UNDERLAYS and MIDDLEBOXES

READING: SECTION 8.

COS 461: Computer Networks
Spring 2010 (MW 3:00-4:20 in COS 105)

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http://www.cs.princeton.edu/courses/archive/spring10/cos461/

Outline today

- Network-layer principles
  - Globally unique identifiers and simple packet forwarding
  - Middleboxes and tunneling to violate these principles…
- Underlay tunnels
  - Across routers within AS, build networks "below" IP route
  - Provide better control, flexibility, QoS, isolation, …
- Network Address Translation (NAT)
  - Multiple machines w/ private addrs behind a single public addr
- Firewalls
  - Discarding unwanted packets
- LAN appliances
  - Improving performance and security
  - Using a middlebox at sending and receiving sites

We saw tunneling "on top of" IP.
What about tunneling "below" IP?

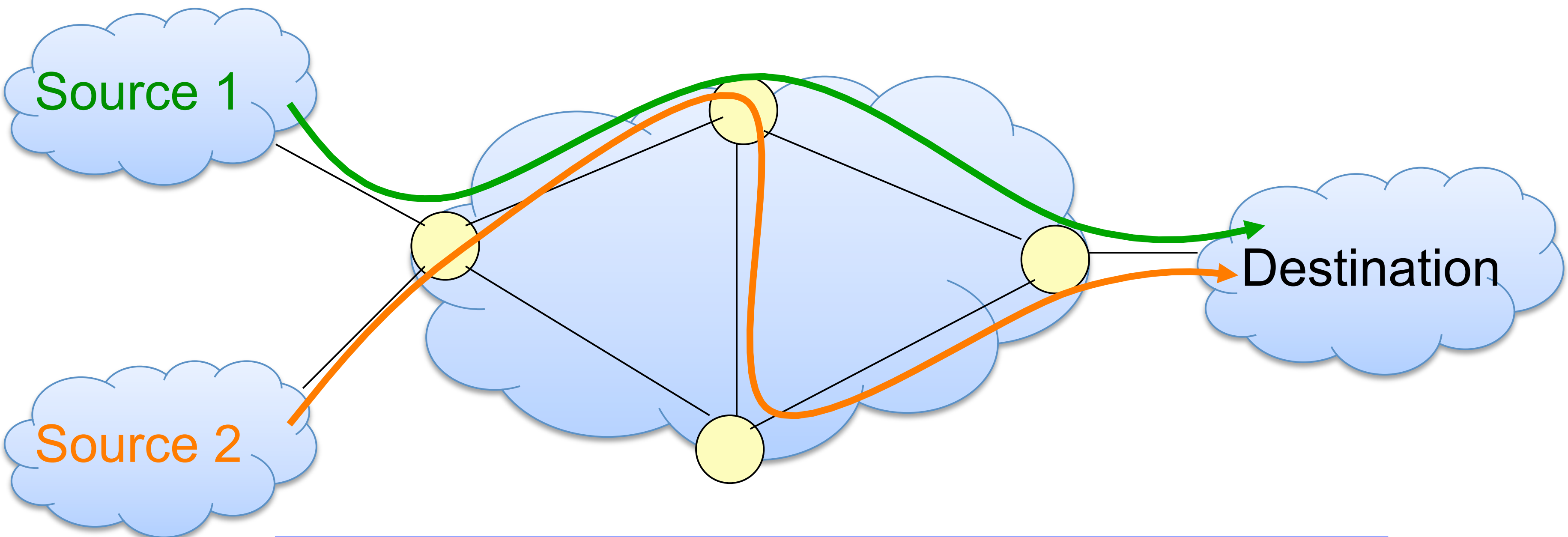
Introducing

Multi-Protocol Label Switching

(MPLS)

MPLS Overview

- **Main idea:** Virtual circuit
  - Packets forwarded based only on circuit identifier



Router can forward traffic to the same destination on different interfaces/paths.

MPLS Overview

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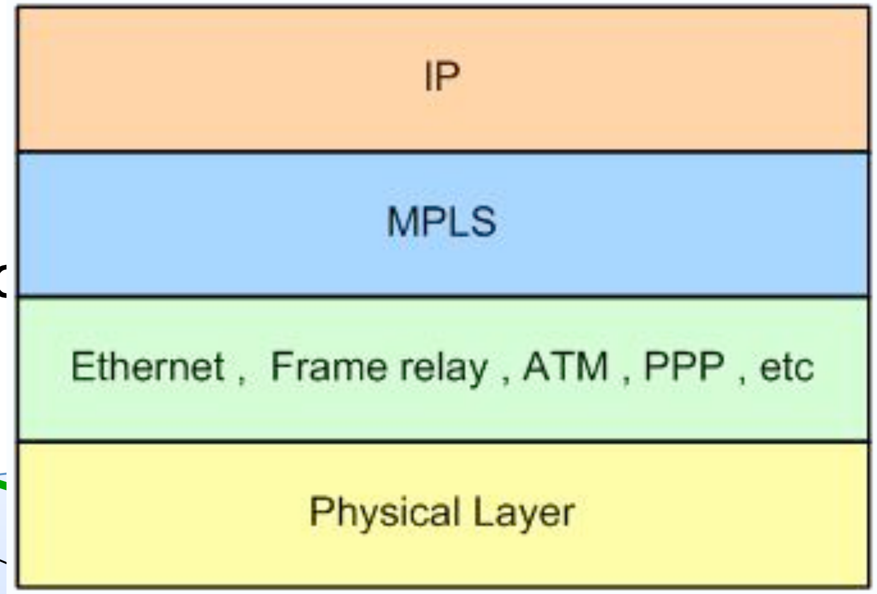
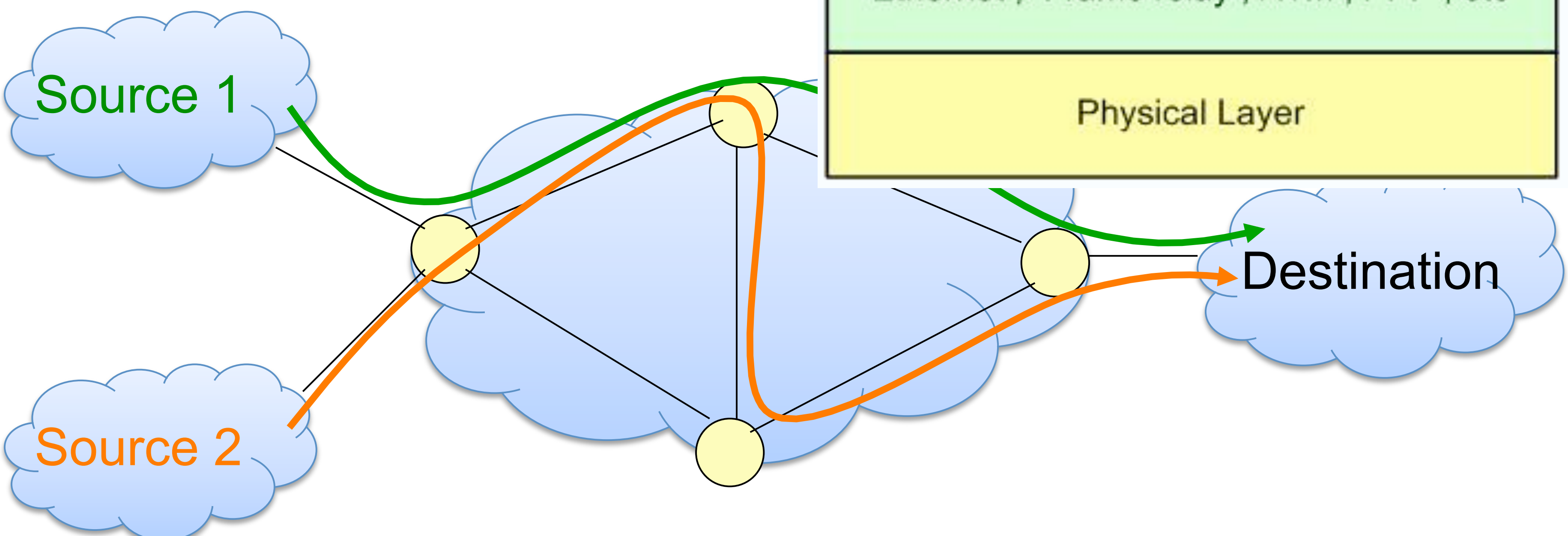
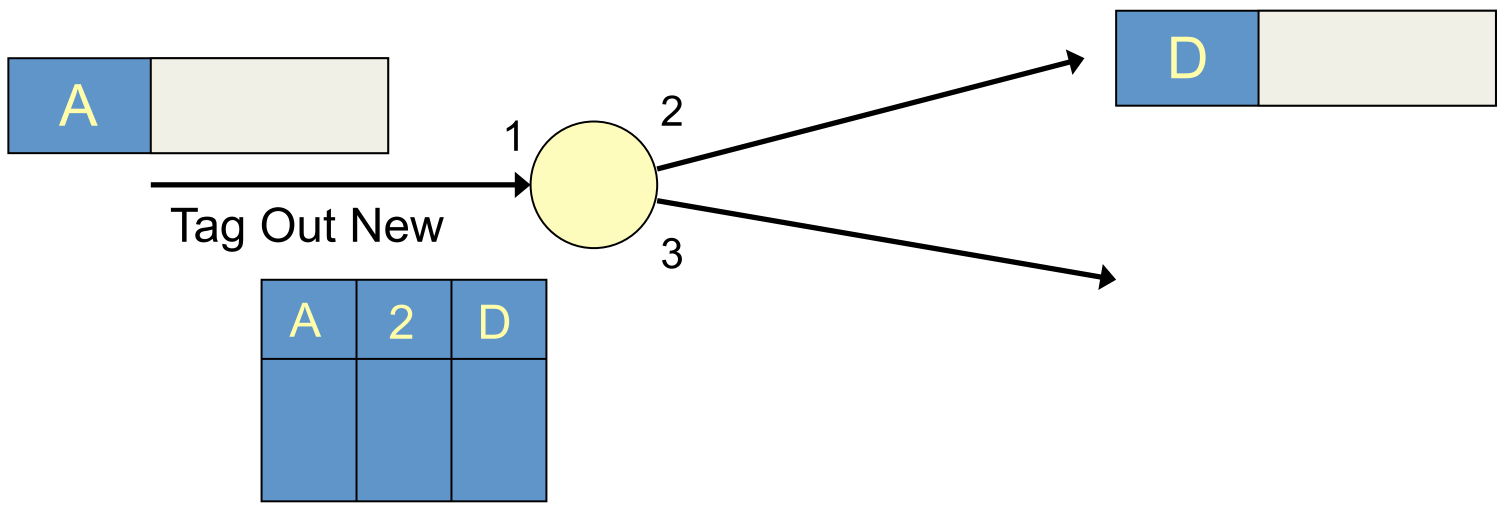




