Firewalls

Controlling Networks

- motivation
  - harden a network against external attack
  - the more public facing network services you run the greater the risk
  - MINIMIZE ATTACK SURFACE
- one approach: disable services you don't need
  - you may be running some you don't realize
  - sometimes you need to allow trusted remote users in
  - hard to scale
    - you have hundreds or thousands of systems and services
    - different OSs, hardware, etc.

Reducing Complexity

- reduce risk by blocking **outsiders** from accessing network
- put a **firewall** that monitors and controls all traffic to and from the outside
  - single point that can "disable services" for thousands of hosts
  - e.g., if a security threat in a popular software is found

Firewall Security Policy

- effectiveness of firewall relies on the security policy
  - **who** is allowed to talk to **whom**
  - **which** services are allowed to be used
- distinguish between inbound and outbound connections
  - **inbound**: attempts by external users to connect to services on internal machines
  - **outbound**: attempts by internal users to connect to services on external machines
- firewall more like the moat around the castle
  - control access to specific things

Firewall Locations

- between internal LAN and external network
- at gateways of sensitive subnetworks within LAN
  - e.g., payroll's network separated within corporate network
- on end-user machines
  - "personal firewall"
  - runs in OS of each machine
  - can provide "application-specific" rules

Inbound and Outbound

- **threat model** may suggest that inbound connections are riskier
  - internal users are authenticated
    - e.g., by logging into a computer
    - e.g., by having physical access
  - external users can be anyone on the internet
- example security policy
  - internal users can connect to any service
  - external users are restricted
    - **permit** connections to www service on port 80 and 443
    - **deny** connections to printer service port 631

Default Policy

- policy may specify permit and deny for different machines
- but how to treat traffic not mentioned in policy?
  - **default allow**
    - permit external access to services
    - shut off access as problems are seen
  - **default deny**
    - deny everything except specific things needed
    - e.g., ssh, web, etc.
    - add more when users complain
    - audit and approve changes

Default Policy

- which does design principles recommend?
- which notices flaws faster and with less risk?
- balance and consequence of false positives and false negatives
  - always relevant for imperfect binary decision making

Packet Filters

- most basic kind of firewall is a **packet filter**
  - a router with a list of **access control rules**
  - checks each received packet against the rules to decide what to do
    - forward to correct host
    - drop the packet entirely
  - each rule specifies which packets it applies to based on packet's header
    - is stateless, only considers the packet as is
    - use source / dest IP, ports, protocol names to judge
    - use * as a wildcard to match everything

Packet Filters

- stateless
  - cannot examine packet's context
  - e.g., payload information
- filtering rules based on header
  - pattern matching packet header fields
  - e.g, IP addresses, ports
  - e.g., TCP flags

Packet Filters Example

- allow tcp 1.2.3.4:1025 -> 10.0.0.1:80
  - firewall permits any TCP packet if
    - it is from 1.2.3.4
    - it is to 10.0.0.1
    - it is from port 1025
    - it is to port 80
- allow tcp 1.2.3.4:* -> 10.0.0.1:80
  - same as above but any source port okay

Packet Filter Examples

- rules can be ordered
  - first rule that applies decides
- examples
  - second rule inconsequential
    - deny tcp 1.2.3.4:* -> 10.0.0.1:*
    - allow tcp 1.2.3.4:* -> 10.0.0.1:80
  - allows port 80, disallows all other ports
    - allow tcp 1.2.3.4:* -> 10.0.0.1:80
    - deny tcp 1.2.3.4:* -> 10.0.0.1:*
  - deny tcp *:* -> *:*
    - default block everything
    - put this rule last and make everything before exceptions

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Extra features for convenience such as
port ranges, other headers, IP groups

FTP Example

- File Transfer Protocol (FTP)
  - client:2352 -> server:21 “use port 3573”
    - 2352 and 3573 are random ports
  - server:21 -> client:2352 “OK”
  - server:20 -> client:3573 “data...”
- this is a problem for firewalls
  - rules like allowing ports greater than 1023 used
  - but not ideal

Firewall Weakness

- do not prevent application-specific attacks
  - if a web server has a vulnerability, firewall will not block attack string
- no authentication
  - claimed source IP addresses can be spoofed
  - ingress filtering to ensure they are reasonable
    - i.e., list IP addresses for each interface
  - spoofed internal address can be detected
- vulnerable to misconfiguration
  - firewalls can have thousands of filtering rules
  - easy to introduce subtle errors
  - these need to be tested with unit tests like a program
    - e.g., lists to allow and deny and check

