Week 11 - Heap Exploitation

Introduction to Offensive Security

What is the heap?

- Dynamically allocated memory
  - Request memory
  - Release memory
- Allocated at runtime
- Pointers used to reference data

Why use the heap?

- Stack variables are local (can’t be accessed between functions)
  - Heap is persistent
- Allocate as much as you want
  - Unsure at runtime how much space needed
- Commonly used for larger objects

Heap Implementations

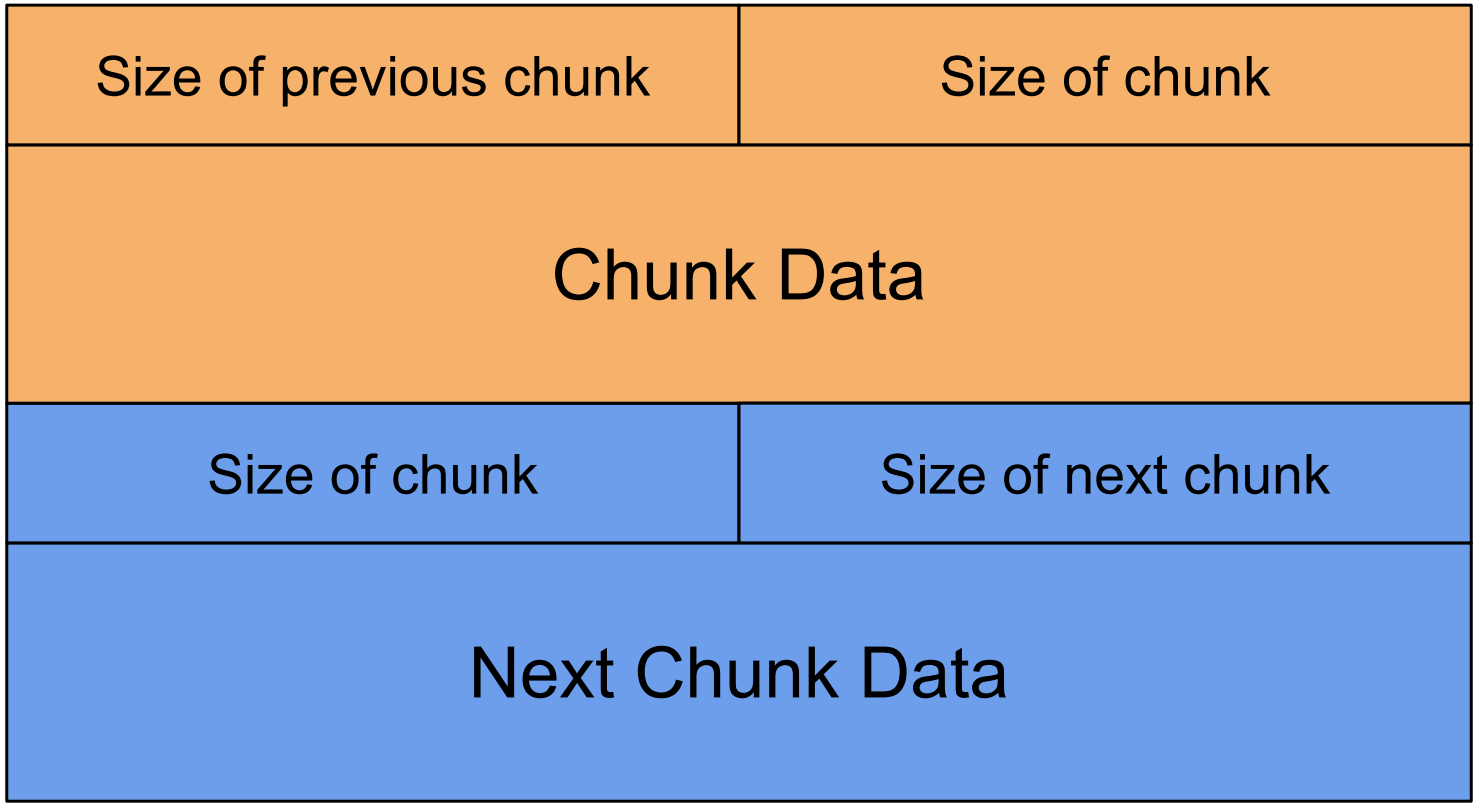
- Many implementations have slightly different behavior
  - avrlibc
  - dlmalloc
  - tcmalloc
- Different implementations have different tradeoffs

- For class we're focusing on the glibc implementation of malloc

How to use the heap?

