Operating Systems

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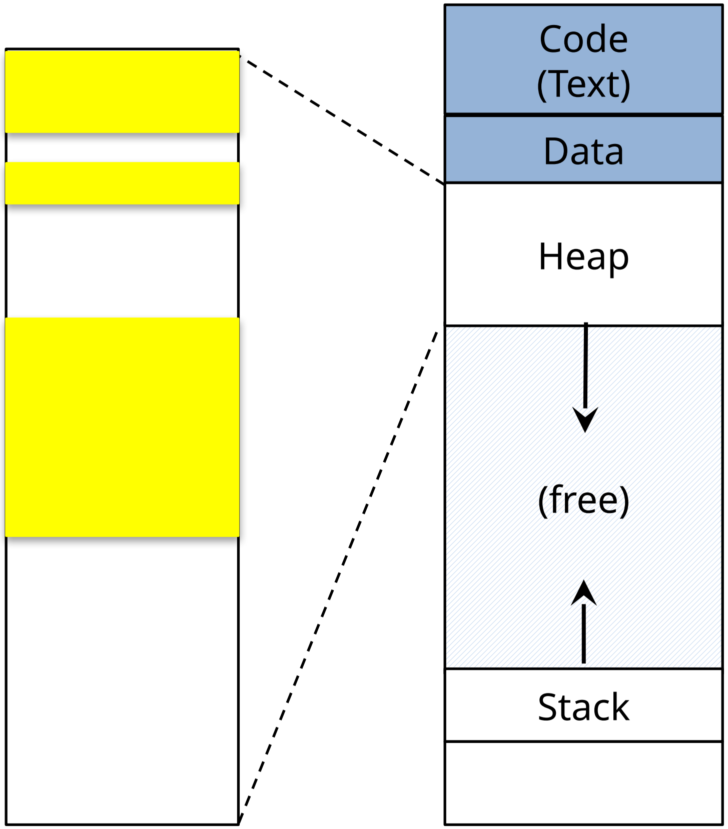
17. Free-Space Management

Managing heap

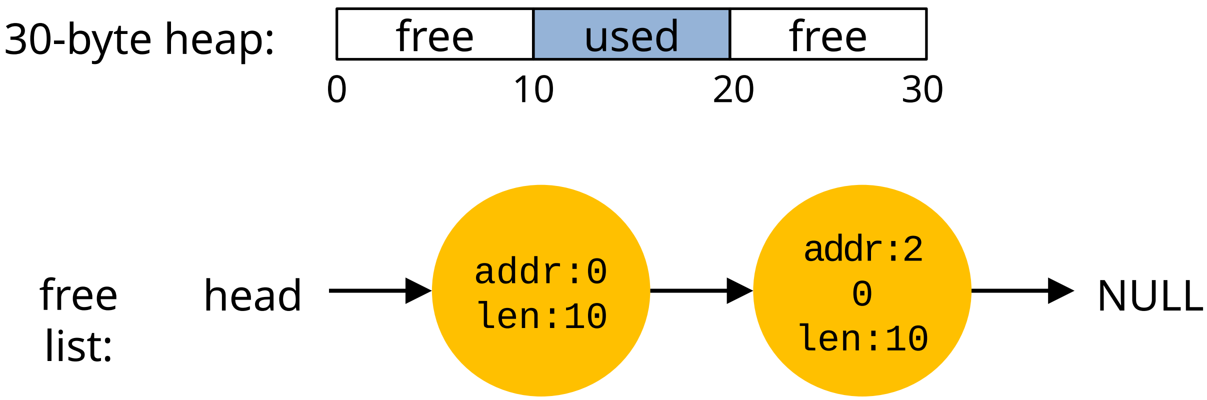
```
malloc()
free()
```
in **`libc`**

<u>To manage the memory in a heap</u>



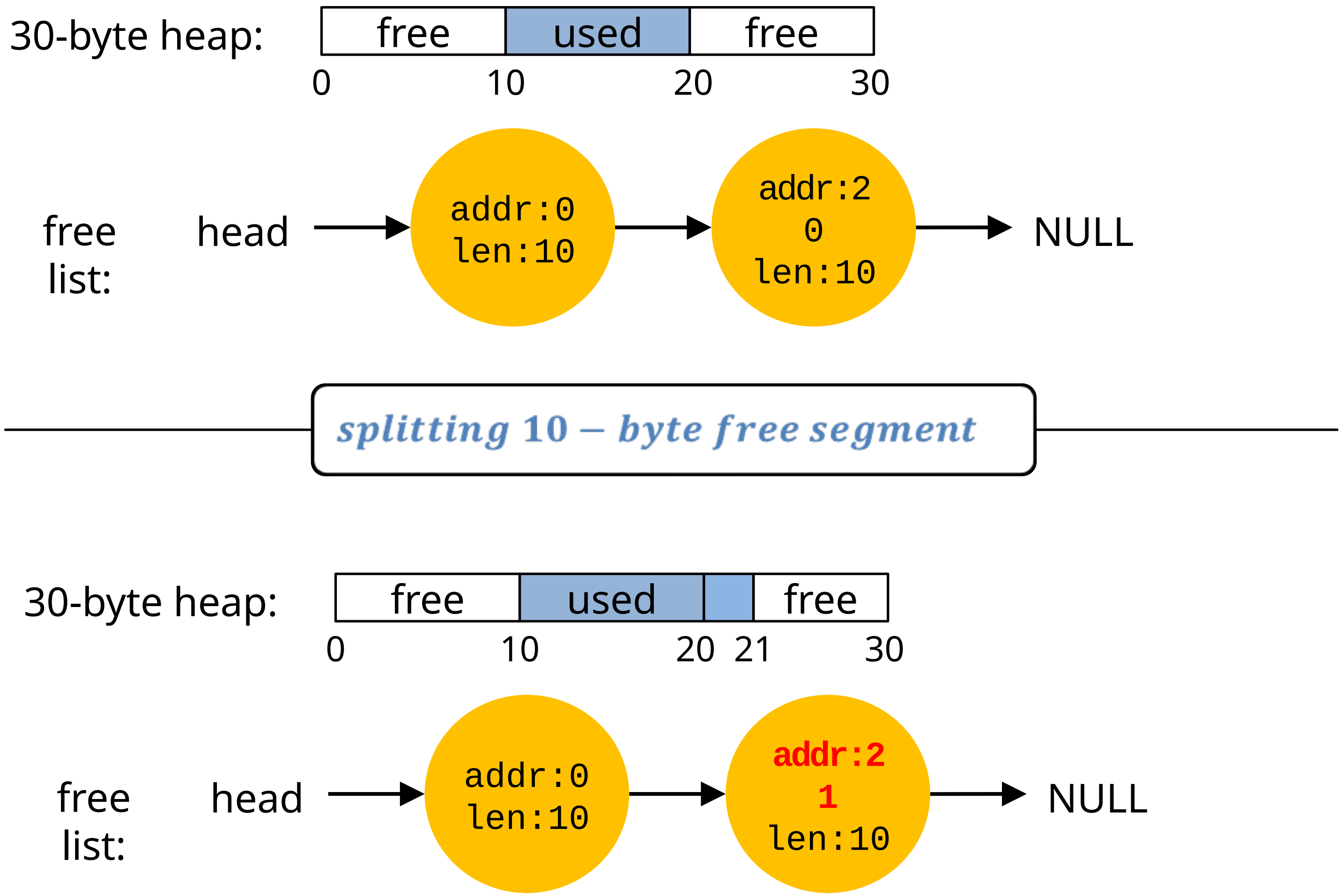
Splitting

- Finding a free chunk of memory that can satisfy the request and splitting it into two.
  - When request for memory allocation is **smaller** than the size of free chunks.



