B. Defence Techniques

Jin Hong

jin.hong@uwa.edu.au

Demo preparation

- Nothing fancy, some visualisations.
  - Web vulnerability scanning
    - https://pentest-tools.com/website-vulnerability-scanning/website-scanner
    - https://www.criminalip.io/
  - MTDSim
    - From github: https://github.com/MoeBuTa/MTDSimTime

Vulnerability

- What is a vulnerability?
  - ?

- Vulnerabilities arise from bugs in applications or design flaws in the system
- Vulnerabilities can be found in all layers of the system

Vulnerability Scanning

- Vulnerability scanning can
  - Identify _____ in the system applications and designs
  - Find what _____ are running
  - Ensure vulnerabilities are _____ correctly
  - Part of a pre-emptive step to _____ vulnerabilities before attackers exploit them

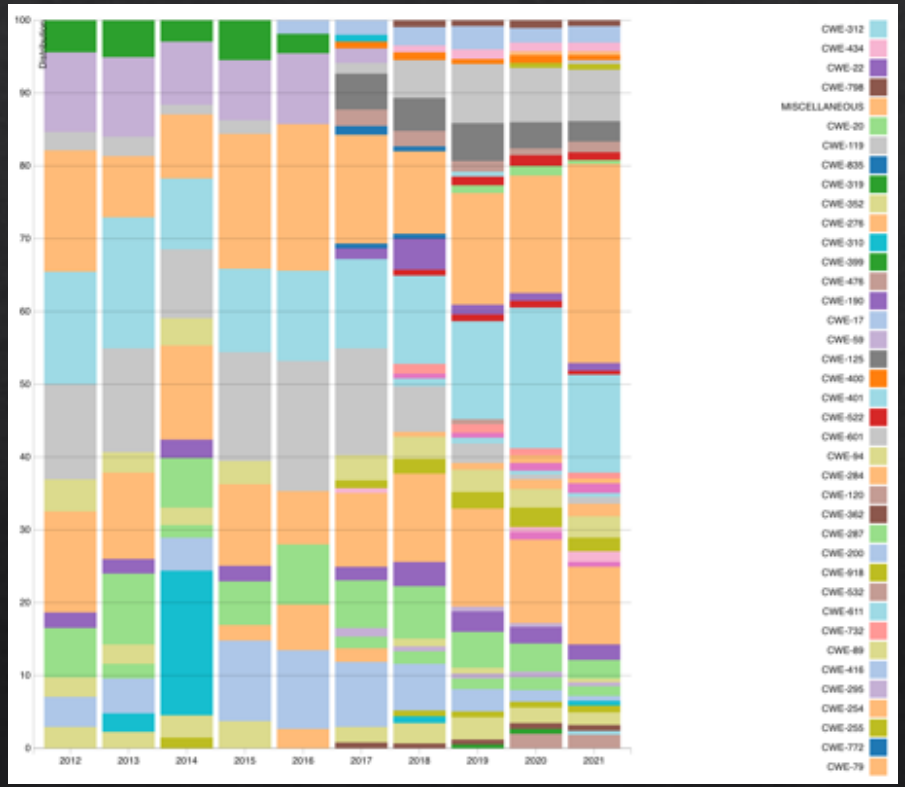
Vulnerability Scanning

- "Scanning" is means of **collecting information** about computer systems and the entities they belong to
- Attackers also conduct "scanning" in the pre-attack phase, or more commonly known as **reconnaissance**

Vulnerability Scanning

- How are vulnerabilities discovered?
  - Known vulnerabilities using tools
  - New vulnerabilities by humans
    - Hacker groups
    - Security companies or
    - Researchers
  - E.g., a group may discover a vulnerability related to a software (could be by accident or through a directed research)
  - Vulnerability is disclosed to the public
    - **When?**

Vulnerability Scanning

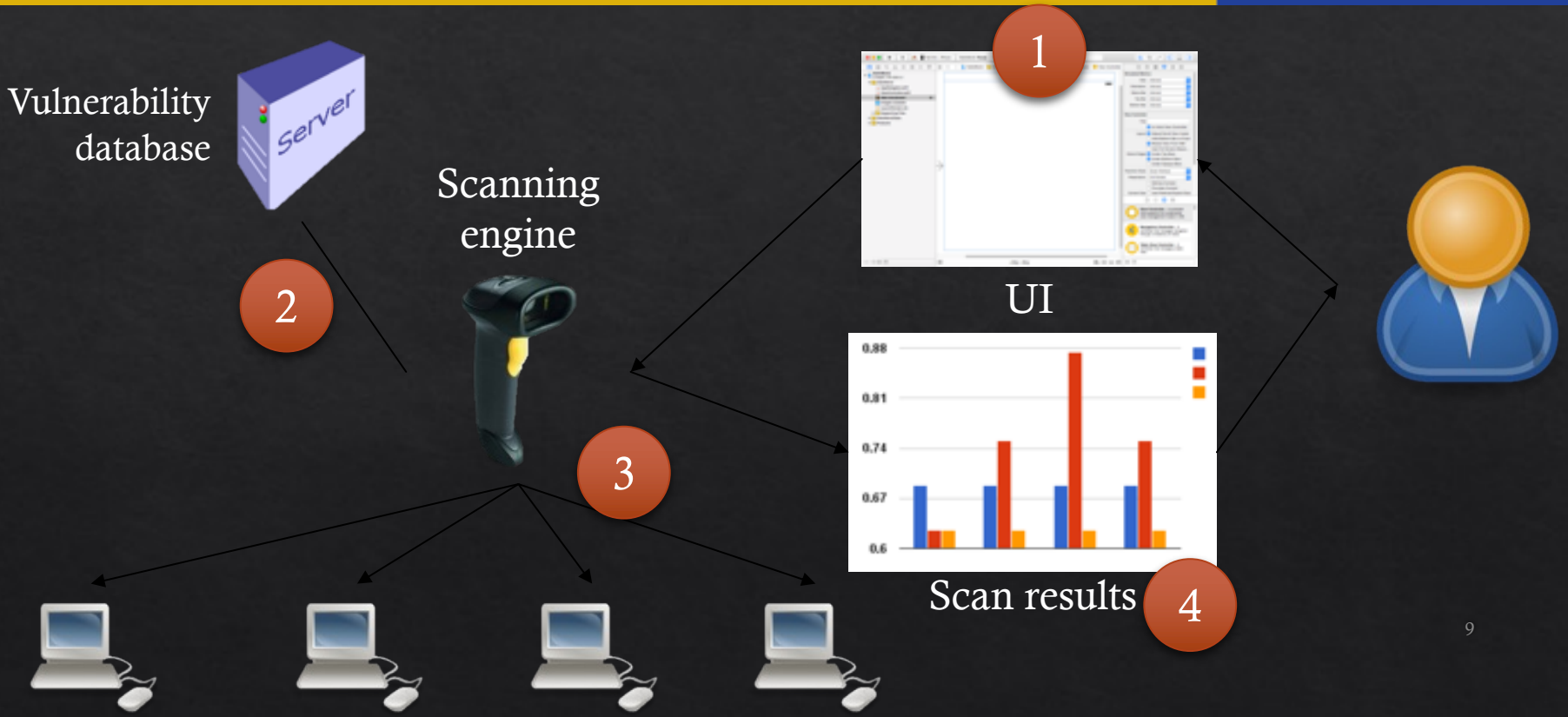


https://nvd.nist.gov/general/visualizations/vulnerability-visualizations/cwe-over-time#vuln-type-total-by-year-title