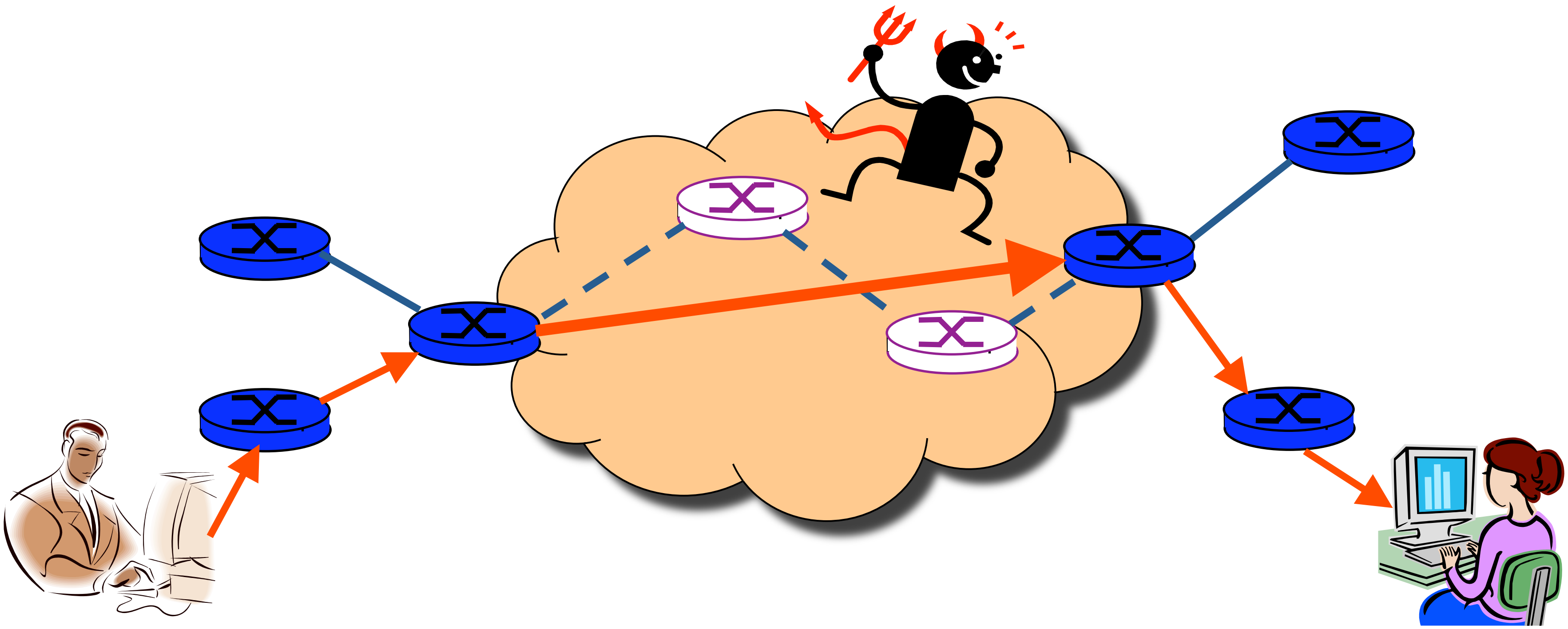
Router can forward traffic to the same destination on different interfaces/paths.

Circuit Abstraction: Label Swapping



- **Label-switched paths (LSPs):** Paths are "named" by the label at the path's entry point
- At each hop, MPLS routers:
  - Use label to determine outgoing interface, new label
  - Thus, push/pop/swap MPLS headers that encapsulate IP
- **Label distribution protocol:** responsible for disseminating signalling information

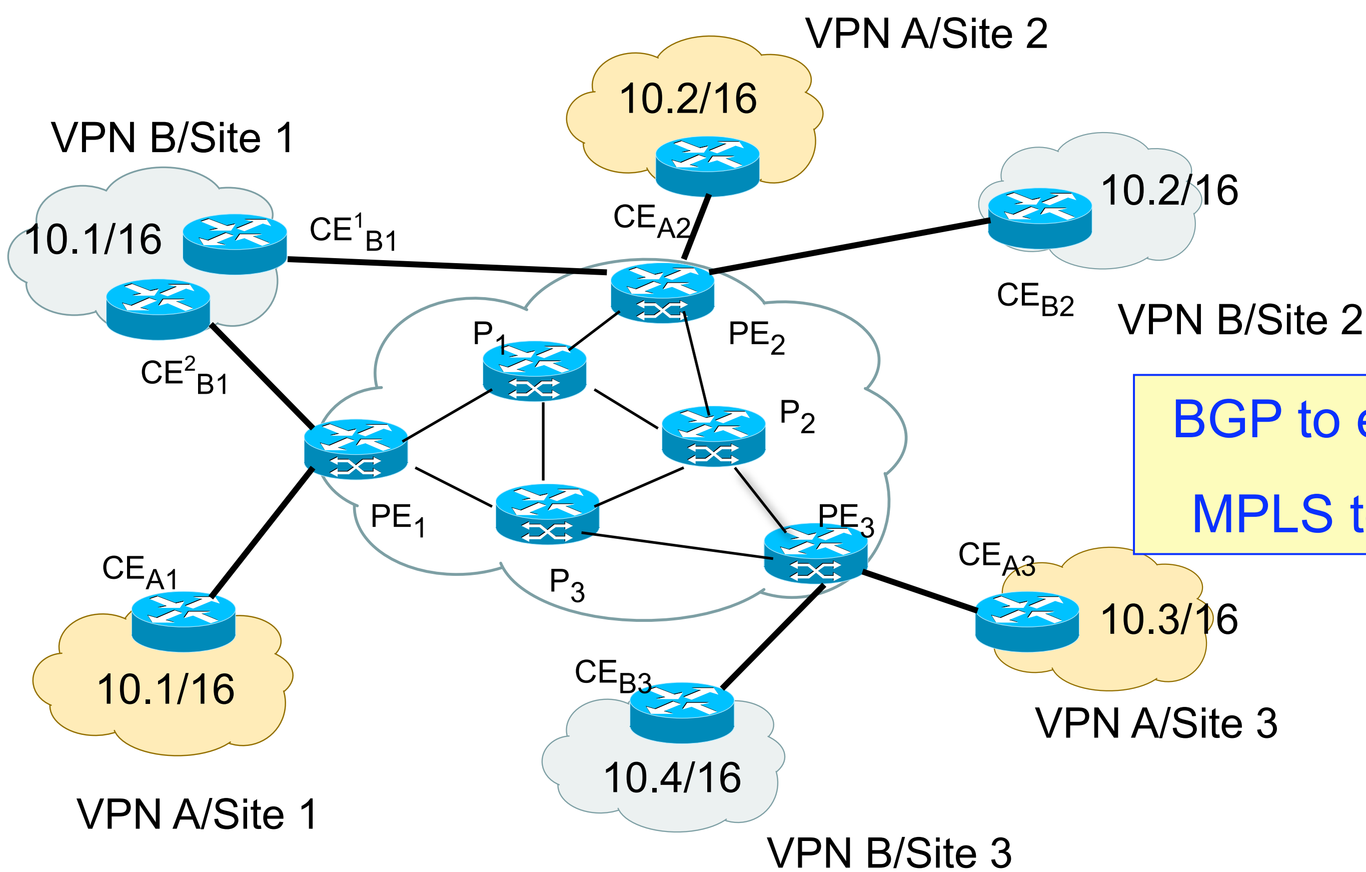
Reconsider security problem



Layer 3 Virtual Private Networks

- Private communications over a public network
- A set of sites that are allowed to communicate with each other
- Defined by a set of administrative policies
  - Determine both connectivity and QoS among sites
  - Established by VPN customers
  - One way to implement: BGP/MPLS VPN (RFC 2547)

