Free-Space management

Operating System (OS)

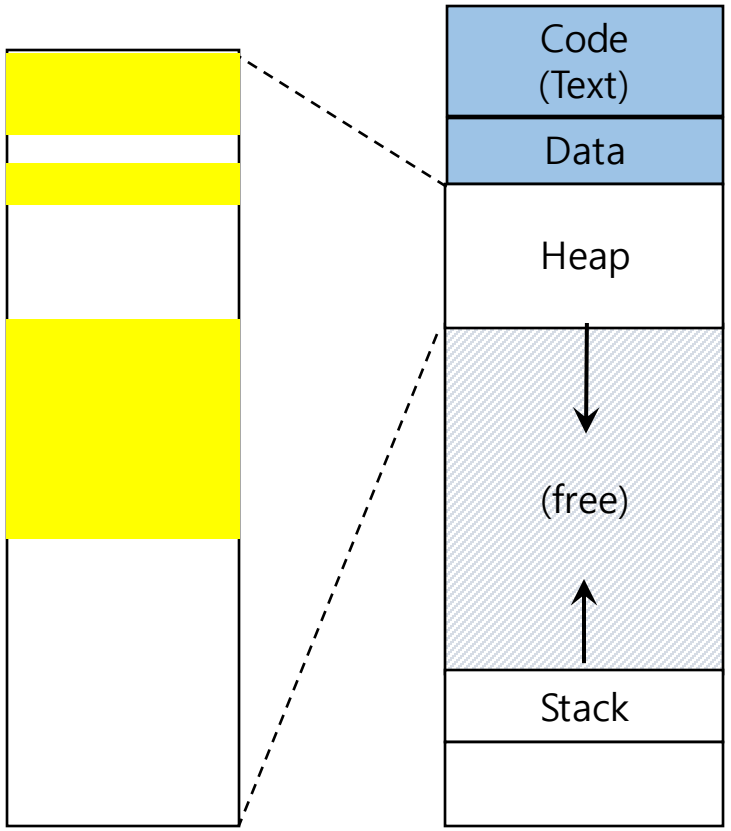
안인규

강의자료는 KAIST 원유집 교수님 OS 강의 자료를 참고했습니다.

Managing heap

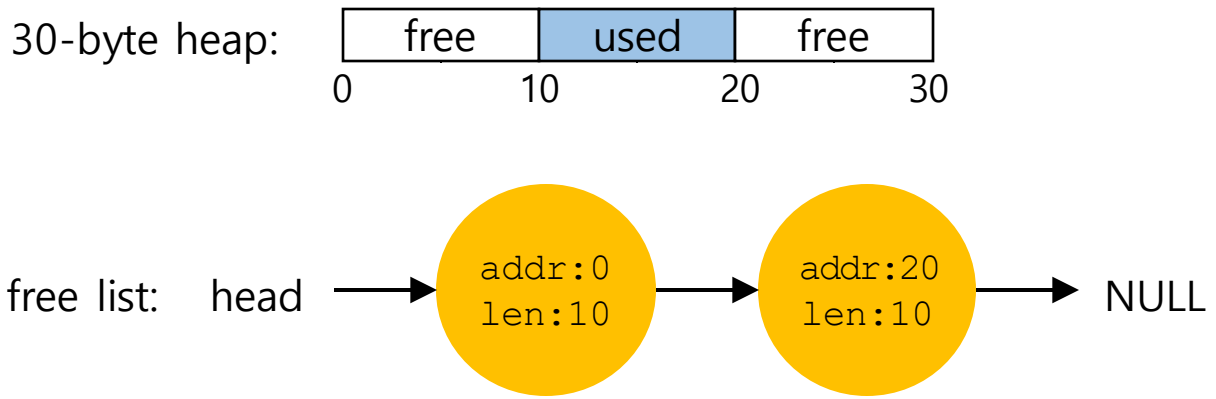
`malloc()`
`free()`
in **`libc`**

To manage the memory in a heap



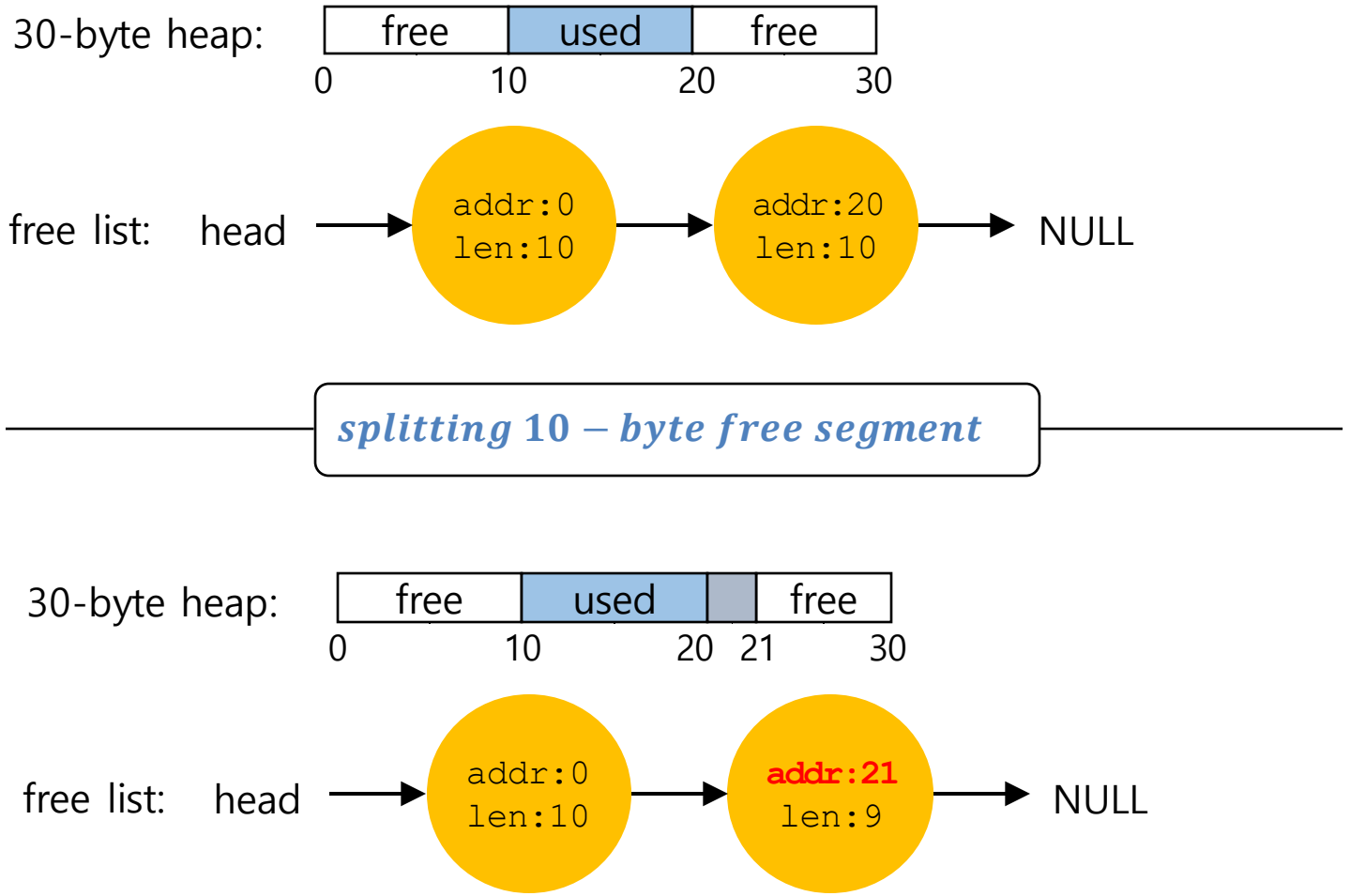
Splitting

- 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



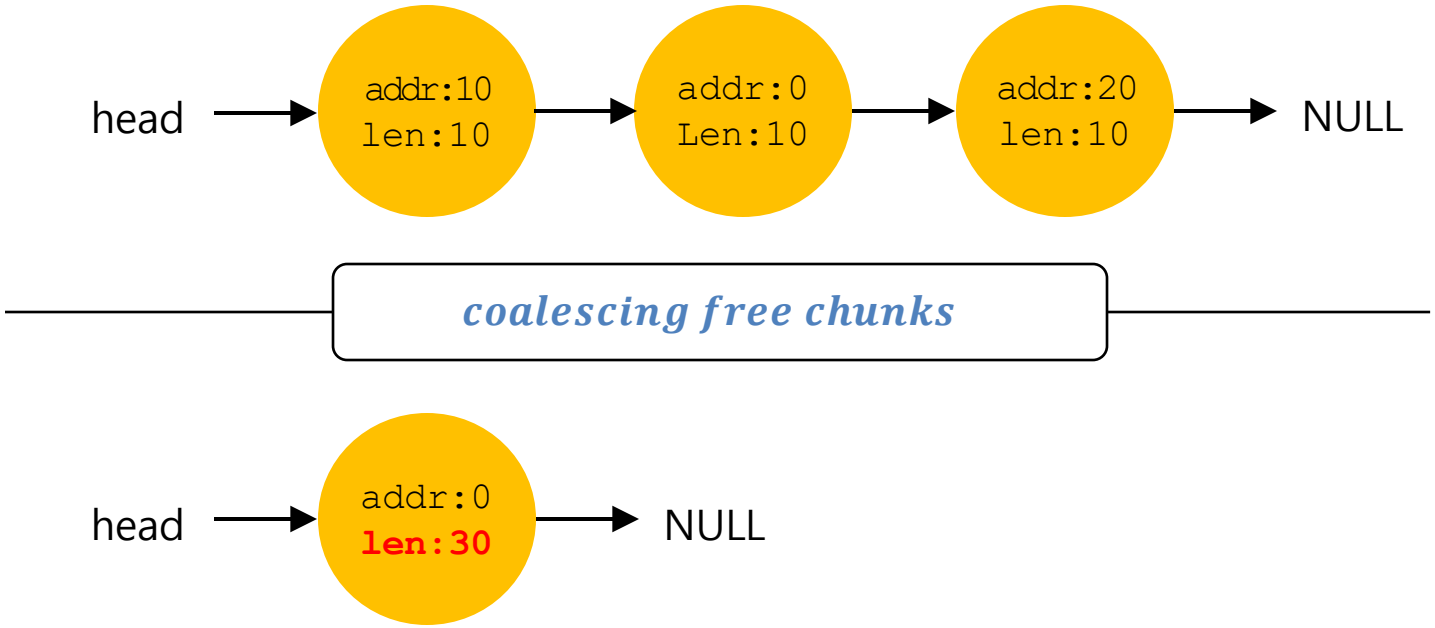
Splitting (Cont.)

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



Coalescing (병합)

