



University of Colorado **Boulder**

Fundamentals of Data Communications CSCI 5010

OSI Model

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Review

- **OSI Model**

- Names and Numbers
- Focus on Layers 1-4
- Encapsulation & Decapsulation
- Protocol Datagram Units (PDU)
 - ***Layers 1-4***
- Devices at each layer (1-3)

- **TCP & UDP**

- Connectionless vs connection
 - ***Pro/con***

- **ARP**

- Process (in depth)
- MAC
- IP Address

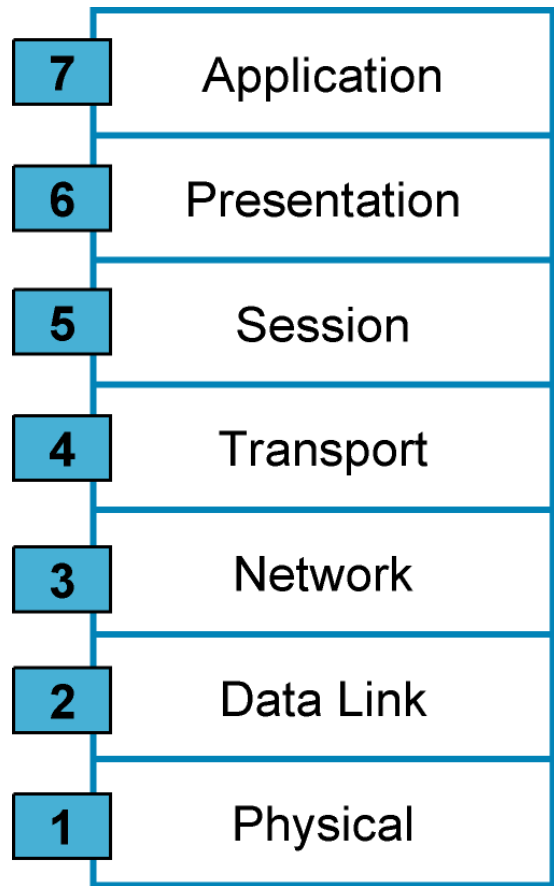
- **Default Gateway**

Understanding Host-to-Host Communications



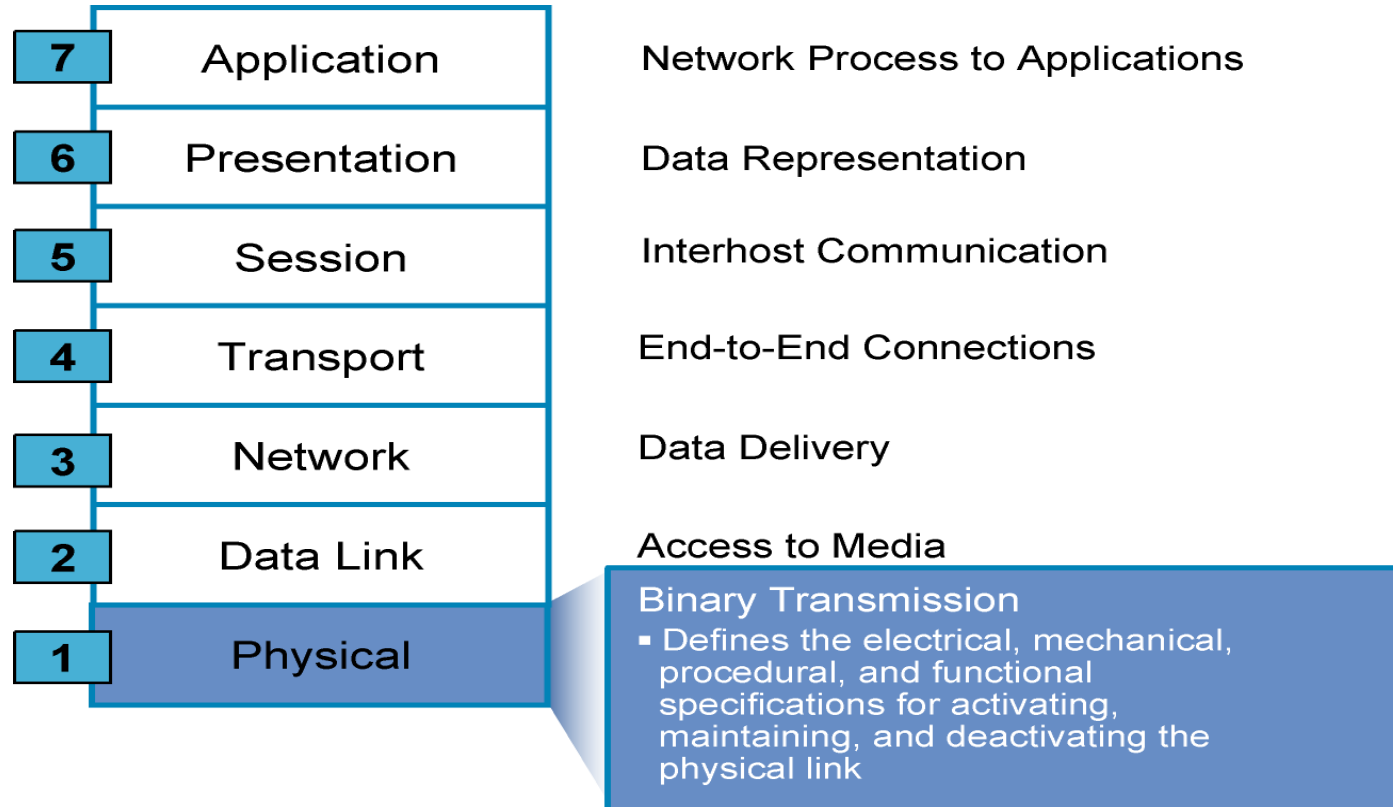
- Theoretical model that specifies how data gets from the application on one machine, across a network, to the application on another machine.
- Older model
 - ***Proprietary***
 - ***Application and combinations software controlled by one vendor***
- Standards-based model
 - ***Multivendor software***
 - ***Layered approach***

Why a Layered Network Model?



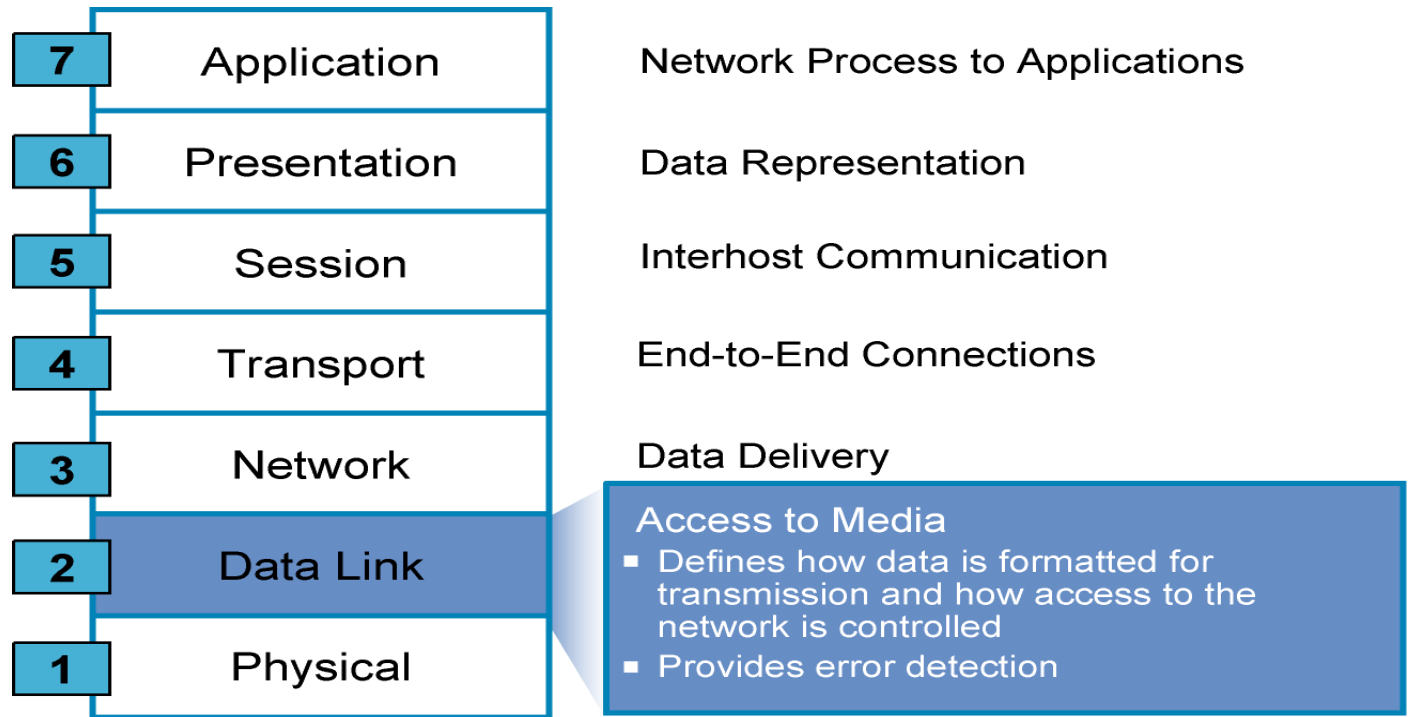
- Reduces complexity
- Standardizes interfaces
- Facilitates modular engineering
- Ensures interoperable technology
- Accelerates evolution
- Simplifies teaching and learning
- **Make sure to learn the name and corresponding number for each layer!**

The Seven Layers of the OSI Model



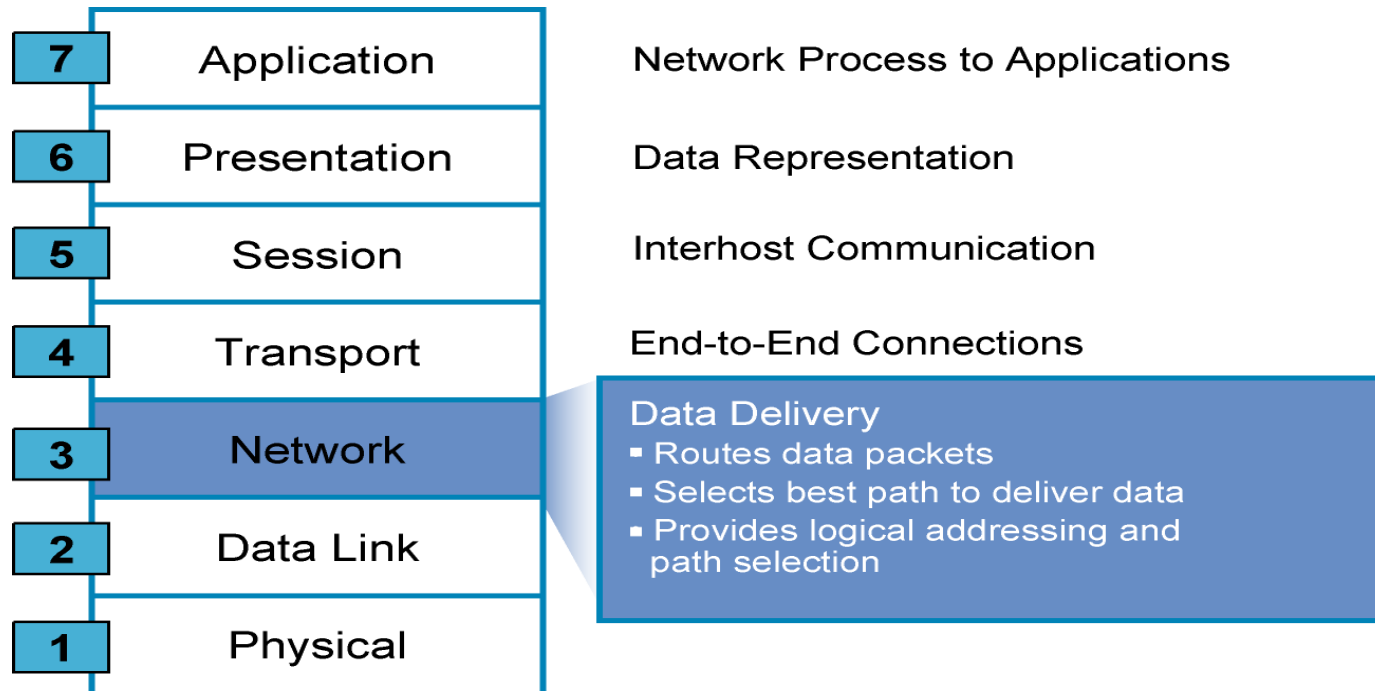
- Electrical Signals
- PDU = Bits (1s and 0s)
- Examples = Serial, Repeater, Hub, physical cabling/power, etc.

The Seven Layers of the OSI Model (Cont.)



- Ethernet uses MAC addresses (physical addressing)
- PDU = Frames
- Examples = Switch, NIC, Bridge

The Seven Layers of the OSI Model (Cont.)

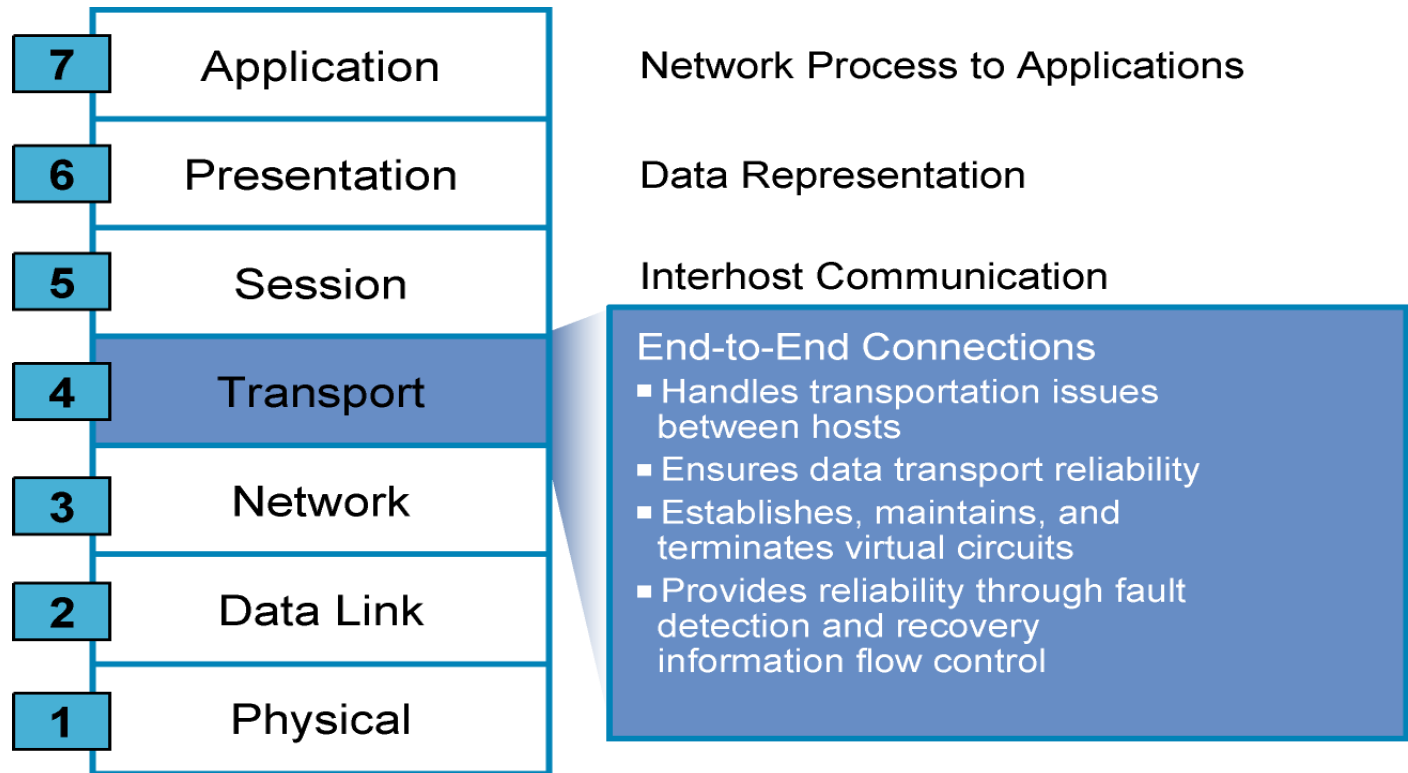


- Uses Internet Protocol (IP) / IP addresses (logical addressing)
- PDU = Packets
- Examples = Routers

Exercise

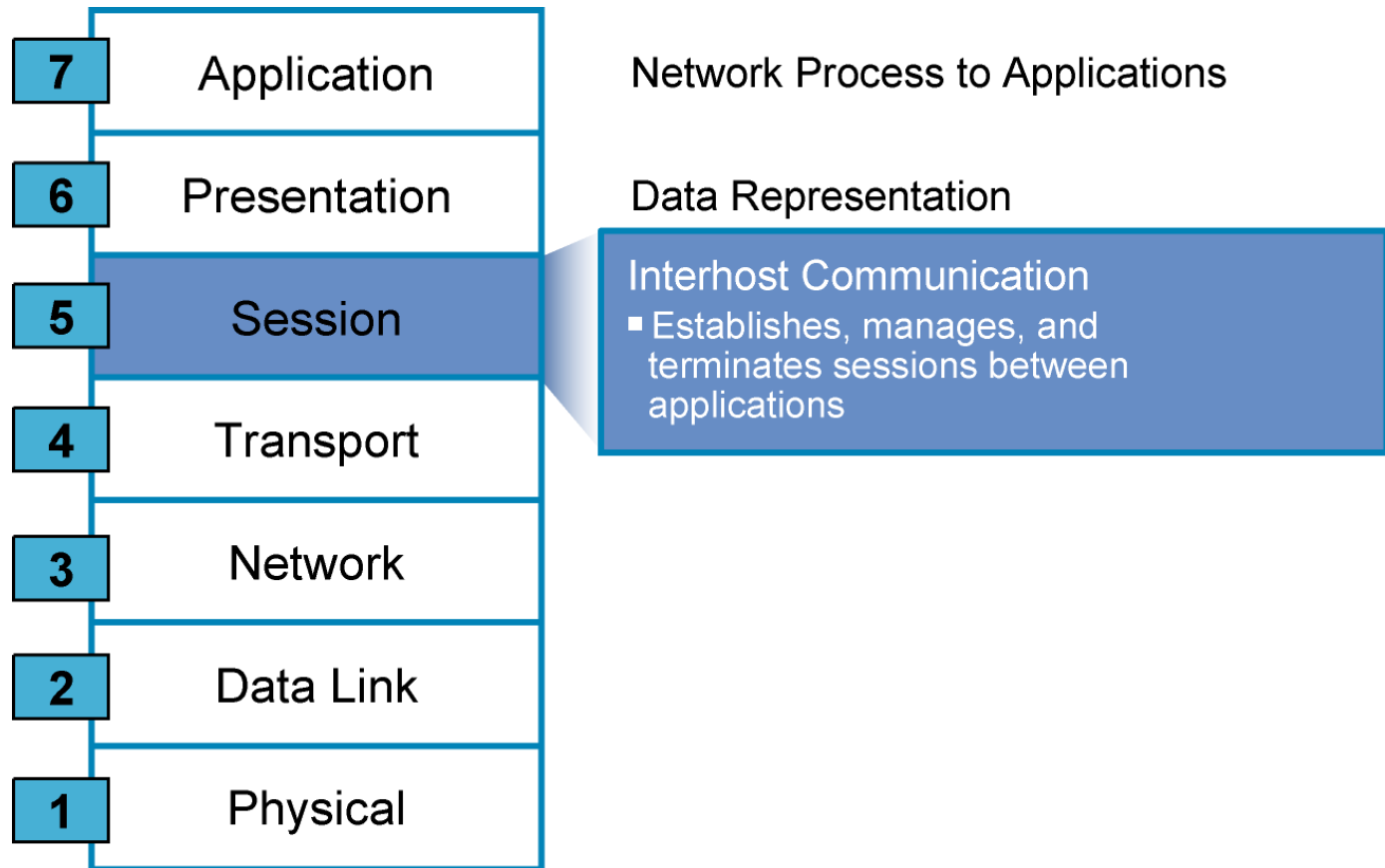
- **On your laptop**
 - Find your MAC address
 - *hint*
 - Find your IP address
- **To do this, you will need to use command prompt/terminal**
 - Search > “cmd” > enter
 - ipconfig/all

The Seven Layers of the OSI Model (Cont.)

