Linux Memory Forensics: Dissecting the User Space Process Heap

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Agenda

Introduction

Motivation

Heap Fundamentals

Evaluation

Demo

Conclusion

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Introduction

- Most of the previous work in the memory forensics area focused on information residing in the kernel space.
- The user space is however also a rich source of artifacts/data, valuable for the investigator, especially the heap.
- Might contain for example passwords or (en/de)crypted data from
  - legitimate software (Mail Client, Password Manager, …)
  - malware (passwords used for encrypted communication, decrypted binary data, …)

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Introduction

- For Windows, there is a plugin to analyze the heap in a more detailed way, thanks to the research by Michael Cohen.
  - http://www.rekall-forensic.com/docs/References/Papers/p1138-cohen.pdf

- But there was no public available plugin for any heap implementation for Linux (at least as far as we know).

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Introduction

- Existing plugins that investigate the Linux process memory space for artifacts/data, normally search the whole memory dump or the heap/stack as a big blob for a given pattern.

- Depending on the data of interest, there are however not always specific patterns marking data of interest, or these patterns are yet not known to the investigator.

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Challenge: Pattern-less data

- Data of interest, which is not identifiable by a special pattern and also not easily distinguishable from data surrounding it.
  - An IP address stored as an integer
  - A password, not consisting of printable characters
  - …

`9dcfa4b5f5a9de67`**`2db4728b05de2197`**`05deca9575e4f9471a51e5a8627`

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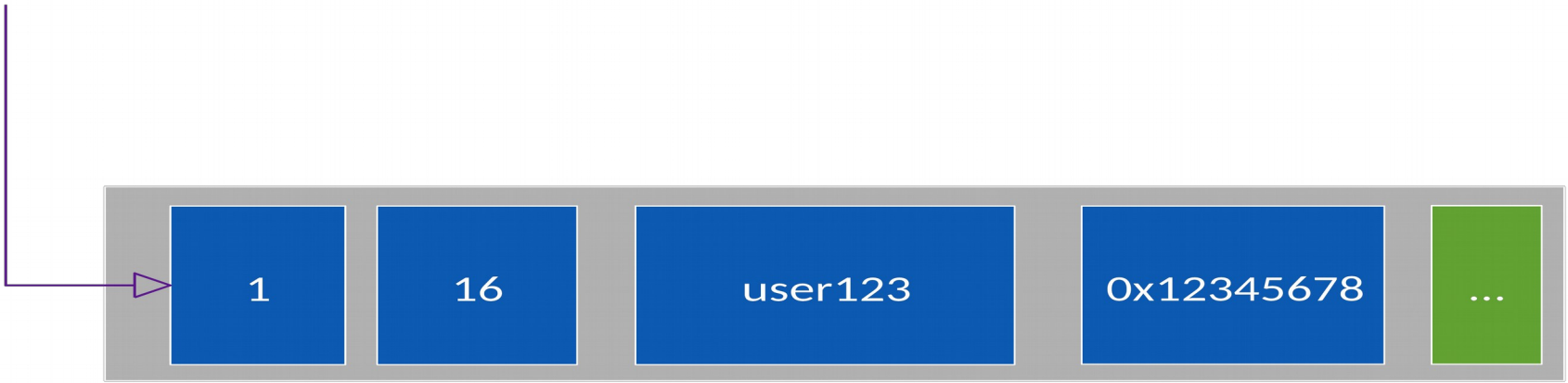
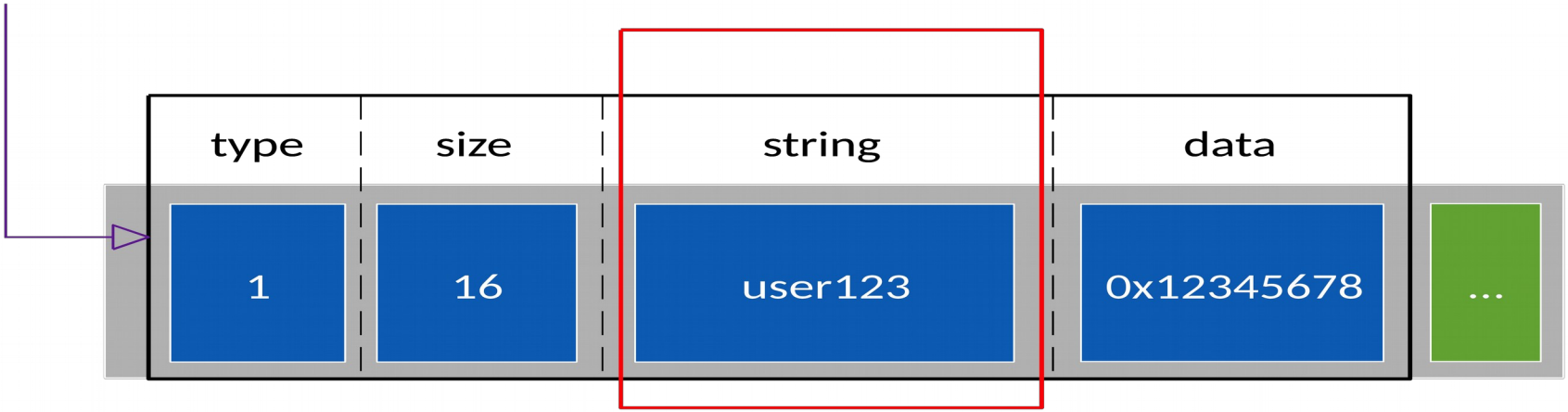
Challenge: A pointer to a Struct



