# Chapter 04: TCP/IP Protocol suite Delivery and Forwarding of IP Packets

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# Objectives

- To discuss the delivery of packets in the network layer and distinguish between direct and indirect delivery.
- To discuss the forwarding of packets in the network layer and distinguish between destination-address–based forwarding and label-based forwarding.
- To discuss different forwarding techniques, including next-hop, network-specific, host-specific, and default.
- To discuss the contents of routing tables in classful and classless addressing and some algorithms used to search the tables.

# Delivery

Direct and Indirect

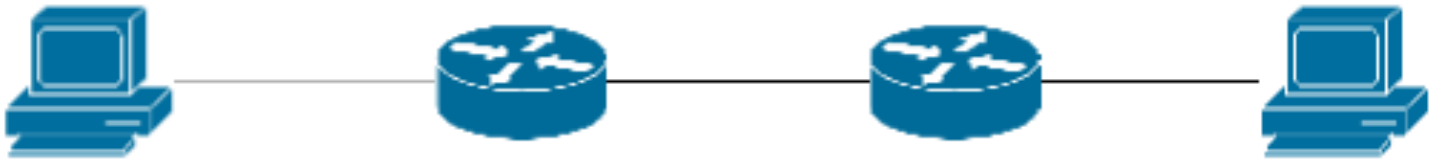
# Direct Delivery

- Occurs when the source and destination of the packet are located on the same physical network or if the delivery is between the last router and the destination host.
- The sender uses the destination IP address to find the destination physical address (with ARP) to create link layer frame for actual delivery.

# Indirect Delivery

- Indirect delivery occurs when the source and destination of the packet are not on the same physical network. The packet goes from router to router until it reaches the one connected to the same physical network as its final destination.
- In an indirect delivery, the sender uses the destination IP address and a routing table to find the IP address of the next router to which the packet should be delivered. The sender then uses ARP to find the physical address of the next router delivered. The last delivery is always a direct delivery.

# Indirect Delivery



# Forwarding

Forwarding means to place the packet in its route to its destination. Since the Internet today is made of a combination of links (networks), forwarding means to deliver the packet to the next hop (which can be the final destination or the intermediate connecting device)

Because IP is a connectionless protocol, forwarding is based on the destination address of the IP datagram; when the IP is used as a connection-oriented protocol, forwarding is based on the label attached to an IP datagram.

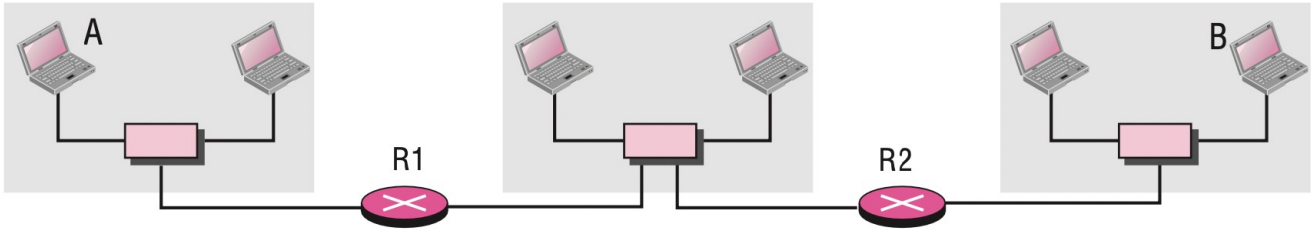
# Forwarding Based on Destination Address

- This is a traditional approach, forwarding requires a host or a router to have a routing table. When a host has a packet to send or when a router has received a packet to be forwarded, it looks at this table to find the route to the final destination.
- However, this solution is inefficient in an internetwork such as the Internet because the number of entries needed in the routing table would make table lookups inefficient.

# Forwarding Techniques

**Next-Hop**:

The routing table holds only the address of the next hop instead of information about the complete route. The entries of a routing table must be consistent with each other.




A

| Destination | Route |
|---|---|
| Host B | R1, R2, Host B |

R1

| Destination | Route |
|---|---|
| Host B | R2, Host B |

R2

| Destination | Route |
|---|---|
| Host B | Host B |

a. Routing tables based on route

A

| Destination | Next Hop |
|---|---|
| Host B | R1 |

R1

| Destination | Next Hop |
|---|---|
| Host B | R2 |

R2

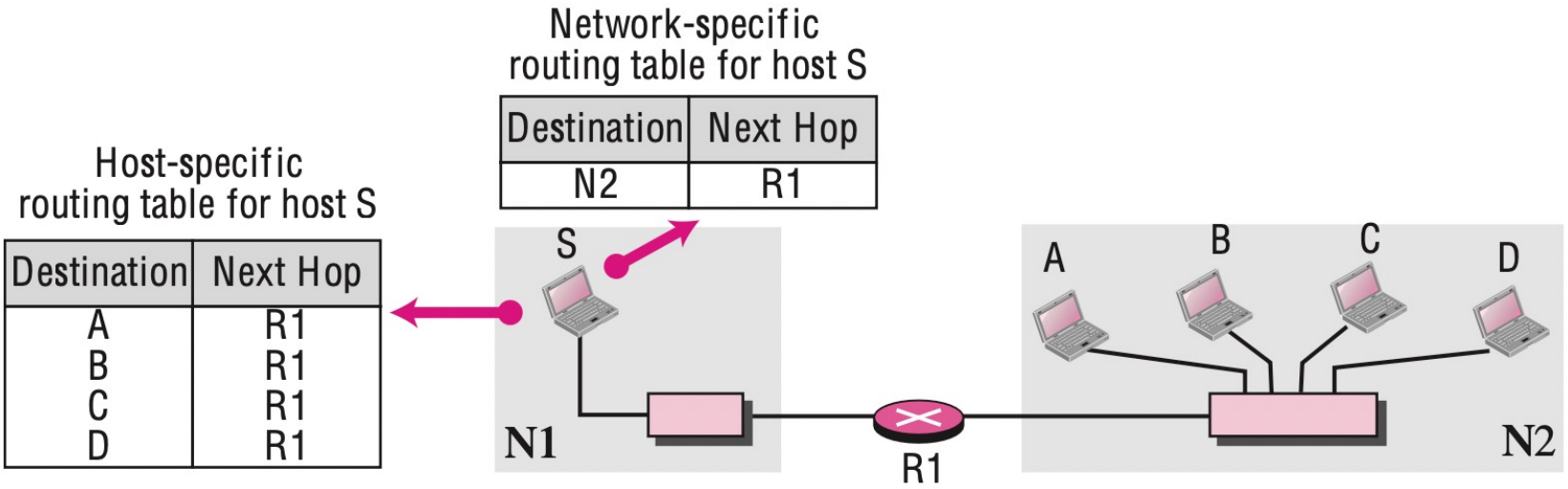
| Destination | Next Hop |
|---|---|
| Host B | --- |

