WOOT'24 Artifact Evaluation, Exploiting Android's Hardened Memory Allocator

Philipp Mao Elias Valentin Boschung Marcel Busch Mathias Payer
EPFL, Lausanne, Switzerland

1 Overview

1.1 Abstract

The artifact contains the tooling used to develop the exploits. It further contains exploit examples for our two exploitation techniques along with the files needed to reproduce our case study.

1.2 Description & Requirements

How to Access The artifact is publicly available at `https://github.com/HexHive/scudo-exploitation`.

Security, privacy or ethical concerns The artifact does not contain any threat to the system it's run on.

Hardware Dependencies The scudo libraries and the case study require an x86_64 machine to be run.

The tooling is architecture independent, however we designed the showcase of our exploits and tooling to be run on an x86 machine.

Software Dependencies We provide dockerfiles for our artifact evaluation, thus only `Docker` is required.

1.3 Evaluation Goals

The main focus of our artifact is making our tooling public and providing examples for our exploitation techniques to the community. We further include the necessary data to reproduce our case study to show the applicability of our exploitation techniques to real targets.

The evaluation should check if the example exploitation scripts work and if the gdb plugin is usable. The evaluation should also check if the case study reproduces.

2 Case Study

Paper Claim In our paper we claim that we leverage the forged CommitBase exploitation technique to exploit the system server on Android 14 to get code execution. In this part of the artifact evaluation this claim is tested.

Evaluation To reproduce our case study we provide a Dockerfile that sets up an Android emulator with the vulnerable library, along with installing the exploit app.

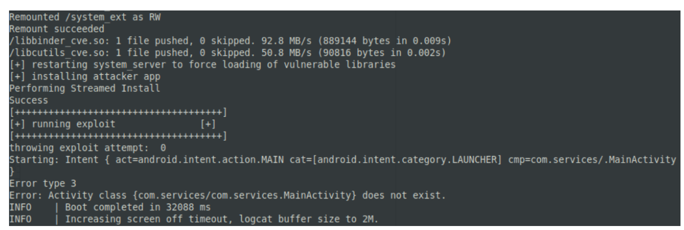
Build the docker in the `case-study` folder:

```
docker build . -t cve_emu
```

Then run the emulator along with the exploit:

```
docker run -rm -name emu -device /dev/kvm -it
cve_emu /bin/bash
```

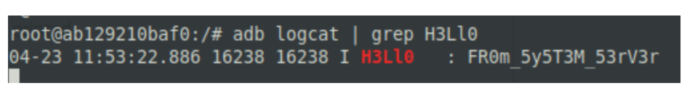
It takes a little while as we reboot the emulator once to make the libraries vulnerable. Once the following text is printed we are attempting the exploit.



After this text has been printed, in another terminal run the following commands:

```
docker exec -it emu /bin/bash
adb logcat | grep H3Ll0
```

This greps the logcat output for the print that we execute in our ropchain. After about 5-20 attempts the following should be printed:



When this is printed, our exploit was successfully reproduced. If our exploit succeeds a ROP chain is executed which uses __android_log_print to print the H3Ll0 string to logcat.

3 GDB Tooling, Scudocookie Library & Exploit examples

Paper Claims In the paper we claim that we discovered two exploitation techniques for Scudo, forged CommitBase and safe Unlink. We further claim that we developed a GDB plugin and a python3 library to help debug/exploit Scudo. In this part of the artifact evaluation all of these claims are checked by running two example exploits against a simple heap menu program and then debugging the exploit using our GDB plugin.

Evaluation The example exploits are located in the `exploits/` folder. In the following we provide a walkthrough of this part of the artifact and showcase how our gdb tooling and python3 `scudocookie` library can help in debugging the exploit. We designed this part of the artifact evaluation so the evaluator can follow along. Alternatively, for an evaluator familiar with pwntools exploitation, the exploitation scripts should be self-explanatory.

Our exploit examples use a simple heap menu program which exposes a number of memory corruption primitives to the user, arbitrary allocations and frees, heap under/overflows etc.. The program is located at `exploits/malloc-menu-linux/malloc-menu-linux`. We also bundle all local dependencies along with two versions of scudo.

3.1 Setup

In the `exploits/` folder run the following commands: `./build_docker.sh`.

3.2 Forged CommitBase

Start the docker using `./run_docker.sh` and navigate to the mounted folder using `cd /mnt/exploits`.