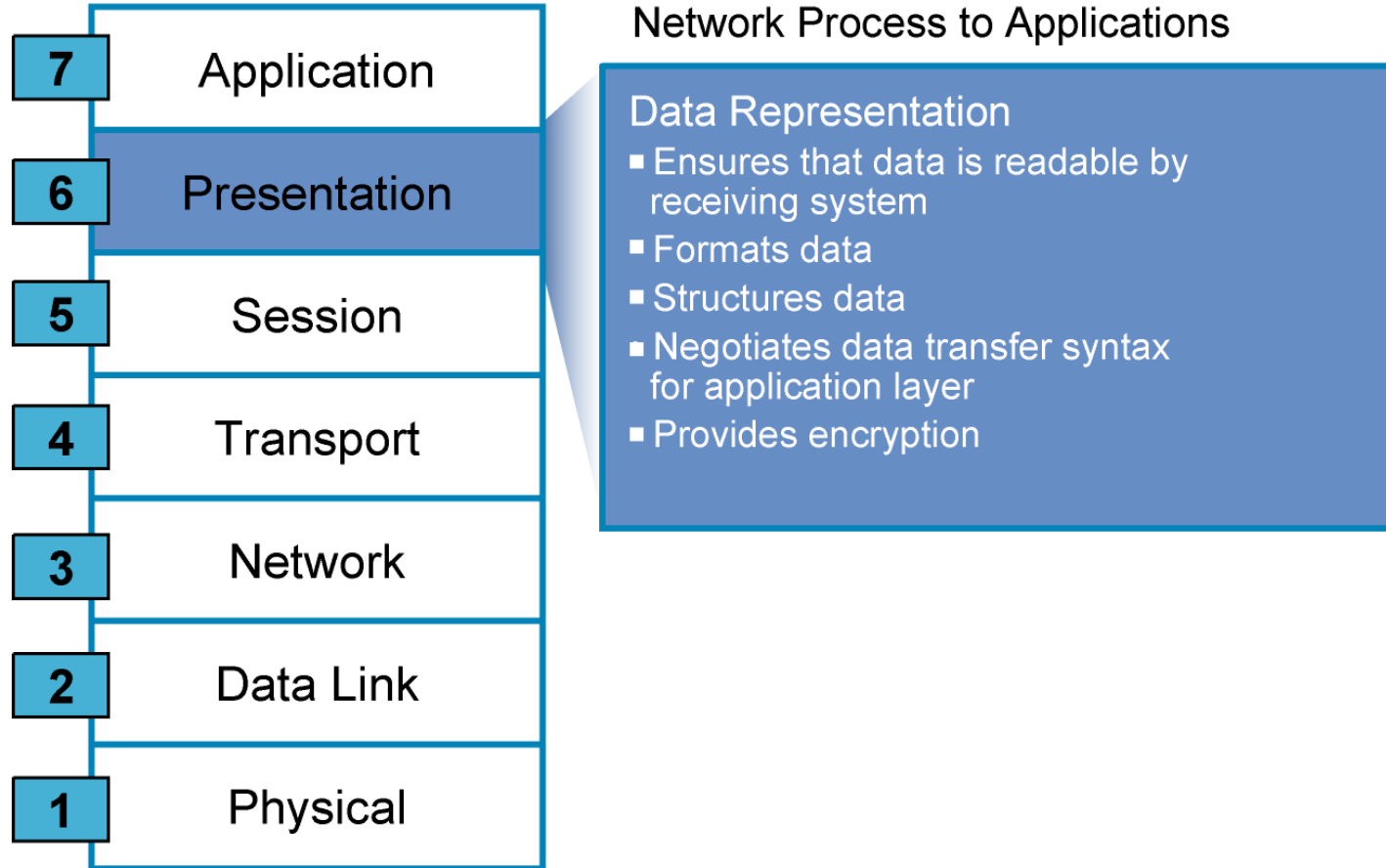


- PDU = Segments
- Examples = TCP & UDP

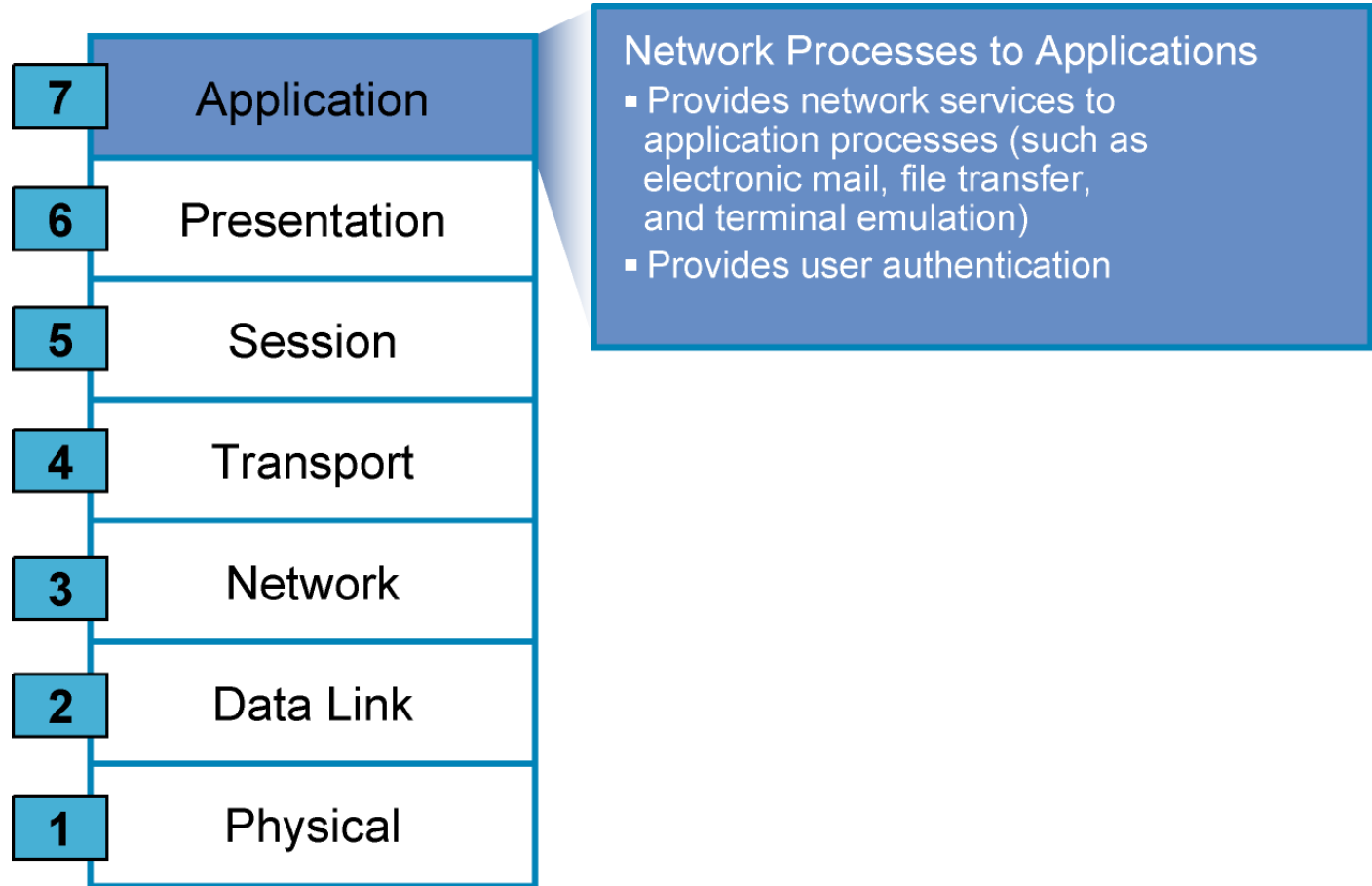
The Seven Layers of the OSI Model (Cont.)



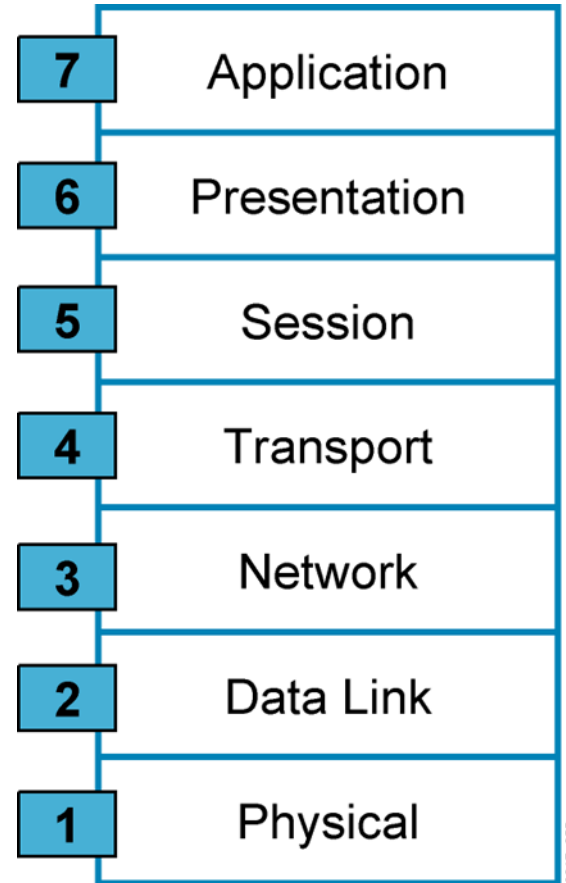
The Seven Layers of the OSI Model (Cont.)



The Seven Layers of the OSI Model (Cont.)



- **Assignment**
- **Perfect**
- **Sam's**
- **Touch**
- **Not**
- **Do**
- **Please**



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The Postal Analogy

How would the OSI compare to the regular Post Office

Application

Presentation

Session

Transport

Network

Data-Link

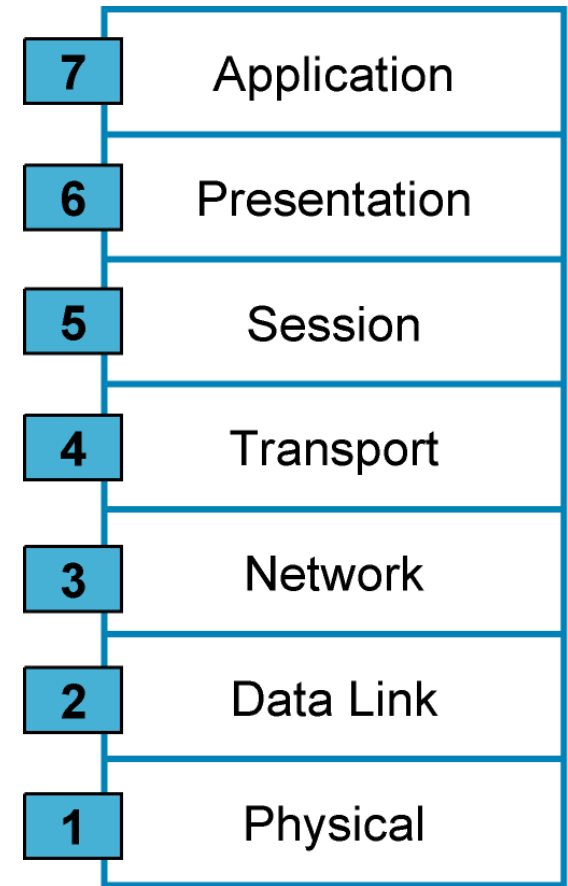
Physical

- **A-** Write a 20 page letter to a foreign country.
- **P-** Translate the letter so the receiver can read it.
- **S-** Insure the intended recipient can receive letter.
- **T-** Separate and number pages. Like registered mail, tracks delivery and requests another package if one is “lost” or “damaged” in the mail.
- **N-** Postal Center sorting letters by zip code to route them closer to destination.
- **D-** Local Post Office determining which vehicles to deliver letters.
- **P-** Physical Trucks, Planes, Rail, autos, etc which carry letter between stations.



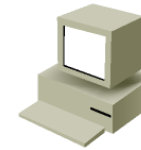
Data Encapsulation & De-encapsulation

- Data or data packets
 - ***The information sent on a network***
- If one computer wants to send data to another computer, the data must first be packaged
 - ***encapsulation***
- When the remote device receives a sequence of bits, the physical layer at the remote device passes the bits up the OSI model to the data link layer for manipulation
 - ***de-encapsulation***

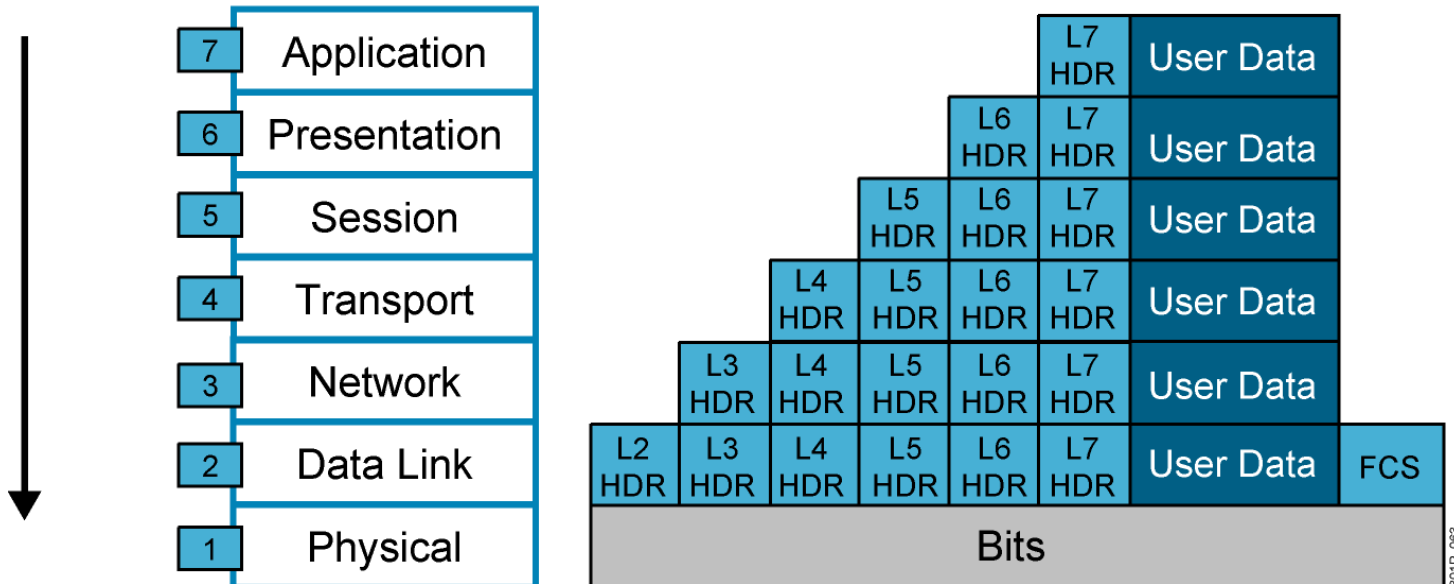


Data Encapsulation

Sender



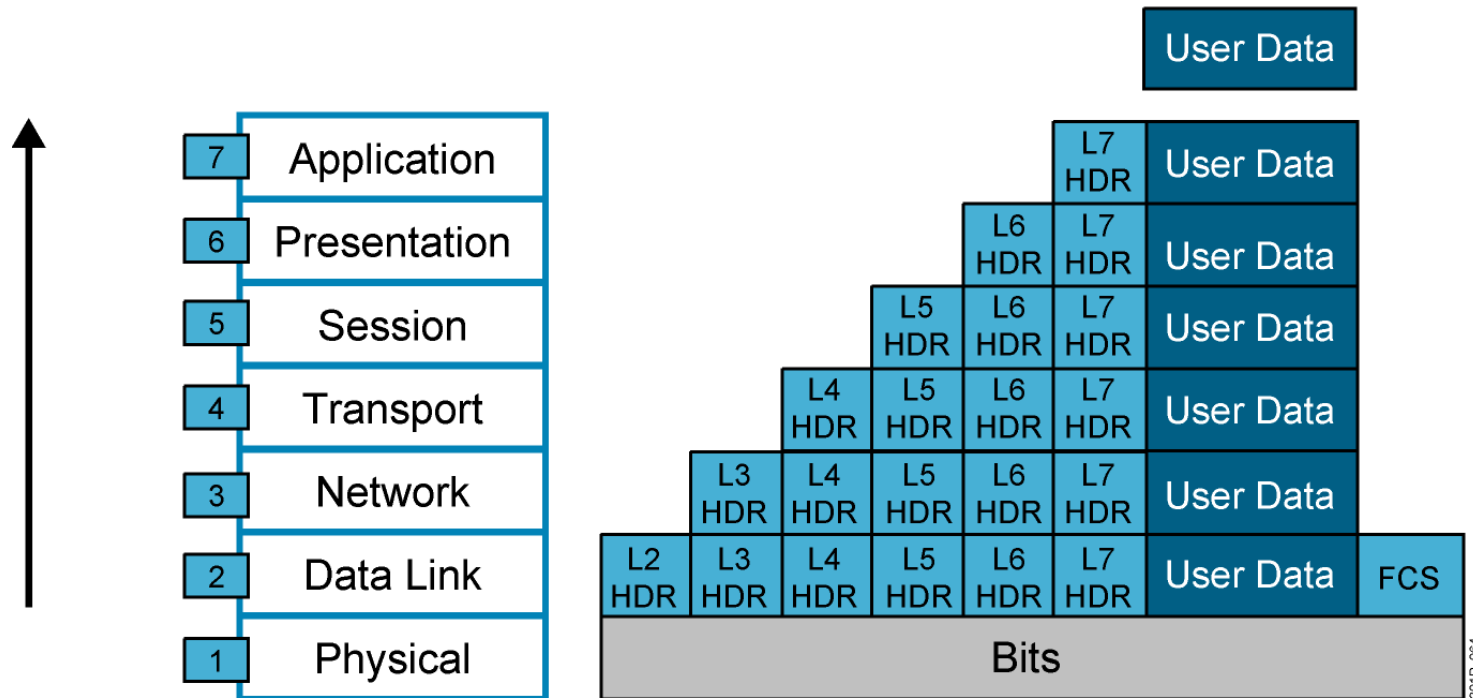
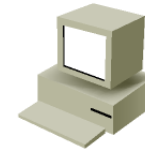
User Data



HDR = Header

Data De-Encapsulation

Receiver



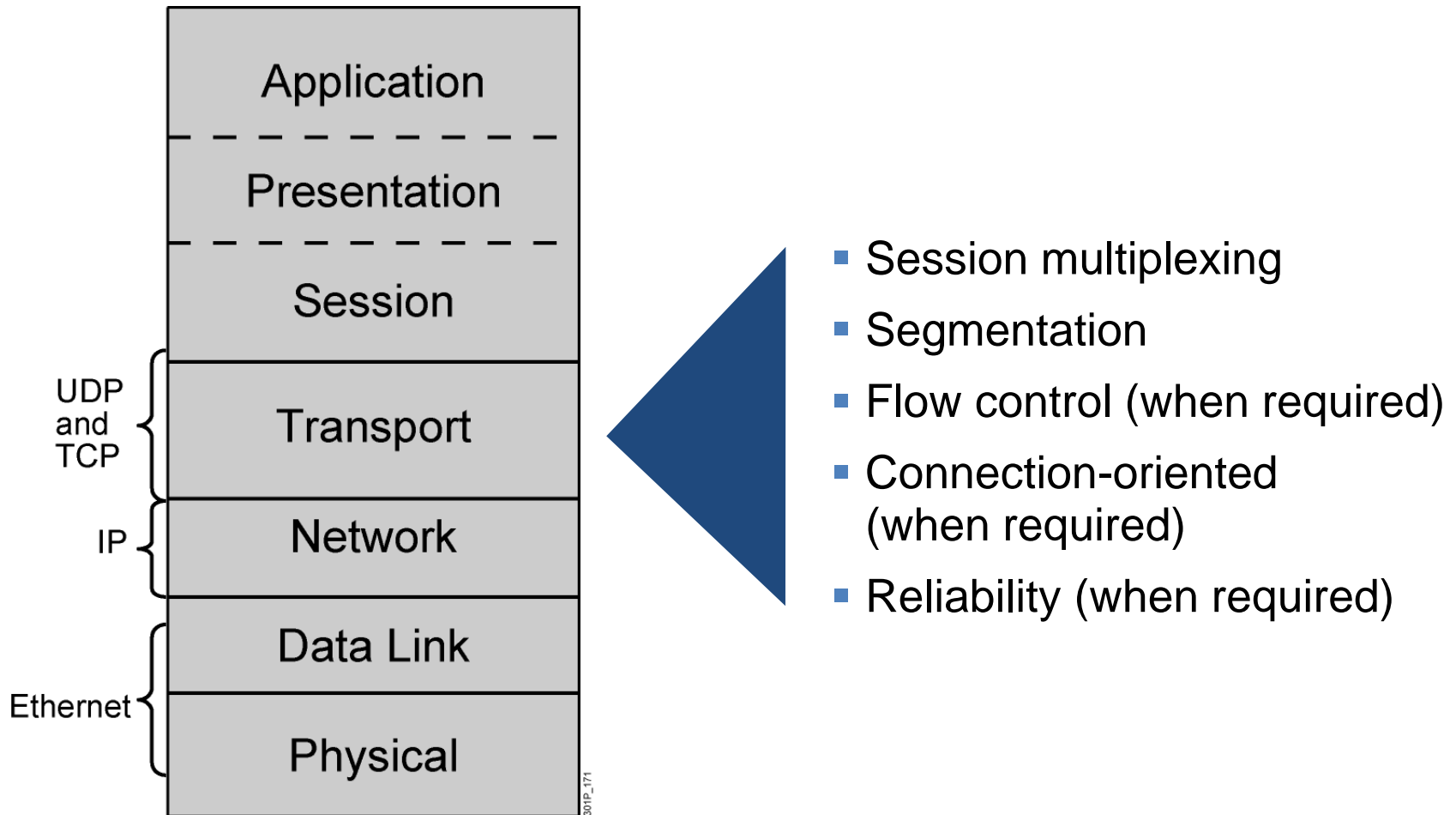
HDR = Header

Example Analogy

- **Russian nesting doll**



Transport Layer – TCP & UDP



Transport Layer – TCP & UDP

- **Hide the network requirements from the application layer**
- **Connection-oriented**
 - Reliable transport
 - TCP
 - *connection-oriented*
 - *provides error checking*
 - *delivers data reliably*
 - *operates in full-duplex mode*
- **Connectionless**
 - Best-effort transport
 - UDP
 - *provides applications with access to the network layer without the overhead of the reliability mechanisms of TCP.*
 - *Connectionless / best-effort*

