Meta

The Curious Case of Memory Growth

A Debugging Story

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Agenda

01 Setting the Stage

02 Searching for Answers

03 Root Cause Explained

04 Hindsight

Setting the Stage

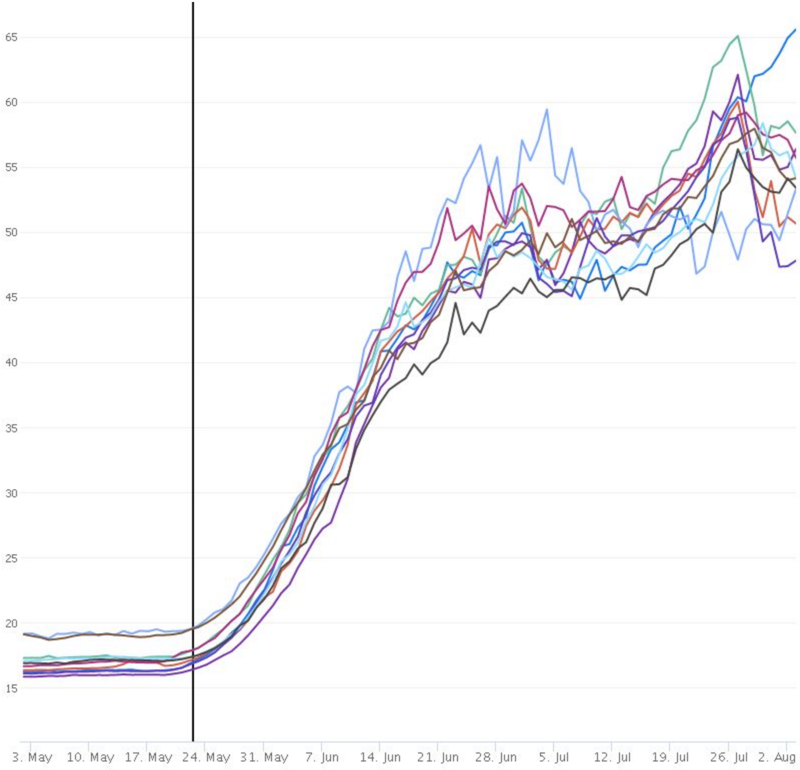
Specification

- CentOS Stream 8
  - Could also reproduce on Fedora 34
- Upgrading from systemd 247 to systemd 248 (latest is 251)
  - Built from the specfile in the Hyperscale SIG
    - Based on the Fedora rawhide specfile for systemd 248.2
- Kernel 5.6+

What We Saw

- Average memory for systemd-journald grew from ~17 MB to ~50 MB
- Issue reported as the systemd 248 update was ongoing
  - Memory growth did not directly correlate with systemd roll out

Memory (MB) Average per Day



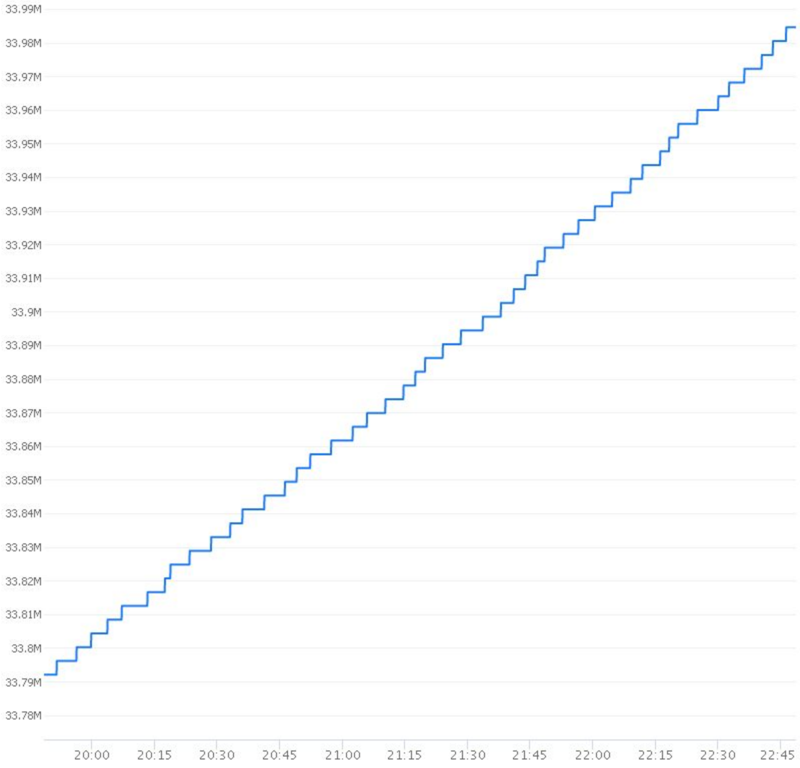
Probing a Host

```
# pmap -x 800
800: /usr/lib/systemd/systemd-journald
Address          Kbytes RSS    Dirty  Mode  Mapping
000055908738e000 160    152    0      r-x-- systemd-journald (deleted)
00005590875b5000 8      8      8      r---- systemd-journald (deleted)
00005590875b7000 4      4      4      rw--- systemd-journald (deleted)
00005590875b8000 378952 378796 378796 rw--- [ anon ]
...some lines omitted for brevity...
```

Was it the roll out?

- Normally systemd daemons restart into the new binary during updates.
- Noticed that systemd-journald did not!
  - This is fixed in systemd 249+
- Correctly monitoring systemd-journald 247 vs 248 confirmed the regression was due to the roll out.

