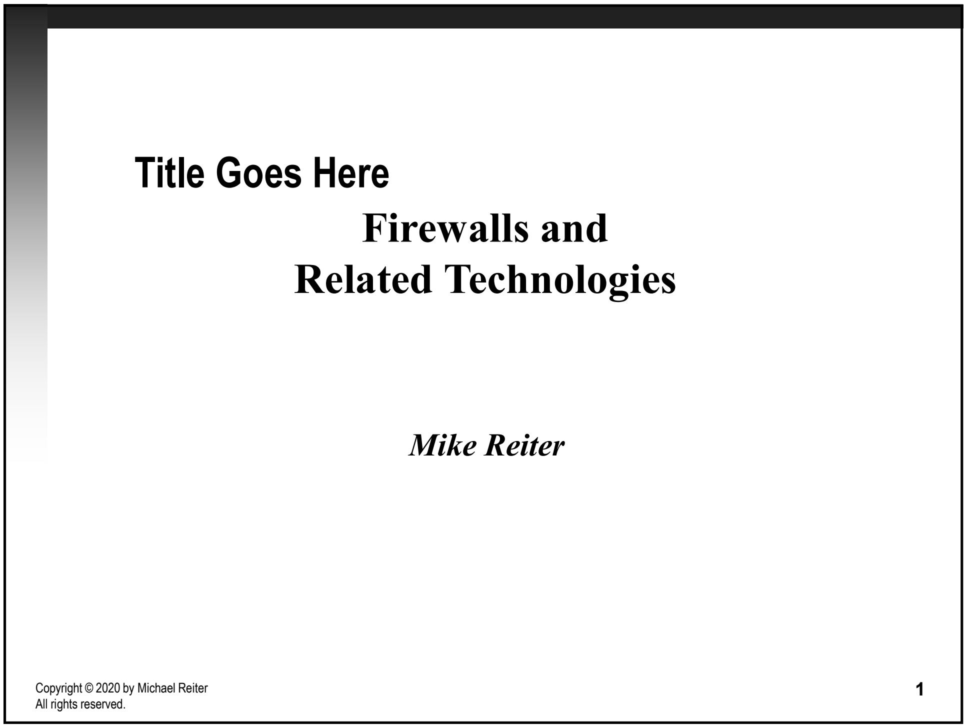

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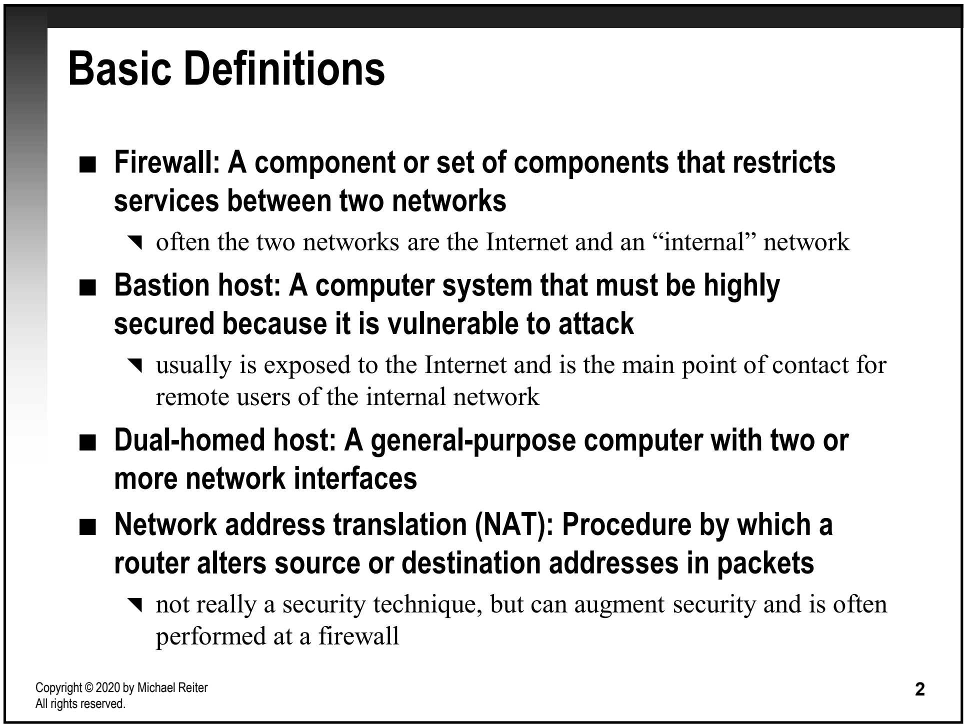
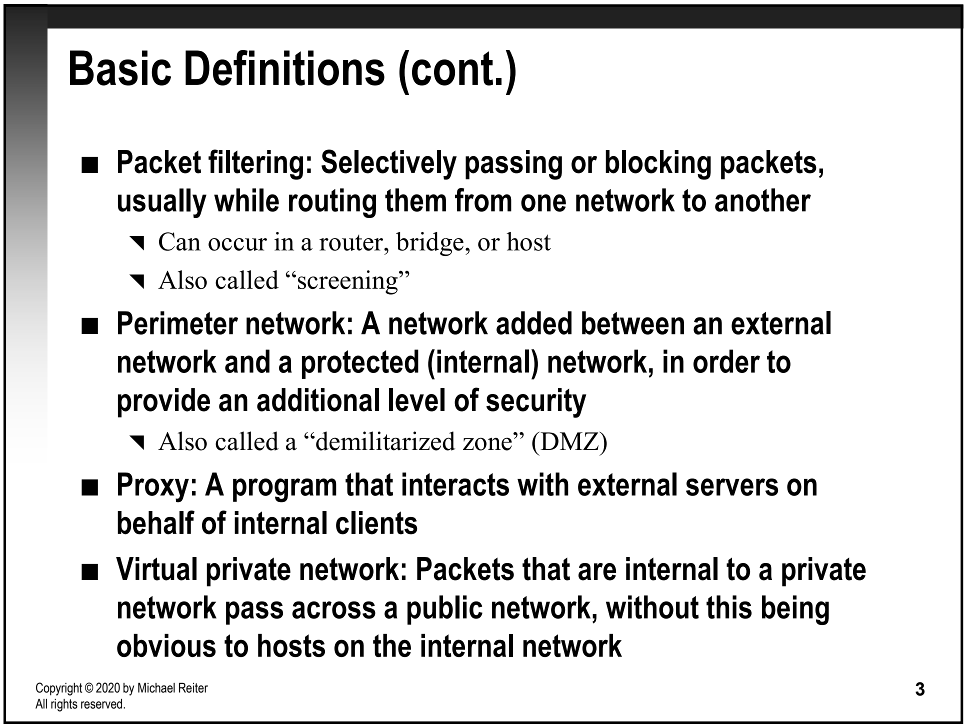
Firewalls and Related Technologies

Mike Reiter



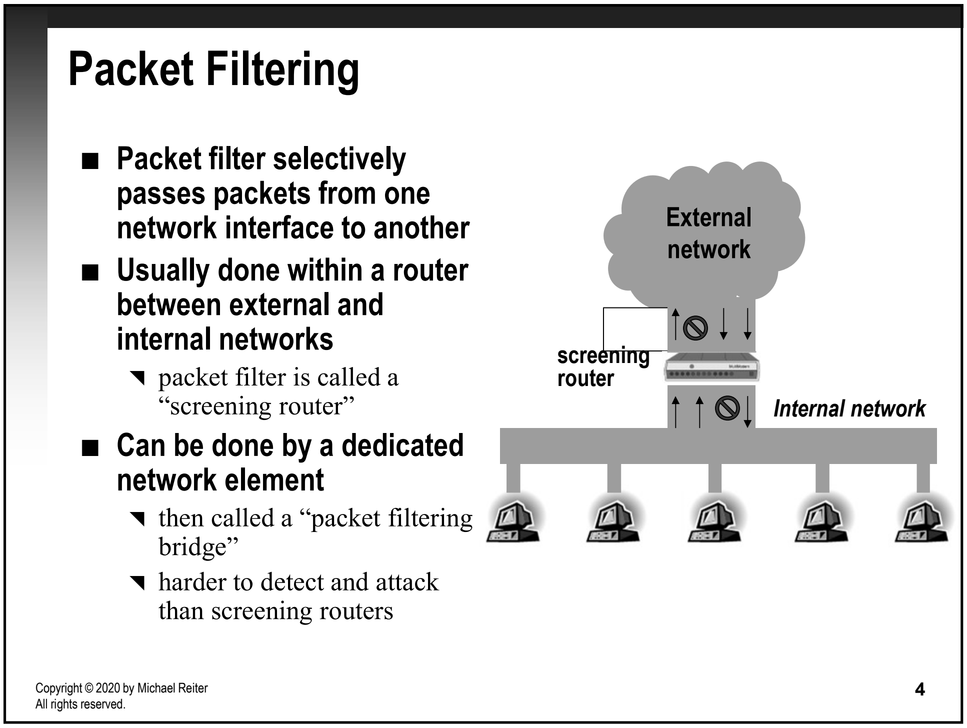
Basic Definitions

- **Firewall: A component or set of components that restricts services between two networks**
  - often the two networks are the Internet and an "internal" network
- **Bastion host: A computer system that must be highly secured because it is vulnerable to attack**
  - usually is exposed to the Internet and is the main point of contact for remote users of the internal network
- **Dual-homed host: A general-purpose computer with two or more network interfaces**
- **Network address translation (NAT): Procedure by which a router alters source or destination addresses in packets**
  - not really a security technique, but can augment security and is often performed at a firewall



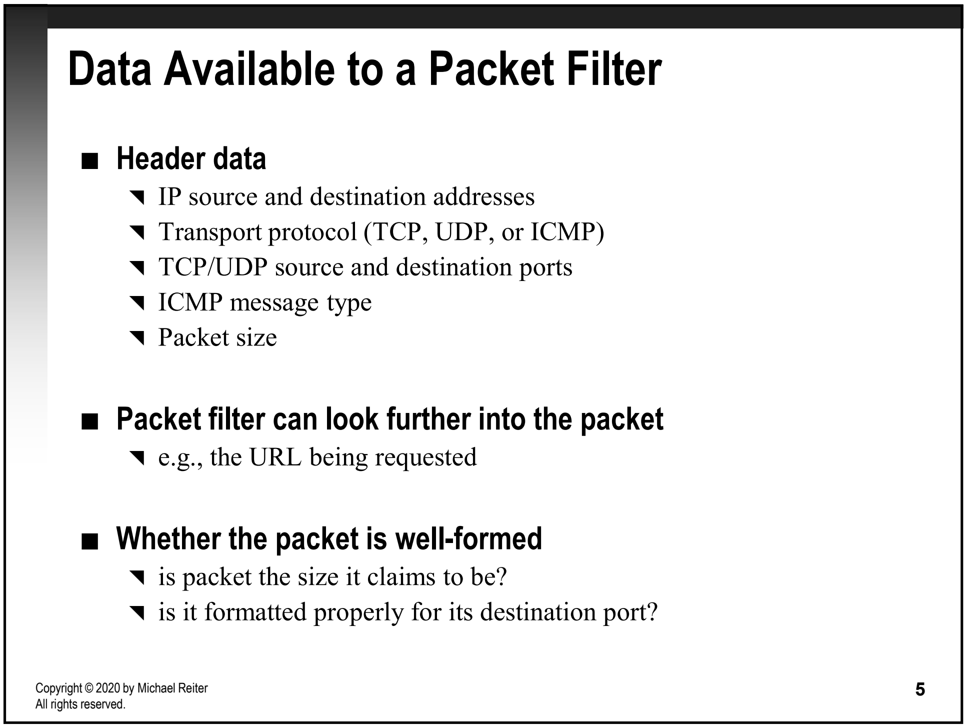
Basic Definitions (cont.)

- **Packet filtering: Selectively passing or blocking packets, usually while routing them from one network to another**
  - Can occur in a router, bridge, or host
  - Also called “screening”
- **Perimeter network: A network added between an external network and a protected (internal) network, in order to provide an additional level of security**
  - Also called a “demilitarized zone” (DMZ)
- **Proxy: A program that interacts with external servers on behalf of internal clients**
- **Virtual private network: Packets that are internal to a private network pass across a public network, without this being obvious to hosts on the internal network**



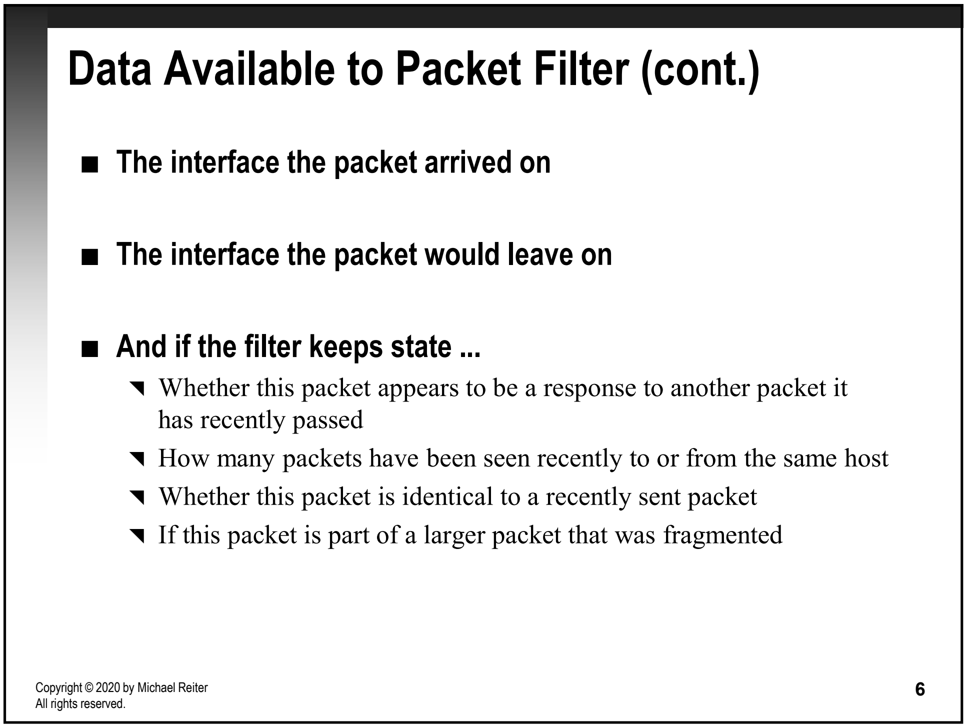
Packet Filtering

- **Packet filter selectively passes packets from one network interface to another**
- **Usually done within a router between external and internal networks**
  - packet filter is called a “screening router”
- **Can be done by a dedicated network element**
  - then called a “packet filtering bridge”
  - harder to detect and attack than screening routers



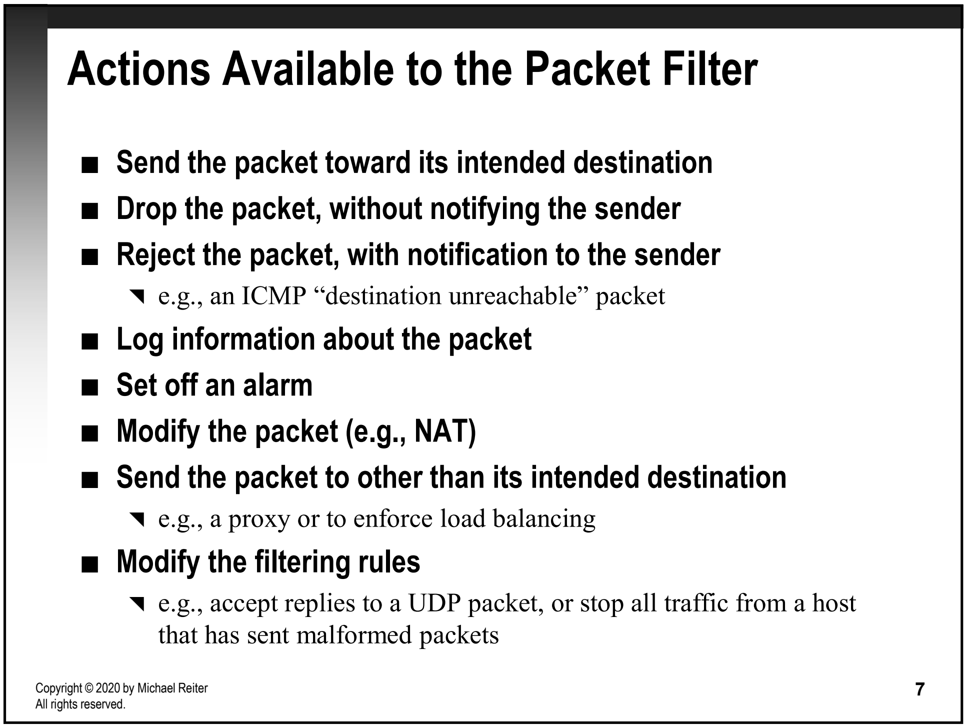
Data Available to a Packet Filter

- **Header data**
  - IP source and destination addresses
  - Transport protocol (TCP, UDP, or ICMP)
  - TCP/UDP source and destination ports
  - ICMP message type
  - Packet size
- **Packet filter can look further into the packet**
  - e.g., the URL being requested
- **Whether the packet is well-formed**
  - is packet the size it claims to be?
  - is it formatted properly for its destination port?



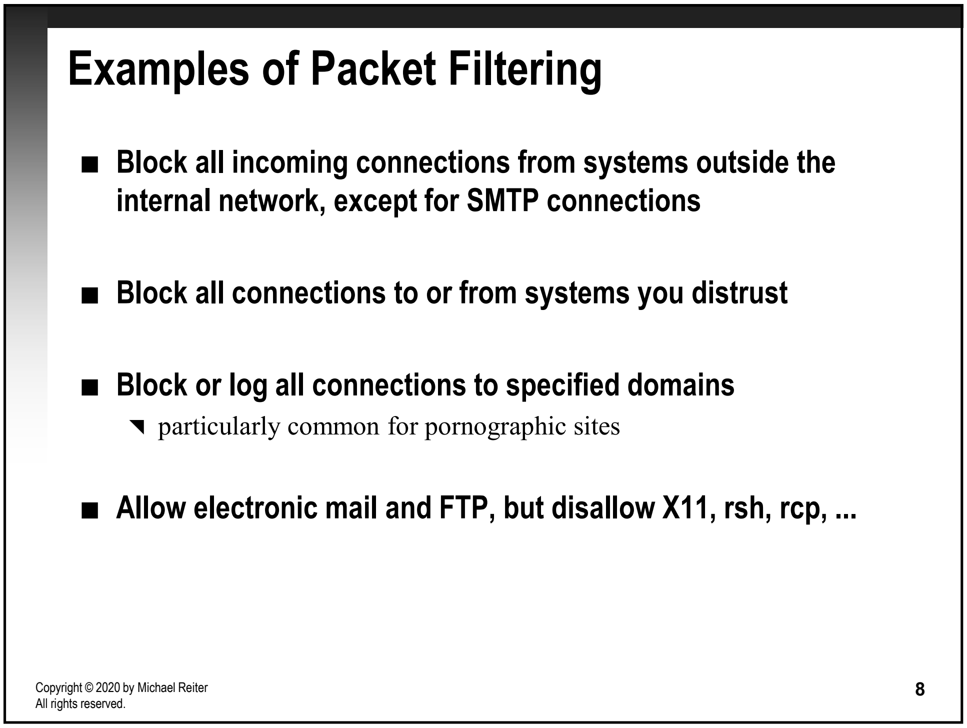
Data Available to Packet Filter (cont.)

