Computer and Network Security: Firewalls

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Outline

- What are Firewalls?
- Firewall Theory
- Types of Firewalls
- Implementing Firewalls
- Circumventing Firewalls

Securing Networks

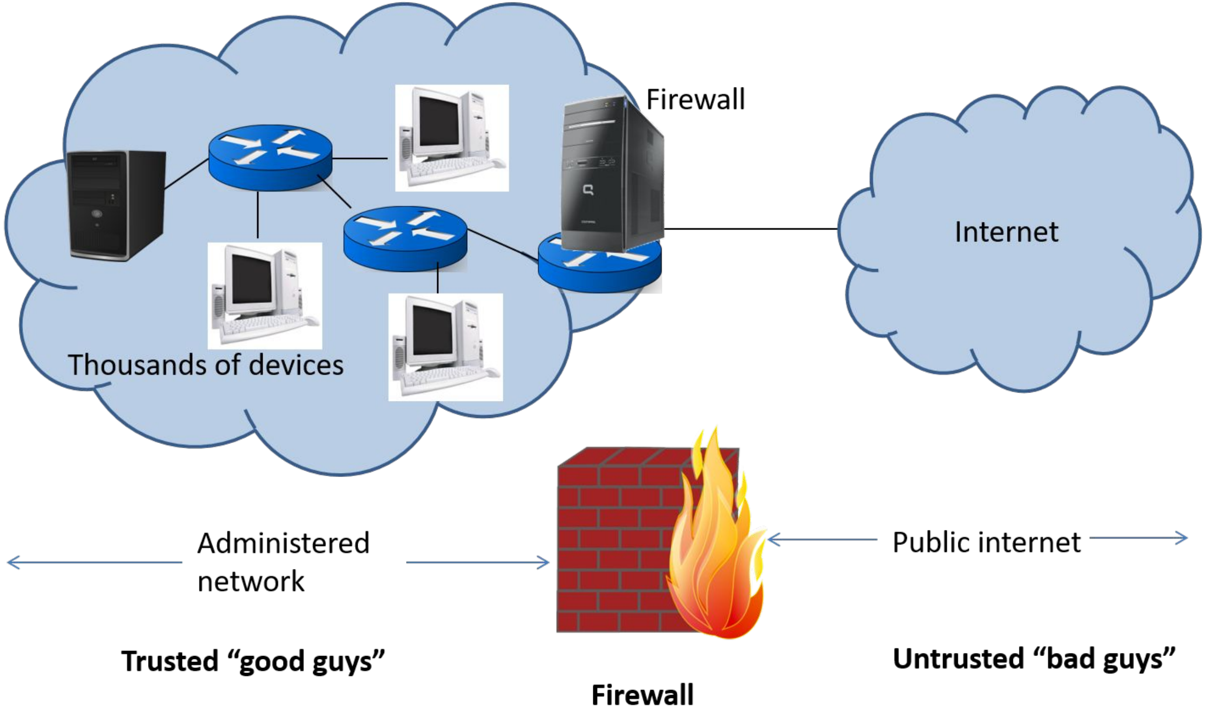
- Organization has many networked computing devices. How to protect them?
  - Very large surface area for possible attack
- How about defence mechanisms in each system?
  - Disable unused services, insist use of secure protocols etc
  - Challenge: Systems use different OS, hardware, provide different services
    - Complex Management, just does not scale
- How is it done in real-life?

Real Life Situation

- How is security provided in a large campus like IIT Bombay or a big mall with many shops?
  - Guard all entrances (check posts)
  - Check identity/bags of those entering and leaving at these check posts
- Firewalls do same in the networking world

Firewalls

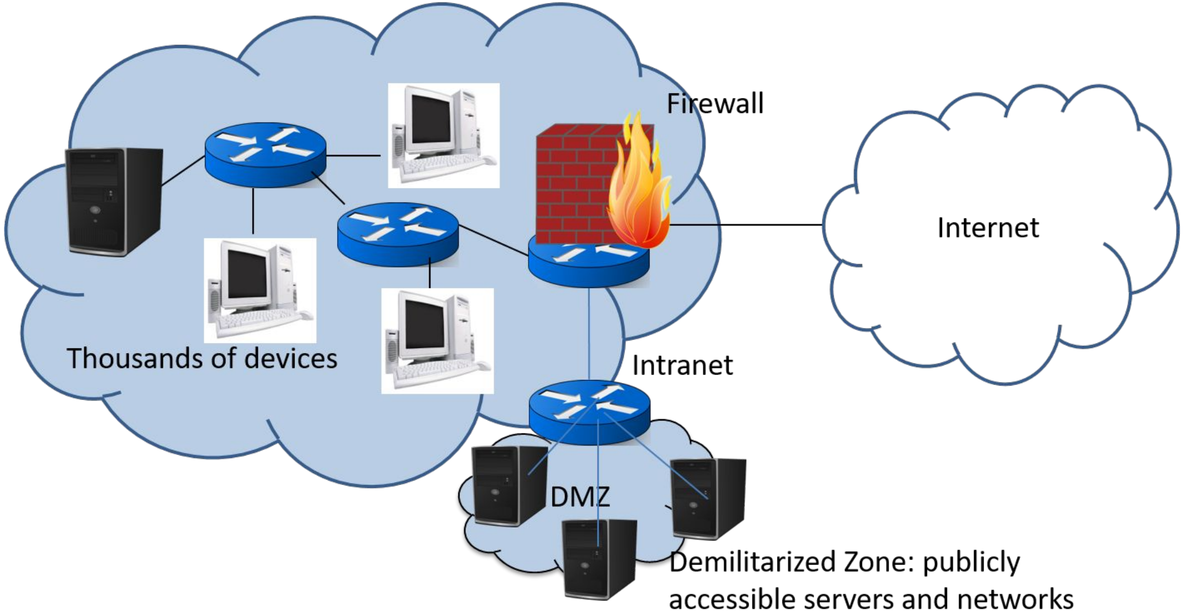
- Isolates the internal network from external Internet
- Implement a security policy