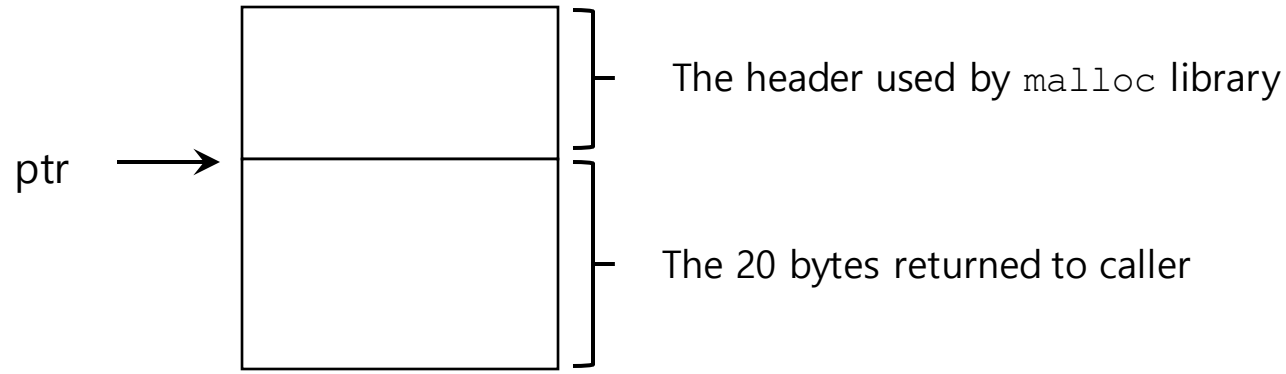
- If a user requests memory that is **bigger than free chunk size**, the list will **not find** such a free chunk.
- Coalescing: **Merge** returning a free chunk with existing chunks into a large single free chunk if **addresses** of them are **nearby**.



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);
```

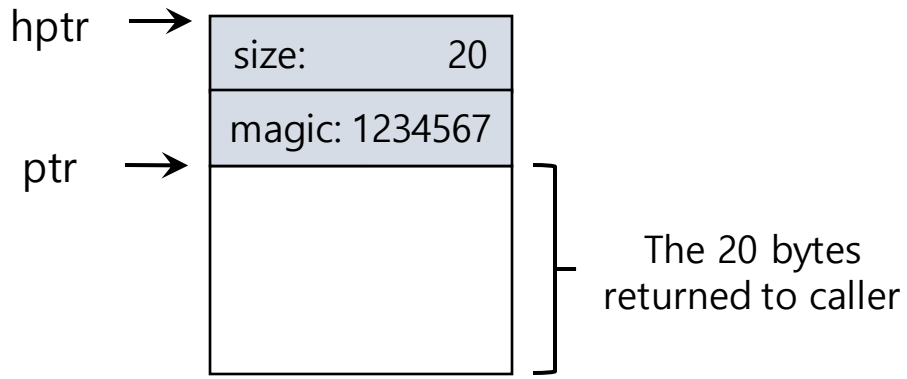


An Allocated Region Plus Header

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.)