Reliable vs. Best-Effort Comparison

	Reliable	Best-Effort
Connection Type	Connection-oriented	Connectionless
Protocol	TCP	UDP
Sequencing	Yes	No
Uses	<ul style="list-style-type: none">▪ E-mail▪ File sharing▪ Downloading	<ul style="list-style-type: none">▪ Voice streaming▪ Video streaming

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UDP Characteristics

- Operates at transport layer of OSI and TCP/IP models
- Provides applications with access to the network layer without the overhead of reliability mechanisms
- Is a **connectionless** protocol
 - *Faster*
- Provides limited error checking
- Provides **best-effort delivery**
 - *Real-time communications*
 - Voice & Video
- Has no data-recovery features



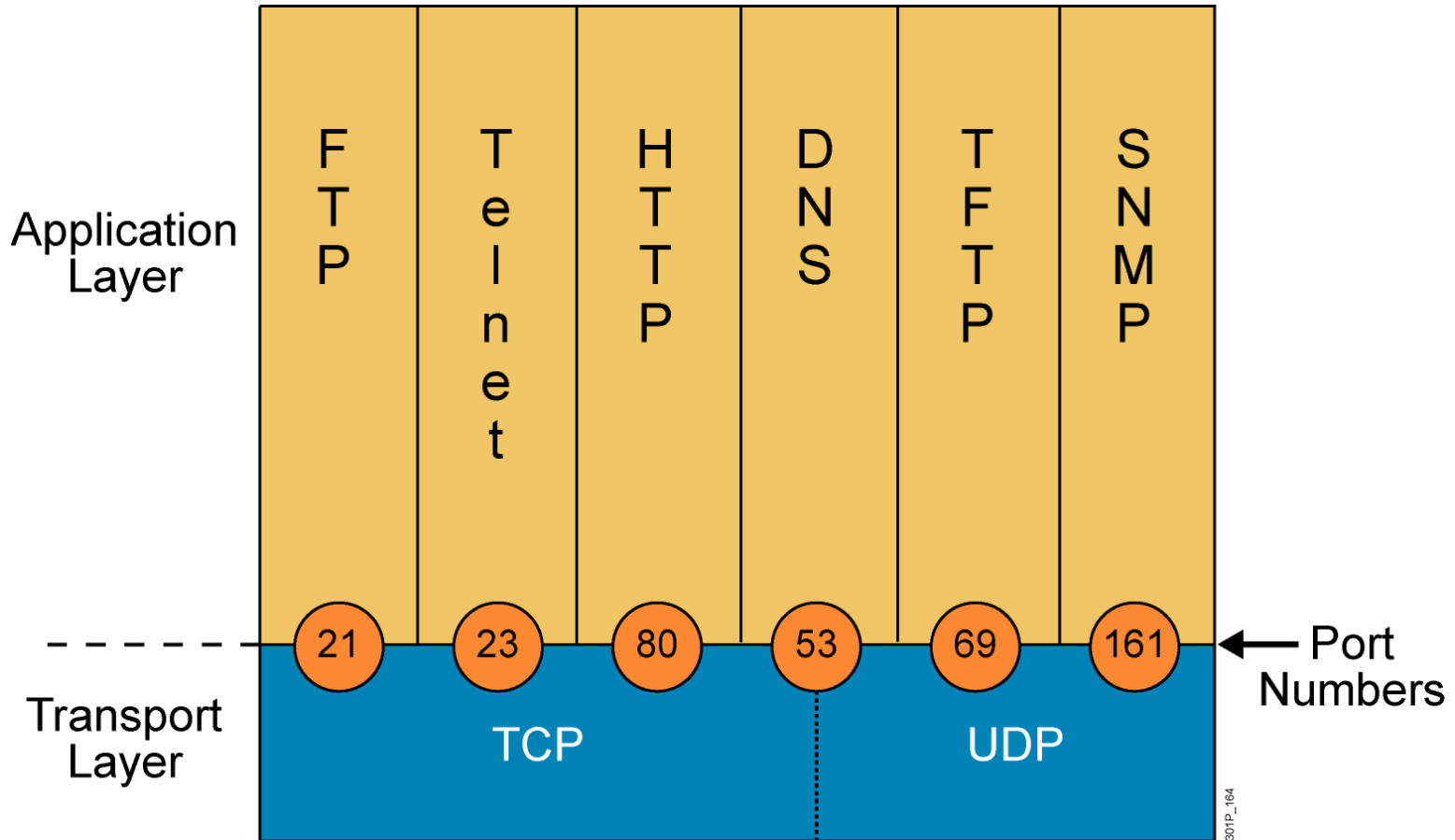
TCP Characteristics

- Transport layer of the TCP/IP stack
- Access to the network layer for applications
- **Connection-oriented** protocol
 - *reliable*
- Full-duplex mode operation
- Error checking
- Sequencing of data packets
- Acknowledgement of receipt
- Data-recovery features

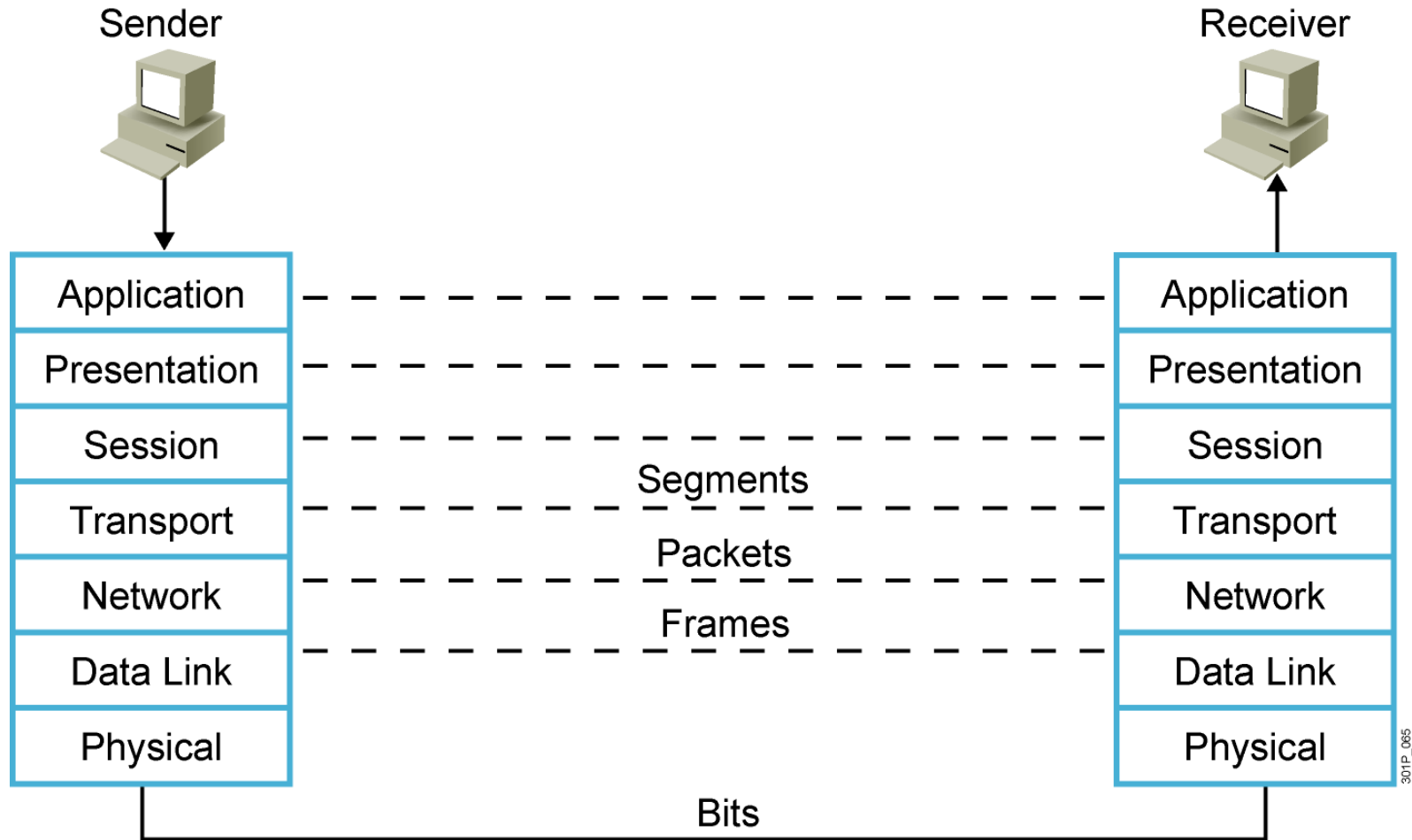
TCP

- Flow control
 - ***Prevents sending to a host and overflowing the buffer***
 - Results in slowing down the network
- Sequencing of segments / acknowledgment
 - ***When a single segment is sent, receipt is acknowledged, and the next segment is then sent***
 - ***Send <-> Ack***
- Window size
 - ***Allows a specified number of unacknowledged segments to be sent***
 - ***Sliding window***
 - window that can change size dynamically to accommodate the flow of segments

Mapping L4 to L7 (Applications)

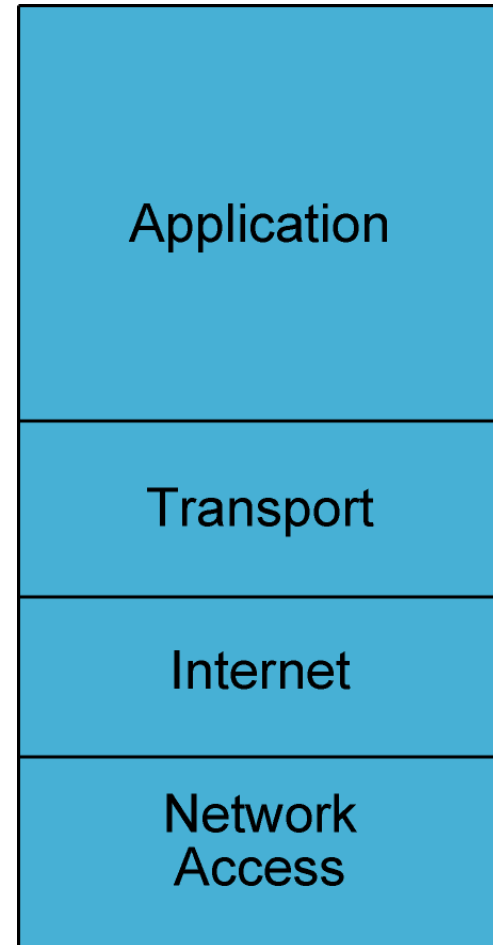


Peer-to-Peer Communication



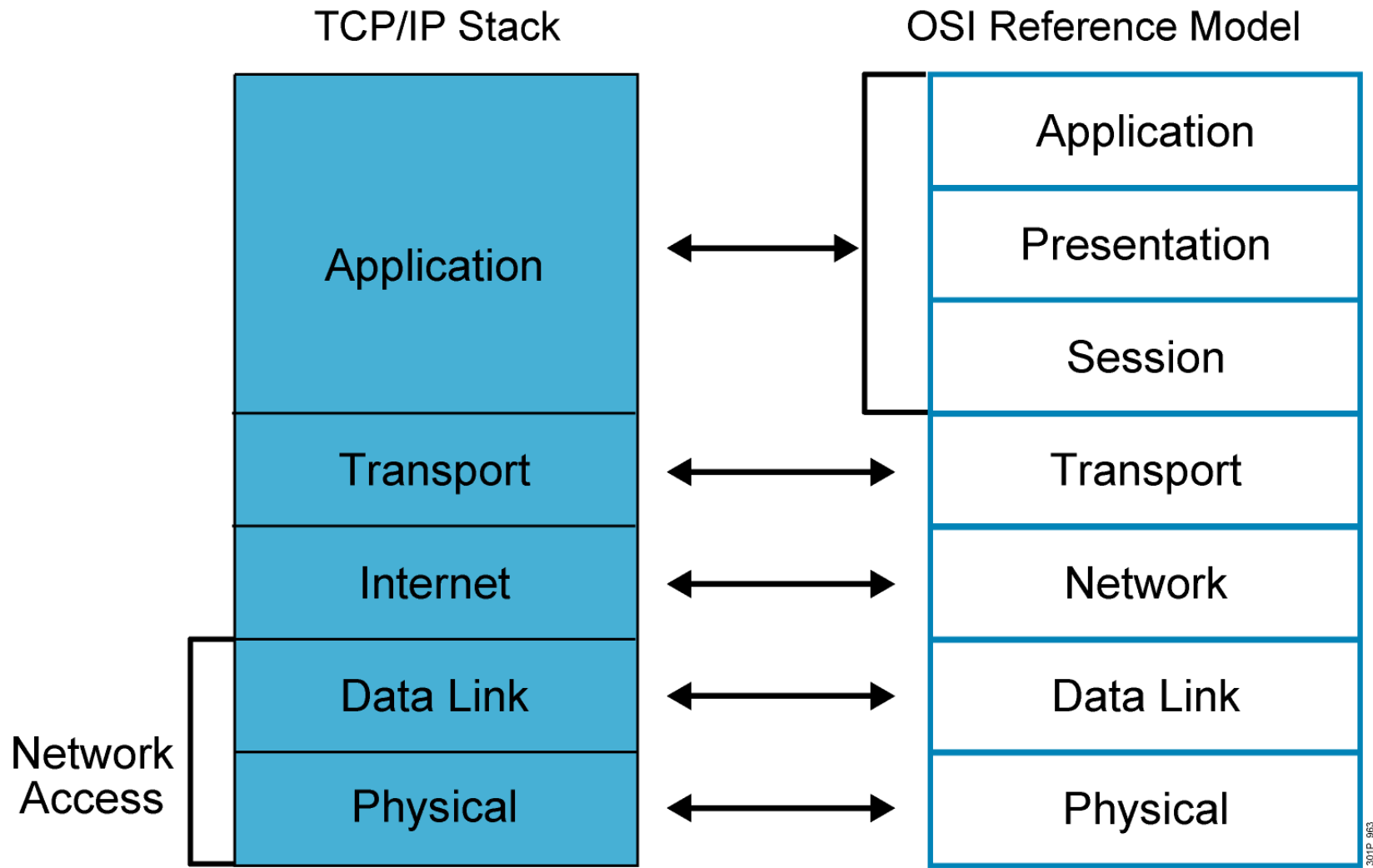
TCP/IP Stack

- Defines four layers
- Uses different names for Layers 1 through 3
- Combines Layers 5 through 7 into single application layer

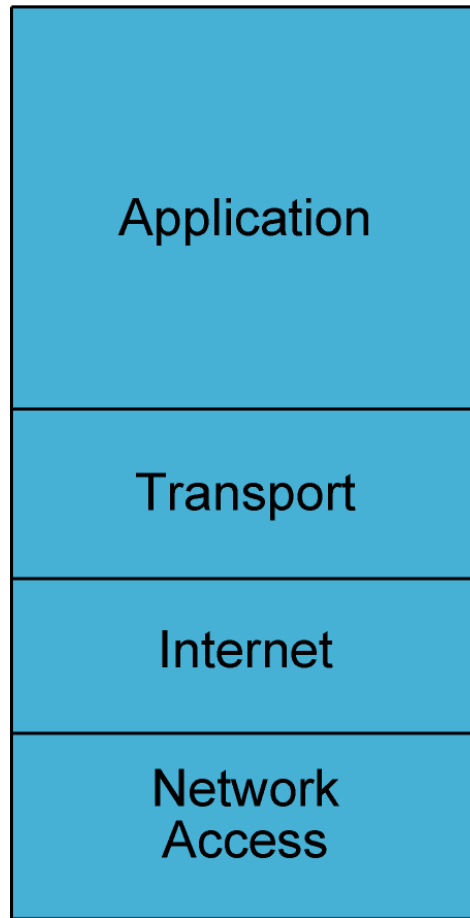


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TCP/IP Stack vs. OSI Model



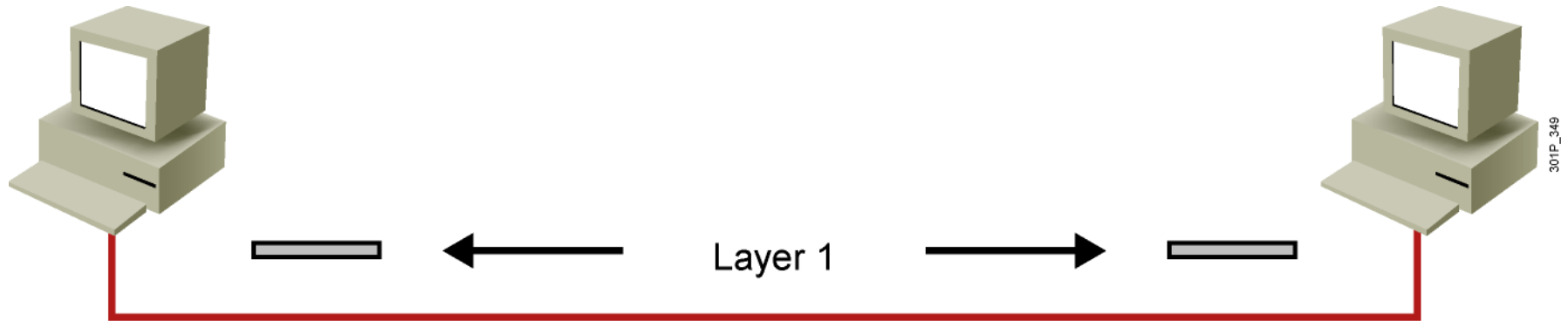
TCP/IP Application Layer Overview



- File transfer
 - FTP (20/21)
 - TFTP (69)
 - Secure Copy Protocol (SCP – 22)
- E-mail
 - Simple Mail Transfer Protocol (SMTP - 25)
- Remote login
 - Telnet (23)
 - SSH (22)
- Network management
 - Simple Network Management Protocol (SNMP - 161)
- Name management
 - Domain Name System (DNS - 53)