- **The interface the packet arrived on**
- **The interface the packet would leave on**
- **And if the filter keeps state ...**
  - Whether this packet appears to be a response to another packet it has recently passed
  - How many packets have been seen recently to or from the same host
  - Whether this packet is identical to a recently sent packet
  - If this packet is part of a larger packet that was fragmented



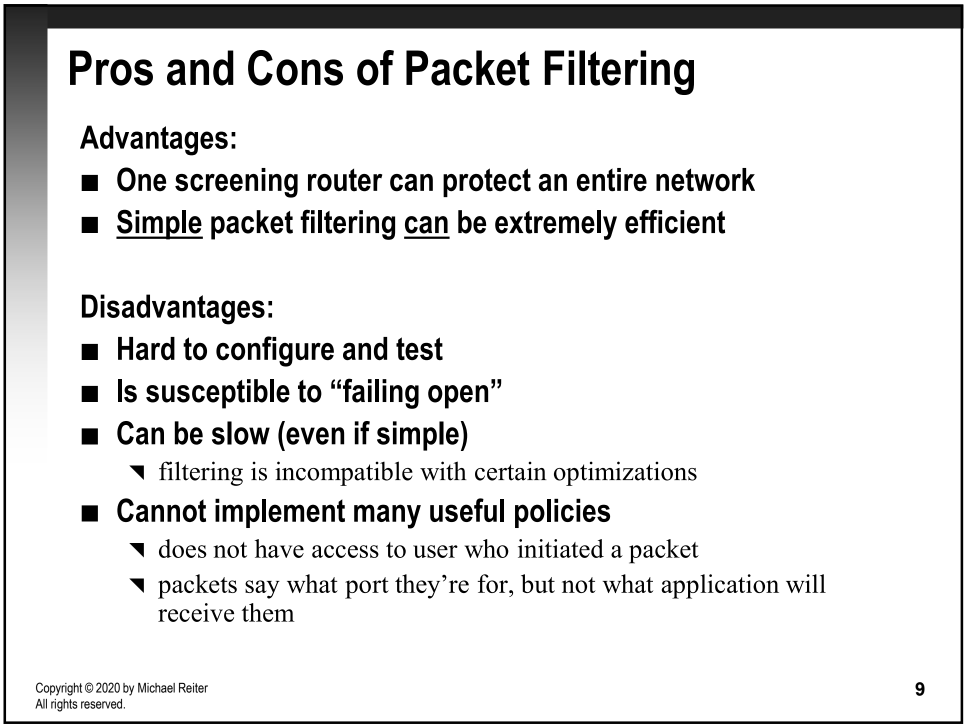
Actions Available to the Packet Filter

- Send the packet toward its intended destination
- Drop the packet, without notifying the sender
- Reject the packet, with notification to the sender
  - e.g., an ICMP “destination unreachable” packet
- Log information about the packet
- Set off an alarm
- Modify the packet (e.g., NAT)
- Send the packet to other than its intended destination
  - e.g., a proxy or to enforce load balancing
- Modify the filtering rules
  - e.g., accept replies to a UDP packet, or stop all traffic from a host that has sent malformed packets



Examples of Packet Filtering

- Block all incoming connections from systems outside the internal network, except for SMTP connections
- Block all connections to or from systems you distrust
- Block or log all connections to specified domains
  - particularly common for pornographic sites
- Allow electronic mail and FTP, but disallow X11, rsh, rcp, ...



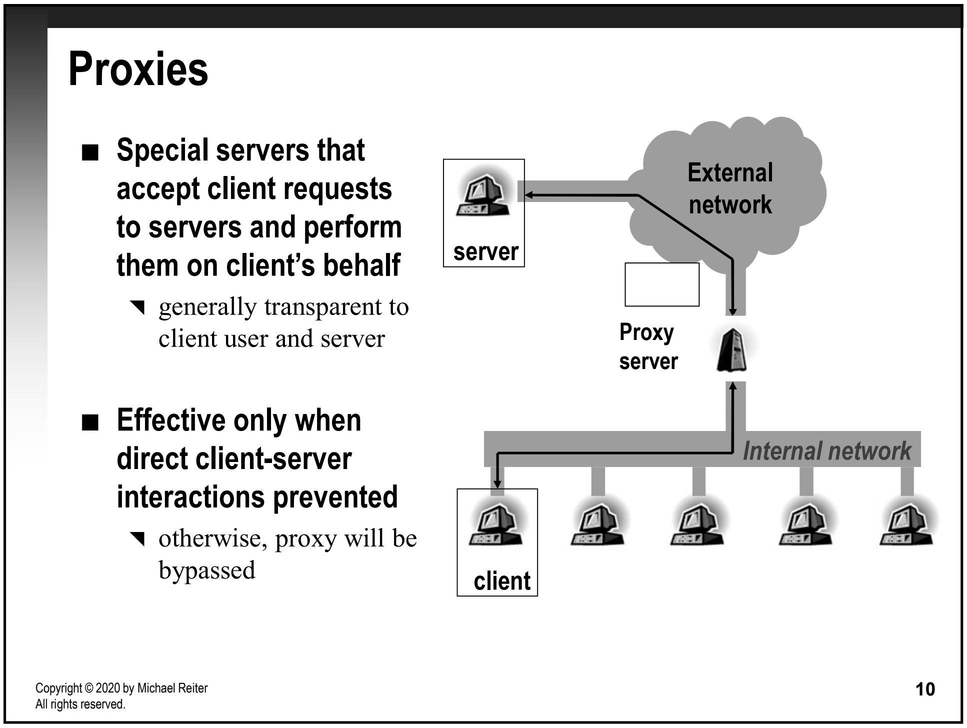
Pros and Cons of Packet Filtering

Advantages:

- **One screening router can protect an entire network**
- **Simple packet filtering can be extremely efficient**

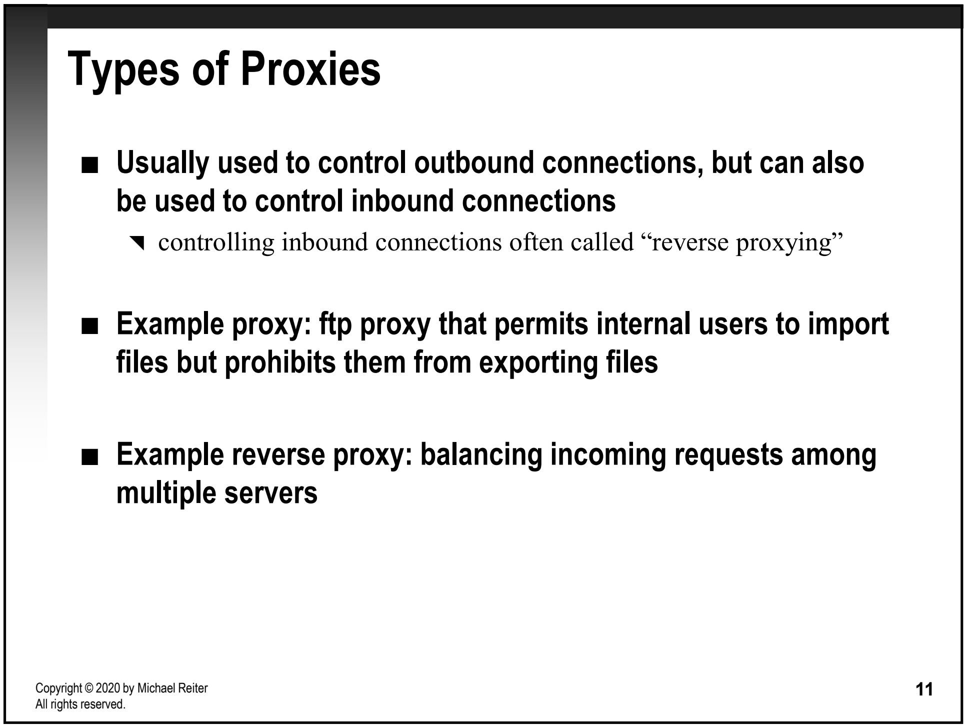
Disadvantages:

- **Hard to configure and test**
- **Is susceptible to “failing open”**
- **Can be slow (even if simple)**
  - filtering is incompatible with certain optimizations
- **Cannot implement many useful policies**
  - does not have access to user who initiated a packet
  - packets say what port they’re for, but not what application will receive them



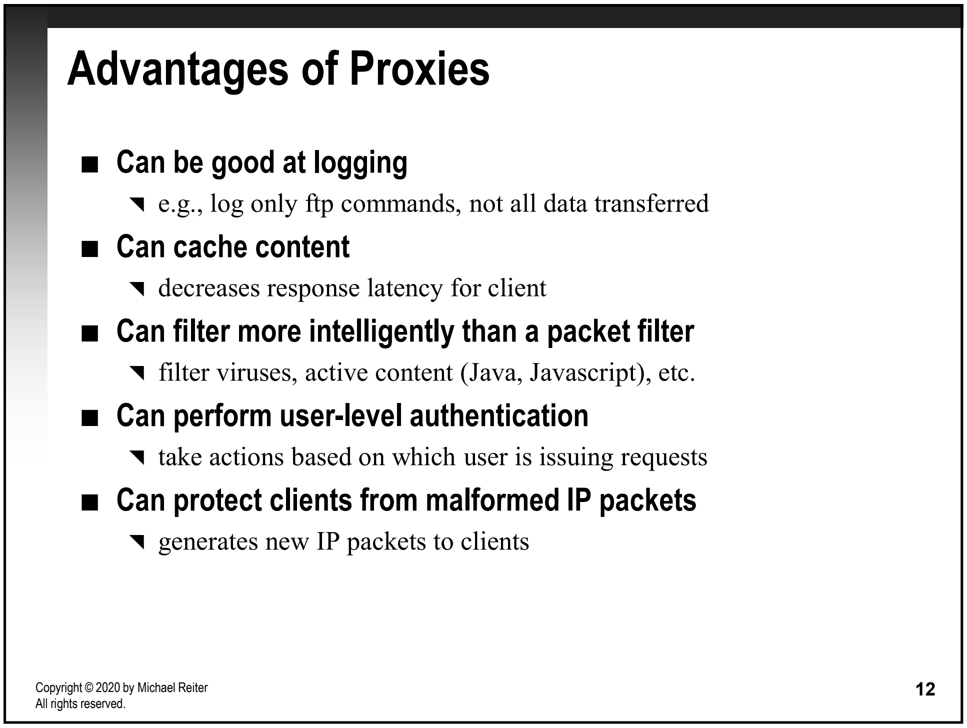
Proxies

- **Special servers that accept client requests to servers and perform them on client’s behalf**
  - generally transparent to client user and server
- **Effective only when direct client-server interactions prevented**
  - otherwise, proxy will be bypassed



Types of Proxies

- Usually used to control outbound connections, but can also be used to control inbound connections
  - controlling inbound connections often called “reverse proxying”
- Example proxy: ftp proxy that permits internal users to import files but prohibits them from exporting files
- Example reverse proxy: balancing incoming requests among multiple servers



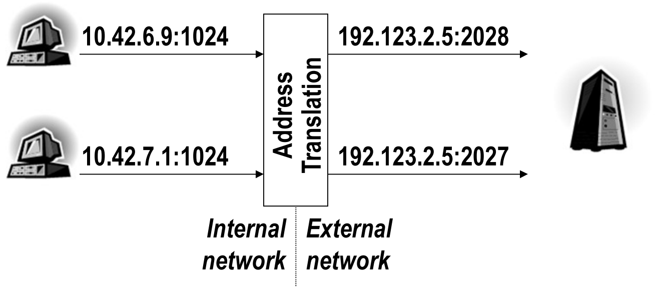
Advantages of Proxies

- Can be good at logging
  - e.g., log only ftp commands, not all data transferred
- Can cache content
  - decreases response latency for client
- Can filter more intelligently than a packet filter
  - filter viruses, active content (Java, Javascript), etc.
- Can perform user-level authentication
  - take actions based on which user is issuing requests
- Can protect clients from malformed IP packets
  - generates new IP packets to clients

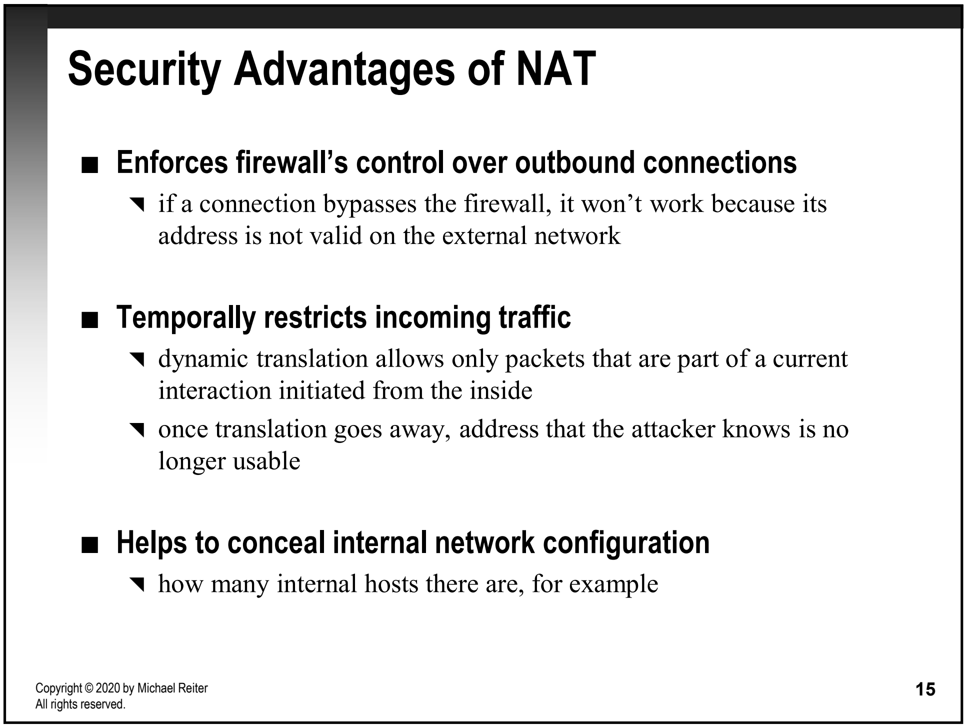
Disadvantages of Proxies

- Proxy availability lags behind introduction of new services
- Typically a new proxy is required for each service
  - though some can be run through generic proxies
- Usually require modifications to client applications

Network Address Translation (NAT)

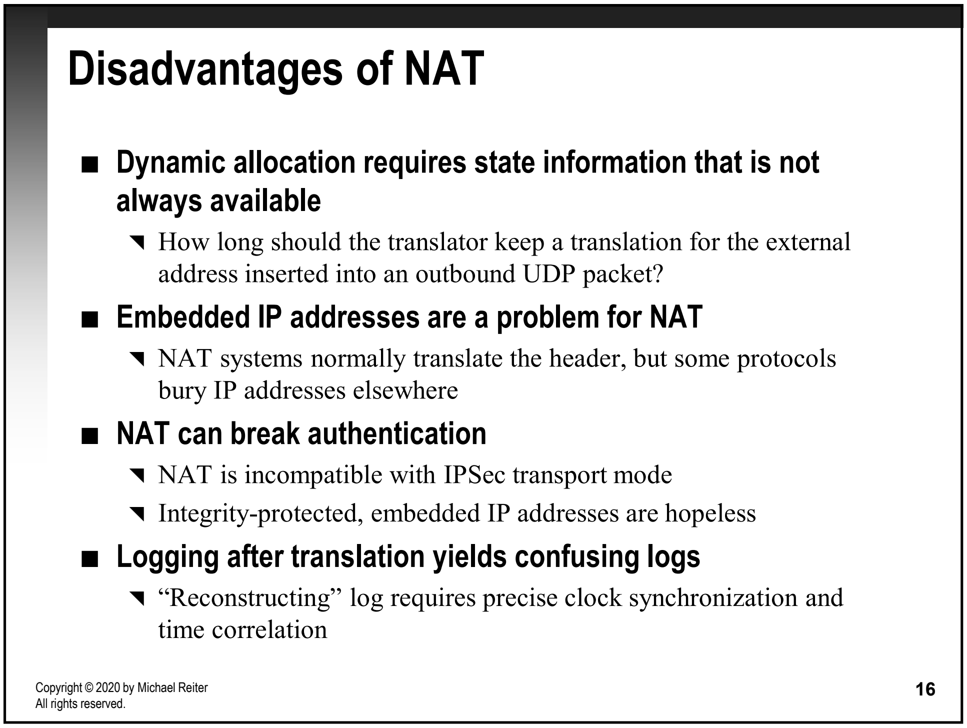


- Can dynamically allocate external address and port for each connection initiated by an internal host
- Not only (or even primarily) a security technology
  - mainly used to multiplex numerous IP addresses over a few



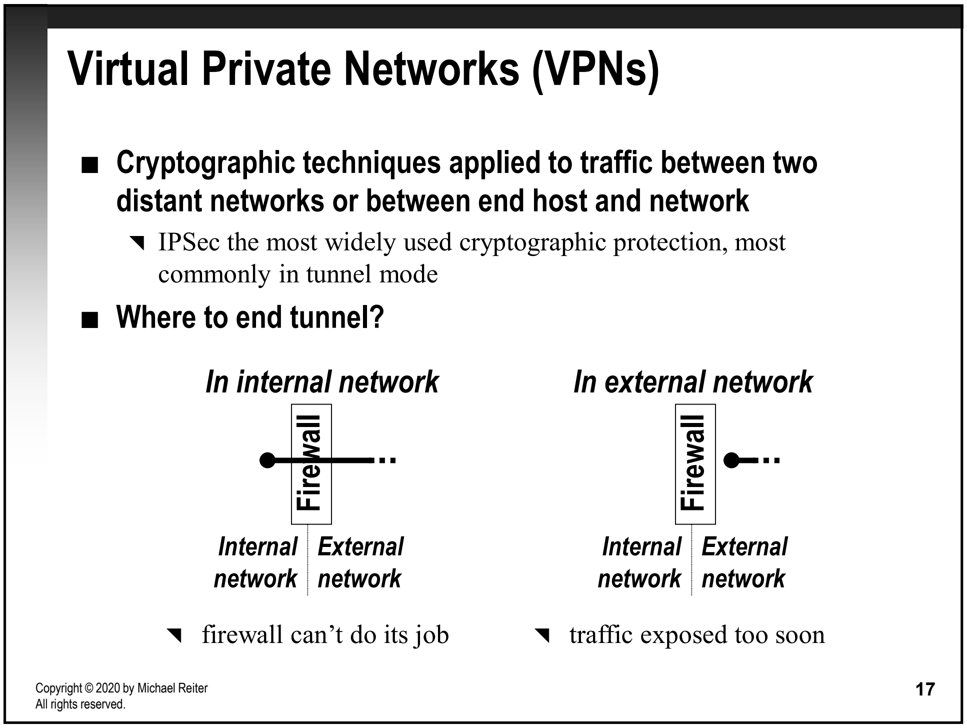
Security Advantages of NAT

- **Enforces firewall's control over outbound connections**
  - if a connection bypasses the firewall, it won't work because its address is not valid on the external network
- **Temporally restricts incoming traffic**
  - dynamic translation allows only packets that are part of a current interaction initiated from the inside
  - once translation goes away, address that the attacker knows is no longer usable
- **Helps to conceal internal network configuration**
  - how many internal hosts there are, for example



