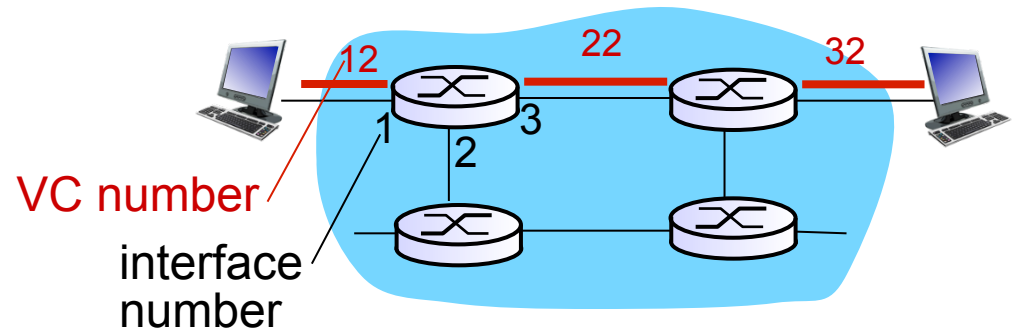
- performance-wise
 - network actions along source-to-dest path
-
- ❖ call setup, teardown for each call *before* data can flow
 - ❖ each packet carries VC identifier (not destination host address)
 - ❖ every router on source-dest path maintains “state” for each passing connection
 - ❖ link, router resources (bandwidth, buffers) may be *allocated* to VC (dedicated resources = predictable service)

[VC implementation]

a VC consists of:

1. *path* from source to destination
 2. *VC numbers*, one number for each link along path
 3. *entries in forwarding tables* in routers along path
- ❖ packet belonging to VC carries VC number (rather than dest address)
 - ❖ VC number can be changed on each link.
 - new VC number comes from forwarding table

[VC forwarding table]



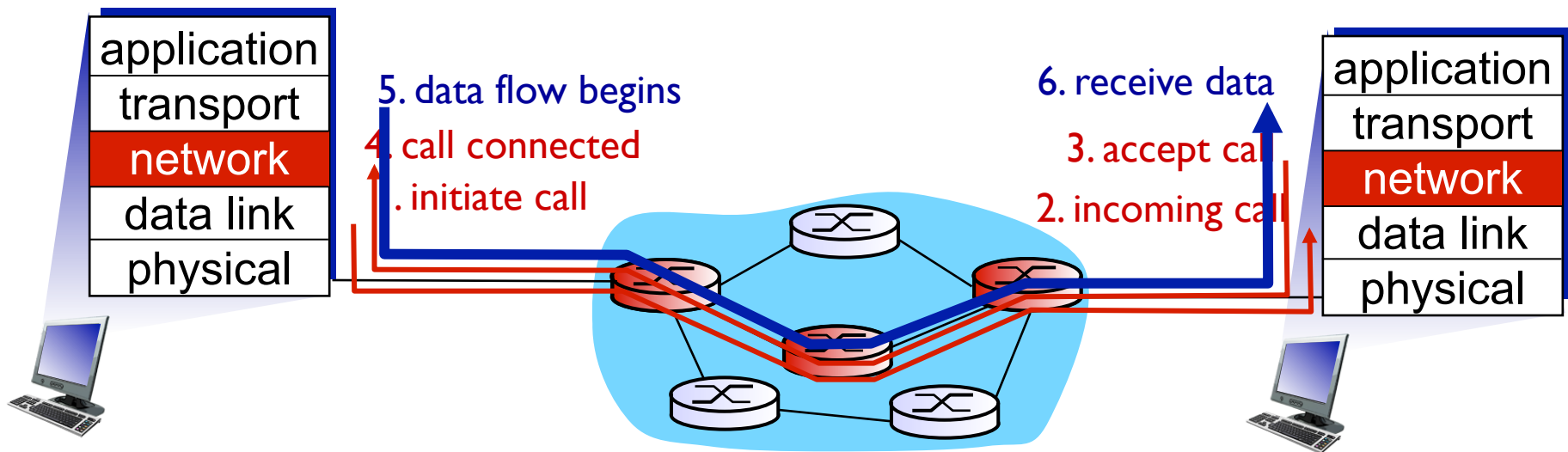
*forwarding table in
northwest router:*

Incoming interface	Incoming VC #	Outgoing interface	Outgoing VC #
1	12	3	22
2	63	1	18
3	7	2	17
1	97	3	87
...