Layer 3 BGP/MPLS VPNs

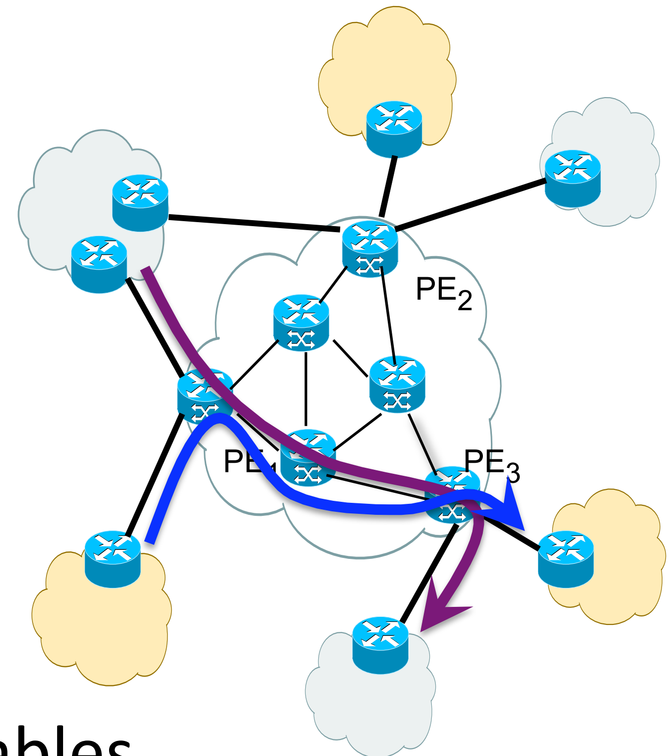


BGP to exchange routes

MPLS to forward traffic

- **Isolation:** Multiple logical networks over a single, shared physical infrastructure
- **Tunneling:** Keeping routes out of the core

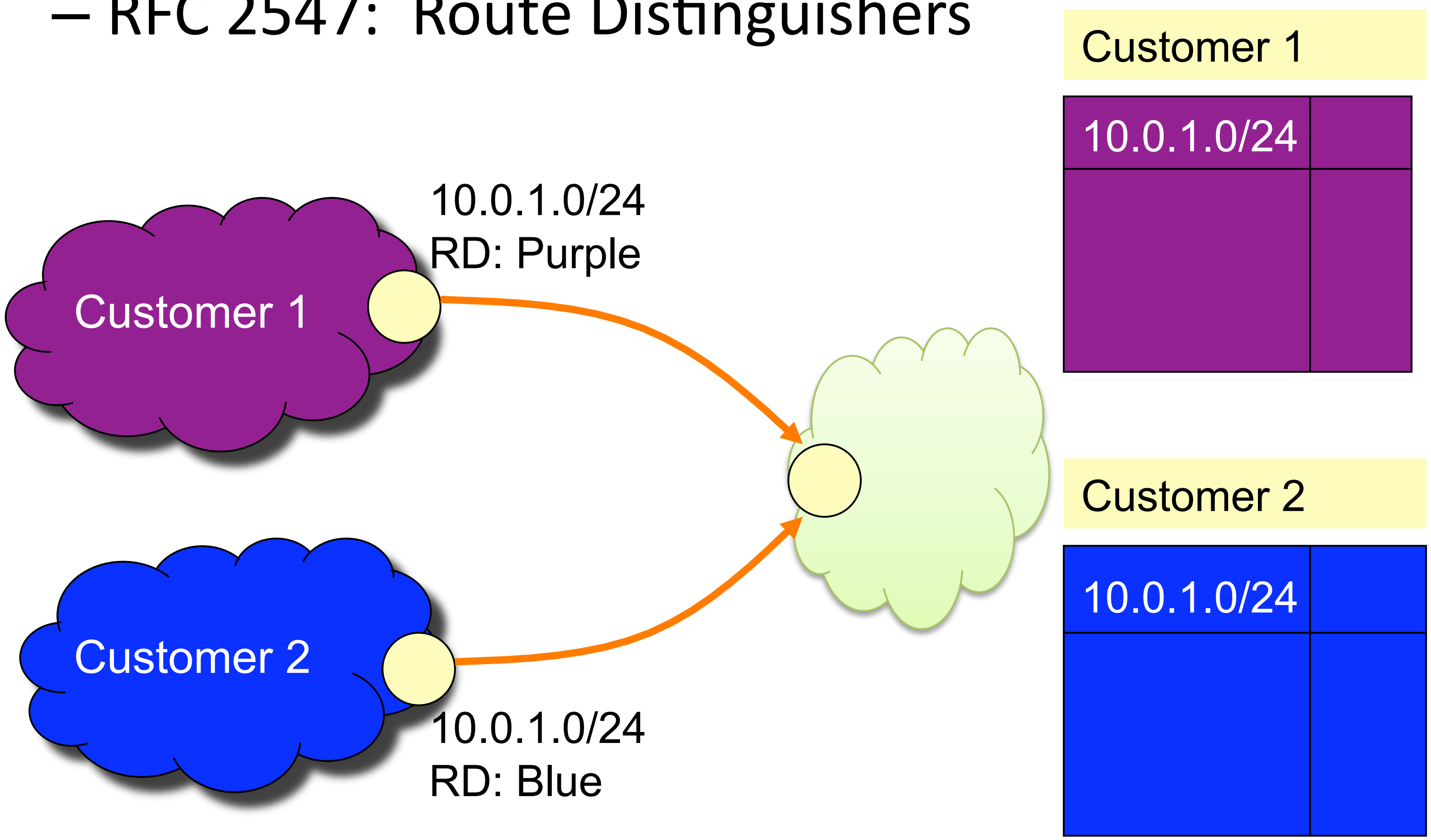
High-Level Overview of Operation



- IP packets arrive at provider edge router (PE)
- Destination IP looked up in forwarding table
  - Multiple "virtual" forwarding tables
- Datagram sent to customer's network using tunneling (*i.e.,* an MPLS label-switched path)

Virtual Routing and Forwarding

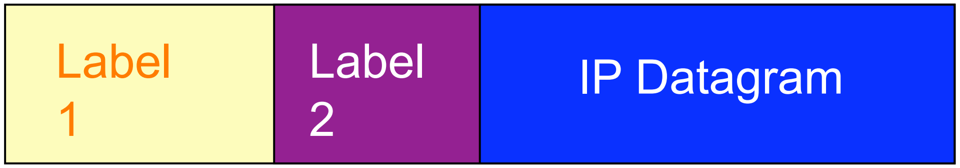
- Separate tables per customer at each router
  - RFC 2547: Route Distinguishers



Forwarding in BGP/MPLS VPNs

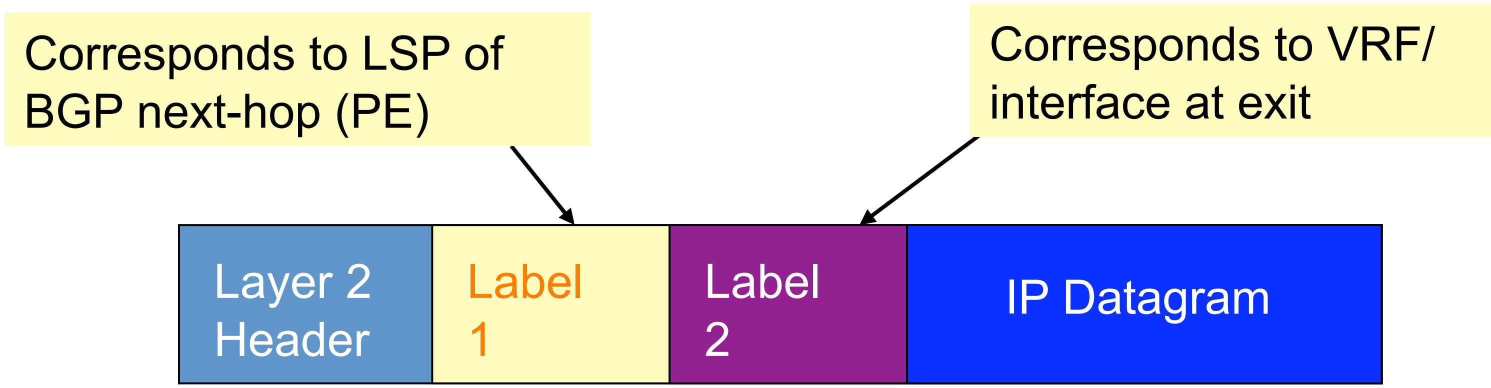
- **Step 1:** Packet arrives at incoming interface
  - Site VRF determines BGP next-hop and Label #2

