Operating System Labs

Yuanbin Wu
CS@ECNU

Operating System Labs

- Project 2 Due
  - 21:00, Oct. 23
- Project 3
  - Group of 3
  - If you can not find a partner, drop us an email
  - You now have 3 “late days”, but start early!
  - We will have oral test at week 12 (Nov. 21)

Operating System Labs

- C Memory API
- Free Memory Management

C Memory API

- Type of memory
  - Stack
  - Heap

C Memory API

- Stack
  - Allocated / Deallocate automatically
  - By the compiler
  - Automatic memory

C Memory API

- Stack
  - Example (local variable)

```
void func()
{
    int x = 0;
    ...
}
```

  - You only declare the variable
  - Compiler will allocate it when call the function
  - Also deallocate it when func returns

C Memory API

- Heap
  - Allocated / Deallocate explicitly
  - By you, the programmer

C Memory API

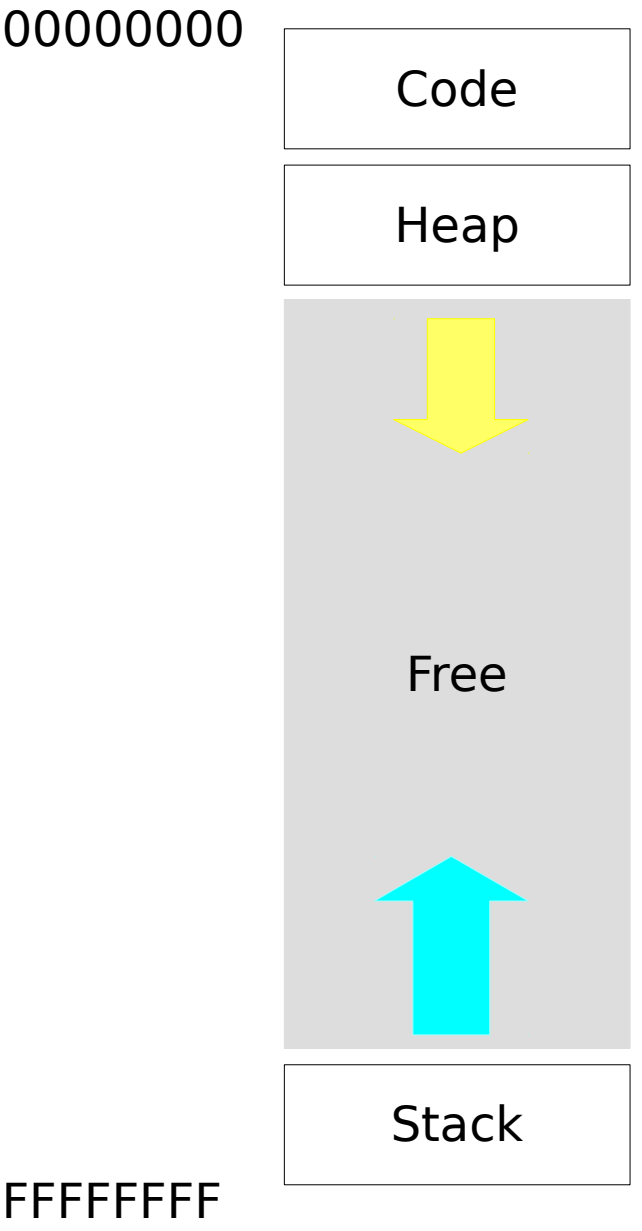
- Heap
  - Example (malloc)

```
void func()
{
    int *ptr = (int*)malloc(sizeof(int));
    ...
}
```

  - Both stack and heap allocation
  - When func returns,
    - Stack memory will be deallocated
    - Heap memory is still there

C Memory API

- Stack and Heap
  - Heap
    - From low addr to high addr
  - Stack
    - From high addr to low addr
- Let's see



C Memory API

- Malloc

```
#include <stdlib.h>
void *malloc(size_t size);
```

  - If failed, return NULL

- Free

```
#include <stdlib.h>
void free(void* ptr);
```

C Memory API

- Common errors
  - Forget to allocate memory
  - Not allocating enough memory
  - Forget to initialize allocated memory
  - Forget to free memory
  - Free memory before you are done with it
  - Free memory repeatedly
  - Call free() incorrectly

C Memory API

- Segment fault

```
char *src = "hello";
char *dst;          // oops! unallocated
strcpy(dst, src); // segfault and die
```

- run this code, it will likely lead to a

segmentation fault

- It is a fancy term for

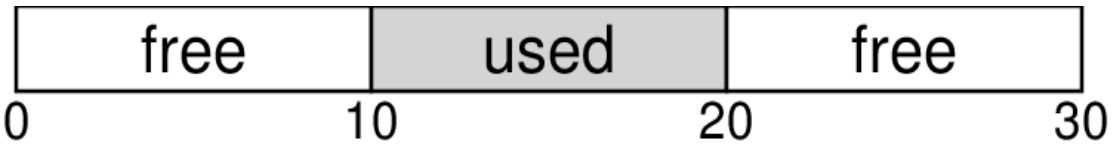
YOU DID SOMETHING WRONG WITH MEMORY
YOU FOOLISH PROGRAMMER AND I AM ANGRY.