- malloc(size_t n)
  - Returns a pointer to newly allocated chunk of at least n bytes
  - Should align to 16 bytes (implementation specific)
    - Last nibble (4 bits) of malloc addresses should be 0
    - Includes heap metadata
    - Simplifies malloc internals

Malloc Chunk



Malloc Metadata

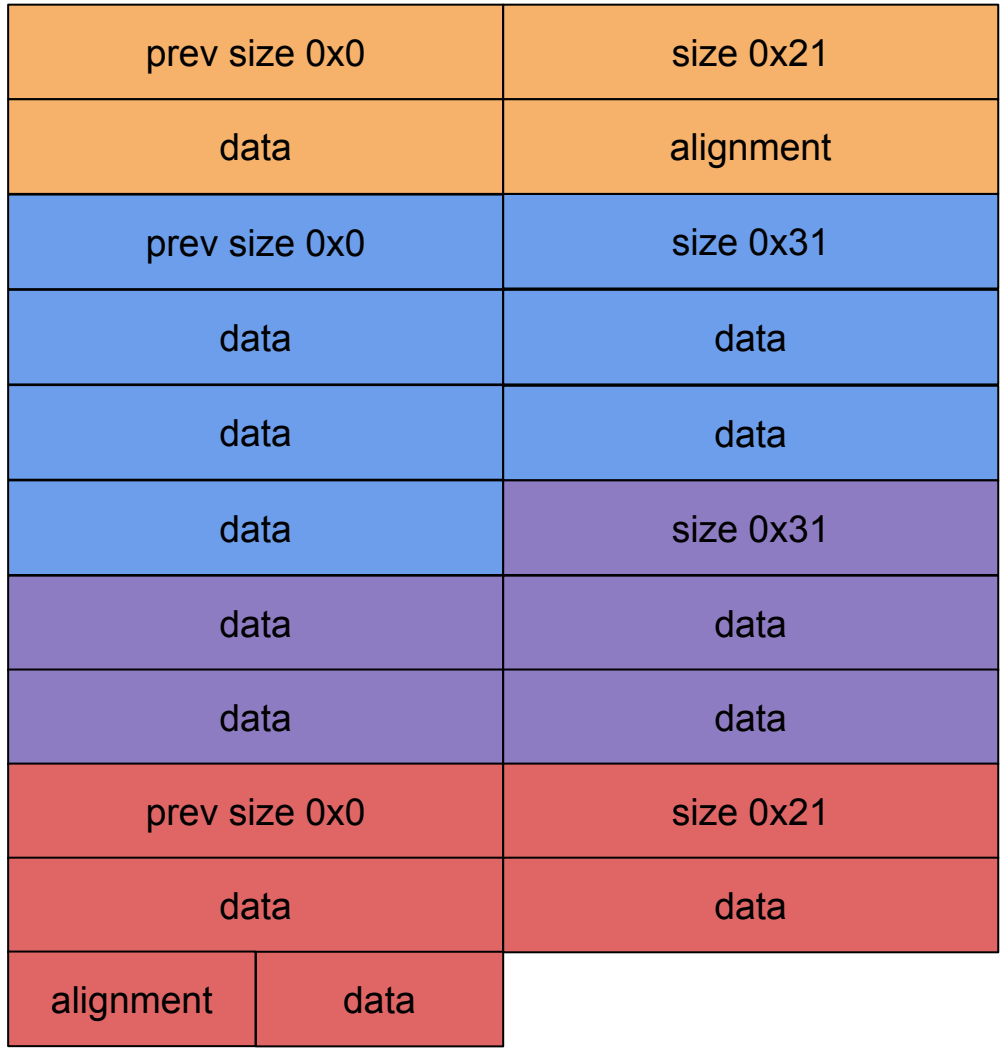
- Last 3 bits of size contain flags
  - PREV_INUSE – Set when previous chunk is allocated
  - IS_MMAPPED – Set when chunk is mmap’d (for larger allocations)
  - NON_MAIN_ARENA – When using a thread specific arena
- 0x21 – Size is 0x20 and previous chunk is allocated