- Step 2: BGP next-hop lookup, add corresponding LSP (also at site VRF)

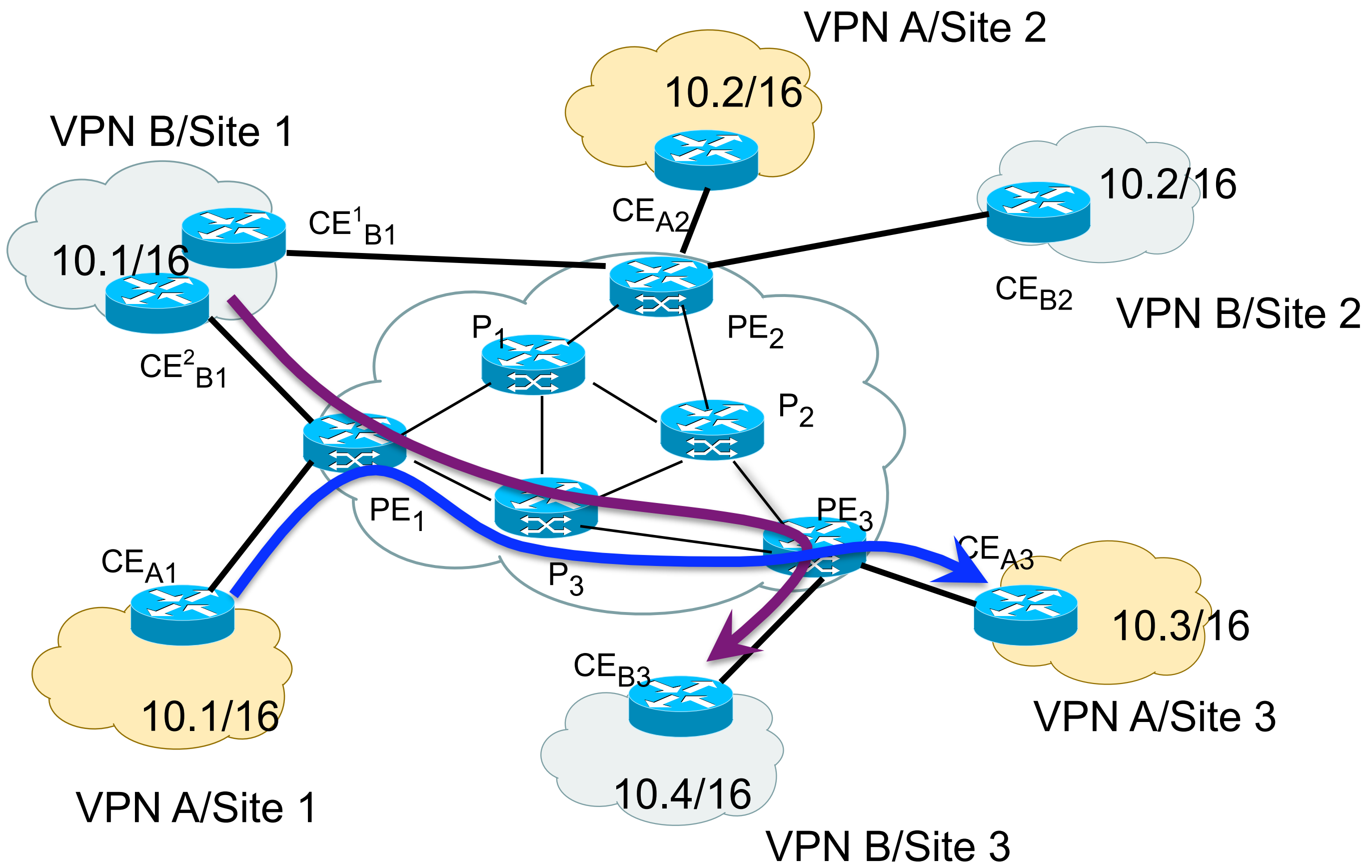


Forwarding

- PE and P routers have BGP next-hop reachability through the backbone IGP
- Labels are distributed through LDP (hop-by-hop) corresponding to BGP Next-Hops
- **Two-Label Stack** is used for packet forwarding
  - Top label indicates Next-Hop (interior label)
  - Second label indicates outgoing interface / VRF (exterior label)



Forwarding

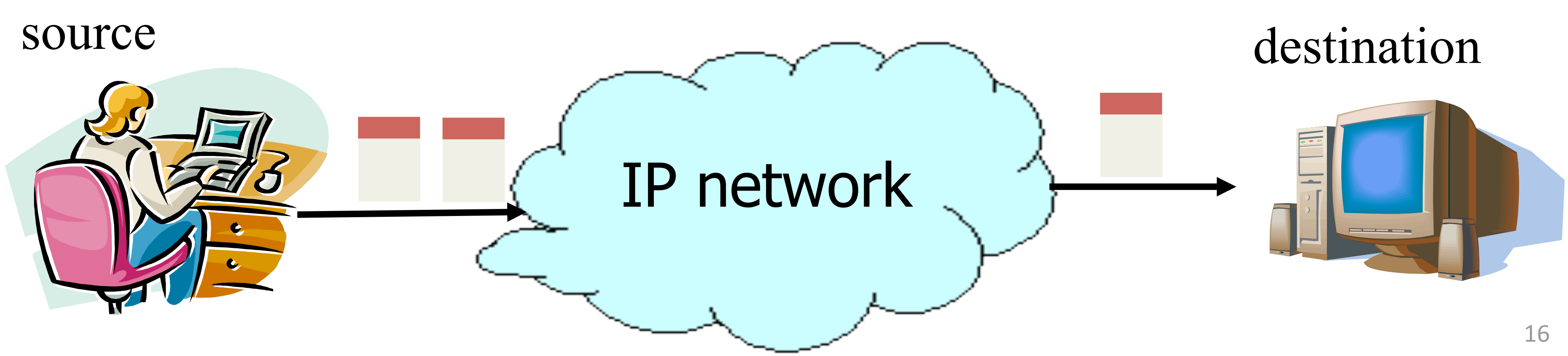


Layer 2 Header	Label 1	Label 2	IP Datagram

Middleboxes

Network-Layer Principles

- Globally unique identifiers
  - Each node has a unique, fixed IP address
  - … reachable from everyone and everywhere
- Simple packet forwarding
  - Network nodes simply forward packets
  - … rather than modifying or filtering them



Internet Reality

- Host mobility
  – Changes in IP addresses as hosts move
- IP address depletion
  – Dynamic assignment of IP addresses
  – Private addresses **(10.0.0.0/8, 192.168.0.0/16, …)**
- Security concerns
  – Discarding suspicious or unwanted packets
  – Detecting suspicious traffic
- Performance concerns
  – Controlling how link bandwidth is allocated
  – Storing popular content near the clients

Middleboxes

- Middleboxes are intermediaries
  - Interposed in-between the communicating hosts
  - Often without knowledge of one or both parties
- Examples
  - Network address translators
  - Firewalls
  - Traffic shapers
  - Intrusion detection systems
  - Transparent Web proxy caches
  - Application accelerators
  - Tunnel endpoints

Two Views of Middleboxes

- An abomination
  - Violation of layering
  - Cause confusion in reasoning about the network
  - Responsible for many subtle bugs
- A practical necessity
  - Solving real and pressing problems
  - Needs that are not likely to go away