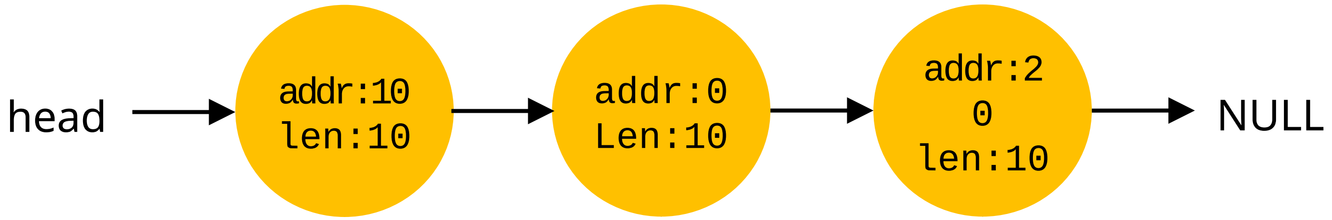
Splitting(Cont.)

- Two 10-bytes free segment with **1-byte request**



Coalescing

- If a user requests memory that is **bigger than free chunk size**, the list will **not find** such a free chunk.
- Coalescing: **Merge** returning a free chunk with existing chunks into a large single free chunk if **addresses** of them are **nearby**.

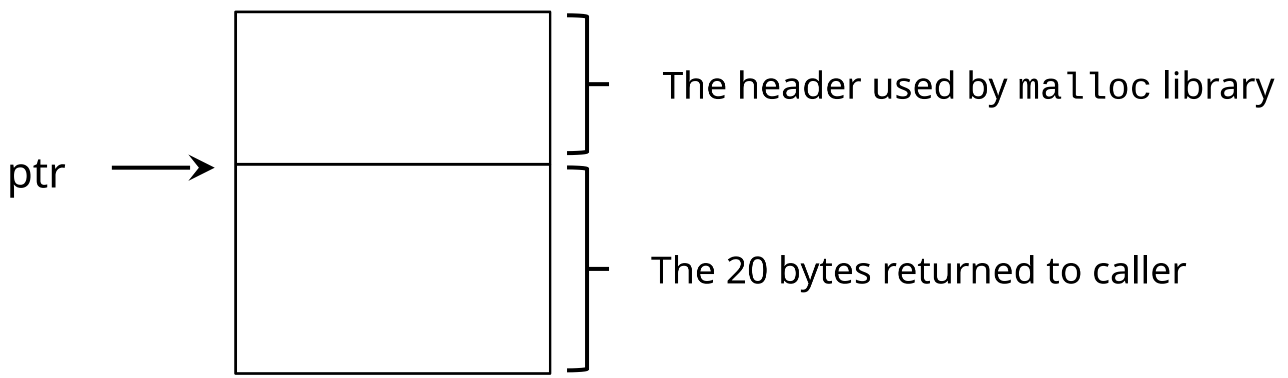


$$T_{average\ response} = \frac{0+1+2}{3} = 1sec$$

Tracking The Size of Allocated Regions

- The interface to `free(void *ptr)` does **not take** a **size parameter**.
  - How does the library **know the size** of memory region that will be back **into free list**?

```
ptr =
malloc(20);
```

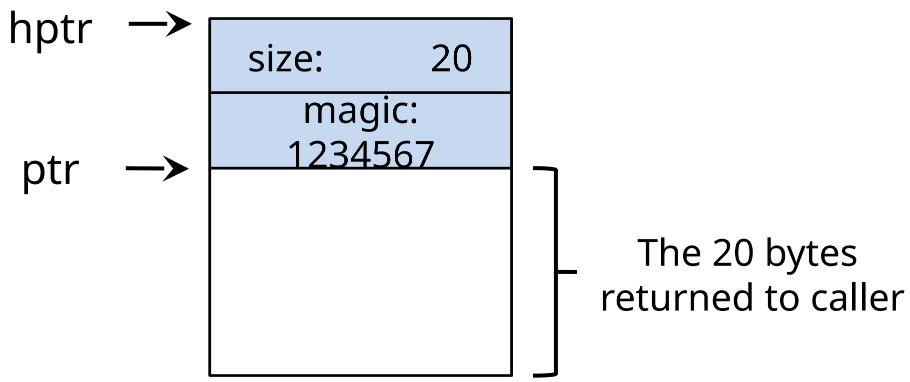


An Allocated Region Plus Header

The Header of Allocated Memory Chunk

```
typedef struct __header_t {
        int size;
        int magic;
} header_t;
```

Actual chuck size of malloc(N) = N + size of header
Here, 28 Byte



The Header of Allocated Memory Chunk(Cont.)

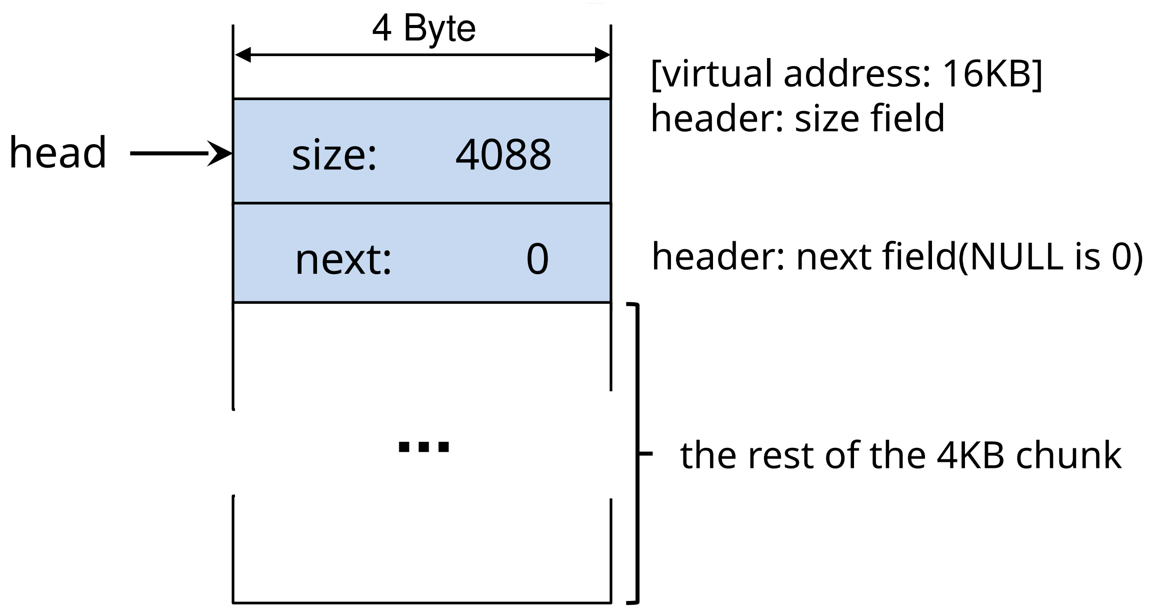
```
void free(void *ptr) {
    header_t *hptr = (void *)ptr – sizeof(header_t);
    …
    assert(hptr->magic==1234567) ;
    …
}
```

Embedding A Free List

```
typedef struct __node_t {
      int size;
      struct __node_t *next;
} nodet_t;
```

Heap Initialization

```
// mmap() returns a pointer to a chunk of free space
node_t *head = mmap(NULL, 4096, PROT_READ|PROT_WRITE,
         MAP_ANON|MAP_PRIVATE, -1, 0);
head->size = 4096 - sizeof(node_t);
head->next = NULL;
```



Embedding A Free List: Allocation

- If a chunk of memory is requested, the library **will first find** a chunk that is **large enough** to accommodate the request.

