Middleboxes

EE 122: Intro to Communication Networks

Fall 2006 (MW 4-5:30 in Donner 155)

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http://inst.eecs.berkeley.edu/~ee122/

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Announcements

- Reminder, phase 1 of Project #3 due this tomorrow evening with **no slip days**
- Section this Friday and next Tues/Weds will discuss phase 2 of Project #3
- No lecture next Weds, Nov 22
- My office hours Weds Nov 22 are by request: i.e., send email in advance (don't be shy!)

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Goals of Today's Lecture

- QoS as leading to questions of network neutrality
- Elements of control: Middleboxes
  - Network address translators (NATs)
  - Firewalls
  - Tunneling
  - Application gateways
- Middleboxes introduce new problems while solving existing ones
  - Erosion of end-to-end semantics
  - Connections become more brittle
  - New apps harder to deploy (impairs innovation)

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Discussion: Limited QoS Deployment

- A lot of mechanism developed for reliable performance
  - Scheduling algorithms (fair queuing, max-min fairness)
  - Traffic descriptions (token bucket)
  - Resource reservations & admission control
  - Intserv for fine-grained QoS
  - Diffserv for aggregate QoS
- But to date it has not proven viable end-to-end
  - Issue #1: complexity of payment
  - Issue #2: the alternative of overprovisioning

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Exploiting Lack of End-to-End QoS

- Suppose an ISP offers their own Internet service
  - E.g., Portal (ala' Yahoo), search engine (ala' Google)
- Then it's in their interest that performance to Yahoo or Google is inferior
  - So customers prefer to use their value-added services
- ISP can
  - recognize traffic to competitor and demote it
  - charge competitor if they want well-provision paths
  - just not put effort/$ into high-capacity interconnects w/ other ISPs; congestion provides traffic demotion directly
- Works particularly well for **large** providers w/ lots of valuable content

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Network Neutrality

- *Network neutrality* = notion that ISPs supply non-discriminatory IP connectivity
- Opposite counterpoint: a Walled Garden
  - Provider only allows you to access their (often value-added) services
  - E.g., AOL's captive Web portal/email/IM
- Highly contentious; potential legal fray
  - E.g., ISPs blocking Voice-over-IP (VOIP)
    - As does China, Panama, Costa Rica
  - E.g., ISPs blocking 25/tcp (SMTP) to curb spammers

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Network Neutrality, con't

- Is Internet access something that ISPs provide as "common carriers"?
  - Transporting goods as service to common public
- Or: will free market forces serve to shape ISP favoritism efficiently?
  - Is there a danger of monopolies emerging?
- Many QoS-sensitive apps can be written in an adaptive style to deal with uncertainties
- But what about stricter apps?
  - Standard example: telesurgery

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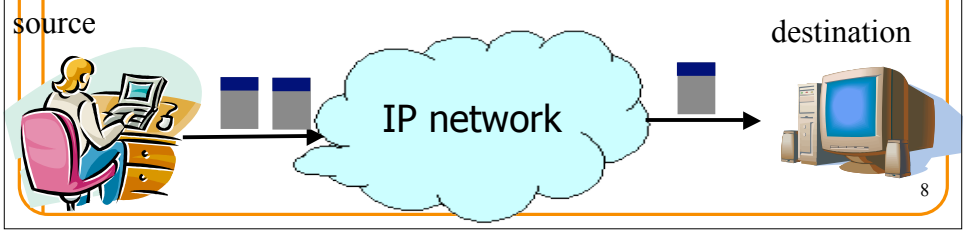
Network-Layer Principles

- 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



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Internet Reality

- Host mobility
  - Changes in IP addresses as hosts move
- IP address depletion
  - Dynamic assignment of IP addresses
  - Use of private addresses
- Security/policy concerns
  - Discarding suspicious or unwanted packets
  - Monitoring activity
- Performance concerns
  - Controlling how link bandwidth is allocated
  - Storing popular content near the clients
  - Network neutrality, or lack thereof

