

CS 458 / 658

Computer Security and Privacy

Module 4 Network Security

Spring 2018

Module outline

- 1 Network concepts
- 2 Threats in networks
- 3 Network security controls
- 4 Firewalls
- 5 Honeypots / honeynets
- 6 Intrusion detection systems

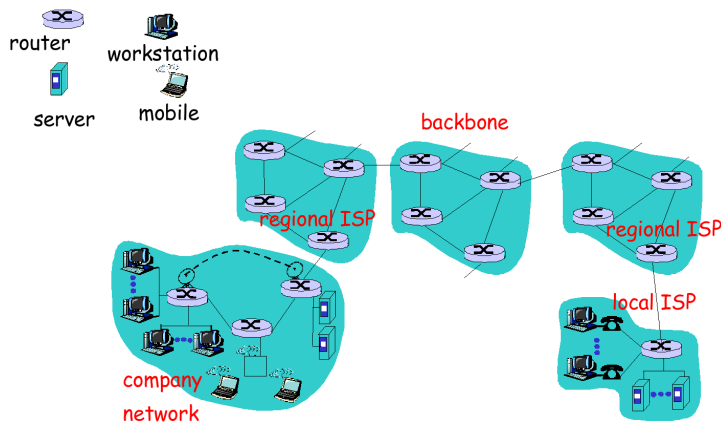
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Architecture of the Internet



Slide adapted from "Computer Networking" by Kurose & Ross

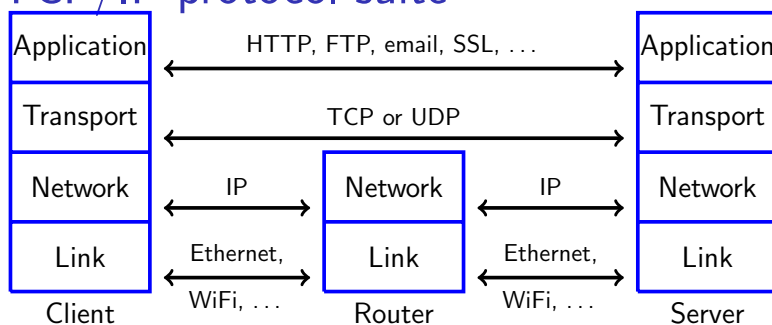
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Characteristics of the Internet

- No single entity that controls the Internet
- Traffic from a source to a destination likely flows through nodes controlled by different entities
- End nodes cannot control through which nodes traffic flows
 - Worse, all traffic is split up into individual packets, and each packet could be routed along a different path
- Different types of nodes
 - Server, laptop, router, UNIX, Windows,...
- Different types of communication links
 - Wireless vs. wired
- TCP/IP suite of protocols
 - Packet format, routing of packets, dealing with packet loss,...

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TCP/IP protocol suite



- Transport and network layer designed in the 1970s to connect local networks at different universities and research labs
- Participants knew and trusted each other
- Design addressed non-malicious errors (e.g., packet drops), but not malicious errors

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Threats in networks

- Intelligence
- Attacks on confidentiality
- Impersonation and Spoofing
- Attacks on integrity
- Protocols failures
- Web site vulnerabilities
- Denial of service
- Botnets
- Threats in active/mobile code
- Script kiddies

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Port scan

- To distinguish between multiple applications running on the same server, each application runs on a “port”
 - E.g., a Web server typically runs on port 80
- Attacker sends queries to ports on target machine and tries to identify whether and what kind of application is running on a port
- Identification based on loose-lipped applications or how exactly application implements a protocol

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Port scan (cont.)

- Loose-lipped systems reveal (non-confidential) information that could facilitate an attack
 - Login application can reveal information about OS or whether a userid is valid
 - Web servers typically return version information
- Nmap tool can identify many applications
 - Useful not only to attackers, but also to system administrators
- Goal of attacker is to find application with remotely exploitable flaw
 - E.g., Apache web server prior to version 1.3.26 is known to be vulnerable to buffer overflow
 - Exploits for these flaws can be found on the Internet

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Loose Lips

Ashley Madison's Password Reset Form

Response for invalid email address

Forgot Password?

Please enter the email address used on your Ad Profile. Your log-in information will be sent to this email address.

Email Address

[Send](#)

Thank you for your forgotten password request. If that email address exists in our database, you will receive an email to that address shortly

For additional service or support, please [Contact Us](#).

