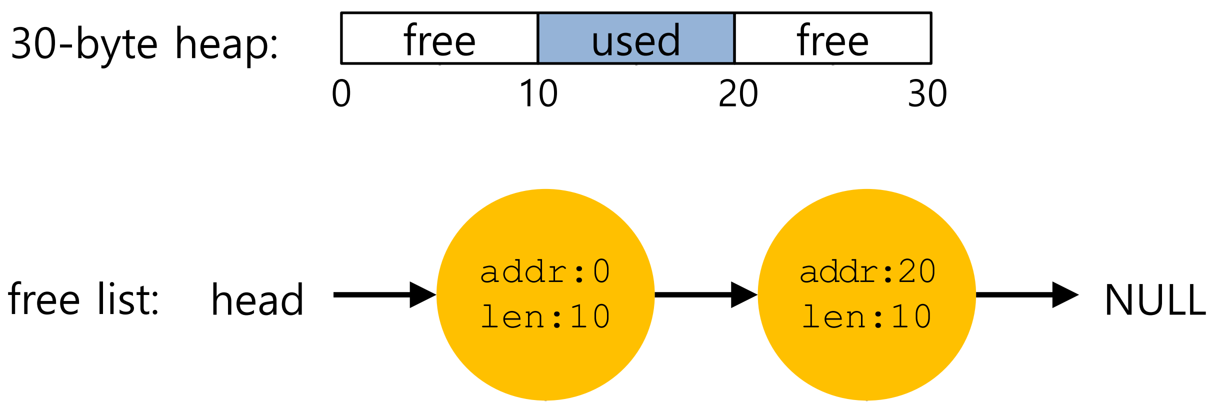
17. Free-Space Management

Operating System: Three Easy Pieces

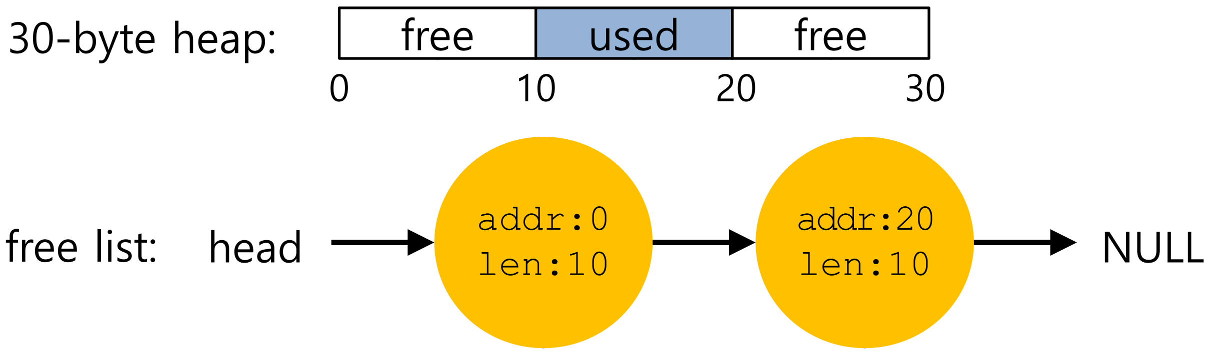
Splitting

- 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.

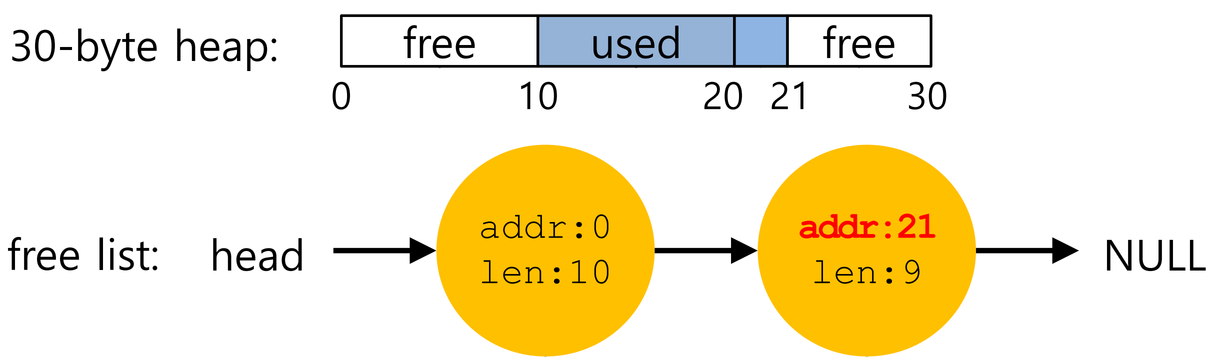


Splitting(Cont.)

