CIS 551 / TCOM 401

Computer and Network Security

Spring 2006
Lecture 18

Announcements

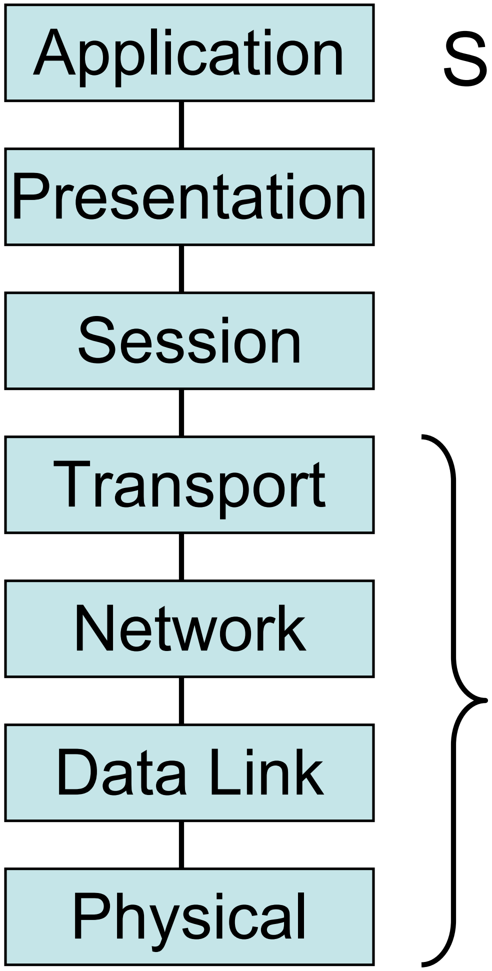
- Project 3
  - Due Date: April 21st (Last day of classes)
  - Updated project description (clarifying some things)
  - Group project: you must work in groups of 2 or 3 people.
    - Mail groups to cis551staff@seas.upenn.edu
    - If you have trouble finding a group, post on the class news group

- Final Exam has been Scheduled:
  - Friday, May 5th
  - 9-11 a.m.
  - Moore 216

Plan for today

- Briefly talk about application level protocols
- Talk about NATs and Firewalls
- Excellent reference:
  - "Firewalls and Internet Security" by Cheswick, Bellovin, and Rubin

Protocol Stack Revisited



Application

Presentation

Session

Transport

Network

Data Link

Physical

SMTP, HTTP, SNMP, FTP, …

So far…

Common Features

- SMTP, HTTP, SNMP, FTP…
  - Request/Reply protocols built on TCP or UDP
  - Designed to handle a fixed set of messages
  - Companion *data format*
  - Many applications

Protocol	Data Format	Programs
SMTP	RFC 822 and MIME	Pine, NSMail, Eudora,Outlook,...
HTTP	HTML	Explorer, Netscape, Opera,…
SNMP	MIB	snmpget, snmpset,…

SMTP: Simple Mail Transfer Protocol

- Data format RFC822
  - Adopted around 1982, extended 1993, 1996
  - http://www.faqs.org/rfcs/rfc822.html
  - ASCII text
  - Header and Body

- MIME: Multipurpose Internet Mail Extensions
  - Mail systems assume ASCII
    - Only 64 valid characters A-Z, a-z, 0-9, +, /
  - Some datatypes include arbitrary binary data (e.g. JPEG)
  - Base64 encoding
    - 3 bytes of data map to 4 ASCII Characters
    - A=0,B=1,…

SMTP

- Mail Reader
  - User edits/reads/search e-mail
- Mail Daemon
  - Process running on each host (port 25)
  - Uses SMTP/TCP to transmit mail to daemons on other machines
  - Most daemons based on Berkley's **sendmail**
- Mail Gateways
  - Store and forward e-mail (much like IP router)
  - Buffers on disk
  - Attempts to resend

