Sapienza Università di Roma

Practical Network Defense

Master's degree in Cybersecurity 2024-25

Penetration testing and vulnerability assessment

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Principles of penetration testing

Vulnerability assessment vs. Penetration testing

- Vulnerability assessment
  - the process of identifying and quantifying vulnerabilities within a system
- Penetration testing
  - the process of evaluating the security of a computer system or network by simulating an attack from malicious outsiders and malicious insiders
    - active analysis
    - active exploitation
  - intent is to identify and demonstrate consequences of security weaknesses
  - should not disrupt the network…

Penetration testing steps

- Planning
- Non-intrusive target search (intelligence gathering)
- Intrusive target search
  - Scan!
- Data analysis
- Threat modeling and Exploitation
- Reporting
- Repeat! → maybe in six months…

Planning

- Scoping and terms
- IP addresses and domains
- Rules of engagement
  - DoS?
  - Social engineering?
- Times, targets, etc.
- Identify goals

Intelligence gathering (OSINT)

- Gather as much information about your target from publicly available information as possible
- Non intrusive search → reconnaissance
  - Use public resources
- Many tools available
  - nslookup, whois, traceroute/tcptraceroute, fierce.pl
  - google hacking
  - business research
  - online resources:
    - www.serversniff.net
    - The Way back machine (www.archive.org)
    - Shodan (www.shodan.io)
    - Recon-ng

Intrusive target search

- Probe and explore the target network
  - Remember: explicit written permission! Otherwise, it is ILLEGAL
- Aims:
  - Find live systems
  - Discover open ports
  - Discover services
  - Enumeration
- All this can be done by network scanners

Threat modeling and vulnerability scan

- It can start once we have the enumerated services
- Identify assets (what are we trying to get?)
  - Data
  - Employees (executives, administrators, etc.)
- Examine gathered information and look for exploitable known vulnerabilities
  - This can be automatized with tools like:
    - nessus
    - nexpose
    - OpenVAS (open source)
    - Nikto (open source)
    - Burp suite
    - Acutenix…

Vulnerability assessment

- Typically conducted remotely
- Usually conducted from outside the network
- It could also be performed within the network
  - Inside NVA
- It could also be performed within single hosts
  - Local NVA
- Typically remote assessment is done first

Data analysis

- Understanding the obtained data, acquired with the previous steps
- Determine missing elements or impartial results
- This step can also be repeated after the exploitation
- Can be time consuming

Exploitation

- The process of validating a discovered vulnerability
  - Can also be unsuccessful because of the vulnerability can not have exploits
- Again, we can use a tool for executing the exploit:
  - metasploit
  - BeEF
  - Throwback

Reporting

- Document everything that can describe the steps that lead to the exploit
- It will be the reference to address found issues
- Include:
  - Description of the exploited/exposed vulnerabilities
  - Analysis of the finding extracted from the reports
  - Recommendations of patches, best practices and solutions to mitigate or remove the risks
  - References to further readings
- Example: https://www.offensive-security.com/reports/sample-penetration-testing-report.pdf

Methodologies

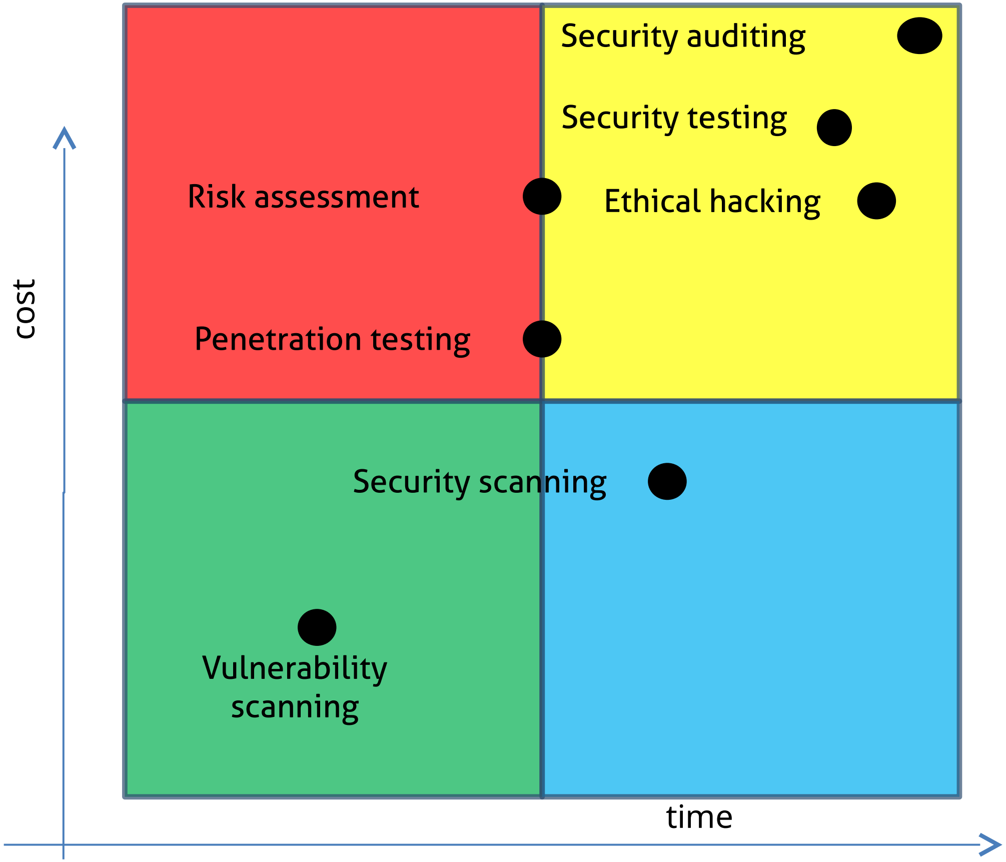
- Different processes and methodologies are available to perform security assessments
  - OSSTMM
  - NIST SP 800-115
    - for a (non-exhaustive) list, check OWASP website
- Provide a standardized approach to conduct penetration tests
- But... attackers don't agree on the methodologies and, more important, don't follow the rules!!\