Challenge: A pointer to a Struct



Goals

- Understand and document **Glibc's** Heap Implementation for forensic purposes.
- Implementation of Rekall plugins that assist an investigator in the analysis process.

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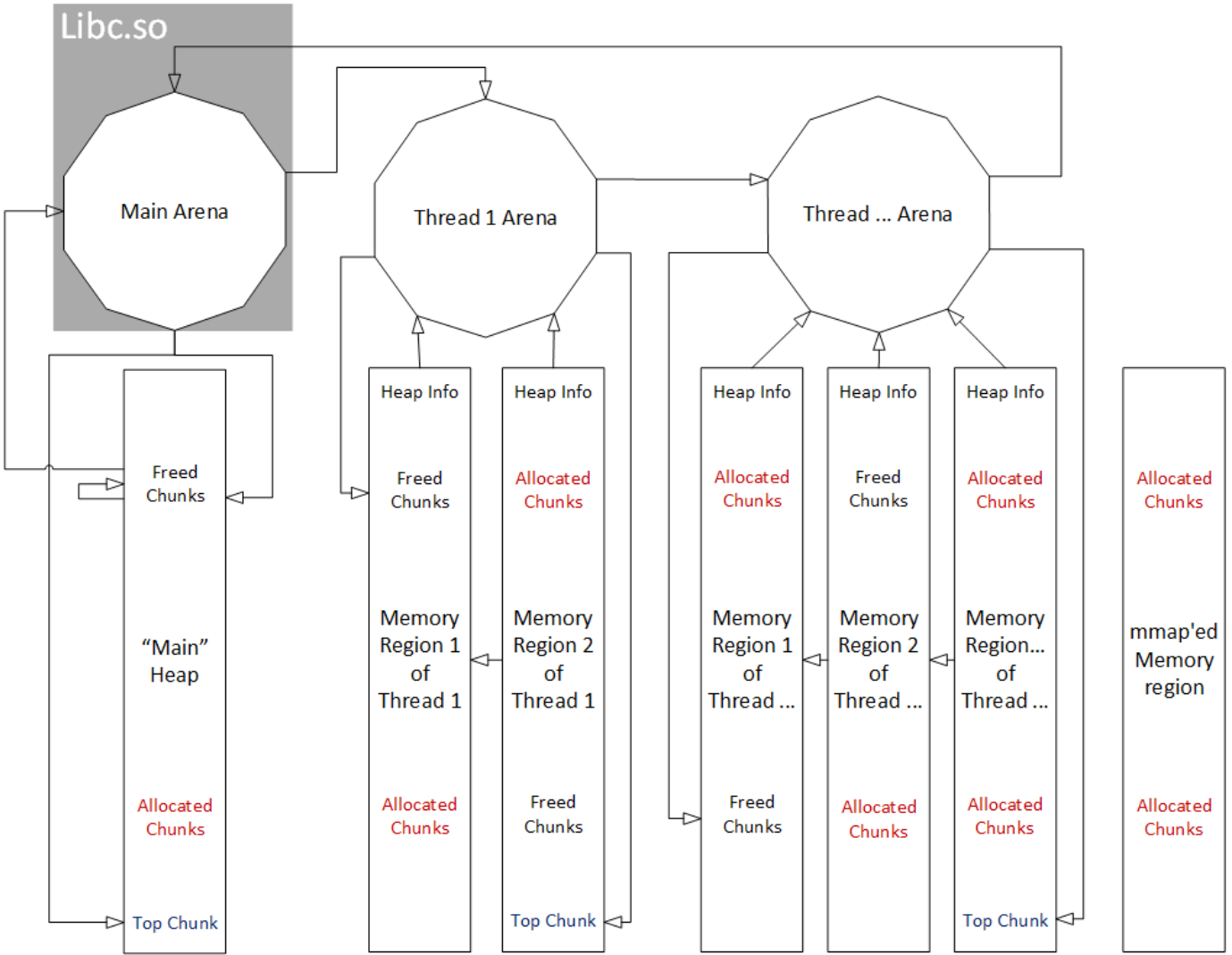
Heap Fundamentals