Firewall Weakness

- stateless filtering is not enough
  - servers run on well known ports, like 20, 21, 25, 80, 443
  - clients use random ports > 1023
    - these must be opened to allow responses
    - but any user-space network program can listen on these ports
  - allowing all connections above 1023 is insecure
  - must maintain state based on outgoing requests that are allowed to introduce temporary rules

Bastion Host

Bastion Host

- your public presence on the Internet
  - a machine that can be directly accessed
- analogy: lobby of a building
  - visitors may or may not be allowed upstairs
- bastion host must be kept secure
  - devote particular attention

Bastion Principles

- keep it simple
  - any software running can have vulnerabilities
  - only run what is needed
- assume it will be compromised
  - most likely machine to be attacked
  - most likely machine to attack your internal network
  - limit Bastion host's access to machines

Bastion Principles

- disable user accounts
  - normal users should not have accounts that allow them access to bastion host
    - vulnerability to attacker (including services for accounts)
    - harder to detect attacks
    - inadvertent subversion of the host's security by users

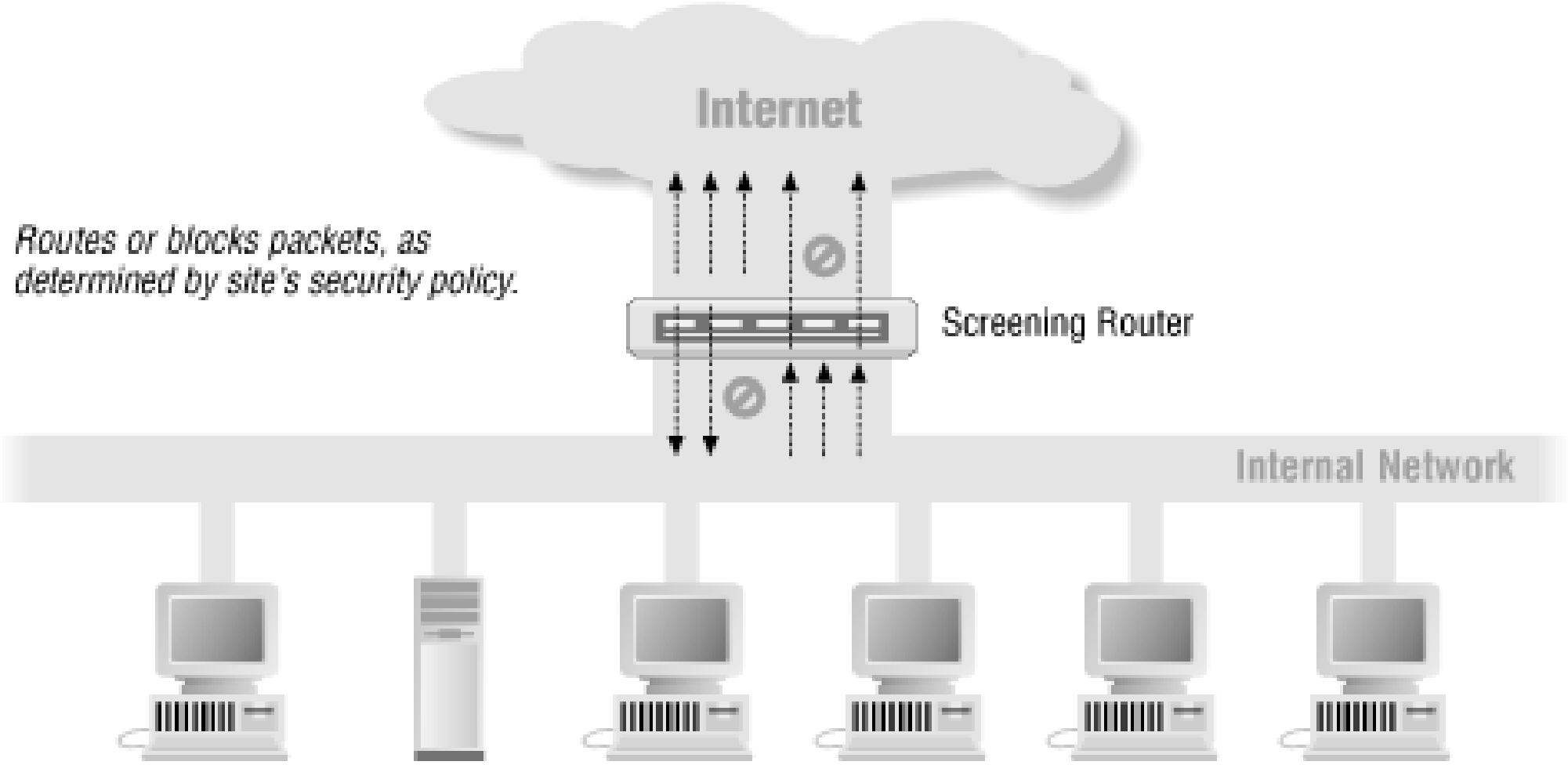
Operating a Bastion

- learn normal usage
  - how many jobs running
  - what CPU and memory usage
  - typical load at different times
- watch for reboots
  - crashes and reboots should be rare
  - should run for months without issue
  - crashes and reboots can be sign of an attack
- do secure backups
  - assume it will be compromised and needs to be rebuilt
  - can find evidence of attack by looking at current and old state
  - keep historical versions

Firewall Layouts

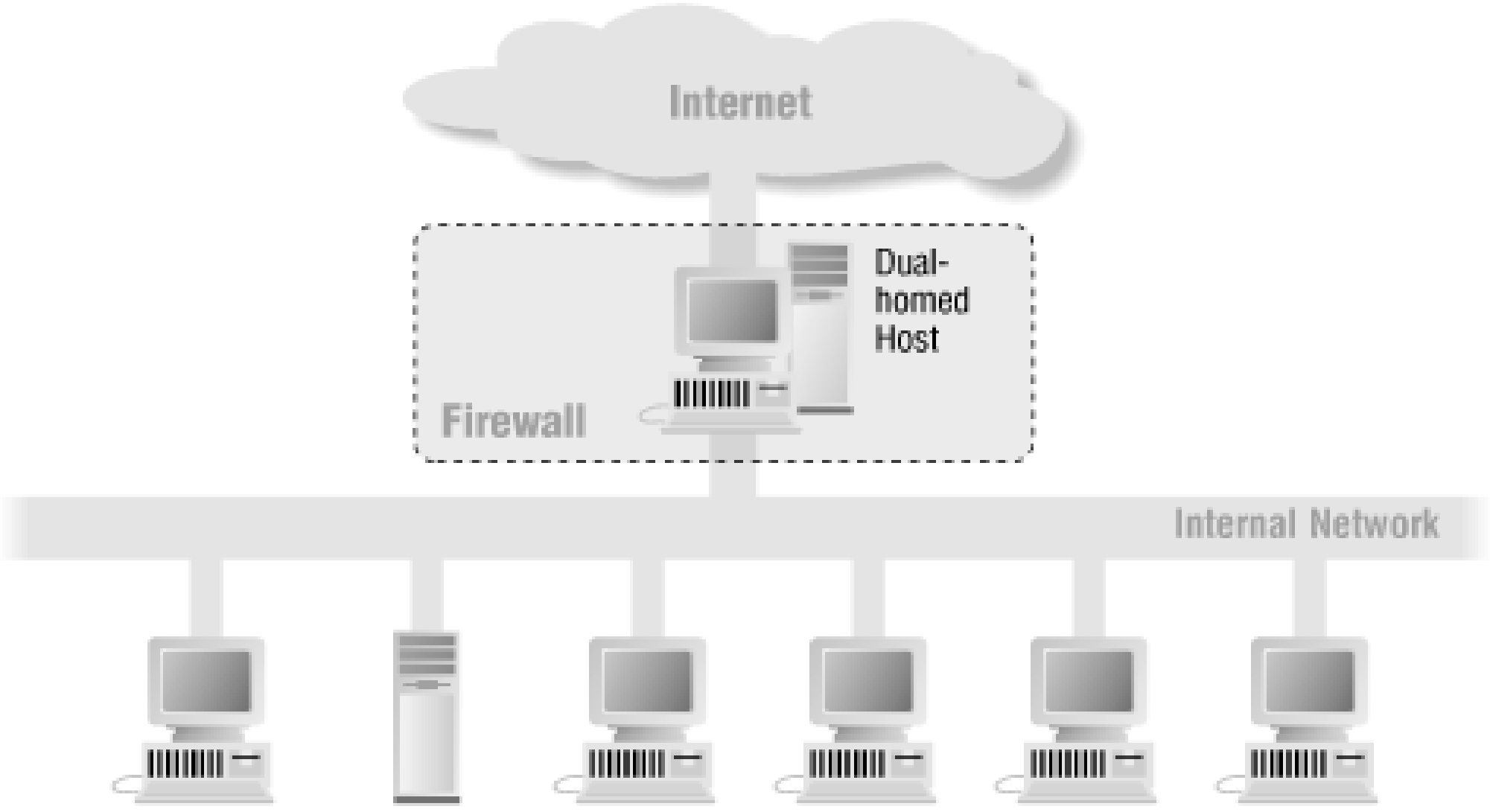
Screening Router

- a router between Internet and machines
- packet filter rules to arbitrate allowed traffic
- low-cost system
  - need a router anyways
- no defense in depth
  - compromised router is a compromised network
- probably what you have at home


