Binary Exploit - II

u1f383 🎃

About

- u1f383 🎃
- Pwner
- Zoolab
- NCtfU / Xx TSJ xX / Goburin’

Outline

- Prior knowledge
  - Memory layout
  - Protection
  - Bypass ASLR
  - One gadget

Outline

- Heap introduction
  - Memory allocation
  - Data structure
- Code tracing
- Vulnerability
  - UAF
  - Heap overflow
  - Double free

Outline

- Exploitation goal
  - Write hook
- Exploitation tech
  - Tcache poisoning
  - Fastbin attack
  - Overlapping chunks

Outline

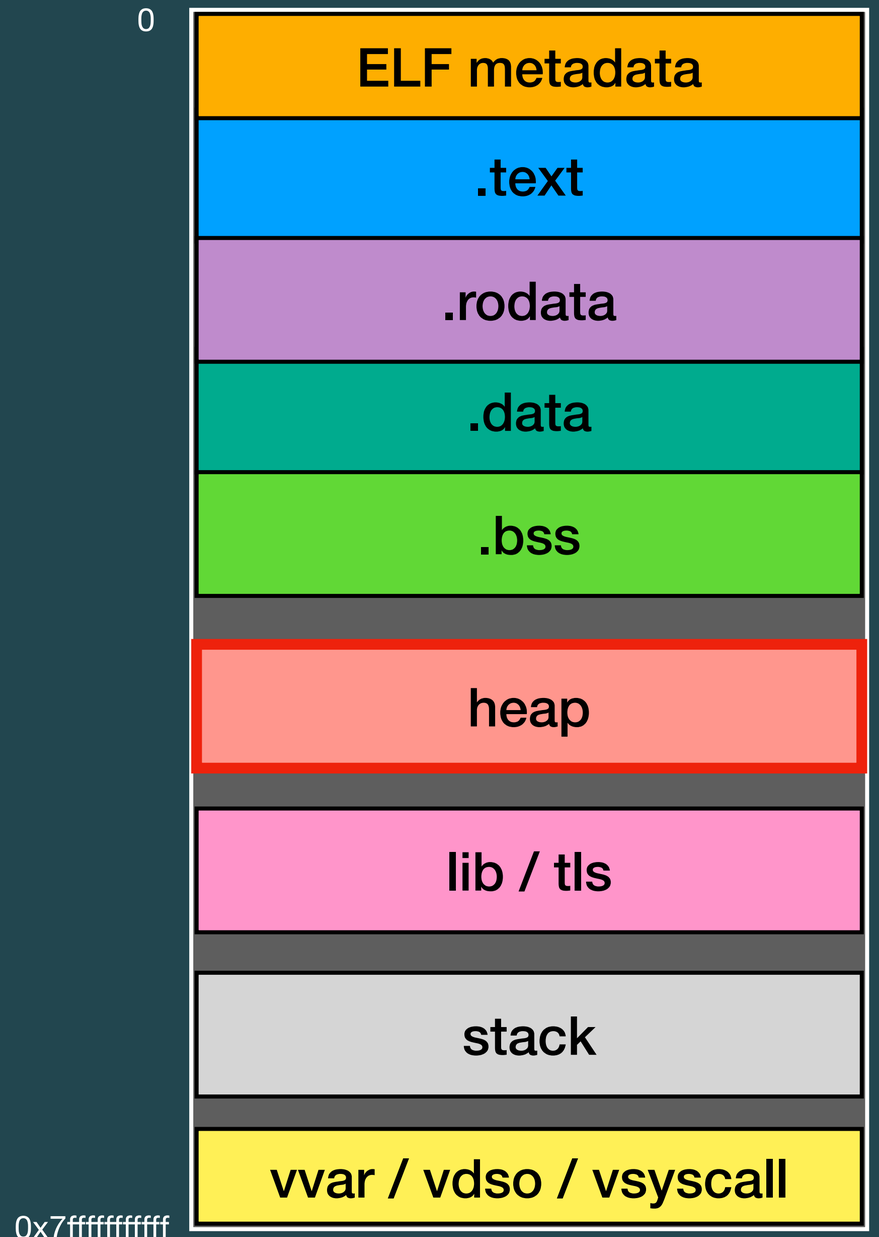
- Safe linking
- How2heap tech
- Appendix

Prior knowledge

$ Prior knowledge

Memory Layout

- .text - 程式碼
- .rodata - read-only data，如字串
- .data - 初始化後的變數
- .bss - 尚未初始化的變數
- heap - 動態分配的記憶體空間
- lib - shared library
- tls - thread local storage
- stack - 用來儲存當前 function 執行狀態的空間



$ Prior knowledge

Protection

- **PIE** - 程式碼會以相對位址的方式表示，而非絕對位址
- **NX** - .text 之外的 section 不會有執行權限
- **Canary** - 在 stack 的結尾塞入一個隨機數，return 前透過檢查是否有被修改來判斷執行是否出現問題
- **RELRO** - 分成 Full / Partial / No 三種型態，分別代表在 runtime 解析外部 function 時使用的不同機制
- **Seccomp** - 制定規則來禁止/允許呼叫特定的 syscall
- **ASLR** - 程式載入時，stack、heap 等記憶體區塊會使用隨機的位址作為 base address

$ Prior knowledge

Bypass ASLR

- 當我們取得某個在 library 當中的位址，由於 offset 皆是固定的，因此只需要減去他在 library 當中的 offset，能得到 library base address，繞過 **ASLR**
- 有了 library base address，也能加上其他 function 的 offset 來取得該 function 在 library 中的位址
- 在 heap exploitation 當中較常用到的 library 變數或 function 有：
  - __malloc_hook
  - __free_hook
  - system()

$ Prior knowledge

One gadget

- library 內會有長得像是 execve("/bin/sh", NULL, NULL) 的程式碼，而在滿足一定的條件下可以直接 get shell，這樣的程式碼片段就稱作 one gadget
- 可以用工具 *one_gadget* 來搜尋
- 不過並不是直接執行就會有 shell，而是必須符合一些條件，如 register 的值，或是 stack layout 等等

```
$ one_gadget /lib/x86_64-linux-gnu/libc.so.6
0xe6c7e execve("/bin/sh", r15, r12)
constraints:
  [r15] == NULL || r15 == NULL
  [r12] == NULL || r12 == NULL

0xe6c81 execve("/bin/sh", r15, rdx)
constraints:
  [r15] == NULL || r15 == NULL
  [rdx] == NULL || rdx == NULL

0xe6c84 execve("/bin/sh", rsi, rdx)
constraints:
  [rsi] == NULL || rsi == NULL
  [rdx] == NULL || rdx == NULL
```

Heap introduction

$ Heap introduction

Basic

- 在 compile time 程式無法確定需要多少空間，因此需要有方法能夠在 runtime 分配以及釋放記憶體，才能有效的利用記憶體
- 服務根據種類以及開發單位，會有不同的記憶體管理機制
  - Glibc - ptmalloc
  - Google - tcmalloc
  - Facebook - jemalloc
  - ...

$ Heap introduction

Basic

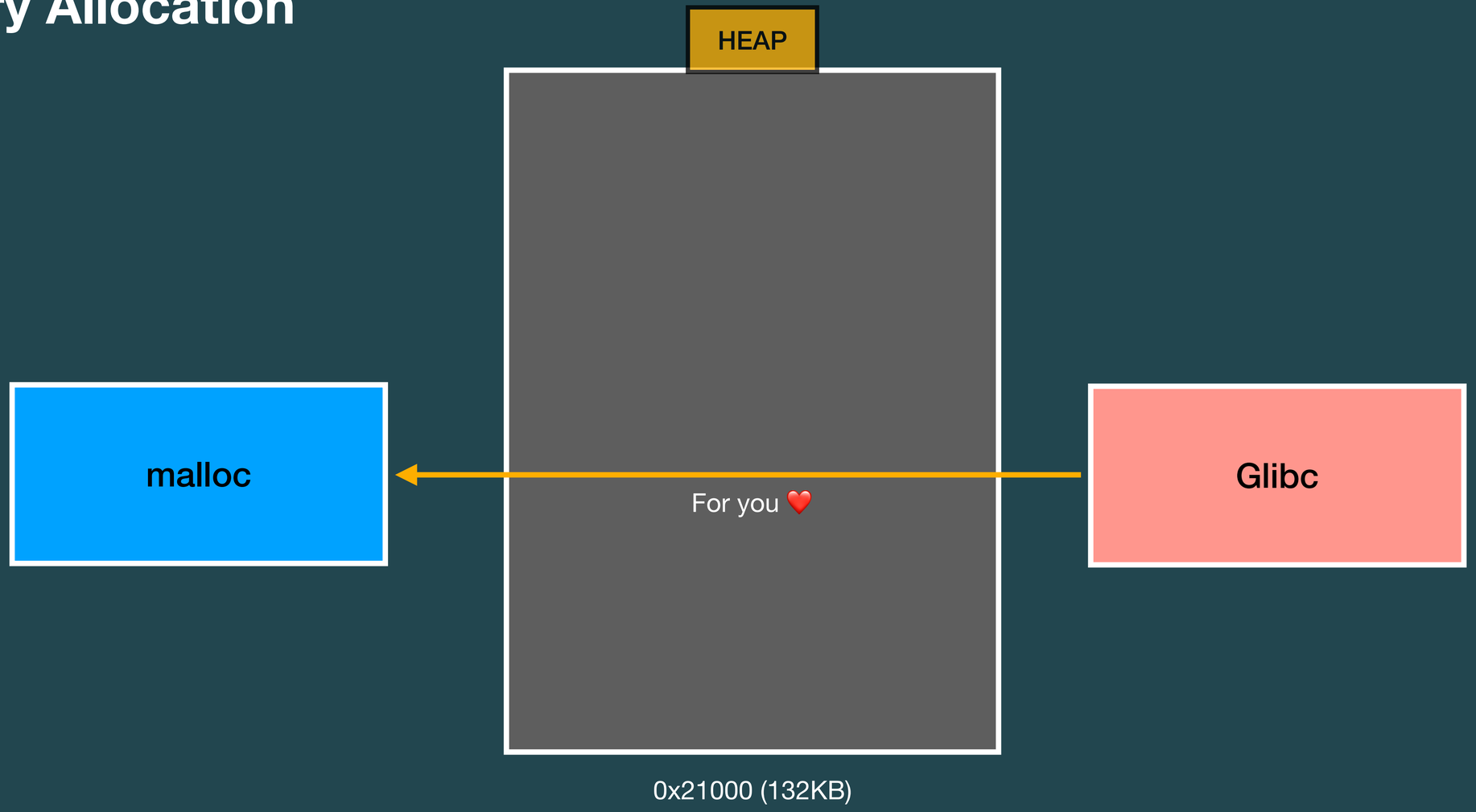
- 在 C 當中，最常用來分配記憶體的 function 為 malloc，而 free 則是用來釋放記憶體
- 其他與 memory allocation 相關的 function
  - realloc - 更新已分配的記憶體大小
  - calloc - 在回傳前清空記憶體的內容

$ Heap introduction

Memory Allocation

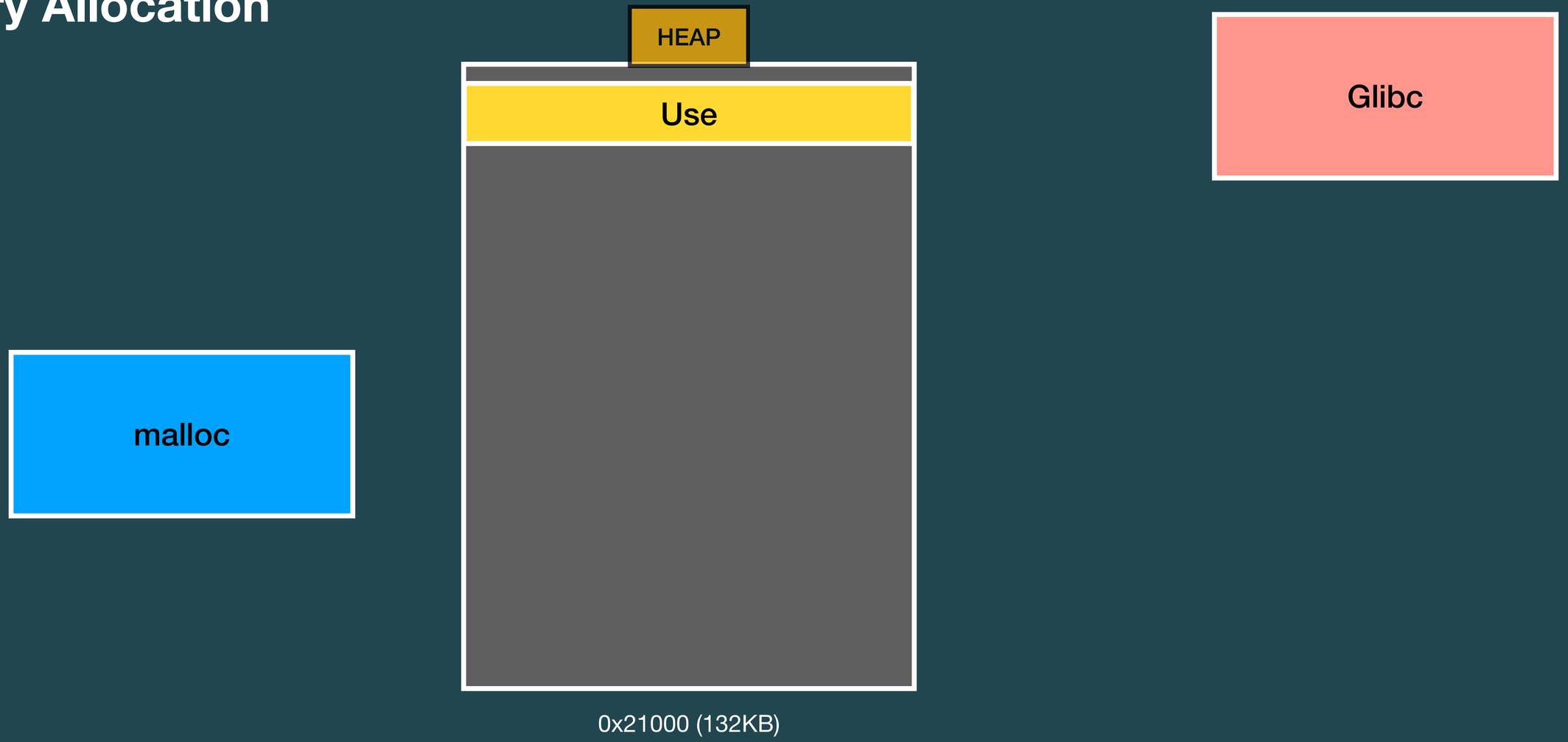
$ Heap introduction

Memory Allocation



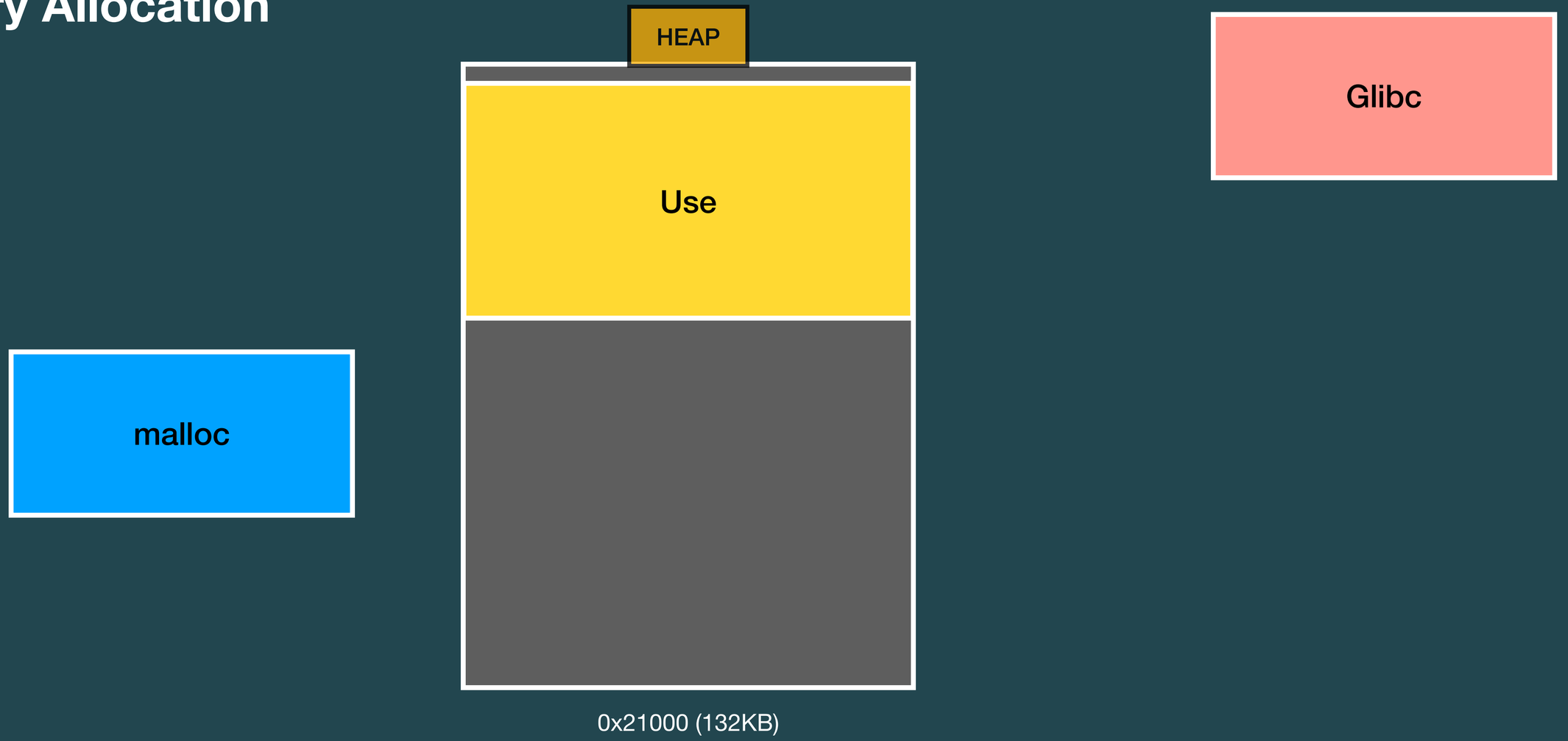
$ Heap introduction

Memory Allocation



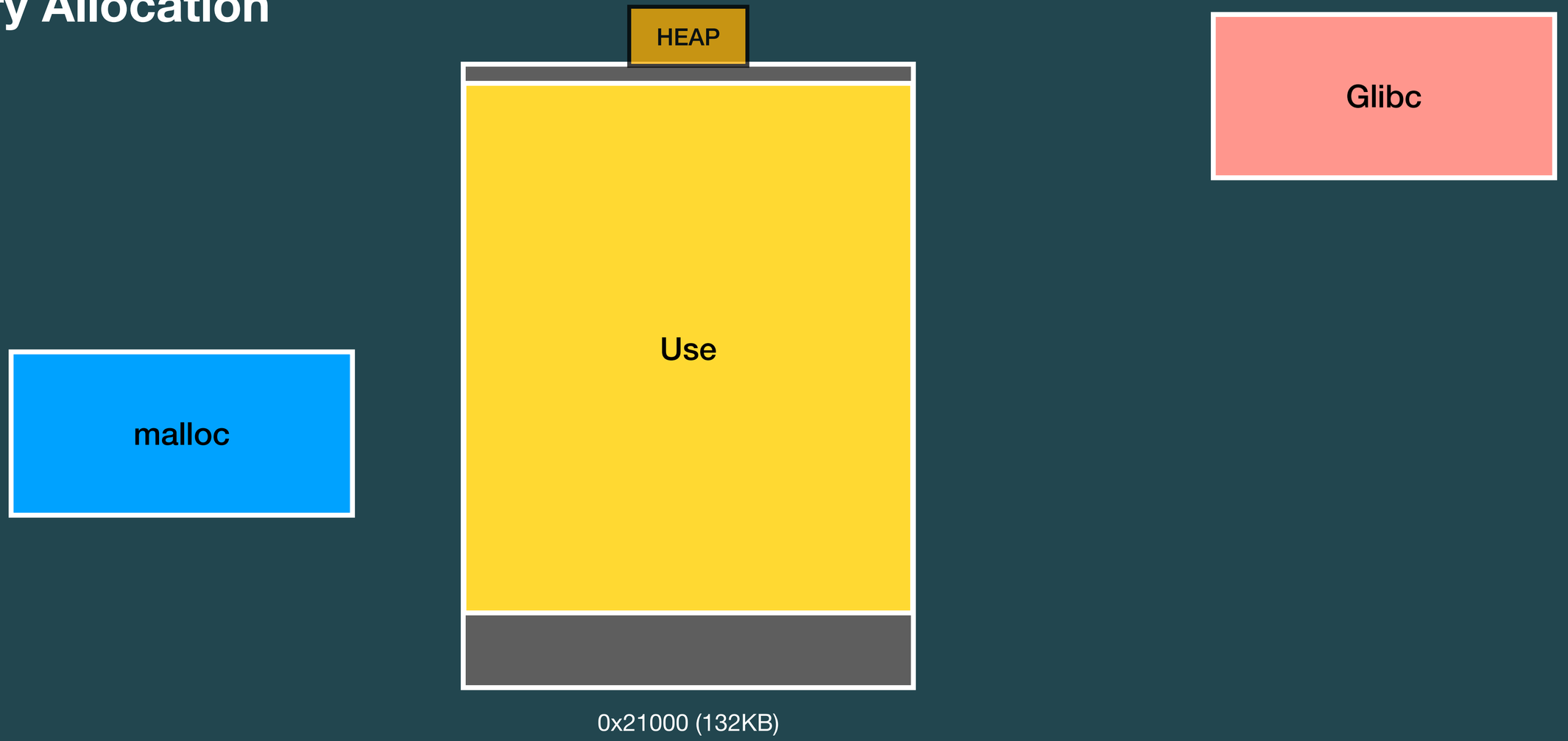
$ Heap introduction

Memory Allocation



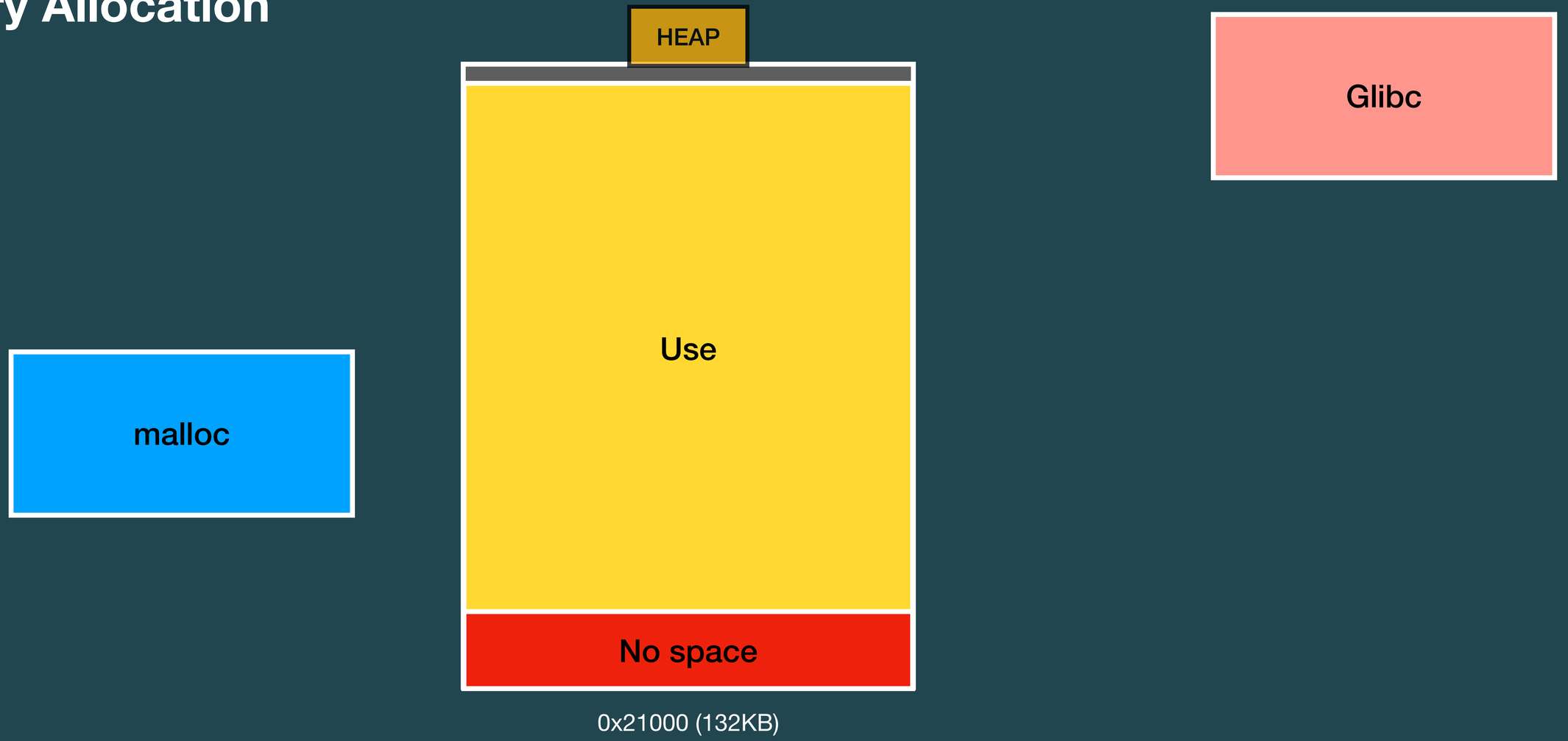
$ Heap introduction

Memory Allocation



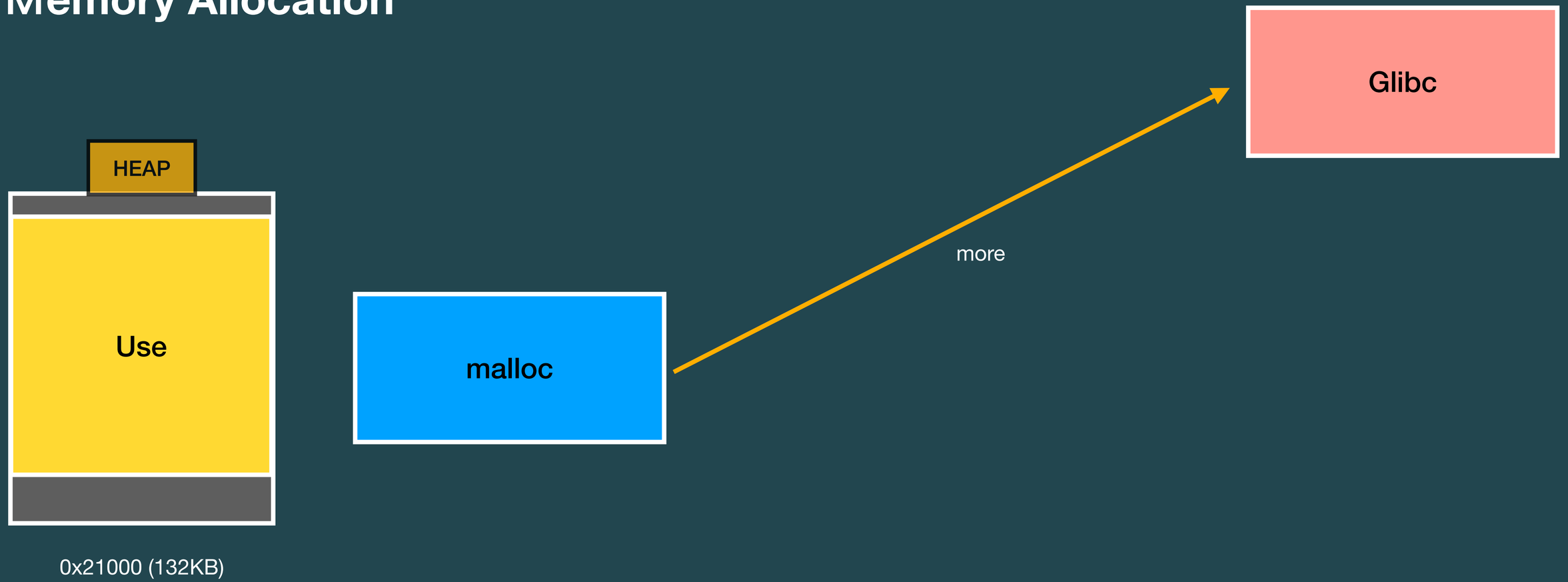
$ Heap introduction

Memory Allocation



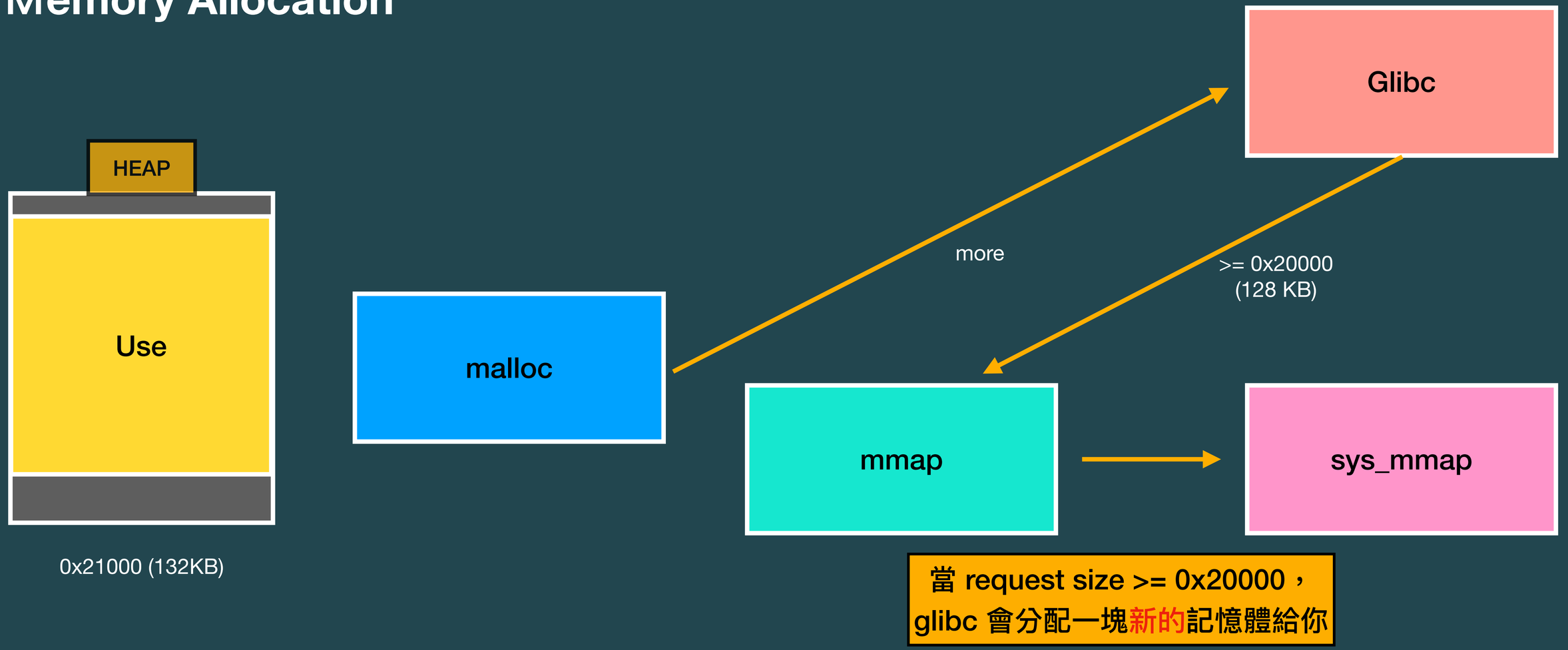
$ Heap introduction

Memory Allocation



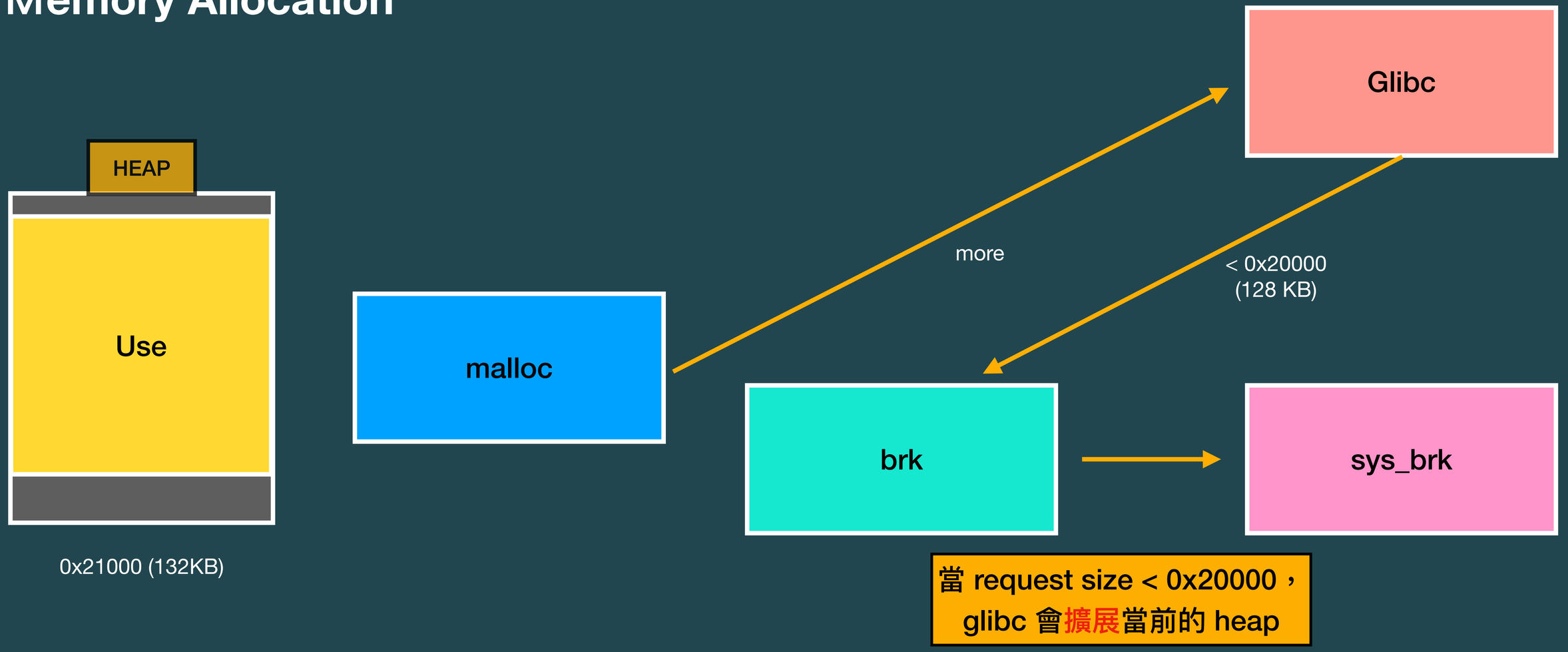
$ Heap introduction

Memory Allocation



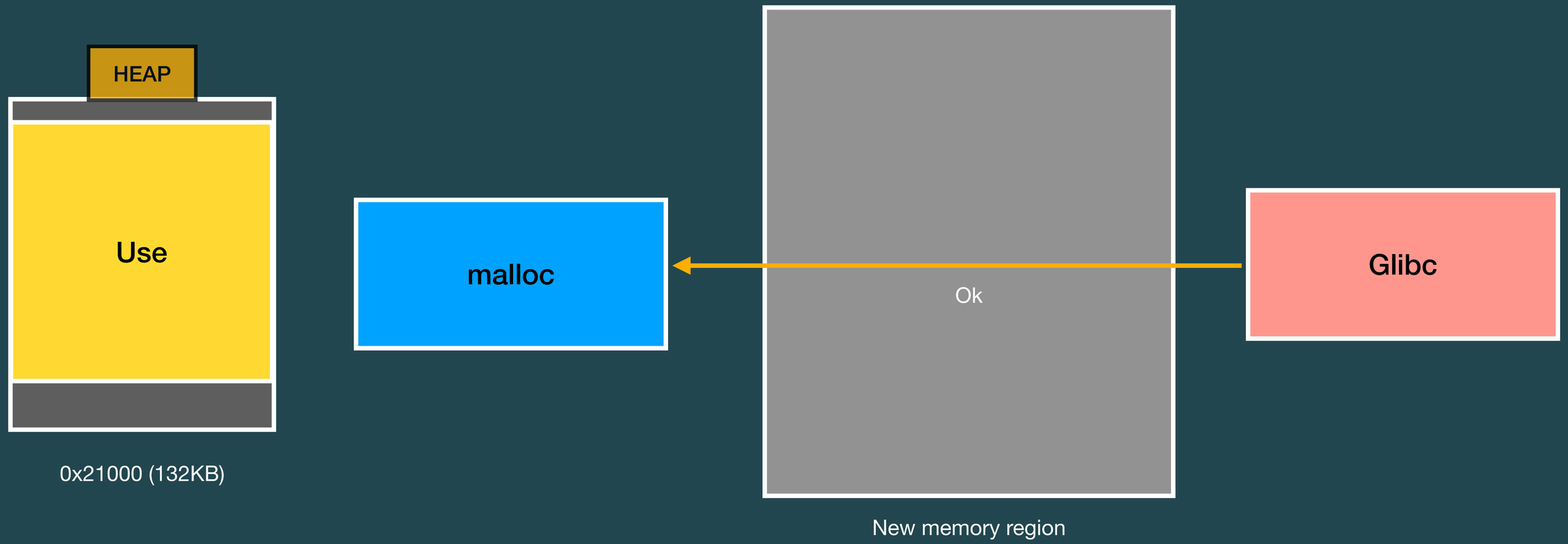
$ Heap introduction

Memory Allocation



$ Heap introduction

Memory Allocation



$ Heap introduction

Memory Allocation

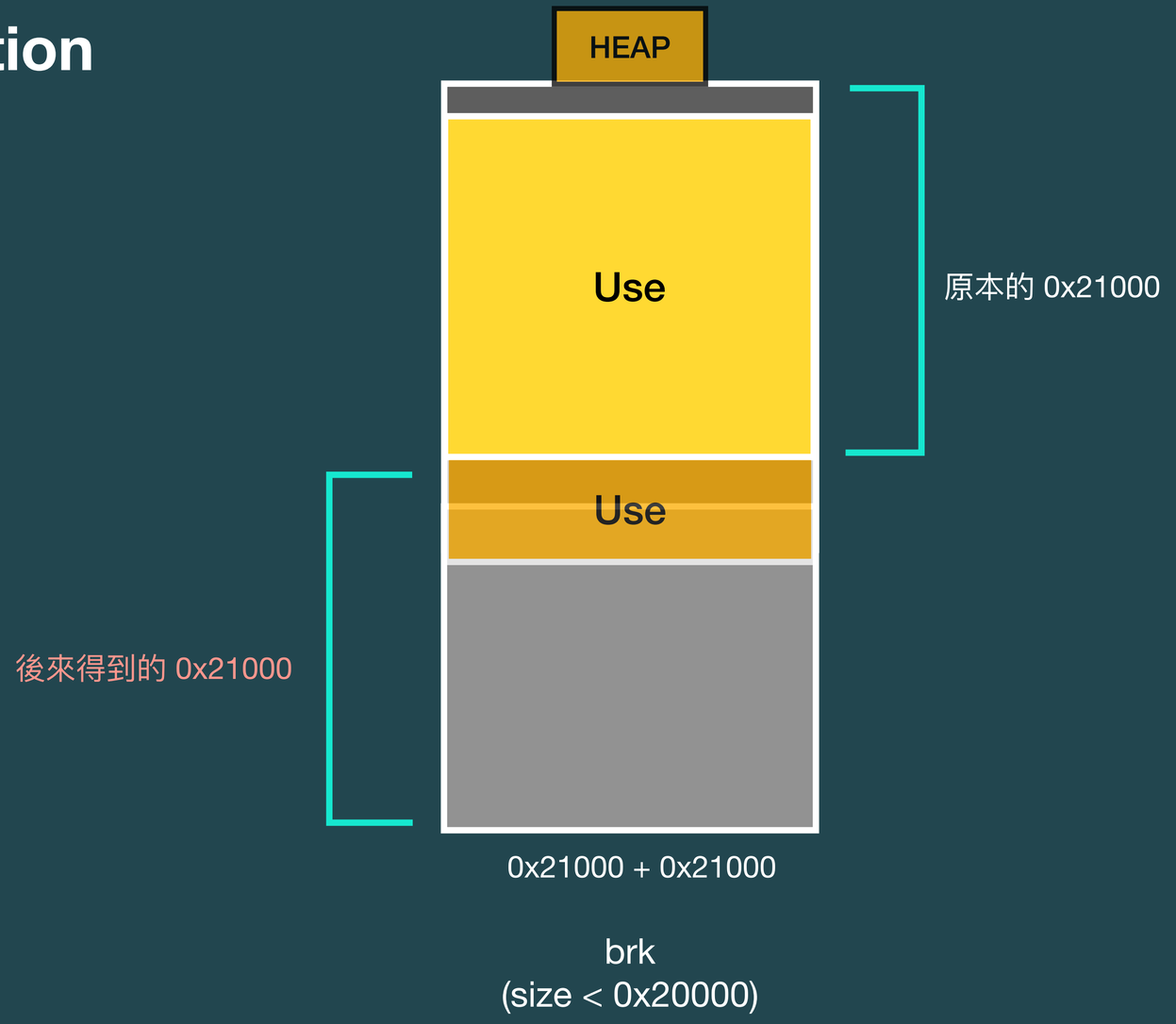
0x21000

對齊 page 後的請求大小

mmap
(size >= 0x20000)

$ Heap introduction

Memory Allocation

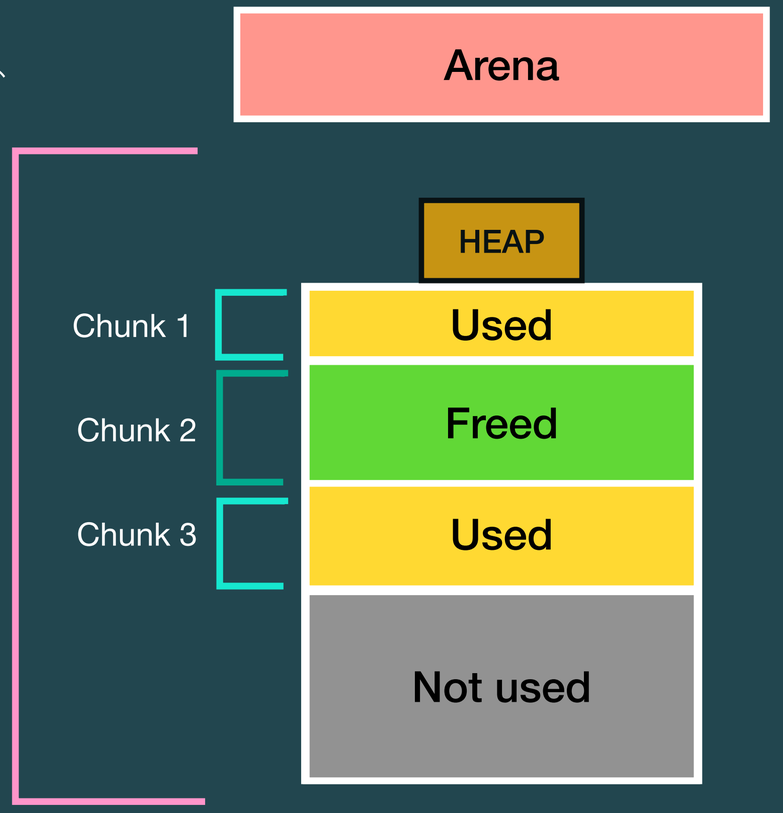


$ Heap introduction

Data Structure

- 整個記憶體的分配機制由三個部分構成：
  - 使用者透過 malloc 取得的小塊記憶體 - chunk
  - 用來分發這些小塊記憶體的大塊記憶體 - heap
  - 用來儲存大塊記憶體的相關資訊的資料結構 - arena

哪些還沒用、
釋放掉的 chunk 位址、
...