Heap Overview



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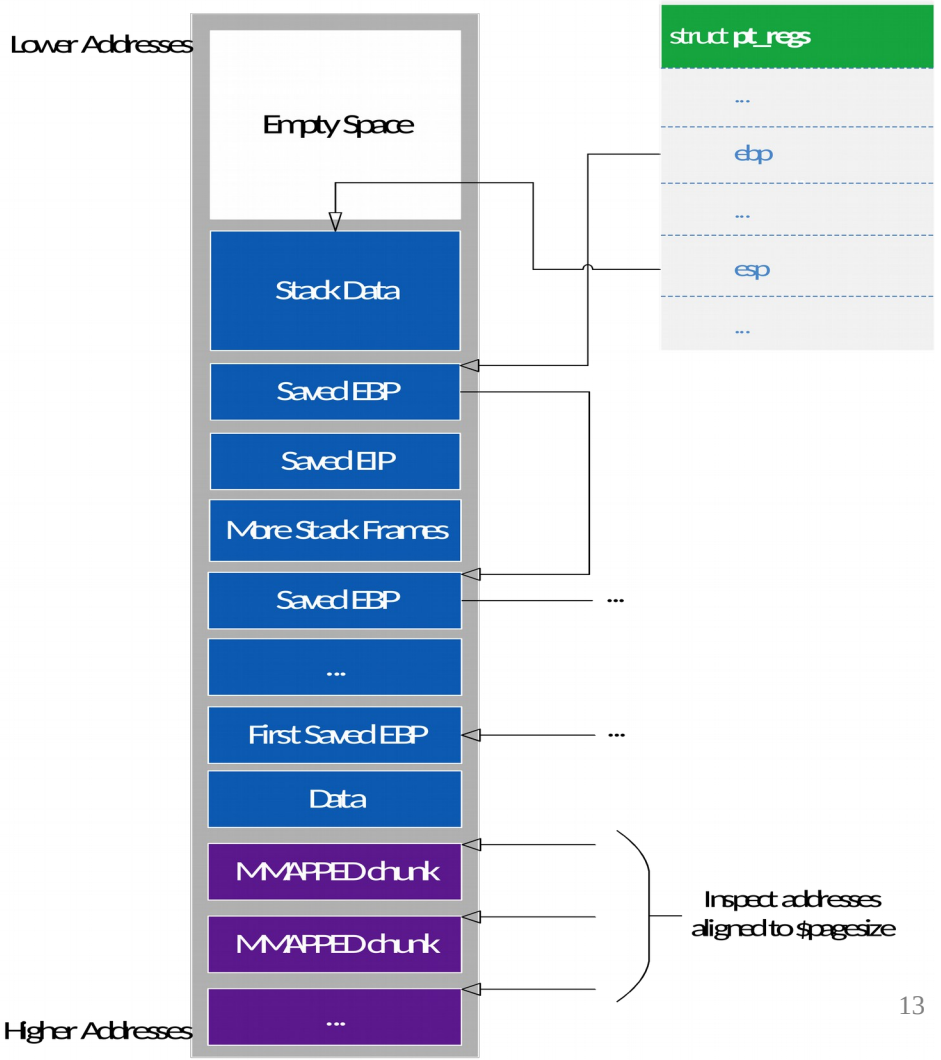
EBP unrolling



