

BACHELOR'S THESIS COMPUTING SCIENCE

# Stronghold: Automating corporate security.

*A novel approach at pipelining the entire security improvement cycle for (Azure) AD and Google Workspace environments.*

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## **Abstract**

This paper outlines a novel approach to the ongoing security improvement cycle for both Microsoft and Google environments. The aim is to develop auditing systems for Active Directory, Azure Active Directory, and Google Workspace. In addition to this, we introduce a tool for auditing websites for known vulnerabilities. We also introduce phishing simulations specifically finetuned for Google and Microsoft environments to do aimed phishing simulations. The aim is a complete toolkit to audit companies that use Microsoft and Google solutions. Therefore the novelty partially lies in direct usability for these systems without having to finetune or adjust. We call the entire system Stronghold, a solution to automate the entire security improvement cycle. Stronghold aims to go from vulnerability detection to remediation within one single encapsulated cycle. Our audit tools either set a new state-of-the-art or are novel in their category. In all of our tools, we introduce a new security remediation pipeline called FRIS. The goal of this pipeline is to offer information, in-depth information, and even direct solutions and scripts for found vulnerabilities. All the results are shown in automatically generated, AI-infused, html reports.

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# Chapter 1

## Introduction

Corporate environments are organizations or businesses that operate intending to generate profits. These environments often handle sensitive information such as financial data, intellectual property, and personal information of employees and customers. Because of this, security is extremely important in corporate environments [5].

There are several reasons why security is often disregarded in corporate environments. One reason is that companies may prioritize cost-cutting measures over security, leading them to neglect investments in strong security measures [1]. Another reason is that some companies may not have a clear understanding of the risks and vulnerabilities that exist within their systems, leading them to underestimate the importance of security [9]. Additionally, some companies may have a culture that does not prioritize security, which can lead to a lack of attention to security protocols and practices [14].

It is common for corporate environments to use solutions from Microsoft or Google for their domains. These companies offer a range of products and services such as email, cloud storage, and productivity tools that are widely used by businesses [12, 60]. Most often used are Google Workspace and Microsoft (Azure) Active Directory. Using solutions from these companies can help organizations streamline their operations and improve productivity, but it is important for companies to also ensure that they have adequate security measures in place to protect their sensitive data [20].

Overall, security is crucial in corporate environments as it helps to protect sensitive information and prevent unauthorized access or breaches [65]. Companies need to prioritize security and invest in strong security measures to protect their assets and maintain the trust of their employees and customers [5].

This paper presents a novel approach to automate Google Workspace and (Azure) AD auditing. The audit tools are automated tools that encapsulate the entire security improvement cycle, with the goal of maximum security improvements with minimum effort. In our code design, vulnerabilities are presented as classes with additional information and even solutions. We call this system FRIS. A class-based methodology that is implemented in all sub-tools. Fris aims to provide the following features:

- Find as many vulnerabilities in the Google/(A)AD environment as possible.
- Offer information about all found vulnerabilities.
- Offer links and further reading for all found vulnerabilities.
- Offer impact analysis for possible patches to make sure the system keeps working properly after patching.
- Offer solutions for all vulnerabilities, completing the pipeline.

This system fits our aims because it offers a complete step-based pattern quickly.

1. Find the problem.
2. Report about the problem.
3. Inform the user about steps to take, impact to analyze, and information to provide to end users.
4. Solve the problem.

The user quickly embarks on a guided journey that allows him/her to improve security without ever having to leave our assessment ecosystem. The ease of usability is further underlined by offering complete web pages and reports. The urgency gets underlined by a set of security scores that are generated based on our findings. Our work for Microsoft is somewhat related to the Purple Knight [11] and the PingCastle [43] tools, which both are security frameworks based upon finding vulnerabilities in (Azure) Active Directory. We differ from these systems by finding more vulnerabilities and by going further than just finding problems, introducing our FRIS pipeline.

Our work for Google is novel. As far as we know, there are no automatic tools to enumerate weaknesses in Google Workspace settings, which was confirmed by a Google employee after a support call from our end [18].

Chapter 2 is about the preliminaries of this research, diving into the Google

Workspace and (Azure) Active Directory infrastructures. It is also about the possible sources of vulnerabilities. Chapter 3 talks about FRIS and the approach we take when generating findings. Chapter 4 dives into AD pen-testing. Chapter 5 dives into google workspace auditing. Chapter 6 dives into phishing simulation for Google/Microsoft environments. Chapter 7 goes into our auditing tools for web environments. Chapter 8 is about a real-life use test scan we did for our Active Directory auditing tool. Chapter 9 talks about related work. Chapters 10 and 11 then provide discussions and conclusions.



## Chapter 2

# Preliminaries

This chapter aims at introducing the concepts that are important to fully understand the depth of the work and the concepts that are discussed in later chapters. It aims to give an extensive overview of the underlying structures that form the foundation of this work. To fully understand vulnerabilities it is quite essential to grasp the structures that facilitate them.

### 2.1 Active Directory

Active Directory is a Microsoft system that functions as a directory service for the Windows domain [13]. It is composed of a set of processes and services, the primary one being the Domain Service Role or Domain Controller. This server authenticates, authorizes, enforces policies, stores information, and provides rights and roles to all members of the Domain. The active directory environment is comprised of multiple components with individual functions and vulnerabilities.

#### 2.1.1 Services

Active Directory (AD) services provide a centralized, secure, and globally managed repository of user and resource data [48]. The main services are authentication, authorization, user management, and information storage. Authentication verifies the identity of a user in the network, while authorization grants access to resources or services. User management tasks include creating, managing, and deleting user accounts. Information storage enables users to store and manage data securely and reliably. Additionally, AD services provide single sign-on (SSO) capabilities, allowing users to access multiple systems and applications with a single login [3]. AD also offers directory synchronization, which allows organizations to keep multiple directories in sync across multiple computers and locations. Overall, Active Directory services provide a robust and secure platform for managing user

and resource data.

### **2.1.2 Group policies**

Group policies enable administrators to centrally manage and control the configuration of users and computers in a domain [59]. Group policies are applied to computers or users in a specific organizational unit (OU) which are placed in a hierarchical structure to divide and manage objects. Group policies can be used to configure user settings and control computer settings such as software installations, system updates, network access, security settings, and user rights [59]. In addition to controlling the configuration of objects, group policies are also used to deploy software and scripts across the network. Group policies enable administrators to manage and control the configuration of users and computers and deploy applications and scripts quickly and easily.

### **2.1.3 Domain name services**

Domain name services (DNS) provide a way to locate resources and services on a network [44]. DNS is used to translate human interpretable names (e.g. `www.example.com`) to IP addresses. DNS resolves the named host or service to its IP address, thus allowing other hosts to connect to it. DNS also provides a way to organize and manage information in the domain. All domain computers are registered with a DNS record, which can also include information about services offered by the host [44]. DNS enables users to access resources quickly and easily by providing an easy way to locate resources and services in the domain.

### **2.1.4 Kerberos**

Kerberos is a network authentication protocol used to authenticate users and services in a secure manner [50]. Kerberos uses tickets to authenticate users and provides strong cryptography to protect the authentication process. Tickets are obtained from a Kerberos server and the client must present the ticket to the service to prove their identity [50]. Kerberos is a trusted third-party authentication protocol and is used by many organizations to authenticate users and services in the domain. The use of Kerberos authentication provides an extra layer of security to the domain and ensures that user credentials are kept safe and secure.

## **2.2 Vulnerabilities inside Active Directory**

Active Directory is a powerful directory solution and is used in many organizations for authentication, authorization, and user management [13]. How-

ever, with the increased use of AD, the threats to its security have increased as well. Some of the common vulnerabilities of AD include weak passwords, incorrect permissions settings, inadequate patch management, and lack of auditing procedures [58]. Additionally, there are security vulnerabilities that exist within the AD framework itself, such as privilege escalation, replication issues, and denial of service attacks [58]. As with any system, vulnerabilities exist even if the system is secure in itself. It is important to identify and address these vulnerabilities to maintain a secure environment.

## **2.3 Azure Directory Passwords**

Azure Directory, like almost every system nowadays, uses passwords for authentication [34]. Passwords in Active Directory are of extreme value, as there is no such thing as Multi-Factor Authentication present in these environments. Hence knowing a password gives you full access to an account. Therefore using tools to examine password strength and choice is a big part of the work we have to do in the assessment of an active directory server.

### **2.3.1 Password policy**

Active Directory uses a global password policy to set certain requirements for passwords [3]. It allows IT administrators to set a minimum password length. It also allows them to require complexity, meaning that of lowercase letters, uppercase letters, numbers, and other symbols, three of these four have to be used in a password. In addition to this, the password policy offers options for password history, disallowing previous passwords and an option for password lockout, to specify after how many attempts a user is locked out and how long it takes before they can log in after a lockout again [59]. Notice that this kind of policy allows for a huge amount of problems to quickly arise. A short minimum password length is an enormous problem because it makes life way too easy for hash crackers. A lockout amount of 0 allows for unlimited login possibilities and password spraying/brute-forcing attacks. Therefore carefully setting up this policy is often one of the most important responsibilities of the AD administrator.

## **2.4 Azure Active Directory**

Azure Active Directory is the cloud-based alternative for Azure Directory [34]. While this version does not have the number of options and depth as Azure Directory, it has a load of different features and defense mechanisms. A substantial example of this is MFA. The system is a little less prone to vulnerabilities due to old mechanisms and systems because it is hosted on

Microsoft's end. It is also newer, meaning fewer vulnerabilities due to old age occur.

### **2.4.1 MFA**

MFA, short for Multi-Factor Authentication, is the new and upcoming standard for authentication [40]. This form of authentication adds a second layer of defense to authentication as it requires users to verify their authentication requires using a second factor. In practice, this is often done by using the Microsoft Authenticator app on their phone. This makes it much harder for hackers to simply crack a hash and use a password because now they also need access to a phone. While MFA is a deal changer in the scene, there are also some weaknesses known.

1. SMS spoofing, the act of spoofing an SMS number to obtain the MFA verification instead. [37]
2. MFA is often required only once in x days, so you can still use a colleague's laptop and use it to bypass MFA.
3. Stolen session cookies can be authenticated for a certain period before asking for MFA again [40].

### **2.4.2 Conditional access**

In Azure Active Directory, one of the first lines of defense becomes conditional access [34]. Conditional access, as given away by the name, lets you block traffic or enforce requirements on it based on certain conditions that you can set up. In practice, this is used to block legacy authentication (non-MFA authentication). But also to require MFA, to block persistent browser sessions, noncompliant devices, etc. It can also be used to block certain countries or exclude certain IP ranges like the company office from MFA [34].

### **2.4.3 Compliance policies and bitlocker**

Two powerful features which we also think are important security mechanisms inside the AAD environment are compliance policies and a BitLocker policy [35]. With compliance policies, we can require devices in our network to be of a certain safe Windows version, in addition to this we can require secure boot to be on and we can also set requirements in how good their computer pin/password should be [35]. Therefore we can require some basic safety precautions for devices that want to be on our network. With a BitLocker policy, we can automatically roll out BitLocker on devices, securing their hard disk and making sure that the data on it is properly protected in case of theft [35].

## 2.5 Google (Cloud) Workspace

The Google Workspace (formerly known as G Suite) is a collection of productivity and collaboration tools offered by Google [32]. It includes a range of services such as Gmail, Google Drive, Google Calendar, and Google Docs, which allow users to communicate, store and access files, schedule events, and create and edit documents online. Some of the key security options within Google Workspace include:

1. Encryption: Google Workspace uses encryption to protect the confidentiality of users' data while it is in transit and at rest [33]. This includes the use of Secure Sockets Layer (SSL) and Transport Layer Security (TLS) for data transmission, as well as AES and SSL encryption for data storage.
2. Two-factor authentication: This is an additional layer of security that requires users to provide a second form of authentication, such as a code sent to their phone, to access their account [24]. This helps to prevent unauthorized access to users' accounts.
3. Access controls: Google Workspace allows administrators to set up user accounts and permissions, which can be used to control access to different tools and services within the suite [29]. This includes setting up roles and permissions for different users, as well as specifying the types of actions that users are allowed to take within the tools.
4. Data loss prevention: Google Workspace includes tools for detecting and preventing the accidental or unauthorized sharing of sensitive data [28]. This includes the ability to set up data loss prevention policies to block the sharing of specific types of data, as well as the ability to track and audit data-sharing activities.
5. Password security: Google Workspace includes tools for managing password security, including the ability to require strong passwords and to enforce password expiration policies [30]. Users can also use tools such as Google's Password Checkup to check the strength and security of their passwords.
6. Session length: Google Workspace allows administrators to set the length of time that user sessions will remain active, which can help to prevent unauthorized access to accounts if a device is left unattended [31]. Administrators can also set up inactivity timeout policies to automatically log users out after a certain period of inactivity.
7. Context-aware access: Google Workspace includes context-aware access controls, which allow administrators to set up policies that grant

or restrict access to certain tools and services based on the context in which they are being used [26]. For example, administrators can set up policies that only allow access to certain tools from specific locations, devices, or networks.

8. Phishing and spam protection: Google Workspace includes tools for detecting and blocking phishing and spam emails [23]. These tools use a combination of machine learning algorithms and user feedback to identify and block malicious emails. Users can also report suspicious emails to help improve the effectiveness of the spam filters.
9. SPF, DKIM, and DMARC: Google Workspace supports the use of SPF (Sender Policy Framework), DKIM (DomainKeys Identified Mail), and DMARC (Domain-based Message Authentication, Reporting, and Conformance) to help protect against email spoofing and phishing attacks [25]. These protocols allow administrators to verify the authenticity of emails that are sent from their domain, and to block emails that fail these checks.
10. External users and external sharing: Google Workspace allows users to share files and collaborate with people outside their organization [27]. However, it is important to be cautious when sharing data with external users, as this can increase the risk of data leaks and other security vulnerabilities. Google Workspace provides tools for managing external sharing, including the ability to set up policies that control who can access shared data and how it can be shared. It is also important to note that mail forwarding to external addresses is disabled by default in Google Workspace to prevent data leaks [27].

## 2.6 Phishing in corporate environments

Phishing can pose significant risks to corporate environments [62]. Phishing involves the use of fraudulent emails or websites to trick individuals into revealing sensitive information, such as login credentials or financial information [6]. In a corporate environment, phishing can pose several risks. These include:

- Phishing attacks can require significant time and resources to investigate and mitigate.
- Data breaches: Phishing attacks can lead to the compromise of sensitive corporate information, such as intellectual property or customer data [36].
- Financial losses: Phishing attacks can result in the theft of financial information or the unauthorized transfer of funds [19].