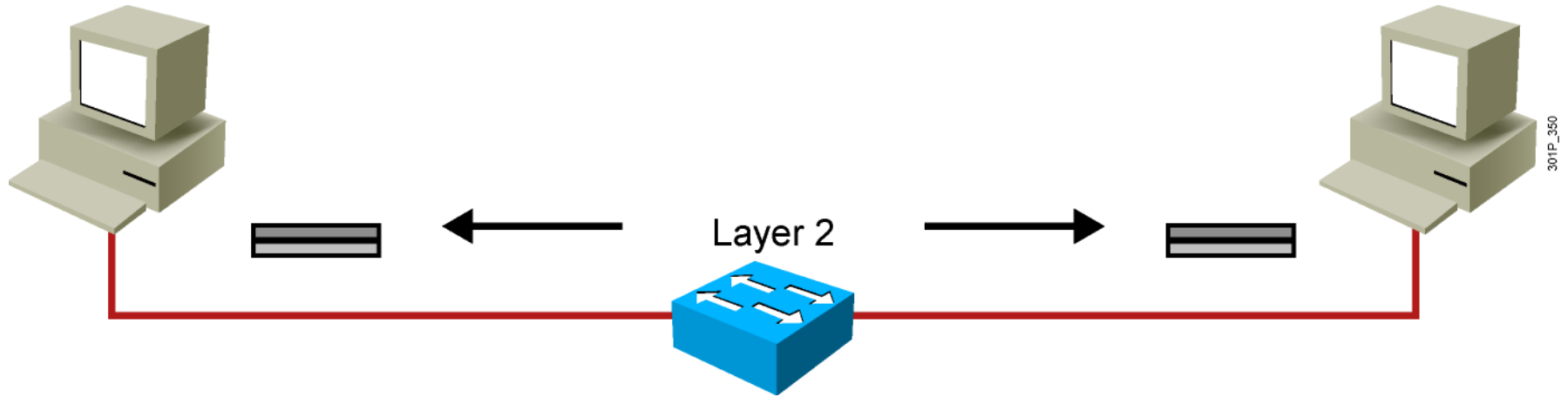
Layer 1 Devices



Ethernet

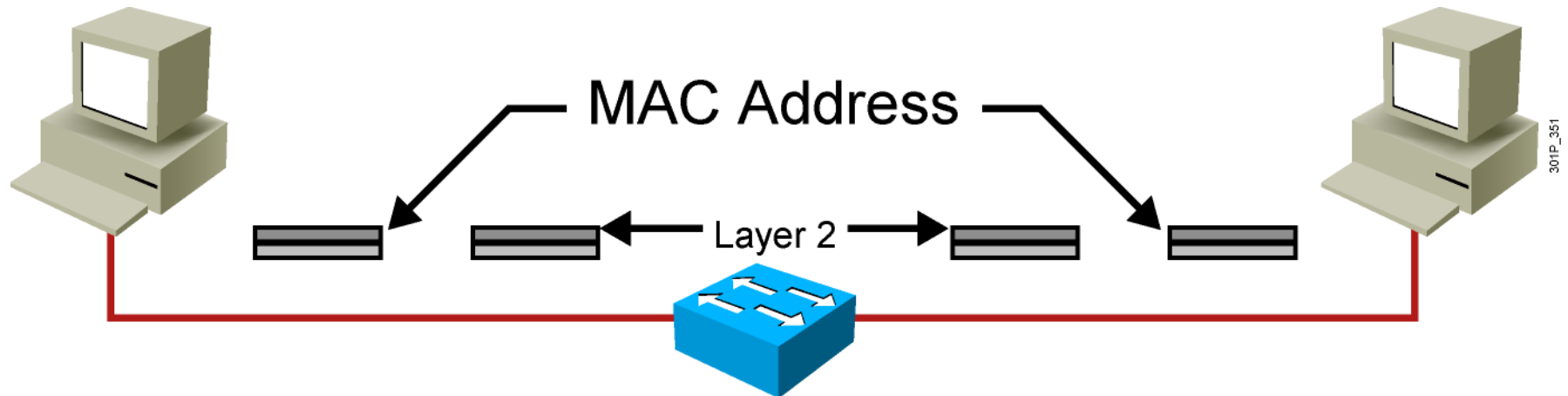
- Layer 1 provides the physical media and its encoding
- PDU = Bits – 1s and 0s
- Examples:
 - ***Serial***
 - ***Repeater / Hub***
 - ***Physical interface of the NIC***
 - ***Electrical signals***
 - ***Power cables***

Layer 2 Devices



- Layer 2 devices provide an interface with the physical media and physical addressing
- PDU = Frames
- Examples:
 - **NIC**
 - **Bridge**
 - **Switch**

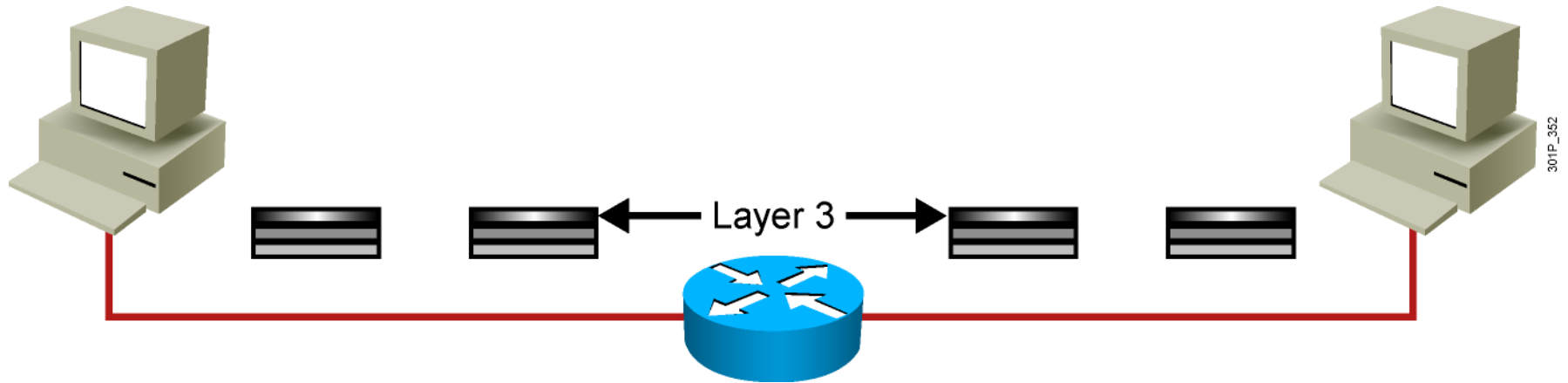
Layer 2 Addressing



- MAC address
 - **48-bit address (in Hexadecimal)**
 - **24 bits vendor specific & 24 bits host specific**
- Assigned to end devices
 - **Unique world-wide**
- This is how devices on the same segment communicate!
- In class exercise
 - **MAC address lookup**
 - Vendor Specific

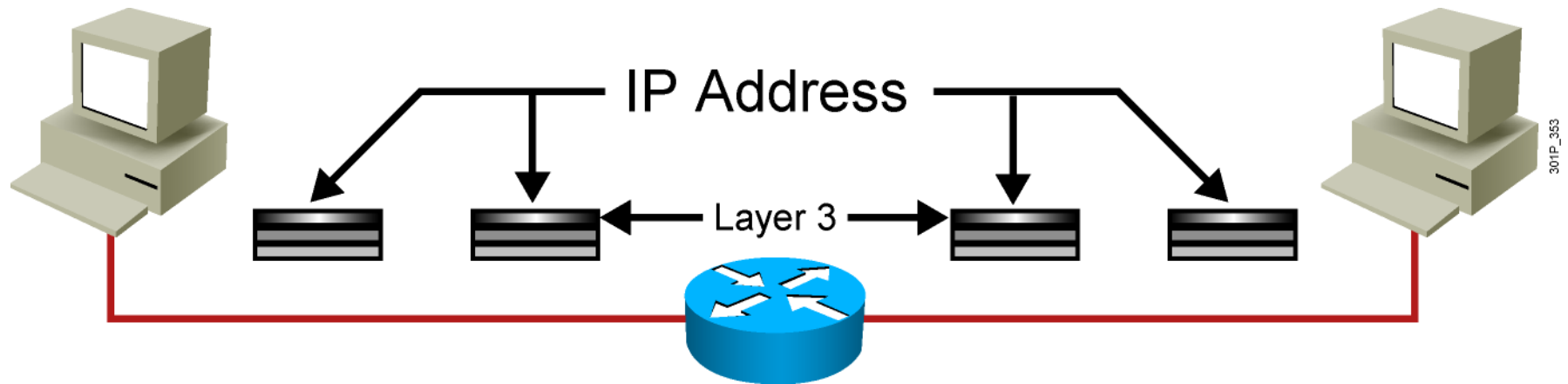


Layer 3 Devices and Their Function



- The network layer provides connectivity and path selection between two host systems.
- In the host, this is the path between the data link layer and the upper layers.
- In the router, it is the actual path across the network (routing and forwarding).

Layer 3 Addressing



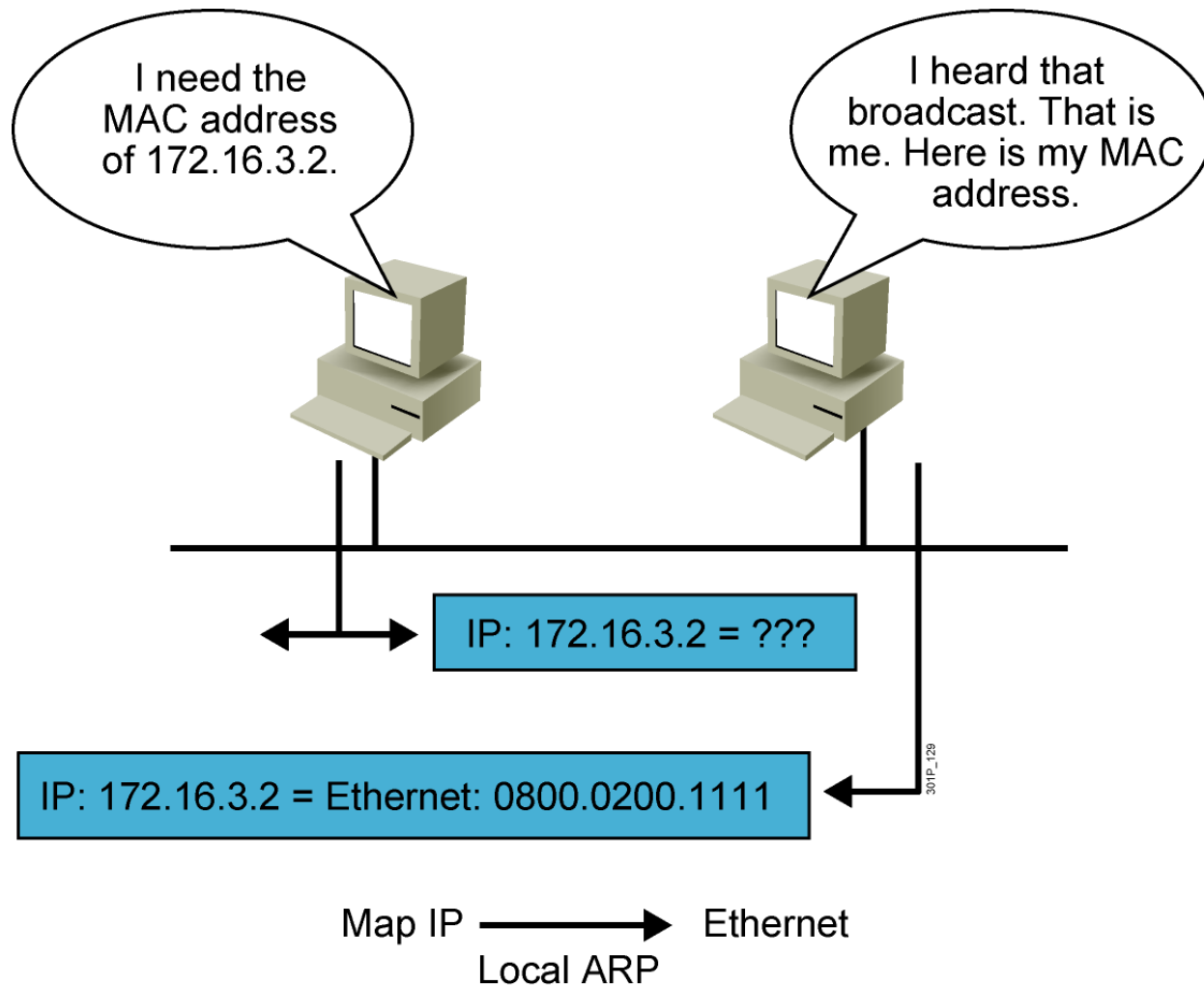
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- Each networking device has its own Layer 3 logical address (IP address)
- PDU = Packets
- Examples:
 - ***Routers***

Address Resolution Protocol (ARP)

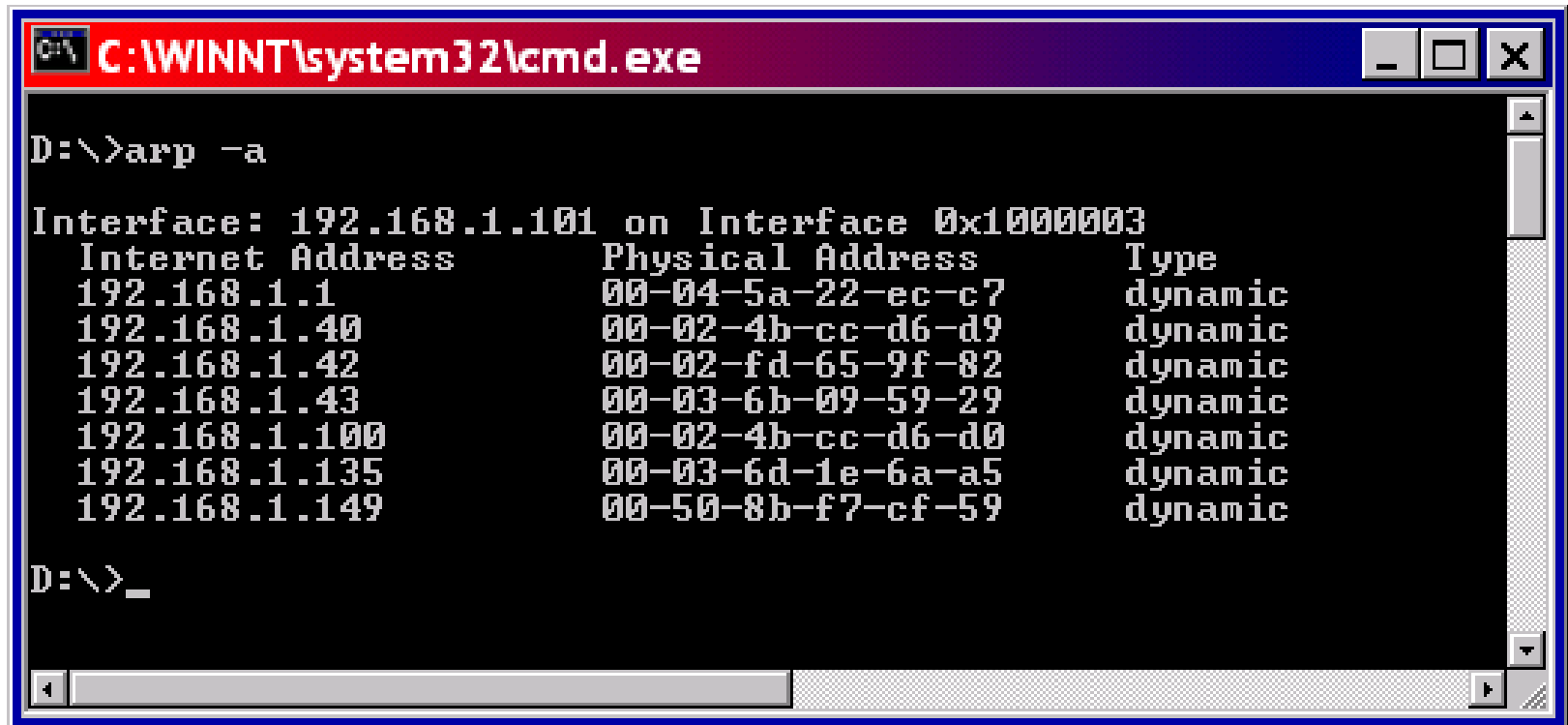
- **Provides a map of IP address to MAC address**
- **“I know the IP address (Layer 3), but I need the MAC address (Layer 2) to talk to it directly on my link (Ethernet).”**
- **Broadcast & Unicast**
 - Same link/network

Address Resolution Protocol (ARP)



ARP (See Appendix B for ARP)

ARP Table



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

D:\>arp -a

Interface: 192.168.1.101 on Interface 0x1000003
Internet Address      Physical Address      Type
192.168.1.1           00-04-5a-22-ec-c7     dynamic
192.168.1.40          00-02-4b-cc-d6-d9     dynamic
192.168.1.42          00-02-fd-65-9f-82     dynamic
192.168.1.43          00-03-6b-09-59-29     dynamic
192.168.1.100         00-02-4b-cc-d6-d0     dynamic
192.168.1.135         00-03-6d-1e-6a-a5     dynamic
192.168.1.149         00-50-8b-f7-cf-59     dynamic