3.2.1 Exploit Functionality

Run the exploit:
`python3 forged_commitbase.py`.

Verify that the target arbitrary write address is the same as the allocated chunk see Figure 1.

The two addresses marked in red should match. If they match, the exploit was able to allocate a chunk at the chosen target address.

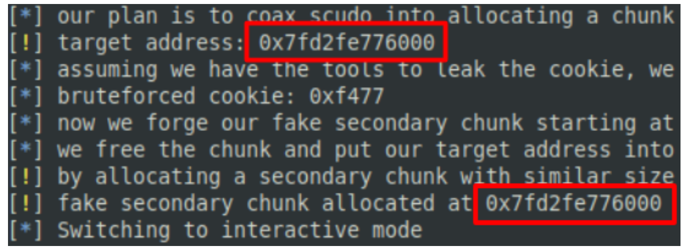


Figure 1: output of running the forged commitbase example exploit script.

3.2.2 GDB Plugin

Having verified the exploit works, let us look at what happens under the hood and do some debugging. First start the exploit with the debugger attached. If you are running the exploits in the docker, first start tmux otherwise we will not be able to attach GDB:

```
tmux
python3 forged_commitbase.py GDB
```

The exploit script automatically sets a breakpoint just after the heap-menus program loop. We first jump to where we allocate our victim chunk. In the gdb pane continue twice:

```
c
c
```

Now we have allocated our victim chunk. Take note of the target address, this is the address where we want to have a chunk get allocated. Copy the victim chunk address from the top program pane and run the following command in gdb in order to inspect the victim chunk.

```
scudo chunk [victim chunk address]
```

This will display some information about the victim chunk. All GDB commands starting with `scudo` are implemented by our Scudo gdb plugin. See Figure 3 for an example output.

In the next step we will overwrite this victim chunk's header. To do this we need to calculate the correct header checksum. This is where our python3 `scudocookie` library comes into play. Assuming we leak the chunk's header and address, we use this library to calculate the cookie used in computing the header's checksum. Afterwards we create a fake secondary chunk header and correctly compute the checksum for that chunk. The relevant lines involved in these steps can be seen, in lines 50 and 56 of the `forged_commitbase.py` exploit. In particular the `forge_header` function uses the `calc_checksum` function from the `scudocookie` library to compute the checksum.

Now keep continuing in GDB (with the `c` command), until the following text is printed: `[*] we free the chunk and put our target address into the secondary chunk free list`

At this point we have finished forging the chunk. In the gdb pane use the following commands to inspect the forged secondary chunk:

scudo chunk [victim chunk addr]
scudo largeblock [victim chunk addr]

The victim chunk should now have Class ID 0 and the `CommitBase` field of the secondary chunk header should point to the target arbitrary write address. See Figure 4 for an example output.

Continue once more in GDB:

c

Now the forged secondary chunk has been freed and our arbitrary write address has been stored in the secondary chunk free list. Inspect the secondary chunk free list using:

scudo largecachedblock

The data from the forged chunk header has been placed into the secondary chunk free list. See Figure 5 for an example output.

Continue one last time in GDB. This will allocate the chunk at the target address. In our example exploit the newly allocated chunk is now allocated in the `Allocator` object, which holds Scudo internal metadata. Inspect the newly allocated chunk:

scudo chunk [newly allocated chunk]
x/20gx [newly allocated chunk]

See Figure 6 for an example output.

3.3 Safe Unlink

Start the docker using `./run_docker.sh` and navigate to the mounted folder using `cd /mnt/exploits`.

3.3.1 Exploit Functionality

Run the exploit: `python3 safe_unlink.py`.

Verify that the allocated chunk via the exploit is located close to the perclass base. see Figure 2.

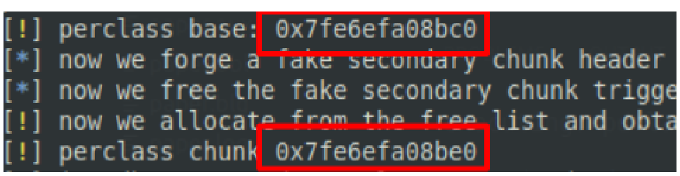


Figure 2: output of running the safe unlink example exploit script.

If the address of the newly allocated chunk is close to the perclass base, this means the exploit was able to allocate a chunk into the perclass structure, giving the attacker control over the free list.