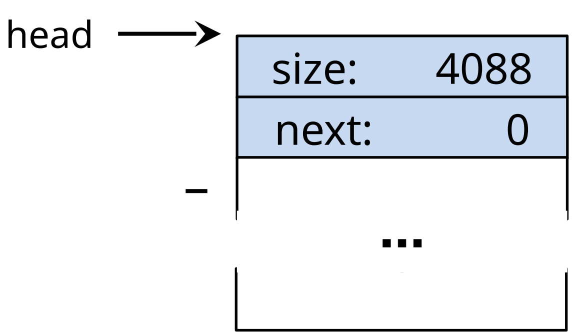
- The library will
  - **Split** the large free chunk into two.
    - **One** for the **request** and the **remaining** free chunk
  - **Shrink** the size of free chunk in the list.

Embedding A Free List: Allocation(Cont.)

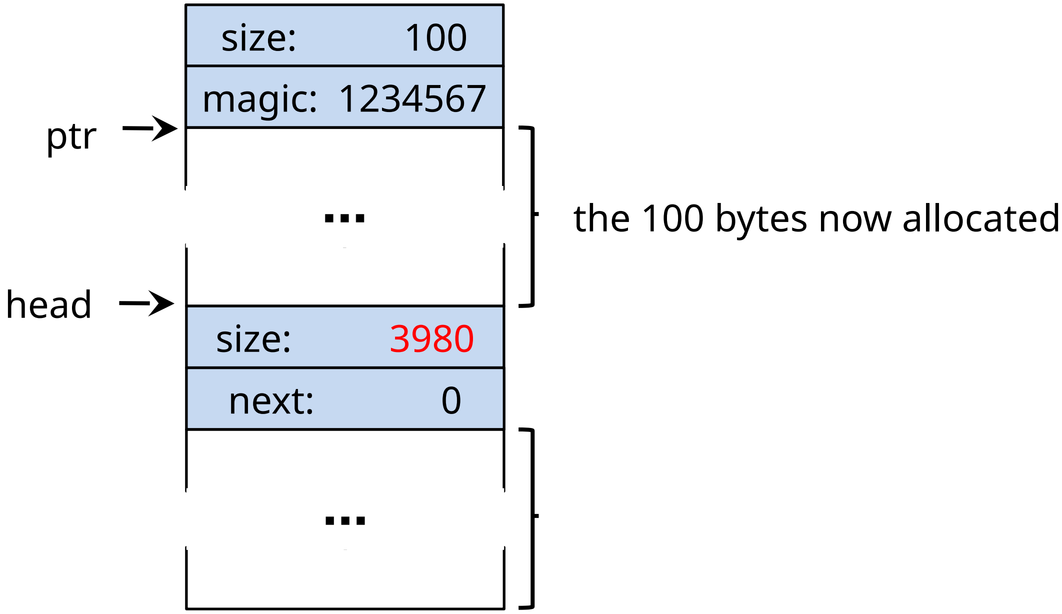
- Example: a request for 100 bytes by `ptr = malloc(100)`

  → 108 byte is returned.