D:\>_
```

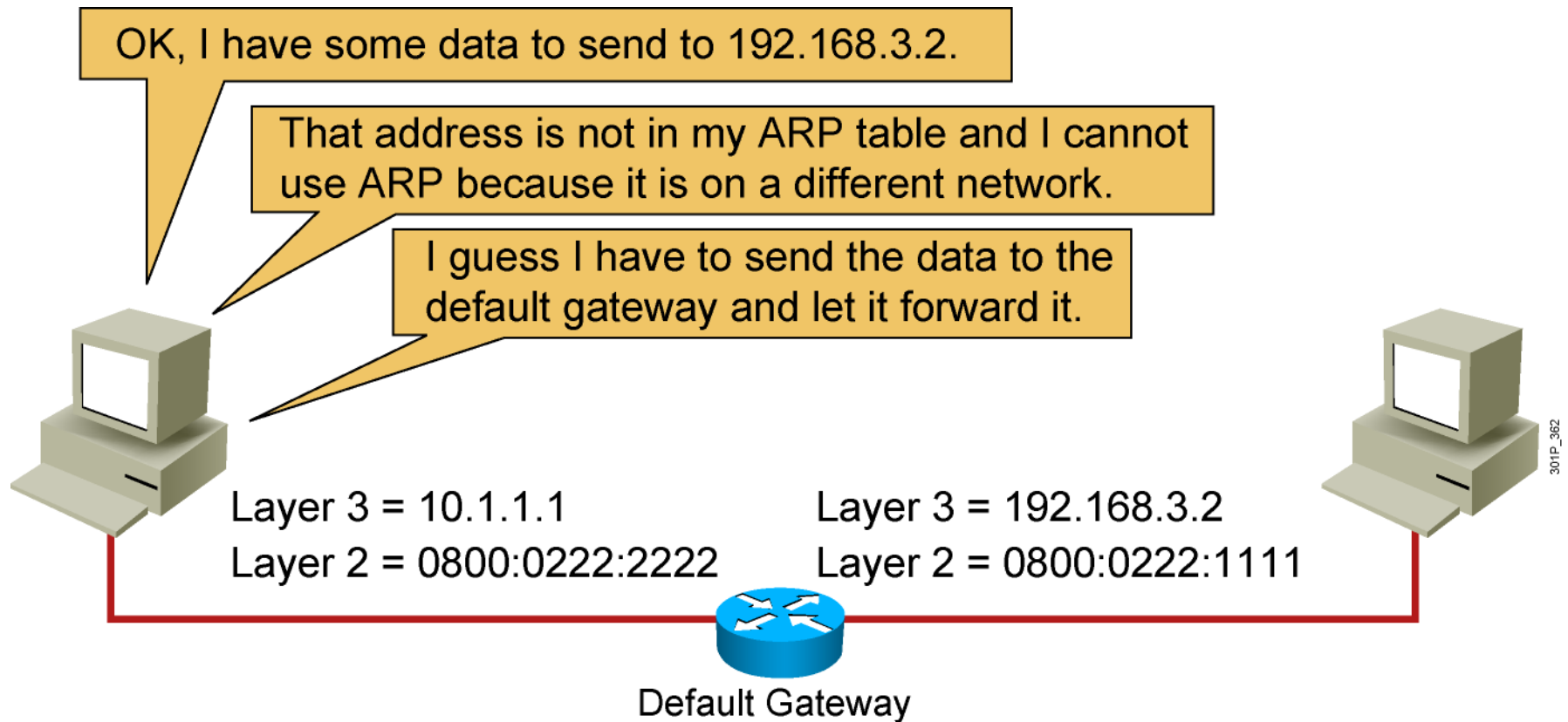

Review

- **ARP**
 - Broadcast
 - Maps known IP address to MAC address
- **MAC address is how devices communicate at Layer 2**
- **IP address is how devices communicate at Layer 3**

Remote Network

- **What happens if you want to send traffic to a device outside of your local network?**
 - IP address
 - Subnet mask
 - ARP
 - Default gateway

Default Gateway

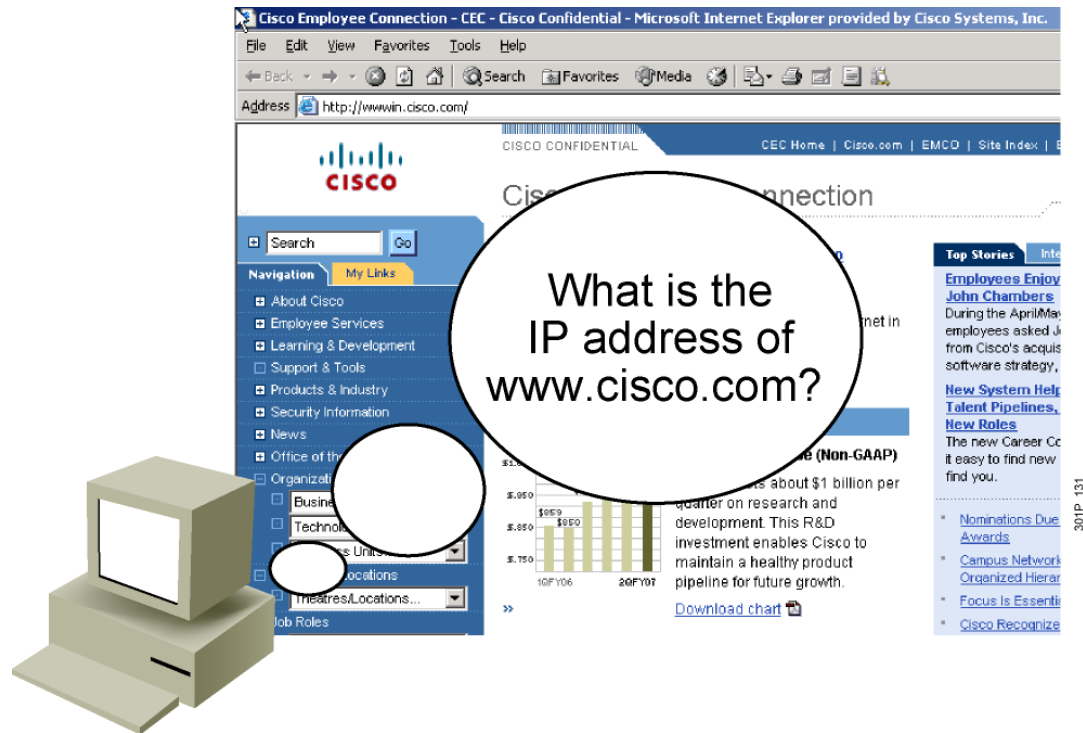


ipconfig/all (Windows) or *ifconfig | more* (Linux/Mac)

Wireless LAN adapter Wi-Fi:

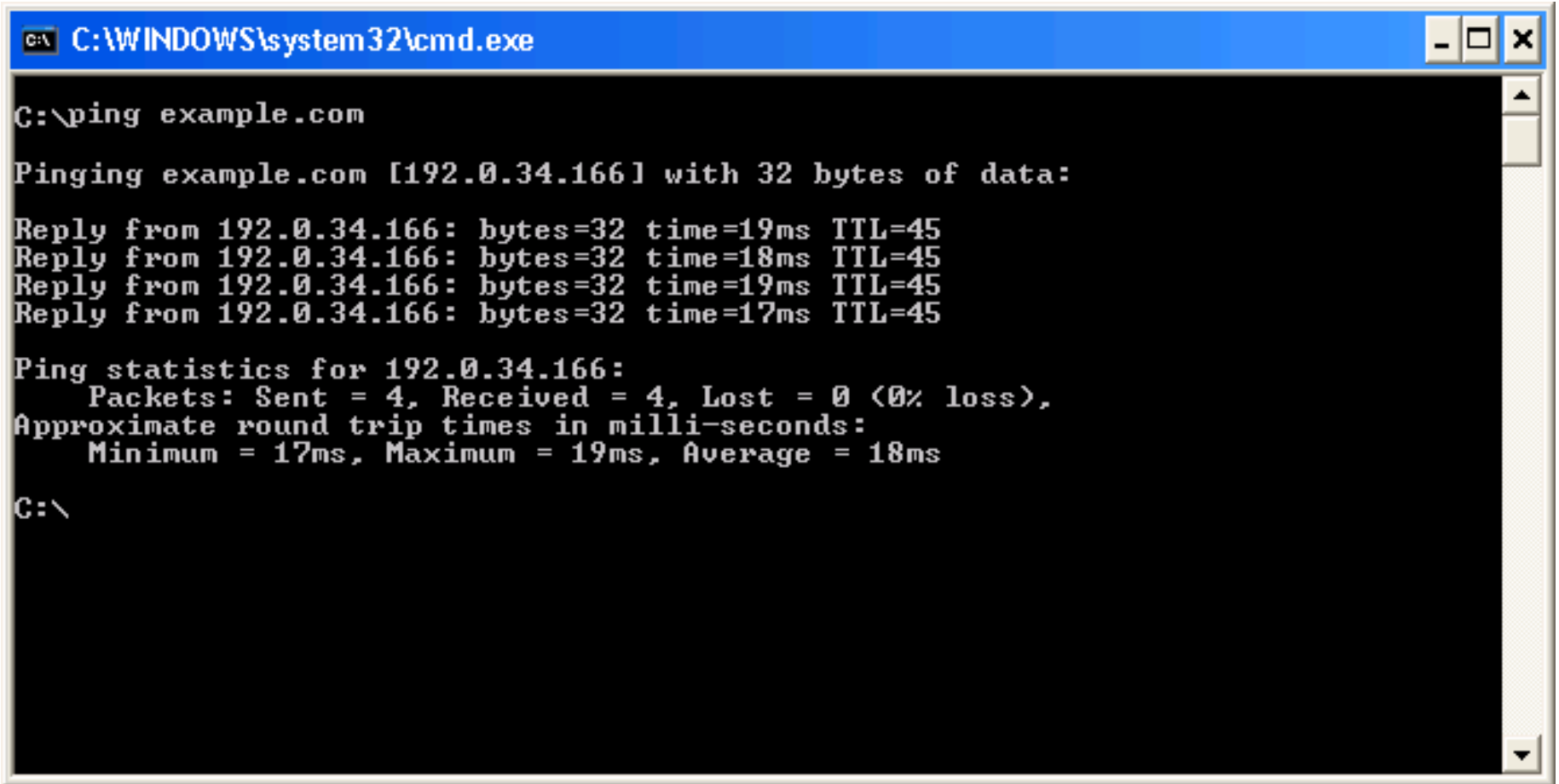
```
Connection-specific DNS Suffix . : 
Description . . . . . : Intel(R) Dual Band Wireless-AC 7260
Physical Address. . . . . : CC-3D-82-87-20-94
DHCP Enabled. . . . . : Yes
Autoconfiguration Enabled . . . . : Yes
Link-local IPv6 Address . . . . . : fe80::dc91:eadf:2fc7:a4c2%15(Preferred)
IPv4 Address. . . . . : 192.168.111.103(Preferred)
Subnet Mask . . . . . : 255.255.255.0
Lease Obtained. . . . . : Monday, August 29, 2016 8:28:21 AM
Lease Expires . . . . . : Tuesday, August 30, 2016 8:28:20 AM
Default Gateway . . . . . : 192.168.111.254
DHCP Server . . . . . : 192.168.111.254
DHCPv6 IAID . . . . . : 80493954
DHCPv6 Client DUID. . . . . : 00-01-00-01-1C-C8-5E-5B-28-80-23-0B-6D-C4
DNS Servers . . . . . : 208.67.222.222
                        208.67.220.220
                        192.168.111.254
NetBIOS over Tcpip. . . . . : Enabled
```

DNS



- Application specified in the TCP/IP suite
- A way to translate human-readable names into IP addresses

Host-Based Tools: ping



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

C:\>ping example.com

Pinging example.com [192.0.34.166] with 32 bytes of data:

Reply from 192.0.34.166: bytes=32 time=19ms TTL=45
Reply from 192.0.34.166: bytes=32 time=18ms TTL=45
Reply from 192.0.34.166: bytes=32 time=19ms TTL=45
Reply from 192.0.34.166: bytes=32 time=17ms TTL=45

Ping statistics for 192.0.34.166:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
    Approximate round trip times in milli-seconds:
        Minimum = 17ms, Maximum = 19ms, Average = 18ms

C:\>
```

ICMP: Internet Control Message Protocol

- Used by hosts & routers to communicate network-level information
 - error reporting: unreachable host, network, port, protocol
 - echo request/reply (used by ping)
- Network-layer “above” IP:
 - ICMP msgs carried in IP datagrams
- ICMP message: type, code plus first 8 bytes of IP datagram causing error

<u>Type</u>	<u>Code</u>	<u>description</u>
0	0	echo reply (ping)
3	0	dest. network unreachable
3	1	dest host unreachable
3	2	dest protocol unreachable
3	3	dest port unreachable
3	6	dest network unknown
3	7	dest host unknown
4	0	source quench (congestion control - not used)
8	0	echo request (ping)
9	0	route advertisement
10	0	router discovery
11	0	TTL expired
12	0	bad IP header

Host-Based Tools: traceroute

```
C:\WINDOWS\system32\cmd.exe
Microsoft Windows XP [Version 5.1.2600]
(C) Copyright 1985-2001 Microsoft Corp.

C:\Documents and Settings\pvancil>tracert yahoo.com

Tracing route to yahoo.com [66.94.234.13]
over a maximum of 30 hops:

  0  1 ms    1 ms    1 ms    rtp-pvancil-vpn.cisco.com [10.83.2.161]
  1  67 ms   59 ms   57 ms   rtp5-access-sdgi-t10.cisco.com [10.82.96.2]
  2  58 ms   58 ms   57 ms   rtp5-access-gw1-vlan100.cisco.com [10.83.100.9]

  3  58 ms   58 ms   57 ms   rtp7-bb-gw1-ge5-8.cisco.com [10.81.254.117]
  4  60 ms   59 ms   57 ms   rtp5-rbb-gw1-ge4-2.cisco.com [10.81.254.181]
  5  58 ms   59 ms   60 ms   rtp5-corp-gw1.cisco.com [10.81.254.194]
  6  59 ms   58 ms   58 ms   rtp7-dmzbb-gw1.cisco.com [64.102.241.135]
  7  60 ms   60 ms   58 ms   rtp1-isp-gw1-g1-2.cisco.com [64.102.254.193]
  8  59 ms   58 ms   58 ms   rtp5-isp-ssw1-v110.cisco.com [64.102.254.174]
  9  59 ms   59 ms   58 ms   rtp5-isp-ssw1-v151.cisco.com [64.102.254.249]
 10  60 ms   60 ms   59 ms   rtp1-isp-gw1-v100.cisco.com [64.102.254.165]
 11  64 ms   66 ms   65 ms   sl-gw20-rly-1-0.sprintlink.net [144.232.244.209]

 12  64 ms   66 ms   68 ms   sl-bb20-rly-3-2.sprintlink.net [144.232.14.29]
 13  66 ms   64 ms   65 ms   sl-bb24-rly-9-0.sprintlink.net [144.232.14.122]

 14  66 ms   66 ms   69 ms   sl-st22-ash-5-0.sprintlink.net [144.232.20.155]

 15  67 ms   68 ms   67 ms   te-4-2.car4.Washington1.Level3.net [4.68.111.169]
 16  67 ms   127 ms  68 ms   ae-2-54.bbr2.Washington1.Level3.net [4.68.121.97]

 17 136 ms   *      137 ms  as-1-0.bbr2.SanJose1.Level3.net [64.159.0.242]
 18 134 ms   136 ms  133 ms  ae-23-52.car3.SanJose1.Level3.net [4.68.123.45]

 19 142 ms   135 ms  135 ms  4.71.112.14
 20 133 ms   134 ms  134 ms  ge-3-0-0-p271.ms2.scd.yahoo.com [216.115.106.19]

 21 135 ms   135 ms  135 ms  ten-2-3-bas1.scd.yahoo.com [66.218.82.221]
 22 136 ms   136 ms  135 ms  w2.rc.vip.scd.yahoo.com [66.94.234.13]

Trace complete.
```

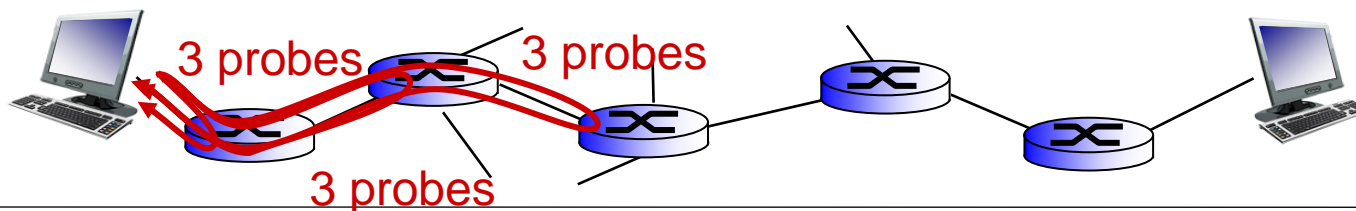

Traceroute and ICMP

- **Source sends series of UDP (depends on OS) segments to destination**
 - first set has TTL = 1
 - second set has TTL=2, etc.
 - unlikely port number
- **When datagram in n th set arrives to n th router:**
 - router discards datagram and sends source ICMP message (type 11, code 0)
 - ICMP message include name of router & IP address

- **When ICMP message arrives, source records RTTs**

Stopping criteria:

- UDP segment eventually arrives at destination host
- Destination returns ICMP “port unreachable” message (type 3, code 3)
- Source stops



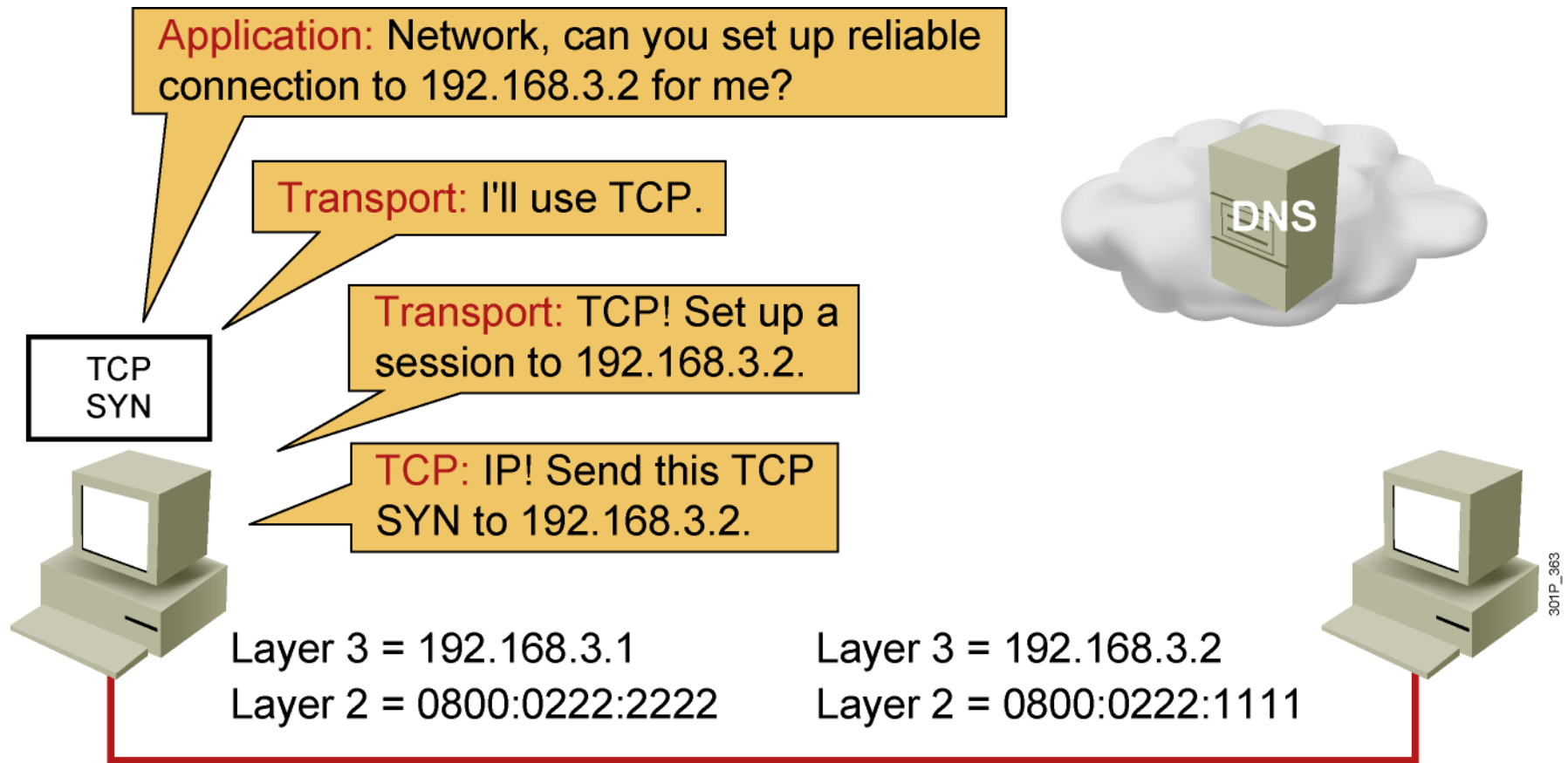
Questions?



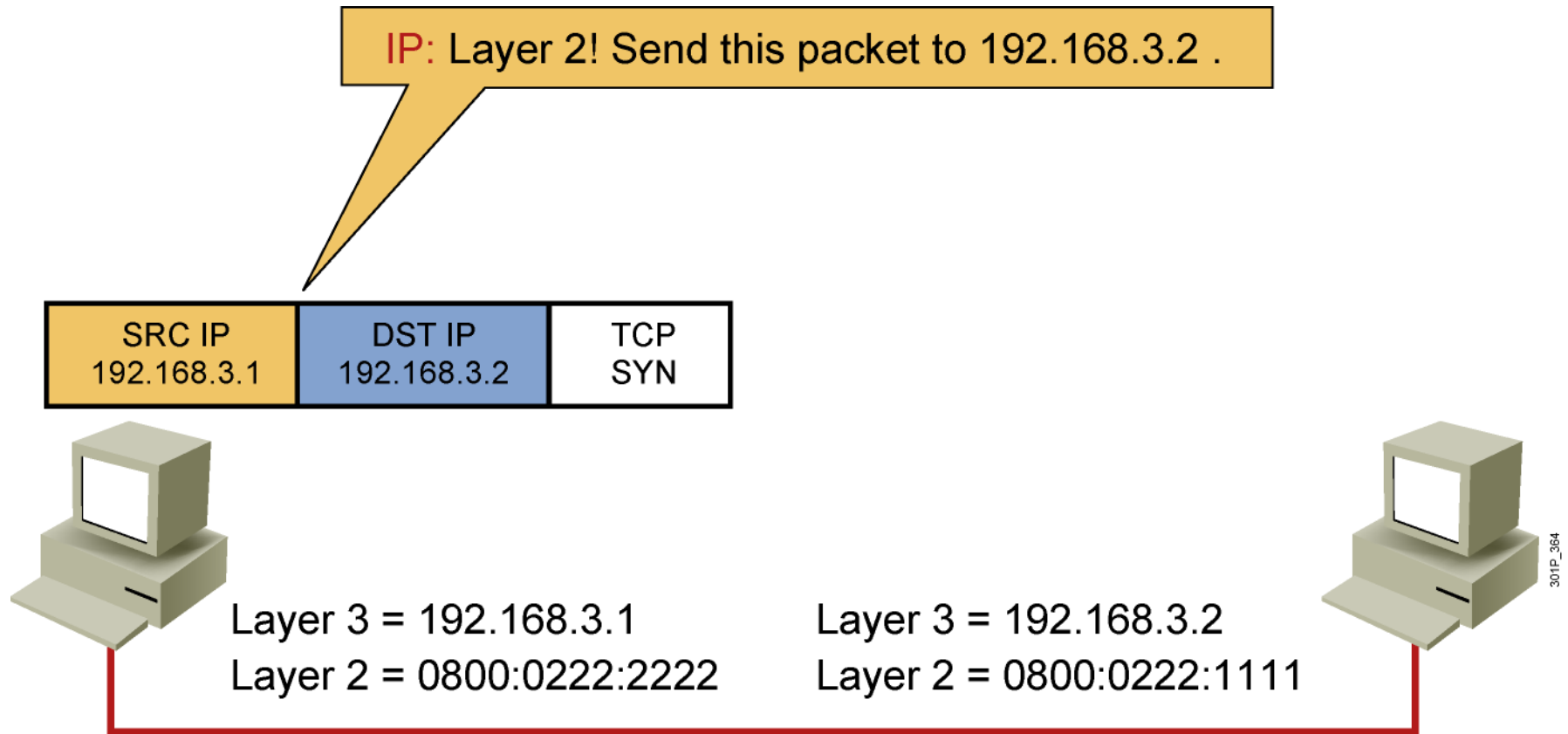
Lab

Appendix B - ARP

Host-to-Host Packet Delivery (1 of 22)



Host-to-Host Packet Delivery (2 of 22)

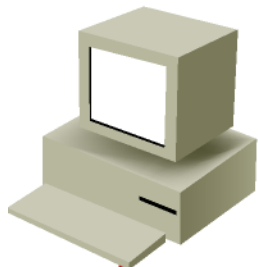


Host-to-Host Packet Delivery (3 of 22)

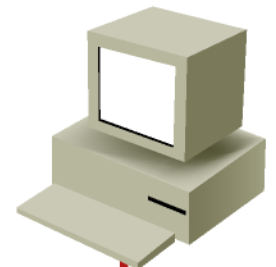
Layer 2: ARP, do you have a mapping for 192.168.3.2?

ARP: Is 192.168.3.2 in my ARP table? No, I guess Layer 2 will have to put the packet in the parking lot until I do an ARP.