3.3.2 GDB Plugin

Same as for the Forged CommitBase exploit run the exploit with GDB attached:

python3 safe_unlink.py GDB

Continue twice until the victim chunk is allocated:

c
c

Similar as before inspect the victim chunk. See Figure 7 for an example output.

scudo chunk [victim chunk addr]

This is the victim chunk whose header we will overwrite. Similar to the last exploit we use the scudocookie library to forge a fake secondary chunk. We also setup the fake linked list as detailed in the paper. Step until you see the following text printed: `[*] now we free the fake secondary chunk triggering the unlinking and placing the address to the perclass structure into the perclass free list itself .`

At this point we have setup the fake linked list between the forged chunk and the perclass free list. Inspect the forged secondary chunk:

scudo chunk [victim chunk addr] scudo largeblock [victim chunk addr]

Inspect the freelist into which we have freed chunks to build the fake linked list:

scudo perclass 1 20

The fake free list is built with the perclass free list and the forged secondary chunk by cleverly freeing chunks that overlap the forged secondary chunk header (more details in the paper). See Figure 8 to see an example output.

Now with the fake linked list built, we can free the chunk to insert a chunk into the free list. Step once in gdb:

c

Inspect the free list again, now a pointer to the free list itself has been inserted into the free list:

scudo perclass 1 20

See Figure 9 for an example output.

Step once more in gdb to allocate a chunk into the free list:

c

Inspect the free list a final time we should see the chunk header in the free list: `scudo perclass 1 20`

See Figure 10 for an example output. This means that our exploit was able to allocate a chunk into the free list and thus gain control over the free list.