Anonymous Memory per 5s



Searching for Answers

Suspicious Commits?

```
$ git log v247..v248 --oneline --no-merges src/libsystemd/sd-journal/ src/journal

...some lines omitted for brevity...
0eaee8281d journald: when we fail to add a new entry to a journal, return the seqno
258190a0d5 mmap-cache: drop ret_size from mmap_cache_get()
104fc4be11 mmap-cache: bind prot(ection) to MMapFileDescriptor
073f50a099 mmap-cache: separate context and window list cache hit accounting
3a595c597a mmap-cache: replace stats accessors with log func
```

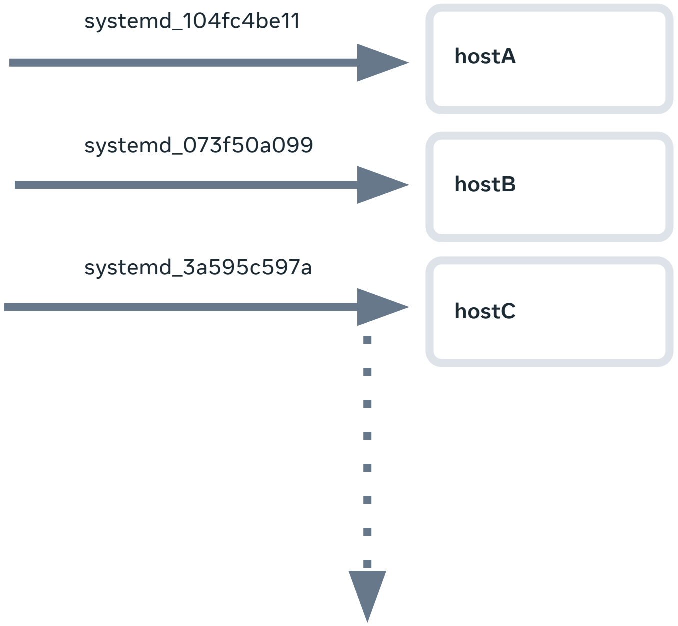
Memory Leak?

```
# valgrind --leak-check=full --show-leak-kinds=all /usr/lib/systemd/systemd-journald

...some lines omitted for brevity...
==1042650== LEAK SUMMARY:
==1042650==    definitely lost: 0 bytes in 0 blocks
==1042650==    indirectly lost: 0 bytes in 0 blocks
==1042650==      possibly lost: 0 bytes in 0 blocks
==1042650==    still reachable: 8,192 bytes in 2 blocks
==1042650==         suppressed: 0 bytes in 0 blocks
```

Bisect

- Started bisecting starting with the “suspicious” commits.
- Put each commits’ build of systemd-journald on separate hosts.
  - Increased logging on those hosts.
- Needed 1-2 days of data to see the regression in our charts.



Trying Things

- strace not the best tool for this job.
- Use eBPF!
  - Great for tracing and observability.
  - Meta is a founding member of the eBPF Foundation!
- Found Brendan Gregg's page for looking at memory leaks and growth (right).
  - Started experimenting with BCC.

https://brendangregg.com/FlameGraphs/memoryflamegraphs.html

Count Calls to malloc()

- BCC’s stackcount.py
  - Used to count events and their stack traces.
- Stacks/allocations were similar between systemd-journald 247 and 248.

```
# /usr/share/bcc/tools/stackcount -U c:malloc -p 800
...cut for brevity...
b'read_one_line_file'
 b'get_process_comm'
 b'client_context_read_basic'
 b'client_context_really_refresh'
 b'client_context_maybe_refresh'
 b'stdout_stream_log'
 b'stdout_stream_line'
 b'stdout_stream_found'
 b'stdout_stream_scan'
 b'stdout_stream_process'
 b'source_dispatch'
 b'sd_event_dispatch'
 b'sd_event_run'
 b'main'
 b'__libc_start_main'
 b'[unknown]'
   1508
```

Memory Leak?

- [BCC's memleak.py]
  - Used to trace outstanding allocations.
- Stacks/allocations were similar between systemd-journald 247 and 248.
- All allocations were eventually deallocated; no leak.

```
$ memleak.py -o 600000 -p 800
...cut for brevity...
[01:38:50] Top 10 stacks with outstanding allocations:
        69 bytes in 2 allocations from stack
                __strdup+0x1e [libc-2.28.so]
                [unknown]
        85 bytes in 3 allocations from stack
                str_realloc+0x44 [libsystemd-shared-247.so]
                get_process_cmdline+0x58d [libsystemd-shared-247.so]
                client_context_read_basic+0x127 [systemd-journald]
                client_context_really_refresh+0xf9 [systemd-journald]
                client_context_maybe_refresh+0x1c9 [systemd-journald]
                client_context_get_internal+0x1d4 [systemd-journald]
                client_context_get+0x49 [systemd-journald]
                server_process_native_message+0x104 [systemd-journald]
                server_process_datagram+0x942 [systemd-journald]
                source_dispatch+0x247 [libsystemd-shared-247.so]
                sd_event_dispatch+0x234 [libsystemd-shared-247.so]
                sd_event_run+0x30a [libsystemd-shared-247.so]
                main+0x4c9 [systemd-journald]
                __libc_start_main+0xf3 [libc-2.28.so]
                [unknown]
        110 bytes in 2 allocations from stack
                __strdup+0x1e [libc-2.28.so]
                [unknown]
```

What We Know So Far

- No leak!
  - Confirmed by 3 tools.
- Initial bisect did not find the blame commit.
- Allocations were similar between systemd-journald 247 and 248.
  - No extra calls to `malloc()` and related functions.
- Allocations tend to start from `client_context_read_basic()`.
  - But systemd's core functions do the allocations (e.g. `read_full_virtual_file()`).
- Used this information to change bisect strategy.

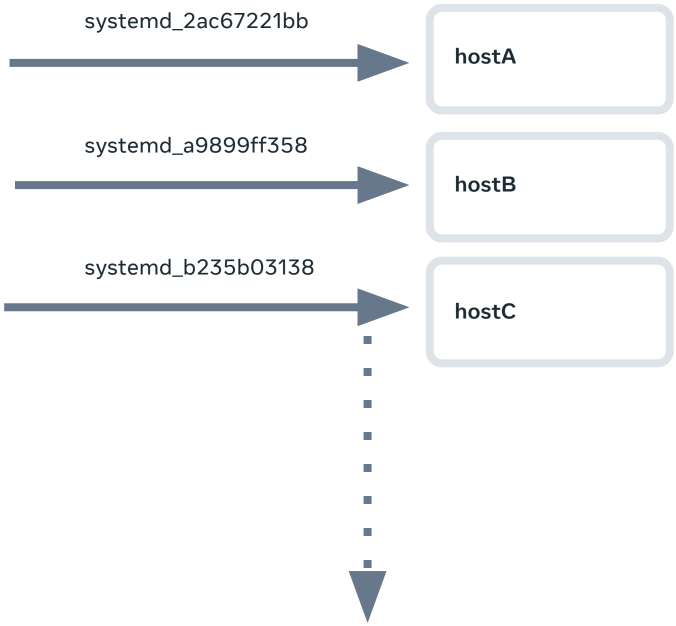
Another Set of Suspicious Commits

```
$ git log v247..v248 --oneline --no-merges src/basic/fileio*

...many lines omitted for brevity...
2ac67221bb basic/fileio: fix reading of not-too-small virtual files
f1a8a66c35 basic/fileio: use malloc_usable_size() to use all allocated memory
a9899ff358 basic/fileio: optimize buffer sizes in read_full_virtual_file()
ca79564309 basic/fileio: simplify calculation of buffer size in...
c5384931b7 fileio: add missing overflow checks to read_full_virtual_file()
b235b03138 fileio: don't use realloc() in read_full_virtual_file()
```

Bisect (Again)

- Another 1-2 days of data to see the regression in our charts.