Disadvantages of NAT

- **Dynamic allocation requires state information that is not always available**
  - How long should the translator keep a translation for the external address inserted into an outbound UDP packet?
- **Embedded IP addresses are a problem for NAT**
  - NAT systems normally translate the header, but some protocols bury IP addresses elsewhere
- **NAT can break authentication**
  - NAT is incompatible with IPSec transport mode
  - Integrity-protected, embedded IP addresses are hopeless
- **Logging after translation yields confusing logs**
  - "Reconstructing" log requires precise clock synchronization and time correlation



Virtual Private Networks (VPNs)

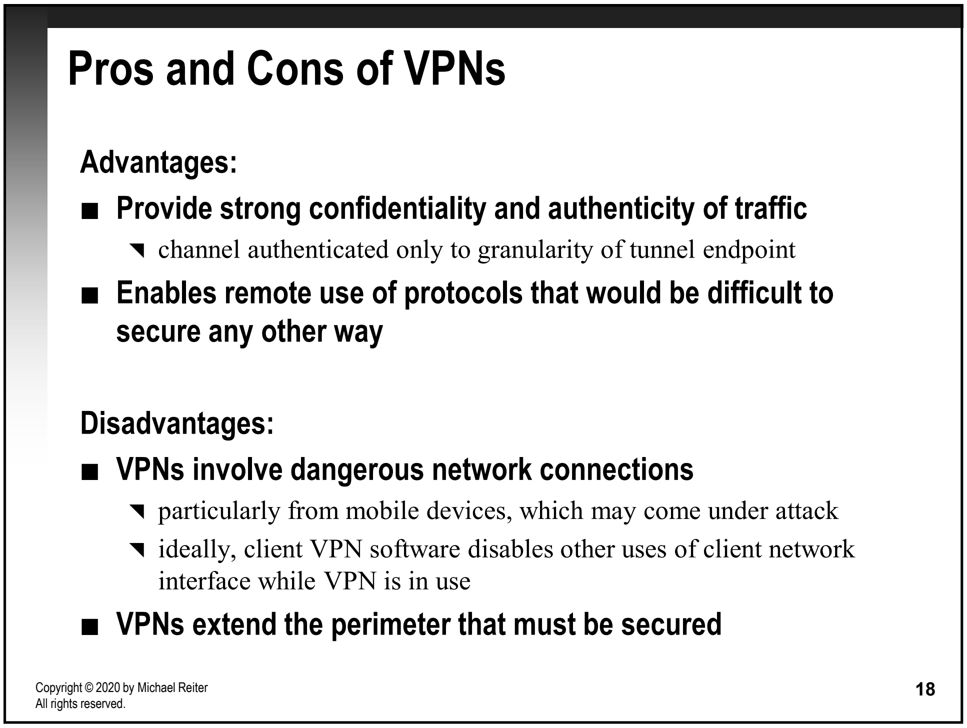
- **Cryptographic techniques applied to traffic between two distant networks or between end host and network**
  - IPSec the most widely used cryptographic protection, most commonly in tunnel mode
- **Where to end tunnel?**

In internal network

In external network

Firewall
Internal network
External network
Firewall
Internal network
External network

- firewall can't do its job
- traffic exposed too soon



Pros and Cons of VPNs

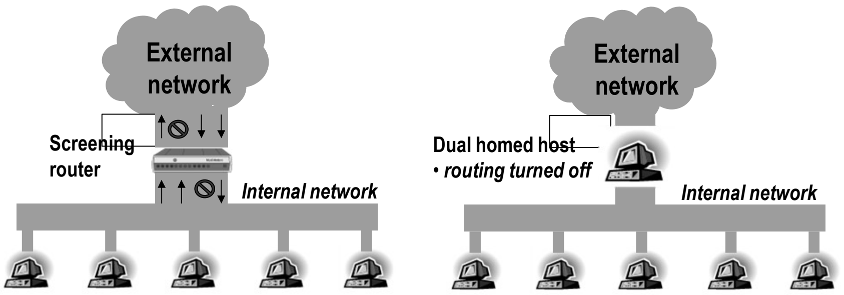
Advantages:

- **Provide strong confidentiality and authenticity of traffic**
  - channel authenticated only to granularity of tunnel endpoint
- **Enables remote use of protocols that would be difficult to secure any other way**

Disadvantages:

- **VPNs involve dangerous network connections**
  - particularly from mobile devices, which may come under attack
  - ideally, client VPN software disables other uses of client network interface while VPN is in use
- **VPNs extend the perimeter that must be secured**

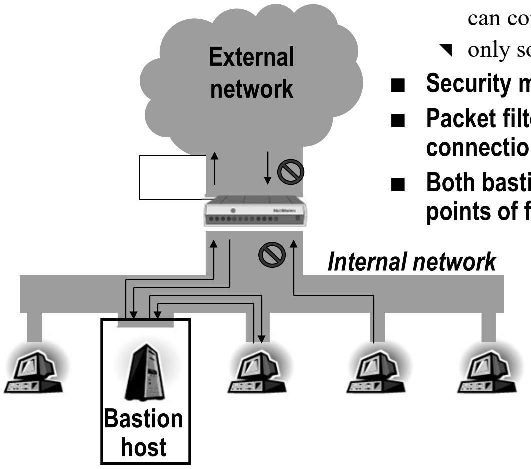
Single Box Architectures



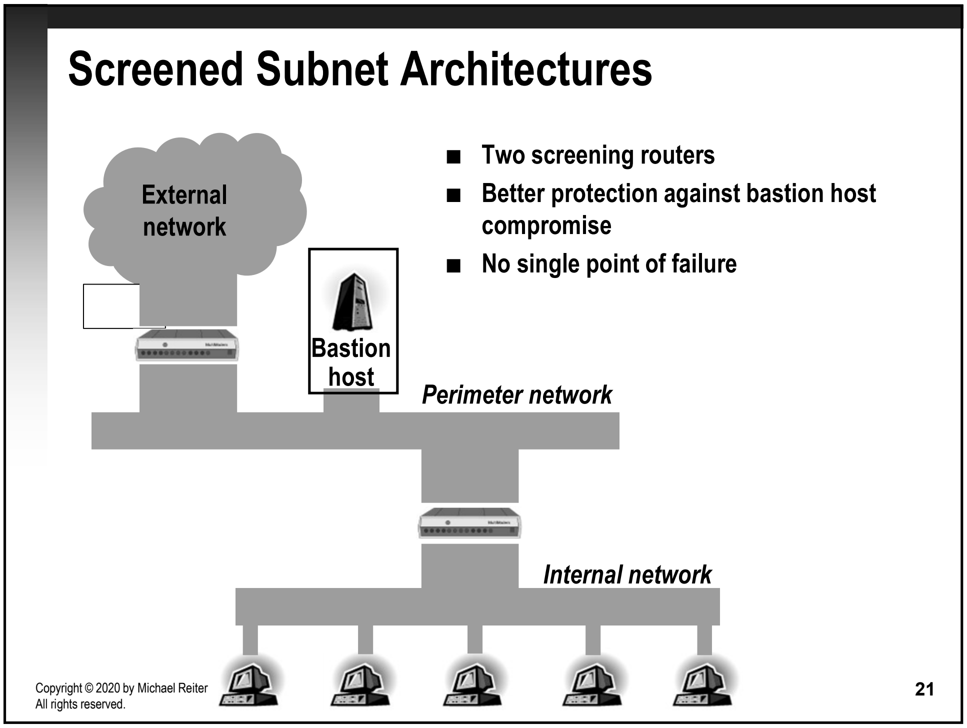
- **Very high performance**
  - a favorite of ISPs
- **Primarily packet filtering**

- **Very high degree of control**
  - everything is proxied, or users must log into it to access outside
- **Challenge: securing the firewall itself and keeping it alive**
  - lots ends up running there

Screened Host Architectures

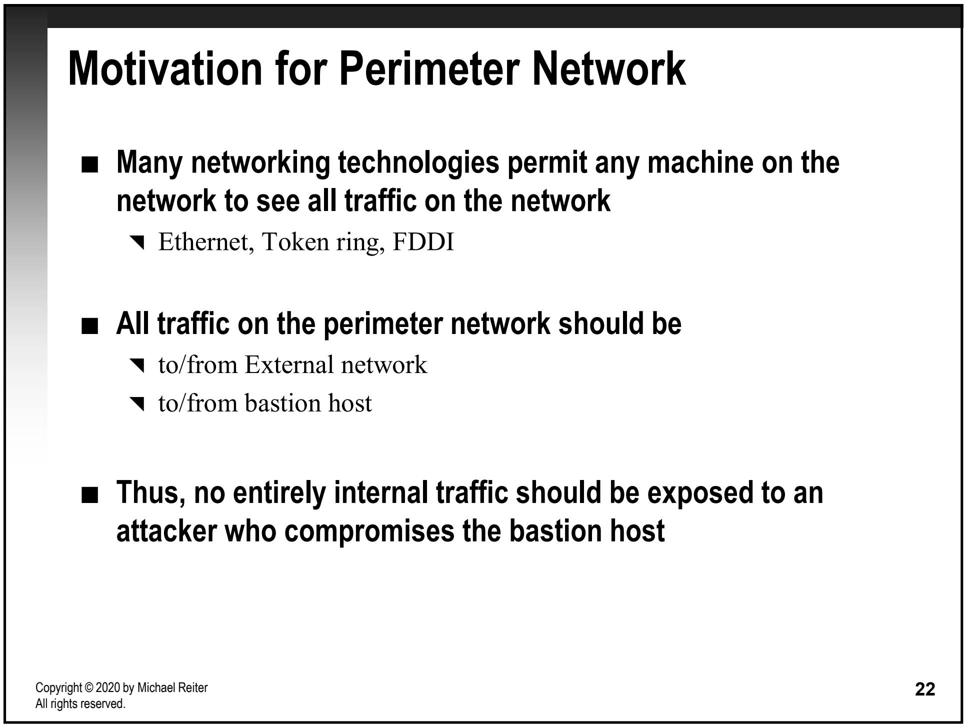


- **Bastion host attached only to internal net**
  - the only computer that external network can connect to
  - only some types of connections allowed
- **Security mainly provided by packet filter**
- **Packet filter can selectively allow some connections from other internal hosts**
- **Both bastion host and router are "single points of failure"**



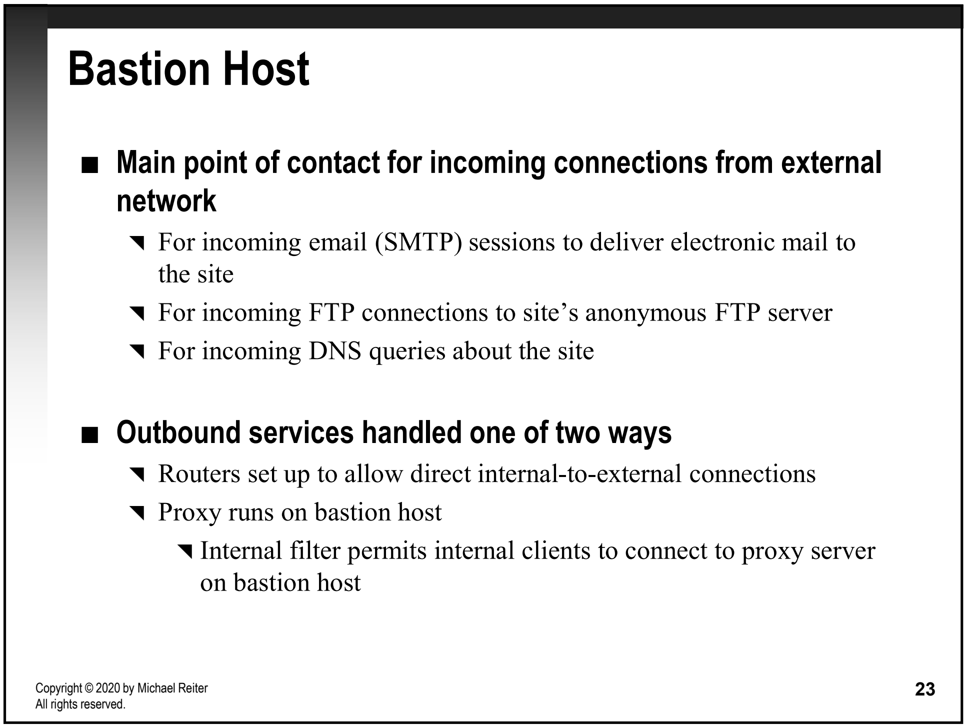
Screened Subnet Architectures

- Two screening routers
- Better protection against bastion host compromise
- No single point of failure



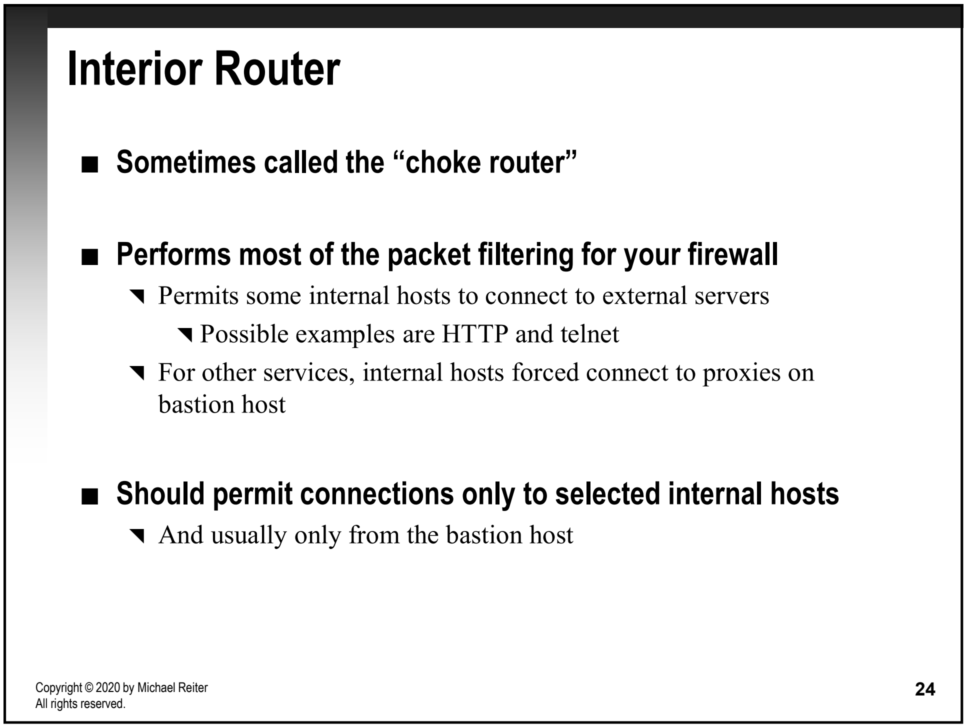
Motivation for Perimeter Network

- Many networking technologies permit any machine on the network to see all traffic on the network
  - Ethernet, Token ring, FDDI
- All traffic on the perimeter network should be
  - to/from External network
  - to/from bastion host
- Thus, no entirely internal traffic should be exposed to an attacker who compromises the bastion host



Bastion Host

- **Main point of contact for incoming connections from external network**
  - For incoming email (SMTP) sessions to deliver electronic mail to the site
  - For incoming FTP connections to site’s anonymous FTP server
  - For incoming DNS queries about the site
- **Outbound services handled one of two ways**
  - Routers set up to allow direct internal-to-external connections
  - Proxy runs on bastion host
    - Internal filter permits internal clients to connect to proxy server on bastion host



Interior Router

- **Sometimes called the “choke router”**
- **Performs most of the packet filtering for your firewall**
  - Permits some internal hosts to connect to external servers
    - Possible examples are HTTP and telnet
  - For other services, internal hosts forced connect to proxies on bastion host
- **Should permit connections only to selected internal hosts**
  - And usually only from the bastion host

Exterior Router

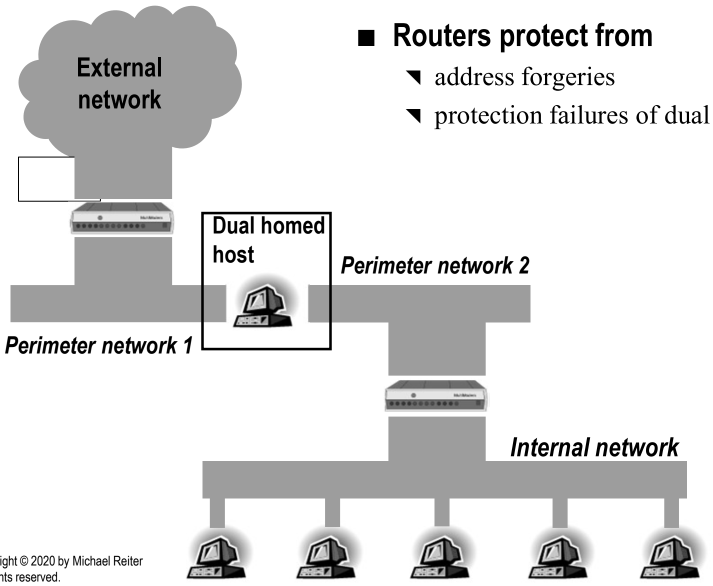
- **Sometimes called the “access router”**
- **Filtering rules**
  - Duplicate many of the filtering rules on the internal router
  - Permit outbound connections from bastion host proxies

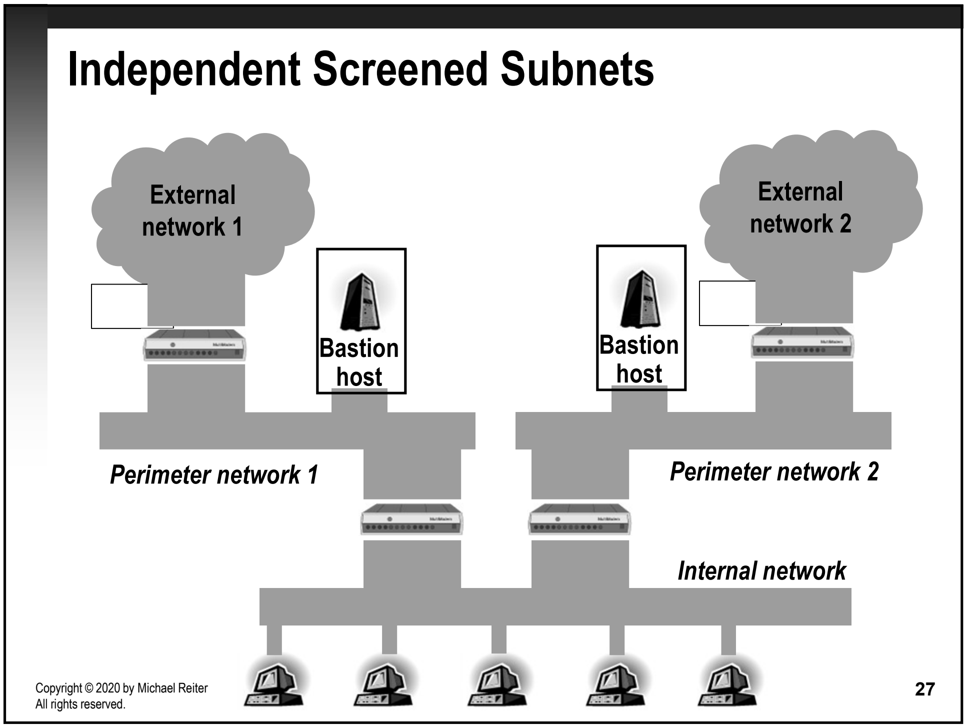
Two main jobs

- **Filters incoming packets with forged source addresses**
  - Prevents outsiders from forging packets that
    - appear to be from hosts on the perimeter network
    - appear to be from hosts on the internal network
- **Filters outgoing packets with forged source addresses**
  - An important part of being a good “network citizen”

