Chapter 1

Introduction to Routing and Packet Forwarding

Note for Instructors

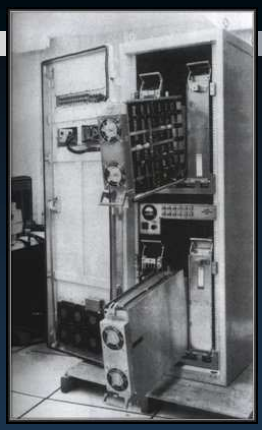
- These presentations are the result of a collaboration among the instructors at St. Clair College in Windsor, Ontario.
- Thanks must go out to Rick Graziani of Cabrillo College. His material and additional information was used as a reference in their creation.
- If anyone finds any errors or omissions, please let me know at:
  - tdame@stclaircollege.ca.

Introduction to Routing and Packet Forwarding

Inside the Router

2811 Router

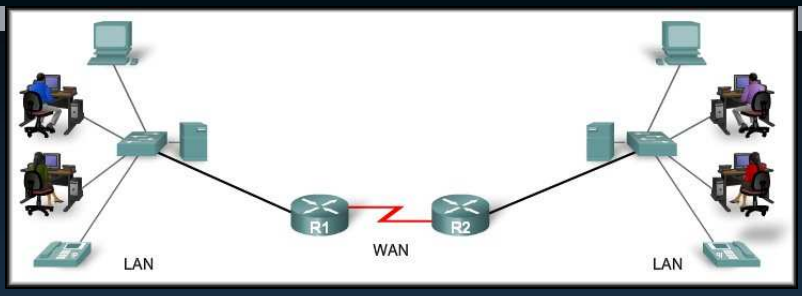
Routers are Computers



Leonard Kleinrock and the first IMP

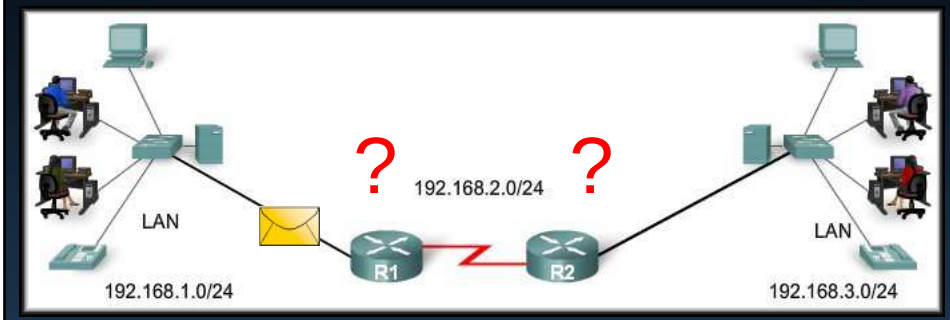
- CPU, RAM, ROM, Operating System
- Advanced Research Projects Agency Network (ARPANET):
  - First router: IMP (Interface Message Processor)
    - Honeywell 516 minicomputer that brought the ARPANET to life on August 30, 1969.

Routers are at the Network Centre



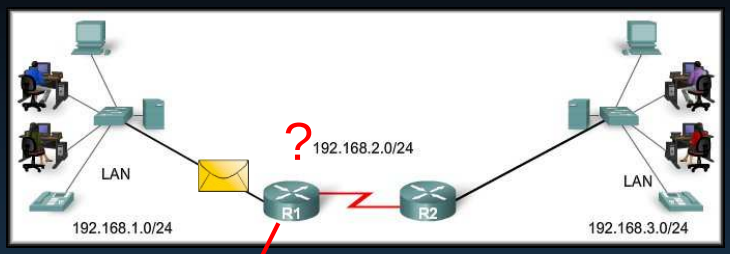
- Routers forward packets from the original source to the final destination.
- Connects multiple networks:
  - Separate interfaces on different IP networks (LAN, WAN)
    - The network of the final destination of the packet.
    - The destination IP address of this packet.
    - A network connected to another router.

Routers Determine the Best Path



- Router's Primary Responsibilities:
  - Determine the best path to send packets.
  - Forward the packets out the correct interface.

Routers Determine the Best Path




```
R1#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
       * - candidate default, U - per-user static route, o - ODR
       P - periodic downloaded static route

Gateway of last resort is not set

C    192.168.1.0/24 is directly connected, FastEthernet0/0
C    192.168.2.0/24 is directly connected, Serial0/0/0
S    192.168.3.0/24 [1/0] via 192.168.2.2
R1#
```

The routing table is a map used to determine the best path.

Routers Determine the Best Path

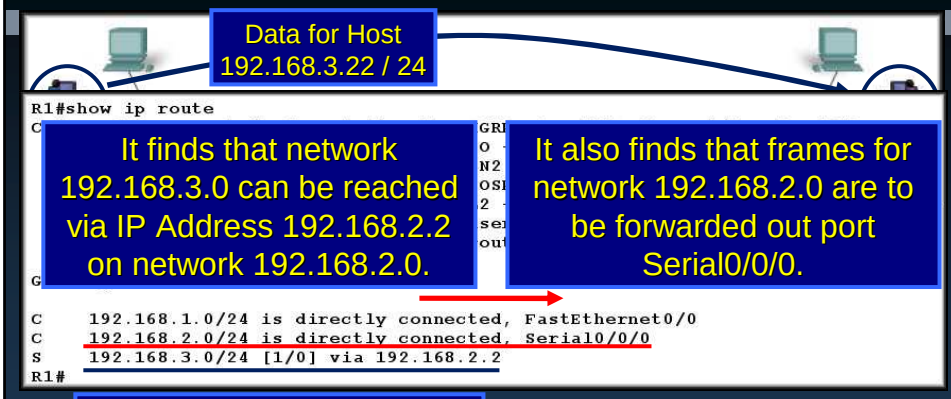
Data for Host 192.168.3.22 / 24

```
C:\WINDOWS\system32\cmd.exe

C:\>route print
===========================================================================
Interface List
0x1 ........................... MS TCP Loopback interface
0x2 ...00 1d 09 d9 d9 ac ...... Broadcom NetXtreme 57xx Gigabit Controller - Packet Scheduler Miniport
===========================================================================
===========================================================================
Active Routes:
Network Destination        Netmask          Gateway       Interface  Metric
          0.0.0.0          0.0.0.0      192.168.1.1   192.168.1.101      20
        127.0.0.0        255.0.0.0        127.0.0.1     127.0.0.1        1
      192.168.1.0    255.255.255.0    192.168.1.101   192.168.1.101      20
    192.168.1.101  255.255.255.255        127.0.0.1     127.0.0.1      20
    192.168.1.255  255.255.255.255    192.168.1.101   192.168.1.101      20
        224.0.0.0        240.0.0.0    192.168.1.101   192.168.1.101      20
  255.255.255.255  255.255.255.255    192.168.1.101   192.168.1.101      1
Default Gateway:       192.168.1.1
===========================================================================
Persistent Routes:
  None

C:\>
```

The host determines that the destination network is different from its network.

The frame is sent to the default gateway (R1).

Routers Determine the Best Path



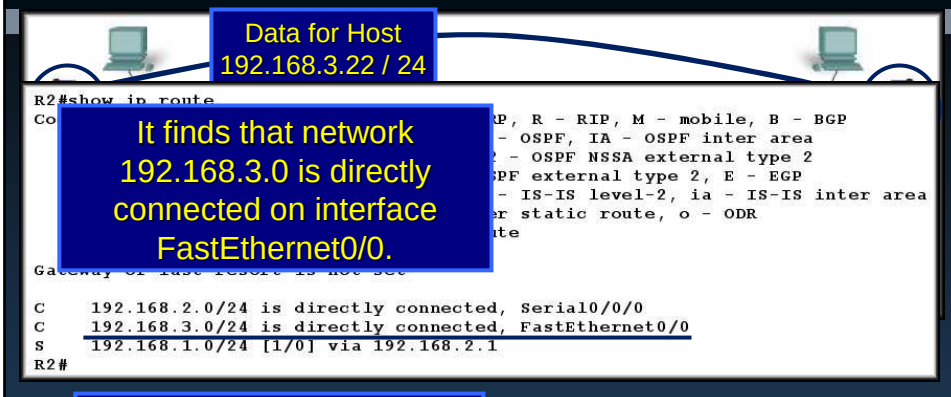
It finds that network 192.168.3.0 can be reached via IP Address 192.168.2.2 on network 192.168.2.0.

It also finds that frames for network 192.168.2.0 are to be forwarded out port Serial0/0/0.

The router decapsulates the frame and uses the destination IP Address to find the destination network in the routing table.

The frame is encapsulated and forwarded out port Serial0/0/0.

Routers Determine the Best Path



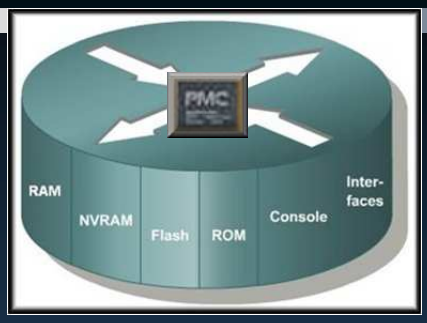
It finds that network 192.168.3.0 is directly connected on interface FastEthernet0/0.

The router decapsulates the frame and uses the destination IP Address to find the destination network in the routing table.

The frame is encapsulated and forwarded out port FastEthernet0/0.