Free Memory Management

Dark Forest of Pointers

Free Memory Management

- Fixed-size unit
  - Paging
  - Problem: internal fragmentation
- Variable-size unit
  - User level memory allocation library
  - Kernel level: VM implemented with segmentation
  - Problem: external fragmentation



Free Memory Management

- Free memory management
  - How to manage variable-size free memory units
  - How to implement
    - malloc(size_t size)
    - free(void *ptr)

Free Memory Management

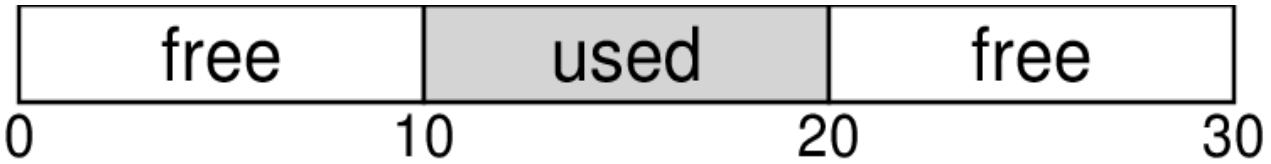
- Assumptions
  - Focus on external fragmentation
  - No compaction
  - Manage a contiguous region of bytes (by mmap() system call)

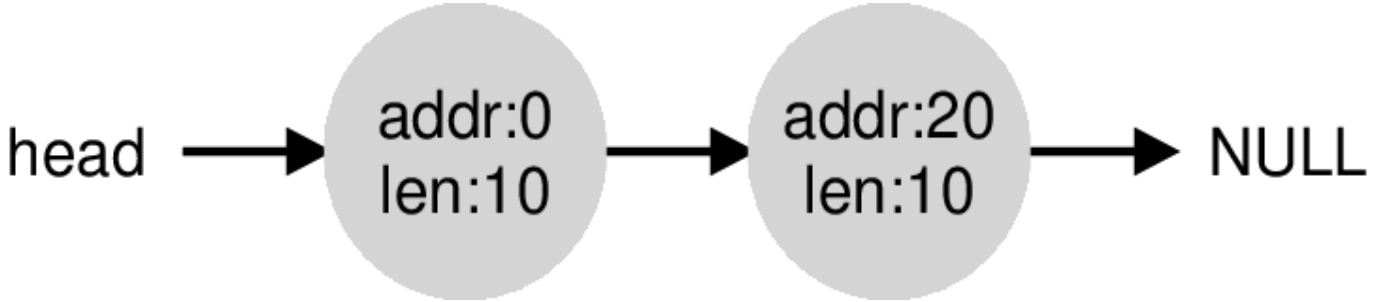
Free Memory Management

- Low-level Mechanisms
  - Splitting and Coalescing
  - Tracking allocated regions
  - Implementation of a free list
- High-level Intelligence
  - Best fit
  - Worst fit
  - First fit
  - Next fit

Free Memory Management

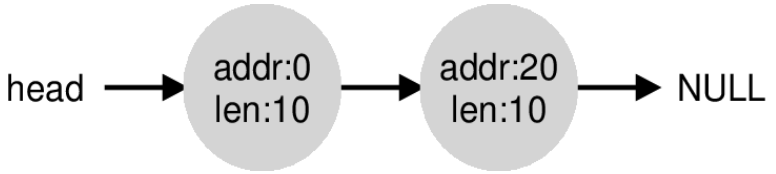
- Splitting and Coalescing
  - Free list: a set of free chunks
  - Two chunks (10 bytes each)