To mitigate these risks, corporate environments need to implement robust phishing prevention measures. One effective approach is the use of phishing simulations, which involve the creation and distribution of simulated phishing attacks to employees [22]. These simulations can help educate employees about the risks of phishing and test their ability to identify and report suspicious emails. Other important background concepts related to phishing simulations include:

- Social engineering: Phishing attacks often rely on social engineering techniques to manipulate individuals into revealing sensitive information or performing certain actions [49].
- Email security: Measures such as authentication and encryption can help protect against the interception of emails and the compromise of sensitive information [21].
- User education: Providing employees with training on how to identify and report suspicious emails can help mitigate the risk of successful phishing attacks [38].

## Chapter 3

# FRIS: A cycle based vulnerability approach

We introduce a novel methodology for the vulnerability-solving process called FRIS. This methodology expands the normal pipeline used by a security officer to encapsulate the information-finding and problem-solving part into the automated and offered pipeline. FRIS is not a tool but an idea that is solidified in all our tools. We use vulnerability classes in all our systems to generate information about vulnerabilities. You can see the original pipeline of auditing tools and our novel extension of it in the figure below:

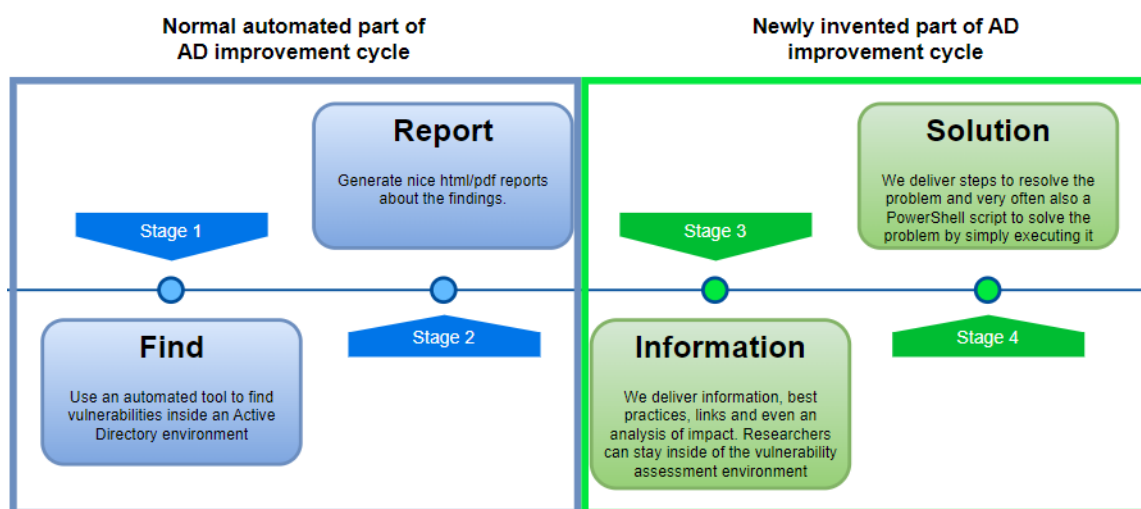


Figure 3.1: The old security improvement cycle vs the new one

Let us go more in-depth about the FRIS cycle, FRIS stands for Find, Report, Inform, Solve. A pipeline we will explain a little bit more in-depth:



1. Find: we find a vulnerability and confirm it in a fully automated manner.
2. Report: we generate HTML documentation about the found vulnerabilities but also an HTML page per single vulnerability. In addition to this, we use our novel scoring system to score the target on multiple categories and to give each vulnerability its unique score.
3. Inform: inside our report, we offer information so that the security researcher using Stronghold is immediately capable to continue his journey inside the vulnerability. Using summaries we wrote, but also links to articles and official documentation, we allow the researcher to catch up on the topic and go more in-depth in a very short amount of time. Ensuring that all needed resources are already in hand reach by providing them to the security researcher through links. We also provide an impact analysis to go in-depth about possible interferences of solutions with the system.
4. Solve: we offer steps that can be followed to solve the problem and often offer a power shell script to immediately patch the vulnerability.

In a normal vulnerability scanning environment the Find step could be done by a vulnerability scanner, after which vulnerabilities are returned/reported and the Security Officer has to find information about the vulnerability/-context himself, we aim to cut time and resources and offer this information immediately. Making sure to also add links to guides and official documentation to further cut time. In addition to this, we offer the solution as well, trying to make this pipeline of solving vulnerabilities as fast and encapsulated as possible.

Note that we not only aim to extend this pipeline towards usability and solving but that we also aim to get a new SOTA in the part of the vulnerability assessment pipeline that is already present, so finding vulnerabilities.

### **3.1 FRIS in action**

To showcase FRIS and its ease, we showcase it in a rather small and simple AD environment. Let us showcase the size of this environment with direct output of our Stronghold scan:

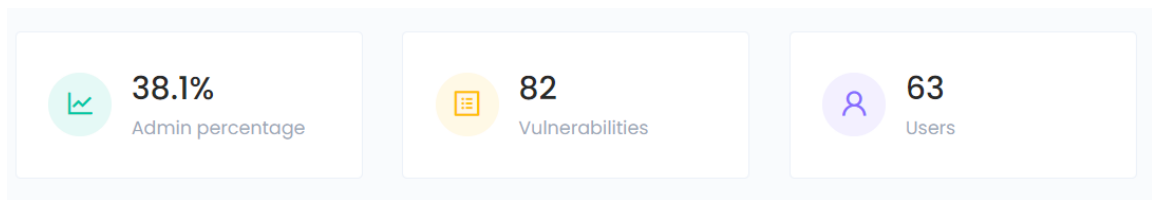



Figure 3.2: Information generated inside a Stronghold report

We already see some interesting things, the environment is rather small (63) users, but the admin percentage is way too big for what you would expect in a properly secured environment. The amount of vulnerabilities found is also quite high. This is a real-life business using Active Directory on which we ran a Stronghold scan. The scan uses its scoring system to score the environment.



Figure 3.3: Scoring an actual corporate environment on security

The scores are very low, let us take a further look at the environment and showcase our new FRIS system. For each vulnerability that Stronghold detects, it creates its database entry using the FRIS methodology, meaning that we can look at one of the critical vulnerabilities and use Stronghold to enforce our security.



## No Password Lockout Treshold

Critical

**Description:**

There is no global password lockout treshold. This allows for easy bruteforcing. It is recommended to change the password lockout treshold to make it higher. This policy is weak because 1: there is no password lockout treshold. This means that it can be easily bruteforced because it does not lockout the account after a certain amount of failed attempts.

Steps to reproduce

Steps to resolve

Links

☐ Open a powershell (ISE prompt)

☐ Run the following command: `Get-ADDefaultDomainPasswordPolicy`

☐ If the command yields a password policy with a password lockout treshold = 0, the password lockout treshold is too low.

Figure 3.4: Examining a critical security flaw found by Stronghold

So there we have it, information about our critical vulnerability. This particular vulnerability makes it easy to just brute-force passwords without ever being locked out, hence why it is indeed quite critical. Now as you can see we can reproduce the presence of the vulnerability by simply following the provided steps, we can also embark further onto our FRIS journey by looking at a link to the official Microsoft password guidelines that are provided:

Steps to reproduce	Steps to resolve	Links
		<input type="checkbox"/> <a href="https://docs.microsoft.com/nl-nl/microsoft-365/admin/misc/password-policy-recommendations?view=o365-worldwide">https://docs.microsoft.com/nl-nl/microsoft-365/admin/misc/password-policy-recommendations?view=o365-worldwide</a>

Figure 3.5: The inform step of FRIS further expanded

Then, for the last step of FRIS, we also still have to solve the actual vulnerability, let us embark on the last step in this journey:

Steps to reproduce	Steps to resolve	Links
	<input type="checkbox"/> After patching: Changing this will require users and services to change their passwords.	
	<input type="checkbox"/> Steps to resolve: Change the password lockout threshold to make it higher. Make sure to reset the passwords of all users afterwards if you want the changes to have affect for existing users immediatly. We deliver a powershell script for this.	
	<input type="checkbox"/> Powershell script: <code>Set-ADDefaultDomainPasswordPolicy -MinPasswordLength 14 -MinPasswordAge 1 -MaxPasswordAge 180 -PasswordHistoryCount 24 -PasswordComplexity -LockoutDuration 30 -LockoutThreshold 5 -ReversibleEncryptionEnabled False</code>	

Figure 3.6: The solving step of FRIS

Perfect, we have got some user communication to do, the impact analysis of FRIS is showcased as well here. The PowerShell script provided updates the entire password policy to conform to Microsoft's best standards.

## Chapter 4

# Active Directory Auditing

In this chapter, we compare our AD (Active Directory) findings with the current state of the art in AD vulnerability finding. To do this we compare our results with Purple Knight [11] by Semperis and with Pingcastle [43].

### 4.1 Comparison

We compare with Purple Knight [11] by Semperis and with Pingcastle [43]. The choice for these tools was based on my personal experience with them and knowing they are used quite frequently in the market of AD auditing. However, to make the choice I also evaluated several different AD auditing tools:

1. <https://github.com/azauditor/ADAudit>. This tool does more auditing as in gathering data instead of extracting vulns from it.
2. <https://github.com/phillips321/adaudit> This specific tool would earn a respective third place behind Pingcastle and Purple Knight in my opinion. It uses Powershell to audit some parts of the AD configuration.
3. Testimo, which works fine for more system admin purposes but is not perfect for AD security yet.
4. Tools like Zbang, Group3r, and Snaffler, which are nice additions but not (full) audit tools on themselves.
5. Tools like Bloodhound, Mimikatz, etc are fine pentest tools but not for full auditing purposes.

## 4.2 Methodology

For this benchmark we only consider serious vulnerabilities, that is, vulnerabilities that are considered by Pingcastle [43] as scoring points for the security score. For Purple Knight, we only consider vulnerabilities that are considered non-baseline. (Warnings and criticals). For our tool Stronghold, we are even harsher, we only consider vulnerabilities that are either medium (score > 6), high or critical. Therefore not counting low-scored medium, low, and baseline vulnerabilities. Note that Stronghold, during the research conducted found around 90-120 vulnerabilities per Active Directory it scanned. Filtering on serious vulnerabilities therefore partially cripples our system. We found it important to not only compare the number of serious vulnerabilities found but to also test how many of the vulnerabilities that other tools found, were found by Stronghold. We therefore directly compare the vulnerabilities found to find any vulnerabilities that Stronghold misses.

## 4.3 Vulnerability kinds

Our tool is meant to be a complete assessment tool of AD systems, vulnerabilities found are configuration-based, but also certificate-based, user-based, or even file based. Examples are no password lockout, and outdated NLTM protocols (which are very common). Also ESC1 till ESC8 (critical certificate issues). Another example is Powershell files that are missing but are called by scheduled tasks. (A user can simply create a PowerShell file and this will be executed with system rights). Our vulnerability codebase is around 9500 lines of code and hence it is hard to give a complete overview of potential misconfigurations/vulnerabilities. Future additions could maybe look more at tools like Bloodhound and how to incorporate weaknesses (which differ from vulnerabilities).

## 4.4 Test Environment

Thanks to Fourtop ICT, I could test Stronghold inside real systems. Fourtop ICT is an MSP company that has multiple clients which leverage Active Directory systems. Most of the time these clients use all kinds of different AD infrastructures. I have worked with Microsoft Server 2008, but I also found a server using Microsoft Server 2022. This makes this environment perfect for testing and developing Stronghold. Note that all of these environments are used daily by companies that differ in size, I tested at companies with 8 users but also at companies with more than 200 users. It is important to me that we catch different Active Directory setups with different amounts of security measures and different amounts of changed settings over the years. The fact that we expose some very serious security flaws in these corporate

environments underlines how helpful this branch of tools can be.

## 4.5 Overlap between tools

When compared to the vulnerabilities that state-of-the-art tools PingCastle [43] and Purple Knight [11] find, Stronghold scores very well, it can find almost all vulnerabilities that these tools find, let us first compare our tool with Pingcastle [43] in 6 different corporate environments:

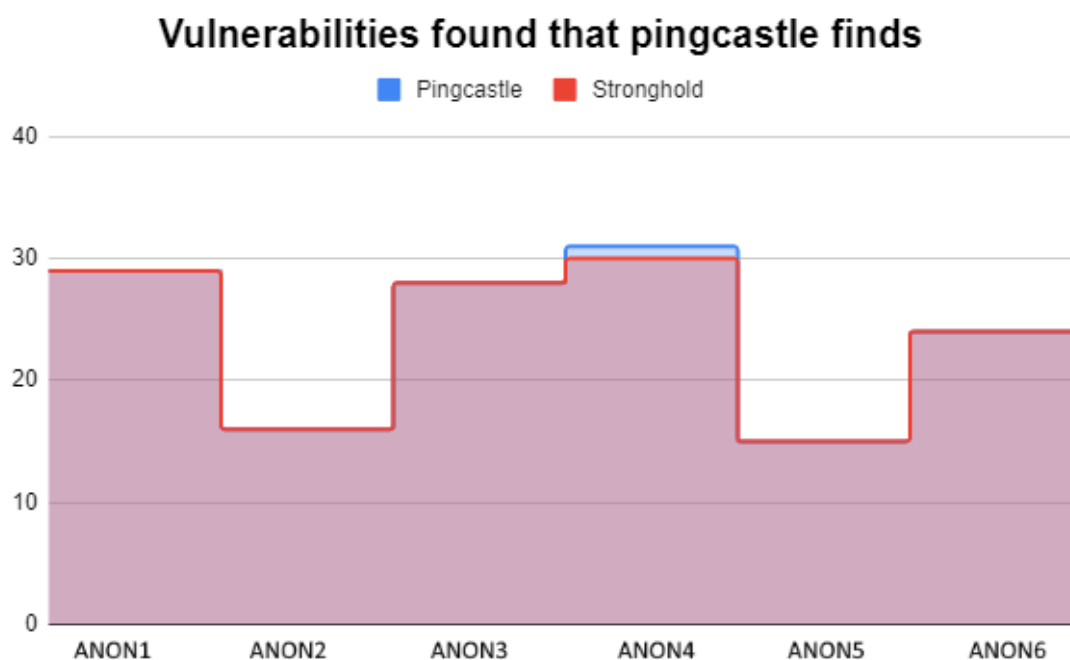


Figure 4.1: Missed vulnerabilities compared with PingCastle

Note that we only consider serious vulnerabilities for this graph, as discussed above. If we look at the results we see that we find almost all vulnerabilities that Pingcastle [43] does. This varies from weak password policies to WSUS being run over an insecure HTTP protection, weak certificates, or exchange permissions leading to privilege escalation. The missing Vulnerability at ANON4 has to do with incomplete subnets. We have written a script to find these as well, but at the time of testing, this was something that didn't work properly for ANON4. Let us now take a look at the vulnerabilities that we find from the ones purple knight found:

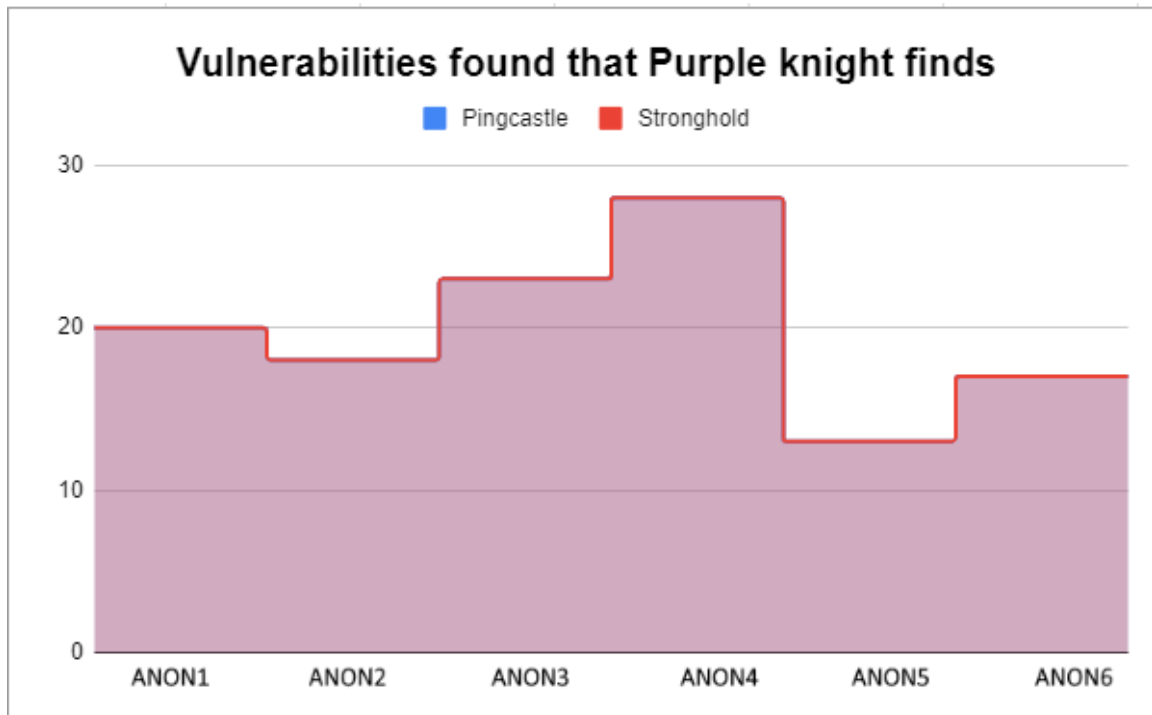


Figure 4.2: Missed vulnerabilities compared with Purple Knight

We see that we can find every vulnerability within our test environments that Purple Knight can find. Purple Knight goes a little bit less into depth and more into the more general checks like properties, DCsync rights, and excessive rights. Some of the vulnerabilities in Purple Knight [11] were not exactly found in the same way. Purple Knight, for instance, finds that the exchange server has a property that allows it to have admin rights. Our system Stronghold finds that exchange has been given many rights and should have its rights reduced. Because our solution fixes the problem that Purple Knight found and because we have found the vulnerability but labeled it otherwise, we find that this is not a vulnerability we missed.



## 4.6 Comparing StrongHold with other AD tools

To fully qualify Stronghold as the new state-of-the-art tool in AD security assessment, we want to directly compare it with its competitors in different environments. The aim is to show that we can consistently outperform the current state of the art to set a new standard in AD pen testing:

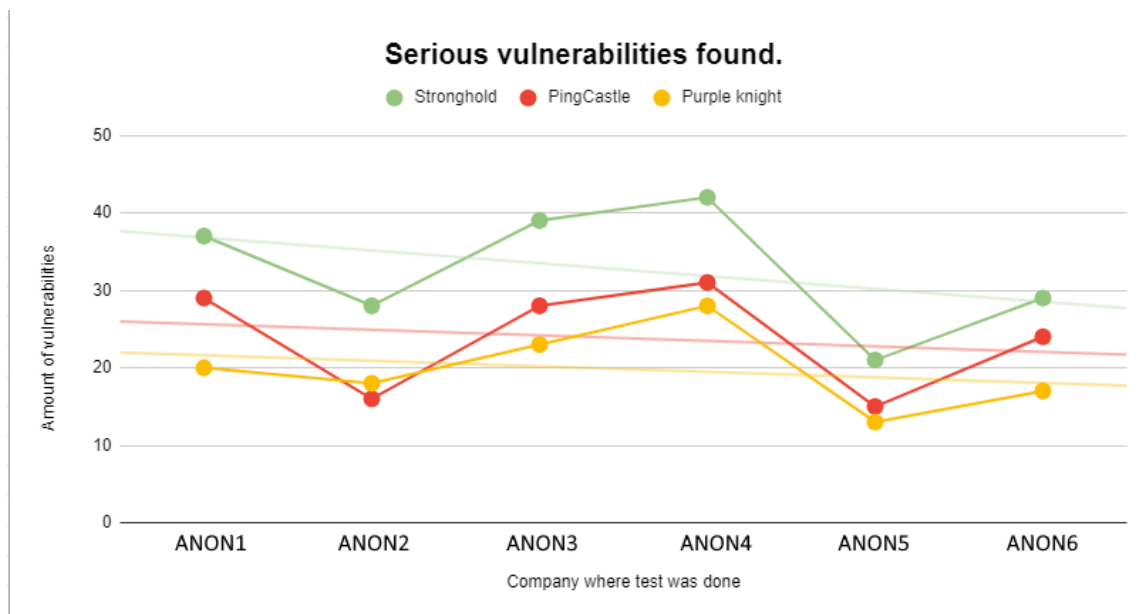


Figure 4.3: Stronghold compared with similar Tools

The test environments were real-life tenants from the MSP that were picked because they differ in size, security level, and age. Some servers are still running on windows server 2008 while others are newer and better. This allows us to examine the tool on a broad amount of different environments and to better test it on a broader set of possible vulnerabilities. Note that we have shown in figures 4.2 and 4.3 that the overlap between pingCastle and Purple Knight is enormous. We set a baseline of achieving the same as these state-of-the-art tools to build from that. Note that the extra vulnerabilities found are often of high or critical severity. Some examples of things that the other tools miss but which we find are ESC1 till ESC8 which are critical vulnerabilities and easy privilege escalations. Other examples are dangerous missing files, with which a user can easily elevate him/herself or GPO abuses to elevate.

## 4.7 In-depth test case

We have scanned the Active Directory environment of a company that has more than 900 users, has 54 domain admins, and has been used for several years. Apart from the number of users, we didn't know anything about this before scanning. Due to RSAT not being available, we might have missed some certificate-based vulnerabilities. There were also minor bugs due to not being able to run directly on a DC, but nothing that should have impacted scanning too much. Note that we have already done research on various AD environments in chapter 4 and have tested FRIS in chapter 3. The size of this company was a bit bigger and the particular company used to be even much bigger than it is now. This means that there were a lot of servers and infrastructure points that were ideal to test our audit tool.

### 4.7.1 Main Report

After running our vulnerability scan system on one of the AD servers in the network we extracted the generated files and inserted them inside of their css/js container. We obtained the following Fortifier report:

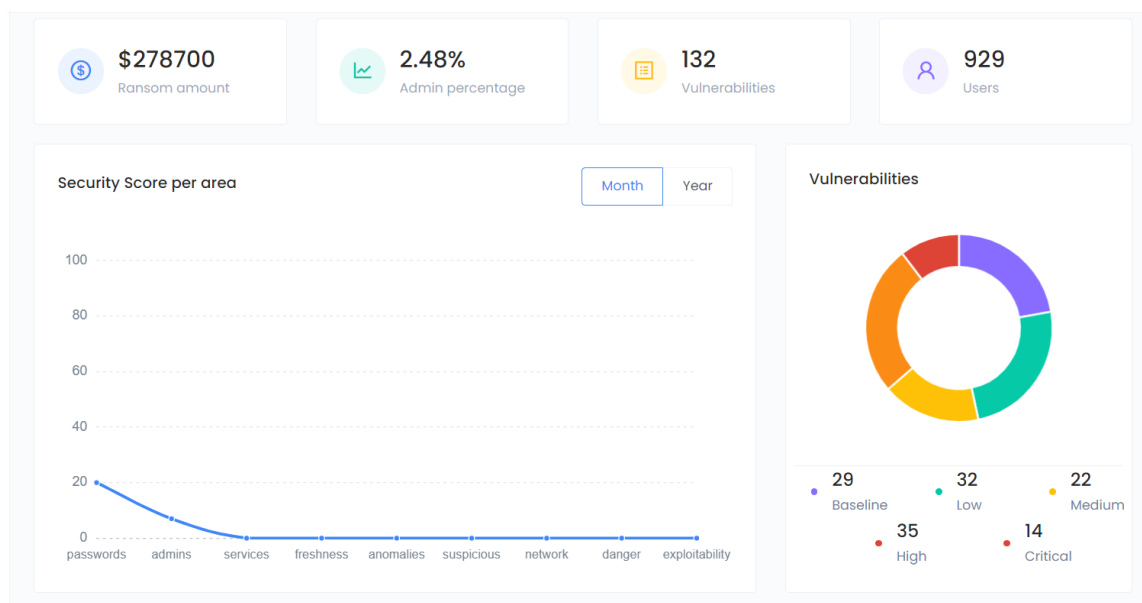


Figure 4.4: Fortifier AD Report

Results show that we have found 132 vulnerabilities, of which 14 are critical and 35 are high. The organization scores 0/100 in almost every category we grade. The exception is password security, as an okayish password policy with minimum length = 8, the complexity required, and a lockout threshold of 5 were implemented. The score for password security is still only 20 due to some critical vulnerabilities we discuss later on. Admin security scores 7 out of a possible 100.

### 4.7.2 Management summary

We will take a look at some of the various vulnerabilities presented to give a complete view of the output fortifier generates, the emphasis will be on the higher vulnerabilities, as they often have more impact and usability, but we will also display some of the lower rated vulnerabilities identified as Fortifier aims to be fairly complete.

Let us start by taking a look at the top 7 vulnerabilities identified:















Vulnerability	Occurences	Category	Severity
 There are windows servers 2003 on this network	9	Freshness	 100
 There are windows servers 2000 on this network	5	Freshness	 100
 Accounts with no password set	1	Anomalies	 99
 ESC6 - EDITF_ATTRIBUTESUBJECTALTNAME2	1	Anomalies	 97
 There are windows servers 2008 on this network	30	Freshness	 96
 Windows has not been updated in more than 120 days	1	Services	 95
 There are windows xp computers on this network	1	Freshness	 95

Figure 4.5: Fortifier top 7

Some serious vulnerabilities can be found. Windows Server 2008 stopped being securely supported by Microsoft in 2020, which means it has been pretty insecure for approximately 3 years at the time of writing. According to Nessus, it is already a 10/10 vulnerability on the CVSS3 scale, windows servers 2000 and 2003 are even worse. In addition to this, approximately 30 accounts were found that had no password set. There also was a certificate that had a very bad parameter that allows arbitrary users to upgrade themselves to domain admin via the creation of malicious certificates. There were also Windows XP computers found that ran critical tasks, namely being an essential factor of an entry pass generation system. In addition, various servers and domain controllers missed 167 days of security patches by Microsoft.

Now let us introduce another 7 very highly rated vulnerabilities:















	Accounts vulnerable to the Kerberoasting attack	1	Anomalies	 92
	54 domain admins found	54	Admins	 91
	46% of domain admins is inactive	1	Admins	 90
	Accounts with passwords in dictionary	1	Anomalies	 90
	SSL 3.0 used for internal servers	1	Anomalies	 86
	Domain admins have delegation rights	42	Admins	 85
	Check the use of Kerberos with weak encryption (DES algorithm)	1	Freshness	 85

Figure 4.6: 7 more high-rated vulnerabilities

The first vulnerability found is about kerberoasting, which allows attackers to try and get the cleartext passwords of privileged domain users. Because a certain value is set, the account is not protected by the lockout password policy and hence the password can be brute-forced on the AD and therefore found relatively weak. 4 admin accounts were vulnerable to this, with three of them having a weak password, reflecting the critical value the vulnerability got assigned.

The second vulnerability is about the number of domain admins, every domain admin (as demonstrated by the kerberoasting above) is a way to pwn the entire domain, therefore there never should exist so many admins.

The third vulnerability is the high amount of inactive admins, admin accounts that are inactive for a long period form an unneeded risk, amplified by the fact that they often belong to users who have left an organization.

There were also passwords of users found in online lookups and dictionaries, 42 users had their passwords leaked, including 3 administrators.

SSL 3.0 was used for internal communication by servers, as SSL 3.0 is long outdated and very vulnerable, this was also reported as high vulnerability.