SRC IP 192.168.3.1	DST IP 192.168.3.2	TCP SYN
-----------------------	-----------------------	------------



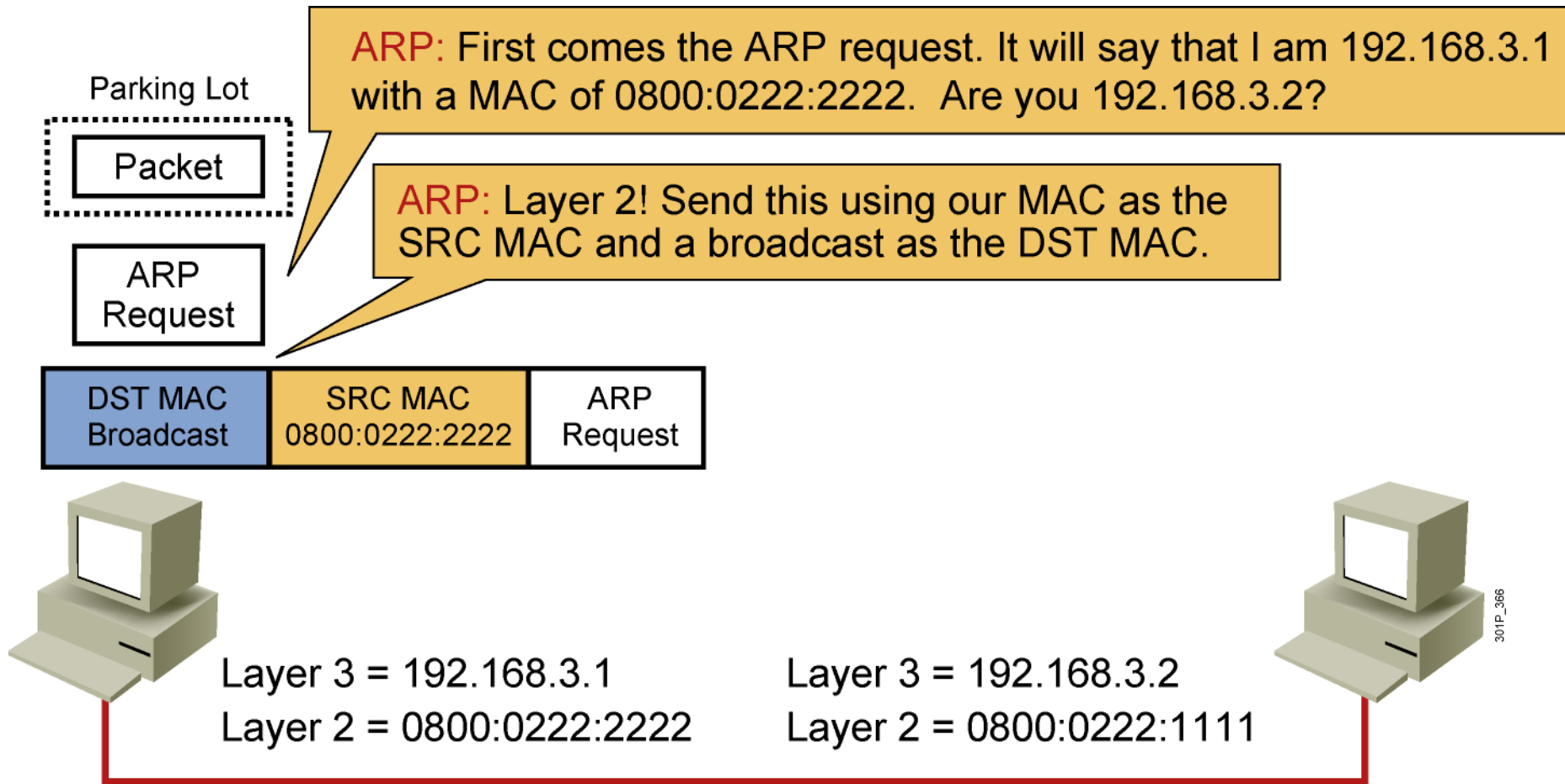
Layer 3 = 192.168.3.1
Layer 2 = 0800:0222:2222



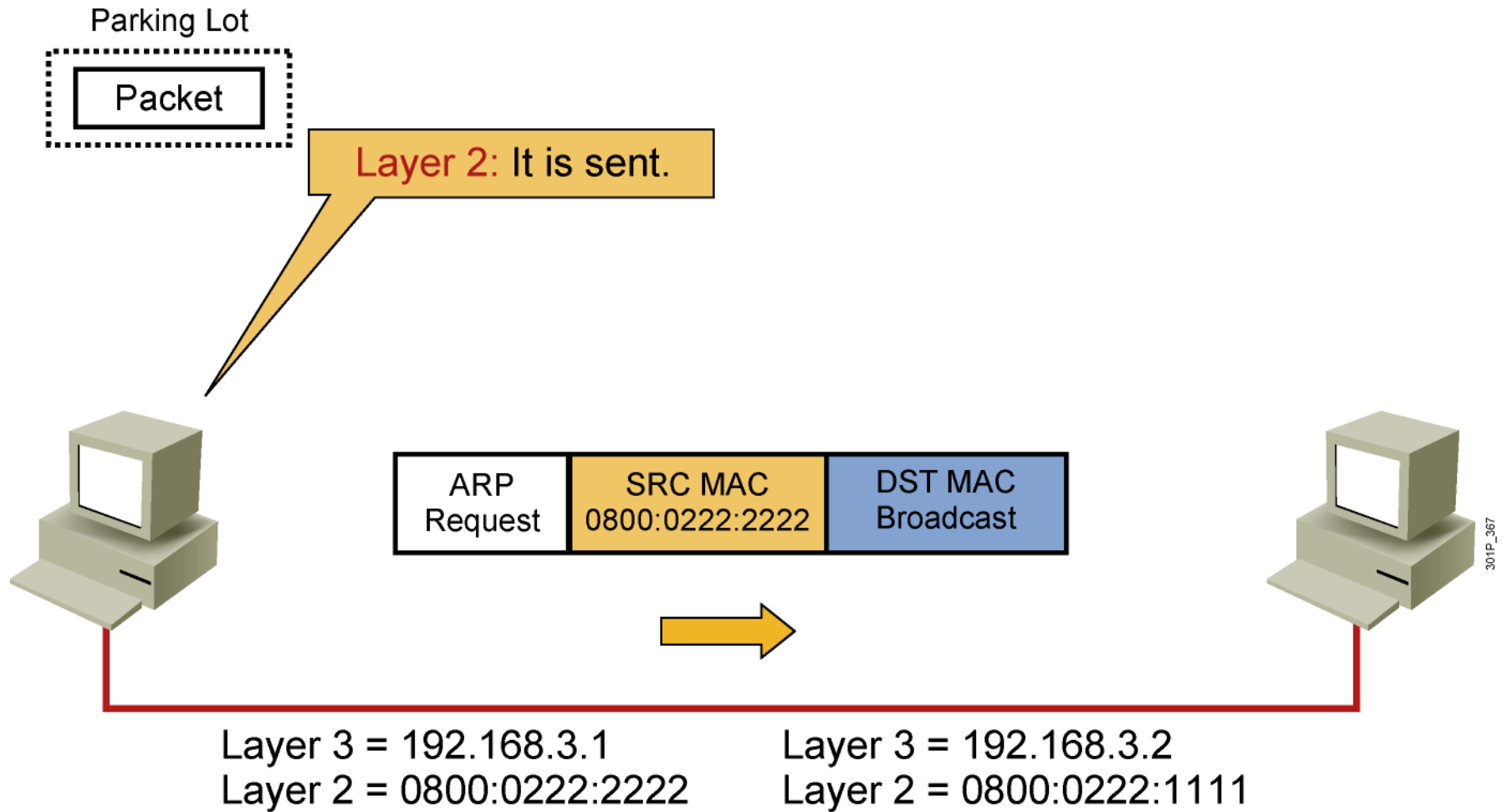
Layer 3 = 192.168.3.2
Layer 2 = 0800:0222:1111

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Host-to-Host Packet Delivery (4 of 22)



Host-to-Host Packet Delivery (5 of 22)

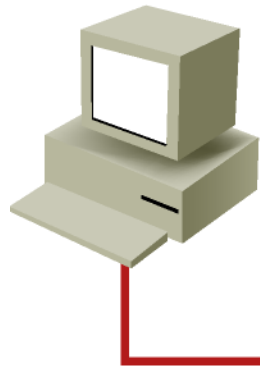


Host-to-Host Packet Delivery (6 of 22)

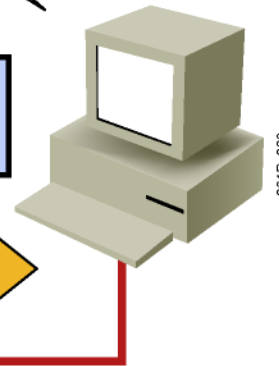
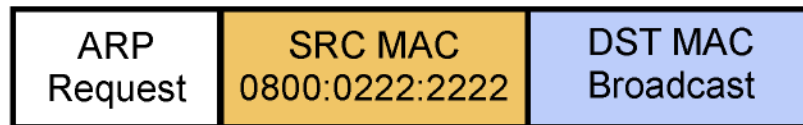
Parking Lot



Layer 2: I just got a frame with a broadcast MAC so I'll process it. The protocol ID indicates that it belongs to ARP. Let me strip the Layer 2 header and send it to ARP.

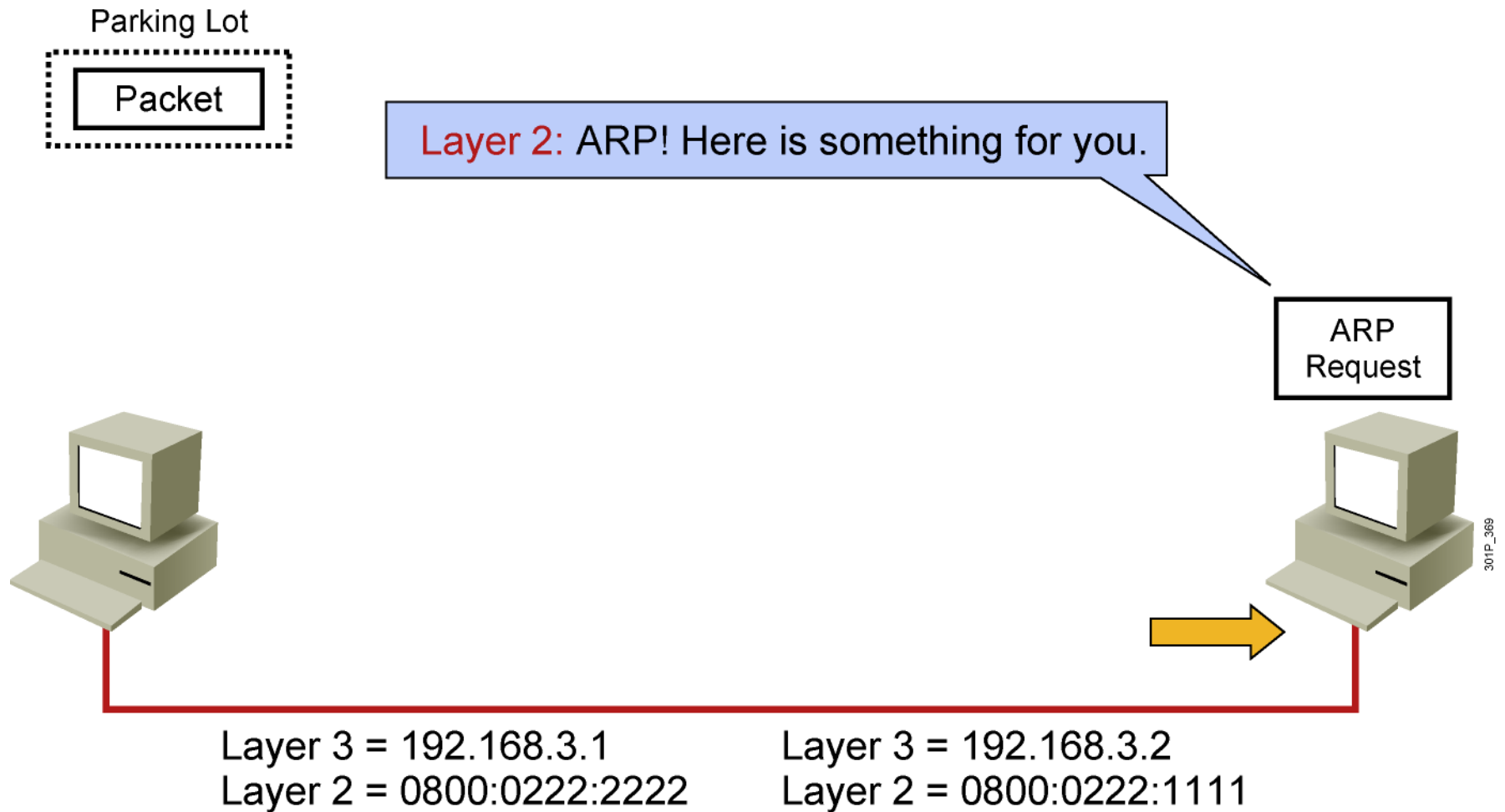


Layer 3 = 192.168.3.1
Layer 2 = 0800:0222:2222

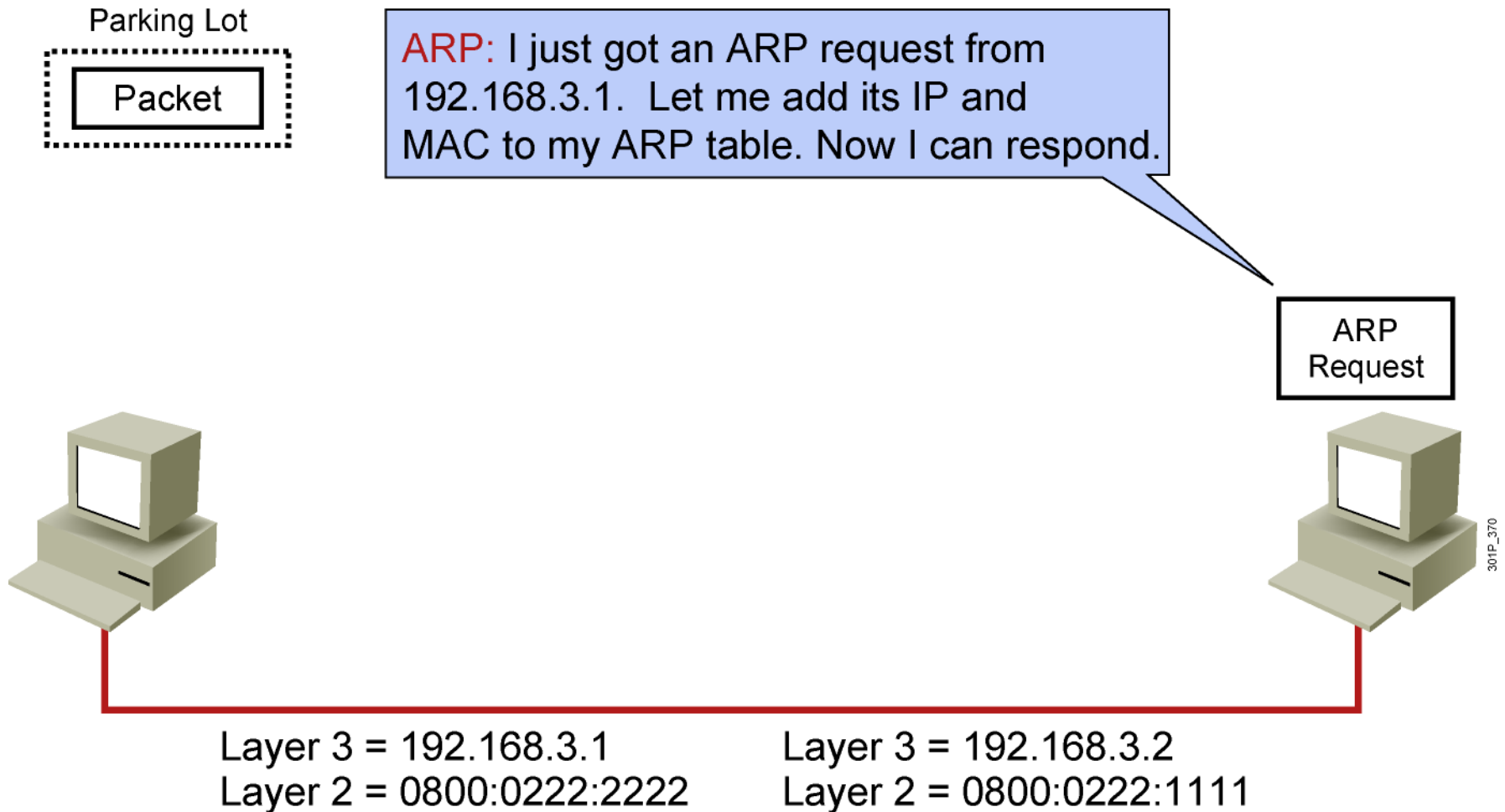


Layer 3 = 192.168.3.2
Layer 2 = 0800:0222:1111

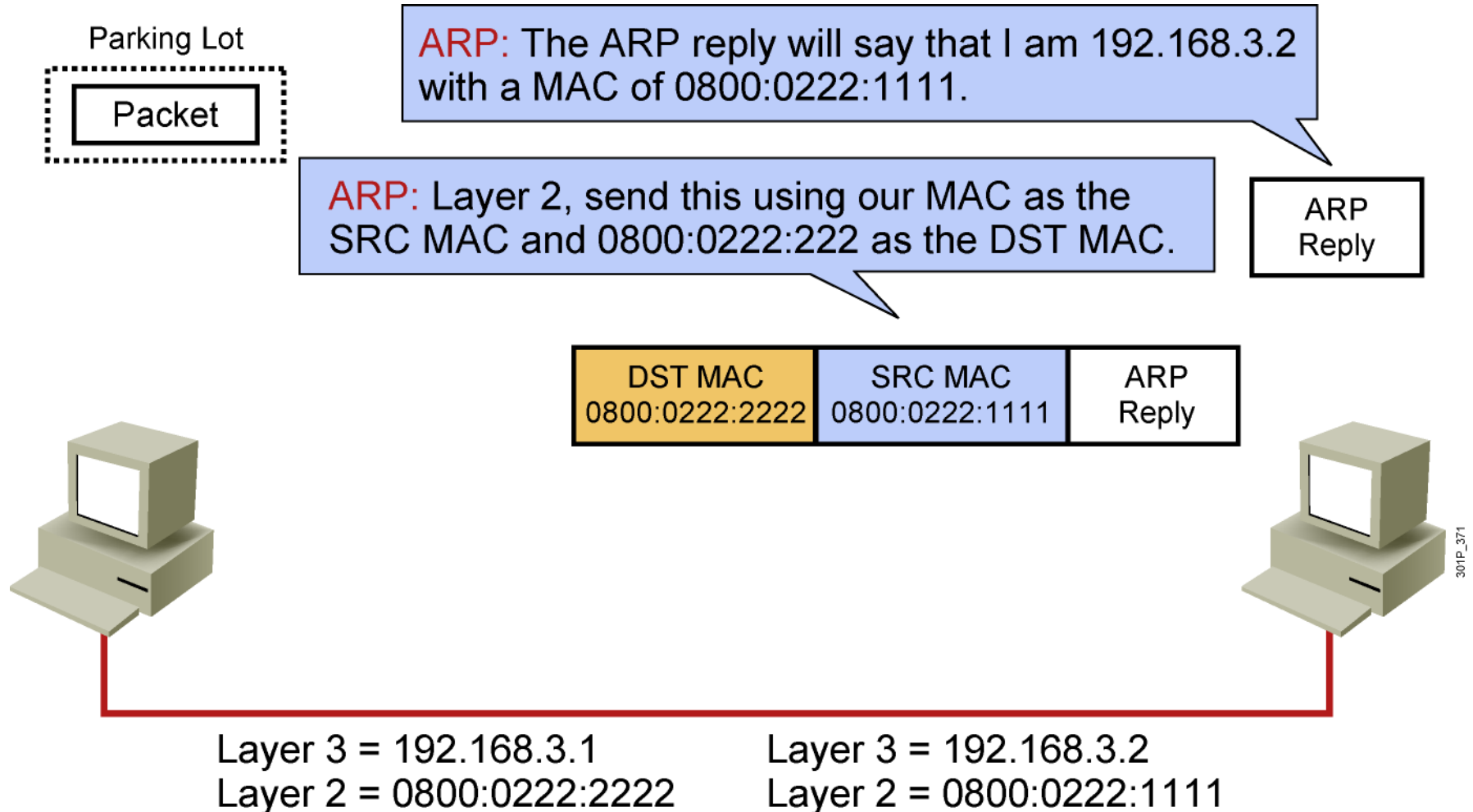
Host-to-Host Packet Delivery (7 of 22)