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

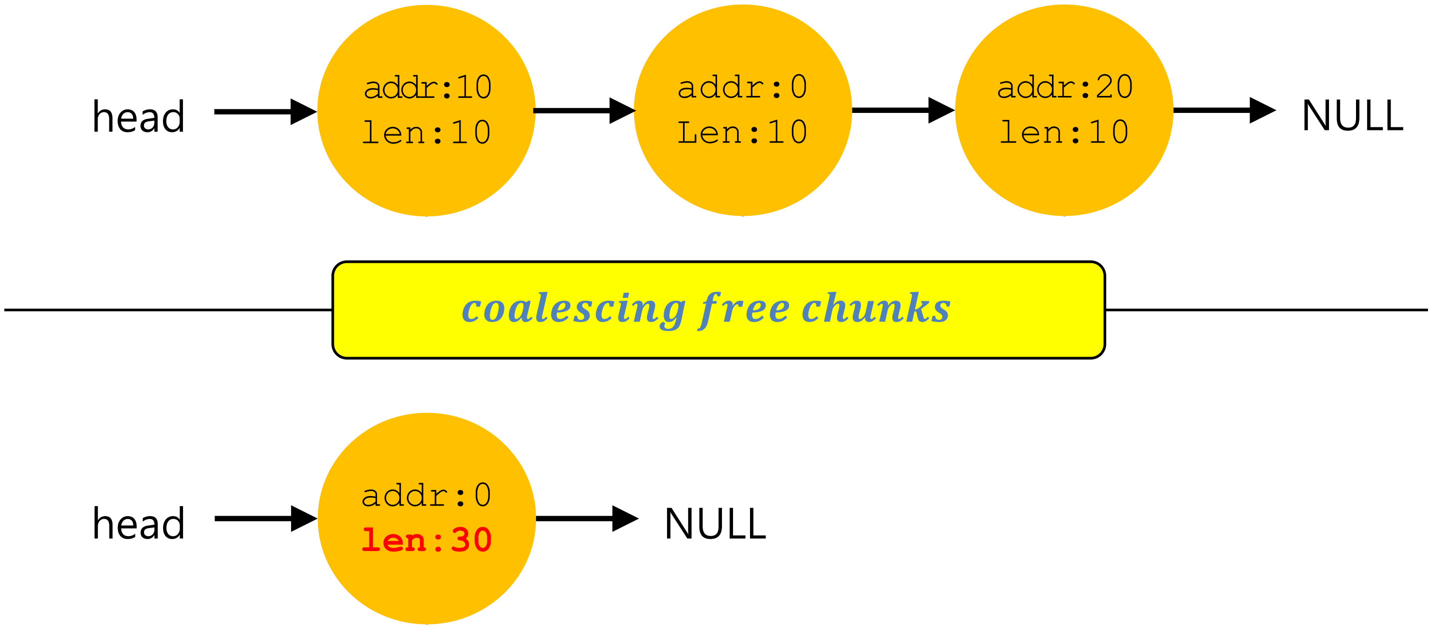


splitting 10 – byte free segment



Coalescing

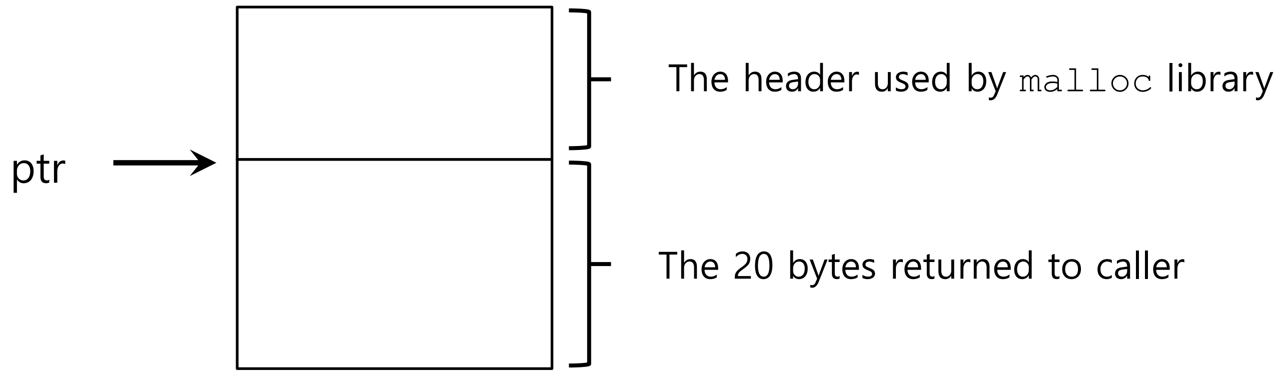
- If a user requests memory that is **bigger than free chunk size**, the list will **not find** such a free chunk.
- Coalescing: **Merge** returning a free chunk with existing chunks into a large single free chunk if **addresses** of them are **nearby**.