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Middleboxes

- Middleboxes are intermediaries
  - Interposed in-between the communicating hosts
  - Often without knowledge of one or both parties
    - "hidden"
- Examples
  - +Network address translators (**NATs**)
  - +Firewalls
  - –Traffic shapers / performance boosters
  - –Intrusion detection/prevention systems
  - –Transparent Web proxy caches
  - –Sign-on "capture" pages

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Two Views of Middleboxes

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

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Network Address Translation

(NAT)

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Motivation Behind 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
  - But *ease-of-deployment often wins long-term*
  - Now, NATs very widely deployed
  - … much more so than IPv6

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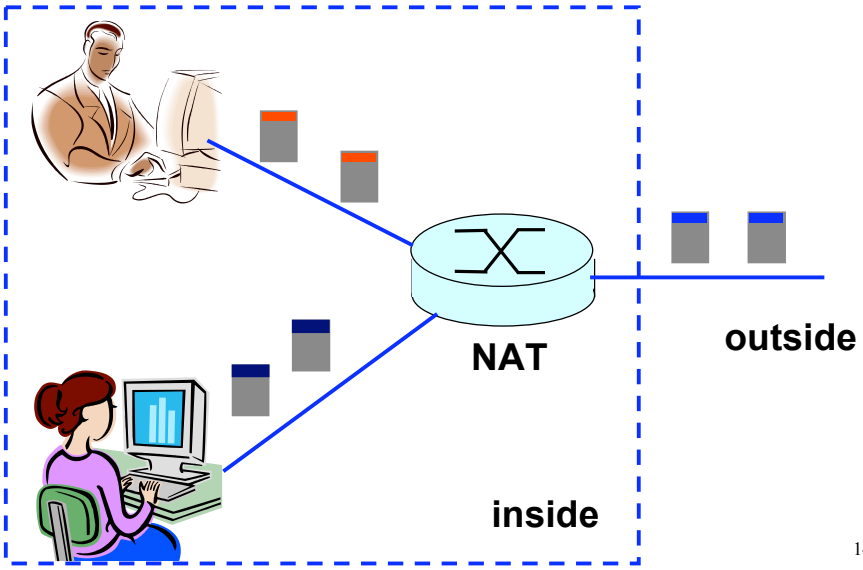
Active Component in the Data Path



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IP Header Translators

- Local network addresses not globally unique
  - E.g., private IP addresses (in 10.0.0.0/8, 172.16.0.0/12, 192.168.0.0/16; see RFC 1918)
- NAT box rewrites IP addresses
  - Make the "inside" look like a single IP address
  - … and change header checksums accordingly
- Outbound traffic: from inside to outside
  - Rewrite the source IP address
- Inbound traffic: from outside to inside
  - Rewrite the destination IP address

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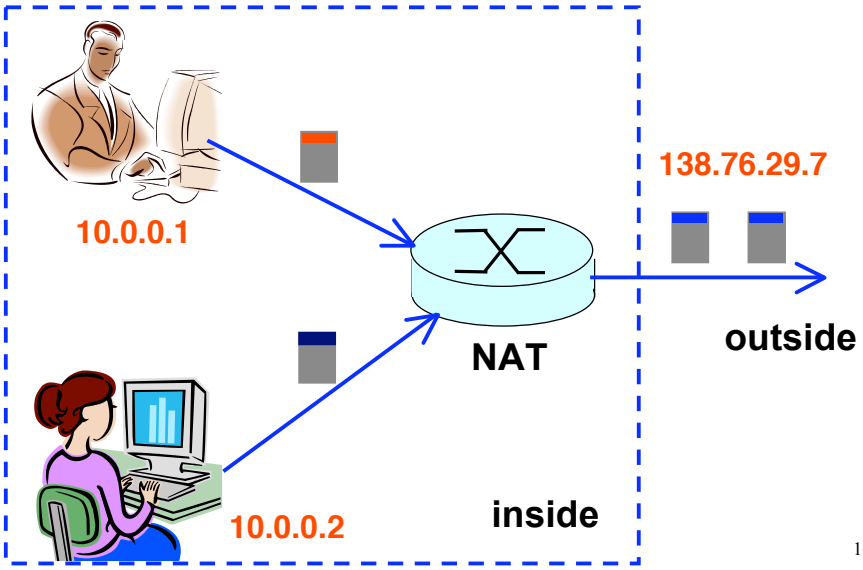
Using a Single Source Address



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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?
- How can we fix this?