Bisect Prevails

- Summary of the commit
  - Instead of allocating 4K and using `realloc()` to expand the buffer, we start with 4MB and `realloc()` to decrease the buffer.
  - Everything is freed properly and memory is returned to libc; so what's the problem?

https://github.com/systemd/systemd/commit/2ac67221bb6270f0fbe7cbd0076653832cd49de2

Root Cause Explained

Allocations in systemd-journald 247

Illustration of the Heap

Allocations in systemd-journald 247

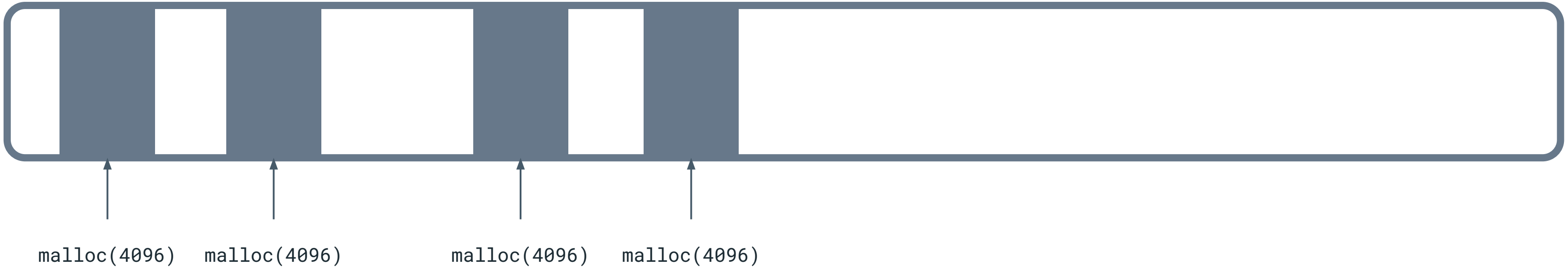
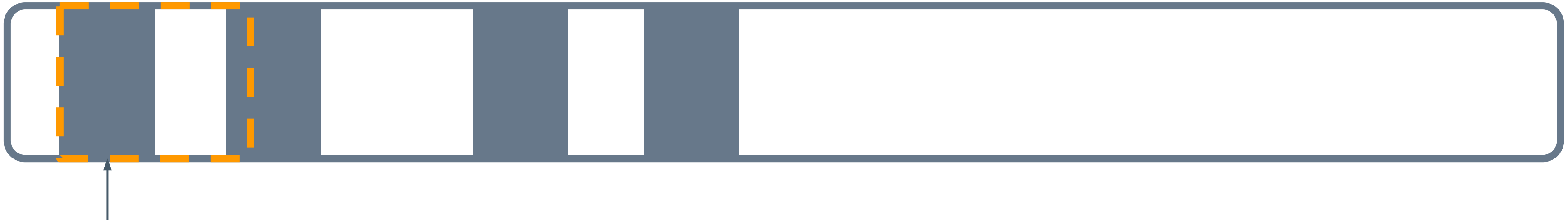


Illustration of the Heap

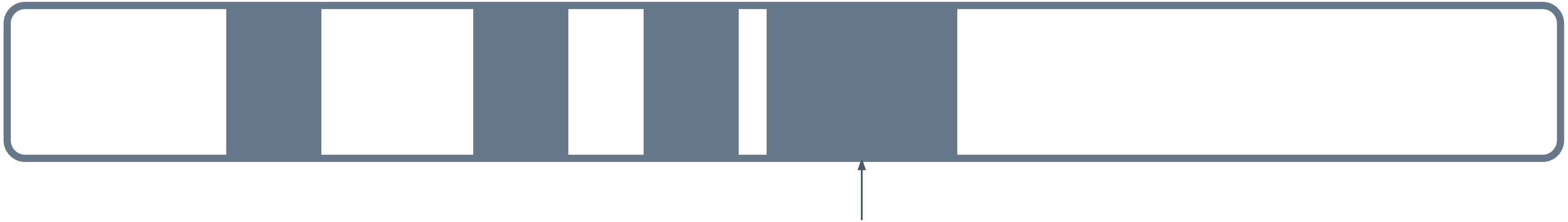
Allocations in systemd-journald 247



realloc(ptr, 8192)

Illustration of the Heap

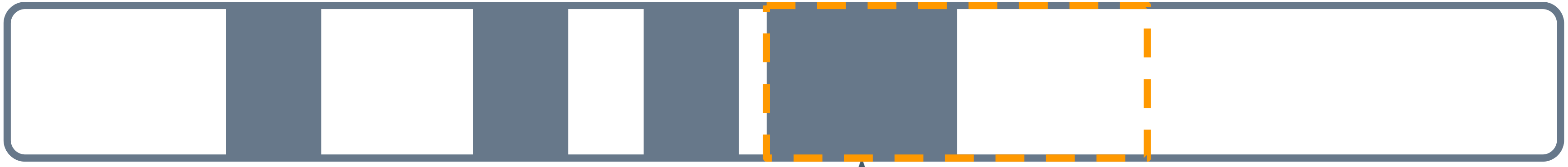
Allocations in systemd-journald 247



realloc(ptr, 8192)