a = malloc(0x8)

b = malloc(0x28)

c = malloc(0x20)

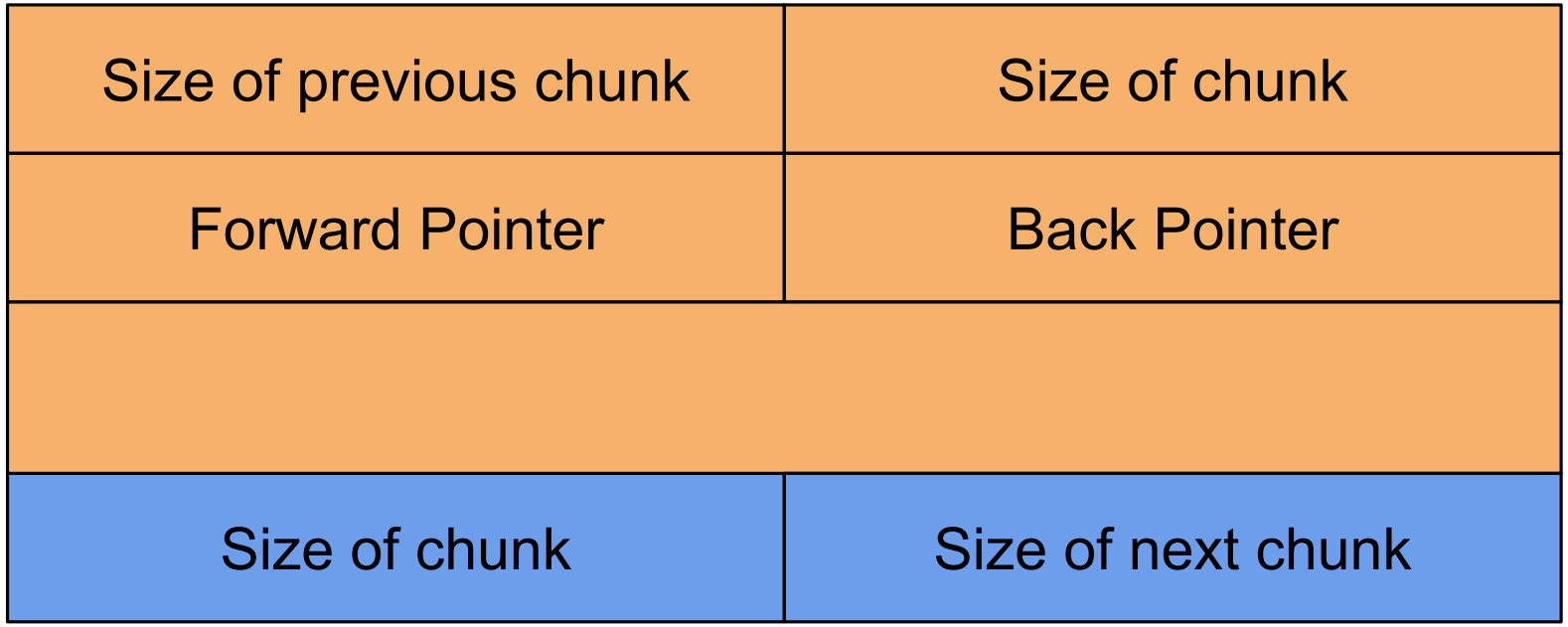
d = malloc(0x14)



How to use the heap? (cont.)