Internet
Routes or blocks packets, as determined by site's security policy.
Screening Router
Internal Network

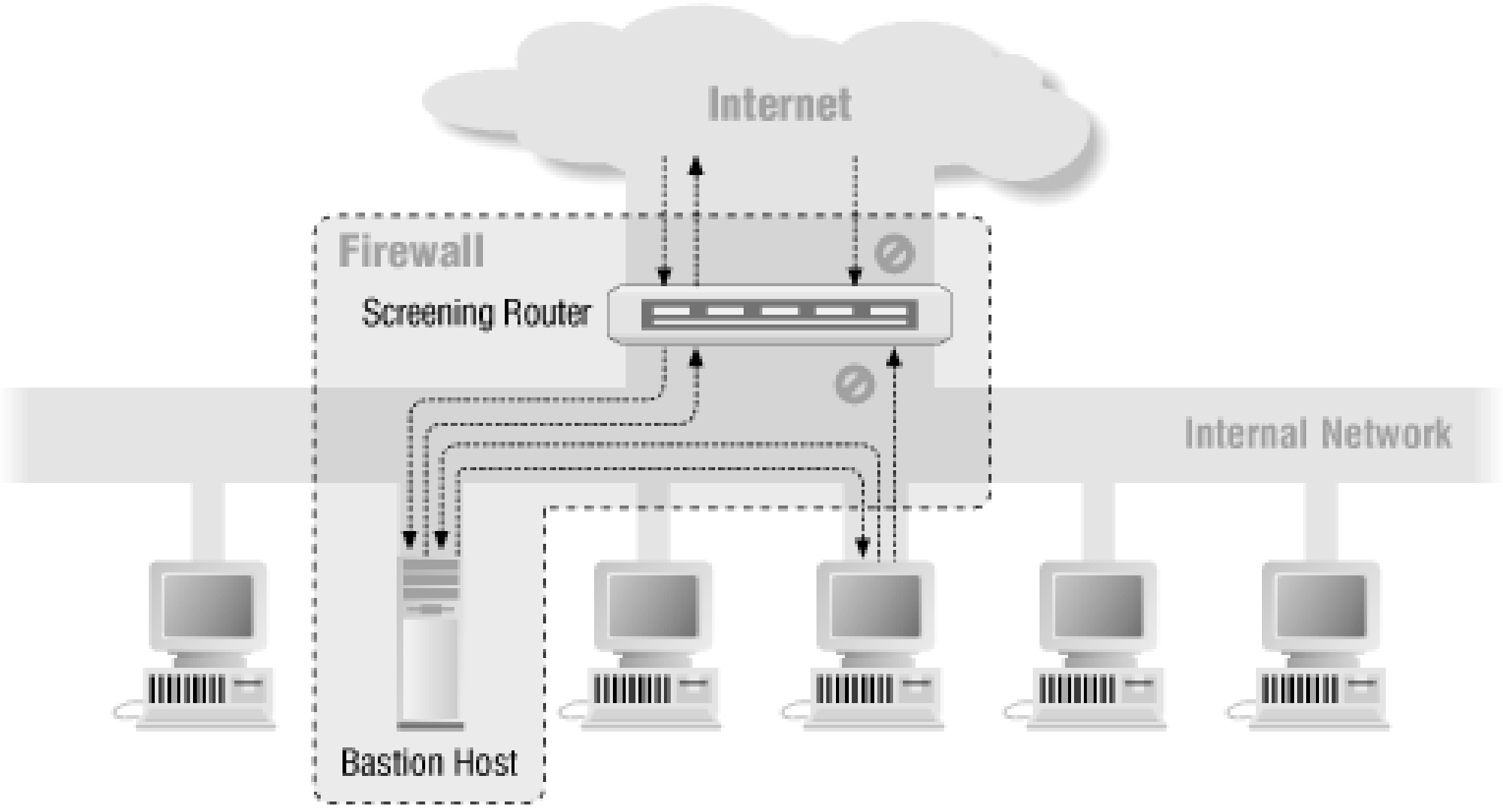
Dual-Homed Host

- a host computer that has two network interfaces
  - one for internet and one for internal network
  - host is thus a bastion host
- acts as a router between these networks
  - can run more complicated analysis
- no systems on Internet can communicate with any internal machine
  - there is no connection, network interfaces are separate
  - dual-homed host must mediate all communication


