Lecture 25: Isolation

Stephen Huang

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1. Principles of Secure Design
2. Firewalls
3. Sandboxing
4. Web Isolation

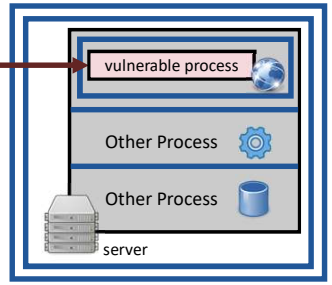
1. Principles of Secure Design

- Methodology
  - As a basic start, establish secure defaults, minimize the attack surface area, and fail securely to those well-defined and understood defaults.
  - Two processes: Product Inception and Product Design.
- Security Principles
  - The principle of Least Privilege and Separation of Duties.
  - The principle of Defense-in-Depth.
  - The principle of Zero Trust
  - The principle of Security-in-the-Open

Secure Product Design Cheat Sheet, https://cheatsheetseries.owasp.org/cheatsheets/Secure_Product_Design_Cheat_Sheet.htm

Principles of Secure Design

- Defense-in-depth: multiple layers of security
  - The attacker has to circumvent all of them to compromise its target.
  - *examples*: multi-factor user authentication, firewalls, etc.



- Compartmentalization
  - divide the system into compartments and isolate them from each other → limit the impact of a compromise
  - **principle of least privilege**: each module should have only the minimum set of privileges needed to serve its purpose

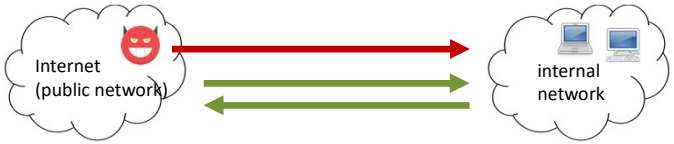
2. Firewalls

- A Firewall is a network security device that monitors and filters incoming and outgoing network traffic based on an organization's established security policies.

Motivation for Firewalls

- A system can consist of hundreds or thousands of computing devices (both servers and clients)
  - many of them may have open ports that are accessible from the Internet
  - various operating systems running various services, implemented by various software, …
  - various software versions, configurations, …
- Challenge
  - keeping everything patched and properly configured is very expensive (or practically impossible)
  - on the other hand, an attacker may succeed by finding just one vulnerability (which it may easily find by scanning the network)

Basic Layout



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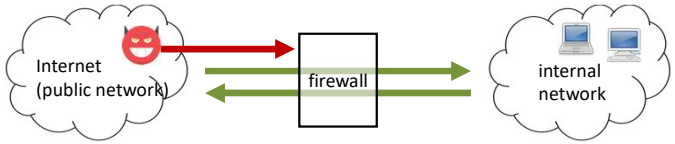


decision whether to allow or deny some traffic is based on a set of rules (*e.g.*, allow connections to the webserver, but deny connections to other machines)

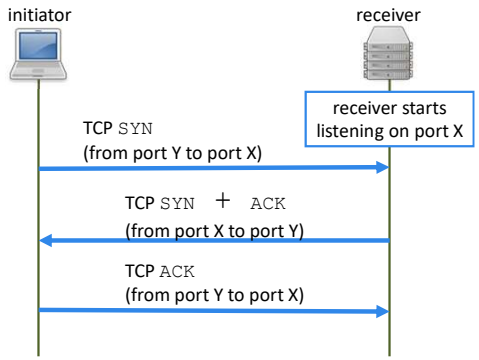
Transport Layer Protocols: TCP & UDP

- TCP or UDP port: communication endpoint
  - for each address and protocol (TCP or UDP), it is identified by a 16-bit number
  - every TCP and UDP packet has a source address and source port as well as a destination address and destination port
- Ports 0 … 1023: reserved for certain application-level protocols
  - on each computer, these ports are permanently assigned to the programs that implement the corresponding services
  - *examples:* HTTP → TCP 80, DNS → TCP / UDP 53, FTP control → TCP 21
- Ports 1024 … 65535: used by client applications
  - client picks an arbitrary port, and connects from this port to the specific port on the server
  - on Unix-like systems, unprivileged processes cannot listen on ports below 1024

TCP Handshake

- TCP uses a three-way handshake to establish a connection

Each packet has zero or more flags: `SYN`, `ACK`, `FIN`, …



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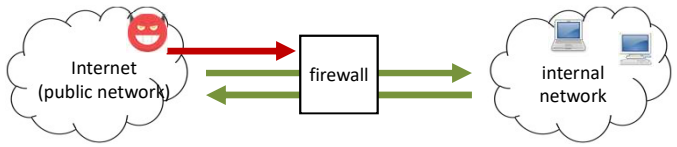