Policy

- Earlier: What **action principals** can take on an **object** (Only Bob may use this machine)
- Here: Who can talk with whom to get what service?
- Two types of connections:
  - Inbound: External users talk with internal users
  - Outbound: Internal users talk with external users

- Sample policy:
  - Insiders can access any outside service
  - Outsiders can access service only of machines in DMZ (demilitarized zone)



Demilitarized Zone: publicly accessible servers and networks

- Location of Firewall
  - Gateway of any sensitive network (like in previous figure)
  - Can also be at end-hosts

Traffic not captured by the policy?

- Default Allow: Permit access to services
  - Disallow in case of a problem
  - Convenient (people more happy) but dangerous
- Default Deny: Don’t permit access to services
  - Allow when users complain; devise a specific policy
  - Less convenient (people less happy) but more secure
- Good practice: Default Deny
  - More secure and issues can be quickly identified

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- **Firewall Theory**
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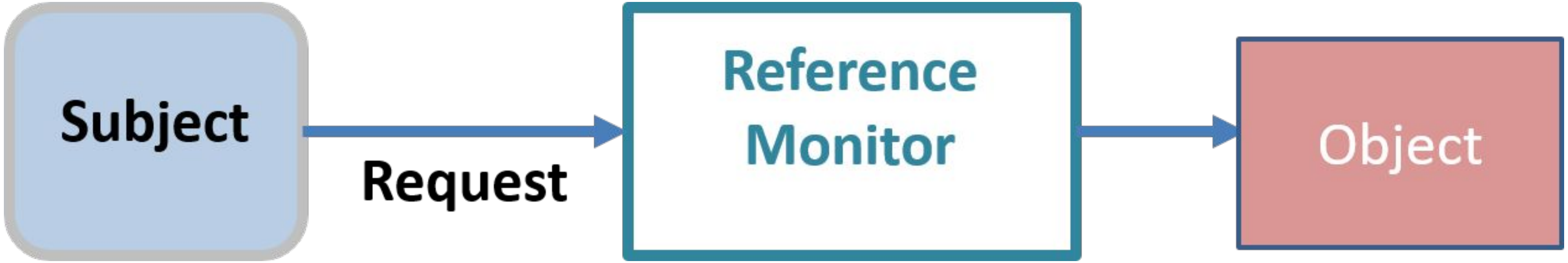
Reference Monitor

- A security concept
- Reference Monitor (RM) examines every request to a controlled resource (object)
- Decides whether to allow or deny the request



Security Properties

Need to ensure three properties

- Always invoked: Every access to the resource is mediated by RM
- Tamper Resistant: Integrity of RM always maintained
  - No code or state change
- Verifiable: Verify RM is doing its job
  - RM needs to be simple to verify this

Firewalls as RM

1. Always Invoked?
   - Firewalls implemented at chokepoints check all incoming and outgoing traffic

- But what about?
  - A user setting up an insecure Wireless AP within organization
  - A user connecting an infected machine to the network
- Need to cover all links
  - These set of links determine security perimeter
  - Difficult to achieve in practice

2. Tamper Resistant?

- Feasible. How?
  - Allow access to firewall machine via stringent authentication mechanisms
  - Physically protect firewall

3. Verifiable?

- Tough in practice when the number of rules are large

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Types of Firewalls

- Stateless Packet Filters
- Stateful Packet Filters
- Application Gateways

Stateless Packet Filters

- Implemented on routers via Access Control Rules
  - List of these rules is called ACL (Access Control List)
  - Different ACLs for each router interface
- Firewall checks each packets individually (hence no state) against rules
  - Only looks at packet headers: Layer 3, Layer 4 headers
    - E.g. Source IP, destination IP, source port, destination port, TCP flags, Packet type (e.g. ICMP), wild cards
  - Rules specify action (allow or drop) against a matching packet
  - Rules are applied top to bottom
    - Go to next rule only if the current rules does not match

Examples

- Only an external client at 12.7.8.9 on port 5000 can connect to a special web service set up within your organization on 21.3.5.6

Action	Src IP	Dst IP	Protocol	Src Port	Dst Port	TCP flags
Allow	12.7.8.9	21.3.5.6	TCP	5000	80	-
Deny	*	21.3.5.6	TCP	*	80	-

Even packets from 12.7.8.9 on any other port will be dropped

Examples

Action	Src IP	Dst IP	Protocol	Src Port	Dst Port	TCP flags
Allow	12.7.8.9	21.3.5.6	TCP	5000	80	-
Deny	*	21.3.5.6	TCP	5000	80	-

vs

Action	Src IP	Dst IP	Protocol	Src Port	Dst Port	TCP flags
Deny	*	21.3.5.6	TCP	5000	80	-
Allow	12.7.8.9	21.3.5.6	TCP	5000	80	-

External client at 12.7.8.9 on port 5000 cannot connect to a special web service any more

Order Matters!