b. Routing tables based on next hop

# Forwarding Techniques

**Network-specific**:

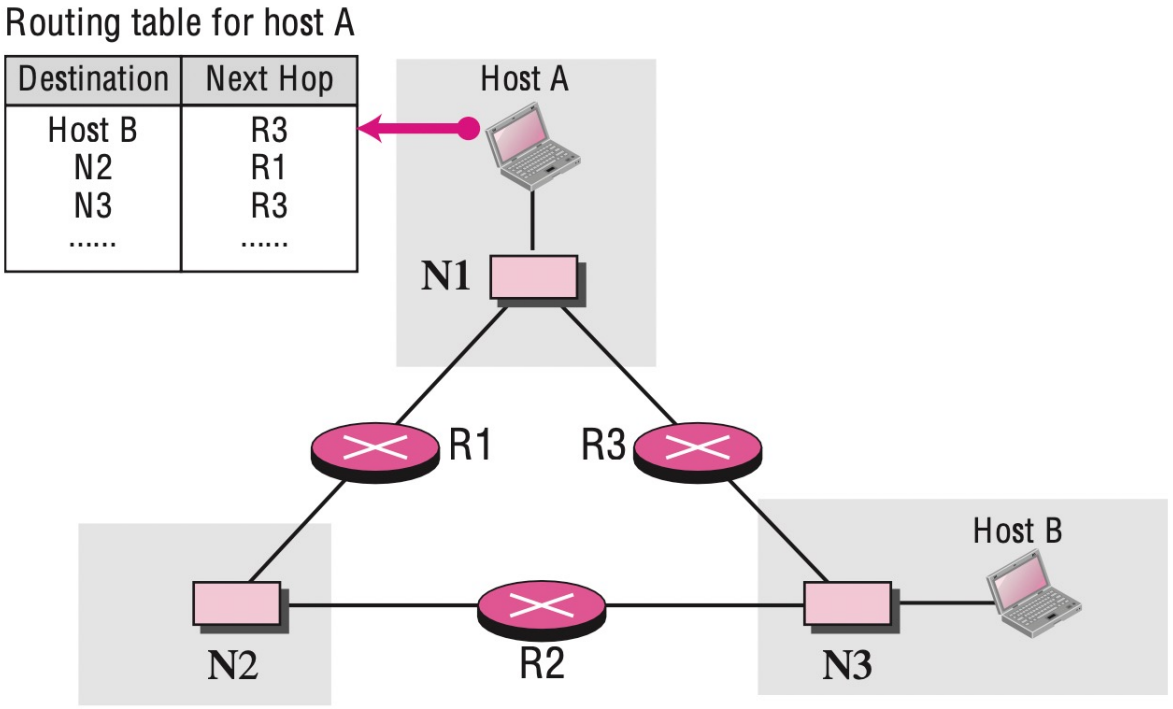
instead of having an entry for every destination host connected to the same physical network, we have only one entry that defines the address of the destination network itself. In other words, all hosts connected to the same network are treated as one single entity.



# Forwarding Techniques

**Host-specific**:

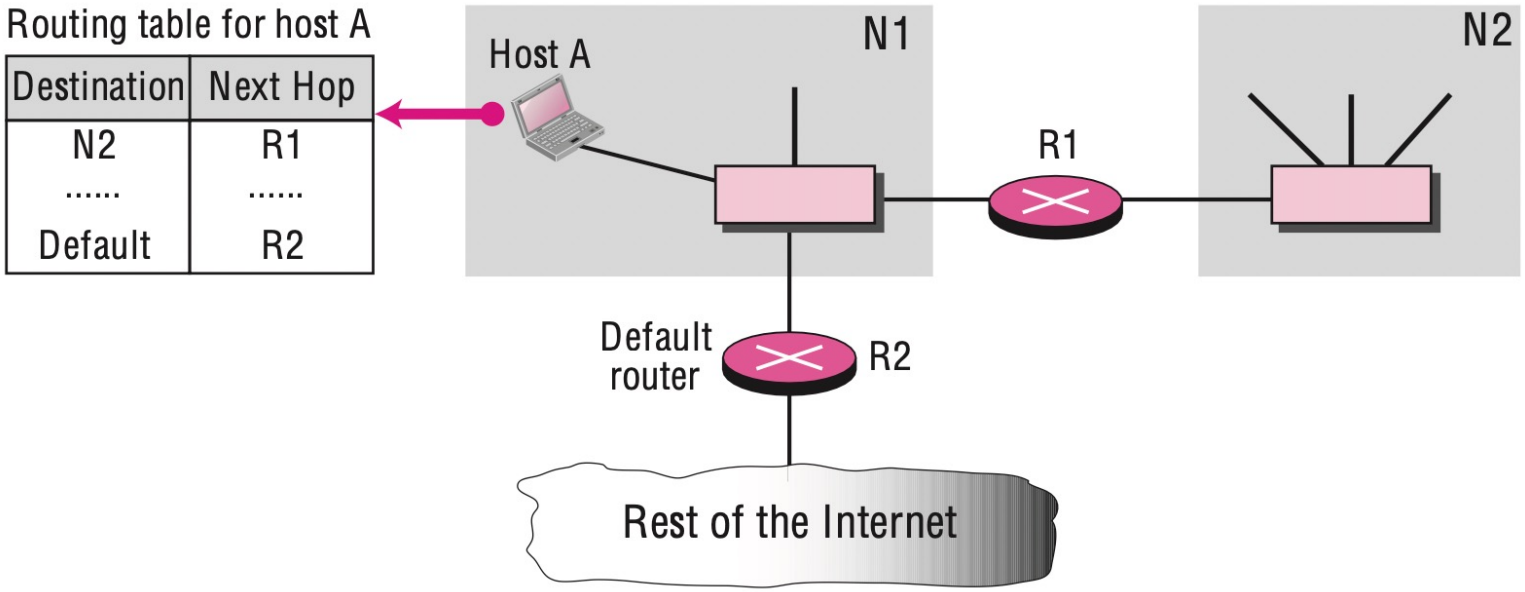
the destination host address is given in the routing table. Here efficiency is sacrificed for other advantages: Although it is not efficient to put the host address in the routing table, there are occasions in which the administrator wants to have more control over routing



# Forwarding Techniques

**Default**:

Host A is connected to a network with two routers. Router R1 routes the packets to hosts connected to network N2. However, for the rest of the Internet, router R2 is used. So instead of listing all networks in the entire Internet, host A can just have one entry called the default (normally defined as network address 0.0.0.0)