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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 (source address, port #) ⇔ (NAT address, new port #)
- Map incoming packets
  - Consult the translation table
  - Map the destination address and port number
  - Local host receives the incoming packet

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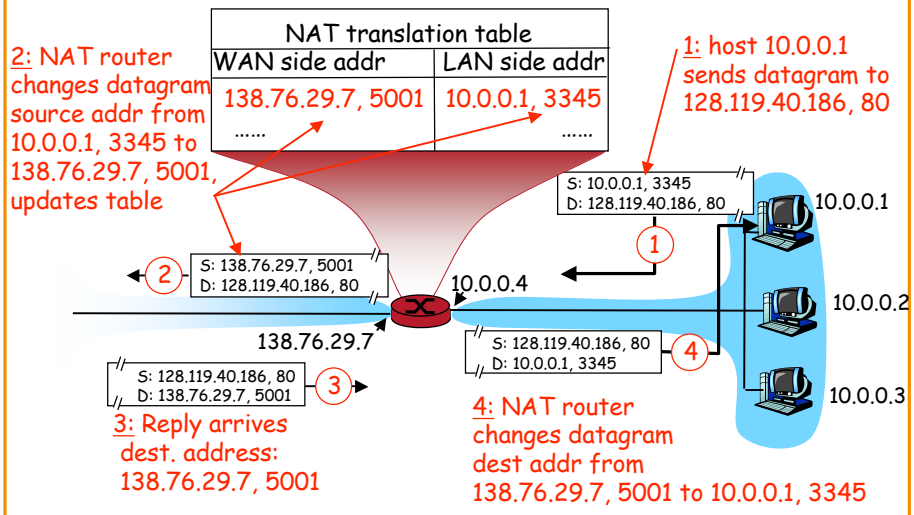
Network Address Translation Example



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Maintaining the Mapping Table

- Create entry upon seeing outbound 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
- Yet another example of "soft state"
  - I.e., removing state if not refreshed for a while
- Makes Internet connectivity more brittle

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The Problem is Broader

- Do IP addresses only appear in IP headers?
- Also appear in application payloads to facilitate rendezvous (subsequent conn's)
  - E.g., `http://141.16.9.1/good_stuff.html`
  - E.g., `PORT 141,16,9,1,4,21` (FTP)
- NAT needs to fix these up too
  - Otherwise the application breaks
- How hard is that?

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Modifying Addresses Gets Messy

- Problem #1: what if replacement has different number of bytes than original?
  - Okay, we must adjust TCP sequence numbers
  - **And**: rewrite ACKs
- Problem #2: what if revised packet > MTU?
  - Um, send multiple pkts (or allow fragmentation)
- Problem #3: what if we don't know where in the payload the app embeds addresses?
  - Oops: the app won't work through the NAT
- NATs <u>make it harder to deploy new apps</u>

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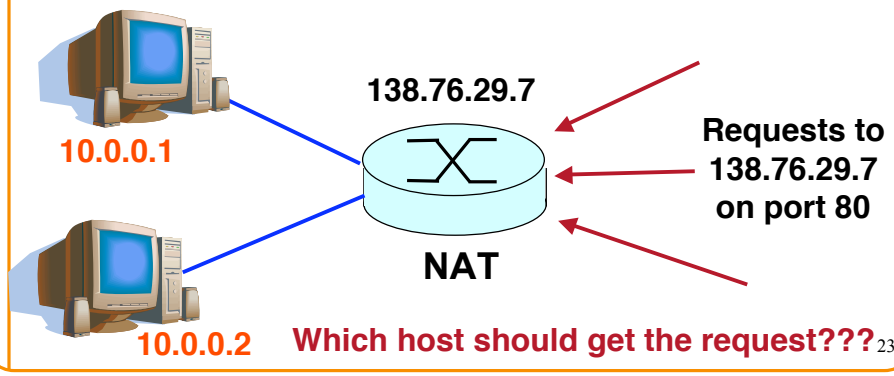
Servers Behind a NAT

- NATs undermine using port #s to address processes
- NAT needs binding in advance for incoming SYNs



Which host should get the request???