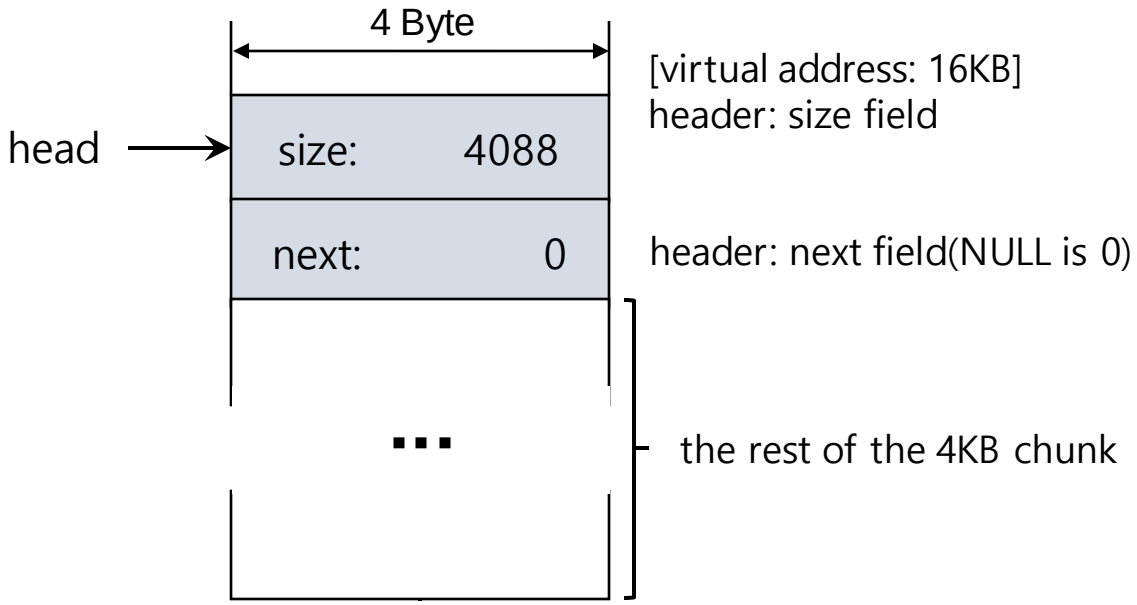
```
void free(void *ptr) {
    header_t *hptr = (void *)ptr - sizeof(header_t);
    …
    assert(hptr->magic==1234567) ;
    …
}
```

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

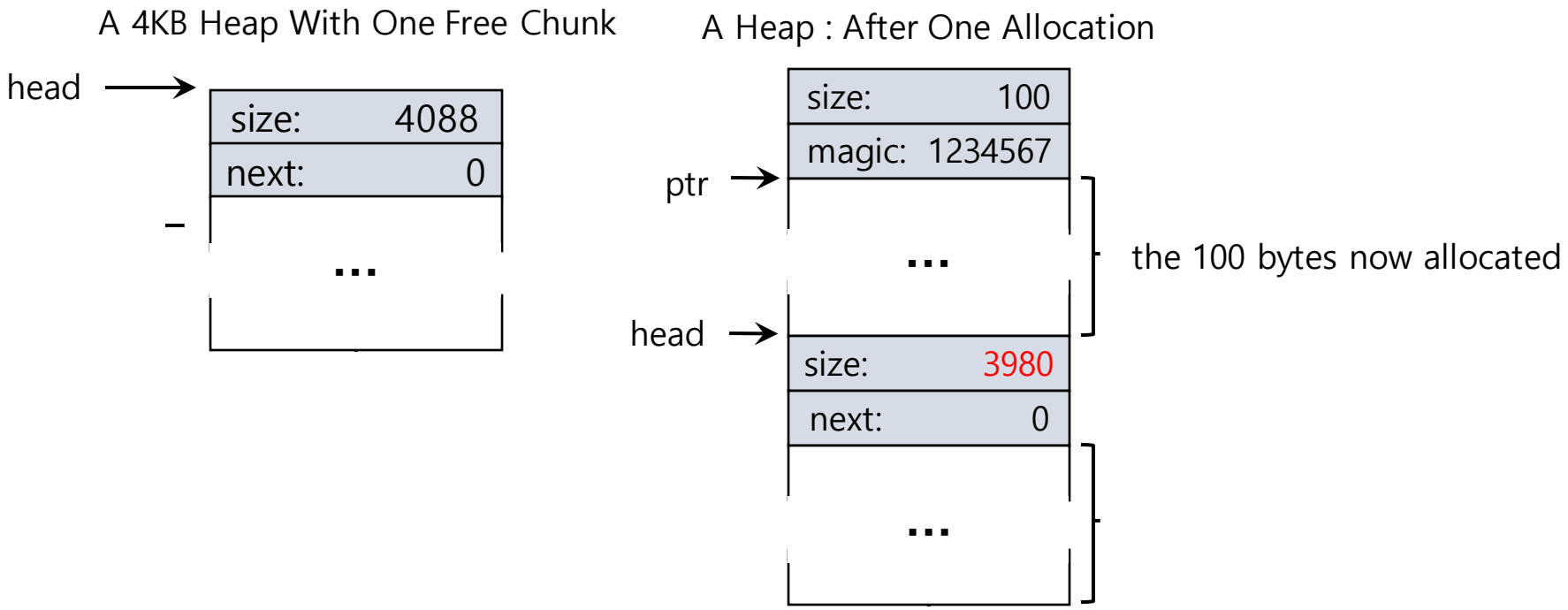
- If a chunk of memory is requested, the library **will first find** a chunk that is **large enough** to accommodate the request.

- 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.

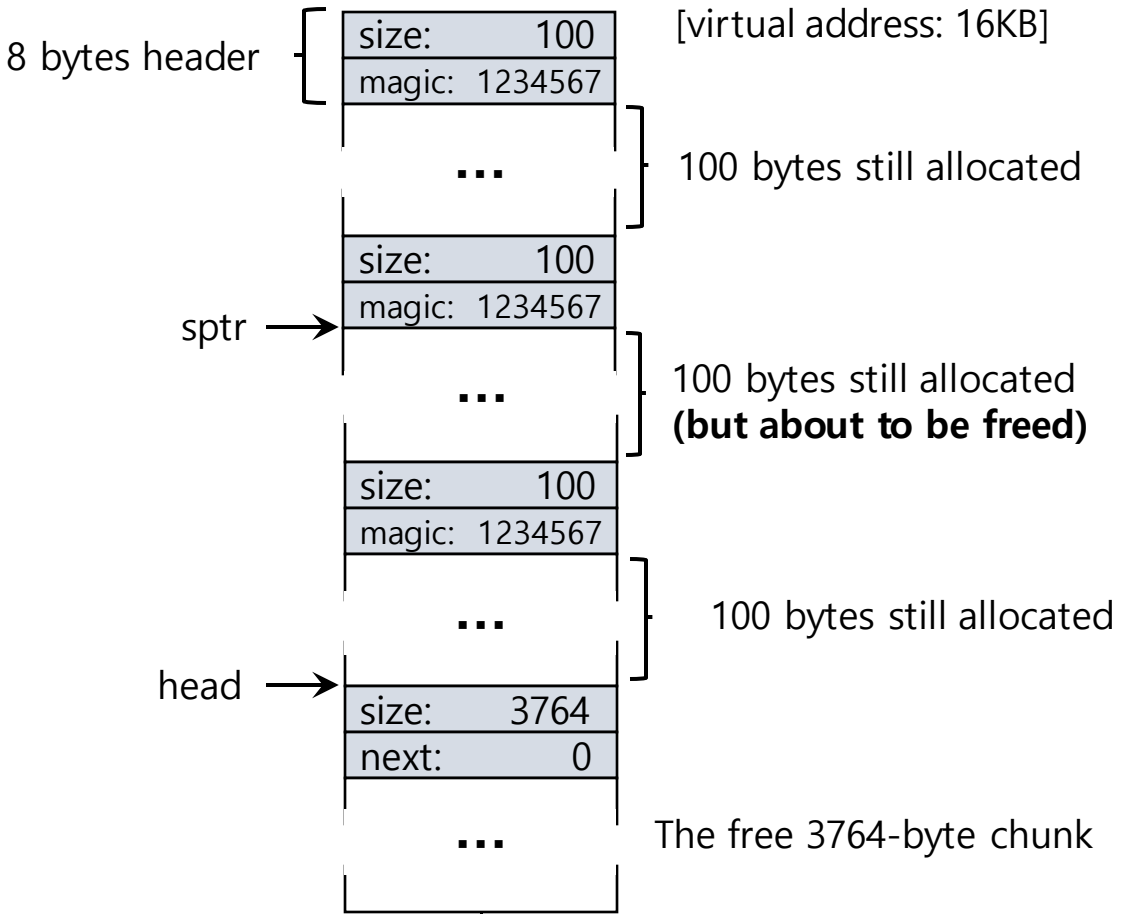
Embedding A Free List: Allocation(Cont.)

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

  → 108 byte is returned.