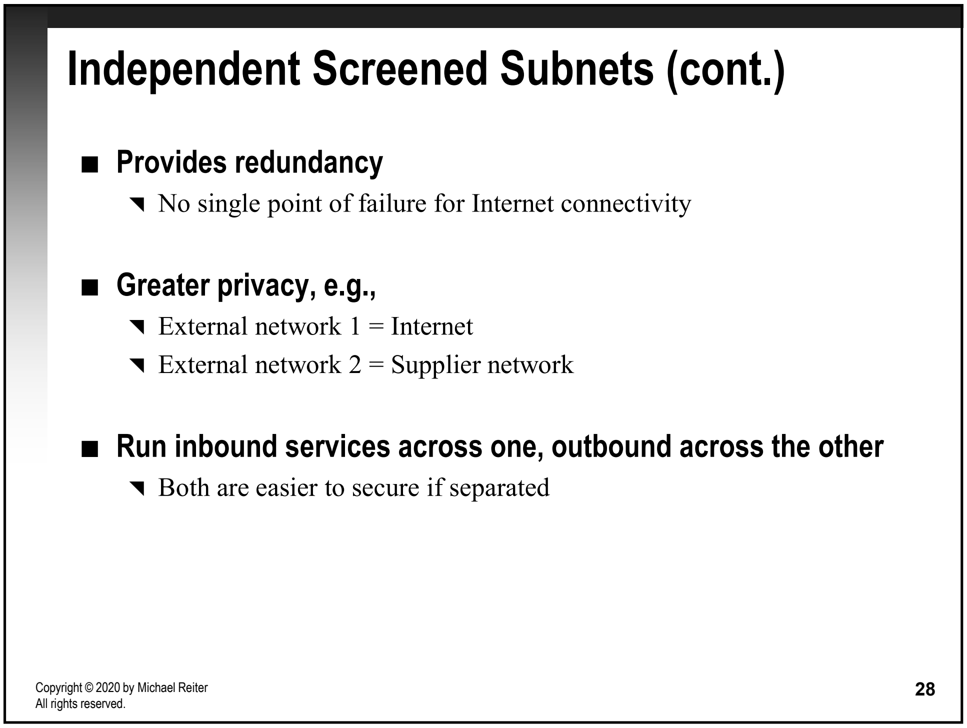
Split-Screened Subnet Architecture

- **Routers protect from**
  - address forgeries
  - protection failures of dual homed host



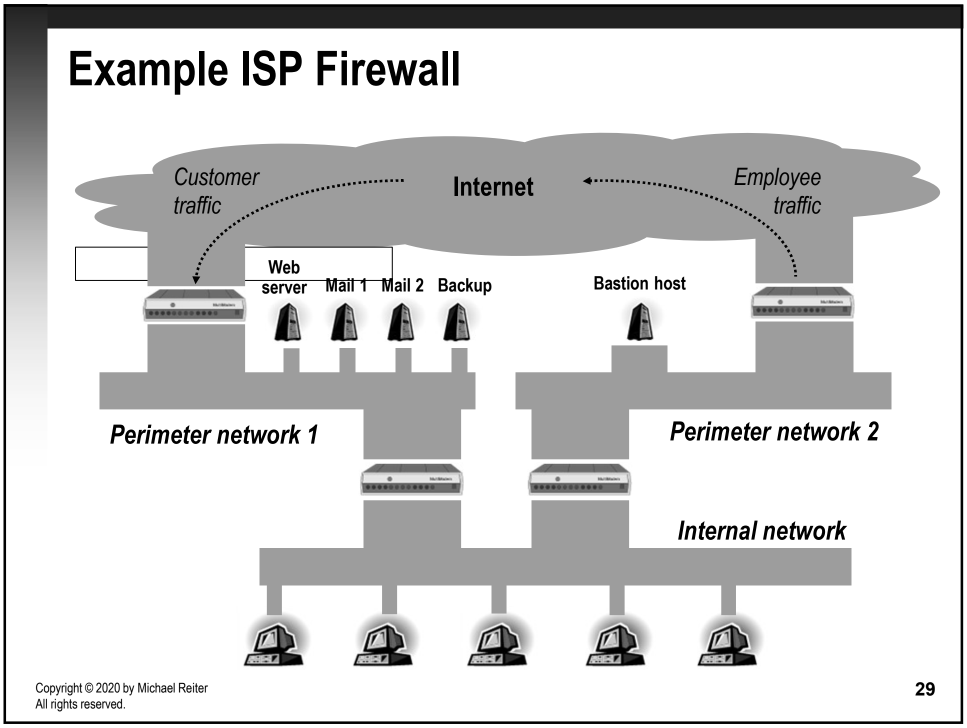


Independent Screened Subnets

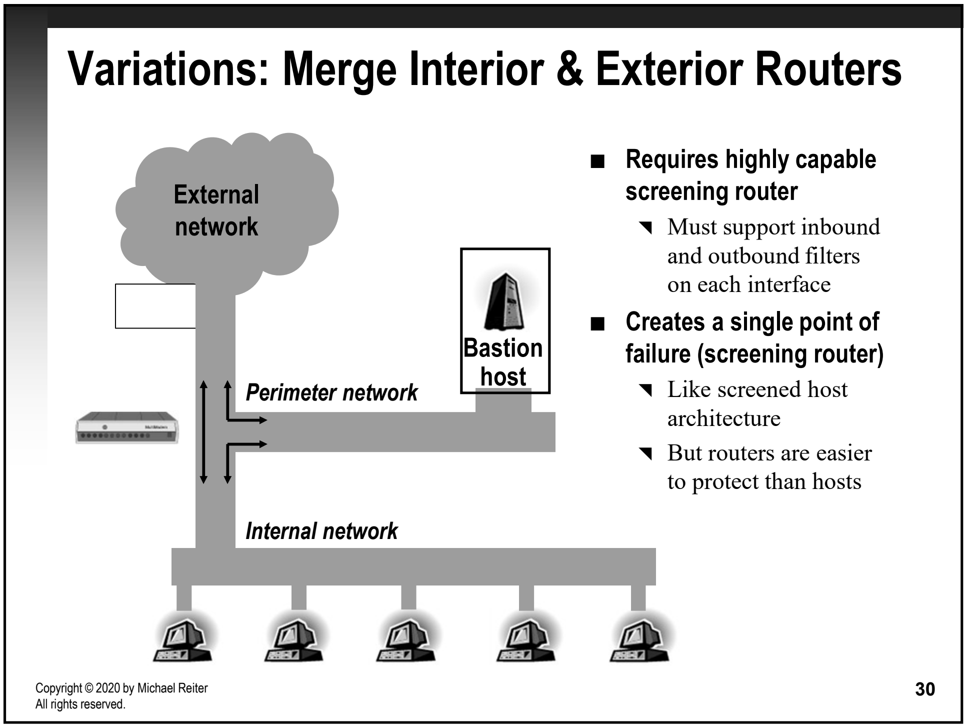


Independent Screened Subnets (cont.)

- **Provides redundancy**
  - No single point of failure for Internet connectivity
- **Greater privacy, e.g.,**
  - External network 1 = Internet
  - External network 2 = Supplier network
- **Run inbound services across one, outbound across the other**
  - Both are easier to secure if separated

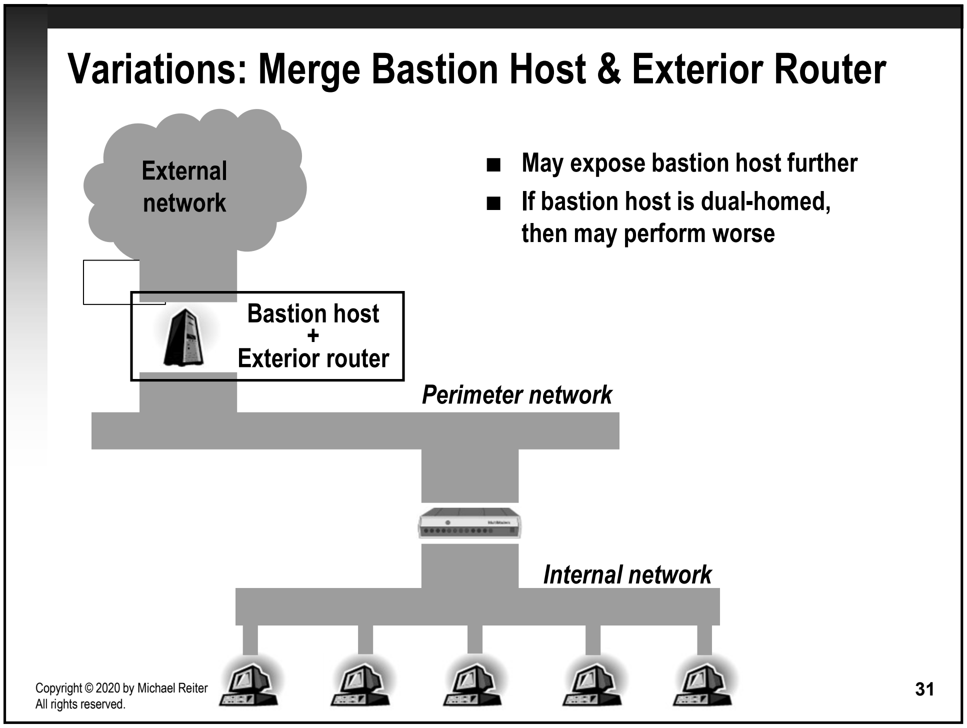


Example ISP Firewall



Variations: Merge Interior & Exterior Routers

- **Requires highly capable screening router**
  - Must support inbound and outbound filters on each interface
- **Creates a single point of failure (screening router)**
  - Like screened host architecture
  - But routers are easier to protect than hosts



Variations: Merge Bastion Host & Exterior Router

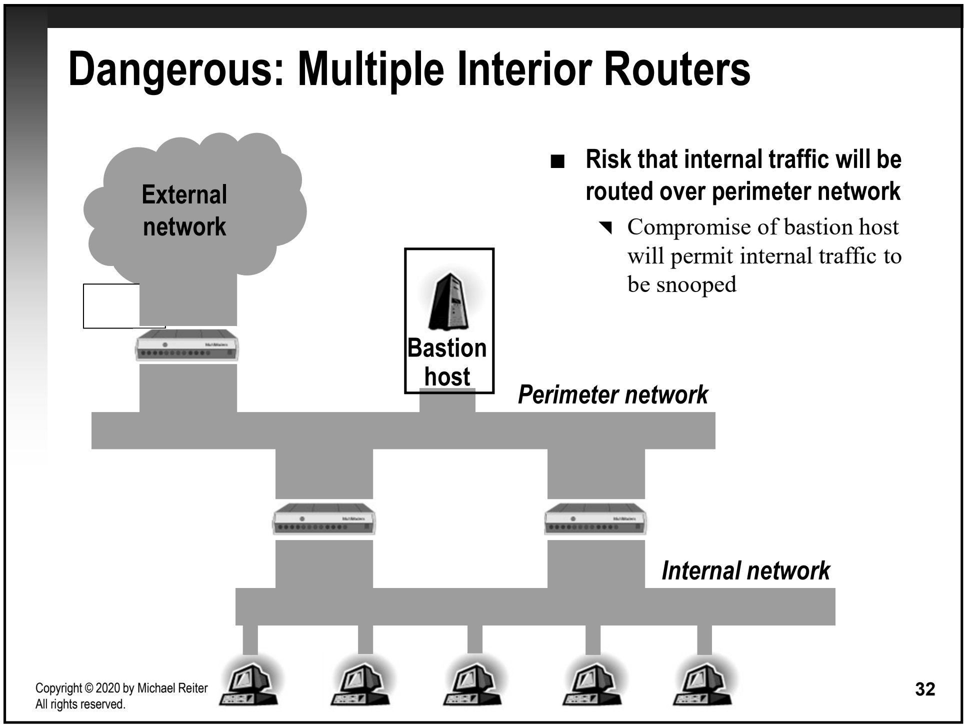
- May expose bastion host further
- If bastion host is dual-homed, then may perform worse

External network

Bastion host
+
Exterior router

Perimeter network

Internal network



Dangerous: Multiple Interior Routers

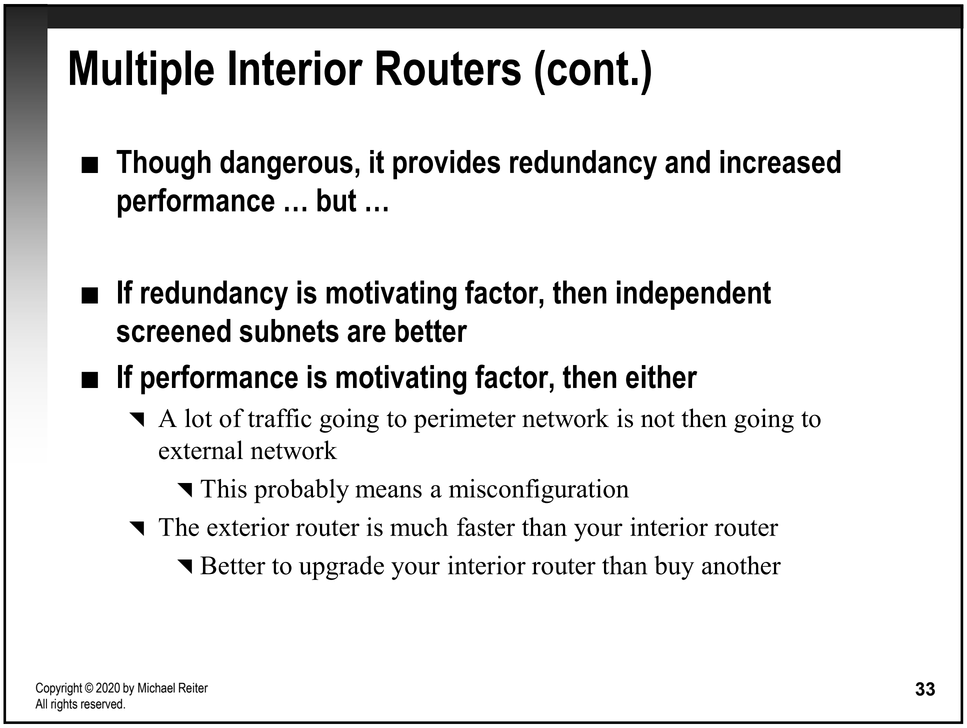
- Risk that internal traffic will be routed over perimeter network
  - Compromise of bastion host will permit internal traffic to be snooped

External network

Bastion host

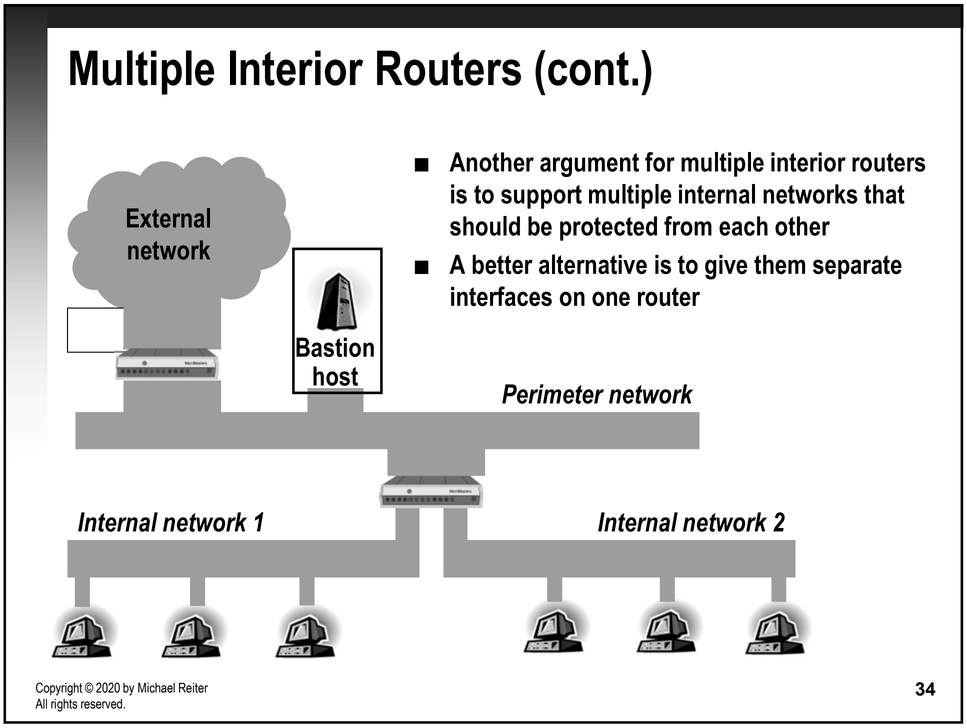
Perimeter network

Internal network



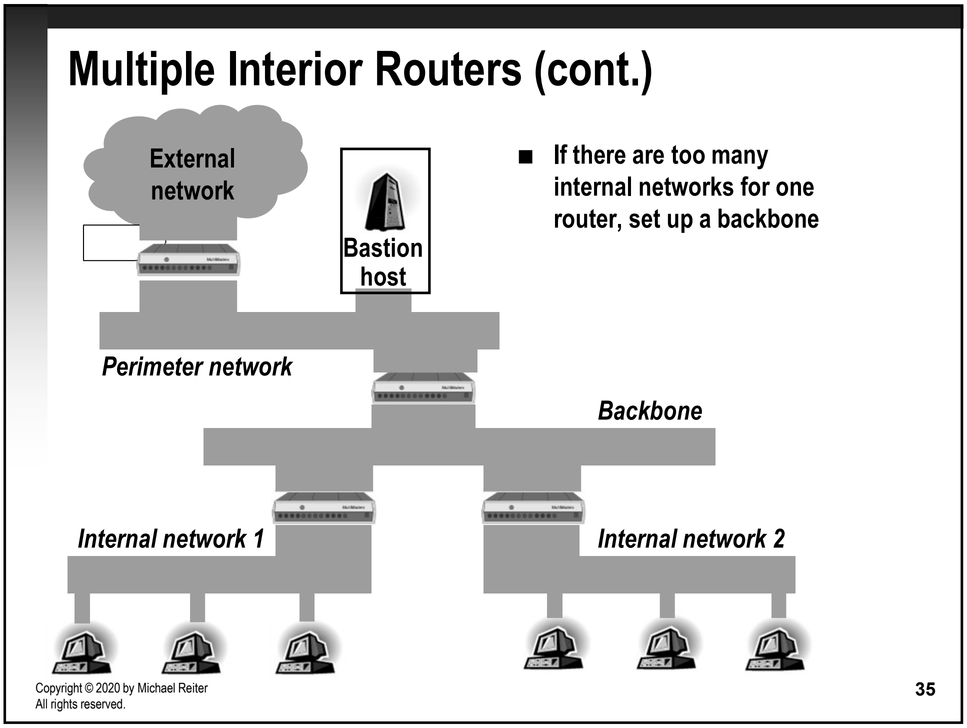
Multiple Interior Routers (cont.)