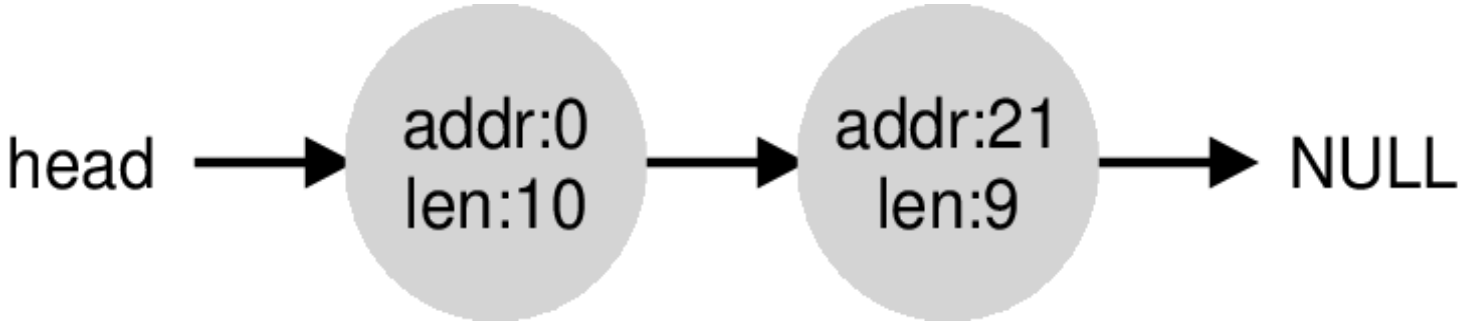




Free Memory Management

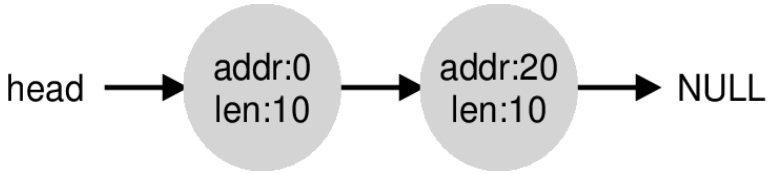
- Splitting and Coalescing
  - request less than 10 bytes? (e.g. malloc(1))
  - Splitting

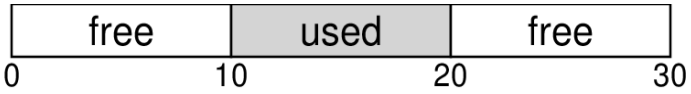


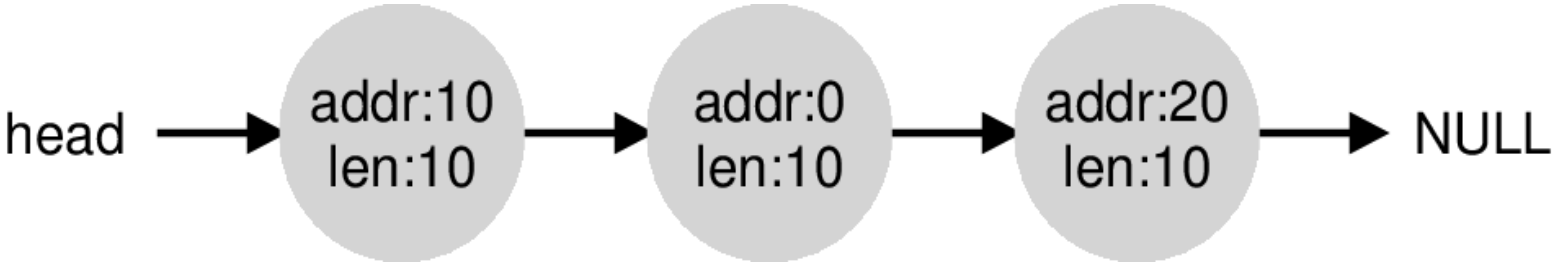


Free Memory Management

- Splitting and Coalescing
  - Free a chunk?







  - Malloc(20)?
  - Coalescing

Free Memory Management

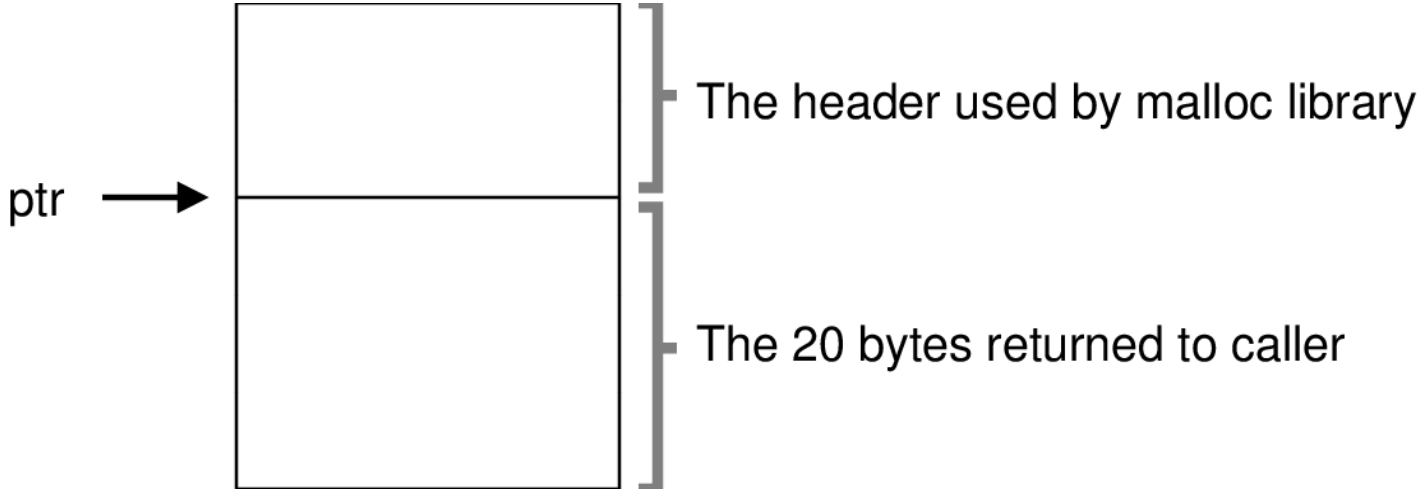
- Tracking Allocated Regions
  - Observation on free(void *ptr)
    - No size parameter
  - Given a pointer, the malloc library could determine the size of region
  - How?
    - Some extra information
    - header of a memory block