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Objections Against NAT

- Difficult to support peer-to-peer applications
  - P2P needs a host to act as a server
- Layering violation (hence messiness)
- NAT violates the end-to-end principle
  - Network nodes should not modify the packets
- Connections become brittle
- Barrier to deployment of new apps
- IPv6 is a cleaner solution
  - Better to migrate than to limp along with a hack

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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

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5 Minute Break

Questions Before We Proceed?

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Firewalls

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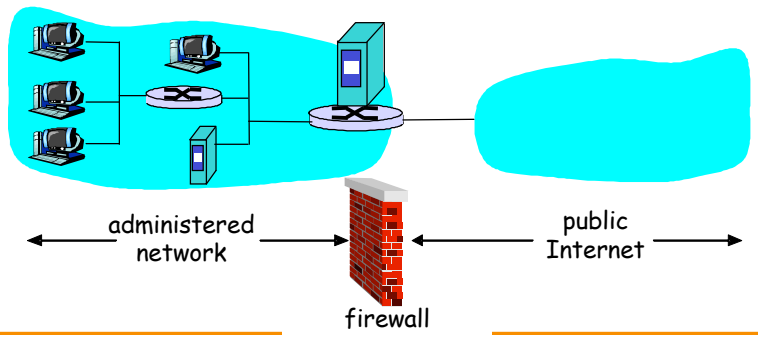
Firewalls

- Isolates organization's internal net from Internet
- Allows some packets to pass, blocks others
  - (Refinement: shape some traffic, allow other unimpeded)
- Twin goals: security and policy enforcement



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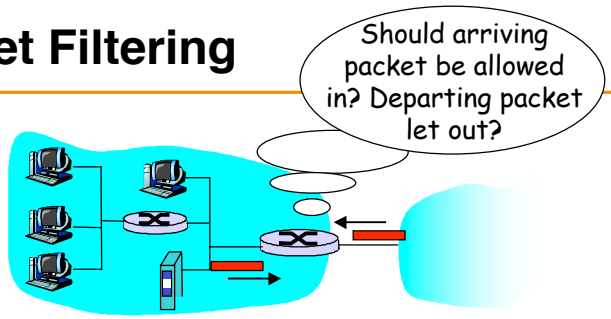
Packet Filtering



- 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
- Simpler versions are stateless
  - But increasingly they need to be stateful

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Packet Filtering Examples

- Block all packets with IP protocol field = 17 or with either source or dest port = 22.
  - All incoming and outgoing UDP flows blocked
  - All SSH connections blocked
- Block inbound TCP with SYN but no ACK
  - Prevents external clients from initiating TCP connections to internal hosts
  - But allows internal clients to connect to outside
- Block all packets with TCP port of Doom3
  - (Oops, let's hope no other app uses that port)
- Block all packets with "reserved" bits set
  - Oops - there goes ECN deployment

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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 a packet's header fields
  - Test yields **permit** or **deny**
- Order matters: first matched rule wins
- E.g.: Alice runs a network in 222.33.0.0/16
  - Wants to let Bob's site access certain hosts
    - Bob is on 111.55.0.0/16
    - Alice's special hosts on 222.33.44.0/24
  - Alice doesn't trust Trudy, inside Bob's network
    - Trudy is on 111.55.66.0/24
  - Alice doesn't want any other traffic from the Internet

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Firewall Configuration, con't

