Introduction to Routing and Packet Forwarding

Routing Protocols and Concepts – Chapter 1

Cisco Networking Academy®
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Objectives

- Identify a router as a computer with an OS and hardware designed for the routing process.
- Demonstrate the ability to configure devices and apply addresses.
- Describe the structure of a routing table.
- Describe how a router determines a path and switches packets

Router as a Computer

- Describe the basic purpose of a router
  - -Computers that specialize in sending packets over the data network. They are responsible for interconnecting networks by selecting the best path for a packet to travel and forwarding packets to their destination
- Routers are the network center
  - -Routers generally have 2 connections:
    - -WAN connection (Connection to ISP)
    - -LAN connection

Routers as a Network Centre

- Each network that a router connects to typically requires a separate interface.
- These interfaces are used to connect a combination of both Local Area Networks (LANs) and Wide Area Networks (WANs).
- LANs are commonly Ethernet networks that contain devices such as PCs, printers, and servers. WANs are used to connect networks over a large geographical area.
- For example, a WAN connection is commonly used to connect a LAN to the Internet Service Provider (ISP) network.

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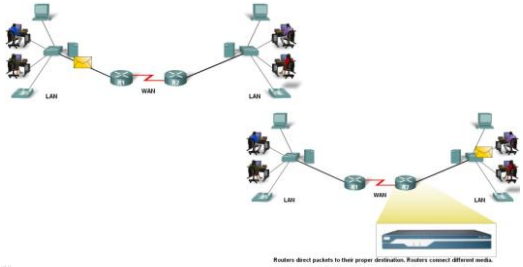
Router as a Computer

- Data is sent in form of packets between 2 end devices
- Routers are used to direct packet to its destination



Routers and Best Path

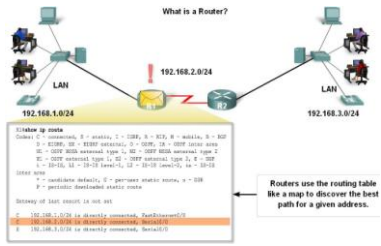
- The primary responsibility of a router is to direct packets destined for local and remote networks by:

1. Determining the best path to send packets
2. Forwarding packets toward their destination

- The router uses its routing table to determine the best path to forward the packet.
- When the router receives a packet, it examines its destination IP address and searches for the best match with a network address in the router's routing table.
- The routing table also includes the interface to be used to forward the packet.
- Once a match is found, the router encapsulates the IP packet into the data link frame of the outgoing or exit interface, and the packet is then forwarded toward its destination.

Router as a Computer

- Routers examine a packet's destination IP address and determine the best path by enlisting the aid of a routing table



Role of a Router

- In the figure, we can follow a packet from the source PC to the destination PC.
- Notice that it is the responsibility of the router to find the destination network in its routing table and forward the packet on toward its destination.
- In this example, router R1 receives the packet encapsulated in an Ethernet frame.
- After decapsulating the packet, R1 uses the destination IP address of the packet to search its routing table for a matching network address.
- After a destination network address is found in the routing table, R1 encapsulates the packet inside a PPP frame and forwards the packet to R2. A similar process is performed by R2.

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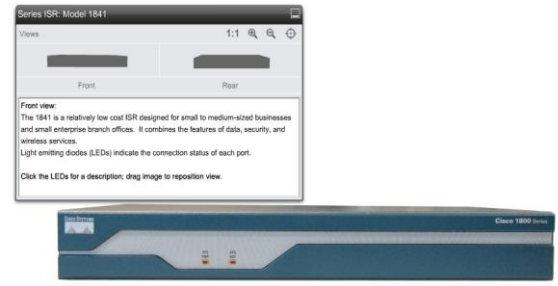
Router as a Computer

- Router components and their functions”

