Heap Exploitation
A Brief Introduction

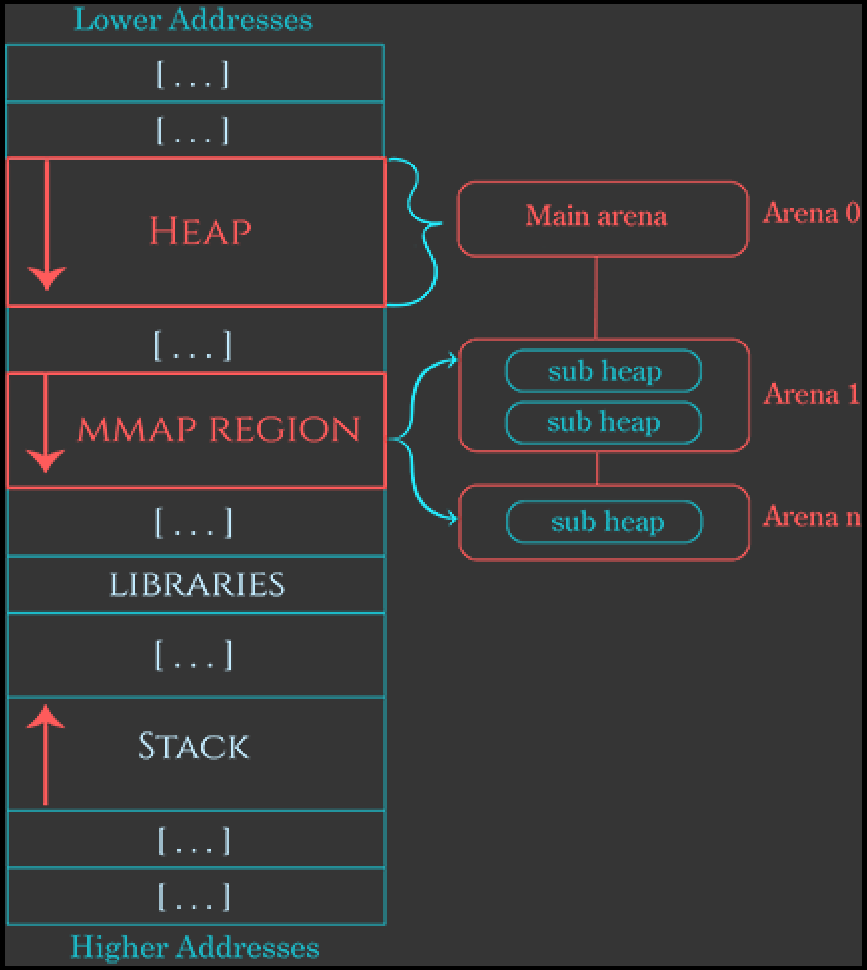
elbee

The heap

Glibc is derived from pthreads malloc (ptmalloc)

malloc(size) – Returns a pointer to the newly allocated chunk on the heap.
free(ptr) – Frees a chunk from allocation and returns it to the heap manager for future allocation.