- Though dangerous, it provides redundancy and increased performance … but …
- If redundancy is motivating factor, then independent screened subnets are better
- If performance is motivating factor, then either
  - A lot of traffic going to perimeter network is not then going to external network
    - This probably means a misconfiguration
  - The exterior router is much faster than your interior router
    - Better to upgrade your interior router than buy another



Multiple Interior Routers (cont.)

- Another argument for multiple interior routers is to support multiple internal networks that should be protected from each other
- A better alternative is to give them separate interfaces on one router



Multiple Interior Routers (cont.)

- If there are too many internal networks for one router, set up a backbone

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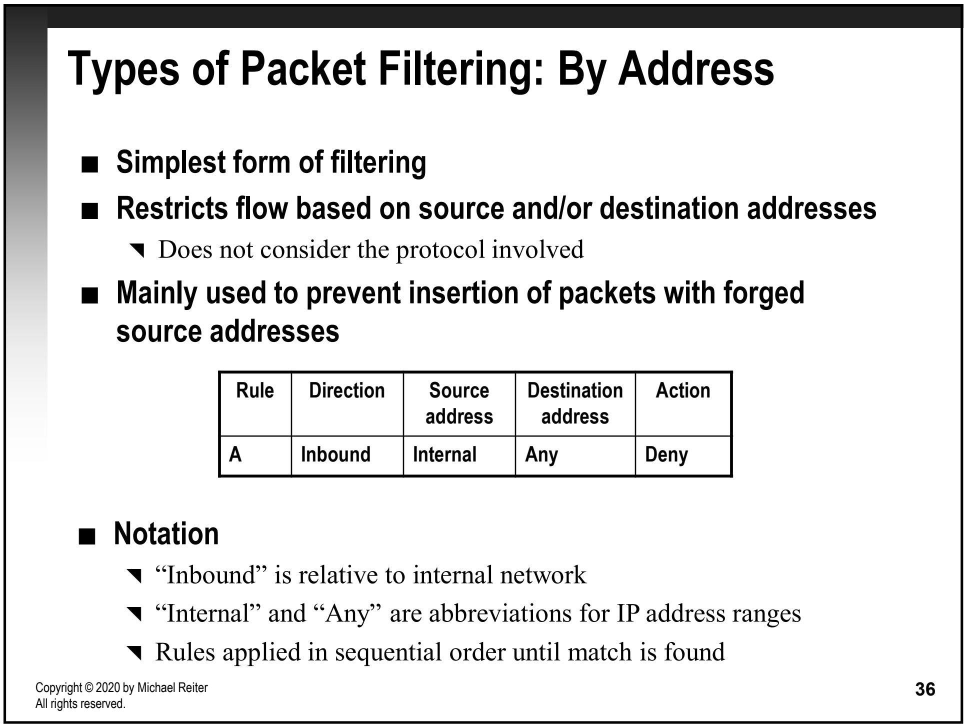

Types of Packet Filtering: By Address

- Simplest form of filtering
- Restricts flow based on source and/or destination addresses
  - Does not consider the protocol involved
- Mainly used to prevent insertion of packets with forged source addresses

Rule	Direction	Source address	Destination address	Action
A	Inbound	Internal	Any	Deny

- Notation
  - "Inbound" is relative to internal network
  - "Internal" and "Any" are abbreviations for IP address ranges
  - Rules applied in sequential order until match is found

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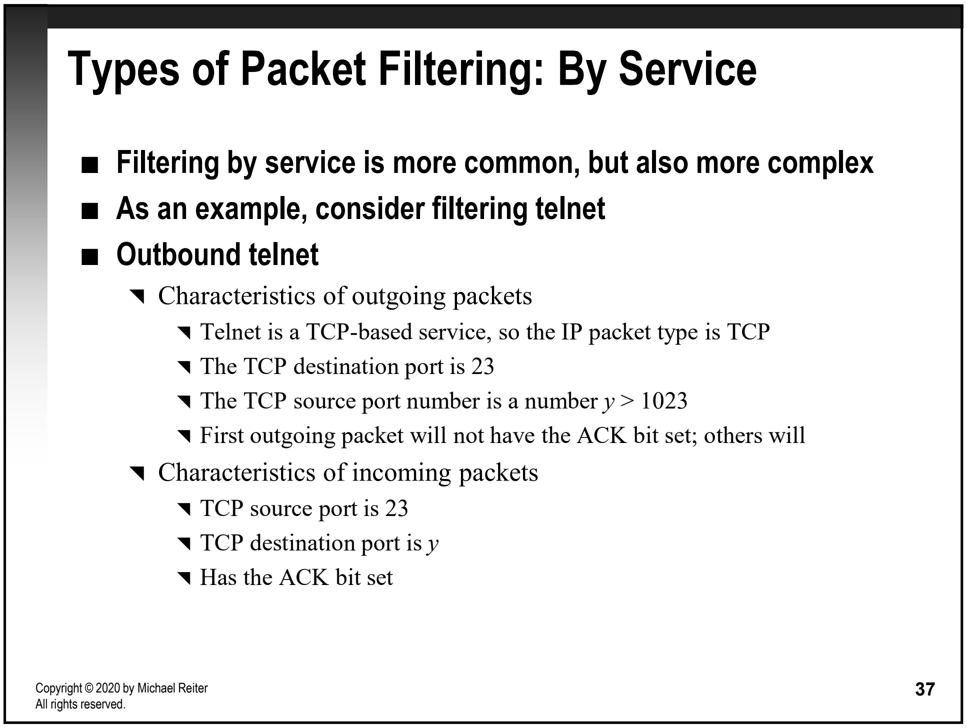
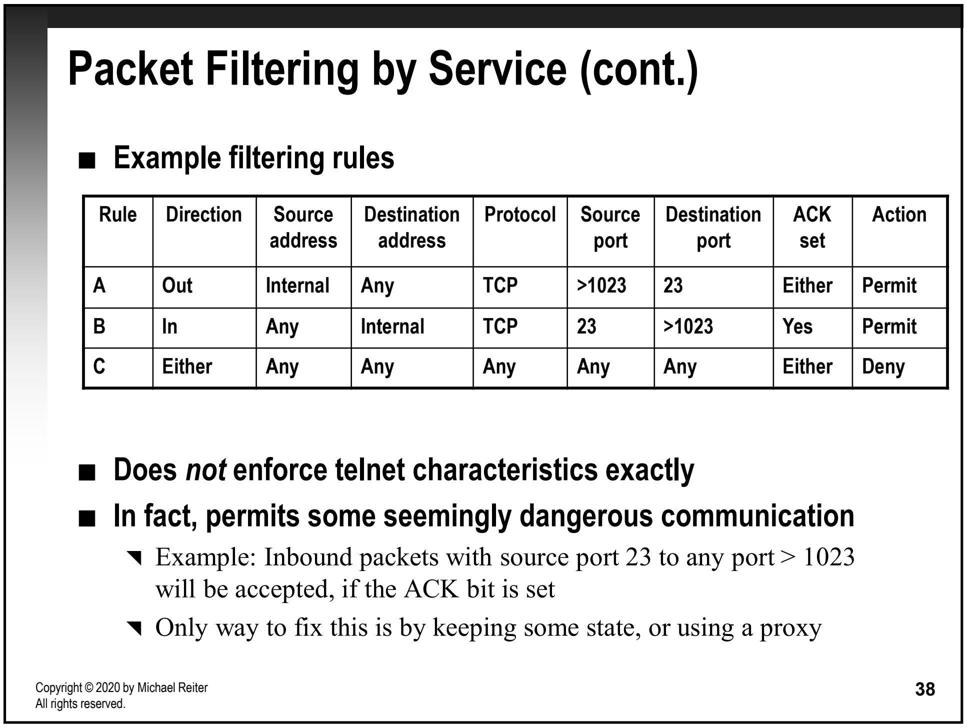


Types of Packet Filtering: By Service

- **Filtering by service is more common, but also more complex**
- **As an example, consider filtering telnet**
- **Outbound telnet**
  - Characteristics of outgoing packets
    - Telnet is a TCP-based service, so the IP packet type is TCP
    - The TCP destination port is 23
    - The TCP source port number is a number $y > 1023$
    - First outgoing packet will not have the ACK bit set; others will
  - Characteristics of incoming packets
    - TCP source port is 23
    - TCP destination port is y
    - Has the ACK bit set

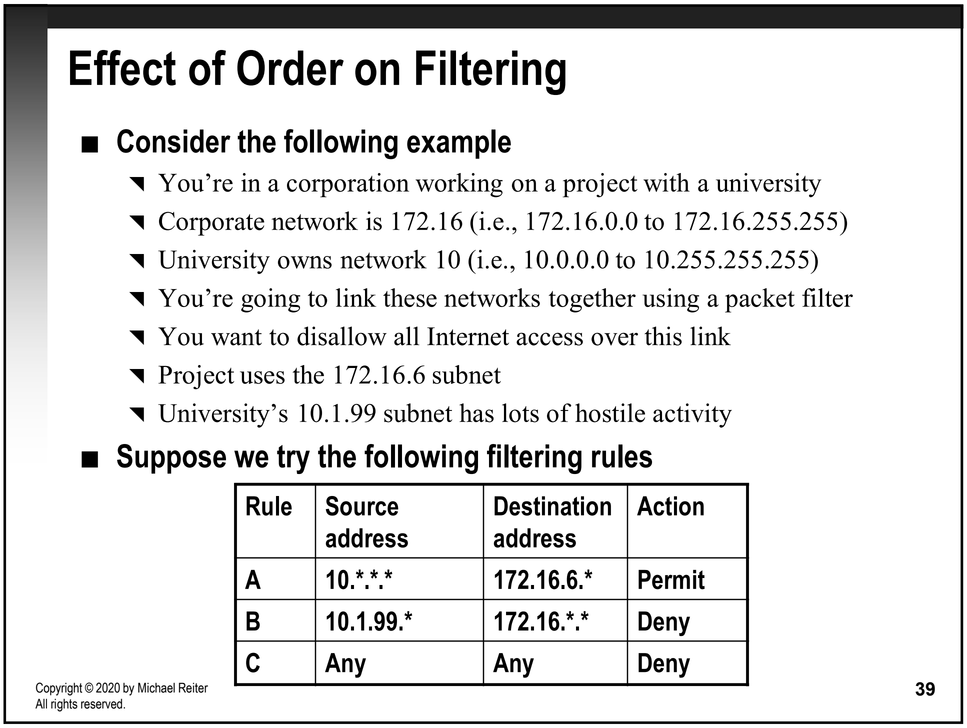


Packet Filtering by Service (cont.)

- **Example filtering rules**

Rule	Direction	Source address	Destination address	Protocol	Source port	Destination port	ACK set	Action
A	Out	Internal	Any	TCP	>1023	23	Either	Permit
B	In	Any	Internal	TCP	23	>1023	Yes	Permit
C	Either	Any	Any	Any	Any	Any	Either	Deny

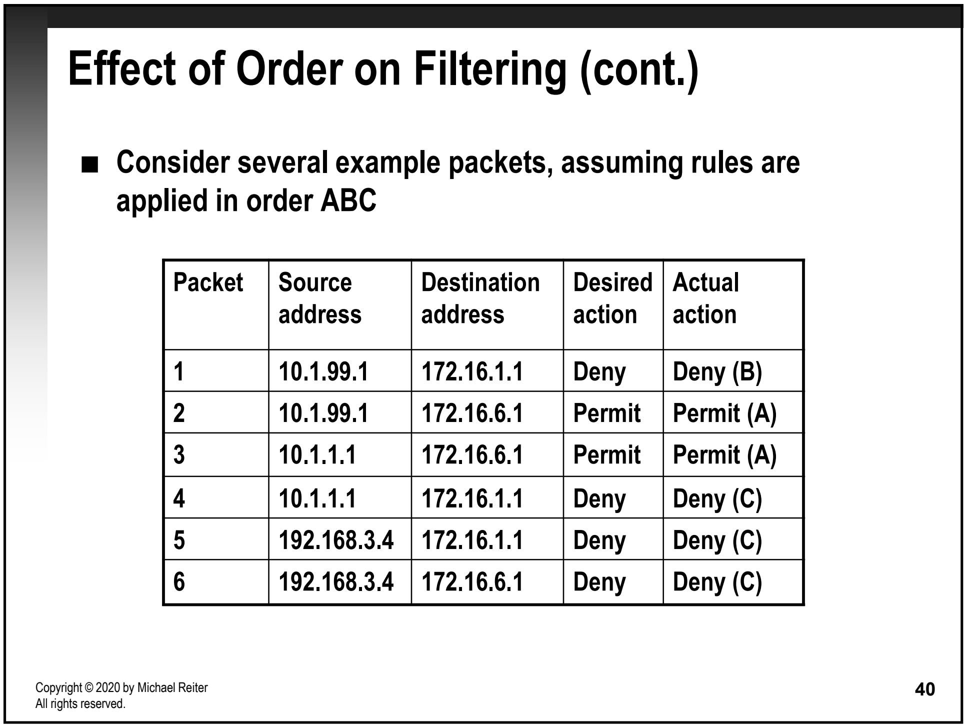
- **Does *not* enforce telnet characteristics exactly**
- **In fact, permits some seemingly dangerous communication**
  - Example: Inbound packets with source port 23 to any port > 1023 will be accepted, if the ACK bit is set
  - Only way to fix this is by keeping some state, or using a proxy



Effect of Order on Filtering

- **Consider the following example**
  - You're in a corporation working on a project with a university
  - Corporate network is 172.16 (i.e., 172.16.0.0 to 172.16.255.255)
  - University owns network 10 (i.e., 10.0.0.0 to 10.255.255.255)
  - You're going to link these networks together using a packet filter
  - You want to disallow all Internet access over this link
  - Project uses the 172.16.6 subnet
  - University's 10.1.99 subnet has lots of hostile activity
- **Suppose we try the following filtering rules**

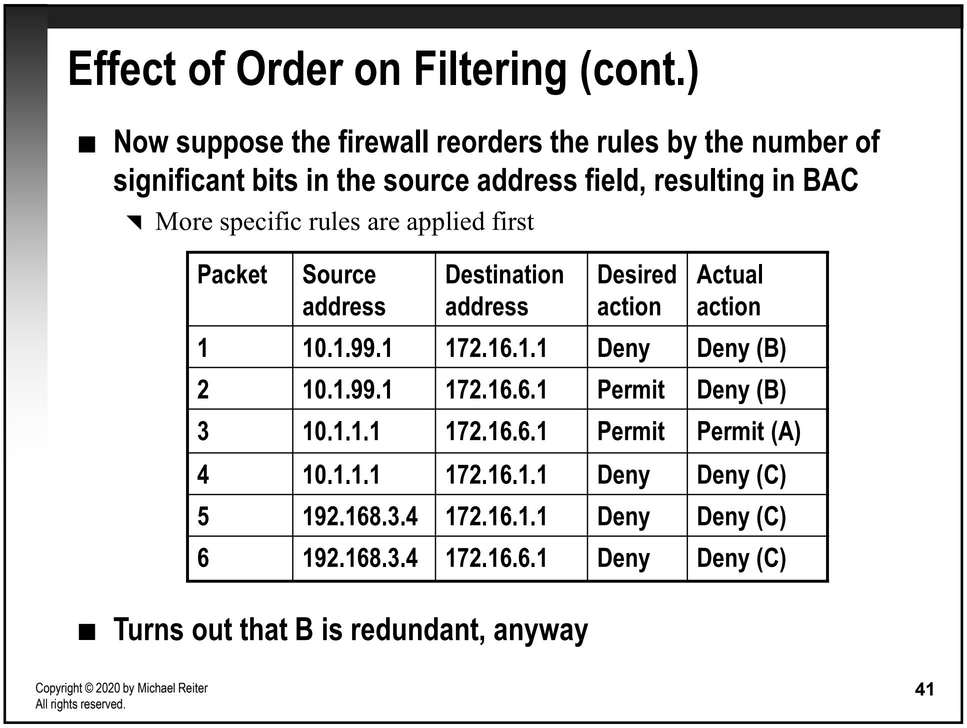
Rule	Source address	Destination address	Action
A	10.*.*.*	172.16.6.*	Permit
B	10.1.99.*	172.16.*.*	Deny
C	Any	Any	Deny



Effect of Order on Filtering (cont.)

- **Consider several example packets, assuming rules are applied in order ABC**

Packet	Source address	Destination address	Desired action	Actual action
1	10.1.99.1	172.16.1.1	Deny	Deny (B)
2	10.1.99.1	172.16.6.1	Permit	Permit (A)
3	10.1.1.1	172.16.6.1	Permit	Permit (A)
4	10.1.1.1	172.16.1.1	Deny	Deny (C)
5	192.168.3.4	172.16.1.1	Deny	Deny (C)
6	192.168.3.4	172.16.6.1	Deny	Deny (C)

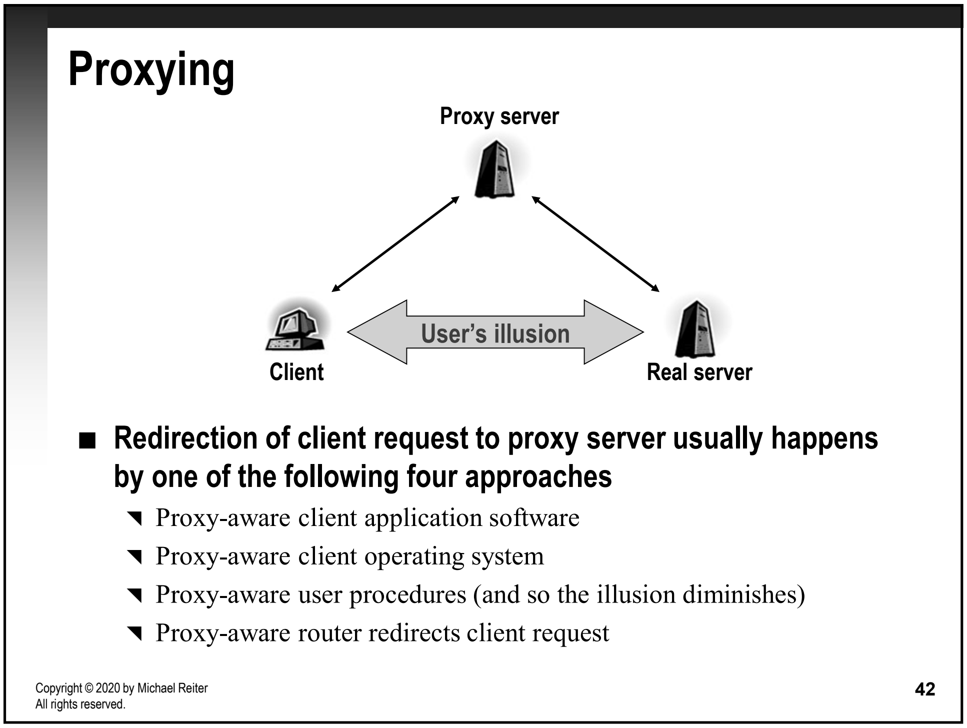


Effect of Order on Filtering (cont.)