- Alice's firewall rules
  - #1: Don't let Trudy machines in
    - **Deny** <src = 111.55.66.0/24, dst = 222.33.0.0/16>
  - #2: Let rest of Bob's network in to special dsts
    - **Permit** <src=111.55.0.0/16, dst = 222.33.44.0/24>
  - #3: Block the rest of the world
    - **Deny** <src = 0.0.0.0/0, dst = 0.0.0.0/0>
- It's easy to introduce subtle errors …
  - And production firewalls can have 1000s of rules

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Subverting Firewalls

- How can we fool a firewall?
- Method #1: abuse its statelessness
  - Consider the rule of "no SYNs w/o ACKs" as a way to prevent connections initiated inbound
  - How can we mislead a firewall about setting of TCP flag bits?

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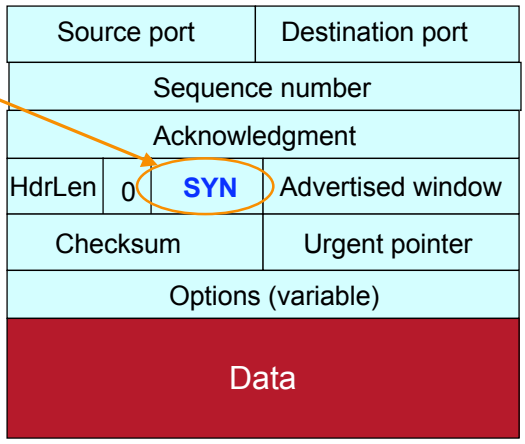
Checking TCP Header for Initial SYN

Firewall will check here, 14 bytes into transport header just after IP header



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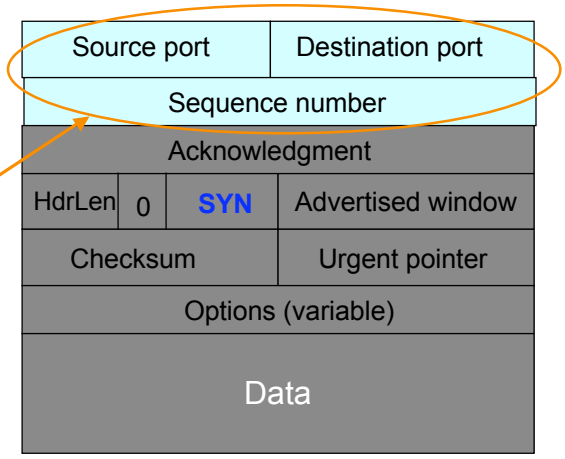
Misleading Stateless Inspection

Split into two **fragments**. First is just 8 bytes of IP payload, i.e., here



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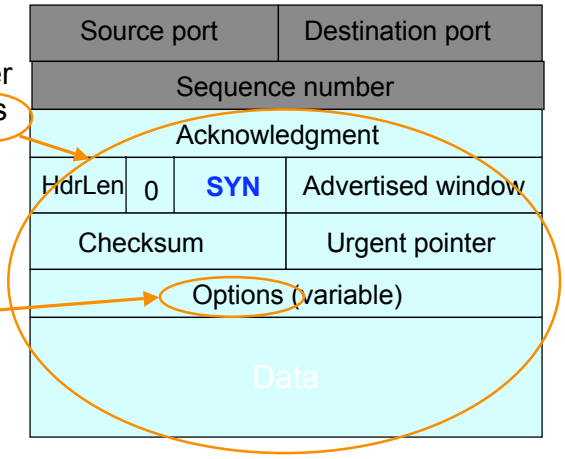
Misleading Stateless Inspection, con't

Second fragment starts 8 bytes later covering all of this

Firewall looks 14 bytes into payload, i.e., here, which is <u>under the control of the attacker</u>



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Subverting Firewalls, con't

- How might a firewall defend against this?
  - Defense #1: reassemble fragments
    - But this costs state
  - Defense #2: **deny** small initial fragments
    - But: legit traffic has these, hence collateral damage
- Subversion Method #2: **abuse ports**
  - Who says that e.g. port 22/tcp = SSH?
    - Why couldn't it be say Skype or BitTorrent?
    - Just requires that client & server agree on app proto