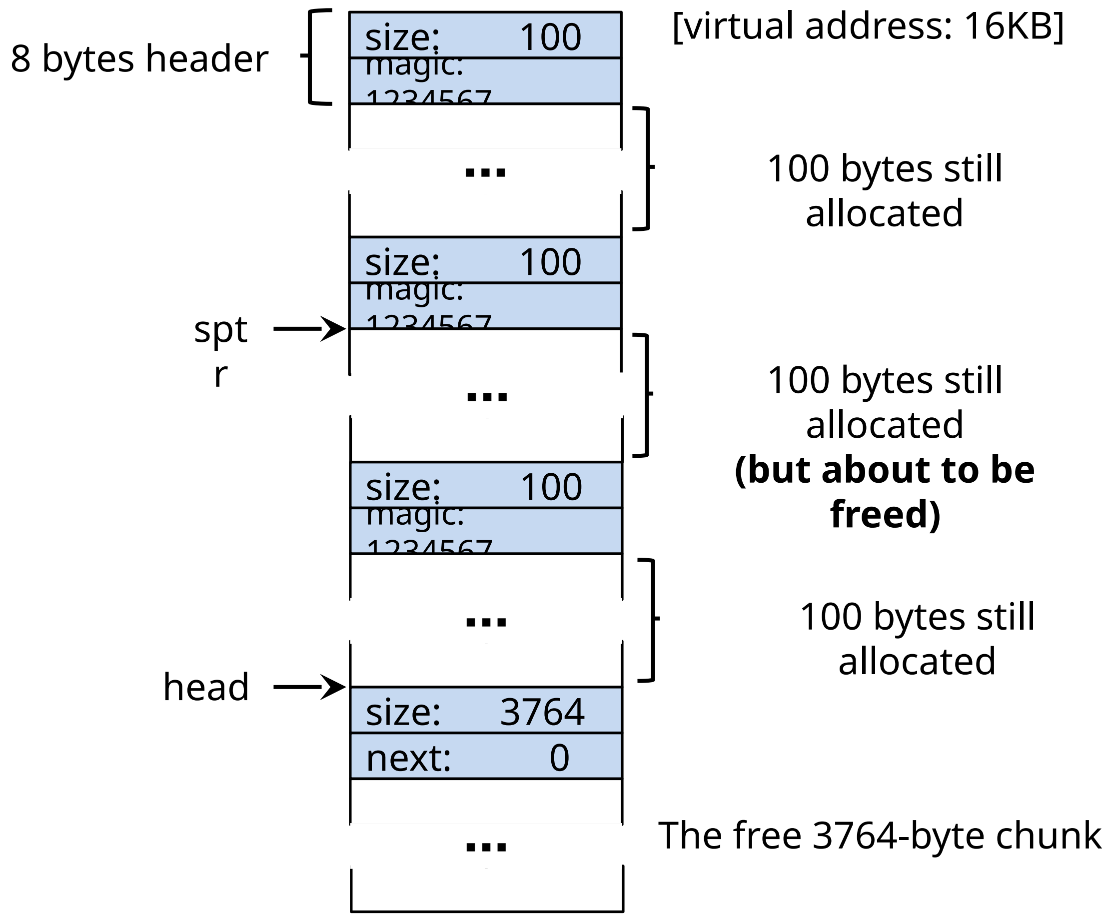
A 4KB Heap With One Free Chunk



A Heap : After One Allocation



Free Space With Chunks Allocated

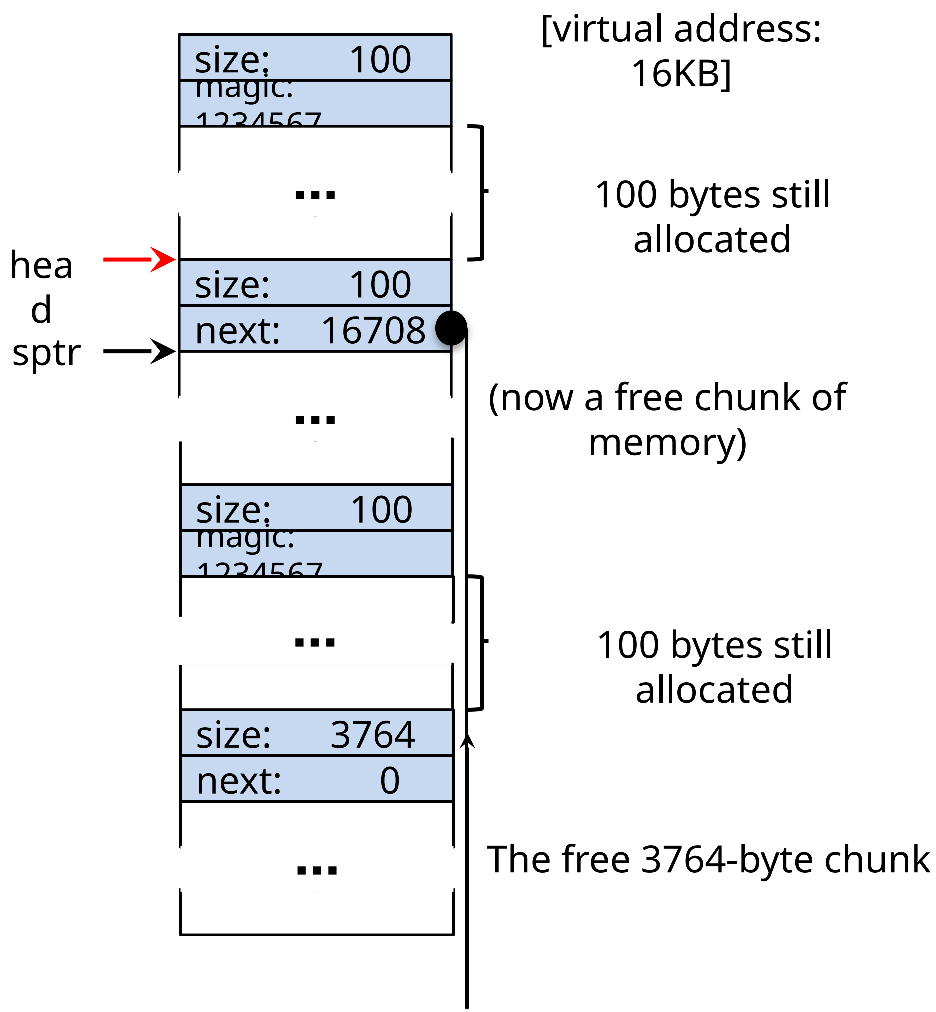


Free Space With Three Chunks Allocated

Free Space With `free()`

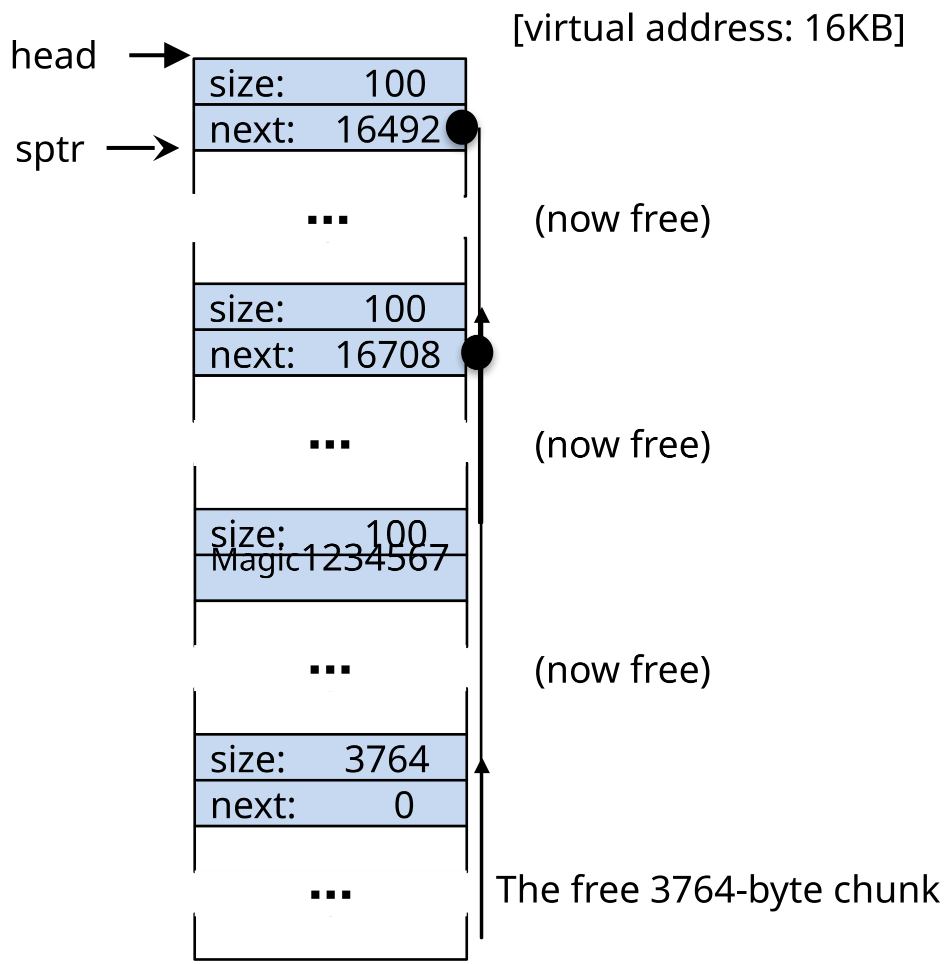
- `free(sptr)`

```
void* tmp = head ;
head = sptr ;
head->next = tmp ;
```



Free Space With **Freed Chunks**

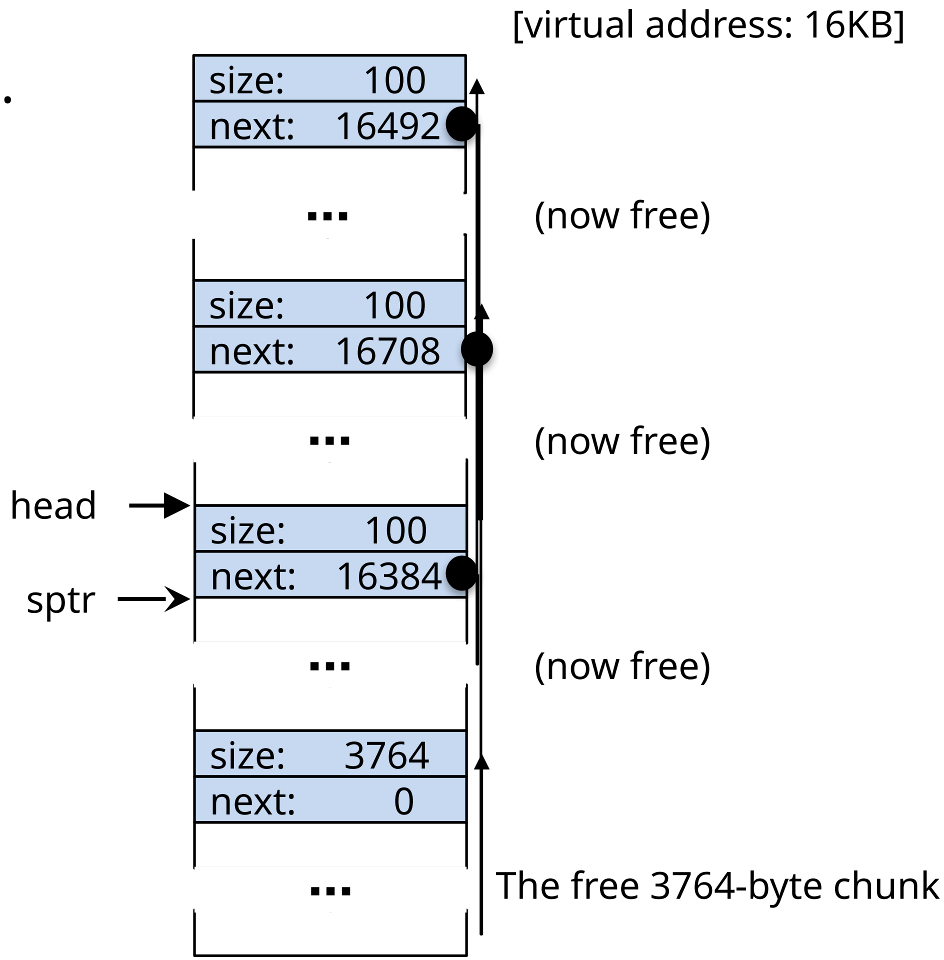
- `free(sptr)`



Free Space With Freed **Chunks**

- free(sptr)