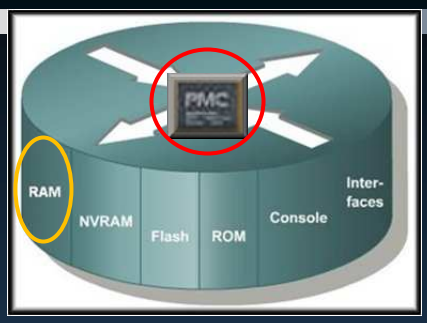
Router CPU and Memory

- Main internal Components:
  - Central Processing Unit (CPU)
  - Random Access Memory (RAM)
  - Read Only Memory (ROM)
  - Flash Memory (Flash)
  - Nonvolatile Random Access Memory (NVRAM)
  - Interfaces



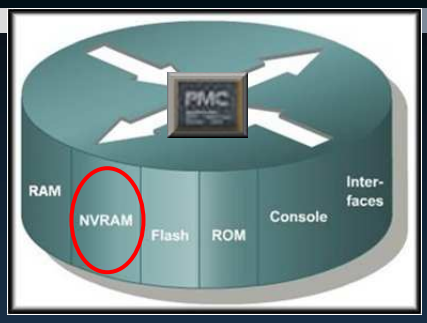
Router CPU and Memory

- Central Processing Unit (CPU)
  - Executes the Cisco IOS operating instructions.
- Random Access Memory (RAM)
  - Stores routing tables.
  - Holds ARP cache.
  - Holds fast-switching cache.
  - Performs packet buffering.
  - Provides temporary memory for the running configuration file of a router while the router is powered on.
  - Loses content when a router is powered down or restarted.



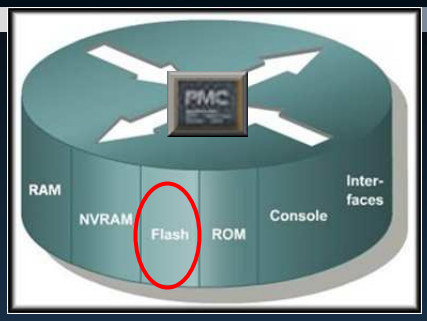
Router CPU and Memory

- Nonvolatile Random Access Memory (NVRAM)
  - Provides storage for the startup configuration file.
  - Retains content when a router is powered down or restarted.



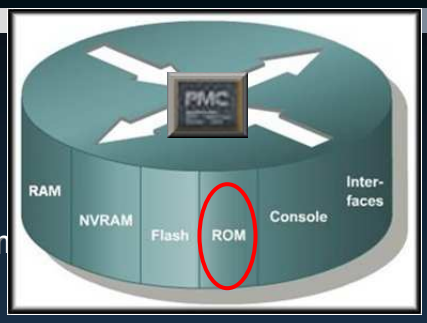
Router CPU and Memory

- Flash Memory (Flash)
  - Holds the IOS image.
  - Allows software to be updated without removing and replacing chips on the processor.
  - Retains content when a router is powered down or restarted.
  - Can store multiple versions of IOS software.
  - Consists of SIMM or PCMCIA cards.



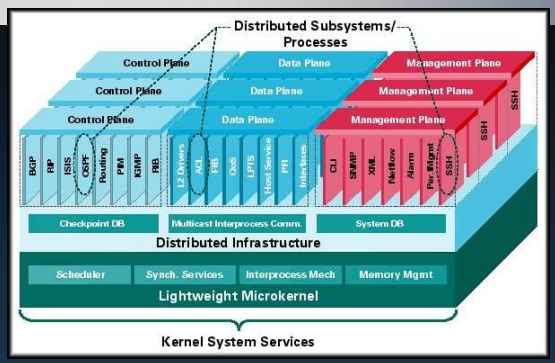
Router CPU and Memory

- Read Only Memory (ROM)
  - Maintains instructions for power-on self test (POST) diagnostics.
  - Stores the bootstrap program and the basic operating system software.
  - Requires replacing pluggable chips on the motherboard for software upgrades.



Internetwork Operating System (IOS)

- Responsible for managing the hardware and software resources of the router.
  - Allocating memory.
  - Managing the file system and processes.
  - Security.
- There are many different IOS images.
  - An IOS image is a file residing on flash that contains the entire IOS for that router.
  - The image itself will vary depending on the model and the features within the IOS.



Router Bootup Process

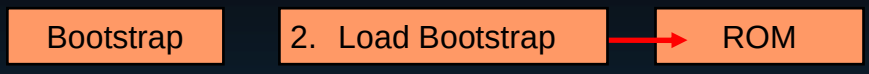
- Four Basic Tasks:
  - POST
  - Bootstrap
  - Cisco IOS
  - Configuration

Router Bootup Process

POST | 1. Perform POST → ROM

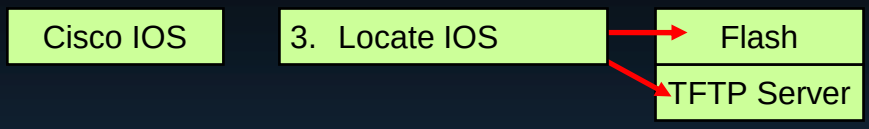
- Step 1: Performing the POST (Power On Self Test)
  - Executes diagnostics from ROM on several hardware components (CPU,RAM, NVRAM).
  - After the POST is successful, the router executes the bootstrap program.

Router Bootup Process



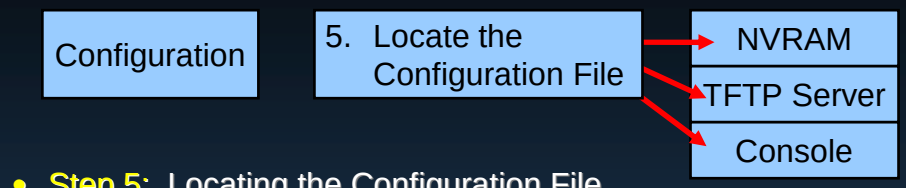
- **Step 2:** Loading the Bootstrap Program
  - The program is copied from ROM into RAM.
  - Executed by CPU.
  - Its main task is to locate the Cisco IOS and load it into RAM.

Router Bootup Process



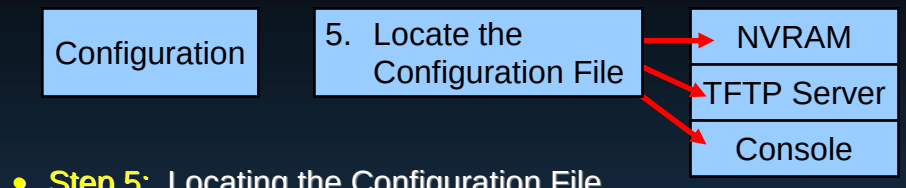
- **Step 3:** Locating Cisco IOS
  - Typically stored in **flash memory**, but it can be stored in other places such as a **TFTP server**.
    - *If a full IOS image cannot be located, a scaled-down version of the IOS is copied from ROM.*
      - This version of IOS is used to help diagnose any problems and to try to load a complete version of the IOS into RAM.
- **Step 4:** Load Cisco IOS
  - Copy the IOS into RAM for execution.

Router Bootup Process



- Step 5: Locating the Configuration File
  - The bootstrap program searches for the previously saved configuration commands (startup configuration file), in NVRAM.
  - If there is no startup configuration, the program searches for a TFTP server.
  - If a TFTP server cannot be found, the router will accept input from the Console.

Router Bootup Process *(FYI)*



- Step 5: Locating the Configuration File
  - If you boot a router that has no start-up configuration file and the WAN links are connected, the router will broadcast out the WAN interface looking for a TFTP server (SLARP).

```
%Error opening tftp://255.255.255.255/network-config
                                              (Timed out)
```

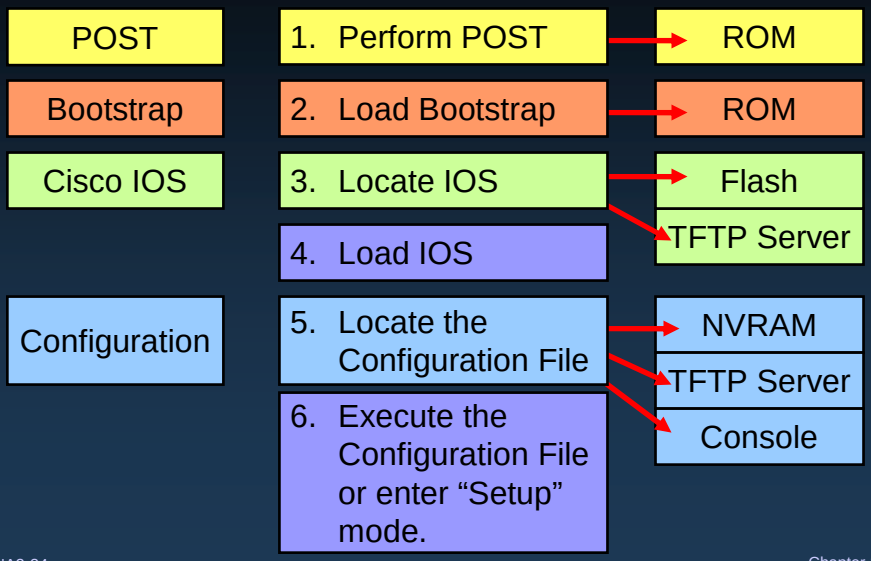
  - To avoid the long delays, make sure that any WAN interfaces are disconnected until you save a start-up configuration.

Router Bootup Process

6. Execute the Configuration File or enter “Setup” mode.

- **Step 6:** Loading the Startup Configuration or Entering Setup Mode.
  - **If a startup configuration file is found in NVRAM**, the IOS loads it into RAM as the running-config file and executes the commands.
  - **If the startup configuration file cannot be located**, the IOS prompts the user to enter setup mode.
  - **If setup mode not used**, a default running-config file is created and input accepted from the console.