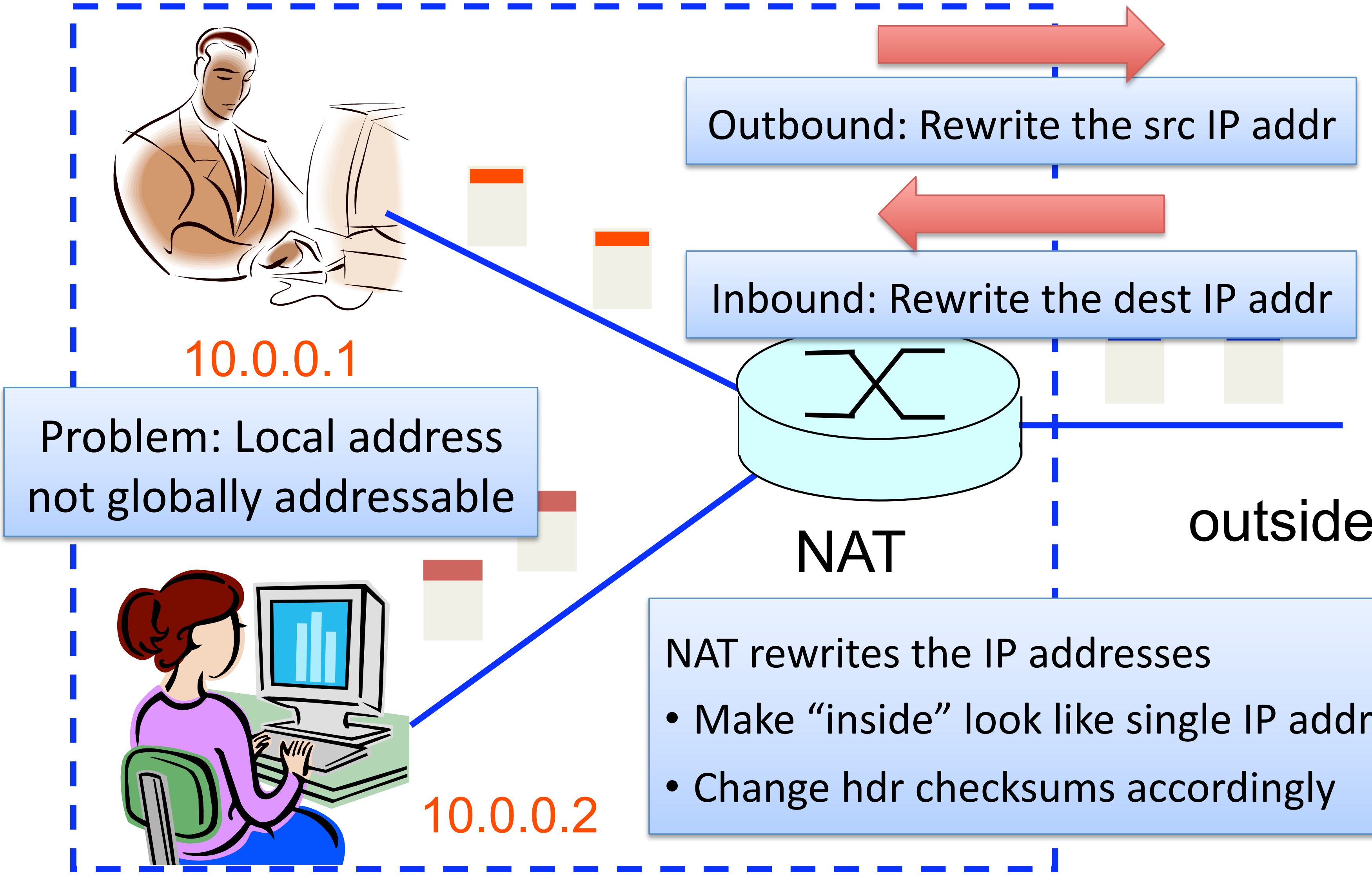
- Would they arise in *any* edge-empowered network, even if redesigned from scratch?

Network Address Translation

History of NATs

- IP address space depletion
  - Clear in early 90s that 2^{32} addresses not enough
  - Work began on a successor to IPv4
- In the meantime…
  - Share addresses among numerous devices
  - … without requiring changes to existing hosts
- Meant to provide temporary relief
  - Intended as a short-term remedy
  - Now, NAT are very widely deployed
  - … much moreso than IPv6 ☺

Active Component in the Data Path



NAT rewrites the IP addresses

- Make “inside” look like single IP addr
- Change hdr checksums accordingly

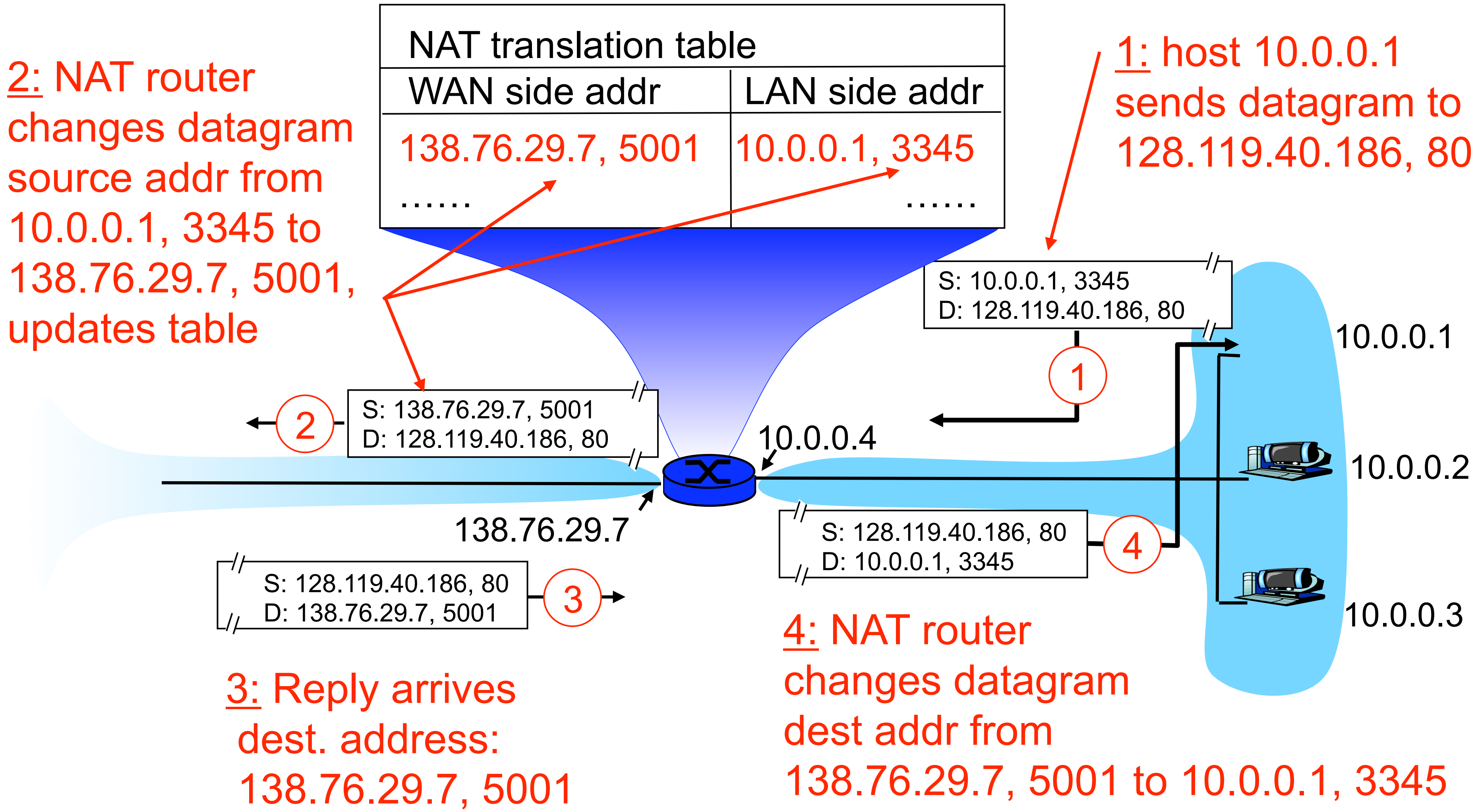
What if Both Hosts Contact Same Site?

- Suppose hosts contact the same destination
  - E.g., both hosts open a socket with local port 3345 to destination 128.119.40.186 on port 80
- NAT gives packets same source address
  - All packets have source address 138.76.29.7
- Problems
  - Can destination differentiate between senders?
  - Can return traffic get back to the correct hosts?

Port-Translating NAT

- Map outgoing packets
  - Replace source address with NAT address
  - Replace source port number with a new port number
  - Remote hosts respond using (NAT address, new port #)
- Maintain a translation table
  - Store map of (src addr, port #) to (NAT addr, new port #)
- Map incoming packets
  - Consult the translation table
  - Map the destination address and port number
  - Local host receives the incoming packet

Network Address Translation Example



Maintaining the Mapping Table

- Create an entry upon seeing a packet
  – Packet with new (source addr, source port) pair
- Eventually, need to delete the map entry
  – But when to remove the binding?
- If no packets arrive within a time window
  – … then delete the mapping to free up the port #s
  – At risk of disrupting a temporarily idle connection
- Yet another example of "soft state"
  – I.e., removing state if not refreshed for a while