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(*e.g.*, allow connections to the webserver, but deny connections to other machines)

Firewalls: Stateless vs. Stateful

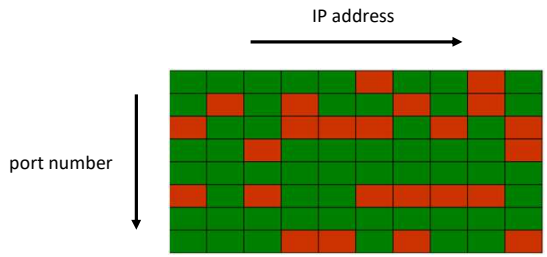
Stateless
(Packet filtering)

- Apply rules to each incoming/outgoing packet individually
- Advantage: does not need to track state → simpler
- Disadvantage: limited functionality, must process rules for every packet

Stateful
(Session filtering)

- Apply rules only to the first few packets of each connection
- Advantage: advanced functionality, does not need to process every packet
- Disadvantage: must track the state of every connection

Illustration of Basic Packet Filtering



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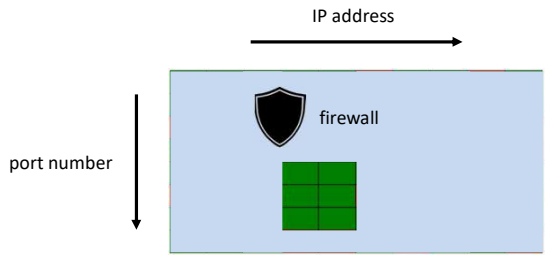


Basic Packet Filtering

- Based on protocol header information
  - network layer: source and destination IP address, higher level protocol (*e.g.*, TCP, UDP, ICMP)
  - transport layer: TCP or UDP ports, TCP flags (SYN, ACK, FIN, …)
  - ICMP message types (*e.g.*, ECHO Request)
- *Example ruleset:*

`from Internet to 129.7.97.54 ∧ TCP port = 80 → ALLOW`

- allow connections from the Internet to our webserver (i.e., port 80 on 129.7.97.54)

`from Internet to LAN ∧ TCP SYN=true ∧ TCP ACK=false → DENY`

- deny connections from the Internet to computers on the internal network

`otherwise → ALLOW`

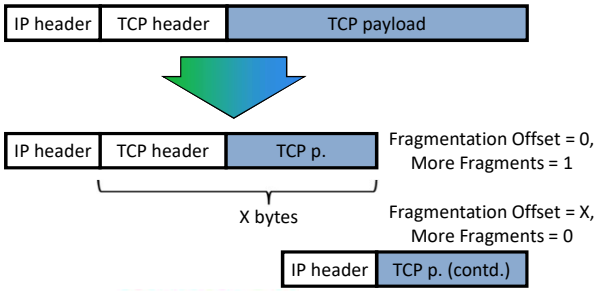
- allow everything else (note that this will allow computers on the Internet to accept connections from the internal network)

Rulesets

- Multiple matching rules
  - first match → first matching rule is applied
  - last match → last matching rule is applied
- Actions
  - usually accept/drop (i.e., allow/deny)
  - can also include logging or alarms
- Ruleset needs to be built for the specific system
  - "off-the-shelf" configuration might not fit the system
- Best practice
  - last (or first) rule should always be a "block everything," so only explicitly allowed traffic will pass through
  - in other words, "whitelist" instead of "blacklist"

Stateless Filtering Limitation

- IP fragmentation: breaking up a single IP packet into multiple packets
  - necessary because some network links have limited datagram size
- Normal fragmentation



IP Packet Fragmentation Attack

- *Example firewall rules:*
  - allow connections on TCP port 25 (SMTP)
  - deny connection on TCP port 23 (Telnet)
- First packet
  - Fragmentation Offset = 0
  - More Fragment = 1
  - TCP header: destination port = 25 → allow
- Second packet
  - Fragmentation Offset = 2 (second packet overwrites all but the first 2 bytes of the previous packet)
  - More Fragment = 0
  - TCP header fragment: destination port = 23
- Firewall allows the second packet because it is just a fragment (not a full header)
- IP packet reassembled at host and received at port 23

Stateful Firewalls and Deep Packet Inspection

- Stateful firewalls
  - keep track of each active connection
  - each packet is evaluated based on the status of the connection
  - disadvantages:
    - computationally more demanding
    - complex → more error-prone implementation
- Deep packet inspection
  - looks into the internals of a packet to check application content or context
  - example: block certain HTTP URLs or malicious executable code
  - may lead to privacy issues

