Chair of Network Architectures and Services
Department of Informatics
Technical University of Munich

Network Security (NetSec)

IN2101 – WS 16/17

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Chapter 3: Firewalls and Security Policies

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Spoofing Protection

Common Errors

- Shadowing
- What Firewalls can’t do

Bastion Hosts

Firewall Architectures

- Simple Packet Filter Architecture
- Dual-Homed Host Architecture
- Screened Host Architecture
- Screened Subnet Architecture – DMZ

- Definition: Security Policy

  "*A security policy, a specific statement of what is and is not allowed, defines the system's security.*" [Bishop03]

- Definition: Security Mechanisms

  "*Security Mechanisms enforce the policies; their goal is to ensure that the system never enters a disallowed state.*" [Bishop03]

- Examples of Security Mechanisms:
  - IPsec gateways, firewalls, SSL, ...

- A system is secure if, started in an allowed state, always stays in states that are allowed.

- The policy defines security, the security mechanisms enforce it.

The 3 Security Components

- Requirements
  - Define security goals
  - , , , , ,
  - “*What do we want?*”
- Policy
  - Rules to implement the requirements
  - “*How to get there?*”
- Mechanisms
  - Enforce the policy

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The 3 Security Components

- Requirements
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  - Data Integrity, Confidentiality, Availability, Authenticity, Accountability, Controlled Access
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The 3 Security Components

- A network admin reports:

  "*Our management wants to ensure that, because of a recent incident, the originators of all internal eMails must now be clearly identifiable. I generated X.509 certificates for all employees and set up their mail clients to always sign their outgoing mails. Unsigned eMails are now dropped by default*"

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- Security Policy:
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- Security Mechanisms:
  X.509 certificates + signatures, dropping of unsigned eMails by mailserver

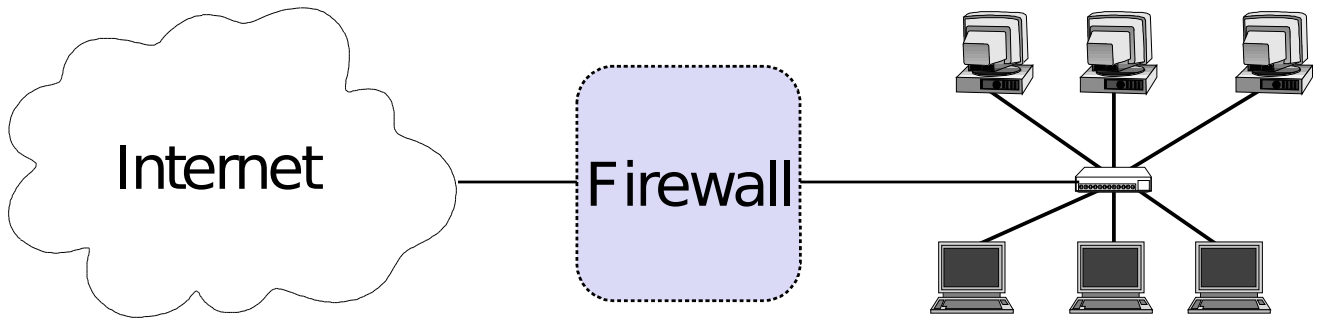
Chapter 3: Firewalls and Security Policies

A closer look at policy-heavy security mechanisms

Network Firewalls

Network Firewalls

- Network Firewalls



- Do not confuse with host-based firewalls!

The Story of Firewalls

- Building construction
  - Keep a fire from spreading from one part of the building to another

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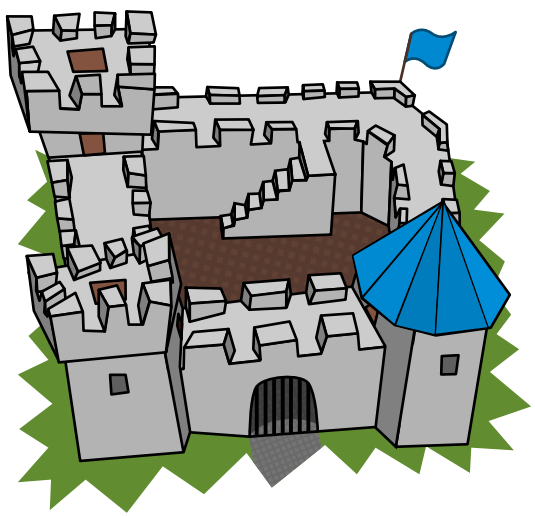
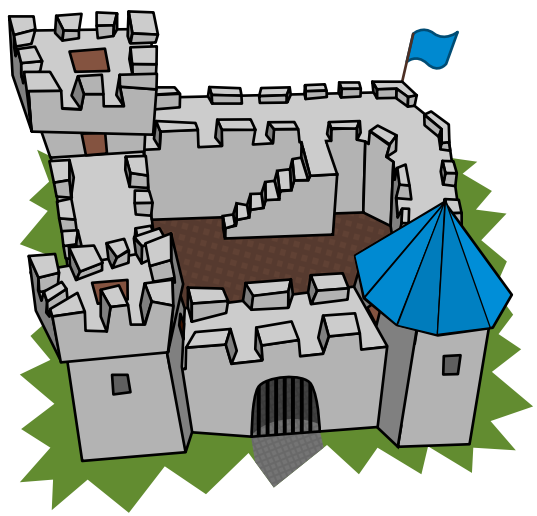


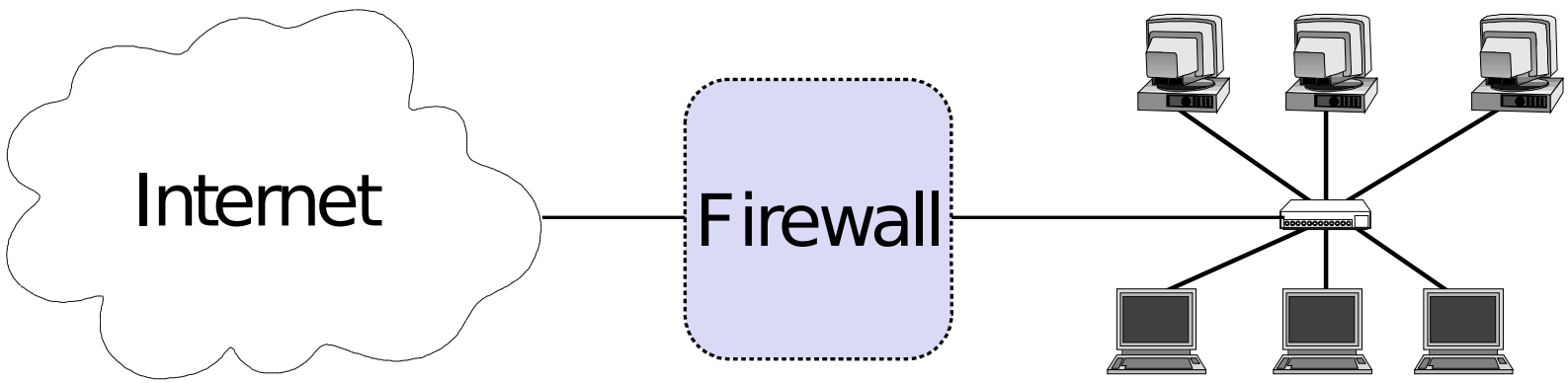
The Story of Firewalls

- Building construction
  - Keep a fire from spreading from one part of the building to another
- Network: Better compared to a moat of a medieval castle
  - Restricts people to enter at one carefully controlled point
  - Prevents attackers from getting close to other defenses
  - Restricts people to leave at one carefully controlled point