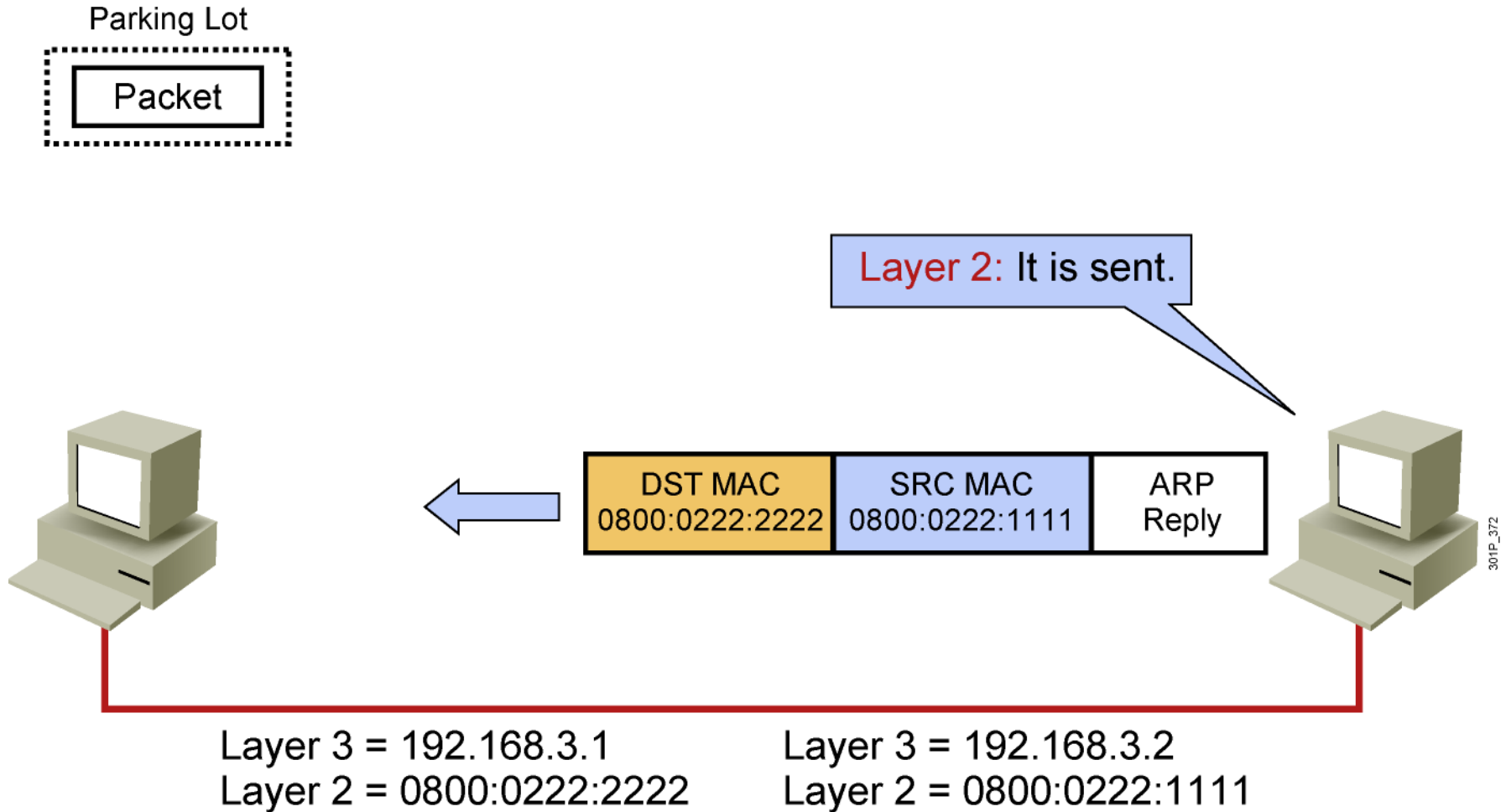
Host-to-Host Packet Delivery (8 of 22)



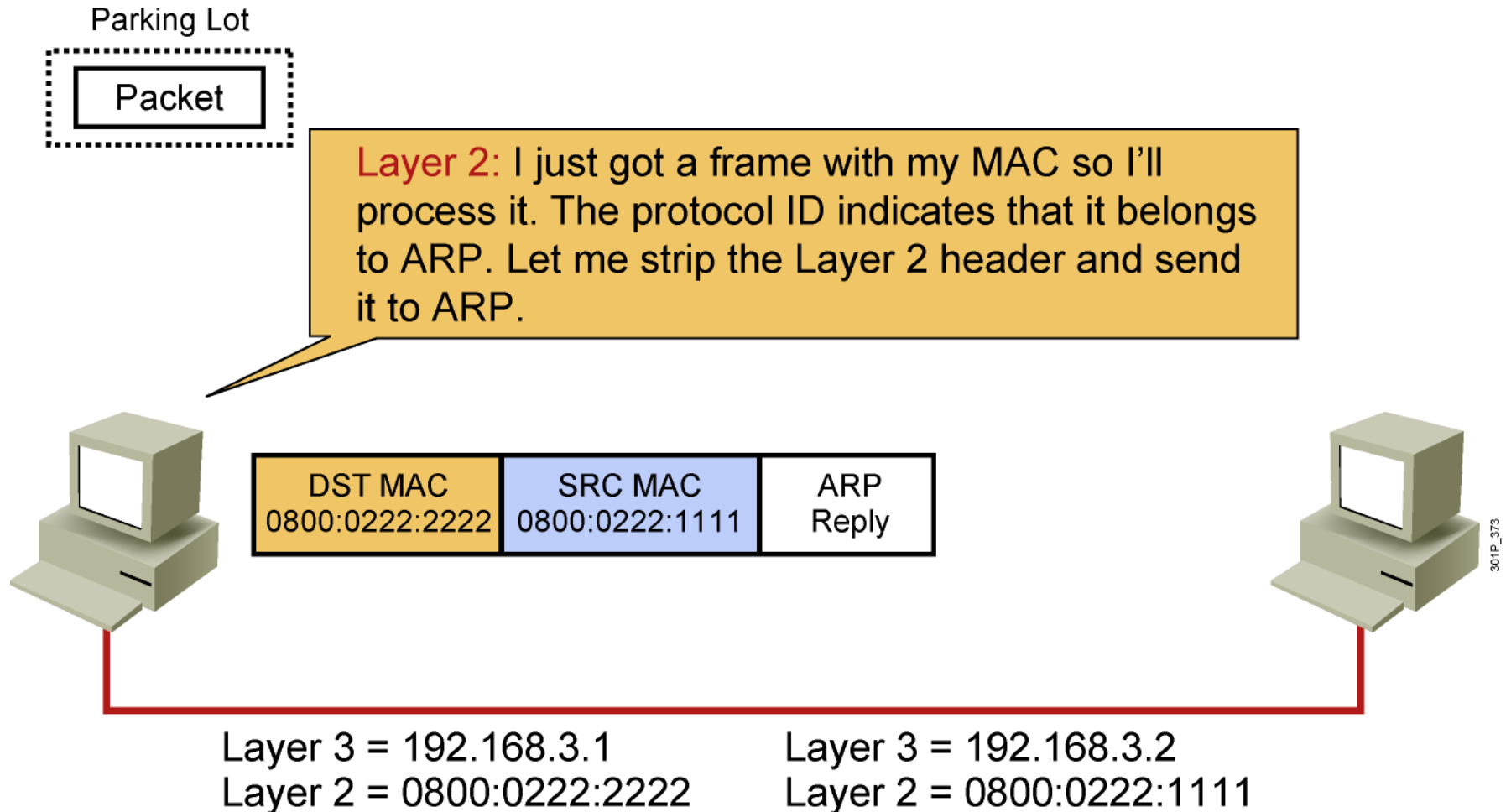
Host-to-Host Packet Delivery (9 of 22)



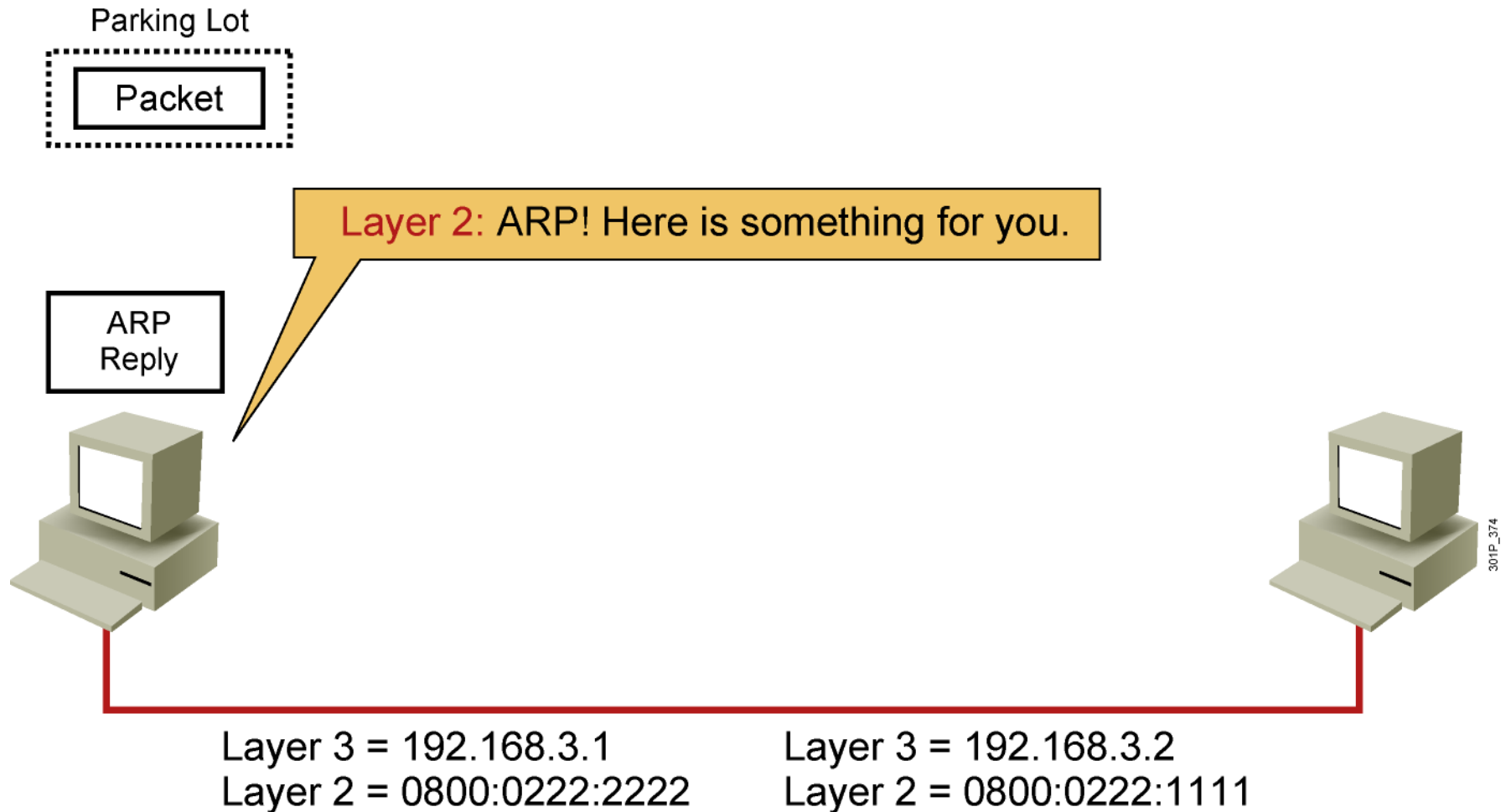
Host-to-Host Packet Delivery (10 of 22)



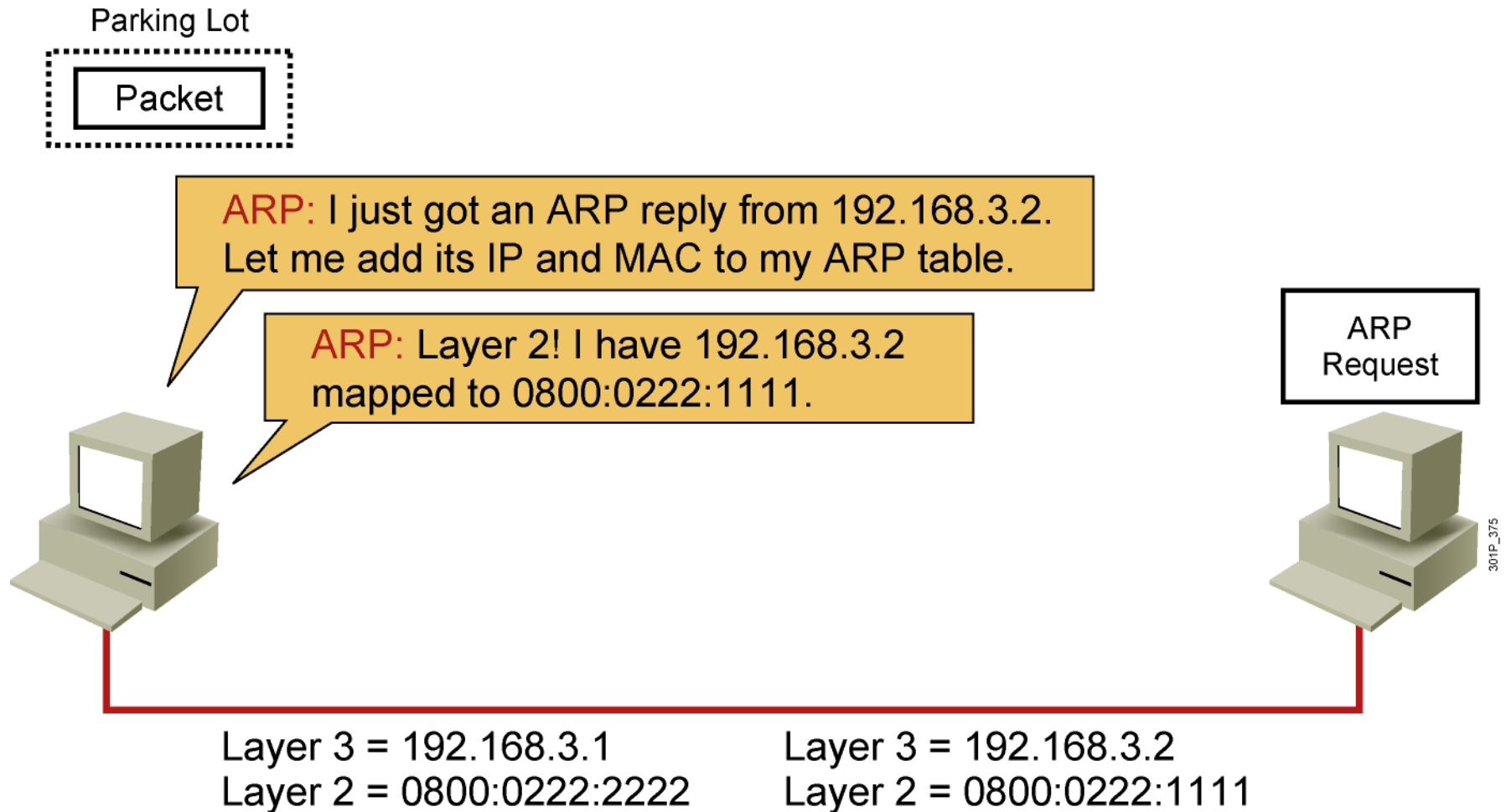
Host-to-Host Packet Delivery (11 of 22)



Host-to-Host Packet Delivery (12 of 22)

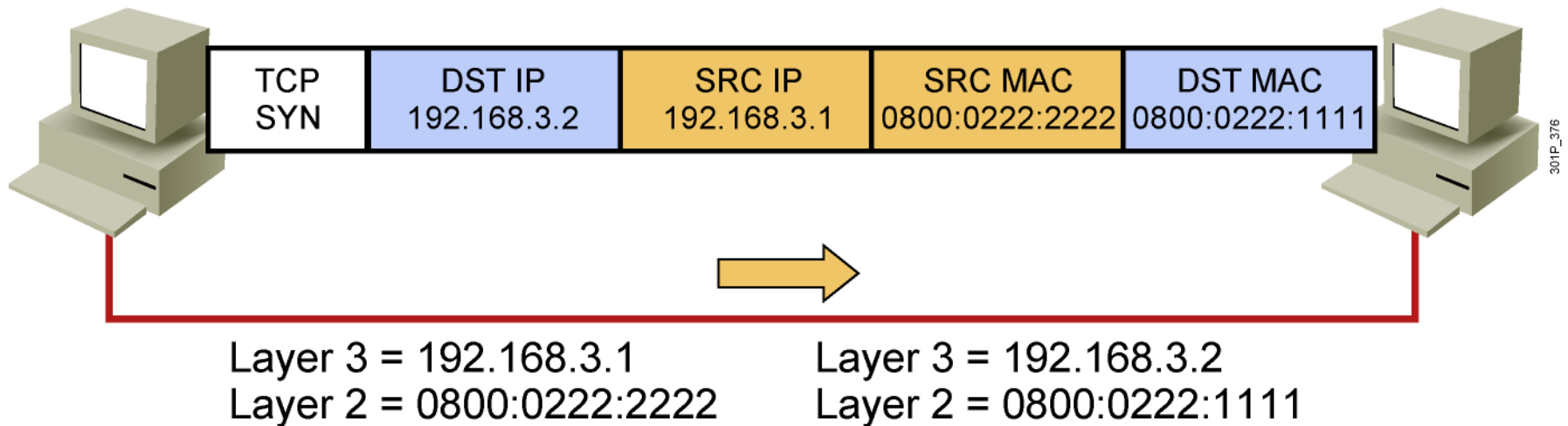


Host-to-Host Packet Delivery (13 of 22)



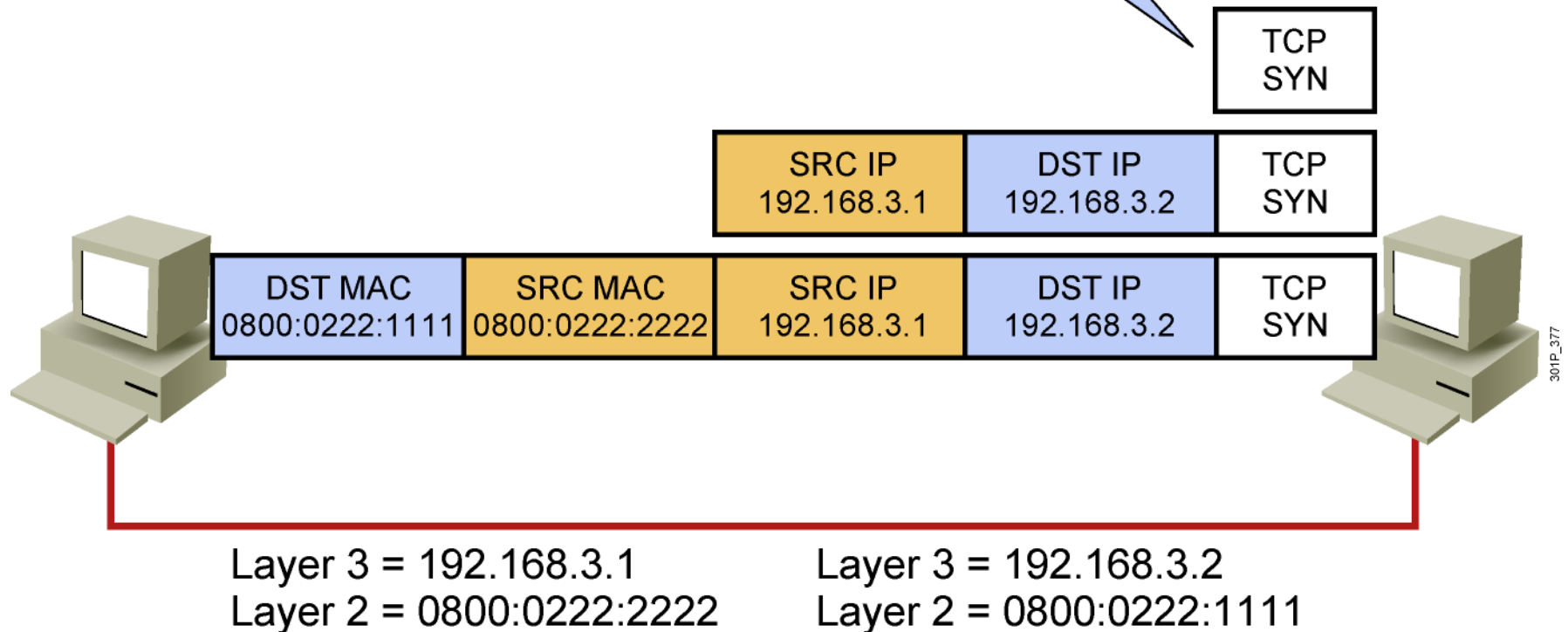
Host-to-Host Packet Delivery (14 of 22)

Layer 2: I can send out that pending packet.