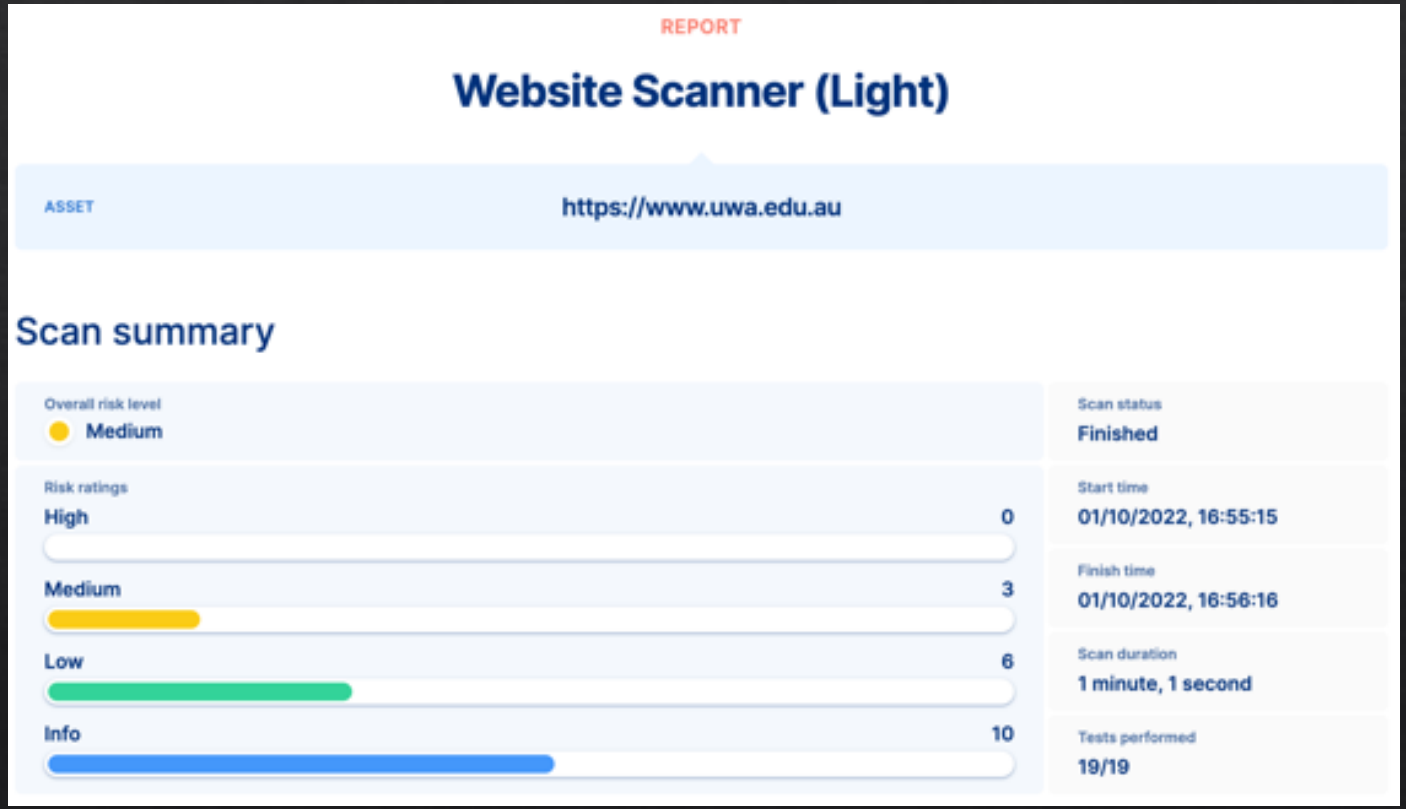
Vulnerability Scanning

- Some widely used canning categories are
  - Port scanners
    - Nmap – https://nmap.org/
  - Network vulnerability scanners
    - Nessus - https://www.tenable.com/products/nessus/nessus-professional
    - OpenVAS - http://www.openvas.org/
    - Qualys, SAINT, etc.
  - Web application vulnerability scanning tools
    - List from OWASP - https://www.owasp.org/index.php/Category:Vulnerability_Scanning_Tools
- There are other types as well
  - E.g., database security scanner, host-based vulnerability scanner etc.

Vulnerability Scanning



Vulnerability Scanning



REPORT

Website Scanner (Light)

ASSET https://www.uwa.edu.au

Scan summary

Overall risk level
Medium

Risk ratings

High	0
Medium	3
Low	6
Info	10

Scan status
Finished

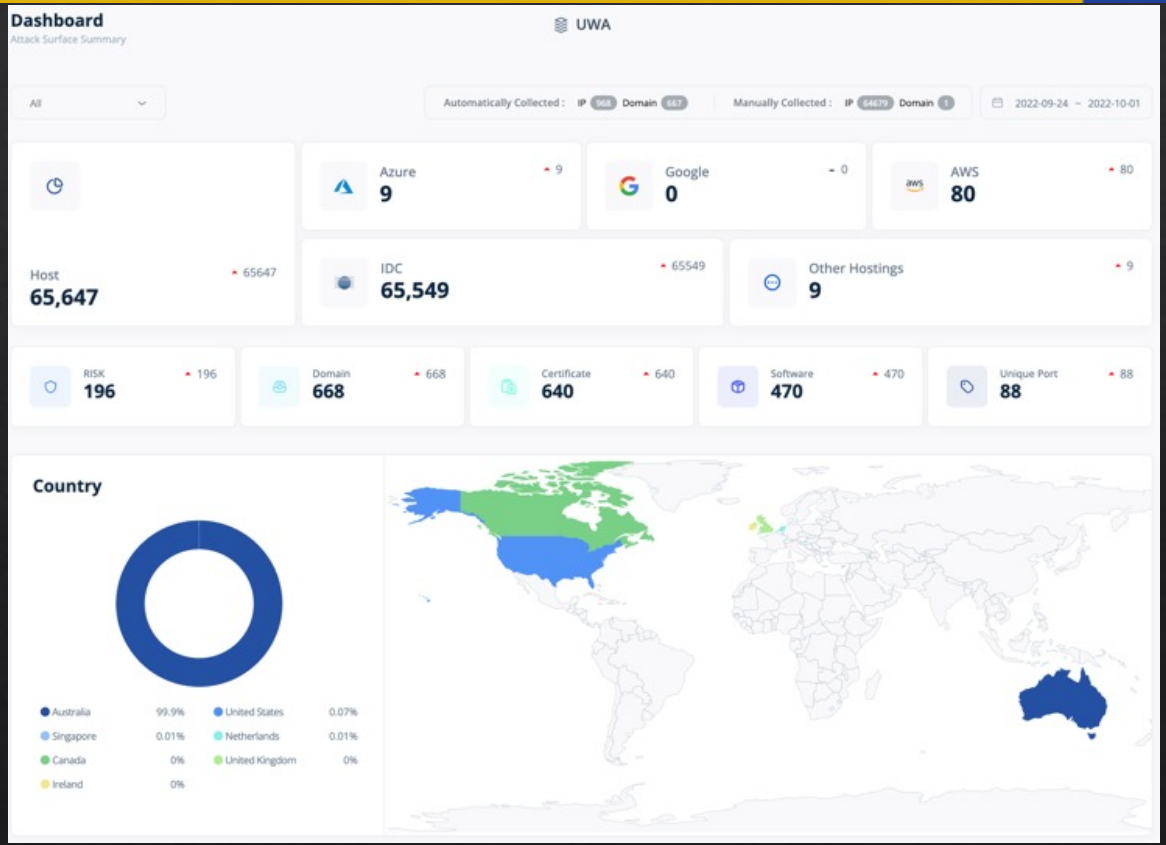
Start time
01/10/2022, 16:55:15

Finish time
01/10/2022, 16:56:16

Scan duration
1 minute, 1 second

Tests performed
19/19

Vulnerability Scanning

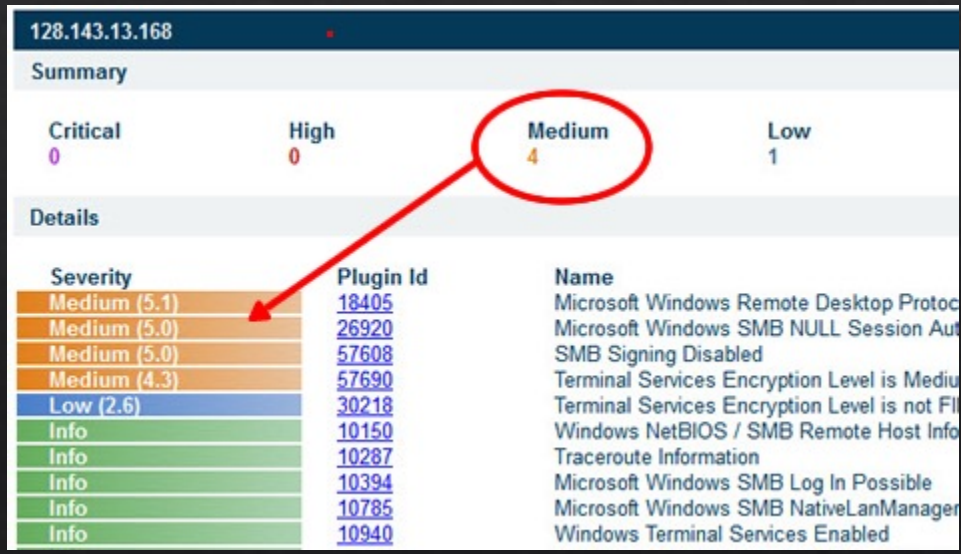


Example: Nessus

- From Tenable©
- Runs on various OSes
  - Linux, Unix-based, Windows etc
- Keeps their own vulnerability database
  - Good or bad?
- Uses Nessus Attack Scripting Language
  - So you can write your own scripts and plugins
- There are various (and many free) plugins available to use
  - https://www.tenable.com/plugins/nessus/families
- Vulnerabilities found are classified based on their risk-factor
- Is a commercial product
  - Currently $3729USD per annum for the professional version (as of 2022)