Another Example

- Organization Policy: Internal users can surf the web; block every thing else □ permit DNS traffic for URL resolutions
  - No connections from outside to inside are allowed
  - But external web traffic corresponding to internal user requests needs to get in
- Organization address: 125.5 / 16

ACL

action	source address	dest address	protocol	source port	dest port	flag bit
allow	125.5/16	outside	TCP	any	80	any
allow	outside	125.5/16	TCP	80	any	ACK
allow	125.5/16	outside	UDP	any	53	---
allow	outside	125.5/16	UDP	53	any	----
deny	all	all	all	all	all	all

- First two rules: Internal users can surf web
  - A TCP connection establishment from outside to inside will have syn bit set, which will be dropped
- Second two rules: Allow DNS traffic to flow

Points to Note

- An organization can have 1000s of such rules
  - Easy to introduce bugs which attackers can exploit
- Systematic evaluation is tough at scale

- Stateless: Can admit dangerous packets

action	source address	dest address	protocol	source port	dest port	flag bit
allow	125.5/16	outside	TCP	any	80	any
allow	outside	125.5/16	TCP	80	any	ACK

  - No TCP connection, but can admit some ACK packets related to it
  - IP Fragmentation attack:
    - First fragment: offset 0, the TCP header has only ack bit set
    - Second fragment: offset X □ overlapping data
      - Not examined by Firewall since it is a second fragment
      - During reassembly, this data overwrites first fragment □ syn bit set, ack bit not set

Stateful Firewalls

- Most firewalls are of this type
- At establishment of connection, make a decision whether to admit or not
  - Any later packet not part of admitted connections are dropped
- Example: TCP
  - Track SYN/FIN; timer to prune inactive connections
  - (in prev example) Packet with just ack bit set will not be admitted
- Drawback: Memory; Can slow down connections

ACL

action	source address	dest address	protocol	source port	dest port	flag bit	Conn check
allow	125.5/16	outside	TCP	any	80	any	
allow	outside	125.5/16	TCP	80	any	ACK	X
allow	125.5/16	outside	UDP	any	53	---	
allow	outside	222.22/16	UDP	53	any	----	X
deny	all	all	all	all	all	all	

Connection Table:

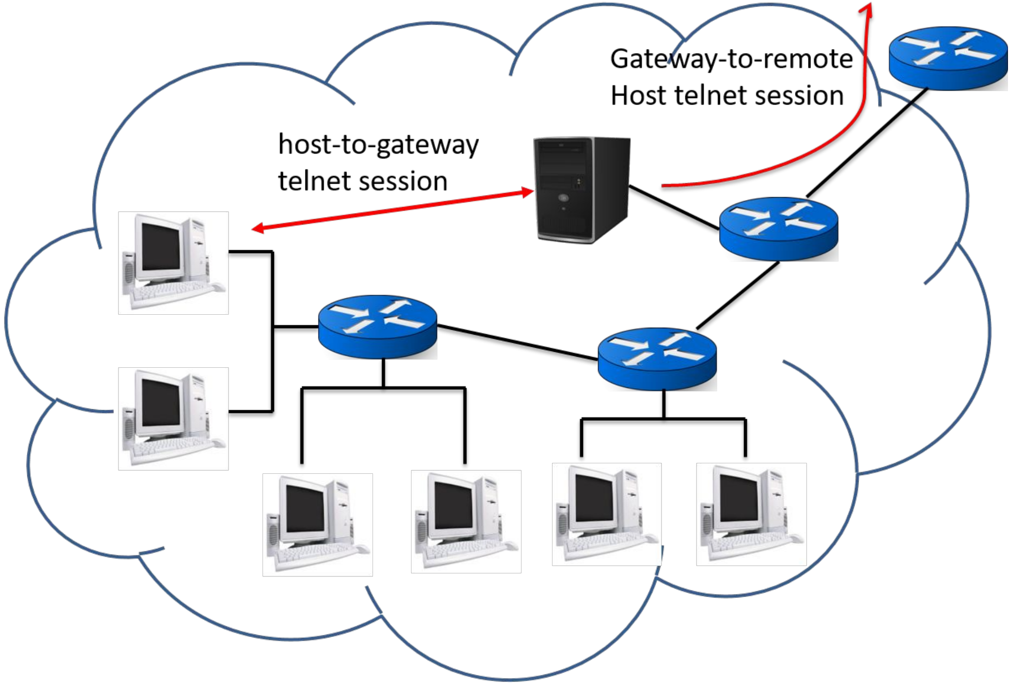
Source Address	Source Port	Destination Address	Destination Port
125.5.12.14	4533	120.12.3.1	80
125.5.19.34	6771	12.14.5.6	80