Free Memory Management

- Tracking Allocated Regions
  - header

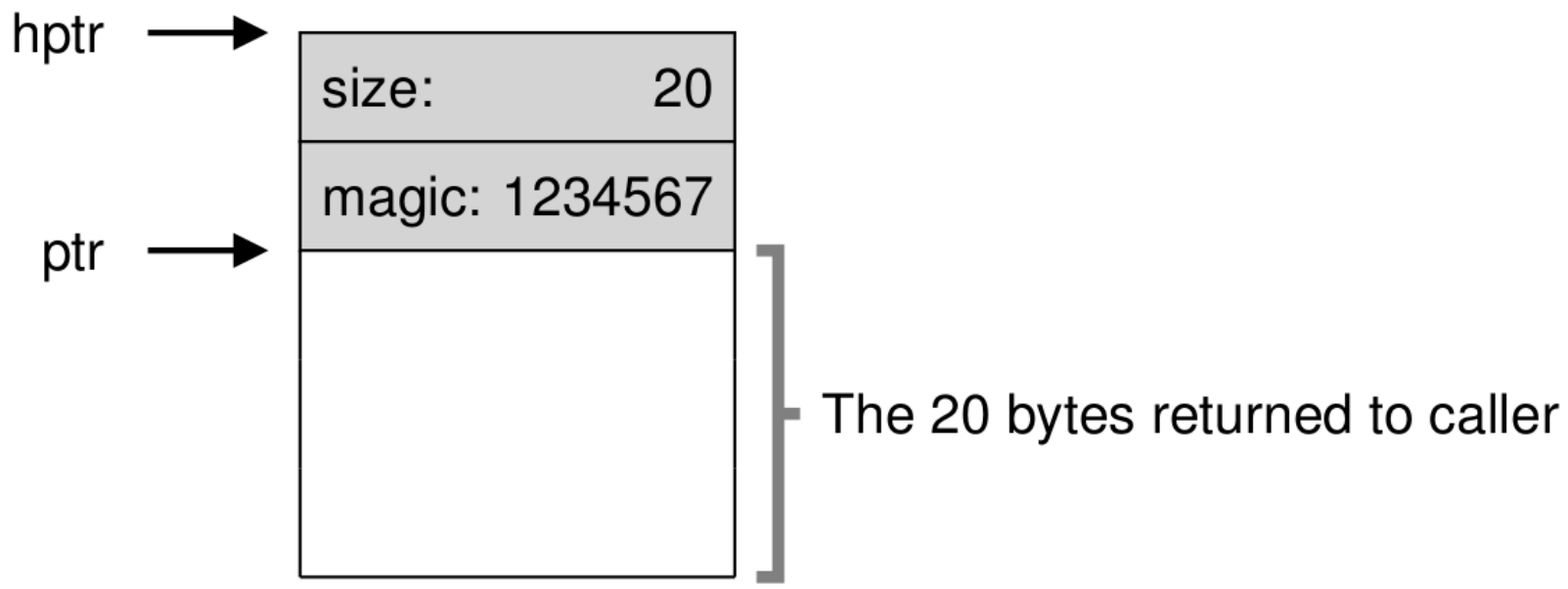
```
typedef struct __header_t {
    int size;
    int magic;
} header_t;
```

  - malloc(20)



Free Memory Management

- Tracking Allocated Regions
  - header: example



Free Memory Management

- Tracking Allocated Regions
  - free(ptr)
    - Get the size of the region

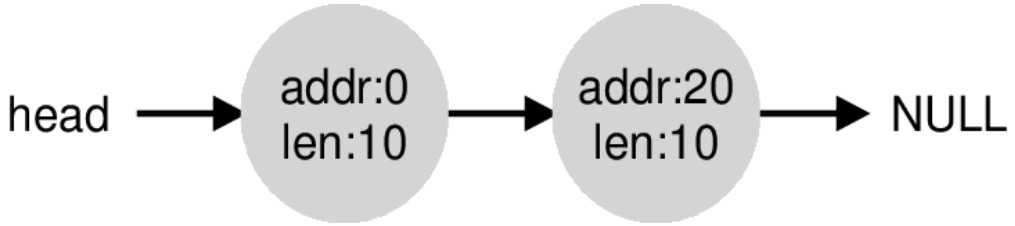
```
void free(void *ptr) {
    header_t *hptr = (void *)ptr - sizeof(header_t);
}
```

    - Check whether ptr is valid

```
assert(hptr->magic == 1234567)
```

Free Memory Management

- Implementation of the Free List
  - Free list



  - Implementation
    - List node (allocate a node when needed)
    - Can NOT do this here!
    - All you have is a given free space
  - How to build a free list inside the free space?