Let us introduce a few more of the high vulnerabilities that were found:








	There are 2 admins that have not logged in for 3 years	2	Freshness	<div><div></div></div> 83
	There are windows windows 7 computers on this network	7	Freshness	<div><div></div></div> 80
	Accounts with missing AES keys	1	Anomalies	<div><div></div></div> 80
	LM hashes present	32	Freshness	<div><div></div></div> 76
	Admins not in protected users group	39	Admins	<div><div></div></div> 75
	Anonymous Access Enabled	1	Anomalies	<div><div></div></div> 75
	Local admin password is very old	1	Admins	<div><div></div></div> 74

Figure 4.7: 7 more high-rated vulnerabilities








	Administrators with passwords older than 6 years	1	Freshness	<div><div></div></div> 73
	A user can add devices to the domain	1	Anomalies	<div><div></div></div> 71
	There are 9 admins that have not logged in for 180 days	9	Freshness	<div><div></div></div> 70
	NLTMAuthentication Not Disabled	1	Passwords	<div><div></div></div> 70
	Tombstone lifetime is too small	1	Anomalies	<div><div></div></div> 70
	LAPS not installed	1	Service	<div><div></div></div> 740
	Insecure DNS Zone <span style="background-color: blue; color: black;">[REDACTED]</span>	1	Service	<div><div></div></div> 70

Figure 4.8: 7 more high-rated vulnerabilities

Let us also show some lower vulnerabilities that are still highly usable for remediation:















	Users with DCSync rights	2	Services	 69
	Pre 2000 group is not empty	1	Services	 66
	Accounts with the same password	1	Anomalies	 65
	There are more than 30% users that have not logged in for 180 days	38.4284176533907	Freshness	 65
	WSUS configuration using HTTP instead of HTTPS	10	Network	 65
	Administrators with passwords older than 3 years	6	Freshness	 65
	Exchange can control DNSAdmins	1	Anomalies	 61

Figure 4.9: 7 randomly chosen medium vulnerabilities











	Domain Admins group is not empty	42	Admins	 35
	DCS have differing operating systems	2	Freshness	 30
	There are users with passwords never set	18	Freshness	 30
	Disabled admins not in protected users group	3	Admins	 25
	Client fallback is disabled for the Netlogon and SYSVOL folders on a domain controller.	1	Services	 22

Figure 4.10: Some low/baseline vulnerabilities

## Chapter 5

# Google Workspace auditing

In this chapter, we introduce a novel system called GoogleAudit which we created to scan Google Workspace for security misconfigurations and vulnerabilities. After discussing with Google support we made sure that to the best of our knowledge, there is no tool at the moment that can enumerate Google Workspace for vulnerabilities.

### 5.1 Methodology

For these tests we look at all kinds of misconfigurations/vulnerabilities, that is vulnerabilities that CVSS3.1 marks as baseline, low, medium, high, or as critical.

I could test GoogleAudit inside real systems. Thanks to a foundation that utilizes a Google Workspace environment with 200 staff and a lot of users. The fact that we expose some very serious security flaws in our test environment underlines how helpful this branch of tools can be. For the sake of not disclosing vulnerabilities, I can not provide further information about the organization that we tested on.

To properly audit the Google Workspace environment, we use Selenium, which is a browser automation tool, to log in to the Google admin console (even with MFA by reproducing a token with the secret key). After logging in, our tool automatically traverses sub-sections of the admin console and gets values of settings, parameters, and users. Based on these values and our vulnerability database, we generate a report filled with vulnerabilities and misconfigurations.



## 5.2 Vulnerability Assessment

At the moment, 29 vulnerabilities can be automatically found within Google Workspace environments. This should be extended in the future to over 100 vulnerabilities and misconfigurations that are possible to be found within Google Workspace environments. The FRIS pipeline, leveraging solutions and dictionary objects for full vulnerability embeddings is maintained in our work for Google Workspace. An example of such an embedding can be found below.

1. ID: 0019
2. Calendar sharing options are set to 'Share all information, and allow managing of calendars
3. Vulnerability description: The calendar sharing options are set to 'Share all information, and allow managing of calendars', this means that anyone who can access the calendar can edit and delete events, and see all attendees and details of the event. They can also throw the entire agenda away or change sharing settings. The impact of such changes by external users is quite high, and therefore we highly recommend disabling this setting.
4. Severity: High
5. Steps to resolve: Go to <https://admin.google.com/ac/managedsettings/435070579839/sharing>, then disable the 'Share all information, and allow managing of calendars' setting, select a setting that disallows outsiders or disallows them from editing or adjusting.
6. Steps to reproduce vulnerability: Go to <https://admin.google.com/ac/managedsettings/435070579839/sharing>, then check the 'Share all information, and allow managing of calendars' setting, if the setting is 'Share all information, and allow managing of calendars', the vulnerability is present.
7. Grade: 7.2
8. Category: Services
9. Script to resolve: NVT
10. link1: <https://support.google.com/a/answer/60765?>
11. link2: <https://webapps.stackexchange.com/questions/38995/cannot-share-more-than-free-busy-outside-of-organization>
12. link3: <https://www.oreilly.com/library/view/hands-on-g-suite/9781789613018/5655910fb4b7-48db-9489-0dda17451a2c.xhtml>

13. Impact analysis: External users will no longer be able to adjust agendas, notify employees of this change, and check who has been actively using this feature to remediate possible problems arising from the change.
14. Count: 1

This embedding helps us in generating complex HTML/pdf reports automatically while helping the user by providing a lot of information and further references. The solution and impact analysis are also always built in. Sometimes even with scripts. The tool simply traverses the Google admin console and some of the possible misconfigurations and prints matches found using selenium. In the future, this should be further linked to our reporting environment.

[illegible]

Figure 5.1: Example of output

### 5.3 Current checks

The checks were added from a top-down point of view of the admin console. Hence they are not added based on severity but just by walking through the console and adding the first possible misconfigurations/vulnerabilities.

1. SSO login bypasses additional verifications. (Score 5.1)
2. Password strength is not enforced. (Score 6.3)
3. Password reuse is allowed. (Score 6.0)
4. Minimum password length is low (2 checks)
5. Maximum password length is low (3 checks)

6. Advanced protection is not enabled. (Score 3.0)
7. Insecure apps are allowed. (Score 7.0)
8. Never ending, long or short user sessions. (5 checks)
9. Never ending, long or short cloud sessions. (3 checks)
10. Calender sharing settings (3 checks). This one could allow external users to adjust company calendars if set wrongly.
11. No warnings on external invitations. (Score 5.0)
12. Secondary calendar sharing settings (3 checks)
13. Insecure default drive sharing settings. (Score 4.0)
14. Users can remove security updates (Score 6.0) (2 checks)
15. DKIM is disabled (Score 6.3)

## 5.4 Future checks

The following checks were not yet added due to time constraints but will be added in the future. (Note that most of the time is in creating FRIS library objects for each vulnerability and doing proper research about it). There might and probably will be even more checks but this is the next step that I required from myself.

1. Checks for POP, IMAP, link protection, identifying links behind shortened URLs, warnings for links to untrusted domains and automatically applying future mail security recommendations.
2. Checks for attachments security, specifically scripts, anomalous attachments, and encrypted ones.
3. Checks for the protection against domain spoofing, employee name spoofing, inbound email spoofing, unauthenticated emails, and inbound group mail spoofing.
4. Checks for aggressive spam filtering, and the not bypassing of spam filters with exclusions.
5. Checks for TLS requirements and the disallowance of automatic mail removal.
6. Checks for insecure group settings, too many admins, insecure admins, weak passwords, and MFA.

The original work was around 2500 lines of code, the tasks that need to be done for the new entries are:

1. Navigate to the page that they are on
2. Read the current configuration with selenium
3. If the current configuration is weak, create a vulnerability class entry (after doing complete research on the individual vulnerability)
4. Add the vulnerability to the vulnerability array.

An educated guess would be that doing this for the remaining tasks takes 4-5 days of full-time work. The only constraint to finish this (apart from someone else needing to have Python and Selenium knowledge) is time.

## Chapter 6

# Besieger: Automatic web pentesting

In this chapter, we introduce a novel system that does complex web server audits. Our system called Besieger is designed solely for automated penetration tests of web-related environments. There are many known web vulnerability scanners for this, however, we wanted a free tool that can get state-of-the-art (SOTA) results in identifying known vulnerabilities. We desire to focus on real-life environments, specializing in realistic real-life vulnerabilities and problems such as outdated software and probable mistakes. We utilize the power of open source for this and try to improve on state-of-the-art DAST tools such as Nessus, Acunetix, Invicti, and Burp Suite Professional. We created the following set of requirements to adhere to:

- Besieger should be fully automated and very easy to use.
- Besieger should have multiple speed options and should consist of a high amount of different modular sub-scanners that are selectable and combineable.
- Besieger should be fully based on free and open-source software.
- Besieger should be a very complete web attack tool, taking into account some OSINT attack vectors, some Google dorking-related attack vectors, and version-related attack vectors.
- Besieger should be able to chain attacks and use the results of earlier modules in later modules.
- Besieger should be able to outperform the current state-of-the-art DAST tools in real-life environments. It is a clear goal to perform better in this kind of environment, we do not care about performing better in test environments or purposely vulnerable web applications.

- Besieger should be able to have a nice and easy console interface and coloring.
- Besieger should be focused on being a complete tool that is usable for Penetration Tests and reports of web applications.

Besieger is a command line tool, the only input it needs is a single URL. After a quick check to ensure the URL is reachable and correct, the scan automatically starts its magic.

```

Besieger 1.0
URL: https://ufsc.br
Status code: 200
Mode: Quick scan
Laying full siege onto web applications to strengthen their security
  
```

Figure 6.1: A first glance at the CLI

## 6.1 Surface level vulnerabilities

When developing a brand new DAST tool, it is important to implement the basic but still often very handy sub-tools. We find it important to review websites based on HTTP settings, headers, and cookie security. These are all fundamental and easy checkable elements that can still lead to some serious vulnerabilities when improperly implemented. They are surface level because you can spot them easily and without doing anything malicious while they are all also easy to spot and find.

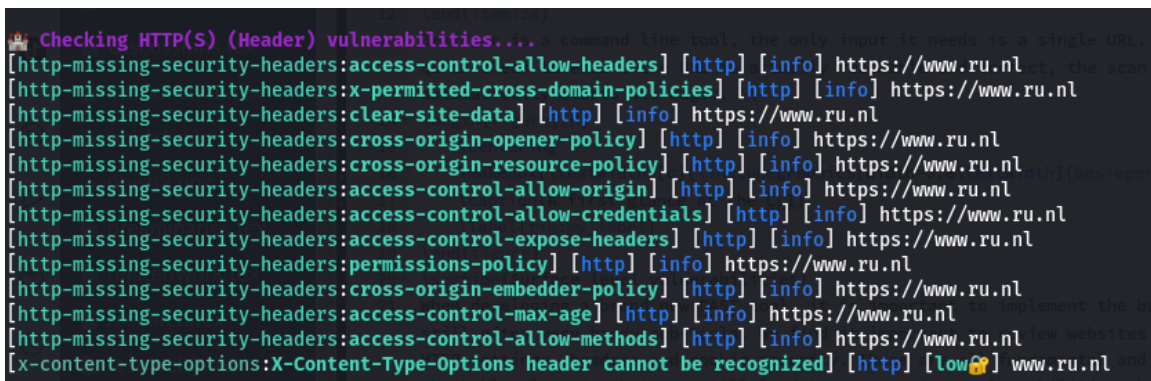
### 6.1.1 HTTP(s) (headers)

Besieger can find the following vulnerabilities:

- Clickjacking
- Missing security headers

- Incorrect security headers
- Content Security Policy bypasses
- HSTS and SRI checks
- Redirection and STS checks

It uses a combination of custom-written code and external tools for this, such as nuclei and the Mozilla observatory. All findings are reported with our custom highlighting and printing system, which is partially inspired by the way nuclei prints its output. Let us show an example from running Besiegers HTTP module on the website of Radboud University (<https://www.ru.nl>):



```

👑 Checking HTTP(S) (Header) vulnerabilities... command line tool, the only input it needs is a single URL.
[http-missing-security-headers:access-control-allow-headers] [http] [info] https://www.ru.nl et, the scan
[http-missing-security-headers:x-permitted-cross-domain-policies] [http] [info] https://www.ru.nl
[http-missing-security-headers:clear-site-data] [http] [info] https://www.ru.nl
[http-missing-security-headers:cross-origin-opener-policy] [http] [info] https://www.ru.nl
[http-missing-security-headers:cross-origin-resource-policy] [http] [info] https://www.ru.nl
[http-missing-security-headers:access-control-allow-origin] [http] [info] https://www.ru.nl
[http-missing-security-headers:access-control-allow-credentials] [http] [info] https://www.ru.nl
[http-missing-security-headers:access-control-expose-headers] [http] [info] https://www.ru.nl
[http-missing-security-headers:permissions-policy] [http] [info] https://www.ru.nl
[http-missing-security-headers:cross-origin-embedder-policy] [http] [info] https://www.ru.nl
[http-missing-security-headers:access-control-max-age] [http] [info] https://www.ru.nl
[http-missing-security-headers:access-control-allow-methods] [http] [info] https://www.ru.nl
[x-content-type-options:X-Content-Type-Options header cannot be recognized] [http] [low👹] www.ru.nl and

```

Figure 6.2: Missing HTTP(s) headers

We see some missing headers, of which none are really dangerous, the most important headers (same-origin-policy, x-frame-options, content-source-policy and anti-XSS header) seem to all be implemented, as can be expected from an organization like Radboud. This makes it even nicer that we have found vulnerabilities using Besieger, there is a low vulnerability inside the X-Content-Type-Options header because the value is set to an in-legitimate value. Our second module also finds a low vulnerability:

```

Bypassing csp policy...
issues in: script-src
Advice: Host whitelists can frequently be bypassed. Consider using 'strict-dynamic' in combination with CSP nonces or hashes.
Advice: Consider adding 'unsafe-inline' (ignored by browsers supporting nonces/hashes) to be backward compatible with older br
missing: object-src
Advice: Missing object-src allows the injection of plugins which can execute JavaScript. Can you set it to 'none'?
missing: base-uri
Advice: Missing base-uri allows the injection of base tags. They can be used to set the base URL for all relative (script) URL
*.google.com
Advice: www.google.com is known to host JSONP endpoints which allow to bypass this CSP.
www.youtube.com
Advice: www.youtube.com is known to host JSONP endpoints which allow to bypass this CSP.
*.facebook.com
Advice: api.facebook.com is known to host JSONP endpoints which allow to bypass this CSP.
*.pinterest.com
Advice: widgets.pinterest.com is known to host JSONP endpoints which allow to bypass this CSP.
*.twitter.com
Advice: syndication.twitter.com is known to host JSONP endpoints which allow to bypass this CSP.
*.instagram.com
Advice: api.instagram.com is known to host JSONP endpoints which allow to bypass this CSP.
https://cdn.jsdelivr.net
Advice: cdn.jsdelivr.net is known to host JSONP endpoints and Angular libraries which allow to bypass this CSP.
https://cdnjs.cloudflare.com
Advice: cdnjs.cloudflare.com is known to host Angular libraries which allow to bypass this CSP.
https://maps.googleapis.com
Advice: maps.googleapis.com is known to host JSONP endpoints which allow to bypass this CSP.

```

Figure 6.3: CSP can be bypassed

The Content Source Policy (CSP) of the Radboud can be bypassed in quite a few ways! It contains a few links not set strictly enough, allowing bypassing via JSONP endpoints and it also misses an object-src and base-URI.