If you are already a member and have accessed this page in error, [click here](#) to login.

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<http://www.troyhunt.com/2015/07/your-affairs-were-never-discrete-ashley.html>

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Intelligence

- Social Engineering
 - Attacker gathers sensitive information from person
 - Often, attacker pretends to be somebody within the person's organization who has a problem and exploits the person's willingness to help (or vice versa)
 - I forgot my password, I locked myself out, there's a problem with your Paypal account,...
- Dumpster diving
- Eavesdropping on oral communication
- Google
 - There's lots of information on the Internet that shouldn't be there
 - The right Google query will find it
- Victim's Facebook profile

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Eavesdropping and wiretapping

- Owner of node can always monitor communication flowing through node
 - Eavesdropping or passive wiretapping
 - Active wiretapping involves modification or fabrication of communication
- Can also eavesdrop while communication is flowing across a link
 - Degree of vulnerability depends on type of communication medium
- Or when communication is accidentally sent to attacker's node
- It is prudent to **assume that your communication is wiretapped**

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Communication media

- Copper cable
 - Inductance allows a physically close attacker to eavesdrop without making physical contact
 - Cutting cable and splicing in secondary cable is another option
- Optical fiber
 - No inductance, and signal loss by splicing is likely detectable
- Microwave/satellite communication
 - Signal path at receiver tends to be wide, so attacker close to receiver can eavesdrop
- All these attacks are feasible in practice, but require **physical expenses/effort**

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Communication media (WiFi)

- WiFi
 - Can be **easily intercepted** by anyone with a WiFi-capable (mobile) device
 - Don't need additional hardware, which would cause suspicion
 - Maybe from kilometers away using a directed antenna
 - WiFi also raises other security problems
 - Physical barriers (walls) help against random devices being connected to a wired network, but are (nearly) useless in case of wireless network
 - Need authentication mechanism to defend against free riders

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Misdelivered information

- Local Area Network (LAN)
 - Connects all computers within a company or a university
 - Technical reasons might cause a packet to be sent to multiple nodes, not only to the intended receiver
 - By default, a network card ignores wrongly delivered packets
 - An attacker can change this and use a **packet sniffer** to capture these packets
- Email
 - Wrongly addressed emails, inadvertent Reply-To-All

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Impersonation

- Impersonate a person by stealing his/her password
 - Guessing attack
 - Exploit default passwords that have not been changed
 - Sniff password (or information about it) while it is being transmitted between two nodes
 - Social engineering
- Exploit trust relationships between machines/accounts
 - Rhosts/rlogin allows user A on machine X to specify that user B on machine Y can act as A on X without having to enter password
 - ssh has a similar mechanism
 - Attacker breaking into machine Y can exploit this
 - Or attacker might be able to masquerade as machine Y

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Spoofing

- Object (node, person, URL, Web page, email, WiFi access point, ...) masquerades as another one
- URL spoofing
 - Exploit typos: www.uwaterlo.ca
 - Exploit ambiguities: www.foobar.com or www.foo-bar.com?
 - Exploit similarities: www.paypa1.com
- Web page spoofing and URL spoofing are used in Phishing attacks
- “Evil Twin” attack for WiFi access points
- Spoofing is also used in session hijacking and man-in-the-middle attacks

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Session hijacking

- TCP protocol sets up state at sender and receiver end nodes and uses this state while exchanging packets
 - e.g., sequence numbers for detecting lost packets
 - Attacker can hijack such a session and masquerade as one of the endpoints
- Web servers sometimes have client keep a little piece of data ("cookie") to re-identify client for future visits
 - Attacker can sniff or steal cookie and masquerade as client
- Man-in-the-middle attacks are similar; attacker becomes stealth intermediate node, not end node

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Traffic analysis

- Sometimes, the mere existence of communication between two parties is sensitive and should be hidden
 - Whistleblower
 - Military environments
 - Two CEOs
- TCP/IP has each packet include unique addresses for the packet's sender and receiver end nodes, which makes traffic analysis easy
- Attacker can learn these addresses by sniffing packets
- More on protecting yourself from this attack later

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Integrity attacks

- Attacker can modify packets while they are being transmitted
 - Change payload of packet
 - Change address of sender or receiver end node
 - Replay previously seen packets
 - Delete or create packets
- Line noise, network congestion, or software errors could also cause these problems
 - TCP/IP will likely detect environmental problems, but fail in the presence of an active attacker
 - How in the case of TCP's checksumming mechanism?