Router Bootup Process



Verifying the Router Bootup Process

- The **show version** command is used to view information

```
Router#show version
Cisco Internetwork Operating System Software
IOS (tm) C2600 Software (C2600-I-M), Version 12.2(28), RELEASE SOFTWARE (fc5)

Technical Support: http://www.cisco.com/techsupport
Copyright (c) 1986-2005 by cisco Systems, Inc.
Compiled Wed 27-Apr-04 19:01 by miwang
Image text-base: 0x8000808C, data-base: 0x80A1FECC
ROM: System Bootstrap, Version 12.1(3r)T2, RELEASE SOFTWARE (fc1)

CDATA[Copyright (c) 2000 by cisco Systems, Inc.
ROM: C2600 Software (C2600-I-M), Version 12.2(28), RELEASE SOFTWARE (fc5)
System returned to ROM by reload
System image file is "flash:c2600-i-mz.122-28.bin"
cisco 2621 (MPC860) processor (revision 0x200) with 60416K/5120K bytes of memory.
Processor board ID JAD05190MTZ (4292891495)
M860 processor: part number 0, mask 49
Bridging software.
X.25 software, Version 3.0.0.
2 FastEthernet/IEEE 802.3 interface(s)
2 Low-speed serial(sync/async) network interface(s)
32K bytes of non-volatile configuration memory.
16384K bytes of processor board System flash (Read/Write)

Configuration register is 0x2102
Router#
```

IOS Version

Bootstrap Version

Model and CPU

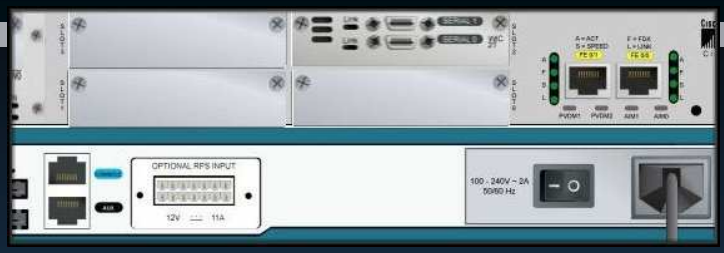
Amount of RAM

Number and type of Interfaces

Amount of NVRAM

Amount of Flash

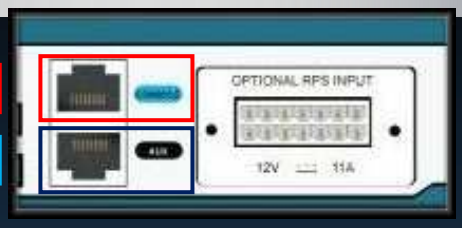
Router Interfaces



- **Port:**
  - Normally means one of the management ports used for administrative access.
- **Interface:**
  - Normally refers to interfaces that are capable of sending and receiving user traffic.

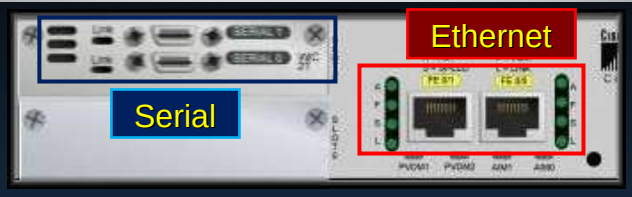
However, these terms are often used interchangeably in the industry and even with IOS output.

Router Interfaces



- **Console Port:**
  - Used to connect a terminal or most likely a PC running terminal emulator software,
  - Must be used during initial configuration of the router.
- **Auxiliary (AUX) Port:**
  - Not all routers have auxiliary ports.
  - At times, can be used similarly to a console port and can also be used to attach a modem.

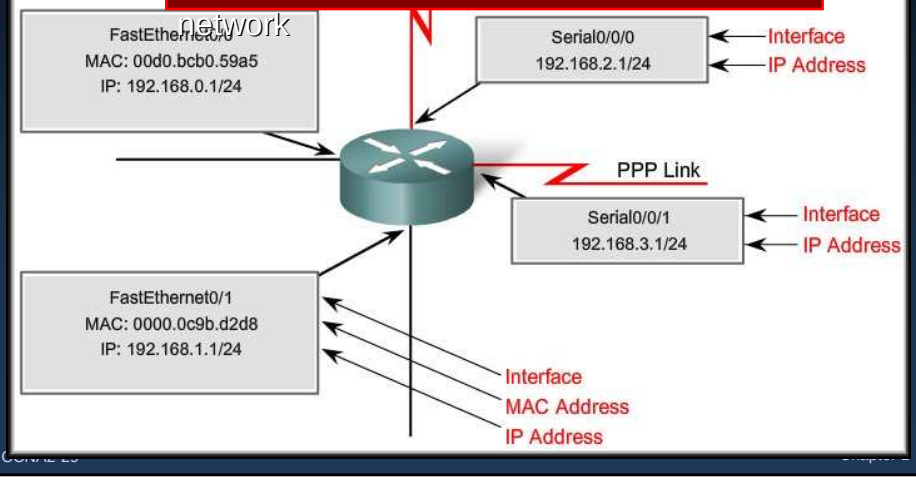
Router Interfaces



- An **interface** on Cisco routers refers to a **physical connector** on the router whose main purpose is to receive and forward packets.
- Routers have multiple interfaces used to connect to multiple networks.
  - Various types of networks.
  - Different types of media and connectors.
  - Different types of interfaces.

Router Interfaces

Every Interface on a router:
- Belongs to a different network
- Is a host on a different network
- Has an IP address on a different network



Interfaces Belonging to Different Networks

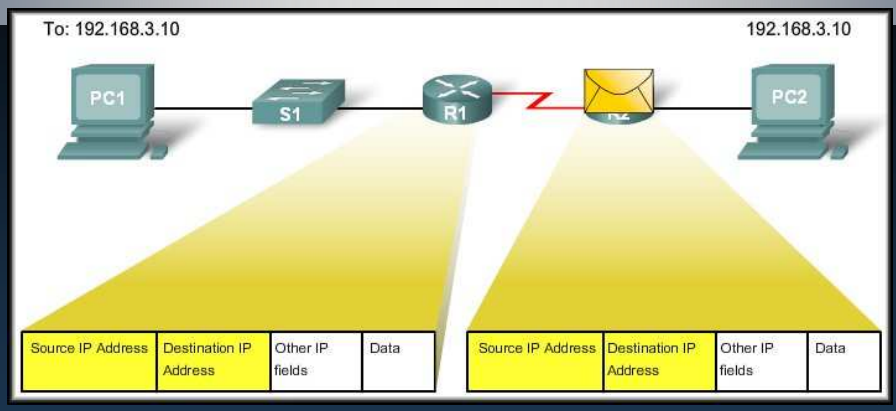
- LAN Interfaces:
  - Ethernet
  - Fast Ethernet
- Used to connect the router to the LAN.
  - Similar to the connection to a PC's Ethernet NIC.
    - Layer 2 MAC address
    - Participates in the Ethernet LAN like any other host.
  - Typically an RJ-45 jack (UTP).
    - Router to Switch: straight-through cable.
    - Router to Router: cross-over cable.
    - PC to Router: cross-over cable.

Interfaces Belonging to Different Networks

- WAN Interfaces:
  - Serial
  - ISDN
  - Frame Relay
- Used to connect routers to external networks, usually over a larger geographical distance.
  - The Layer 2 encapsulation can be different types (PPP, Frame Relay, HDLC).
- Similar to LAN interfaces, each WAN interface has its own IP address and subnet mask, making it a member of a specific network.

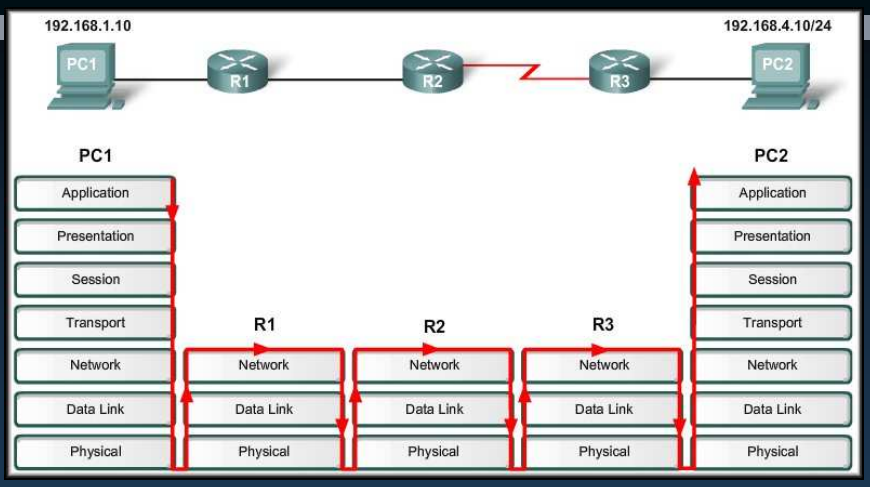
MAC addresses are used only on Ethernet interfaces and are not on WAN interfaces.

Routers and The Network Layer



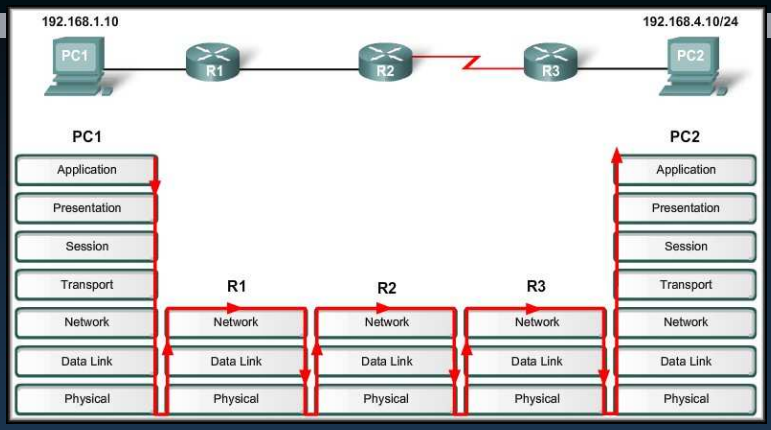
- A router is considered a **Layer 3 device** because its primary forwarding decision is based on the information in the Layer 3 IP packet, specifically the destination IP address.
- This is known as **routing**.