Free Space With Chunks Allocated

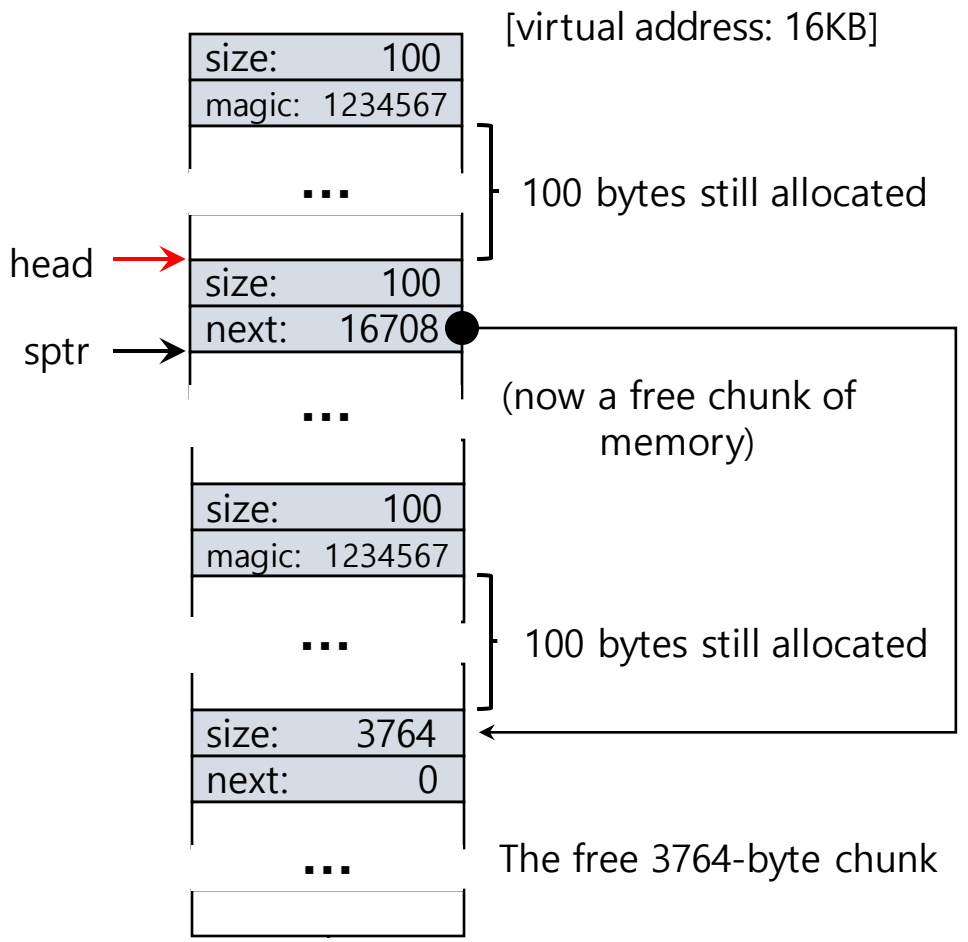


Free Space With Three Chunks Allocated

Free Space With `free()`

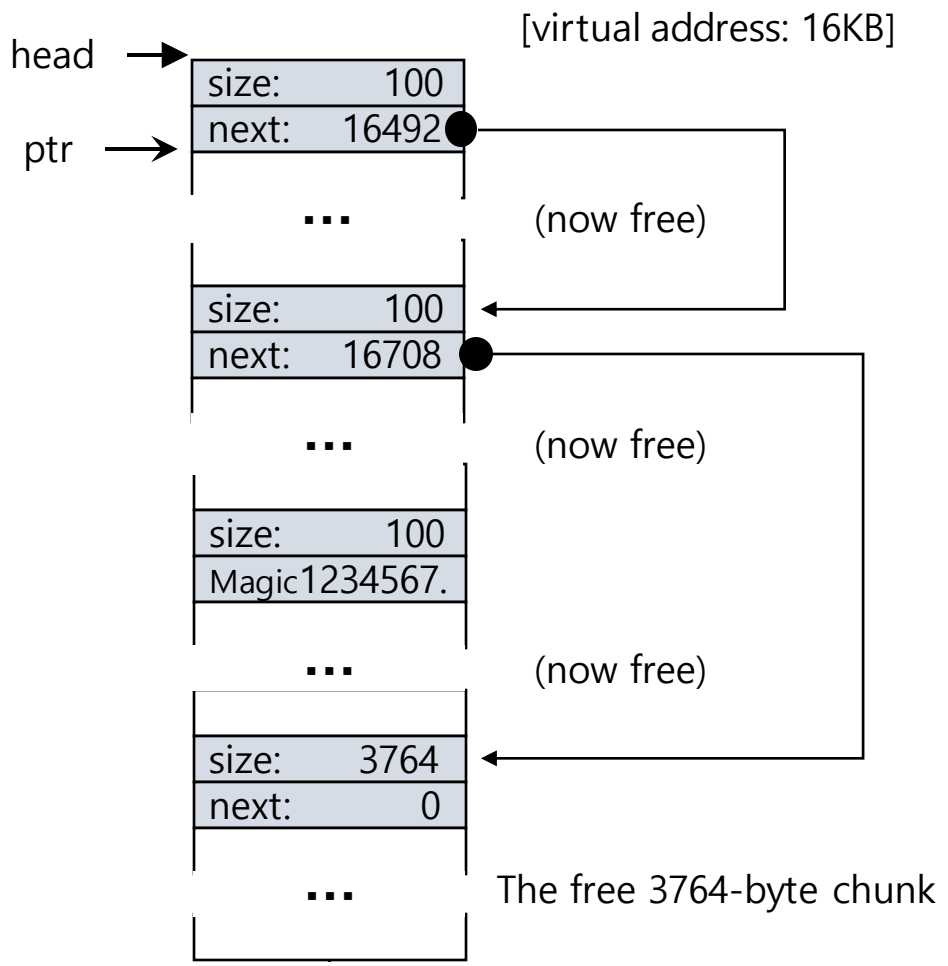
- `free(sptr)`

```
void* tmp = head ;
head = sptr - 8 ;
head->next = tmp ;
```



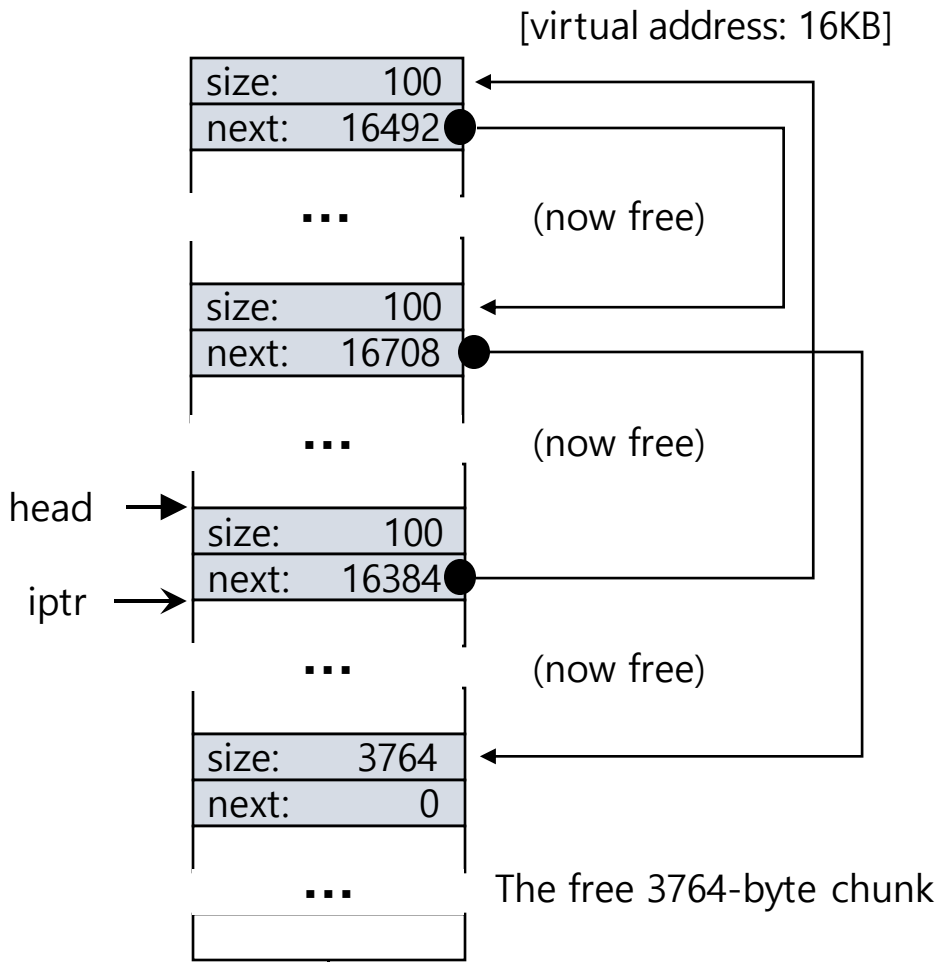
Free Space With Freed Chunks

- `free(ptr)`