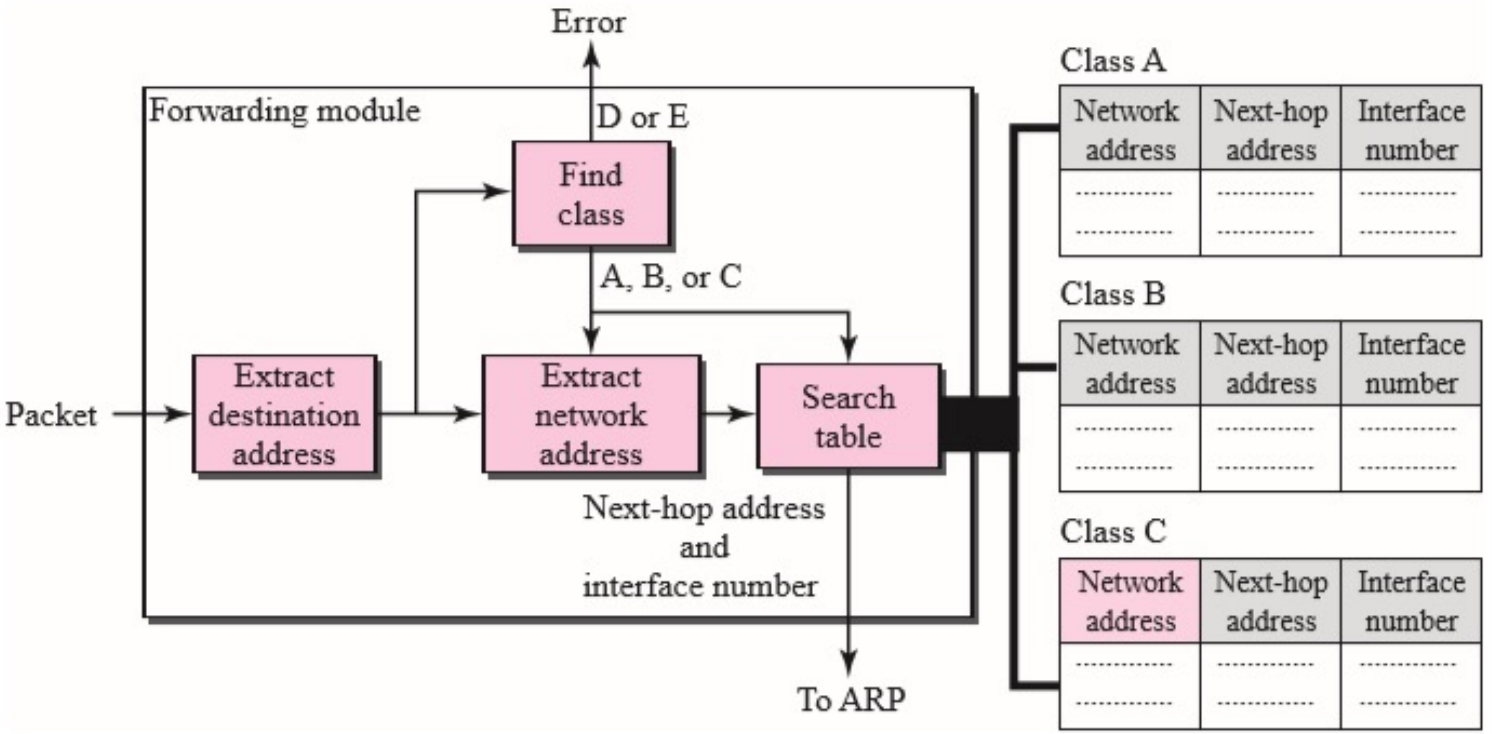
# Forwarding with Classful Addressing

**Forward without subnetting**:

Subnetting happens inside the organization, most of the routers in the global Internet are not involved in subnetting.

- The forwarding module has 3 routing tables, one for each class A,B or C.
- Each routing table has a minimum of 3 columns:
  1. The network address of the destination network indicates where the destination host is located (network-specific forwarding)
  2. The next-hop address indicates to which router the packet must be delivered for an indirect delivery. This column is empty for a direct delivery.
  3. The interface number defines the outgoing port from which the packet is sent out. A router is normally connected to several networks. Each connection has a different numbered port or interface. (m0, m1, m2, …)

# Forwarding module in Classful Address without Subnetting



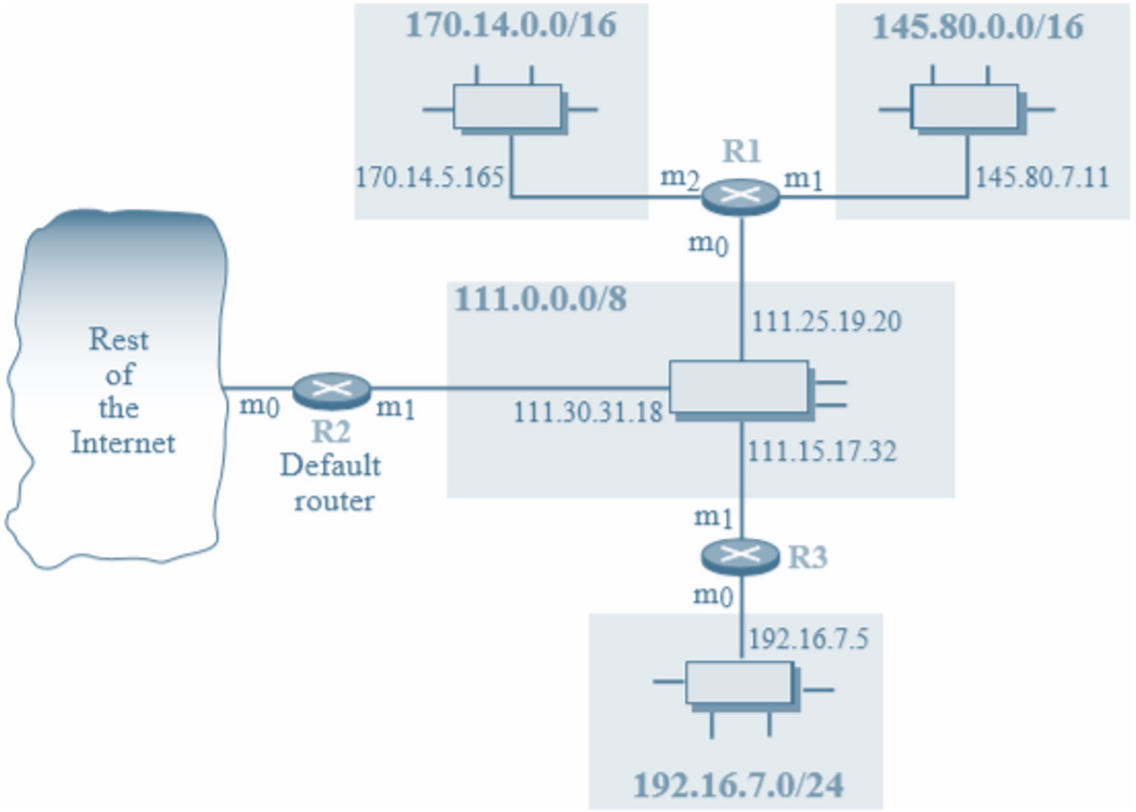
# Forwarding with Classful Addressing

In its simplest form, the forwarding module follows these steps:

1. The destination address of the packet is extracted.
2. A copy of the destination address is used to find the class of the address. This is done by shifting the copy of the address 28 bits to the right. The result is a 4-bit number between 0 and 15. If the result is: 0 to 7, the class is A; 8 to 11, the class is B; 12 or 13, the class is C; 14, the class is D; 15, the class is E.
3. Masking off the rightmost 8, 16, or 24 bits based on the class of the result from Step 2 to extract the network address.
4. The class determines which table is used for searching the network address. If a match is found, the next-hop address and the interface number of the output port are extracted from the table. If no mat.ch is found, the default is used