- free(void* p)
  - Release the chunk of memory pointed to by p
  - Can have unintended effects if p has already been freed
  - Expected that you null out p after
    - p = 0;

Freed Chunk


Size of previous chunk
Size of chunk
Forward Pointer
Back Pointer
Size of chunk
Size of next chunk

Free

free(a)

free(b)

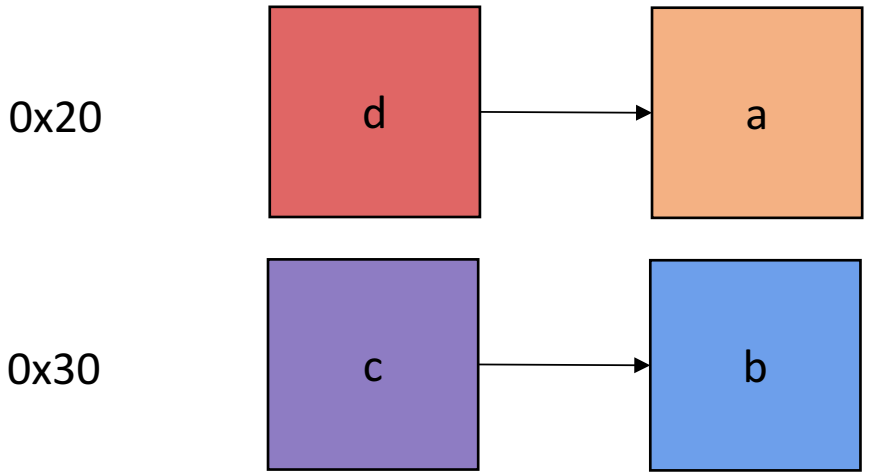
free(c)

free(d)

0x602000	prev size 0x0	size 0x21
0x602010		
0x602020	prev size 0x0	size 0x31
0x602030		data
0x602040	data	data
0x602050	data	size 0x31
0x602060	0x602020	data
0x602070	data	data
0x602080	prev size 0x0	size 0x21
0x602090	0x602000	data
0x6020a0	alignment	data

Malloc First Fit

- malloc tries to reuse space efficiently
- freed chunks are placed in a linked list according to size
- pointers in freed chunks point to forward and back chunk
  - small chunks are stored in singly-linked list (no back pointer)



e = malloc(0x10)

f = malloc(0x10)

Use After Free (UAF)

- What happens when pointers aren’t nulled out after a free?
- Dangling pointers – leftover references to freed chunks
- How can we abuse this?

UAF (cont.)

- Structs are commonly stored on the heap

```
struct example {
        void (* toUpper)(char *);
        char buffer[16];
}
```

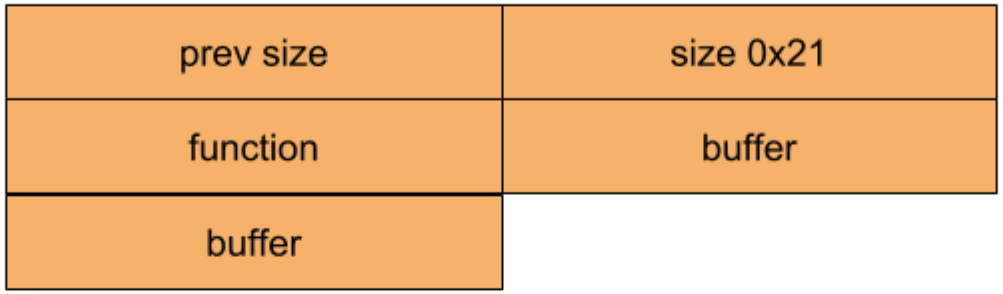
Our example struct converts our buffer to uppercase characters and prints them out

```
struct exploit{
        int number;
        int foo;
        char bar[8];
}
```