- Now suppose the firewall reorders the rules by the number of significant bits in the source address field, resulting in BAC
  - More specific rules are applied first

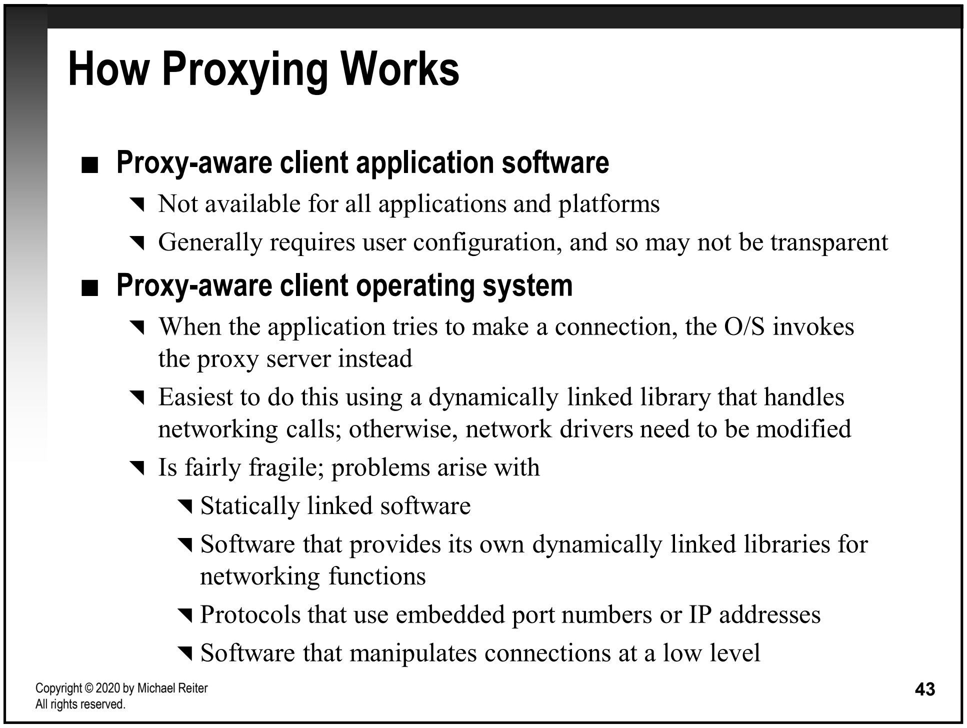
Packet	Source address	Destination address	Desired action	Actual action
1	10.1.99.1	172.16.1.1	Deny	Deny (B)
2	10.1.99.1	172.16.6.1	Permit	Deny (B)
3	10.1.1.1	172.16.6.1	Permit	Permit (A)
4	10.1.1.1	172.16.1.1	Deny	Deny (C)
5	192.168.3.4	172.16.1.1	Deny	Deny (C)
6	192.168.3.4	172.16.6.1	Deny	Deny (C)

- Turns out that B is redundant, anyway



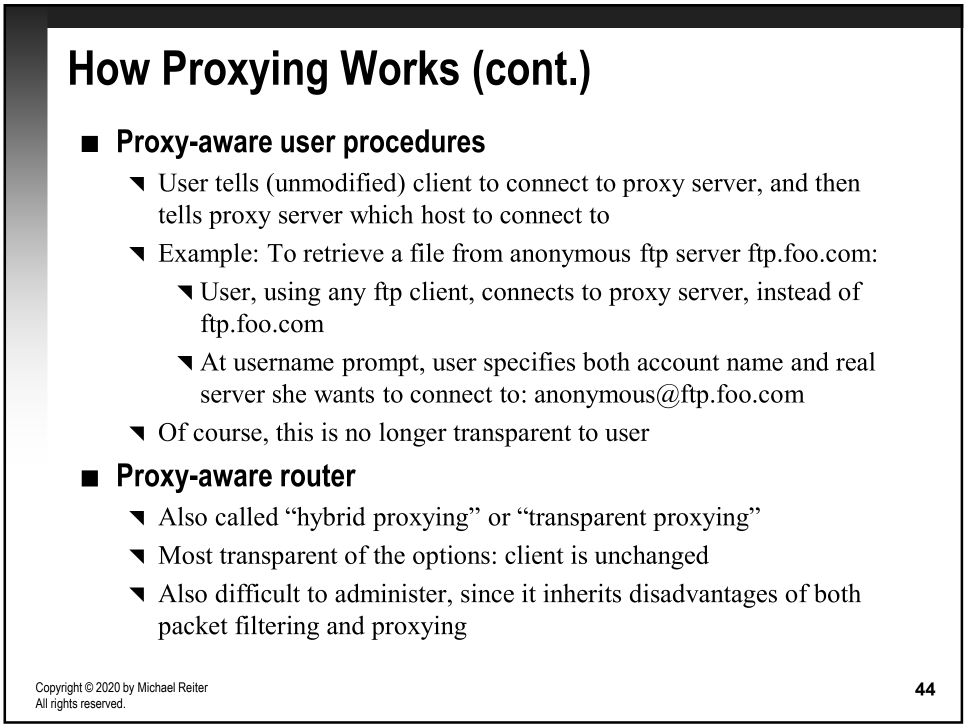
Proxying

- Redirection of client request to proxy server usually happens by one of the following four approaches
  - Proxy-aware client application software
  - Proxy-aware client operating system
  - Proxy-aware user procedures (and so the illusion diminishes)
  - Proxy-aware router redirects client request



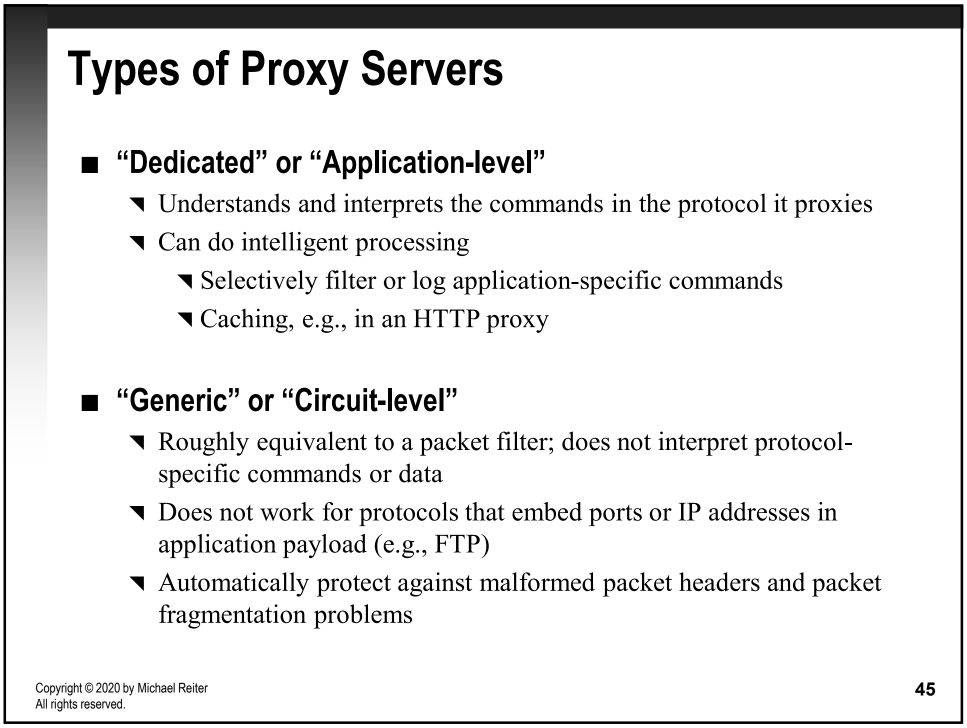
How Proxying Works

- **Proxy-aware client application software**
  - Not available for all applications and platforms
  - Generally requires user configuration, and so may not be transparent
- **Proxy-aware client operating system**
  - When the application tries to make a connection, the O/S invokes the proxy server instead
  - Easiest to do this using a dynamically linked library that handles networking calls; otherwise, network drivers need to be modified
  - Is fairly fragile; problems arise with
    - Statically linked software
    - Software that provides its own dynamically linked libraries for networking functions
    - Protocols that use embedded port numbers or IP addresses
    - Software that manipulates connections at a low level



How Proxying Works (cont.)

- **Proxy-aware user procedures**
  - User tells (unmodified) client to connect to proxy server, and then tells proxy server which host to connect to
  - Example: To retrieve a file from anonymous ftp server ftp.foo.com:
    - User, using any ftp client, connects to proxy server, instead of ftp.foo.com
    - At username prompt, user specifies both account name and real server she wants to connect to: anonymous@ftp.foo.com
  - Of course, this is no longer transparent to user
- **Proxy-aware router**
  - Also called “hybrid proxying” or “transparent proxying”
  - Most transparent of the options: client is unchanged
  - Also difficult to administer, since it inherits disadvantages of both packet filtering and proxying



Types of Proxy Servers

- **“Dedicated” or “Application-level”**
  - Understands and interprets the commands in the protocol it proxies
  - Can do intelligent processing
    - Selectively filter or log application-specific commands
    - Caching, e.g., in an HTTP proxy
- **“Generic” or “Circuit-level”**
  - Roughly equivalent to a packet filter; does not interpret protocol-specific commands or data
  - Does not work for protocols that embed ports or IP addresses in application payload (e.g., FTP)
  - Automatically protect against malformed packet headers and packet fragmentation problems

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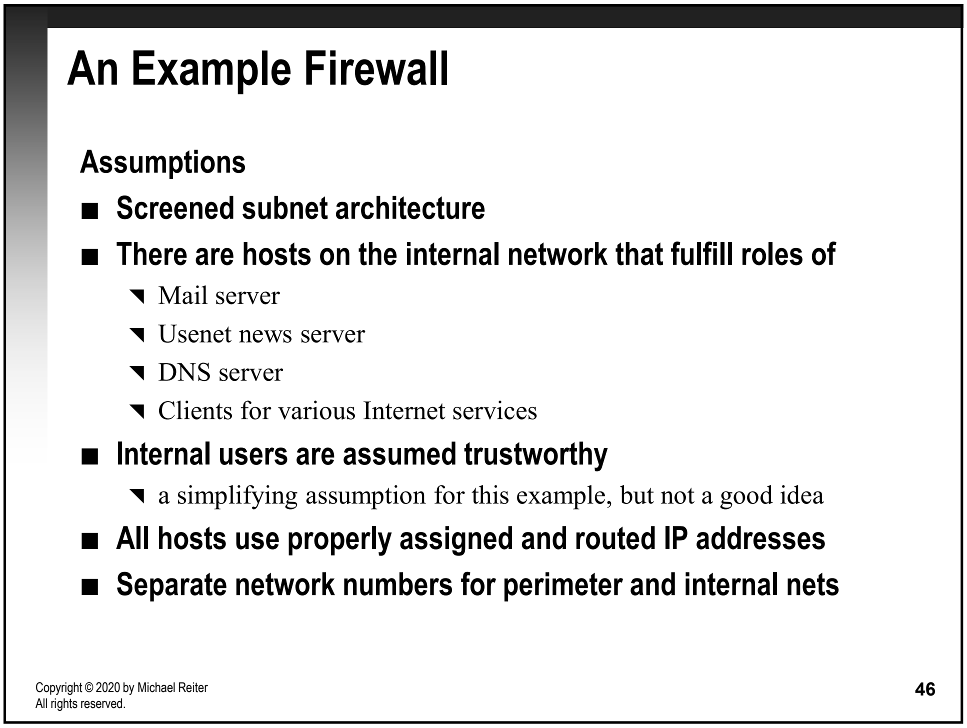

An Example Firewall

Assumptions

- **Screened subnet architecture**
- **There are hosts on the internal network that fulfill roles of**
  - Mail server
  - Usenet news server
  - DNS server
  - Clients for various Internet services
- **Internal users are assumed trustworthy**
  - a simplifying assumption for this example, but not a good idea
- **All hosts use properly assigned and routed IP addresses**
- **Separate network numbers for perimeter and internal nets**

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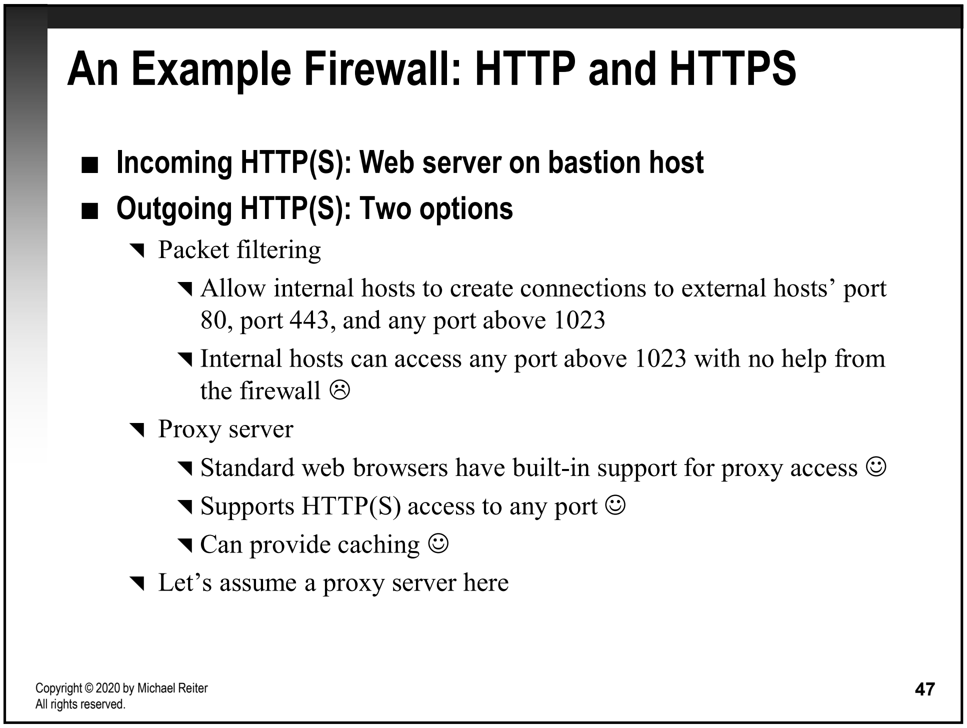
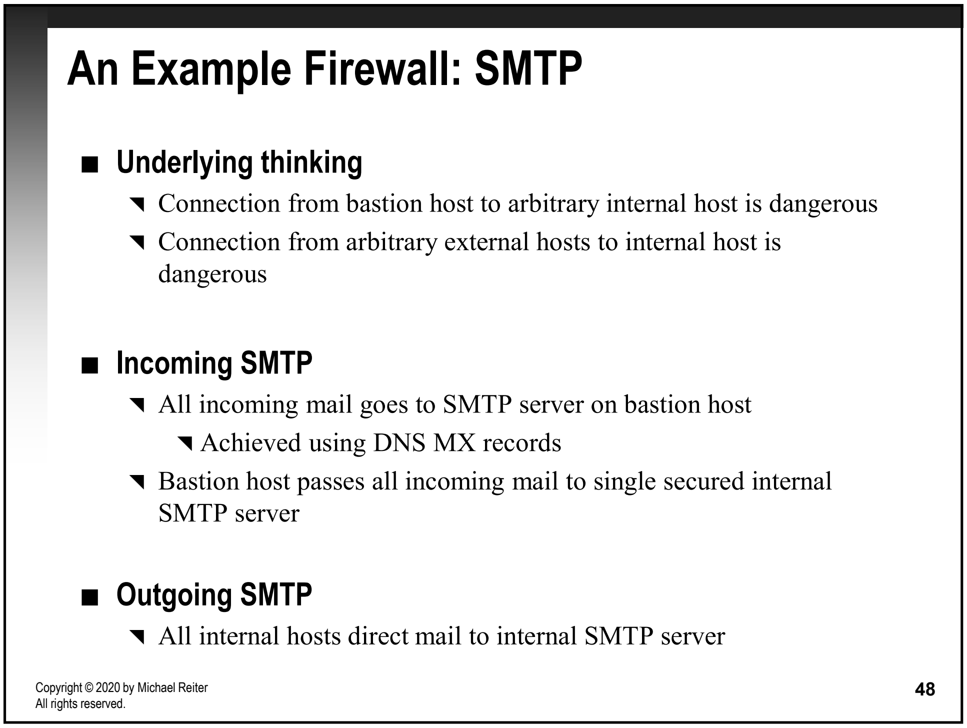


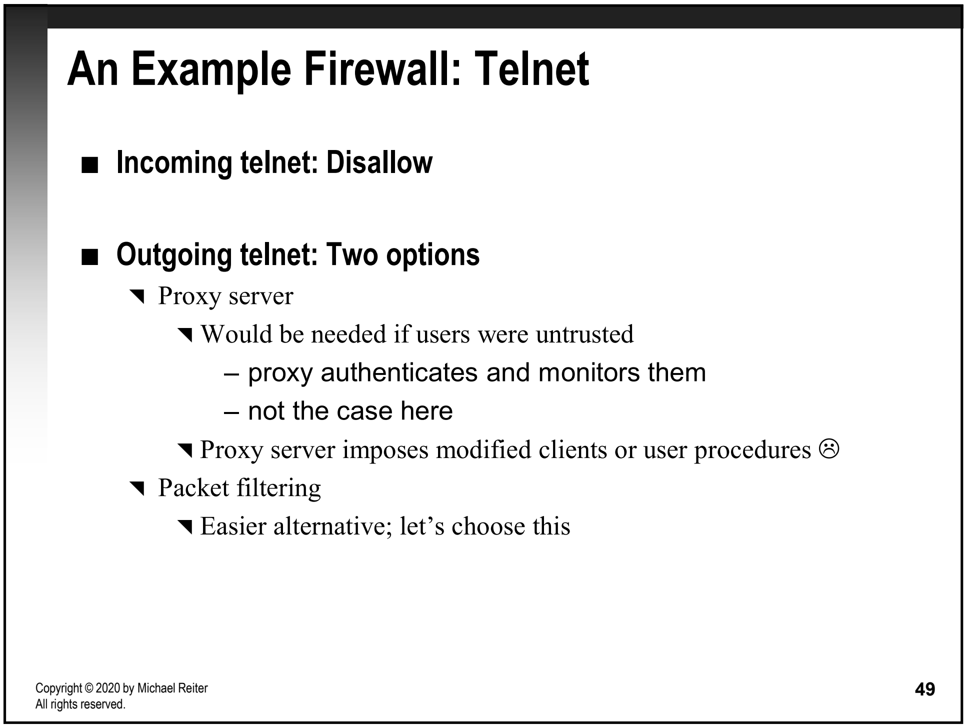
An Example Firewall: HTTP and HTTPS

- **Incoming HTTP(S): Web server on bastion host**
- **Outgoing HTTP(S): Two options**
  - Packet filtering
    - Allow internal hosts to create connections to external hosts' port 80, port 443, and any port above 1023
    - Internal hosts can access any port above 1023 with no help from the firewall ☹
  - Proxy server
    - Standard web browsers have built-in support for proxy access ☺
    - Supports HTTP(S) access to any port ☺
    - Can provide caching ☺
  - Let's assume a proxy server here