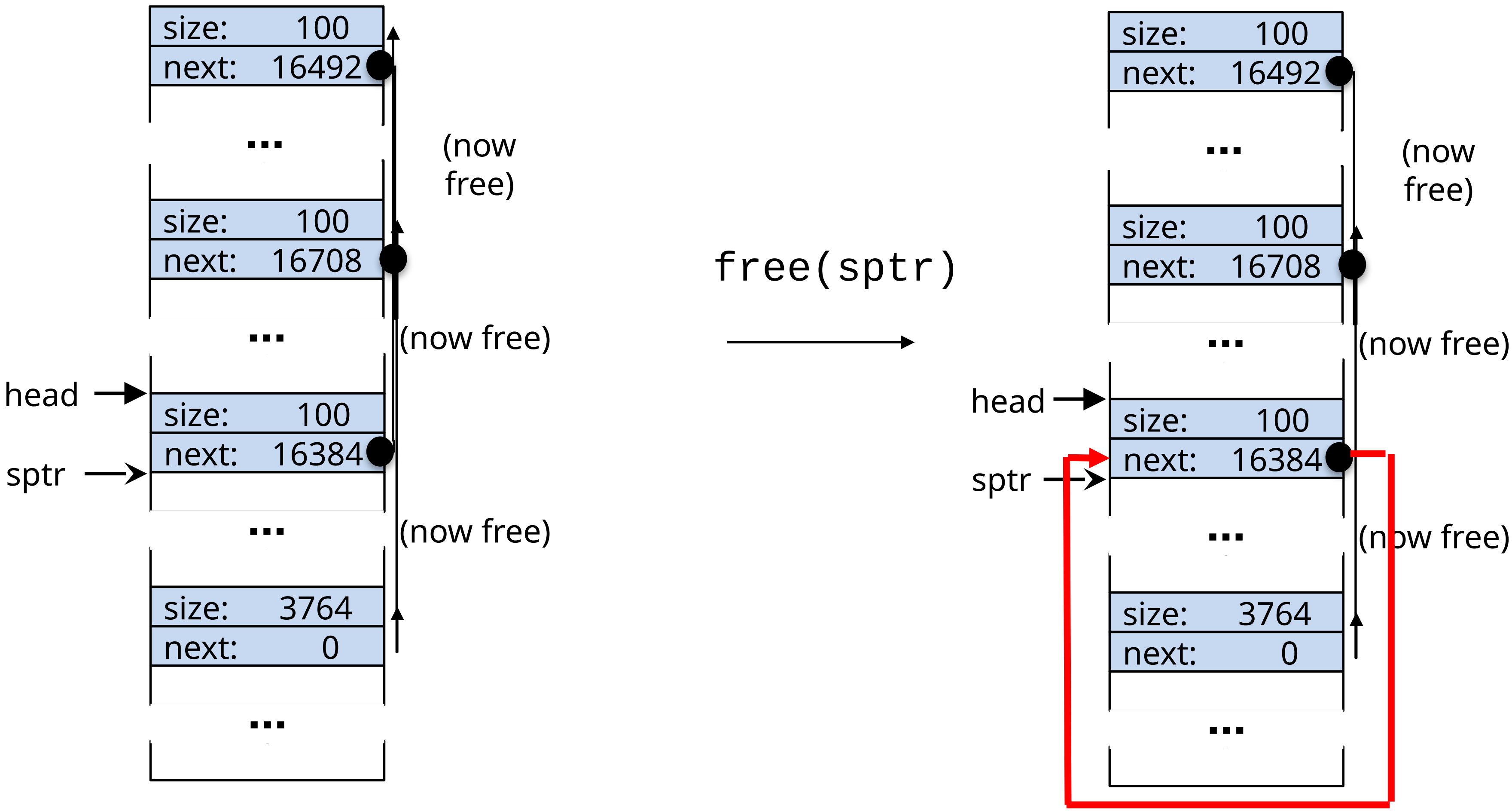
- **Coalescing** is needed in the list.



Double free

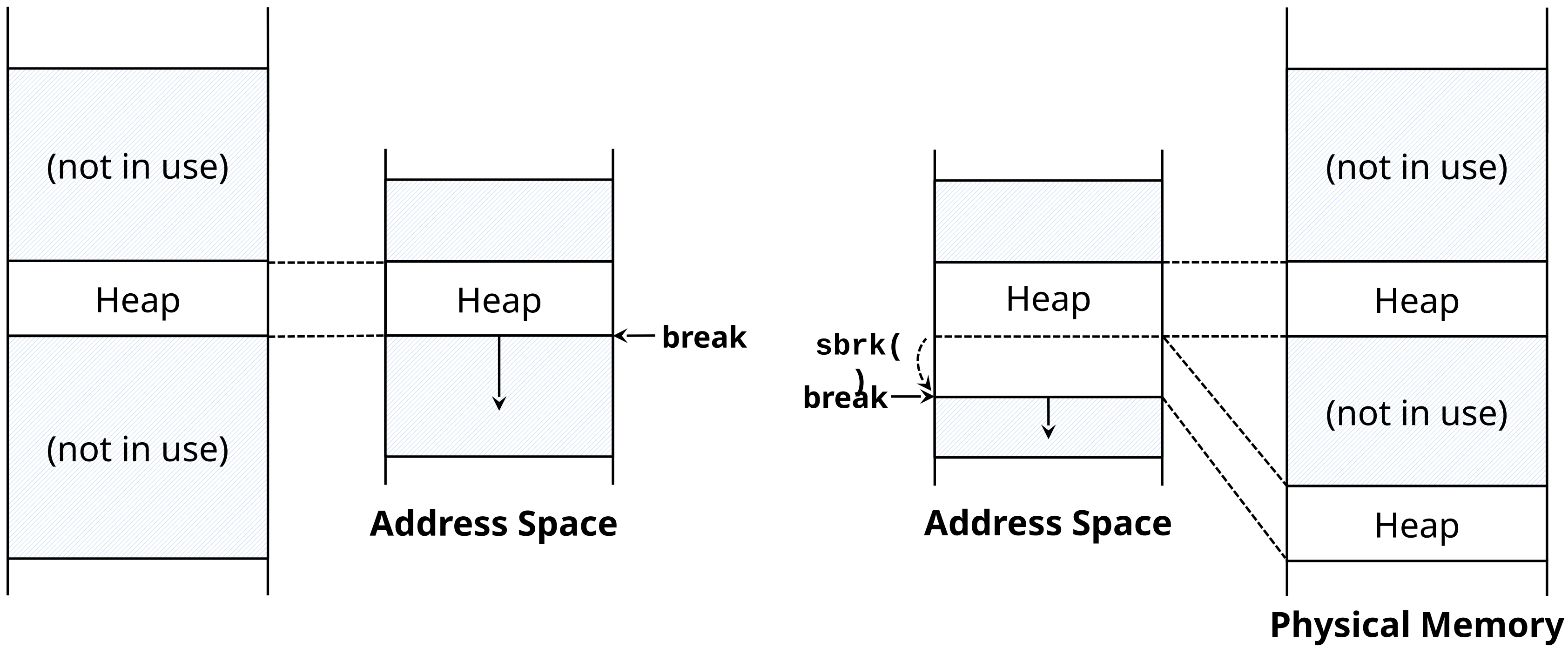
- Free(sptr): dangling reference

[virtual address: 16KB]



Growing The Heap

- Most allocators **start** with **a small-sized heap** and then **request more** memory from the OS when they run out.
  - e.g., `sbrk()`, `brk()` in most UNIX systems.