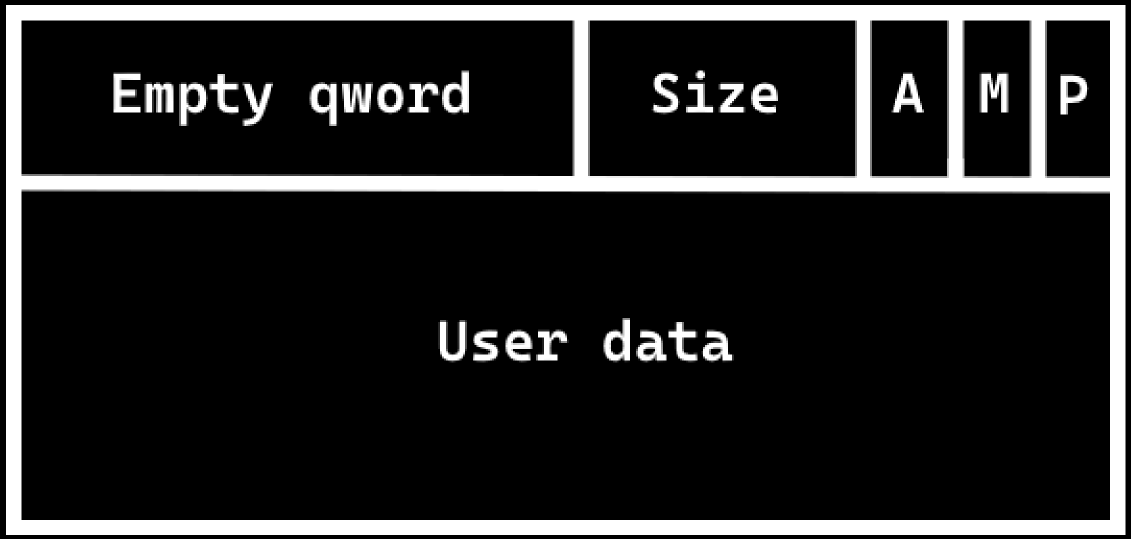
Different threads have different heaps and their own arenas. We're mostly dealing with the main arena. Arenas store heap metadata used by malloc and free to service requests. (e.g. Heads of free lists, maximum serviceable request size, etc) The main arena is located in the libc section.



https://azeria-labs.com/heap-exploitation-part-1-understanding-the-glibc-heap-implementation/

Chunk anatomy

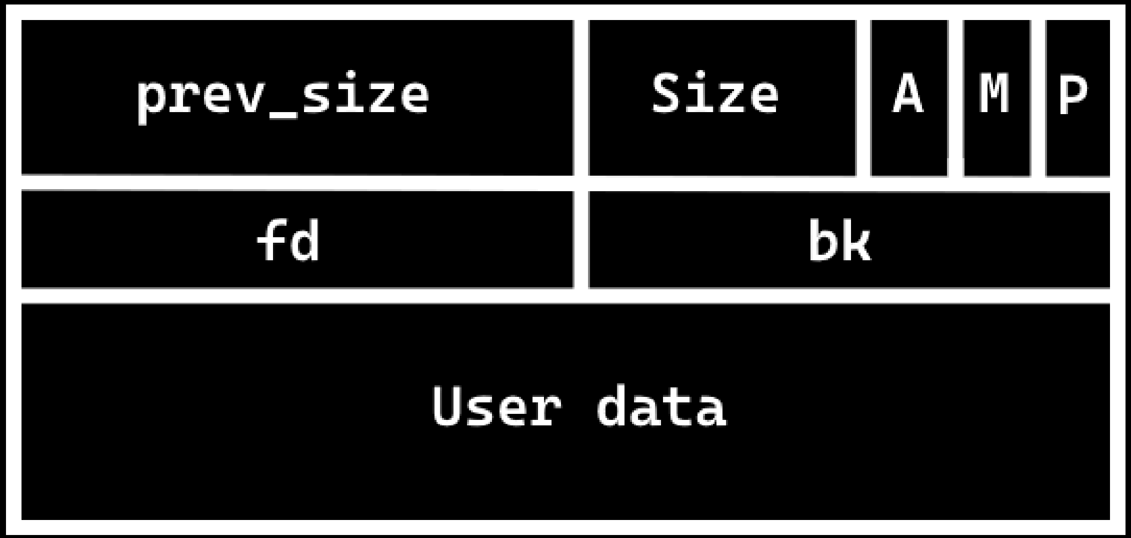
Chunks are sized to the nearest 8-byte aligned serviceable size. Heap chunks have metadata in them used by malloc and free when servicing future requests. Freeing a chunk does not delete it, it just modifies the chunk to prepare it for future allocation in the event it meets a request.



A = Chunk is not in the main heap & was allocated.
M = Chunk was mmapped and will be treated directly.
P = The previous chunk is not free.

Freed chunk anatomy

Freebins are linked lists of freed chunks. Depending on the chunk, it will be stored in its corresponding list: the tcache, fastbins or unsortedbin (where the chunk is further sorted into the smallbin or largebin by malloc). If a chunk is not a fast or tcache chunk and an adjacent chunk is also free (prev_inuse) the chunks may be consolidated, this is also true with the top chunk. The head of a bin is stored in the arena and linked members are stored inline in the freed chunk in its first two qwords of user data.