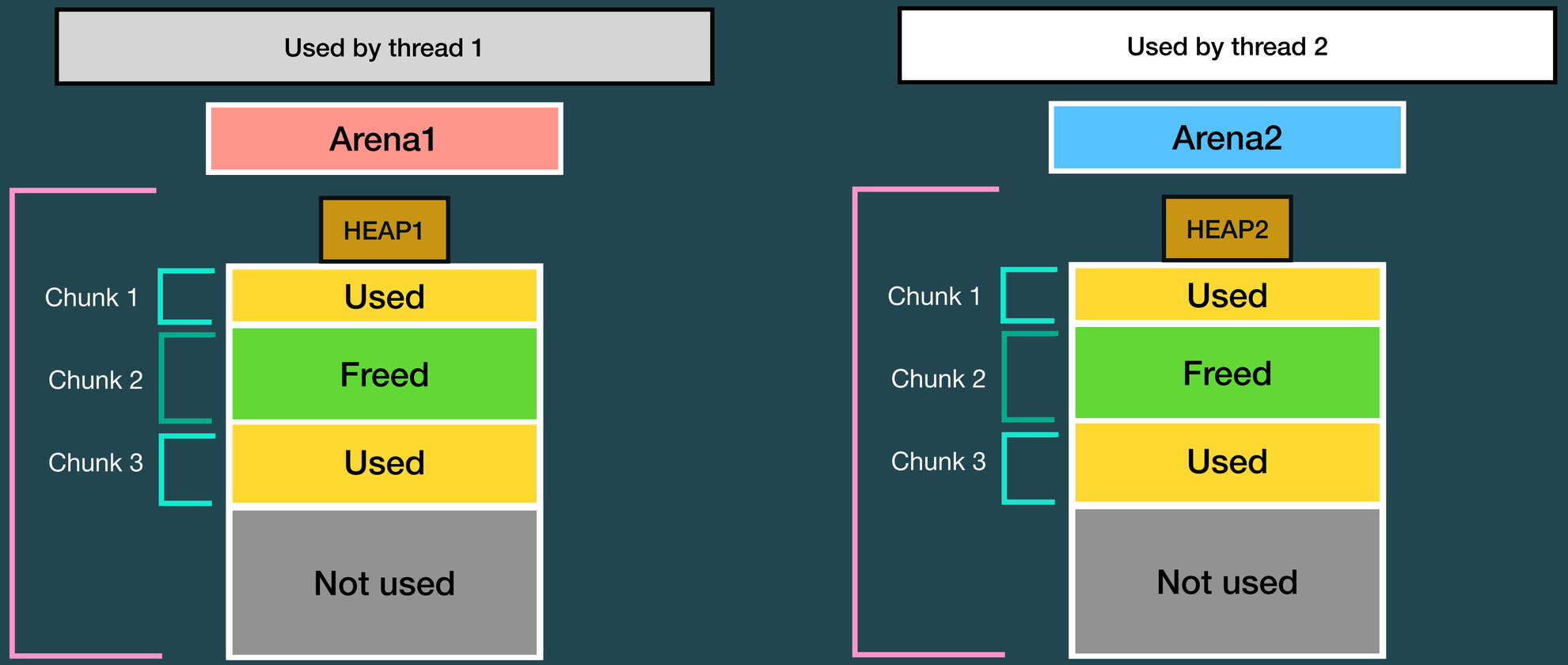
$ Heap introduction

Data Structure

- Chunk - **struct malloc_chunk**
- Heap - **struct _heap_info**
  - 每個 thread 會有一個 heap
- Arena - **struct malloc_state**
  - 正常情況下，每個 thread 會有一個 arena
  - 但是在 thread 的數量太多的情況下，多個 thread 會共同使用一個 arena
  - main thread 使用的 arena 稱作 main_arena

$ Heap introduction

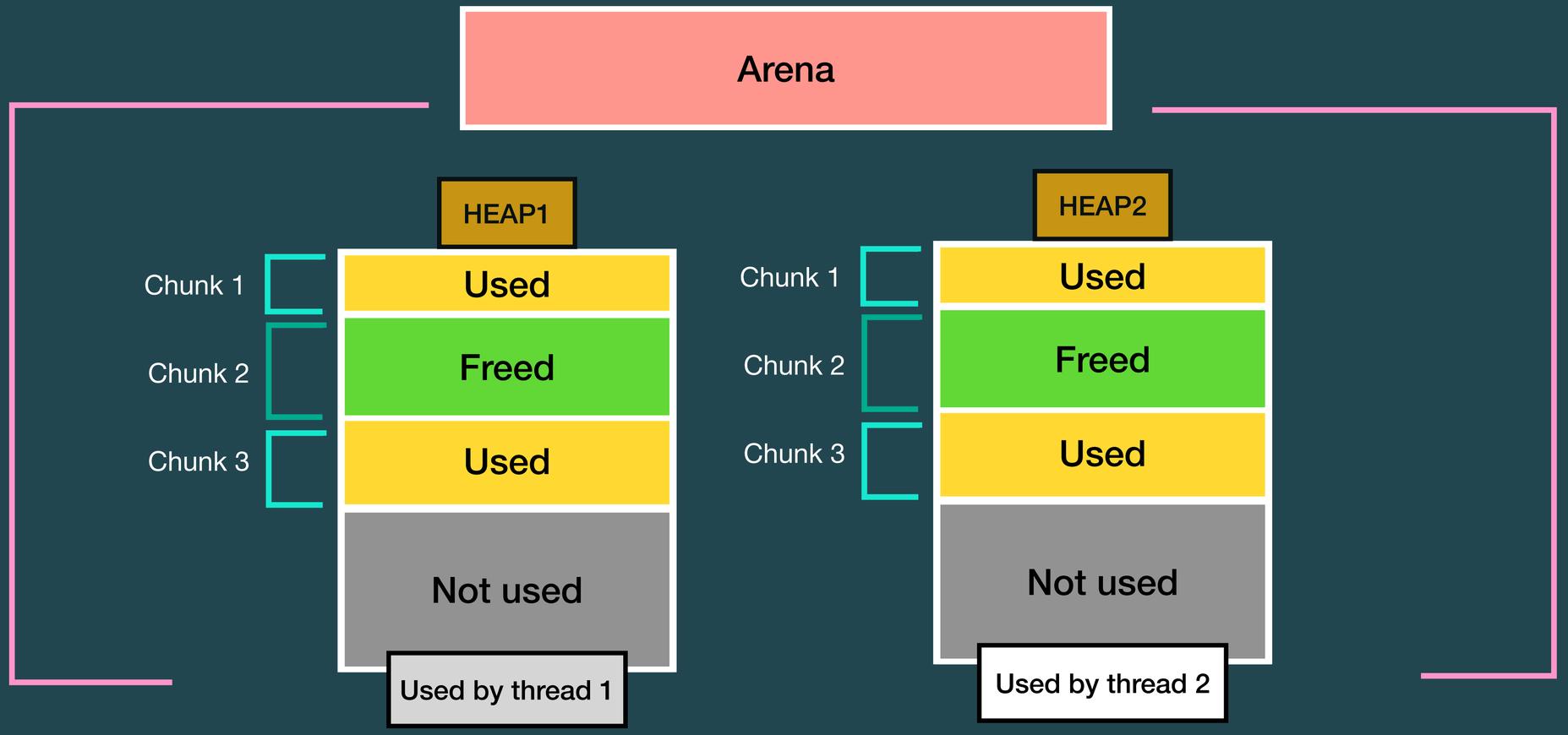
Data Structure



正常情況

$ Heap introduction

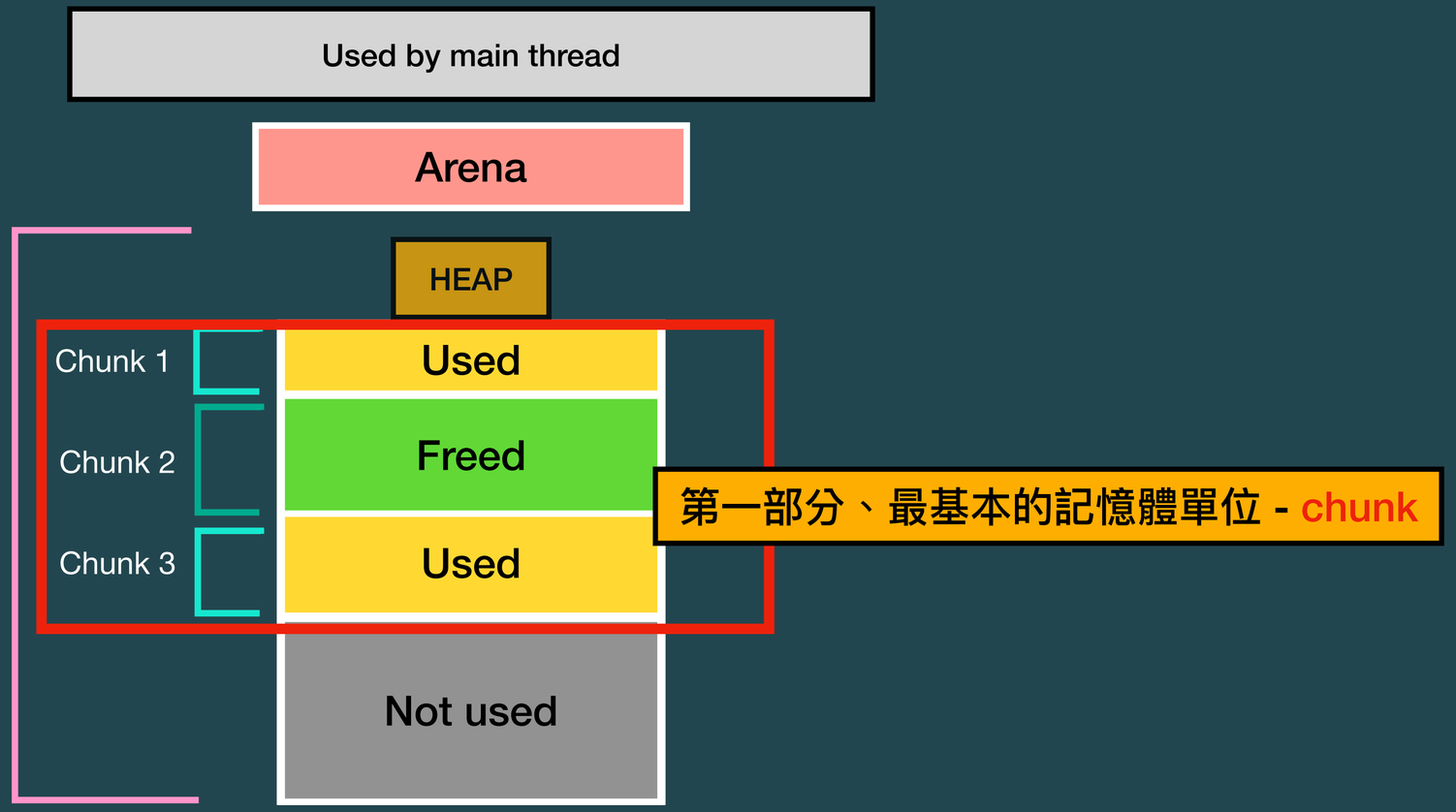
Data Structure



Thread 太多

$ Heap introduction

Data Structure



$ Heap introduction

Data Structure - Chunk

- **Chunk** 為動態記憶體分配的基本單位，最小為 0x20 bytes
- 會對齊 0x10 bytes，也就是大小會是 0x20, 0x30, 0x40 ...
- 正在使用中的 chunk 稱作 **allocated** chunk
- 已被釋放的 chunk 稱作 **freed** chunk
  - 在釋放時，chunk 會根據情況放在不一樣的回收區，稱作 **bin**
  - 後續再請求記憶體時，就會從這些 **bin** 取出 chunk 給使用者用
  - Chunk 的結構與在 bin 當中的 freed chunk 的連接方式有很大的關係

$ Heap introduction

Data Structure - Chunk

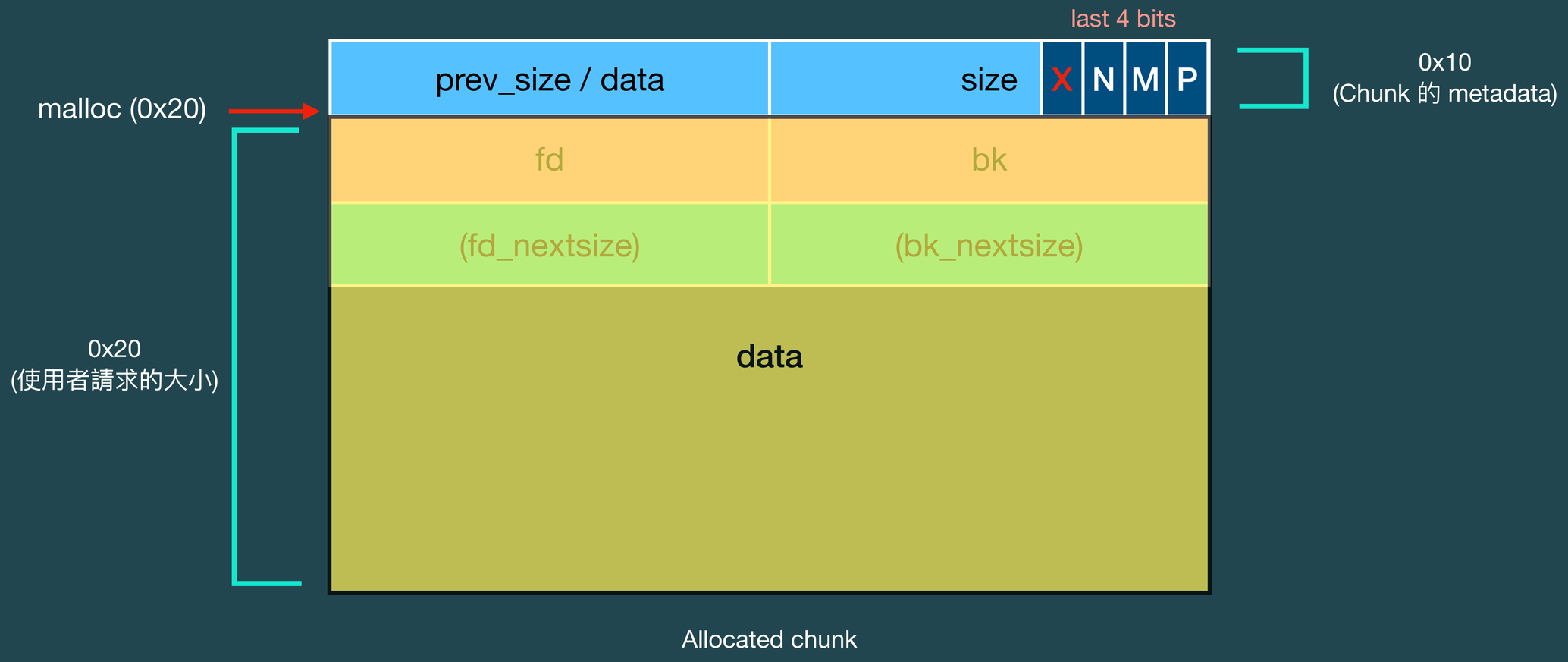
u1f383@u1f383:/ ⌥⌘1

```
$
struct malloc_chunk {

  INTERNAL_SIZE_T      mchunk_prev_size;  /* 如果前一個為 freed chunk，儲存其大小 */
  INTERNAL_SIZE_T      mchunk_size;       /* 儲存當前 chunk 的大小 */

  /* ———————————— 以下只有 freed chunk 才會使用 ———————————— */
  struct malloc_chunk* fd;         /* forward */
  struct malloc_chunk* bk;         /* back */

  /* —— 以下只有 large bin chunk 才會使用 —— */
  struct malloc_chunk* fd_nextsize;
  struct malloc_chunk* bk_nextsize;
};
```

https://elixir.bootlin.com/glibc/glibc-2.31/source/malloc/malloc.c#L1048

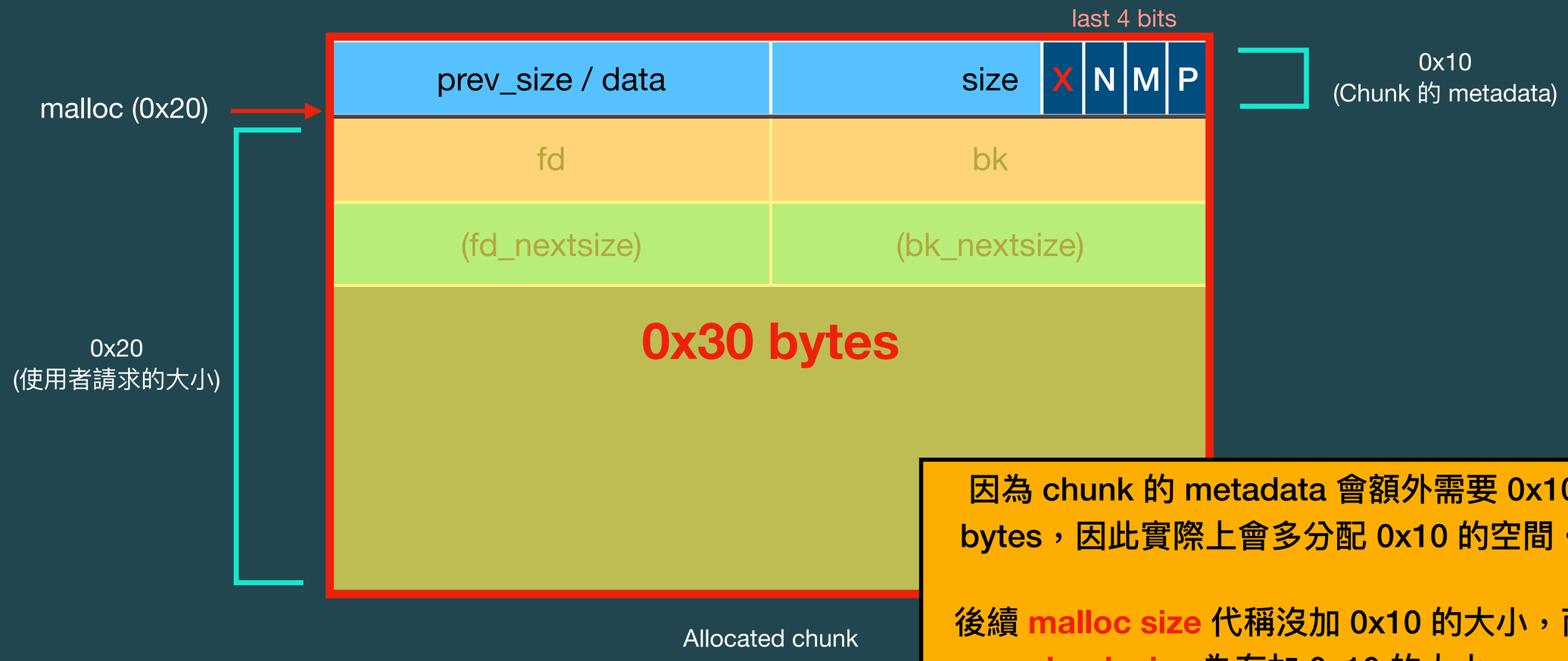
$ Heap introduction

Data Structure - Chunk



$ Heap introduction

Data Structure - Chunk

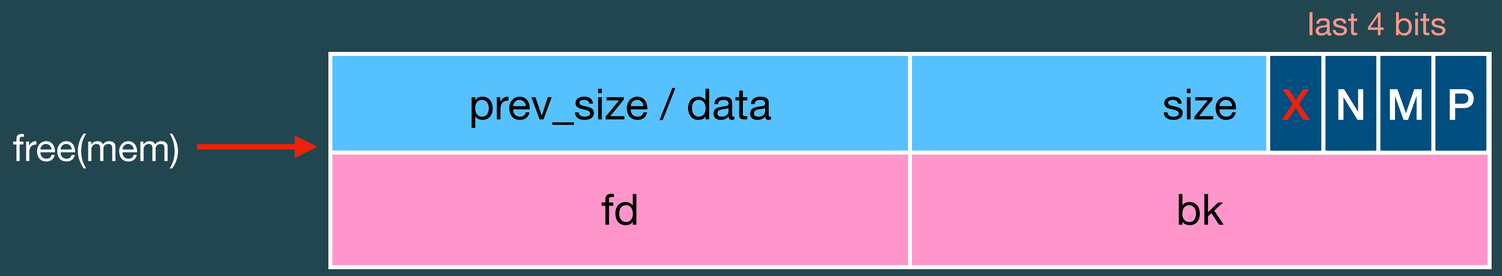


因為 chunk 的 metadata 會額外需要 0x10 bytes，因此實際上會多分配 0x10 的空間。

後續 **malloc size** 代稱沒加 0x10 的大小，而 **chunk size** 為有加 0x10 的大小。

$ Heap introduction

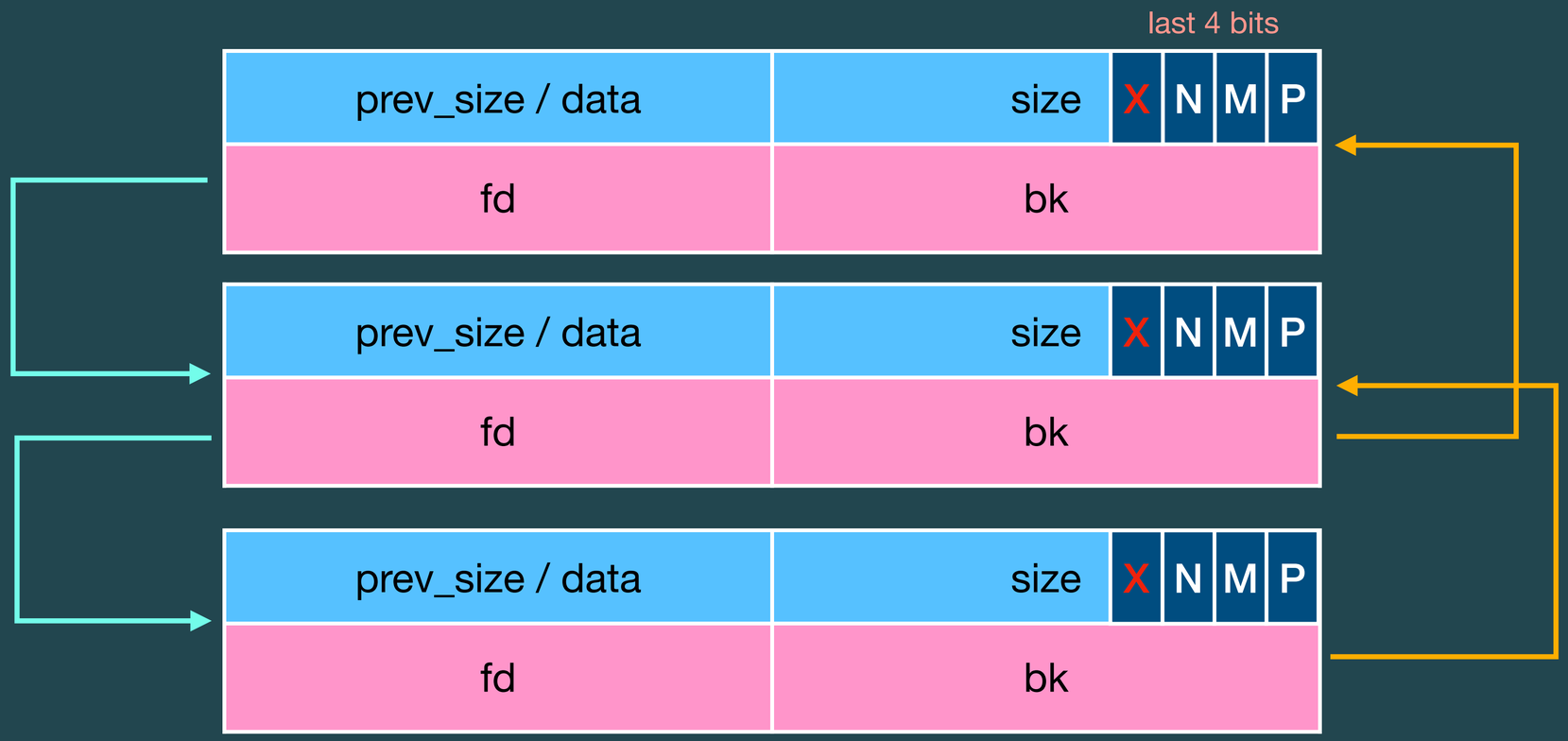
Data Structure - Chunk



freed chunk

$ Heap introduction

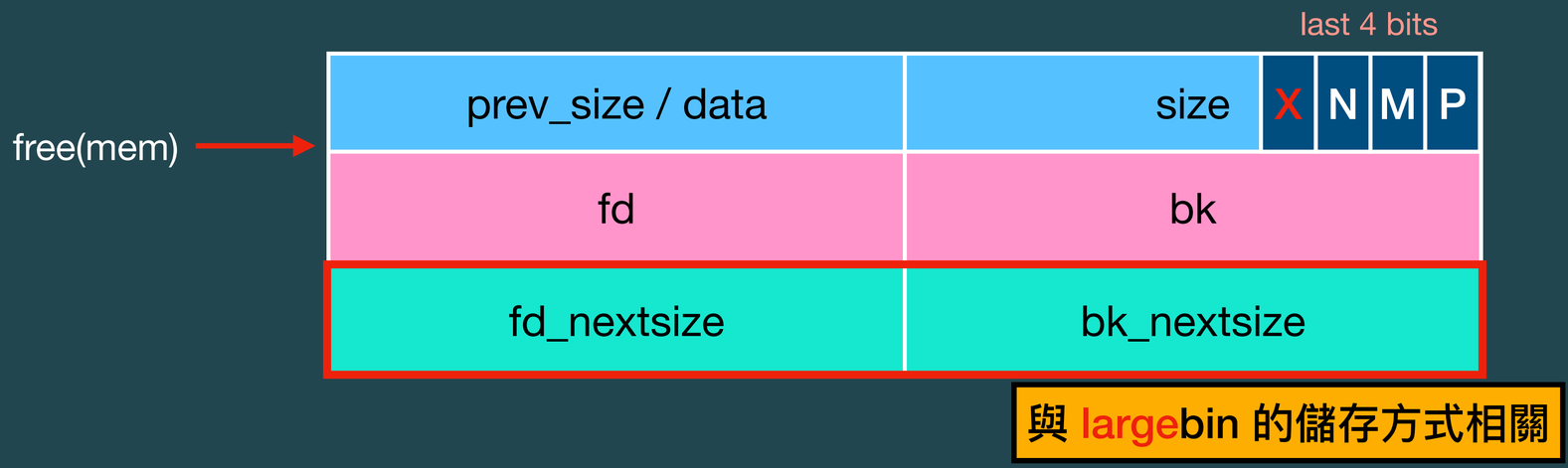
Data Structure - Chunk



freed chunk

$ Heap introduction

Data Structure - Chunk

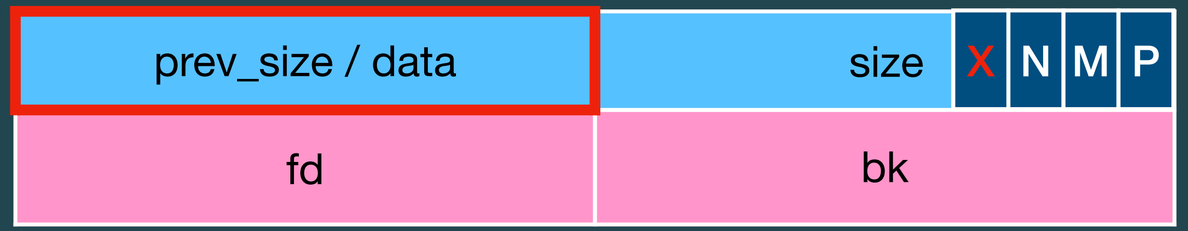


large bin chunk

$ Heap introduction

Data Structure - Chunk

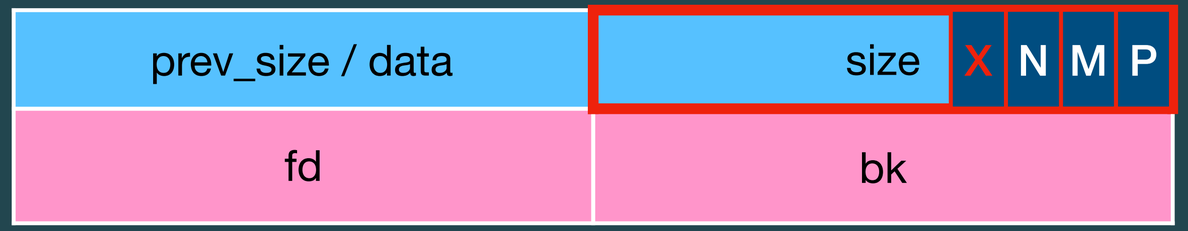
- **prev_size / data -** 看前一塊 chunk 是否正在使用
  - 如果前一塊為 **freed chunk -** 存前一塊 chunk 的 chunk size (prev_size)
  - 如果前一塊為 **allocated chunk -** 用來給前一塊 chunk 存資料 (data)
- 因為 chunk 可以多使用下個 chunk 的 data 欄位，因此在請求記憶體時能夠多分配 8 bytes
  - E.g. malloc size 為 0x28 時會拿到 chunk size 為 0x30 的 chunk —> 0x28 (request) - 0x8 (data) + 0x10 (header) —對齊0x10—> 0x30
  - 0x29 則會拿到 chunk size 0x40 的 chunk 0x31—對齊0x10—> 0x40



$ Heap introduction

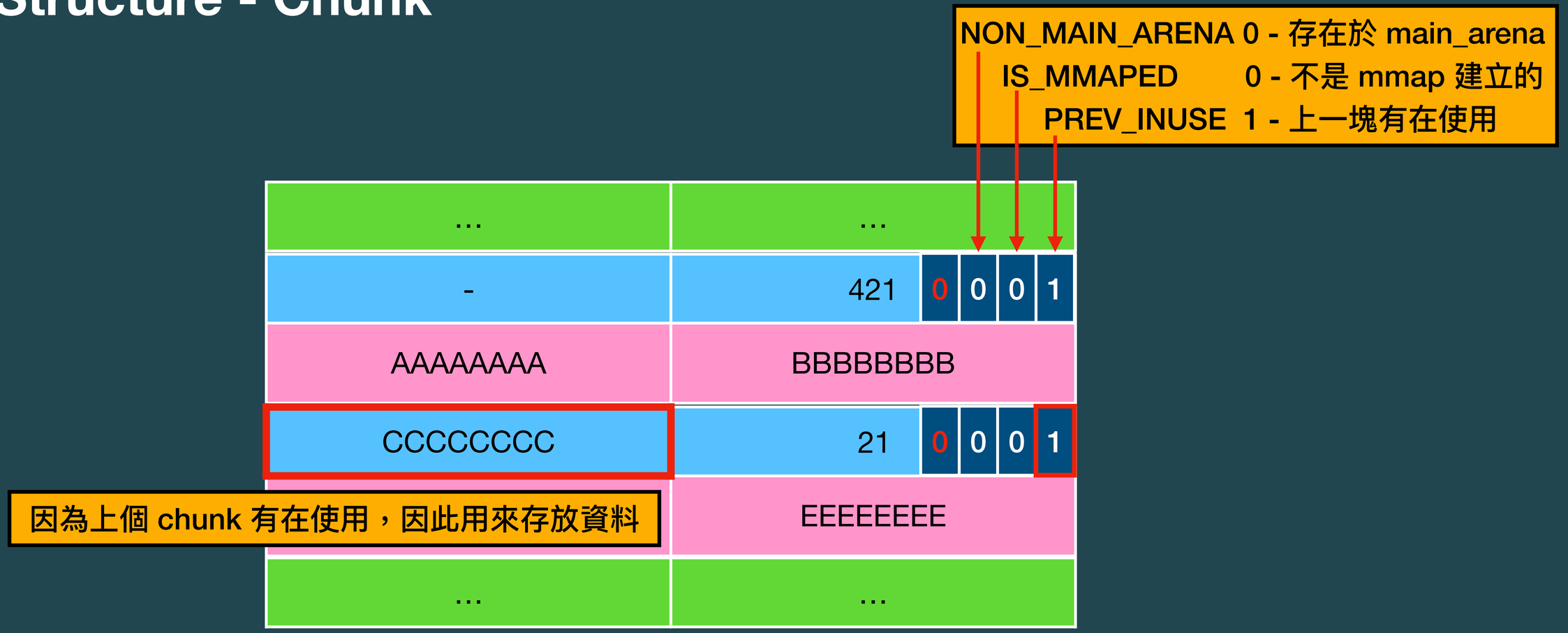
Data Structure - Chunk

- **size -** 存 chunk 的 chunk size，並且 size 會對齊 0x10 bytes (0b10000)
- 由於對齊，末四個 bits 會沒用到 (0b10000)，因此做為 chunk 的 metadata
  - **X -** 沒用
  - **N (NON_MAIN_ARENA) -** chunk 是否存在於 main_arena
  - **M (IS_MMAPPED) -** chunk 是否透過 mmap 建立的
  - **P (PREV_INUSE) -** 前一塊是否正在使用



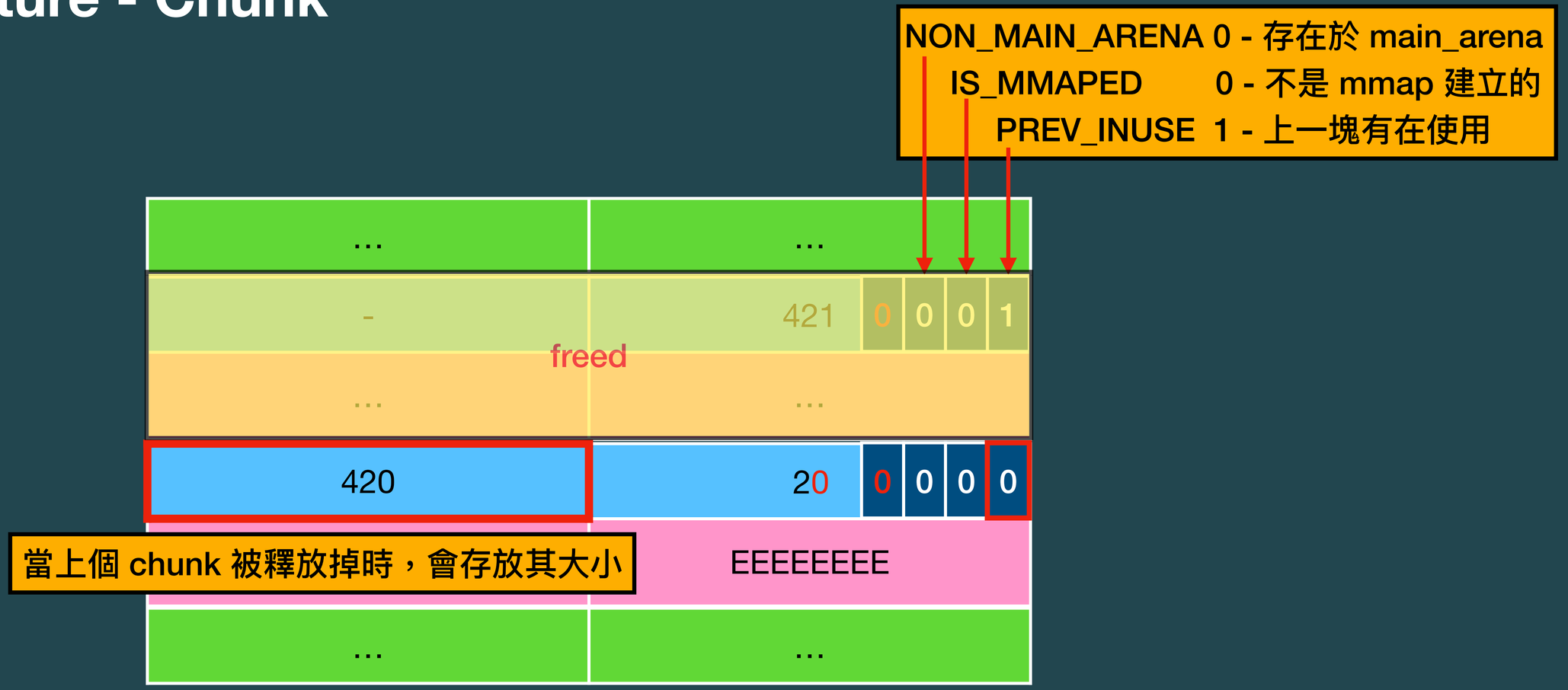
$ Heap introduction

Data Structure - Chunk



$ Heap introduction

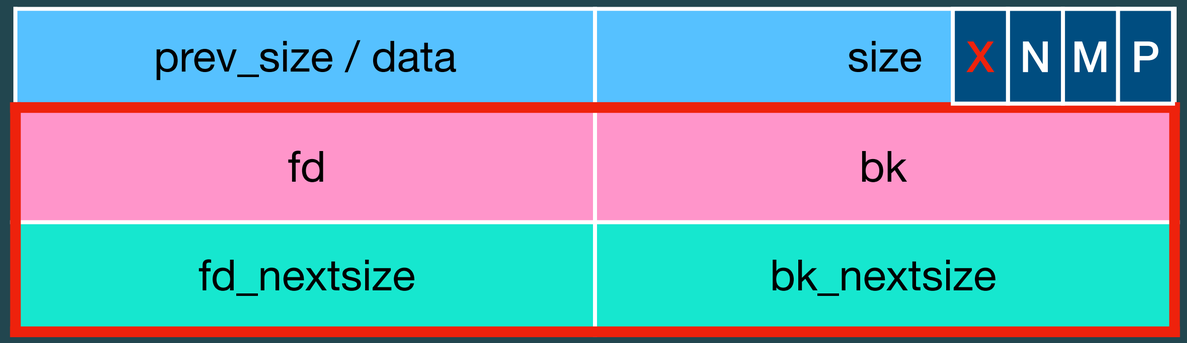
Data Structure - Chunk



$ Heap introduction

Data Structure - Chunk

- **fd -** 指向同個 bin 中的下一塊 freed chunk (forward)
- **bk -** 指向同個 bin 中的上一塊 freed chunk (back)
- **fd_nextsize -** 在 large bin 的 freed chunk 指向下一個大小的 freed chunk
- **bk_nextsize -** 在 large bin 的 freed chunk 指向上一個大小的 freed chunk



$ Heap introduction

Data Structure - Chunk

- bin 用來紀錄 freed chunk，而根據 chunk 的大小與 glibc 的優化機制，一共分成 5 種不同的 bin

名稱	Chunk size	使用方式	優先度	補充
Tcache bin	0x20 ~ 0x410	FILO (stack)	最高 (1)	被 free 後，並不會 unset 下個 chunk 的 PREV_INUSE bit
Fastbin	0x20 ~ 0x80	FILO (stack)	2	被 free 後，並不會 unset 下個 chunk 的 PREV_INUSE bit
Small bin	0x20 ~ 0x3f0	FIFO (queue)	3	-
Large bin	>= 0x400	FIFO (queue)	最低 (5)	-
Unsorted bin	>= 0x90	-	4	當對應大小的 tcache 滿時才會進來