Illustration of the Heap

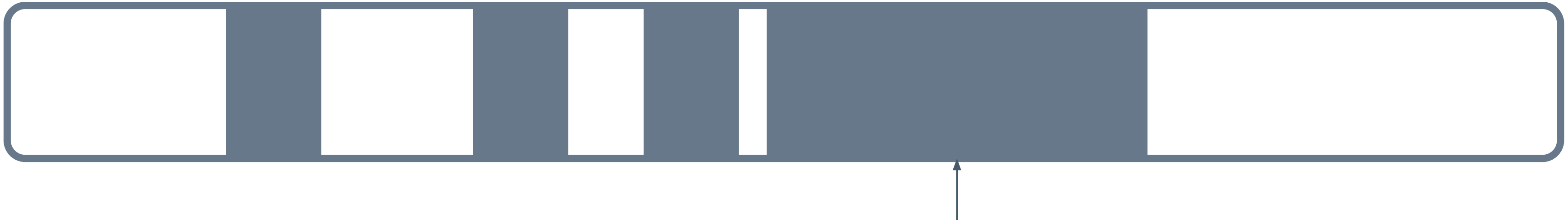
Allocations in systemd-journald 247



`realloc(ptr, 16384)`

Illustration of the Heap

Allocations in systemd-journald 247



`realloc(ptr, 16384)`

Illustration of the Heap

Allocations in systemd-journald 247

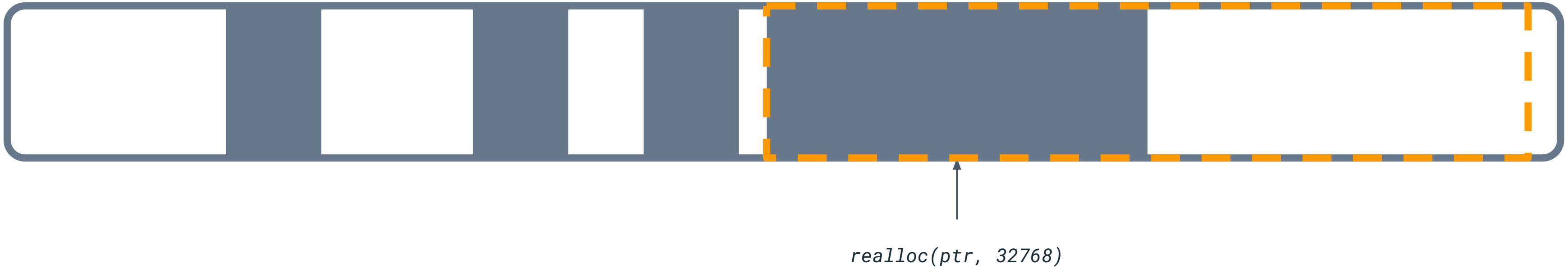
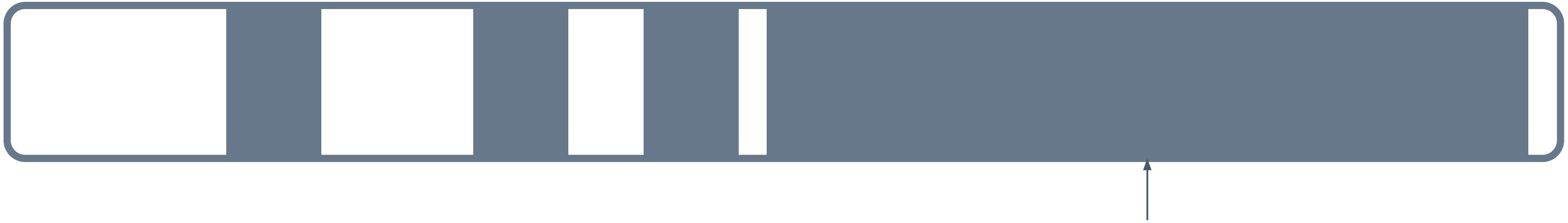