Free Space With Freed Chunks

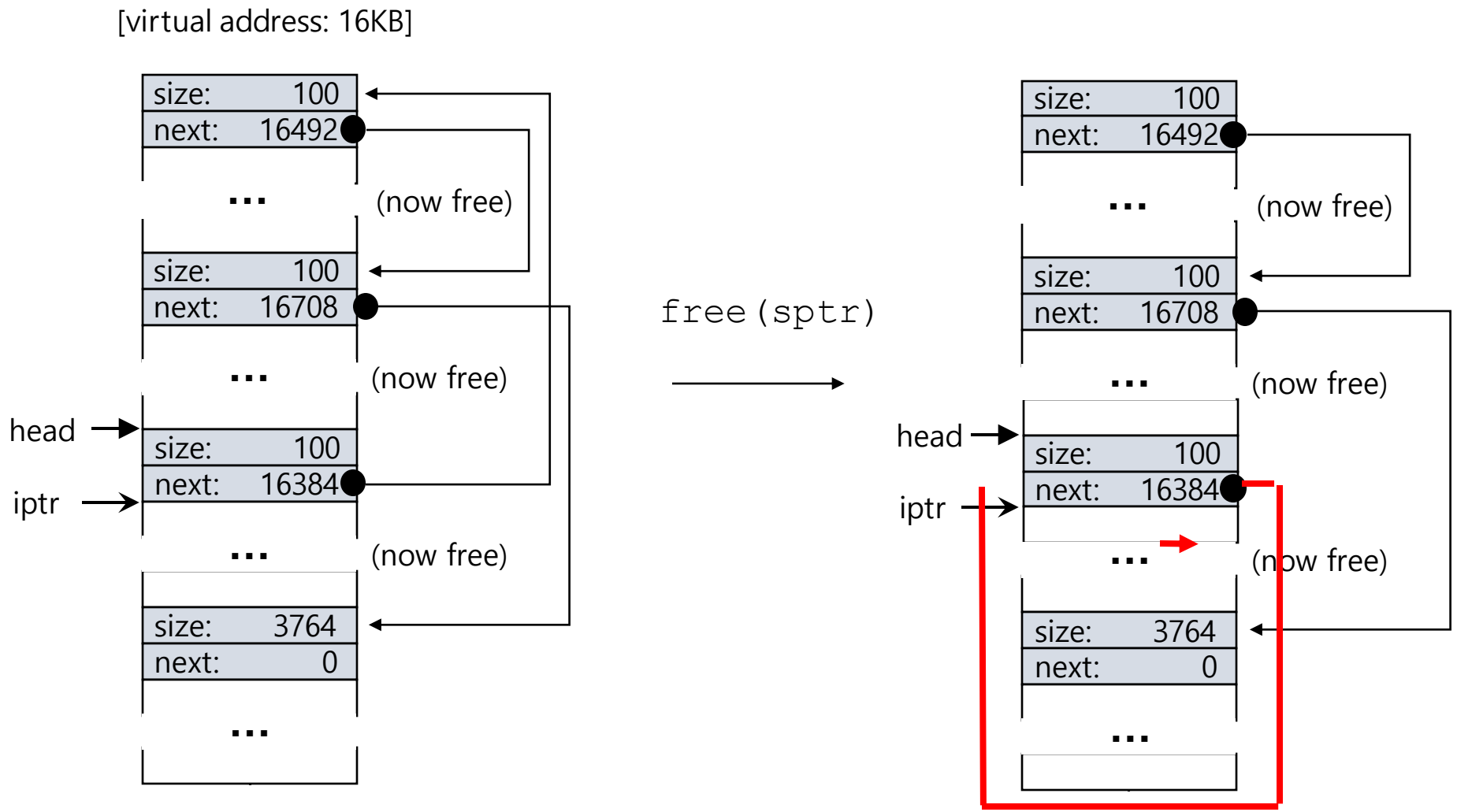
- free(iptr)
- **Coalescing** is needed in the list.



Double free

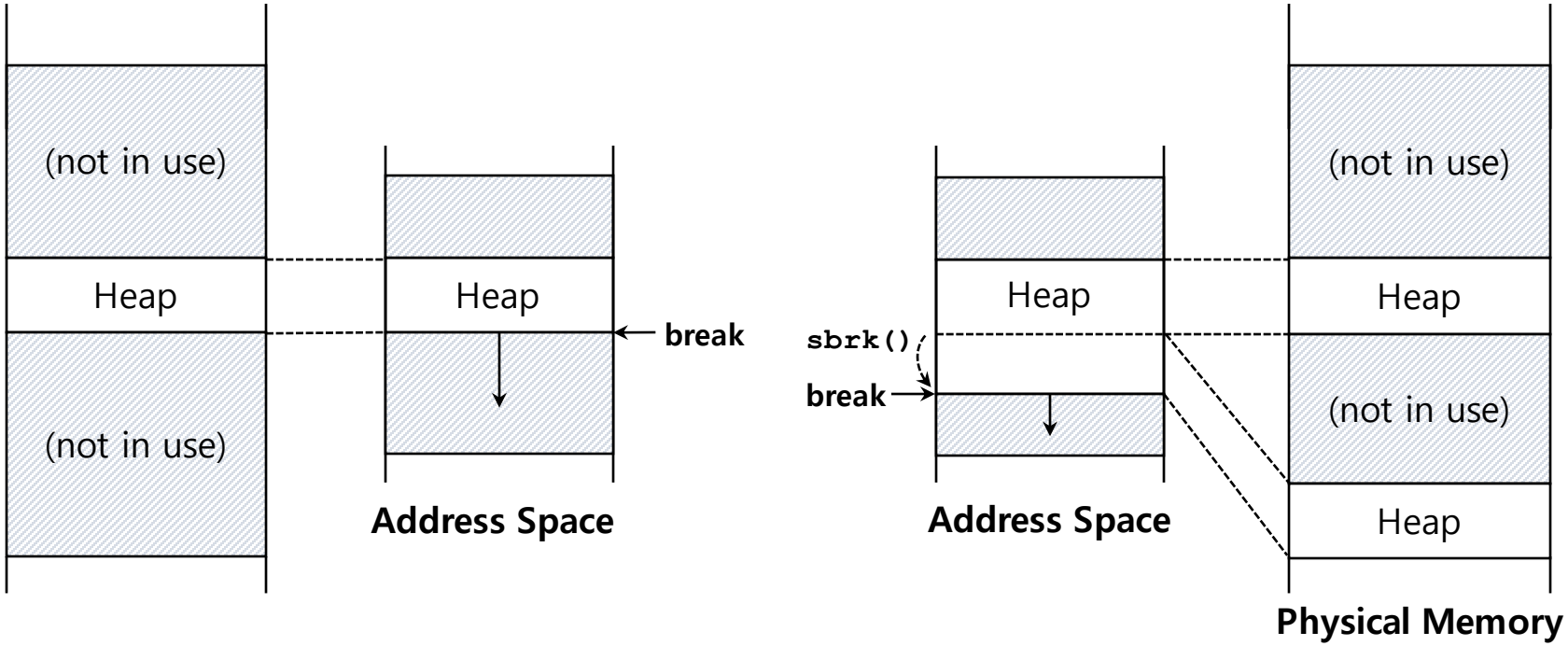
```
free(iptr)
    void* tmp = head ;
    head = iptr - 8 ;
    head->next = tmp ;
```

- Free(iptr): dangling



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.