Example

- Block all telnet connections to the outside world
- But permit a few select users to telnet outside
- How about user IP in the ACL?
  - IP spoofing issues
  - User may want to telnet from any machine
- How achieved?
  - Need to look at application data

Application Gateway

- Users telnet to gateway
- Gateway authenticates the user (e.g. passwd based)
- Gateway telnets to destination
  - Gateway acts as a relay
- Firewall ACL permits telnet connections only from gateway


Gateway-to-remote Host telnet session
host-to-gateway telnet session

Drawbacks of Application Gateways

- Different applications need different gateways
- Client should know which gateway to connect to

Personal Firewalls

- Saw how firewalls protect networks
- Firewalls can protect personal machines too!
  - User defines ACL rules; checked against all incoming and outgoing packets
  - Collect logs to monitor and debug
  - Combine with virus scanners for better security

Firewall Drawbacks

- Interfere with some applications (e.g. Skype)
- Don’t solve all problems
  - Server vulnerabilities can be exploited (SQL injection, buffer overflow)
  - Protocol implementations can be exploited
  - Most DDOS attacks cannot be prevented
  - Insider attacks cannot be prevented
- More rules/misconfiguration □ susceptible to attacks
- Can only prevent “known” attacks

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Firewall Implementation (in Linux)

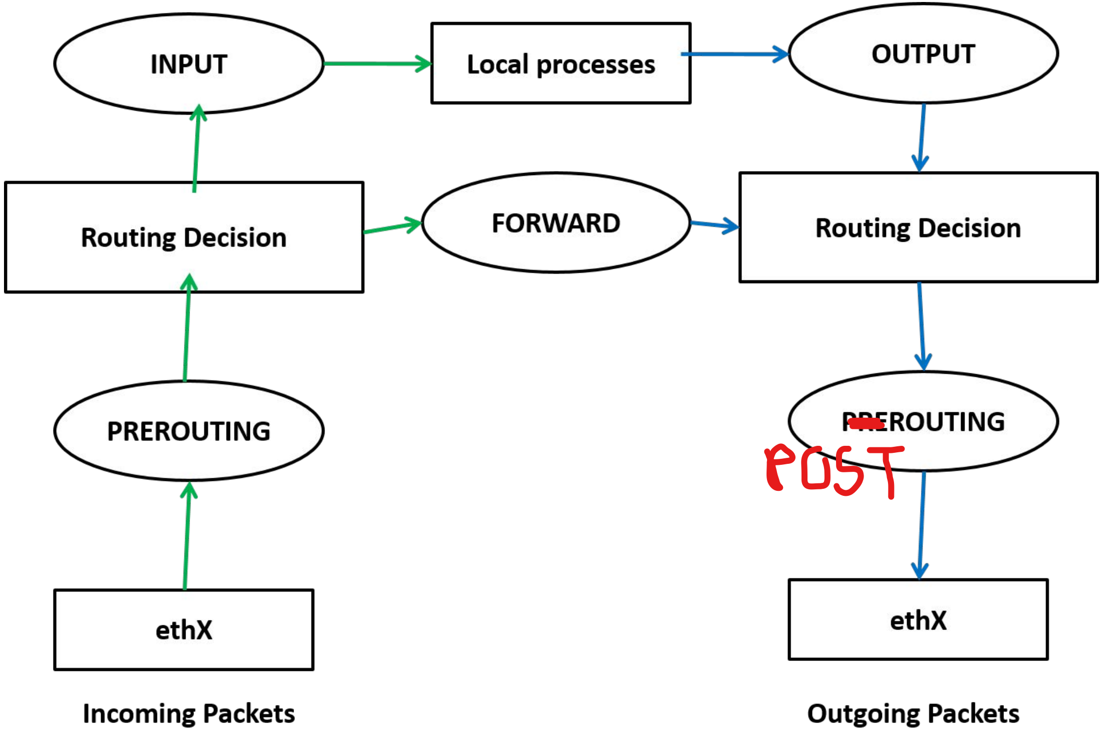
- Netfilter hooks (kernel’s packet filtering framework)
- IPTables (user level firewall tool)

Firewall Implementation

- IP packet processing happens at kernel level
- How to modify processing to implement firewall functionality?
  - Kernel level code changes difficult
- Newer kernels provide hooks at several points of packet processing □ netfilter hooks
- Can write kernel modules that register with these hooks and get packets to process
  - Still not so easy

NetFilter Hooks

- 5 hooks provided by kernel (oval boxes)



IPTables

- Permit operation at user-space
  - Program built on top of netfilter hooks
- Uses Tables to organize rules
  - Rule related with NAT put in NAT table
  - Rule related to allow/deny packets put in Filter table
- 5 Tables:
  - Filter: filters packet
  - NAT: Nat related functionality
  - Mangle: alters IP headers (e.g. TTL)
  - RAW: mark packets to opt out of connection tracking
  - Security: SElinux related functions