1. **CPU** - Executes operating system instructions
2. **Random access memory (RAM)** - Contains the running copy of configuration file. Stores routing table. RAM contents lost when power is off
3. **Read-only memory (ROM)** - Holds diagnostic software used when router is powered up. Stores the router’s bootstrap program.
4. **Non-volatile RAM (NVRAM)** - Stores startup configuration. This may include IP addresses (Routing protocol, Hostname of router)
5. **Flash memory** - Contains the operating system (Cisco IOS)
6. **Interfaces** - There exist multiple physical interfaces that are used to connect network. Examples of interface types:
   A. -Ethernet / fast Ethernet interfaces
   B. -Serial interfaces
   C. -Management interfaces

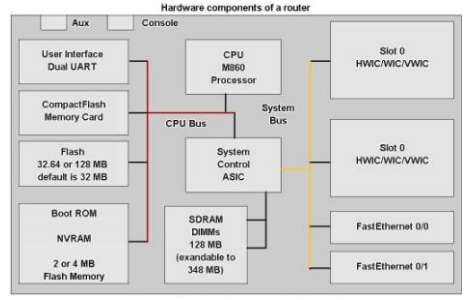
Front View



Rear View

Router as a Computer

- Router components



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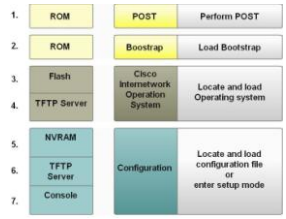
Router as a Computer

- Major phases to the router boot-up process
  - Test router hardware
    - Power-On Self Test (POST)
    - Execute bootstrap loader
  - Locate & load Cisco IOS software
    - -Locate IOS
    - -Load IOS
  - Locate & load startup configuration file or enter setup mode
    - -Bootstrap program looks for configuration file



POST and Bootstrap

- **1. The Power-On Self Test (POST)** is a common process that occurs on almost every computer during bootup.
- The POST process is used to test the router hardware. When the router is powered on, software on the ROM chip conducts the POST.
- During this self-test, the router executes diagnostics from ROM on several hardware components including the CPU, RAM, and NVRAM.
- After the POST has been completed, the router executes the bootstrap program.
- 2. **Loading the Bootstrap Program**
- After the POST, the bootstrap program is copied from ROM into RAM. Once in RAM, the CPU executes the instructions in the bootstrap program. The main task of the bootstrap program is to locate the Cisco IOS and load it into RAM.

Loading IOS

- Locating the Cisco IOS software. The IOS is typically stored in flash memory, but can also be stored in other places such as a TFTP (Trivial File Transfer Protocol) server.
- If a full IOS image can not be located, a scaled-down version of the IOS is copied from ROM into RAM. This version of IOS is used to help diagnose any problems and can be used to load a complete version of the IOS into RAM.
- **Note**: A TFTP server is usually used as a backup server for IOS but it can also be used as a central point for storing and loading the IOS. IOS management and using the TFTP server is discussed in a later course.
- Loading the IOS. Some of the older Cisco routers ran the IOS directly from flash, but current models copy the IOS into RAM for execution by the CPU.
- **Note**: Once the IOS begins to load, you may see a string of pounds signs (#), as shown in the figure, while the image decompresses.

Locating the Startup Configuration File.

- After the IOS is loaded, the bootstrap program searches for the startup configuration file, known as startup-config, in NVRAM.
- This file has the previously saved configuration commands and parameters including:
  - interface addresses
  - routing information
  - Passwords
  - any other configurations saved by the network administrator
- If the startup configuration file, startup-config, is located in NVRAM, it is copied into RAM as the running configuration file, running-config.

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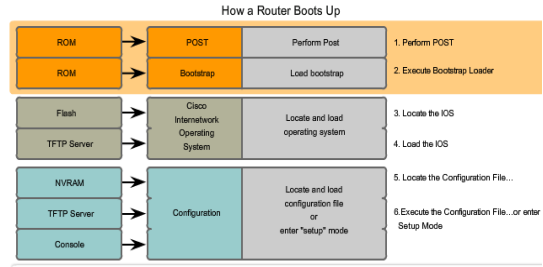
Executing the Configuration File

1. **If a startup configuration** file is found in NVRAM, the IOS loads it into RAM as the running-config and executes the commands in the file, one line at a time. The running-config file contains interface addresses, starts routing processes, configures router passwords and defines other characteristics of the router.
2. **Enter Setup Mode (Optional)**. If the startup configuration file can not be located, the router prompts the user to enter setup mode. Setup mode is a series of questions prompting the user for basic configuration information. Setup mode is not intended to be used to enter complex router configurations, and it is not commonly used by network administrators.