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Integrity attacks (cont.)

- DNS cache poisoning
 - Domain Name System maps host names (www.uwaterloo.ca) to numerical addresses (129.97.128.40), as stored in packets
 - Attacker can create wrong mappings

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Protocol failures

- TCP/IP assumes that all nodes implement protocols faithfully
- E.g., TCP includes a mechanism that asks a sender node to slow down if the network is congested
 - An attacker could just ignore these requests
- Some implementations do not check whether a packet is well formatted
 - E.g., the value in the packet's length field could be smaller than the packet's actual length, making buffer overflow possible
 - Potentially disastrous if all implementations are from the same vendor or based on the same code base

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Protocol failures (cont.)

- Protocols can be very complex, behaviour in rare cases might not be (uniquely) defined
- Some protocols include broken security mechanisms
 - WEP (see later)

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Web site vulnerabilities

- Web site defacements
- Accessing a URL has a web server return HTML code
 - Tells browser how to display web page and how to interact with web server
 - Attacker can examine this code and find vulnerabilities
- Attacker sends malicious URL to web server
 - to exploit a buffer overflow
 - to invoke a shell or some other program
 - to feed malicious input to a server-side script
 - to access sensitive files
 - E.g., by including “../” in a URL or by composing URLs different from the “allowed ones” in the HTML code

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Web site vulnerabilities (cont.)

- HTTP protocol is stateless, so web server asks client to keep state when returning a web page and to submit this state when accessing next web page
 - Cookie or URL (<http://www.store.com?clientId=4342>)
- Attacker can submit **modified** state information
 - Web server might fall victim to incomplete mediation

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Web site vulnerabilities (cont.)

- Cross-site scripting (XSS)/request forgery (CSRF) attacks (code injection)
- Attacker adds his/her own HTML code to somebody else's web page
 - E.g., in the comments section of a blog
- Other users download and execute this code when downloading the web page
 - XSS: Code steals sensitive information (e.g., cookie) contained in the web page and sends it to attacker
 - <http://www.attacker.com/aliceCookie=secretValue>
 - CSRF: Code performs malicious action at some web site (e.g., user's bank) if user is currently logged in there
 - <http://www.bank.com/transferMoneyToAttacker>

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Denial of service (DoS)

- Cutting a wire or jamming a wireless signal
- Flooding a node by overloading its Internet connection or its processing capacity
- Ping flood
 - Node receiving a ping packet is expected to generate a reply
 - Attacker could overload victim
 - Different from “ping of death”, which is a malformed ping packet that crashes victim’s computer
- Smurf attack
 - Spoof (source) address of sender end node in ping packet by setting it to victim’s address
 - Broadcast ping packet to all nodes in a LAN

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Denial of service (cont.)

- Exploit knowledge of implementation details about a node to make node perform poorly
- SYN flood
 - TCP initializes state by having the two end nodes exchange three packets (SYN, SYN-ACK, ACK)
 - Server queues SYN from client and removes it when corresponding ACK is received
 - Attacker sends many SYNs, but no ACKs
- Send packet fragments that cannot be reassembled properly
- Craft packets such that they are all hashed into the same bucket in a hash table

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Denial of service (cont.)

- Black hole attack (AKA packet drop attack)
 - Routing of packets in the Internet is based on a distributed protocol
 - Each router informs other routers of its cost to reach a set of destinations
 - Malicious router announces low cost for victim destination and discards any traffic destined for victim
 - Has also happened because of router misconfiguration
- DNS attacks
 - DNS cache poisoning can lead to packets being routed to the wrong host

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Reflection & Amplification DDoS Attack

- An attack where the victim is flooded with legitimate-looking traffic that originates from unsuspecting network nodes on the Internet
 - **Amplification:** A vulnerable network node (e.g., a home wifi router) runs a service (e.g., SNMP) that responds to queries with much more data than the query itself
 - **Reflection:** The attacker spoofs the source address of the queries to that of the victim so that the vulnerable network nodes send (reflect) responses to the victim
- Hard to combat:
 - The response traffic is coming from innocent nodes
 - It is hard to identify the real source (perhaps bots) of the queries due to spoofing

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Distributed denial of service (DDoS)

- If there is only a single attacking machine, it might be possible to identify the machine and to have routers discard its traffic (see later)
- More difficult if there are lots of attacking machines
- Most attacking machines participate without knowledge of their owners
 - Attacker breaks into machines using Trojan, buffer overflow, . . . and installs malicious software
 - Machine becomes a **zombie/bot** and waits for attack command from attacker
 - A network of bots is called a **botnet**
 - How would you turn off a (classic) botnet (i.e., one with a central command node)?

