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Tooling and Analysis of the Scudo Allocator

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Bachelor Thesis

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If debugging is the process of removing software bugs,
then programming must be the process of putting them in.
— Edsger Dijkstra

Dedicated to my study companion since Covid-19, my plush bear.

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Lausanne, June 9, 2023 Elias Valentin Boschung

Abstract

Heap related memory corruptions are a major concern. To understand the cause and impact of such heap bugs, developers and analysts rely on tools that allow them to dynamically inspect the state of the heap. LLVM's Scudo heap implementation is a hardened memory allocator that attempts to prevent exploitation of common heap related bugs. Since Android 11, Scudo is used as the main memory allocator for Android apps. Due to its novelty only little documentation exists on how Scudo works internally, and no tooling exists to inspect the state of the Scudo heap. In this project we analyse the way Scudo manages the heap and develop a tool to analyse the state of the Scudo heap at runtime. We implement our tool as an extras plugin into the popular GEF plugin for GDB. We demonstrate that we can leverage our tool to triage heap related bugs in Android native libraries running on Android 11 (Security patch level 1 January 2021).

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Chapter 1

Introduction

Bugs related to heap memory are one of the most frequent problems encountered by C developers, since in bigger projects it can very quickly get hard to track all the resources that are open and which were already closed. It is very tedious to track all of such errors down, and just a single oversight might create a bug that opens a huge security vulnerability. Additionally, nowadays, many apps are so complex that they use various third-party libraries to do different tasks, since re-implementing everything on your own would be a waste of time. However, one hardly has the time to check the whole source code of every library one uses, so one has to trust the library developers to have done their work correctly. An example of where such trust was the cause of a major vulnerability is a remote code execution in WhatsApp that was found in 2019, where a simple double free in a third-party GIF library allowed an attacker to get arbitrary remote code execution. [1]

Since checking all the code of all third-party libraries is practically not feasible, it is important to be able to debug heap bugs when they are found, in order to understand how they happen, the consequences an exploit using the bug might have, and to be able to fix the bug rapidly. In order to encourage and assist developers in this process, there needs to be some freely available tools that make dynamic debugging of the heap easier.

Since Android devices are used daily by millions of users, with many thousands to millions of different apps, the attack surface for exploits is huge. That might well be one of the reasons that Android uses the new and mostly unknown heap allocator called Scudo. [3] Scudo tries to mitigate some of the potential vulnerabilities due to heap bugs directly in the allocator, while keeping a high performance for memory allocations. However, since it is relatively new, there exists only spare documentation of how Scudo functions internally, and there are no tools to dynamically analyze the Scudo heap.

The *Androlib* project is an ongoing project at the HexHive lab to fuzz Android native libraries. As a result of fuzzing campaigns carried out, *Androlib* has discovered a number of crashes in native libraries. While it is doable to triage the crashes in some categories, heap-related crashes are difficult to analyse due to the Scudo allocator, as no tooling to inspect the Scudo heap exists.

The goal of this project is therefore to implement a tool that allows to dynamically inspect the Scudo heap. One of the main challenges is to understand the Scudo allocator internals and then to create appropriate tooling to help with the analysing of those crashes. While there is a bit of documentation around Scudo, there is not really a comprehensive overview of all detailed inner workings of Scudo, and no tools tailored for debugging crashes related to Scudo.

Since *Androlib* uses gdb and gef for it's triaging setup, we implement our tool as a gef-extras plugin, that can be easily loaded into gdb with gef and adds some commands for inspecting the Scudo heap.

We evaluate our tool by triaging seven heap-related crashes on a real Android device. We plan to open source our tool to make it available to the community.

Chapter 2

Scudo Internals

The Scudo hardened allocator divides the heap allocations it is asked to do into two big types of allocations, based on the size of the chunk to be allocated. The smaller chunks are handled by the primary allocator inside Scudo, which is designed to optimize performance as much as possible by adapting to finer grained size differences between these smaller chunks. All the big chunks are handled by the secondary allocator, which is less optimized, since the most frequent chunks are the small ones and thus the primary allocator has a bigger impact on performance than the secondary allocator.