Open Source Security Testing Methodology Manual

- An OSSTMM audit is an **accurate measurement of security** at an operational level that is void of assumptions and anecdotal evidence.
- **Consistent** and **repeatable**.
- As an open source project, it allows for any security tester to contribute ideas for performing more accurate, actionable, and efficient security tests.
  - Version 4 still draft

OSSTMM 3
The Open Source Security Testing Methodology Manual
Contemporary Security Testing and Analysis
Open Source Security Testing Methodology Manual
OSSTMM
www.osstmm.org
Created by Pete Herzog
Developed by ISECOM
ISECOM
INSTITUTE FOR SECURITY AND OPEN METHODOLOGIES

Types of security test



OSSTMM

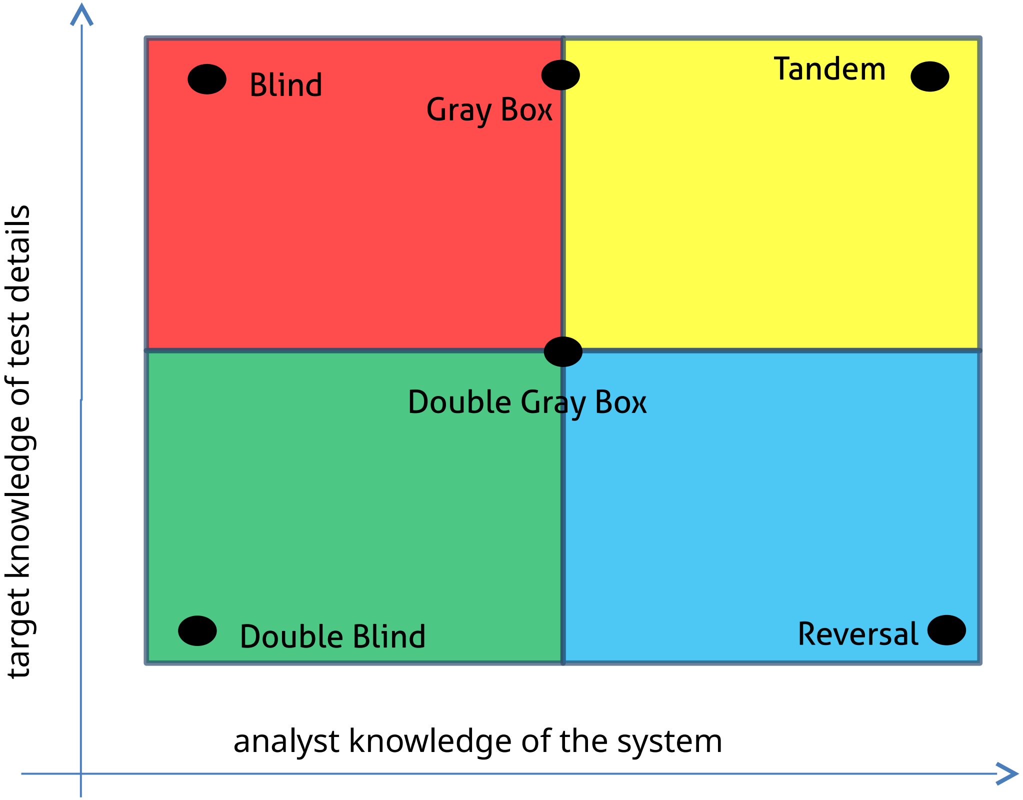
Security tests

- **Vulnerability Scanning**: **automated** checks for known vulnerabilities against a system or systems in a network.
- **Security Scanning**: vulnerability scans which include **manual** false positive verification, network weakness identification, and customized, professional analysis.
- **Penetration Testing**: a goal-oriented project which simulates an attack from a malicious hacker. It includes gaining privileged access by pre-conditional means.
- **Risk Assessment**: security analysis through interview and mid-level research which includes business justification, legal justifications, and industry specific justifications.

Security tests 2

- **Security Auditing**: a hands-on, privileged security inspection of the OS and Applications of a system or systems within a network or networks.
- **Ethical Hacking**: a penetration test of which the goal is to discover security flaws in the system and the network within the predetermined project time limit.
- **Security Testing**: and its military equivalent, the Posture Assessment, is a project-oriented risk assessment of systems and networks through the application of professional analysis on a security scan where penetration is often used to confirm false positives and false negatives as project time allows.

Security test typologies


Blind
Gray Box
Tandem
Double Gray Box
Double Blind
Reversal
target knowledge of test details
analyst knowledge of the system

OSSTMM

Typologies

- **Blind**:
  - The analyst engages the target with no prior knowledge of its defenses, assets, or channels.
  - The target is prepared for the audit, knowing in advance all the details of the audit.
  - A blind audit primarily tests the skills of the analyst. The breadth and depth of a blind audit can only be as vast as the analyst's applicable knowledge and efficiency allow.
- **Double Blind**:
  - The analyst engages the target with no prior knowledge of its defenses, assets, or channels.
  - The target is not notified in advance of the scope of the audit, the channels tested, or the test vectors.
  - A double blind audit tests the skills of the analyst and the preparedness of the target to unknown variables of agitation. The breadth and depth of any blind audit can only be as vast as the analyst's applicable knowledge and efficiency allows. This is also known as a **Black Box**.

Typologies 2

- **Gray Box**
  - The analyst engages the target with limited knowledge of its defenses and assets and full knowledge of channels.
  - The target is prepared for the audit, knowing in advance all the details of the audit.
  - A gray box audit tests the skills of the analyst. The nature of the test is efficiency. The breadth and depth depends upon the quality of the information provided to the analyst before the test as well as the analyst's applicable knowledge.
  - This type of test is often referred to as a **Vulnerability Test** and is most often initiated by the target as a self-assessment.
- **Double Gray Box:**
  - The analyst engages the target with limited knowledge of its defenses and assets and full knowledge of channels.
  - The target is notified in advance of the scope and time frame of the audit but **not the channels tested or the test vectors**.
  - A double gray box audit tests the skills of the analyst and the target's preparedness to unknown variables of agitation. The breadth and depth depends upon the quality of the information provided to the analyst and the target before the test as well as the analyst's applicable knowledge. This is also known as a **White Box** test.