### 6.1.2 Cookie vulnerabilities

Besieger currently contains two cookie audit modules, one is manual and external and the other one is automated. Our first module is part of our Manual check library, which we will discuss in depth later. It automatically shows results from some websites that audit the input website on cookie privacy and compliance laws. The second module was custom-coded and checked for the presence of the secure flag, the same site flag, and the httponly flag. We also check for the presence of session cookies and session ids, and adjust the height of the vulnerability based on this information. Let us show some of the results of this module on the website of Brazilian University: ufsc.br.



```
🏠 Checking cookie vulnerabilities...
Name: PHPSESSID
Value: oqm81m3ftfss2d8vabsthoo5m0
Domain: ufsc.br
This session cookie is NOT secure
This session cookie does not have httponly attribute
This session cookie does not have SameSite attribute
```

Figure 6.4: Insecure session cookies

This example website uses highly insecure session cookies, we use `http-cookiejar` to detect cookies and session cookies. In this case, the name also gives away that this is the ID for a PHP session. This particular cookie has none of the flags set that should be used to properly protect the cookie.

## 6.2 Version identification and exploitation

The process of detecting software versions and identifying potential vulnerabilities requires the use of multiple tools and techniques [54]. One such tool is Wappalyzer, which specializes in fingerprinting technologies and employs a combination of regular expressions and dynamic detections to accurately identify software components and their versions [64]. Another tool, Nuclei, is a fast and customizable vulnerability scanner that uses templates to identify software versions and potential vulnerabilities [52]. Additionally, Nmap, a widely-used network scanning tool, is employed for port fingerprinting, which can help uncover vulnerable services running on target systems [45]. Web scraping techniques are also used on websites like `webtechsurvey.com`, employing the Selenium framework to gather information about software components [57].

By combining the fingerprints obtained from these tools, it is possible to cross-reference them against known vulnerability databases, such as the National Vulnerability Database (NVD) [51], Searchsploit [56], and Vulners [63]. This process often uncovers numerous vulnerabilities that might be missed by other scanners, increasing the chances of identifying exploitable software components [54]. This method works surprisingly well.

## 6.3 Fuzzing and crawling

Fuzzing and crawling are essential techniques for identifying security vulnerabilities in web applications and services [61]. Tools like Katana [39], Arjun [7], and dirsearch [15] are employed to identify and fuzz endpoints. These fuzzing tools are then used to check for various security issues, such as

SQL injection, cross-site scripting (XSS), and path traversal [53]. Moreover, this process can help identify potentially sensitive or configuration files that might be exposed [61].

## 6.4 DNS and subdomain enumeration

Automated investigation of DNS records is conducted to check for blacklists, misconfigurations, and settings such as SPF, DKIM, and DMARC [2]. If an open SMTP service is detected by Nmap, a submodule is used to audit it [45]. For subdomain enumeration, multiple tools like Amass [4] are combined to generate passive lists of subdomains, followed by active tools and wordlists to generate possible subdomains [17].

The results are filtered based on their HTTP response codes, and further checks for subdomain takeover and identification of secrets on all domains are performed [2]. These domains can also be used for further manual labor if necessary.

## 6.5 Web Application Firewalls (WAF)

To identify WAFs and attempt bypasses, multiple tools are used. Techniques for bypassing WAFs include searching DNS history for the original IP behind the WAF and checking if the WAF does not support certain offered ciphers [8]. A benchmark of the WAF's performance is compared to a median to evaluate how effectively it stops malicious queries [41].

## 6.6 SSL and ciphers

SSL and cipher configurations are inspected for potential misconfigurations and weaknesses [55]. This includes checking for outdated protocols like SSL 2.0/3.0 and TLS 1.0/1.1, as well as weak ciphers, server bugs, and lack of forward secrecy [47]. Additionally, normal checks for TLS/SSL configurations are performed to ensure the security and robustness of the encrypted communication [55]. We integrate testssl.sh under the hood with all parameters. But we filter the extensive results based on their color to only return the actual vulnerabilities/misconfigurations. Because of this, the detection is state-of-the-art. However, there is no novelty here and the integration is just made for the sake of completeness.

## 6.7 Additional attacks

Besieger uses a wide range of additional attacks, such as a manual tour around Censys, Shodan, and various Google dorks. It also has specific at-

tacks on Drupal and WordPress, checks for secrets, tries HTTP request smuggling, de-serialization attacks, header poisoning, CSRF, and more. However, for the sake of brevity, not all features are included.

## 6.8 Results on live websites

We have benchmarked our tool with nuclei (the most Github-starred open-source web scanner) Acunetix and Nessus (two commercial (web) vulnerability scanners that I happen to own) and burp suite professional. (Another commercial web pen-testing tool that I happen to own). We have chosen a variety of real and intentionally vulnerable websites. We used iecetee.com (my website) three anonymous education-related websites and Google gruyere (an intentionally vulnerable website). For our Nessus scan, we did not do a basic scan but one with all optional checks and advanced options enabled to improve vulnerability finding. Nessus was not able to do a proper scan for two websites, so its results are somewhat crippled. We picked the resulting vulnerabilities based on the CVSS3 score, with as exception that we excluded HSTS, SRI, and untrusted certificate vulnerabilities as given by Nessus or Acunetix as medium vulnerabilities. We did not consider these vulnerabilities from Besieger as well, (it finds the same ones).

### 6.8.1 Benchmarking

For this subsection, we have evaluated tools on vulnerabilities with a CVSS3.1 score of medium or above. If CVSS3.1 was not available we used CVSS3.0 or CVSS to classify the vulnerabilities.

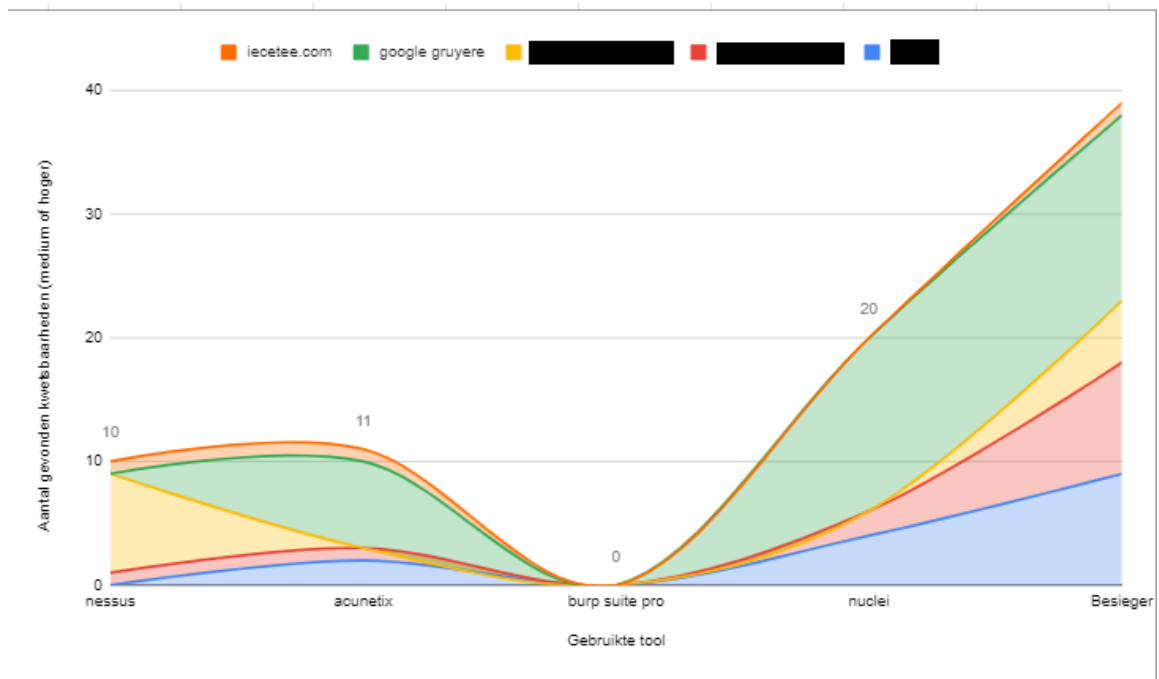


Figure 6.5: Besieger comparison for Medium+ vulns

As the graph shows, Besieger seems very capable of competing against some of these tools. Acunetix is a fully specialized web app scanning tool while Nessus is more of a network scanner tool. The results show that on the limited set of tools and websites, Besieger improves on what the current tools are capable of. We did the same tests but then with vulnerabilities that are either high or worse.

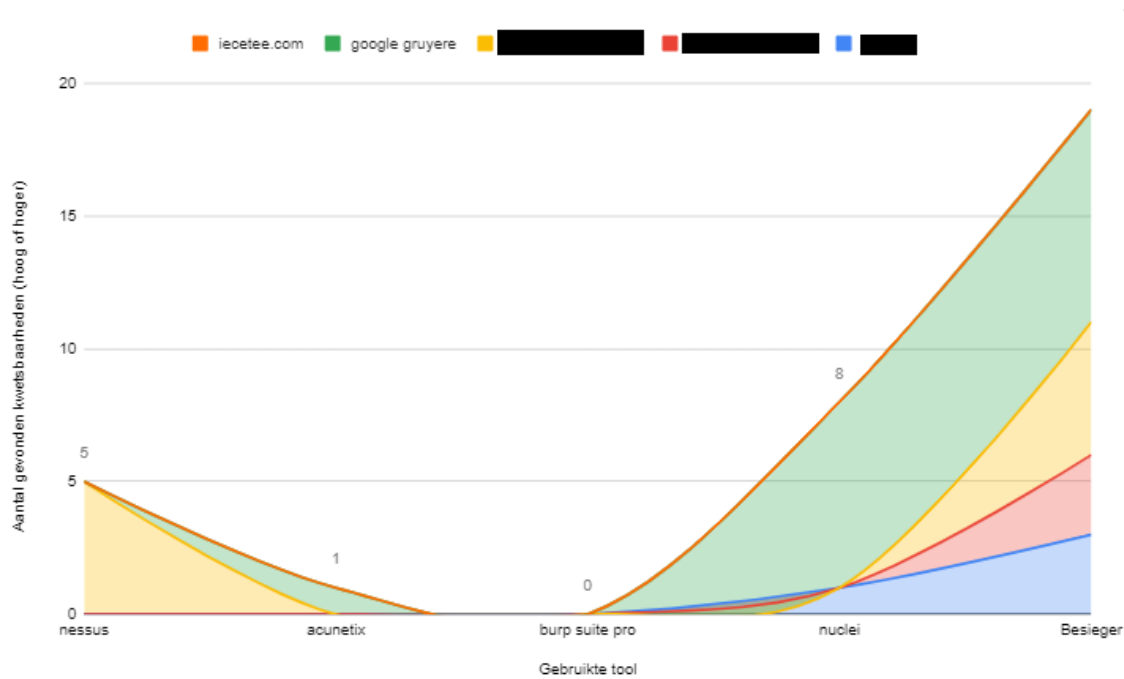


Figure 6.6: Besieger comparison for High+ vulns

When looking for high vulnerabilities, Acunetix quickly gets worse. Nessus and Nuclei still prove to be very adequate scanning tools in this regard. However, it is here where in my opinion Besieger shines as it identifies almost 20 high+ vulnerabilities compared to 5 for Nessus, 1 for Acunetix, and 8 for Nuclei. Again we did the same tests but then with vulnerabilities that are classified as critical by their CVSS score.

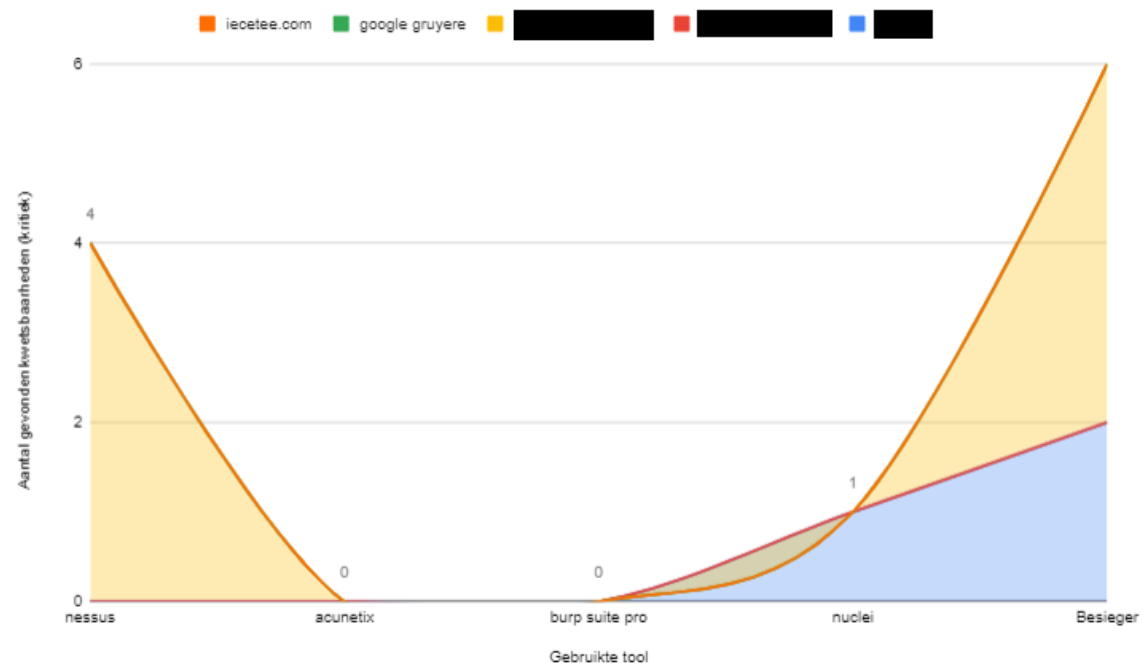


Figure 6.7: Besieger comparison for Critical vulns

Here Nessus further qualifies itself as an amazing DAST scanner, even surpassing Nuclei. Besieger is still the best in finding vulnerabilities, finding 6 critical vulnerabilities compared to 4 for Nessus and 1 for nuclei.

## 6.8.2 Specific vulnerabilities

We have documented all the specific vulnerabilities found by the different tools to gather a complete view of the vulnerabilities they find and some overlap that we expected to occur.