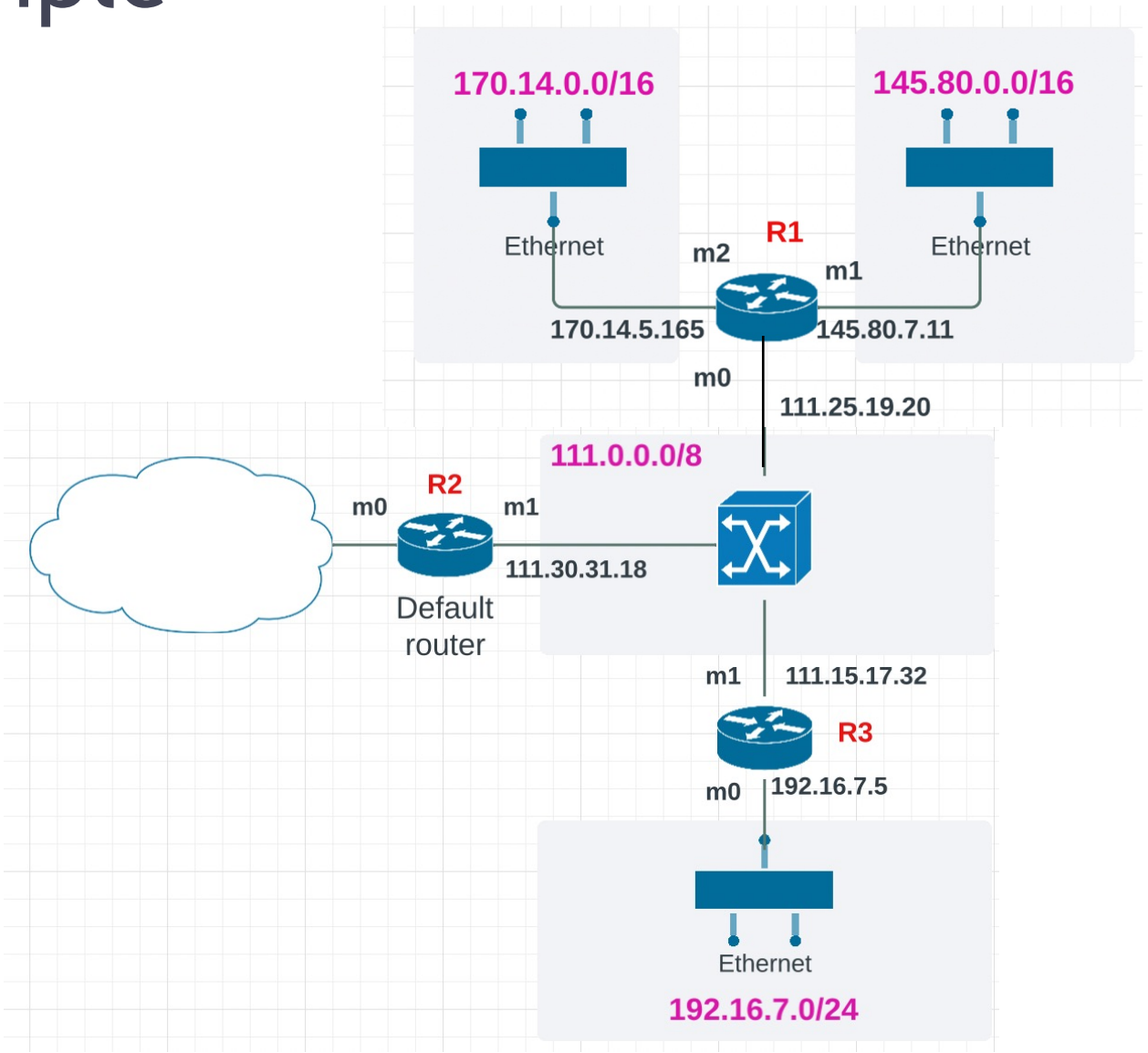
# Example

Find the routing tables for router R1 in the figure:




Default: 111.30.31.18, m0

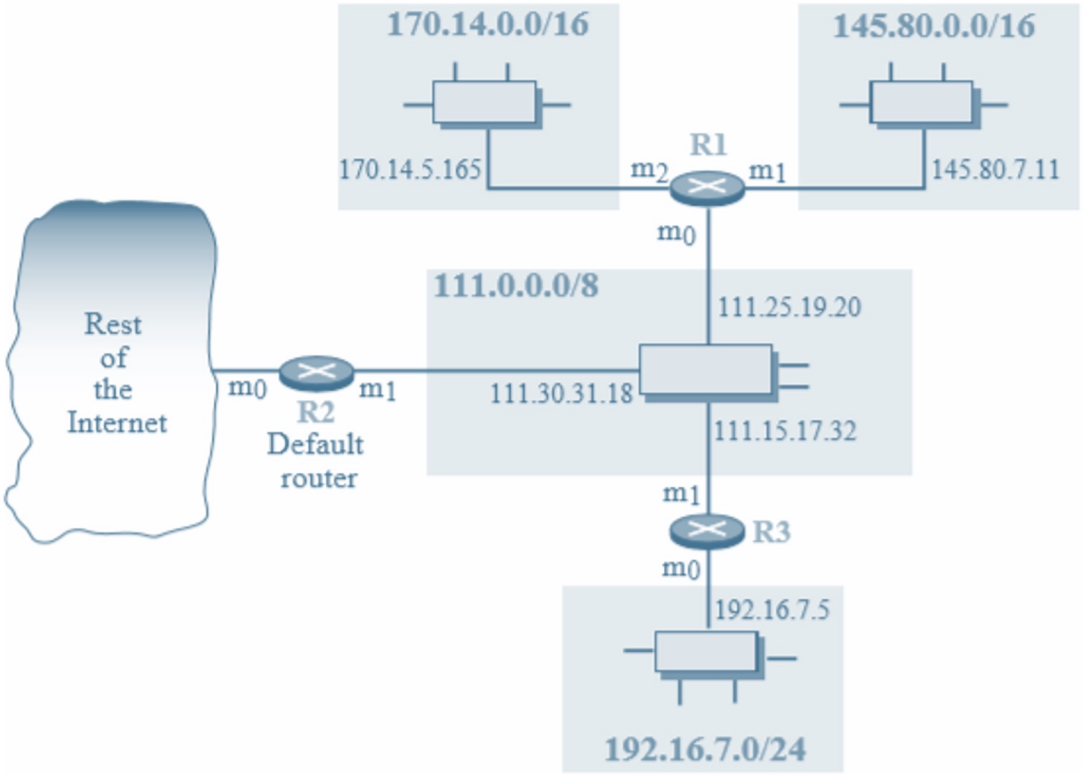
# Example


170.14.0.0/16
145.80.0.0/16
Ethernet
Ethernet
R1
m2
m1
170.14.5.165
145.80.7.11
m0
111.25.19.20
111.0.0.0/8
R2
m0
m1
111.30.31.18
Default
router
m1
111.15.17.32
R3
m0
192.16.7.5
Ethernet
192.16.7.0/24

# Example

How the packet is forwarded in these 2 cases:

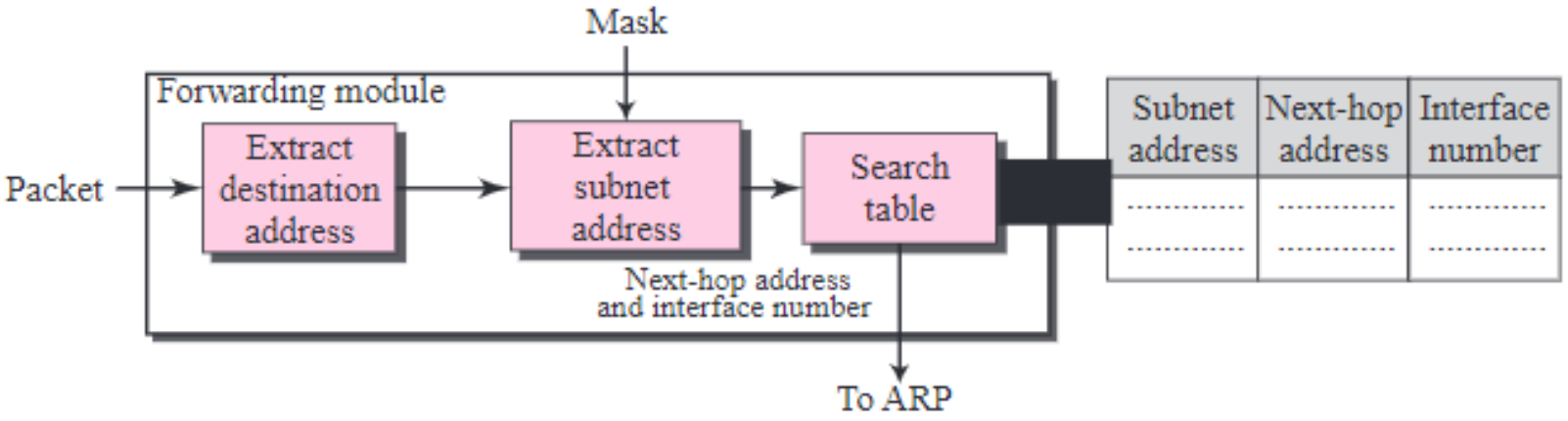
1. Router R1 receives a packet with destination address 192.16.7.14.
2. Router R1 receives a packet with destination address 167.24.160.5




Default: 111.30.31.18, m0

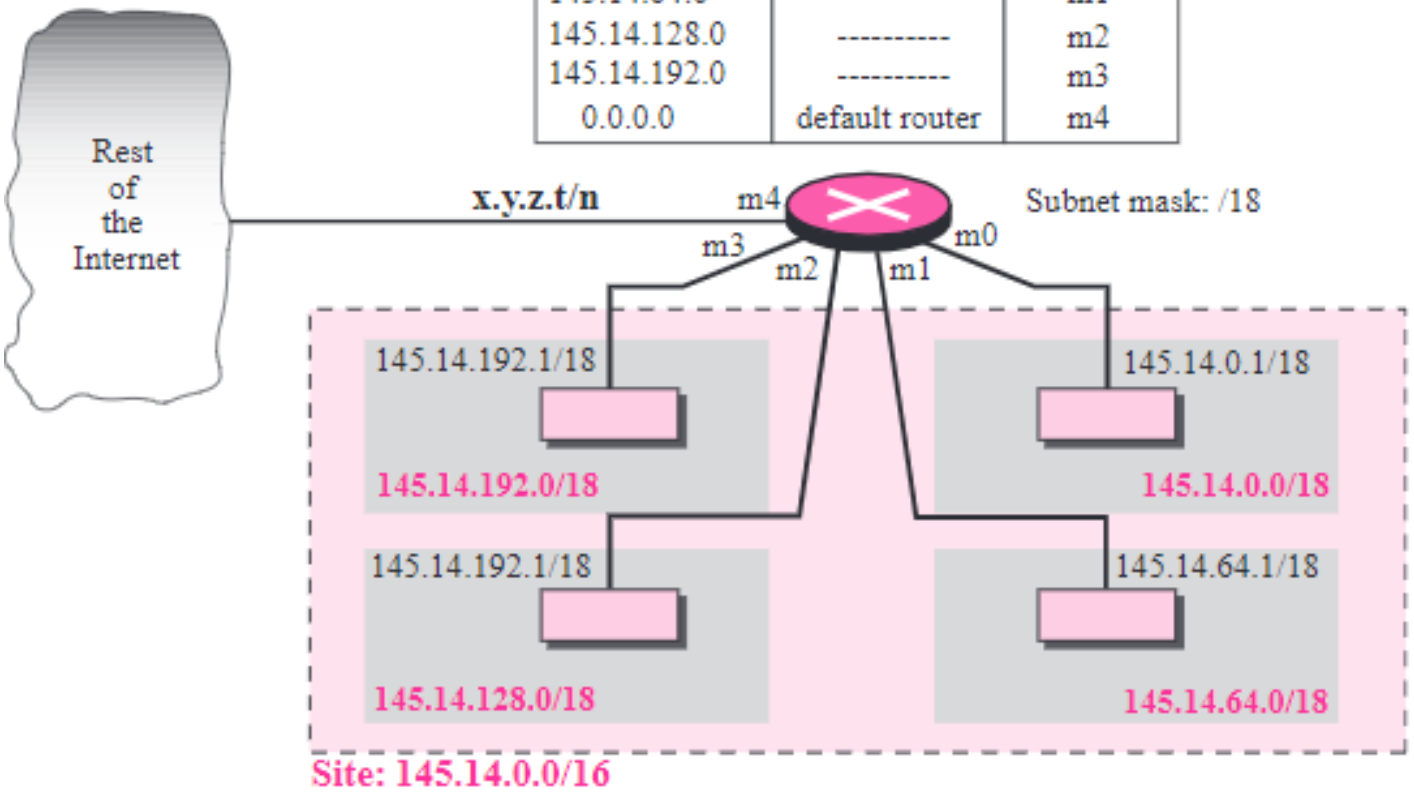
# Forwarding with Classful Addressing

- **Forward with subnetting**: Subnetting happens inside the organization, most of the routers in the global Internet are not involved in subnetting.
- If the organization is using variable-length subnetting, we need several tables; otherwise, we need only one table.



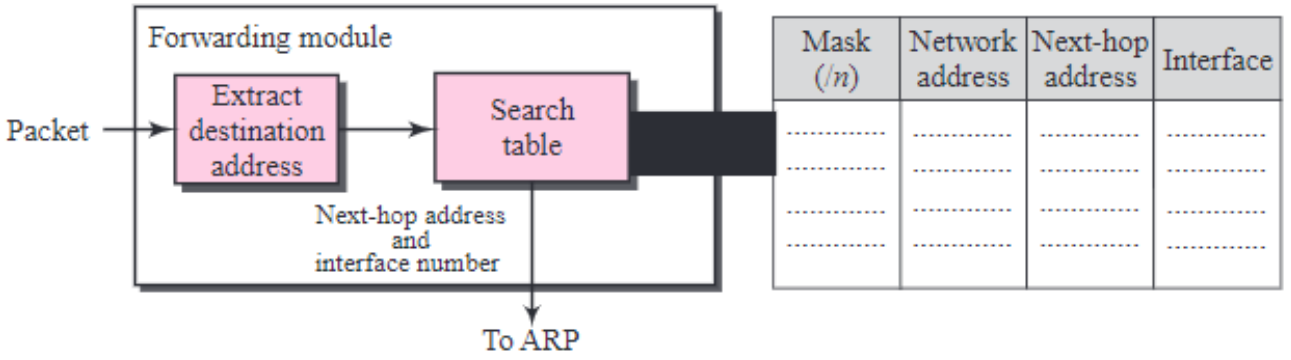
# Example

| Subnet address | Next-hop address | Interface number |
|---|---|---|
| 145.14.0.0 | ---------- | m0 |
| 145.14.64.0 | ---------- | m1 |
| 145.14.128.0 | ---------- | m2 |
| 145.14.192.0 | ---------- | m3 |
| 0.0.0.0 | default router | m4 |