Example: Nessus

- Nessus can scan various types of vulnerabilities
  - Windows vulnerabilities
  - Insecure scripts
    - E.g., Common Gateway Interface
  - RPC (remote procedure call) program vulnerabilities
  - Firewall misconfigurations
  - FTP insecure implementations
  - Etc.
- Provides ranking of them



Vulnerability database

- Widely used vulnerability database

Vulnerability database

- CVE provides a list of standardised names for vulnerabilities
  - These vulnerabilities are publicly known
  - Security experts form editorial board and provide the description
  - E.g., CVE-2014-0160
    The (1) TLS and (2) DTLS implementations in OpenSSL 1.0.1 before 1.0.1g do not properly handle Heartbeat Extension packets, which allows remote attackers to obtain sensitive information from process memory via crafted packets that trigger a buffer over-read, as demonstrated by reading private keys, related to d1_both.c and t1_lib.c, aka the **Heartbleed** bug.
- MITRE Corporation maintains CVE and moderates the editorial board discussions

http://cve.mitre.org

Vulnerability database

- NVD is a comprehensive cybersecurity vulnerability database
  - Maintained by NIST, an US organisation
  - Synchronised with CVE vulnerability naming standard
  - Provides some security metrics about the vulnerability
    - E.g., CVSS base score, vectors, etc.
    - CVE-2014-0160 has the CVSS BS of 5.0

http://nvd.nist.gov

Vulnerability Scanning: Summary

- Requires continuous efforts to discover and mitigate vulnerabilities
- Difficult to address problems with new and unknown vulnerabilities
  - E.g., zero-day vulnerabilities
- Global efforts are made to address issues associated with each steps of vulnerability scanning
  - E.g., improve anomaly detection using AI and machine learning

Sandboxing

- Often we have untrusted code that we wish to run
  - E.g., program from Internet including toolbars, viewers, codecs etc
- We should contain that code in a zone such that if it misbehaves, we can easily kill it
- Create the zone through confinement – sandboxing!

Sandboxing

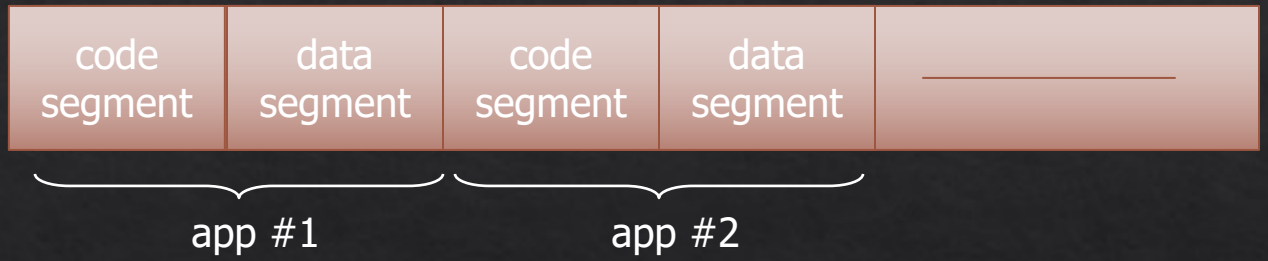
- **Confinement**: To contain the application in an isolation to ensure it does not carry out unapproved actions
- Can be implemented at many levels:
  - **Hardware**: run application on isolated hw (air gap)
  - **Virtual machines**: isolate OS's on single hardware
  - **System call interposition**: Isolates a process in a single operating system
  - **Software Fault Isolation** (SFI): Isolating threads sharing same address space
  - **Application specific**: e.g. browser-based confinement

SFI

- Software Fault Isolation
- **Problem**: legitimate and malicious applications running in the same address space
  - E.g., device drivers trying to corrupt kernel
- **Solution**
  - Separate applications into different address spaces
  - Instructions are added before memory operations and verify behaviour (e.g., illegal memory access)

SFI

- Partition process memory into segments



- Locate unsafe instructions (e.g., jmp, load, store)
  - Add safety instructions for memory access
  - Add guards before unsafe instructions at compile time
  - Validate guards when loading them

SFI

- Reconstruct code instructions for safety
- Untrusted code (applications) should only be able to
  - Jump within its domain's code segment
  - Write within its domain's data segment

Unsafe instruction

```
STR R0, R1          ; write R1 to Mem[R0]
```

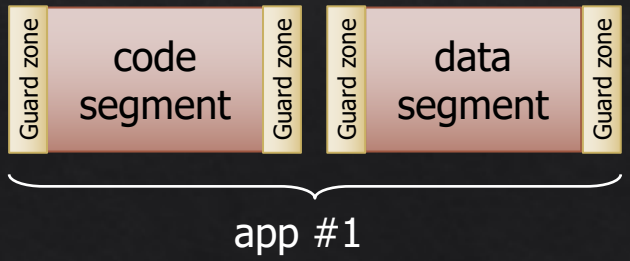
Rewritten instruction by sandbox

```
MOV  Ra, R0         ; copy R0 into Ra
SHR  Rb, Ra, Rc     ; Rb = Ra >> Rc, get the segment ID
CMP  Rb, Rd         ; Rd holds the data segment ID
BNE  fault          ; wrong data segment ID
STR  Ra, R1         ; Ra in data segment, so write
```

STR – store
MOV – move
SHR – shift logical right
CMP – compare
BNE – branch on not equal

SFI

- Some instructions use register and offset addressing
  - i.e., needs extra space for the instruction
- Add guard zone to each segment to avoid calculating the offset



SFI

- Verifier ensures **all** instructions are safe
- Verifier checks **no privileged** instructs are in the code
- Verifier also checks relevant instructions are **within** the code/data segments
- If the sandboxed code **fails** any checks, verifier *rejects* the code