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**?
- Most allocators store **extra information** in a **header** block.

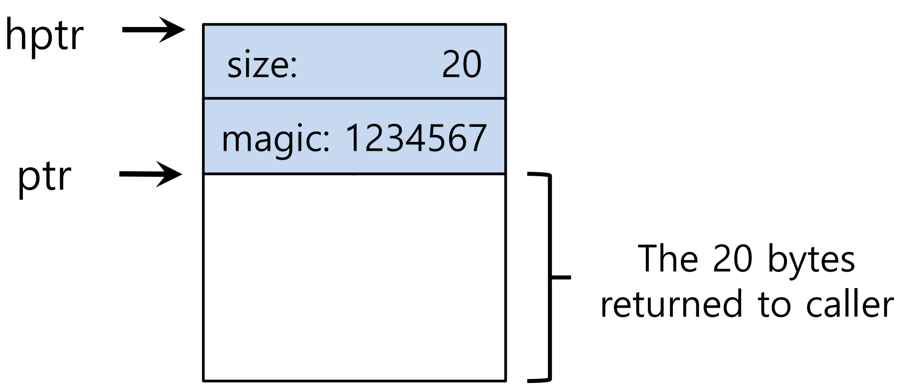
```
ptr = malloc(20);
```



An Allocated Region Plus Header

The Header of Allocated Memory Chunk

- The header minimally **contains the size** of the allocated memory region.
- The header may also contain
  - Additional pointers to speed up deallocation
  - A magic number for integrity checking



Specific Contents Of The Header

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

A Simple Header

The Header of Allocated Memory Chunk(Cont.)

- The **size** for free region is the **size of the header plus the size of the space** allocated to the user.
  - If a user **request `N` bytes**, the library searches for a free chunk of **size `N` plus the size of the header**

- Simple pointer arithmetic to find the header pointer (& check).

```
void free(void *ptr) {
        header_t *hptr = (void *)ptr - sizeof(header_t);
        assert(hptr->magic == 1234567 && "Heap is corrupt");
        ...
}
```

Embedding A Free List

- The memory-allocation library **initializes** the heap and **puts** the first element of **the free list** in the **free space**.
  - The library **can't use** `malloc()` to build a list **within itself**.

Embedding A Free List(Cont.)

- Description of a node of the list

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

- Building heap and putting a free list
  - Assume that the heap is built via `mmap()` system call.

```
// 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;
```

A Heap With One Free Chunk

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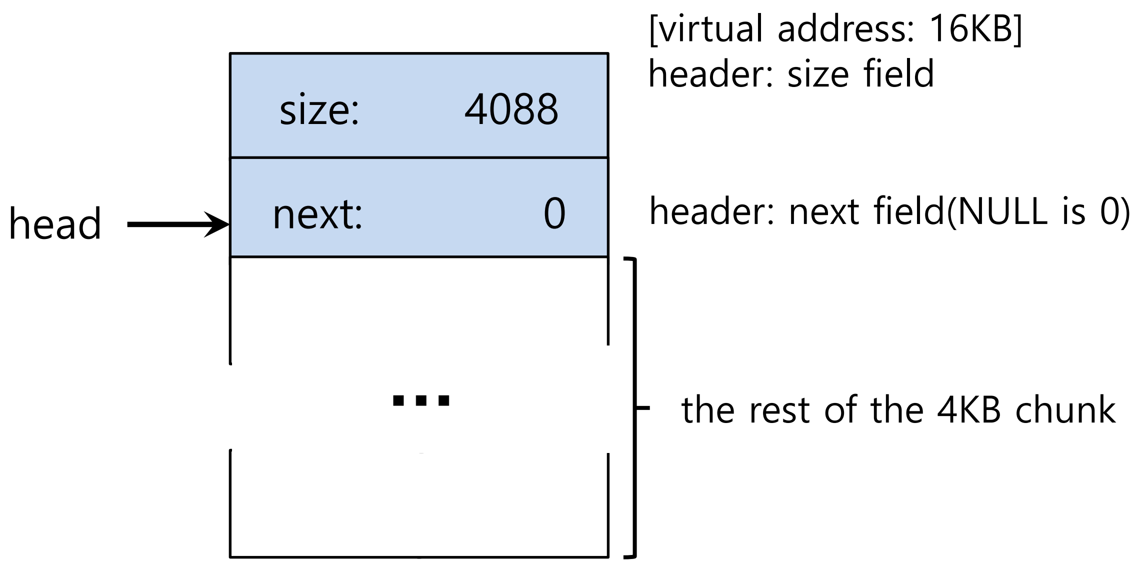