$ Heap introduction

Data Structure - Chunk

- **Tcache (bin) -** 剛被釋放的 chunk 的快取空間
- **Fastbin -** 儲存大小較小的 chunk
- **Small bin -** 儲存大小中等的 chunk
- **Large bin -** 儲存大小較大的 chunk
- **Unsorted bin -** 剛被釋放的 chunk 的暫存區
- 在 tcache / fastbin / smallbin 當中，每隔 0x10 大小會有一個 subbin
  - E.g. fastbin 的 chunk size 為 0x20~0x80，因此會有 0x20、0x30、…、0x80 subbin

$ Heap introduction

Data Structure - Tcache

- **Tcache** 存放 chunk size 為 0x20 ~ 0x410 的 chunk，使用方式為 FILO
- 每個 subbin 最多只能存放 **7 個** chunk，彼此用單向的 linked list 相連
- 優先度最高，在對應大小的 tcache 滿後 (存放 7 個) 才會改用其他 bin

$ Heap introduction

Data Structure - Tcache

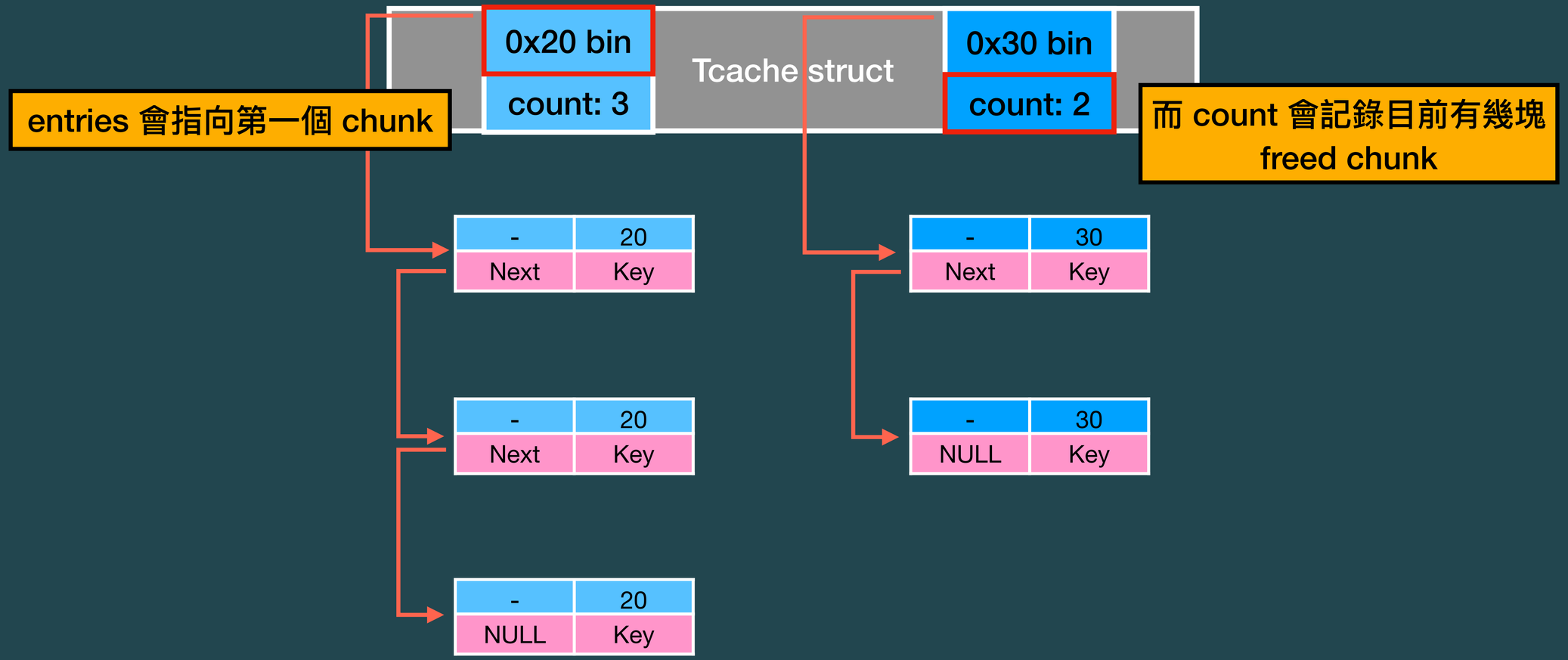
- struct tcache_entry 結構特別用來描述在 tcache 當中的 chunk
- struct tcache_perthread_struct 結構用來記錄 subbin 的第一塊 tcache chunk 位址，以及目前 subbin 共有多少個 tcache chunk
  - heap 初始化時就會被分配，大小為 0x290

```
u1f383@u1f383:/
$
typedef struct tcache_entry
{
  struct tcache_entry *next;
  struct tcache_perthread_struct *key;
} tcache_entry;
```

```
u1f383@u1f383:/
$
typedef struct tcache_perthread_struct
{
  /* TCACHE_MAX_BINS 大小為 64 */
  uint16_t counts[TCACHE_MAX_BINS];
  tcache_entry *entries[TCACHE_MAX_BINS];
} tcache_perthread_struct;
```

$ Heap introduction

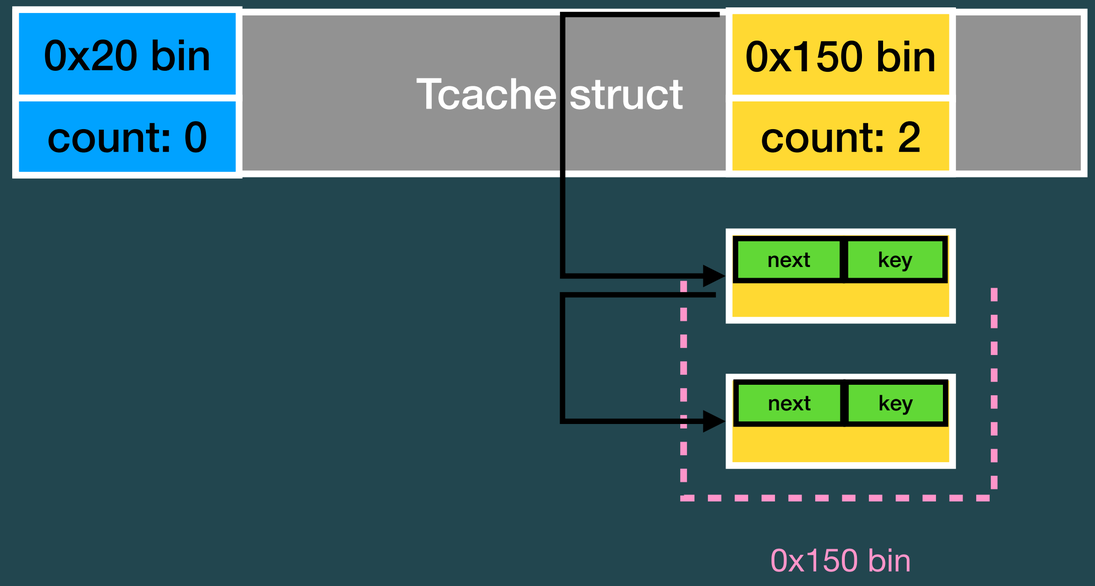
Data Structure - Tcache



$ Heap introduction

Data Structure - Tcache

```
a = malloc(0x10);
b = malloc(0x10);
c = malloc(0x10);
d = malloc(0x10);

free(a);
malloc(0x10);
free(b);
free(c);
free(d);
```

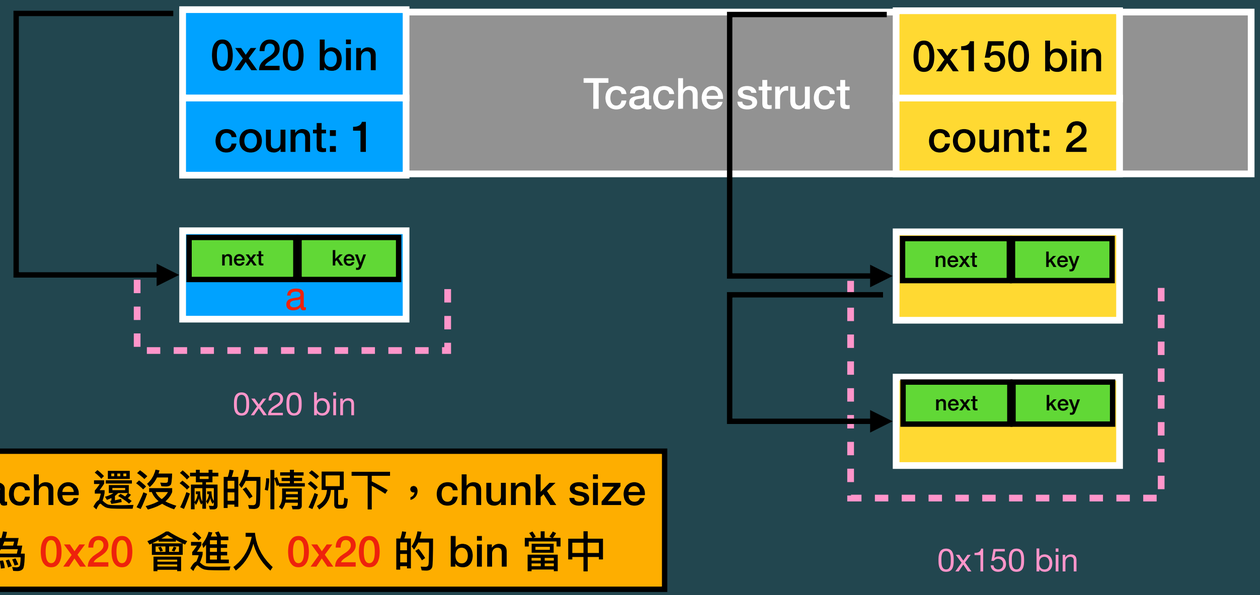


Tcache instance

$ Heap introduction

Data Structure - Tcache

```
a = malloc(0x10);
b = malloc(0x10);
c = malloc(0x10);
d = malloc(0x10);

free(a);
malloc(0x10);
free(b);
free(c);
free(d);
```



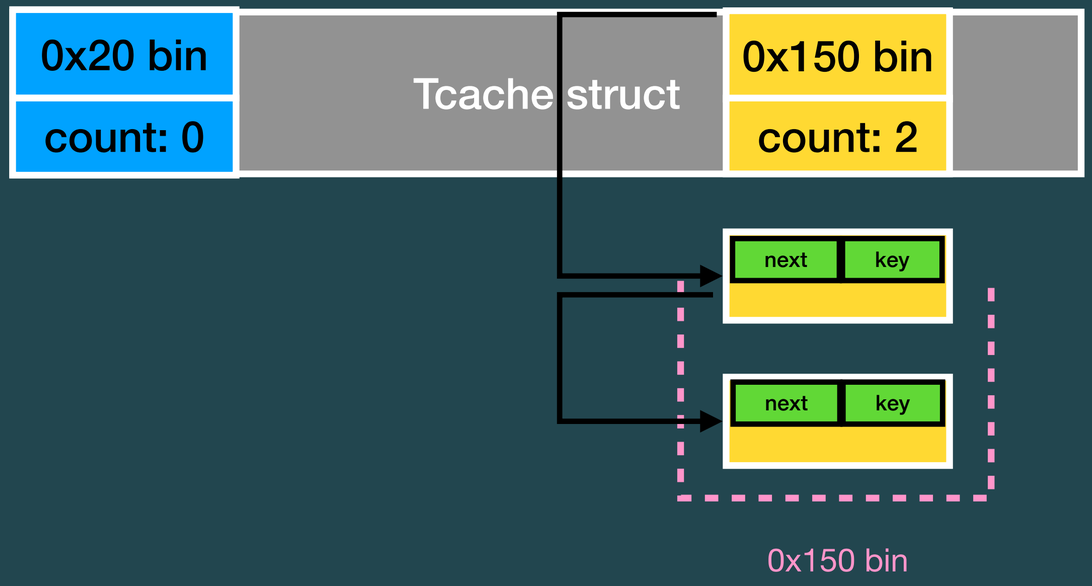
tcache 還沒滿的情況下，chunk size 為 0x20 會進入 0x20 的 bin 當中

Tcache instance

$ Heap introduction

Data Structure - Tcache

```
a = malloc(0x10);
b = malloc(0x10);
c = malloc(0x10);
d = malloc(0x10);

free(a);
malloc(0x10);
free(b);
free(c);
free(d);
```

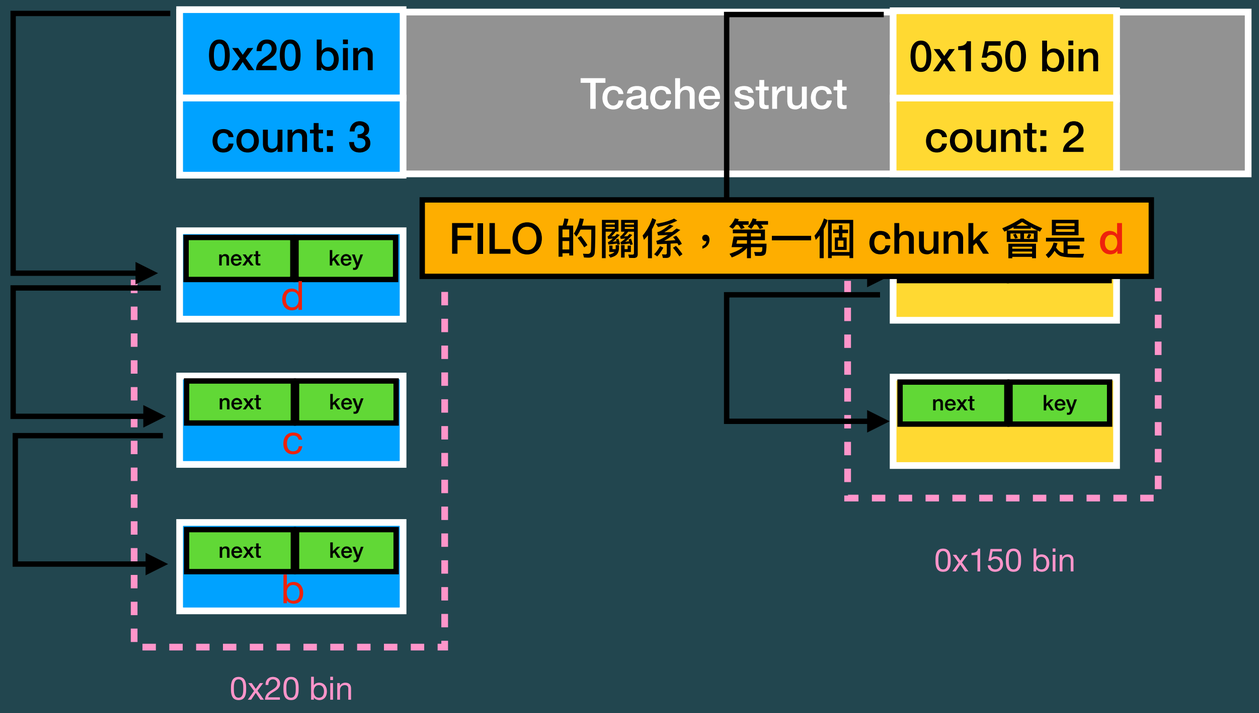


Tcache instance

$ Heap introduction

Data Structure - Tcache

```
a = malloc(0x10);
b = malloc(0x10);
c = malloc(0x10);
d = malloc(0x10);

free(a);
malloc(0x10);
free(b);
free(c);
free(d);
```

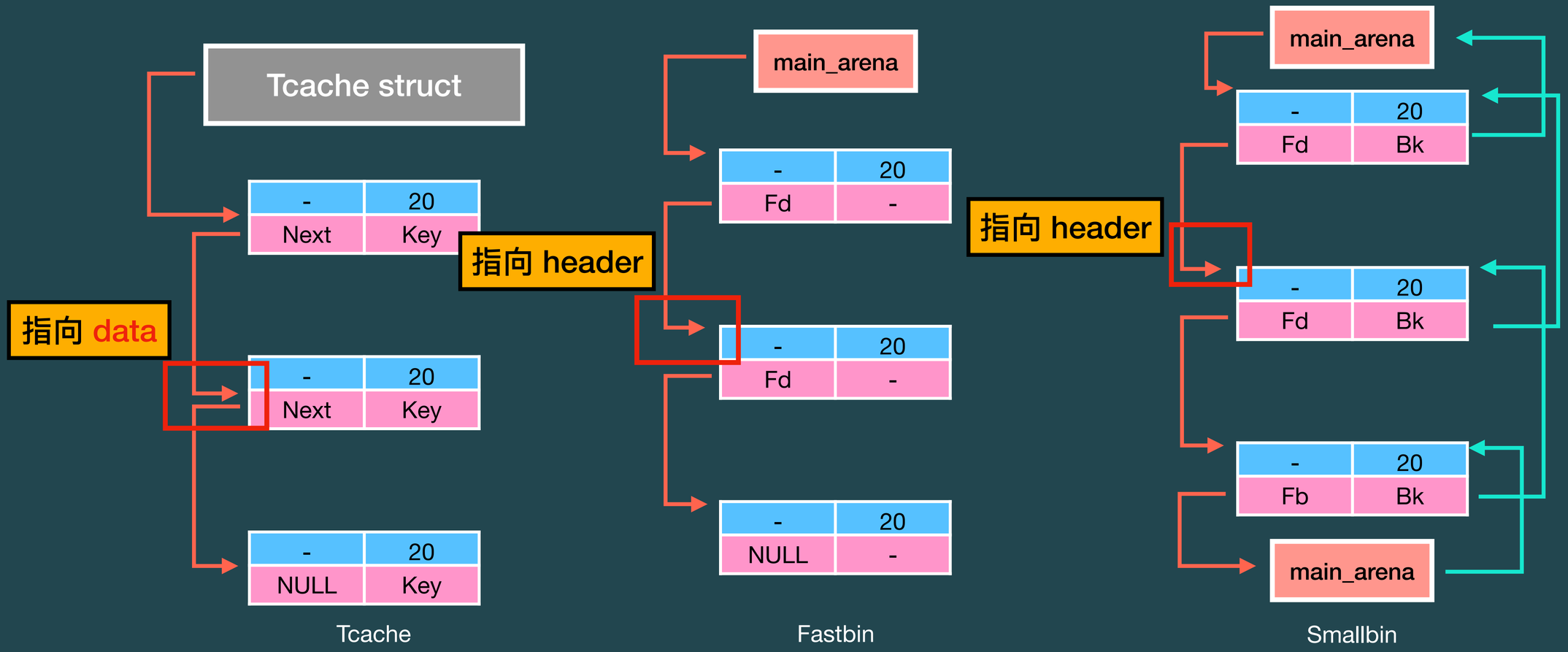


Tcache instance

$ Heap introduction

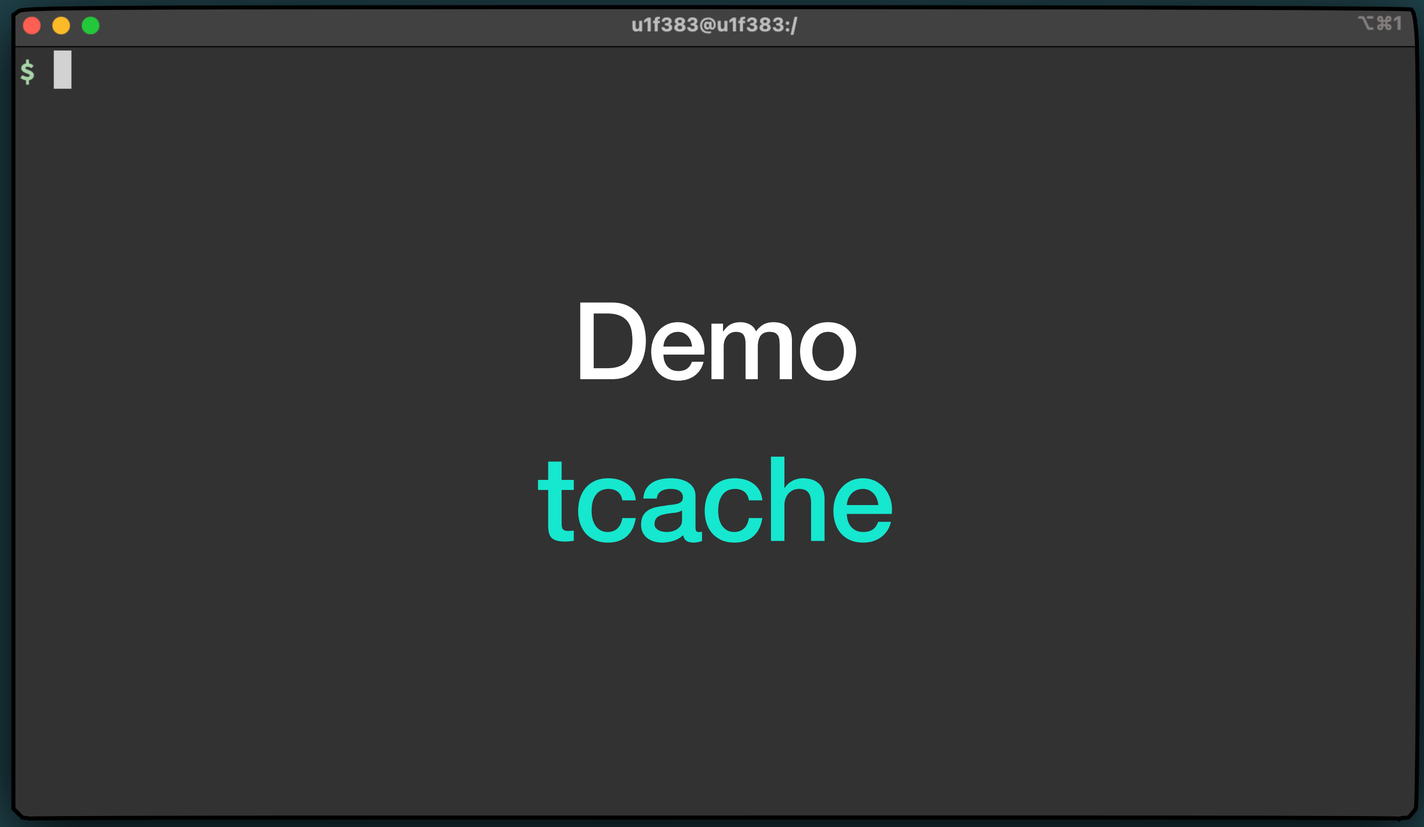
Data Structure - Tcache

- Tcache 的 fd 不像其他種類的 chunk 指向 header，而是指向 data



$ Heap introduction

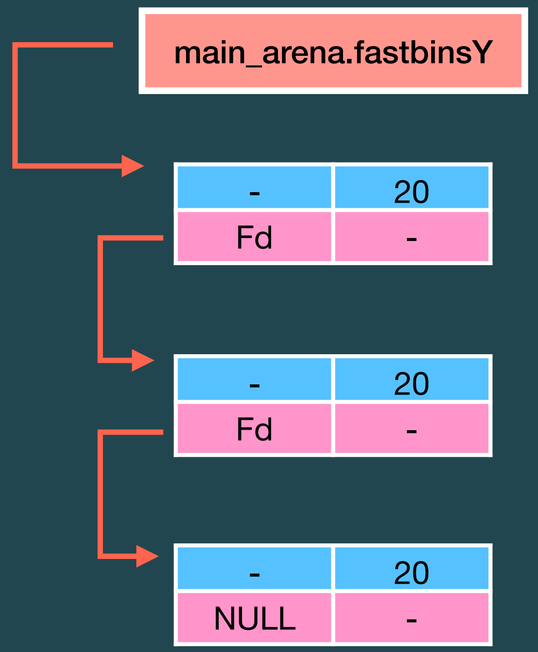
Data Structure - Tcache



$ Heap introduction

Data Structure - Fastbin

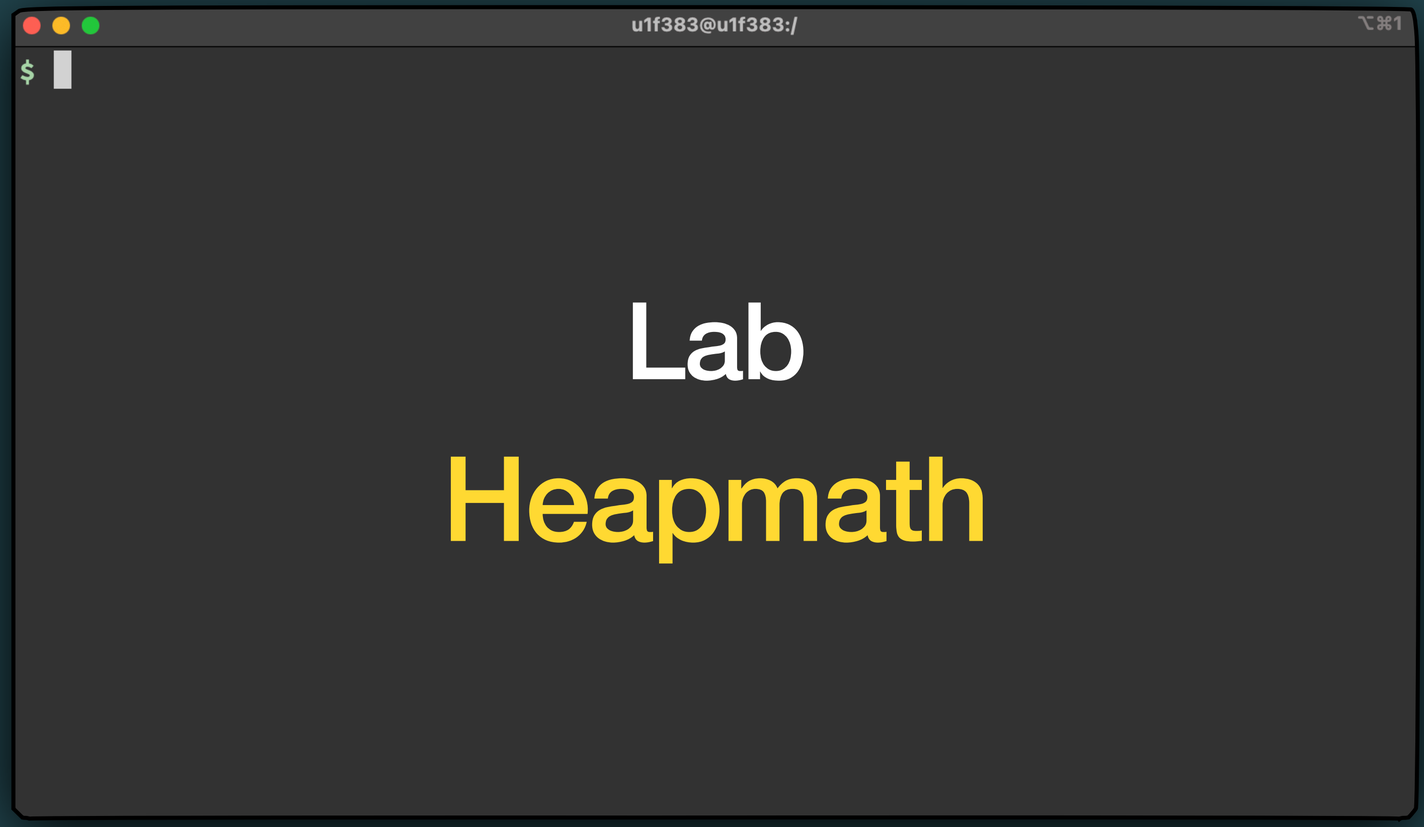
- **Fastbin** 存放 chunk size 為 0x20 ~ 0x80 的 chunk，並且數量沒有限制
- 使用方式與 tcache 相同，為 FILO
- 當 tcache 滿時，如果 free 大小為 0x20 ~ 0x80 的 chunk，則會直接進入 fastbin



$ Heap introduction

Data Structure - Fastbin

$ Heap introduction



$ Heap introduction

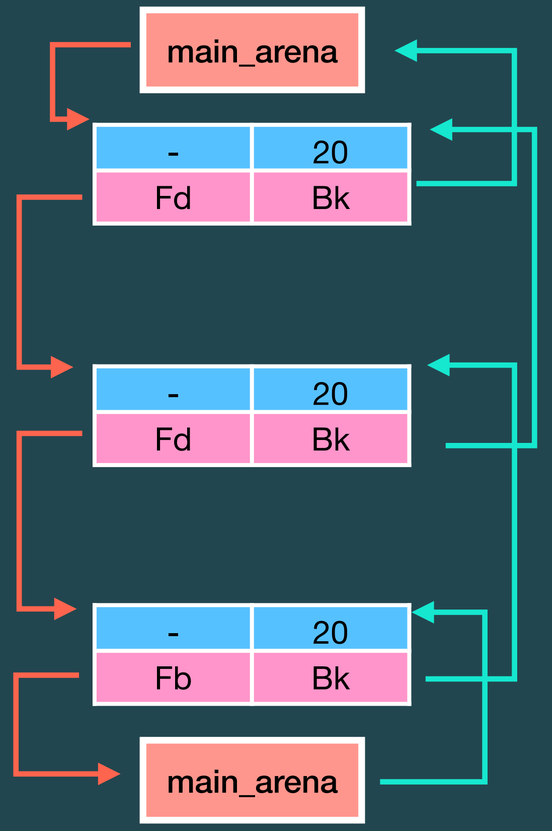
Lab - Heapmath

- 了解 tcache、fastbin bin 的連接方式是非常基本的
- 此 lab 會需要回答：
  - Freed chunk 在 tcache 內的連接順序
  - 一組 chunk 的距離運算
  - Tcache fd 的計算
  - Fastbin fd 的計算

$ Heap introduction

Data Structure - Small bin

- **Smallbin** 存放 chunk size 為 0x20 ~ 0x3f0 的 chunk
- 使用方式為 FIFO
- 其中 0x20 ~ 0x80 的大小與 fastbin 重疊
  - 直接 free 的 chunk 會進 fastbin
  - 從 unsorted bin 放回去時會進 smallbin



Smallbin

$ Heap introduction

Data Structure - Small bin

$ Heap introduction

Data Structure - Large bin

- **Largebin** 存放 chunk size >= 0x400 的 chunk，使用方式為 FIFO
- 每個 subbin 都存放多種不同 size 的 chunk
  - 32 bins — +0x40
    - 0x400, 0x410, 0x420, 0x430 ➔ 0-bin
    - 0x440, 0x450, 0x460, 0x470 ➔ 1-bin
    - ...

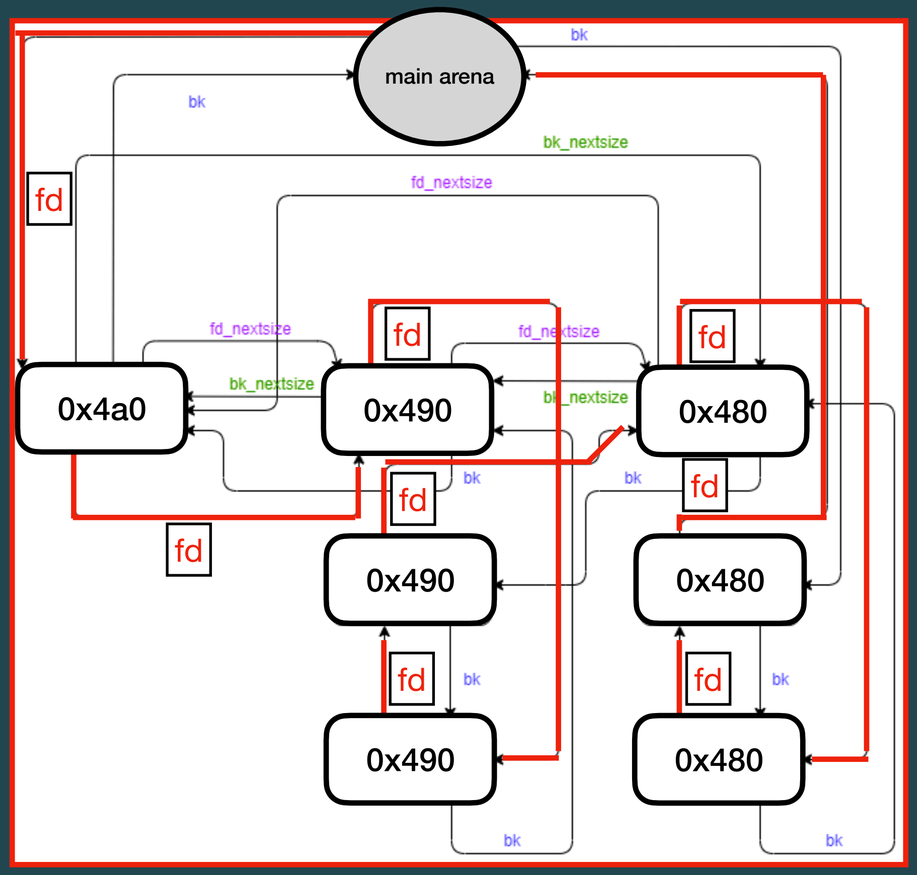
$ Heap introduction

Data Structure - Large bin

- 每個 subbin 都存放多種不同 size 的 chunk (cont.)
  - 16 bins — +0x200
  - 8 bins — +0x1000
  - 4 bins — +0x8000
  - 2 bins — +0x40000
  - 1 bins — the rest
- 使用 fd_nextsize 與 bk_nextsize 將不同 size 的 chunk 串起來

$ Heap introduction

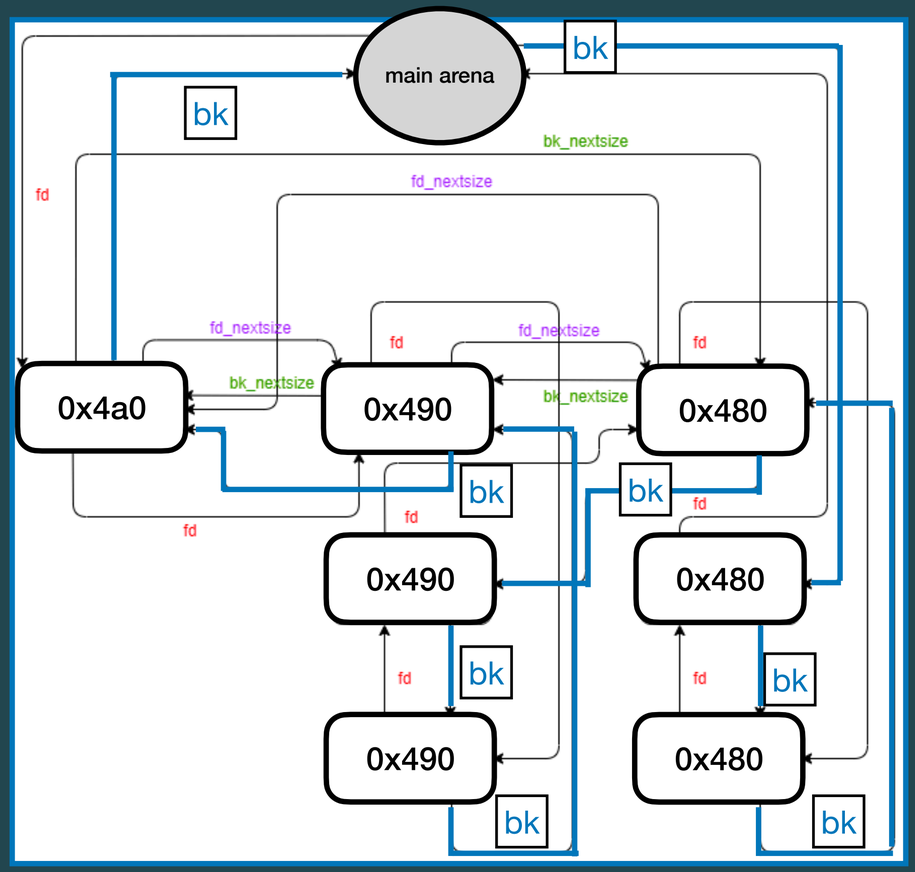
Data Structure - Large bin



2-bin

$ Heap introduction

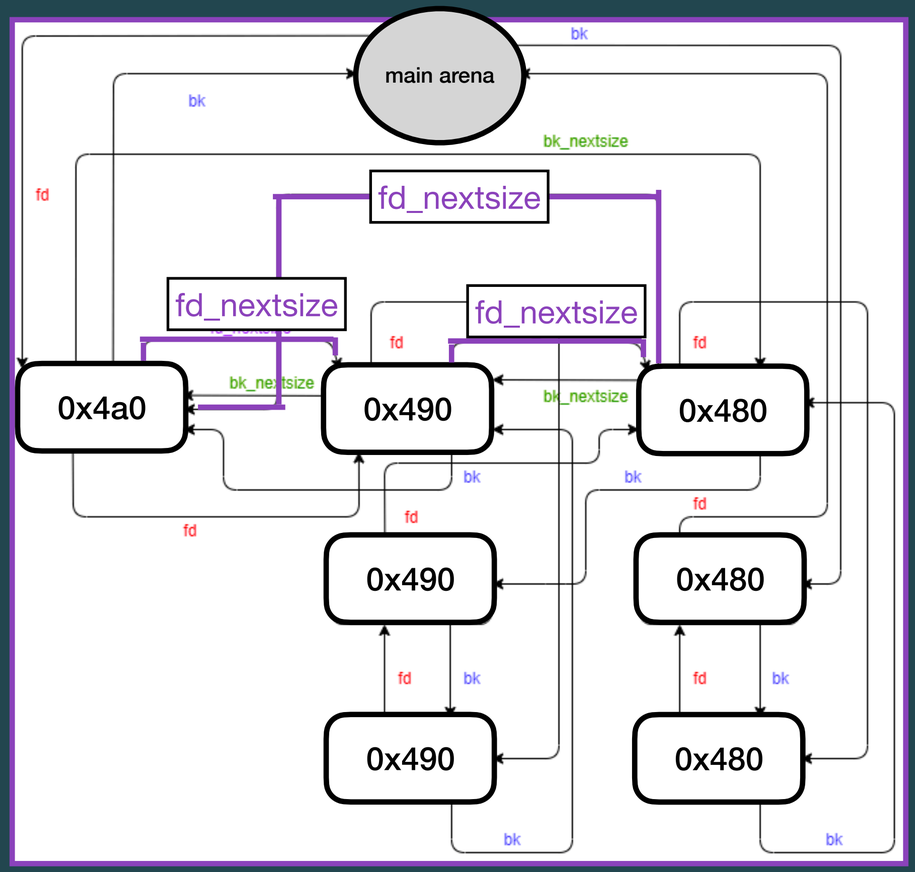
Data Structure - Large bin



2-bin

$ Heap introduction

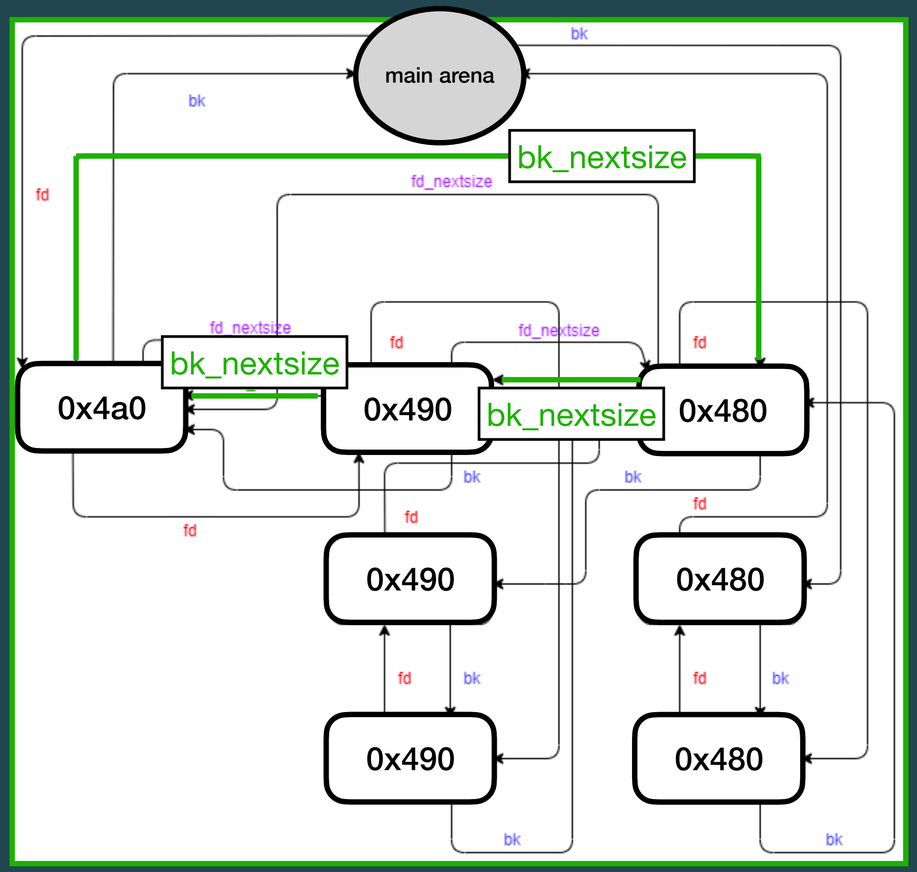
Data Structure - Large bin



2-bin

$ Heap introduction

Data Structure - Large bin



2-bin

$ Heap introduction

Data Structure - Large bin

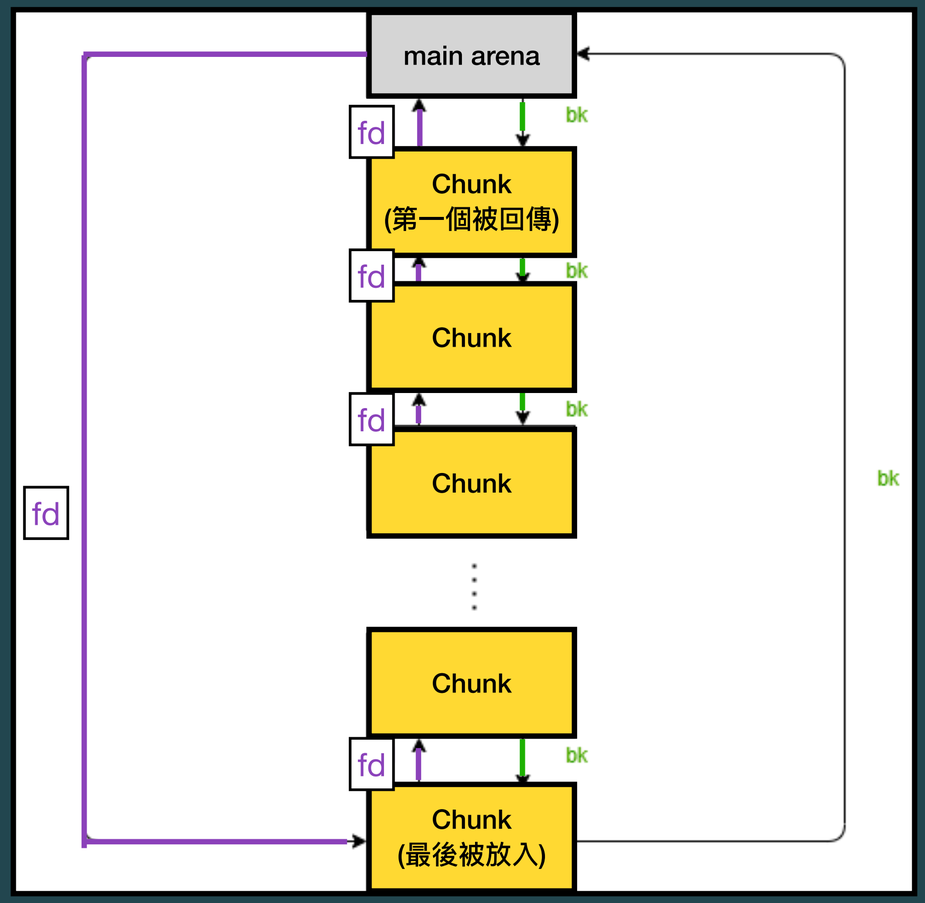
$ Heap introduction

Data Structure - Unsorted bin

- **Unsorted bin -** 對應大小的 tcache 已經滿的情況下，並且 chunk size 非 fastbin chunk 的大小，則此 chunk 被 free 後會暫存在 unsorted bin
  - 當收到請求後，如果對應大小的 tcache、fastbin、smallbin 為空，則會遍歷整個 unsorted bin
  - 若 unsorted bin 中有 chunk 的大小 >= (請求的大小 + 0x20)，會直接從該塊 chunk 切下來回傳
    > 0x20 為最小的 chunk size
  - 若沒有，則會將這些暫存的 chunk 放至對應的 bin (small bin, large bin, ...)