IPTables

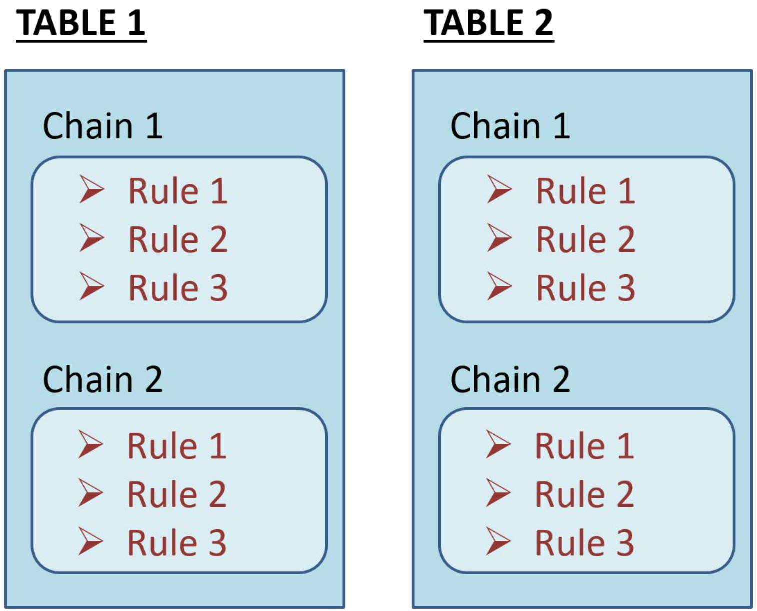


TABLE 1

Chain 1

- Rule 1
- Rule 2
- Rule 3

Chain 2

- Rule 1
- Rule 2
- Rule 3

TABLE 2

Chain 1

- Rule 1
- Rule 2
- Rule 3

Chain 2

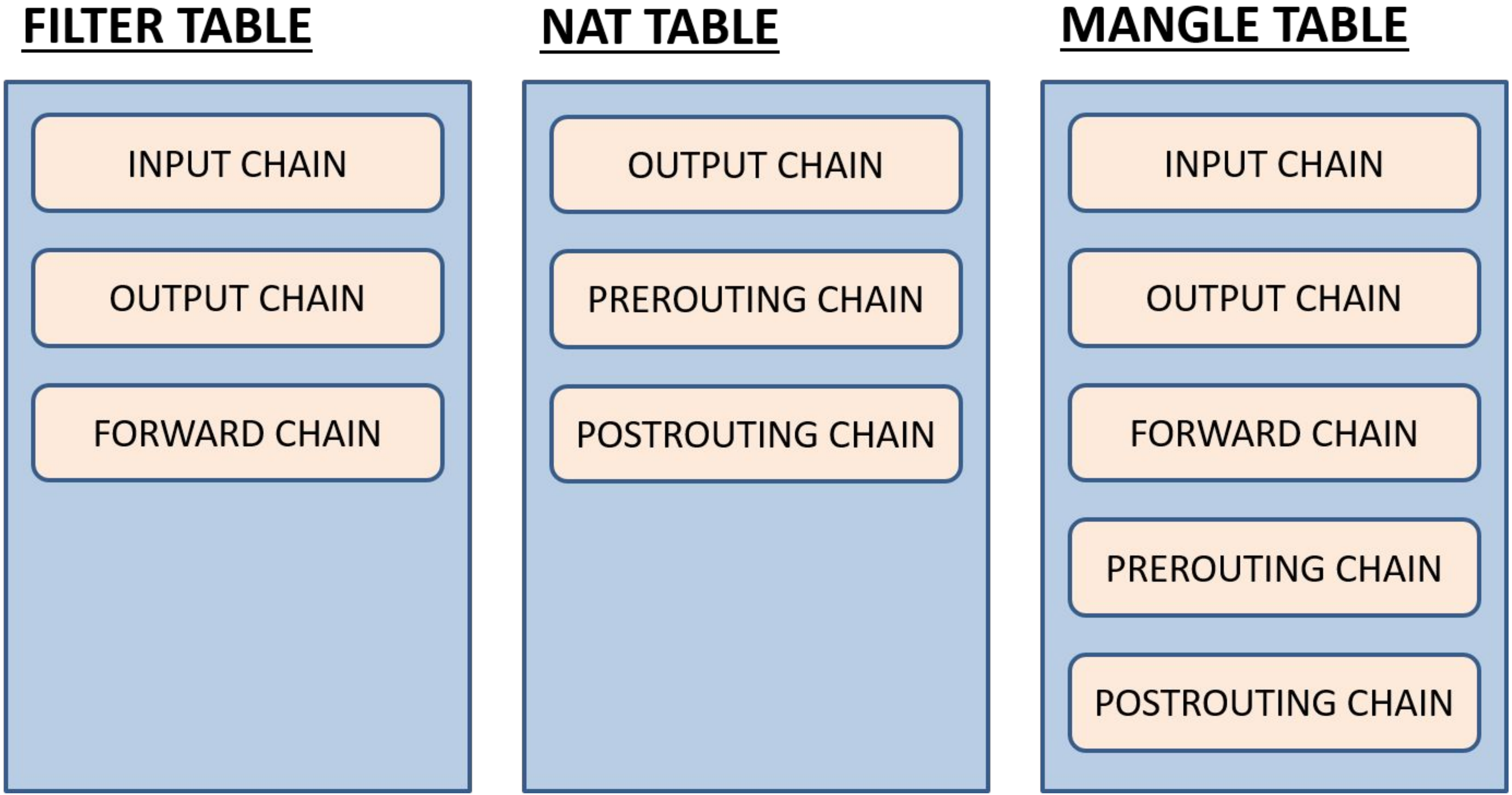
- Rule 1
- Rule 2
- Rule 3

Uses tables to organize firewall rules

IP tables is a bunch of Tables (tables represent a type of action; e.g. Filter, Nat etc)