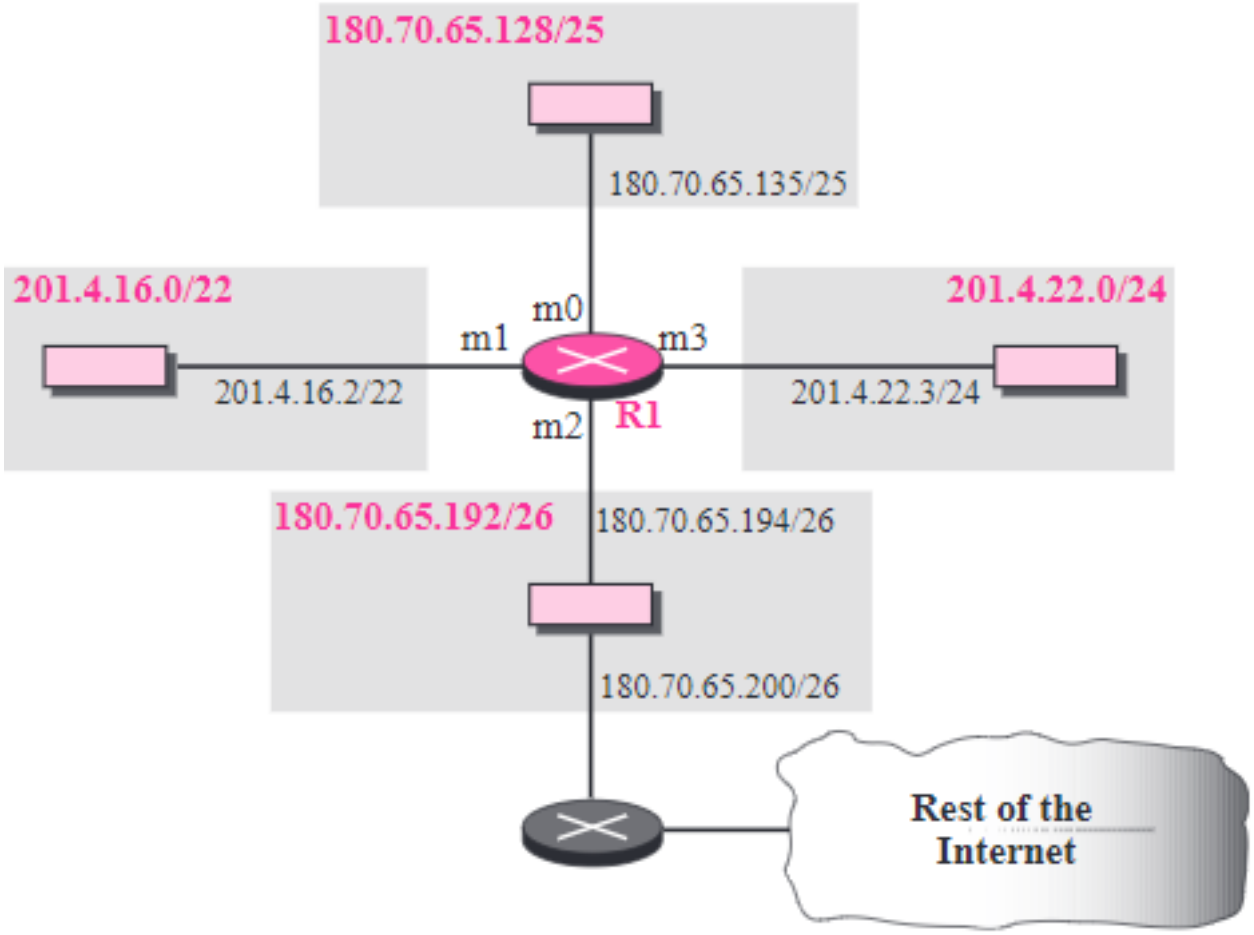
# Forwarding with Classless Addressing

- The routing table in classful addressing has 3 columns, for classless, we have one additional Mask (/n) column.

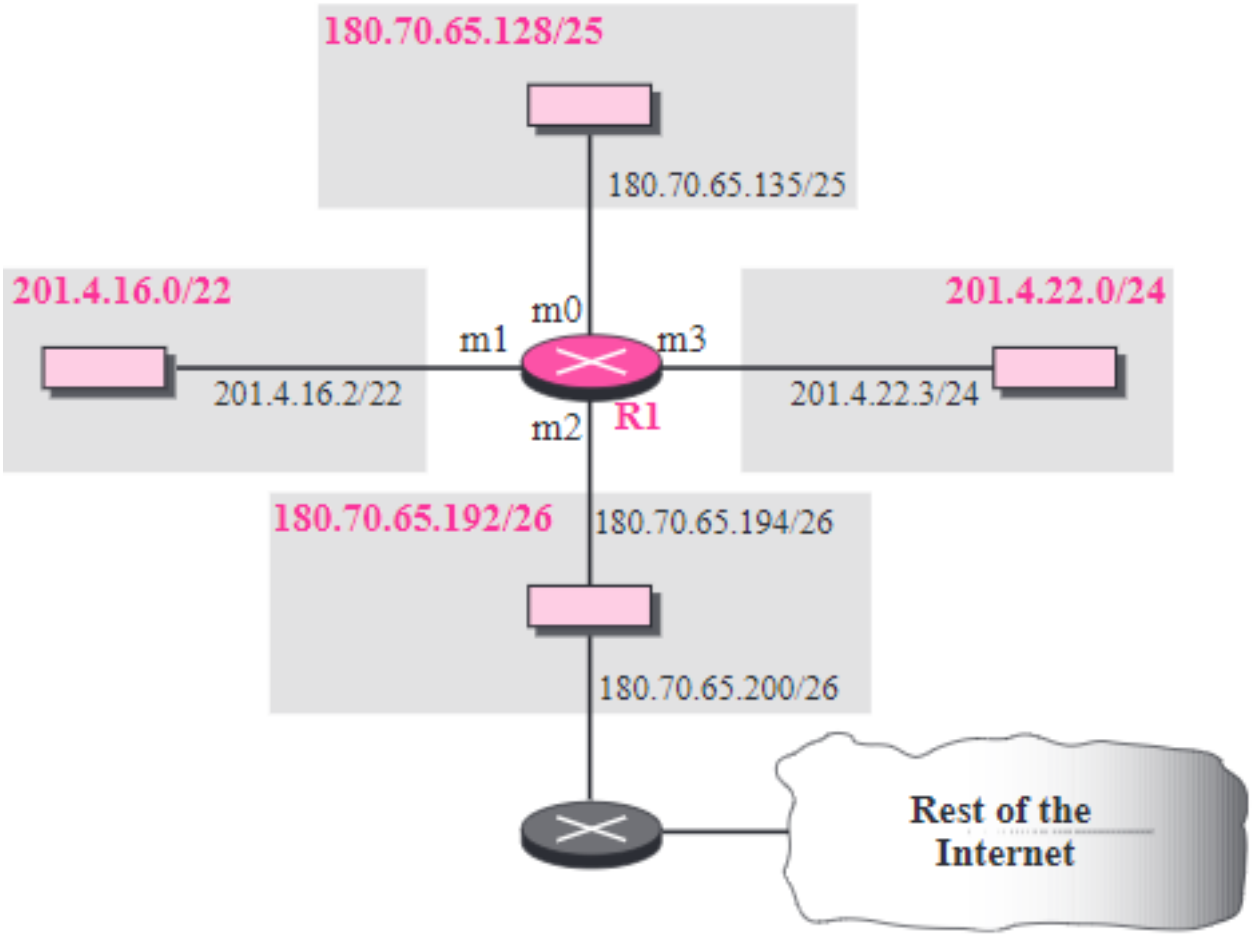


# Example

- Create the routing table for router R1 in figure?