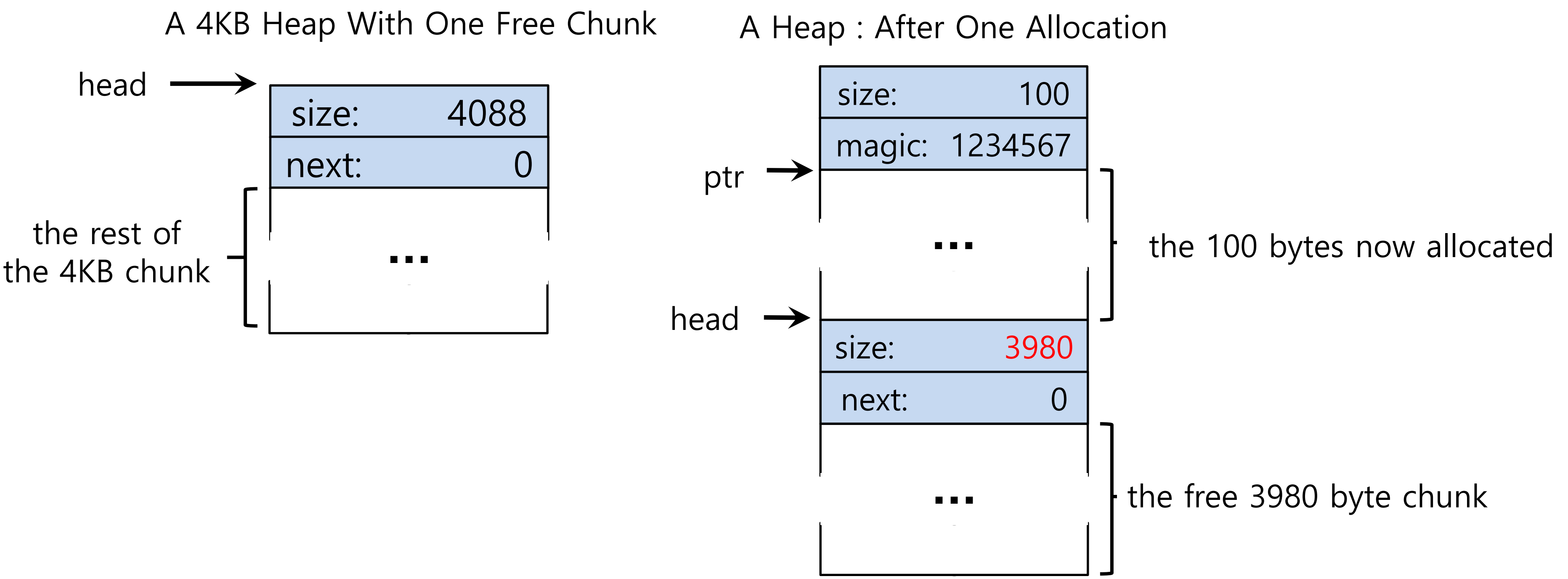
Embedding A Free List: Allocation

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

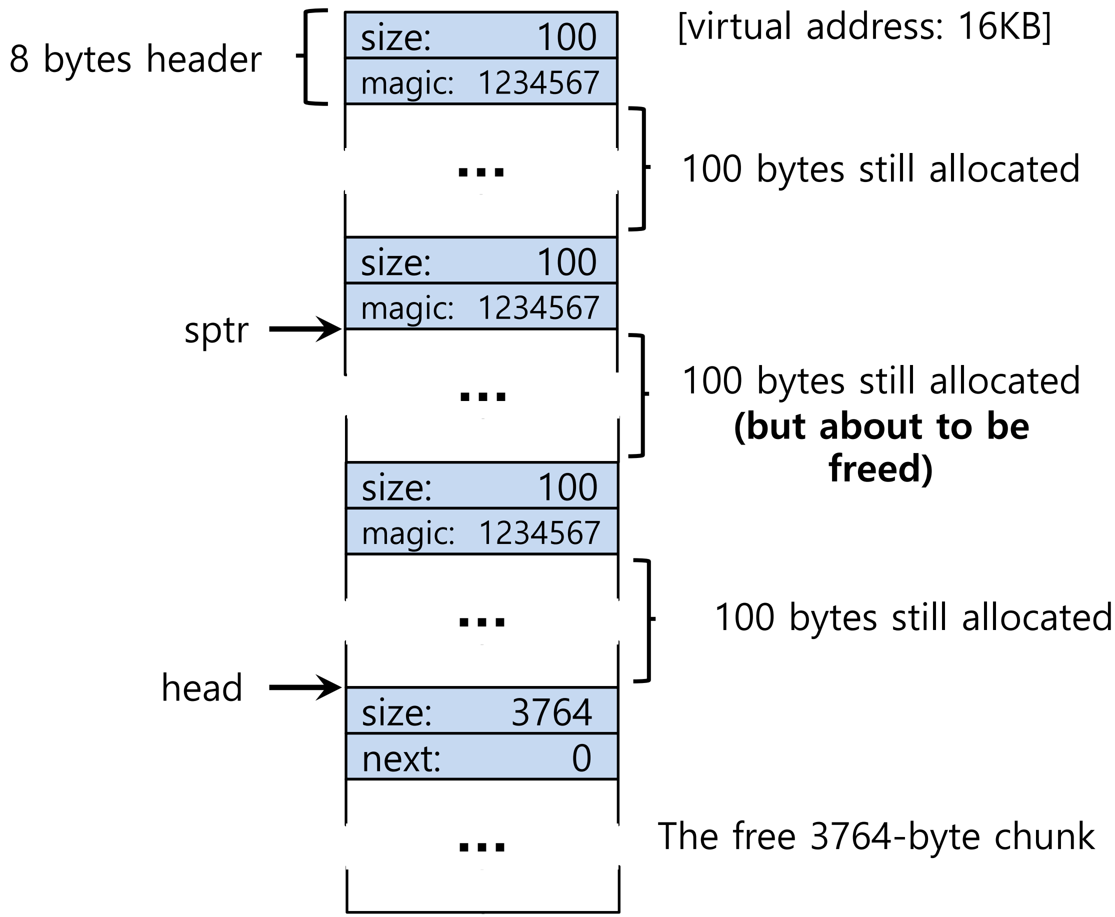
- The library will
  - **Split** the large free chunk into two.
    - **One** for the **request** and the **remaining** free chunk
  - **Shrink** the size of free chunk in the list.

Embedding A Free List: Allocation(Cont.)

- Example: a request for 100 bytes by `ptr = malloc(100)`
  - Allocating 108 bytes out of the existing one free chunk.
  - shrinking the one free chunk to 3980(4088 minus 108).