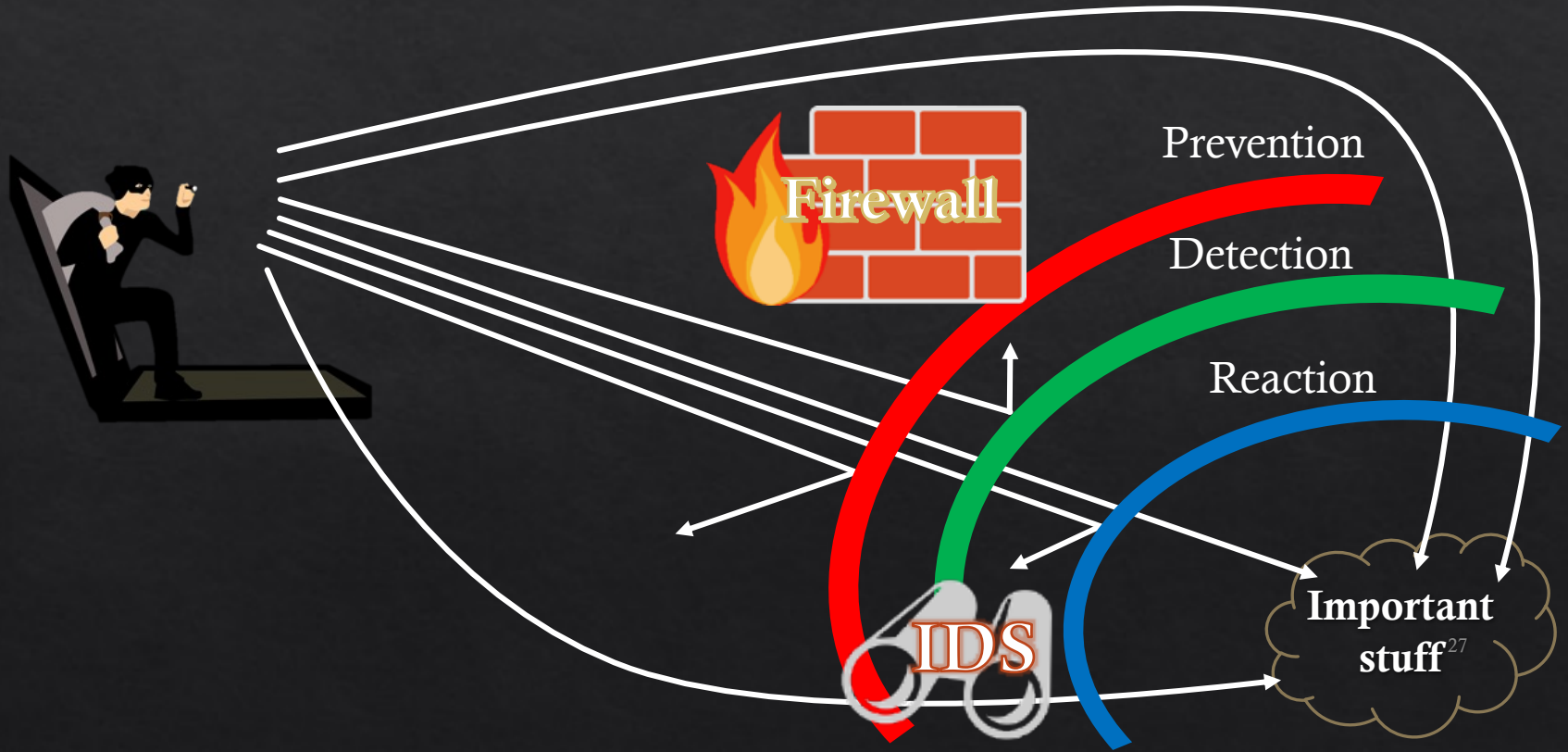
SFI

- Provides a **good** performance with a little overhead
  - Typically around 4% processing overhead
- Confines writes and control transfers in extension's data and code segments, respectively
- Prevent execution of **privileged** instructions
- However, more **difficult** to implement on x86 architectures
  - It was not designed for x86 in the first place
  - Variable length instructions: hard to place guards
  - Many instructions that affects the memory: need more guards

Sandboxing summary

- Various techniques for sandboxing in different layers of the system
- It is difficult to fully isolate malicious code, due to dependencies
- Defining sandboxing policy is one of the top key challenges

Tools


Firewall
Prevention
Detection
Reaction
IDS
Important stuff

Firewall

- We create networks and subnets **everywhere**
  - Need to ensure that bad things don't come into our networks
- Forms the **first** barrier for protecting LANs
- Sits **between** the premises network and the Internet
- Typically, **all traffic** from outside to inside passes through the firewall
- Unauthorised traffic will be **filtered** by the firewall

Firewall

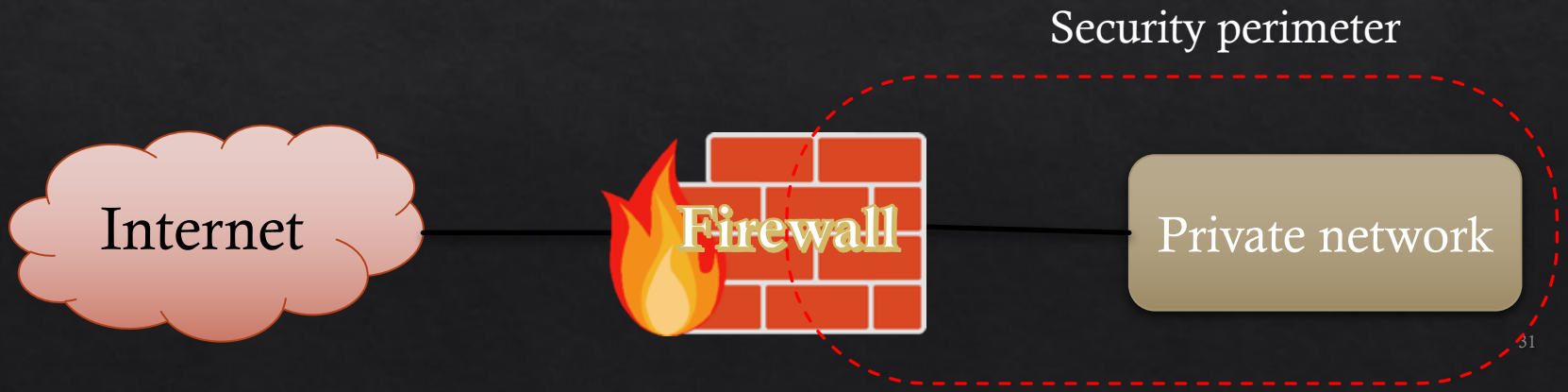
- What are the things examined by a firewall?
  - IP address
  - Protocol headers, payload, or port number
  - Track of client-server sessions
  - Application level protocols

Types of Firewalls

- Packet filtering firewall (Gen 1)
- Stateful inspection firewall (Gen 2)
- Application proxy firewall (Gen 3)
- Circuit-level proxy firewall (Gen 3)

Gen1: Packet filtering

- Defines a set of rules for each IP packet
- Apply the rules to determine the packet is forwarded or dropped



Gen1: Packet filtering

- Filtering rules are based on the following
  - Source IP address
  - Destination IP address
  - Transport level address (e.g., TCP or UDP port number)
  - IP protocol field
  - Interfaces
    - A firewall with 3 or more ports, which interface the packet came from or is going to

Gen1: Packet filtering

- A list of rules are established using the information
- If the incoming (or outgoing) packet matches to one of the rules, that rule is **invoked** (forward/discard)
- What happens when there is no matching rule?

Gen1: Packet filtering

Action	Ourhost	Port	Theirhost	Port	comment
Block	*	*	*	*	Default
Allow	*	25	*	*	Connect to SMTP

Gen1: Packet filtering

Action	Ourhost	Port	Theirhost	Port	comment
allow	*	*	*	25	Connect to the mail server

- Q: What could be a potential problem with this rule?

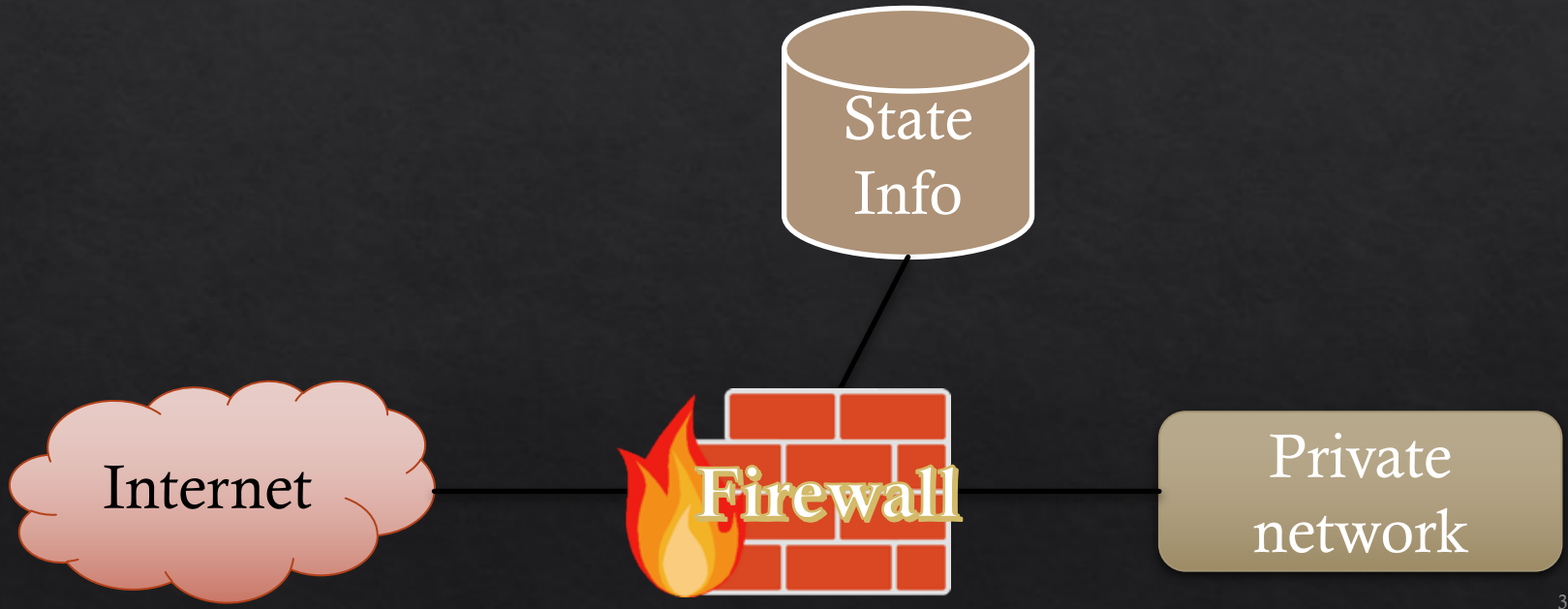
Gen1: Packet filtering

- Advantages:
  - Simple
  - Typically transparent to users and are very fast
- Disadvantages:
  - Cannot prevent attacks at the application layer
  - Limited logging capabilities
  - No advanced user authentication
  - TCP/IP protocol bugs can be exploited – e.g., IP spoofing