Show the forwarding process if a packet arrives at R1 with the destination address 180.70.65.140



# Key Routing concepts

Routing metrics, Static vs Dynamic Routing, Routing protocol, Autonomous System, Convergences, Routing algorithms

# Routing metric/cost

- Path Length
- Reliability
- Routing Delay
- Bandwidth
- Load

# Static vs Dynamic Routing Table

A routing table can be either static or dynamic.

- A *static table* is one with manual entries.
- A *dynamic table* is one that is updated automatically when there is a change somewhere on the internet.

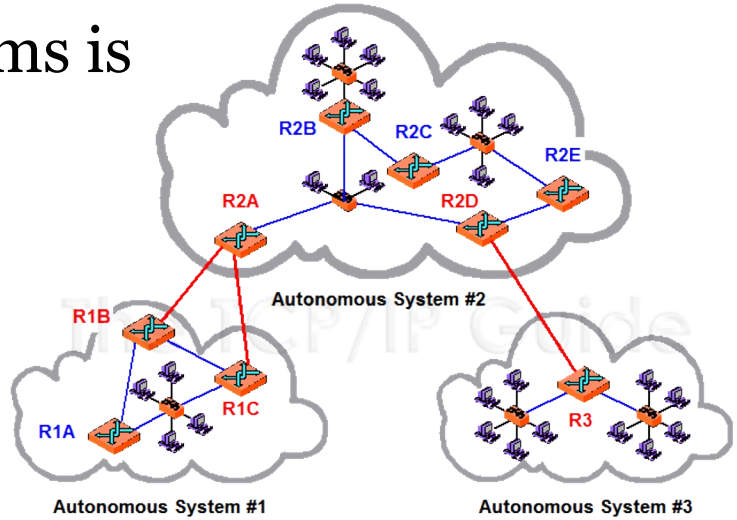
An internet needs dynamic routing tables. The tables need to be updated as soon as there is a change on the internet. For instance, they need to be updated when a link is down, and they need to be updated whenever a better route has been found.

# Routing Protocols

- Routing protocols have been created in response to the demand for dynamic routing tables.
- A routing protocol is a combination of rules and procedures that lets routers on the internet inform each other of changes. It allows routers to share whatever they know about the internet or their neighborhood.
- Routing protocols can be either an *interior protocol (intradomain)* or an *exterior protocol (interdomain)*.

# Autonomous System (AS)

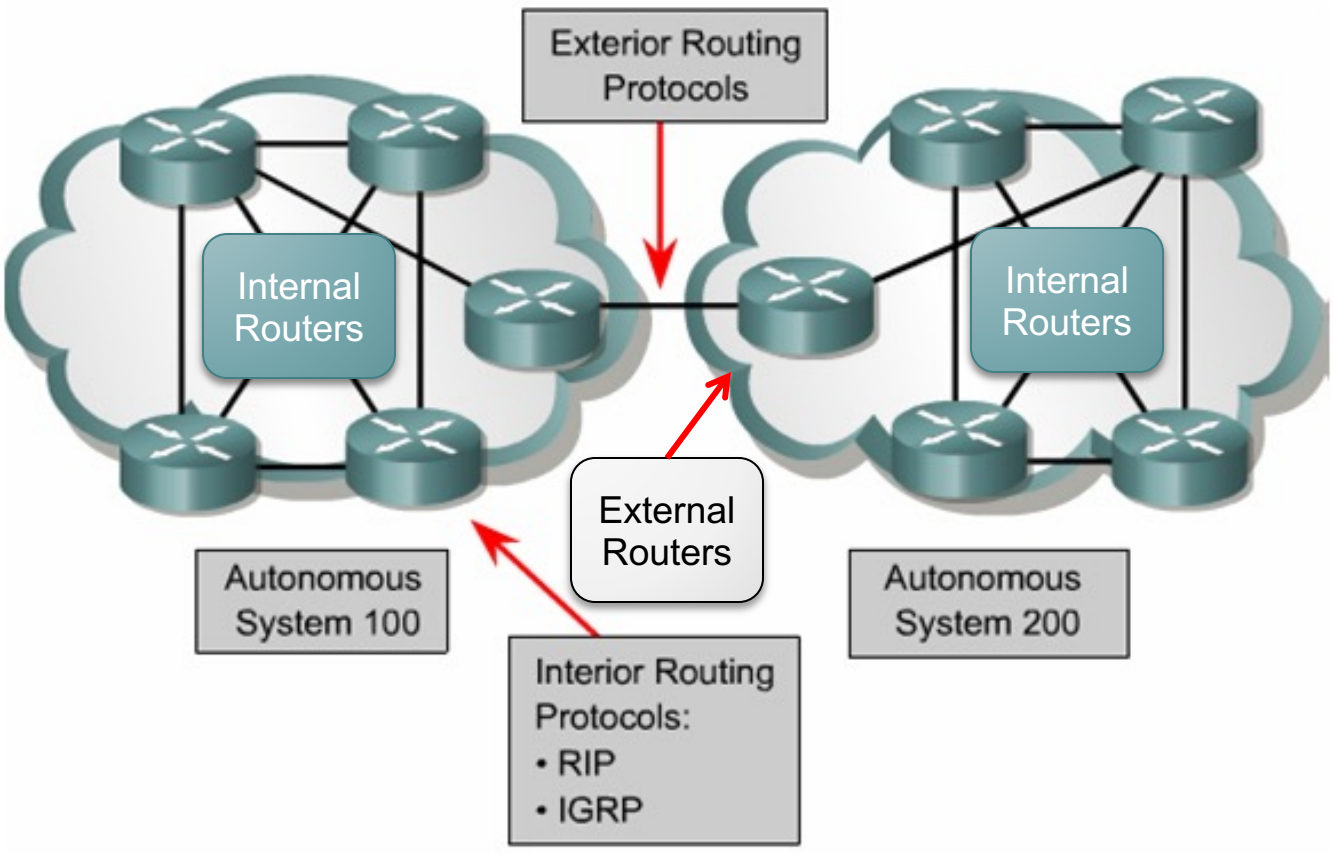
- An **autonomous system (AS)** is a group of networks and routers under the authority of a single administration.
- Routing inside an autonomous system is referred to as *intra-domain routing*. Routing between autonomous systems is referred to as *inter-domain routing*



# Interior and Exterior Gateway Protocols

- Routing protocols used within an autonomous system are called interior gateway protocols or intradomain protocols
- Routing protocols that route between autonomous systems are called exterior gateway protocols or interdomain protocols.

# Interior & Exterior Routing Protocols



# Convergence

- How much time a router takes to react to network topology changes.
- The convergence time varies depending on the routing algorithm. Fast convergence minimizes the chance of lost packets caused by inaccurate routing information.

# Routing Algorithms

- Routing algorithms determine how a router gathers and reports reachability information, how it deals with topology changes, and how it determines the optimal route to a destination.
- Can be classified as:
  - Static or Dynamic
  - Interior or Exterior

# Static Routes & Dynamic Routing Protocols

- Static routes are route tables that are manually configured, these routes do not change unless being reconfigured.
- Most routing protocols today use dynamic routing algorithms, which adjust to changing network circumstances by analyzing incoming routing update messages

# Distance Vector Protocols

- Distance vector algorithms define routes by distance (# of hops to the destination) and direction (for the next-hop router).
- Distance vector protocols use *distance vector* algorithms (Bellman-Ford algorithms): each router send all or some portion of its routing table to its neighbors. These routes are then broadcast to the directly connected neighbor routers. Each router uses these updates to verify and update the routing tables.