2.1 Chunk Header

ClassId	8 bits
State	2 bits
OriginOrWasZeroed	2 bits
SizeOrUnusedBytes	20 bits
Offset	16 bits
Checksum	16 bits

Figure 2.1: Layout of the Scudo chunk header

The chunks allocated by both the primary and the secondary allocator store some metadata in a combined header. This header is then stored just in front of the actual content of the chunk, such that it can easily be checked whenever the chunk gets accessed. An overview of the contents of this header can be seen in Figure 2.1. The ClassId identifies the class the chunk belongs to in case it was allocated by the primary allocator, with a ClassId of 0 meaning that the chunk was allocated by the secondary allocator. The header also contains information about the state of the chunk, which can be allocated, quarantined or available, as well as the origin of the allocation, e.g., malloc or new, which can be used to detect errors when the type of deallocation does not match the type of the allocation. Furthermore, the header includes the size for the primary chunks or the amount of unused bytes for the secondary chunks and an offset, which is the distance from the beginning of the returned chunk to the beginning of the actual backend allocation. Finally, the header contains a checksum, which is generated using a cookie (a random number generated during the initialization of the allocator), the heap address of the chunk, and the actual content of the header. This checksum is used for guarding against programming errors as well as attackers, and it is checked each time the header is loaded.

2.2 Primary Allocator

The primary allocator structures the heap into Classes (also named Regions), the amount of which depend on the configuration. These classes are identified by a ClassId, starting from 1. The ClassId 0 is reserved for allocating the internal structures used by Scudo to keep track of the free chunks. Each of the classes gets its own region in memory where it can allocate chunks, giving some separation between chunks of different classes, unlike the standard libc heap allocator, where the heap is a single big region in memory. This can also be seen in Figure 2.2, where we see that each class/region has its own beginning address, and also tracks its own mapped and allocated space.

```
gef➤  scudo regions
Region(base=0x7ffff7b750c0, region_begin=0x7fd2f75ce000, mapped=0x40000, allocated=0x2000, num_batches=1)
Region(base=0x7ffff7b75180, region_begin=0x7fd3f75d7000, mapped=0x0, allocated=0x0, num_batches=0)
Region(base=0x7ffff7b75240, region_begin=0x7fd4f75c9000, mapped=0x0, allocated=0x0, num_batches=0)
Region(base=0x7ffff7b75300, region_begin=0x7fd5f75cd000, mapped=0x40000, allocated=0x1e00, num_batches=1)
Region(base=0x7ffff7b753c0, region_begin=0x7fd6f75cc000, mapped=0x0, allocated=0x0, num_batches=0)
Region(base=0x7ffff7b75480, region_begin=0x7fd7f75c8000, mapped=0x0, allocated=0x0, num_batches=0)
Region(base=0x7ffff7b75540, region_begin=0x7fd8f75c8000, mapped=0x0, allocated=0x0, num_batches=0)
Region(base=0x7ffff7b75600, region_begin=0x7fd9f75d2000, mapped=0x0, allocated=0x0, num_batches=0)
```

Figure 2.2: Example of the division of classes/regions by using the developed plugin

The classes have a given size of the chunks that can be allocated in that class, which increases with the ClassId, with the exact numbers depending again on the configuration. An excerpt of the class sizes on Android 11 can be seen in Figure 2.3.

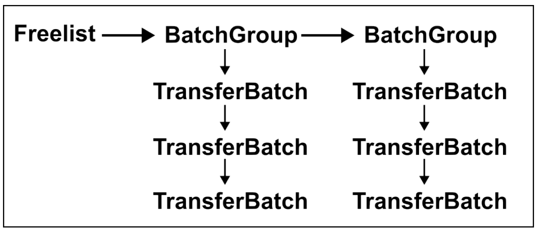
So the chunk that is actually returned by the primary allocator might be bigger than what was asked for, but this helps against having to do expensive bookkeeping to avoid fragmentation inside the classes.

So when an allocation request is made to Scudo, and it is small enough to fit into one of the primary allocator regions, then the primary allocator first finds the smallest class that still contains chunks big enough for the requested size. It then checks in the cache associated to that class, to find a chunk that is already available. However, if the cache is empty, meaning that there are no readily available free chunks, the primary allocator tries to refill the cache with some new chunks. For that purpose, it looks up the freelist of TransferBatches for the given class, and if it is not empty

ClassId	Size of chunks
0	special
1	0x20
2	0x30
3	0x40
4	0x50
...	...
36	0x30010
37	0x38010
38	0x40010