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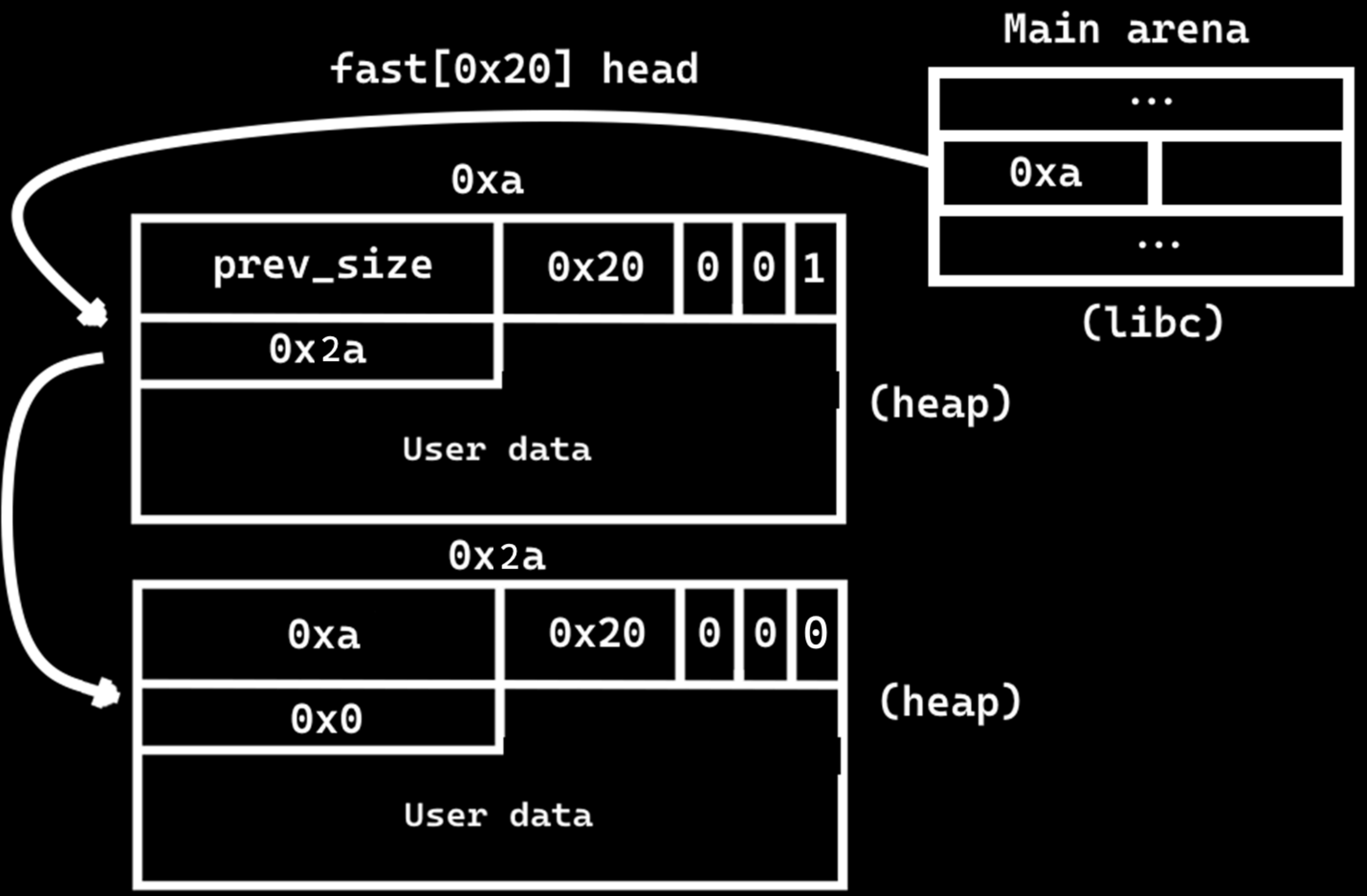