RFC822 Headers

- <CRLF>-terminated lines containing pairs of form **`type: value`**
- Many valid Header types
- Some headers filled out by client
  - **`To: stevez@cis.upenn.edu`**
  - **`Subject: CSE551`**
- Others filled out by mail delivery system
  - **`Date:`**
  - **`Received:`**
  - **`From:`**

```
From: Steve Zdancewic <stevez@cis.upenn.edu>
MIME-Version: 1.0
To: stevez@cis.upenn.edu
Subject: Example Mail
Content-Type: multipart/mixed; boundary="------------020307000708030506070607"

This is a multi-part message in MIME format.
--------------020307000708030506070607
Content-Type: text/plain; charset=us-ascii; format=flowed
Content-Transfer-Encoding: 7bit

This is the body.

--------------020307000708030506070607
Content-Type: text/plain; name="example.txt"
Content-Transfer-Encoding: 7bit
Content-Disposition: inline; filename="example.txt"

Hello

--------------020307000708030506070607
Content-Type: image/jpeg; name="doc.jpg"
Content-Transfer-Encoding: base64
Content-Disposition: inline; filename="doc.jpg"

/9j/4AAQSkZJRgABAQEASABIAAD//gAXQ3JlYXRlZCB3aXRoIFRoZSBHSU1Q/9sAQwAIBgYH
BgUIBwcHCQkICgwUDQwLCwwZEhMPFB0aHx4dGhwcICQuJyAiLCMcHCg3KSwwMTQ0NB8n
OT04…
```

SMTP security

- SMTP provides no authentication
  - Easy to spoof sending address
  - Very familiar problem found in Spam
- Sendmail program is a notorious source of vulnerabilities
  - Complicated, concurrent program
  - Needs privileges to write to all mail files
  - See www.sendmail.org

  - Sendmail hit by data interception
    Thursday 23 March 2006
    "*Internet security researchers have discovered a* serious flaw in Sendmail*. The flaw could allow remote attackers to take control of users' PCs."*

MIME security

- Mime allows ability to mail executable content
  - Primary transmission vector for worms and viruses
- MIME allows external references to files:

```
Content-Type: Message/External-body;
   name="foo.txt";
   site="ftp.cis.upenn.edu";
   access-type="anon-ftp";
   directory="bar"
Content-Type: text/plain
```

NATs and Firewalls

- Problem: Protecting or isolating one part of the network from other parts

- Need to filter or otherwise limit network traffic
  - How to configure this information?

- Questions:
  - What information do you use to filter?
  - Where do you do the filtering?

Kinds of Firewalls

- Personal firewalls
  - Run at the end hosts
  - e.g. Norton, Windows, etc.
  - Benefit: has more application/user specific information

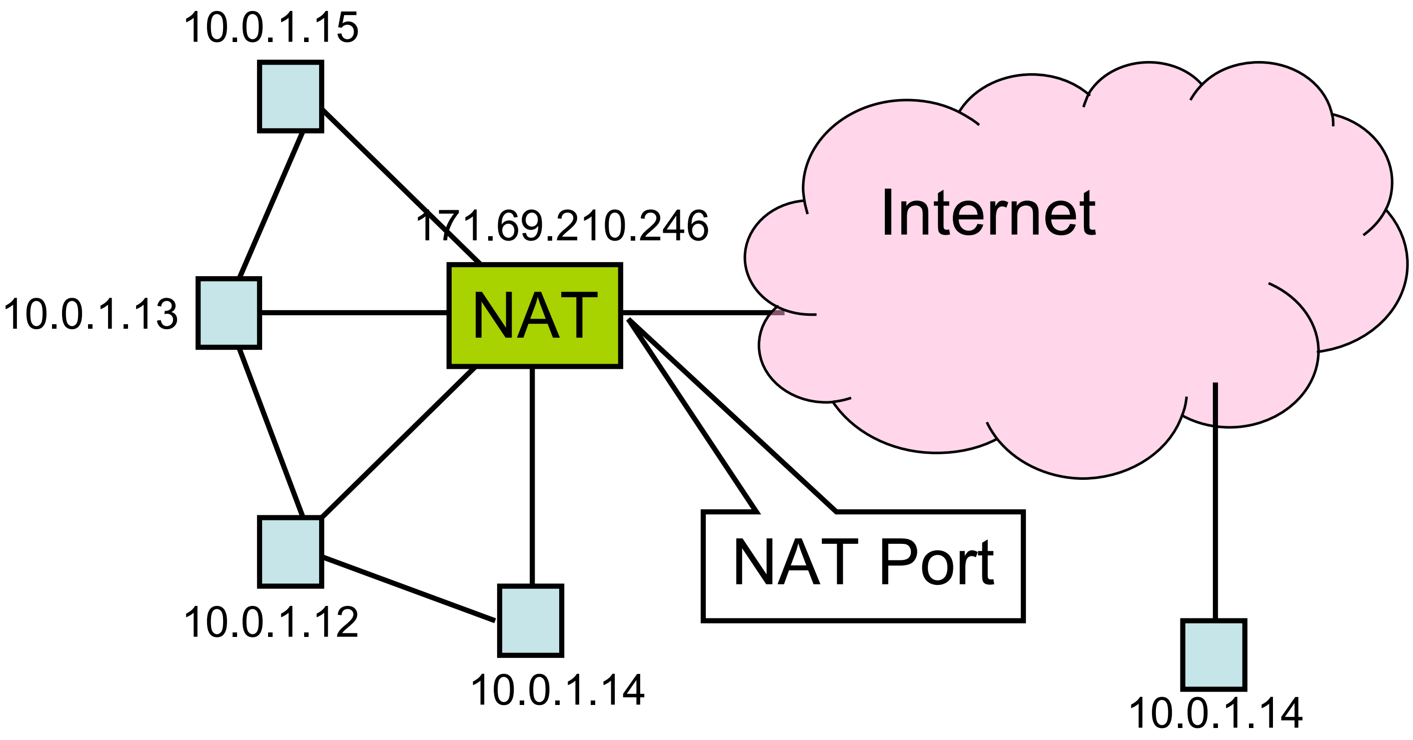
- Network Address Translators
  - Rewrites packet address information