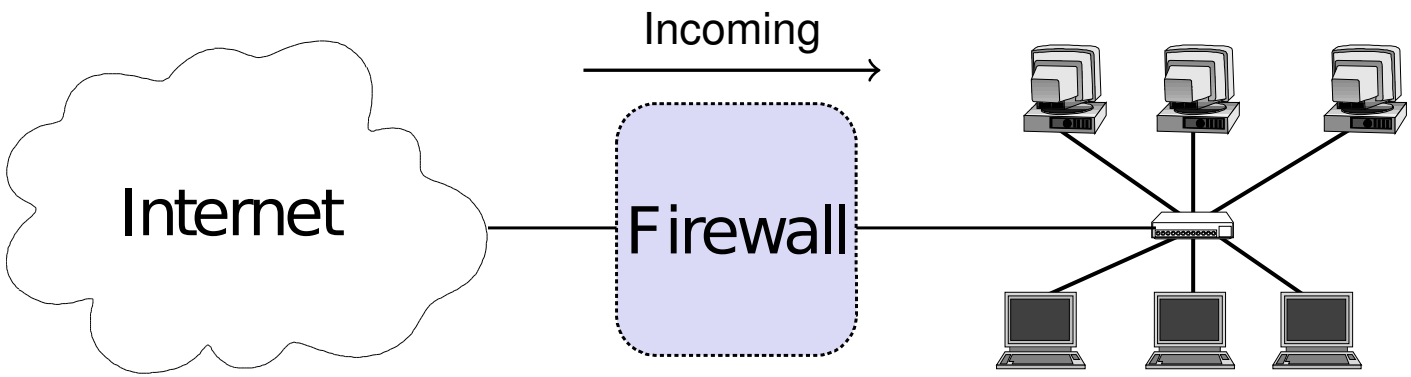


Placing Firewalls

- Controlled Access at the network level
- Install where a protected subnetwork is connected to a less trusted network
- If not specified otherwise, we assume
  - Firewall is placed between Internet and local network



Incoming and Outgoing Packets



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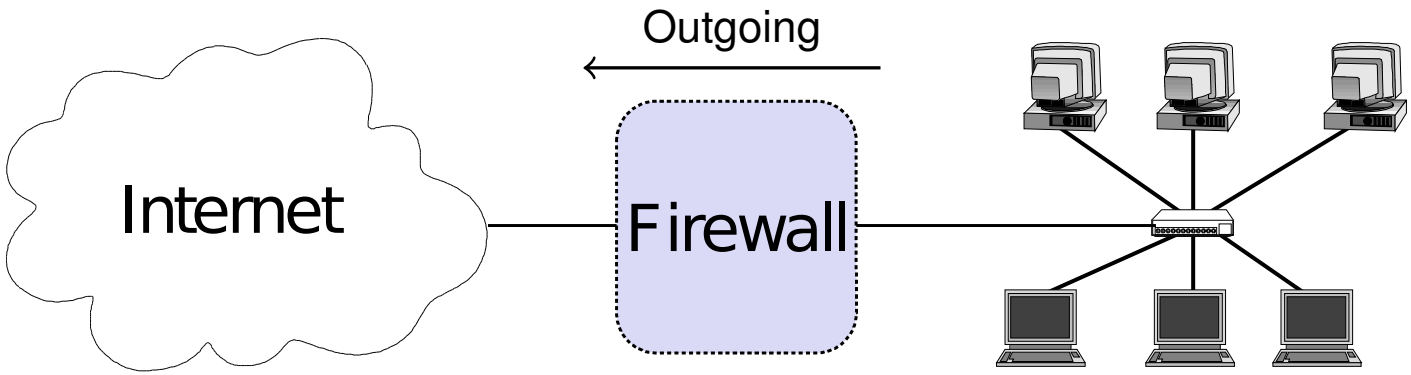

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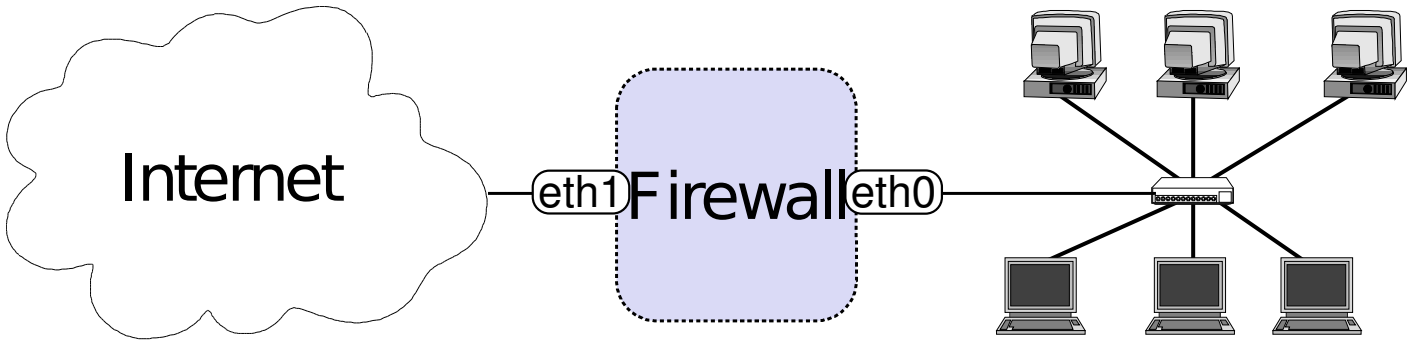

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  - On each interface, there are incoming and outgoing packets

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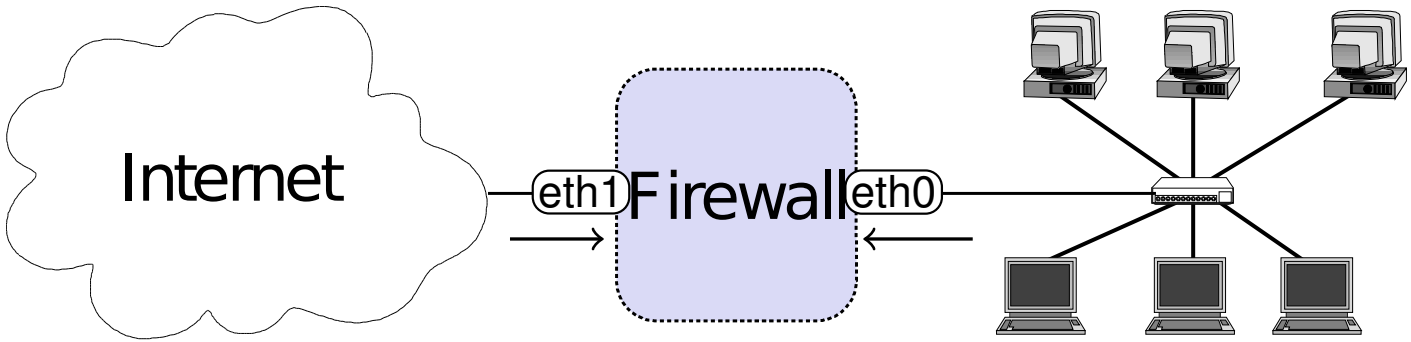

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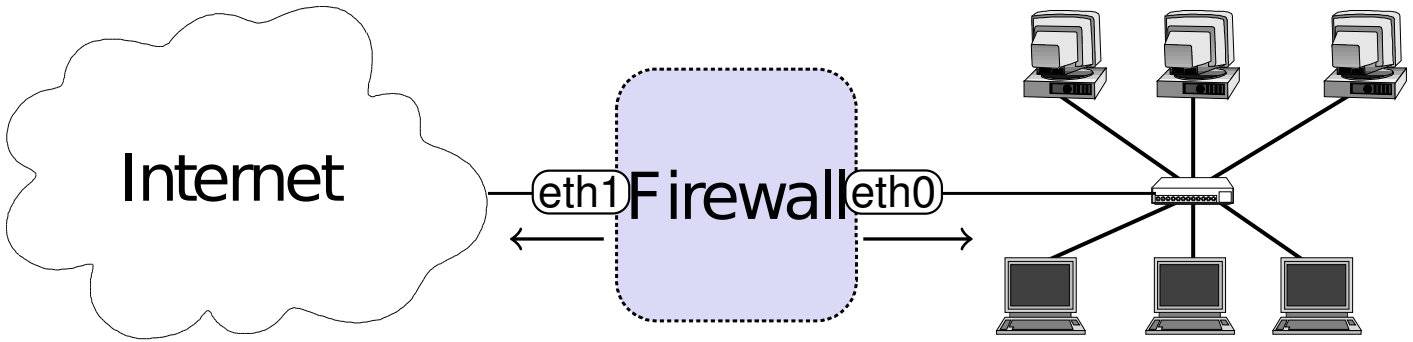

