SIGPwny

SP2025 Week 06 • 2024-03-09

PWN IV - Heap Exploitation

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Announcements

- DiceCTF 2025 Quals on 3/28, the Friday after spring break!
  - Starts at 4:00 pm, come in person!

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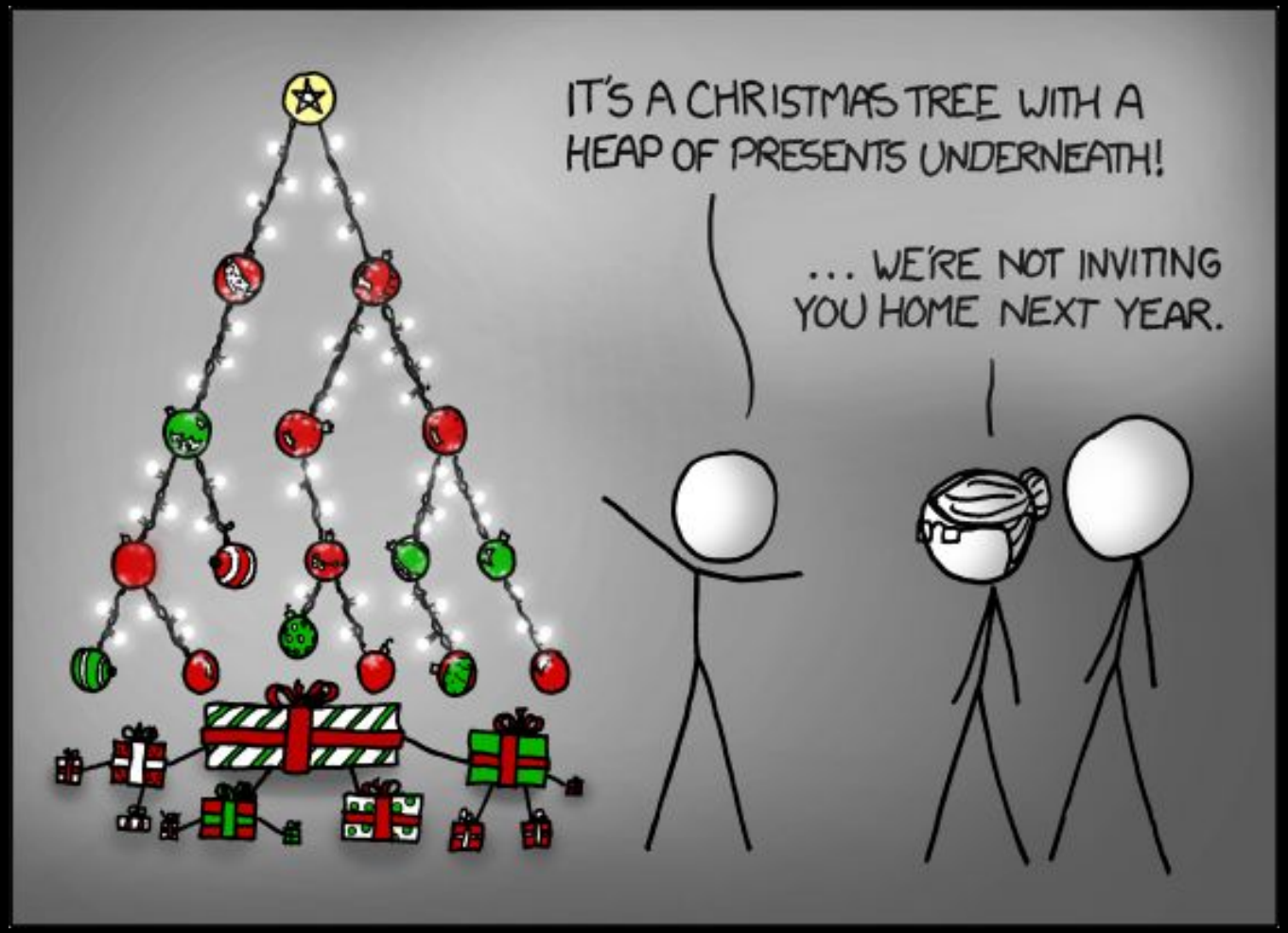


Memory Layout

Bottom of memory
(0x0000000000000000)

Top of memory
(0xFFFFFFFFFFFFFFFF)

The Heap

Memory Allocation

- We've seen static stack allocation
- C does support Variable Length Arrays
- How to we return an address to the buffers?

```
int* buffers(int size){
  char buf[256];
  char buf2[size];
  return buf2;
}
```

The Heap

- The Heap ≠ Heap ADT
- Allows Dynamic Memory Allocation
- Allocations are preserved across function calls