Typologies 3

- **Tandem**
  - The analyst and the target are prepared for the audit, both knowing in advance all the details of the audit.
  - A tandem audit tests the protection and controls of the target. However, it cannot test the preparedness of the target to unknown variables of agitation.
  - The true nature of the test is thoroughness as the analyst does have full view of all tests and their responses. The breadth and depth depends upon the quality of the information provided to the analyst before the test (transparency) as well as the analyst's applicable knowledge. This is often known as an **In-House Audit** or a **Crystal Box** test and the analyst is often part of the security process.
- **Reversal**
  - The analyst engages the target with full knowledge of its processes and operational security, but the target knows nothing of what, how, or when the analyst will be testing.
  - The true nature of this test is to audit the preparedness of the target to unknown variables and vectors of agitation. The breadth and depth depends upon the quality of the information provided to the analyst and the analyst's applicable knowledge and creativity. This is also often called a **Red Team exercise**.

Vulnerability assessment

Penetration testing steps

- Planning
- Non-intrusive target search (intelligence gathering)
- Intrusive target search
  - Scan!
- Data analysis
- Threat modeling and Exploitation
- Reporting

What is a Vulnerability?

"A weakness in the computational logic (e.g., code) found in software and hardware components that, when exploited, results in a negative impact to confidentiality, integrity, or availability"

- Mitigation of the vulnerabilities in this context typically involves coding changes, but could also include specification changes or even specification deprecations (e.g., removal of affected protocols or functionality in their entirety).

What is a Vulnerability Scanner?

Something that Discovers and enumerates vulnerabilities on systems or applications.

-Q – Does a Scanner Protect my network?
-A – No.

Vulnerability scanners strength

- Very good at checking for hundreds (or thousands) of potential problems quickly
  - Automated
  - Regularly
- Can help identify rogue machines
- Helpful in inventory devices on the network
- Provide a generic risk level
- Explain why the item is a risk
- Provide detailed information on how to apply remediation
  - The differences of how your scanner does the above items are some of the key differences between the scanners

Types of vulnerability scanners

- Agent vs. agent-less
  - Agents are monitoring software running on each end node and communicate with a central scanner
  - Highly customizable and very precise information
- Passive vs. active
  - Passive scanners rely on monitoring network traffic and are completely unobtrusive
  - Can complement Active scanners
  - Real-time monitor of new entities in the network or configuration changes

Challenges of Vulnerability scanners

- Typically slower than simpler port scanners
- Some scanning / testing may disrupt operations (DDoS testing)
- False positive rate may be high and require human judgment
  - However false positives are preferred over false negatives
    - Better alert on something that's not there than miss stuff
- Vulnerability DB must be updated frequently
  - Always playing catch-up to changing threats
- Security resources are often decentralized
- The security organization often doesn't own the network or system
- Determining if the fix was actually made
  - Ignoring it → accepting it

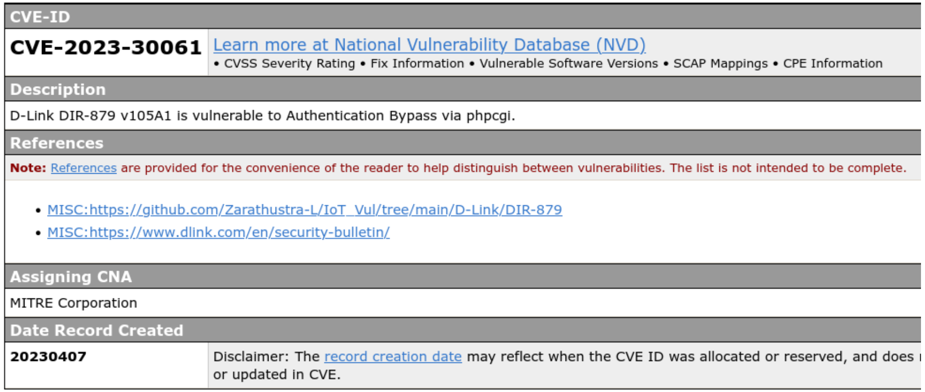
How do vulnerability scanners work?

- 1) Discovery
  - Check to see if the target is responding to network traffic
- 2) Port Scans
  - Find what ports are listening on the system
- 3) Service Detection
  - Based on the ports listening, talk to them to “guess” what they are based on patterns and other information
- 4) Operating System Detection
  - Based on the available information, “guess” the operating system

How do vulnerability scanners work?

5) Vulnerability Assessment

- Based on the available information, determine the vulnerabilities that may exist on the system
- Often listed by the “CVE” identifier



CVE-ID	
CVE-2023-30061	Learn more at National Vulnerability Database (NVD) • CVSS Severity Rating • Fix Information • Vulnerable Software Versions • SCAP Mappings • CPE Information
Description	
D-Link DIR-879 v105A1 is vulnerable to Authentication Bypass via phpcgi.	
References	
Note: References are provided for the convenience of the reader to help distinguish between vulnerabilities. The list is not intended to be complete.	
• MISC:https://github.com/Zarathustra-L/IoT_Vul/tree/main/D-Link/DIR-879 • MISC:https://www.dlink.com/en/security-bulletin/	
Assigning CNA	
MITRE Corporation	
Date Record Created	
20230407	Disclaimer: The record creation date may reflect when the CVE ID was allocated or reserved, and does or updated in CVE.

What is a CVE?