Main arena
fast[0x20] head
...
0xa
...
(libc)
0xa
prev_size
0x20
0
0
1
0x2a
User data
(heap)
0x2a
0xa
0x20
0
0
0
0x0
User data
(heap)

Demo

Materials can be found at
https://faultpoint.com/assets/filebin/malloc_demo.c
https://faultpoint.com/assets/filebin/malloc_demo
https://faultpoint.com/assets/filebin/template.py

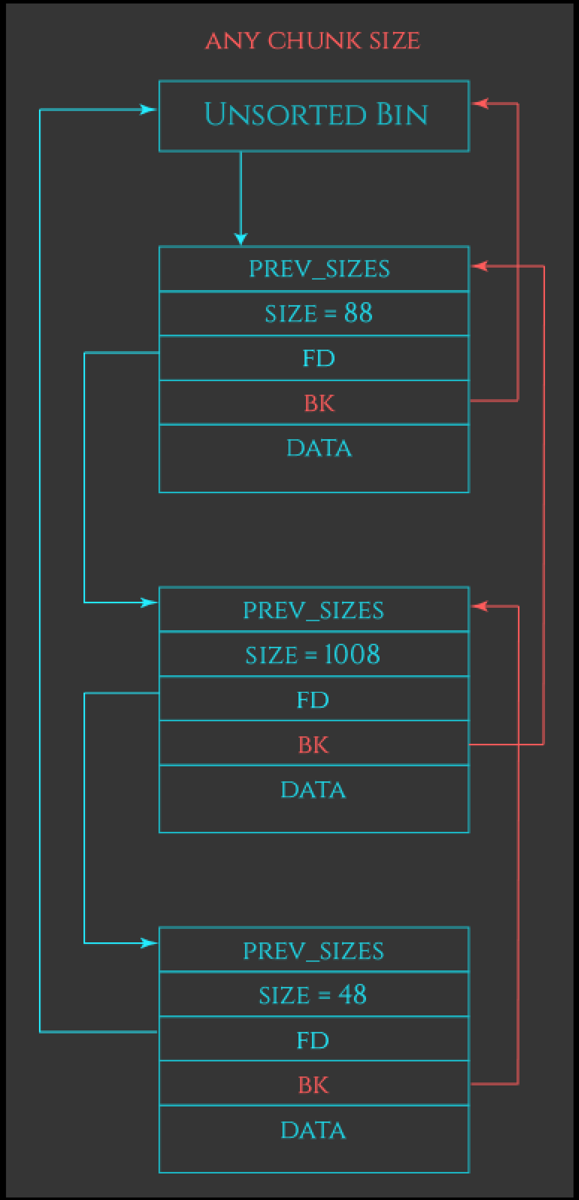
Fastbins

The fastbins are a singly linked freelist that stores chunks of sizes 0x20 to 0xb0. It is singly linked so only the first qword of user data is utilized as an fd. Malloc has a fast size integrity check when allocating from these bins (more on glibc exploit mitigations later). Chunks that are fast-sized will be put into the corresponding fastbin depending on if the tcache is disabled or the corresponding tcache entry is full.

```
0x555555559260  0x0000000000000000      0x0000000000000000      ................
0x555555559270  0x0000000000000000      0x0000000000000000      ................
0x555555559280  0x0000000000000000      0x0000000000000000      ................
0x555555559290  0x0000000000000000      0x0000000000000021      ........!.......         <-- fastbins[0x20][5]
0x5555555592a0  0x0000000555555559      0x0000000000000000      YUUU............
0x5555555592b0  0x0000000000000000      0x0000000000000021      ........!.......         <-- fastbins[0x20][4]
0x5555555592c0  0x000055500000c7c9      0x0000000000000000      ....PU..........
0x5555555592d0  0x0000000000000000      0x0000000000000021      ........!.......         <-- fastbins[0x20][3]
0x5555555592e0  0x000055500000c7e9      0x0000000000000000      ....PU..........
0x5555555592f0  0x0000000000000000      0x0000000000000021      ........!.......         <-- fastbins[0x20][2]
0x555555559300  0x000055500000c789      0x0000000000000000      ....PU..........
0x555555559310  0x0000000000000000      0x0000000000000021      ........!.......         <-- fastbins[0x20][1]
0x555555559320  0x000055500000c7a9      0x0000000000000000      ....PU..........
0x555555559330  0x0000000000000000      0x0000000000000021      ........!.......         <-- fastbins[0x20][0]
0x555555559340  0x000055500000c649      0x0000000000000000      I...PU..........
0x555555559350  0x0000000000000000      0x0000000000020cb1      ................         <-- Top chunk
pwndbg> p/x main_arena.fastbinsY[0]
$3 = 0x555555559330
pwndbg> fastbins
fastbins
0x20: 0x555555559330 —▸ 0x555555559310 —▸ 0x5555555592f0 —▸ 0x5555555592d0 —▸ 0x5555555592b0 ◂— ...
pwndbg>
```