Images

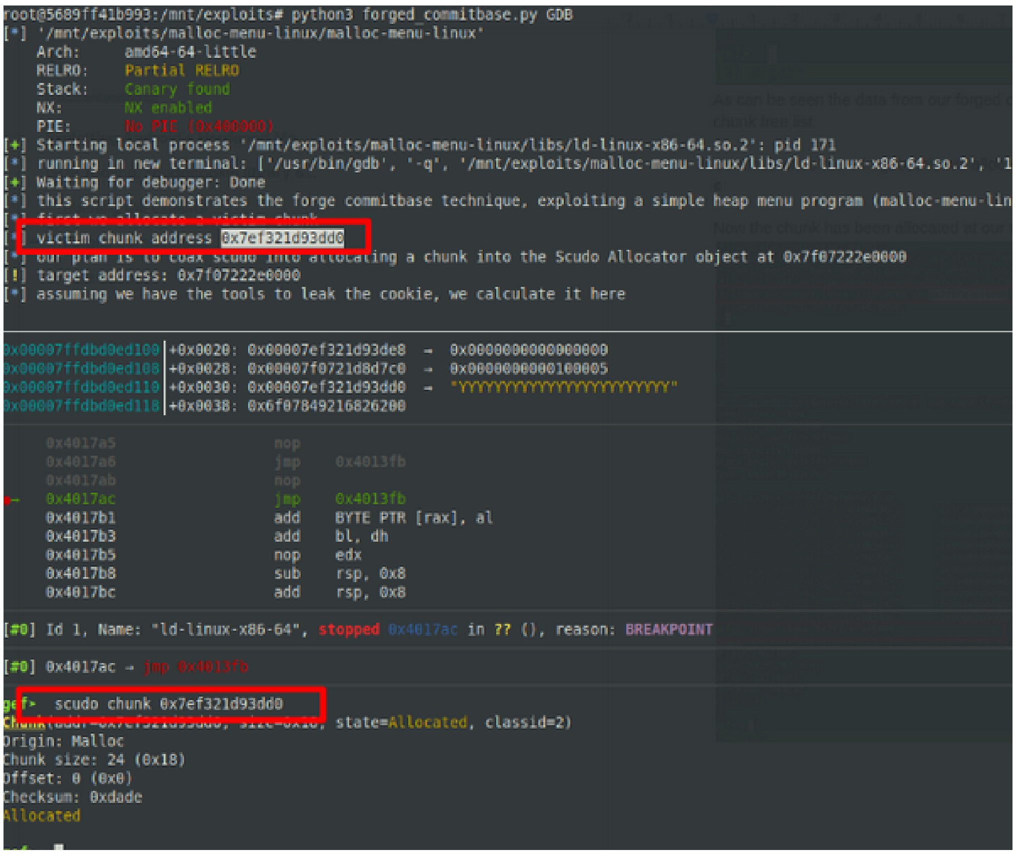


Figure 3: Forged CommitBase: The chunk state after the victim chunk is allocated

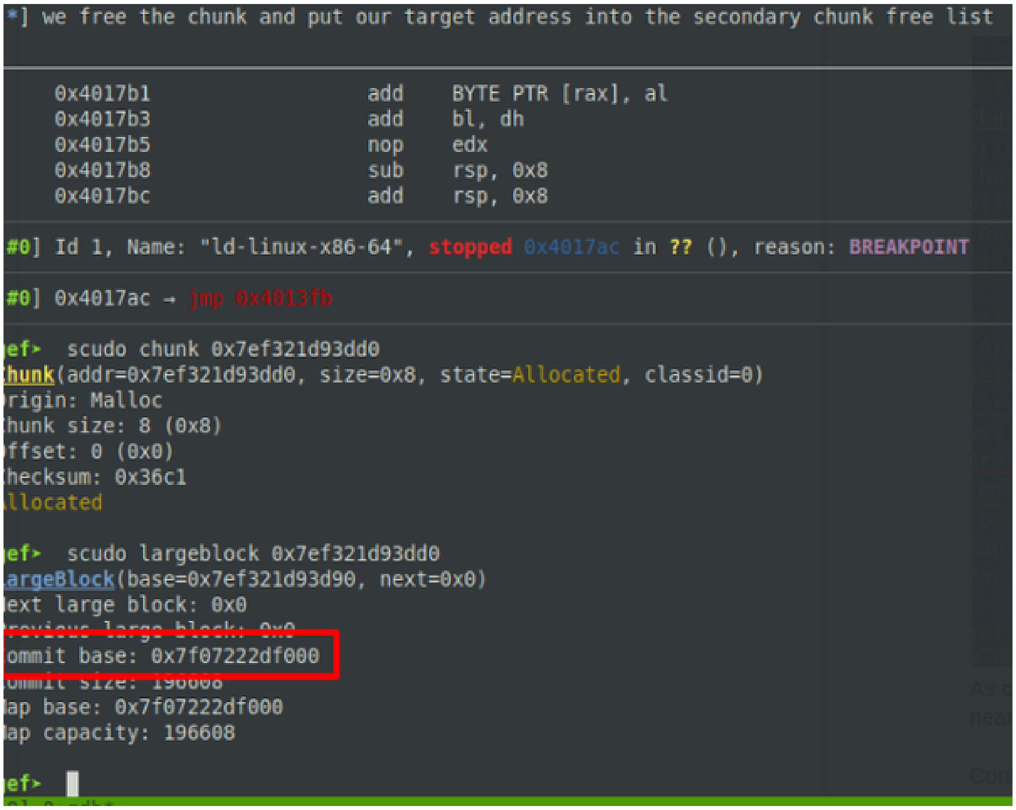


Figure 4: Forged CommitBase: The forged secondary chunk.

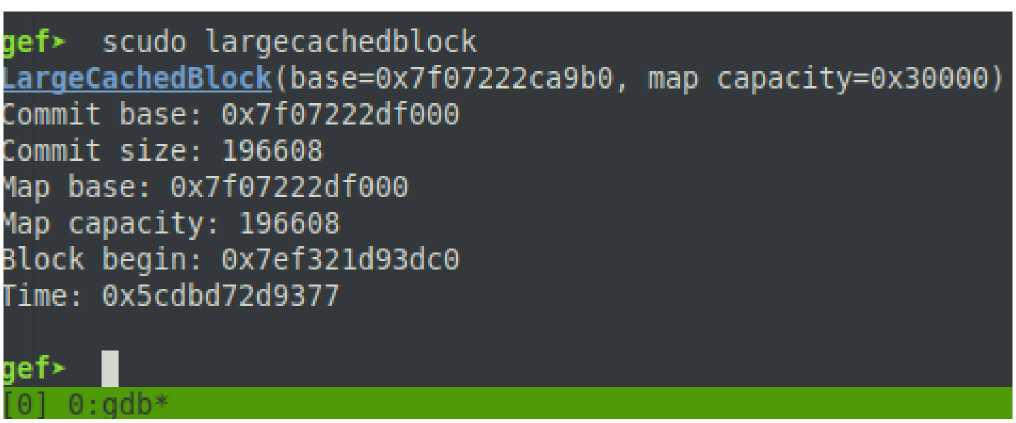


Figure 5: Forged CommitBase: The secondary chunk free list containing our target write address