- Filter Based
  - Operates by filtering based on packet headers

- Proxy based
  - Operates at the level of the application
  - e.g. HTTP web proxy

Network Address Translation

- Idea: Break the invariant that IP addresses are globally unique



NAT Behavior

- NAT maintains a table of the form:

  <client IP> <client port> <NAT ID>

- Outgoing packets (on non-NAT port):
  - Look for client IP address, client port in the mapping table
  - If found, replace client port with previously allocated NAT ID (same size as PORT #)
  - If not found, allocate a new unique NAT ID and replace source port with NAT ID
  - Replace source address with NAT address

NAT Behavior

- Incoming Packets (on NAT port)
  - Look up destination port number as NAT ID in port mapping table
  - If found, replace destination address and port with client entries from the mapping table
  - If not found, the packet is not for us and should be rejected

- Table entries expire after 2-3 minutes to allow them to be garbage collected

Benefits of NAT

- Only allows connections to the outside that are established from *inside.*
  - Hosts from outside can only contact internal hosts that appear in the mapping table, and they're only added when they establish the connection
  - Some NATs support firewall-like configurability

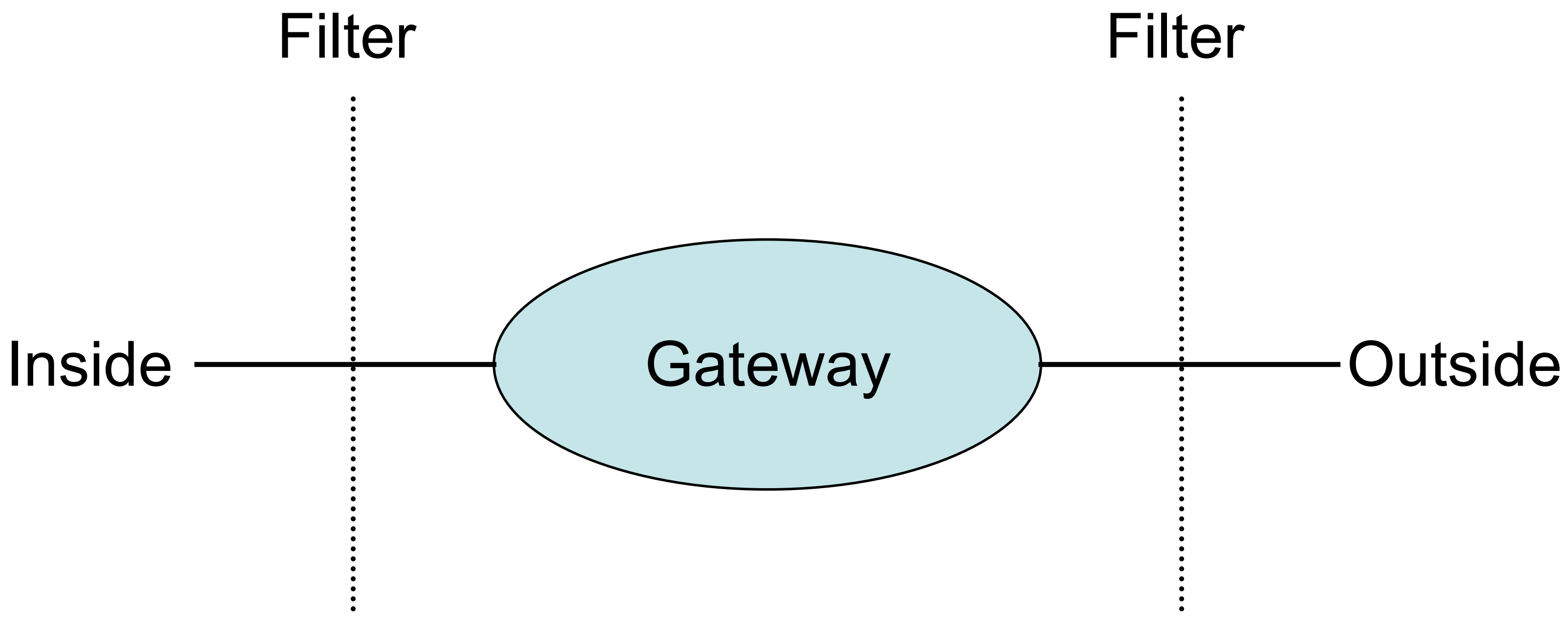
- Can simplify network administration
  - Divide network into smaller chunks
  - Consolidate configuration data