VC routers maintain connection state information!

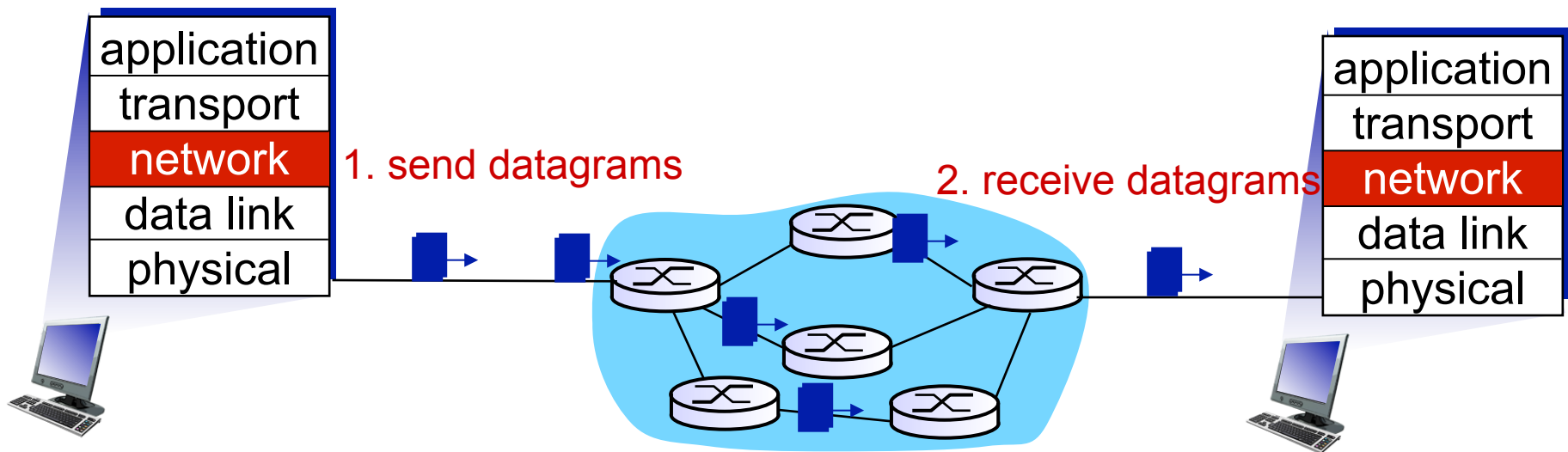
[Virtual circuits: signaling protocols]

- ❖ used to setup, maintain teardown VC
- ❖ used in ATM, frame-relay, X.25
- ❖ not used in today's Internet
- ❖ sometimes used on top of today's IP (MPLS)