Illustration of the Heap

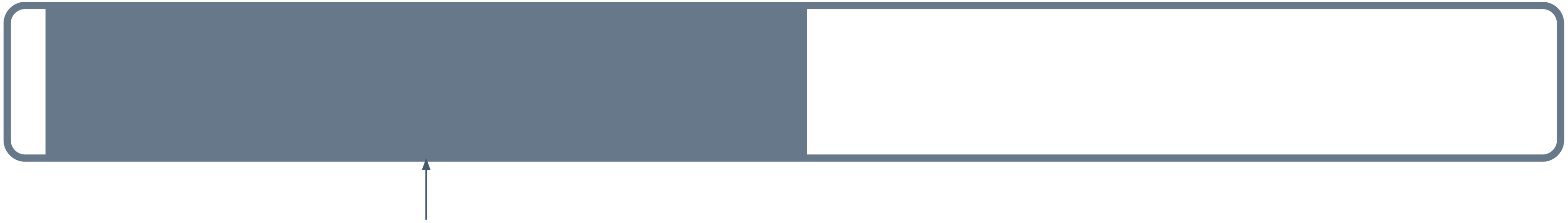
Allocations in systemd-journald 247



`realloc(ptr, 32768)`

Illustration of the Heap

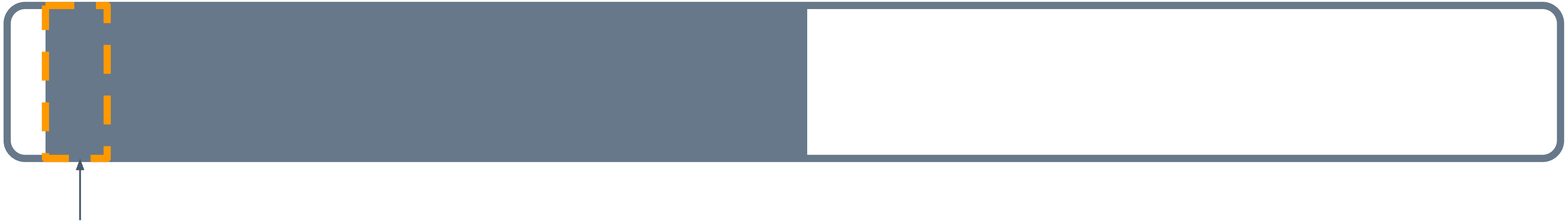
Allocations in systemd-journald 248



`malloc(4194304)`

Illustration of the Heap

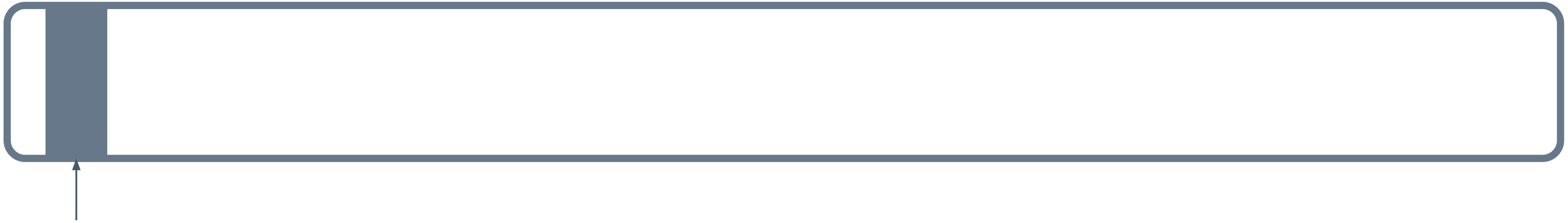
Allocations in systemd-journald 248



`realloc(ptr, 4096)`

Illustration of the Heap

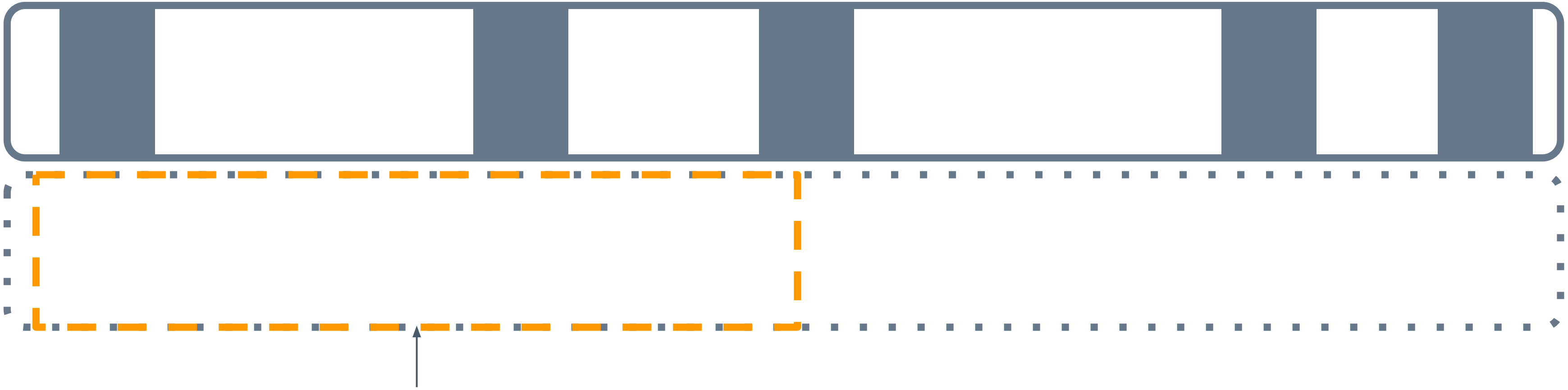
Allocations in systemd-journald 248