Unsortedbin

Non-fast-sized chunks that don't border the top will be placed into the unsortedbin, a doubly-linked circular freelist. Next time malloc is called, the unsortedbin will be searched for a chunk that is serviceable. During iteration it will sort chunks it comes across into the smallbins or largebins, it will only sort up until an allocation is found. Its first two qwords of user data contain an fd and bk respectively. A dummy chunk is also linked into the main_arena. Since chunks are consistently unlinked from the unsortedbin, unsortedbin metadata can be targeted in unlinking attacks. If no exact sized chunk exists after a search, the last remaining closest fit chunk will be remaindered.



https://azeria-labs.com/heap-exploitation-part-2-glibc-heap-free-bins/

Tcache (>2.26)

- Why the tcache
- What is the tcache
- How does the tcache work
- Security risks

In a lot of scenarios, the presence of the tcache can make exploitation easier!

Techniques

Some of the first heap exploitation techniques were in the malloc maleficarum. For every libc version, people have been discovering new techniques that utilize corruption on the heap to modify stuff such as metadata or important glibc structures.

https://github.com/shellphish/how2heap
https://0x434b.dev/overview-of-glibc-heap-exploitation-techniques

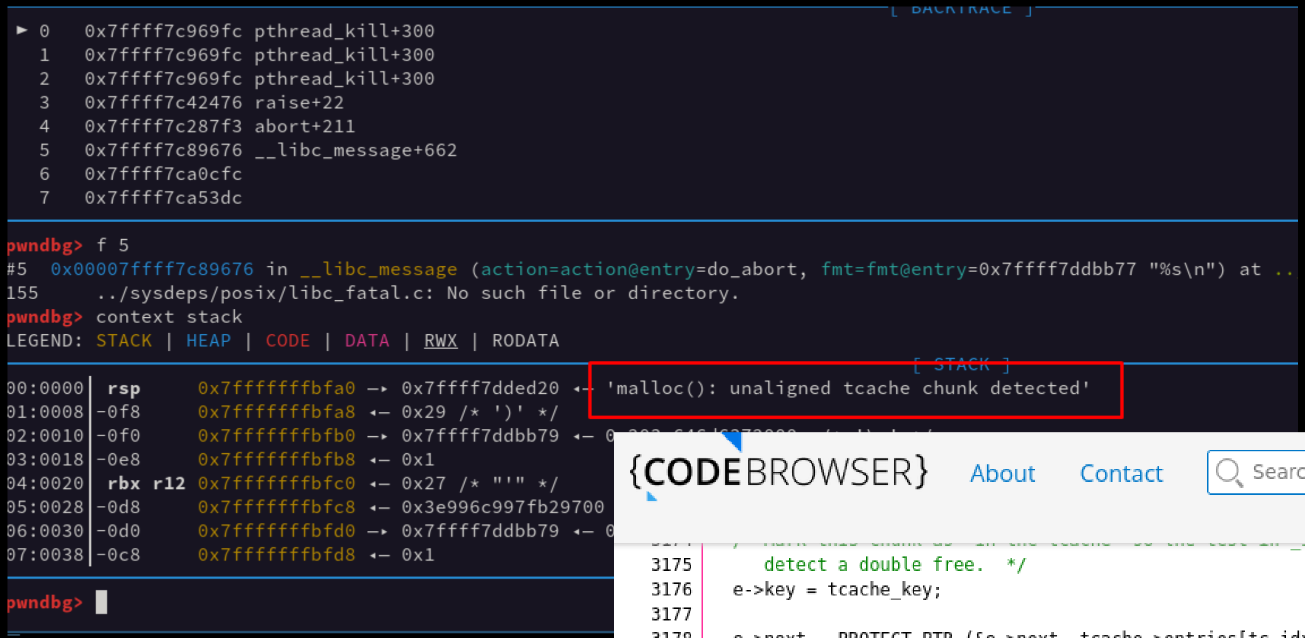
Exercise

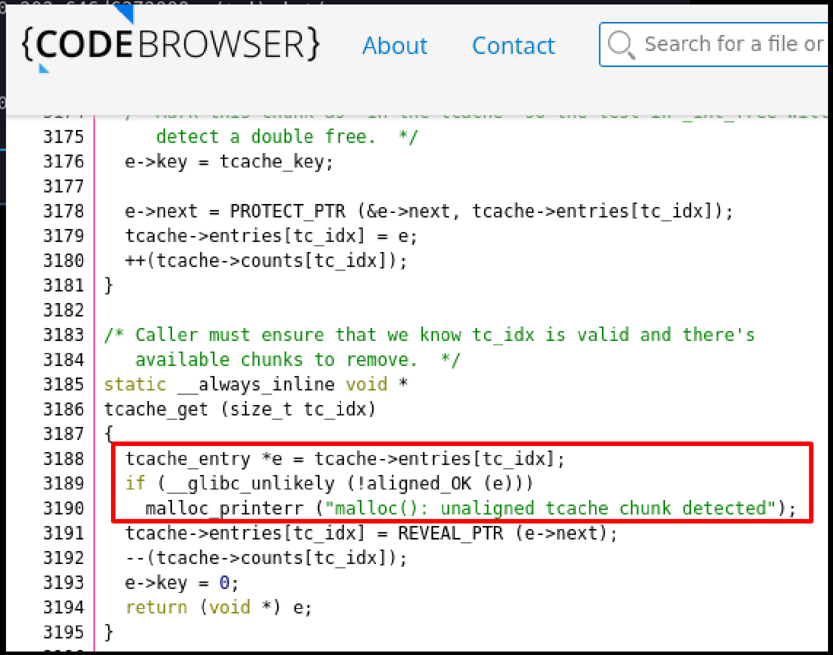
Because of the nature of how ptmalloc stores data, even small, off-by-one vulnerabilities can be leveraged to gain full code execution.