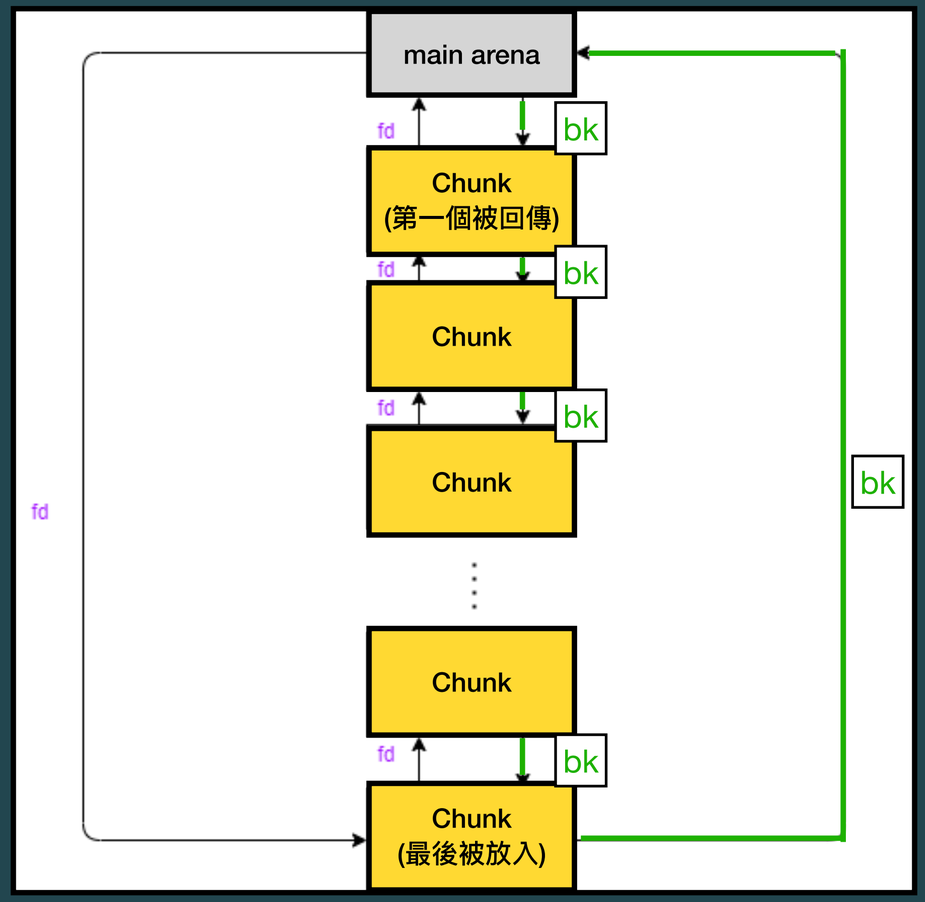
$ Heap introduction

Data Structure - Unsorted bin



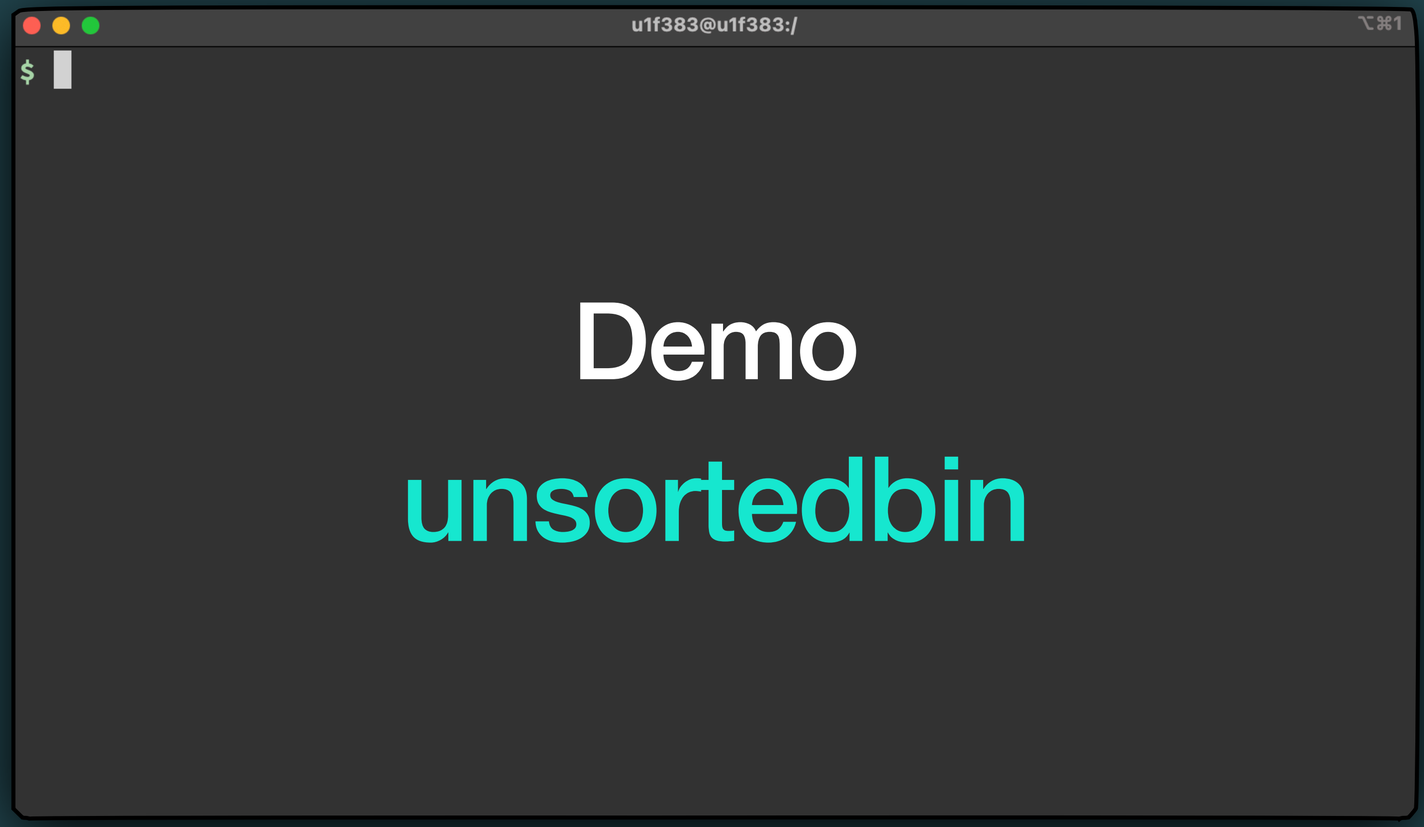
$ Heap introduction

Data Structure - Unsorted bin



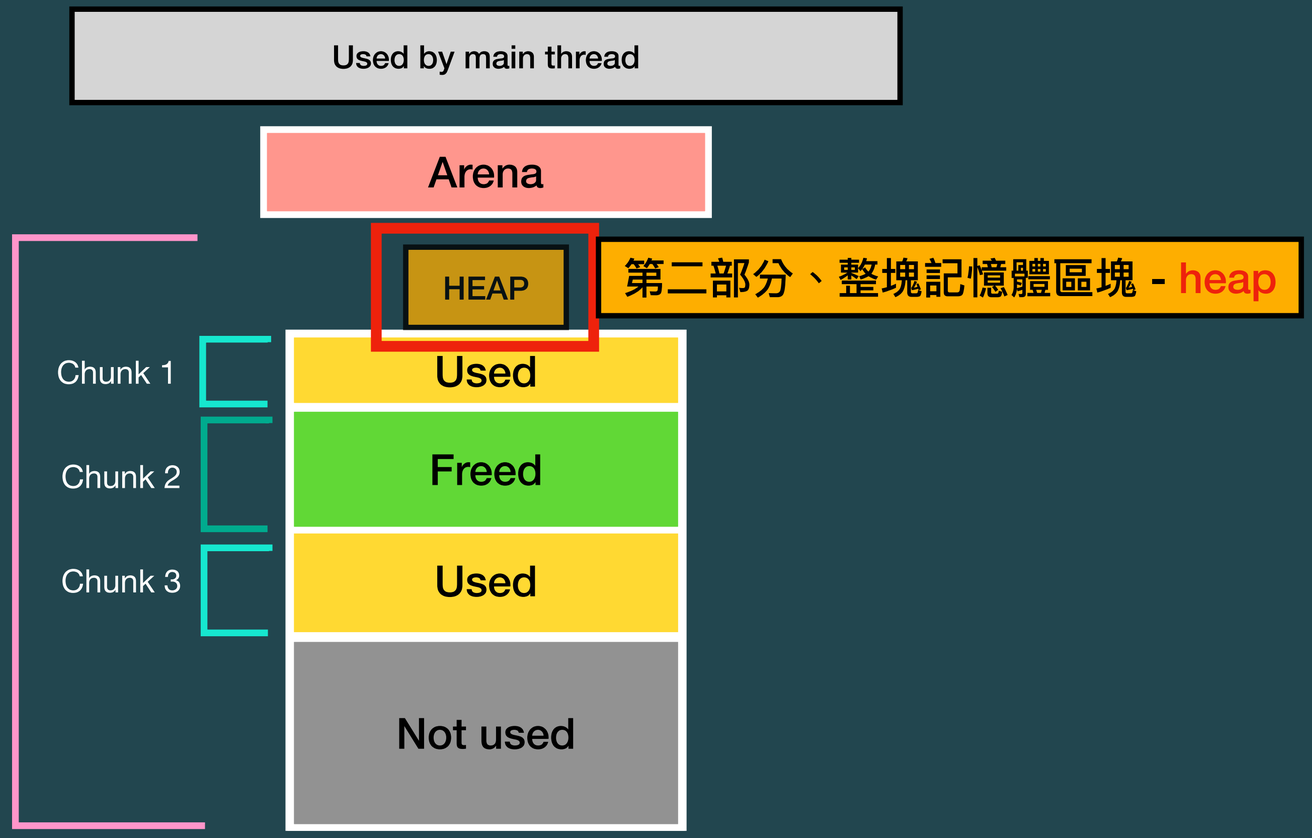
$ Heap introduction

Data Structure - Unsorted bin



$ Heap introduction

Data Structure - Heap



$ Heap introduction

Data Structure - Heap

u1f383@u1f383:/ ⌥⌘1

```
$
```

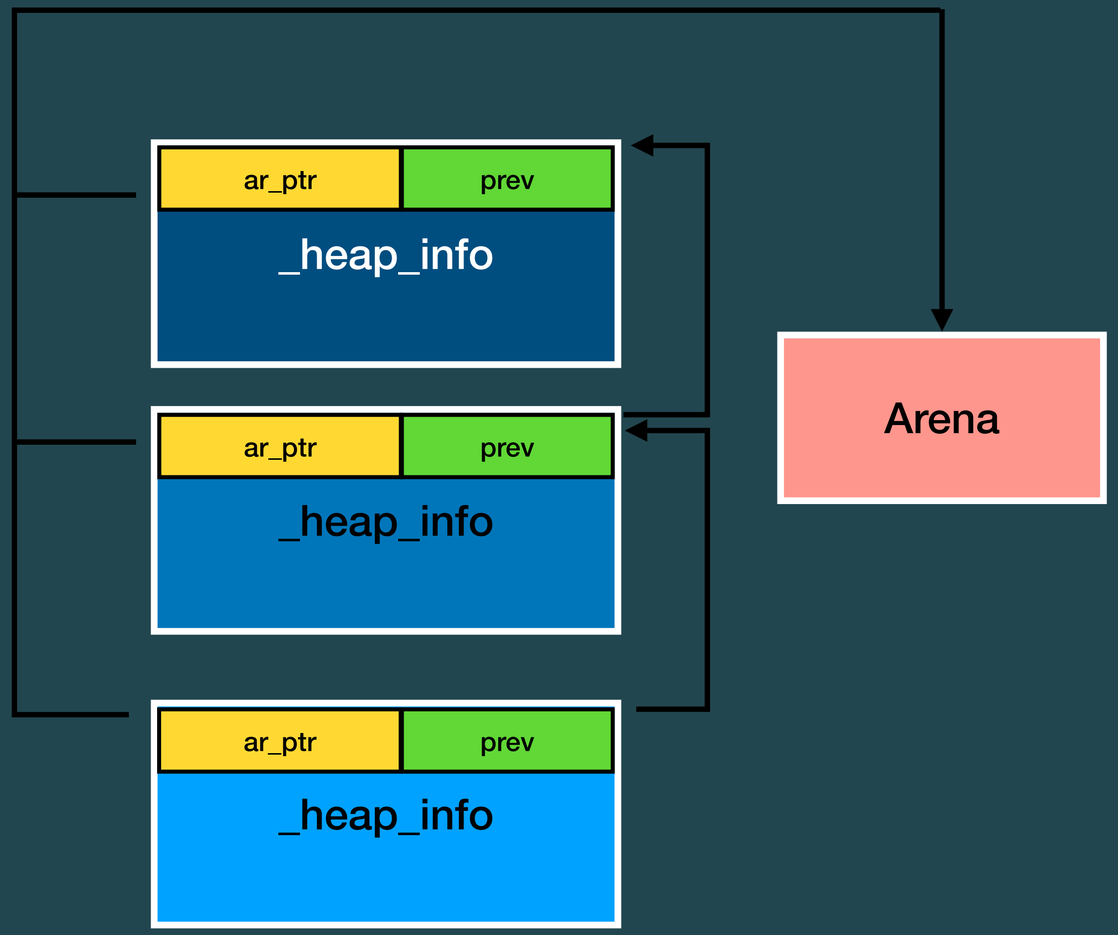
```c
typedef struct _heap_info
{
  mstate ar_ptr;             /* 指向當前 heap 使用的 arena */
  struct _heap_info *prev; /* 指向上一塊 heap */
  size_t size;               /* 當前 heap 的大小 */
  size_t mprotect_size;    /* prot 為 RROT_READ|PROT_WRITE 的空間大小 */

  /* 用來做 alignment */
  char pad[-6 * SIZE_SZ & MALLOC_ALIGN_MASK];
} heap_info;
```

https://elixir.bootlin.com/glibc/glibc-2.31/source/malloc/arena.c#L53

$ Heap introduction

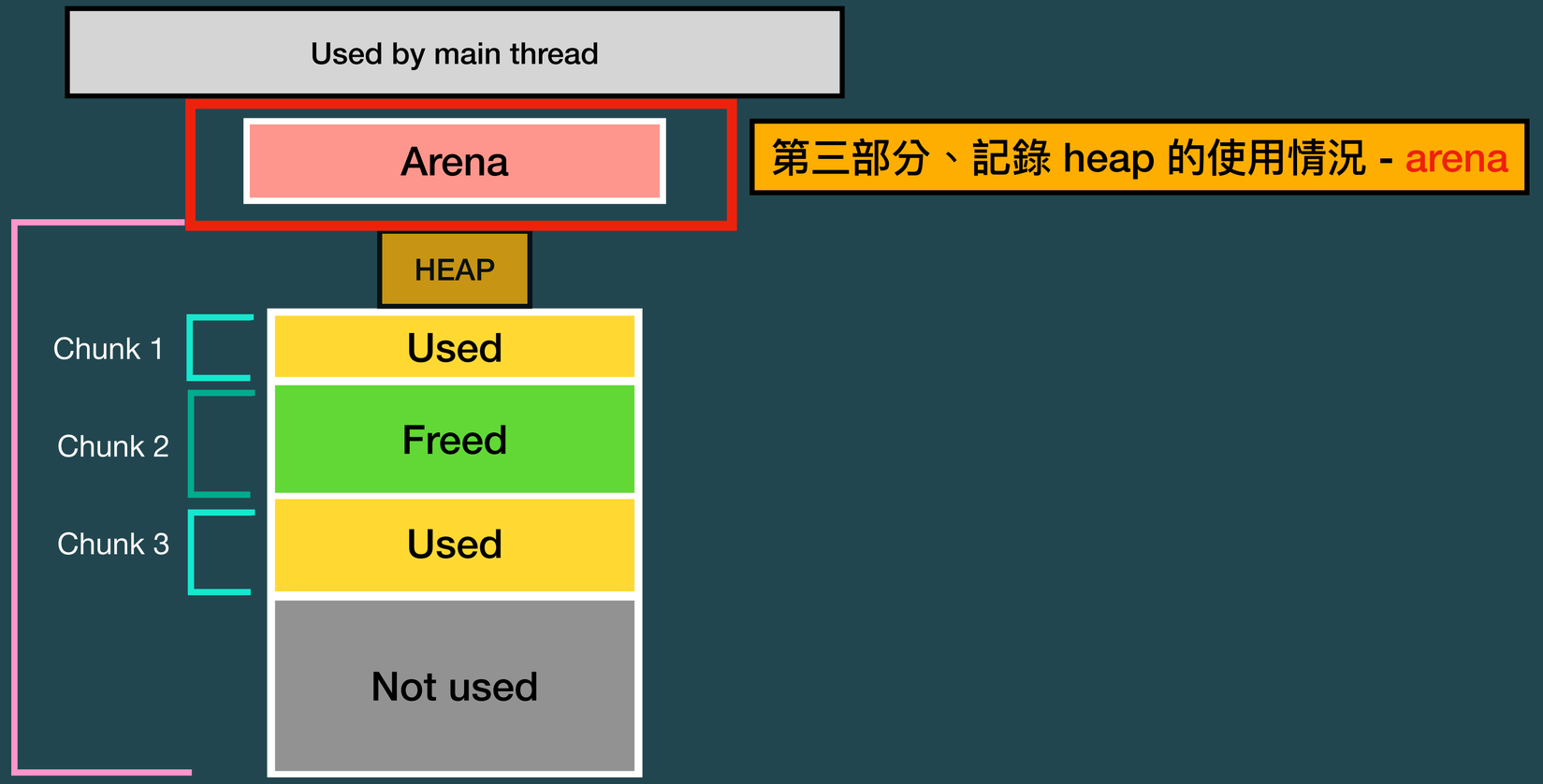
Data Structure - Heap

- Size 與 mprotect_size 預設為 0x21000
- Main thread 本身是沒有 _heap_info，
  因此 heap exploit 並不常用到 _heap_info



$ Heap introduction

Data Structure - Arena



$ Heap introduction

Data Structure - Arena

u1f383@u1f383:/ ⌥⌘1

```
$
```

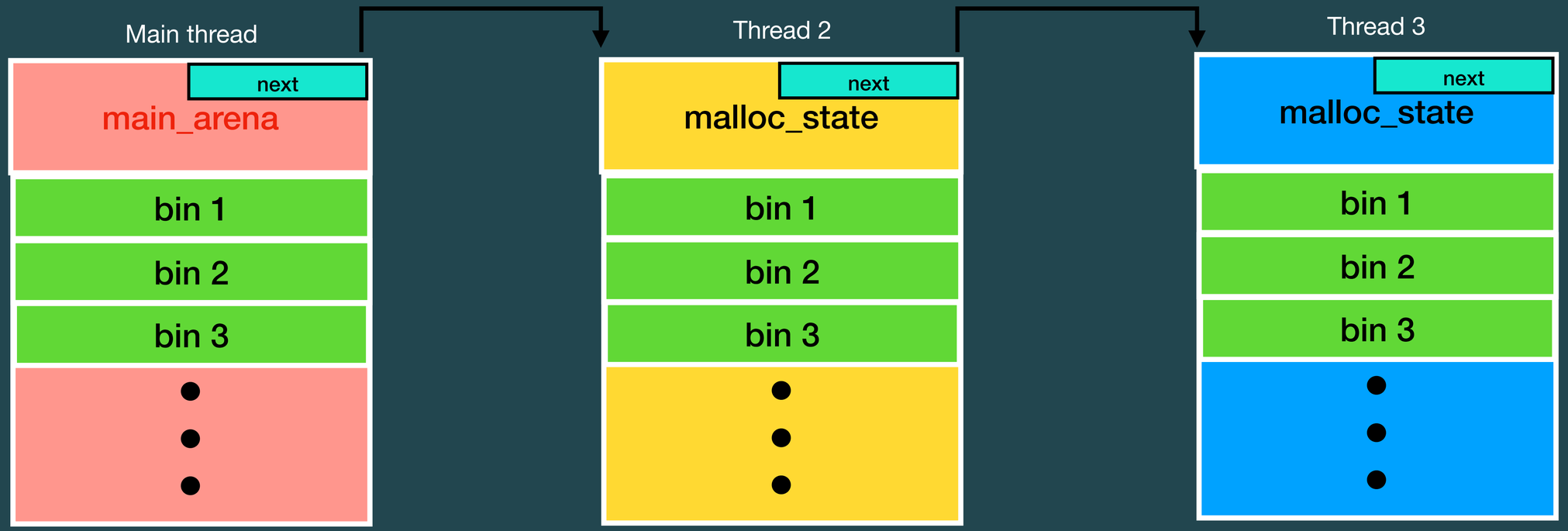
```c
struct malloc_state /* 也稱作 arena */
{
  /* fastbins 陣列，NFASTBINS 為 10 */
  mfastbinptr fastbinsY[NFASTBINS];
  /* 指向 top chunk 的位址 */
  mchunkptr top;
  /* 指向最近被切的 chunk 所剩下的 chunk */
  mchunkptr last_remainder;
  /* small bin, large bin 還有 unsorted bin 都在這 */
  mchunkptr bins[NBINS * 2 - 2];


  /* 以下 member 相較來說不是這麼重要 */
  struct malloc_state *next;
  struct malloc_state *next_free;
  INTERNAL_SIZE_T attached_threads;
  INTERNAL_SIZE_T system_mem;
  INTERNAL_SIZE_T max_system_mem;
};
```


https://elixir.bootlin.com/glibc/glibc-2.31/source/malloc/malloc.c#L1655

$ Heap introduction

Data Structure - Arena

- Main thread 的 malloc_state 也稱作 **main_arena**
- 由於後續只考慮一個 thread 的情況，基本上只會使用到 **main_arena**



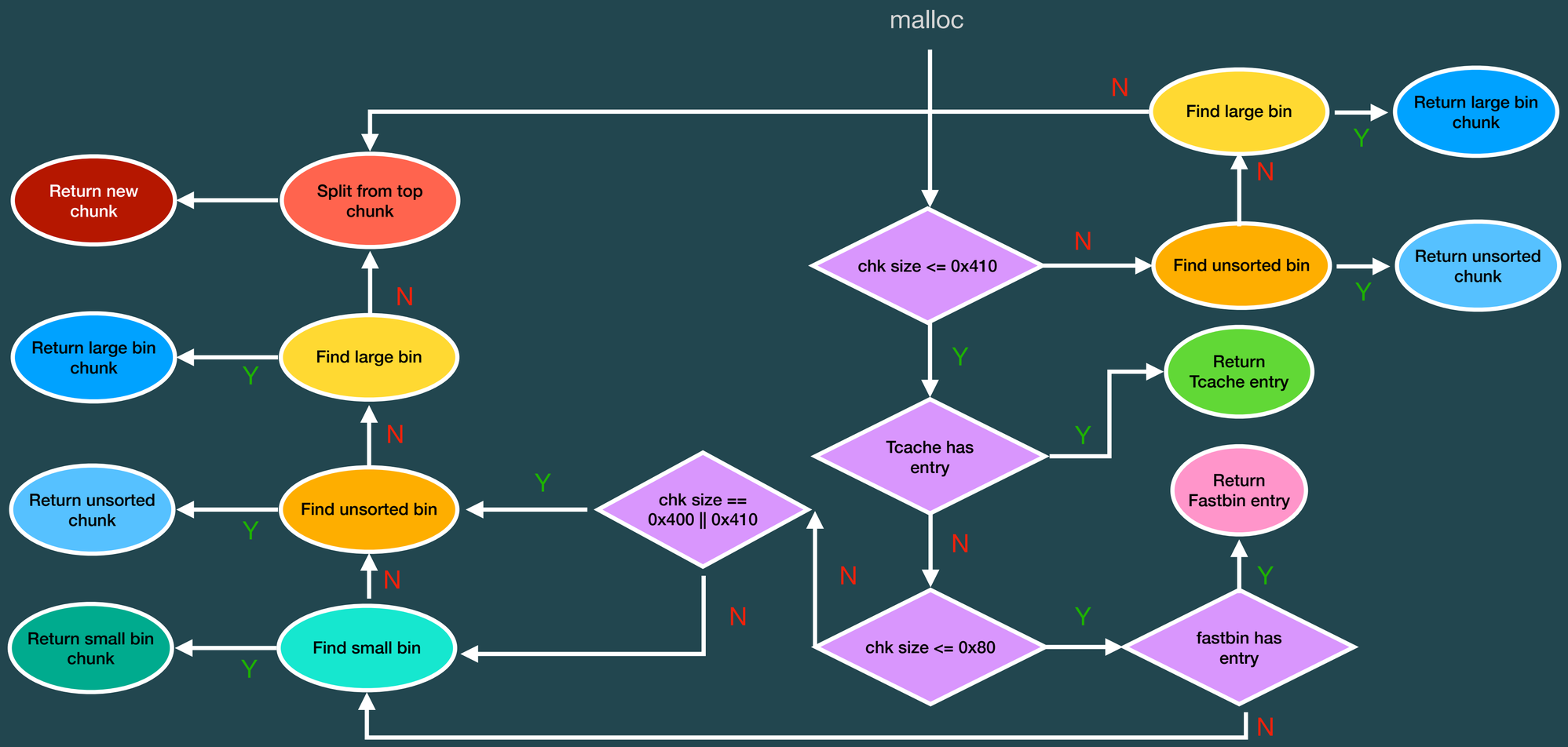
$ Heap introduction

Data Structure - Arena

Code tracing

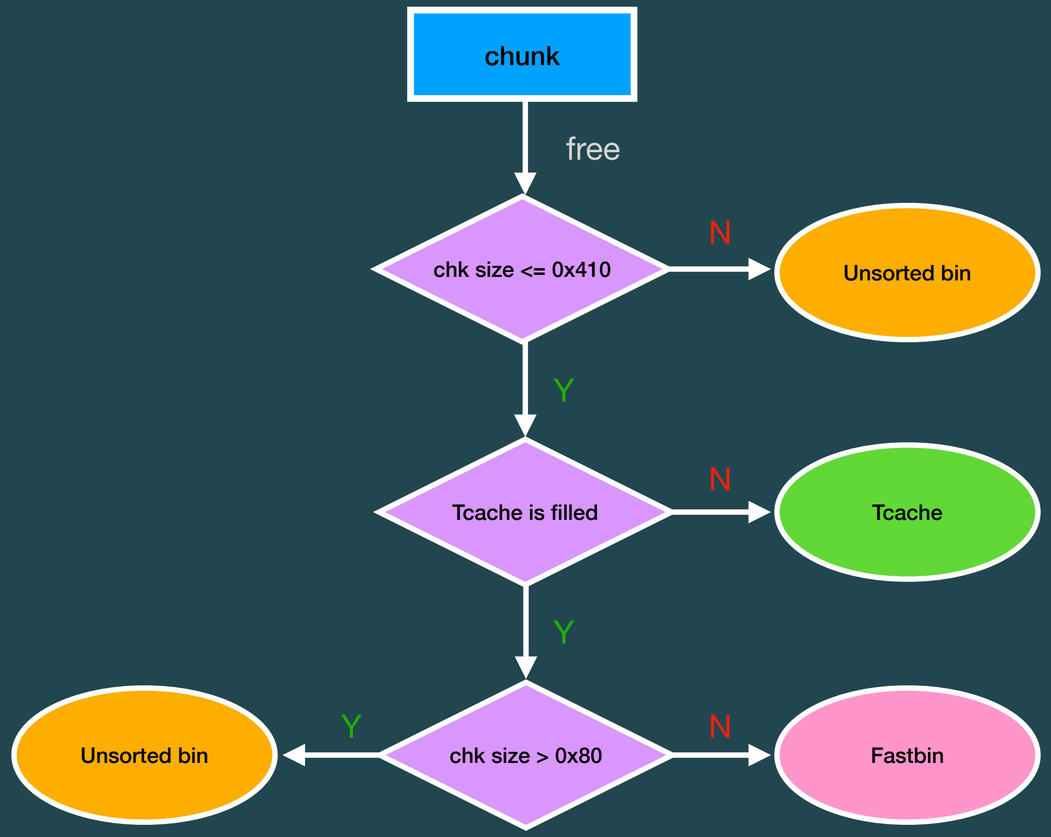
$ Code tracing

Malloc



$ Code tracing

Free



Vulnerability

$ Vulnerability

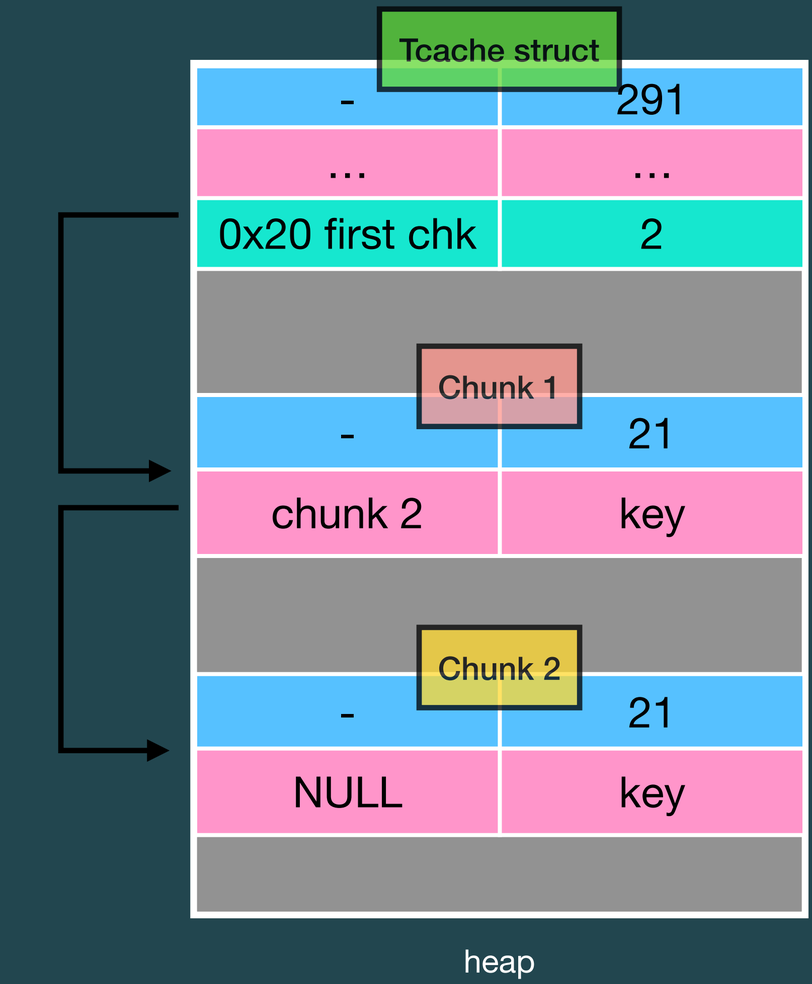
UAF

- Use-After-Free
- Chunk 在被 free 後並沒有把 pointer 設為 NULL，導致使用到已經被釋放的記憶體
- 這種指向已釋放資源的 pointer 又稱 dangling pointer

$ Vulnerability

UAF - Example

```
unsigned long *a = malloc(0x10);
*a = 0xdeadbeef;
free(a);
*a = 0xdeadbeef;
malloc(0x10);
malloc(0x10);
```

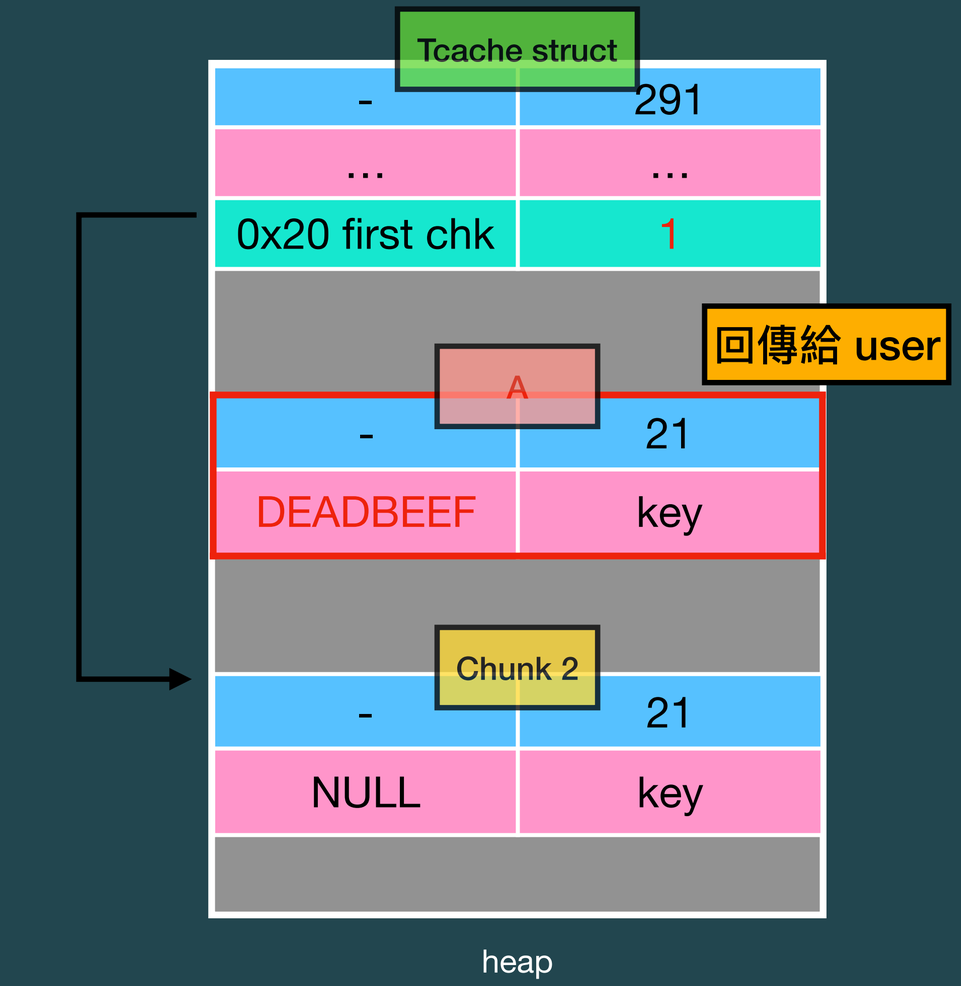


heap

$ Vulnerability

UAF - Example

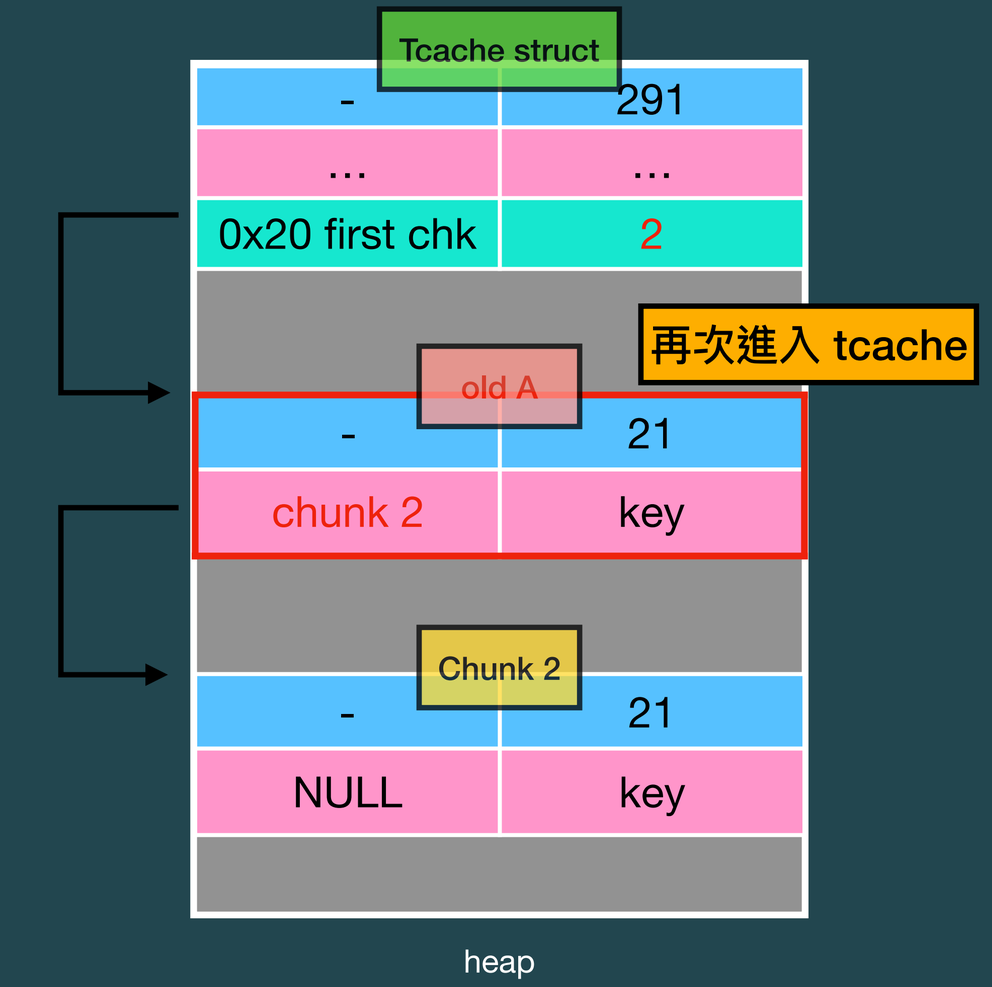
```
unsigned long *a = malloc(0x10);
*a = 0xdeadbeef;
free(a);
*a = 0xdeadbeef;
malloc(0x10);
malloc(0x10);
```



$ Vulnerability

UAF - Example

```
unsigned long *a = malloc(0x10);
*a = 0xdeadbeef;
free(a);
*a = 0xdeadbeef;
malloc(0x10);
malloc(0x10);
```