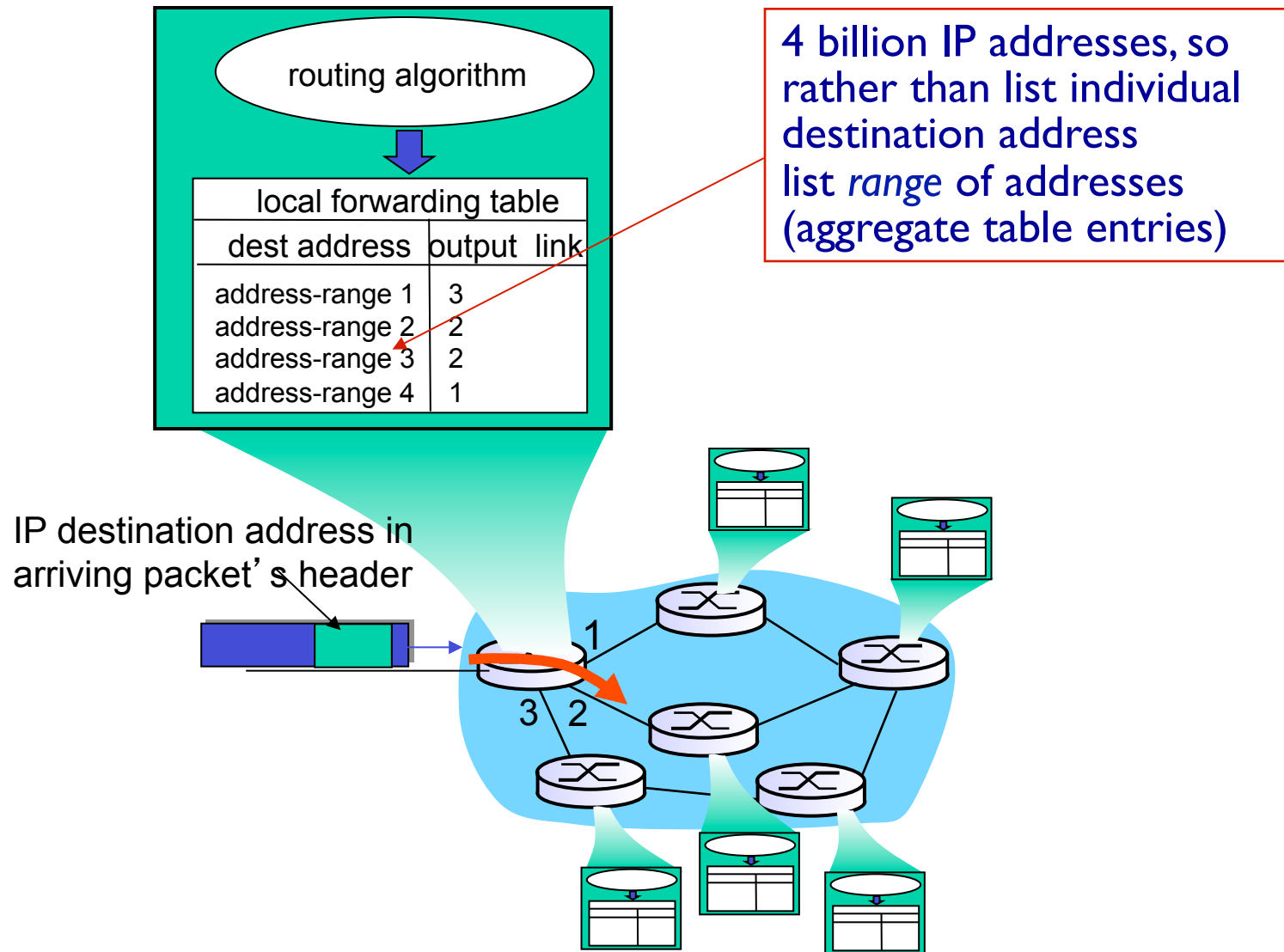


Datagram networks

- ❖ 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



Datagram forwarding table



Datagram forwarding table

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

Q: but what happens if ranges don't divide up so nicely?

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 00010**110** 10100001

which interface?

DA: 11001000 00010111 00011000 10101010

which interface?

[Datagram or VC network: why?]

Internet (datagram)

- ❖ data exchange among computers
 - “elastic” service, no strict timing req.
- ❖ many link types
 - different characteristics
 - uniform service difficult
- ❖ “smart” end systems (computers)
 - can adapt, perform control, error recovery
 - **simple inside network, complexity at “edge”**

ATM (VC)

- ❖ evolved from telephony
- ❖ human conversation:
 - strict timing, reliability requirements
 - need for guaranteed service
- ❖ “dumb” end systems
 - telephones
 - **complexity inside network**