Figure 2.3: Sizes of the classes on Android 11

it just takes all the chunks of the first TransferBatch in the freelist and moves them to the cache of the class. One TransferBatch holds a certain number of chunks defined by the configuration, which is the same for all classes. In case the freelist is out of TransferBatches, the allocator will allocate some new TransferBatches to fill up the freelist. The amount of TransferBatches allocated at one such time depends on the configuration, but it is typically smaller the bigger the class gets, as one TransferBatch represents more actual memory the bigger the class is. The allocator will also map more space for a specific class if the amount of TransferBatches to be created does not fit into the existing mapped space. Since the transfer batches that are currently in one of the freelists need to be stored somewhere as well, the first class with ClassId 0 is reserved for this use. The allocations requested by the user will never directly use this class, instead when a freelist for one of the classes needs to be refilled with new TransferBatches, these are allocated in this first class, and they are freed when they are moved to the cache of the class.



(a) Latest version

(b) Version shipped with Android 11

Figure 2.4: Layout of the freelist for each of the classes

Additionally, while not yet present in the version of Scudo shipped with Android 11, the latest Scudo version includes a type that regroups multiple transfer batches, into a BatchGroup, as illustrated in Figure 2.4a. Instead of the freelist for a given class containing a list of transfer batches, it now has a list of batch groups, which contain a list of transfer batches each. The overall functionality of the allocator doesn't change however, the change is just supposed to get even more performance for the frequent allocations of the primary allocator.

2.3 Secondary Allocator

The secondary allocator is a bit less sophisticated, since it does not need to be able to do as many allocations and deallocations as the primary allocator, and the optimizations of the primary allocator would not be that efficient for the bigger and therefore generally more variable sizes the secondary allocator has to handle. Instead, the secondary allocator just keeps a simple cache of the previously freed chunks, and if there is no matching chunk in its cache upon a request for a new allocation, it maps some new memory for that chunk. For bookkeeping, the secondary allocator simply keeps a doubly linked list of all chunks currently in use and keeps track of the details of each allocated chunk in a special header that is prepended to the combined header.

Chapter 3

Implementation

The structure of the gef-extras plugin is heavily inspired by the existing structure of the tooling for the standard libc heap allocator used in most Linux systems, which is included in the gef plugin for gdb. [2] The Scudo plugin therefore offers multiple commands for the different structures present in Scudo. These commands take generally some address to a memory region, and create an object by reading out the data from that memory address and parsing it according to the predefined structure.

The most basic command is the `scudo chunk` command, which given the address of a chunk on the heap, reads the header in front of the chunk and displays the info contained in it. The design of the output is the same as for the standard libc heap commands included in gef, with the allocation state being highlighted in color, as can be seen in Figure 3.1. In the actual implementation, a chunk is represented as a class, and like in gef, the different information is stored as properties of the class. Similarly, the data is read from memory using the `gef.memory.read` function, and then structured as a type using the ctypes library to represent the different types used in Scudo. The `str` method on the class is implemented to display a short summary of the most essential info, while the `psprint` method shows the extended information display, as shown in Figure 3.1.

The next two commands concern the region info, with respectively the `scudo region` and `scudo regions` commands. Both of work with the same `ScudoRegionInfo` class, which is defined like the Scudo chunk with a ctypes structure to represent the types in the Scudo c code, and with properties for all the information extracted. The one special thing about the region info class is the padding, since the structure is padded to the Scudo cache line size for faster access. So the plugin first builds an unpadded version of the ctypes structure, and then adds the required padding to get a multiple of the Scudo cache line size to the structure to get the final version.

The info included in the RegionInfo structure includes the list of transfer batches for that region, the number of popped and pushed blocks, the amount of memory mapped and allocated inside the region, the random state generated for the region as well as information about the last release of

```
gef➤  scudo chunk 0x7fd5f75d7b70
Chunk(addr=0x7fd5f75d7b70, size=0x32, state=Quarantined, classid=3)
Origin: Malloc
Chunk size: 50 (0x32)
Offset: 0 (0x0)
Checksum: 0xb3c8
Quarantined

gef➤  scudo chunk 0x7fe2f75d4410
Chunk(addr=0x7fe2f75d4410, size=0x3e8, state=Allocated, classid=0)
Origin: Malloc
Chunk size: 1000 (0x3e8)
Offset: 0 (0x0)
Checksum: 0xfe18
Allocated
```

Figure 3.1: Example of the Scudo chunk command in gef

blocks to the operating system.