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New Generation Botnets

- Today's botnets are very sophisticated
- Virus/worm/trojan for propagation, exploit multiple vulnerabilities
- Stealthiness to hide from owner of computer
- Code morphing to make detection difficult
- Bot usable for different attacks (spam, DDoS,...)

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Botnets (cont.)

- Distributed, dynamic & redundant control infrastructure
 - P2P system for distributing updates
 - “Fast Flux”
 - A single host name maps to hundreds of addresses of infected machines
 - Machines proxy to malicious websites or to “mothership”
 - Machines are constantly swapped in/out of DNS to make tracking difficult
 - Domain Generation Algorithm
 - Infected machine generates a large set (50,000 in the case of Conficker) of domain names that changes every day
 - It contacts a random subset of these names for updates
 - To control the botnet, authorities would have to take control of 50,000 different domain names each day

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Botnets (cont.)

- Earlier worms (Nimda, Slammer) were written by hackers for **fame** with the goal to spread worm as fast as possible
 - Caused disruption and helped detection
- Today’s botnets are controlled by crackers looking for **profit**, which rent them out
 - Criminal organizations
- Spread more slowly, infected machine might lie dormant for weeks

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Sample botnet: Storm

- In September 2007, **Storm Worm** botnet included hundreds of thousands or even millions of machines
- Bots were used to send out junk emails advertising web links that when clicked attempted to download and install worm, or to host these websites
- Botnet was also rented out for pharmacy and investment spam
- As a self-defence mechanism, it ran DDoS attacks against Internet addresses that scanned for it
- Authors were thought to reside in St. Petersburg, Russia
- Problem: implementation of p2p protocol created >10 times normal traffic (=> detectable)

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Sample botnet: Mirai

- In fall 2016, Mirai botnet attacked several high-profile targets, including a popular security blog and a large DNS provider
- Attack traffic of so far unseen 1 Tbps or more
- Botnet consisted of 600,000 IoT devices (routers, cameras) infected due to unchanged default passwords
- Distribution based on self-propagating worm
- Each bot flooded targets with UDP, TCP, and HTTP traffic, no amplification or reflection
- Botnet is now believed to be part of a rivalry between Minecraft server operators

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Active code

- To reduce load on server, server might ask client to execute code on its behalf
 - Java, JavaScript, ActiveX, Flash, Silverlight
 - Invoke another application (Word, iTunes, Steam...)
 - Maybe inadvertently (see XSS attack)
- Obviously, this can be dangerous for client
- Java 1.1 ran in a sandbox with limited capabilities, code is checked for correctness
 - No writing to a file, no talking to random network nodes
 - Similar for JavaScript
 - But it could still use up CPU or memory resources, wreak havoc with display, or play annoying music

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Active code (cont.)

- Java 1.2+ can break out of sandbox if approved by user
 - What's the problem here?
- Worse: Java 7 runs signed applets out of sandbox **by default**
- Third-party applications
 - Turn out to be a huge problem, for all browsers
 - Malicious input parameters, Word macros...
 - Potentially disastrous if application has full access rights to a user's account

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Active code (cont.)



- **Privileged:** The application will run with unrestricted access which may put your computer and personal information at risk.
- **Sandboxed:** The application will run with restricted access that is intended to protect your computer and personal information.

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Script kiddies

- For all of the discussed attacks, exploit code and complete attack scripts are available on the Internet
- **Script kiddies** can download scripts and raise an attack with minimum effort
- There are even tools that allow easy building of individual attacks based on existing exploits
 - E.g., Metasploit Framework

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Design and implementation

- Use controls against security flaws in programs that we talked about earlier
- **Always check inputs**, don't ever trust input from a client
 - Use a white list of allowed characters, not a black list of forbidden ones

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Blacklist vs whitelist



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Segmentation and separation

- Don't put all a company's servers on a single machine
- Deploy them on multiple machines, depending on their functional and access requirements
- If a machine gets broken into, only some services will be affected
- E.g., the web server of a company needs to be accessible from the outside and is therefore more vulnerable
- Therefore, it shouldn't be trusted by other servers of the company, and it should be deployed outside the company firewall (see DMZ later)