- Traffic logging

Drawbacks of NAT

- Rewriting IP addresses isn’t so easy:
  - Must also look for IP addresses in other locations and rewrite them (may have to be protocol-aware)
  - Potentially changes sequence number information
  - Must validate/recalculate checksums
- Hinder throughput
- May not work with all protocols
  - Clients may have to be aware that NAT translation is going on
- Slow the adoption of IPv6?
- Limited filtering of packets / change packet semantics
  - For example, NATs may not work well with encryption schemes that include IP address information

Firewalls



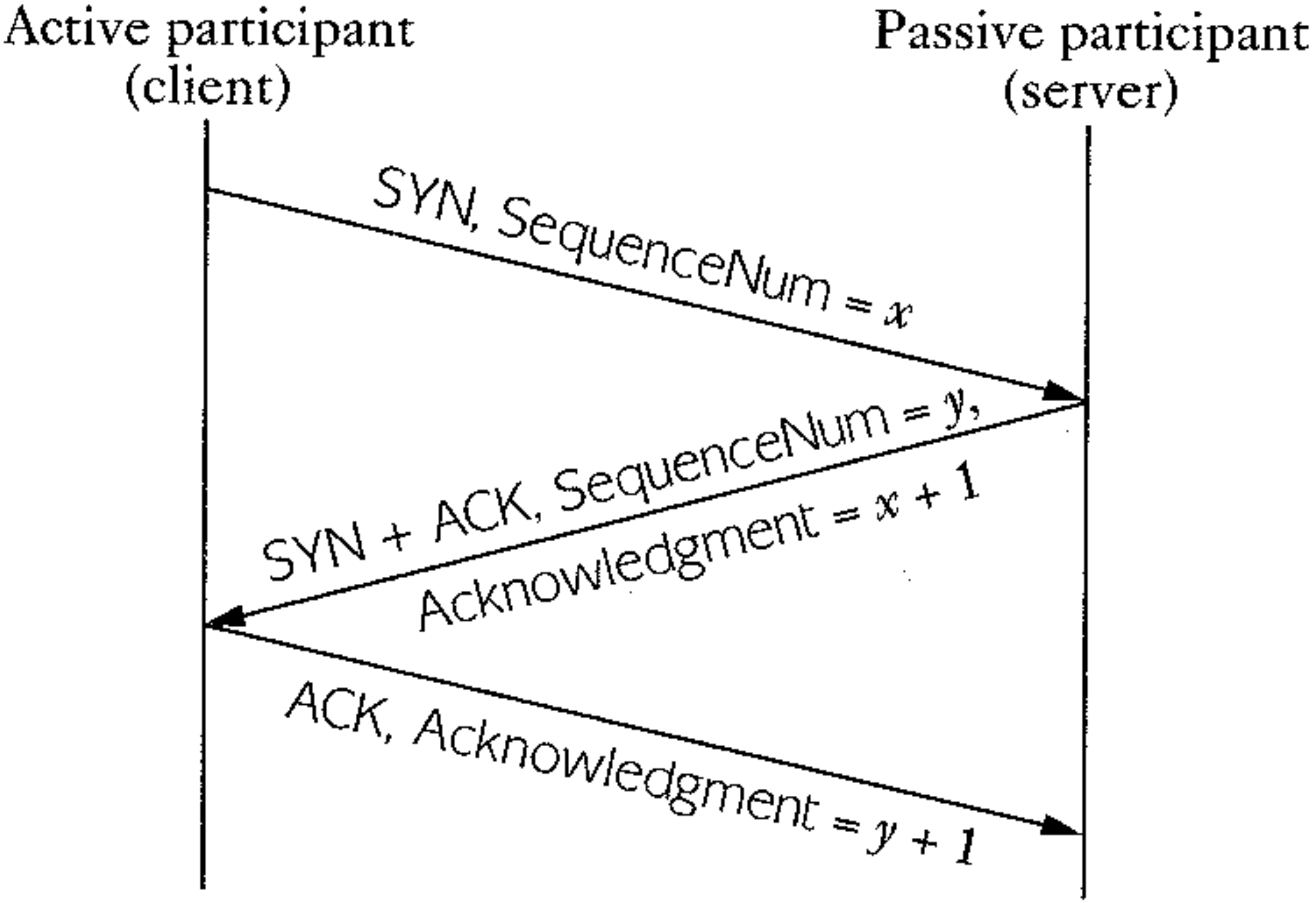
- Filters protect against “bad” packets.
- Protect services offered internally from outside access.
- Provide outside services to hosts located inside.