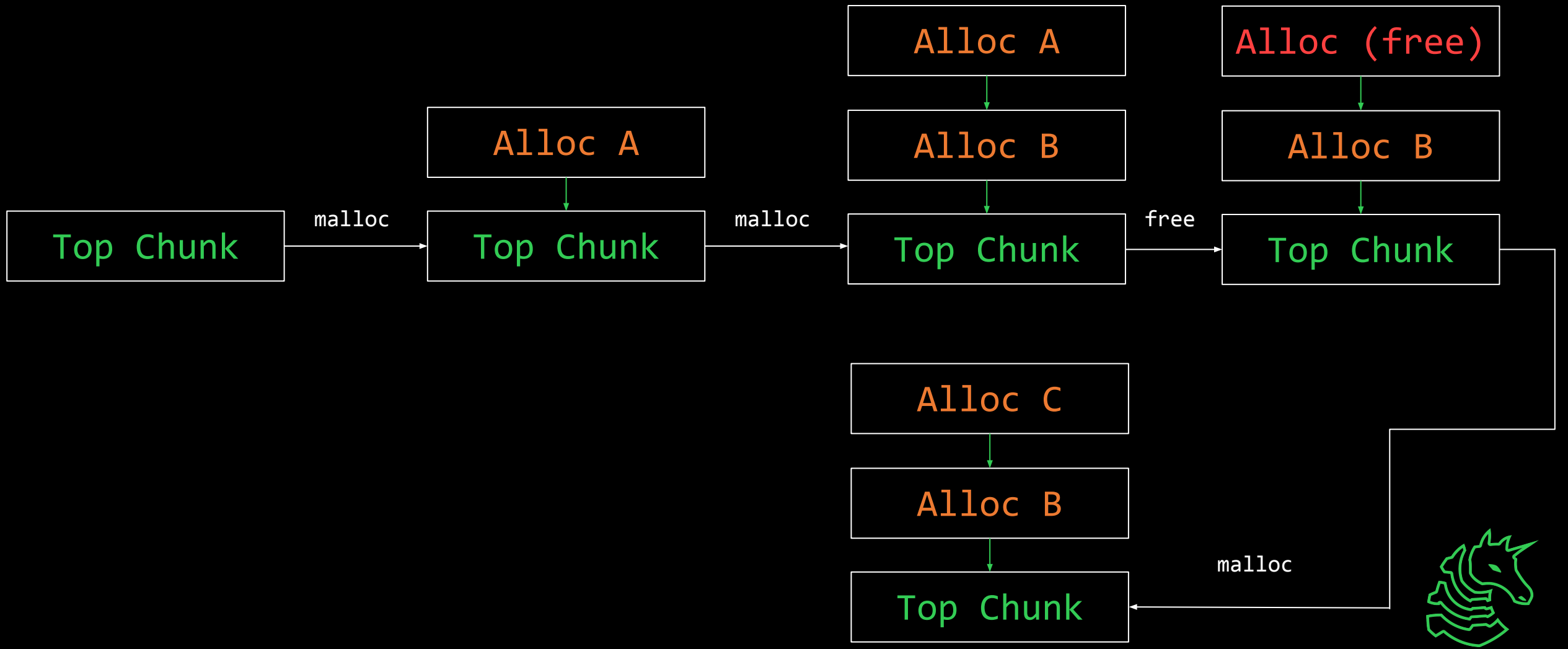
- `malloc(int size)`: Returns a pointer to allocated data
- `free(int* ptr)` : Frees the allocation located at `ptr`.

- Regardless what you put, the minimum allocation will make a 32 byte chunk with 24 bytes of usable memory (64-bit).

Using the Heap

```
void example(int size){
  int* buf = malloc(sizeof(int)*size);
  for (int i=0; i<size; ++i){
    buf[i] = i;
  }
  free(buf);
}
```

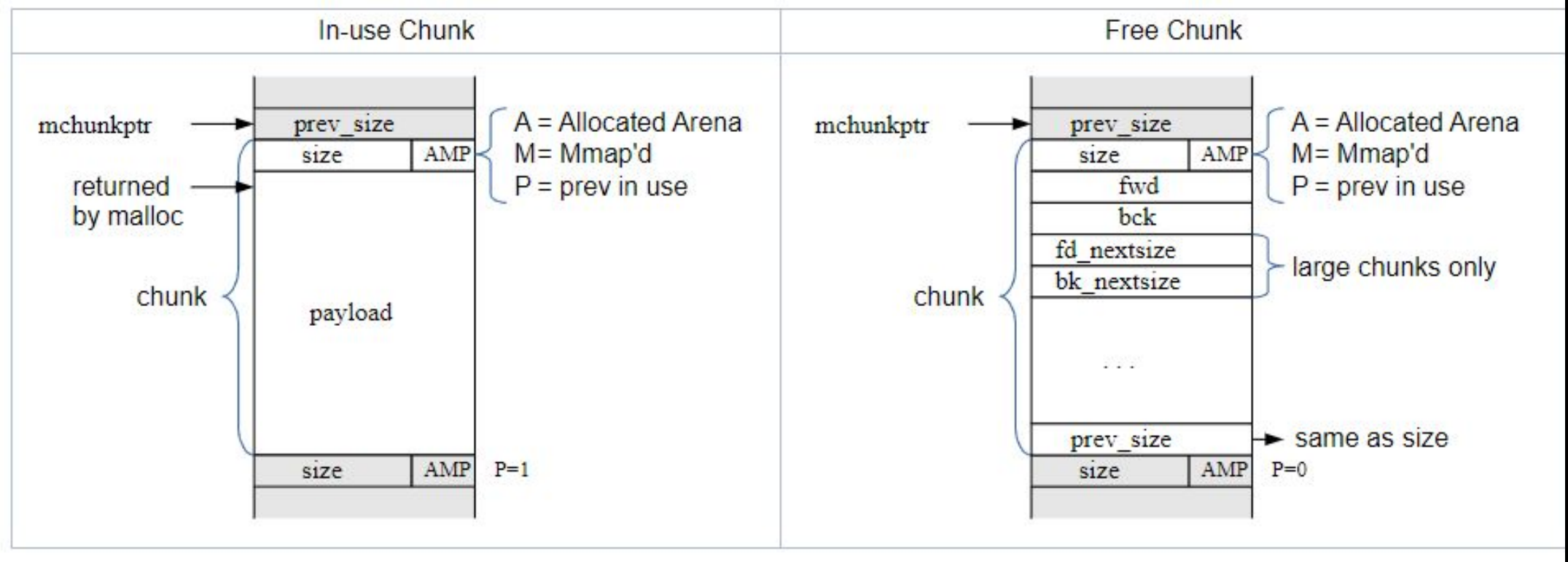
Basic Model of the Heap



What happens when you free

- When you free a chunk, it gets added to a free list
- If you malloc with a similar size, malloc checks the free list first
- glibc provides many optimizations to make allocations and reallocations fast!
- When you hear bins, think a double/single linked list.
- Extra metadata gets placed into a chunk to maintain the list