Imagine you have a single null byte overflow into an adjacent chunk, how could you utilize this to achieve an arbitrary write?

GLIBC Mitigations

Many of these techniques have been partly or fully mitigated with checks and asserts implemented in different glibc versions. If you encounter a mitigation, the best way to learn what its doing is to read the source.





Other utility functions such as realloc (resize chunks) and calloc (zeros out returned chunks) behave slightly different but all implement int_malloc the same. Not all mitigations are full proof.

Challenge

The earlier provided demo binary as discussed is vulnerable to a read and write after free. The goal of this challenge is to exploit the demo binary using the provided python template to drop a shell. There are 2 ways (and possibly more) you can achieve this.

Hint: If you get stuck, try researching the “safe linking” mitigation introduced in glibc 2.32.

Download challenge binary and template solve
https://faultpoint.com/assets/filebin/malloc_demo
https://faultpoint.com/assets/filebin/template.py

Resources

https://github.com/shellphish/how2heap (Shellphish how2heap)
https://azeria-labs.com/heap-exploitation-part-1-understanding-the-glibc-heap-implementation/ (Azeria labs)
https://guyinatuxedo.github.io/25-heap/index.html (Nightmare)
https://www.youtube.com/watch?v=6-Et7M7qJJg (Max Kamper's Introduction to Glibc Heap Exploitation presentation)
https://www.udemy.com/course/linux-heap-exploitation-part-1/ (HeapLab, not free)
There are also some heap challenges you can practice with on TCTF.

Questions?