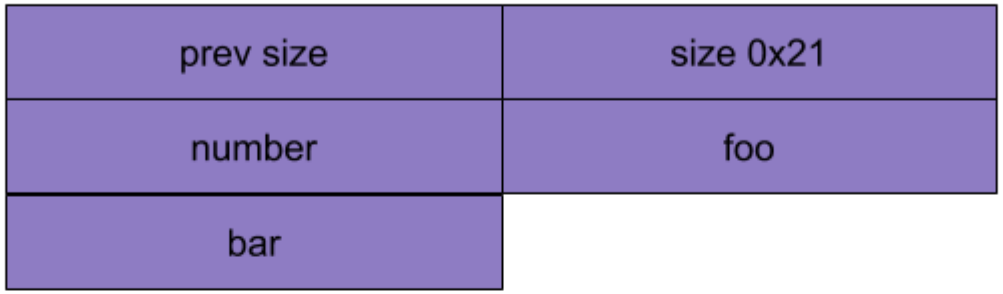
UAF (cont.)

Create an example struct on the heap

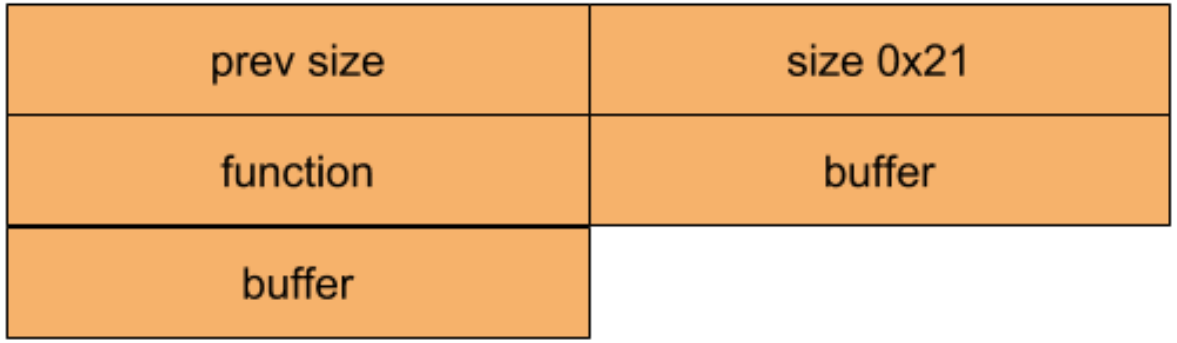
a = malloc(0x18)

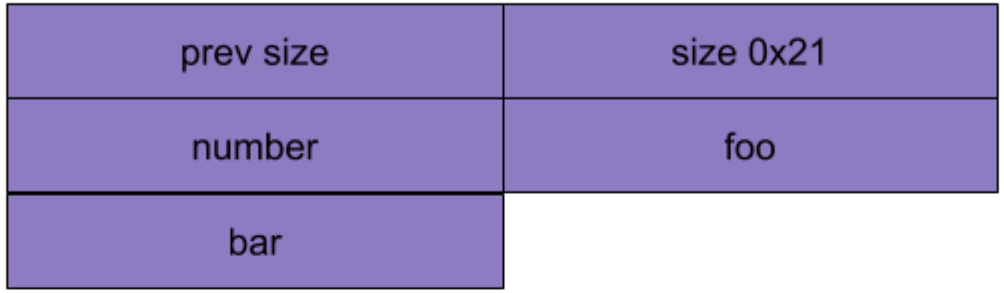


Free the example struct and create exploit struct



Exploit





What can we write into the exploit struct

- any arbitrary function (system?)
- /bin/sh;

What happens if we still have a reference to the example struct?

- Call system on /bin/sh;

UAF (cont.)

- What if we don’t have a convenient function pointer?
- Often there will be option to edit a value in the struct
- Overwrite GOT? Return address?