- **C**ommon **V**ulnerabilities and **E**xposures
- They are included in the NVD, the National Vulnerability Database, a dictionary of common names (i.e., CVEs) for publicly known information security vulnerabilities, operated by the NIST
- CVE is the industry standard for vulnerability and exposure identifiers
- CVE Entries — also called "CVEs," "CVE IDs," and "CVE numbers" by the community — provide reference points for data exchange so that cybersecurity products and services can speak with each other

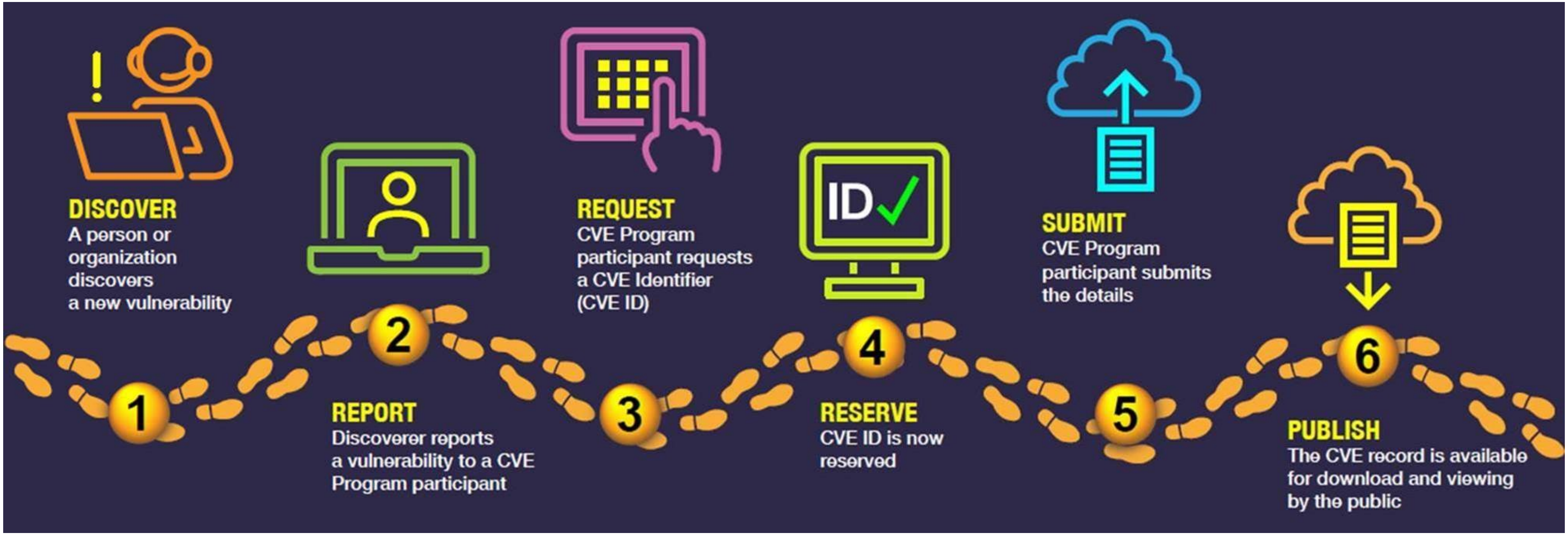
https://www.cve.org/About/Overview

CVE and CVSS

- When a new vulnerability is discovered, the MITRE Corporation pubblicly assigns a **Common Vulnerability and Exposure** (CVE) number
- The vulnerability is then analyzed by the US National Institute of Standards and Technology (NIST), which adopts a mechanism knon as **Common Vulnerability Scoring System** (CVSS) and provides a severity score and 8 commonly adopted security attributes of the vulnerability

https://nvd.nist.gov/vuln

CVE Record Lifecycle



1. **DISCOVER** A person or organization discovers a new vulnerability

2. **REPORT** Discoverer reports a vulnerability to a CVE Program participant

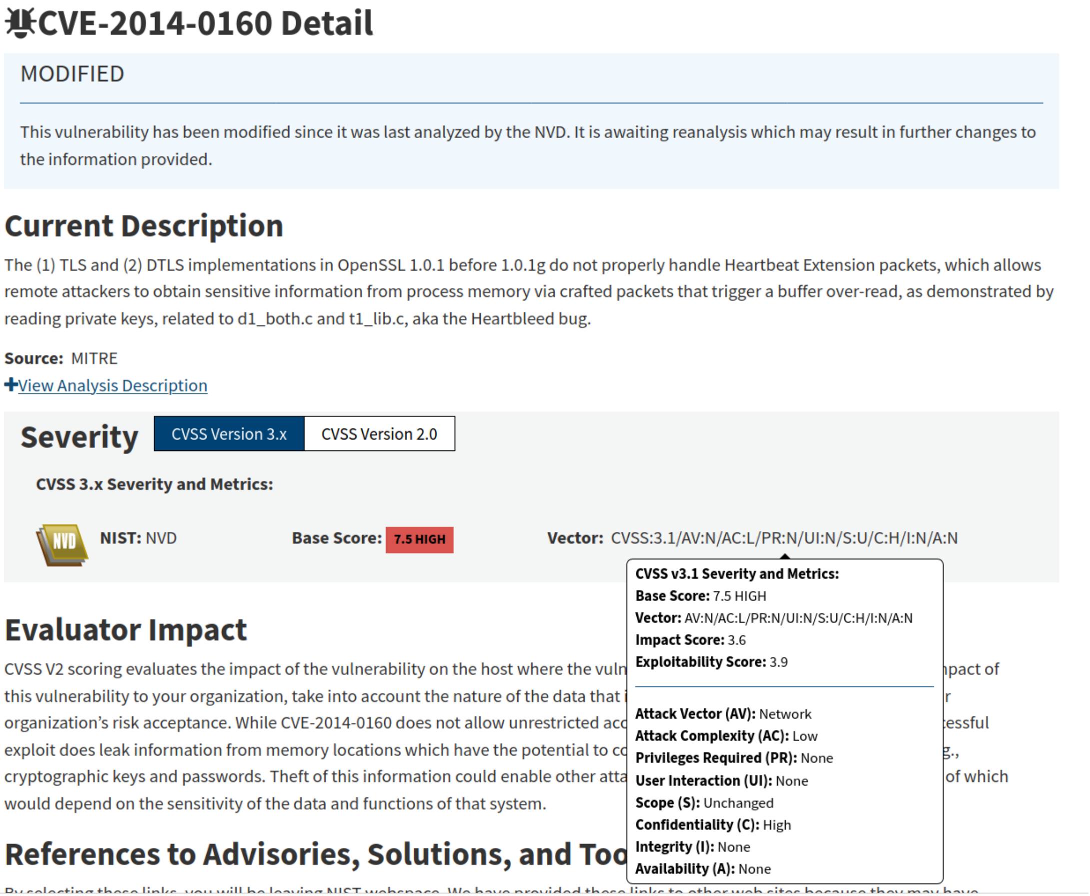
3. **REQUEST** CVE Program participant requests a CVE Identifier (CVE ID)