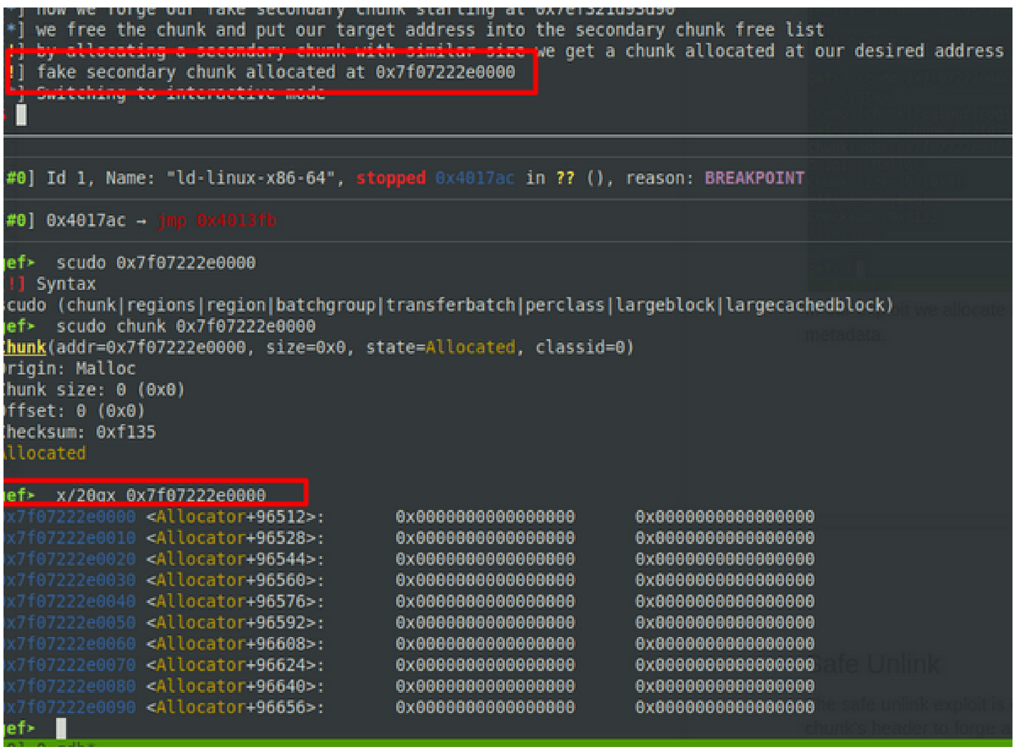


Figure 6: Forged CommitBase: The chunk allocated at our target address.