UAF Info Leaks

- Often string pointers will be stored on the heap
- Overwrite with info you want to leak

UAF Mitigations

- Don’t leave references to freed chunks

UAF in the wild

- Popular vulnerability especially in browser exploits
- Doesn’t require memory corruption
- Can be used for info leaks

- Detecting UAF in complex applications can be very difficult
  - Just not leaving dangling pointers is easy to say, hard in practice
- Exist only in certain states of execution
  - Hard to detect statically

Heap overflows

- Similar to buffer overflows but fewer protections
  - Canaries aren’t a thing in the heap
- Similar to UAF, just need to write over function pointers or strings

Things to take into account

- Heap is affected by ASLR
- Typically only Read and Write
  - No shellcode

Heap Spray

- Not an exploit, more of a technique to make exploits more reliable
- Fill heap with large amount of data relevant to exploit
- Helps assist with ASLR
- On 32 bit systems, address space is 4GB
  - If we spray with 3GB of data, 75% chance that 0x23456789 (random address) exsits
- 64 bit system has 2^{64} bytes of address space
  - Not realistic for spraying
  - Still useful if you can narrow down target to spray

Heap Grooming/Feng Shui

- Heap allocations are predictable
- Doing the same allocations and deallocations leads to same result
  - If malloc implementation is identical
- Arrange chunks in such a way that makes exploiting easier

Metadata Exploits

- Exploit the metadata of the chunk
- Force malloc internal functions to give arbitrary write or read
  - Manipulate size of chunks to create overlaps
  - Overwrite forward and back pointers
- Very popular in CTFs

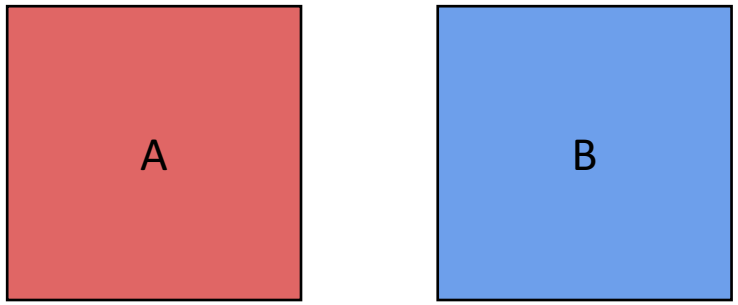
- Come to lab if you're interested in learning more

Double Free

- Expected that a freed chunk will not be freed again
- What if we break the rules?
- Check exists to prevent double freeing a chunk
- What if we free another chunk in between a double free?

Double Free (cont.)

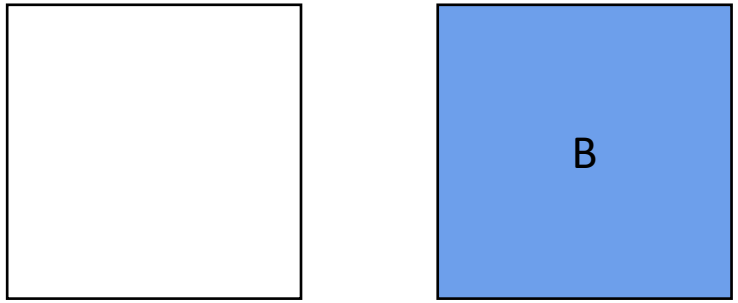
Create two chunks



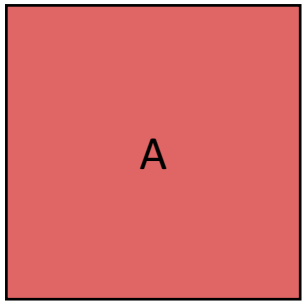
Free List

Double Free (cont.)