Filtering Firewalls

- Filtering can take advantage of the following information from network and transport layer headers:
  - Source
  - Destination
  - Source Port
  - Destination Port
  - Flags (e.g. ACK)

- Some firewalls keep state about open TCP connections
  - Allows conditional filtering rules of the form “if internal machine has established the TCP connection, permit inbound reply packets”

Three-Way Handshake


Active participant (client)
Passive participant (server)
SYN, SequenceNum = x
SYN + ACK, SequenceNum = y,
Acknowledgment = $x + 1$
ACK, Acknowledgment = $y + 1$

Ports

- Ports are used to distinguish applications and services on a machine.
- Low numbered ports are often reserved for server listening.
- High numbered ports are often assigned for client requests.

- Port 7 (UDP,TCP): echo server
- Port 13 (UDP,TCP): daytime
- Port 20 (TCP): FTP data
- Port 21 (TCP): FTP control
- Port 23 (TCP): telnet
- Port 25 (TCP): SMTP
- Port 79 (TCP): finger
- Port 80 (TCP): HTTP
- Port 123 (UDP): NTP
- Port 2049 (UDP): NFS
- Ports 6000 to 6xxx (TCP): X11

Filter Example

Action	ourhost	port	theirhost	port	comment
block	*	*	BAD	*	untrusted host
allow	GW	25	*	*	allow our SMTP port

Apply rules from top to bottom with assumed *default* entry:

Action	ourhost	port	theirhost	port	comment
block	*	*	*	*	default

Bad entry intended to allow connections to SMTP from inside:

Action	ourhost	port	theirhost	port	comment
allow	*	*	*	25	connect to their SMTP

This allows all connections from port 25, but an outside machine can run *anything* on its port 25!