Free Memory Management

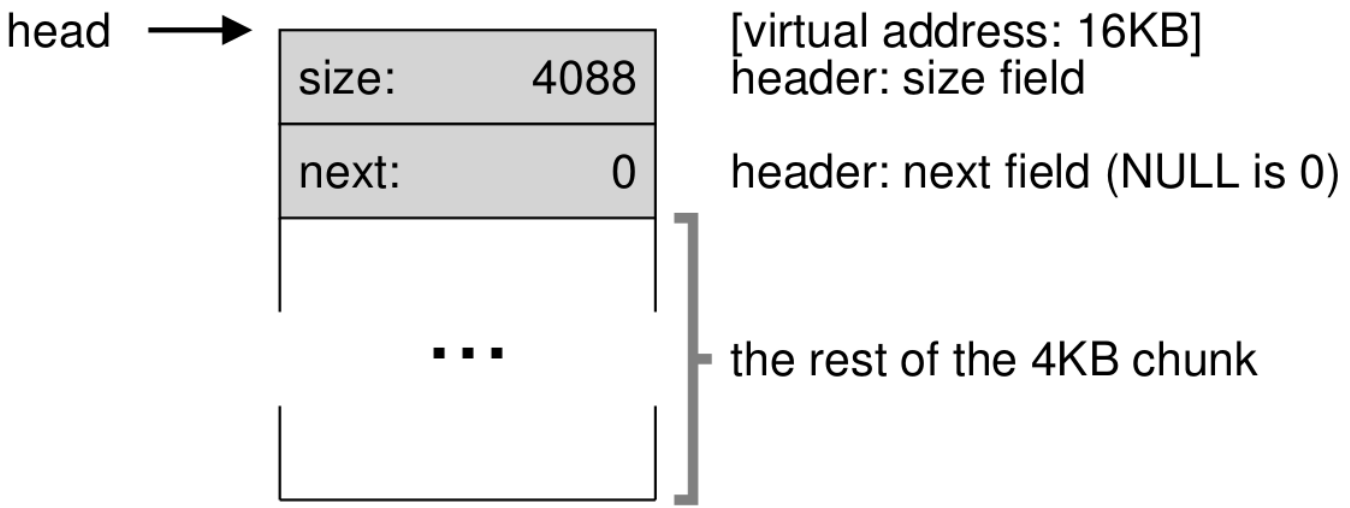
- Implementation of the Free List
  - Node in free list

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

Free Memory Management

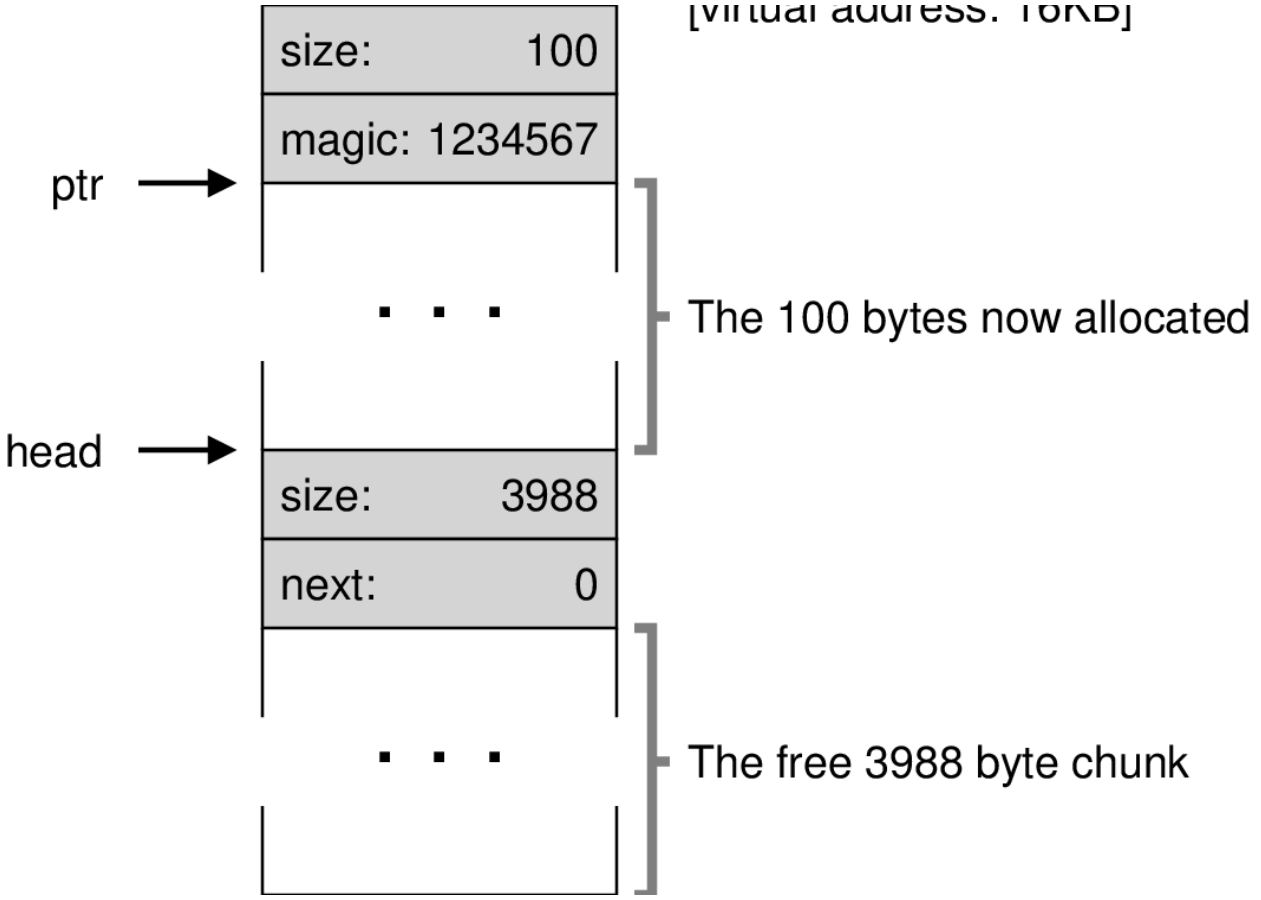
- Implementation of the Free List
  - Initialization (e.g. 4096)

```
// 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;
```