4. **RESERVE** CVE ID is now reserved

5. **SUBMIT** CVE Program participant submits the details

6. **PUBLISH** The CVE record is available for download and viewing by the public

CVE and CVSS of Heartbleed



CVE-2014-0160 Detail

MODIFIED

This vulnerability has been modified since it was last analyzed by the NVD. It is awaiting reanalysis which may result in further changes to the information provided.

Current Description

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.

Source: MITRE

+View Analysis Description

Severity

CVSS 3.x Severity and Metrics:

NIST: NVD **Base Score:** 7.5 HIGH **Vector:** CVSS:3.1/AV:N/AC:L/PR:N/UI:N/S:U/C:H/I:N/A:N

CVSS v3.1 Severity and Metrics:
Base Score: 7.5 HIGH
Vector: AV:N/AC:L/PR:N/UI:N/S:U/C:H/I:N/A:N
Impact Score: 3.6
Exploitability Score: 3.9

Attack Vector (AV): Network
Attack Complexity (AC): Low
Privileges Required (PR): None
User Interaction (UI): None
Scope (S): Unchanged
Confidentiality (C): High
Integrity (I): None
Availability (A): None

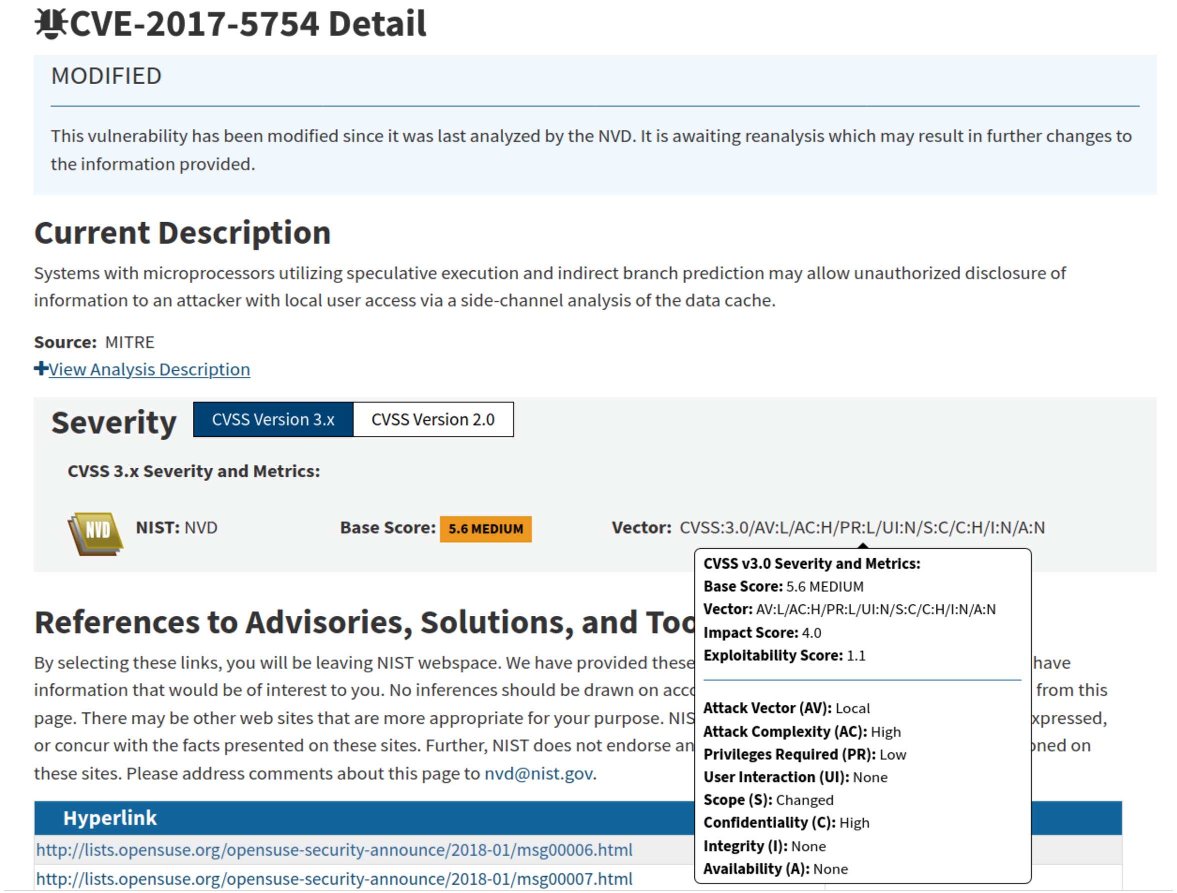
Evaluator Impact

CVSS V2 scoring evaluates the impact of the vulnerability on the host where the vuln npact of this vulnerability to your organization, take into account the nature of the data that i r organization's risk acceptance. While CVE-2014-0160 does not allow unrestricted acc essful exploit does leak information from memory locations which have the potential to co g., cryptographic keys and passwords. Theft of this information could enable other atta of which would depend on the sensitivity of the data and functions of that system.