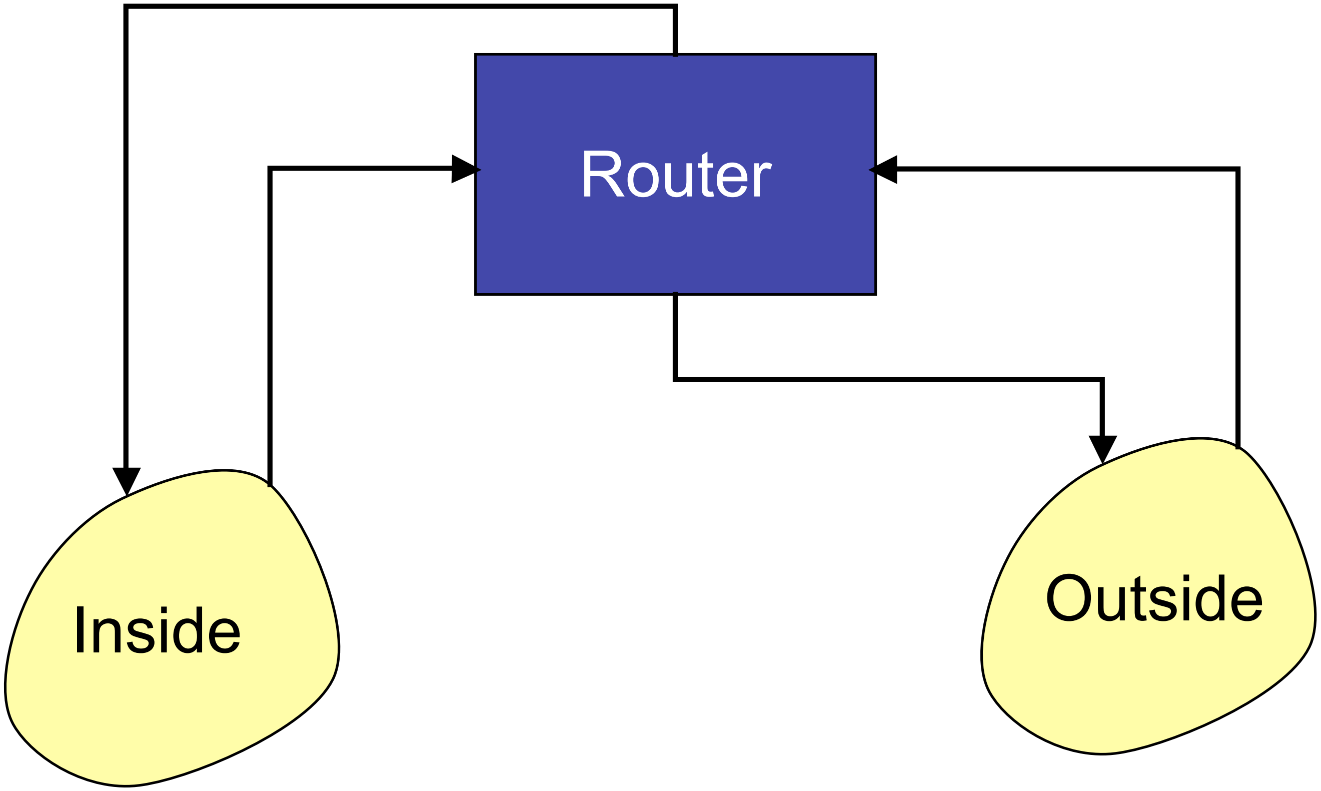
Filter Example Continued

Permit *outgoing* calls to port 25.

Action	src	port	dest	port	flags	comment
allow	123.45.6.*	*	*	25	*	their SMTP
allow	*	25	*	*	ACK	their replies

This filter doesn’t protect against IP address spoofing. The bad hosts can “pretend” to be one of the hosts with addresses 123.45.6.* .

When to Filter?



On Input or Output

- Filtering on *output* can be more efficient since it can be combined with table lookup of the route.
- However, some information is lost at the output stage
  - e.g. the physical input port on which the packet arrived.
  - Can be useful information to prevent address spoofing.
- Filtering on *input* can protect the router itself.

Recommend: Filter ASAP

Action	src	port	dest	port	comment
block	BAD	*	*	*	we don’t trust them
allow	*	*	GW	25	connect to our SMTP
allow	GW	25	*	*	our reply packets

Is preferred over:

Action	src	port	dest	port	comment
block	*	*	BAD	*	subtle difference
allow	*	*	GW	25	connect to our SMTP
allow	GW	25	*	*	our reply packets

Example of a Pitfall

- Filter output to allow incoming and outgoing mail, but prohibit all else.

Action	dest	port	comment
allow	*	25	incoming mail
allow	*	>= 1024	outgoing responses
block	*	*	nothing else

- Apply this output filter set to both interfaces of the router. Does it work?
- Unintended consequence: allows all communication on high numbered ports!

Principles for Firewall Configuration

- Least Privileges:
  - Turn off everything that is unnecessary (e.g. Web Servers should disable SMTP port 25)

- Failsafe Defaults:
  - By default should reject
  - (Note that this could cause usability problems…)

- Egress Filtering:
  - Filter outgoing packets too!
  - You know the valid IP addresses for machines internal to the network, so drop those that aren't valid.
  - This can help prevent DoS attacks in the Internet.