Gen2: Stateful inspection

- Generation 1 firewalls do not examine higher layer context
- Generation 2 firewalls address this problem by examining each IP packet in context
  - Keeps the track of client-server sessions
  - Check each packet validity – e.g., does it belong to someone?
- Provides better capabilities to detect bogus packets

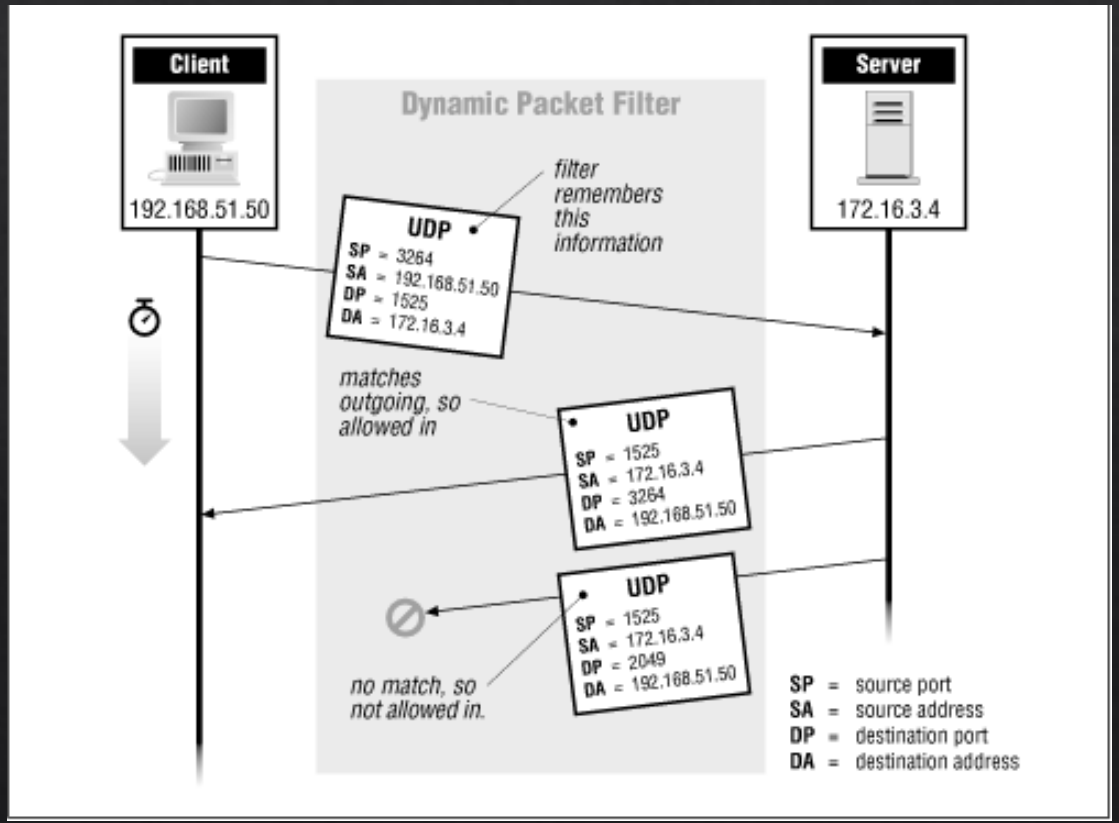
Gen2: Stateful inspection



Gen2: Stateful inspection

- TCP connections (typically)
  - Server port number < 1024
  - Client port number between 1024 and 16383
- Permanent assignments
  - (20, 21 -> FTP), (23 -> Telnet), (25 -> SMTP), (80 -> HTTP)
- If client wants to use port 2048, firewall must allow incoming traffic on this port
- Sol: To keep track of the outgoing requests

Gen2: Stateful inspection



Gen2: Stateful inspection

- The firewall keeps track of currently established connections

Source IP	Source Port	Dest. IP	Dest. Port	Con. State
192.168.1.100	1030	210.9.34.11	80	Established
192.168.1.103	1875	173.46.34.101	25	Established
192.43.1.101	2248	192.168.1.6	80	Established
210.168.1.113	1056	192.168.1.6	80	Established
222.99.1.73	1301	168.39.45.67	79	Established

- The packet filter allows incoming traffic to high-numbered ports only for those packets that fit the profile

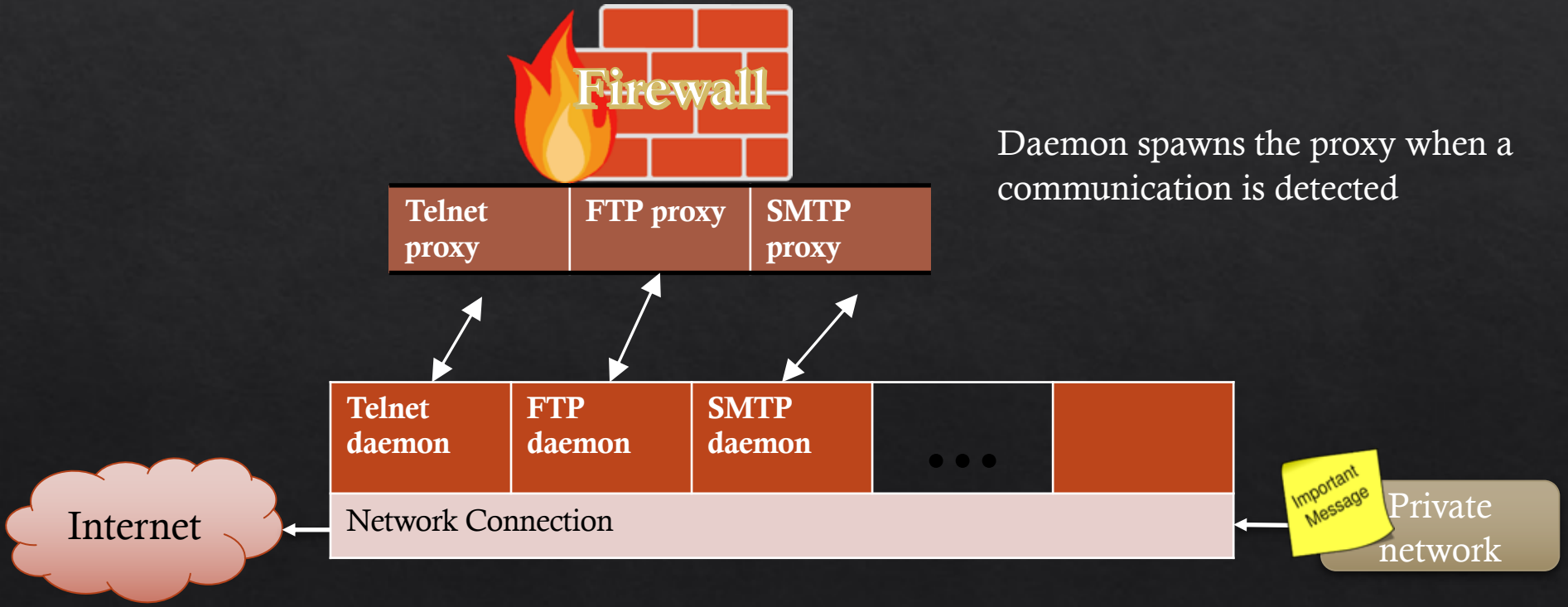
Gen2: Stateful inspection

- Options to keep track of the TCP sequence numbers
  - To prevent attacks that depend on the sequence number
  - Q: What attack was it?
  - E.g., session hijacking
- Some may also inspect application data for well known protocols
  - e.g., FTP

Gen3: Application proxy

- Application proxy (application level gateway)
- Relays application-level traffic

Gen3: Application proxy



Daemon spawns the proxy when a communication is detected

Gen3: Circuit-level proxy

- Proxy at the transport layer (TCP/IP model)
  - Establishes two TCP connections
- Typically used for **trusted** inside users
- Monitors TCP data packet handshaking and session fulfilment of firewall rules and policies
- Does **not filter** individual packets
- Relays TCP segments **without examining** contents
- Enforce a security function
  - That determines which connections will be allowed

Gen3 and more

- Application level
  - Considers commands in the application protocols
- Circuit level
  - Does not consider application protocols, but
  - Provides service for a wide variety of different protocols
- Multi-level firewalls

Firewalls summary

The Goods	The Bads

• All communication goes through a single point
• Specific location(s) for monitoring events
• Provides a platform for various Internet functions not security related
  • e.g., serve as the platform for IPSec
	• Attackers can bypass firewall
	• Cannot protect from internal threats
	• Improper network design can be penetrated from outside
	  • e.g., not so secure wireless LAN
	• Infected devices can be brought into the internal network
	  • e.g., laptop, tablets, mobile phones, USB

Other cool tools

- There are many other tools that are useful for defence (as well as attacks), such as
  - Wireshark
  - Metasploit
  - Nessus
  - Snort
  - Burp
  - OpenVAS
  - Etc.