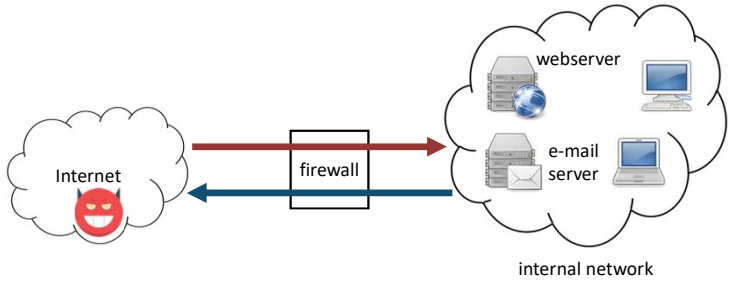
Application-Layer Firewalls

- Basic packet inspection considers only the first four networking layers (up to the transport layer).
- It operates at the OSI model's application layer (or Layer 7).
- While traditional firewalls focus on packet filtering and IP addresses, application-layer firewalls dive deeper, inspecting the data's content to make more informed security decisions.
  - It's like a meticulous security guard who checks not just your ID, but also the contents of your bag before letting you inside a building.

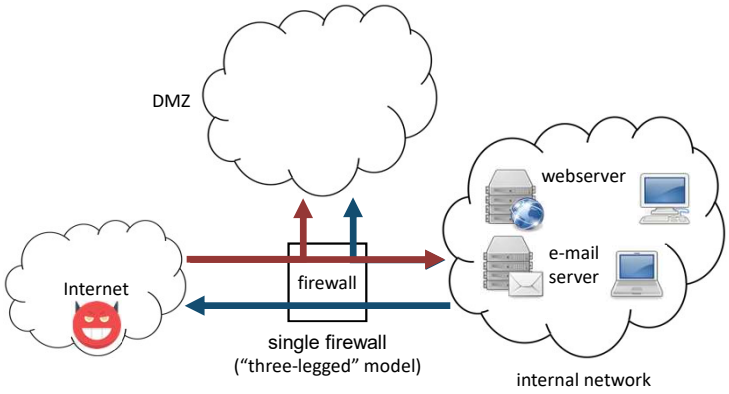
Application-Layer Firewalls

- Application-layer firewall
  - "understands" certain application-level protocols (e.g., FTP, DNS, HTTP)
  - rules can be defined in terms of these protocols
    - e.g., limit HTTP requests to certain paths or limit FTP to certain commands
- Proxying firewall
  - application-layer firewalls are sometimes implemented as proxies
  - client TCP connection is received by the proxy, which then connects to the actual server
  - proxy can inspect and forward traffic

Firewall



Demilitarized Zone (DMZ)



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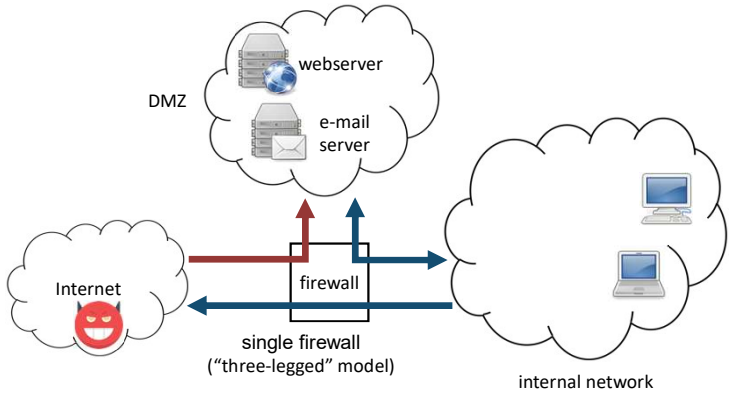
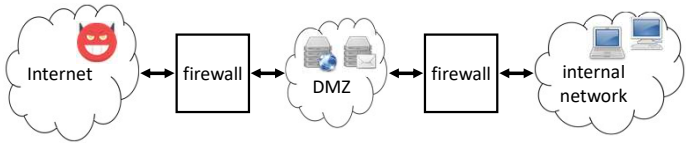
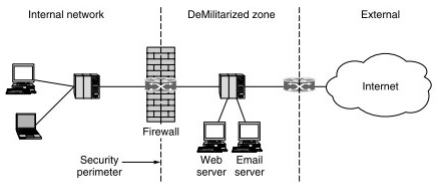


DMZ with Dual Firewalls



- More secure
  - The attacker needs to compromise/bypass two firewalls.
  - Misconfiguration has a lower impact.