Managing Free Space: Basic Strategies

- Best Fit:
  - Finding free chunks that are **big or bigger than the request**
  - Returning the **one of smallest** in the chunks **in the group** of candidates

- Worst Fit:
  - Finding the **largest free chunks** and allocation the amount of the request
  - **Keeping the remaining chunk** on the free list.

Managing Free Space: Basic Strategies(Cont.)

- First Fit:
  - Finding the **first chunk** that is **big enough** for the request
  - Returning the requested amount and remaining the rest of the chunk.

- Next Fit:
  - Finding the first chunk that is big enough for the request.
  - Searching at **where one was looking** at instead of the begining of the list.

Examples of Basic Strategies

- Allocation Request Size 15

head → 10 → 30 → 20 → NULL

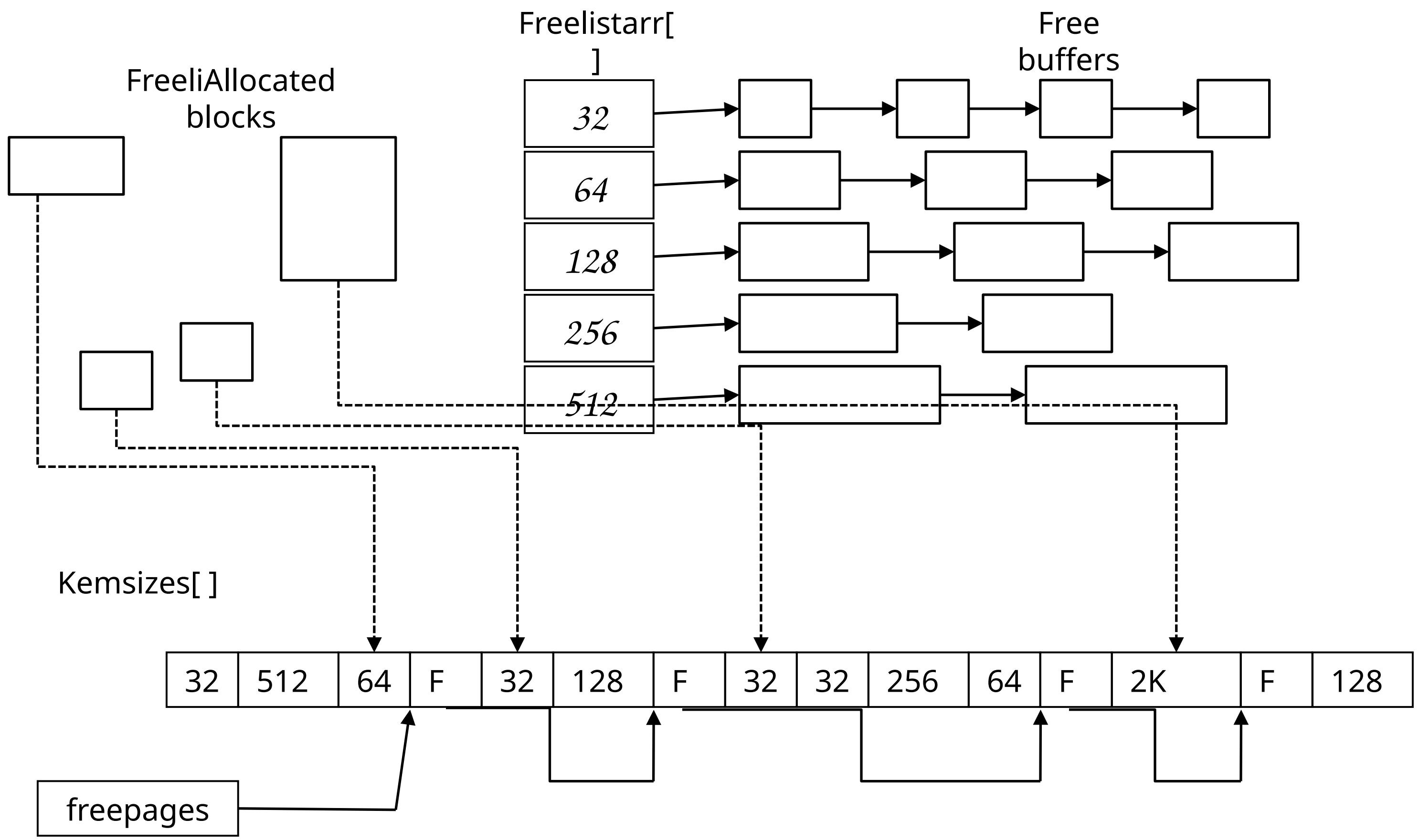
- Result of Best-fit

head → 10 → 30 → 5 → NULL

- Result of Worst-fit

head → 10 → 15 → 20 → NULL

Segregated List: McKusick-Karels Allocator (4.3 BSD)



McKusick-Karels Allocator

- Used in 4.3BSD and Digital UNIX.
- Management
  - Contiguous set of pages
  - Same buffer size within a page
- Manage pages by page usage array(kmemsizes[]).
  - Element of kmemsizes: free | size of buffer
- `malloc()` allocates the requested sized buffer from the free list.
- `malloc()` invoke a routine that acquires free page and splits by a requested size if free list is empty.
- How much memory should dedicate to the pool of memory that serves specialized requests of a given size?