Internet
Dual-
homed
Host
Firewall
Internal Network

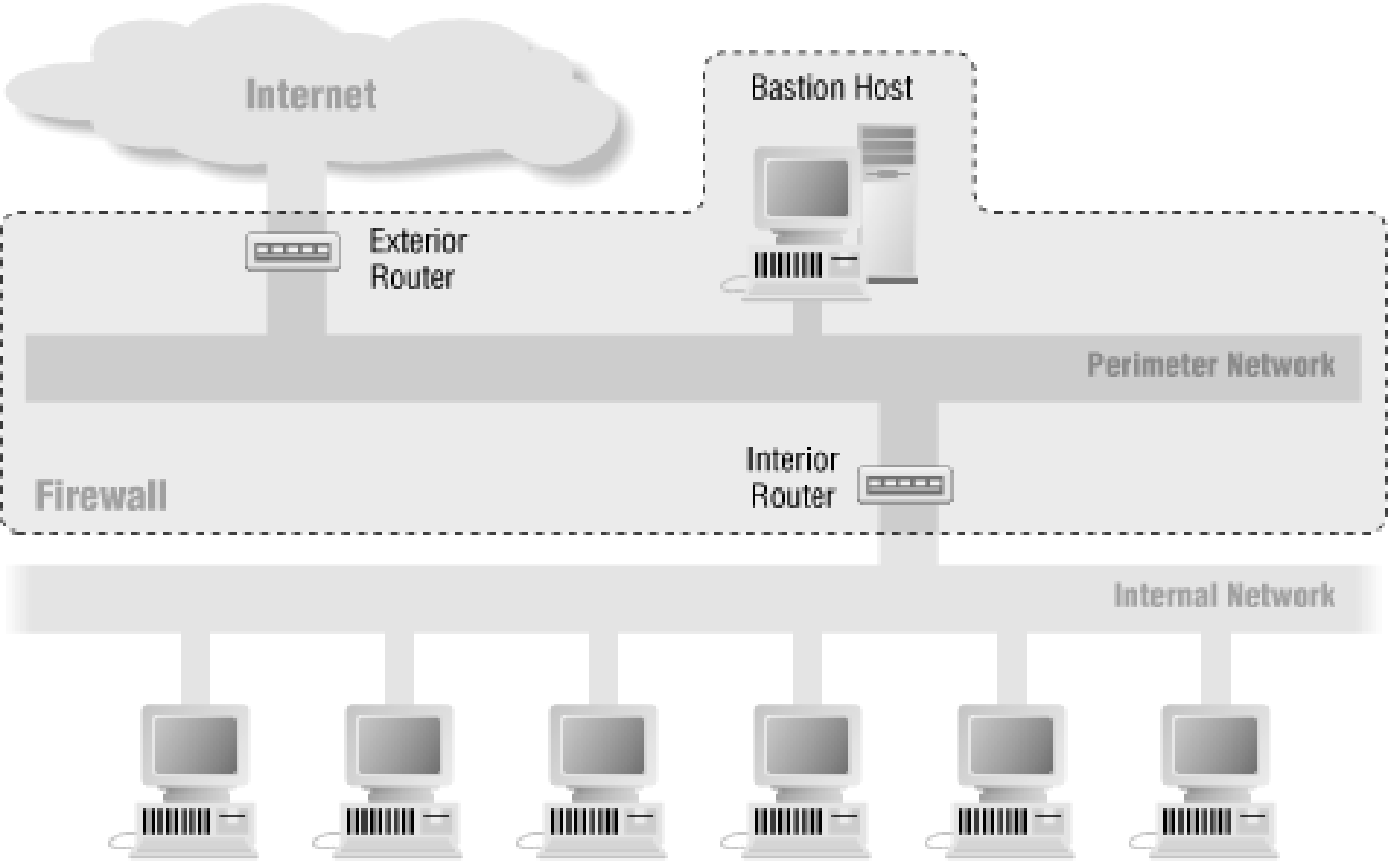
Screened Host

- a router screens traffic and only allows to particular bastion hosts
- bastion hosts are on the same internal network as other machines
- bastion host can, e.g., receive mail from the Internet
  - local machines can retrieve mail from bastion host
- not appropriate if bastion host serves many connections
  - e.g., acts as a webserver, file server, etc.