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Redundancy

- Avoid single points of failure
 - Even if you don't have to worry about attackers
 - Disk crash, power failure, earthquake, . . .
- (Important) servers should be deployed in a redundant way on multiple machines, ideally with different software to get genetic diversity and at different locations
- Redundant servers should be kept in (close) sync so that backup servers can take over easily
 - Test this!
 - Keep backup copies at a safe place in case you get hit by Murphy's law

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Access controls

- ACLs on routers
 - All traffic to a company typically goes through a single (or a few) routers
 - In case of flooding attack, define router ACL that drops packets with particular source and destination address
 - ACLs are expensive for high-traffic routers
 - Difficult to gather logs for forensics analysis
 - Source addresses of packets in flood are typically spoofed and dynamic
- Firewalls
 - Firewalls have been designed to filter traffic, maybe based on other criteria than just packet addresses

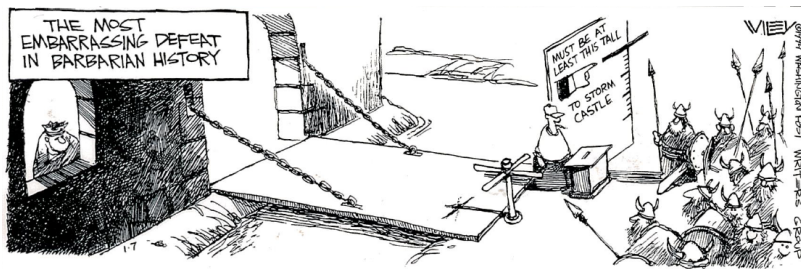
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Firewalls



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Firewalls

- Firewalls are the castles of the Internet age
- **All traffic** into/out of a company has to go through a small number of gates (choke points)
 - Wireless access point should be outside of firewall
- **Choke points** carefully examine traffic, especially incoming, and might refuse it access
 - Two strategies: "permit everything unless explicitly forbidden" or "forbid everything unless explicitly allowed"
- Company firewalls do not protect against attacks on company hosts that originate within the company
 - Need **multiple layers of defense / defense in depth**

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Types of firewalls

- Packet filtering gateways / screening routers
- Stateful inspection firewalls
- Application proxies
- Personal firewalls
- Firewalls are attractive targets for attackers, they (except personal ones) are typically deployed on designated computers that have been stripped of all unnecessary functionality to limit attack surface

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Packet filtering gateways

- Simplest type
- Make decision based on **header of a packet**
 - Header contains source and destination addresses and port numbers, port numbers can be used to infer type of packet
 - 80 -> Web, 22 -> SSH
 - E.g., allow Web, but not SSH
- Ignore payload of packet
- Can drop spoofed traffic
 - uWaterloo's firewall could drop all packets originating from uWaterloo whose source address is not of the form 129.97.x.y
 - And traffic originating from outside of uWaterloo whose source address is of the form 129.97.x.y
 - Does this eliminate spoofed traffic completely?

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Stateful inspection firewalls

- More expensive than packet filtering
- Keep **state** to identify packets that belong together
 - When a client within the company opens a TCP connection to a server outside the company, firewall must recognize response packets from server and let (only) them through
 - Some application-layer protocols (e.g., FTP) require additional (expensive) inspection of packet content to figure out what kind of traffic should be let through
- IP layer can fragment packets, so firewall might have to re-assemble packets for stateful inspection

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Application proxy

- Client talks to proxy, proxy talks to server
 - Specific for an application (email, Web, ...)
 - Not as transparent as packet filtering or stateful inspection
 - **Intercepting proxy** requires no explicit configuration by client (or knowledge of this filtering by client)
 - All other traffic is blocked
- For users within the company wanting to access a server outside the company (forward proxy) and vice versa (reverse proxy)
- Proxy has full knowledge about communication and can do sophisticated processing
 - Limit types of allowed database queries, filter URLs, log all emails, scan for viruses
- Can also do strong user authentication

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Personal firewalls

- Firewall that runs on a (home) user's computer
 - Especially important for computers that are always online
- Typically “forbid everything unless explicitly allowed”
 - Definitely for communication originating from other computers
 - Maybe also for communication originating on the user's computer
 - Why? What's the problem here?