`realloc(ptr, 4096)`

Illustration of the Heap

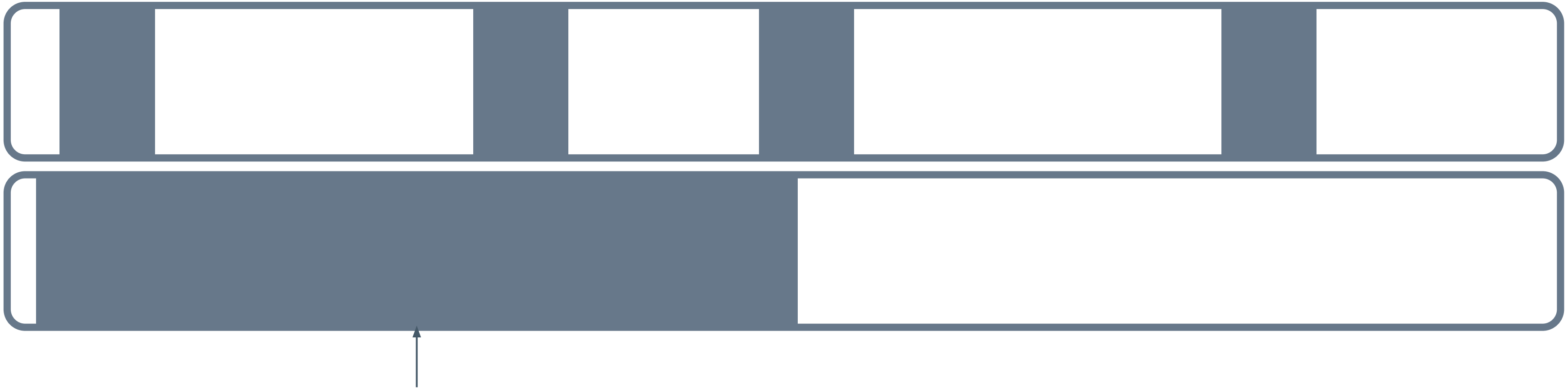
Allocations in systemd-journald 248



`malloc(4194304)`

Illustration of the Heap

Allocations in systemd-journald 248



`malloc(4194304)`

Illustration of the Heap

Allocations in systemd-journald 248

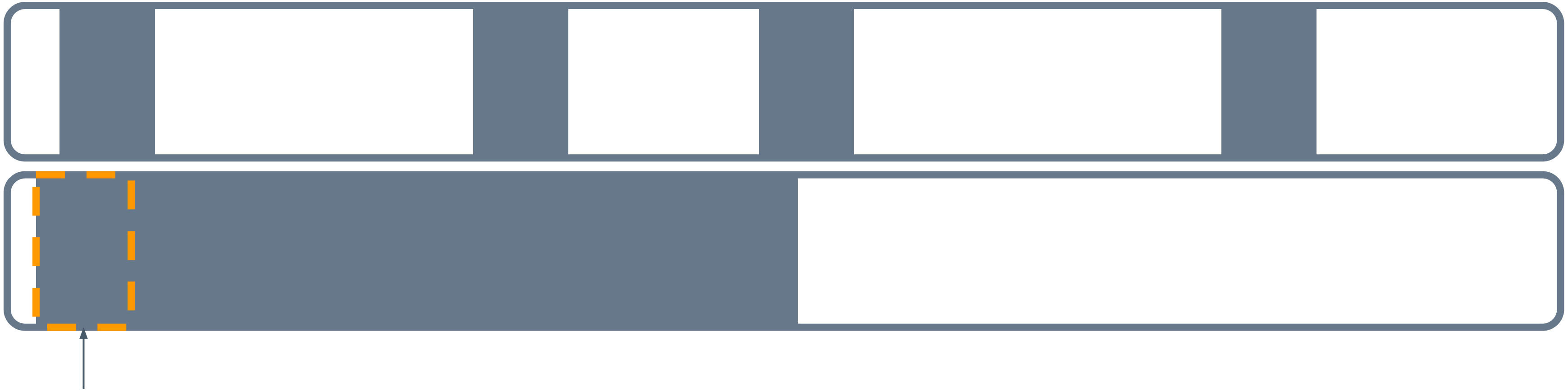


Illustration of the Heap

Allocations in systemd-journald 248

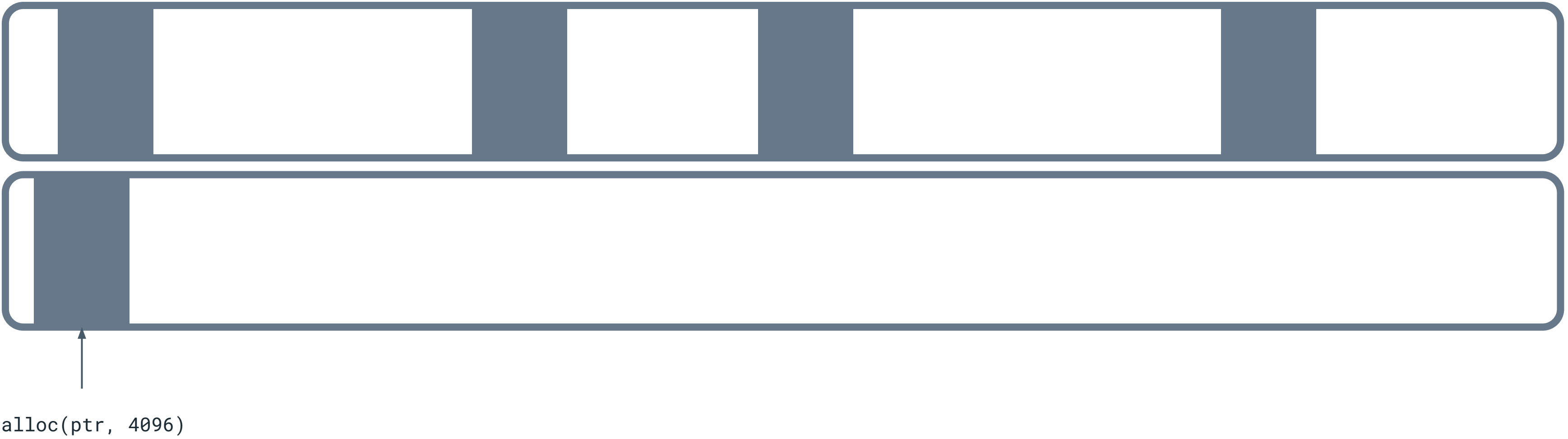
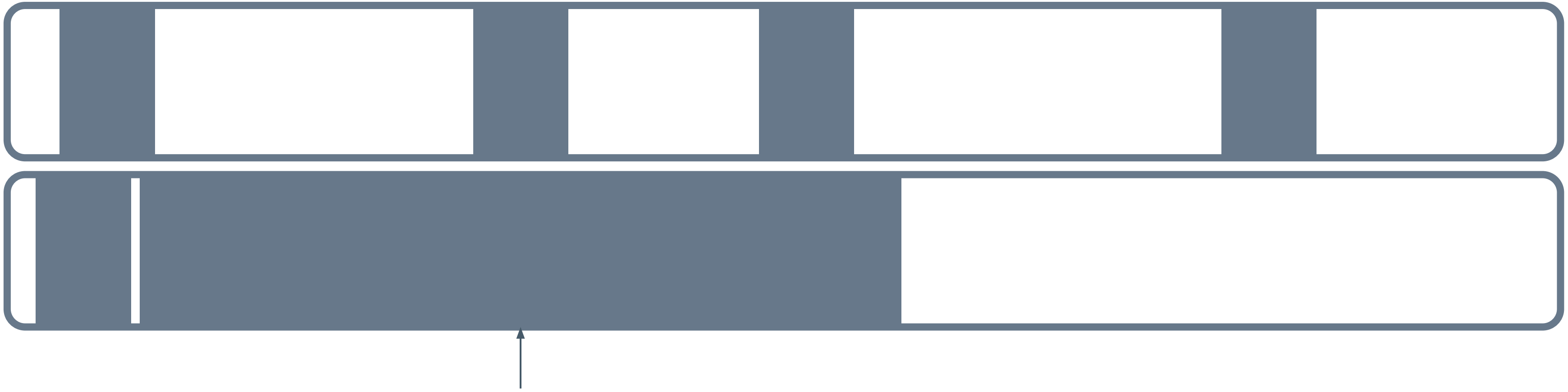