Moving Target Defense

- Simply MTD, is a defense mechanism that continuo changes the attack surface to thwart cyberattacks
- Different types of changes can be made in the system, and they can be categorised into three

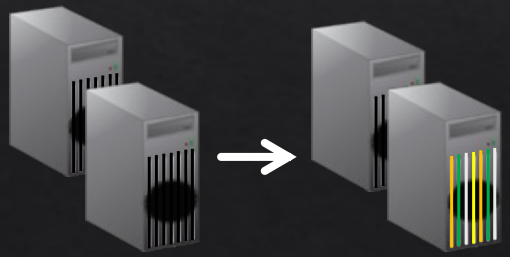
Shuffle

Every *t* seconds

Virtual IP: X

Virtual IP: Y

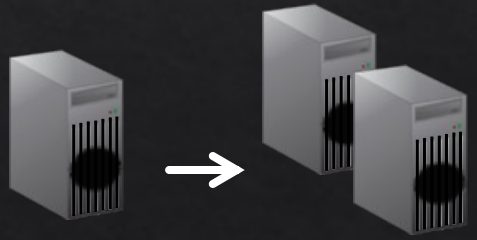
Diversity



2 Apache Servers

1 Apache, 1 Windows Servers

Redundancy



Single server

One additional replica server

MTD

- MTD can also be implemented in different layers of the system
  - For example:
    - Application layer – code regeneration/diversification
    - Transport layer – routing node redundancy
    - Internet layer – IP shuffling and virtualisation

MTD

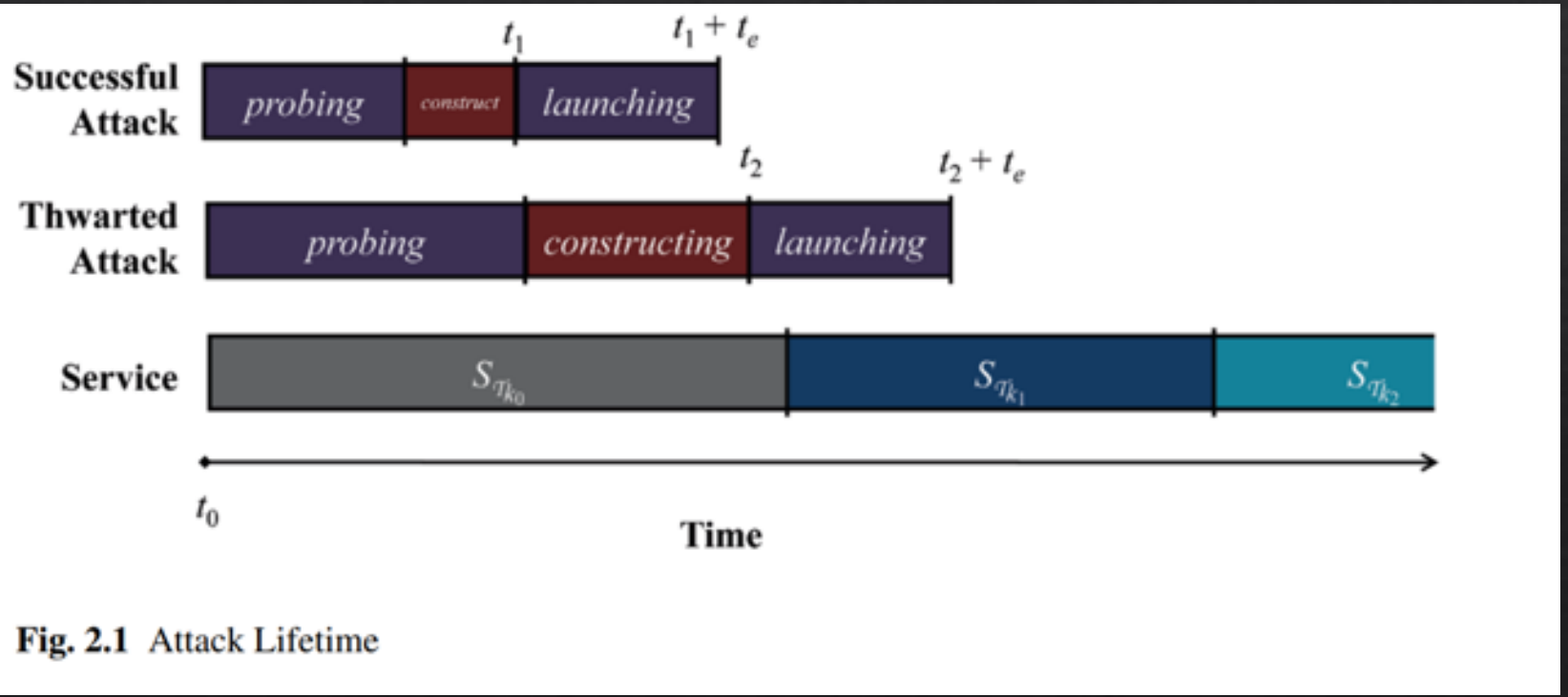


Fig. 2.1 Attack Lifetime

Evans, David, Anh Nguyen-Tuong, and John Knight. "Effectiveness of moving target defenses." Moving Target Defense. Springer New York, 2011. 29-48.

MTD Shuffle

- The MTD shuffle technique **changes** the configuration of the system such that connections/dependencies are altered but the operations are maintained
  - E.g., changing the routing table in the SDN
- Existing vulnerabilities are **not removed**, but it redirects the attack sequence to be taken
  - Hence, delaying the reconnaissance process, as well as breaking an ongoing attack

MTD Shuffle

- Example: Openflow Random Host Mutation
  - Typically, a host has one (physically) IP address
  - In HF-RHM scheme, each host has a physical IP address and a virtual IP address
  - Only the SDN controller knows the physical IP address of each host
  - Virtual IP (vIP) addresses are used for establishing communication channels
  - vIP addresses are shuffled every x seconds, OF switches are updated to redirect flows and update the existing communications
  - Attackers probing for IP addresses loses the identified victim host as vIP shuffles

Jafarian, Jafar Haadi, Ehab Al-Shaer, and Qi Duan. "Openflow random host mutation: transparent moving target defense using software defined networking." *Proceedings of the first workshop on Hot topics in software defined networks*. ACM, 2012.