Booting Process

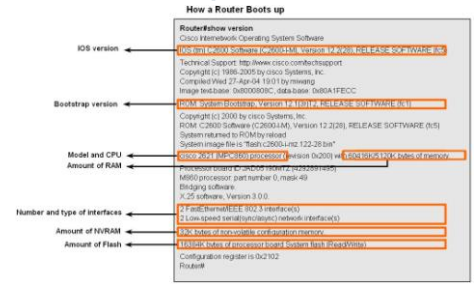


Router as a Computer

- Verify the router boot-up process:

  -The show version command is used to view information about the router during the bootup process. Information includes:
  - Platform model number
  - Image name & IOS version
  - Bootstrap version stored in ROM
  - Image file name & where it was loaded from
  - Number & type of interfaces
  - Amount of NVRAM
  - Amount of flash
  - Configuration register

Router as a Computer



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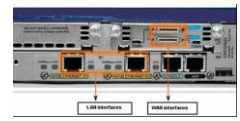
Router as a Computer

- Router Interface is a physical connector that enables a router to send or receive packets
- Each interface connects to a separate network
- Consist of socket or jack found on the outside of a router
- Types of router interfaces:
  - -Ethernet
  - -Fastethernet
  - -Serial
  - -DSL
  - -ISDN
  - -Cable

Router as a Computer

- Two major groups of Router Interfaces

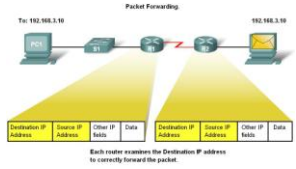
  LAN Interfaces:
  - Are used to connect router to LAN network
  - Has a layer 2 MAC address
  - Can be assigned a Layer 3 IP address
  - Usually consist of an RJ-45 jack



- WAN Interfaces
  - Are used to connect routers to external networks that interconnect LANs.
  - Depending on the WAN technology, a layer 2 address may be used.
  - Uses a layer 3 IP address

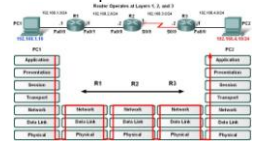
Router as a Computer

- Routers and the Network Layer
  - Routers use destination IP address to forward packets
  - The path a packet takes is determined after a router consults information in the routing table.
  - After router determines the best path
  - Packet is encapsulated into a frame
  - Frame is then placed on network medium in form of Bits



Router as a Computer

- Routers Operate at Layers 1, 2 & 3
  - Router receives a stream of encoded bits
  - Bits are decoded and passed to layer 2
  - Router de-encapsulates the frame
  - Remaining packet passed up to layer 3
    - -Routing decision made at this layer by examining destination IP address
  - Packet is then re-encapsulated & sent out outbound interface



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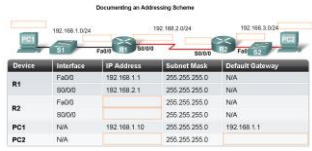
Configure Devices and Apply Addresses

- Implementing Basic Addressing Schemes
- When designing a new network or mapping an existing network you must provide the following information in the form of a document:
  - -Topology drawing that Illustrates physical connectivity
  - –Address table that provides the following information:
    - Device name
    - Interfaces used
    - IP addresses
    - Default gateway

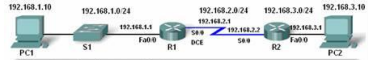


Device	Interface	IP Address	Subnet Mask	Default Gateway
R1	Fa0/0	192.168.1.1	255.255.255.0	N/A
	S0/0/0	192.168.2.1	255.255.255.0	N/A
R2	Fa0/0		255.255.255.0	N/A
	S0/0/0		255.255.255.0	N/A
PC1	N/A	192.168.1.10	255.255.255.0	192.168.1.1
PC2	N/A		255.255.255.0	