Free Chunk

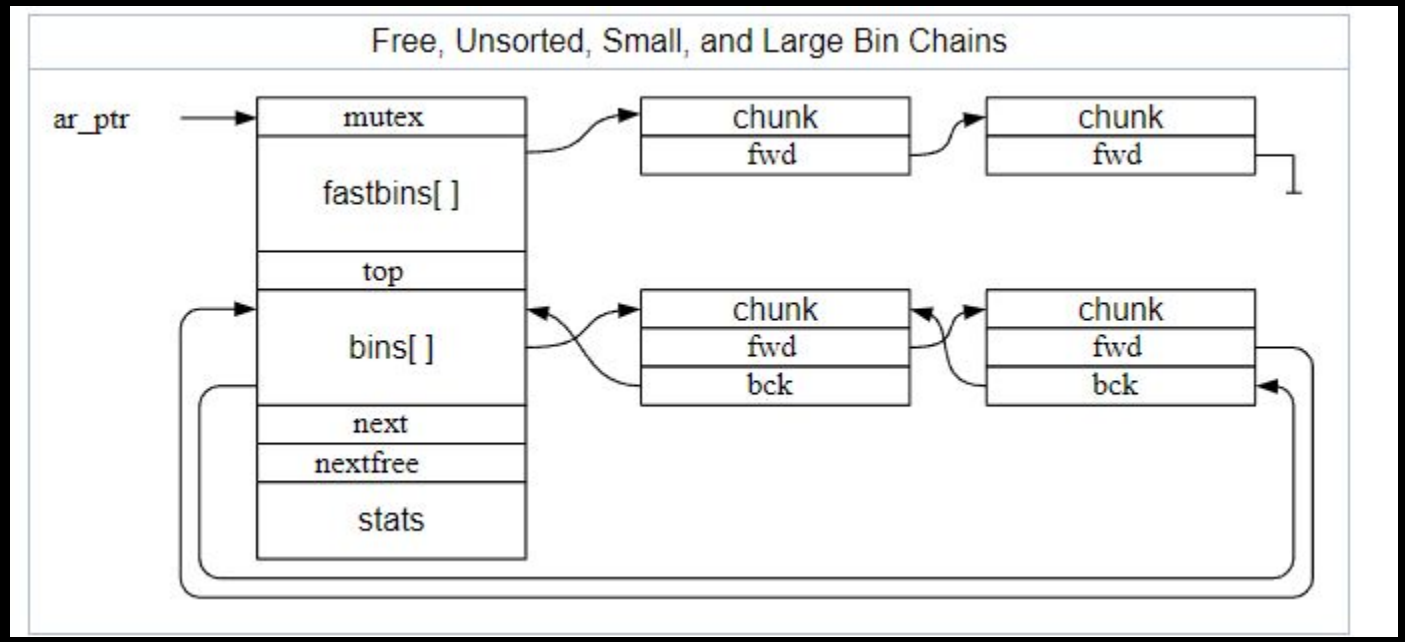

In-use Chunk
mchunkptr
prev_size
size
AMP
returned
by malloc
chunk
payload
size
AMP
P=1
A = Allocated Arena
M= Mmap'd
P = prev in use
Free Chunk
mchunkptr
prev_size
size
AMP
fwd
bck
fd_nextsize
bk_nextsize
chunk
large chunks only
. . .
prev_size
size
AMP
P=0
same as size
A = Allocated Arena
M= Mmap'd
P = prev in use

Coalesce and Split

- Coalescing free chunks into one big chunk
  - Done when several adjacent chunks are free and not reused
  - Some bins prevent immediate coalescing
- Splitting a large chunk into a remainder chunk
  - Sometimes an alloc is smaller than a free chunk available
  - malloc will split the chunk into one of the correct size and a remainder chunk
- A large chunk may coalesce with the top chunk if adjacent
- When the top chunk gets too large, malloc will release the memory to the system.

Bins

- Malloc will reserve memory from the system when it needs
- It will try to keep that memory available for reuse for as long as possible
- Free chunks have to be efficiently available for all chunk sizes



Tcache Bins

- Introduced glibc2.26: Thread-specific bins for small allocations
- 64 bins, max count of 7, min size of 0x20, max size of 0x410
  - Subtract 8 for metadata, so min size for bin is 24 bytes or less.
- Each new thread gets a new tcache
  - Don't worry about this for now, multithread heap pwn is super advanced
- Singly-Linked, Only forward ptrs
- Because of their speed, there is lacking security checks within them

Fast Bins

- The "overflow" for tcache
- 10 bins, between 0x20 and 0xb0
  - Sometimes only 7 are active…
- The "in-use" bit is maintained to prevent coalescing
  - The fast bin may be flushed and coalesced if large chunks are available
- Singly Linked

Unsorted Bin

- The laundry pile of memory chunks
- When you free, and it doesnt fall in tcache/fast, it goes here
- malloc waits to see if you immediately reuse this chunk
- If not, it will sort it into a **small** or **large** bin