Routers Operate at Layers 1, 2 and 3



- A router makes its primary forwarding decision at Layer 3.
- It also participates in Layer 1 and Layer 2 processes.

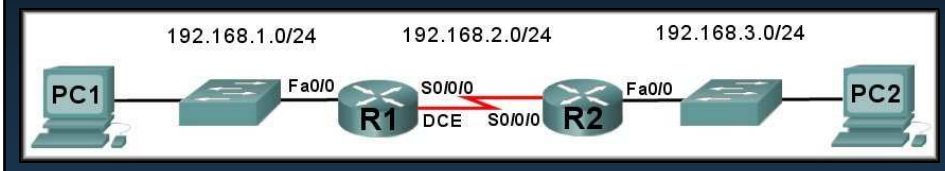
Routers Operate at Layers 1, 2 and 3



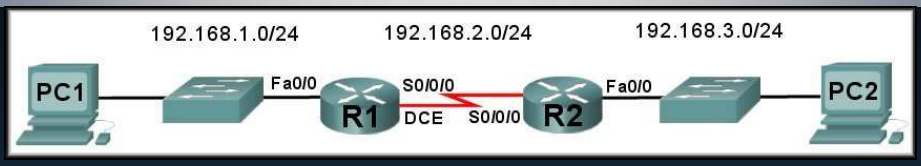
- Encapsulates the **Layer 3 IP packet into the data portion** of a Layer 2 data-link frame appropriate for the exit interface.
- The Layer 2 frame will then be **encoded into the Layer 1** physical signals.

Introduction to Routing and Packet Forwarding

CLI Configuration and Addressing



Populating an Address Table

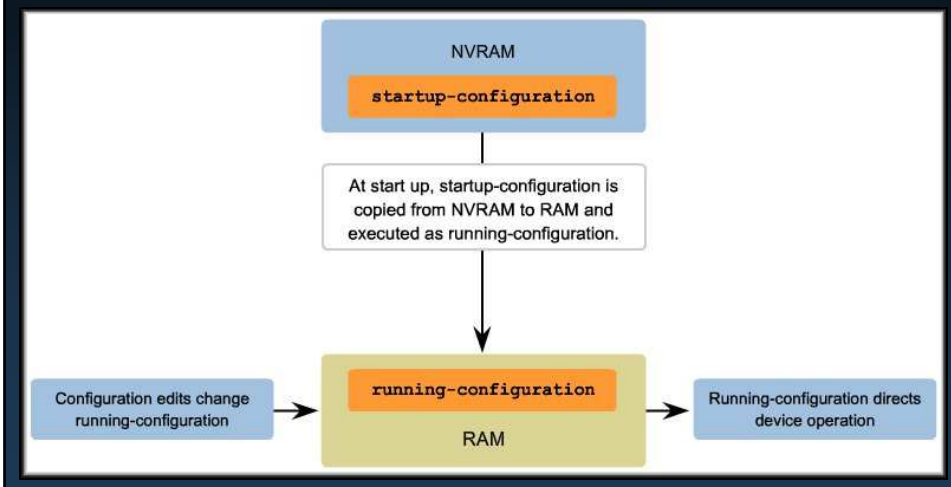


Device	Interface	IP Address	Subnet Mask	Default Gateway
R1	Fa0/0			
	S0/0/0			
R2	Fa0/0			
	S0/0/0			
PC1	N/A			
PC2	N/A			

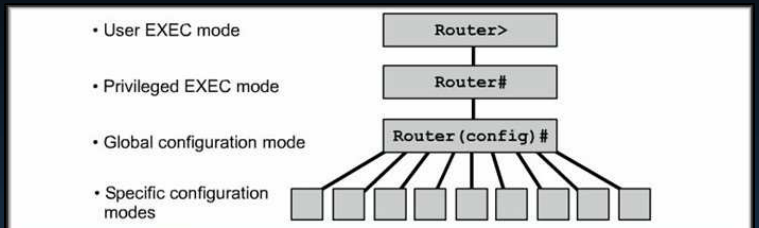
Basic Router Configuration

- When configuring a router, begin with performing certain **basic tasks**.
  - Naming the router.
  - Setting passwords.
  - Configuring a banner.
  - Configuring interfaces.
  - Verifying basic configuration and router operations.
  - Saving changes on a router.

Basic Router Configuration



Basic Router Configuration



Configuration Mode	Prompt
Interface	`Router(config-if)#`
Subinterface	`Router(config-subif)#`
Controller	`Router(config-controller)#`
Map-list	`Router(config-map-list)#`
Map-class	`Router(config-map-class)#`
Line	`Router(config-line)#`
Router	`Router(config-router)#`
IPX-router	`Router(config-ipx-router)#`
Route-map	`Router(config-route-map)#`

Basic Router Configuration

- User and Privileged Modes:

```
Router>                          user mode
Router> enable
Router#                          privilege mode
Router# configure terminal
Router(config)# exit
Router# config t
```

- Configure Host Name:

```
Router(config)# hostname [name]
```

Basic Router Configuration

- Configure Passwords:

Privilege password:

```
Router(config)# enable secret [password]
```

Console password:

```
Router(config)# line console 0
Router(config-line)# password [password]
Router(config-line)# login
```

Telnet password:

```
Router(config)# line vty 0 4
Router(config-line)# password [password]
Router(config-line)# login
```


Basic Router Configuration

- Configure Banner Message of the Day:

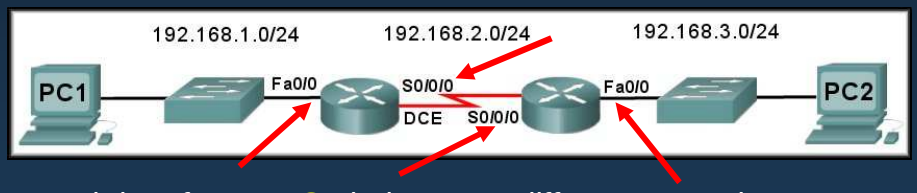
```
Router(config)# banner motd [# message #]
```

  - In the real world, probably a good idea.
    - Scheduled down time, etc.
  - In the lab, not necessary unless specifically instructed to do so.

Basic Router Configuration

- Configure Interfaces:

```
Router(config)# interface [type][number]
Router(config-if)# ip address [address] [mask]
Router(config-if)# description [description]
Router(config-if)# no shutdown
```



- Each interface MUST belong to a different network.

Basic Router Configuration

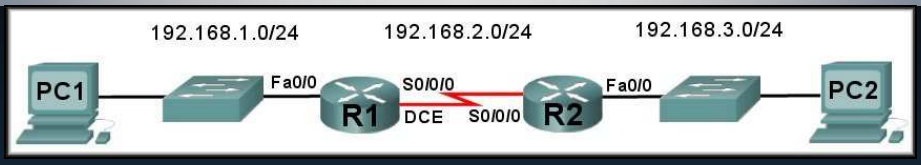
- Verifying the Configuration:

```
Router# show running-config
Router# show ip route
Router# show ip interface brief
Router# show interfaces
```

- Saving the Configuration:

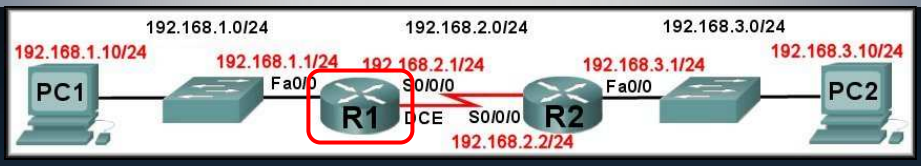
```
Router# copy running-config startup-config
```

Basic Router Configuration



Device	Interface	IP Address	Subnet Mask	Default Gateway
R1	Fa0/0	192.168.1.1	255.255.255.0	N/A
	S0/0/0	192.168.2.1	255.255.255.0	N/A
R2	Fa0/0	192.168.3.1	255.255.255.0	N/A
	S0/0/0	192.168.2.2	255.255.255.0	N/A
PC1	N/A	192.168.1.10	255.255.255.0	192.168.1.1
PC2	N/A	192.168.3.10	255.255.255.0	192.168.3.1

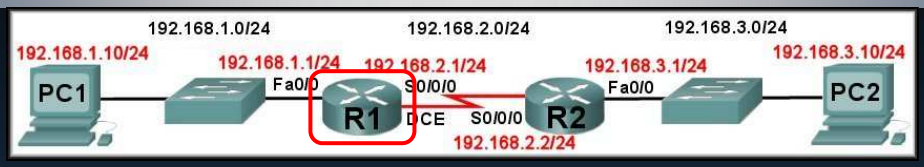
Basic Router Configuration – R1



- Configure Host Name:

```
Router>
Router>enable
Router#
Router#configure terminal
Router(config)#hostname R1
R1(config#)
```

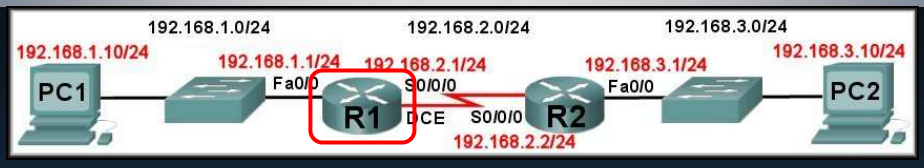
Basic Router Configuration – R1



- Configure Privilege Password:

```
R1(config#)enable secret class
```

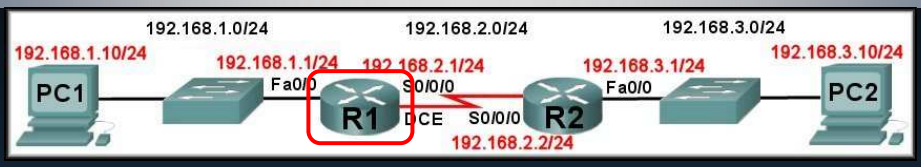

Basic Router Configuration – R1



- Configure Passwords:

```
R1(config)#line console 0
R1(config-line)#password cisco
R1(config-line)#login
R1(config)#line vty 0 4
R1(config-line)#password cisco
R1(config-line)#login
R1(config-line)#exit
```