# Distance Vector Routing Protocols

There are four distance vector IPv4 IGPs:

- **RIPv1**: First generation legacy protocol
- **RIPv2**: Simple distance vector routing protocol
- **IGRP**: First generation Cisco proprietary protocol (obsolete and replaced by EIGRP)
- **EIGRP**: Advanced version of distance vector routing

# Link-State Protocols

- The *link-state* protocols, also known as shortest path first (SPF), share information with neighboring routers.
- Each router builds a link-state advertisement (LSA), which contains information about each link and directly connected neighbor router.

# Link-State Protocols

The *link-state* database stored in each router consists of parameters:

- Router id
- Neighor id
- Link cost
- Sequence # of the LSA
- Age of LSA entry

# Link-State Routing Protocols

Link-state protocols work best in situations where:

- The network design is hierarchical, usually occurring in large networks.
- Fast convergence of the network is crucial
- The administrators have good knowledge of the implemented link-state routing protocol

There are two link-state IPv4 IGPs:

- **OSPF**: Popular standards-based routing protocol
- **IS-IS**: Popular in provider networks

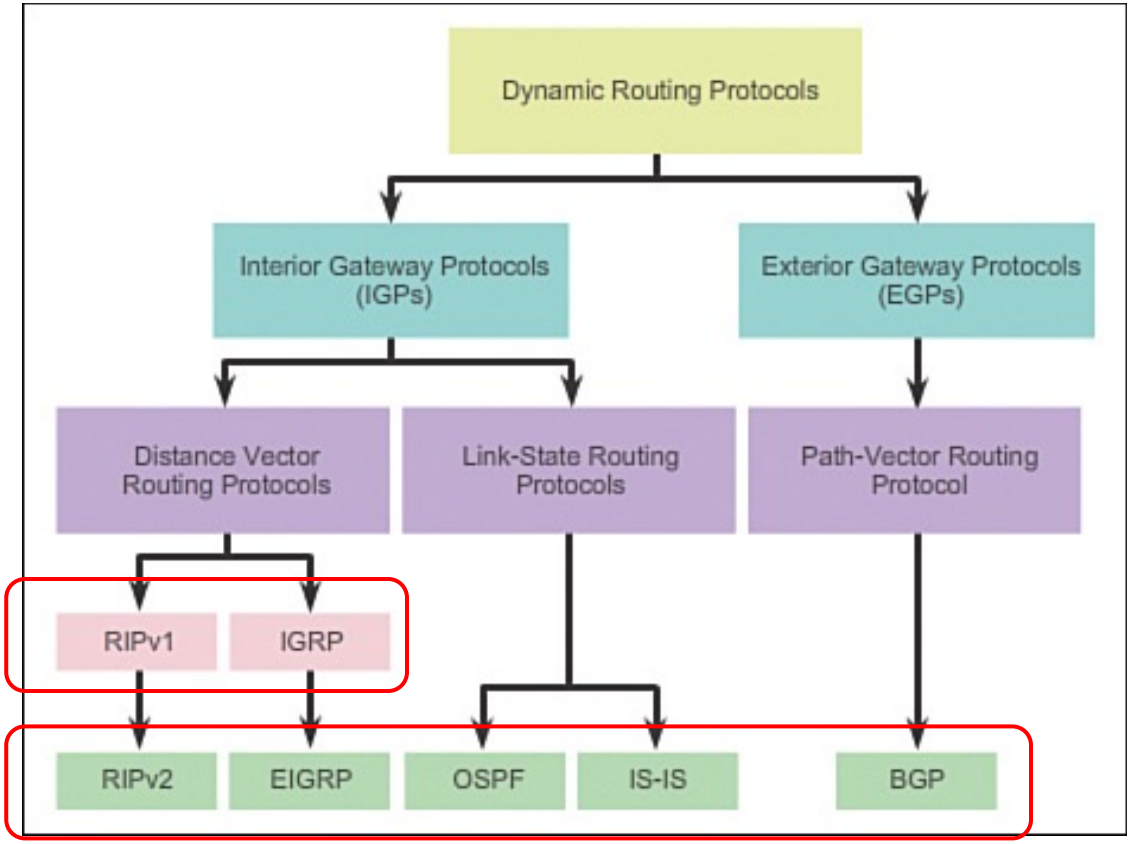
# Classifying routing protocols

By

- Purpose: IGPs, EGPs
- Operation: Distance vector, Link-State, Path-vector
- Behavior: Classful, classless

For example:

- **RIPv1 (legacy)**: IGP, distance vector, classful protocol
- **OSPF**: IGP, link-state, classless protocol



# Routing Protocols Characteristics

- **Speed of convergence**: how quickly the routers in the network topology share routing information and reach a state of consistent knowledge. The faster the convergence, the more preferable the protocol.
- **Scalability**: how large a network can become, based on the routing protocol that is deployed. The larger the network is, the more scalable the routing protocol needs to be.
- **Classful or classless**

# Routing Protocols Characteristics

- **Resource usage**: the requirements of a routing protocol such as memory space (RAM), CPU utilization, and link bandwidth utilization. Higher resource requirements necessitate more powerful hardware to support the routing protocol operation, in addition to the packet forwarding processes.
- **Implementation and maintenance**: the level of knowledge that is required for a network administrator to implement and maintain the network based on the routing protocol deployed.

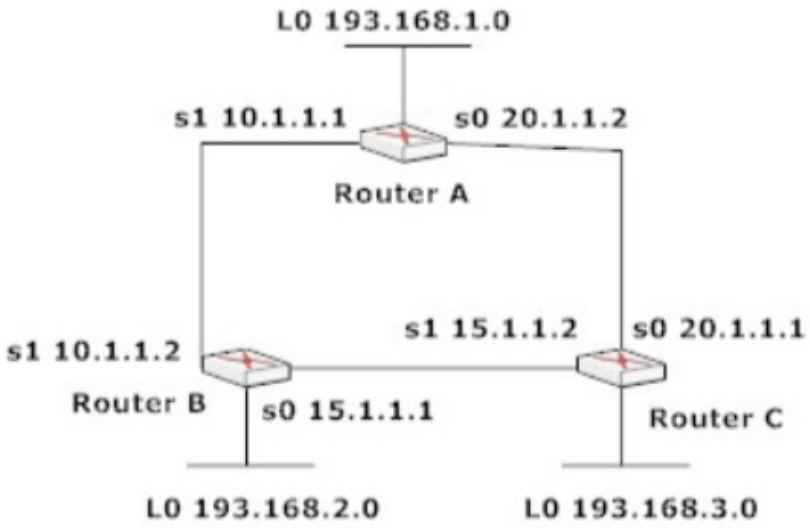
# Static routing lab

# Configuration

router# *configure terminal*
router(config)# *ip route <dest net> <mask> <gw>*
router# *show ip route*
Example:

- ip route 192.168.15.0 255.255.255.0 203.162.39.1

# Example




RouterA#configure terminal

RouterA(config)#ip route 15.0.0.0  255.0.0.0 10.1.1.2

RouterA(config)#ip route 193.168.2.0 255.255.255.0 10.1.1.2

RouterA(config)#ip route 193.168.3.0 255.255.255.0 20.1.1.2

RouterA(config)#exit

RouterA#