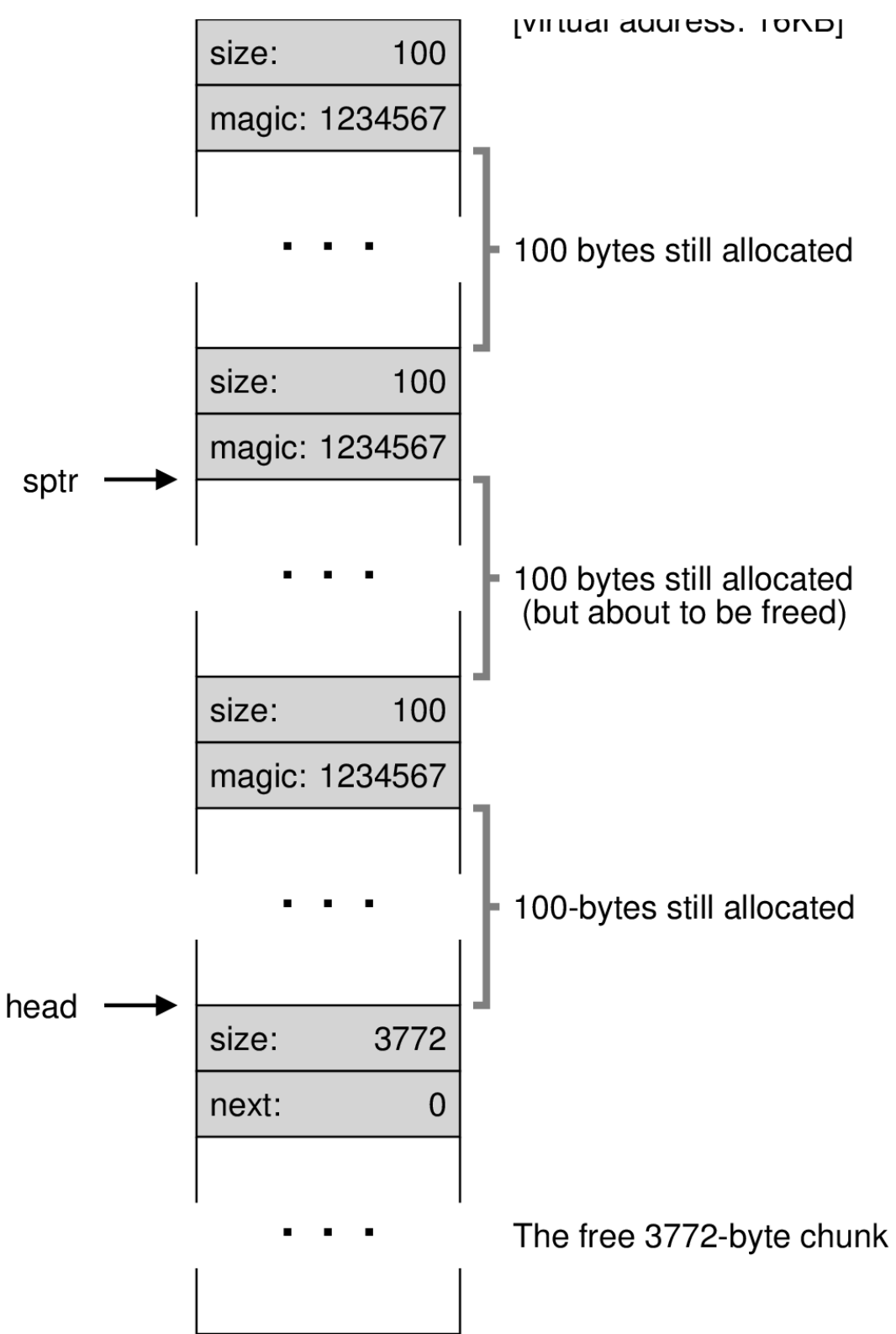


Free Memory Management