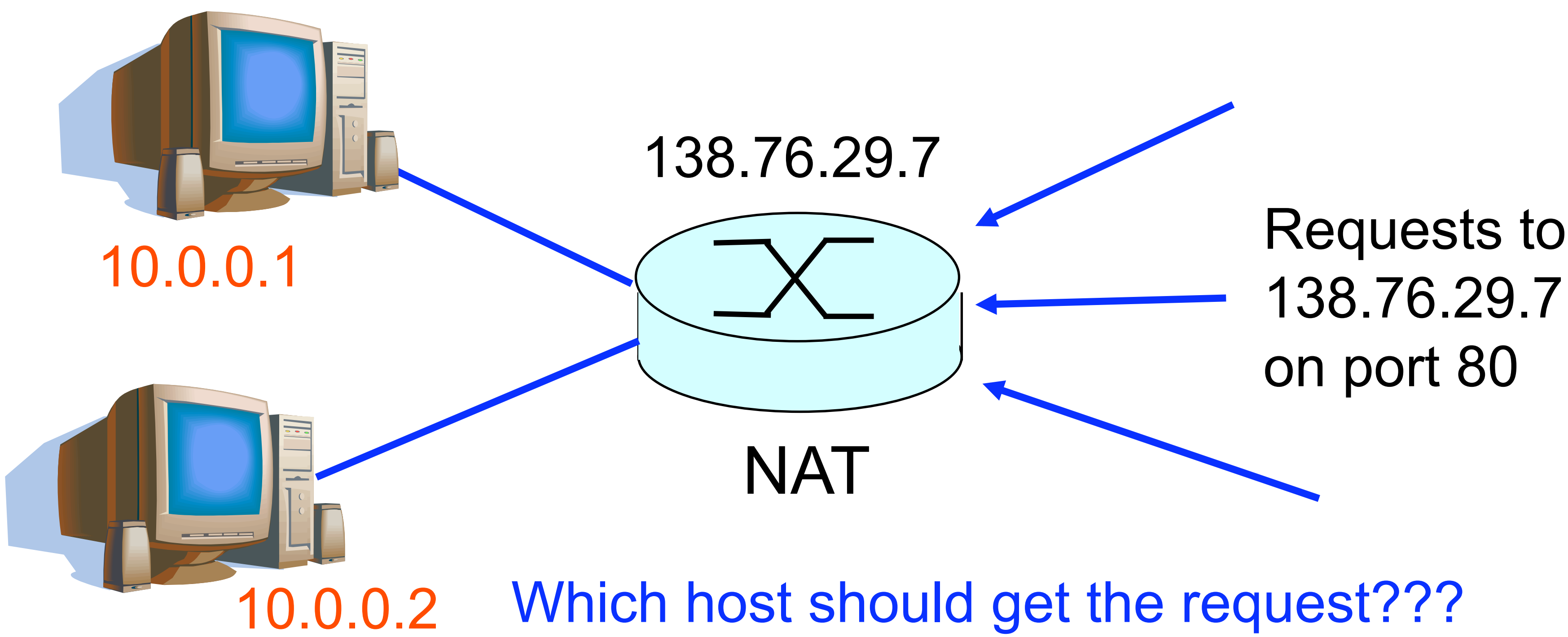
Where is NAT Implemented?

- Home router (e.g., Linksys box)
  - Integrates router, DHCP server, NAT, etc.
  - Use single IP address from the service provider
  - … and have a bunch of hosts hiding behind it

- Campus or corporate network
  - NAT at the connection to the Internet
  - Share a collection of public IP addresses
  - Avoid complexity of renumbering end hosts and local routers when changing service providers

Practical Objections Against NAT

- Port #s are meant to identify *sockets*
  - Yet, NAT uses them to identify *end hosts*
  - Makes it hard to run a server behind a NAT



Which host should get the request???

Running Servers Behind NATs

- Running servers is still possible
  - Admittedly with a bit more difficulty
- By explicit configuration of the NAT box
  - E.g., internal service at <dst 138.76.29.7, dst-port 80>
  - … mapped to <dst 10.0.0.1, dst-port 80>
- More challenging for P2P applications
  - Especially if *both* peers are behind NAT boxes
- Solutions possible here as well
  - Existing work-arounds (e.g., in Skype)
  - Ongoing work on "NAT traversal" techniques

Principled Objections Against NAT

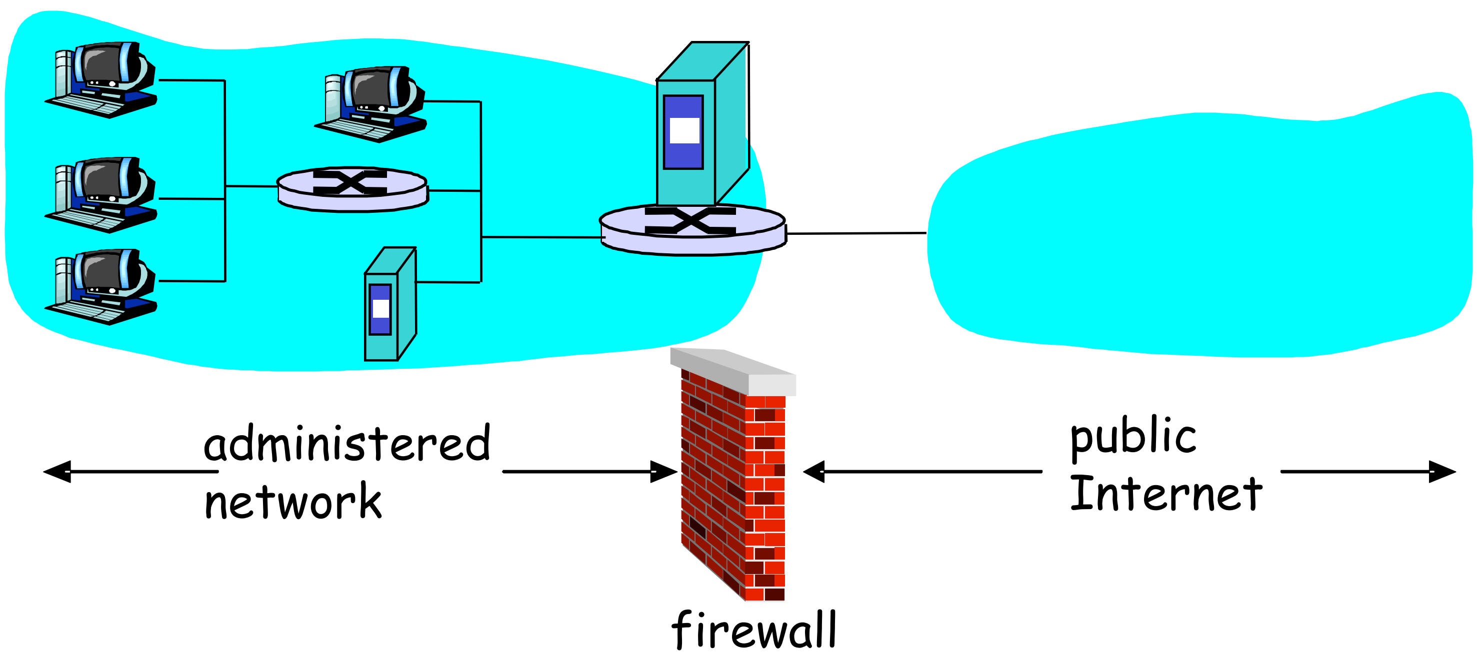
- Routers are not supposed to look at port #s
  - Network layer should care *only* about IP header
  - … and *not* be looking at the port numbers at all
- NAT violates the *end-to-end* argument
  - Network nodes should not modify the packets
- IPv6 is a cleaner solution
  - Better to migrate than to limp along with a hack

That's what you get when you design a network that puts power in the hands of end users!

Firewalls

Firewalls

Isolates organization's internal net from larger Internet, allowing some packets to pass, blocking others.



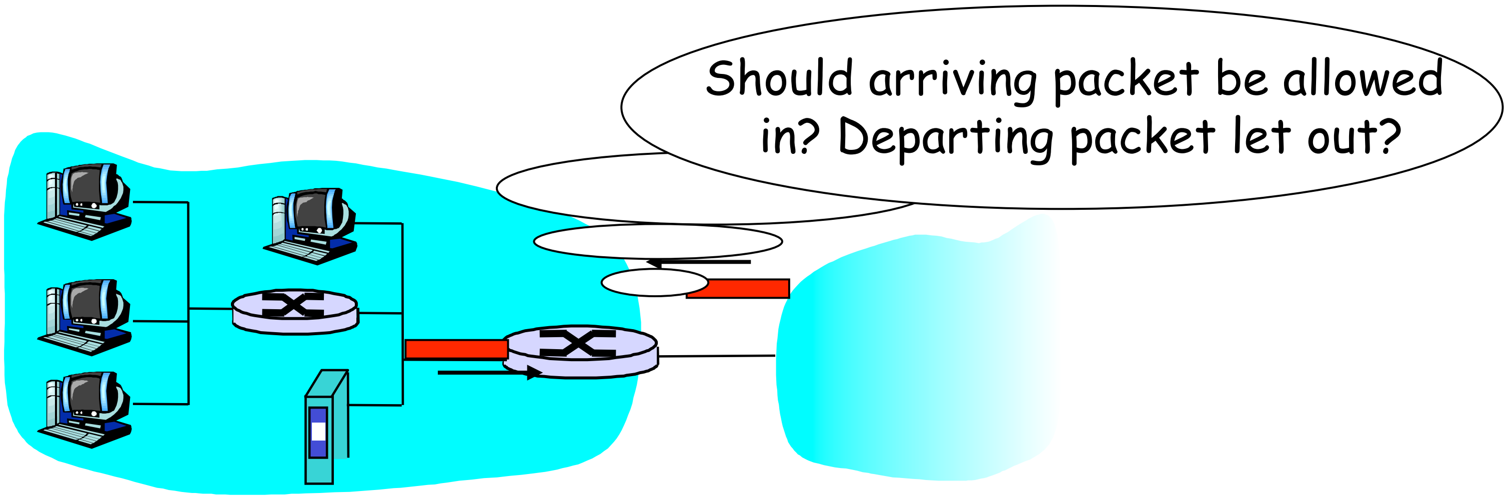
Internet Attacks: Denial of Service

- Denial-of-service attacks
  - Outsider overwhelms the host with unsolicited traffic
  - … with the goal of preventing any useful work
- Example: attacks by botnets
  - Bad guys take over a large collection of hosts
  - … and program these hosts to send traffic to your host
  - Leading to excessive traffic
- Motivations for denial-of-service attacks
  - Malice (e.g., just to be mean)
  - Revenge (e.g., for some past perceived injustice)
  - Greed (e.g., blackmailing)