Configure Devices and Apply Addresses

- Basic Router Configuration
- A basic router configuration should contain the following:
  - -Router name - Host name should be unique
  - -Banner - At a minimum, banner should warn against unauthorized use
  - -Passwords - Use strong passwords
  - -Interface configurations - Specify interface type, IP address and subnet mask. Describe purpose of interface. Issue no shutdown command. If DCE serial interface issue clock rate command.
- After entering in the basic configuration the following tasks should be completed
  - -Verify basic configuration and router operations.
  - -Save the changes on a router

Configure Devices and Apply Addresses



Basic router configuration command syntax	
Naming the router	Router(config)# hostname name
Setting Passwords	Router(config)# enable secret password
	Router(config)# line console 0
	Router(config-line)# password password
	Router(config-line)# login
	Router(config)# line vty 0 4
	Router(config-line)# password password
	Router(config-line)# login
Configuring an interface	Router(config)# interface type number
	Router(config-if)# ip address address mask
	Router(config-if)# description description
	Router(config-if)# no shutdown
Configuring a message-of-the-day banner	Router(config)# banner motd # message #
Saving changes on a router	Router# copy running-config startup-config
Examining the output of show commands	Router# show running-config
	Router# show ip route
	Router# ip interface brief
	Router# interfaces

Configure Devices and Apply Addresses

- Verify Basic Router Configuration
  - -Issue the *show running-config* command
  - -Save the basic router configuration by Issuing the *copy running-config startup-config* command
  - -Additional commands that will enable you to further verify router configuration are:
    - Show running-config - Displays configuration currently in RAM
    - Show startup-config - Displays configuration file NVRAM
    - Show IP route - Displays routing table
    - Show interfaces - Displays all interface configurations
    - Show IP int brief - Displays abbreviated interface configuration information

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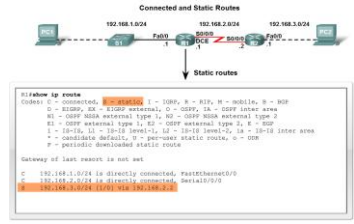
Routing Table Structure

- Routing Table is stored in ram and contains information about:
  - Directly connected networks - this occurs when a device is connected to another router interface
  - Remotely connected networks - this is a network that is not directly connected to a particular router
  - Detailed information about the networks include source of information, network address & subnet mask, and Ip address of next-hop router
- Show ip route command is used to view a routing table

Routing Table Structure

- Adding a connected network to the routing table
  - -Router interfaces
    - Each router interface is a member of a different network
    - Activated using the *no shutdown* command
    - In order for static and dynamic routes to exist in routing table you must have directly connected networks

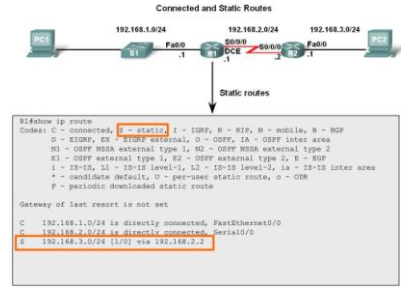


Routing Table Structure

- Static routes in the routing table
  - -Includes: network address and subnet mask and IP address of next hop router or exit interface
  - -Denoted with the code **S** in the routing table
  - -Routing tables must contain directly connected networks used to connect remote networks before static or dynamic routing can be used
- When to use static routes
  - -When network only consists of a few routers
  - -Network is connected to internet only through one ISP
  - -Hub & spoke topology is used on a large network

Routing Table Structure

- Connected and Static routes



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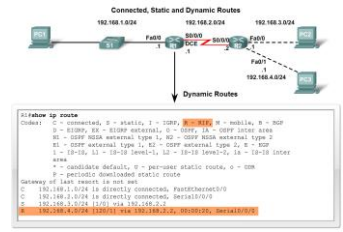
Routing Table Structure

- Dynamic routing protocols
  - -Used to add remote networks to a routing table
  - -Are used to discover networks
  - -Are used to update and maintain routing tables
- Automatic network discovery
  - -Routers are able discover new networks by sharing routing table information