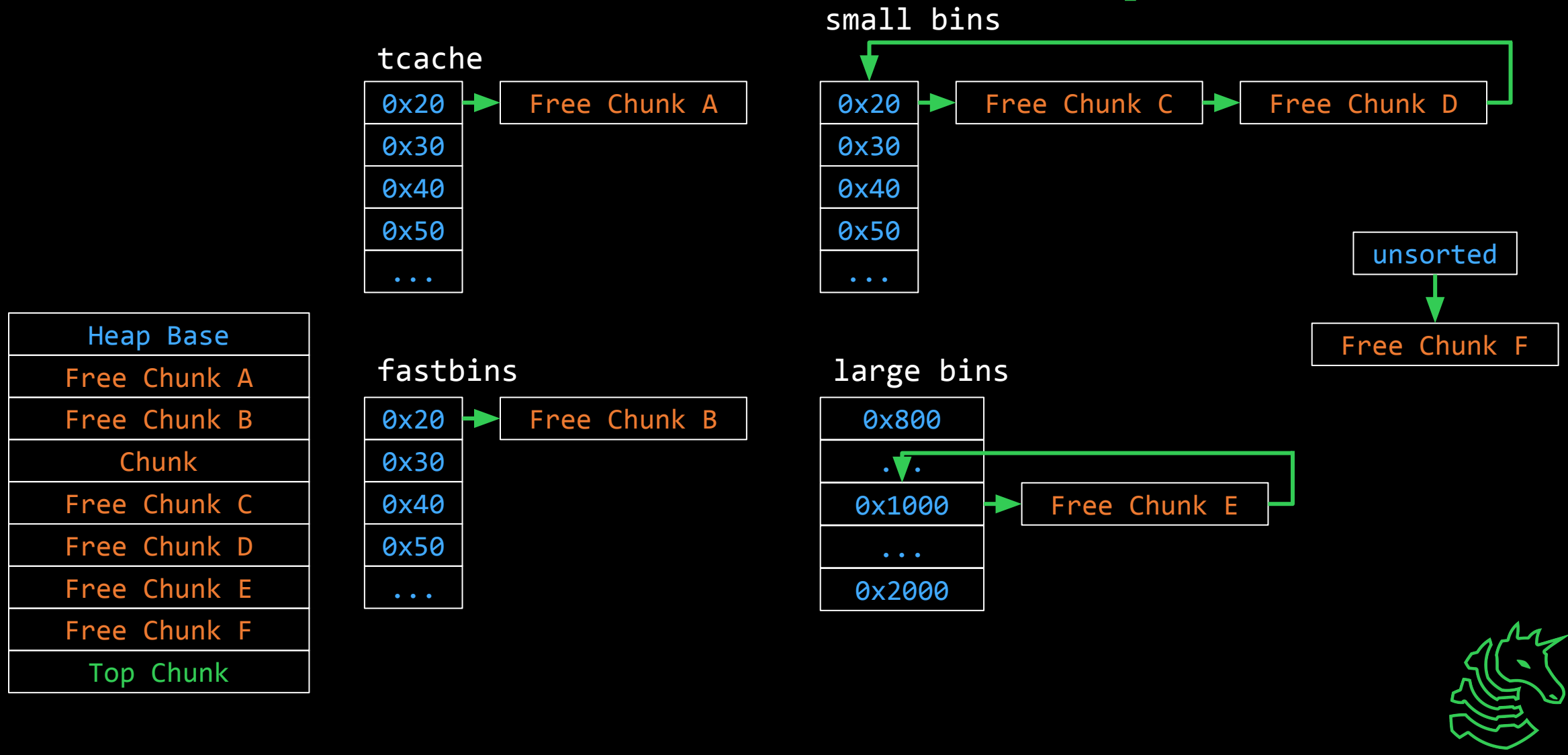
Small Bins

- Like fast bins, fixed size in every bin
- 61 bins, starting at size 32 and up to 1024
- Adjacent chunks can be combined and moved to different bins
- Circular Doubly Linked

Large Bins

- Stores a *range* of memory allocations in each bin
- 63 bins
- Memory allocations are inserted in a bin *in sorted order*
- An exponentially smaller number of bins are used for exponentially larger allocations
  - there are 32 bins that store allocations within 64 byte differences from each other
  - there are 2 bins that store allocations within 256kb differences
  - there is 1 "everything else" bin.
- Circular Doubly Linked

Still a Basic Model of the Heap



Malloc's Brothers

- `calloc(items, size)` allocates `items*size` bytes, and **c**lears it to zero.
  - Does NOT use the tcache!
- `realloc(ptr, size)` changes the allocation size of `ptr` to `size`.
  - A horrifying amalgamation of free and malloc.
  - Will cause coalescing and splits if you increase/decrease size

Malloc is Horrible to Understand

- There's still many optimizations, behaviors, and interactions not covered
- Looking at the glibc source code is informative but not easy
- It also changes version to version…
- The best way to understand malloc's memory patterns is to just experiment
  - Especially when doing challenges, as glibc versions change.