Internet Attacks: Break-Ins

- Breaking in to a host
  - Outsider exploits a vulnerability in the end host
  - … with the goal of changing the behavior of the host
- Example
  - Bad guys know a Web server has a buffer-overflow bug
  - … and, say, send an HTTP request with a long URL
  - Allowing them to run their own code
- Motivations for break-ins
  - Take over the machine to launch other attacks
  - Steal information stored on the machine
  - Modify/replace the content the site normally returns

Packet Filtering



- Internal network connected to Internet via firewall
- Firewall filters packet-by-packet, based on:
  - Source IP address, destination IP address
  - TCP/UDP source and destination port numbers
  - ICMP message type
  - TCP SYN and ACK bits
  - Deep packet inspection on packet contents (DPI)

Packet Filtering Examples

- Block all packets with IP protocol field = 17 and with either source or dest port = 23.
  - All incoming and outgoing UDP flows blocked
  - All Telnet connections are blocked
- Block inbound TCP packets with SYN but no ACK
  - Prevents external clients from making TCP connections with internal clients
  - But allows internal clients to connect to outside
- Block all packets with TCP port of Quake

Firewall Configuration

- Firewall applies a set of rules to each packet
  - To decide whether to permit or deny the packet
- Each rule is a test on the packet
  - Comparing IP and TCP/UDP header fields
  - … and deciding whether to permit or deny
- Order matters
  - Once packet matches a rule, the decision is done

Firewall Configuration Example

- Alice runs a network in 222.22.0.0/16
  - Wants to let Bob's school access certain hosts
    - Bob is on 111.11.0.0/16
    - Alice's special hosts on 222.22.22.0/24
  - Alice doesn't trust Trudy, inside Bob's network
    - Trudy is on 111.11.11.0/24
  - Alice doesn't want any other traffic from Internet

- Rules
  - #1: Don't let Trudy's machines in
    - Deny (src = 111.11.11.0/24, dst = 222.22.0.0/16)
  - #2: Let rest of Bob's network in to special dsts
    - Permit (src=111.11.0.0/16, dst = 222.22.22.0/24)
  - #3: Block the rest of the world
    - Deny (src = 0.0.0.0/0, dst = 0.0.0.0/0)

A Variation: Traffic Management

- Permit vs. deny is too binary a decision
  - Maybe better to classify the traffic based on rules
  - … and then handle the classes of traffic differently
- Traffic shaping (rate limiting)
  - Limit the amount of bandwidth for certain traffic
  - E.g., rate limit on Web or P2P traffic
- Separate queues
  - Use rules to group related packets
  - And then do round-robin scheduling across groups
  - E.g., separate queue for each internal IP address

Firewall Implementation Challenges

- Per-packet handling
  - Must inspect every packet
  - Challenging on very high-speed links
- Complex filtering rules
  - May have large # of rules
  - May have very complicated rules
- Location of firewalls
  - Complex firewalls near the edge, at low speed
  - Simpler firewalls in the core, at higher speed

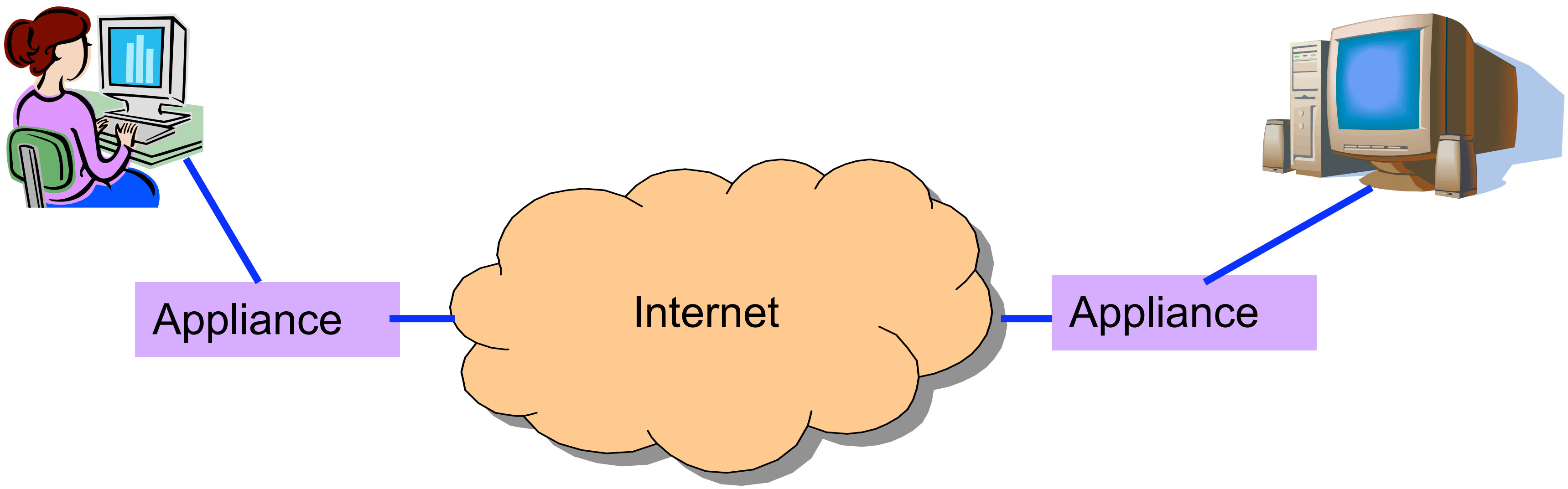
Clever Users Subvert Firewalls

- Example: filtering dorm access to a server
  - Firewall rule based on IP addresses of dorms
  - … and the server IP address and port number
  - Problem: users may log in to another machine
    - E.g., connect from the dorms to another host
    - … and then onward to the blocked server
- Example: filtering P2P based on port #s
  - Firewall rule based on TCP/UDP port numbers
    - E.g., allow only port 80 (e.g., Web) traffic
  - Problem: software using non-traditional ports
    - E.g., write P2P client to use port 80 instead

LAN Appliances
aka WAN Accelerators
aka Application Accelerators

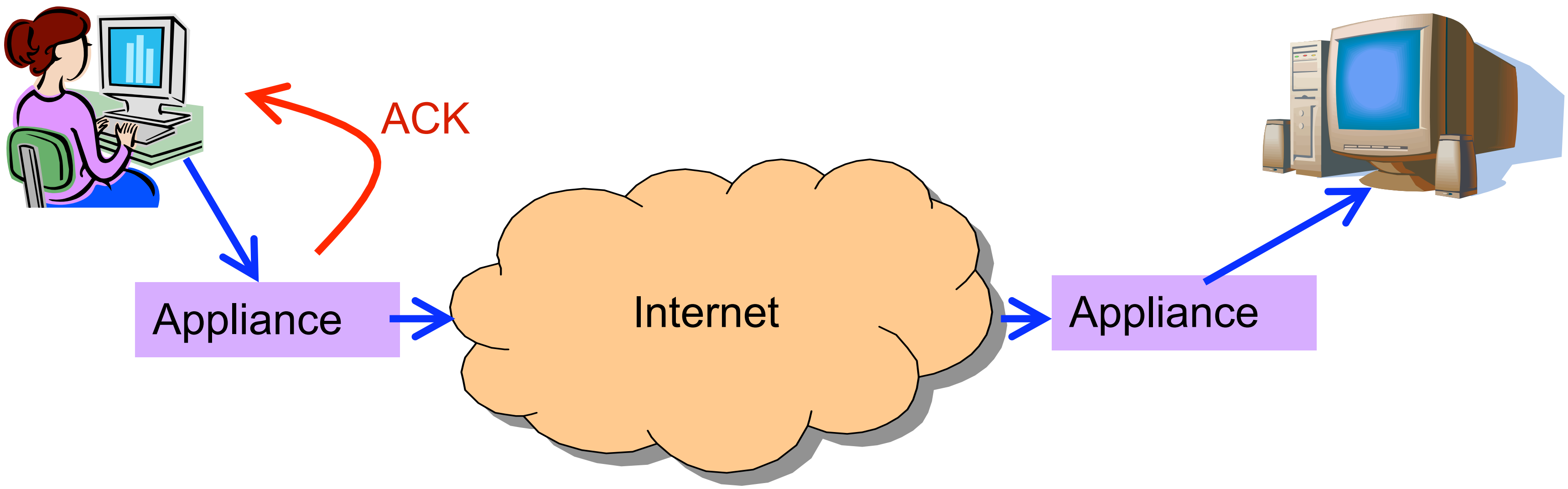
(Following examples are “tunnels” between on-path middleboxes)