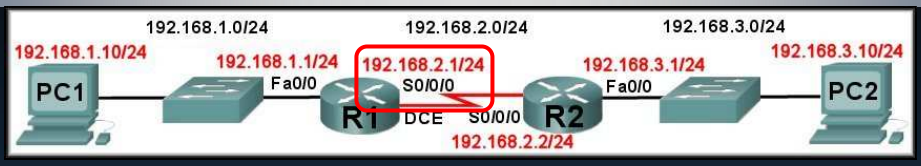
Basic Router Configuration – R1



- Configure Banner Message of the Day:
  - Enter a text message. End with the character '#'.

```
R1(config)#banner motd #
**********************************************
WARNING!! Unauthorized Access Prohibited!!
**********************************************
#
R1(config)#
```

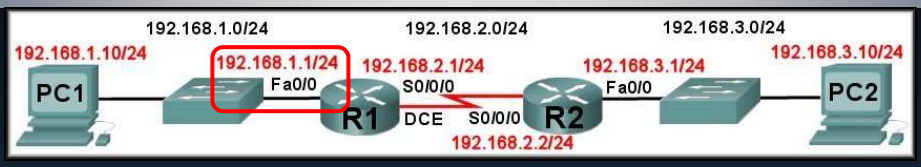

Basic Router Configuration – R1



- WAN Interface Configuration:

```
R1(config)#interface Serial0/0/0
R1(config-if)#ip address 192.168.2.1
                         255.255.255.0
R1(config-if)#description Link to R2
R1(config-if)#clockrate 64000     (DCE Only)
R1(config-if)#no shutdown
```

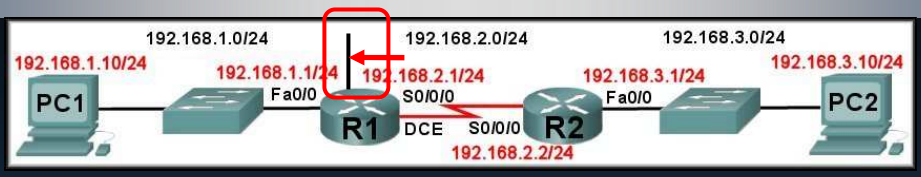
Basic Router Configuration – R1



- LAN Interface Configuration:

```
R1(config)#interface FastEthernet0/0
R1(config-if)#ip address 192.168.1.1
                         255.255.255.0
R1(config-if)#description R1 LAN
R1(config-if)#no shutdown
```

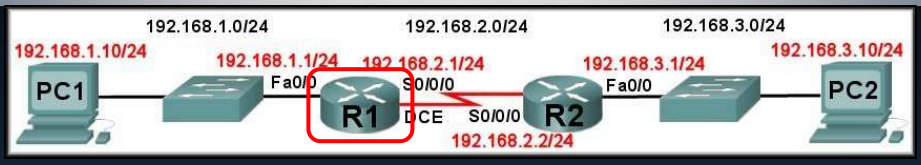

Basic Router Configuration – R1



- Each Interface Belongs to a Separate Network:

```
R1(config)#interface FastEthernet0/1
R1(config-if)#ip address 192.168.1.2
                         255.255.255.0
192.168.1.0 overlaps with FastEthernet0/0
R1(config-if)#no shutdown
192.168.1.0 overlaps with FastEthernet0/0
FastEthernet0/1: incorrect IP address
                         assignment
```

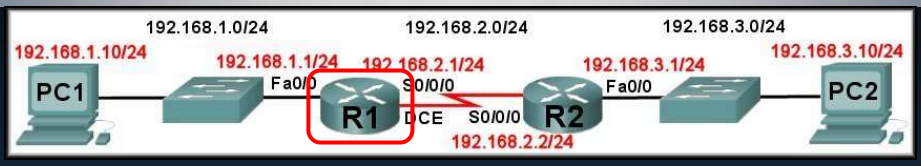
Basic Router Configuration – R1



- Verifying Basic Router Configuration:

```
R1#show running-config
!
version 12.3
!
hostname R1
!
interface FastEthernet0/0
description R1 LAN
ip address 192.168.1.1 255.255.255.0
!
interface Serial0/0
```

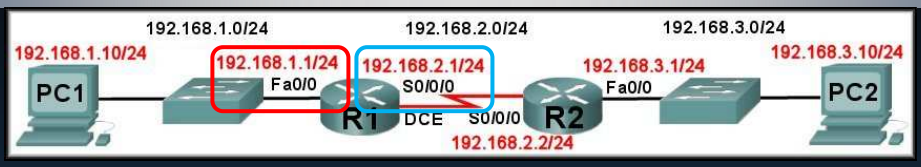

Basic Router Configuration – R1



- Saving the Configuration:

```
R1#copy running-config startup-config
R1#show startup-config
!
version 12.3
!
hostname R1
!
interface FastEthernet0/0
description R1 LAN
ip address 192.168.1.1 255.255.255.0
!
```

Basic Router Configuration – R1



- Show the Routing Table:

```
R1# show ip route
Codes: C - connected, S - static
            .
            .          (Output Omitted)
            .
Gateway of last resort is not set

C    192.168.1.0/24 is directly connected,
FastEthernet0/0
C    192.168.2.0/24 is directly connected,
                                    Serial0/0/0
```


Introduction to Routing and Packet Forwarding

Building the Routing Table

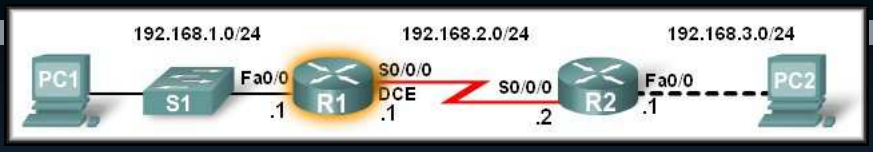
```
R1# show ip route

Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
* - candidate default, U - per-user static route, o - ODR
P - periodic downloaded static route

Gateway of last resort is not set

C    192.168.1.0/24 is directly connected, FastEthernet0/0
C    192.168.2.0/24 is directly connected, Serial0/0/0
```

Introducing the Routing Table

```
R1# show ip route

Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
* - candidate default, U - per-user static route, o - ODR
P - periodic downloaded static route

Gateway of last resort is not set

C    192.168.1.0/24 is directly connected, FastEthernet0/0
C    192.168.2.0/24 is directly connected, Serial0/0/0
```

- The routing table is a data file in RAM that is used to store route information about:
  - Directly connected networks
  - Remote networks

Introducing the Routing Table



- A directly connected network is a network that is directly attached to one of the router interfaces.
- When activated, it is added to the routing table.

```
R1# show ip route

Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
* - candidate default, U - per-user static route, o - ODR
P - periodic downloaded static route

Gateway of last resort is not set

C    192.168.1.0/24 is directly connected, FastEthernet0/0
C    192.168.2.0/24 is directly connected, Serial0/0/0
```

Directly Connected Networks


```
R1# show ip route

Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
* - candidate default, U - per-user static route, o - ODR
P - periodic downloaded static route

Gateway of last resort is not set

C    192.168.1.0/24 is directly connected, FastEthernet0/0
C    192.168.2.0/24 is directly connected, Serial0/0/0
```

Codes:
Indicate how the route was learned.

Directly Connected Networks


```
R1# show ip route

Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
D - EIGRP, EX -                                   OSPF inter area
N1 - OSPF NSSA                                    external type 2
E1 - OSPF exter                                   type 2, E - EGP
                L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
                date default, U - per-user static route, o
P - periodic downloaded static route

Gateway of last resort is not set

C    192.168.1.0/24 is directly connected, FastEthernet0/0
C    192.168.2.0/24 is directly connected, Serial0/0/0
```

Network Address and Subnet Mask

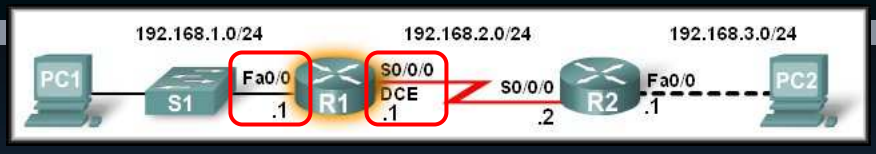
Code

Exit Interface

Directly Connected Networks

- A **remote network** is a network that is not directly connected to a router.
  - Remote networks are added to the routing table using two methods:
    - **Dynamic Routing Protocols:**
      - Routes to remote networks that were learned automatically by the router.
    - **Static Routes:**
      - Routes manually configured.
  - *Either or both methods can be used in the same router.*

Directly Connected Networks



- **Before any static or dynamic routing** is configured:
  - The router only knows about its own **directly connected networks.**
  - **Static and dynamic routes cannot exist** in the routing table without first configuring a router's own directly connected networks.
  - **The router cannot send packets out an interface** unless that interface is enabled with an IP address and subnet mask.

Static Routing

```
R1# show ip route

Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
<output omitted>

Gateway of last resort is not set

C   192.168.1.0/24 is directly connected, FastEthernet0/0
C   192.168.2.0/24 is directly connected, Serial0/0/0
S   192.168.3.0/24 [1/0] via 192.168.2.2
```

- A **static route** is defined using the:
  - Network address and subnet mask of the remote network.
  - The IP address of the next-hop router.
- Static routes are denoted with the code **S** in the routing table.