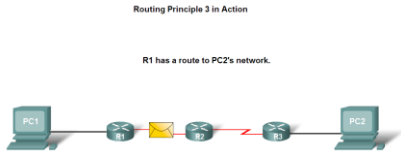
Routing Table Structure

- Maintaining routing tables
  - -Dynamic routing protocols are used to share routing information with other router & to maintain and up date their own routing table.
- IP routing protocols. Example of routing protocols include:
  - -RIP
  - -IGRP
  - -EIGRP
  - -OSPF



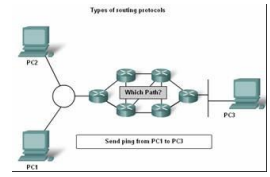
Routing Table Structure

- Routing Table Principles
  - -3 principles regarding routing tables:
    - Every router makes its decisions alone, based on the information it has in its routing table.
    - Different routing table may contain different information
    - A routing table can tell how to get to a destination but not how to get back



Routing Table Structure

- Effects of the 3 Routing Table Principles
  - -Packets are forwarded through the network from one router to another, on a hop by hop basis.
  - -Packets can take path "X" to a destination but return via path "Y" (Asymmetric routing).



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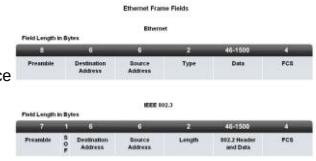
Router Paths and Packet Switching

- Internet Protocol (IP) packet format contains fields that provide information about the packet and the sending and receiving hosts
- Fields that are importance for CCNA students:
  - -Destination IP address
  - -Source IP address
  - -Version & TTL
  - -IP header length
  - -Precedence & type of service
  - -Packet length

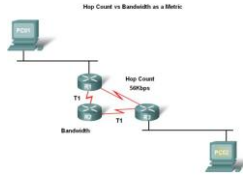
Router Paths and Packet Switching

- MAC Layer Frame Format
- MAC Frames are also divided into fields. They include:
  - -Preamble
  - -Start of frame delimiter
  - -Destination MAC address
  - -Source MAC address
  - -Type/length
  - -Data and pad
  - -Frame check sequence



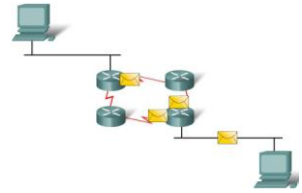
Router Paths and Packet Switching

- A **Metric** is a numerical value used by routing protocols help determine the best path to a destination
  - –The smaller the metric value the better the path
- 2 types of metrics used by routing protocols are:
  - -Hop count - this is the number of routers a packet must travel through to get to its destination
  - -Bandwidth - this is the "speed" of a link also known as the data capacity of a link



Router Paths and Packet Switching

- **Equal cost metric** is a condition where a router has multiple paths to the same destination that all have the same metric
- To solve this dilemma, a router will use Equal Cost Load Balancing. This means the router sends packets over the multiple exit interfaces listed in the routing table.



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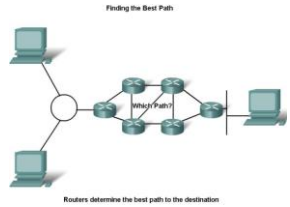
Router Paths and Packet Switching

- **Path determination** is a process used by a router to pick the best path to a destination
- One of 3 path determinations results from searching for the best path
  - Directly connected network
  - Remote network
  - No route determined

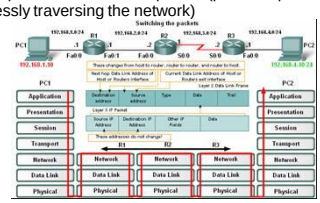


Router Paths and Packet Switching

- **Switching Function** of Router is the process used by a router to switch a packet from an incoming interface to an outgoing interface on the same router.
  - -A packet received by a router will do the following:
    - Strips off layer 2 headers.
    - Examines destination IP address located in Layer 3 header to find best route to destination.
    - Re-encapsulates layer 3 packet into layer 2 frame.
    - Forwards frame out exit interface.