Tables are a bunch of chains (chains represent netfilter hooks, e.g. Input, Pre-routing etc)

Chains are a bunch of firewall rules



FILTER TABLE

- INPUT CHAIN
- OUTPUT CHAIN
- FORWARD CHAIN

NAT TABLE

- OUTPUT CHAIN
- PREROUTING CHAIN
- POSTROUTING CHAIN

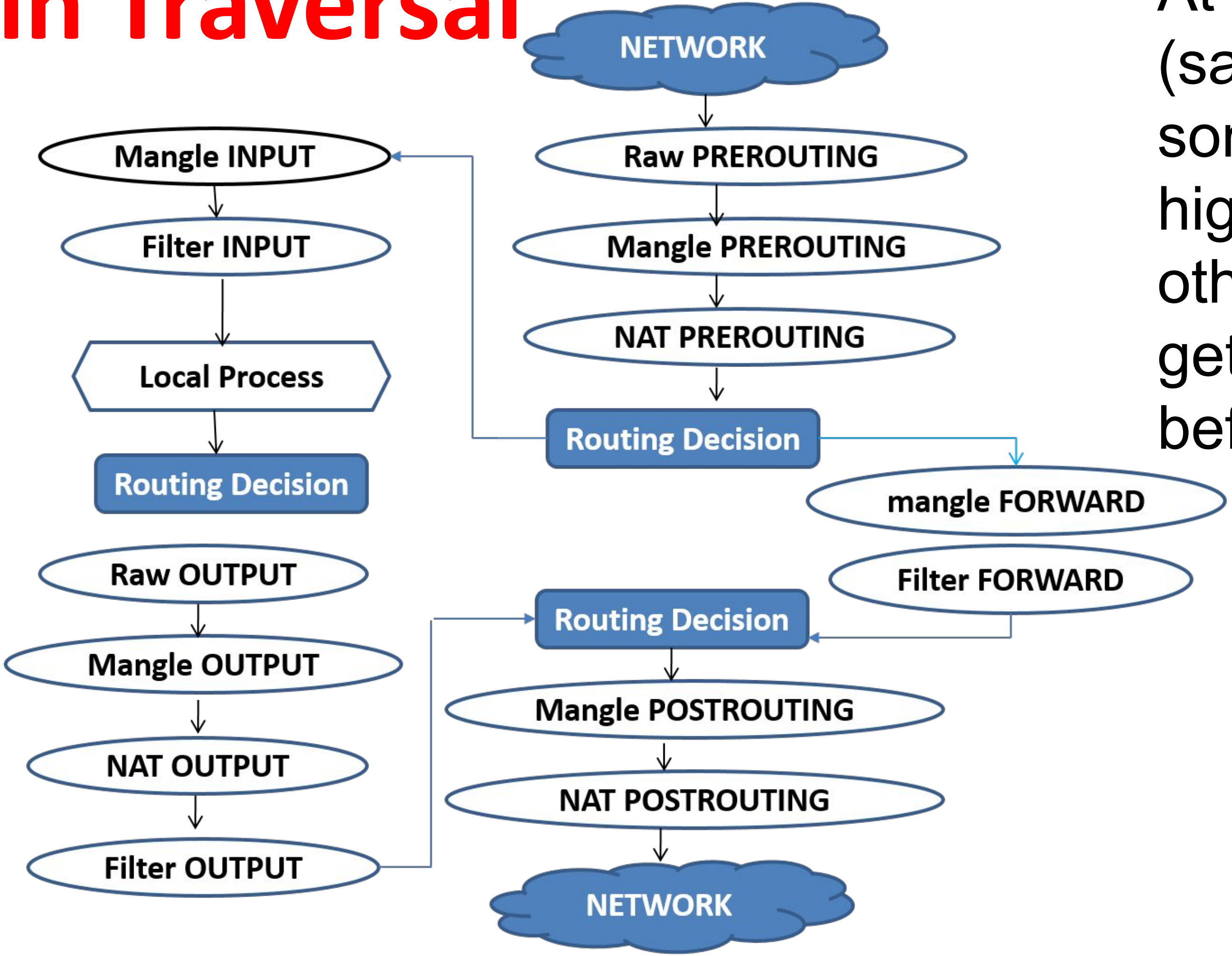
MANGLE TABLE

- INPUT CHAIN
- OUTPUT CHAIN
- FORWARD CHAIN
- PREROUTING CHAIN
- POSTROUTING CHAIN

Tables/Chains→	PREROUTING	INPUT	FORWARD	OUTPUT	POSTROUTING
raw	✓			✓	
mangle	✓	✓	✓	✓	✓
nat (DNAT)	✓			✓	
filter		✓	✓	✓	
security		✓	✓	✓	
nat (SNAT)		✓			✓

Not all tables used at every hook
At a hook, tablets are processed in the above order
(top to bottom; e.g raw > mangle > nat)