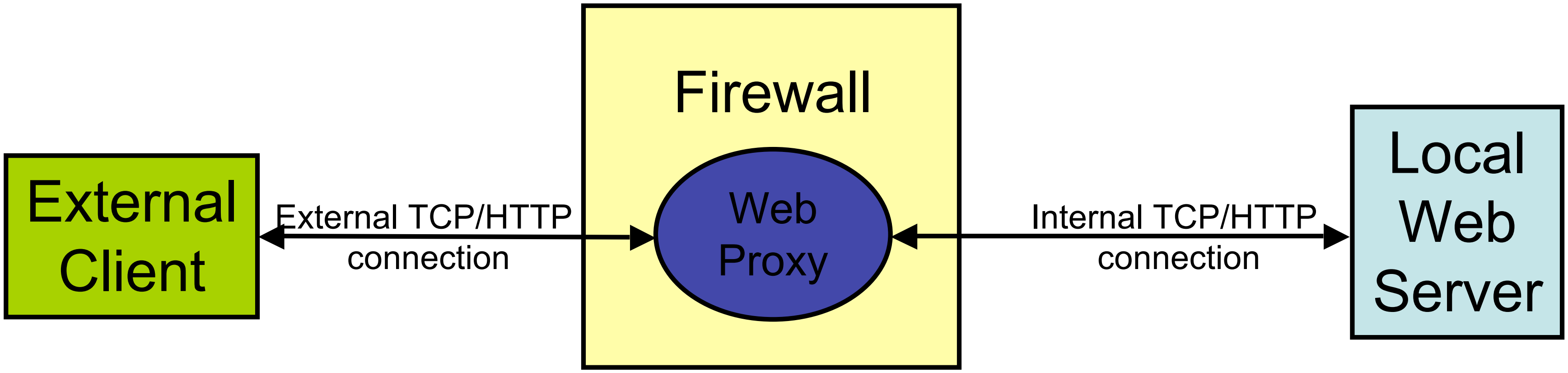
Example “real” firewall config script

```
############
# FreeBSD Firewall configuration.
# Single-machine custom firewall setup. Protects somewhat
# against the outside world.
############

# Set this to your ip address.
ip="192.100.666.1"
setup_loopback

# Allow anything outbound from this address.
${fwcmd} add allow all from ${ip} to any out

# Deny anything outbound from other addresses.
${fwcmd} add deny log all from any to any out

# Allow inbound ftp, ssh, email, tcp-dns, http, https, imap, imaps,
# pop3, pop3s.
${fwcmd} add allow tcp from any to ${ip} 21 setup
${fwcmd} add allow tcp from any to ${ip} 22 setup
${fwcmd} add allow tcp from any to ${ip} 25 setup
${fwcmd} add allow tcp from any to ${ip} 53 setup
${fwcmd} add allow tcp from any to ${ip} 80 setup
${fwcmd} add allow tcp from any to ${ip} 443 setup
…
```

Another problem with Filtering

- Handling IP Fragments
  - Possible for ACK and SYN flag bits in a TCP packet could end up in a different IP fragment than the port number
  - There are malicious tools that intentionally break up traffic in this way
  - Fix: Problem is "tiny" initial IP fragment, so require that initial IP fragment be > 16 bytes (or better yet, large enough for whole TCP header).

Proxy-based Firewalls



- Proxy acts like *both* a client and a server.
- Able to filter using application-level info
  - For example, permit some URLs to be visible outside and prevent others from being visible.
- Proxies can provide other services too
  - Caching, load balancing, etc.
  - FTP and Telnet proxies are common too

Benefits of Firewalls

- Increased security for internal hosts.
- Reduced amount of effort required to counter break ins.
- Possible added convenience of operation within firewall (with some risk).
- Reduced legal and other costs associated with hacker activities.

Drawbacks of Firewalls

- Costs:
  - Hardware purchase and maintenance
  - Software development or purchase, and update costs
  - Administrative setup and training, and ongoing administrative costs and trouble-shooting
  - Lost business or inconvenience from broken gateway
  - Loss of some services that an open connection would supply.
- False sense of security
  - Firewalls don't protect against viruses…
  - Can almost always "tunnel" one protocol on top of another: e.g. mail protocol on top of HTTP