The data of this `RegionInfo` structure is stored in an array, with an entry for each of the regions/classes. The array is part of the primary allocator class, and so the plugin finds it by using the offset from the `Allocator` symbol to get the first entry in the array. The `scudo regions` command then simply displays a list of short information about each region, as seen in Figure 3.2.

```
gef➤  scudo regions
Region(base=0x7ffff7b750c0, region_begin=0x7fd2f75ce000, mapped=0x40000, allocated=0x2000, num_batches=1)
Region(base=0x7ffff7b75180, region_begin=0x7fd3f75d7000, mapped=0x0, allocated=0x0, num_batches=0)
Region(base=0x7ffff7b75240, region_begin=0x7fd4f75c9000, mapped=0x0, allocated=0x0, num_batches=0)
Region(base=0x7ffff7b75300, region_begin=0x7fd5f75cd000, mapped=0x40000, allocated=0x1e00, num_batches=1)
Region(base=0x7ffff7b753c0, region_begin=0x7fd6f75cc000, mapped=0x0, allocated=0x0, num_batches=0)
Region(base=0x7ffff7b75480, region_begin=0x7fd7f75c8000, mapped=0x0, allocated=0x0, num_batches=0)
Region(base=0x7ffff7b75540, region_begin=0x7fd8f75c8000, mapped=0x0, allocated=0x0, num_batches=0)
Region(base=0x7ffff7b75600, region_begin=0x7fd9f75d2000, mapped=0x0, allocated=0x0, num_batches=0)
```

Figure 3.2: Example of the Scudo regions command in gef

The `scudo region` command on the other hand displays more detailed information about a specific region, which can be specified either by giving the address to the RegionInfo structure, by giving the max allocation size of the region, or by the index in the array, which corresponds to its ClassId. An example of the display can be seen in Figure 3.3, which shows the special region which holds the transfer batches.

The next two commands concern the free list of the primary allocator, as they display the information about the batch groups and the transfer batches. Both of these commands are very simple, since both of them basically contain a list of another structure. Also since there isn't one universal point where all of them are stored, the commands need to be provided with the address of the batch group or transfer batch to output. Since the batch groups are a new addition, the

```
gef➤  scudo region --index 3
Region(base=0x7ffff7b75300, region_begin=0x7fd5f75cd000, mapped=0x40000, allocated=0x1e00, num_batches=1)
Free list:
        Number free: 1
        First free: 0x7fd2f75cf980
        Last free: 0x7fd2f75cf980

Region stats:
        Popped blocks: 10
        Pushed blocks: 0

Random state: 2791513300

Release to OS:
        Pushed blocks at last release: 0x0
        Ranges released: 0x0
        Last released bytes: 0x0
        Last release at ns: 37685423746953
```

Figure 3.3: Example of the Scudo region command in gef

command doesn't work on a real Android 11 phone, however it works when using the standalone compiled version from the llvm repository. It shows detailed information about the batch group, including the address of the next batch group, since the batch groups form a linked list, the number of pushed blocks, and the information about the doubly linked list of transfer batches it contains. While this detailed view can be seen in Figure 3.4, when specifying a number as argument with `--number X`, it will instead display a short version for this amount of batch groups in the linked list, with the first one being the one specified by address.

```
gef➤  scudo batchgroup 0x7fd2f75cf980
BatchGroup(base=0x7fd2f75cf980, num_batches=7, first_batch=0x7fd2f75cf600, pushed_blocks=80)
Next batch group: 0x0
Compact base addr: 0x3feafba
Max cached per batch: 10
Pushed blocks: 80
Pushed blocks at last checkpoint: 0
Batches:
        Number batches: 7
        First batch: 0x7fd2f75cf600
        Last last: 0x7fd2f75cf900
```

Figure 3.4: Example of the Scudo batch group command in gef

The `scudo transferbatch` command simply outputs the addresses of every batch it contains, as well the address of the next transfer batch, which can be seen in Figure 3.5. Since the transfer batches also form a linked list similarly to the batch groups, the number argument can be specified in the same way to get an overview of that number of transfer batches.