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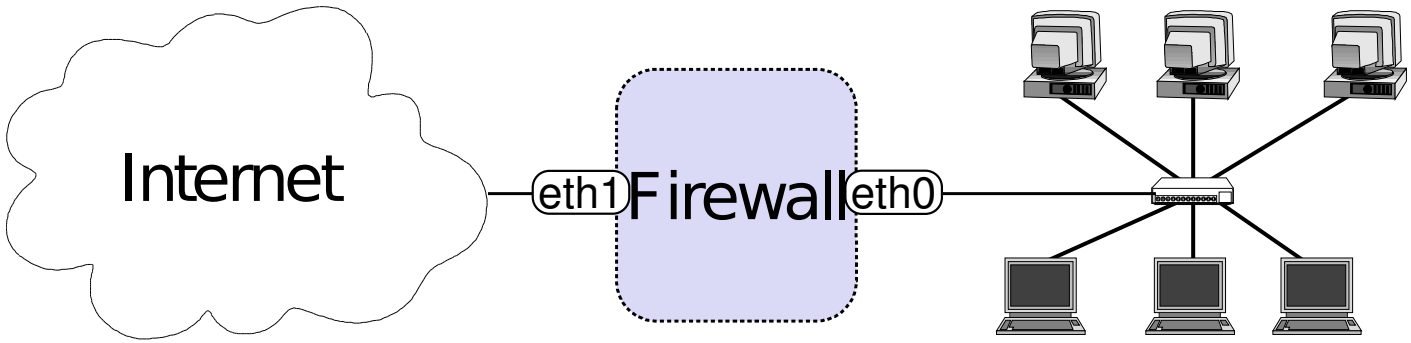

- For convenience:

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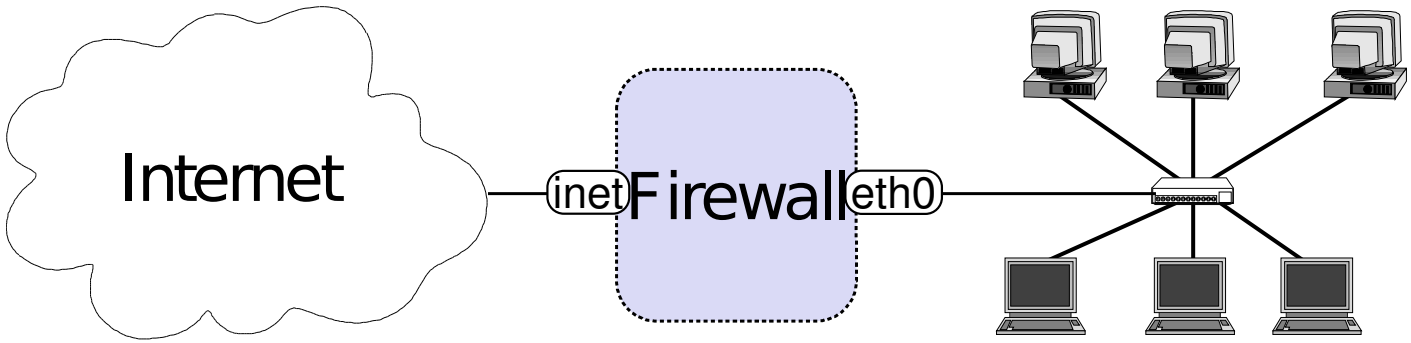

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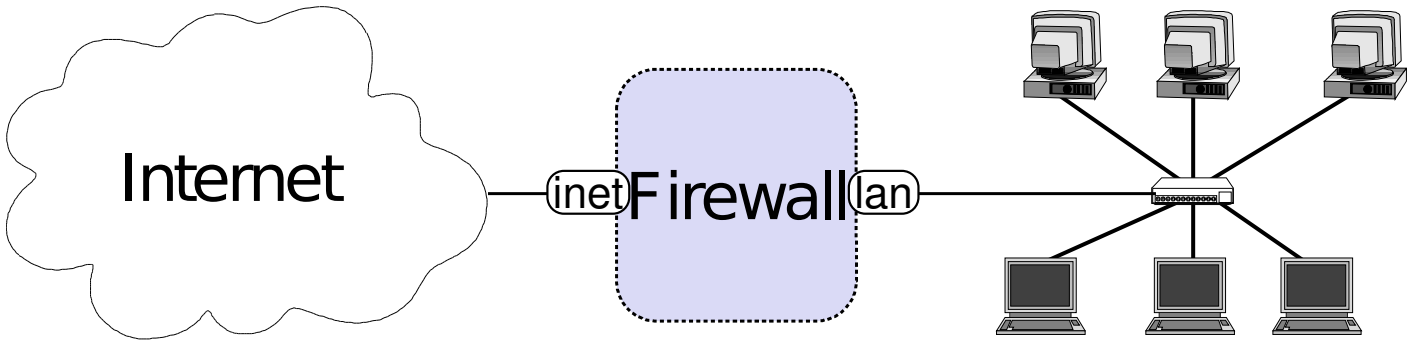

- For convenience:
- `# ip link set eth1 name inet`
- `# ip link set eth0 name lan`

What does a Firewall do?

- By default: nothing!

What does a Firewall do?

- By default: nothing!
- Needs to be configured.

Strategies

- Whitelisting
  - Default deny strategy: Everything not explicitly permitted is denied
- Blacklisting
  - Default permit strategy: Everything not explicitly forbidden is permitted

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- Best Practice: Whitelisting

Example: Strict Whitelisting

Rule	Iface	Src IP	Dst IP	Protocol	Src Port	Dst Port	State	Action
A	lan	192.168.0.0/16	0.0.0.0/0	TCP	> 1023	80	New,Est.	Accept
B	inet	0.0.0.0/0	192.168.0.0/16	TCP	80	> 1023	Est.	Accept
C	*	0.0.0.0/0	0.0.0.0/0	*	*	*	*	Drop

- Policy: Allow outgoing HTTP (TCP port 80), deny the rest
- LAN can initiate outgoing HTTP connections
  - Example: SYN
- The Internet may respond to established connections
  - Example: SYN,ACK
- LAN may use established connections
  - Example: ACK, HTTP GET / HTTP/1.0
- Everything else is prohibited
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Configuring Firewalls

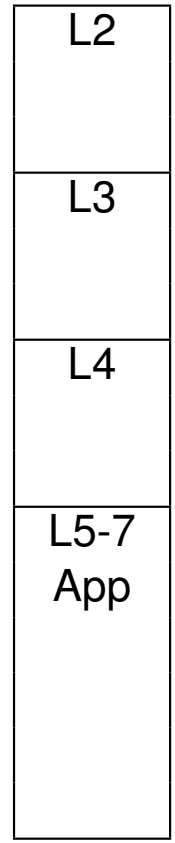
- A firewall is configured by a ruleset
  - Actually: rulelist
- For every packet, the ruleset is processed sequentially until a matching rule is found
- A rule consists of
  - Match condition
  - Action

Rules

- Actions
  - Accept
  - Drop, Reject
  - Log
  - ...
- Match Conditions
  - Incoming interface
  - All l2-l4 packet fields
    - MAC addresses, IP addresses, protocol, ports, flags, ...
  - Stateful matches
    - The firewall tracks connections for you
    - e.g. with the IP-5-tuple
  - Further advanced conditions
    - rate limiting, locally tagged packets, ...

Details on Packet Fields

- Link Layer (l2) – Ethernet
  - EtherType
    - Usually: `0x0800` (IPv4)
    - Handle other EtherTypes: e.g. Drop `0x86DD` (IPv6)
  - Ethernet MAC Address
    - Easily spoofable!
    - `# ifconfig eth0 hw ether de:ad:be:ef:de:ad`
- Network Layer (l3) – IPv4
  - IP addresses
  - Transport protocol
    - TCP, UDP, ICMP, ...
  - Flags: IP fragment
  - Options: E.g. source routing
    - Please drop source routing!