MTD Shuffle

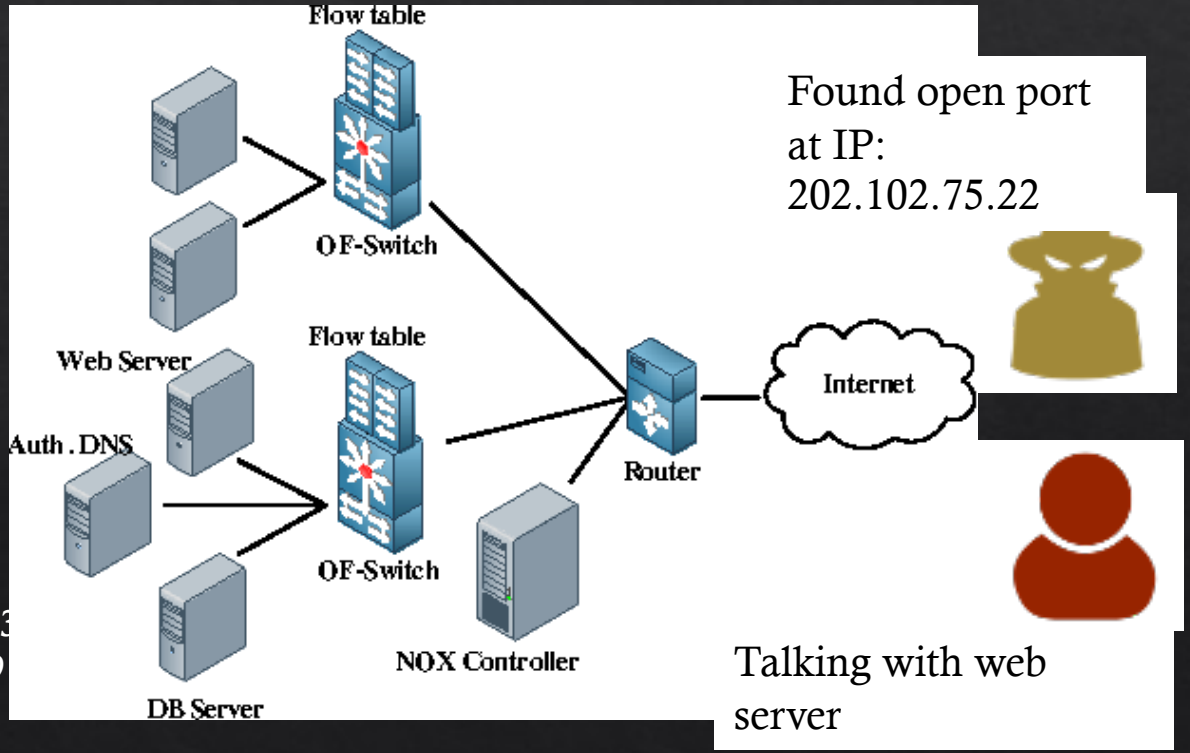
1

Attacker found vulnerabilities in the web server by scanning

rIP: 192.168.0.33
vIP: 202.102.75.22

rIP: 192.168.0.32
vIP: 202.100.64.84

rIP: 192.168.0.103
vIP: 202.116.3.89



MTD Shuffle

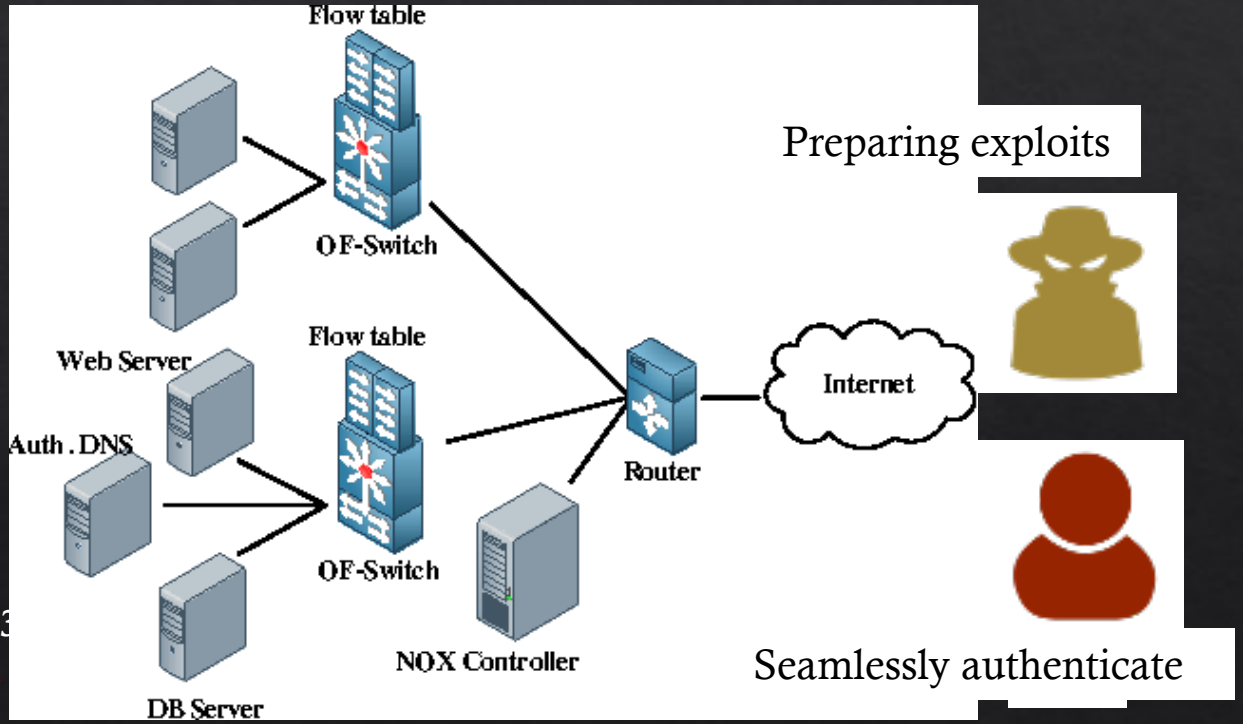
2

SDN controller shuffles vIP

rIP: 192.168.0.33
vIP: 202.122.78.14

rIP: 192.168.0.32
vIP: 202.167.69.41

rIP: 192.168.0.103
vIP: 202.198.43.1



MTD Shuffle

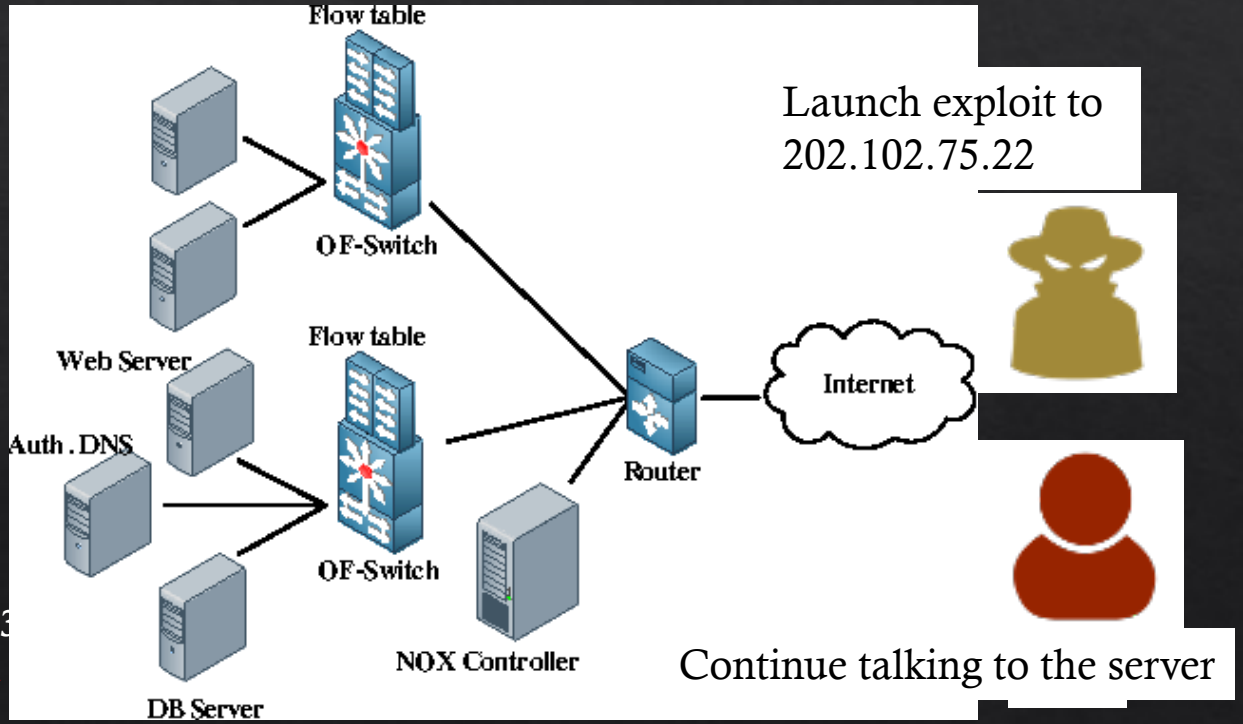
3

Attacker cannot reach the target

rIP: 192.168.0.33
vIP: 202.122.78.14

rIP: 192.168.0.32
vIP: 202.167.69.41

rIP: 192.168.0.103
vIP: 202.198.43.1



MTD Shuffle

- What are some issues to consider using shuffle?