27	Vulnerabilities found nuclei		Vulnerabilities found acunetix		Vulnerabilities found Nessus	
28	ANON1	cvss3	ANON2	cvss3	ANON3	cvss3
29	cve-2022-1595 (login url leakage)		5,3 expired ssl certificate	5,3	apache multiple vuln < 2.4.56	9,8
30	docker compose config leaked		5,3 <a href="#">google gruyere</a>		php multiple vuln	9,8
31	cve-2017-5487 (username leakage)		5,3 xss (uid)		cli generic sql injection	7,5
32	cve-2020-35489 (file upload bypass to RCE)		10 xss (upload_file)		6,1 phpmadmin multiple vulns	9,8
33	ANON2	cvss3			5,4 remote Dos	5,8
34	host header injection		4,3 tls 1.1		5,4 phpmadmin info disclosure	5
35	cve-2017-5487 (username leakage)		5,3 weak cipher suites		5,1 phpmadmin path disclosure	5,3
36	<a href="#">google gruyere</a>	cvss3	sweet32	7,5	openssl vulns	9,1
37	cve-2006-1681		4,3 password field GET	5,3	<a href="#">ieetee.com</a>	
38	cve-2020-12447		7,5 <a href="#">ieetee.com</a>		jquery < 3.5.0 multiple xss	6,1
39	cve-2020-2036		8,8 jquery < 3.5.0 multiple xss	6,1	ANON2	
40	cve-2020-35736		7,5 ANON1		wordpress user enum	5
41	nginx-module-vts-xss		6,1 unencrypted connection	5,4		
42	cve-2020-2096		6,1 web page poisoning Dos	5,3		
43	cve-2018-16288		8,6			
44	targa-camera-lfi		8,6			
45	cve-2021-25864		7,5			
46	cve-2020-28351		6,1			
47	generic-linux-lfi		8,6			
48	oracle-ebs-xss		6,1			
49	cve-2018-5233		5,4			
50	weak-cipher-suites		5,1			

Figure 6.8: Specific vulnerabilities found other tools

Note that even though we expected some overlap, the found overlap was very minimal. Nessus found quite some high and critical vulnerabilities at ANON3 while all the other scanners seem to miss them. The vulnerabilities nuclei finds are then not found by any of the other scanners. Except for the WordPress user enum at ANON2, some XSS at ANON2, and the overlap on ieetee.com. This shows that in DAST scanning using multiple tools can be very handy. Let us now also look at the findings from Besieger.

Vulnerabilities found Besieger			
<a href="#">ieetee.com</a>	cvss3	<b>ANON1</b>	
jquery < 3.5.0 multiple xss	6,1	jquery 1.12.4 multiple xss	6,1
<b>ANON2</b>	cvss3	cve-2022-1595 (login url leakage)	5,3
host header injection	4,3	docker compose config leaked	5,3
cve-2017-5487 (username	5,3	cve-2017-5487 (username leakage)	5,3
apache 2.4.6	7,5	cve-2020-35489 (file upload bypass to RCE)	10
cve-2017-3731	7,5	http access enabled	7
php 7.4.16	7,5	tinymce CSRF	4,3
expired ssl certificaat	5,3	multiple wordpress vulns	9,8
cve-2022-3590	5,9	fancybox xss	4,3
cve-2023-2745	6,1	google gruyere (google gruyere)	cvss3
multiple wordpress vulns	6,1	cve-2006-1681	4,3
<b>ANON3</b>		cve-2020-12447	7,5
apache multiple vuln < 2.4.	9,8	cve-2020-2036	8,8
openssl vulns	9,1	cve-2020-35736	7,5
perl 5.16.3 multiple vulns	8,6	nginx-module-vts-xss	6,1
php 5.5.15 multiple vulns	9,8	cve-2020-2096	6,1
mod perl 2.0.8 headers	10	cve-2018-16288	8,6
		targa-camera-lfi	8,6
		cve-2021-25864	7,5
		cve-2020-28351	6,1
		generic-linux-lfi	8,6
		oracle-ebs-xss	6,1
		cve-2018-5233	5,4
		weak-cipher-suites	5,1
		multiple dangerous CSRF	7,5

Figure 6.9: Specific vulnerabilities found Besieger

We can conclude that most vulnerabilities that Besieger finds are version related. Our custom system of regex + scanning-based identification of subsystems proves very useful in finding vulnerabilities inside these systems. We do miss certain vulnerabilities like the SQL injection at ANON3 and some of the lower or Phpmyadmin vulnerabilities found there. This shows that Besieger is not perfect, but that it can and will set a new State of the art result in version identification coupled with finding vulnerabilities inside of these versions.



## Chapter 7

# Corporate Phishing Simulation

In this chapter, we introduce a system that does complex phishing simulations on Google and Microsoft-based environments. Our system called GateKnocker is designed solely for phishing attacks on these two corporate environments. There are many known phishing tools and phishing simulations. Such as gophish or zphisher. However, we wanted to build a system that can function inside our current FRIS environment, while also having the usability, sophistication, and specialization options we require. The power of the tool lies in automating it from a Gmail/outlook perspective with Selenium and with targeted templates tuned for this specific set of companies. Its techniques and ideas are not novel but it fits well inside our ecosystem. We created the following set of requirements to adhere to:

- GateKnocker should be fully automated and very easy to use.
- GateKnocker should be diverse in its attacks and amount of sophistication used.
- Gateknocker should be able to use sophisticated techniques like email spoofing or link masking techniques.
- Gateknocker should be able to use fully customized HTML templates for Microsoft and Google environments.
- Gateknocker should be able to identify mistakes by employees on a per-user basis and should report clicking on a per-user basis.
- Gateknocker should include pre-written awareness emails and customized quizzes for Microsoft and Google environments.
- Gateknocker should be able to generate HTML documentation within our FRIS ecosystem.

The two key components to focus on are sophistication and usability.

## 7.1 Methodology

Our methodology is developed based on maximum performance increase for the spotting of phishing by employees. Therefore the goal is not only to assess the current state of phishing identification within an environment but also to maximize the skill set of identifying phishing for the employees concerned. Bruner [10] showed that repetition is vital for all learning. In addition, this research from [42] proves that making mistakes is an essential factor in learning as it helps us adjust wrong behavior. Taking this research into account, our system must use a systematic approach to repeat certain information in different ways, while also making sure said challenges are not too easy, so employees become aware of the mistakes they make while identifying phishing. We introduce our system called AT IT:

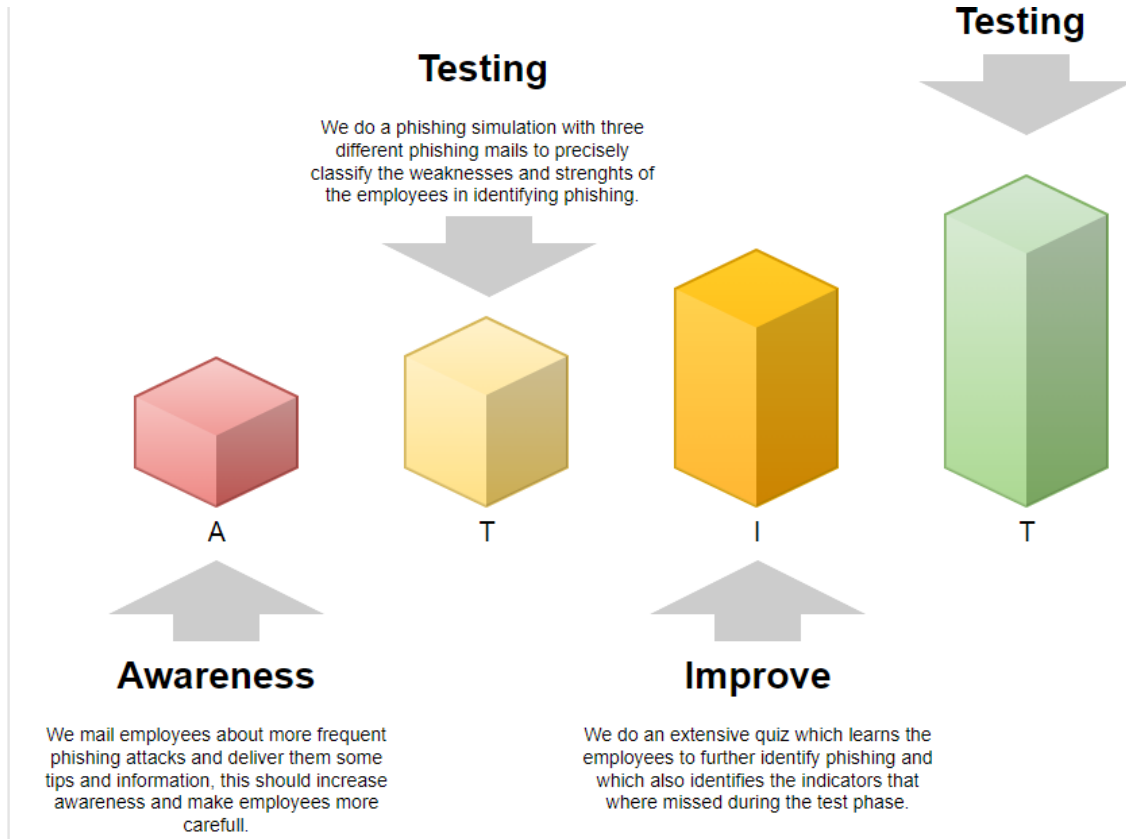


Figure 7.1: Our phishing learning system

ATIT, which stands for Alert, Test, Improve Test, is our system to gradually keep improving phishing awareness. Employees start with a set of knowledge about phishing and how to detect it, we amplify this knowledge by improving their awareness. Our initial Alert Step. We then Test to get an initial view of employee performance. We follow up with our Improve step: a lengthy quiz aimed at identifying indicators of phishing and improving from past mistakes. We finish with a retest inside a new simulation to make a precise measure of made progress. This leaves us with a set of employees that are fine-tuned on the task of phishing identification, [16] While this also makes it possible to statistically grasp the improvements we made.

We have 4-fold repetition and a 3-fold ability to learn from made mistakes, adhering to the methodology we developed. We get a 3-fold chance to properly document and report our results within our FRIS ecosystem. We generate a report of the first simulation, where key awareness is pointed toward the mistakes that are most often made and the percentage of mistakes made. We specify our biggest area of growth here and use our quiz and tips to further train the employees. After the quiz, we generate a report of the results from the quiz and compare this with previous iterations to be able to report on the abilities of this particular batch of employees. We then retest and generate a third report on the performance of the employees after fine-tuning and on the improvements that were made using our AT IT methodology.

## 7.2 Iterative Improvement

Iterative improvement is the act of approximating the ideal result in small steps. [46] In phishing environments, awareness created by phishing simulations and education becomes less over time. Research from [66] shows that the percentage of clicks in phishing simulations continues to lower over time, even after 20 simulation campaigns were run. We believe that in phishing, the employees that have the hardest time identifying phishing are the weakest link. As they are, by far, the biggest probable way of entry a phishing campaign could find into your environment. Hence, taking into account the algorithm for iterative improvement and the ongoing improvements shown when simulating for a longer period. We try to implement our idea of Iterative Improvement within our AT IT ecosystem: We take the users that were tricked by our test, together with the 10 percent of worst-scoring employees on our quiz, and apply a follow-up learning step and simulation to reiterate their improvement cycle. We do this after one month has passed. We also advise companies to redo phishing simulations every x year, to make sure they stay up to date with the latest sophisticated attacks discovered in the world of phishing.

## 7.3 Sophistication

We subdivide the number of users inside an organization into three groups, with three different types of attacks and three different phishing emails. This approach is aimed to test the environment for multiple different sources of attack and sophistication. In addition, the attacks are highly customized for the environment they try to penetrate.

### 7.3.1 Attack 1

The first attack is not aimed to surpass anti-spam (if present), as many phishing attacks will get detected and classified as spam. Instead of this, it is aimed to give a realistic simulation of the reaction of your environment and employees. (Which means some emails could go into spam) Let us show our HTML example for a Google environment:

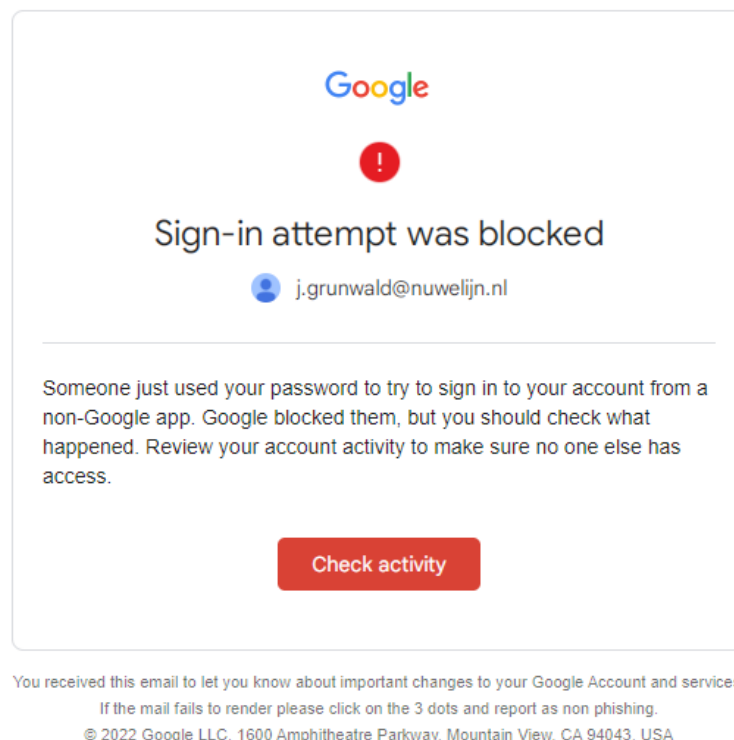


Figure 7.2: GateKnocker first attack

This attack is designed to be sophisticated and to get people to recognize the familiar Google 'check activity' dashboard. It tests how well people spot this sophisticated attack and how well people check links and their spam sections. We can execute the attack with or without a handy piece of

software called Maskurl. This means that we can either use a bit.ly link or a `https://www.google.com/security-measures@ZDfA` kinda link. The HTML uses personal information (the victim's email) and looks realistic. We have a similar-looking example for Microsoft businesses:

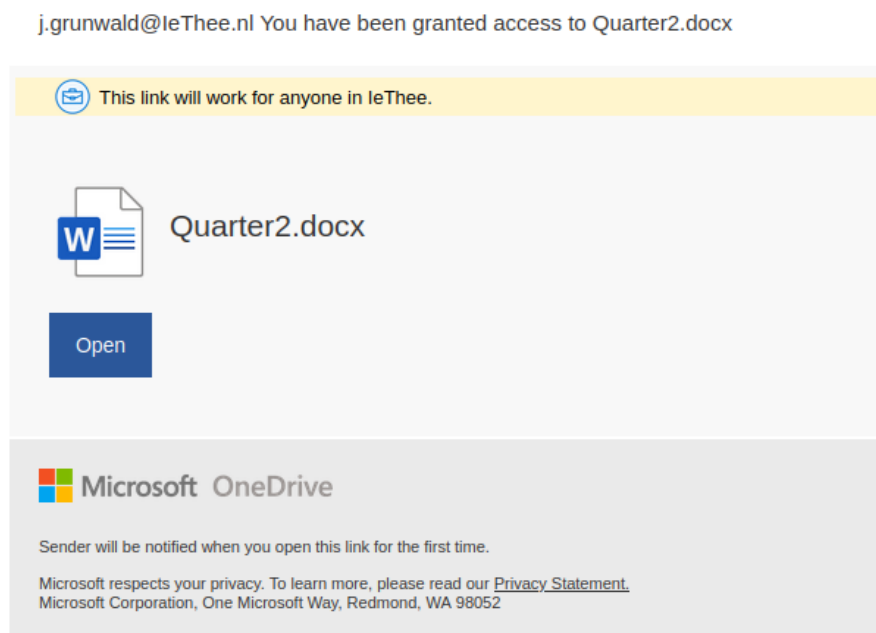


Figure 7.3: GateKnocker first attack

Note that while these attacks are sophisticated, they are also realistic and have even some built-in flaws we hope employees can use to recognize phishing/spam and which we can point out after a successful phishing simulation. The flaws here are:

- Send from a Gmail/outlook account closely related to the organization (for example for IeThee the mail comes from IeThee@gmail.com). The fact that the company domain is not used is an indication of possible phishing and should also mark emails as external when an environment is properly set up.
- Sophisticated emails like these should be marked as spam, which is a huge indicator that there could be something wrong with this mail.
- The name of the sender is Googl Support or Microsof Support. Notice the missing letter that should be an indicator of something being off.
- The link is either a bit.ly link or a Google @ZDfA link, both are hidden but when hovering over the link should be an indicator of phishing.