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MMAPPED Chunks

- The identified MMAPPED chunks can be verified, when the offset to the *malloc_par* struct is given (must be gathered from the Glibc library of the target system).

- This struct contains the number and size of all MMAPPED chunks.

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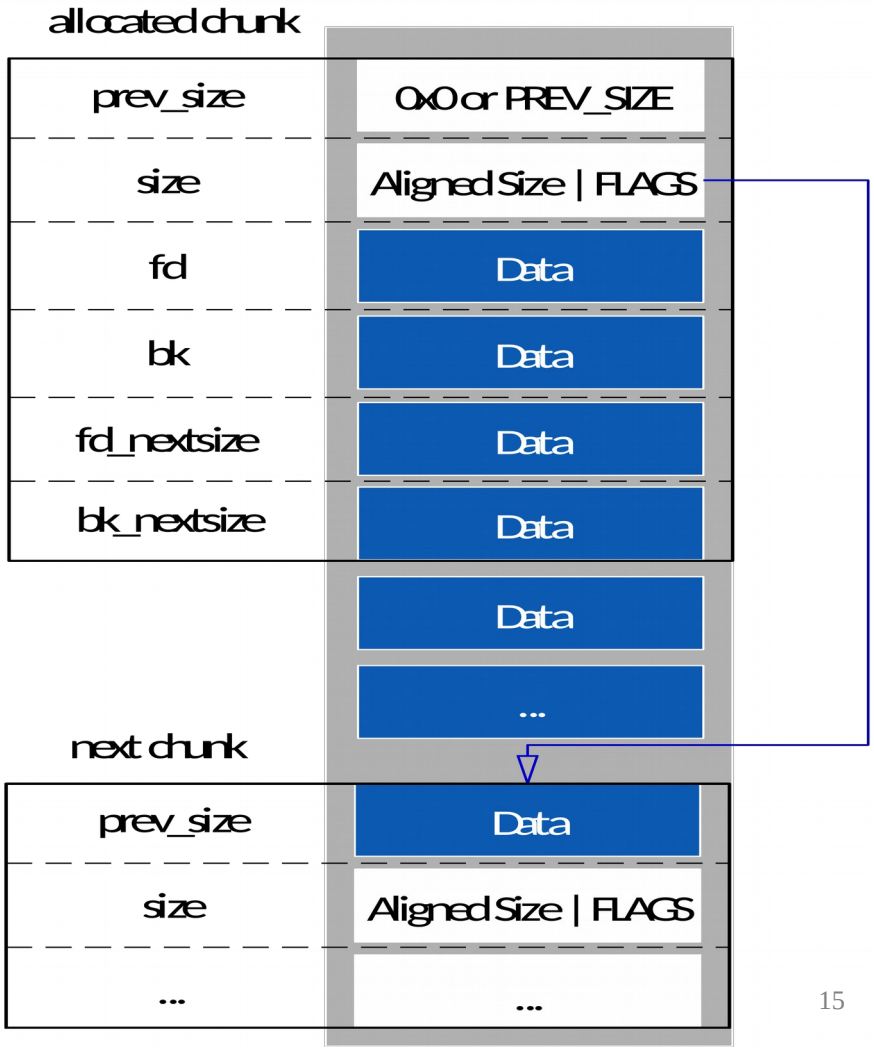
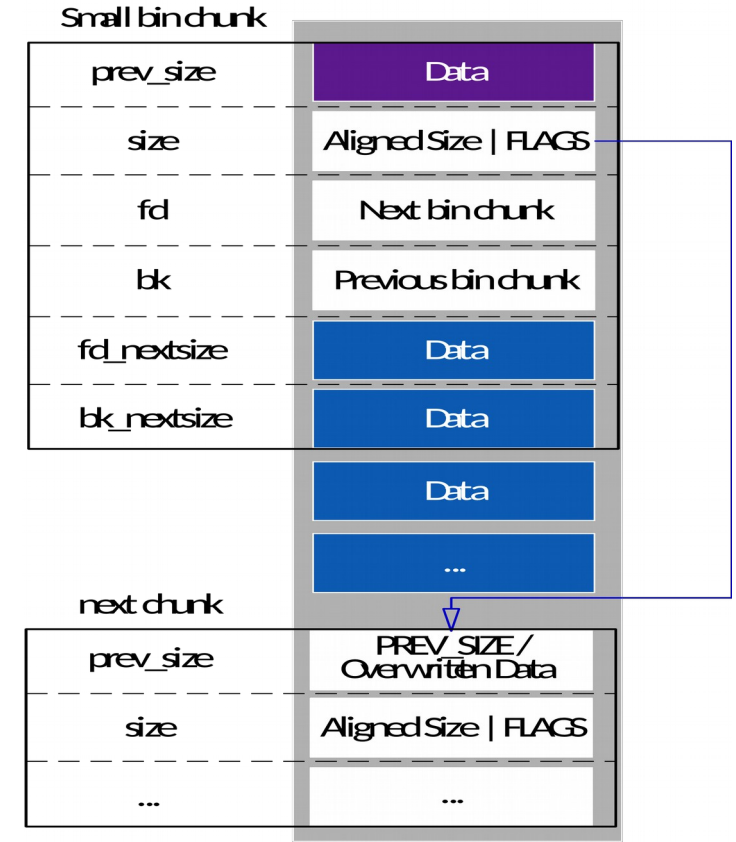
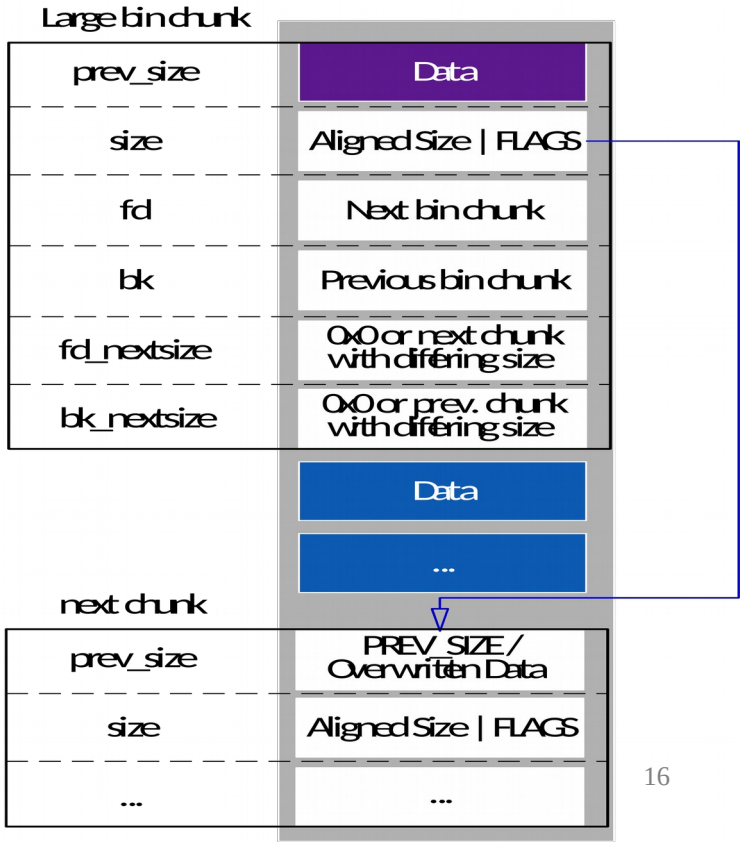
Allocated chunk