Chain Traversal



At a given hook (say Pre-routing), some tables have higher priority ove others (e.g. raw gets handled before mangle)

Rules

- Rules have a matching component and a target
  - When matching criteria met, target is executed
  - When matching criteria not met, move to next rule
- Target: accept, drop, queue, return
- Example: iptables –t filter –A OUTPUT –p tcp --dport 80 –j drop
  - Filter table, OUTPUT chain, match: tcp protocol, with destination port as 80, target: drop
  - You cannot access HTTP from the machine

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Circumventing Firewalls: Inside to Outside

University setting:

- Students spending lot of time gaming (external server) an not studying
- Policy: Block traffic to this service
- Suppose the service runs on port 7777
- Firewall rule in the university

Policy	Src.addr	Src.port	Protocol	Dst.addr	Dst.port
Deny	*	*	UDP	*	7777

- Gaming server losing traffic. How can they get around this?

Solution

- Move service to port 53 (DNS)
  - There is nothing binding a port to a service (arose out of convenience in locating services)
  - Client / server need to agree on the ports
- Can the university deny traffic of this port?
  - No since legitimate DNS traffic will also be dropped

Twist to the problem

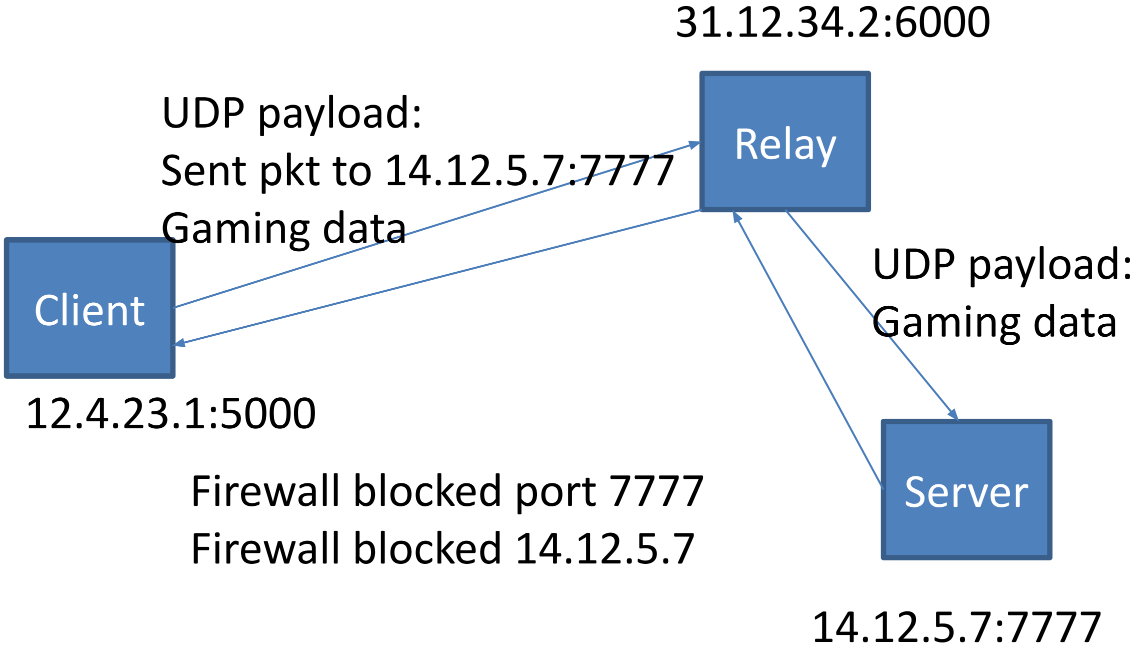
- What if the gaming server not interested in changing port? How can a student still access the service?

(or)

- What if the university blocked the IP address of the gaming server?

Relay based Solution

- Use a relay
- Firewall will allow relay traffic
  - If it is blocked, moved to another relay



Generic Solution: Tunneling

- Allows a foreign protocol to run over a network that does not support it
  - E.g. IPv6 over IPv4 networks
- Based on encapsulation (encapsulate one protocol inside another)
  - Previous example: UDP within UDP
  - Another example: IP within SMTP
    - Use an IP packet as an email attachment;
    - End point decapsulates and acts on it
- Inner protocol cannot bypass firewall; Outer protocol can bypass