At Connection Point to the Internet



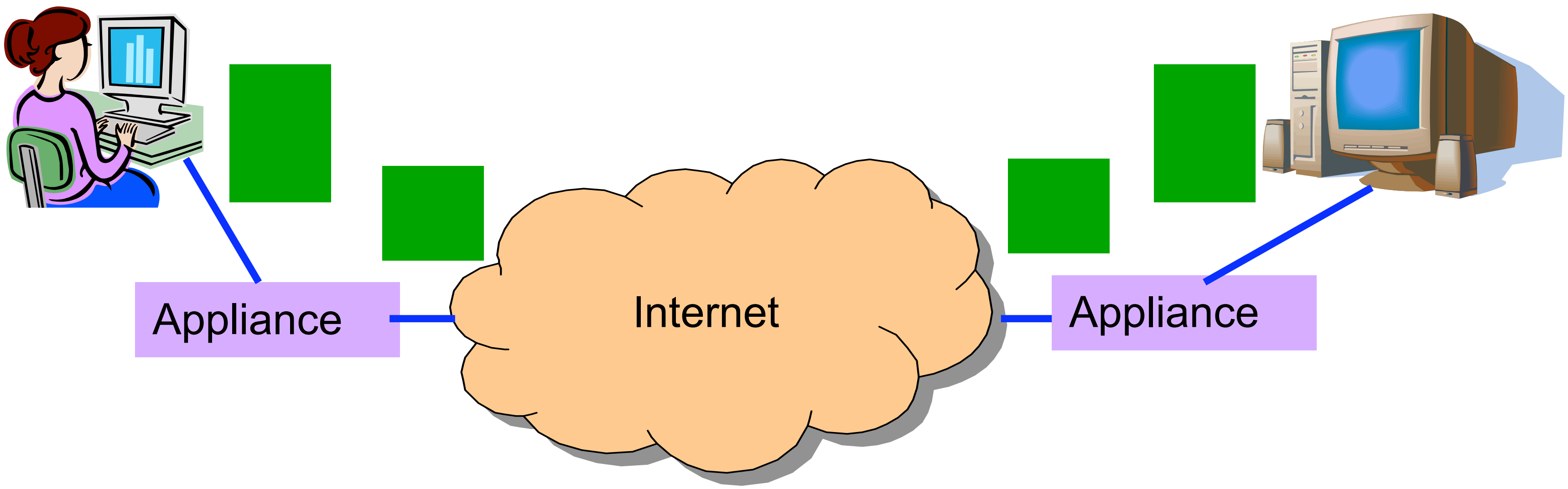
- Improve performance between edge networks
  - E.g., multiple sites of the same company
  - Through buffering, compression, caching, …
- Incrementally deployable
  - No changes to the end hosts or the rest of the Internet
  - Inspects the packets as they go by, and takes action

Example: Improve TCP Throughput



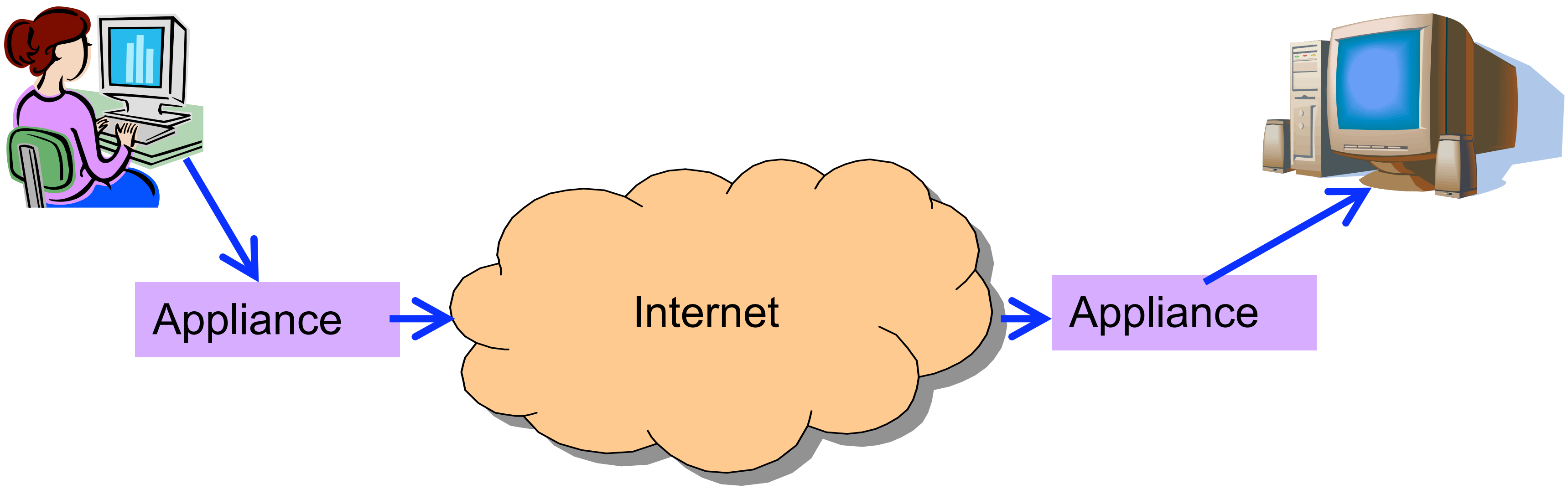
- Appliance with a lot of local memory
- Sends ACK packets quickly to the sender
- Overwrites receive window with a large value
- Or, even run a new and improved version of TCP

Example: Compression



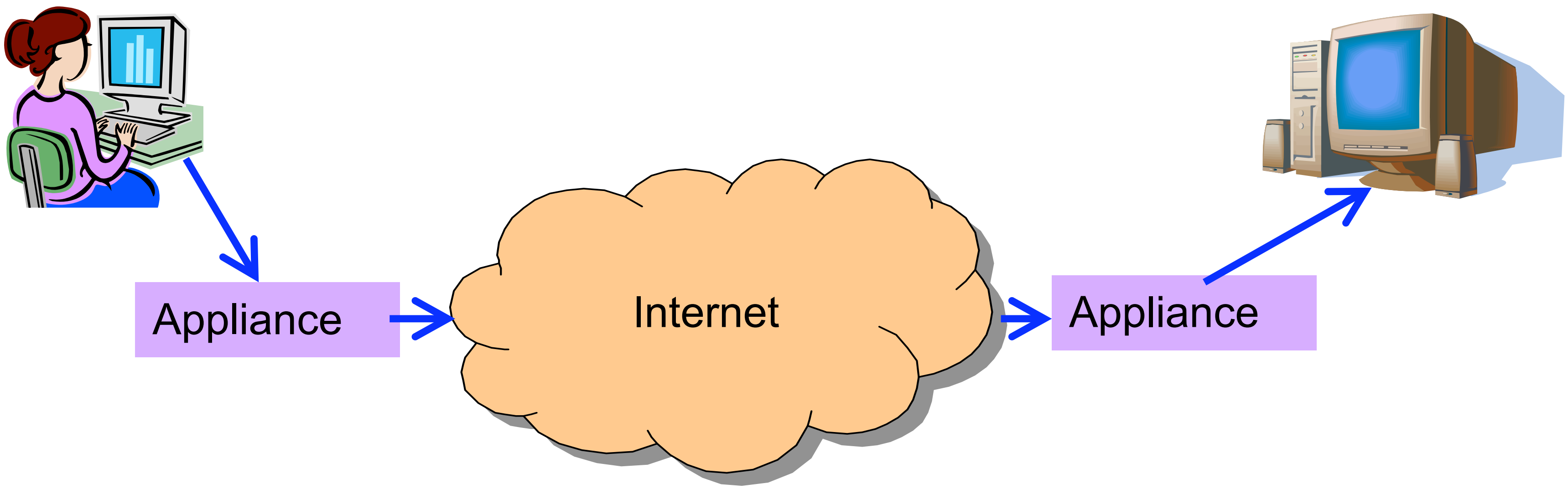
- Compress the packet
- Send the compressed packet
- Uncompress at the other end
- Maybe compress across successive packets

Example: Caching



- Cache copies of the outgoing packets
- Check for sequences of bytes that match past data
- Just send a pointer to the past data
- And have the receiving appliance reconstruct

Example: Encryption



- Two sites share keys for encrypting traffic
- Sending appliance encrypts the data
- Receiving appliance decrypts the data
- Protects the sites from snoopers on the Internet

Conclusions

- Middleboxes address important problems
  - Getting by with fewer IP addresses
  - Blocking unwanted traffic
  - Making fair use of network resources
  - Improving end-to-end performance
- Middleboxes cause problems of their own
  - No longer globally unique IP addresses
  - No longer can assume network simply delivers packets