MTD Diversity

- Diversity technique provides replacement of an existing component/service, with **different implementation/configuration** that provides the **same functionalities**
- Existing vulnerabilities may be **replaced** with a new set of vulnerabilities
  - E.g., replaced the Windows-based computer to Mac

MTD Diversity

- Example: Compiler generated software diversity
  - A version of software has a specific signature/binary
  - There are number of instructions to carry out the software task
  - These instructions can be remapped with other (single or combinations) instructions to do the same operations
    - Simply, 3+5 is the same as 14-6

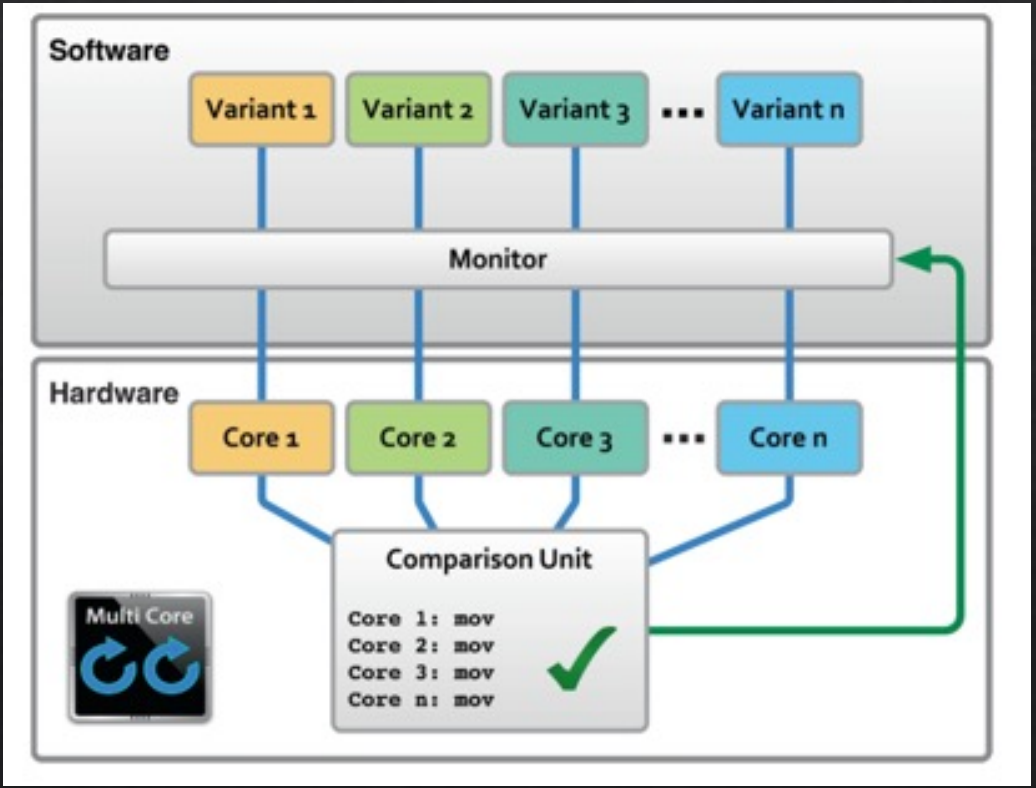
```
movl   %edx, %eax
xchgl  %edx, %eax
```

can be replaced with

```
leal   (%edx), %eax
xchgl  %edx, %eax
```


Jackson, Todd, et al. "Compiler-generated software diversity." *Moving Target Defense*. Springer, New York, NY, 2011. 77-98.

MTD Diversity



Variant monitor and comparison units are added to ensure the same operations by the variant software

Jackson, Todd, et al. "Compiler-generated software diversity." *Moving Target Defense*. Springer, New York, NY, 2011. 77-98.

MTD Diversity

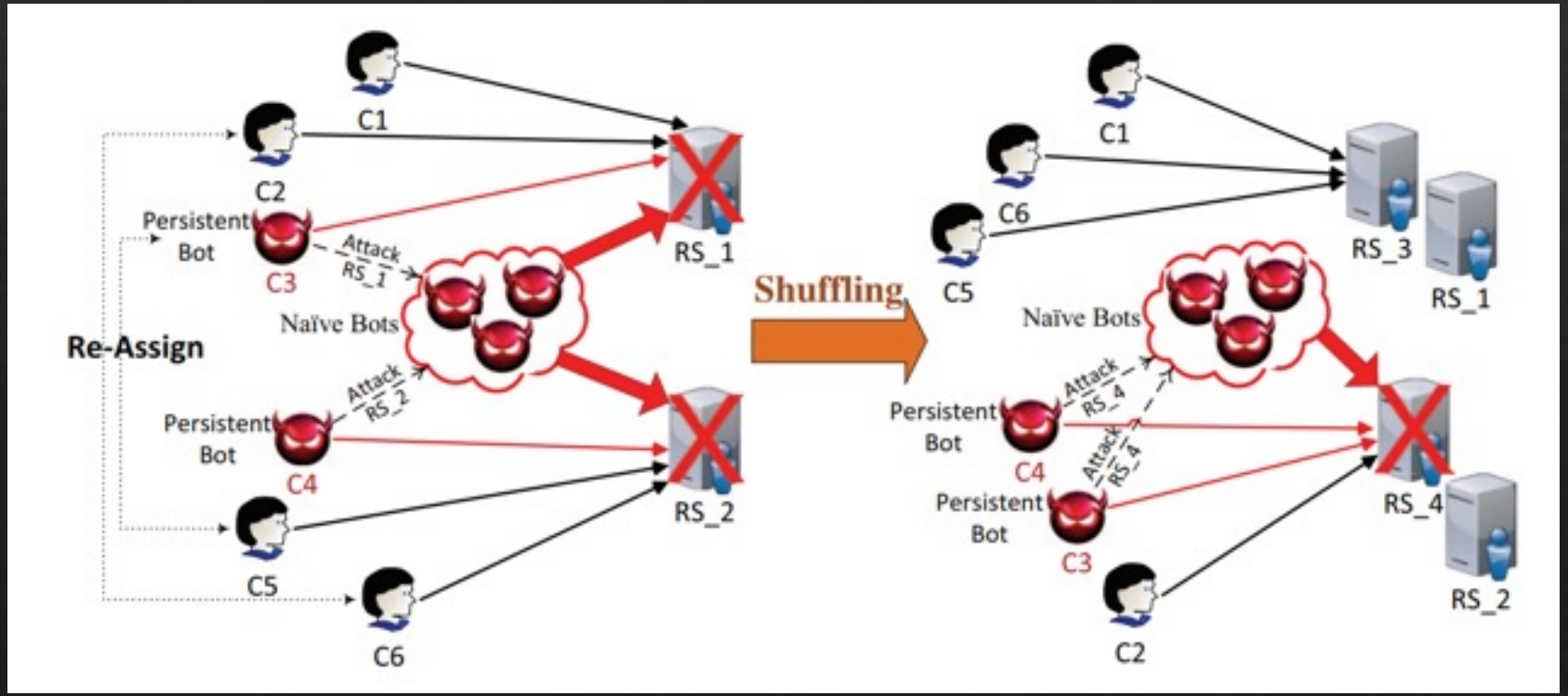
- What are some issues to consider using diversity?

MTD Redundancy

- Redundancy aims to ensure the availability of the system
- Replicas provide resources to handle high usage of the system
- It can be used in conjunction with other MTD techniques to provide defense against attackers
- For example DDoS attacks

Jia, Quan, et al. "Catch me if you can: A cloud-enabled DDoS defense." *Dependable Systems and Networks (DSN), 2014 44th Annual IEEE/IFIP International Conference on*. IEEE, 2014.

MTD Redundancy



Jia, Quan, et al. "Catch me if you can: A cloud-enabled DDoS defense." Dependable Systems and Networks (DSN), 2014 44th Annual IEEE/IFIP International Conference on. IEEE, 2014.

MTD Redundancy

- By adding redundant servers and shuffling identified bots to the same server, we can ensure the **availability** of the cloud resources to legitimate users
- Problems with redundancy techniques include

MTD

- Visualisation demo

MTD summary

- Different MTD techniques provide **different** approaches to ensure the **security objectives** of the system
- Still work to do in order to
  - Assess the effectiveness of MTD techniques
    - Models, metrics, methods, etc.
  - Combinations of MTD techniques
    - Applicable layers, compatibility etc.