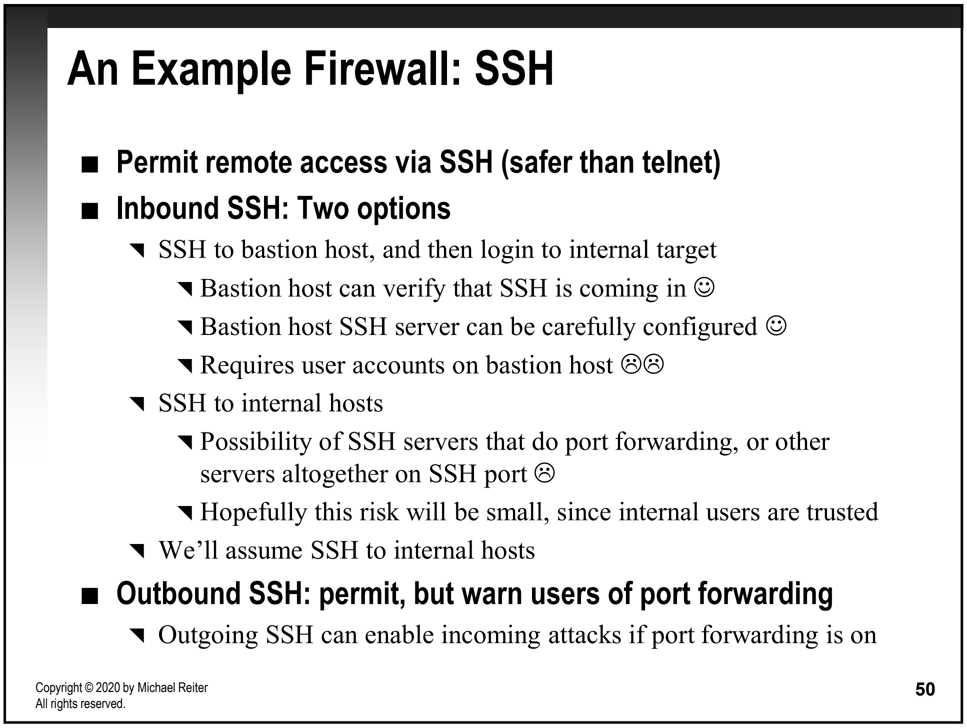
An Example Firewall: SMTP

- **Underlying thinking**
  - Connection from bastion host to arbitrary internal host is dangerous
  - Connection from arbitrary external hosts to internal host is dangerous
- **Incoming SMTP**
  - All incoming mail goes to SMTP server on bastion host
    - Achieved using DNS MX records
  - Bastion host passes all incoming mail to single secured internal SMTP server
- **Outgoing SMTP**
  - All internal hosts direct mail to internal SMTP server



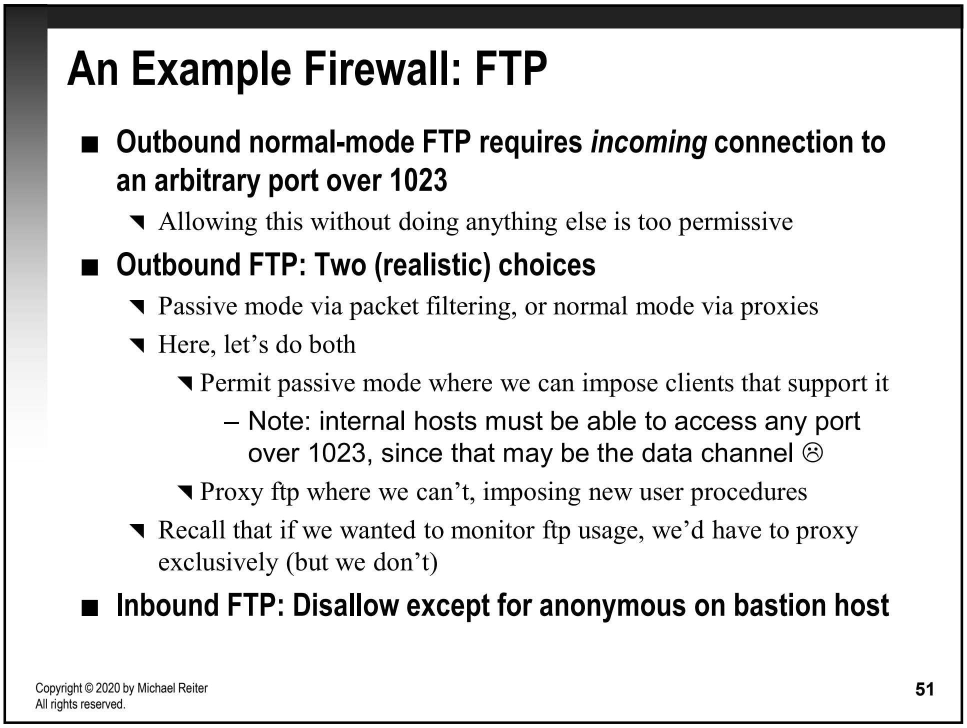
An Example Firewall: Telnet

- **Incoming telnet: Disallow**
- **Outgoing telnet: Two options**
  - Proxy server
    - Would be needed if users were untrusted
      - proxy authenticates and monitors them
      - not the case here
    - Proxy server imposes modified clients or user procedures ☹
  - Packet filtering
    - Easier alternative; let’s choose this



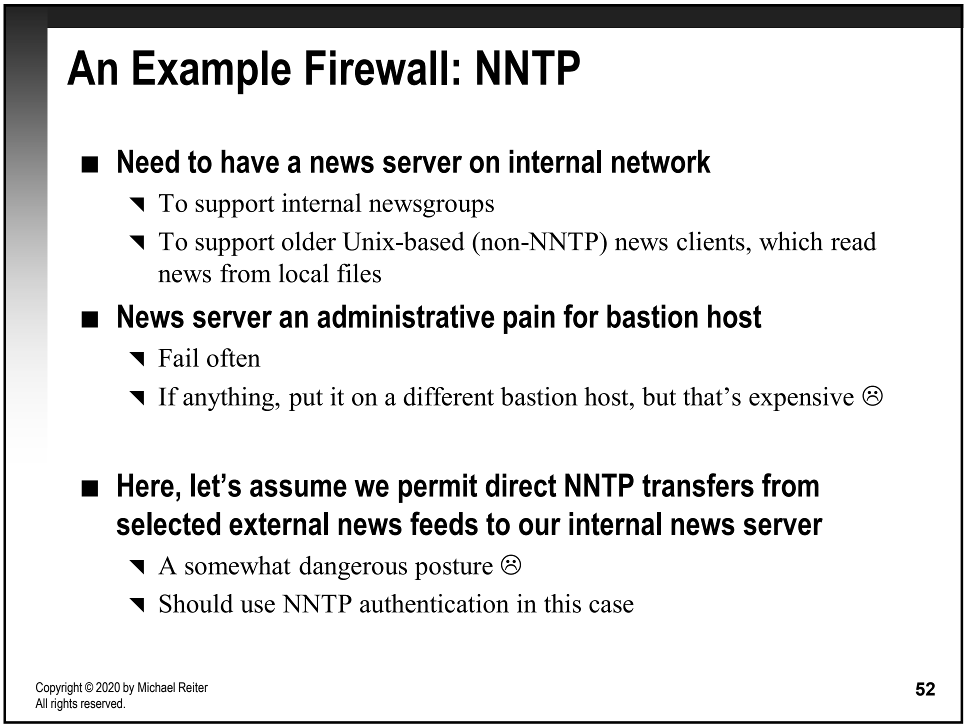
An Example Firewall: SSH

- **Permit remote access via SSH (safer than telnet)**
- **Inbound SSH: Two options**
  - SSH to bastion host, and then login to internal target
    - Bastion host can verify that SSH is coming in ☺
    - Bastion host SSH server can be carefully configured ☺
    - Requires user accounts on bastion host ☹☹
  - SSH to internal hosts
    - Possibility of SSH servers that do port forwarding, or other servers altogether on SSH port ☹
    - Hopefully this risk will be small, since internal users are trusted
  - We’ll assume SSH to internal hosts
- **Outbound SSH: permit, but warn users of port forwarding**
  - Outgoing SSH can enable incoming attacks if port forwarding is on



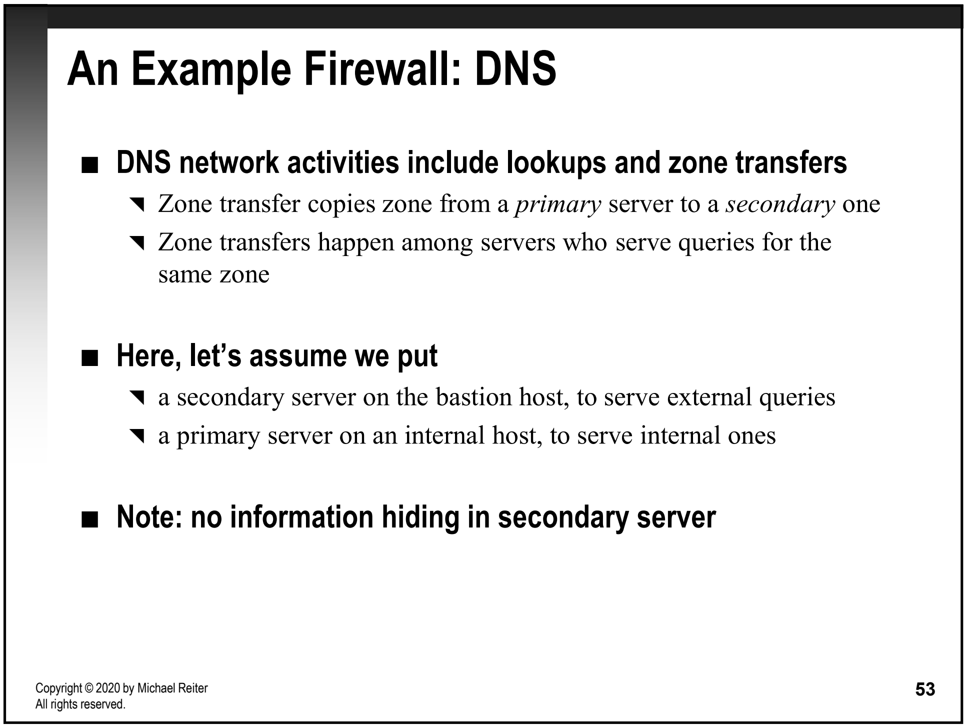
An Example Firewall: FTP

- **Outbound normal-mode FTP requires *incoming* connection to an arbitrary port over 1023**
  - Allowing this without doing anything else is too permissive
- **Outbound FTP: Two (realistic) choices**
  - Passive mode via packet filtering, or normal mode via proxies
  - Here, let’s do both
    - Permit passive mode where we can impose clients that support it
      - Note: internal hosts must be able to access any port over 1023, since that may be the data channel ☹
    - Proxy ftp where we can’t, imposing new user procedures
  - Recall that if we wanted to monitor ftp usage, we’d have to proxy exclusively (but we don’t)
- **Inbound FTP: Disallow except for anonymous on bastion host**



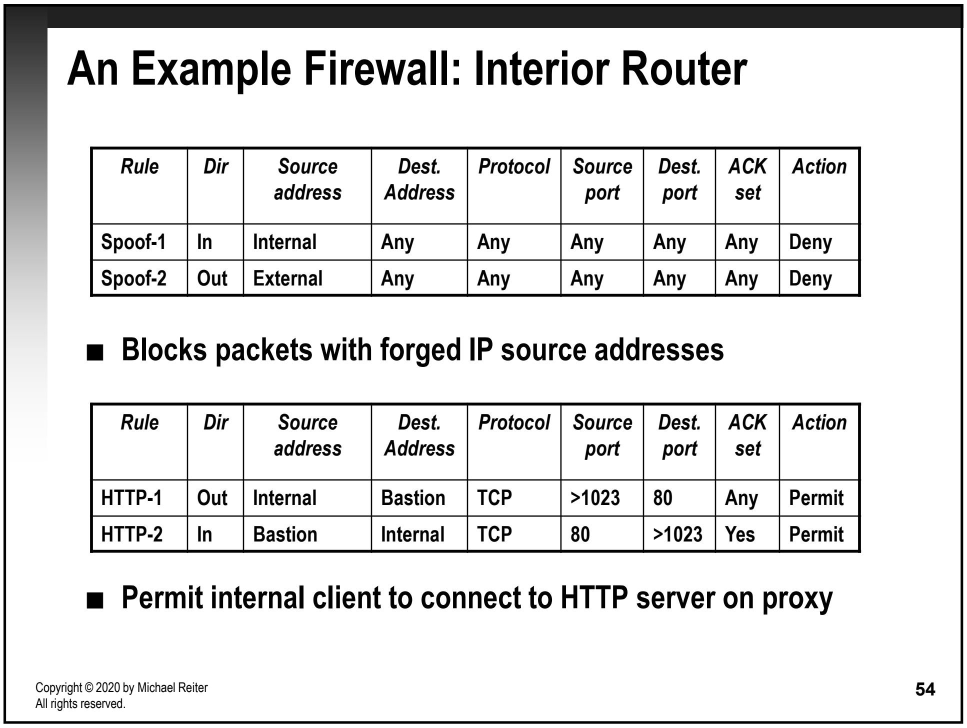
An Example Firewall: NNTP

- **Need to have a news server on internal network**
  - To support internal newsgroups
  - To support older Unix-based (non-NNTP) news clients, which read news from local files
- **News server an administrative pain for bastion host**
  - Fail often
  - If anything, put it on a different bastion host, but that’s expensive ☹
- **Here, let’s assume we permit direct NNTP transfers from selected external news feeds to our internal news server**
  - A somewhat dangerous posture ☹
  - Should use NNTP authentication in this case



An Example Firewall: DNS

- DNS network activities include lookups and zone transfers
  - Zone transfer copies zone from a *primary* server to a *secondary* one
  - Zone transfers happen among servers who serve queries for the same zone
- Here, let’s assume we put
  - a secondary server on the bastion host, to serve external queries
  - a primary server on an internal host, to serve internal ones
- Note: no information hiding in secondary server



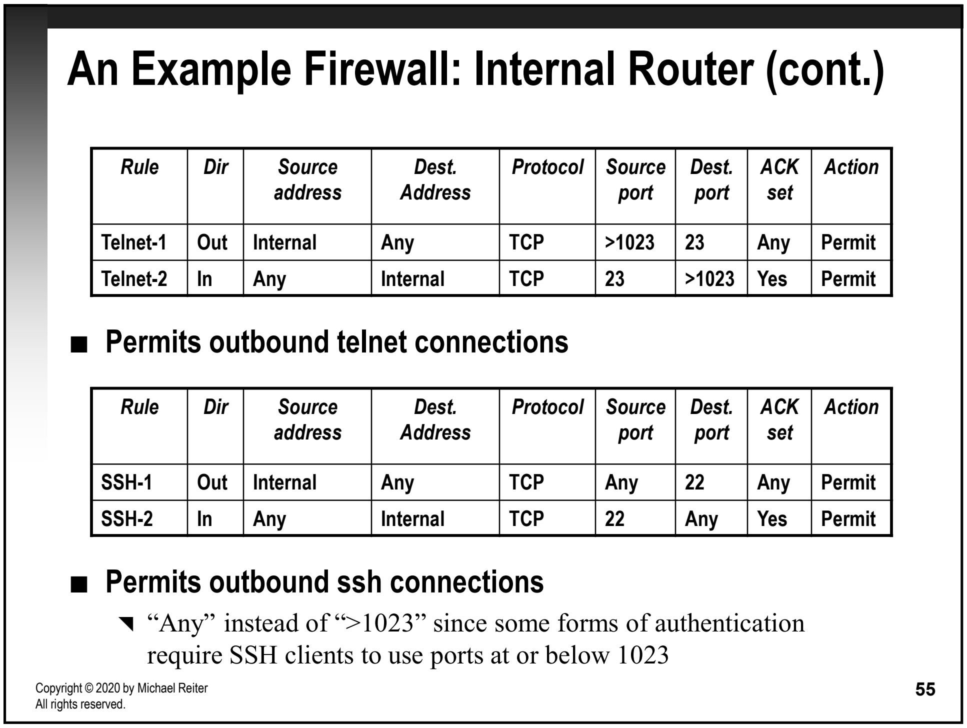
An Example Firewall: Interior Router

Rule	*Dir*	*Source address*	*Dest. Address*	*Protocol*	*Source port*	*Dest. port*	*ACK set*	*Action*
Spoof-1	In	Internal	Any	Any	Any	Any	Any	Deny
Spoof-2	Out	External	Any	Any	Any	Any	Any	Deny

- Blocks packets with forged IP source addresses

Rule	*Dir*	*Source address*	*Dest. Address*	*Protocol*	*Source port*	*Dest. port*	*ACK set*	*Action*
HTTP-1	Out	Internal	Bastion	TCP	>1023	80	Any	Permit
HTTP-2	In	Bastion	Internal	TCP	80	>1023	Yes	Permit

- Permit internal client to connect to HTTP server on proxy



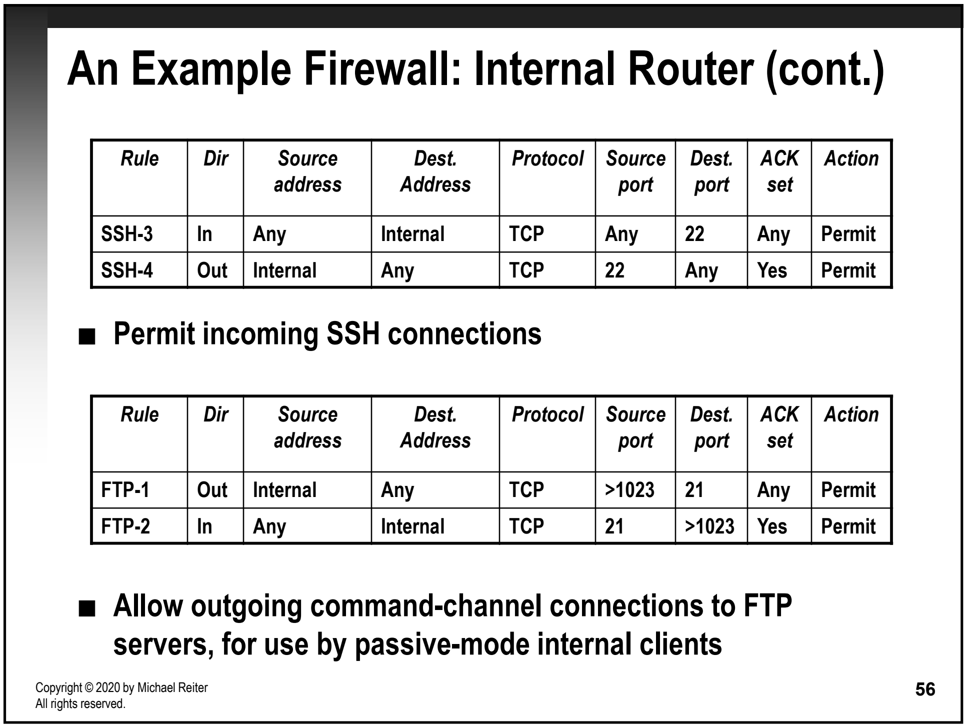
An Example Firewall: Internal Router (cont.)