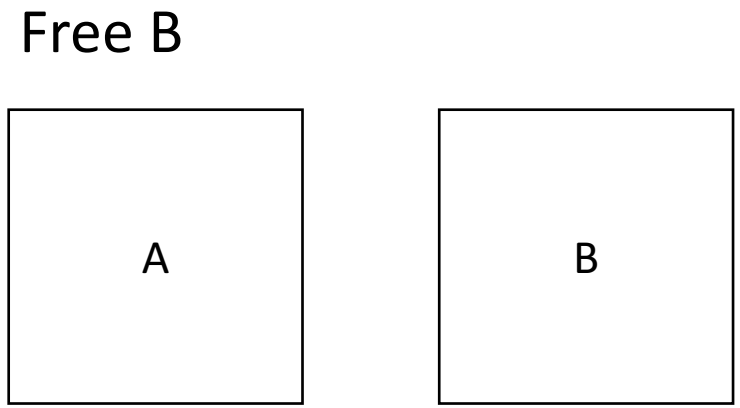
Free A

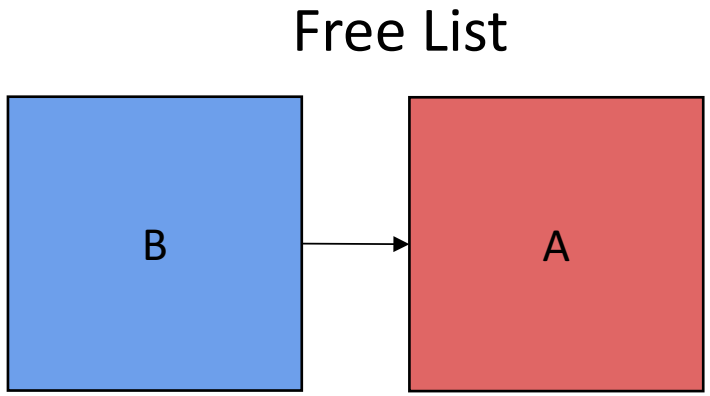


Free List

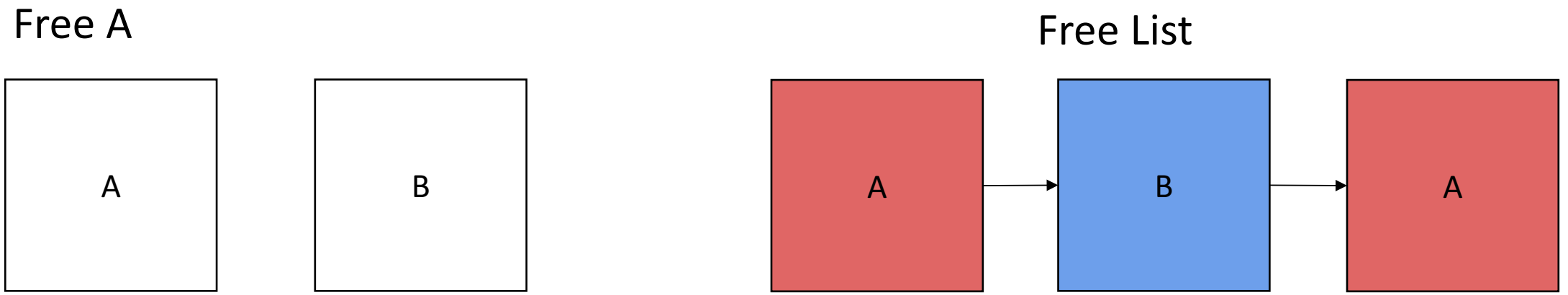


Double Free (cont.)



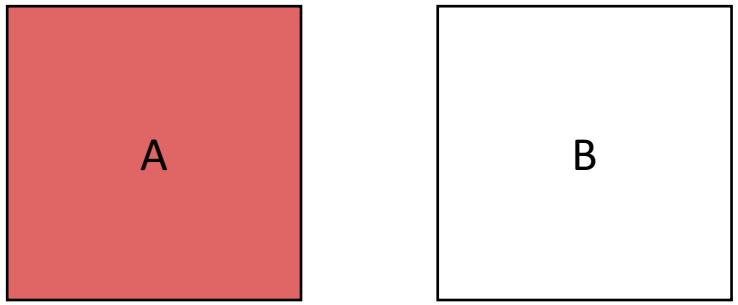


Double Free (cont.)