Router Paths and Packet Switching

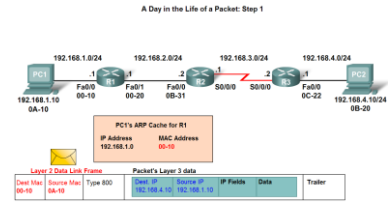
- As a packet travels from one networking device to another
  - -The Source and Destination IP addresses **NEVER** change
  - -The Source & Destination MAC addresses **CHANGE** as packet is forwarded from one router to the next.
  - -TTL field decrement by one until a value of zero is reached at which point router discards packet (prevents packets from endlessly traversing the network)



Router Paths and Packet Switching

- Path determination and switching function details. PC1 Wants to send something to PC 2 here is part of what happens

  Step 1 - PC1 encapsulates packet into a frame. Frame contains R1's destination MAC address



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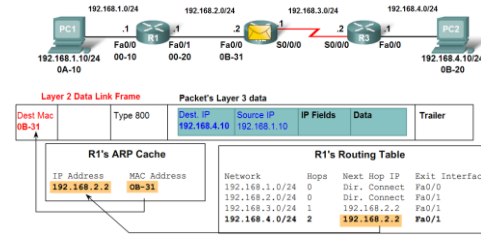
Router Paths and Packet Switching

Step 2 - R1 receives Ethernet frame.

- R1 sees that destination MAC address matches its own MAC.
- R1 then strips off Ethernet frame.
- R1 Examines destination IP.
- R1 consults routing table looking for destination IP.
- After finding destination IP in routing table, R1 now looks up next hop IP address.
- R1 re-encapsulates IP packet with a new Ethernet frame.
- R1 forwards Ethernet packet out Fa0/1 interface.

Router Paths and Packet Switching

A day in a life of a packet: Step 2

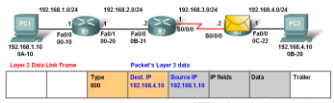


Router Paths and Packet Switching

- Path determination and switching function details. PC1 Wants to send something to PC 2 here is part of what happens

Step 3 - Packet arrives at R2

- R2 receives Ethernet frame
- R2 sees that destination MAC address matches its own MAC
- R2 then strips off Ethernet frame
- R2 Examines destination IP
- R2 consults routing table looking for destination IP
- After finding destination IP in routing table, R2 now looks up next hop IP address
- R2 re-encapsulates IP packet with a new data link frame
- R2 forwards Ethernet packet out S0/0 interface



Router Paths and Packet Switching

- Path determination and switching function details. PC1 Wants to send something to PC 2 here is part of what happens

Step 4 - Packet arrives at R3

- R3 receives PPP frame
- R3 then strips off PPP frame
- R3 Examines destination IP
- R3 consults routing table looking for destination IP
- After finding destination IP in routing table, R3 is directly connected to destination via its fast Ethernet interface
- R3 re-encapsulates IP packet with a new Ethernet frame
- R3 forwards Ethernet packet out Fa0/0 interface

Step 5 - IP packet arrives at PC2. Frame is decapsulated & processed by upper layer protocols.

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Summary

- Routers are computers that specialize in sending data over a network.
- Routers are composed of:
  - -Hardware i.e. CPU, Memory, System bus, Interfaces
  - -Software used to direct the routing process
    - IOS
    - Configuration file
- Routers need to be configured. Basic configuration consists of:
  - -Router name
  - -Router banner
  - -Password(s)
  - -Interface configurations i.e. IP address and subnet mask
- Routing tables contain the following information
  - -Directly connected networks
  - -Remotely connected networks
  - -Network addresses and subnet masks
  - -IP address of next hop address

Summary

- Routers determine a packets path to its destination by doing the following
  - Receiving an encapsulated frame & examining destination MAC address.
  - If the MAC address matches then Frame is de-encapsulated so that router can examine the destination IP address.
  - If destination IP address is in routing table or there is a static route then Router determines next hop IP address. Router will re-encapsulate packet with appropriate layer 2 frame and send it out to next destination.
  - Process continues until packet reaches destination.
  - Note - only the MAC addresses will change the source and destination IP addresses do not change.

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