Rule	*Dir*	*Source address*	*Dest. Address*	*Protocol*	*Source port*	*Dest. port*	*ACK set*	*Action*
Telnet-1	Out	Internal	Any	TCP	>1023	23	Any	Permit
Telnet-2	In	Any	Internal	TCP	23	>1023	Yes	Permit

- **Permits outbound telnet connections**

Rule	*Dir*	*Source address*	*Dest. Address*	*Protocol*	*Source port*	*Dest. port*	*ACK set*	*Action*
SSH-1	Out	Internal	Any	TCP	Any	22	Any	Permit
SSH-2	In	Any	Internal	TCP	22	Any	Yes	Permit

- **Permits outbound ssh connections**
  - "Any" instead of ">1023" since some forms of authentication require SSH clients to use ports at or below 1023



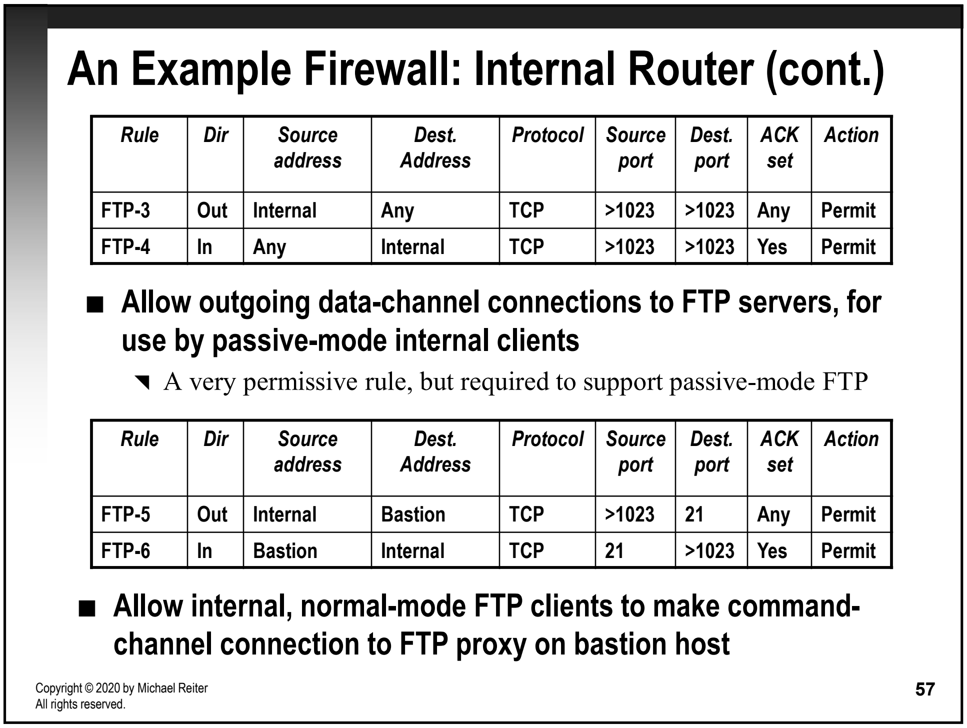
An Example Firewall: Internal Router (cont.)

Rule	*Dir*	*Source address*	*Dest. Address*	*Protocol*	*Source port*	*Dest. port*	*ACK set*	*Action*
SSH-3	In	Any	Internal	TCP	Any	22	Any	Permit
SSH-4	Out	Internal	Any	TCP	22	Any	Yes	Permit

- **Permit incoming SSH connections**

Rule	*Dir*	*Source address*	*Dest. Address*	*Protocol*	*Source port*	*Dest. port*	*ACK set*	*Action*
FTP-1	Out	Internal	Any	TCP	>1023	21	Any	Permit
FTP-2	In	Any	Internal	TCP	21	>1023	Yes	Permit

- **Allow outgoing command-channel connections to FTP servers, for use by passive-mode internal clients**



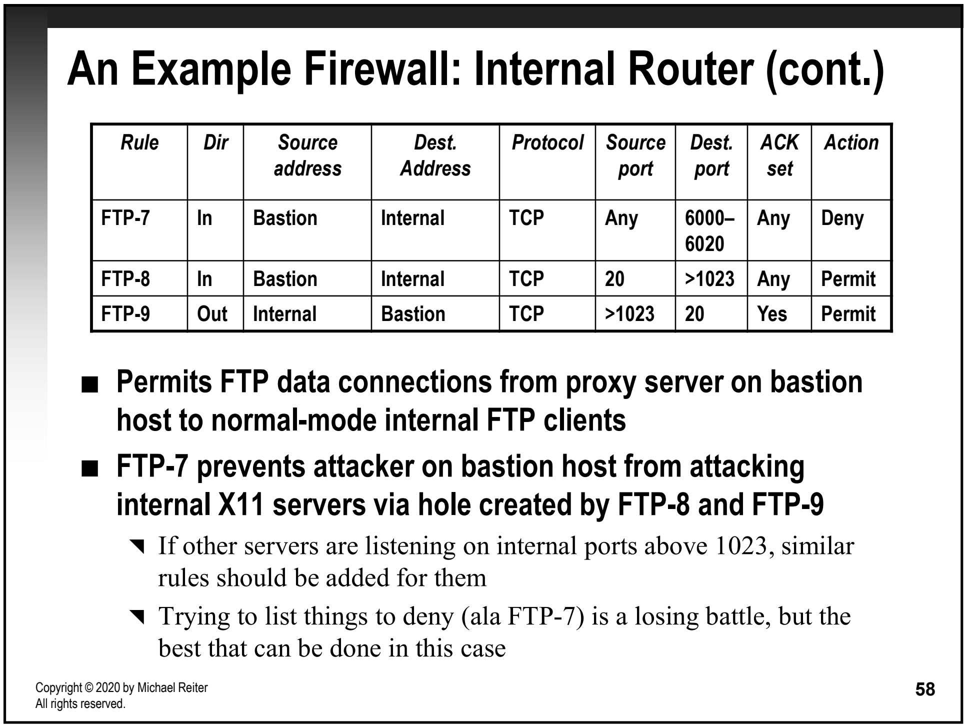
An Example Firewall: Internal Router (cont.)

Rule	*Dir*	*Source address*	*Dest. Address*	*Protocol*	*Source port*	*Dest. port*	*ACK set*	*Action*
FTP-3	Out	Internal	Any	TCP	>1023	>1023	Any	Permit
FTP-4	In	Any	Internal	TCP	>1023	>1023	Yes	Permit

- **Allow outgoing data-channel connections to FTP servers, for use by passive-mode internal clients**
  - A very permissive rule, but required to support passive-mode FTP

Rule	*Dir*	*Source address*	*Dest. Address*	*Protocol*	*Source port*	*Dest. port*	*ACK set*	*Action*
FTP-5	Out	Internal	Bastion	TCP	>1023	21	Any	Permit
FTP-6	In	Bastion	Internal	TCP	21	>1023	Yes	Permit

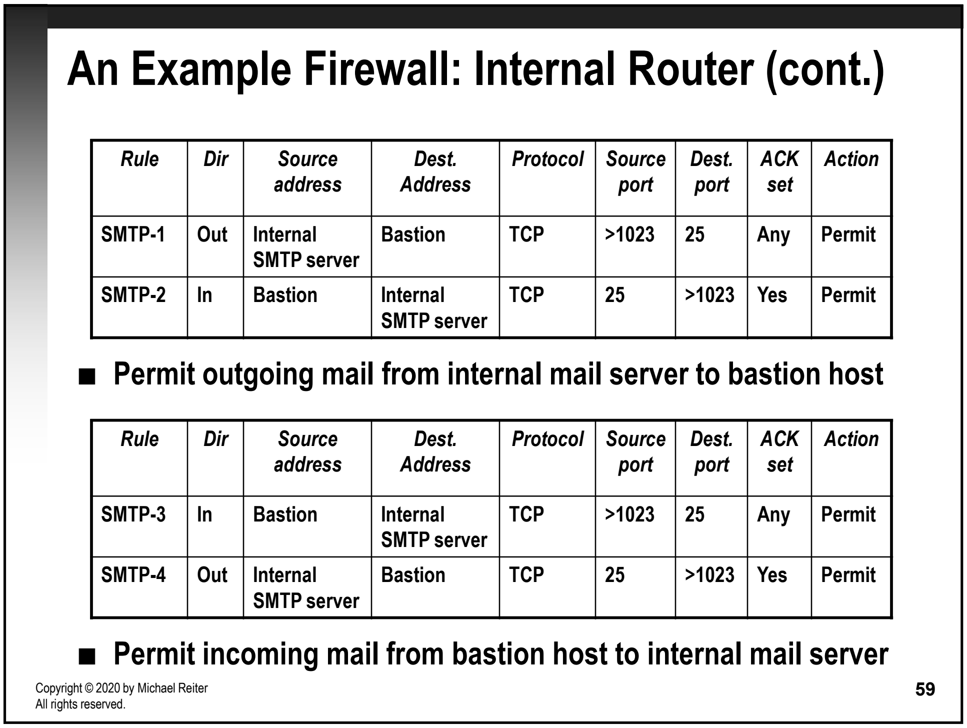
- **Allow internal, normal-mode FTP clients to make command-channel connection to FTP proxy on bastion host**



An Example Firewall: Internal Router (cont.)

Rule	*Dir*	*Source address*	*Dest. Address*	*Protocol*	*Source port*	*Dest. port*	*ACK set*	*Action*
FTP-7	In	Bastion	Internal	TCP	Any	6000–6020	Any	Deny
FTP-8	In	Bastion	Internal	TCP	20	>1023	Any	Permit
FTP-9	Out	Internal	Bastion	TCP	>1023	20	Yes	Permit

- **Permits FTP data connections from proxy server on bastion host to normal-mode internal FTP clients**
- **FTP-7 prevents attacker on bastion host from attacking internal X11 servers via hole created by FTP-8 and FTP-9**
  - If other servers are listening on internal ports above 1023, similar rules should be added for them
  - Trying to list things to deny (ala FTP-7) is a losing battle, but the best that can be done in this case



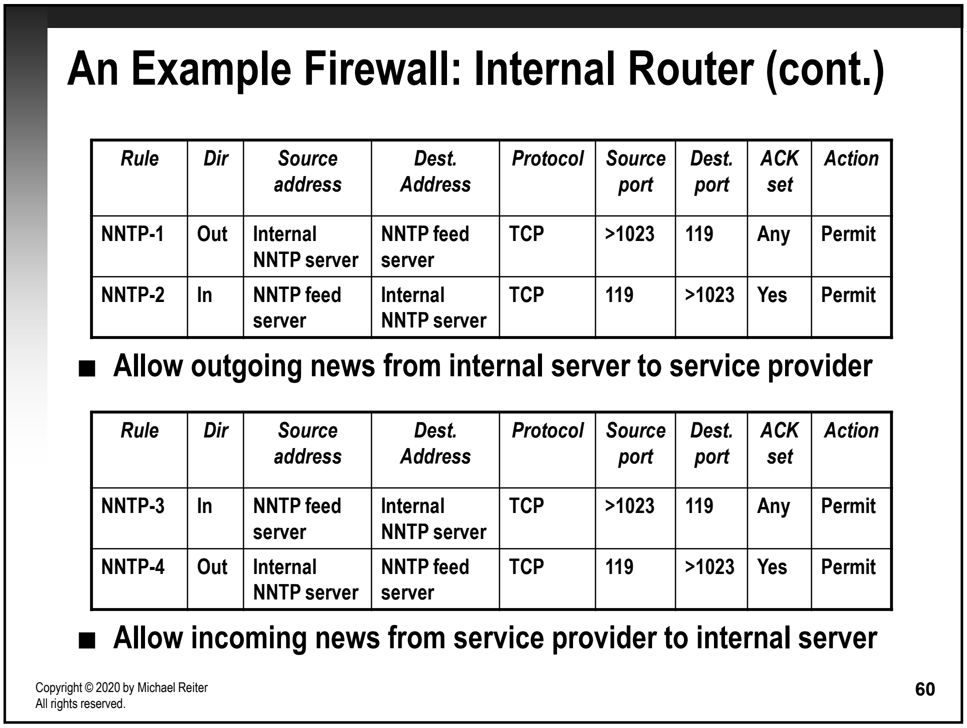
An Example Firewall: Internal Router (cont.)

Rule	Dir	Source address	Dest. Address	Protocol	Source port	Dest. port	ACK set	Action
SMTP-1	Out	Internal SMTP server	Bastion	TCP	>1023	25	Any	Permit
SMTP-2	In	Bastion	Internal SMTP server	TCP	25	>1023	Yes	Permit

- Permit outgoing mail from internal mail server to bastion host

Rule	Dir	Source address	Dest. Address	Protocol	Source port	Dest. port	ACK set	Action
SMTP-3	In	Bastion	Internal SMTP server	TCP	>1023	25	Any	Permit
SMTP-4	Out	Internal SMTP server	Bastion	TCP	25	>1023	Yes	Permit

- Permit incoming mail from bastion host to internal mail server



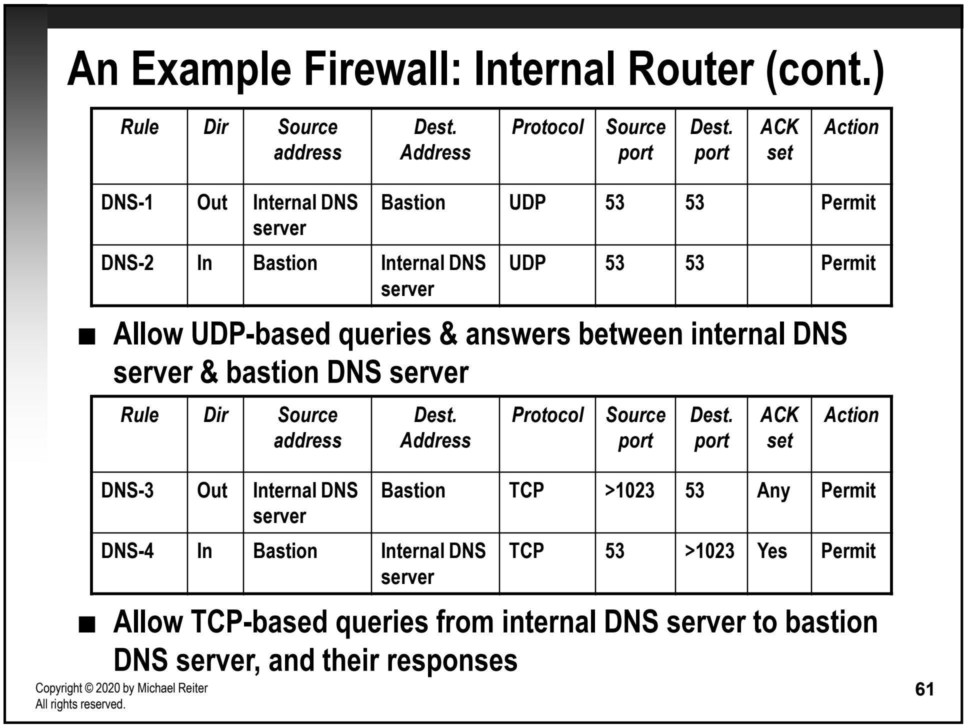
An Example Firewall: Internal Router (cont.)

Rule	Dir	Source address	Dest. Address	Protocol	Source port	Dest. port	ACK set	Action
NNTP-1	Out	Internal NNTP server	NNTP feed server	TCP	>1023	119	Any	Permit
NNTP-2	In	NNTP feed server	Internal NNTP server	TCP	119	>1023	Yes	Permit

- Allow outgoing news from internal server to service provider

Rule	Dir	Source address	Dest. Address	Protocol	Source port	Dest. port	ACK set	Action
NNTP-3	In	NNTP feed server	Internal NNTP server	TCP	>1023	119	Any	Permit
NNTP-4	Out	Internal NNTP server	NNTP feed server	TCP	119	>1023	Yes	Permit

- Allow incoming news from service provider to internal server



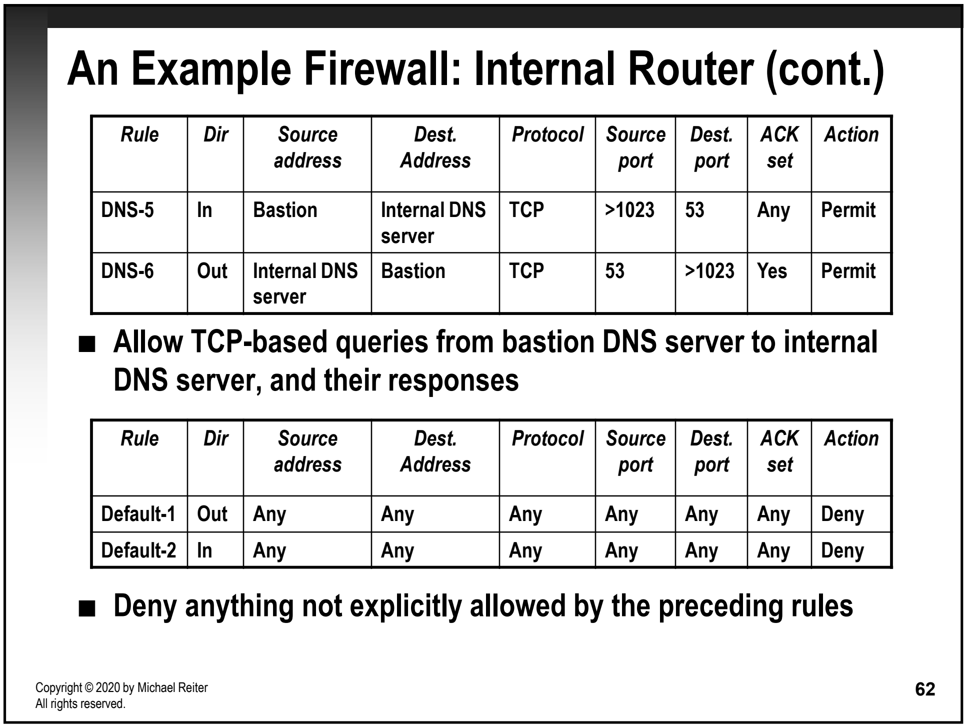
An Example Firewall: Internal Router (cont.)

Rule	*Dir*	*Source address*	*Dest. Address*	*Protocol*	*Source port*	*Dest. port*	*ACK set*	*Action*
DNS-1	Out	Internal DNS server	Bastion	UDP	53	53		Permit
DNS-2	In	Bastion	Internal DNS server	UDP	53	53		Permit

- **Allow UDP-based queries & answers between internal DNS server & bastion DNS server**

Rule	*Dir*	*Source address*	*Dest. Address*	*Protocol*	*Source port*	*Dest. port*	*ACK set*	*Action*
DNS-3	Out	Internal DNS server	Bastion	TCP	>1023	53	Any	Permit
DNS-4	In	Bastion	Internal DNS server	TCP	53	>1023	Yes	Permit

- **Allow TCP-based queries from internal DNS server to bastion DNS server, and their responses**



An Example Firewall: Internal Router (cont.)

Rule	*Dir*	*Source address*	*Dest. Address*	*Protocol*	*Source port*	*Dest. port*	*ACK set*	*Action*
DNS-5	In	Bastion	Internal DNS server	TCP	>1023	53	Any	Permit
DNS-6	Out	Internal DNS server	Bastion	TCP	53	>1023	Yes	Permit

- **Allow TCP-based queries from bastion DNS server to internal DNS server, and their responses**

Rule	*Dir*	*Source address*	*Dest. Address*	*Protocol*	*Source port*	*Dest. port*	*ACK set*	*Action*
Default-1	Out	Any	Any	Any	Any	Any	Any	Deny
Default-2	In	Any	Any	Any	Any	Any	Any	Deny

- **Deny anything not explicitly allowed by the preceding rules**