Static routes are examined in detail in the next chapter.

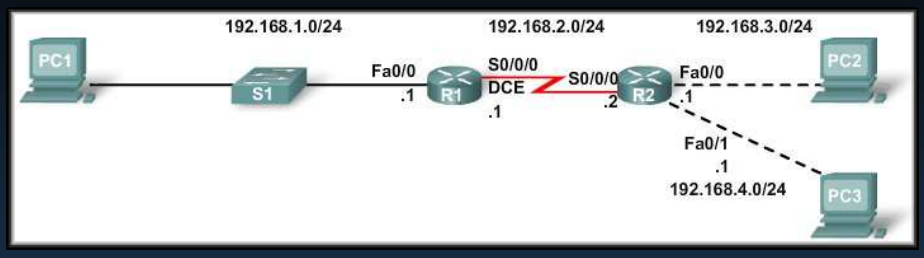
Dynamic Routing

```
R1# show ip route

Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
* - candidate default, U - per-user static route, o - ODR
P - periodic downloaded static route

Gateway of last resort is not set

C 192.168.1.0/24 is directly connected, FastEthernet0/0
C 192.168.2.0/24 is directly connected, Serial0/0/0
S 192.168.3.0/24 [1/0] via 192.168.2.2
R 192.168.4.0/24 [120/1] via 192.168.2.2, 00:00:20, Serial0/0/0
```

- R1 has automatically learned about the 192.168.4.0/24 network from R2 through the dynamic routing protocol RIP **(Routing Information Protocol)**.

RIP will be fully discussed in later chapters.

Dynamic Routing



- Dynamic routing means:
  - Routes are automatically learned from other routers.
  - Each router automatically discovers its neighbour routers.
  - Routers exchange routing table information.

Routing Table Principles

- These principles, listed as follows, are from Alex Zinin's book, *Cisco IP Routing*:
  - Every router makes its decision alone, based on the information it has in its own routing table.
  - The fact that one router has certain information in its routing table does not mean that other routers have the same information.
  - Routing information about a path from one network to another does not provide routing information about the reverse, or return, path.

Routing Table Principles

PC1 “pings” PC2

R1 forwards the packet to R2.

R2 forwards the packet to R3.

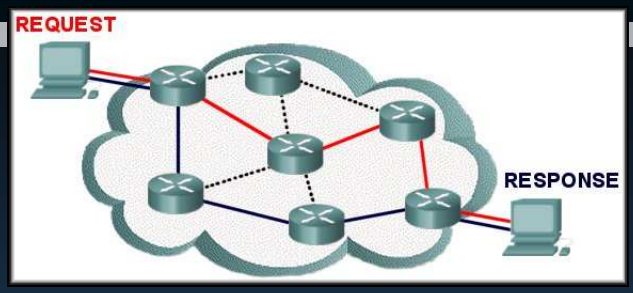
R3 forwards the packet to PC2.

R3 DOES NOT have a route back to PC1.

R3 *drops the packet*. “ping” error.

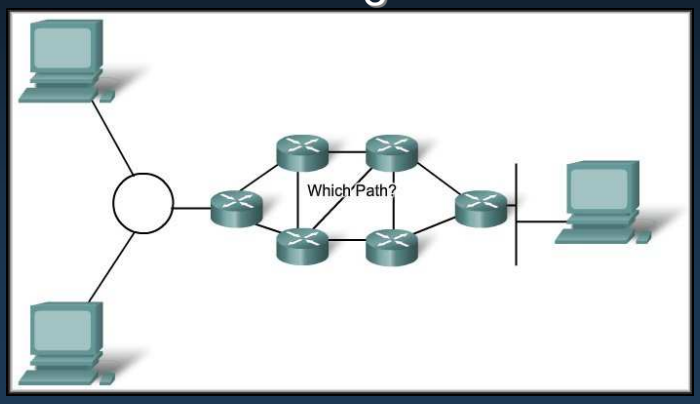
PC2 responds to the “ping”

Asymmetric Routing



- Routers do not necessarily have the same information in their routing tables.
  - Packets can traverse the network using one path.
  - Return through another path.
- Asymmetric routing is more common in the Internet, which uses the BGP routing protocol, than it is in most internal networks.

Path Determination and Switching Functions

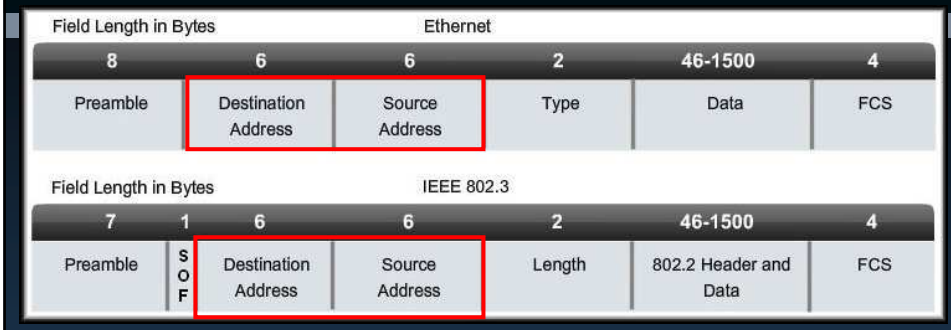


Internet Protocol (IP) Packet Format

Byte 1		Byte 2	Byte 3	Byte 4
Vers.	IHL	Service Type	Packet Length	
Identification			Flag	Frag. Offset
Time to Live		Protocol	Header Checksum	
Source Address				
Destination Address				
Options				Padding

- **Layer 3 addresses:**
  - **Source Address:** Source host address
  - **Destination Address:** Destination host address
  - ***Does not change during the forwarding of the data.***

MAC Layer Frame Format



- Layer 2 addresses:
  - Source address: Sending interface.
  - Destination address: Destination interface.
  - Interface-to-Interface on the same network.
    - *Changes from network to network.*

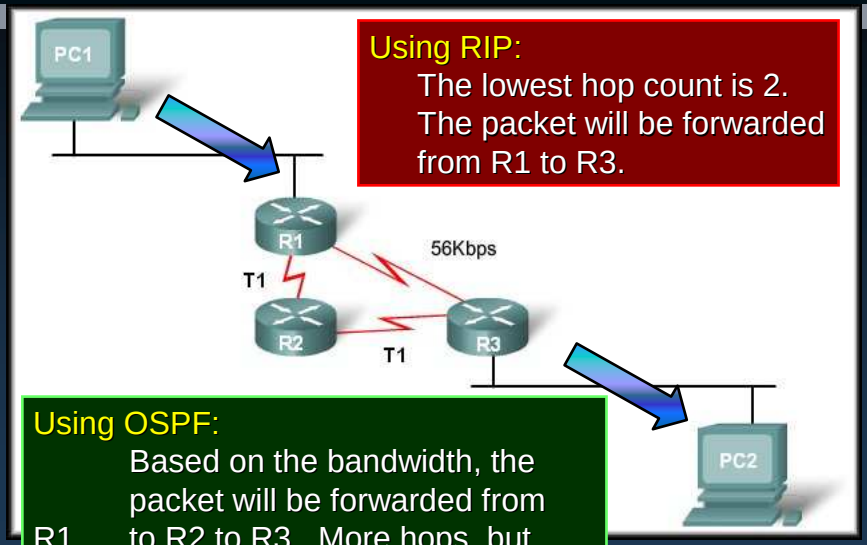
Best Path and Metrics

- If there are multiple paths to a network:
  - Best path determination involves evaluating multiple paths to the same destination and choosing the optimum route.
  - Each path uses a different router interface.
  - Depends on the routing protocol.
    - Metric (value) the protocol uses to determine the distance to the destination network.
    - The best path is the metric that has the lowest value.

Comparing Hop count and Bandwidth Metrics

- Hop Count as a metric:
  - The hop count is the number of routers that a packet must traverse between the source and destination networks.
  - The fewer number of hops (lowest metric), the better the route.
  - Routing Information Protocol (RIP)
- Bandwidth as a metric:
  - The bandwidth is the carrying capacity (speed) of the link.
  - The metric is a calculated value that represents the fastest route to the destination based on the speed of the links between the source and destination.
  - Open Shortest Path First (OSPF)

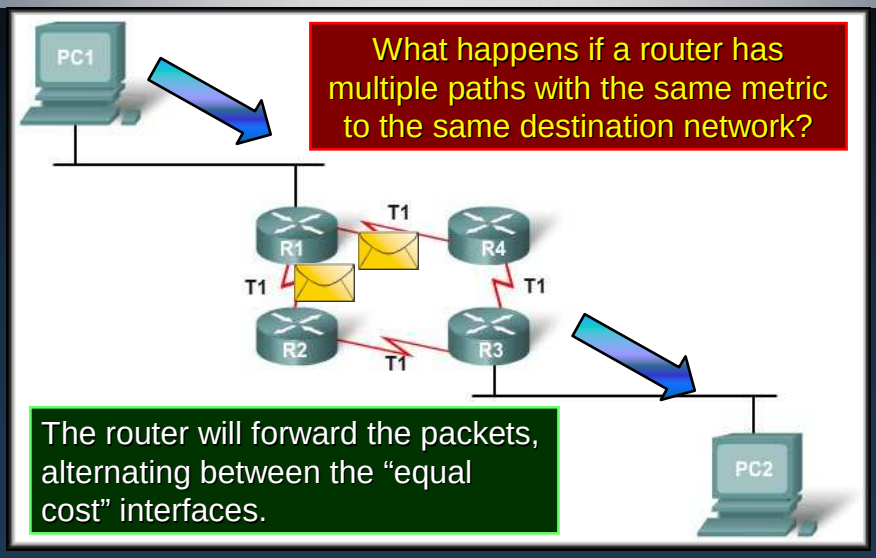
Comparing Hop Count and Bandwidth Metrics



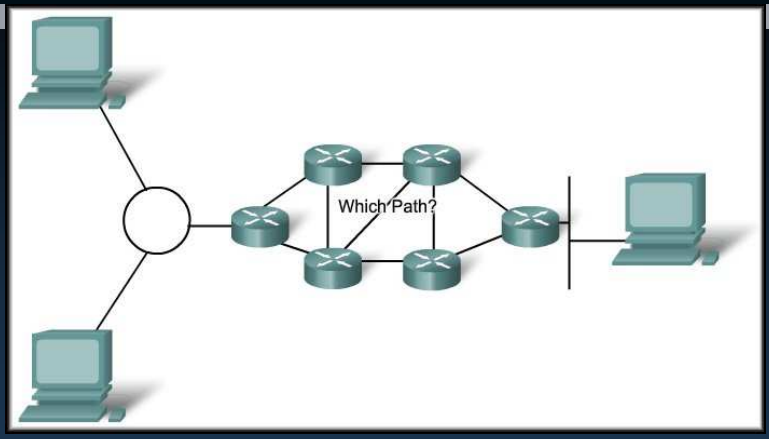
Using RIP:
The lowest hop count is 2. The packet will be forwarded from R1 to R3.