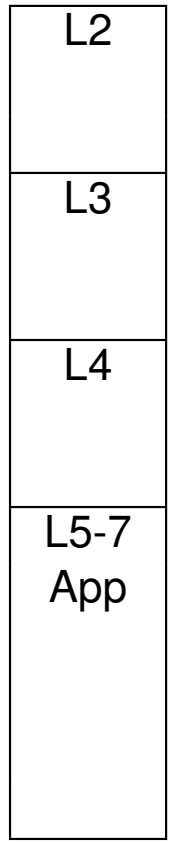
Details on Packet Fields

- Transport Layer (l4) – TCP/UDP
  - Ports
    - Determine the sending / receiving application.
    - Limited degree of confidence
    - Well-Known Ports (0-1023):

      E.g. HTTP (80), DNS (53), HTTPS (443).
    - Registered Ports (1024-49151)

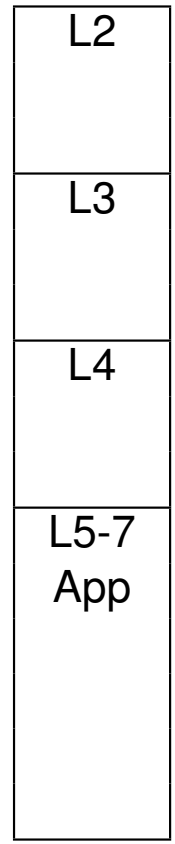
      E.g. IRC (6667), BitTorrent tracker (6969), ...
    - Ephemeral Ports (49152-65535):

      ports meant to be used temporarily by clients.
  - Flags
    - ACK: set in every segment of a connection but the very first
    - SYN: only set in the first two segments
    - RST: ungraceful close of a connection



Details on Packet Fields

- Application Protocol (l5-7)
  - Deep Packet Inspection
  - usually not done by firewalls
  - easier to realize in proxy systems



Stateful Matching

- Arriving packets may generate state in the firewall.
- Connection tracking with the IP-5-tuple
  - (Src IP, Dst IP, Proto, Src Port, Dst Port)

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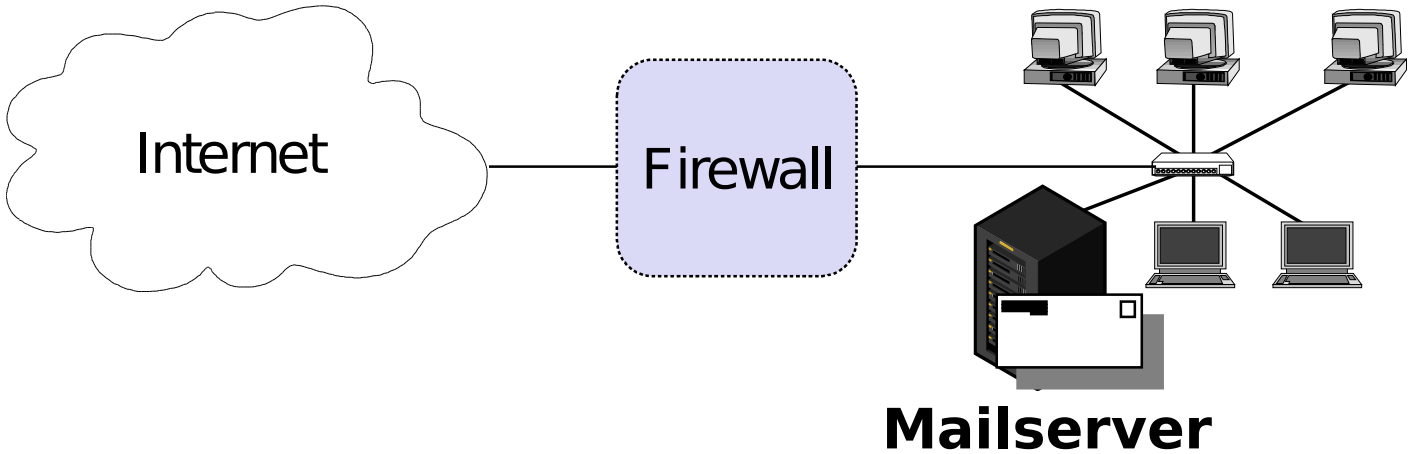
  - Example: Attacker sends spoofed DNS replies in the hope that victim might accept one as an answer to a previous DNS query.

Example: LAN with Mail Server



- Security policy
  - Incoming and outgoing email should be the only allowed traffic into and out of a protected network
  - Email is SMTP, TCP port 25
  - Anyone in the internal network can send out emails to arbitrary mailservers in the Internet
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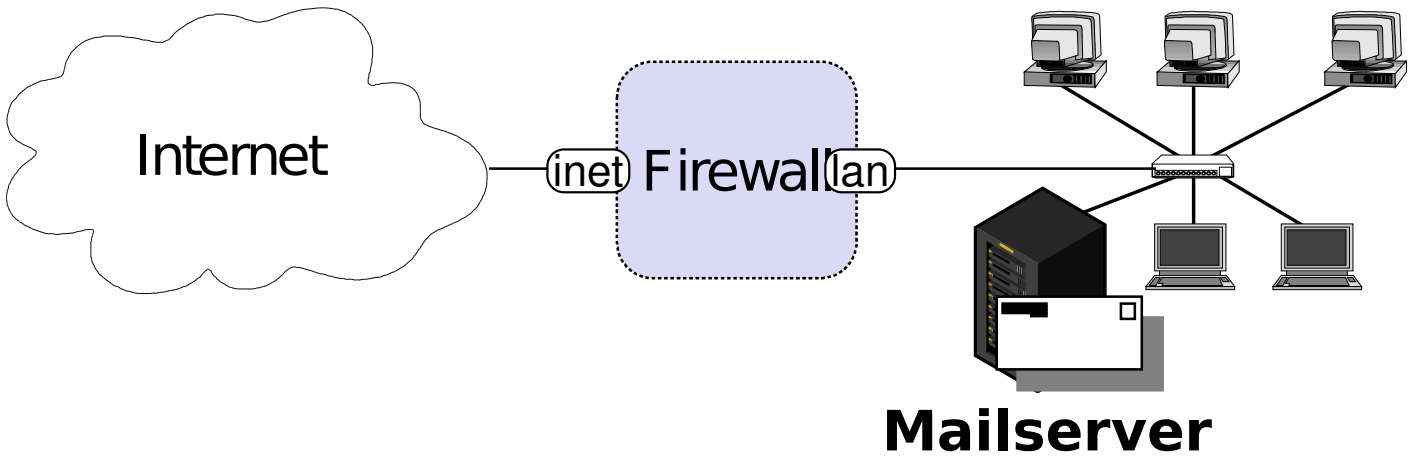

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D	*	*	*	*	*	*	*	Drop

- Rule A allows new incoming SMTP (TCP port 25) connections to establish a connection with the internal Mailserver
- Rule B allows establishing SMTP connection from the internal network to the Internet
- Rule C allows all established connections. Only with rule A and B, a connection can be in the ESTABLISHED state.
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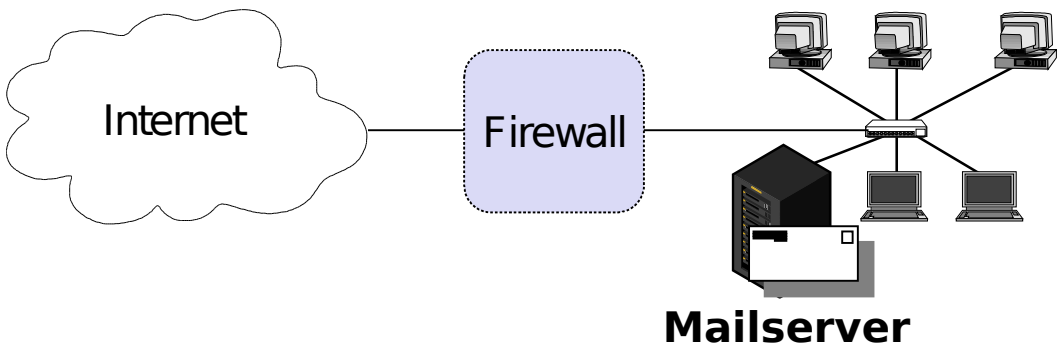
- Any difference? No, only TCP can get into Est. state!

Example: LAN with Mail Server
Discussion

- Can we do better?
  - Internet hosts can establish connections to the Mailserver
- Can we prevent his?