Buddy System

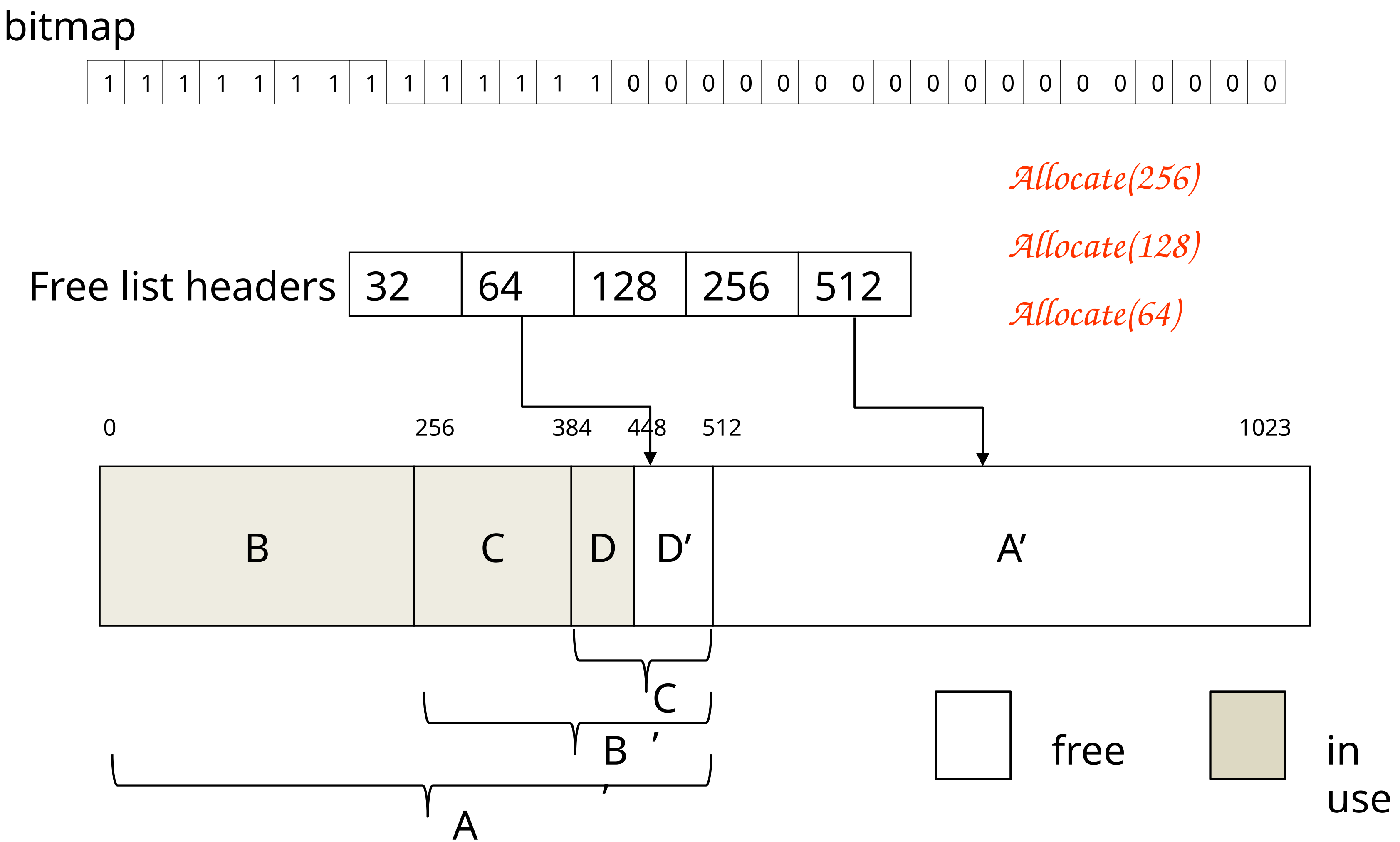
- Create the small buffers by repeatedly halving a large buffer and coalesce the adjacent free buffers.
- When a buffer is split, each half is called the buddy of the other.
- Minimum size is 32byte.
- Use a bitmap to monitor each 32-byte chunk of the block.

Detailed step

- Allocate 256 byte
  - Split the block into A and A’. Puts A’ in the 512 byte free list.
  - Split A into B and B’. Put B’ in the 256 byte free list.
  - Return B to the client
- Allocate 128 Byte
  - Split B’ into C and C’. Put C’ in the free list.
  - Return C to the client.
- Allocate 64 byte.
  - Split c’ into D and D’. Put D’ in the free list.
  - Return D to the client.
- Allocate 128
  - Split A’ into E and E’. Put E’ in the free list of 256 byte
  - Split E into F and F’. Put F’ in the free list of 128 byte
  - Allocate F.

Example

- Maintain freelist for every buffer size(32-512).

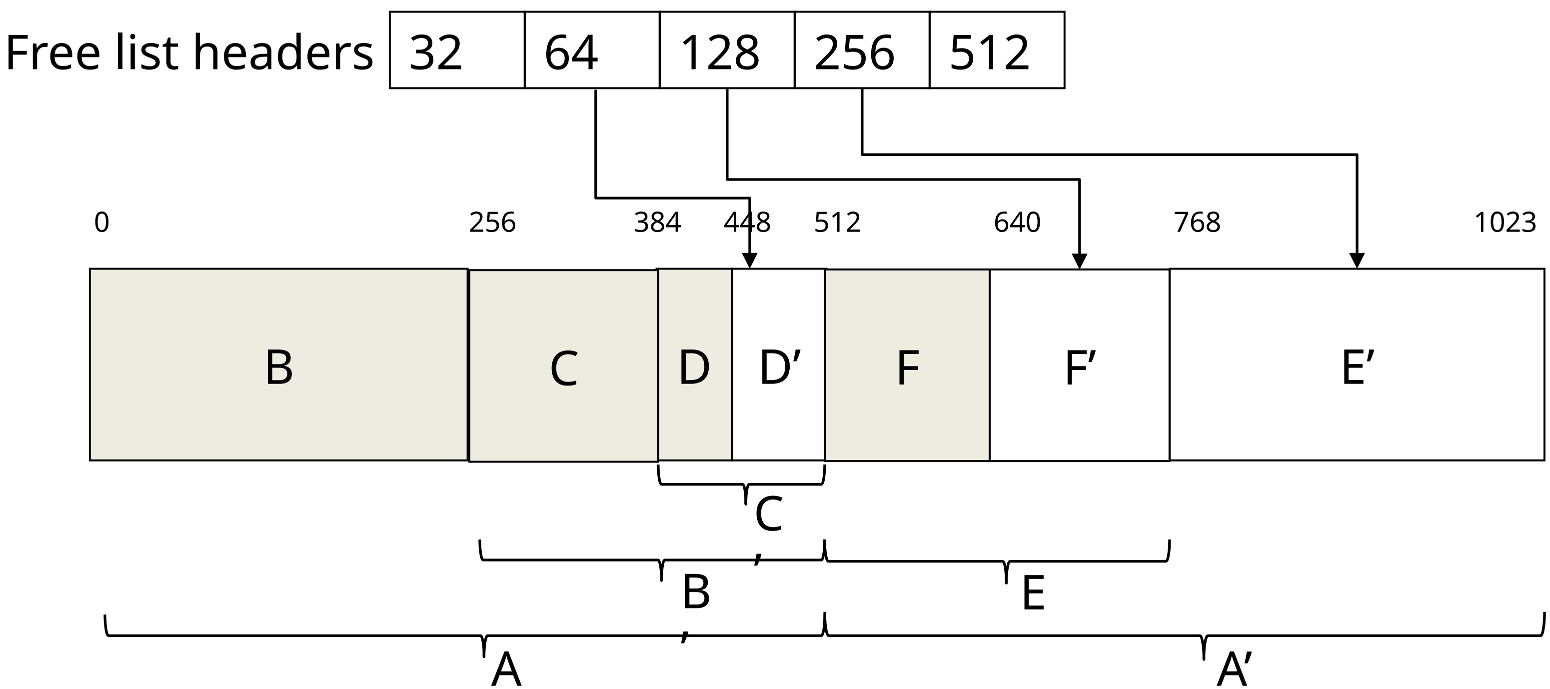


Example

bitmap

1	1	1	1	1	1	1	1	0	0	0	0	1	1	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0

Allocate(128)