References to Advisories, Solutions, and Too

By selecting these links, you will be leaving NIST webspace. We have provided these links to other web sites because they may have

CVE and CVSS of Meltdown



CVE-2017-5754 Detail

MODIFIED

This vulnerability has been modified since it was last analyzed by the NVD. It is awaiting reanalysis which may result in further changes to the information provided.

Current Description

Systems with microprocessors utilizing speculative execution and indirect branch prediction may allow unauthorized disclosure of information to an attacker with local user access via a side-channel analysis of the data cache.

Source: MITRE

+View Analysis Description

Severity

CVSS 3.x Severity and Metrics:

NVD **NIST:** NVD **Base Score:** 5.6 MEDIUM **Vector:** CVSS:3.0/AV:L/AC:H/PR:L/UI:N/S:C/C:H/I:N/A:N

CVSS v3.0 Severity and Metrics:
Base Score: 5.6 MEDIUM
Vector: AV:L/AC:H/PR:L/UI:N/S:C/C:H/I:N/A:N
Impact Score: 4.0
Exploitability Score: 1.1

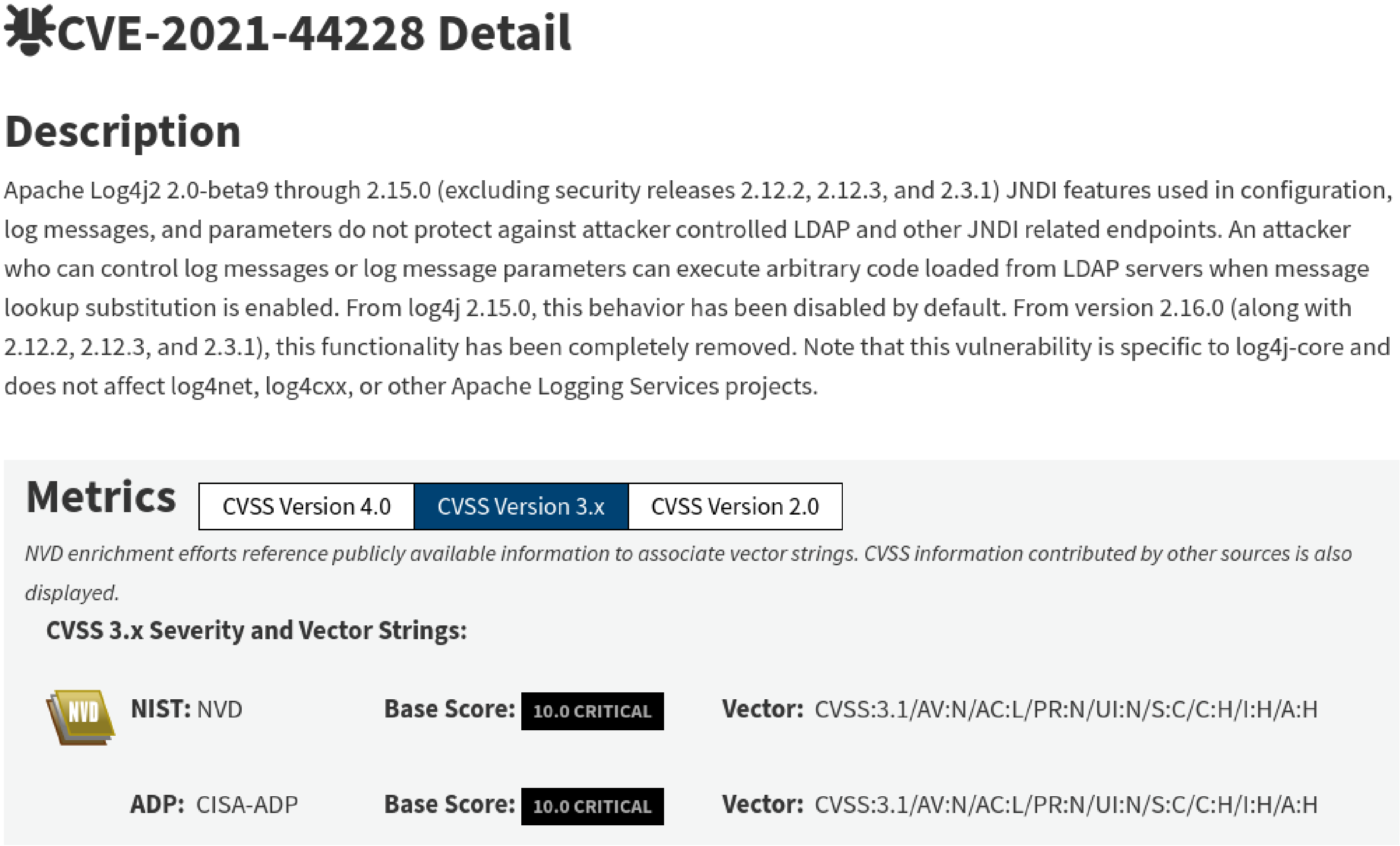
Attack Vector (AV): Local
Attack Complexity (AC): High
Privileges Required (PR): Low
User Interaction (UI): None
Scope (S): Changed
Confidentiality (C): High
Integrity (I): None
Availability (A): None

References to Advisories, Solutions, and Too

By selecting these links, you will be leaving NIST webspace. We have provided these have information that would be of interest to you. No inferences should be drawn on acc from this page. There may be other web sites that are more appropriate for your purpose. NIS xpressed, or concur with the facts presented on these sites. Further, NIST does not endorse an ned on these sites. Please address comments about this page to nvd@nist.gov.