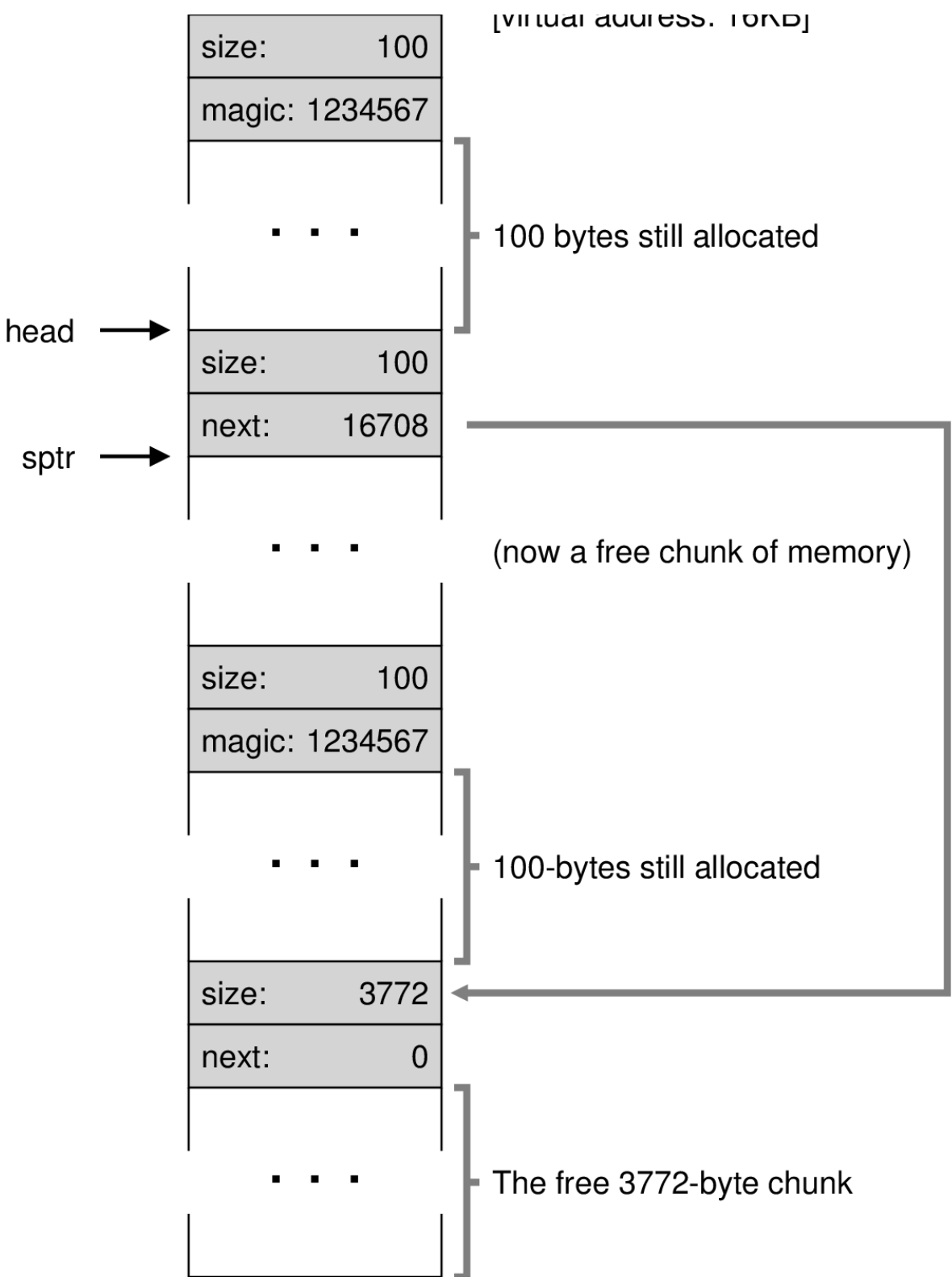
- Implementation of the Free List
  - malloc(100)