The next command concerns the cache, which is actually the first place the primary allocator tries to look for free chunks to allocate for the user. While again the content of each per class structure is fairly simple with a list of the chunks it contains and the maximal number of chunks it can contain, there was a particular challenge about implementing this command, which was to find the location of the actual array. Since Scudo was designed for multi threading, there actually exists a

```
gef➤  scudo transferbatch 0x7fd2f75cf600
TransferBatch(base=0x7fd2f75cf600, num_batches=10)
Next transfer batch: 0x7fd2f75cf680
Number batches: 10
        Batch #0: 0x7fd5f75cdc00
        Batch #1: 0x7fd5f75ce560
        Batch #2: 0x7fd5f75cd6c0
        Batch #3: 0x7fd5f75cd060
        Batch #4: 0x7fd5f75ce0e0
        Batch #5: 0x7fd5f75cda80
        Batch #6: 0x7fd5f75cdae0
        Batch #7: 0x7fd5f75ce380
        Batch #8: 0x7fd5f75cd240
        Batch #9: 0x7fd5f75ce860
```

Figure 3.5: Example of the Scudo transfer batch command in gef

cache for each thread, and as such the per class array of each thread is not simply stored at an offset from the Allocator symbol. However, there luckily is a trick to find the different per class arrays of the different threads, as the cache of each thread contains some statistics about the allocated and free blocks in that cache. In order to have some global statistics over all the different threads, Scudo stores some global stats, that include a linked list of all the local stats of the different threads. So in order to get the address of the per class array of a thread, the plugin gets the linked list of statistics from its offset to the Allocator symbol and then follows the linked list the number of times to reach the statistics for the correct thread. Since the statistics are stored right after the per class array in the cache, the plugin then simply subtracts the size of the per class array to get the address of the first entry in the class array. For that reason the `scudo perclass` command also takes two arguments, the first being the thread ID and the second being the class ID, which uniquely define the entry to get. If the IDs are omitted a default value of 0 is taken. An example of the output can be seen in Figure 3.6.

The last command is the only one concerning the secondary allocator specifically, and it reads out the special header that is prepended to the normal chunk header for any secondary chunk. The normal Scudo chunk command still works for secondary chunks as well though. The large block command gives information about the commit and map base addresses and sizes, as well as the next and previous large blocks in the linked list. The command can either be provided by an address to read out the corresponding large block, or if the address is omitted it will take the first block from the list of blocks in use. An example can be seen in Figure 3.7. A `--number X` argument can optionally be specified to get once again a list of short information about that amount of large blocks.

While the whole plugin is contained in a single file to follow the gef standard, the organization with classes and using the ctypes structures allows for a flexibility in adapting and evolving the

```
gef➤  scudo perclass
PerClass(base=0x7ffff75c97c0, count=6)
Number chunks: 6
Maximal number chunks: 16
Class size: 0
        Chunk #0: 0x7fd2f75ceb00
        Chunk #1: 0x7fd2f75ceb80
        Chunk #2: 0x7fd2f75cec00
        Chunk #3: 0x7fd2f75cec80
        Chunk #4: 0x7fd2f75ced00
        Chunk #5: 0x7fd2f75ced80
```

Figure 3.6: Example of the Scudo per class command in gef

```
gef➤  scudo largeblock 0x7fd2f1566ec0
LargeBlock(base=0x7fd2f1566ec0, next=0x0)
Next large block: 0x0
Previous large block: 0x0
Commit base: 0x7fd2f1566000
Commit size: 100003840
Map base: 0x7fd2f1565000
Map size: 100012032
```

Figure 3.7: Example of the Scudo large block command in gef

plugin. As such it would be quite easy to adapt the plugin for any minor changes in the Scudo structure should it evolve in the future, or adapted to support older versions of Scudo, with one such version already being implemented for the version of Scudo that was shipped with Android 11. The main changes for this older version of Scudo included that the batch groups did not exist yet, some minor reordering of some fields in some of the structures, which also caused some of the offsets from the Allocator symbol to be changed.

Chapter 4

Evaluation

To evaluate our tool, we first want to show that we can install and use the tool on a real android phone, and then that it can help with investigating crashes taken from real android apps using native libraries.

4.1 Setup on real Android phone

During the main development process the plugin was tested with the standalone version of Scudo compiled with debug symbols from the llvm repository. In order to get the plugin loaded by gef, the folder containing the plugin file needs to be specified as gef-extras plugin directory. The easiest way to do this is to run `gef config gef.extra_plugins_dir /path/to/plugin/dir`. In order to use multiple different gef extra plugins that may be located at different paths, multiple paths can be specified separated by semicolons. Also, the configuration can be saved using `gef save`, which will create a gef.rc file that will be loaded in order to keep the settings between restarts of gdb.