### 7.3.2 Attack 2

The second attack will use email spoofing as its primary weapon, email spoofing is an attack in which we use a mail tool to send the email as if it comes from someone inside the organization. In this example, we use the fact that we send out phishing awareness emails earlier and fake a mail from internal IT staff that asks you to enable enhanced phishing protection settings and provides a link. We spoof the email address of someone working in IT and copy their mail signature to the end of our phishing mail, we then provide a link that is either a bit.ly link or a Google @ZDfA link that directs to accounts recovery settings. We test credibility, email spoofing detection, and the use of credible information in phishing. We make sure there are also some weaknesses in this attack. The first one is a banner/spam section which should be attached by properly configured anti-spam.

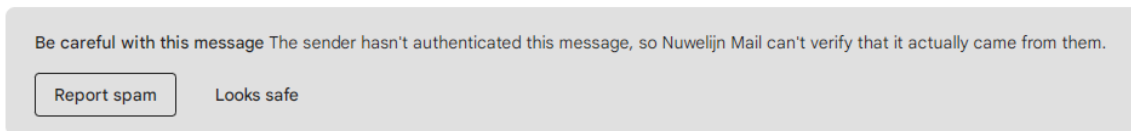


Figure 7.4: Email spoofing warning banner

Other weaknesses are:

- The link can be spotted again.
- The sender has no profile picture in spoofed mail while he has one in non-spoofed mail.
- The email should enter the spam section if spam settings are configured well enough.

### 7.3.3 Attack 3

The third attack is the most simple but also the most effective, as in our experience, it seems to bypass the spam settings. We do not use links to track who failed this attack. We create a simple email message from Google support that asks a user if they can ask a single local IT personnel to disable the MFA of the victim. Leaving him/her vulnerable to attacks, we then monitor who of the victims mails our IT personnel asking him to disable the Multi-Factor Authentication. The email tests common sense and user reaction when not helped with banners/spam filters. There are some weaknesses in this mail again:

- Send from a Gmail/outlook account closely related to the organization (for example for IeThee the mail comes from IeThee@gmail.com). The

fact that the company domain is not used is an indication of possible phishing and should also mark emails as external when an environment is properly set up.

- The name of the sender is Googl Support or Microsof Support. Notice the missing letter that should be an indicator of something being off.
- The mail asks to disable security settings, which should be a red flag without any other indicators already.

### 7.3.4 Uniquely identifying every user

We use the website wasitviewed.com and Python to create custom emails for every user we mail to. We swap in their details and also create a unique link on Wasitviewed. Wasitviewed mails us whenever one of these links is clicked, sending us the unique identifier as well and excluding traffic from bots and our IP. This way our phishing bot can automatically register how many users fell for our traps and also exactly which users. Which is very handy information to register and use to automate our reporting step.

## 7.4 Quiz

A phishing quiz is a tool that presents users with a series of simulated phishing attempts and asks them to identify the signs of phishing. This type of quiz can be an effective way to educate users about the types of tactics that attackers may use and help them become more vigilant in recognizing phishing attacks. We use our quiz to make sure our employees are trained to recognize the key patterns of phishing attacks, with a focus on the grammar of phishing emails, email addresses where emails are from, emails trying to be someone they are not, phishing and spam banners, email spoofing, and link authentication. With these examples and tips, we hope to use iterative improvement to take small steps in correcting the mistakes employees make in identifying phishing. We also introduce the examples employees were tricked by in our phishing simulation, allowing them to see the exact indicators they missed and providing a sense of urgency to our quiz. We specify these indicators and ask users to identify all indicators in various emails, training them on this and also telling them how to identify the ones they missed by automatic grading and tips provided in the Google Forms/Microsoft Forms environments.

## 7.5 Performance and design

The system is designed to perform well, it has the following features for in-depth phishing simulation.

1. The automated use of email spoofing in phishing campaigns.
2. The automated use of mail masking.
3. Reports which users click on links on a per-user basis, allowing us to see who clicked on what link.
4. Fully automatic sending of phishing emails based on a list of email addresses.

In using sophisticated attacks lies no novelty, the novelty in our system is provided by the specialization towards Gmail/outlook and in the introduction of a further phishing simulation pipeline.

1. We created HTML templates used for specific use against Gmail and outlook users, by exploiting real warning html from their respective security platforms.
2. All our phishing emails have specific mistakes that are identifiable, such as one of the template emails being automatically sent by an account with the name Googl Support. (Note the missing e). We use these mistakes in our phishing quiz to show users what they missed.
3. Our Google and Microsoft phishing quizzes are built inside Google Forms and Microsoft Forms and use the specific Google and Microsoft phishing templates in their questions.
4. Phishing posters and awareness material is made in accordance with the other tools.
5. Complex reports are generated that fit inside of the pdf reporting environment that is used in all our tools collectively.

The idea is to establish GateKnocker as the world's first highly specific phishing simulation chain for Gmail and outlook. It goes beyond just sending emails by providing users with a full awareness improvement cycle.



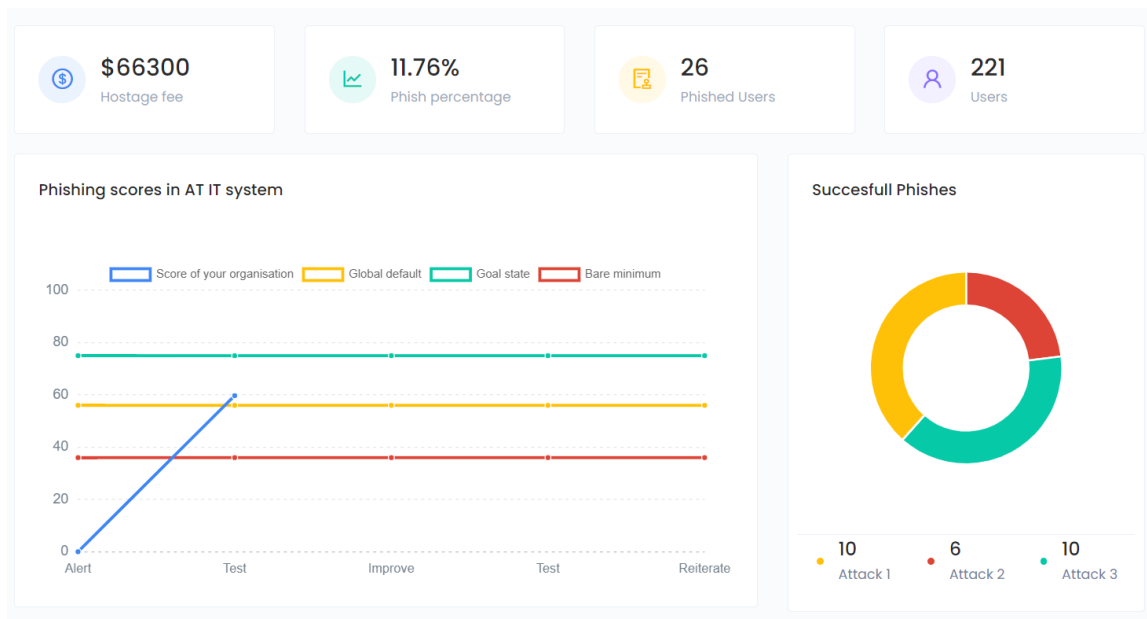


Figure 7.5: Automatic generated phishing report

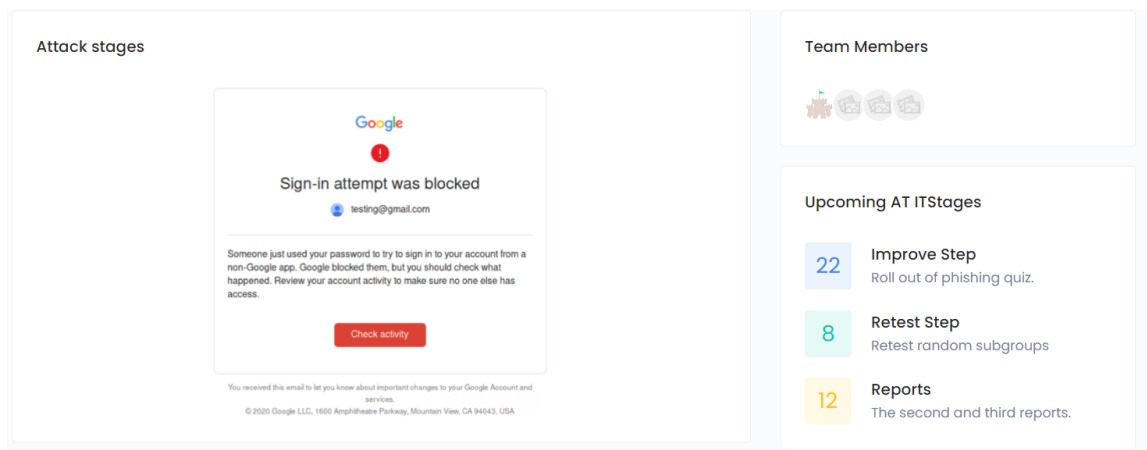


Figure 7.6: Phases and AT-IT plan for management



Figure 7.7: Anonymized individual responses

## Chapter 8

# Related Work

### 8.0.1 Active Directory

Currently, there are a number of approaches to improve the security of AD. These include manual processes such as setting up Group Policies and Security Policies, as well as various tools, such as Microsoft's Security Compliance Manager and Microsoft's Advanced Group Policy Management. These tools can be used to detect and address security vulnerabilities in AD, but they are labor-intensive and require extensive expertise.

In addition, there are a number of open-source and third-party solutions available for AD security, such as Splunk, Rapid7, AlienVault, and Qualys. These solutions provide automated vulnerability scanning and reporting, but they do not provide a comprehensive solution for the entire security improvement cycle and they do not adhere to the high standards set by for example PingCastle and Purple Knight.

### 8.0.2 FRIS

There are a lot of tools that generate automatic reports for vulnerabilities. Pingcastle does it for AD, but tools like Nessus, OpenVas and acunetix do it as well. There are no tools to the best of our knowledge tho, that provide scripts AND step by step solutions to fix vulnerabilities immediatly, while providing a set of steps to walk trough, identifying possible negative impact.

### 8.0.3 Google Workspace

There are numerous firms and companies that audit Google Workspace and Google cloud environments. However there is no automatic tool that does it yet. We also provide solutions and explanations while working with MFA based account scanning for optimal security of the scanner.

#### 8.0.4 Web penetration testing

While there are numerous tools for automatically finding version based vulnerabilities. There are to the best of my knowledge no such tools that use Artificial Intelligence to automatically convert found versions to common platform enumerations and use these to query a set of online database such as NVD, vulners, exploitdb and a few others. Using this system combined with advanced version detection systems based on regex and changes in versions to identify versions, provides a State of the art performance in the specific field of version based vulnerability identification. The combination of Wappalyzer, nuclei, whatweb, webtechsurvey.com and GPT based source code version identification sets a new standard in specifically website version identification. Version identification itself is enough to compete with some of the household names in web vulnerability scanning, such as DAST tools acunetix and burp suite pro that cost hundreds if not thousands per year for automatic website scanning.

## Chapter 9

# Discussions

### 9.1 Discussion points

In this study, we proposed the Stronghold system, a novel approach to automating the security improvement cycle for both Microsoft and Google environments. Our primary aim was to develop tools that could effectively address vulnerabilities in Active Directory, Azure Active Directory, Google Workspace, and Google Cloud while also providing automatic auditing, phishing simulations, and remediation capabilities. Although we had ambitious goals, we were able to achieve significant success in several aspects of our research.

#### 9.1.1 Interpretation of results

The Stronghold system demonstrated state-of-the-art results in vulnerability detection and remediation. As shown in sections 4.6, 5.2, and 6.8. Furthermore, we introduced the FRIS pipeline, which provided valuable information, further research, and direct solutions for addressing the discovered vulnerabilities. These results highlight the potential of the Stronghold system to effectively combat security threats in corporate environments, particularly in scenarios where budget constraints often lead to the negligence of security issues.

#### 9.1.2 Comparison with previous research

Compared to PingCastle and Purple Knight, the Stronghold system offers a more comprehensive approach to security improvement, as was shown in section 4.6. By targeting both Microsoft and Google environments and incorporating a seamless process from vulnerability detection to remediation, our system offers a unique solution to address the ever-evolving cybersecurity landscape. While also providing direct solutions to problems. It offers

better results than previous DAST web vulnerability scanning tools, specifically in the areas of version-based vulnerability identification, as shown in section 6.8.