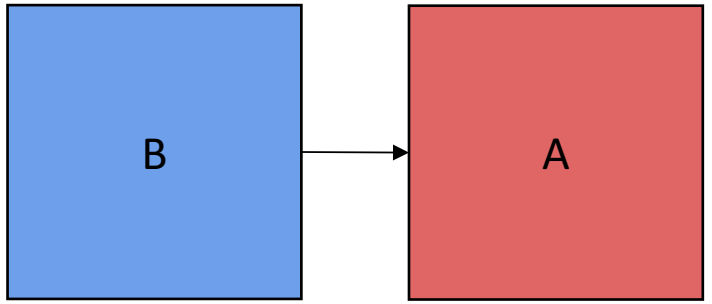


Double Free (cont.)

Malloc new chunk

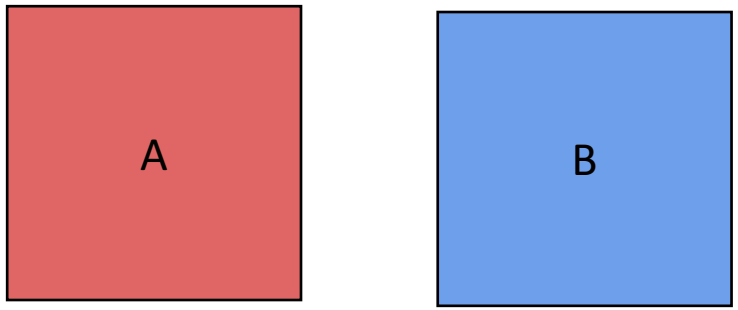


Free List

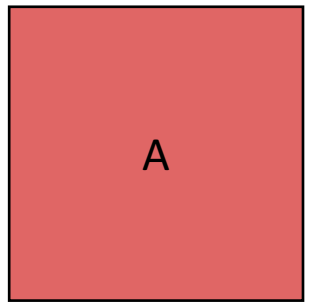


Double Free (cont.)

Malloc another chunk

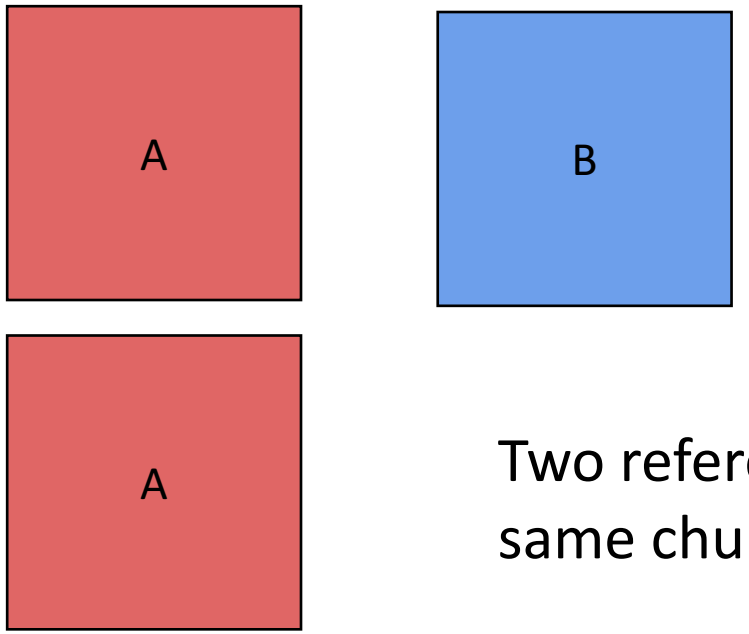


Free List



Double Free (cont.)

Malloc another chunk



Two references to the same chunk

Free List

Double Free Exploit

- We have two references to the same chunk
- How to exploit?
- Similar to UAF, you can write in an exploitable struct
- Freeing a chunk places forward pointers in the chunk
  - Leads to heap leak