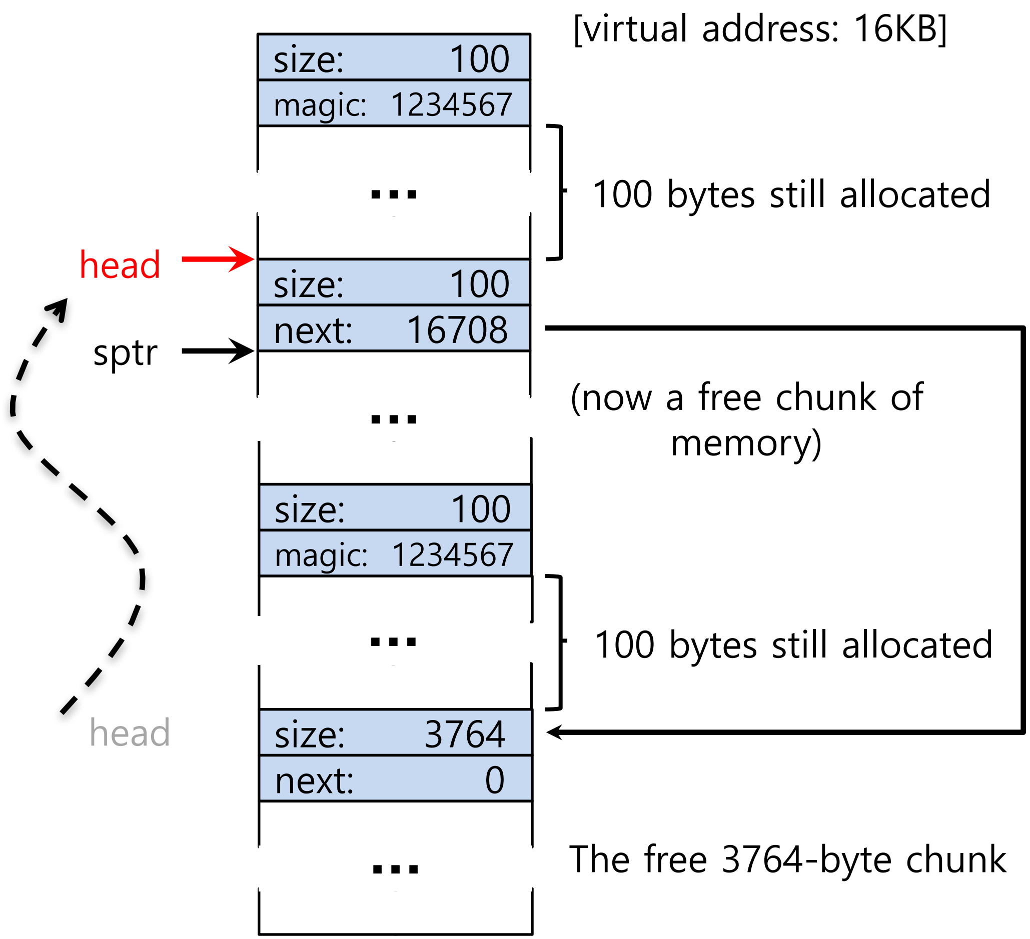
Free Space With Chunks Allocated



Free Space With Three Chunks Allocated

Free Space With `free()`

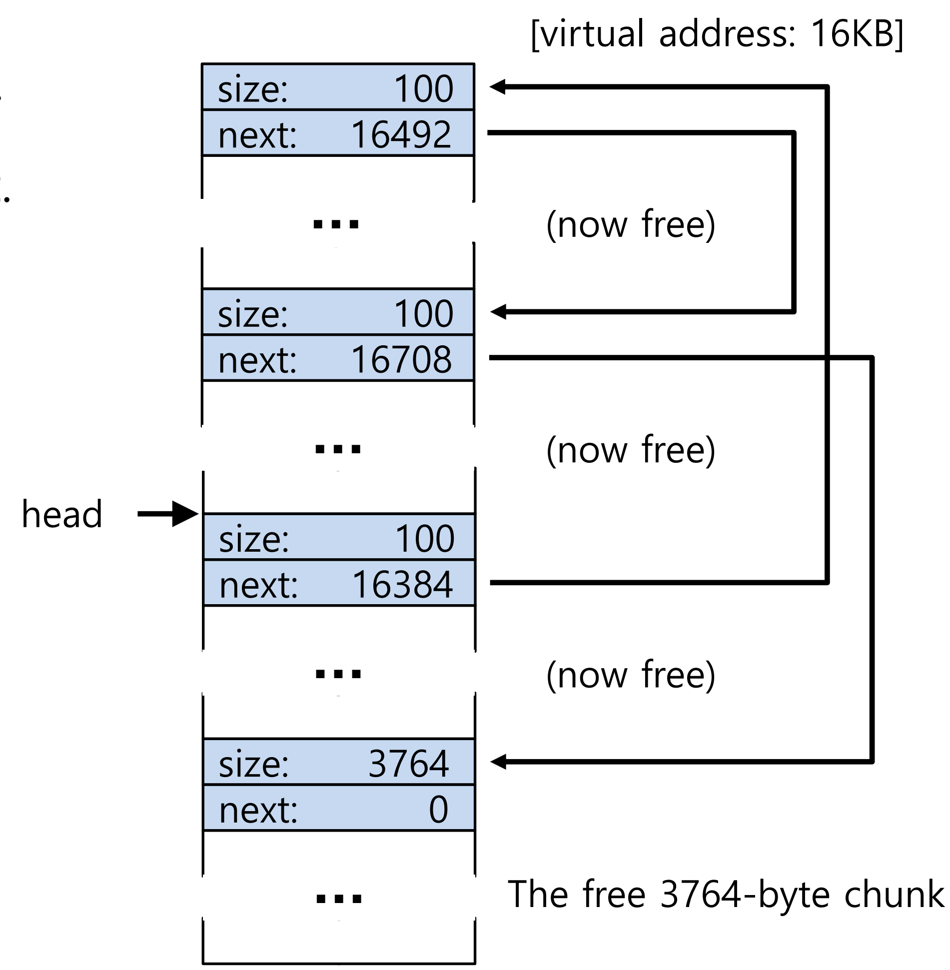
- Example: `free(sptr)`
  - The 100 bytes chunks is **back into** the free list.
  - The free list will **start** with **a small chunk**.
    - The list header will point the small chunk