Various Configurations



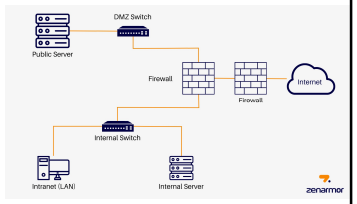
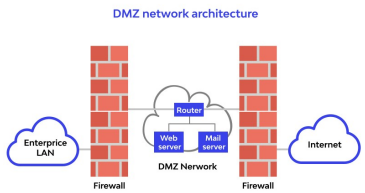
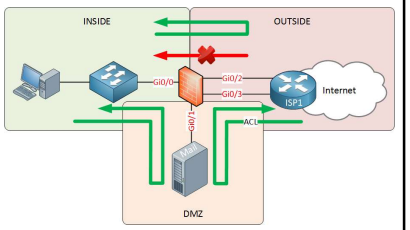


Figure 8-29. A firewall protecting an internal network.





Firewall Implementations

- Many operating systems come with built-in firewalls, *e.g.*,
  - Windows Firewall
  - Linux kernel: Netfilter framework
    - `iptables`: command-line tool for configuration
- Many routers have basic firewall functionality
- Dedicated hardware devices
  - special hardware and software for filtering
  - advantage: performance
  - disadvantage: expensive and usually harder to manage

Firewall Limitations

- Firewalls cannot protect against
  - attacks that bypass them (*e.g.*, USB drive with malware)
  - internal-threats (*e.g.*, disgruntled employee)
- A firewall can become a single point of failure
  - just like any other machine, a firewall can have vulnerabilities
  - if the security of an entire network depends on a firewall, then compromising the firewall can have devastating effects

3. Sandboxing

Sandbox

- Sandbox: security mechanism for separating a running program (or one part of a running program) from the rest of the system
- Typically used to run untested or untrusted code (possibly from untrusted sources)
  - potentially vulnerable applications that are exposed to untrusted data (e.g., PDF viewer, e-mail client, web browser)
  - client-side scripts (~JavaScript) on webpages, macros, etc.
  - plug-ins, extensions, smartphone applications, etc.
- Sandboxed code has limited access to system resources (*e.g.*, files, memory, network) → reduces the impact of security vulnerabilities in sandboxed software

`chroot` Jail

```
int chroot(const char *path)
```

- Available on all Unix operating systems
- Changes the root directory from `/` to the given `path` for the process
- Can be performed only with root user privileges
- After `chroot`, nothing outside the new root directory is available
  - system libraries and commands (*e.g.*, `libc`, `bash`) cannot be used, unless a copy was made available in the new root
- By definition, it should be undoable
  - however, a root user can get out
    → drop root privileges before executing the untrusted code

Using `chroot`

- Development and testing
  - set up a complete environment in a directory and chroot into it before running the software that is under development or testing
- Security
  - if an attacker compromises a process running in a "chroot jail," then it can access and modify only the files inside the jail
  - *example*:
    - HTTP, e-mail, and FTP servers (*e.g.*, Postfix and OpenSSH SFTP)
    - before handling a client, `chroot` into a directory and relinquish root privileges
- Disadvantages
  - all or nothing access to parts of a file system

Linux Secure Computing Mode

`int seccomp(SECCOMP_SET_MODE_STRICT, 0, NULL)`

- Sandboxing tool in the Linux kernel
  - introduced in kernel version 2.6.12
- Once a process enters `seccomp` mode, it cannot make any system calls, except for
  - `exit(…), sigreturn(…)`
  - `read(int filedescriptor, …)`
  - `write(int filedescriptor, …)`

  → read and write files that were opened before entering `seccomp` mode
- Typical usage: open necessary files and network connections, and enter `seccomp` mode

seccomp-bpf

`int seccomp(SECCOMP_SET_MODE_FILTER, 0, &filter)`

- Extension to secure computing mode that enables more fine-grained filtering of system calls
- Berkeley Packet Filter
  - enables user-space processes to filter network packets using filters
  - in `seccomp`, it is used to filter system calls
  - `&filter` points to a struct `sock_fprog`, which contains the filter
- Used by, for example,
  - Google Chrome (sandbox for Adobe Flash and renderers)
  - Firefox (sandbox for child processes and plugins)
  - vsftpd (default FTP server for many Linux distributions)