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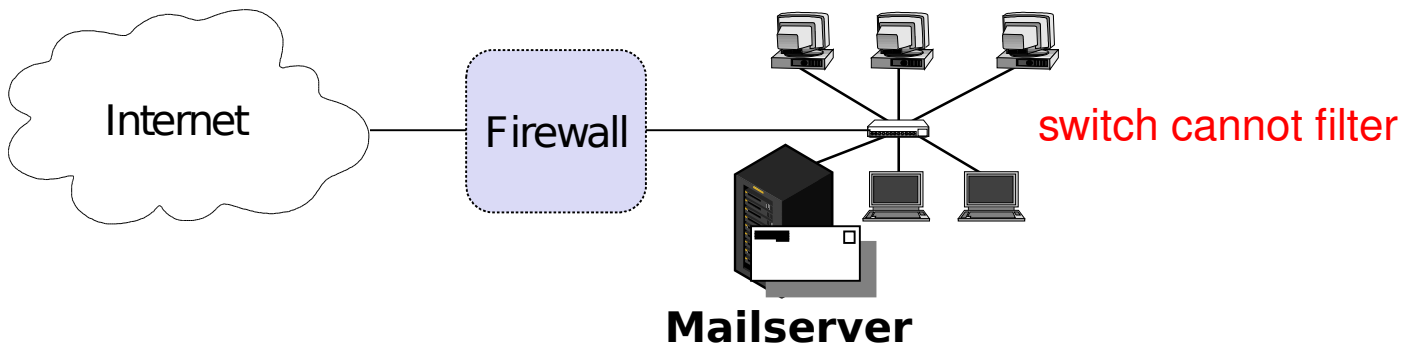

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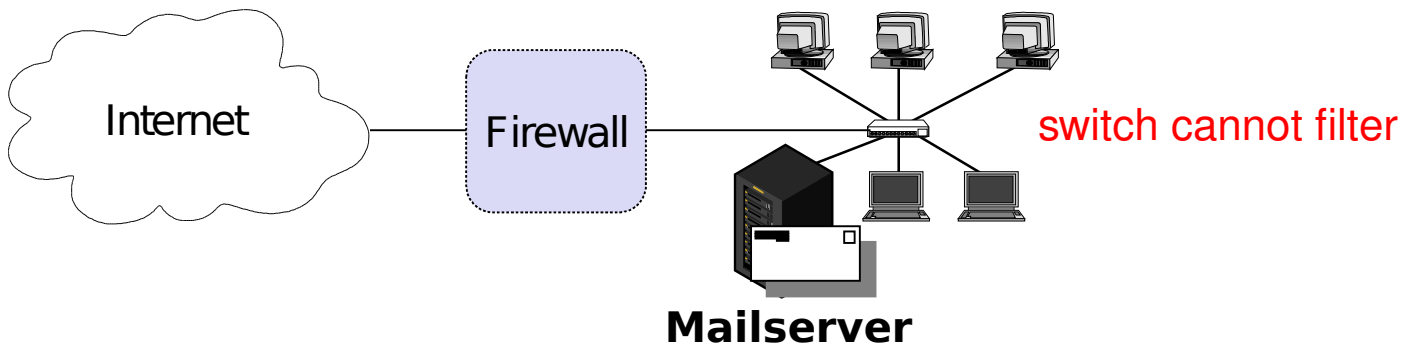

- This subverts the security policy
- Simple fix 1: Check the security requirements, update the policy
- Simple fix 2: Replace the internal switch by a second firewall

Example: LAN with Mail Server
Possible Weaknesses

- In the range of the well-known ports, is Mailserver on TCP dest. port 25 (incoming) the only entity which can exchange traffic with the Internet?
- Assume we are `tcpdump`ing on the firewall.

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  - Now, for `shadymail.example`, using source port 25, the internal host is reachable on the well-known port 25!
  - Fix: make sure that only source ports $>$ 1023 are allowed to establish a connection

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Example: LAN with Mail Server
Tuning

- Firewall rules are matched sequentially
- Few packets will establish a new connection
- Many packets will use an established connection
- Move rule C to the front
- A connection can only be in ESTABLISHED state by rule A and B, the transformation preserves the semantics

Rule	Iface	Src IP	Dst IP	Protocol	Src Port	Dst Port	State	Action
C	*	*	*	*	*	*	Est.	Accept
A	inet	external	mailserver	TCP	> 1023	25	New	Accept
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D	*	*	*	*	*	*	*	Drop

Example: LAN with Mail Server
Best Practice: Put the ESTABLISHED rule first

- Performance
  - Our firewall (September 2014)
  - $>$ 15 billion packets, 19+ Terabyte data since the last reboot
  - $>$ 95% of all packets match the ESTABLISHED rule
- Management
  - First rule: “enable stateful matching”
  - All following rules: Access control list

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- Many network boxes have stateless firewall features embedded
  - Router access lists
  - Some switches
  - ...

Stateful vs. Stateless Firewalls

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- Hardware is cheap

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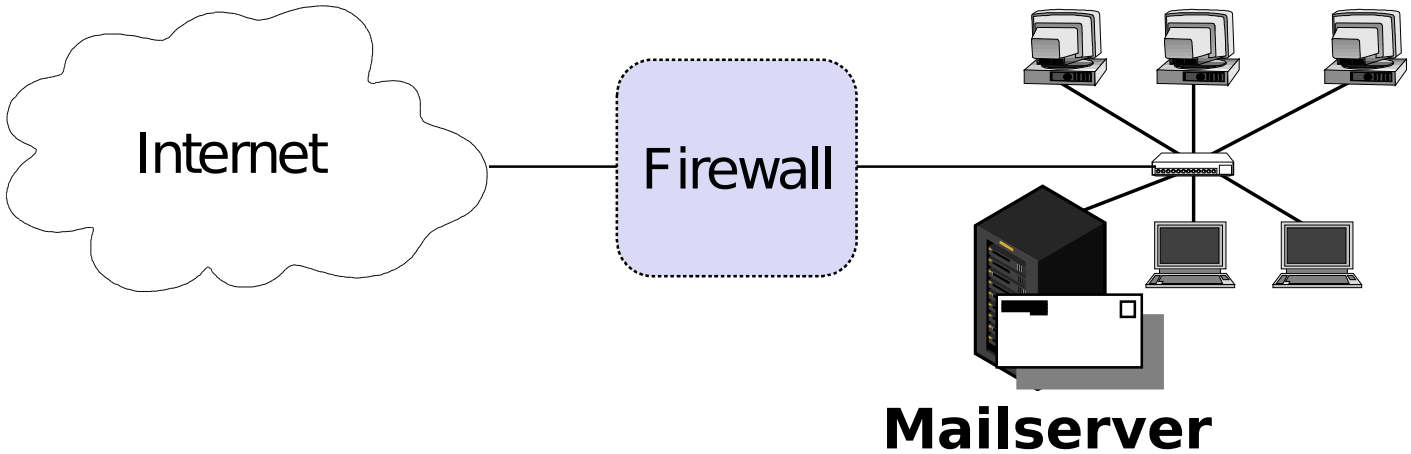

- Security policy
  - Incoming and outgoing email should be the only allowed traffic into and out of a protected network
  - Email is SMTP, TCP port 25
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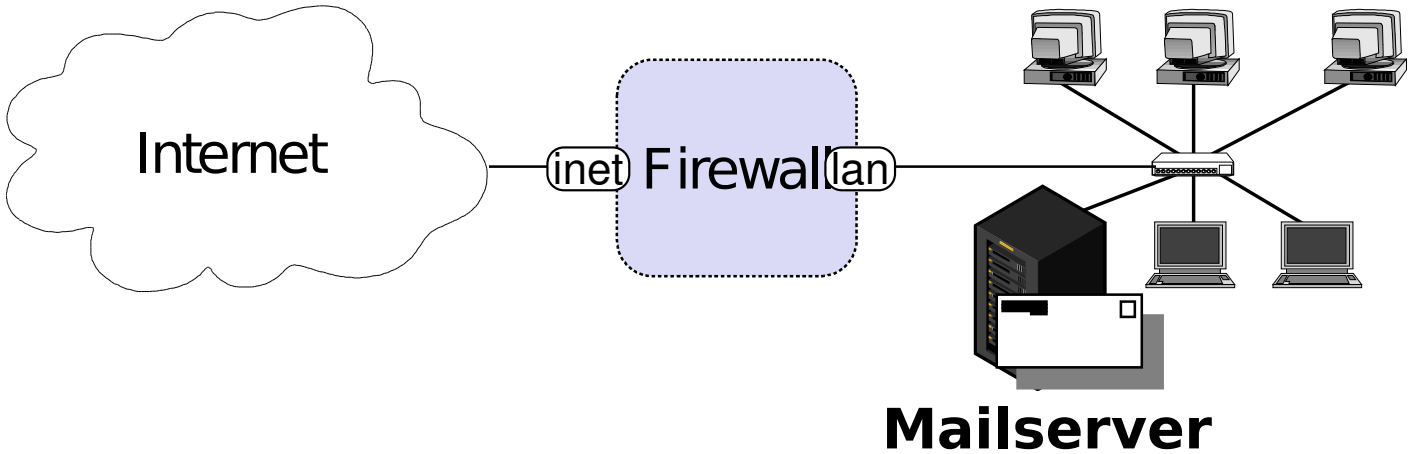