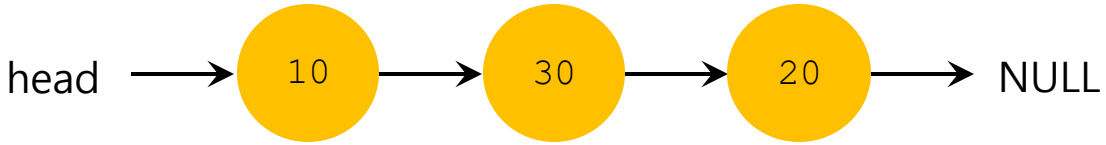
Managing Free Space: Basic Strategies(Cont.)

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

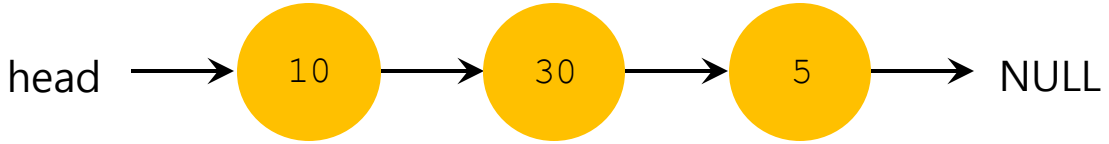
- Next Fit:
  - Finding the first chunk that is big enough for the request.
  - Searching at **where one was looking** at instead of the beginning of the list.

Examples of Basic Strategies

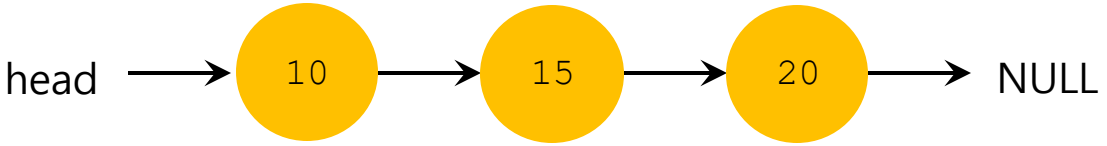
- Allocation Request Size 15



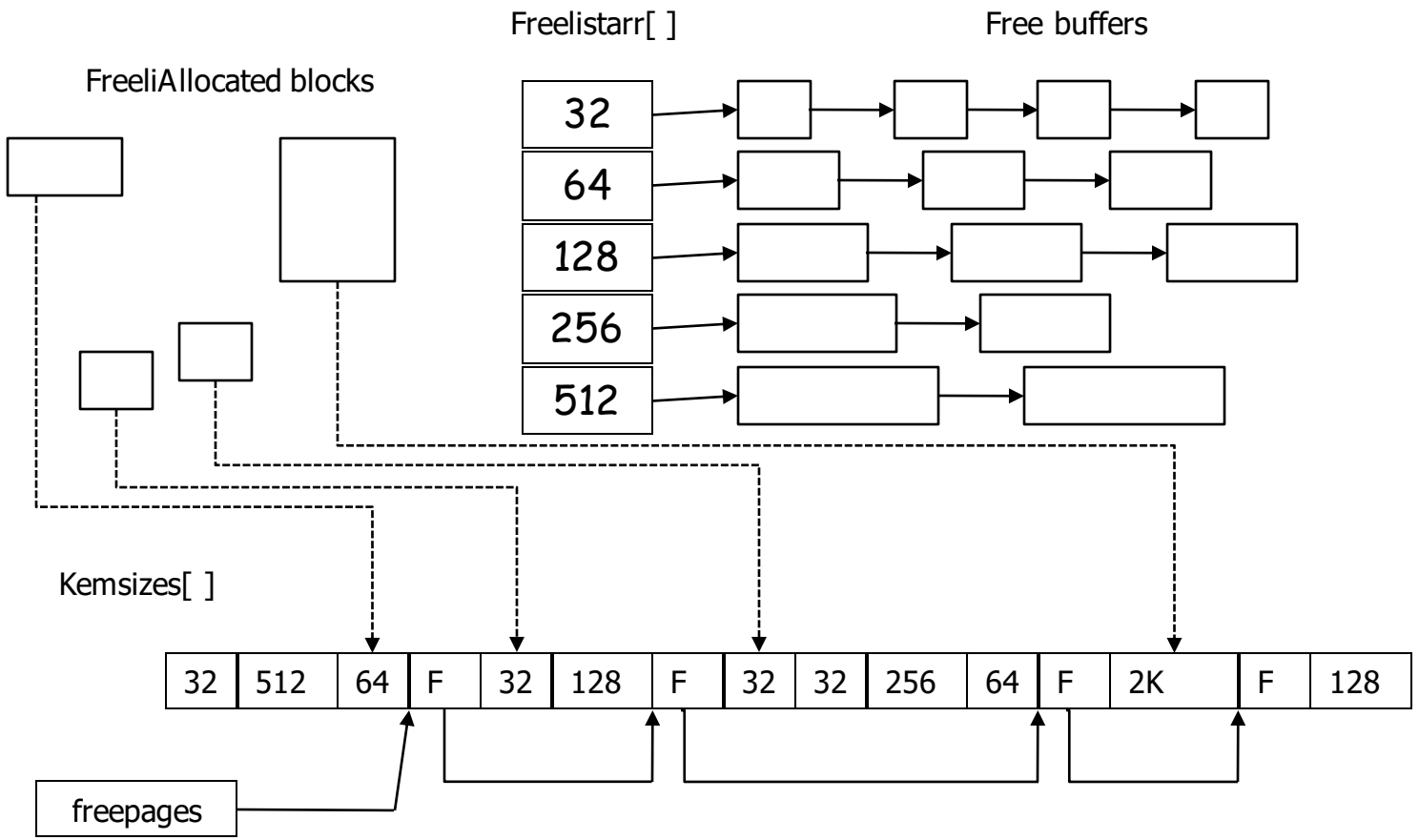
- Result of Best-fit



- Result of Worst-fit



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