Illustration of the Heap

Allocations in systemd-journald 248



`malloc(4194304)`

Illustration of the Heap

Allocations in systemd-journald 248

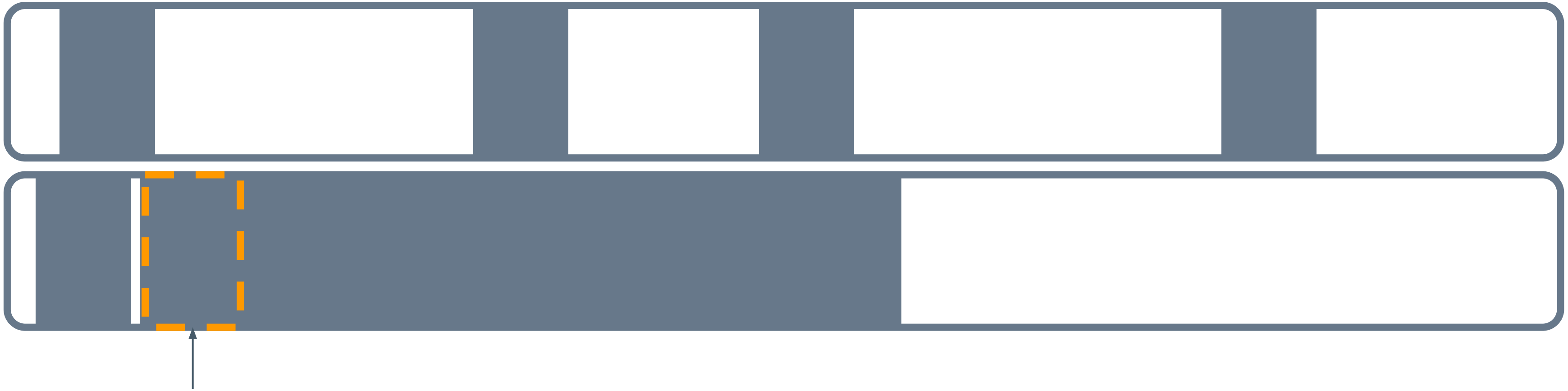


Illustration of the Heap

Allocations in systemd-journald 248

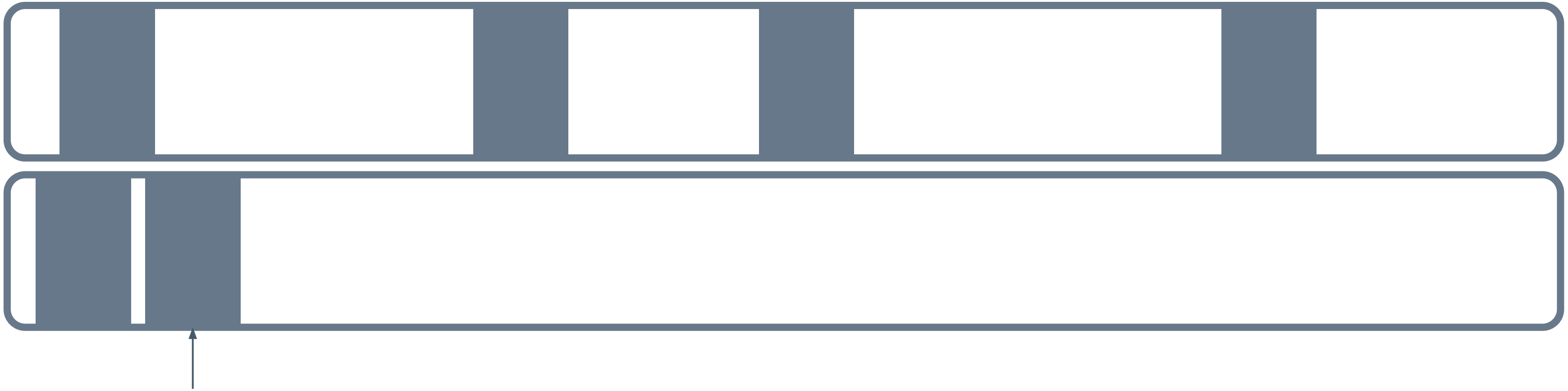


Illustration of the Heap

Allocations in systemd-journald 248

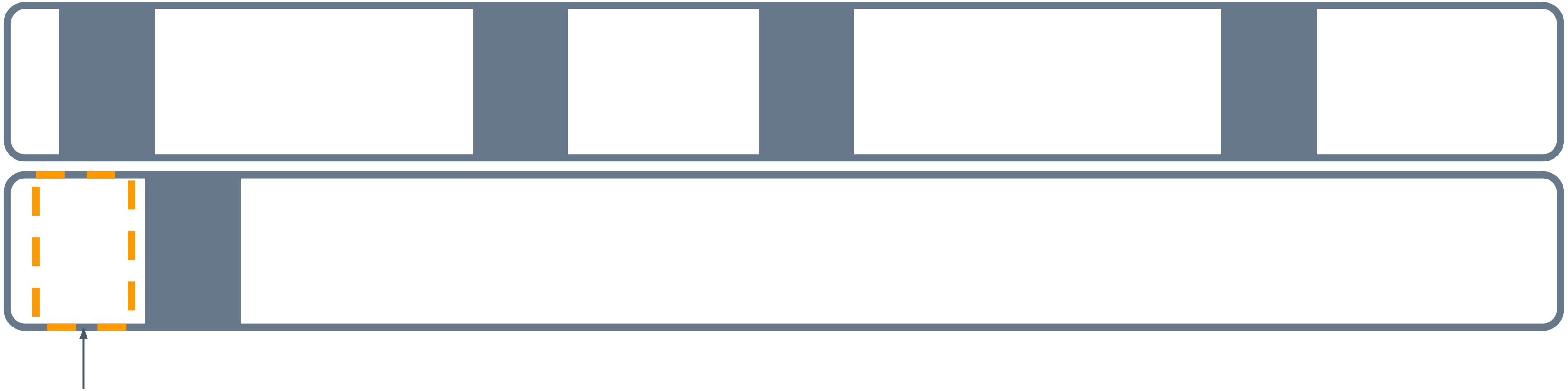


Illustration of the Heap

Fix Merged

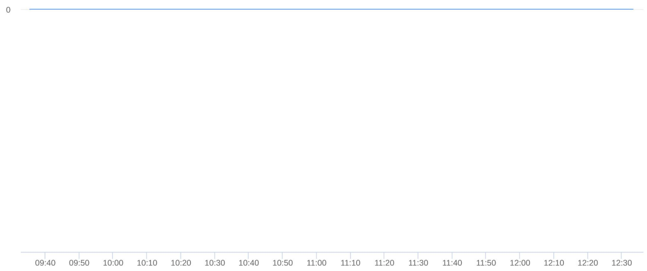
- Summary of the fix:
  - Partially revert back to previous behavior.
  - Allocate 4K and use `realloc()` to expand the buffer as needed.
- Meta was the first to notice and fix it!

https://github.com/systemd/systemd/commit/5aaa55d841249f057fd69e50cf12a52e9781a6ce