Isolation Based on Unix Access Control

- *Reminder:* traditional Unix access control
  - each user has a user ID and a set of group memberships
  - when a user starts a process, the process inherits the user's user ID and set of group memberships
  - each file has
    - owner (user ID) and group (group ID)
    - read, write, and execution rights for owner, group, and others
- Sandboxing: run untrusted code as an unprivileged user
  - for example, use `setuid` to run an executable as a dummy user
  - dummy user's access can be restricted using traditional Unix access control
  - using Linux namespaces, the running process can be further separated

Android Application Sandbox

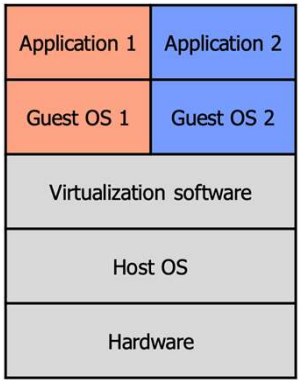
- Smartphones allow users to easily download and install applications → OS must prevent applications (*e.g.*, trojans) from doing harm
- On Android, each application has a unique Unix user ID and group ID
- Application data is stored in `/data/data/<app-name>`
  - read-writable only with the corresponding user / group IDs
- Applications run in separate processes with their own user IDs and group IDs
- Application permissions are implemented using Unix groups, *e.g.*,
  - `WRITE_EXTERNAL_STORAGE` permission: `sdcard_rw` group (can read/write `/mnt/sdcard`)
  - `INTERNET` permission: `inet` group (can create IP sockets)

Other Sandbox Approaches

- Linux Security Modules
  - framework that allows extending the traditional Unix access control to various computer-security models
  - allows a security module to intercept system calls that would result in accessing important kernel objects
  - *examples:* SELinux, AppArmor
- `ptrace`
  - system call available on most Unix systems
  - enables a process to control another process (*e.g.*, manipulate file descriptors and memory, install breakpoints)
  - commonly used by debuggers (*e.g.*, `gdb`)
  - can be used to implement a sandbox

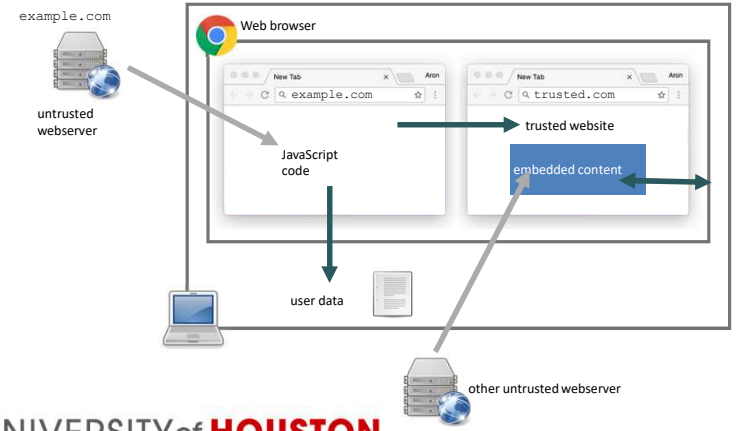
Virtual Machines

- Virtual machines can also be used for sandboxing
- Widely used in cloud computing
  - *Microsoft Azure*
  - *HP Public Cloud*
  - *IBM Cloud Services*
  - …



4. Web Isolation

Code Isolation in Web Browsers



Embedding Example

- HTML page source:

```
<iframe style="width:
122px; height: 20px;
border: none;"
src="https://www.facebook.c
om/v2.3/plugins/like.php?ap
p_id=24725…"></iframe>
```

HTML5 `iframe` Sandbox

- Motivation
  - lot of websites embed content from other domains (*e.g.*, advertisements, Facebook modules)
  - third-party widgets can run Javascript, which may open pop-ups or navigate to another page

Sandboxed Embedding

- Without sandboxing:

```
<iframe src="untrusted.html"></iframe>
```

- With sandboxing:

```
<iframe src="untrusted.html" sandbox></iframe>
```

  - disables plugins
  - blocks script execution
  - blocks form submission
  - treats content as if it was from a globally unique origin
  - blocks navigating the top-level window or other frames on the page (excluding child frames of the sandboxed content)
  - blocks popup windows

Refining the Sandbox

- Manually allow some features

```
<iframe src="untrusted.html"
    sandbox="allow-forms"></iframe>
```

  - `allow-forms`: allows form submission
  - `allow-popups`: allows displaying pop-ups
  - `allow-same-origin`: treats content as being from the same origin
  - `allow-scripts`: allows script execution
  - `allow-top-navigation`: allows the iframe content to navigate its top-level browsing context

Next Topic

- Isolation
- Denial of Service
- Conclusion