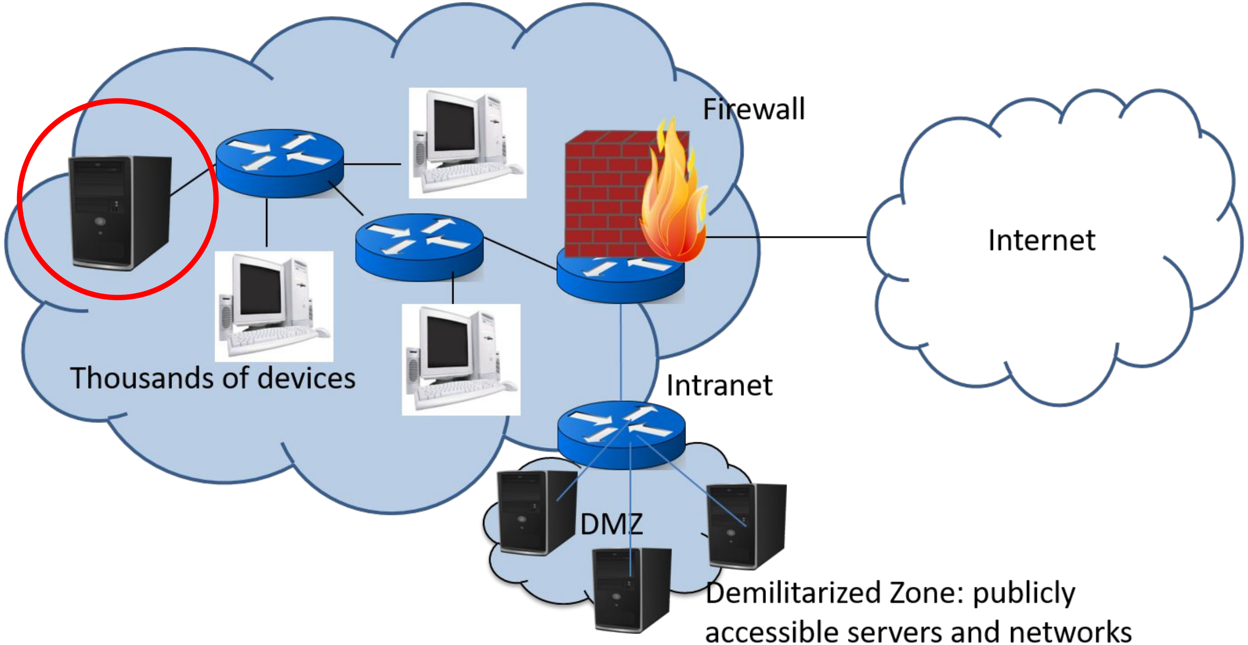
Circumventing Firewalls: Outside to Inside

How can an outside attacker sneak in?

- Figure out some flaw in the firewall
- Need some insider client support
- Not so easy!

Outside to Inside: Allowing Valid Users

- Firewall does not allow outsiders to access machines in intranet
- How to provide access for a genuine employee who is traveling?

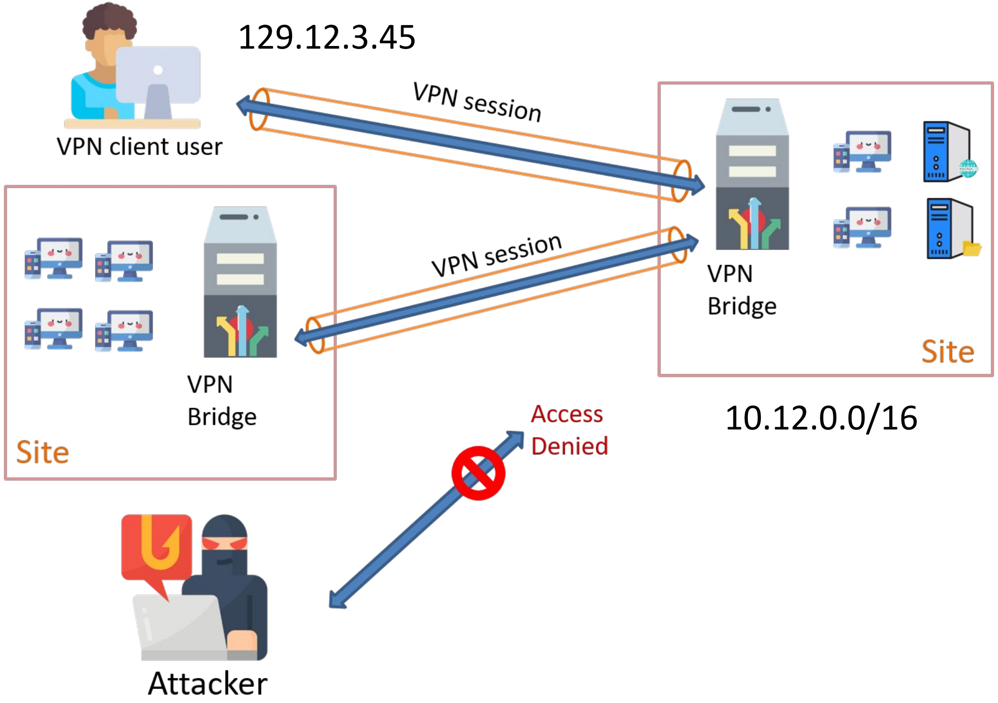

Firewall
Internet
Thousands of devices
Intranet
DMZ
Demilitarized Zone: publicly accessible servers and networks

Virtual Private Networks (VPNs)

- Based on Tunneling
  - VPN server acts as a relay
  - Outer header is directed to VPN server
  - Inner header appears as if VPN client is in local LAN
- Authentication, confidentiality, integrity handled by the tunnel

Inner header src: 10.12.11.7; dst: Local service

Outer header src: 129.12.3.45; dst: VPN server



Summary

- Firewalls provide perimeter security but are not fool proof
- Three types of firewalls: stateless, stateful and application gateway
- Implementation in Linux
  - netfilter hooks (kernel space) and iptables at user space
- Tunneling can circumvent firewalls for illegitimate (gaming) and legitimate use (VPNs)