Using OSPF:
Based on the bandwidth, the packet will be forwarded from R1 to R2 to R3. More hops, but faster lines.

Equal Cost Load Balancing



Packet Forwarding



- Two Functions:
  - Path Determination
  - Switching

Path Determination

- *The process of how the router determines which path to use when forwarding a packet.*
  - The router searches its routing table for a network address that matches the packet's destination network.
  - One of three path determinations results from this search.
    - Directly connected network.
    - Remote network.
    - No route determined.

Path Determination

- Directly Connected Network:
  - R1 receives a packet destined for PC1.
  - R1 looks in the routing table and determines that the destination network is out its FastEthernet port.
  - *The packet is forwarded directly to the device with the packet's destination IP address.*

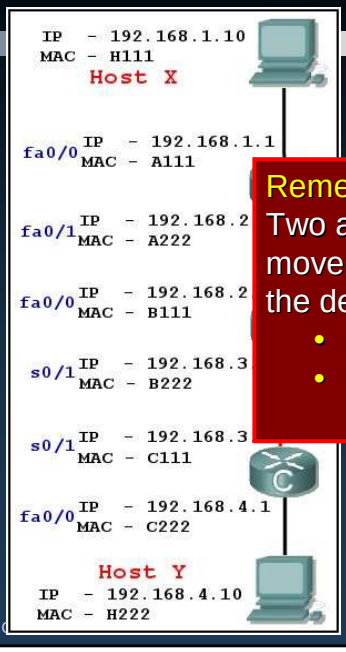
Path Determination

- Remote Network:
  - R1 receives a packet from PC1 whose ultimate destination is PC2.
  - R1 looks in the routing table and determines that the path to the destination network is via its WAN port.
  - *The packet is forwarded to another router. Remote networks can only be reached by forwarding packets to another router.*

Path Determination

- No Route Determined:
  - R1 receives a packet from PC1 whose ultimate destination is PC2.
  - R1 looks in the routing table and cannot find a path to a directly connected network or remote network.
  - *If the router does not have a default route, the packet is discarded. The router sends an Internet Control Message Protocol (ICMP) Unreachable message to the source IP address of the packet.*

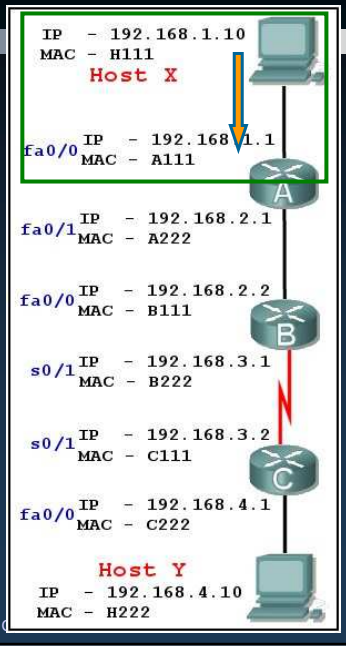
Switching Function



- Host X sends a packet to Host Y.
- A router generally relays a packet ther, using function – rding stages these routers use to route and switch this packet.

Remember:
Two addresses are needed to move a packet from the source to the destination.
- MAC Address
- IP Address

Switching Function



Layer 2 Destination	Layer 2 Source	Layer 3 Destination	Layer 3 Source
A111	H111	192.168.4.10	192.168.1.10

- Host X begins by encapsulating a packet with Host Y's IP address and Router A's MAC address.

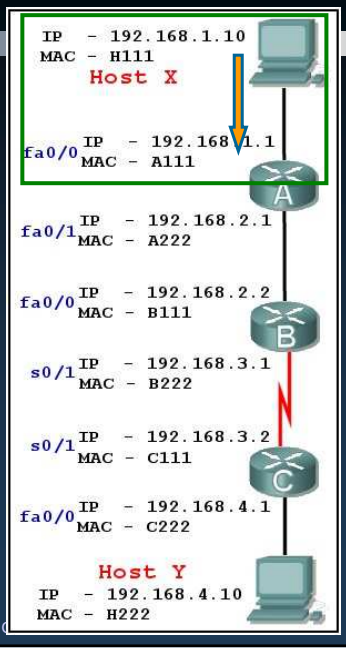
How does Host X know to forward packets to Router A's MAC address not directly to Host Y?

Host X determines that the destination is NOT on the same network. (More Later)

Queries the router for the router's MAC address (more later).

The packet is forwarded to the default gateway.

Switching Function



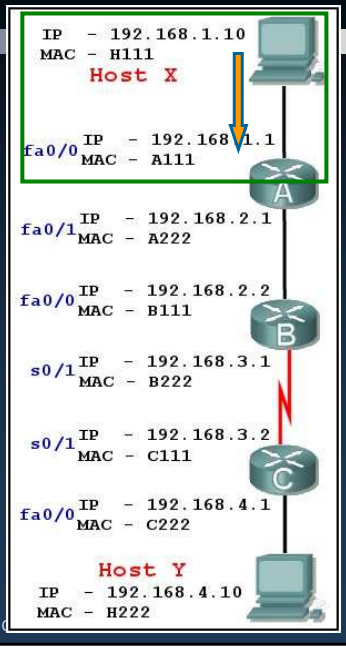
Layer 2 Destination	Layer 2 Source	Layer 3 Destination	Layer 3 Source
A111	H111	192.168.4.10	192.168.1.10

- Router A receives the packet on port fa0/0.

NOW what happens?

Router A uses the destination IP address to search its routing table for network 192.168.4.0/24. It finds that it has a **next hop** address of **192.168.2.2** and an exit port of **fa0/1.**

Switching Function



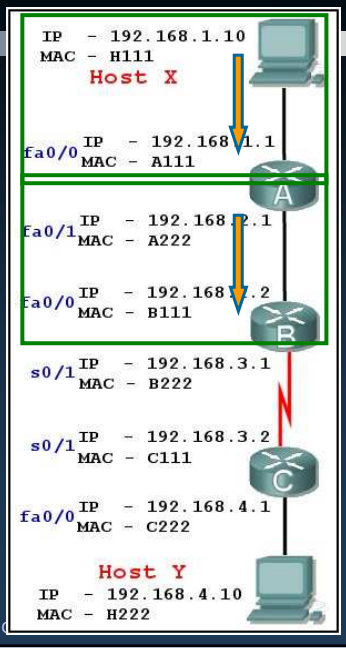
Layer 2 Destination	Layer 2 Source	Layer 3 Destination	Layer 3 Source
A111	H111	192.168.4.10	192.168.1.10

- Router A knows that the exit port is an Ethernet interface.

NOW what happens?

Router A looks in a table of IP address to MAC address for all connected networks. If the network isn't there, it queries Router B for it's MAC address.

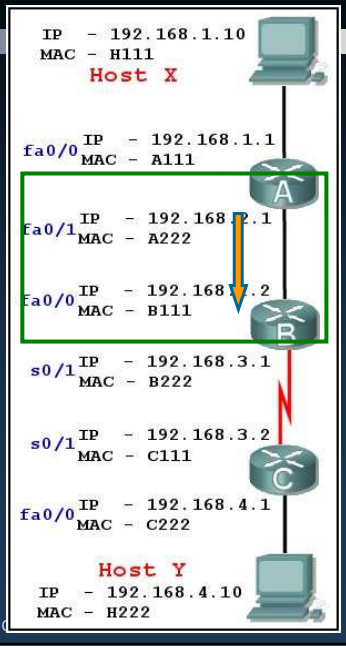
Switching Function



Layer 2 Destination	Layer 2 Source	Layer 3 Destination	Layer 3 Source
B111	A222	192.168.4.10	192.168.1.10

- Router A now has all of the information it needs to forward the packet. It knows that the destination MAC address is B111 and that the exit port is fa0/0.
- Router A now re-encapsulates the frame, **changing the Layer 2 addresses** and **switches** the frame out port fa0/1.