Exploitation

A 30000-foot view of pwn

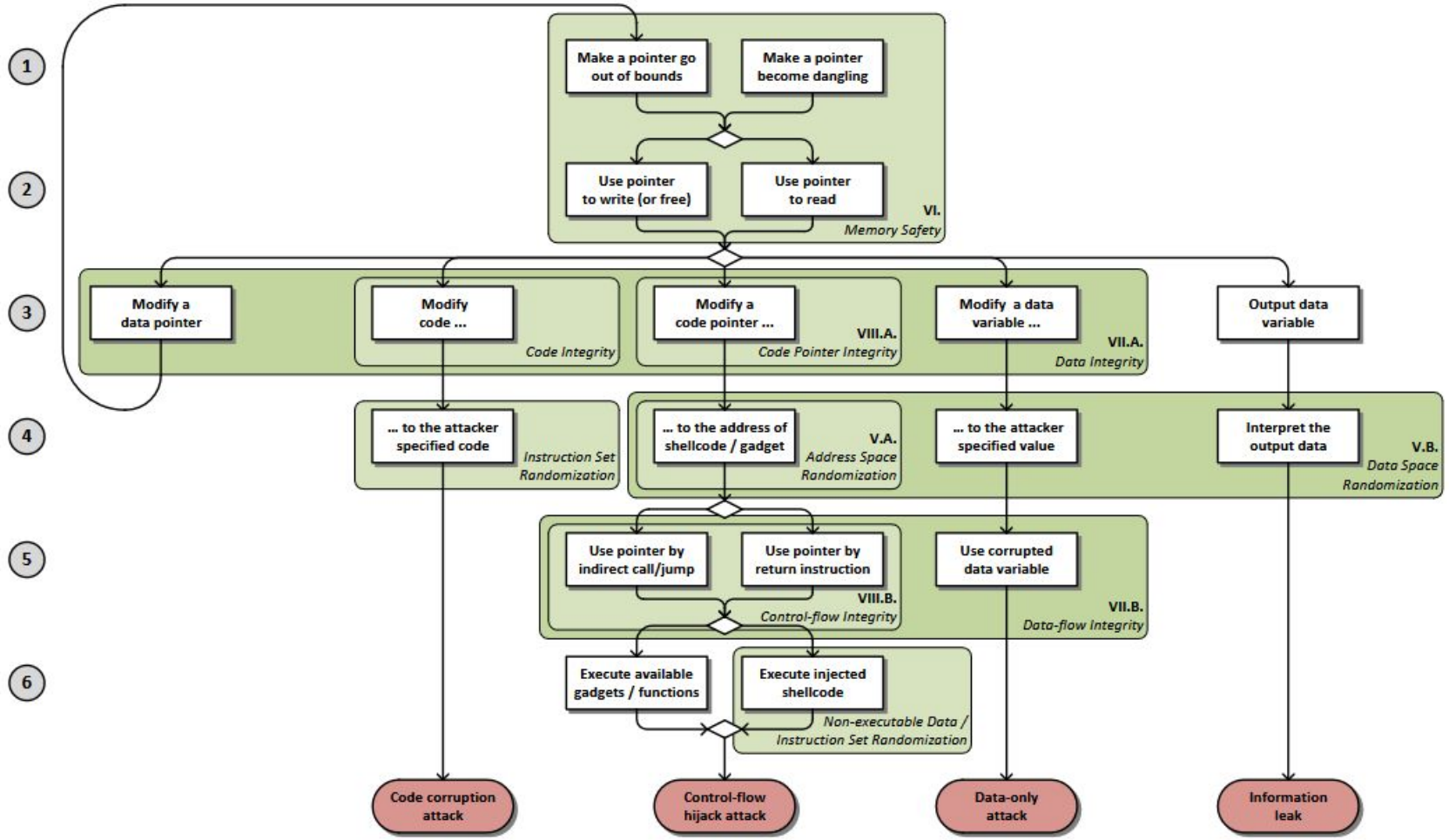


Figure 1. Attack model demonstrating four exploit types and policies mitigating the attacks in different stages

Source: “SoK: Eternal War in Memory” (Szekeres, et al. 2013)