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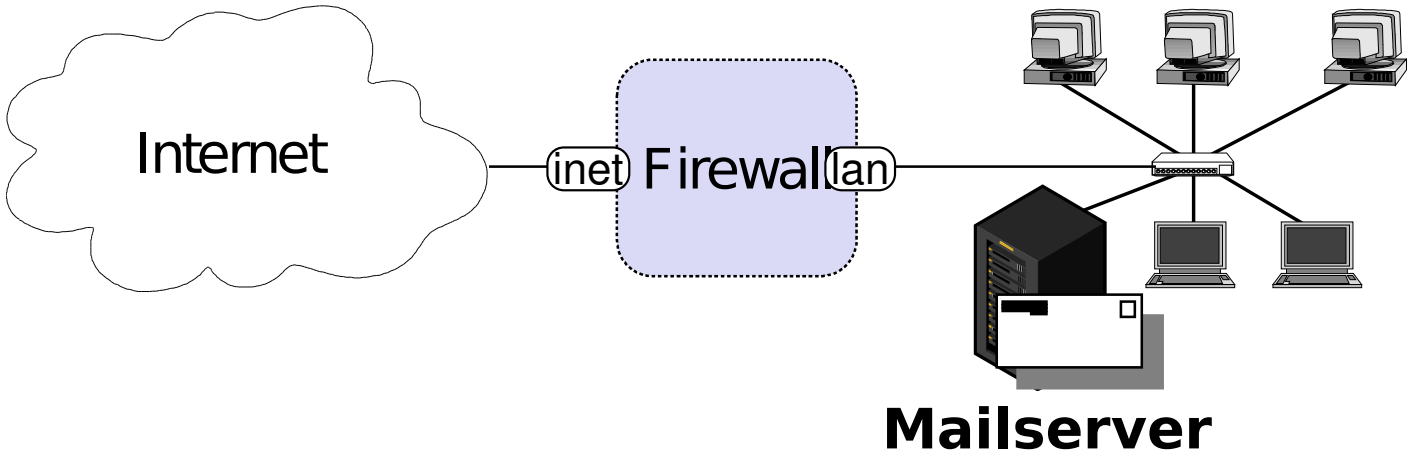

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B_1	lan	internal	external	TCP	*	25		Accept
B_2	inet	external	internal	TCP	*	$>$ 1023		Accept
C	*	*	*	*	*	*		Drop

- Rule A_1 allows incoming email to enter the network.
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Example: LAN with Mail Server (Stateless)
Discussion

- Packets with spoofed IP addresses
  - Inbound packets must have an external source address
    Rules A_1 and B_2
    $\longrightarrow$ successfully blocked
  - Same for outbound packets; Rules A_2 and B_1
- Telnet traffic
  - telnet server: TCP port 23
  - Allowed inbound traffic must be to port 25 or port $>$ 1023
    $\longrightarrow$ incoming packets to initiate telnet connection blocked
  - Same for outgoing telnet connections

Example: LAN with Mail Server (Stateless)
Discussion – A possible attack

- Ruleset does not block the X11-protocol for the Mailserver
  - X11-server listens at port 6000, clients use port numbers > 1023
  - X11-protocol allows reading/manipulating the display and keystrokes
  - Incoming X11-request is not blocked (Rule B_2)
  - neither is any answer (Rule A_2)

Example: LAN with Mail Server (Stateless)
Fix # 1

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B_1	lan	internal	external	TCP	> 1023	25		Accept
B_2	inet	external	internal	TCP	25	> 1023		Accept
C	*	*	*	*	*	*		Drop

- Fixing the flaw: include source ports
  - Outbound traffic to ports > 1023 only allowed if the source port is 25 (Rule A_2)
    $\longrightarrow$ traffic from internal X-clients or -servers blocked
  - Same for inbound traffic to ports > 1023 (Rule B_2)
- Fix the attack: use non-standard port 25 for attacking X-client
  - Firewall will let this traffic pass

Example: LAN with Mail Server (Stateless)
Fix # 2

Rule	Iface	Src IP	Dst IP	Protocol	Src Port	Dst Port	Ack	Action
A_1	inet	external	mailserver	TCP	> 1023	25	*	Accept
A_2	lan	mailserver	external	TCP	25	> 1023	Yes	Accept
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B_2	inet	external	internal	TCP	25	> 1023	Yes	Accept
C	*	*	*	*	*	*	*	Drop

- Checking whether the TCP ACK flag is set
- ACK flag not set is required for establishing new connection
  - C.f. TCP 3-way handshake
- Rule of thumb: ACK $\approx$ not NEW

The ACK flag

- ACK flag: approximate the state of TCP connections
- Assumes that information in packets can be trusted
  - Attacker could send SYN/ACK as initial packet
  - Passes the firewall.
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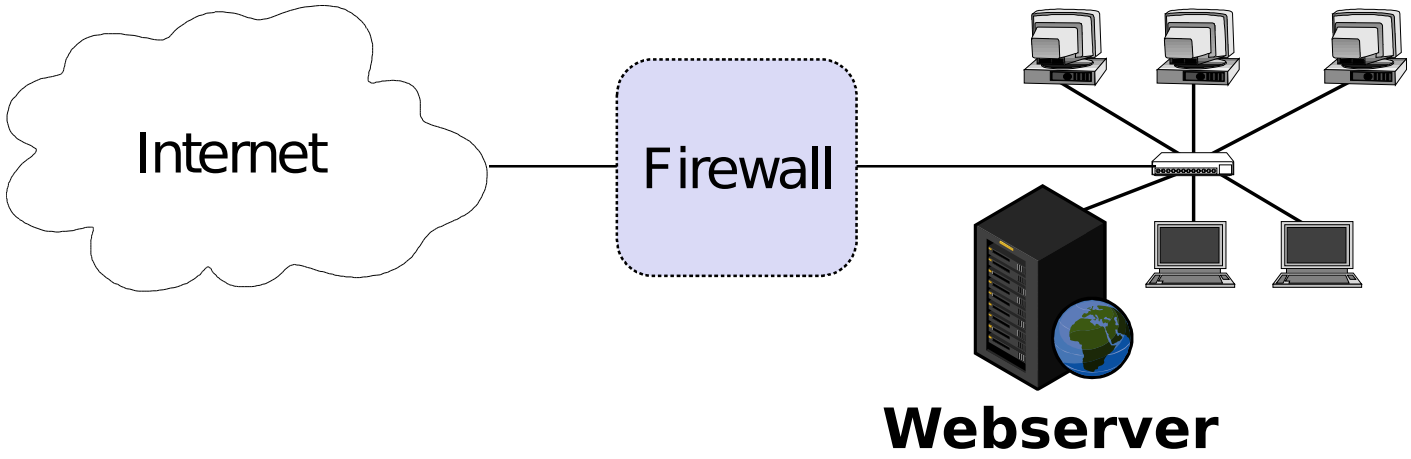
- Protocols such as UDP don’t have state information
  - Not possible to differentiate between initiator and responder.
  - UDP has no ACK field: Always set ACK to *

Example: LAN with Web Server



- Security policy
  - Allow HTTP traffic initiated by external hosts to webserver
  - Allow internal hosts to initiate HTTP and DNS
    - HTTP: TCP port 80
    - DNS: UDP port 53
  - Do not allow other communication, in particular no communication initiated by external hosts to the local hosts other than the webserver.