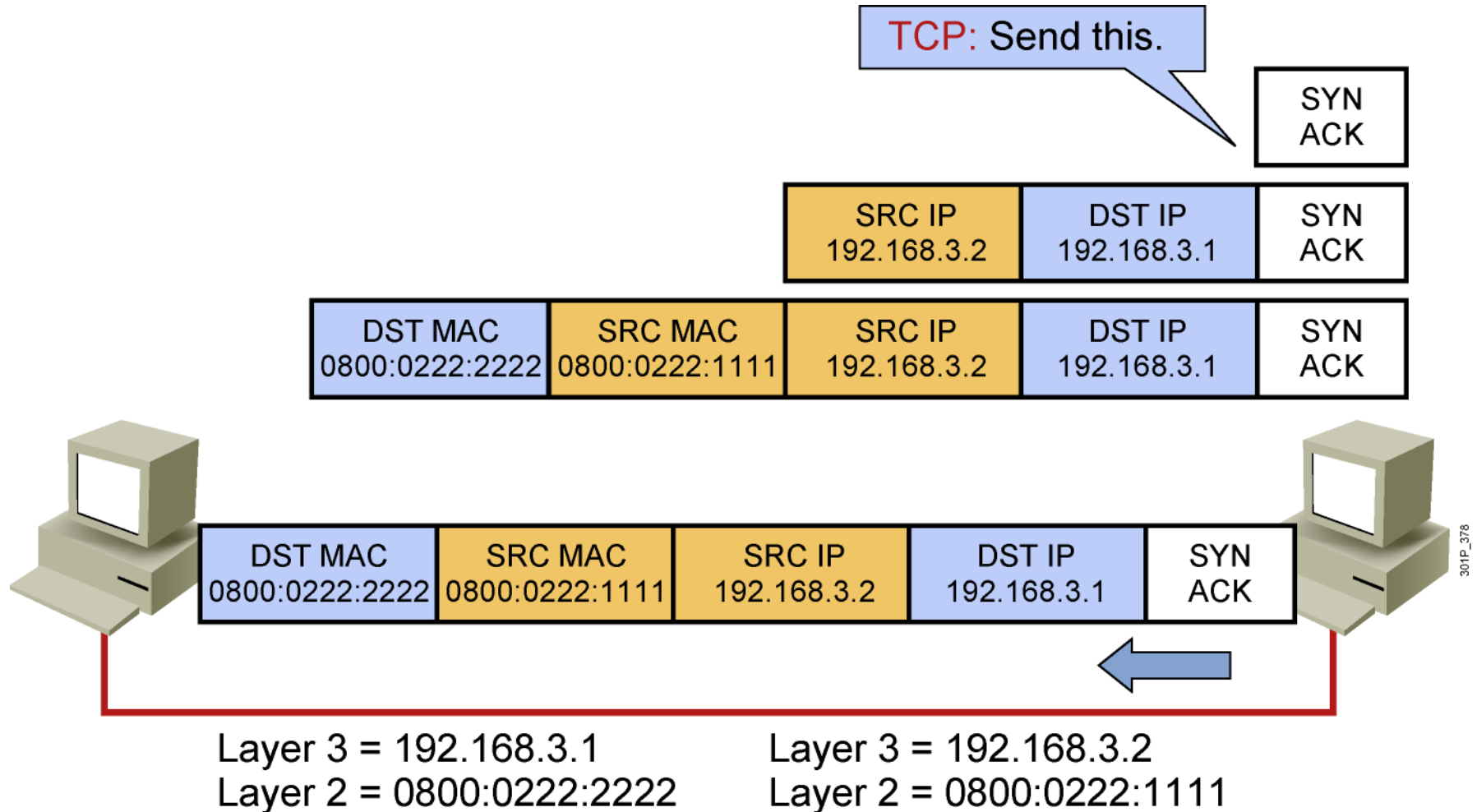


Host-to-Host Packet Delivery (15 of 22)

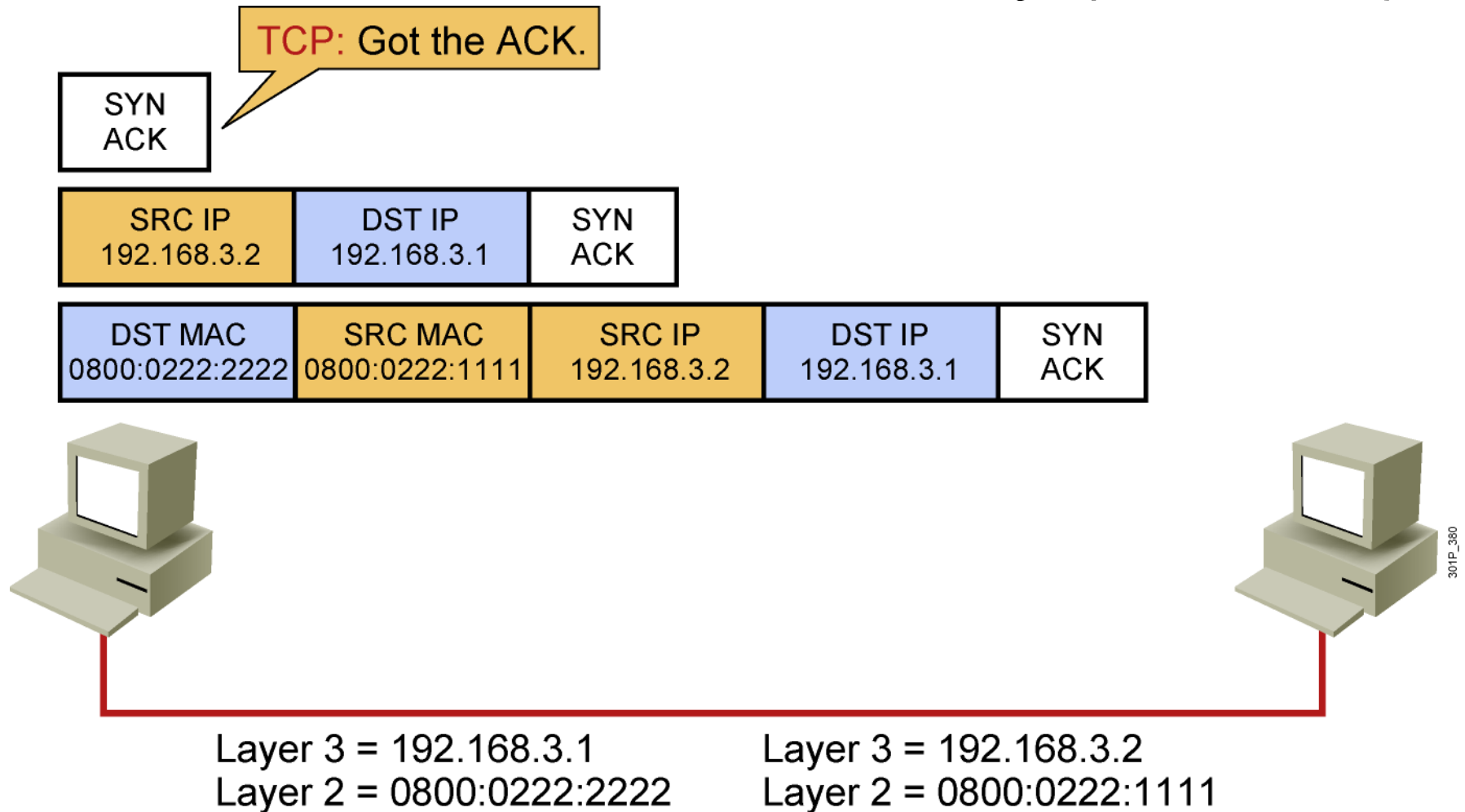
TCP: I need to send a SYN ACK to the TCP SYN that I received.



Host-to-Host Packet Delivery (16 of 22)



Host-to-Host Packet Delivery (17 of 22)



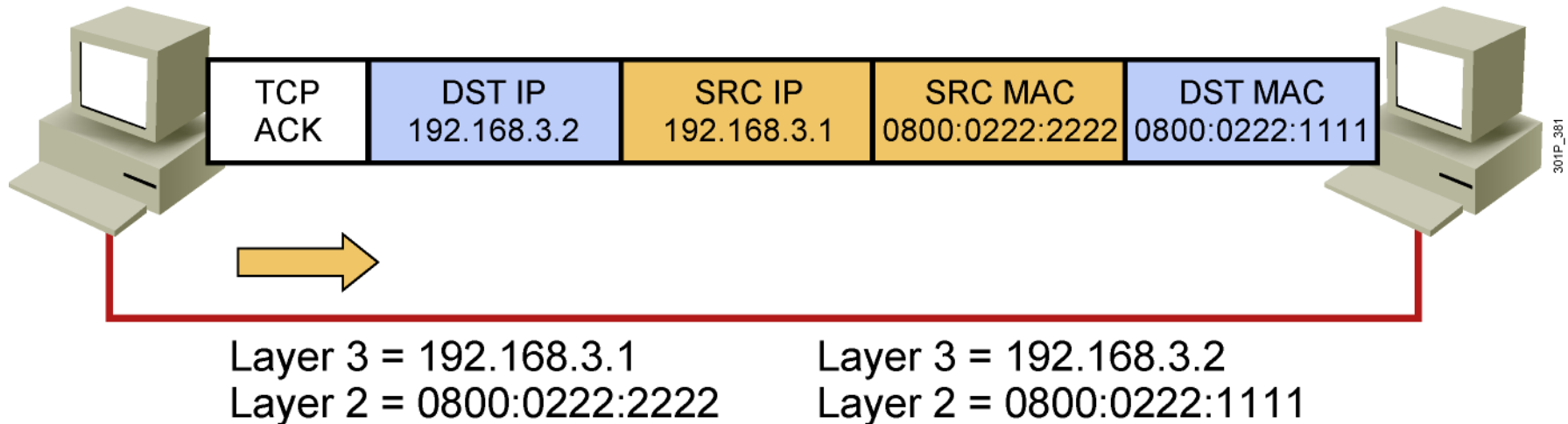
Host-to-Host Packet Delivery (18 of 22)

TCP: I need to let the other end know I got the SYN ACK to complete the session establishment.

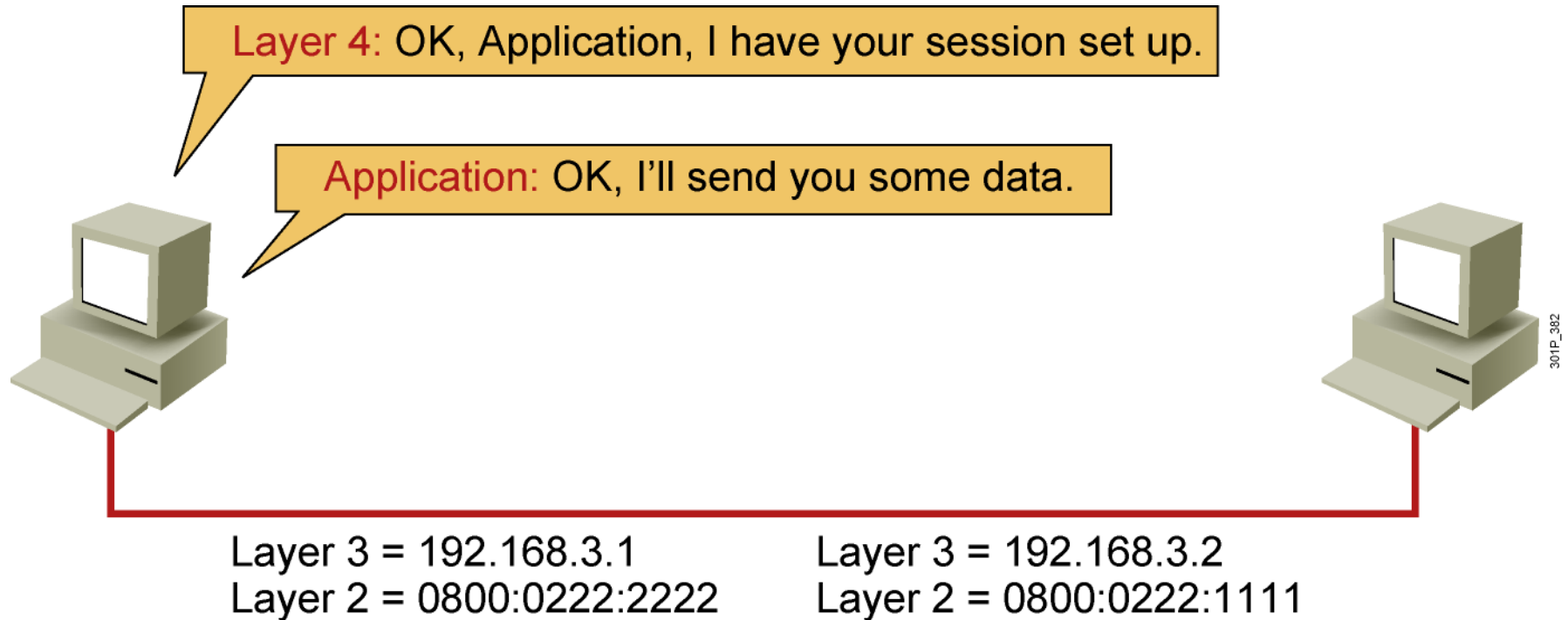
TCP
ACK

SRC IP 192.168.3.1	DST IP 192.168.3.2	TCP ACK
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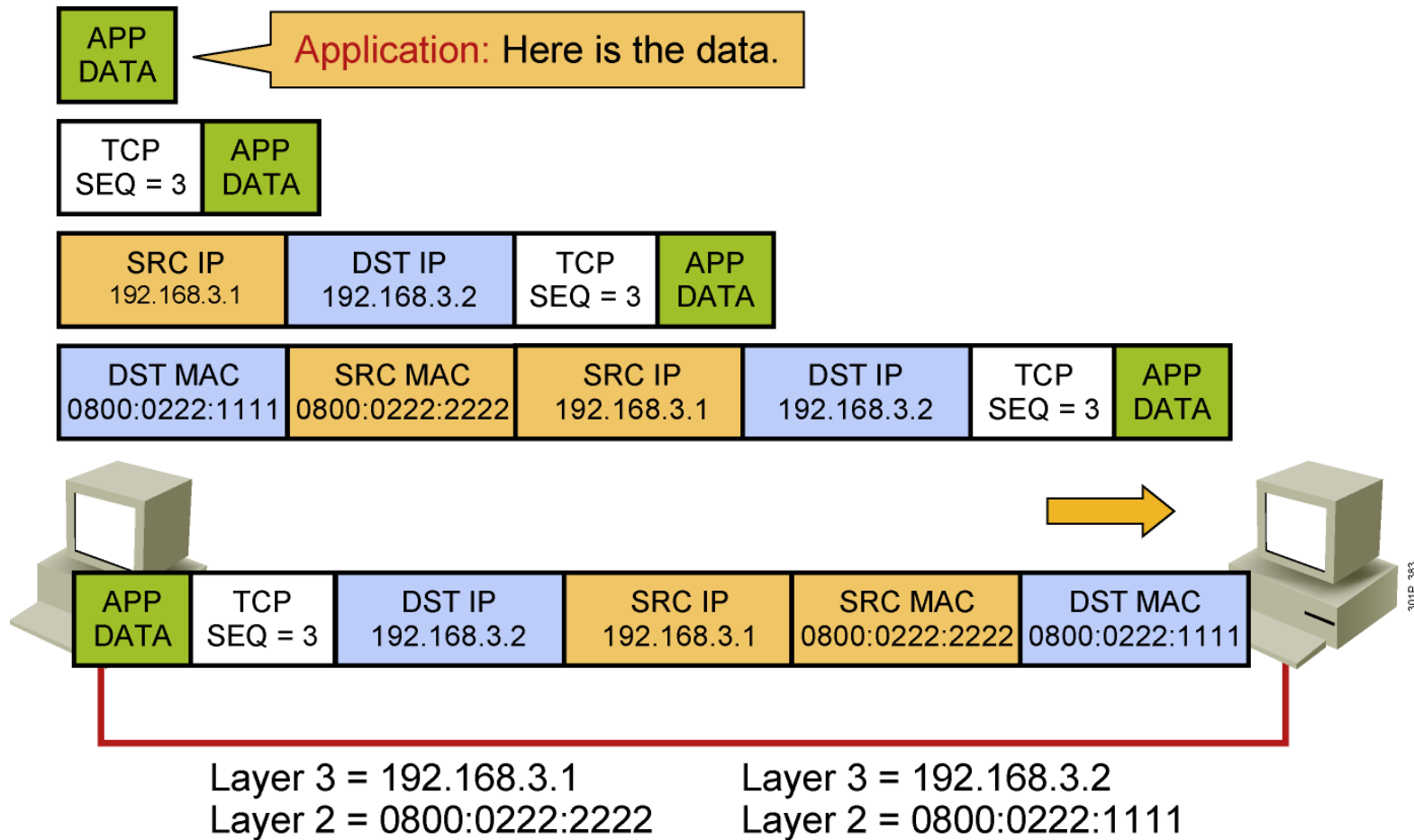
DST MAC 0800:0222:1111	SRC MAC 0800:0222:2222	SRC IP 192.168.3.1	DST IP 192.168.3.2	TCP ACK
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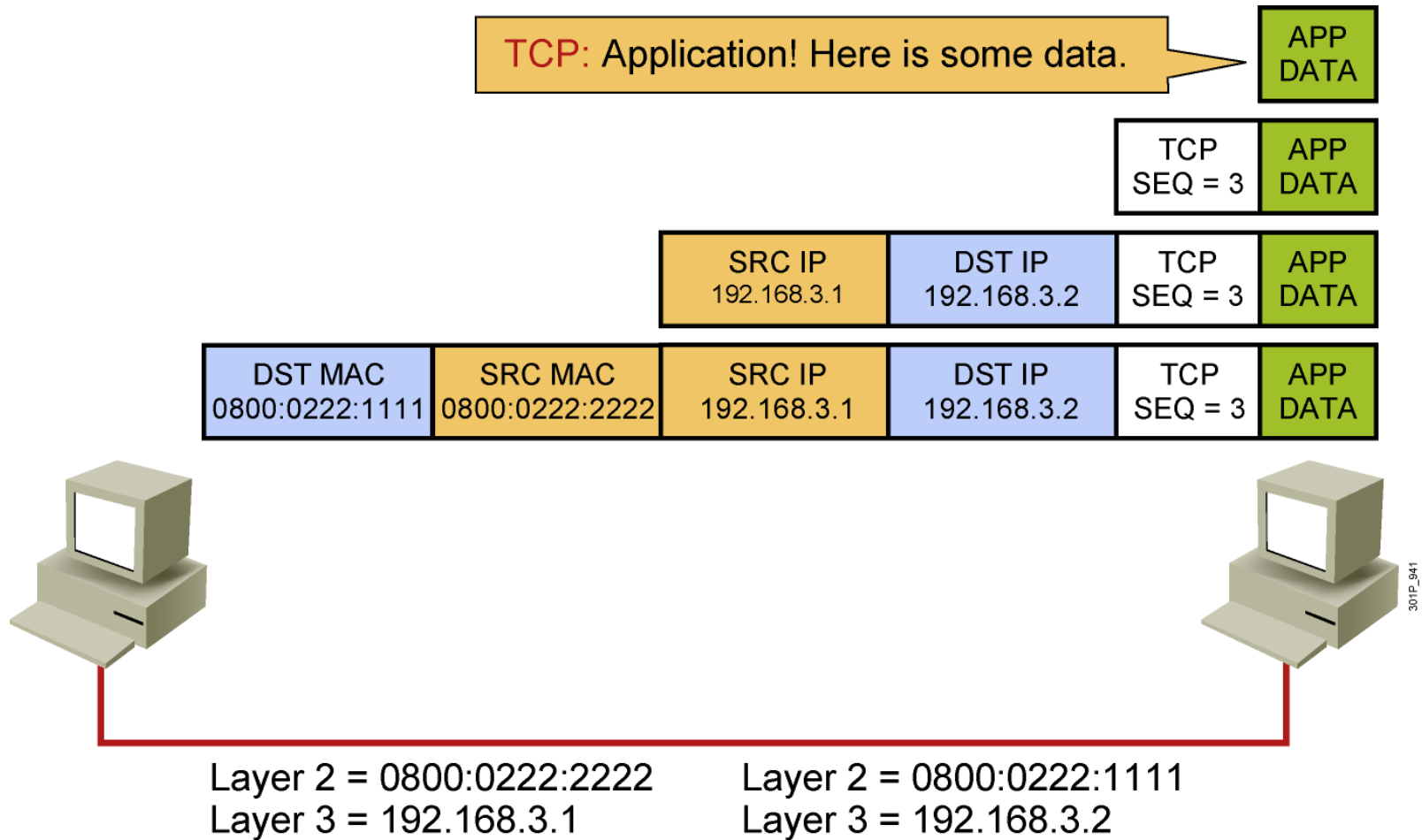
Host-to-Host Packet Delivery (19 of 22)



Host-to-Host Packet Delivery (20 of 22)



Host-to-Host Packet Delivery (21 of 22)



Host-to-Host Packet Delivery (22 of 22)

I need to send an ACK to the data that I received.

ACK = 4
SEQ = 3

SRC IP 192.168.3.2	DST IP 192.168.3.1	ACK = 4 SEQ = 3
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DST MAC 0800:0222:2222	SRC MAC 0800:0222:1111	SRC IP 192.168.3.2	DST IP 192.168.3.1	ACK = 4 SEQ = 3
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