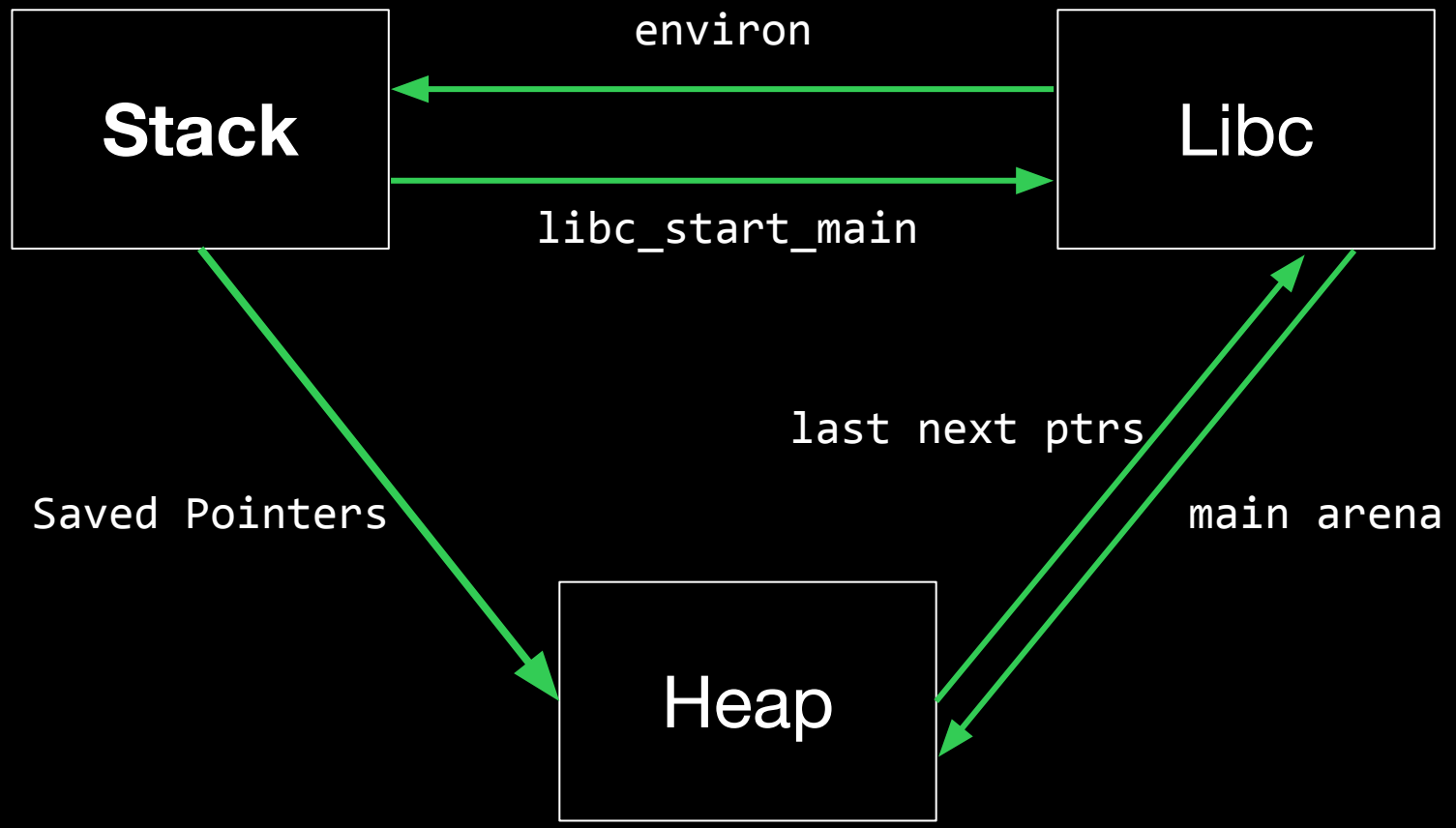
Exploiting Programs

- We want arbitrary code execution:
  - Control the return address on the stack
  - Return to libc for useful functions
- Two Primitives:
  - Arbitrary Read
  - Arbitrary Write
- If we can get an arbitrary write to the stack, we can control program flow
- If we can get an arbitrary read, we can leak libc addresses

Goals with Heap Exploitation

- Make malloc:
  - return a chunk somewhere interesting
- Make libc merge invalid chunk
  - malloc has optimizations to coalesce adjacent free chunks
  - If you corrupt chunk sizes, you can get malloc to coalesce memory that it's not supposed to
  - Usual result is overlapping chunks

Leak Traversal

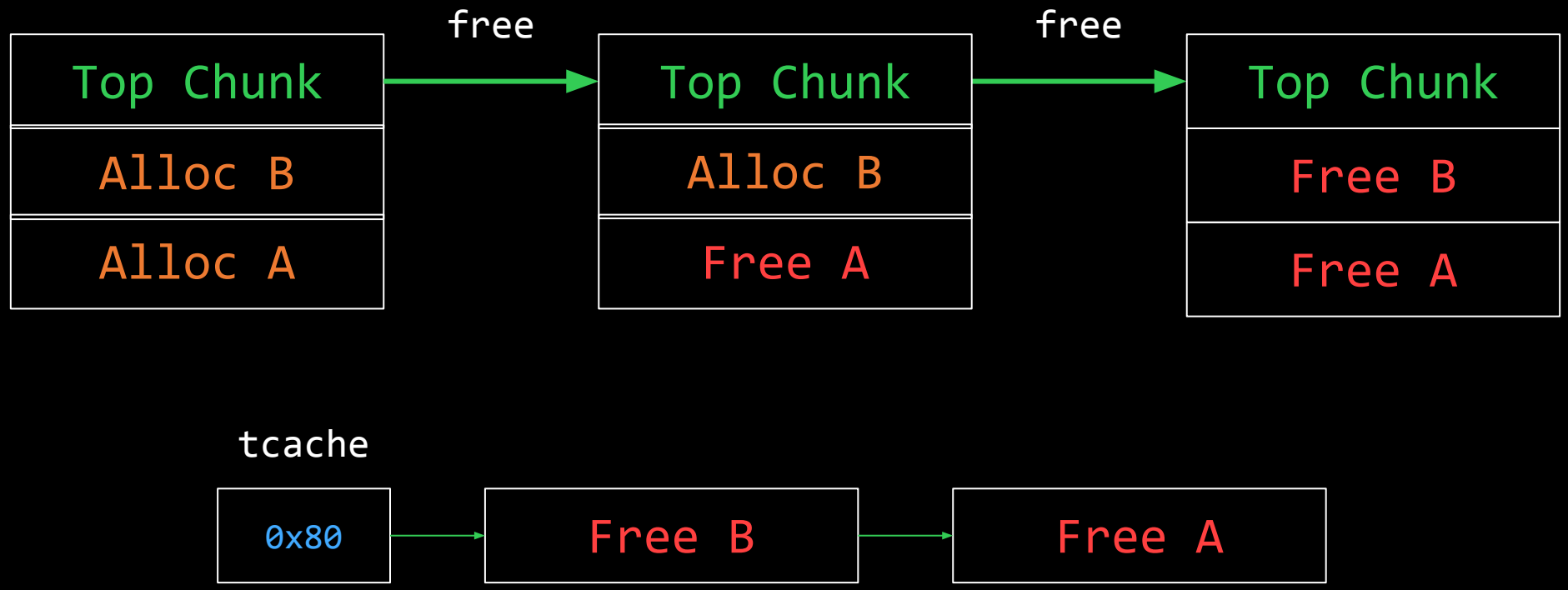


Use After Free (UAF)