Since the main development was done on the standalone version, the first step to evaluate the plugin was to actually test it on a real android phone. The test device was a Samsung Galaxy S10, which was already rooted using Magisk and had gdb and gef installed using the Termux app. Access to the phones console and copying of the plugin to the phone was done using adb.

While the plugin installation and loading worked without problem on the phone, it rapidly became evident that the plugin did not work as intended and instead returned some random looking numbers for most commands. So after some investigation, it was discovered that the Scudo version shipped with Android 11, which was installed on the testing device, differed in multiple points from the most recent version on the llvm repository. The plugin was therefore copied and adapted into a version for Android 11, which notably does not contain the batch groups, as well as differing in some minor changes in different structures.

4.2 Crash Triage

4.2.1 Overview

In order to evaluate the actual functioning of the plugin, it was tested with some of the crashes found in the *Androlib* fuzzing campaign. The starting of the corresponding apps and causing the crashes was already set up automatically, including opening gdb before starting to run the program in order to allow for the setting of any breakpoints if needed. In Figure 4.1 we can see an overview of the crashes analyzed. We will show two detailed case studies and how the plugin and some specific commands helped in analyzing them in the next section.

Package name	Crash # from Androlib	Crash reason
com.skt.smartbill	BT5	invalid free
	BT7	double free
	BT13	double free
heartratemonitor.heartrate.pulse.pulseapp	BT1	header corruption
com.ahnlab.v3mobileplus	BT1	double free
com.kbankwith.smartbank	BT2	double free
	BT3	invalid free

Figure 4.1: Overview of the crashes triaged

4.2.2 Case studies

V3MobilePlus Backtrace 1

The next crashed analysed is part of `com.ahnlab.v3mobileplus` app, numbered backtrace 1 in *Androlib*. Again the first step was to find the line in the library right before the crash happened, in order to be able to investigate before the crash. So we set a breakpoint at `BIN_Free+28`, and after continuing over the breakpoint three times we are right before the call to `free` that causes the crash.

First we check the most simple thing, the header of the chunk that is about to be freed. As can be seen in Figure 4.2, there seems to indeed be a problem with the chunk, since it is already marked as available, but the program wants to free it. So either it tries to free a chunk it has already freed, or it tries to free a chunk it actually never allocated. In order to investigate a bit further, we can check the first place the chunk would have been put if it was previously allocated and freed, in the cache's PerClass. Since the chunk has only a size of 9, we know it resides in the first class, with ClassId 1. The output of checking this PerClass info can be seen in Figure 4.3.

```
gef➤  scudo chunk $x0

Chunk(addr=0x7d5daca2b0, size=0x9, state=Available, classid=1)
Was zeroed: True
Chunk size: 9 (0x9)
Offset: 0 (0x0)
Checksum: 0x86d6
Available
```

Figure 4.2: Chunk header that causes a crash when freed

```
gef➤  scudo perclass 0 1

PerClass(base=0x7fbdd2cdb0, count=21)
Number chunks: 21
Maximal number chunks: 28
Class size: 32
        Chunk #0: 0x7d5dacaac0
        Chunk #1: 0x7d5daca620
        Chunk #2: 0x7d5dacaa80
        Chunk #3: 0x7d5dacaa40
        Chunk #4: 0x7d5daca600
        Chunk #5: 0x7d5dacaae0
        Chunk #6: 0x7d5daca6e0
        Chunk #7: 0x7d5daca760
        Chunk #8: 0x7d5dacaaa0
        Chunk #9: 0x7d5daca840
        Chunk #10: 0x7d5daca7c0
        Chunk #11: 0x7d5daca880
        Chunk #12: 0x7d5daca460
        Chunk #13: 0x7d5daca2c0
        Chunk #14: 0x7d5dac9f40
        Chunk #15: 0x7d5daca420
        Chunk #16: 0x7d5daca040
        Chunk #17: 0x7d5daca2a0
        Chunk #18: 0x7d5daca180
        Chunk #19: 0x7d5daca000
        Chunk #20: 0x7d5dac9fc0
```