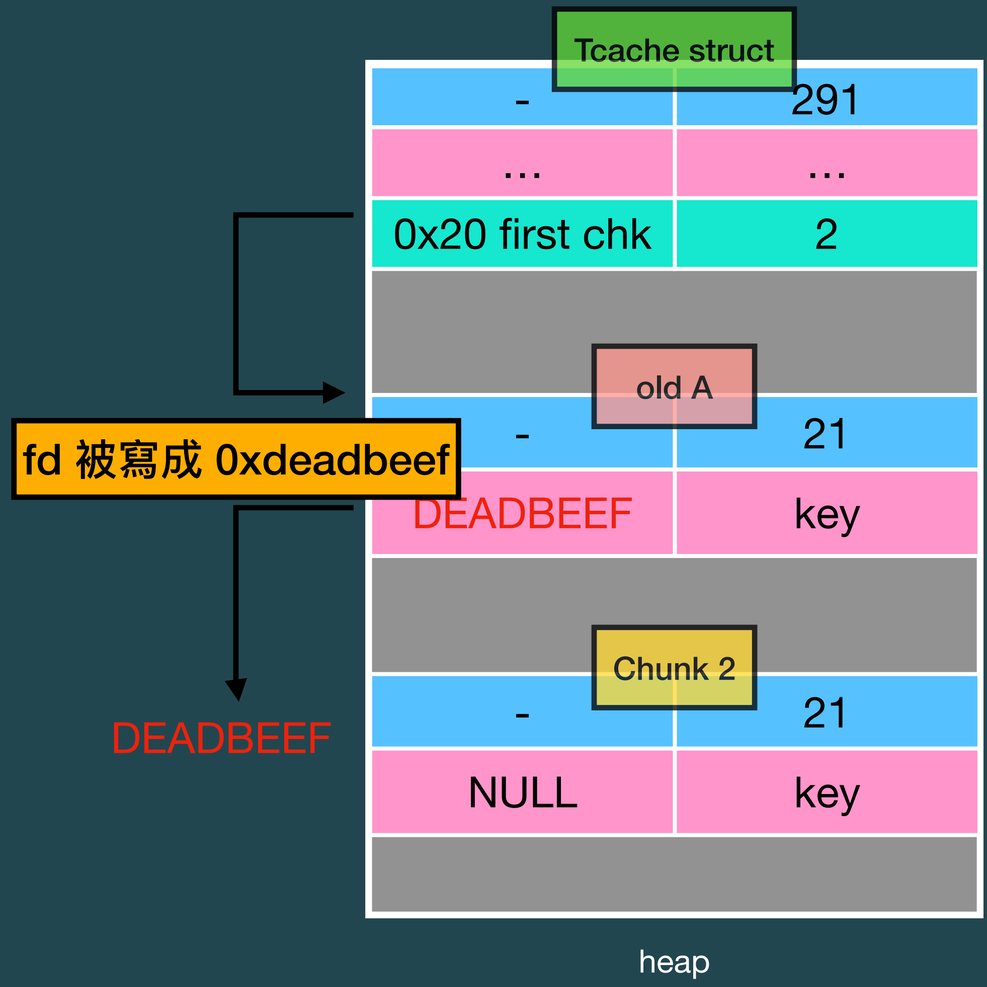
heap

$ Vulnerability

UAF - Example

```
unsigned long *a = malloc(0x10);
*a = 0xdeadbeef;
free(a);
*a = 0xdeadbeef;
malloc(0x10);
malloc(0x10);
```

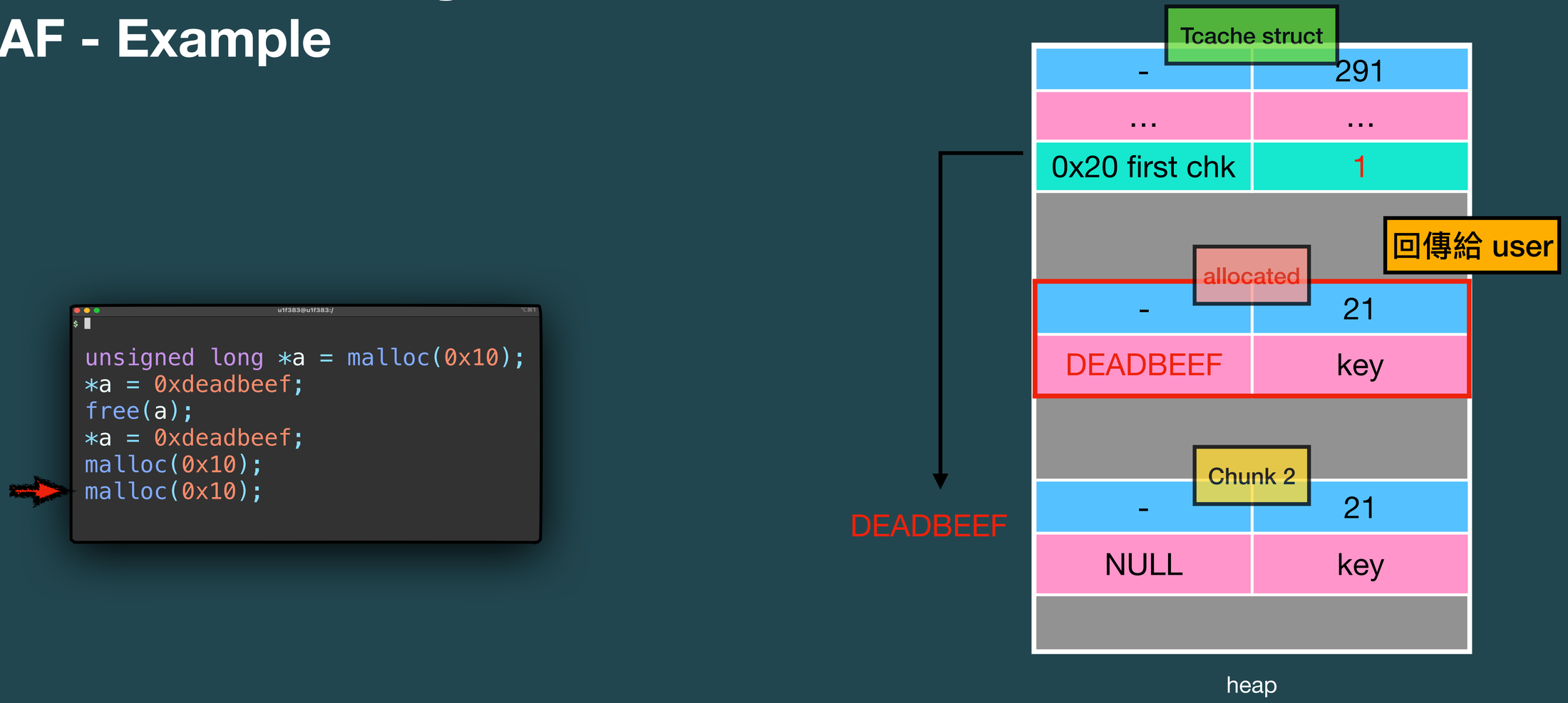
a 被釋放後仍被使用



$ Vulnerability

UAF - Example

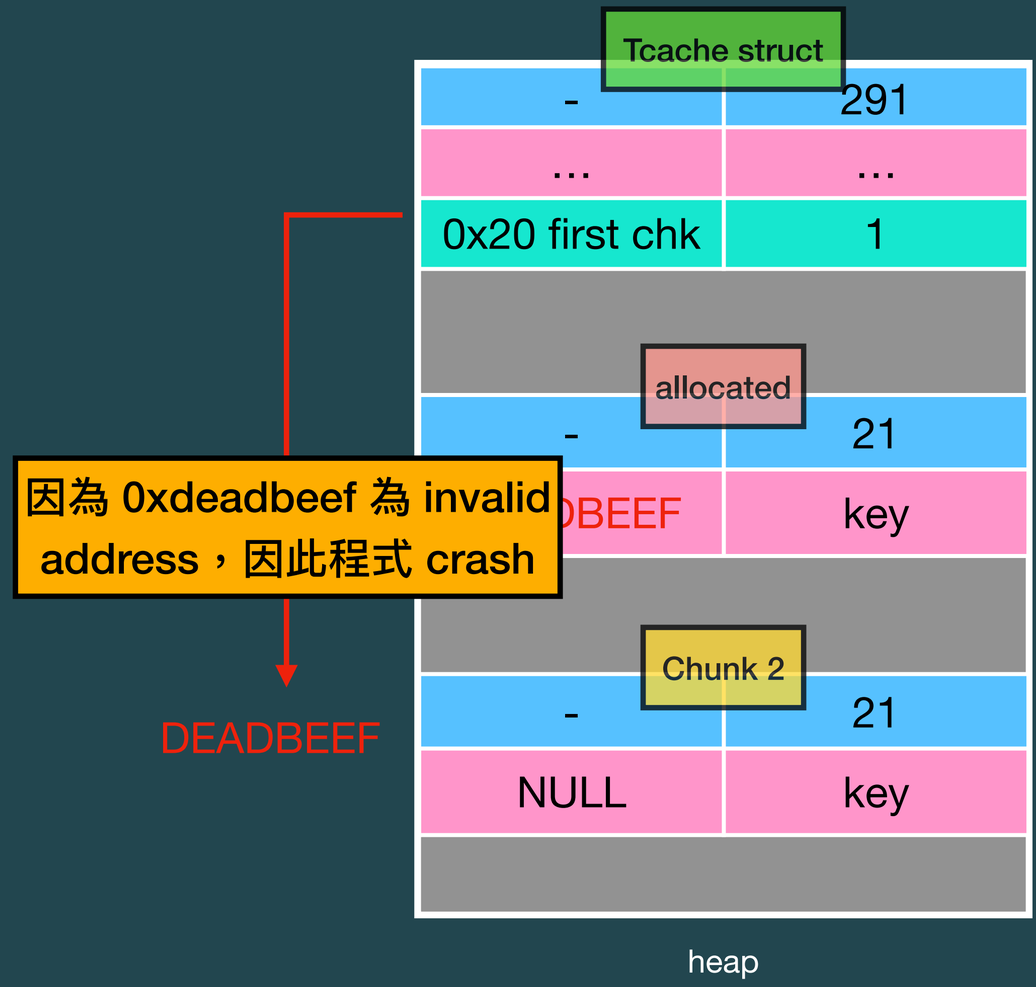
```
unsigned long *a = malloc(0x10);
*a = 0xdeadbeef;
free(a);
*a = 0xdeadbeef;
malloc(0x10);
malloc(0x10);
```



$ Vulnerability

UAF - Example

```
unsigned long *a = malloc(0x10);
*a = 0xdeadbeef;
free(a);
*a = 0xdeadbeef;
malloc(0x10);
malloc(0x10);
```



$ Vulnerability

UAF

$ Vulnerability

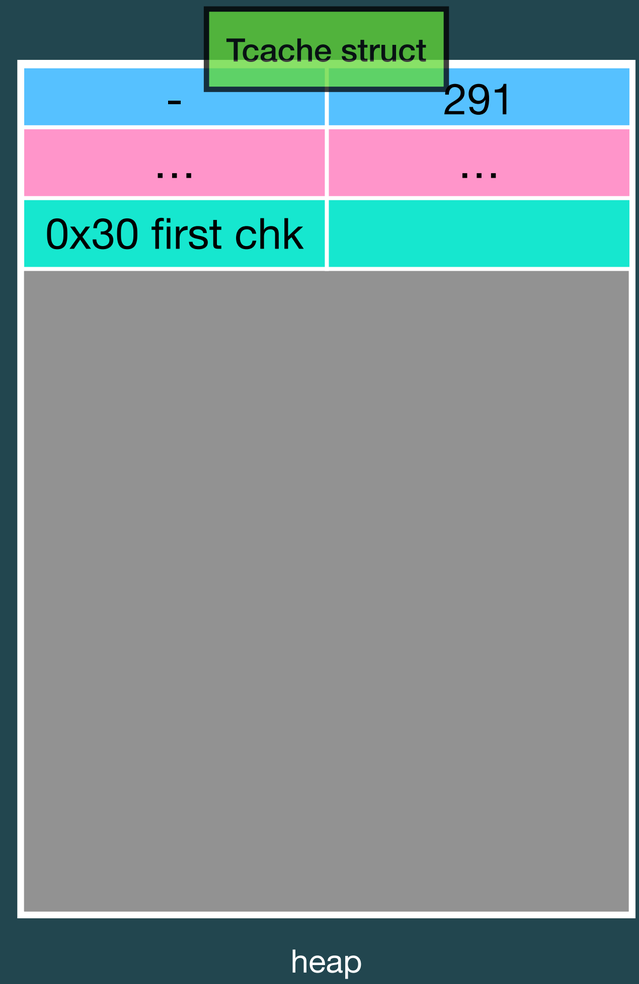
Heap overflow

- 在讀取資料時並沒有檢查好長度，導致可以越界寫到其他 chunk
  - 如果越界寫到的是 allocated chunk，可以寫 chunk 內的
    - 敏感資料，例如 function pointer
    - Size，就可以釋放任意 size 的 chunk
  - 如果越界寫到的是 freed chunk，可以寫 chunk 的
    - Fd、bk，改變 linked list 的連接
    - PREV_INUSE bit，讓 glibc 誤以為上一塊 chunk 已經被釋放

$ Vulnerability

Heap overflow - Example

```
unsigned long *chk1 = malloc(0x10);
void *chk2 = malloc(0x10);
chk1[3] = 0x31;
free(chk2);
```

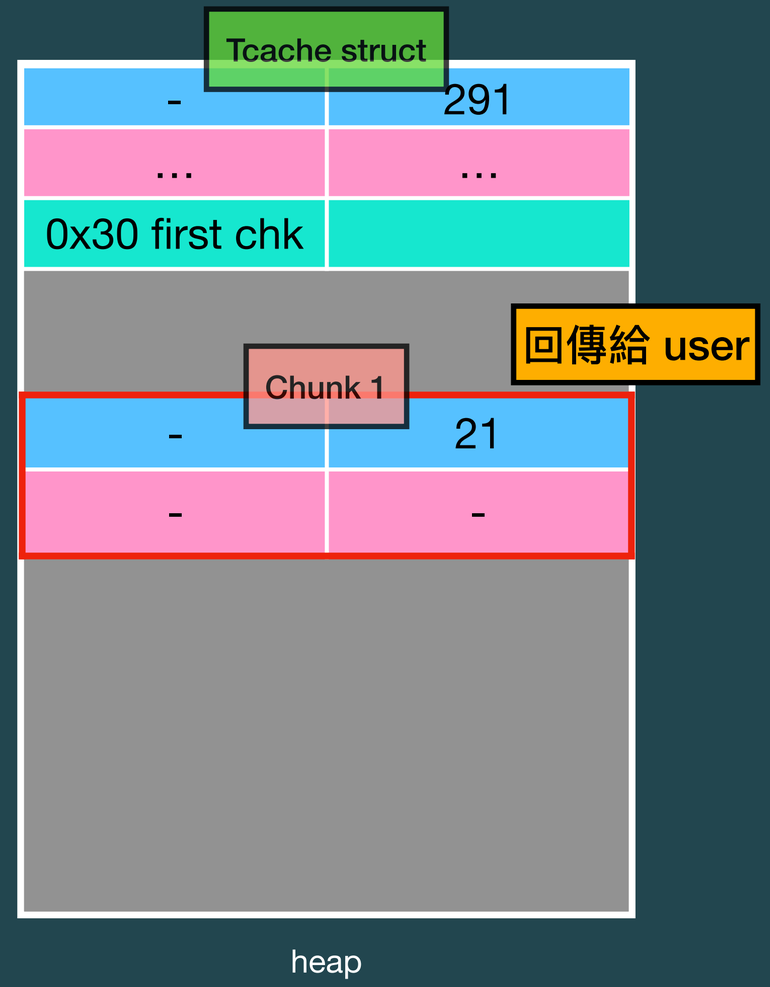


heap

$ Vulnerability

Heap overflow - Example

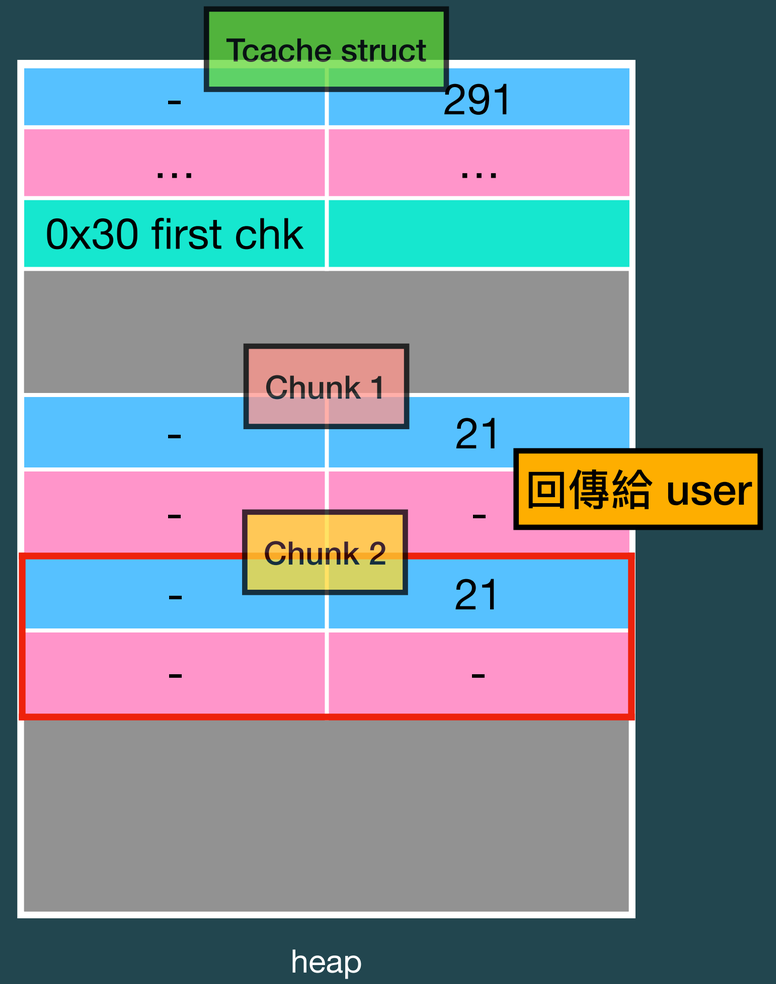
```
unsigned long *chk1 = malloc(0x10);
void *chk2 = malloc(0x10);
chk1[3] = 0x31;
free(chk2);
```



$ Vulnerability

Heap overflow - Example

```
unsigned long *chk1 = malloc(0x10);
void *chk2 = malloc(0x10);
chk1[3] = 0x31;
free(chk2);
```



$ Vulnerability

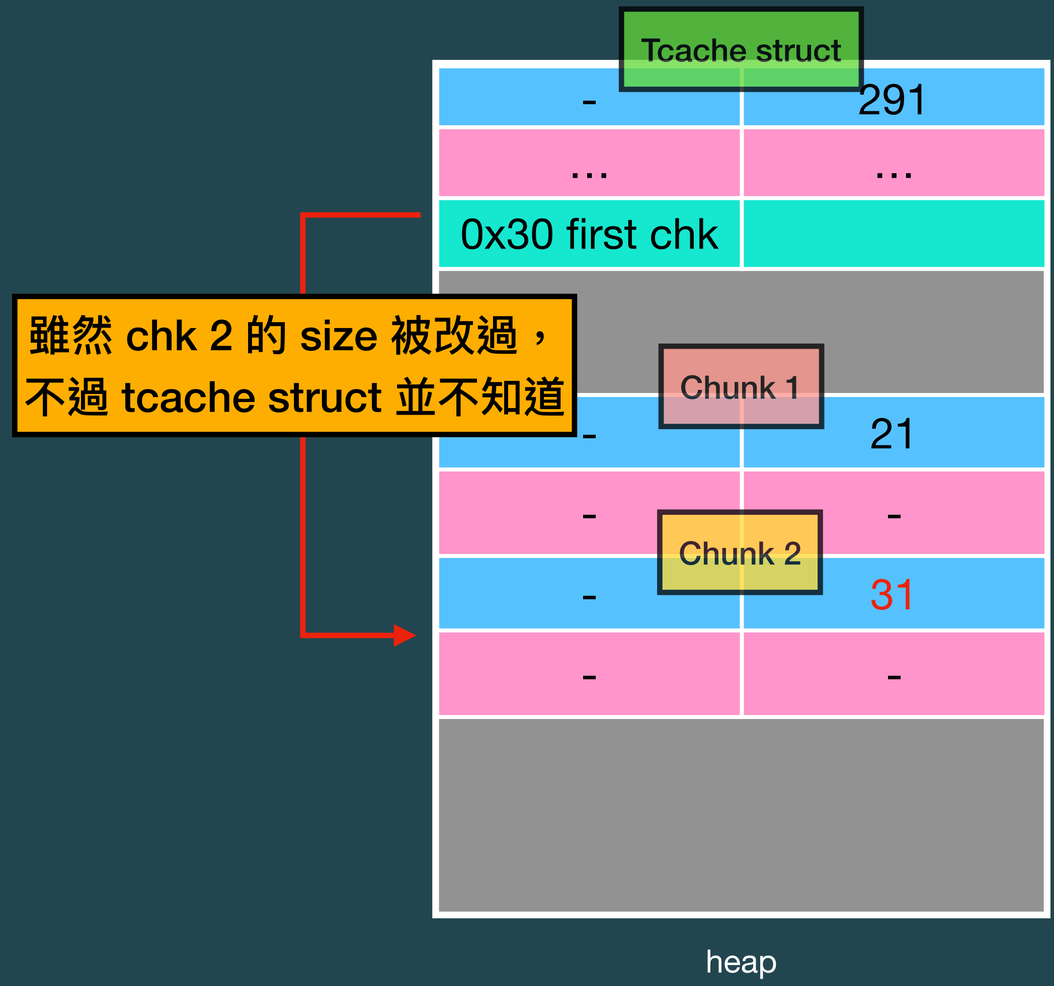
Heap overflow - Example

```
unsigned long *chk1 = malloc(0x10);
void *chk2 = malloc(0x10);
chk1[3] = 0x31;
free(chk2);
```

$ Vulnerability

Heap overflow - Example

```
unsigned long *chk1 = malloc(0x10);
void *chk2 = malloc(0x10);
chk1[3] = 0x31;
free(chk2);
```



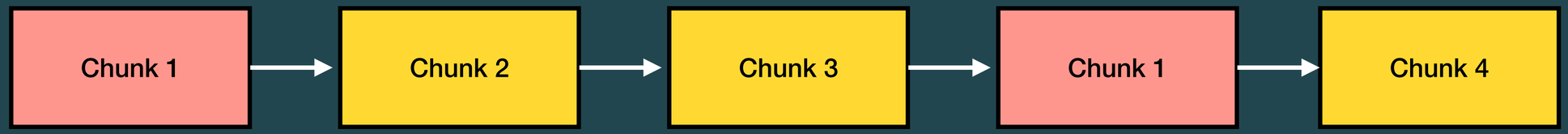
$ Vulnerability

Heap overflow - Example

$ Vulnerability

Double Free

- 當 chunk 被 free 兩遍，導致 bin 當中記錄了兩個相同的 chunk，就被稱作 double free
- 當透過 malloc 取出 chunk 時，因為 chunk 仍被 bin 所記錄，因此對 chunk 做修改就等於直接改動了 freed chunk
- 由於 double free 常發生，因此 glibc 當中有許多檢查機制來偵測這些異常的行為，如果要利用的話，就需要繞過那些檢查機制，讓 glibc 認為目前的行為是合法的

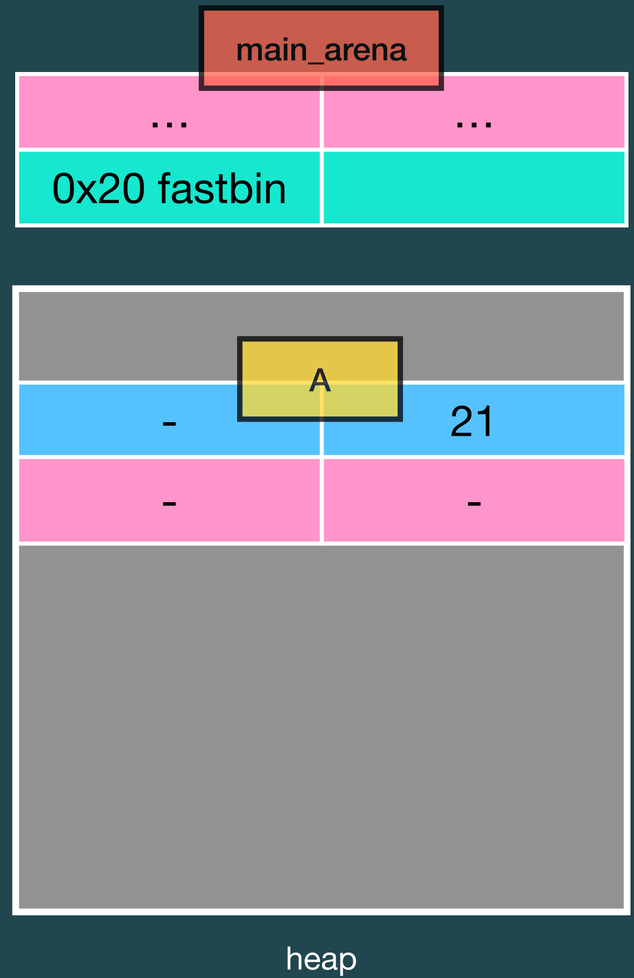


$ Vulnerability

Double Free - Example

假設 tcache 已經被填滿

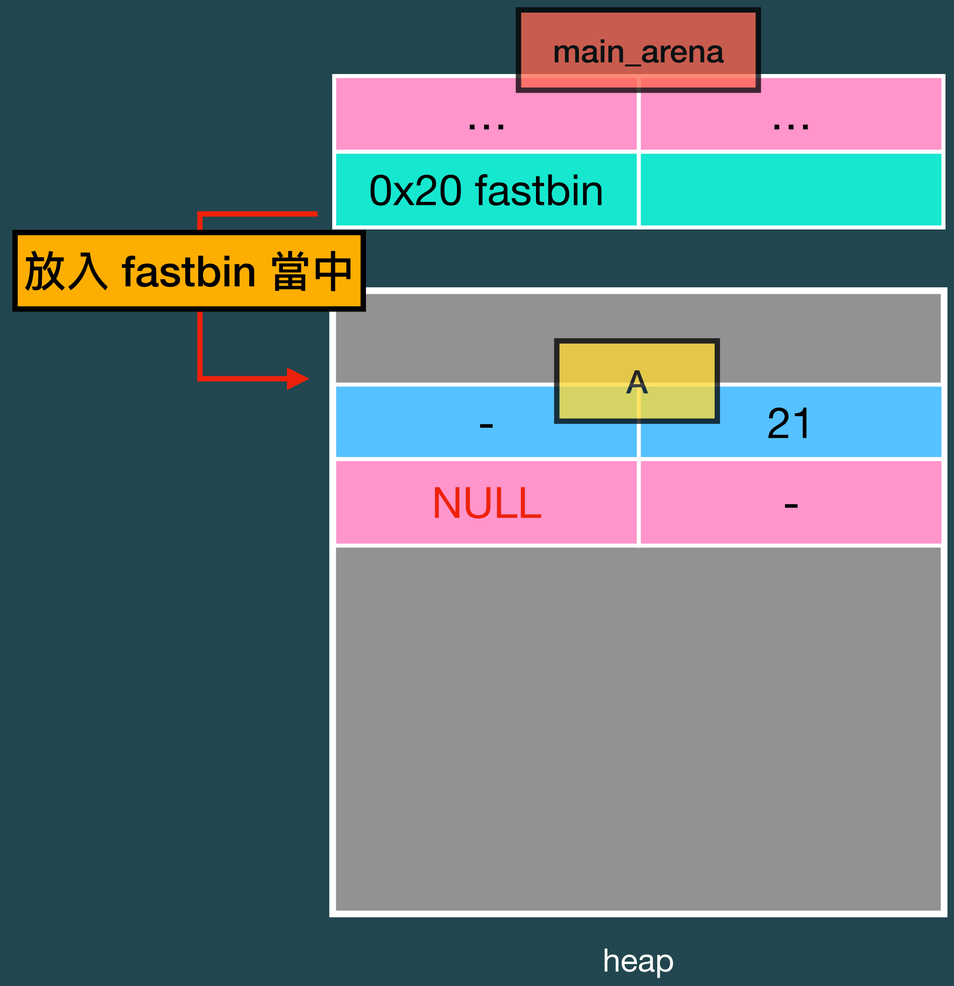
```
free(A);
free(A);
```



$ Vulnerability

Double Free - Example

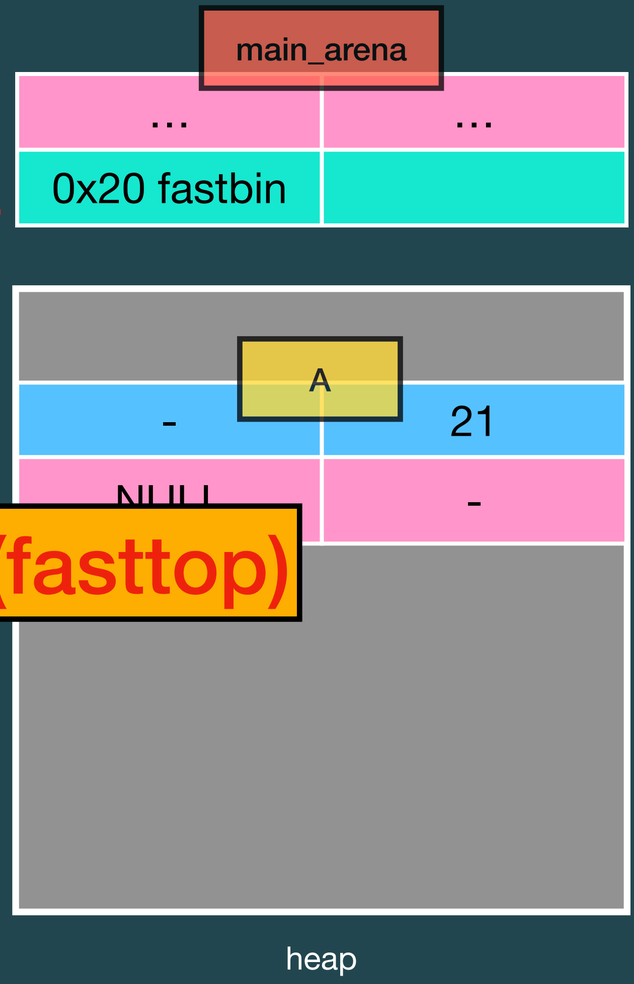
```
free(A);
free(A);
```



$ Vulnerability

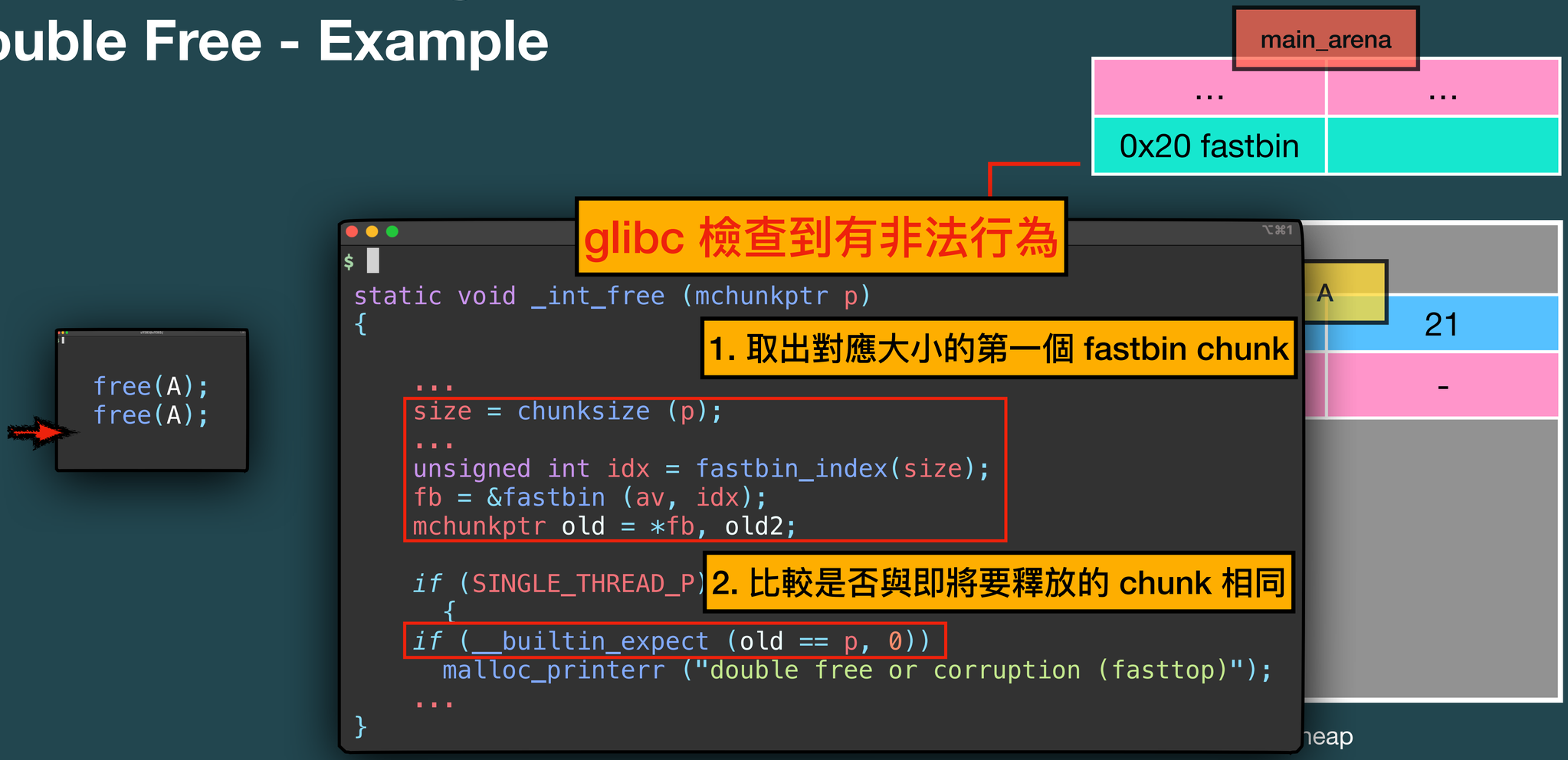
Double Free - Example

double free or corruption (fasttop)



$ Vulnerability

Double Free - Example

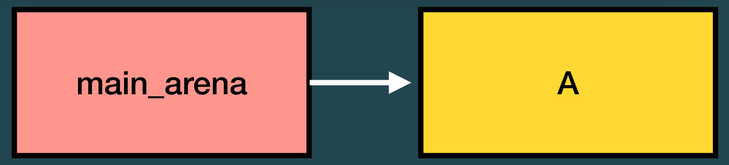


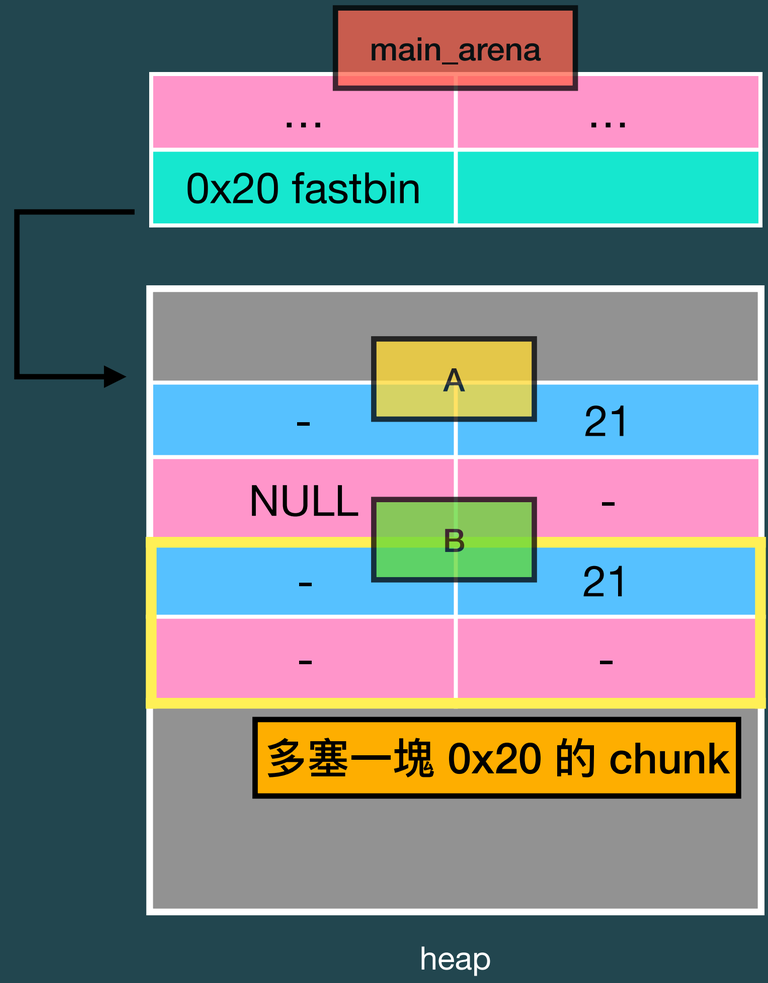
https://elixir.bootlin.com/glibc/glibc-2.31/source/malloc/malloc.c#L4263

$ Vulnerability

Double Free - Example

```
free(A);
free(B);
free(A);
// clean tcache
A = malloc(0x10);
*A = 0xdeadbeef;
malloc(0x10);
malloc(0x10);
malloc(0x10); // 0xdeadbeef
```

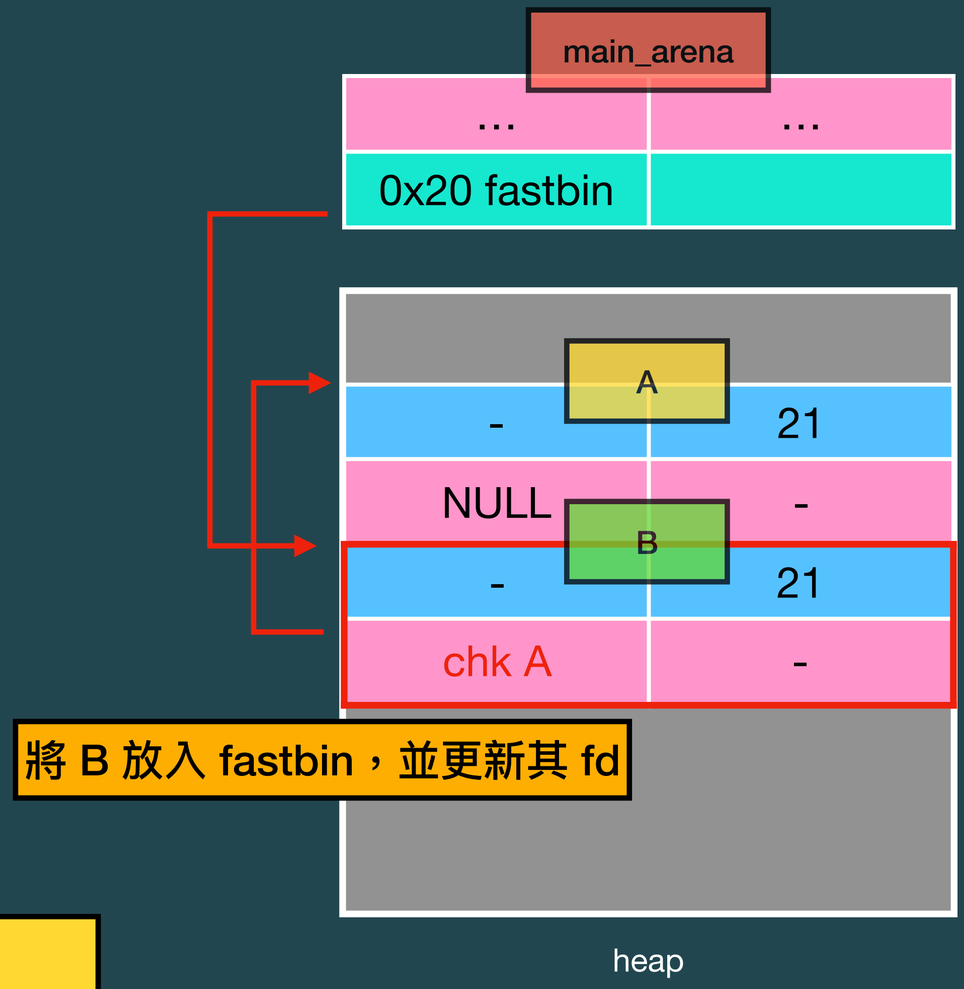




$ Vulnerability

Double Free - Example

```
free(A);
free(B);
free(A);
// clean tcache
A = malloc(0x10);
*A = 0xdeadbeef;
malloc(0x10);
malloc(0x10);
malloc(0x10); // 0xdeadbeef
```