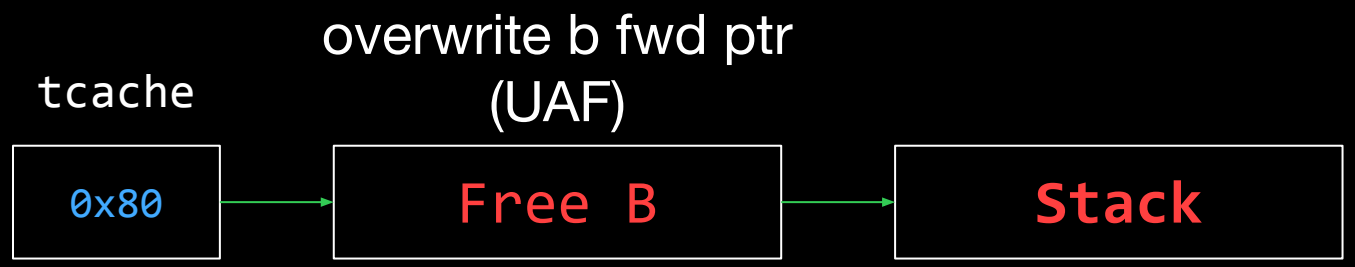
- When you free a pointer, you are responsible for clearing the variable storing the pointer (`ptr = NULL;`)
- Nothing stops you from reading/writing through that pointer post-free
- This allows you to affect many aspects of malloc's state
  - Preload chunks with data
  - Modify Chunk sizes
  - Modify fwd/bk pointers(!!)

Example: tcache poisoning

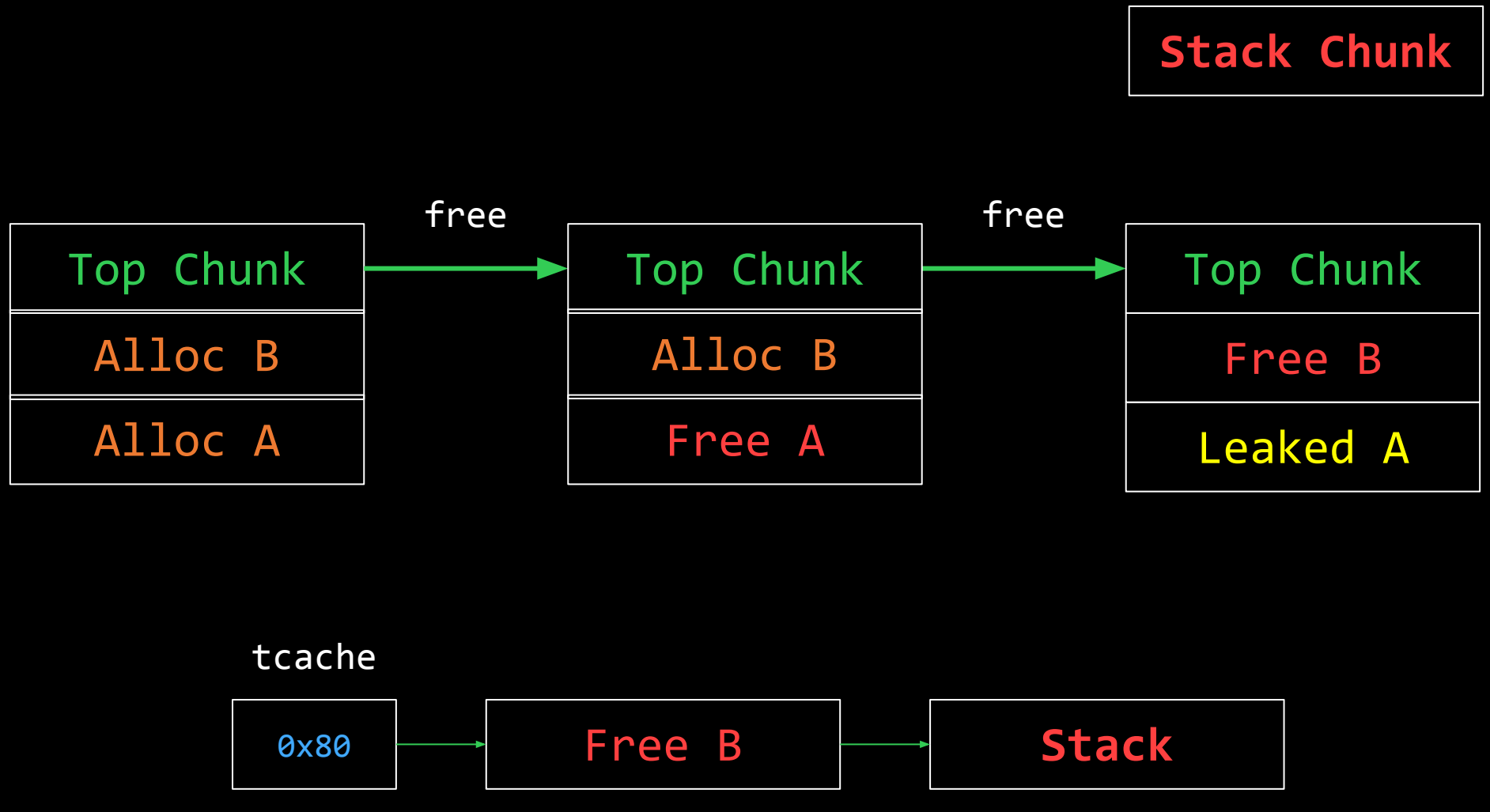
Example: tcache poisoning



Example: tcache poisoning



Example: tcache poisoning



Safe Linking

- malloc attempts to """encrypt""" single-linked list pointers
- `(pos >> 12) ^ ptr`
- By taking the position of where the ptr is stored, you encrypt it with the ASLR bits of the position.
- But if the position and the ptr are in the same page, then you can get the heap base:

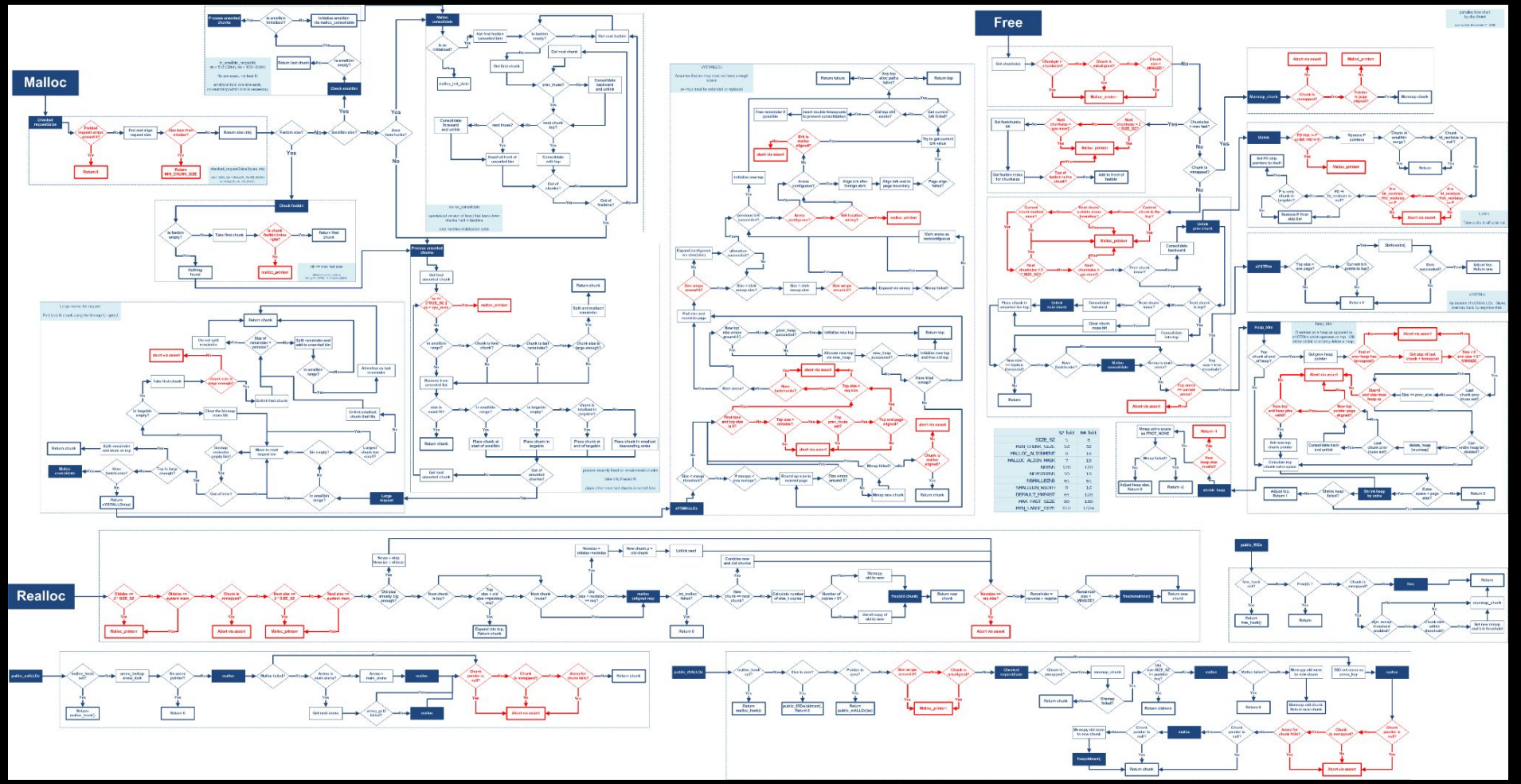
```
def deobfuscate(val):
    mask = 0xfff << 52
    while mask:
        v = val & mask
        val ^= (v >> 12)
        mask >>= 12
    return val
```

Double Free

- The free bit does not always mean free
  - (the one thing an indicator bit should do)
- Calling `free` on an already free'd chunk *can* add it to a free list twice
  - malloc tries to prevent trivial double frees (2 in a row)
  - the tcache checks an entire list (only 7)
- Fast bins are vulnerable!
- Modify the free metadata of the received chunk

A complete model of the Heap

(please do not waste time on this)



pwndbg tools

- `heap`
  - Displays the state & address of all heap chunks
- `bins/tcachebins/fastbins/smallbins/largebins`
  - Displays the state and chunks in each bin
- `vis_heap_chunks`
  - Shows a hex dump of the heap, color codes chunks, and marks chunks in bins

Resources

https://github.com/shellphish/how2heap

Resources

- https://github.com/shellphish/how2heap
  - has more resources linked!
- https://azeria-labs.com/heap-exploitation-part-1-understanding-the-glibc-heap-implementation/
- https://heap-exploitation.dhavalkapil.com/

Next Meetings

`2025-03-13` • **This Thursday**

- LAN party!!

`2024-03-16` • **This Weekend**

- No meeting, have a good break!

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Meeting content can be found at sigpwny.com/meetings.

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