In memory




Small bin chunk
prev_size
Data
size
Aligned Size | FLAGS
fd
Next bin chunk
bk
Previous bin chunk
fd_nextsize
Data
bk_nextsize
Data
Data
...
next chunk
prev_size
PREV_SIZE / Overwritten Data
size
Aligned Size | FLAGS
...
...


Large bin chunk
prev_size
Data
size
Aligned Size | FLAGS
fd
Next bin chunk
bk
Previous bin chunk
fd_nextsize
0x0 or next chunk with differing size
bk_nextsize
0x0 or prev. chunk with differing size
Data
...
next chunk
prev_size
PREV_SIZE / Overwritten Data
size
Aligned Size | FLAGS
...
...

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Another Challenge: Extracting Strings from the Heap

"**He said:** I will kill him"

- might become

non_printable_chars " I will kill him"

"**Please, do not** kill him**"**

- might become

non_printable_chars "**I'll** kill him"

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Evaluation

- Test Environment: Arch Linux x86/x64, Kernel Version 4.4.5-ARCH with Glibc Versions 2.20 – 2.24
- Self written programs, which use Glibc‘s *mallinfo* function.
- Analyzing all processes running in the test environments.
- Reading a lot of source code. Mainly from:
  - malloc/malloc.c
  - malloc/malloc.h
  - malloc/arena.c

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Evaluation

- Background checks are performed during the execution of each plugin.
  - For each chunk: Size/address alignment, allocation status, flags, …
  - Some special tests for MMAPPED chunks, and a comparison to the information from the *malloc_par* struct.
  - Does following all chunks in a memory region lead to the expected end?
  - Comparison of the size information from all arenas with all objects from the heap.

Demo Time?

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Conclusion

- The plugins ease the analysis process and serve more reliable information.
- They enable to gather all parts belonging to the heap (e.g. also hidden MMAPPED chunks).

- Limitations
  - Only Glibc support (officially, versions 2.20 – 2.25).
  - MMAPPED chunks without debug symbols can’t reliably be identified.
  - Swapped pages

- Future Work
  - Add linked list detector to the heaprefs plugin.
  - Keep up with new Glibc versions.

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Links

- The paper:
  - https://authors.elsevier.com/sd/article/S1742287617301895
- The technical report (contains more heap details):
  - https://opus4.kobv.de/opus4-fau/frontdoor/index/index/docId/8340
- The plugins are merged in the Rekall project:
  - https://github.com/google/rekall
- Blogpost, containing a brief manual:
  - https://insinuator.net/2017/07/release-of-glibc-heap-analysis-plugins-for-rekall/

Thank you for your Attention!

Questions? Feedback? Suggestions? Criticism?