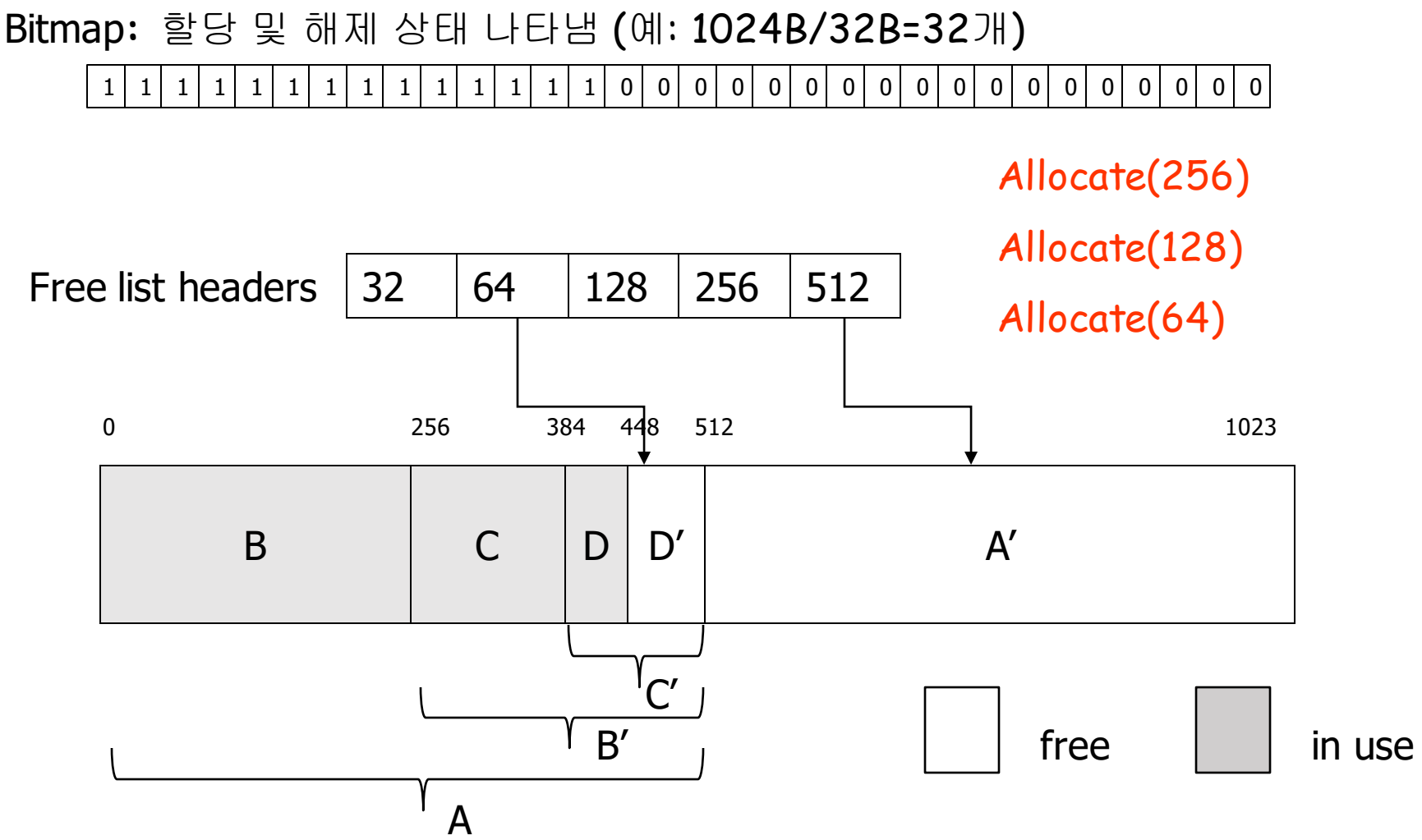
- Create the small buffers by repeatedly halving a large buffer and coalesce the adjacent free buffers.
- When a buffer is split, each half is called the buddy of the other.
- Minimum size is 32byte.
- Use a bitmap to monitor each 32-byte chunk of the block.

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).

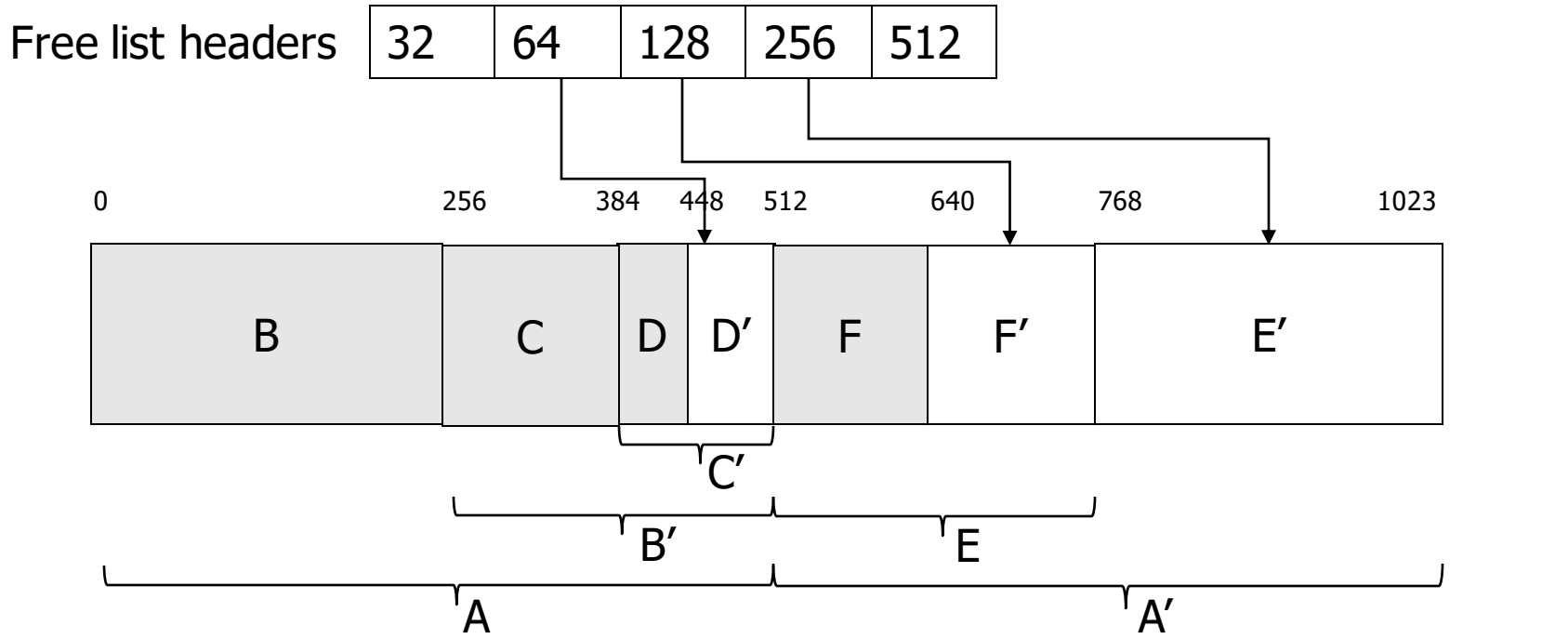


Example

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)

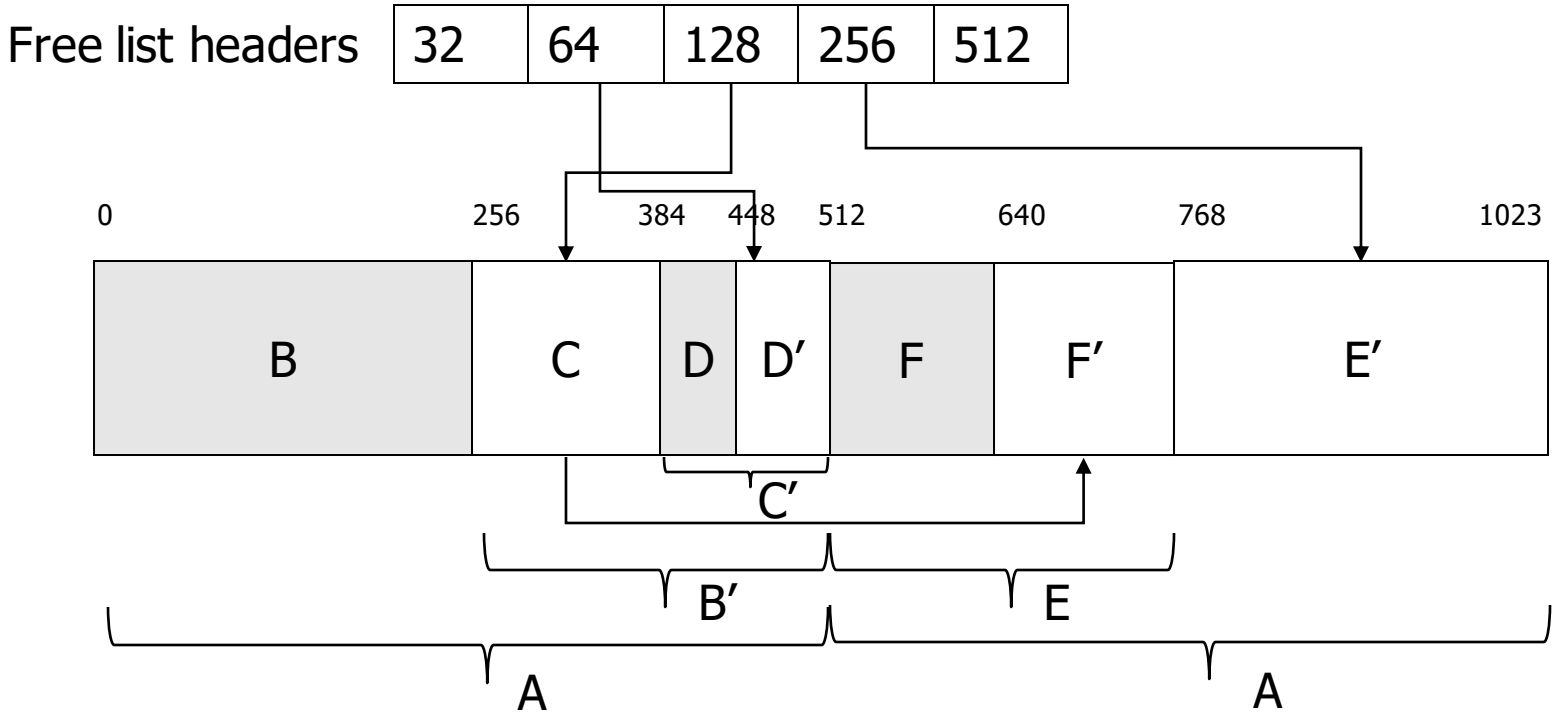


Example

bitmap

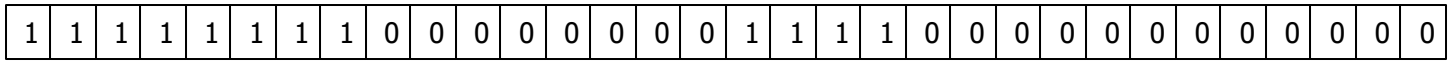
1	1	1	1	1	1	1	1	0	0	0	0	1	1	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0