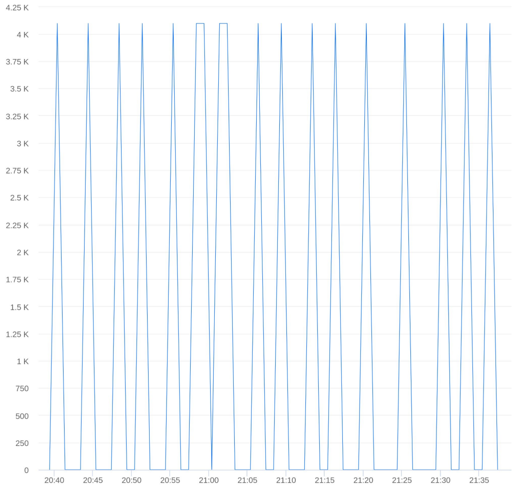
Hindsight

Rate of Change of Anonymous Memory

systemd 247



systemd 248



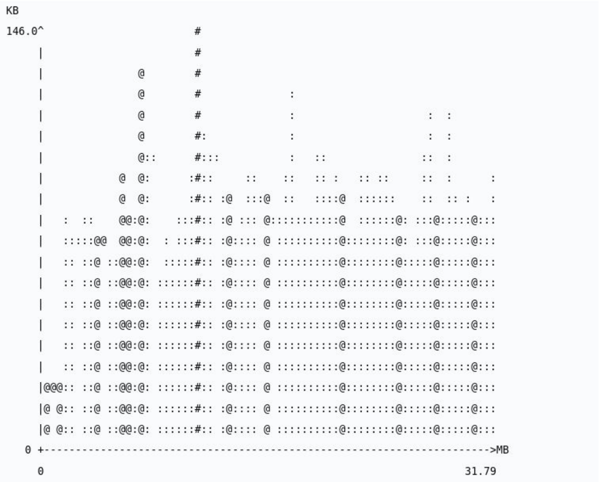
mtrace()

- Part of glibc.
- Function call:
    - Insert at the beginning of the program to record memory allocation and deallocations.
    - Records the data to a text file.
- Command line tool:
    - Uses the text file and binary to tell you about unfreed memory.

Massif: a heap profiler

timeout 20m /usr/local/bin/valgrind --tool=massif --time-unit=B /usr/lib/systemd/systemd-journald

systemd-journald 247



```
KB
146.0^                        #
     |                        #
     |               @        #
     |               @        #              :
     |               @        #              :                     :  :
     |               @        #:             :                     :  :
     |               @::      #:::           :   ::               ::  :
     |            @  @:      :#::     ::    ::   :: :   :: ::     ::  :      :
     |            @  @:      :#:: :@  :::@  ::   ::::@  ::::::    ::  :: :   :
     |   :  ::    @@:@:    :::#:: :@ ::: @:::::::::::@  ::::::@: :::@:::::@:::
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     |@ @:: ::@ ::@@:@: ::::::#:: :@:::: @ ::::::::::@::::::::@:::::@:::::@:::
   0 +----------------------------------------------------------------------->MB
     0                                                                   31.79
```
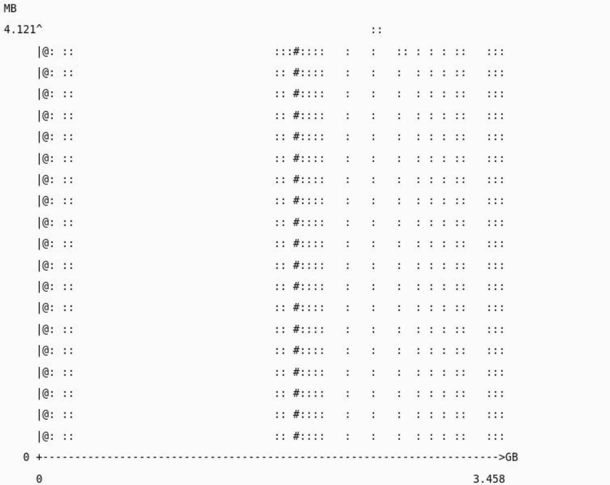

systemd-journald 248



```
MB
4.121^                                                   ::
     |@: ::                               :::#::::   :   :   :: : : : ::   :::
     |@: ::                               :: #::::   :   :   :  : : : ::   :::
     |@: ::                               :: #::::   :   :   :  : : : ::   :::
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   0 +----------------------------------------------------------------------->GB
     0                                                                   3.458
```
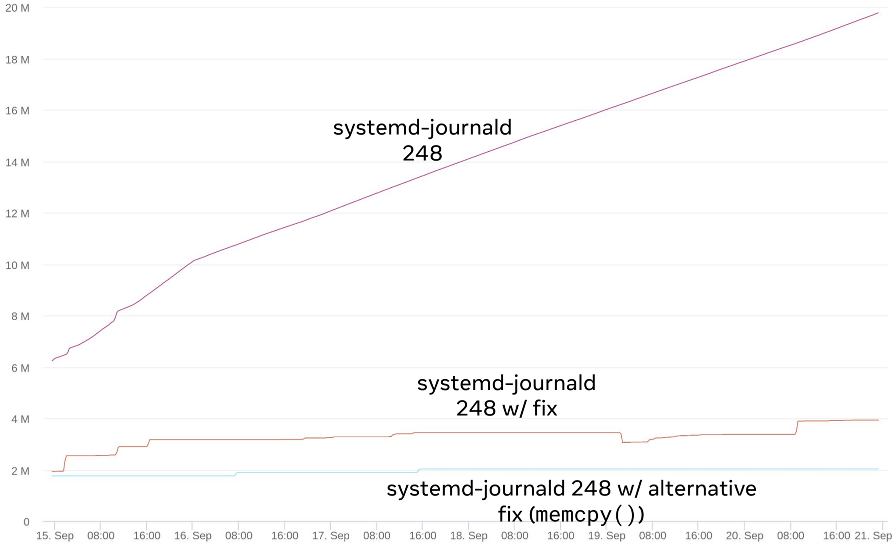

Another Way?

- Instead of `realloc()`, do `malloc()` and `memcpy()`.
- The reallocation would be copied to create less fragmentation.
- More `malloc()` calls, more copies.

Memory Usage (MB) Over 24 Hours



Takeaways

- Invest in monitoring, logging, and visualizations!
- Usable stack traces are a blessing.
  - Needs frame pointers.
- Always be willing to learn and pick up new tools!
  - eBPF is amazing: BCC, bpftrace, etc.
  - Valgrind is more than memcheck: massif, callgrind, helgrind, etc.

Questions?

THANK YOU FOR YOUR TIME

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Extra Slides

Specification

```
$ cat /etc/systemd/journald.conf

[Journal]
ForwardToSyslog = true
RuntimeMaxUse = 10M
Storage = volatile
```