Free Space With Freed Chunks

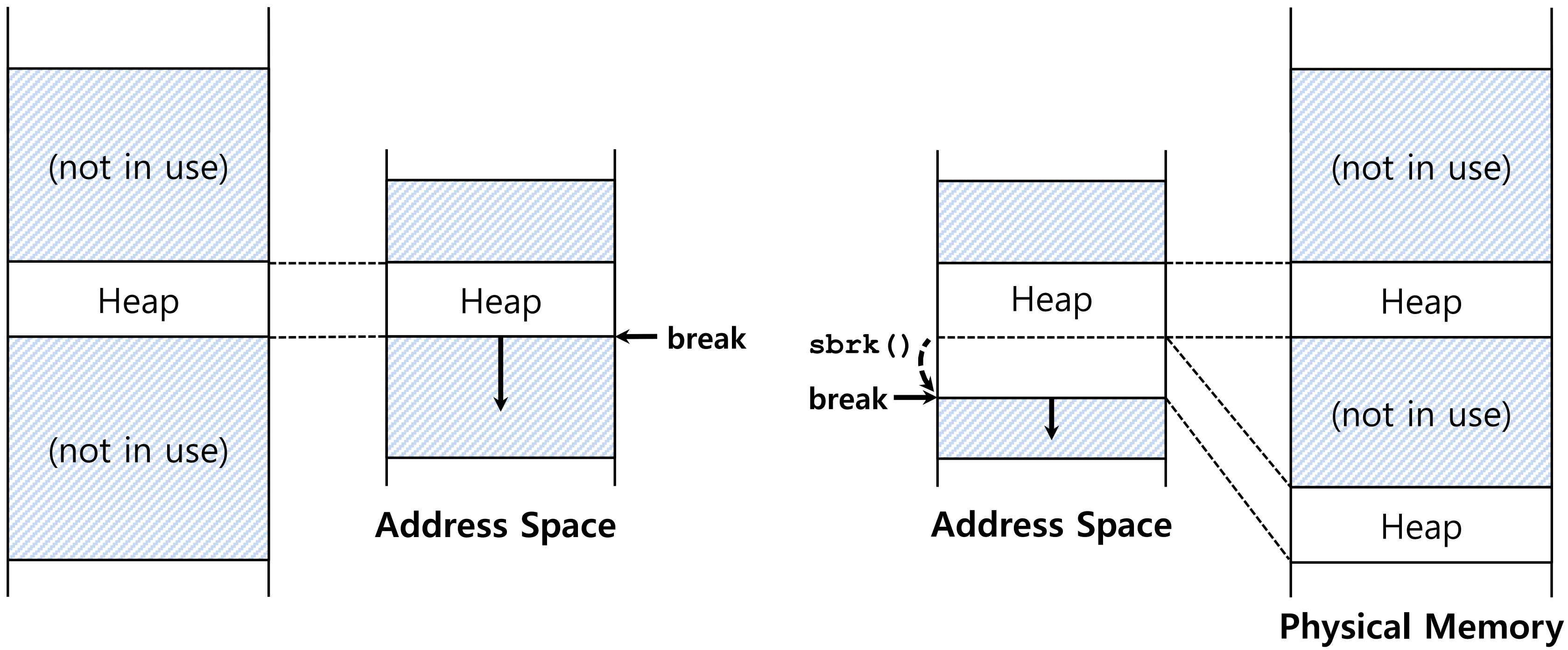
- Let's assume that the last two in-use chunks are freed.

- **External Fragmentation** occurs.
  - **Coalescing** is needed in the list.



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.

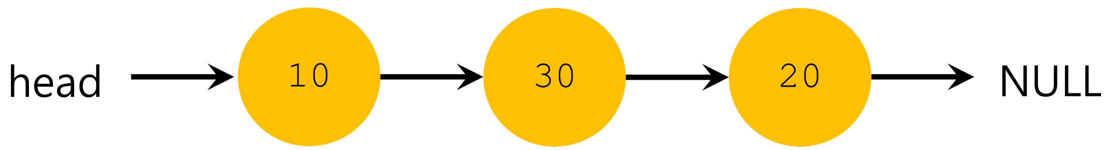
Managing Free Space: Basic Strategies(Cont.)

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

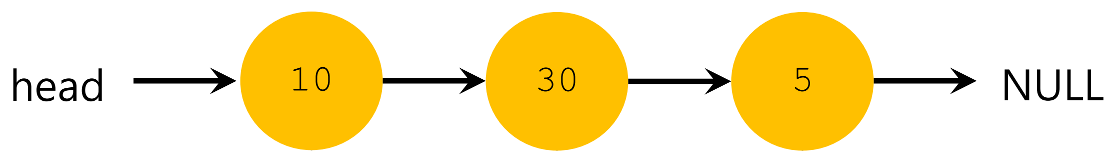
- Next Fit:
  - Finding the first chunk that is big enough for the request.
  - Searching at **where one was looking** at instead of the begging of the list.