Release(C, 128)

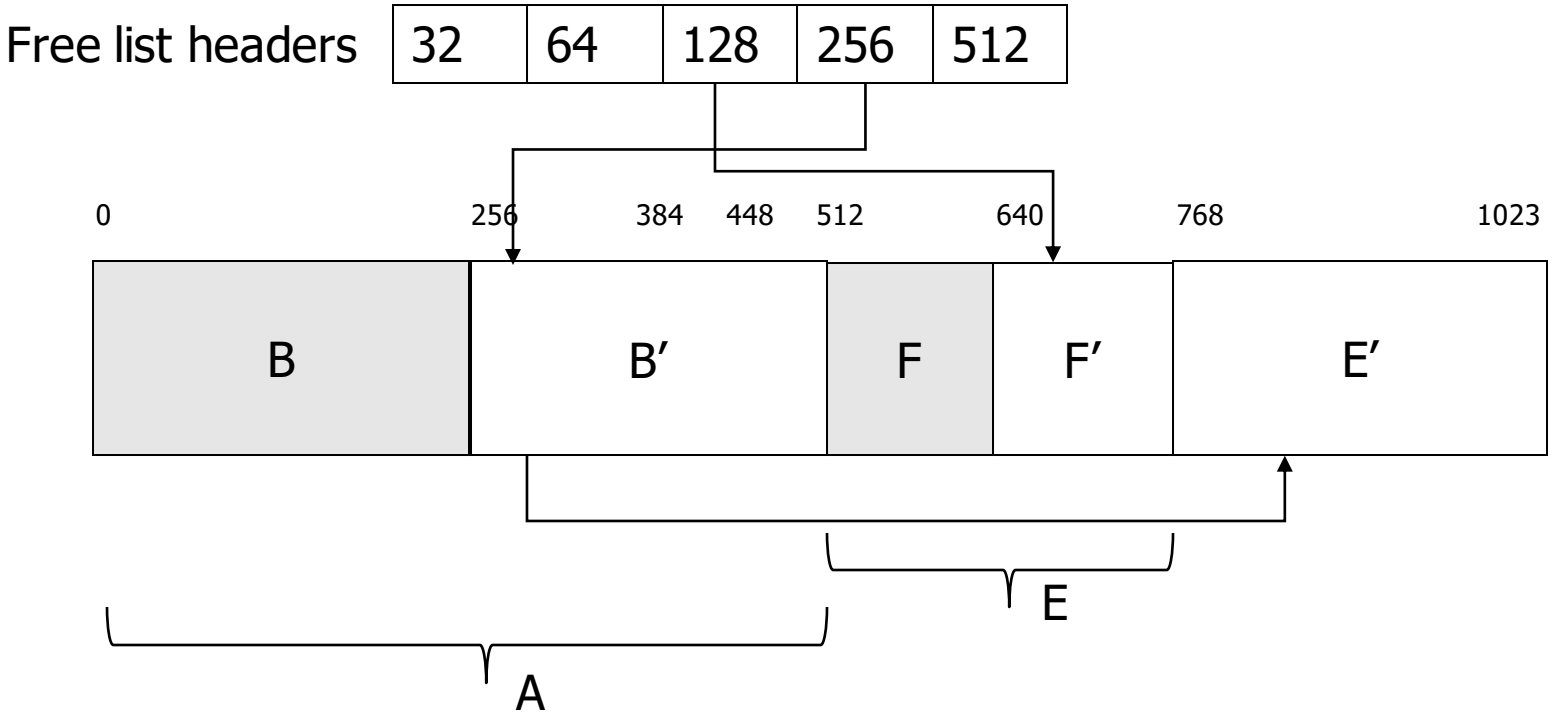


Example

bitmap



Release(D, 64)



Analysis

- Characteristic
  - 2의 거듭제곱 크기로 할당하기 때문에 Internal Fragmentation이 발생할 수 있음
  - Buddy 블록을 주소와 크기만으로 쉽게 찾을 수 있음
  - Coalescing (병합)을 위해 bitmap을 사용
- Advantage
  - 인접한 free buffe들을 효과적으로 Coalescing할 수 있음
  - Easy exchange of memory between the allocator and the paging system
- Disadvantage
  - Performance degrade: 버퍼가 해제될 때마다, 가능한 한 많이 coalescing을 시도하기 때문에 오버헤드 발생
  - 해제 과정에서는 버퍼의 주소와 크기 모두 필요 (기존에는 free(ptr))
  - Partial release가 제대로 처리되지 않음 (→ Internal Fragmentation)