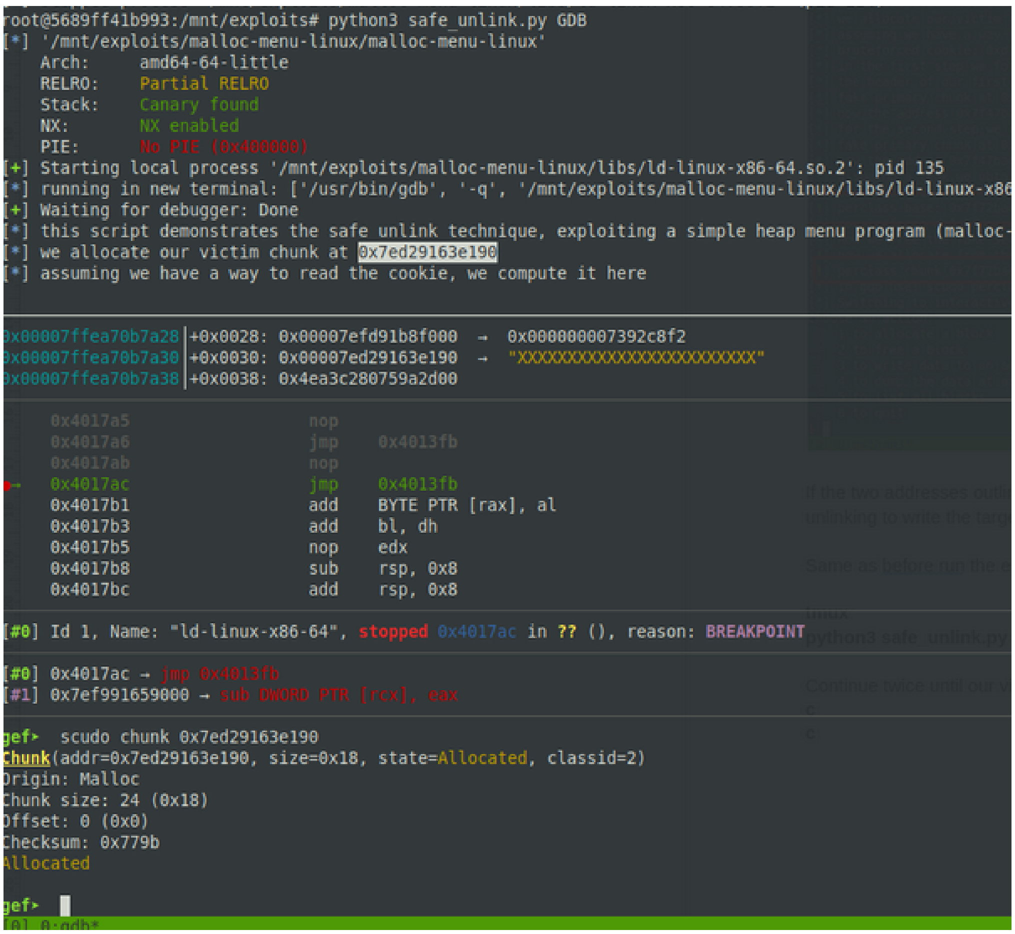


Figure 7: Safe Unlink: The chunk state after the victim chunk is allocated.

```
gef➤  scudo chunk 0x7ed29163e190
Chunk(addr=0x7ed29163e190, size=0x8, state=Allocated, classid=0)
Origin: Malloc
Chunk size: 8 (0x8)
Offset: 0 (0x0)
Checksum: 0x9b84
Allocated

gef➤  scudo largeblock 0x7ed29163e190
LargeBlock(base=0x7ed29163e150, next=0x7efd91638bd0)
Next large block: 0x7efd91638bd0
Previous large block: 0x7efd91638bd0
Commit base: 0xdeadbeef
Commit size: 196608
Map base: 0xdeadbeef
Map size: 196608

gef➤  scudo perclass 1 20
PerClass(base=0x7efd91638bc0, count=2)
Number chunks: 2
Maximal number chunks: 2
Class size: 2048
        Chunk #0: 0x7ed29163e150
        Chunk #1: 0x7ed29163e150

gef➤
```

Figure 8: Safe Unlink: The fake linked list between the perclass free list and forged secondary chunk.

```
gef➤  scudo perclass 1 20
PerClass(base=0x7efd91638bc0, count=2)
Number chunks: 2
Maximal number chunks: 2
Class size: 2048
        Chunk #0: 0x7efd91638bd0
        Chunk #1: 0x7efd91638bd0
```

Figure 9: Safe Unlink: An address to the perclass free list has been inserted into the perclass free list itself.

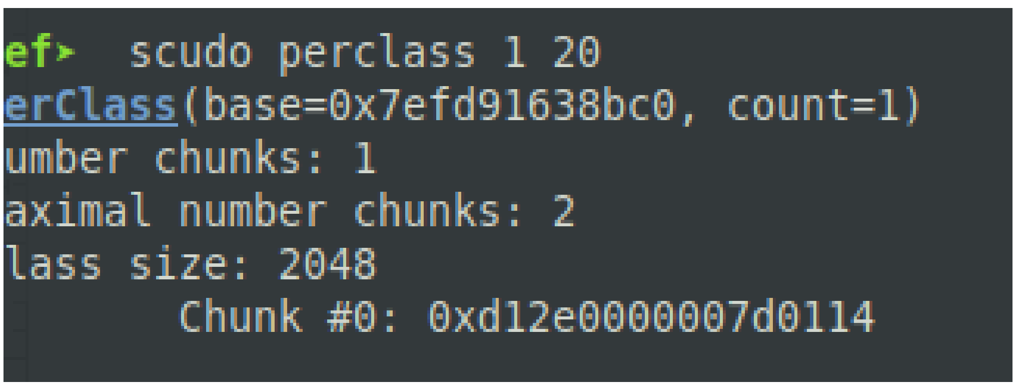


Figure 10: Safe Unlink: A chunk has been allocated into the perclass free list. What can be seen is the chunk header.