Examples of Basic Strategies

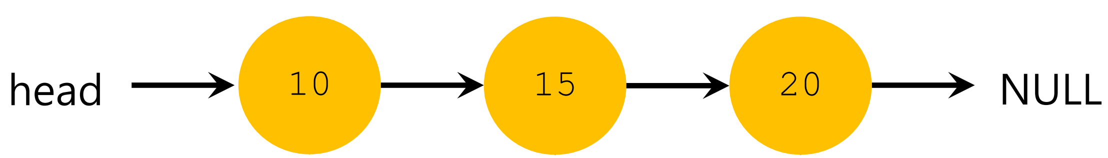
- Allocation Request Size 15



- Result of Best-fit



- Result of Worst-fit



Other Approaches: Segregated List

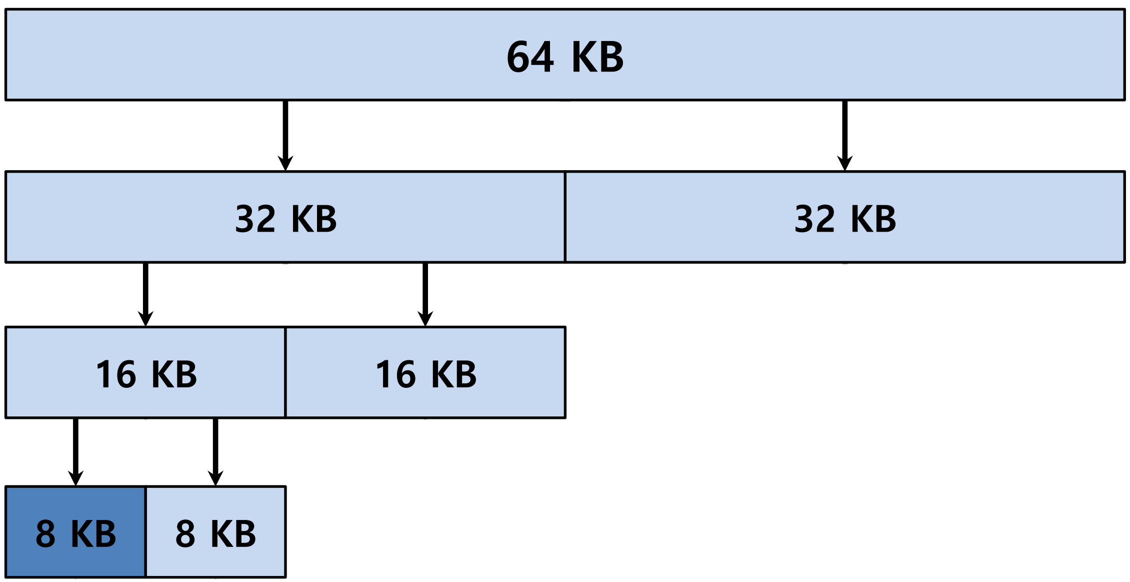
- Segregated List:
  - Keeping free chunks in different size in a separate list for the size of popular requests (for the application)
  - New Complication:
    - **How much** memory should dedicate to **the pool of memory** that serves **specialized requests** of a given size?
  - **Slab allocator** handles this issue.

Other Approaches: Segregated List(Cont.)

- Slab Allocator (Kernel Heap in Solaris, Jeff Bonwick)
  - Allocate a number of object caches.
    - The objects are likely to e requested frequently.
    - e.g., locks, file-system inodes, etc.
  - **Request some memory** from a more general memory allocator when **a given cache is running low** on free space.

Other Approaches: Buddy Allocation

- Binary Buddy Allocation
  - The allocator **divides free space** by two **until a block** that is big enough to accommodate the request is **found**.



Example: 64KB free space for 7KB request

Other Approaches: Buddy Allocation(Cont.)

- Buddy allocation can suffer from **internal fragmentation**.

- Buddy system makes **coalescing** simple.
  - **Coalescing** two blocks in to the next level of block.

Other Ideas

- Scaling issues in most of previous approaches
- Trade complexity for performance: use more complex structures
  - Balanced binary trees
  - Splay trees
  - Partially-ordered trees
  - …
- Multiprocessor advent increase the relevance of memory allocators (contention)
- Just a small intro of the 1000s of ideas about the subject

- Disclaimer: Disclaimer: This lecture slide set is used in AOS course at University of Cantabria. Was initially developed for Operating System course in Computer Science Dept. at Hanyang University. This lecture slide set is for OSTEP book written by Remzi and Andrea Arpaci-Dusseau (at University of Wisconsin)