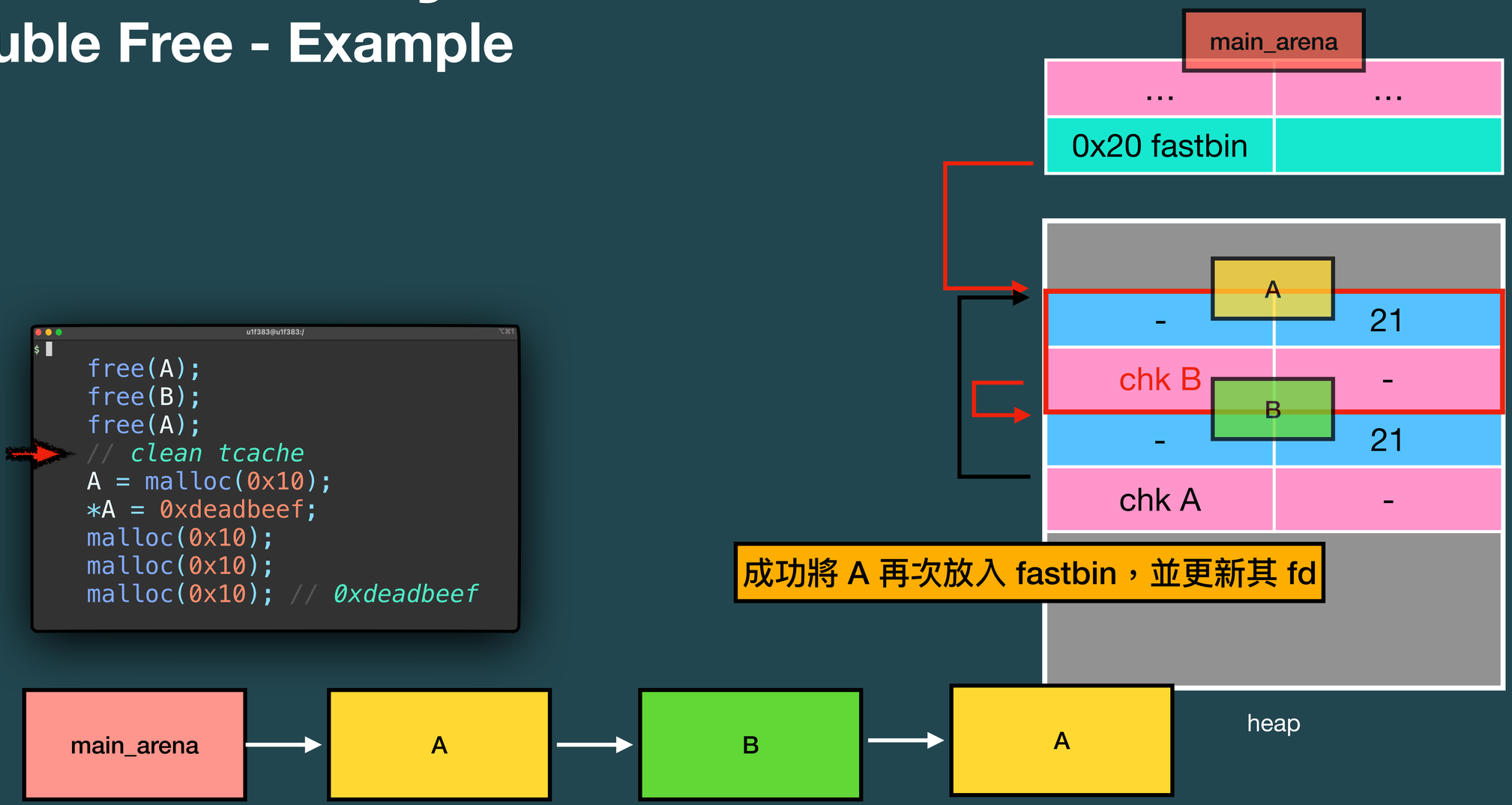
$ Vulnerability

Double Free - Example

$ Vulnerability

Double Free - Example

```
free(A);
free(B);
free(A);
// clean tcache
A = malloc(0x10);
*A = 0xdeadbeef;
malloc(0x10);
malloc(0x10);
malloc(0x10); // 0xdeadbeef
```

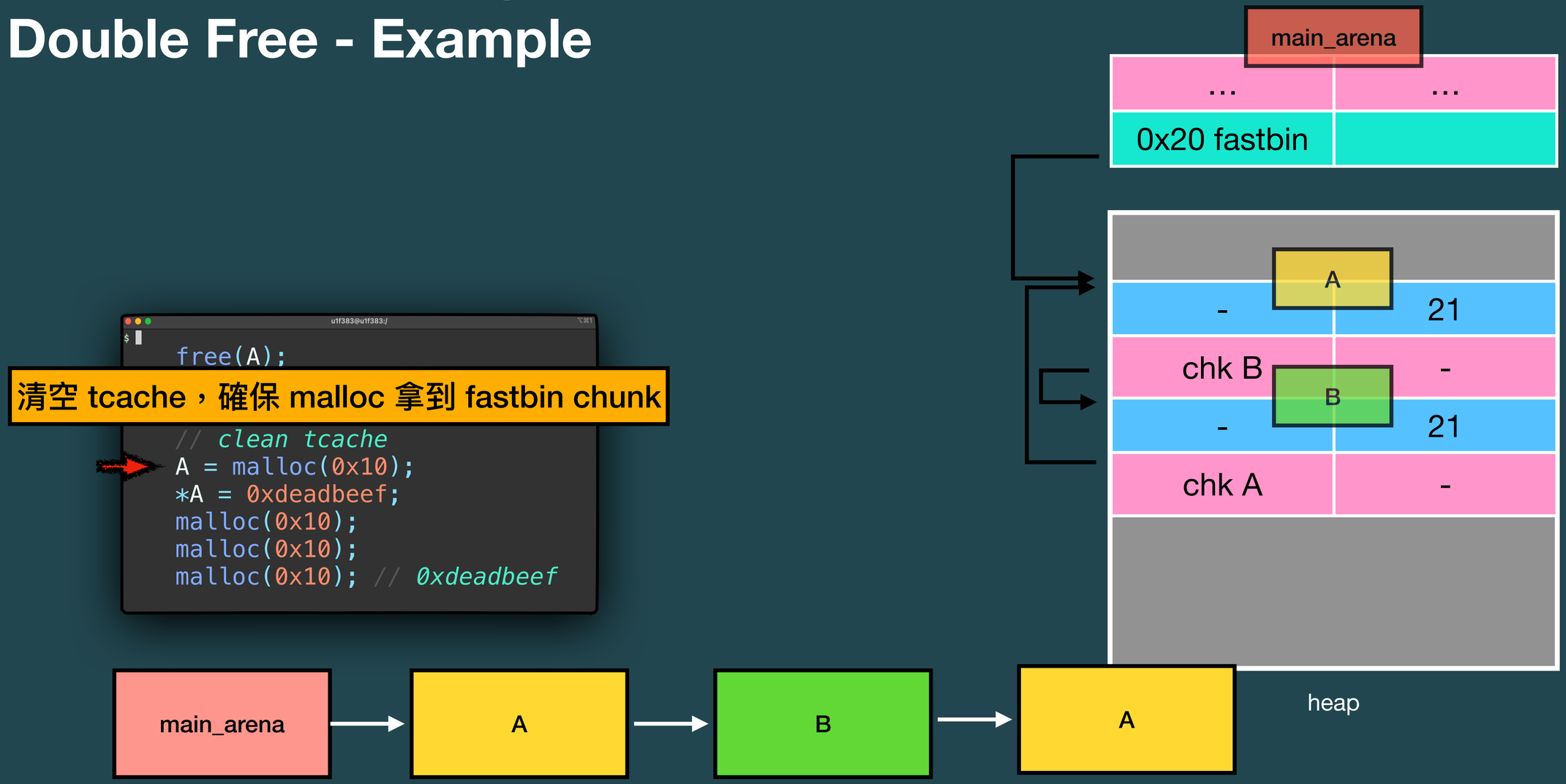


$ Vulnerability

Double Free - Example

```
free(A);
// clean tcache
A = malloc(0x10);
*A = 0xdeadbeef;
malloc(0x10);
malloc(0x10);
malloc(0x10); // 0xdeadbeef
```

清空 tcache，確保 malloc 拿到 fastbin chunk

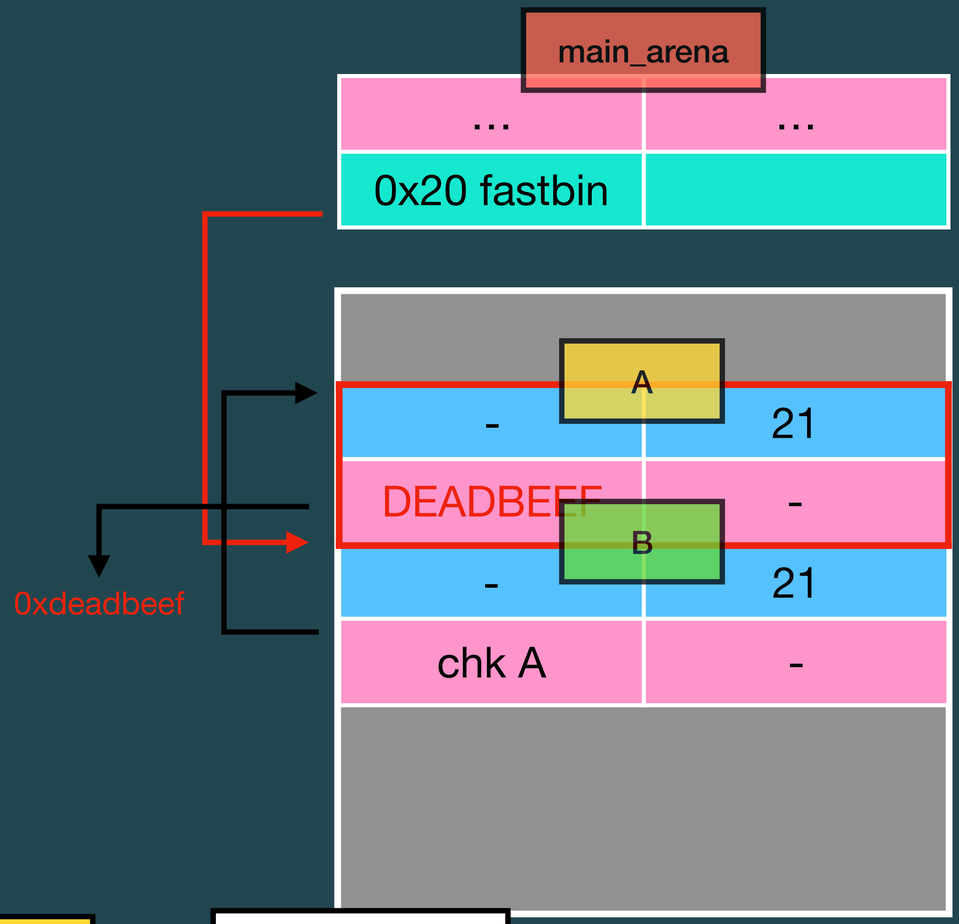


$ Vulnerability

Double Free - Example

```
free(A);
free(B);
A = malloc(0x10);
*A = 0xdeadbeef;
malloc(0x10);
malloc(0x10);
malloc(0x10); // 0xdeadbeef
```

取出 chk A，並且將 fd 改成 0xdeadbeef

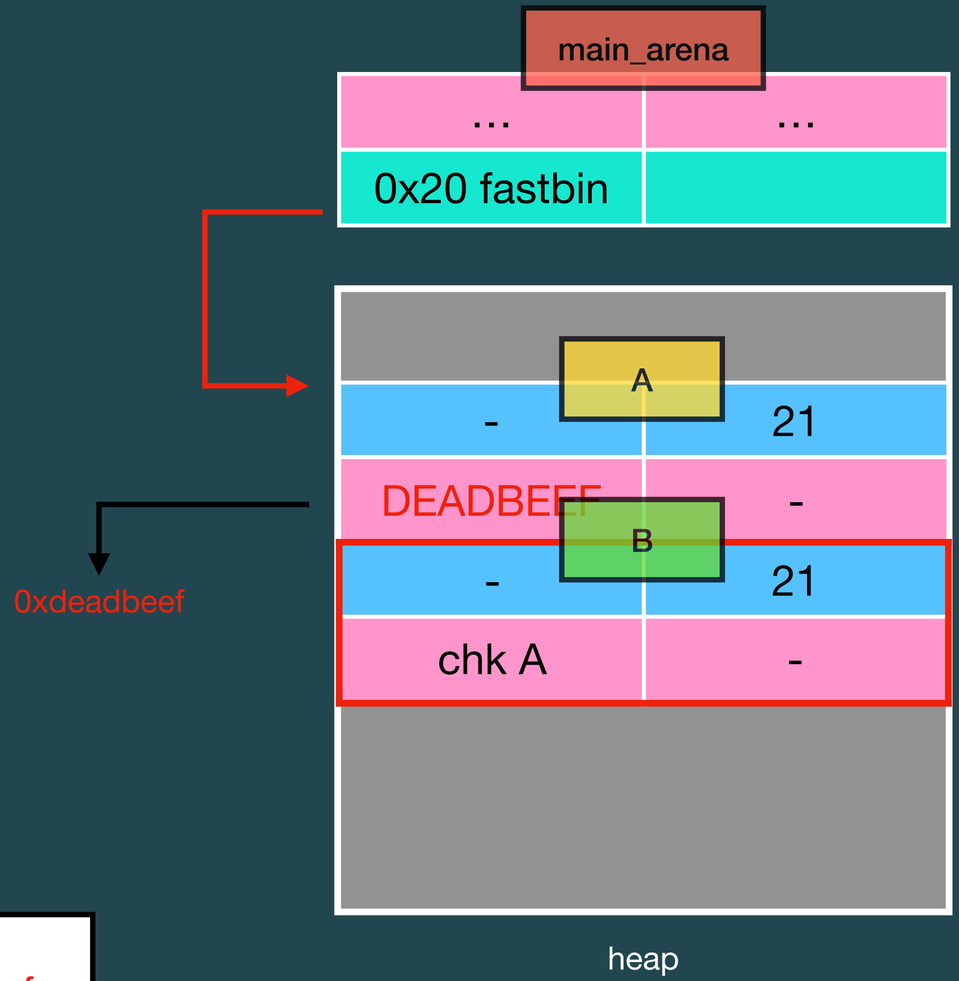


$ Vulnerability

Double Free - Example

```
free(A);
free(B);
free(A);
// clean tcache
A = malloc(0x10);
*A = 0xdeadbe
malloc(0x10);
malloc(0x10);
malloc(0x10); // 0xdeadbeef
```

取出 chk B

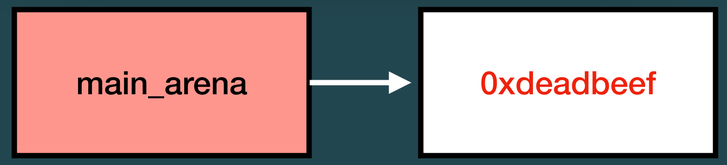


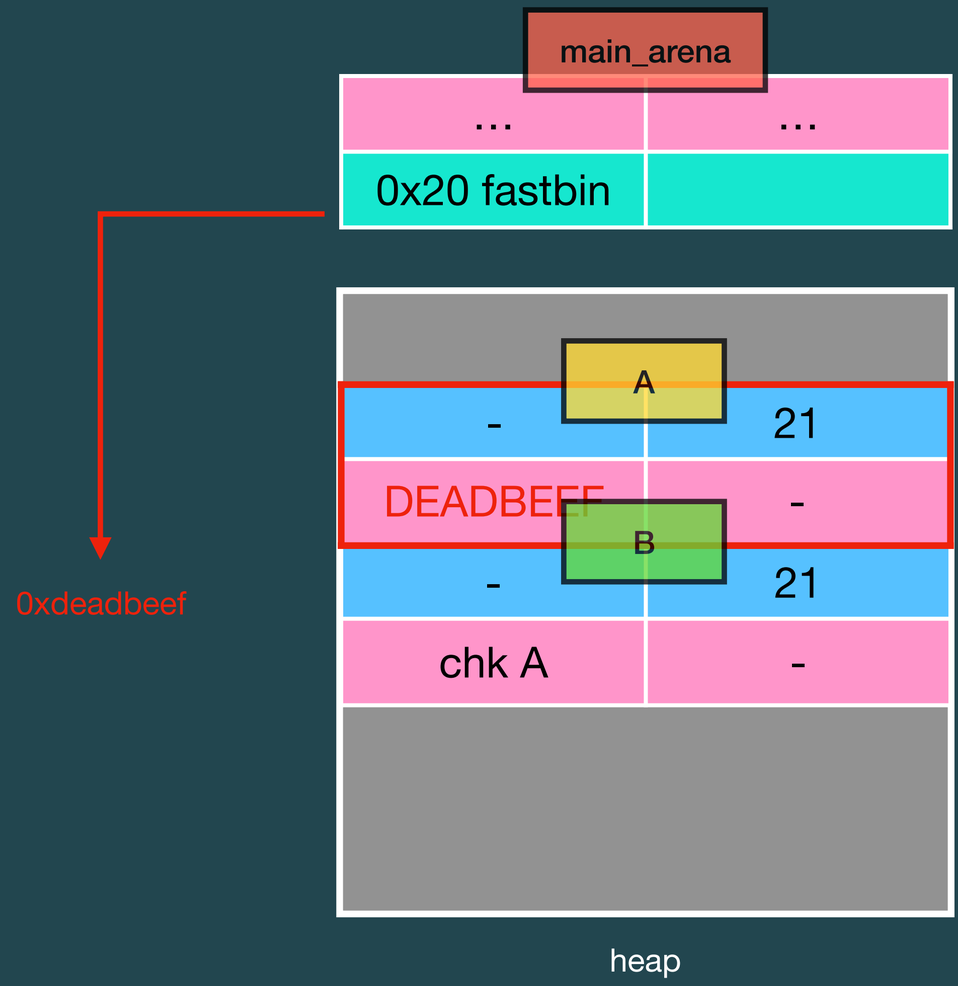
$ Vulnerability

Double Free - Example

```
free(A);
free(B);
free(A);
// clean tcache
A = malloc(0x10);
*A = 0xdeadbeef;
malloc(0x10); // 0xdeadbeef
```

再次取出 chk A，此時 0x20 fastbin 指向 0xdeadbeef



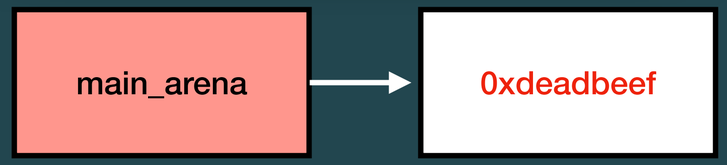


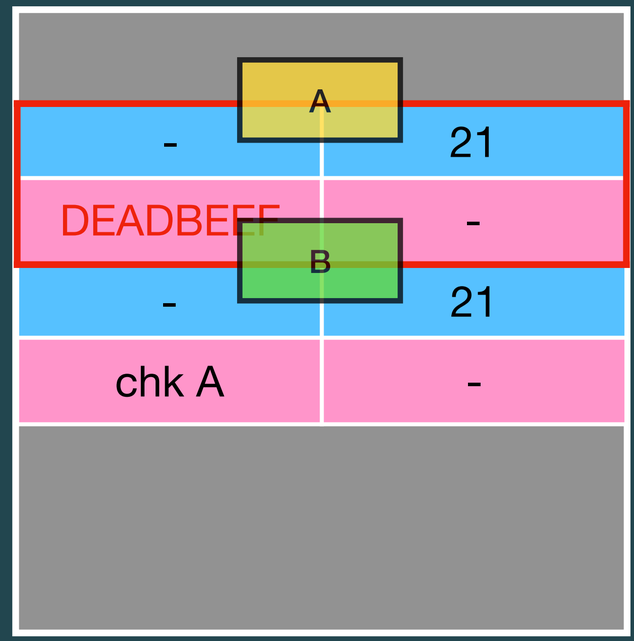
$ Vulnerability

Double Free - Example

```
free(A);
free(B);
free(A);
// clean tcache
A = malloc(0x10);
*A = 0xdeadbeef;
malloc(0x10);
malloc(0x10);
malloc(0x10); // 0xdeadbeef
```

程式 crash，因為 0xdeadbeef 為 invalid address





heap

$ Vulnerability

$ Vulnerability

Lab - Market

- 程式設計中需要好好的初始化，並且在釋放記憶體時清除相關敏感資料
- 若初始化的流程是使用者可以控制的，則很有可能透過殘留在記憶體內的資料做利用

Exploitation goal

$ Exploitation goal

hook

- 跟記憶體分配相關的 function 都可以加上 hook 來自定義行為
- 常見的有 __free_hook、__malloc_hook 以及 __realloc_hook
- 透過定義這些 hook ，可以讓程式在呼叫 hooked function 時，跳轉至我們在 hook 中所寫入的位址

$ Exploitation goal

__free_hook

- __free_hook 不為 NULL 時，內容可以作為 function pointer 取代 free 的行為
- 例如寫入 system 的位址後，若 chunk 內容為 “/bin/sh”，則在呼叫 free 時會變成執行 system(“/bin/sh”)

u1f383@u1f383:/ ⌥⌘1

```
$
void
__libc_free (void *mem)
{
  mstate ar_ptr;
  mchunkptr p;                          /* chunk corresponding to mem */

  void (*hook) (void *, const void *)
    = atomic_forced_read (__free_hook);
    if (__builtin_expect (hook != NULL, 0))
    {
      (*hook)(mem, RETURN_ADDRESS (0));
      return;
    }
  ...
}
```

$ Exploitation goal

__malloc_hook, __realloc_hook

- __malloc_hook 與 __realloc_hook 不為 NULL 時，內容可以作為 function pointer 取代 malloc / realloc 的行為
- 寫入 one gadget，在呼叫 malloc / realloc 時被 trigger

u1f383@u1f383:/

```
$
void *
__libc_malloc (size_t bytes)
{
  mstate ar_ptr;
  void *victim;

  _Static_assert (PTRDIFF_MAX <= SIZE_MAX / 2,
                  "PTRDIFF_MAX is not more than half of SIZE_MAX");

  void *(*hook) (size_t, const void *)
    = atomic_forced_read (__malloc_hook);
  if (__builtin_expect (hook != NULL, 0))
    return (*hook)(bytes, RETURN_ADDRESS (0));
  ...
}
```

__malloc_hook

u1f383@u1f383:/

```
$
void *
__libc_realloc (void *oldmem, size_t bytes)
{
  mstate ar_ptr;
  INTERNAL_SIZE_T nb;         /* padded request size */

  void *newp;             /* chunk to return */

  void *(*hook) (void *, size_t, const void *) =
    atomic_forced_read (__realloc_hook);
  if (__builtin_expect (hook != NULL, 0))
    return (*hook)(oldmem, bytes, RETURN_ADDRESS (0));
  ...
}
```

__realloc_hook

Exploitation tech

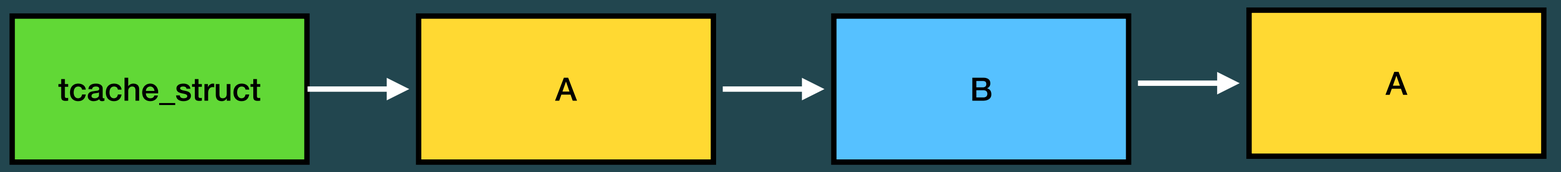
$ Exploitation tech

- 由於攻擊手法會根據功能跟情況有所不同，在此只介紹 how2heap repo 所記錄 glibc-2.31 的攻擊方法中，常見的三種利用方式
  - Tcache poisoning
  - Fastbin attack (fastbin dup)
  - Overlapping chunks

$ Exploitation tech

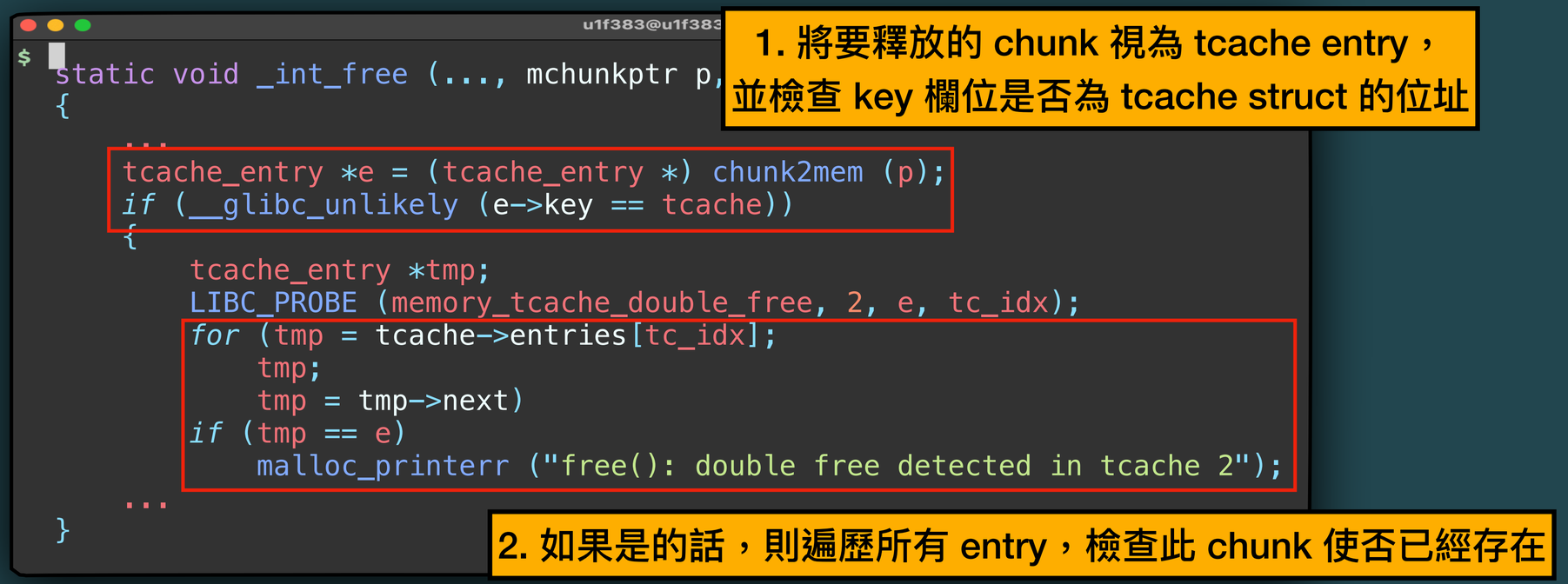
Tcache poisoning

- **Explanation** - 使用 double free 讓 tcache 當中存在兩個相同的 chunk，並利用修改 fd 的方式，將對應位址視為 chunk 分配給 user
  - Tcache 拿 chunk 時並不會檢查 chunk size 是否合法，因此常會拿 __free_hook 寫 system
- **Protection1** - 當釋放 chunk 時，如果 chunk + 8 (key) 位置的值與當前 heap 的 &tcache_struct 相等，則會遍歷所有 entry，檢查是否有相同的 chunk，確保沒有 double free 的發生



$ Exploitation tech

Tcache poisoning

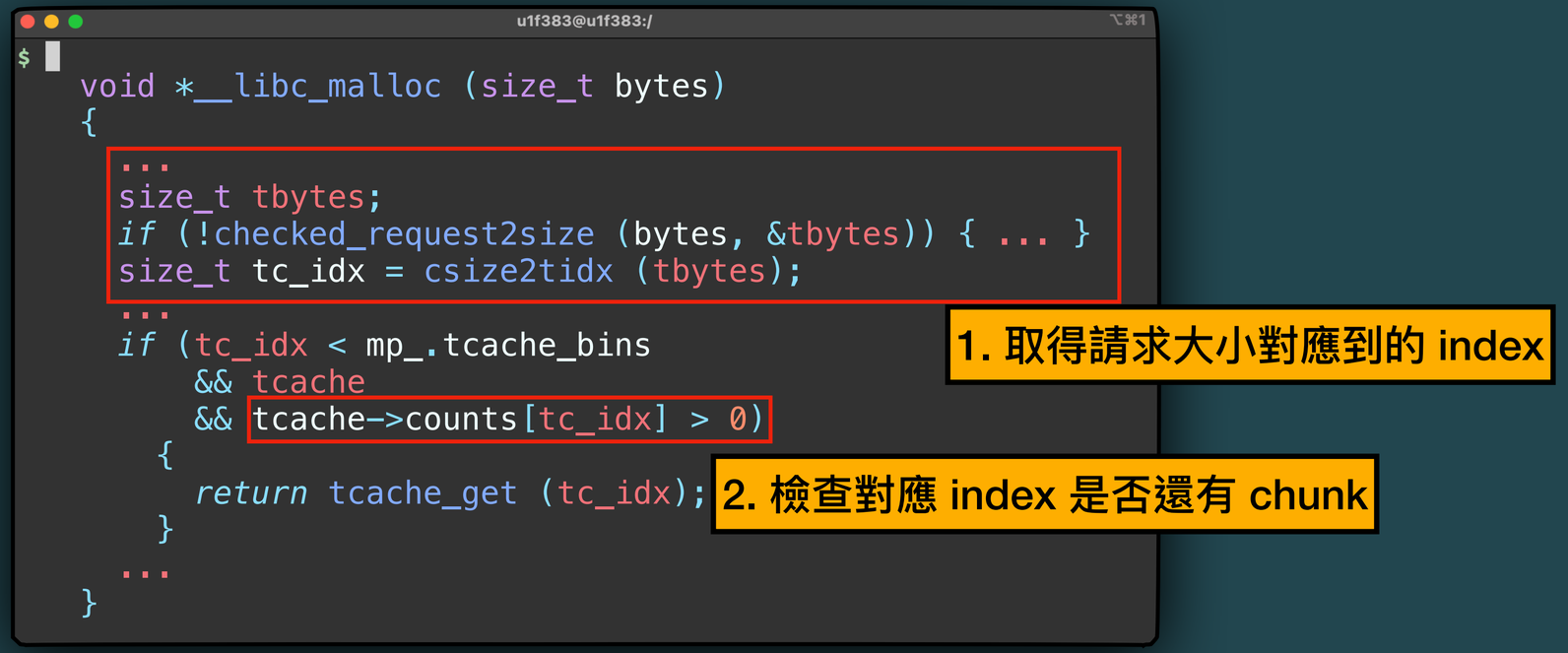


https://elixir.bootlin.com/glibc/glibc-2.31/source/malloc/malloc.c#L4187

$ Exploitation tech

Tcache poisoning

- **Protection2** - 當取出 chunk 時，會檢查對應大小的 counter 是否大於 0，如果是的話才會取出 tcache_struct 當中指向的第一塊 chunk



https://elixir.bootlin.com/glibc/glibc-2.31/source/malloc/malloc.c#L3049

$ Exploitation tech

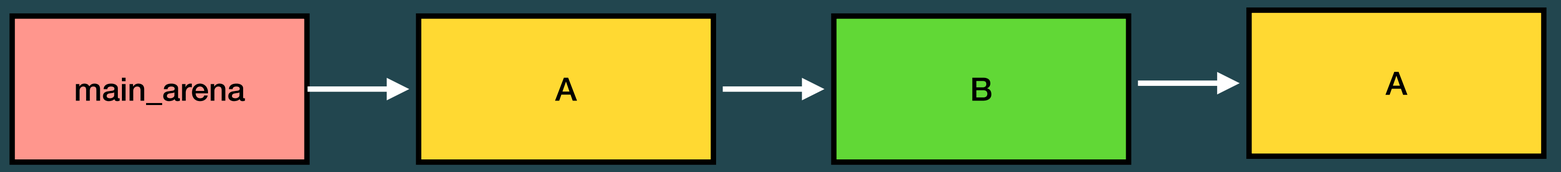
Tcache poisoning

- **Bypass Protection1** - 透過 UAF 或是 heap overflow，修改 chunk 的 key 欄位
- **Bypass Protection2**
  - 拿到 tcache_struct 的 chunk 後修改 counts 欄位成非 0 的值
  - 多次 free 相同的 chunk

$ Exploitation tech

Fastbin Attack

- **Explanation** - 使用 double free 讓 tcache 當中存在兩個相同的 chunk，並利用修改 fd 的方式，將對應位址視為 chunk 分配給 user
- **Protection1** - 當釋放 chunk 時，檢查 fastbin 的第一個 chunk 與此 chunk 是否相同，確保沒有 double free 的發生 (link)
- **Protection2** - 在取得 chunk 時，會檢查請求大小是否與被回傳的 chunk 的大小相同



$ Exploitation tech

Fastbin Attack

u1f383@u1f383:/

```
$ static void *_int_malloc (..., size_t bytes)
  {
    ...
    if (!checked_request2size (bytes, &nb)) { ... }
    if ((unsigned long) (nb) <= (unsigned long) (get_max_fast ()))
      {
        idx = fastbin_index (nb);
        mfastbinptr *fb = &fastbin (av, idx);
        mchunkptr pp;
        victim = *fb;

        if (victim != NULL)
      {
        *fb = victim->fd;
        if (__glibc_likely (victim != NULL))
          {
            size_t victim_idx = fastbin_index (chunksize (victim));
            if (__builtin_expect (victim_idx != idx, 0))
              malloc_printerr ("malloc(): memory corruption (fast)");
    ...
  }
```

1. 取得 chunk size，並檢查是否位於 fastbin 的範圍內

2. 取得第一個 fastbin chunk，存在變數 victim

3. 檢查 victim 對應到的 fastbin index 是否與當前請求的 size 相同，
舉例來說，請求 0x30 但是卻拿到 0x40 大小的 chunk

$ Exploitation tech

Fastbin Attack

- **Bypass Protection1** - 能利用 free(a); free(b); free(a); 的方式繞過檢查
- **Bypass Protection2**
  - 因為 library address 都為 **0x7f** 開頭，而 0x70 為合法的 fastbin size，因此可以通過 fastbin 的保護機制
  - 而 __malloc_hook 上方會有 library address，因此可以先取得上方的 chunk，在寫 one gadget 到 __malloc_hook 來做 exploit

$ Exploitation tech

Overlapping chunks

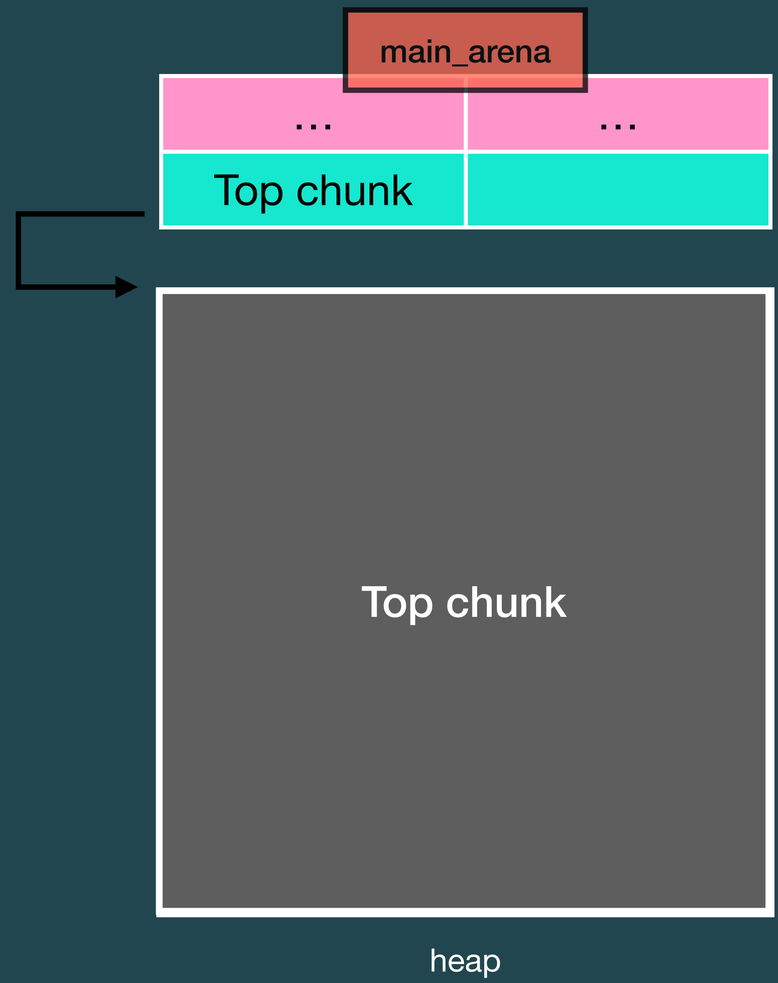
- **Explanation** - 透過修改 chunk size，讓 chunk 在被釋放時 trigger consolidation，使得正在使用的 chunk 與已經釋放的 chunk 有部分重疊，也就代表
  - 使用中的 chunk 可以更改 freed chunk 中的 fd、bk
  - freed chunk 在被分配時，會分配到與使用中的 chunk 相同的區塊，可以修改敏感資料
- **Consolidation** -當釋放記憶體時，若檢查到相鄰的 chunk 沒有被使用，會將其合併成一塊更大的 freed chunk
  - 為 glibc 用來減少 heap fragmentation 的機制
  - Chunk 在被合併前，會先透過 unlink 的機制來離開原本的 bin

$ Exploitation tech

Overlapping chunks

分配大小不會進 tcache 的 chunk A

```
$
A = malloc(0x410);
B = malloc(0x10);

*(A-1) = 0x421 + 0x20; // 0x20 == B 的 chunk size
free(A); // consolidate to top chunk

A = malloc(0x430);
total = (0x430 / 8);
A[total - 2] = 0xdeadbeef;
B[0] == 0xdeadbeef;
```

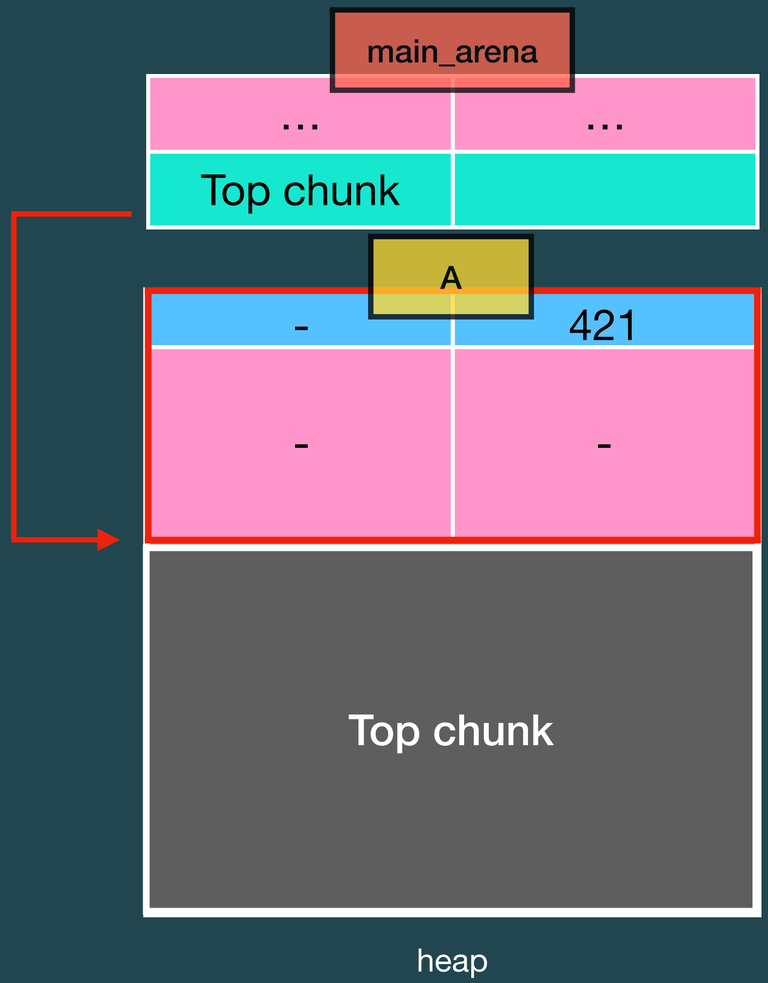


$ Exploitation tech

Overlapping chunks

```
u1f383@u1f383:/
$
A = malloc(0x
B = malloc(0x10);

*(A-1) = 0x421 + 0x20; // 0x20 == B 的 chunk size
free(A); // consolidate to top chunk

A = malloc(0x430);
total = (0x430 / 8);
A[total - 2] = 0xdeadbeef;
B[0] == 0xdeadbeef;
```

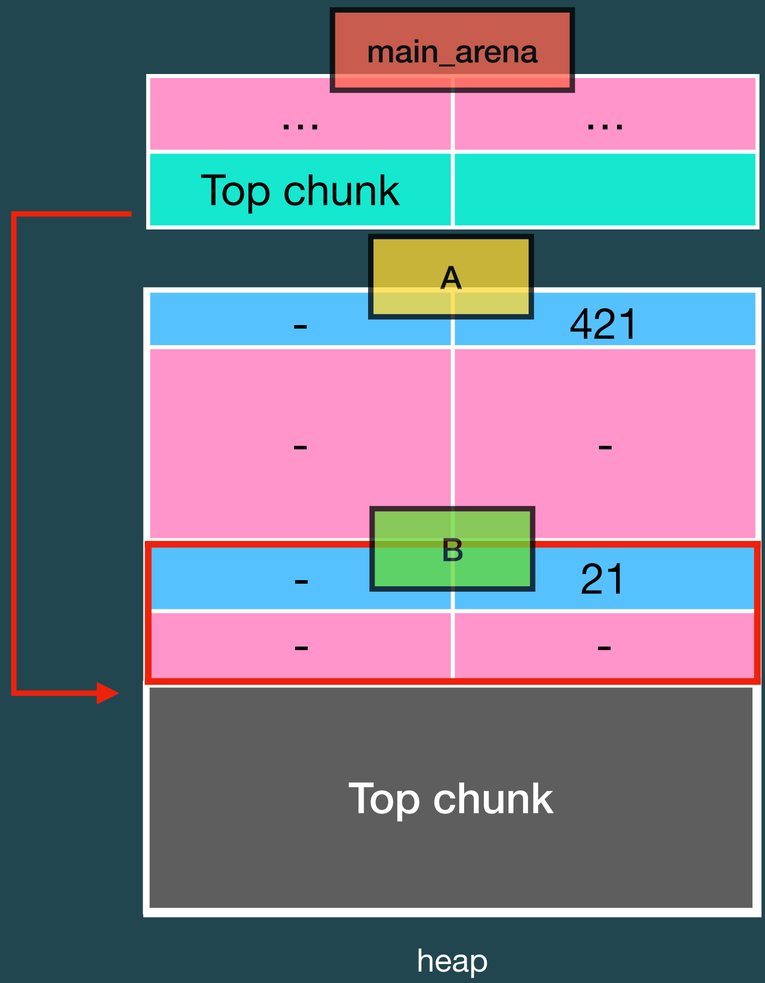
分配要被 overlap 的 chunk B



$ Exploitation tech

Overlapping chunks

```
u1f383@u1f383:/
$
A = malloc(0x410);
B = 修改 chunk size，剛好涵蓋整個 chunk B

*(A-1) = 0x421 + 0x20; // 0x20 == B 的 chunk size
free(A); // consolidate to top chunk

A = malloc(0x430);
total = (0x430 / 8);
A[total - 2] = 0xdeadbeef;
B[0] == 0xdeadbeef;
```