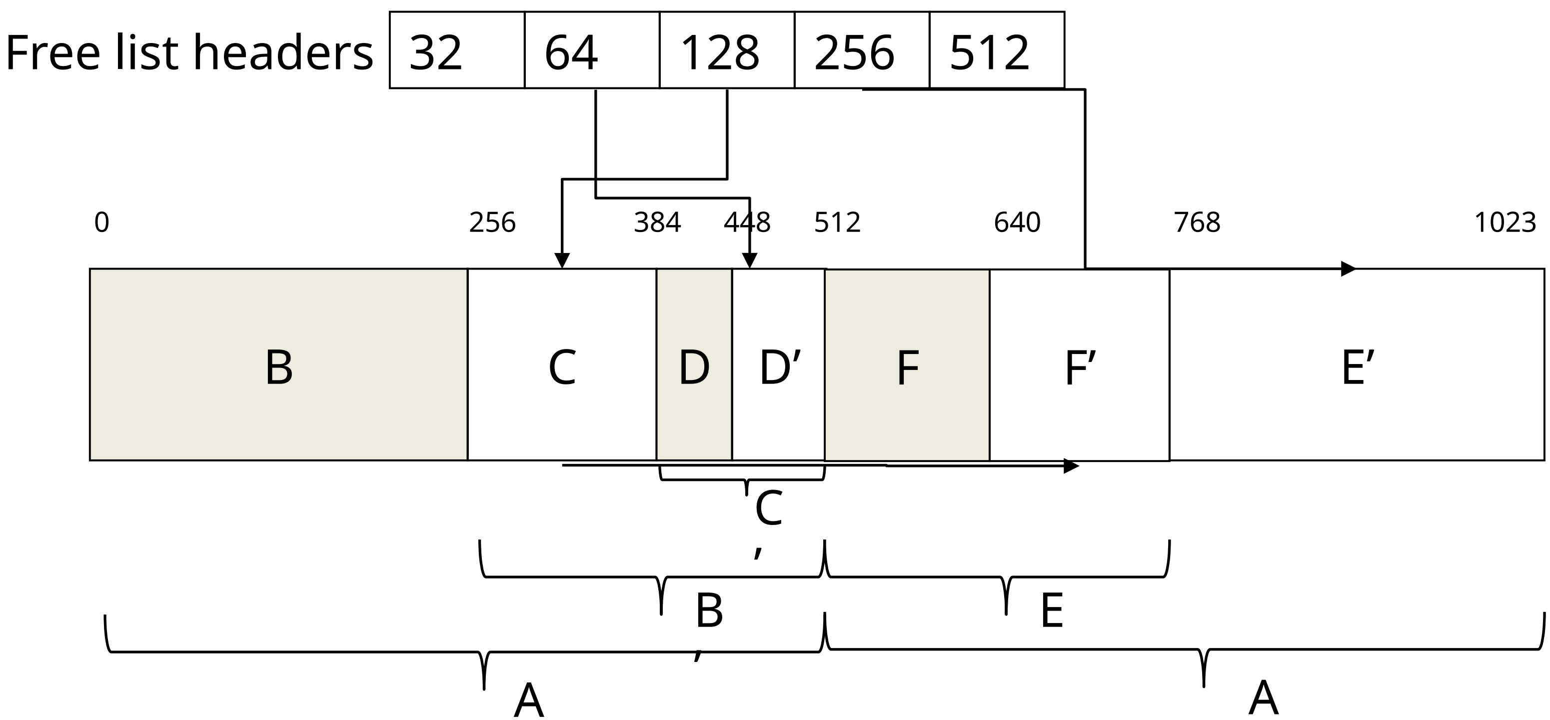


Example

bitmap

1	1	1	1	1	1	1	1	0	0	0	0	1	1	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0

Release(C, 128)



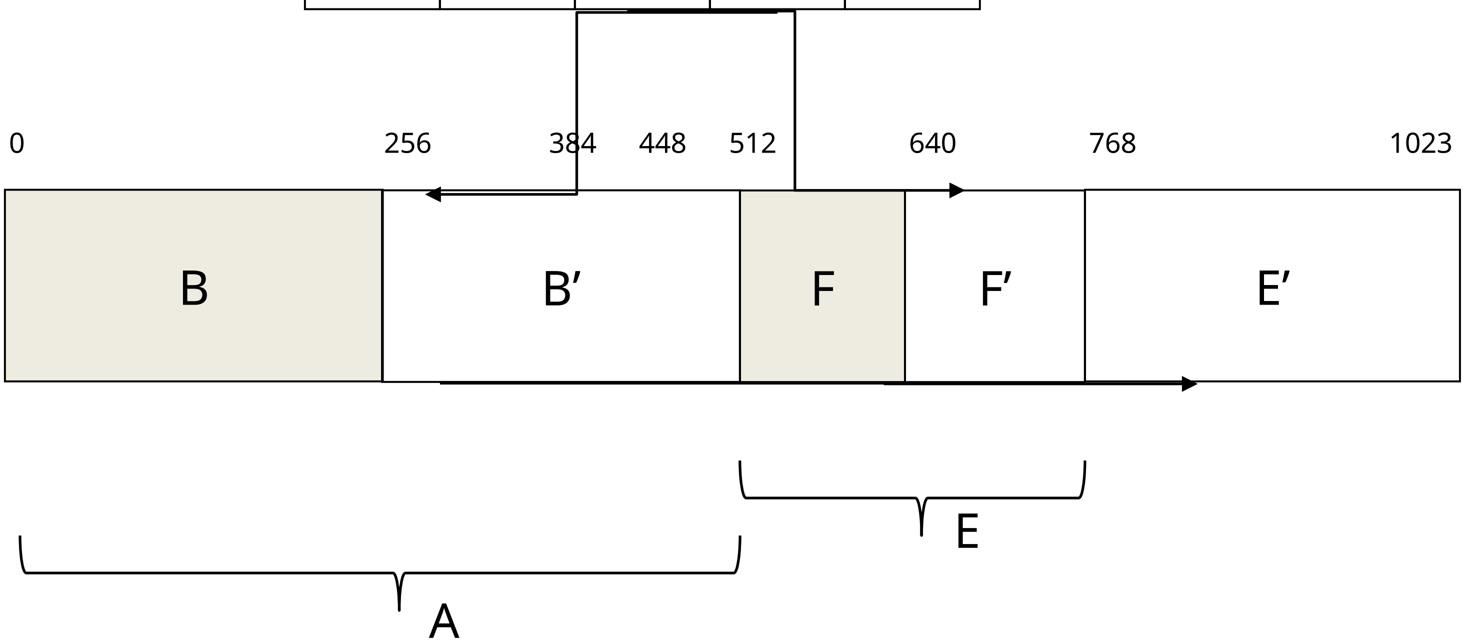
Example

bitmap

1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0

Release(D, 64)

Free list headers					
	32	64	128	256	512



Analysis

- Characteristic
  - Internal fragmentation by power-of-two allocation
  - Easy to find a buddy of a buffer by address and size
  - Use bitmap for coalescing.
- Advantage
  - Does a good job of coalescing adjacent free buffers.
  - Easy exchange of memory between the allocator and the paging system
- Disadvantage
  - Performance degrade: every time a buffer is released, the allocator tries to coalesce as much as possible.
  - Release routine needs both the address and size of the buffer.
  - Partial release is insufficient.

Slab allocator

- Advanced form of segregated list
- Slab: a set of kernel pages
  - Consists of same objects, e.g. inodes, locks, sockets
  - They are all initialized before allocation.
- Using object
  - Allocate memory and Construct the object
  - Use the object.
  - Deconstruct it, Free the memory.
- Construction
  - Initialization of various fields
- Object reuse
  - It is better to reuse possible data structures rather than release

Memory allocation

- libc
  - Based on linked list
- kernel
  - Buddy: allocating memory to process
  - Slab: allocating memory for small kernel objects (proc structure, inode, socket and etc.)