Hyperlink
http://lists.opensuse.org/opensuse-security-announce/2018-01/msg00006.html
http://lists.opensuse.org/opensuse-security-announce/2018-01/msg00007.html

CVE and CVSS of Apache Log4shell



CVE-2021-44228 Detail

Description

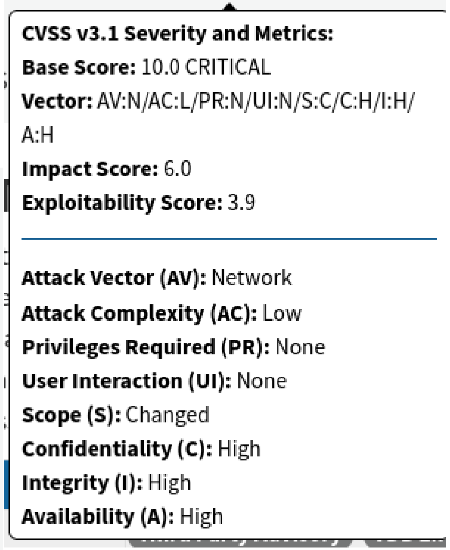
Apache Log4j2 2.0-beta9 through 2.15.0 (excluding security releases 2.12.2, 2.12.3, and 2.3.1) JNDI features used in configuration, log messages, and parameters do not protect against attacker controlled LDAP and other JNDI related endpoints. An attacker who can control log messages or log message parameters can execute arbitrary code loaded from LDAP servers when message lookup substitution is enabled. From log4j 2.15.0, this behavior has been disabled by default. From version 2.16.0 (along with 2.12.2, 2.12.3, and 2.3.1), this functionality has been completely removed. Note that this vulnerability is specific to log4j-core and does not affect log4net, log4cxx, or other Apache Logging Services projects.

Metrics

NVD enrichment efforts reference publicly available information to associate vector strings. CVSS information contributed by other sources is also displayed.

CVSS 3.x Severity and Vector Strings:

NIST: NVD	**Base Score:** 10.0 CRITICAL	**Vector:** CVSS:3.1/AV:N/AC:L/PR:N/UI:N/S:C/C:H/I:H/A:H
ADP: CISA-ADP	**Base Score:** 10.0 CRITICAL	**Vector:** CVSS:3.1/AV:N/AC:L/PR:N/UI:N/S:C/C:H/I:H/A:H



CVSS v3.1 Severity and Metrics:
Base Score: 10.0 CRITICAL
Vector: AV:N/AC:L/PR:N/UI:N/S:C/C:H/I:H/A:H
Impact Score: 6.0
Exploitability Score: 3.9

Attack Vector (AV): Network
Attack Complexity (AC): Low
Privileges Required (PR): None
User Interaction (UI): None
Scope (S): Changed
Confidentiality (C): High
Integrity (I): High
Availability (A): High

Buffer overflow and other types of vulnerabilities

- Generally one reason: improper input validation
- But also:
  - Memory exposure/leakage
  - Bad configurations
  - Bad implementations
  - Default credentials
  - Force use of weak/legacy protocols

Vulnerability scanner principles

- Probing specific services/protocols for weaknesses
  - Not just generic IP addresses like “nmap”
- Most useful when working from pre-gathered info
  - From databases or other network scanning
- Similar to virus scanning software
  - Contain a database of vulnerability signatures that the tool searches for on a target system
  - Cannot find vulnerabilities not in the database
    - New vulnerabilities are discovered often
    - Vulnerability database must be updated regularly