$ Exploitation tech

Overlapping chunks

u1f383@u1f383:/ ⌥⌘1

```
$ 
static void _int_free (..., mchunkptr p, ...)
{
  ...
  size = chunksize (p);
  ...
  else if (!chunk_is_mmapped(p)) {
    ...
    /* consolidate backward */
    if (!prev_inuse(p)) {
      // ... some operation
      unlink_chunk (av, p);
    }
    ...
    if (nextchunk != av->top) {
      nextinuse = inuse_bit_at_offset(nextchunk, nextsize);
      /* consolidate forward */
      if (!nextinuse) {
        unlink_chunk (av, nextchunk);
        size += nextsize;
      }
      ...
    } else { /* consolidate with top chunk */
      size += nextsize;
      set_head(p, size | PREV_INUSE);
      av->top = p;
      check_chunk(av, p);
    }
    ...
}
```

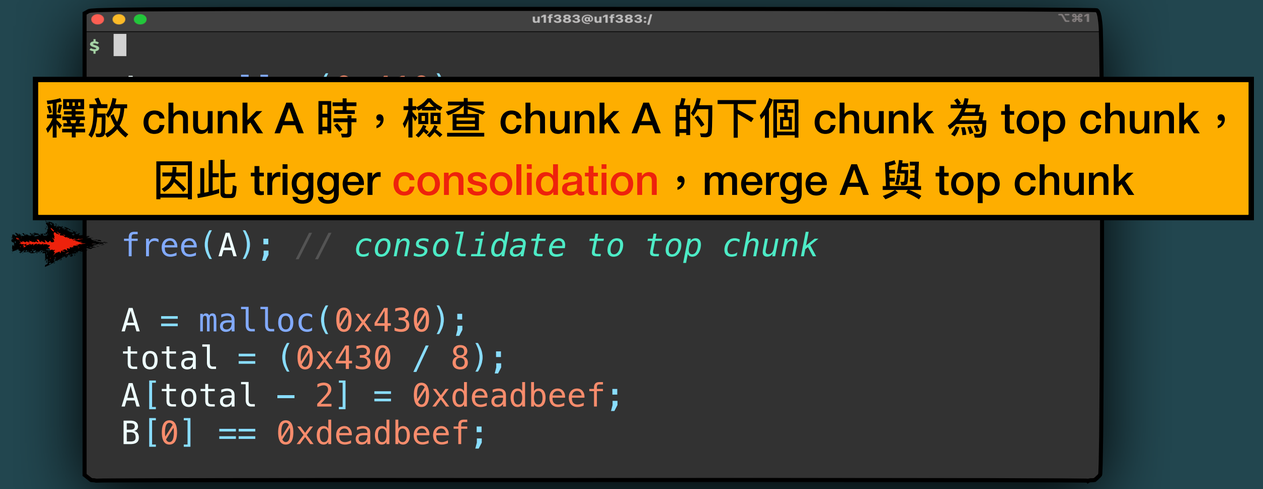
1. 當前一塊 chunk 沒有在使用，則 trigger consolidate，並且用 unlink_chunk 來離開 bin

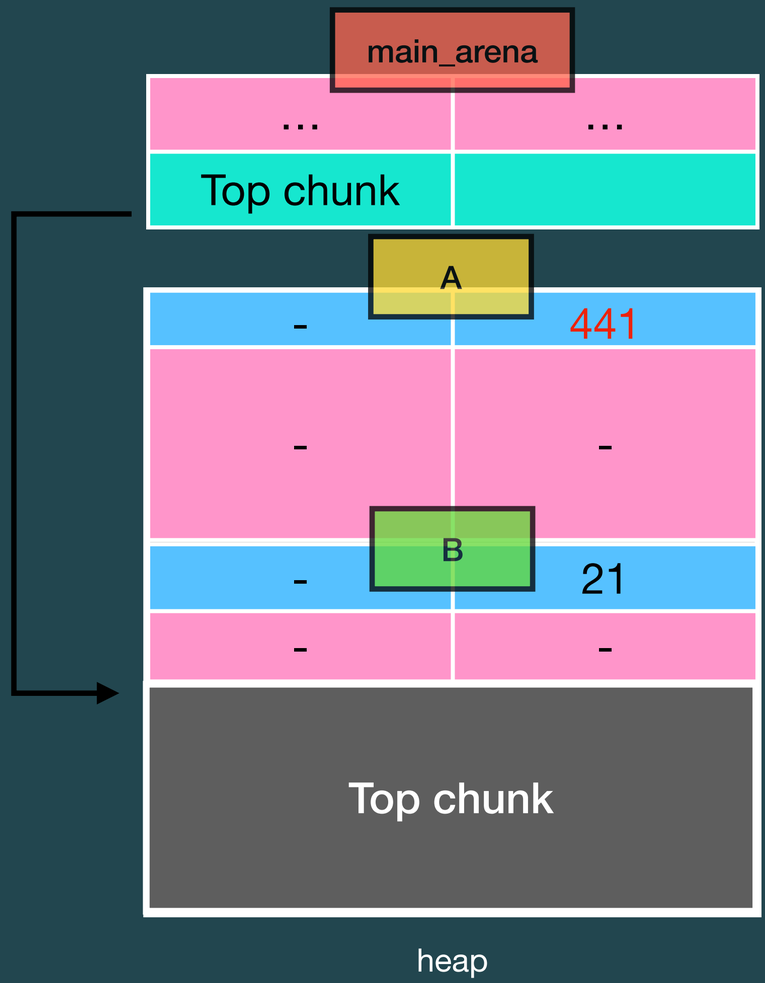
2. 下一塊 chunk 沒在用，並且不是 top chunk 的話，一樣 trigger consolidate

3. 如果下一塊是 top chunk，則與 top chunk 做 consolidate

$ Exploitation tech

Overlapping chunks



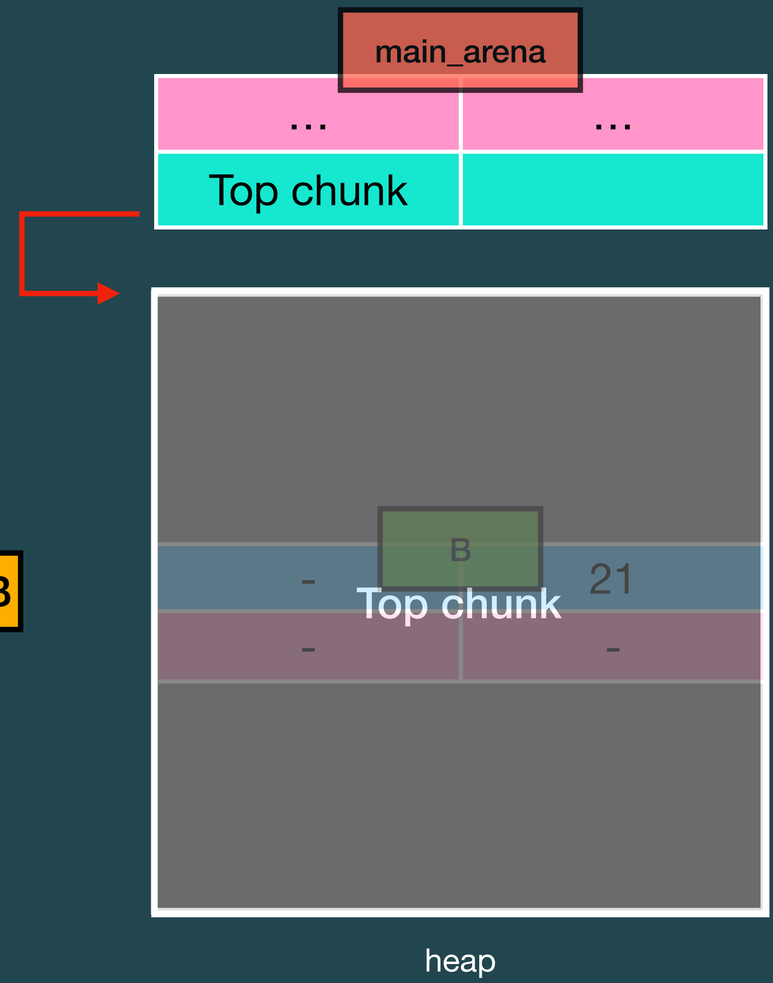


$ Exploitation tech

Overlapping chunks

```
u1f383@u1f383:/
$
A = malloc(0x410);
B = malloc(0x10);

*(A-1) = 0x421 + 0x20; // 0x20 == B 的 chunk size

A = malloc(0x430);
total = (0x430 / 8);
A[total - 2] = 0xdeadbeef;
B[0] == 0xdeadbeef;
```

此時 B 已經包含在 top chunk，分配 0x440 大小的 chunk 會包含 chunk B

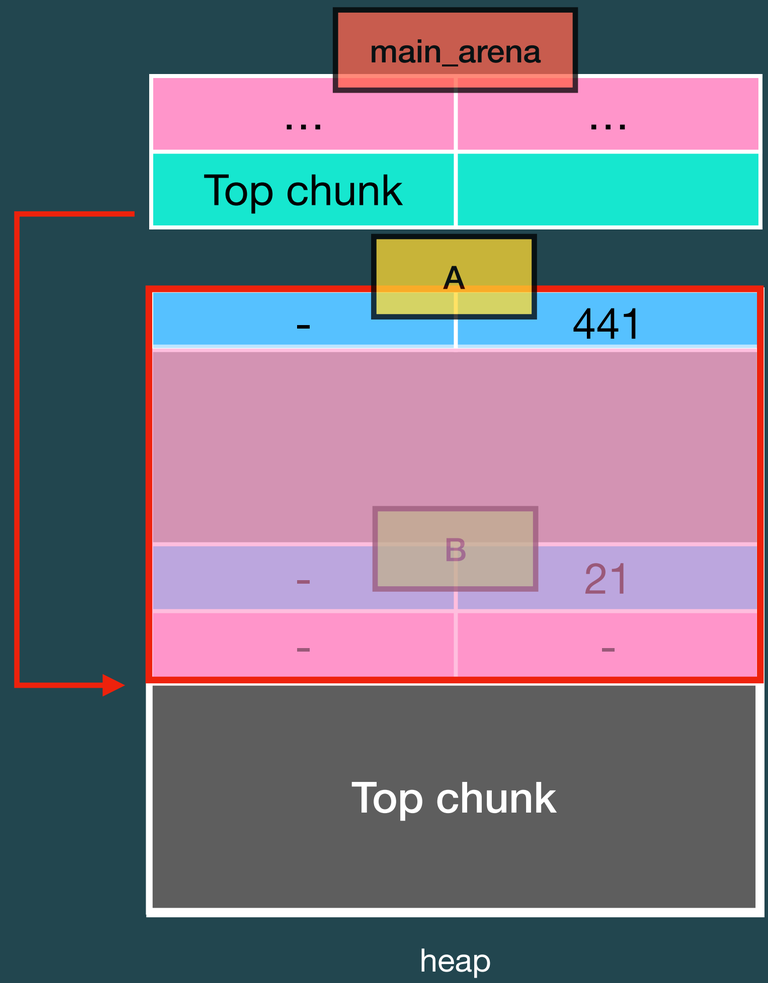


$ Exploitation tech

Overlapping chunks

```
u1f383@u1f383:/
$
A = malloc(0x410);
B = malloc(0x10);

*(A-1) = 0x421 + 0x20; // 0x20 == B 的 chunk size
free(A); // consolidate to top chunk
A = malloc(0x430);
total = (0x430 / 8);
A[total - 2] = 0xdeadbeef;
B[0] == 0xdeadbeef;
```

當修改 chunk A 時，chunk B 也會受到影響

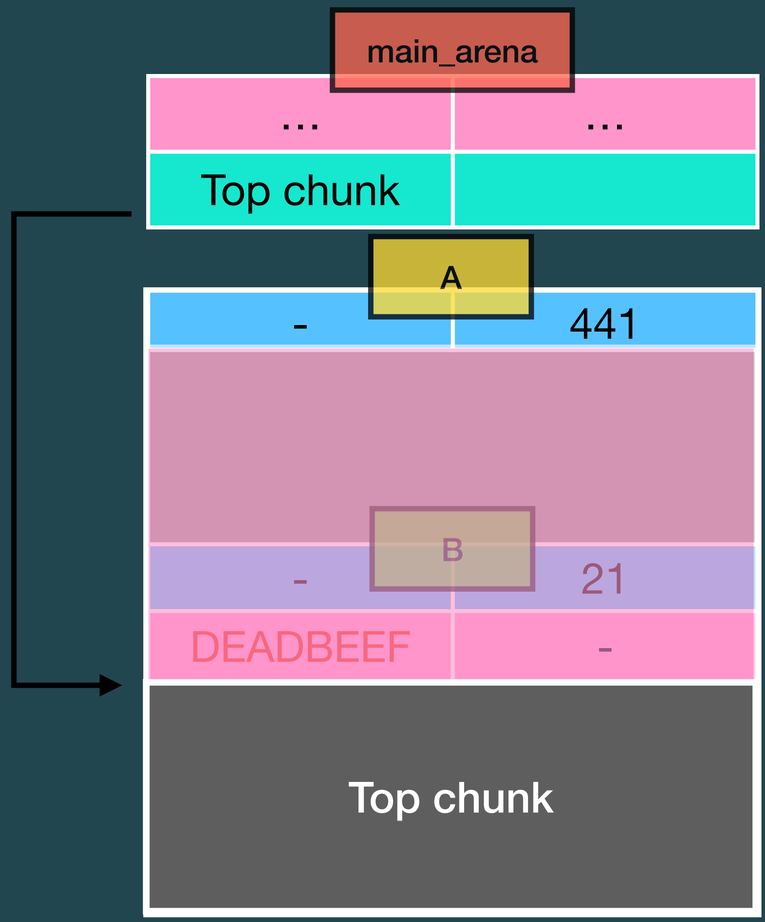


$ Exploitation tech

Overlapping chunks

```
u1f383@u1f383:/
$
A = malloc(0x410);
B = malloc(0x10);

*(A-1) = 0x421 + 0x20; // 0x20 == B 的 chunk size
free(A); // consolidate to top chunk

A = mal
total =
A[total
B[0] == 0xdeadbeef;
```

此範例中單純蓋寫 chunk B 的資料，
而 size 或是 fd 也是很好的利用點



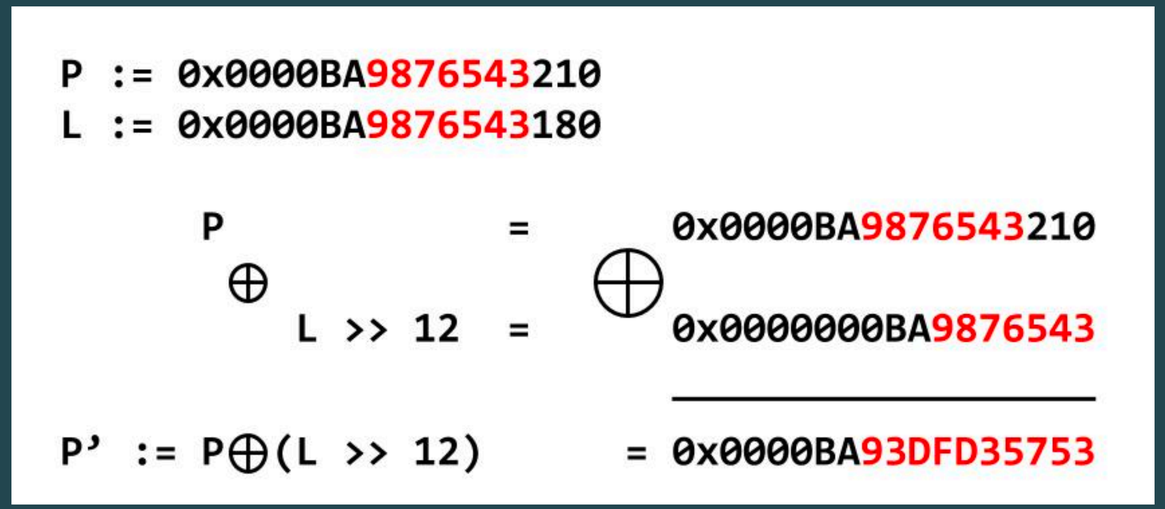
heap

Safe linking

$ Safe linking

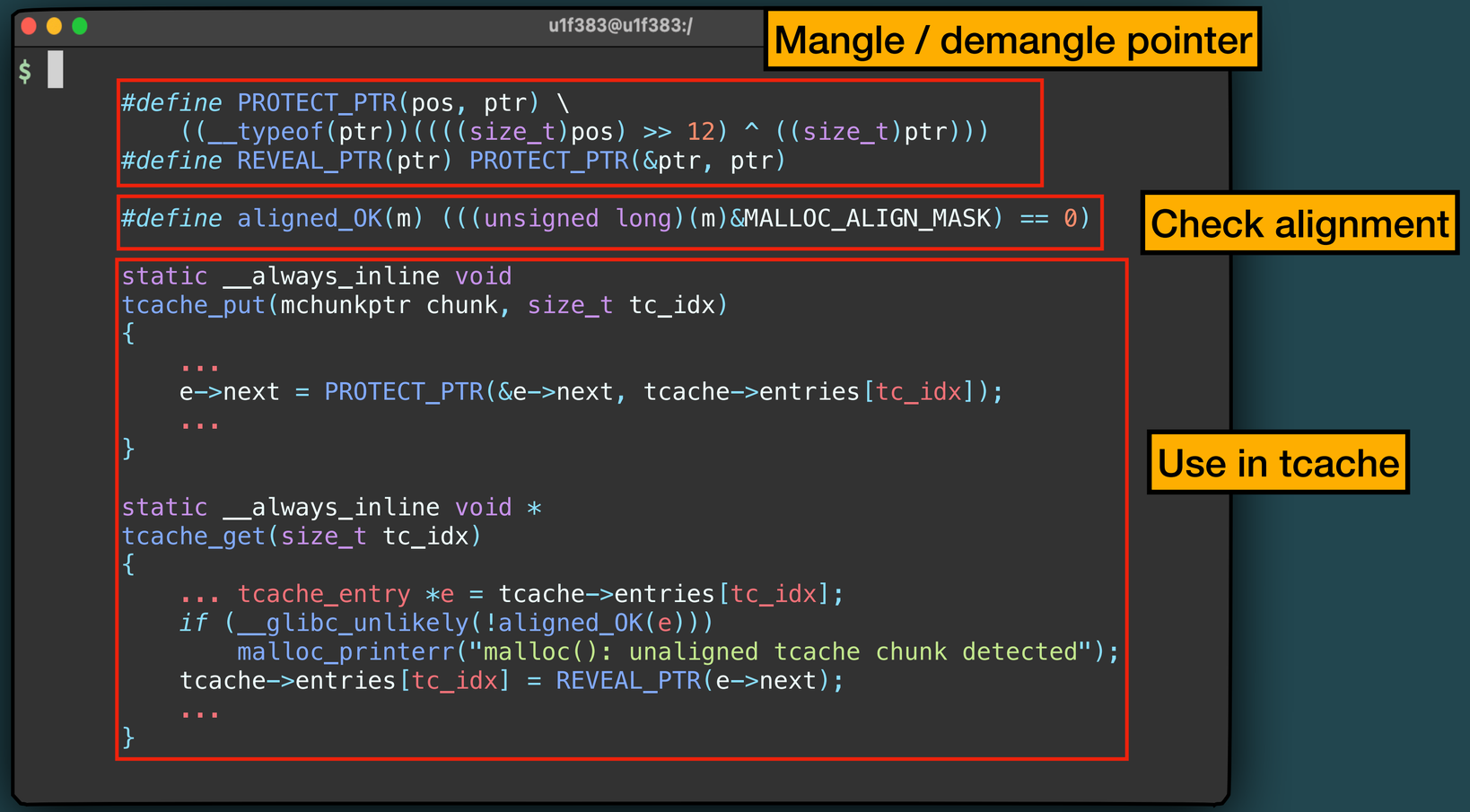
Introduction

- 在 glibc 2.32 引入，會將 tcache 的 next 與 fastbin 的 fd 的 pointer 與所在位址的 >> 12 做 XOR
- 從 tcache 取出 entry 時，會檢查位址是否對齊 0x10
- 下圖 **P** 為 chunk 存放的 pointer value ； **L** 為 chunk 位址



$ Safe linking

Introduction



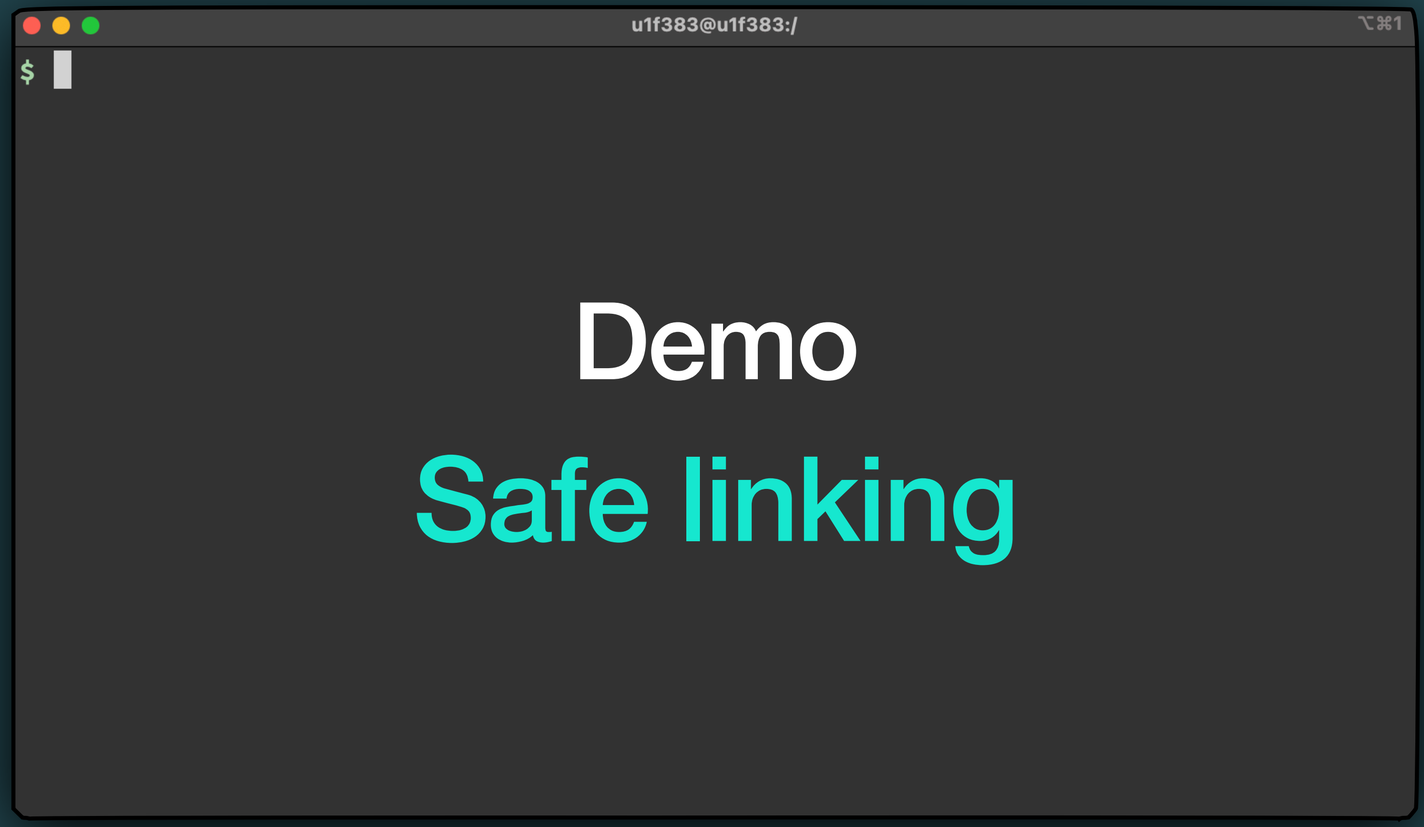
$ Safe linking

Bypass

- 如果 tcache chunk 的 next 欄位為 NULL，則 xor 就是直接存放 heap >> 12
  - 從 tcache 取出 chunk 時並不會清空 next 欄位，因此 chunk 會殘留 heap >> 12 的值
- 若可以控制 tcache_perthread_struct，其內部會直接存放沒有做 XOR 的 heap pointer，也可以拿來利用

$ Safe linking

Bypass



How2heap tech

$ How2heap tech

	2.31	2.32	2.34
fastbin_dup	✅	✅	✅
fastbin_reverse_into_tcache	✅	✅	✅
house_of_botcake	✅	✅	✅
house_of_einherjar	✅	✅	✅
house_of_lore	✅	✅	✅
house_of_mind_fastbin	✅	✅	✅
large_bin_attack	✅	✅	✅
mmap_overlapping_chunks	✅	✅	✅
overlapping_chunks	✅	✅	✅
poison_bull_byte	✅	✅	✅
tcache_house_of_spirit	✅	✅	✅
tcache_poisoning	✅	✅	✅
tcache_stashing_unlink_attack	✅	✅	✅
unsafe_unlink	✅	✅	✅
decrypt_safe_linking		✅	✅

$ How2heap tech

Tcache stashing (fastbin_reverse_into_tcache)

u1f383@u1f383:/ ⌥⌘1

```
$
        size_t victim_idx = fastbin_index(chunksize(victim));
        if (__builtin_expect(victim_idx != idx, 0))
            malloc_printerr("malloc(): memory corruption (fast)");
        check_remalloced_chunk(av, victim, nb);
        /* While we're here, if we see other chunks of the same size,
            stash them in the tcache.  */
        size_t tc_idx = csize2tidx(nb);
        if (tcache && tc_idx < mp_.tcache_bins)
        {
            mchunkptr tc_victim;

            /* While bin not empty and tcache not full, copy chunks.  */
            while (tcache->counts[tc_idx] < mp_.tcache_count && (tc_victim = *fb) != NULL)
            {
                if (SINGLE_THREAD_P)
                    *fb = tc_victim->fd;
                else
                {
                    REMOVE_FB(fb, pp, tc_victim);
                    if (__glibc_unlikely(tc_victim == NULL))
                        break;
                }
                tcache_put(tc_victim, tc_idx);
            }
        }
        void *p = chunk2mem(victim);
        alloc_perturb(p, bytes);
        return p;
```

1. 在從 fastbin 取得 chunk 並回傳前，會檢查 tcache 是否滿了

2. 如果還沒滿，就取出來剩下的 fastbin chunk 放到 tcache，直到 tcache 滿了或 fastbin 沒了

$ How2heap tech

Smallbin stashing (tcache_stashing_unlink_attack) & House of lore

u1f383@u1f383:/ ⌥⌘1

```
$
```

```
if (in_smallbin_range(nb))
{
    idx = smallbin_index(nb);
    bin = bin_at(av, idx);

    if ((victim = last(bin)) != bin)
    {
        bck = victim->bk;
        if (__glibc_unlikely(bck->fd != victim))
            malloc_printerr("malloc(): smallbin double linked list corrupted");
        set_inuse_bit_at_offset(victim, nb);
        bin->bk = bck;
        bck->fd = bin;
    }
     ...
}
...
```

從 smallbin 取出 chunk 時，會檢查 victim->bk->fd == victim，
也就是自己的下一塊 chunk 的 fd 是否指向自己

$ How2heap tech

Smallbin stashing (tcache_stashing_unlink_attack) & House of lore

u1f383@u1f383:/ ⌥⌘1

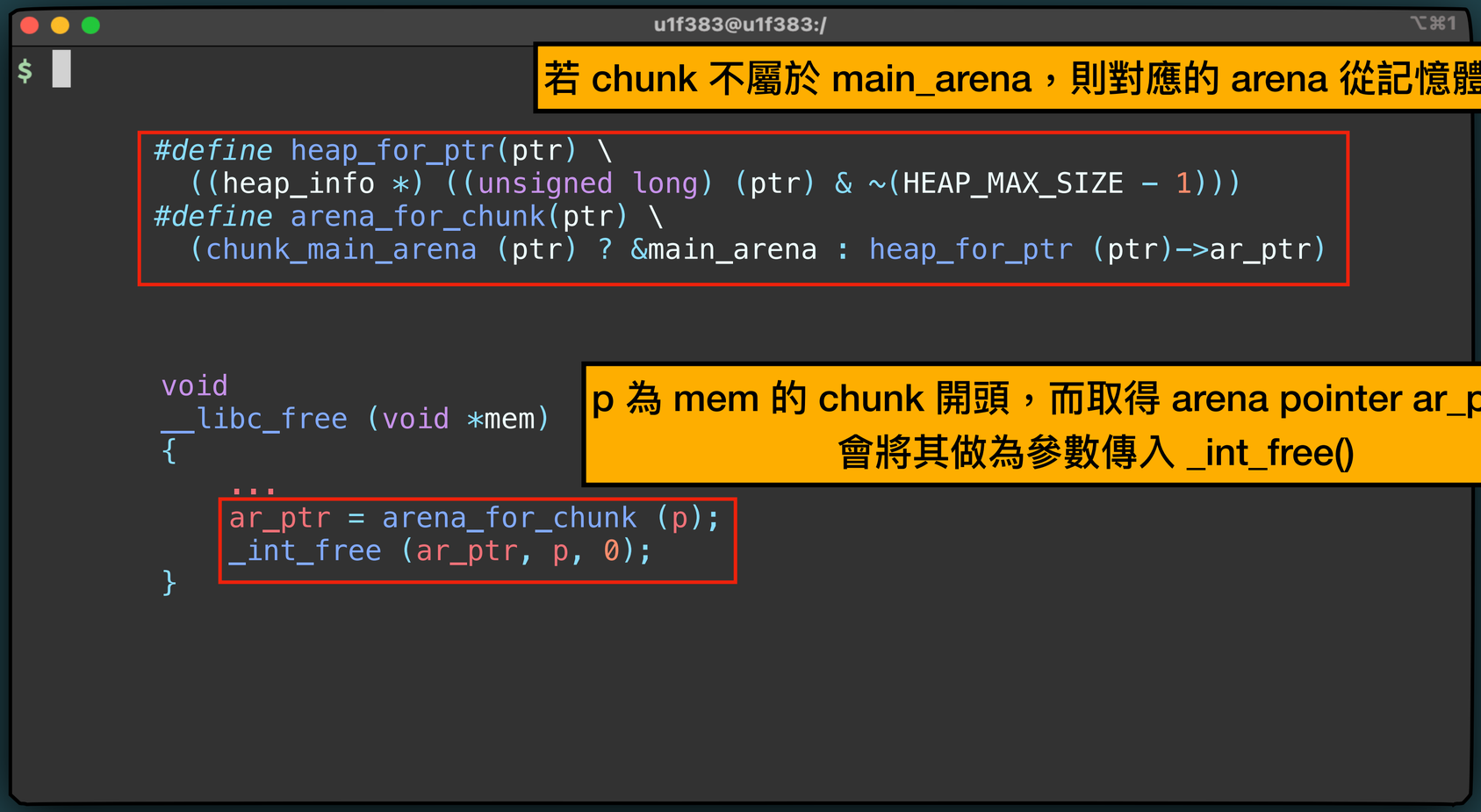
```
$
```

```
/* While we're here, if we see other chunks of the same size,
      stash them in the tcache.  */
size_t tc_idx = csize2tidx(nb);
if (tcache && tc_idx < mp_.tcache_bins)
{
    mchunkptr tc_victim;

    /* While bin not empty and tcache not full, copy chunks over.  */
    while (tcache->counts[tc_idx] < mp_.tcache_count && (tc_victim = last(bin)) != bin)
    {
        if (tc_victim != 0)
        {
            bck = tc_victim->bk;
            set_inuse_bit_at_offset(tc_victim, nb);
            if (av != &main_arena)
                set_non_main_arena(tc_victim);
            bin->bk = bck;
            bck->fd = bin;

            tcache_put(tc_victim, tc_idx);
        }
    }
}
```

與 tcache stashing 相同，不過來源從 fastbin 變成 smallbin

$ How2heap tech

house_of_mind_fastbin



$ How2heap tech

large_bin_attack

u1f383@u1f383:/ ⌥⌘1

```
$
        if (in_smallbin_range(size)) { ... }
        else
        {
            victim_index = largebin_index(size);
            bck = bin_at(av, victim_index);
            fwd = bck->fd;

            /* maintain large bins in sorted order */
            if (fwd != bck)
            {
                /* Or with inuse bit to
                size |= PREV_INUSE;
                /* if smaller than smal
                assert(chunk_main_arena
                if ((unsigned long)(size) < (unsigned long)chunksize_nomask(bck->bk))
                {
                    fwd = bck;
                    bck = bck->bk;

                    victim->fd_nextsize = fwd->fd;
                    victim->bk_nextsize = fwd->fd->bk_nextsize;
                    fwd->fd->bk_nextsize = victim->bk_nextsize->fd_nextsize = victim;
                }
            }
        }
```

1. bck 為 main_arena (av) 對應的 largebin 位址，而 fwd 則是第一塊 largebin chunk

2. 如果 largebin 內有 chunk 的話

3. 請求的 chunk size 小於 largebin 當中最小的 chunk，經過 pointer 的更新後回傳給使用者

$ How2heap tech

unsafe_unlink

u1f383@u1f383:/

```
$
```

```
static void unlink_chunk(mstate av, mchunkptr p)
{
    if (chunksize(p) != prev_size(next_chunk(p)))
        malloc_printerr("corrupted size vs. prev_size");

    mchunkptr fd = p->fd;
    mchunkptr bk = p->bk;

    if (__builtin_expect(fd->bk != p || bk->fd != p, 0))
        malloc_printerr("corrupted double-linked list");

    fd->bk = bk;
    bk->fd = fd;
    if (!in_smallbin_range(chunksize_nomask(p)) && p->fd_nextsize != NULL) {
        if (p->fd_nextsize->bk_nextsize != p || p->bk_nextsize->fd_nextsize != p)
            malloc_printerr("corrupted double-linked list (not small)");

        if (fd->fd_nextsize == NULL) {
            if (p->fd_nextsize == p)
                fd->fd_nextsize = fd->bk_nextsize = fd;
            else {
                fd->fd_nextsize = p->fd_nextsize;
                fd->bk_nextsize = p->bk_nextsize;
                p->fd_nextsize->bk_nextsize = fd;
                p->bk_nextsize->fd_nextsize = fd;
            }
        }
        else {
            p->fd_nextsize->bk_nextsize = p->bk_nextsize;
            p->bk_nextsize->fd_nextsize = p->fd_nextsize;
        }
    }
}
```

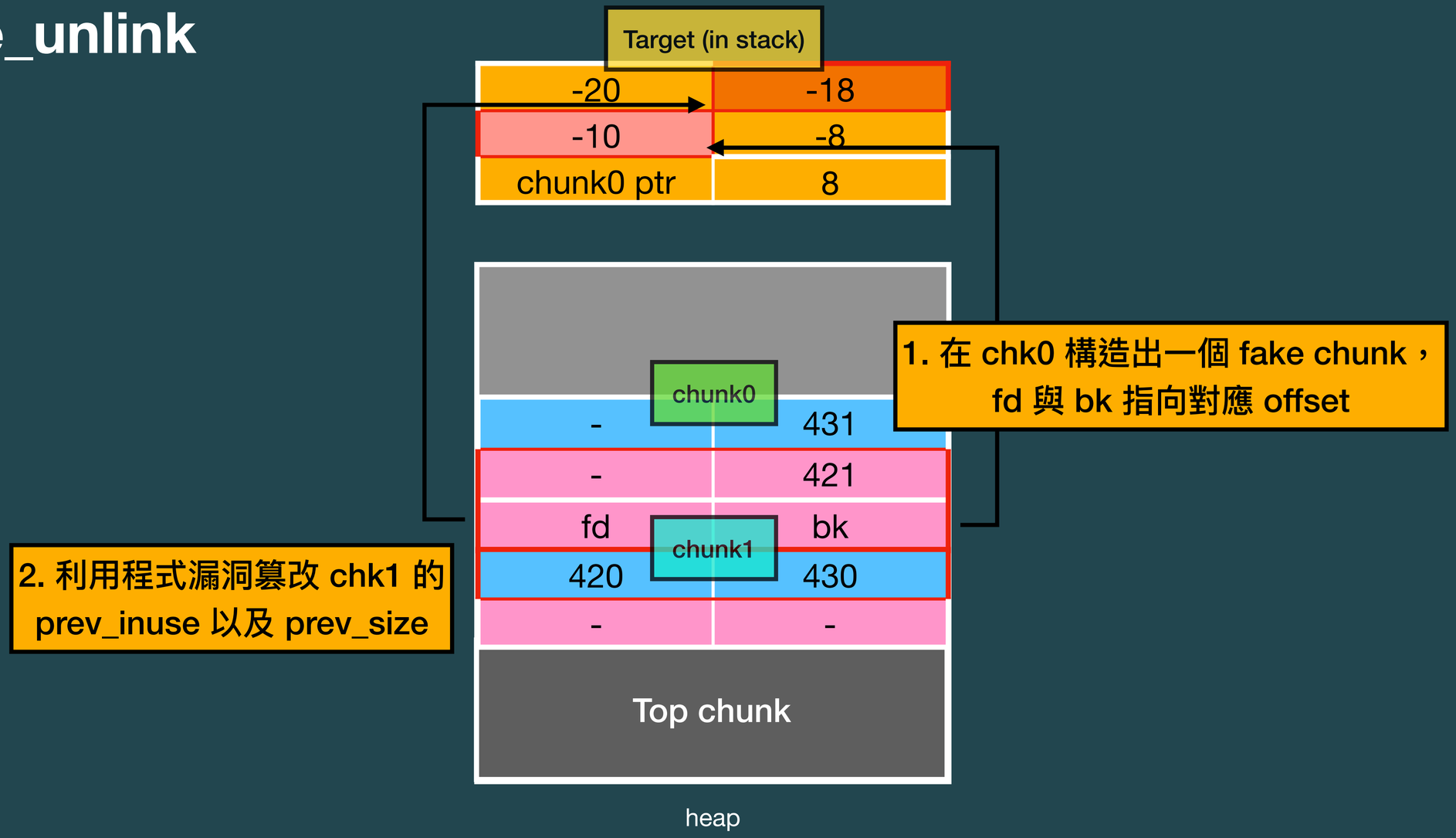
1. 檢查下個 chunk 的 prev_size 是否等於自己 &&
前一個的下一個要是自己 && 後一個的上一個要是自己