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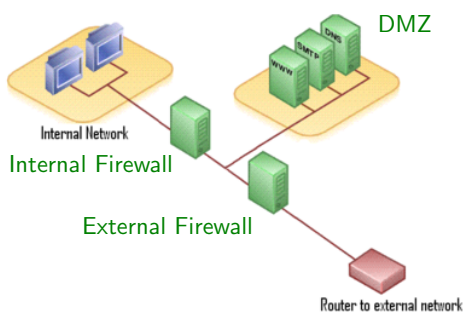
Personal firewalls (cont.)

- Protect against attacks on servers running on computer
 - Servers that are running unnecessarily (e.g., Windows XP before SP 1 suffered from this)
 - Servers that are wrongly configured and that allow access from other computers (or that cannot be configured to disallow this)
 - Servers that have a remotely exploitable bug

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Demilitarized Zone (DMZ)

- Subnetwork that contains an organization's external services, accessible to the Internet
- Deploy external and internal firewall
 - External firewall protects DMZ
 - Internal firewall protects internal network from attacks lodged in DMZ



Source: Wikipedia

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Honeypots / honeynets

- Set up an (unprotected) computer or an entire network as a trap for an attacker
- System has no production value, so **any activity is suspicious**
 - Any received email is considered spam
- Observe attacker to learn about new attacks, to identify and stop attacker, or to divert attacker from attacking real system
- Obviously, attacker should not be able to learn that attacked system is a honeypot/-net
 - Cat-and-mouse game
- Also, attacker might be able to use honeypot/-net to break into real system

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Types of honeypots/-nets

- Low interaction
 - Daemon that emulates one or multiple hosts, running different services
 - Easy to install and maintain
 - Limited amount of information gathering possible
 - Easier for the attacker to detect than high interaction honeynets
- High interaction
 - Deploy real hardware and software, use stealth network switches or keyloggers for logging data
 - More complex to deploy
 - Can capture lots of information
 - Can capture unexpected behaviour by attacker

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Intrusion detection systems (IDSs)

- Firewalls do not protect against inside attackers or insiders making mistakes and can be subverted
- IDSs are next line of defense
- Monitor activity to identify malicious or suspicious events
 - Receive events from sensors
 - Store and analyze them
 - Take action if necessary
- Host-based and network-based IDSs
- Signature-based and heuristic/anomaly-based IDSs

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Host-based and network-based IDSs

- Host-based IDSs
 - Run on a host to protect this host
 - Can exploit lots of information (packets, disk, memory, . . .)
 - Miss out on information available to other (attacked) hosts
 - If host gets subverted, IDS likely gets subverted, too
- Network-based IDSs
 - Run on dedicated node to protect all hosts attached to a network
 - Have to rely on information available in monitored packets
 - Typically more difficult to subvert
- Distributed IDSs combine the two of them

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Signature-based IDSs

- Each (known) attack has its signature
 - E.g., many SYNs to ports that are not open could be part of a port scan
- Signature-based IDSs try to detect attack signatures
- Fail for new attacks or if attacker manages to modify attack such that its signature changes
 - Polymorphic worms
- Might exploit statistical analysis

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Heuristic/anomaly-based IDSs

- Look for behaviour that is out of the ordinary
- By modelling good behaviour and raising alert when system activity no longer resembles this model
- Or by modelling bad behaviour and raising alert when system activity resembles this model
- All activity is classified as good/benign, suspicious, or unknown
- Over time, IDS learns to classify unknown events as good or suspicious
 - Maybe with machine learning

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Example: Tripwire

- Anomaly-based, host-based IDS, detects file modifications
- Initially, compute digital fingerprint of each system file and store fingerprints at a safe place
- Periodically, re-compute fingerprints and compare them to stored ones
- (Malicious) file modifications will result in mismatches
- Why is it not a good idea to perform the second step directly on the production system?

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IDS discussion

- Stealth mode
 - Two network interfaces, one for monitoring traffic, another one for administration and for raising alarms
 - First one has no published address, so it does not exist for routing purposes (passive wiretap)
- Responding to alarms
 - Type of response depends on impact of attack
 - From writing a log entry to calling a human
- False positives/negatives
 - Former might lead to real alarms being ignored
 - IDS might be tunable to strike balance between the two
 - In general, an IDS needs to be monitored to be useful

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Recap

- Network concepts
- Threats in networks
- Network security controls
- Firewalls
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- Intrusion detection systems

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