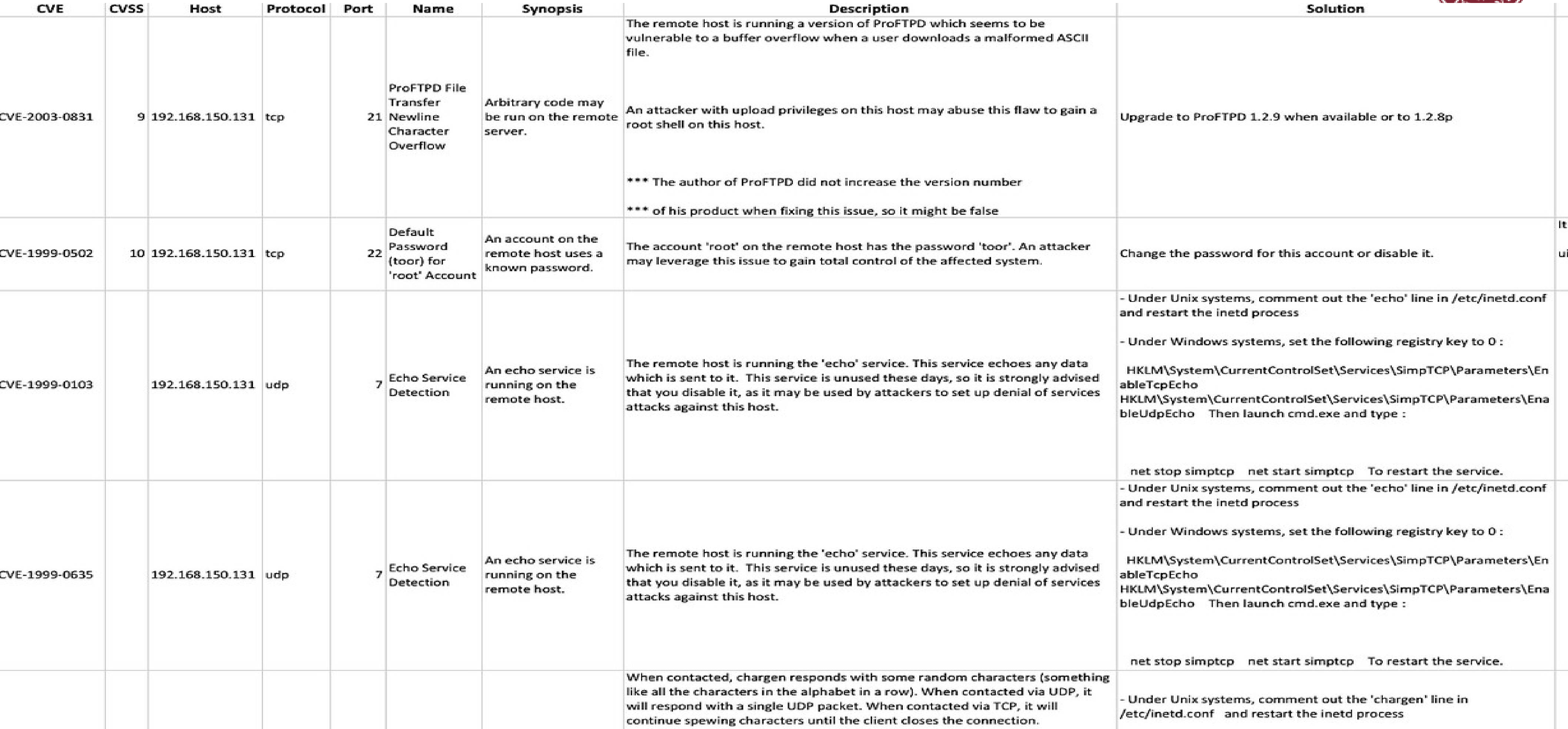
Vulnerability scanner methodology

- Manual Attempts and Permutation (fuzzers)
  - Very long time
- Manual Version Probe
  - Slightly better, but still very slow
- Custom Protocol-Specific Attacks
  - requires special knowledge
- Automated Vuln-Scanner
  - simple, fairly reliable, fast, thorough

Process the found vulnerabilities

- Vulnerability Data is just a big spreadsheet style list or a report.
- By itself, vulnerability scan data lacks context
  - Can’t expect folks to act on 1,000 page reports
- Need to provide some prioritization
  - What are the biggest risks in your environment?
  - What is the level of risk that is acceptable in your environment?
  - What is the threat level that exists in your industry?
- Turn the data into **actionable information**

You start with something like this..



CVE	CVSS	Host	Protocol	Port	Name	Synopsis	Description	Solution	
CVE-2003-0831	9	192.168.150.131	tcp	21	ProFTPD File Transfer Newline Character Overflow	Arbitrary code may be run on the remote server.	The remote host is running a version of ProFTPD which seems to be vulnerable to a buffer overflow when a user downloads a malformed ASCII file. An attacker with upload privileges on this host may abuse this flaw to gain a root shell on this host. *** The author of ProFTPD did not increase the version number *** of his product when fixing this issue, so it might be false	Upgrade to ProFTPD 1.2.9 when available or to 1.2.8p	
CVE-1999-0502	10	192.168.150.131	tcp	22	Default Password (toor) for 'root' Account	An account on the remote host uses a known password.	The account 'root' on the remote host has the password 'toor'. An attacker may leverage this issue to gain total control of the affected system.	Change the password for this account or disable it.	It ui
CVE-1999-0103		192.168.150.131	udp	7	Echo Service Detection	An echo service is running on the remote host.	The remote host is running the 'echo' service. This service echoes any data which is sent to it. This service is unused these days, so it is strongly advised that you disable it, as it may be used by attackers to set up denial of services attacks against this host.	- Under Unix systems, comment out the 'echo' line in /etc/inetd.conf and restart the inetd process - Under Windows systems, set the following registry key to 0 : HKLM\System\CurrentControlSet\Services\SimpTCP\Parameters\EnableTcpEcho HKLM\System\CurrentControlSet\Services\SimpTCP\Parameters\EnableUdpEcho Then launch cmd.exe and type : net stop simptcp net start simptcp To restart the service.	
CVE-1999-0635		192.168.150.131	udp	7	Echo Service Detection	An echo service is running on the remote host.	The remote host is running the 'echo' service. This service echoes any data which is sent to it. This service is unused these days, so it is strongly advised that you disable it, as it may be used by attackers to set up denial of services attacks against this host.	- Under Unix systems, comment out the 'echo' line in /etc/inetd.conf and restart the inetd process - Under Windows systems, set the following registry key to 0 : HKLM\System\CurrentControlSet\Services\SimpTCP\Parameters\EnableTcpEcho HKLM\System\CurrentControlSet\Services\SimpTCP\Parameters\EnableUdpEcho Then launch cmd.exe and type : net stop simptcp net start simptcp To restart the service.	
							When contacted, chargen responds with some random characters (something like all the characters in the alphabet in a row). When contacted via UDP, it will respond with a single UDP packet. When contacted via TCP, it will continue spewing characters until the client closes the connection.	- Under Unix systems, comment out the 'chargen' line in /etc/inetd.conf and restart the inetd process	

Using Vulnerability Scan Data

- Analyze the Data and Add Context
  - How are composed the systems and networks?
  - Which are the “controls” in place?
  - The Default CVSS Risk Scoring is scored for systems on the Internet!
- Prioritize the Findings
  - CVSS Scores are a baseline severity
  - Risk & Risk Appetite should vary by company
  - What is most important for the target company?

Actionable information

- Make a “Remediation“, or “Go Fix it” plan
  - Resources are limited & factor into what gets fixed
  - Usually it is impossible to say “Go Fix Everything“, mainly for very big environment
- Can be useful to ask why are the vulnerabilities there in the first place
  - Address the root causes can truly reduce the long term security exposure
  - If not properly managed, the same kind of vulnerabilities will be back!

Trends in Vulnerability Scanners

- More features
  - Configuration management
  - Application & System vulnerabilities
  - Helping Analyze the Data
  - Helping Report on the Data
  - Confirming the Data

- Specialized Scanners
  - ERP Systems
  - SCADA Scanners
  - Database Scanners
  - Application Scanners

Common System Vulnerability Scanners

Nessus
McAfee Vulnerability Manager
QualysGuard
Retina
Nmap
Nexpose
OpenVAS
Core Impact
Saint
………

Application Scanner Tools

IBM AppScan
WebInspect
Netsparker
Burp Suite
ParosPro
Nessus
QualysGuard WAS
Zed Attack Proxy
sqlmap
W3AF
Acunetix Freed Edition
Safe3WVS
arachni
Skipfish
N-Stalker
Watobo
SyHunt Mini

That’s all for today

- **Questions?**
- References:
  - OSSTMM
  - https://www.cve.org/
  - https://nvd.nist.gov/
  - https://greenbone.github.io/docs/latest/