Internet
Firewall
Screening Router
Internal Network
Bastion Host

Screened Subnet

- adds a "perimeter network" or de-militarized zone (DMZ)
  - puts bastion hosts in the DMZ
  - has an "external" screening router between the Internet and the DMZ
  - has an "internal" screening router between the DMZ and the internal network
- allows bastion hosts to offer services to Internet
  - assumes they may be compromised
  - router protects internal machines
- different screening policies between the external and internal routers


Internet
Bastion Host
Exterior
Router
Perimeter Network
Interior
Router
Firewall
Internal Network

Screened Subnet

- perimeter network gives additional layer of security
  - attacker who breaches perimeter is still prevented from internal network
- a compromised machine may be able to examine all traffic on the network
  - e.g., Ethernet based networks
  - this limits the snooping to the perimeter
  - i.e., not between two internal network machines that may not be using encryption

Screened Subnet

- interior router
  - also called choke router
    - control point of monitor, control, and packet rejection
  - protects internal network from both internet and perimeter
    - can replicate rules that the external router should have implemented
    - can ensure no data is passing through that is internal-traffic only
  - limit services from bastion host to internal network as much as possible
    - e.g., DNS, SMTP

Screened Subnet

- exterior router
  - also called access router
  - protects perimeter net and internal net from Internet
  - generally allow almost anything outbound from perimeter
    - little filtering, not complicated
  - users may have such a router and not realize
    - e.g., provided by your ISP

Screened Subnet

- exterior router
  - one thing it can do is check forged senders
  - a packet "to" interior or perimeter "from" either cannot pass inbound on external router
  - prevents many types of attacks
  - impossible to tell afterwards
    - e.g., internal router cannot detect a spoofed packet "from" perimeter

A Screened Subnet is
almost always appropriate.

Variations

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it's OK to use multiple bastion hosts

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e.g., for redundancy, performance, separation of services, etc.

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it's OK to merge the interior router and the exterior router provided you have multiple interfaces and can specify different rules for them.

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security concern is not large because filtering role of external router is minimal.

Non-Variations

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Bastion host and interior router perform different security roles that are not complementary.

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it also requires consistent configs

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it's OK to use multiple exterior routers

e.g., because you have multiple connections

the threat of compromise increases

but we assume such devices are exposed.

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E.g., because a service needs to be granted but it is not just made into a bastion host on perimeter.

Why Have Firewalls Been Successful?

- central control
  - easy administration and update
  - single point of control
    - one config file to change
    - rapid response after changing
- easy to deploy
  - transparent to end users
  - simply add a device on the network that sits in front of the Internet
- addresses problem
  - security vulnerabilities in network services are rampant
  - easier to disable access to them than to secure them
  - easier to disable access if a new vulnerability appears

Firewalls Disadvantages

- functionality loss
  - some network stuff may not work
  - some apps don't work with both endpoints behind firewalls
- **insider** threat
  - firewalls assume that insiders are trusted
    - inbound versus outbound
  - this may not be the case
  - firewalls create a **security perimeter**
    - threats can come from laptops and cell phones that are compromised

Circumventing Firewalls

- packet filters have a **limited contextual model**
  - they look at headers
    - network and transport layer
  - they don't look at packets
    - application layer
  - using port 22 for ssh is a convention, not a rule
    - nothing preventing it on another port
    - ports like udp/53 for DNS are hard to block
- encrypted content is the norm
  - cannot be intercepted by a router without strenuous effort

Circumvention Technique: Abuse Ports

- port 53/udp is for DNS
  - typically this has to be allowed for the Internet to work
  - but why can't it be BitTorrent traffic instead?
    - provided client and server agree
    - port numbers are just a convention, not a rule
- how to get remote service to agree?
  - you could ask them to run it on a different port
  - you can run your own service and have it forward
    - "IP-over-DNS"

Circumvention with a Relay

- user runs a **relay**
  - a program listening on a port that is not blocked
  - e.g., HTTP
  - this program is running on a different network that is not behind a firewall
- user sends innocuous-looking traffic to their relay
- the traffic says "send the rest of the packet to IP:port"
- relay relays the traffic to the intended destination
- relay sends the reply back to the user
- how can this be detected?