### 9.1.3 Limitations and future research

Despite our successes, there were limitations to our study. We acknowledge that improvements can be made in the Web, and Google components of the Stronghold system. Mainly in building more checks and adding more building blocks, as shown in section 5.4. Moreover, we hope to surpass the current state-of-the-art in even more benchmarks in future research by doing trials with multiple additional tools on bigger and more diverse benchmark sets. It is also essential to continually update and refine our system to keep up with the rapidly changing cybersecurity landscape.

### 9.1.4 Implications

The Stronghold system has significant implications for the security of corporate environments utilizing Microsoft and Google platforms. By providing an effective, user-friendly, and cost-efficient solution to identify and address vulnerabilities, organizations can better protect their digital assets and reduce the risk of cyberattacks. Furthermore, the development of the FRIS pipeline offers valuable resources for IT professionals to research and remediate detected vulnerabilities, further strengthening the overall security posture of their organizations.

## 9.2 Future work

- It would be very nice to do an official benchmark on a broader set of Active Directory systems. Especially with even bigger systems. It would also be nice to do these benchmarks with multiple tools, adding ones like Testimo and Adaudit.
- A good addition would be to implement the additional Google Workspace checks. (Around 70) This will improve the coverage and results from Google system audits.
- A full comparison with multiple DAST web scanning tools on more websites would help us identify weaknesses in Besieger and would help us further establish it as state-of-the-art in version detection and version vulnerability detection.
- Further integration of GPT-4 inside of Besieger to do further analysis of website javascript and source code. GPT-4 has proven to be a very

good Code scanner that could have advantages even from a black box perspective.

- I am currently working very hard on extending the frameworks that were laid out in Besieger for web testing. Creating a phased approach would allow us to do full external pen tests.
  1. Find passive subdomains.
  2. Bruteforce subdomains with wordlists.
  3. Check which subdomains are alive from the combined list, separated into multiple Txt files per status code (200, 403 for example)
  4. Find open ports
  5. Use tools like Nessus and Besieger and automatic pentest tools like PentestGPT to automatically audit and pentest every subdomain.
  6. Extract all findings and create one big report using GPT-4.

All steps are working in this except for improving further and improving PentestGPT in particular. When done it would be a nice system for full external automated pentests that build upon the systems provided here. The system is named BeSieger.

- All tools should be enhanced to add scheduled scanning, automated mail notifications, automated discovery of new subdomains, and automatic re-reporting. This would add features to make our systems passive scanning tools that keep evaluating for possible security holes.
- Automatic generation of 3D networks with all the sub-fields we audit for inside the main section of our automatically generated report. This would allow for a more comprehensive and detailed visualization of the networks being tested and the sub-scores of departments.
- A segmentation graph generator that generates graphs of networks audited and the segmentation in them based on simple inputs. This would provide a clear overview of the different segments and sub-networks within a network.
- Rumourwatcher: an employee OSINT model that gets info about employees from several sources like social media websites and generates password lists from these. To the best of my knowledge, this is a new task as existing tools can create password lists from information but I want to also scrape this information automatically.

- A large language model like GPT-4 that is finetuned on pen-testing/hacking books and info. This would be a language model that has been trained on large amounts of pen-testing and hacking information to assist in identifying vulnerabilities, generating attack scenarios, and more. This is not yet done as finetuning still has to be released to the public. I have access to GPT-4 and I am waiting for finetuning to become available to the public.
- Eventually all tools should be integrated into a continuous scanning architecture with central databases and multi-agent options. A complete infrastructure for this in a modular, async way with automated systems will be the subject of my research internship at SURF. I hope to then take this framework and create a fully functioning full company analysis system in my master thesis, in which I plan to expand my master internship to fully integrate additional components such as AD, Azure, and Google, into this async automata-based design. The result should be a single automated tool embedded in all of the company sub-systems which allows for continuous scans every single day. The system is adopted for speed, running internet lines that allow for scanning with a few GB of network speed per second to scan networks of the size of SURF's ip ranges (8 million IPs) daily.



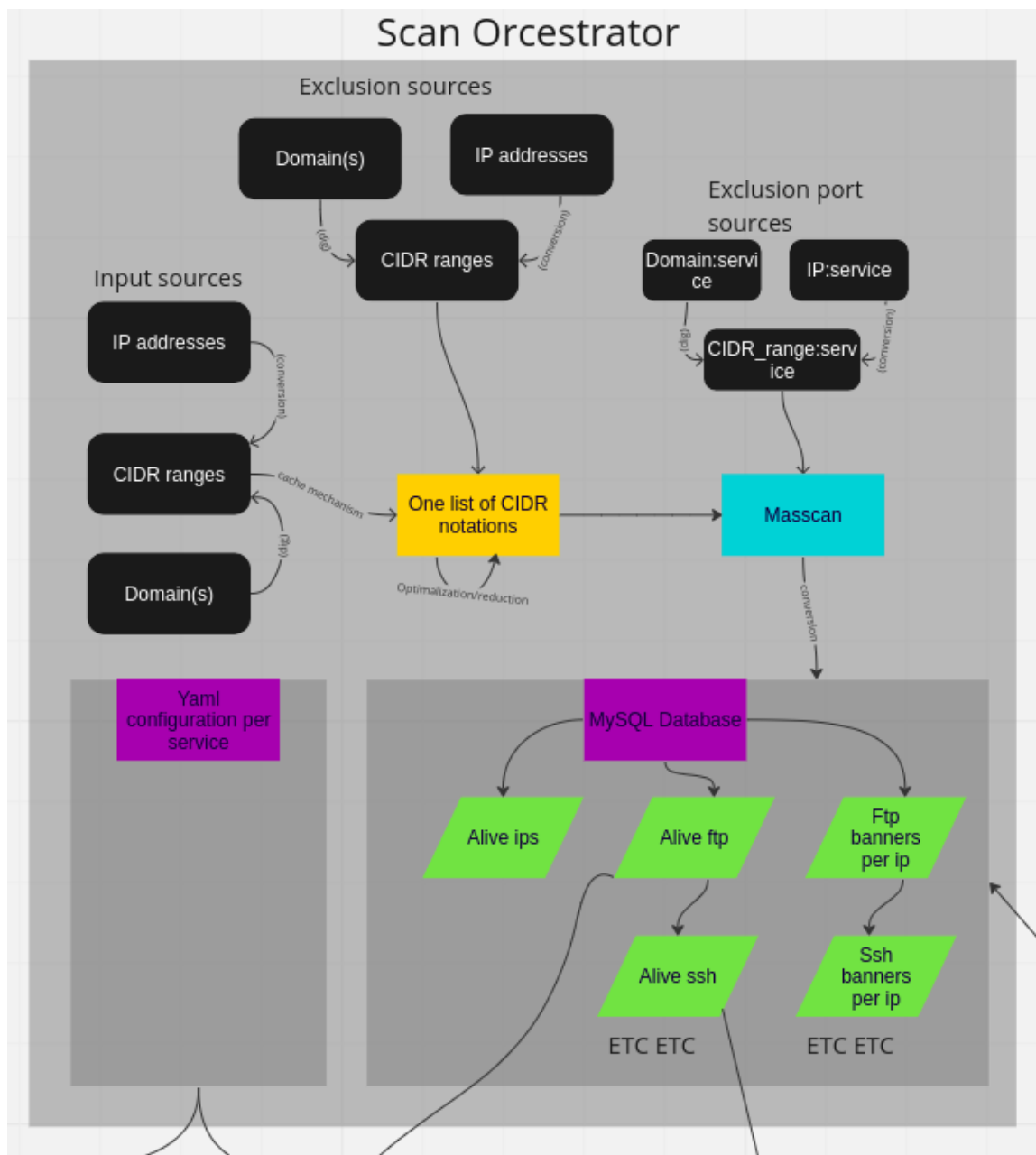


Figure 9.1: The orchestrator

The orchestrator as portrayed above does prescanning with Masscan, saving IPs, open ports, and banners into a MySQL database. It also uses a single .yaml configuration file to create modular sub-component-based scanning classes that just use different templates but act the same way.

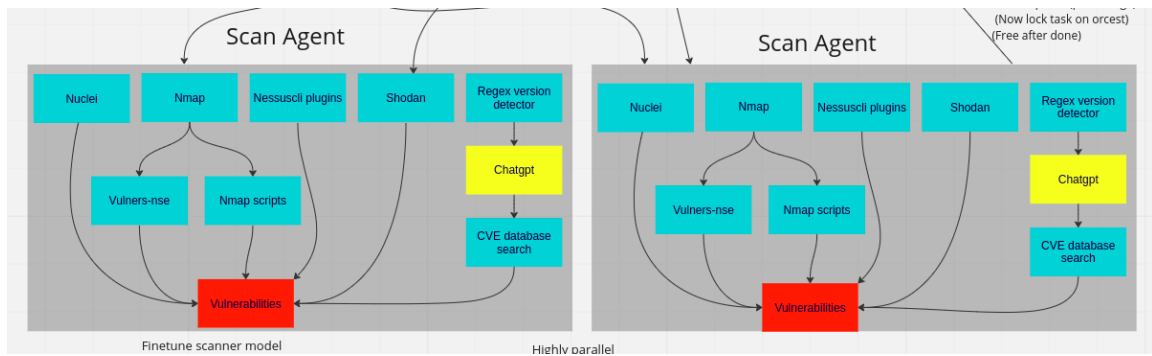


Figure 9.2: Scanning agents

We combine Nuclei, Nessus, and Nmap with open-source intelligence feeds such as Shodan, Censys, and netlas.io. We enrich this with our custom version-based scanners and GPT-based analyses and pen-testing. Possibly combined with agent modules on the PC's protected this gives a very in-depth analysis. Note that the scanner classes as discussed earlier are base classes and they can be enriched by individual components such as Wpscan or web scanners such as Acunetix for specific which are added inside the superclasses of specific ports.

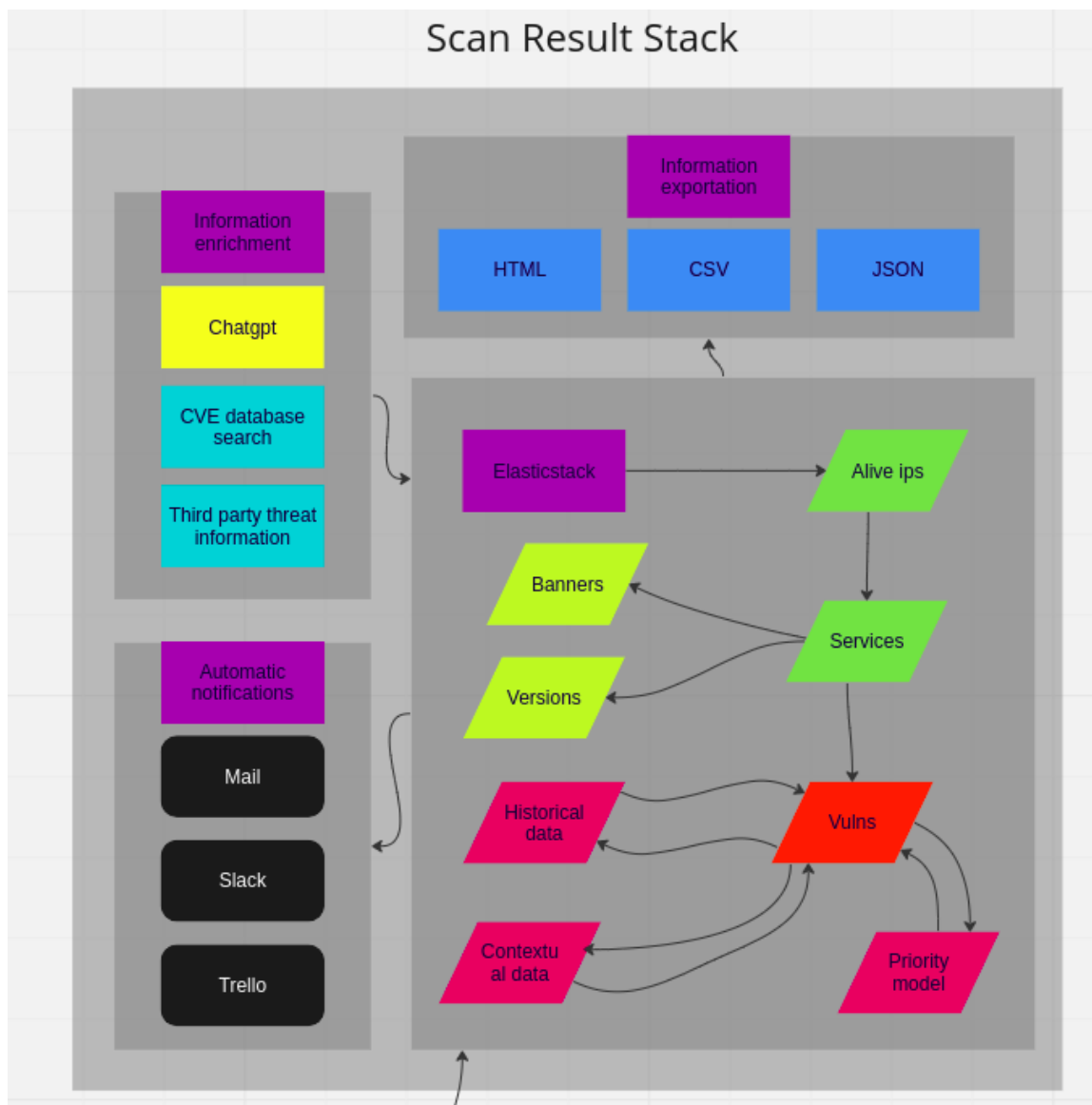


Figure 9.3: Elasticsearch reporting

Our agents give feedback on running to our orchestrator but send all output to our single elastic stack-based scan result stack, which aims to enrich information, generate reports, and automate notifications. It allows for direct SIEM integration by giving output that is parseable such as JSON or CSV.

## Chapter 10

# Conclusions

In conclusion, our research demonstrates the potential of the Stronghold system to address the ongoing security improvement cycle in both Microsoft and Google environments. Our system for Google Workspace is novel (section 5.1/5.2), while our system for Active Directory has been shown to consistently improve on the current state-of-the-art by finding more vulnerabilities in every test subject (section 4.6). We further improved on existing solutions by using FRIS and by adding solution scripts directly to vulnerability reports, being the first AD auditing tool to do so (section 3). We also implemented a web application scanning system to set a new state-of-the-art in finding vulnerabilities based on not properly updated web components (section 6.8). Combined, this presents Stronghold as a big step forward in the domains of AD-, Google Workspace- and web auditing, while also providing complementary systems for phishing simulations (section 7). We hope to further expand on this to provide a vulnerability-scanning ecosystem that allows companies to monitor vulnerabilities in all of their systems and environments in real time.

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