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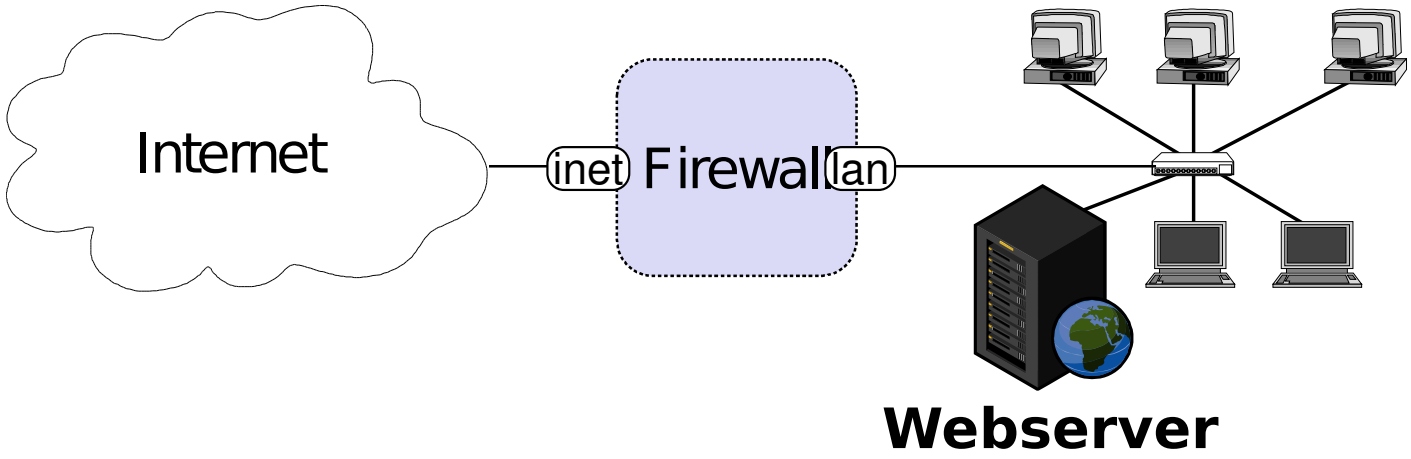

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Stateful Firewall

Rule	Iface	Src IP	Dst IP	Protocol	Src Port	Dst Port	State	Action

- First rule?

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E	*	*	*	*	*	*	*	Drop

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B_1	inet	external	webserver	TCP	> 1023	80	*	Accept
B_2	lan	webserver	external	TCP	80	> 1023	Yes	Accept
C_1	lan	internal	external	TCP	> 1023	80	*	Accept
C_2	inet	external	internal	TCP	80	> 1023	Yes	Accept
D_1	lan	internal	external	UDP	> 1023	53	-	Accept
D_2	inet	external	internal	UDP	53	> 1023	-	Accept

- A first rule comparable to the stateful case? No.
- Allow HTTP traffic initiated by external hosts to webserver?
- Allow internal hosts to initiate HTTP? and DNS?

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D_1	lan	internal	external	UDP	> 1023	53	-	Accept
D_2	inet	external	internal	UDP	53	> 1023	-	Accept
E	*	*	*	*	*	*	*	Drop

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  - Rule of thumb: UNIV $\setminus$ (Your IPs $\cup$ Special Purpose IPs)
- Spoofing must always be filtered close to the source. Why?

Spoofing Protection
Example

- Assume your institution owns 131.159.20.0/24

Rule	Iface	Src IP	Dst IP	Action
A	lan	! 131.159.20.0/24	*	Drop
B	inet	131.159.20.0/24	*	Drop
B	inet	192.168.0.0/16	*	Drop
B	inet	10.0.0.0/8	*	Drop
B	inet	172.16.0.0/12	*	Drop
B	*	*	*	Accept

- There are more addresses you might want to drop [RFC6890]

Automatic Spoofing Protection

- The Linux kernel offers some spoofing protection for free
- `/proc/sys/net/ipv4/conf/all/rp_filter`
- If a packet arrives at interface *i*, the kernel checks
  - Is the source IP of the packet reachable through *i*
  - If not, drop the packet
- Only considers local routing and interface configuration

Common Errors

- How is your firewall management interface reachable?
  - From the Internet? From the complete internal network?
  - Via telenet? Via UPnP?
- What is allowed over the Internet?
  - NetBIOS? NFS? RPC? Telnet?
  - Other ICMP than Unreachable, Fragmentation Needed, TTL Exceeded, Ping?
  - IP header options?
- IPv4 and IPv6?
  - Are the rule sets compliant?
- Outbound rule ANY? (c.f. spoofing)
  - Even private IP ranges or IP ranges that don't belong to you?
- Policy's vs. Firewalls understanding of Inbound and Outbound?
  - If `eth0` is your internal interface and the firewall says inbound on eth0, policy might say outbound.

Shadowing

"refers to the case where all the packets one rule intends to deny (accept) have been accepted (denied) by preceding rules" [fireman06]

Rule	Iface	Src IP	Dst IP	Action
A	*	*	192.168.0.0/16	Accept
B	*	*	192.168.42.0/24	Drop

- Rule B will never match!

Another Example

- No spoofing for the following networks:
  - eth0 $\longleftrightarrow$ 10.0.0.0/16
  - eth1 $\longleftrightarrow$ 10.1.0.0/16
  - eth2 $\longleftrightarrow$ 10.2.0.0/16
- Accessible by all three networks: 10.1.1.1

Rule	Iface	Src IP	Dst IP	Action
A	eth0	! 10.0.0.0/16	*	Drop
B	eth1	! 10.1.0.0/16	*	Drop
C	*	*	10.1.1.1	Accept
D	eth2	! 10.2.0.0/16	*	Drop
E	*	*	*	Drop

- Correct?

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B	eth1	! 10.1.0.0/16	*	Drop
C	*	*	10.1.1.1	Accept
D	eth2	! 10.2.0.0/16	*	Drop
E	*	*	*	Drop

- Correct?
- Anyone at eth2 can send spoofed packets to 10.1.1.1

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B	eth1	! 10.1.0.0/16	*	Drop
C	*	*	10.1.1.1	Accept
D	eth2	! 10.2.0.0/16	*	Drop
E	*	*	*	Drop

- Correct?
- Anyone at eth2 can send spoofed packets to 10.1.1.1
- Rule D is partly shadowed

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- can't protect against connections that don't go through it
- can't protect against completely new threats
- can't fully protect against viruses
- does not perform cryptographic operations, e.g. message authentication
- can't set itself up correctly

Bastion Hosts

- Definition:

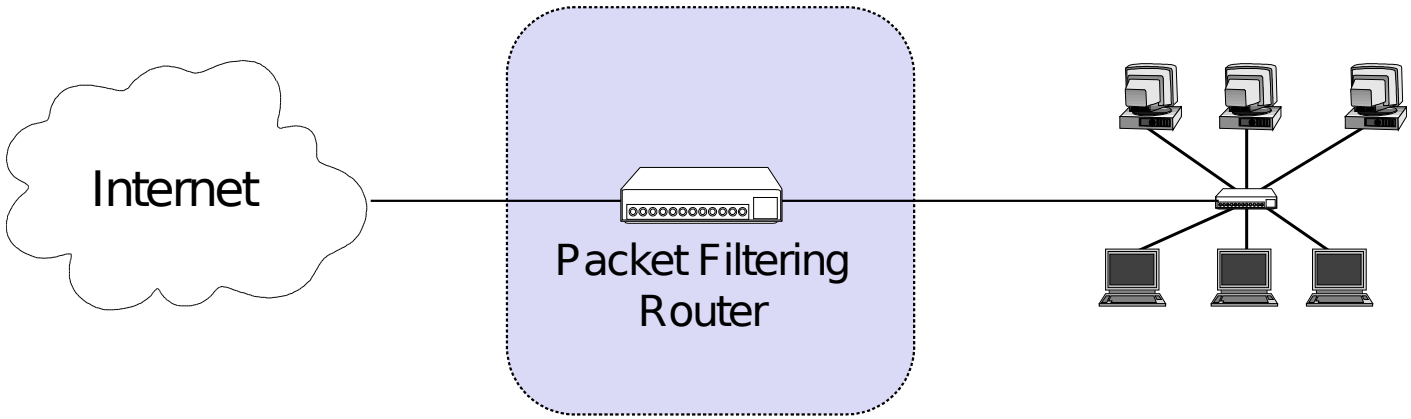
  "*A bastion host is a host that is more exposed to the hosts of an external network than the other hosts of the network it protects.*"

- A bastion host may serve for different purposes:
  - Packet filtering
  - Providing proxy services
  - A combination of both