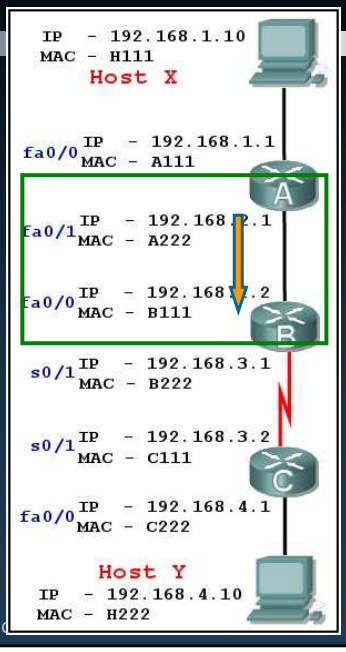
Switching Function



Layer 2 Destination	Layer 2 Source	Layer 3 Destination	Layer 3 Source
B111	A222	192.168.4.10	192.168.1.10

- Notice that the Layer 3 addresses in the packet *DID NOT* change!
- Also notice that the ***routing table*** was used to find:
  - The next hop Layer 3 address
  - The next hop Layer 2 address
  - The exit port to use to forward the frame.

Switching Function



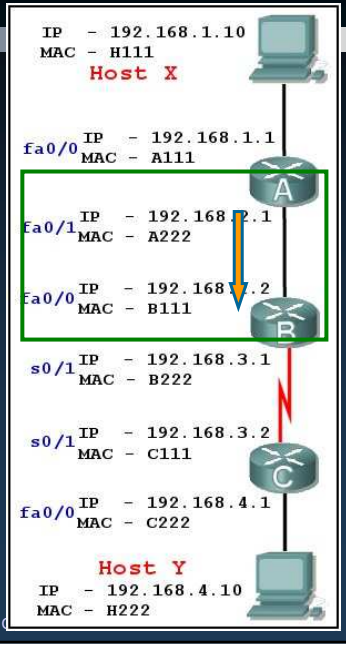
Layer 2 Destination	Layer 2 Source	Layer 3 Destination	Layer 3 Source
B111	A222	192.168.4.10	192.168.1.10

- Router B receives the packet.

NOW what happens?

Router B uses the destination IP address to search its routing table for network 192.168.4.0/24. It finds that it has a next hop address of **192.168.3.2** and an exit port of **s0/1 – a serial interface.**

Switching Function



Layer 2 Destination	Layer 2 Source	Layer 3 Destination	Layer 3 Source
B111	A222	192.168.4.10	192.168.1.10

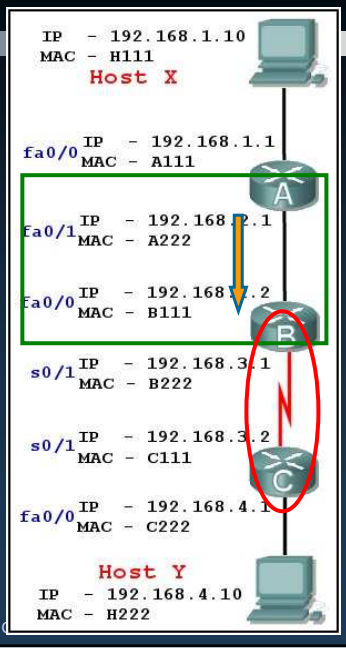
- Router B knows that the exit port is a **serial interface**.

NOW what happens?

Since the exit interface is a serial interface, **NOT** an Ethernet interface, Router B ***does not need*** the Layer 2 address for the next hop.

Remember, serial interfaces are like a pipe – one way in and one way out.

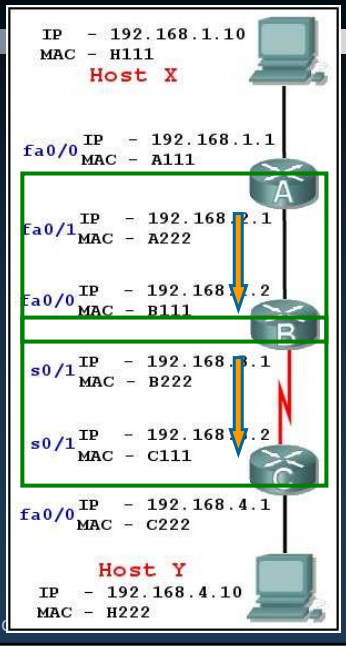
Switching Function



Layer 2 Destination	Layer 2 Source	Layer 3 Destination	Layer 3 Source
B111	A222	192.168.4.10	192.168.1.10

- When the interface is a point-to-point serial connection, the routing table process does not even look at the next-hop IP address.
- Router B now encapsulates the IP packet into the proper data link frame, using the proper serial encapsulation (HDLC, PPP, etc.).

Switching Function



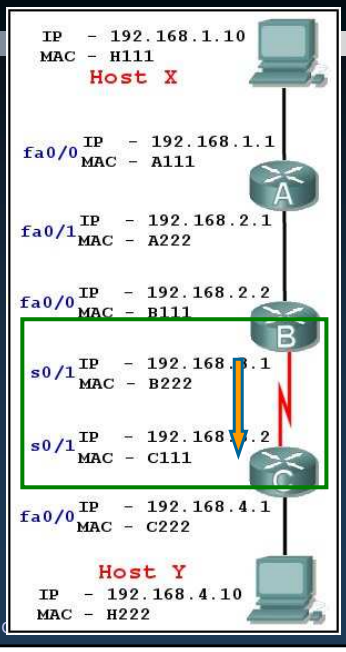
Layer 2 Destination	Layer 2 Source	Layer 3 Destination	Layer 3 Source
FFFF	B222	192.168.4.10	192.168.1.10

The destination Layer 2 address is set to a **broadcast** since there is only one end to the pipe.

The source Layer 2 address is set to the **exit port of Router B** – the source of the frame.

Finally, the frame is **switched** out port s0/1 on Router B.

Switching Function



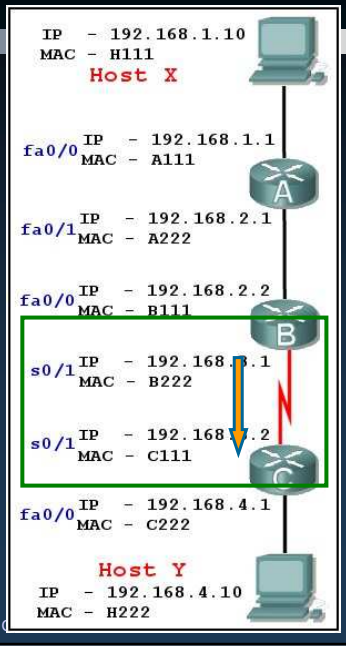
Layer 2 Destination	Layer 2 Source	Layer 3 Destination	Layer 3 Source
FFFF	B222	192.168.4.10	192.168.1.10

- Router C receives the frame on the serial interface - port s0/1

NOW what happens?

Router C uses the destination IP address to search its routing table for network 192.168.4.0/24. It finds that the network is a **directly connected network** with an exit interface of fa0/0.

Switching Function

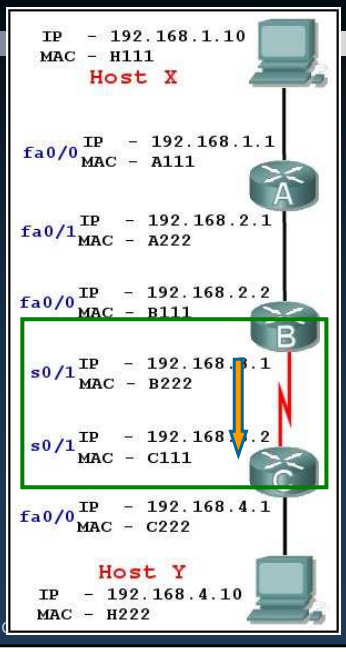


Layer 2 Destination	Layer 2 Source	Layer 3 Destination	Layer 3 Source
FFFF	B222	192.168.4.10	192.168.1.10

- Router C realizes that this destination IP address is on **the same network as one of its interfaces** and it can send the packet ***directly to the destination*** and not another router.

- Since the exit interface is on an directly connected Ethernet network, Router C must obtain the destination's MAC address.

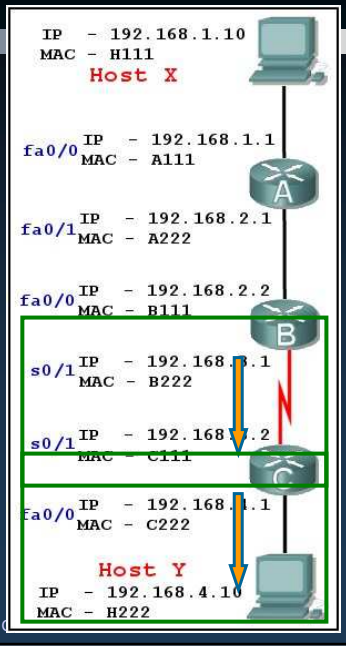
Switching Function



Layer 2 Destination	Layer 2 Source	Layer 3 Destination	Layer 3 Source
FFFF	B222	192.168.4.10	192.168.1.10

- Router C looks in a table of IP address to MAC address for all connected networks.
- If the entry was not in the table, Router C would need to send a query out fa0/0 that says, **"What is the MAC address for this IP address?"**
- Host Y would send back a reply that says, **"This is the MAC address that matches the IP Address you sent."**

Switching Function



Layer 2 Destination	Layer 2 Source	Layer 3 Destination	Layer 3 Source
H222	C222	192.168.4.10	192.168.1.10

Router C encapsulates the Ethernet frame and uses the **destination MAC address** of Host Y.

The source Layer 2 address becomes the MAC address of the **router's fa0/0 port**.

The frame is **switched** out port fa0/0 to the destination host – Host Y.

Switching Function

Step	Layer 2 Destination	Layer 2 Source	Layer 3 Destination	Layer 3 Source
Host X to Router A	A111	H111	192.168.4.10	192.168.1.10
Router A to Router B	B111	A222	192.168.4.10	192.168.1.10
Router B to Router C	FFFF	B222	192.168.4.10	192.168.1.10
Router C to Host Y	H222	C222	192.168.4.10	192.168.1.10

REMEMBER THAT THE SOURCE AND DESTINATION IP ADDRESSES REMAIN UNCHANGED!!!