2. smallbin 或 unsorted bin 就單純更新 fd bk 即可

3. largebin 如果有多種 size，
就需要額外更新 fd_nextsize 與 bk_nextsize

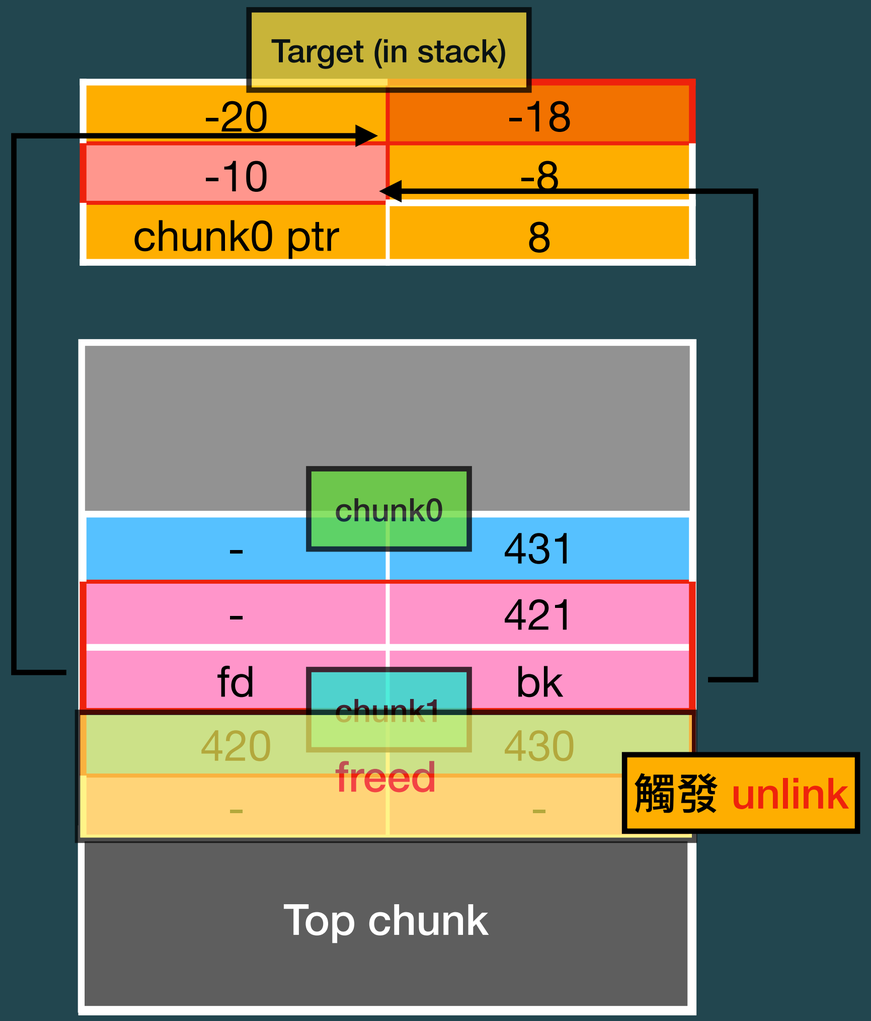
$ How2heap tech

unsafe_unlink



$ How2heap tech

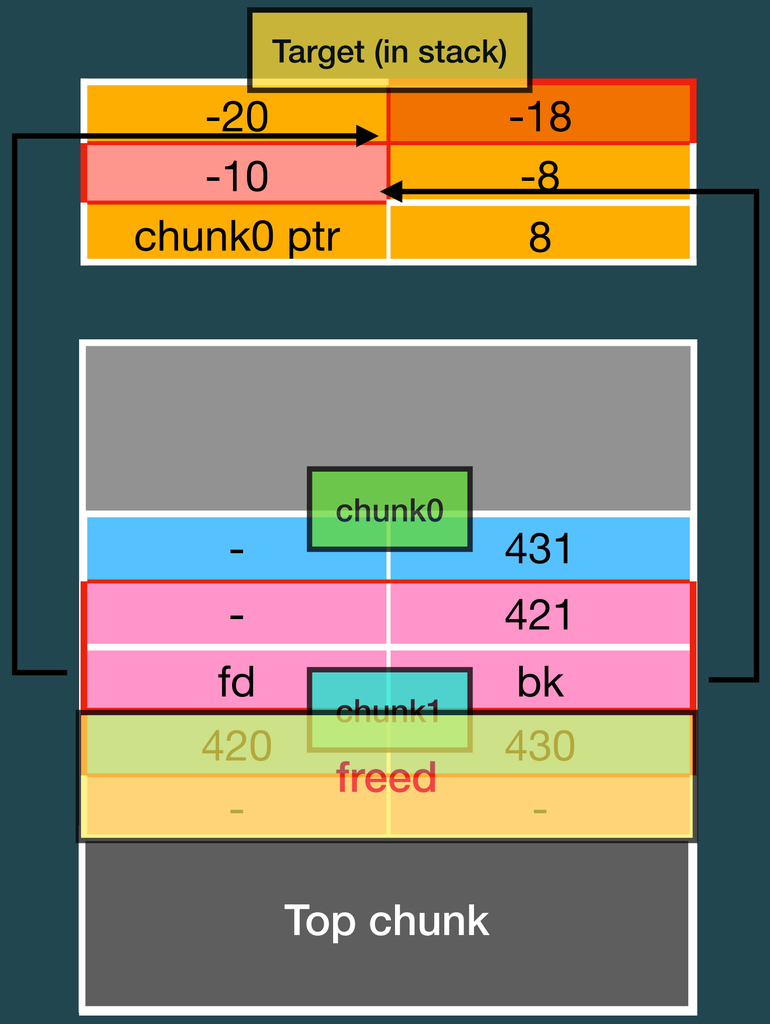
unsafe_unlink

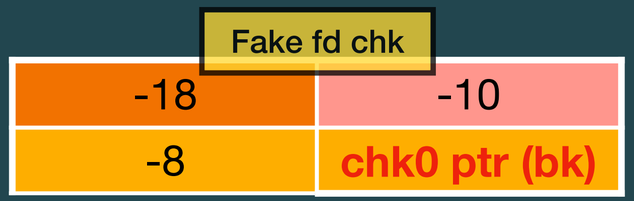


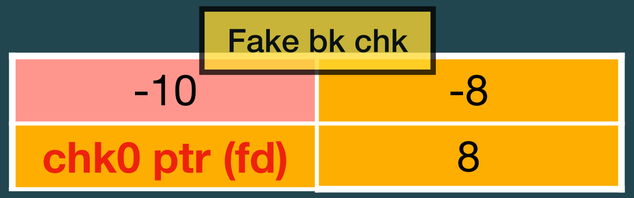
heap

$ How2heap tech

unsafe_unlink





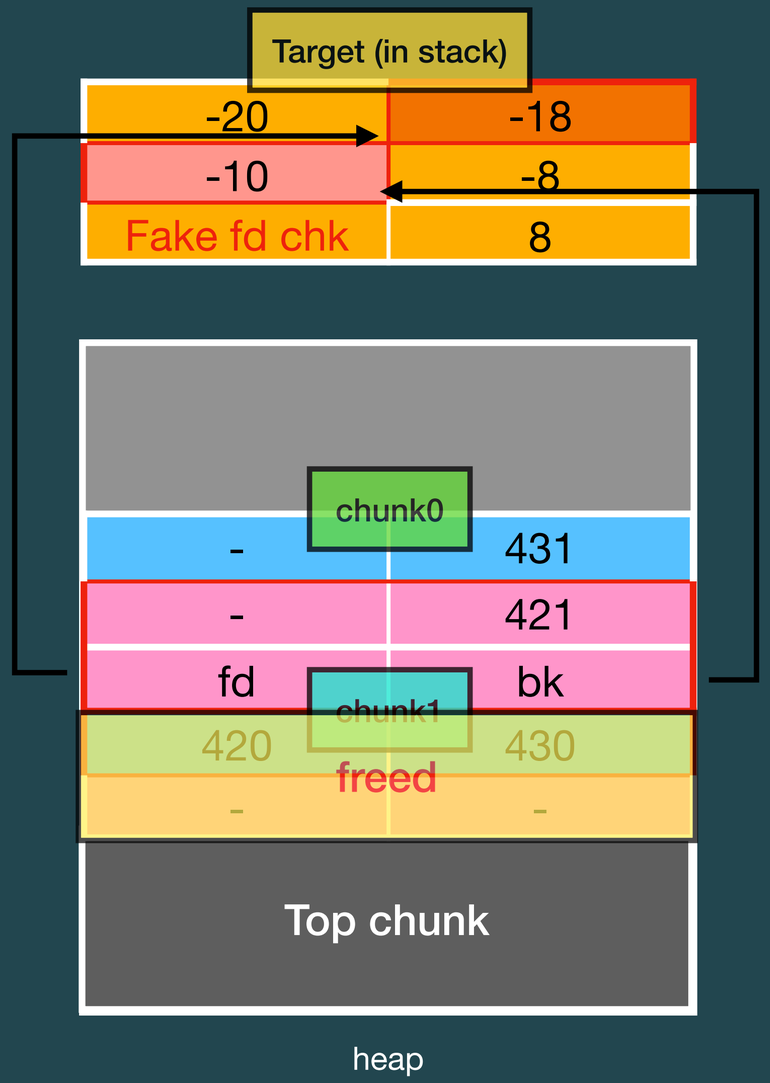


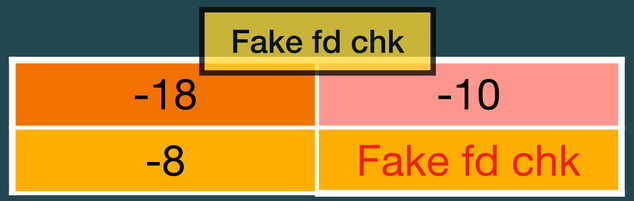
1. 通過 fd->bk 與 bk->fd 的檢查

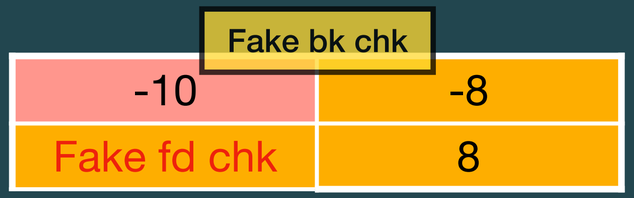
```
if (chunksize(p) != prev_size(next_chunk(p)))
    malloc_printerr("corrupted size vs. prev_size");

mchunkptr fd = p->fd;
mchunkptr bk = p->bk;

if (__builtin_expect(fd->bk != p || bk->fd != p, 0))
    malloc_printerr("corrupted double-linked list");
```

$ How2heap tech

unsafe_unlink





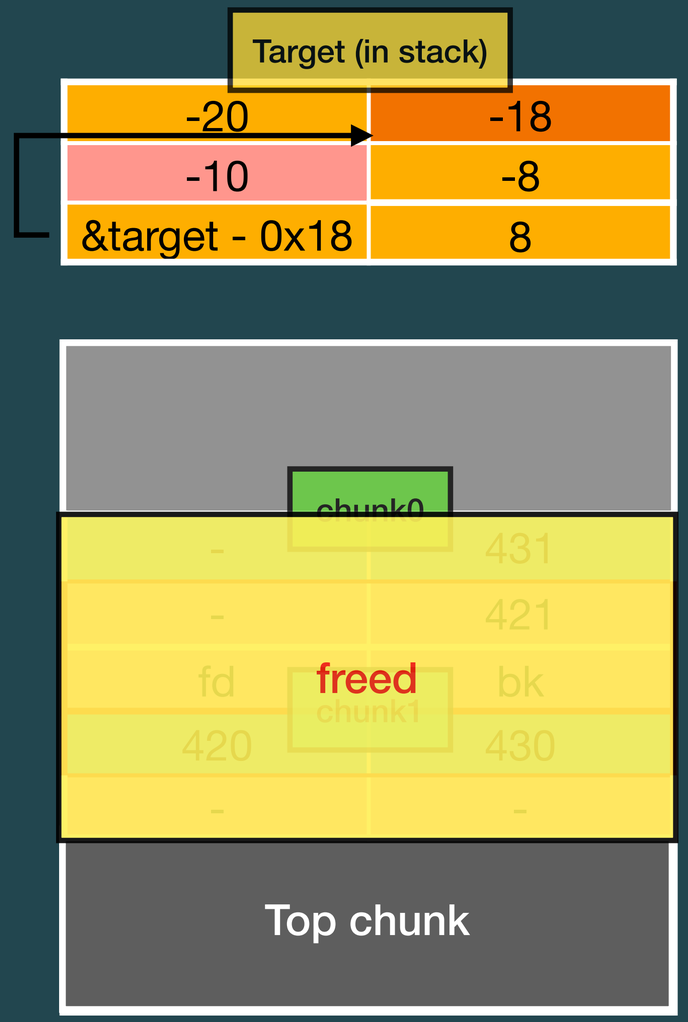


2. chunk0 ptr 會被更新成 fd (&ptr - 0x18)，並因為 p->fd_nextsize 為 NULL，結束 unlink

```
fd->bk = bk;
bk->fd = fd;
if (!in_smallbin_range(chunksize_nomask(p)) &&
    p->fd_nextsize != NULL) {
    ...
}
```

$ How2heap tech

unsafe_unlink



$ How2heap tech


u1f383@u1f383:/
⌥⌘1
$
$ Thanks for listening 🎃

Appendix

$ Appendix

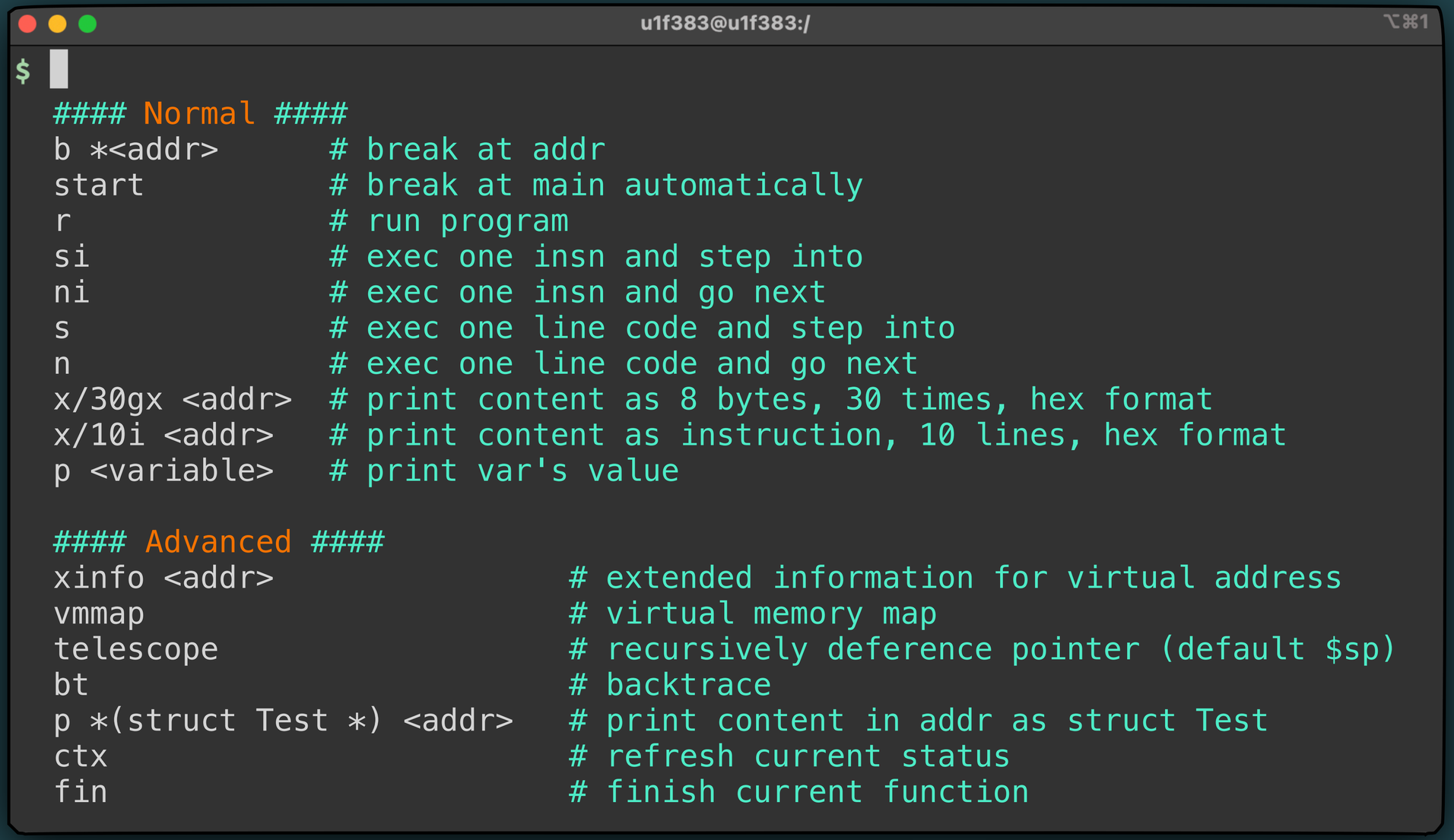
Tools

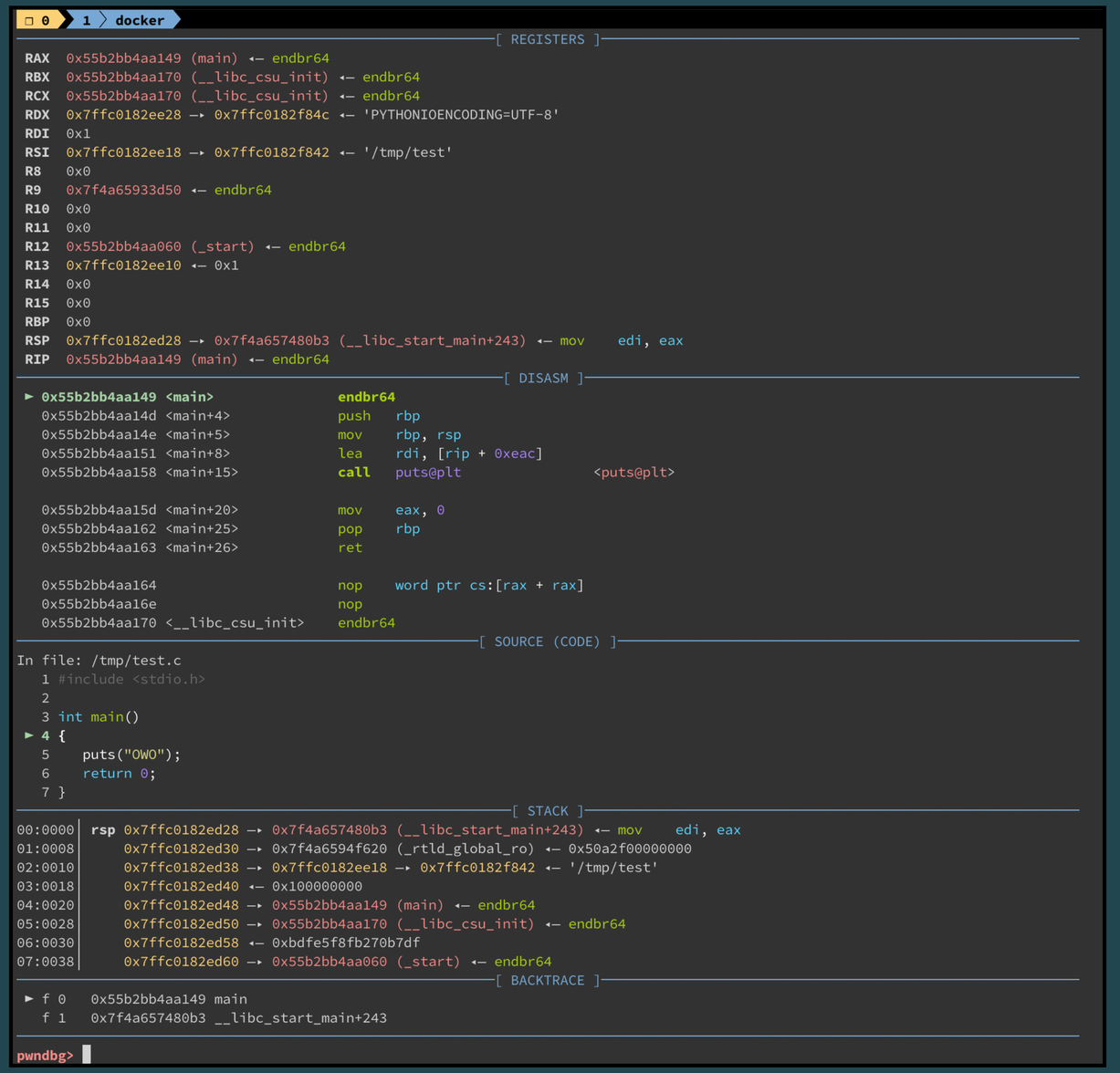
- *gdb* - the GNU debugger

- gdb plugins
  - gef
  - pwndbg
  - pwngdb

u1f383@u1f383:/ ⌥⌘1

```
$ #!/bin/bash

# install gdb
sudo apt install gdb

# install pwndbg
git clone https://github.com/pwndbg/pwndbg
cd pwndbg
./setup.sh

# install gef
bash -c "$(curl -fsSL http://gef.blah.cat/sh)"

# install pwngdb
cd ~/
git clone https://github.com/scwuaptx/Pwngdb.git
cat ~/Pwngdb/.gdbinit >> ~/.gdbinit
```


u1f383@u1f383:/
⌥⌘1
$
Normal
b *<addr>   # break at addr
start   # break at main automatically
r   # run program
si   # exec one insn and step into
ni   # exec one insn and go next
s   # exec one line code and step into
n   # exec one line code and go next
x/30gx <addr>   # print content as 8 bytes, 30 times, hex format
x/10i <addr>   # print content as instruction, 10 lines, hex format
p <variable>   # print var's value
Advanced
xinfo <addr>   # extended information for virtual address
vmmap   # virtual memory map
telescope   # recursively deference pointer (default $sp)
bt   # backtrace
p *(struct Test *) <addr>   # print content in addr as struct Test
ctx   # refresh current status
fin   # finish current function

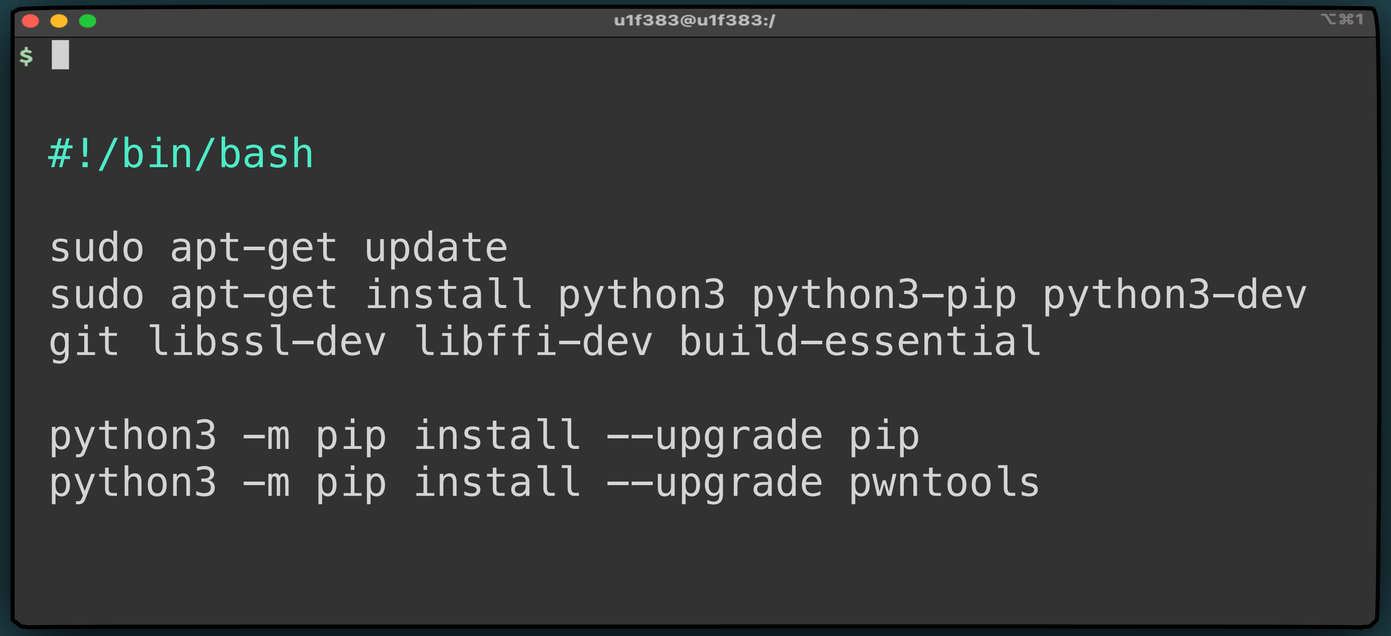

❐ 0
1
docker
[REGISTERS]
RAX 0x55b2bb4aa149 (main) ◂— endbr64
RBX 0x55b2bb4aa170 (__libc_csu_init) ◂— endbr64
RCX 0x55b2bb4aa170 (__libc_csu_init) ◂— endbr64
RDX 0x7ffc0182ee28 —▸ 0x7ffc0182f84c ◂— 'PYTHONIOENCODING=UTF-8'
RDI 0x1
RSI 0x7ffc0182ee18 —▸ 0x7ffc0182f842 ◂— '/tmp/test'
R8 0x0
R9 0x7f4a65933d50 ◂— endbr64
R10 0x0
R11 0x0
R12 0x55b2bb4aa060 (_start) ◂— endbr64
R13 0x7ffc0182ee10 ◂— 0x1
R14 0x0
R15 0x0
RBP 0x0
RSP 0x7ffc0182ed28 —▸ 0x7f4a657480b3 (__libc_start_main+243) ◂— mov edi, eax
RIP 0x55b2bb4aa149 (main) ◂— endbr64
[DISASM]
► 0x55b2bb4aa149 <main> endbr64
0x55b2bb4aa14d <main+4> push rbp
0x55b2bb4aa14e <main+5> mov rbp, rsp
0x55b2bb4aa151 <main+8> lea rdi, [rip + 0xeac]
0x55b2bb4aa158 <main+15> call puts@plt <puts@plt>
0x55b2bb4aa15d <main+20> mov eax, 0
0x55b2bb4aa162 <main+25> pop rbp
0x55b2bb4aa163 <main+26> ret
0x55b2bb4aa164 nop word ptr cs:[rax + rax]
0x55b2bb4aa16e nop
0x55b2bb4aa170 <__libc_csu_init> endbr64
[SOURCE (CODE)]
In file: /tmp/test.c
1 #include <stdio.h>
2
3 int main()
► 4 {
5 puts("OWO");
6 return 0;
7 }
[STACK]
00:0000 rsp 0x7ffc0182ed28 —▸ 0x7f4a657480b3 (__libc_start_main+243) ◂— mov edi, eax
01:0008 0x7ffc0182ed30 —▸ 0x7f4a6594f620 (_rtld_global_ro) ◂— 0x50a2f00000000
02:0010 0x7ffc0182ed38 —▸ 0x7ffc0182ee18 —▸ 0x7ffc0182f842 ◂— '/tmp/test'
03:0018 0x7ffc0182ed40 ◂— 0x100000000
04:0020 0x7ffc0182ed48 —▸ 0x55b2bb4aa149 (main) ◂— endbr64
05:0028 0x7ffc0182ed50 —▸ 0x55b2bb4aa170 (__libc_csu_init) ◂— endbr64
06:0030 0x7ffc0182ed58 ◂— 0xbdfe5f8fb270b7df
07:0038 0x7ffc0182ed60 —▸ 0x55b2bb4aa060 (_start) ◂— endbr64
[BACKTRACE]
► f 0 0x55b2bb4aa149 main
f 1 0x7f4a657480b3 __libc_start_main+243
pwndbg>

gdb + pwndbg

$ Appendix

Tools

- pwntools - an python exploit development library



u1f383@u1f383:/ ⌥⌘1

```
$ #!/usr/bin/python3

from pwn import *
import sys

# specified arch
context.arch = 'amd64'
# specified terminal
context.terminal = ['tmux', 'splitw', '-h']

if len(sys.argv) != 2:
    exit(1)

HOST = 'localhost'
PORT = 9999
BINARY = './test'

# ./exp.py remote
# ./exp.py local
if sys.argv[1] == 'remote':
    # connect to remote server
    r = remote(HOST, PORT)
elif sys.argv[1] == 'local':
    # run program in local
    r = process(BINARY)
else:
    exit(1)

r.interactive()
```

template

u1f383@u1f383:/ ⌥⌘1

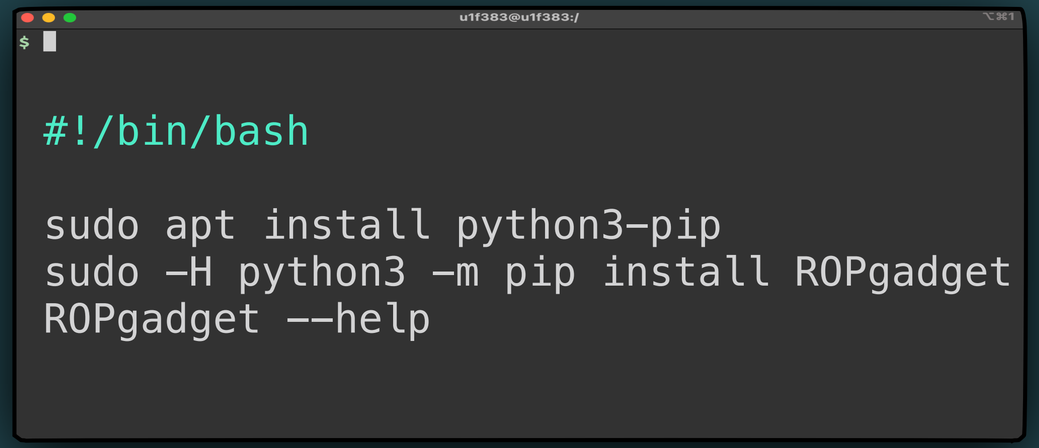
```
$ #!/usr/bin/python3

... # init

r.send('A') # "A"
r.sendline('A') # "A\n"

r.recvline() # recv until line
r.recvuntil('A') # stop until recv 'A'

r.sendafter('A', 'B') # after recv 'A', send 'B'
r.sendlineafter('A', 'B') # after recv 'A', send 'B\n'

# little endian
# b'\x11\x00\xff\xee\xdd\xcc\xbb\xaa'
p64(0xAABBCCDDEEFF0011)

# big endian
# 0xAABBCCDDEEFF0011
u64(b'\x11\x00\xff\xee\xdd\xcc\xbb\xaa')

r.interactive()
```

send / recv

$ Appendix

Tools

- ROPgadget - search helpful ROP gadgets
  - Included in pwntools by default



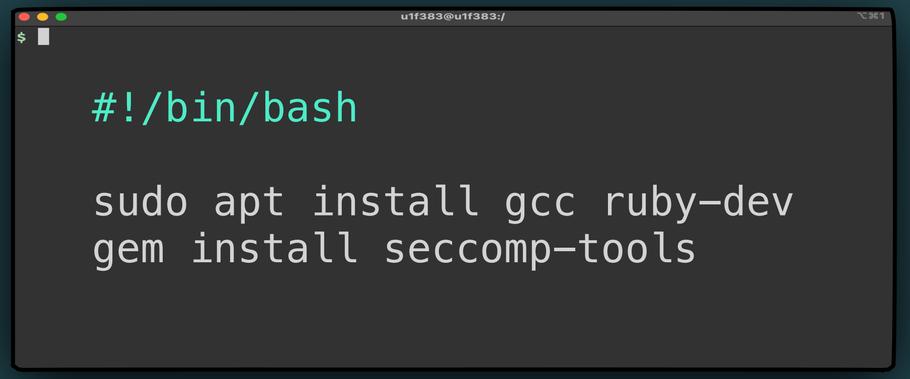
- *ROPgadget* --binary ./test --only "pop|ret"
  - Search gadgets only contain pop XXX ; ret
- *ROPgadget* --binary ./test --string "/bin/sh"
  - Search string “/bin/sh” in binary

$ Appendix

Tools

- seccomp-tools - powerful tools for seccomp analysis

- *seccomp-tools* dump ./test



$ Appendix

Tools

```
22:31:55  u1f383@OWO  /tmp
$ seccomp-tools dump ./test
 line  CODE  JT   JF      K
=================================
 0000: 0x20 0x00 0x00 0x00000004  A = arch
 0001: 0x15 0x00 0x05 0xc000003e  if (A != ARCH_X86_64) goto 0007
 0002: 0x20 0x00 0x00 0x00000000  A = sys_number
 0003: 0x35 0x00 0x01 0x40000000  if (A < 0x40000000) goto 0005
 0004: 0x15 0x00 0x02 0xffffffff  if (A != 0xffffffff) goto 0007
 0005: 0x15 0x00 0x01 0x0000003c  if (A != exit) goto 0007
 0006: 0x06 0x00 0x00 0x7fff0000  return ALLOW
 0007: 0x06 0x00 0x00 0x00000000  return KILL
```

only sys_exit is allowed

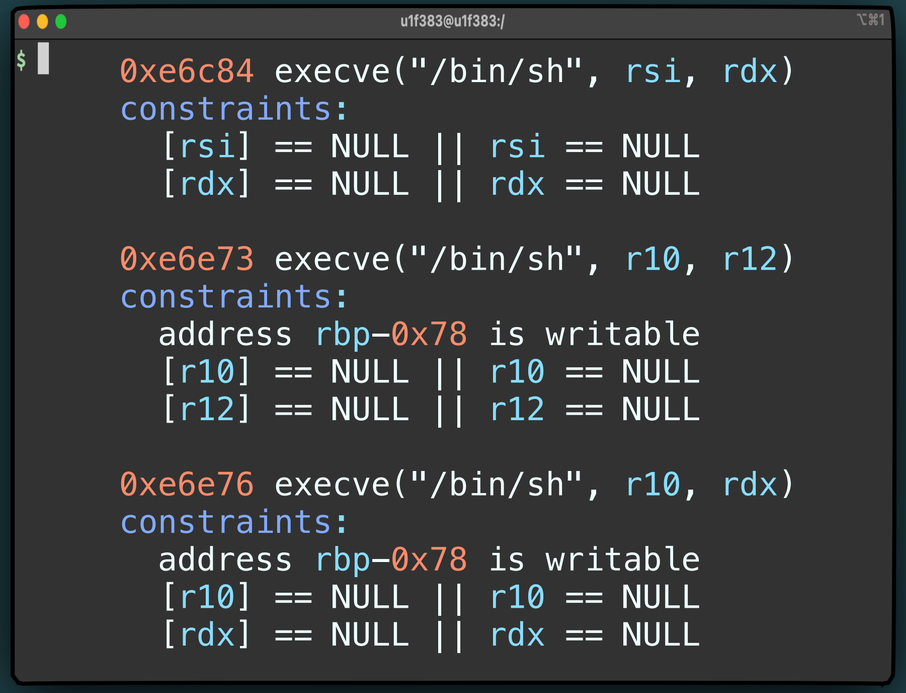
seccomp-tools output

$ Appendix

Tools

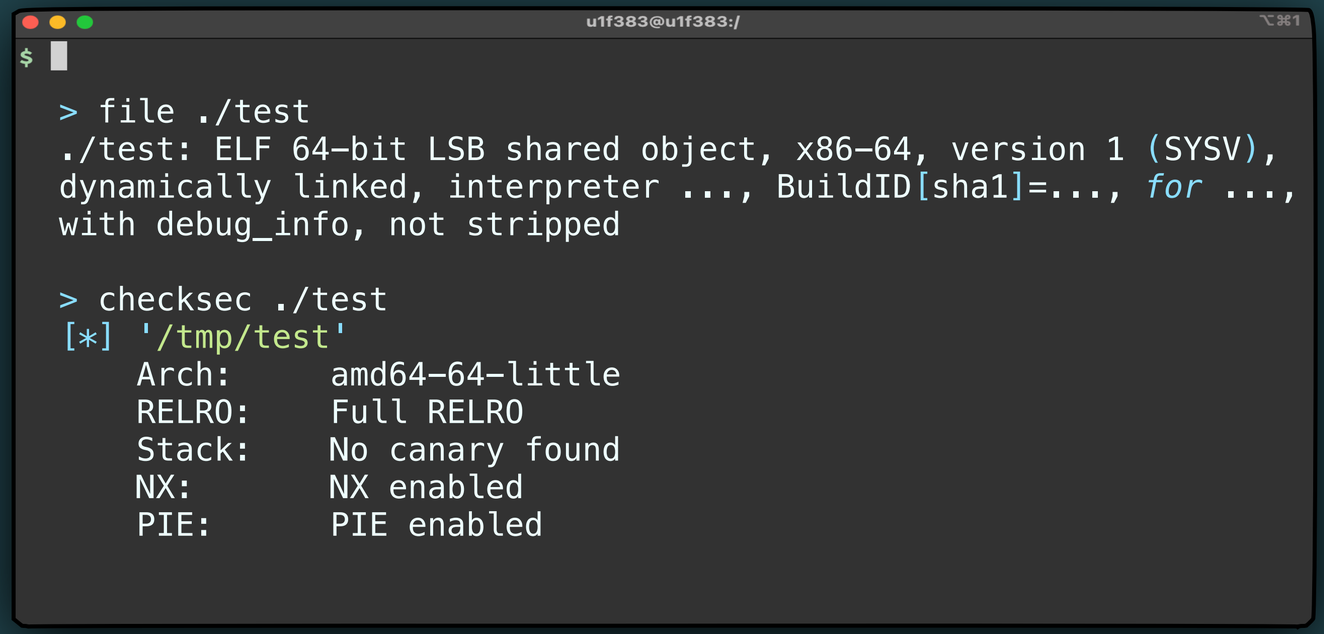
- One_gadget - a good one gadget finder

- *one_gadget* /lib/x86_64-linux-gnu/libc.so.6
- *one_gadget* --level8 /lib/x86_64-linux-gnu/libc.so.6



$ Appendix
Tools

- *file* - determine file type
- *checksec* - a python/linux script to check binary secure settings
  - Included in pwntools by default



$ Appendix

Debug glibc with source code

u1f383@u1f383:/ ⌥⌘1

```
$
```

```
#!/bin/bash

# download glibc source code
apt-get install glibc-source
# go to dir and uncompress
cd /usr/src/glibc
tar xvf glibc-2.31.tar.xz
# create dest dir
mkdir glibc_dbg && cd glibc_dbg
# gawk needs to be installed
apt install gawk
# config
../glibc-2.31/configure --prefix $PWD --enable-debug
# build target
make -j4

# compile c source with specified dynamic linker
gcc -Wl,--dynamic-linker=/usr/src/glibc/glibc_dbg/elf/ld.so -g -o test test.c
# run binary with debugging libc.so
LD_PRELOAD=/usr/src/glibc/glibc_dbg/libc.so ./test

# in gdb
pwndbg> set exec-wrapper env "LD_PRELOAD=/usr/src/glibc/glibc_dbg/libc.so"
```

$ Appendix

Debug glibc with source code

```
   0x55bc0c3d5050 <printf@plt>      endbr64
   0x55bc0c3d5054 <printf@plt+4>    bnd jmp qword ptr [rip + 0x2f75]     <printf>
    ↓
 ► 0x7f556d985b00 <printf>          endbr64
   0x7f556d985b04 <printf+4>        sub    rsp, 0xd8
   0x7f556d985b0b <printf+11>       mov    r10, rdi
   0x7f556d985b0e <printf+14>       mov    qword ptr [rsp + 0x28], rsi
   0x7f556d985b13 <printf+19>       mov    qword ptr [rsp + 0x30], rdx
   0x7f556d985b18 <printf+24>       mov    qword ptr [rsp + 0x38], rcx
   0x7f556d985b1d <printf+29>       mov    qword ptr [rsp + 0x40], r8
   0x7f556d985b22 <printf+34>       mov    qword ptr [rsp + 0x48], r9
   0x7f556d985b27 <printf+39>       test   al, al
```

```
In file: /usr/src/glibc/glibc-2.31/stdio-common/printf.c
   23
   24 /* Write formatted output to stdout from the format string FORMAT.  */
   25 /* VARARGS1 */
   26 int
   27 __printf (const char *format, ...)
 ► 28 {
   29   va_list arg;
   30   int done;
   31
   32   va_start (arg, format);
   33   done = __vfprintf_internal (stdout, format, arg, 0);
```

gdb with source code

$ Appendix

Pwnbox with docker

u1f383@u1f383:/ ⌥⌘1

```
$ #!/bin/bash

set -e
if [ -z "$1" ]; then
    echo "Usage:";
    echo "Build environment:  ./snippet build";
    echo "Up pwnbox daemon:   ./snippet up";
    echo "Get shell:          ./snippet shell";
    echo "Down pwnbox daemon: ./snippet down";
    exit 0
fi

if [ $1 == "build" ]; then
    mkdir pwnbox
    docker build -t pwnbox .
elif [ $1 == "up" ]; then
    docker run -it -d --cap-add=SYS_PTRACE --name pwnbox -v `pwd`/
pwnbox:/pwnbox pwnbox
elif [ $1 == "shell" ]; then
    docker exec -it pwnbox fish
elif [ $1 == "down" ]; then
    docker stop pwnbox
fi
```

How to use

u1f383@u1f383:/ ⌥⌘1

```
$ FROM ubuntu:20.04
MAINTAINER u1f383

ENV DEBIAN_FRONTEND=noninteractive
ENV LC_ALL=en_US.UTF-8

RUN apt update && \
    apt install -yq gcc && \
    apt install -yq gdb && \
    apt install -yq git && \
    apt install -yq ruby-dev && \
    apt install -yq vim-gtk3 && \
    apt install -yq fish && \
    apt install -yq glibc-source && \
    apt install -yq make && \
    apt install -yq gawk && \
    apt install -yq bison && \
    apt install -yq libseccomp-dev && \
    apt install -yq tmux && \
    apt install -yq wget && \
    apt install -yq locales && \
    locale-gen en_US.UTF-8

# compile glibc-2.31
RUN cd /usr/src/glibc && \
    tar xvf glibc-2.31.tar.xz && \
    mkdir glibc_dbg && \
    cd glibc_dbg && \
    ../glibc-2.31/configure --prefix $PWD --enable-debug && \
    make -j4

# install pwndbg
RUN git clone https://github.com/pwndbg/pwndbg ~/pwndbg && \
    cd ~/pwndbg && \
    ./setup.sh

# install pwngdb
RUN git clone https://github.com/scwuaptx/Pwngdb.git ~/Pwngdb && \
    cat ~/Pwngdb/.gdbinit >> ~/.gdbinit && \
    sed -i "s/source ~\/peda\/peda.py//g" ~/.gdbinit

RUN pip3 install pwntools==4.4.0
RUN gem install seccomp-tools one_gadget
RUN ln -s /usr/local/lib/python3.8/dist-packages/bin/ROPgadget /bin/ROPgadget
RUN echo "set-option -g default-shell /bin/fish" > /root/.tmux.conf

CMD ["/bin/fish"]
```

Dockerfile

$ Appendix

Resources

- bootlin-glibc - glibc source code cross referencer
- x64 syscall table - x64 syscall table in linux 4.7
- libc.rip - use symbol offset to find libc version
- glibc-all-in-one - scripts to download & debug & complie glibc
- how2heap - heap exploitation tech collection