Figure 4.3: PerClass right before the crash

```
gef➤  scudo perclass 0 1
240
39
PerClass(base=0x7fbdd2cdb0, count=17)
Number chunks: 17
Maximal number chunks: 28
Class size: 32
        Chunk #0: 0x7d5dacaac0
        Chunk #1: 0x7d5daca620
        Chunk #2: 0x7d5dacaa80
        Chunk #3: 0x7d5dacaa40
        Chunk #4: 0x7d5daca600
        Chunk #5: 0x7d5dacaae0
        Chunk #6: 0x7d5daca6e0
        Chunk #7: 0x7d5daca760
        Chunk #8: 0x7d5dacaaa0
        Chunk #9: 0x7d5daca840
        Chunk #10: 0x7d5daca7c0
        Chunk #11: 0x7d5daca880
        Chunk #12: 0x7d5daca460
        Chunk #13: 0x7d5daca2c0
        Chunk #14: 0x7d5dac9f40
        Chunk #15: 0x7d5daca420
        Chunk #16: 0x7d5daca040
```

Figure 4.4: PerClass at the first break

With this output, we can check if the chunk at address `0x7d5daca2b0` is present in the cache, and indeed we see the address `0x7d5daca2a0`, which corresponds to the address of that chunk including the header. Since it is present towards the end of the list of chunks in the cache, this is most likely the case of a double free, where the chunk was already freed earlier in the app. Indeed, by running through the crash again, we can see that at the first break at `BIN_Free+28`, the cache doesn't contain the offending chunk yet, as can be seen in Figure 4.4. Also by actually looking at the chunk that is to be freed at this first break (Figure 4.5), we see that it is the same chunk we try to free again later, resulting in the program crashing as it tries to free the same chunk twice.

```
gef➤  scudo chunk $x0
Chunk(addr=0x7d5daca2b0, size=0x9, state=Allocated, classid=1)
Origin: Malloc
Chunk size: 9 (0x9)
Offset: 0 (0x0)
Checksum: 0xc21d
Allocated
```

Figure 4.5: State of the chunk at the first break

Smartbill Backtrace 13

This is another crash from the same app as the first crash we analysed. As we once again first check the backtrace, we see that the functions right before the crash are not named functions, so to break at the right point we take the offset from the nearest named function, giving us a break at `Convert_ASN1_to_X509_TBS_CERT+268-0xfdc`.

```
gef➤  scudo chunk $x0
Chunk(addr=0x7d6dafdc50, size=0x18, state=Available, classid=2)
Was zeroed: True
Chunk size: 24 (0x18)
Offset: 0 (0x0)
Checksum: 0x6525
Available
```

Figure 4.6: State of the chunk at the break

As we can see in Figure 4.6, we once again try to free an already available chunk. So of course the next thing to verify is again the cache of the corresponding class. The chunk command told us that its ClassId is 2, so we check the main thread cache for this class, and as we can see in Figure 4.7, the chunk is indeed in the cache at the last position, so we face most likely a double free bug again.

```
gef➤  scudo perclass 0 2
240
39
PerClass(base=0x7fbdcdfea0, count=18)
Number chunks: 18
Maximal number chunks: 28
Class size: 48
        Chunk #0: 0x7d6dafe3c0
        Chunk #1: 0x7d6dafdbb0
        Chunk #2: 0x7d6dafe090
        Chunk #3: 0x7d6dafddc0
        Chunk #4: 0x7d6dafe180
        Chunk #5: 0x7d6dafe420
        Chunk #6: 0x7d6dafda30
        Chunk #7: 0x7d6dafdaf0
        Chunk #8: 0x7d6dafe0c0
        Chunk #9: 0x7d6dafdb80
        Chunk #10: 0x7d6dafe3f0
        Chunk #11: 0x7d6dafdd60
        Chunk #12: 0x7d6dafdbe0
        Chunk #13: 0x7d6dafdf10
        Chunk #14: 0x7d6dafe2a0
        Chunk #15: 0x7d6dafdfa0
        Chunk #16: 0x7d6dafdb50
        Chunk #17: 0x7d6dafdc40
```

Figure 4.7: PerClass of the main thread at the break

Chapter 5

Conclusion

In this project we implemented a plugin for GDB/GEF to help analyse and debug heap related crashes dynamically when the Scudo allocator is used as heap allocator. The plugin works on real Android phones as well as on the standalone Scudo version, and it can easily be loaded inside gef. The commands of the plugin allow the inspection of the most important structures of Scudo, which can be used in investigating real crashes. While the source code of Scudo was already openly accessible and there was some documentation about Scudo, there was no easy way to investigate crashes related to Scudo dynamically and directly on a real phone for real Android apps with native libraries. While the plugin handles the most important structures, it also builds a base which could be extended to analyse further structures used by Scudo, like quarantine related ones.

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