Securing Bastion Hosts

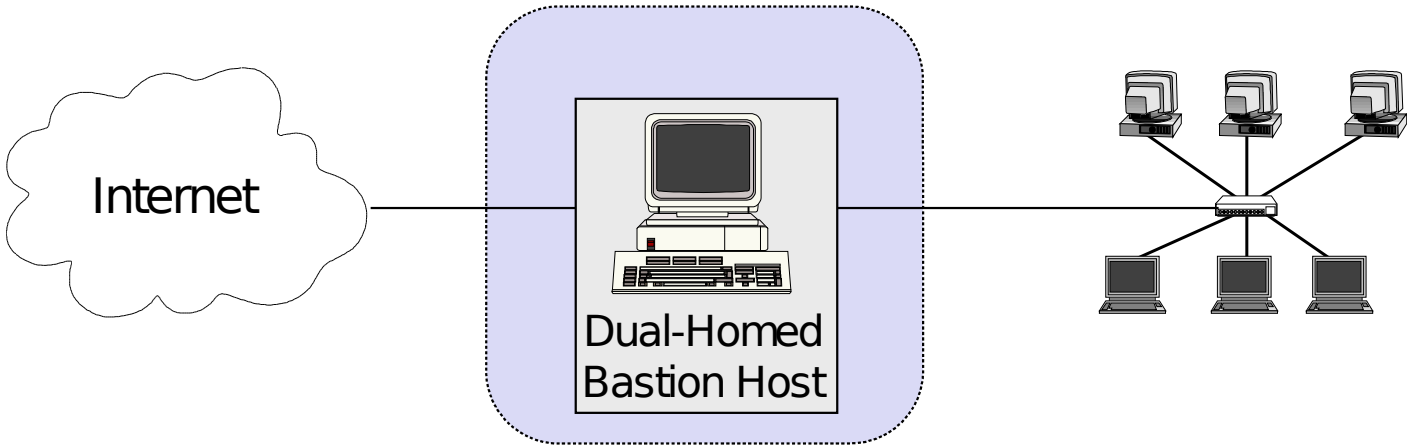
- Keep it simple
- Prepare for the bastion host to be compromised
- Connect in such a way that it cannot sniff internal traffic
- Extensive and tamper-resistant logging
- Reliable hardware configuration and physically secure location
- Disable ssh password login (only public key login)
- Disable user accounts
- Monitor the machine closely (reboots, usage / load patterns, etc.)
- Regular backups

Simple Packet Filter Architecture



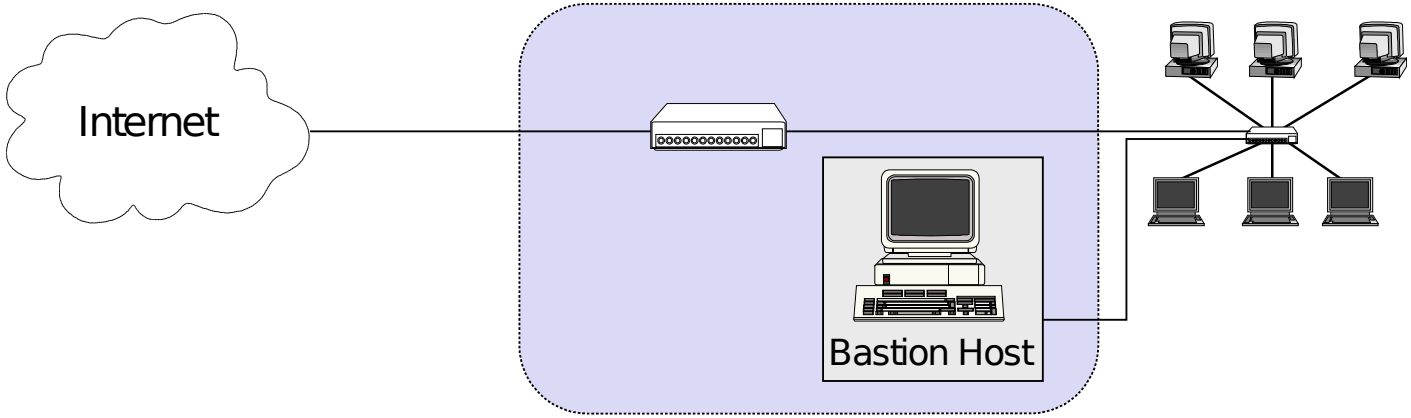
- A packet filtering router or firewall with two interfaces

Dual-Homed Host Architecture



- Dual-Homed: Host is part of two networks (has two NICs)
- Bastion Host is Firewall + Application Proxy
- Drawbacks
  - Bastion Host is bottleneck
  - Compromised Bastion Host is worst-case scenario

Screened Host Architecture



- Packet filter protects network an Bastion Host
- Bastion Host is Proxy (may be accessible from the Internet)
  - Compromised Bastion Host compromises the internal network

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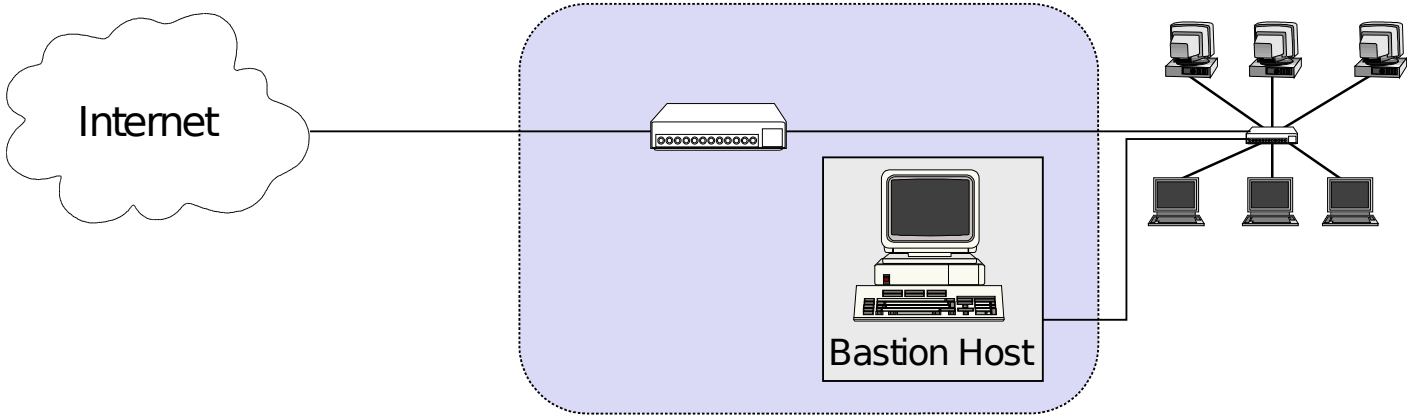
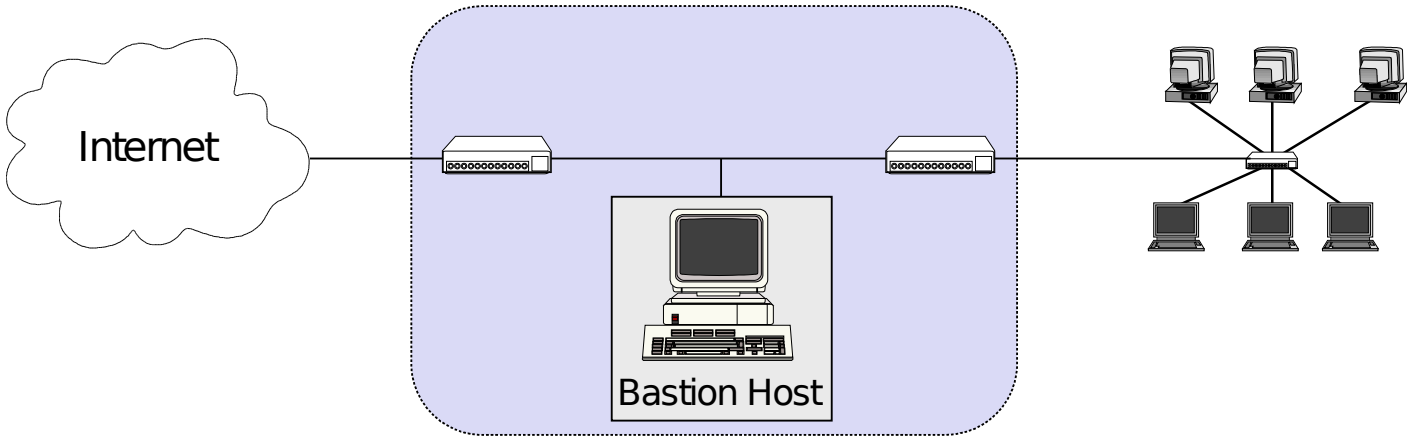


- Packet filter protects network an Bastion Host
- Bastion Host is Proxy (may be accessible from the Internet)
  - Compromised Bastion Host compromises the internal network
- If you have a home server and configured port-forwarding on your router, this is probably your architecture

Screened Subnet Architecture – DMZ



- Demilitarized Zone (DMZ): perimeter network
- Hosts Bastion Host (Proxy) and publicly accessible servers
- Second packet filter in case they are compromised
  $\longrightarrow$ Protection for the internal network
- Requires two firewalls or one firewall with at least 3 NICs

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