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Hiding on Other Ports

- Method #1: use port allocated to another service (how can this be detected?)
- Method #2: **tunneling**
  - Encapsulate one protocol inside another
  - Receiver of "outer" protocol *decapsulates* interior tunneled protocol to recover it
  - Pretty much <u>any</u> protocol can be tunneled over another (with enough effort)
- E.g., tunneling IP over SMTP
  - Just need a way to code an IP datagram as an email message (either mail body or just headers)

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Example: Tunneling IP over Email

From: doesnt-matter@bogus.com
To: my-buddy@tunnel-decapsulators.R.us
Subject: Here's my IP datagram

IP-header-version: 4
IP-header-len: 5
IP-ID: 11234
IP-src: 1.2.3.4
IP-dst: 5.6.7.8
IP-payload: 0xa144bf2c0102…

Program receives this legal email and **builds** an IP packet corresponding to description in email body …
… **injects** it into the network
How can a firewall detect this??

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Tunneling, con't

- E.g., IP-over-ICMP:
  - Encode an IP datagram as the payload of a "ping" packet
- E.g., Skype-over-HTTP:
  - Encode Skype message in URL of requests or header fields (or cookies) of replies
- Note #1: to tunnel, the sender and receiver must both cooperate
- Note #2: tunneling has many legitimate uses too
  - E.g., *overlay* networks that forward packets along paths different from what direct routing would pick
  - E.g., Virtual Private Networks (VPNs)
    - Make a remote machine look like it's local to its home network
    - Tunnel encrypts traffic too for privacy

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Application Gateways

- Middlebox can insert itself between client and server
  - Client deals with middlebox (application gateway), not server
  - Server deals with middlebox, not client
  - Can be done explicitly or transparently
- Example: Web proxy
- Example: SSH gateway
  - Require all SSH in/out of site to go through gateway
  - Gateway logs authentication, inspects decrypted text
  - Site's firewall configured to prohibit any other SSH access

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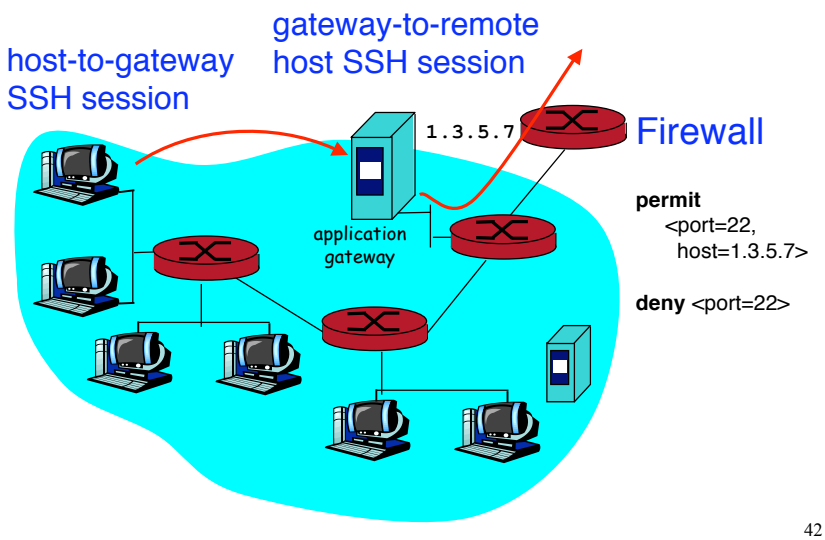
SSH Gateway Example



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Conclusions

- Middleboxes address important problems
  - Using fewer IP addresses
  - Blocking unwanted traffic
  - Monitoring activity
  - Shaping use of network resources
  - Improving/controlling performance (vs. *network neutrality*)
- Middleboxes cause problems of their own
  - Connectivity erodes
    - Notion of addresses, ports weakened
    - Middlebox state management can lead to connection termination
  - Harder to deploy new apps
- Next lecture
  - Security mechanisms ; attacks & defenses

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