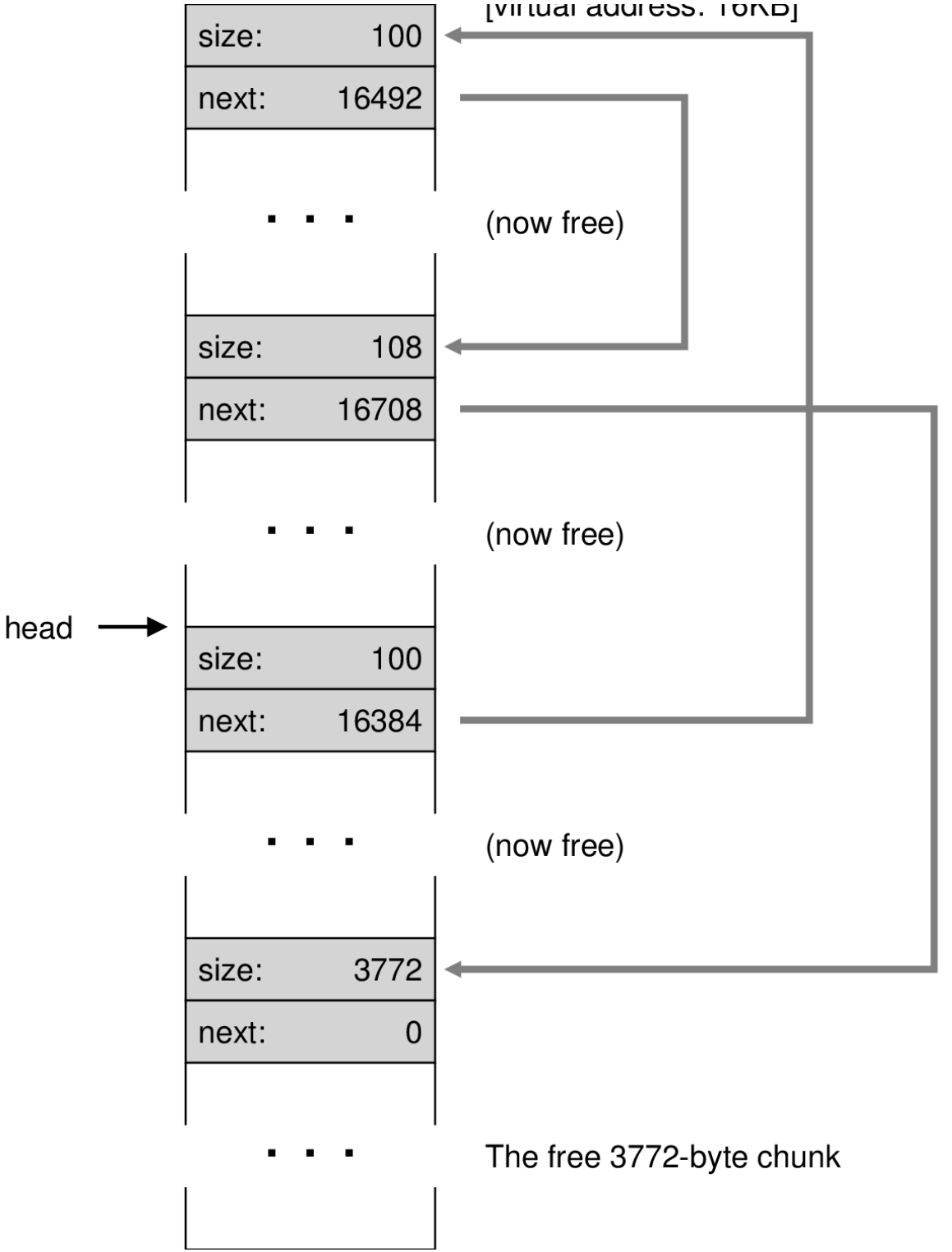
- malloc(100)*3


[virtual address: 16KB]
size: 100
magic: 1234567
. . .
100 bytes still allocated
size: 100
magic: 1234567
sptr
. . .
100 bytes still allocated
(but about to be freed)
size: 100
magic: 1234567
. . .
100-bytes still allocated
head
size: 3772
next: 0
. . .
The free 3772-byte chunk

- Free(16500)
  - 16384+108+8



- Free()*3
- Coalesce
  - Merge adjacent chunks



Free Memory Management

- Growing the Heap
  - What if the heap runs out of space?
    - Return NULL
  - Increase the size of heap
    - OS find free physical pages
    - Map them into address space of the process

Free Memory Management

- Summary of low-level Mechanisms
  - Splitting and Coalescing
  - Tracking allocated regions
  - Implementation of a free list
  - Growing the heap

Free Memory Management

- High-level intelligence
  - How to find the proper nodes in the free list?
    - Less fragmentation
    - Fast allocation
  - Some simple strategies
    - The stream of allocation and free requests can be arbitrary
    - Any strategy could be arbitrarily bad/good

Free Memory Management

- Best Fit
  - Find the smallest feasible node
- Worst Fit
  - Find the largest feasible node
- First Fit
  - Find the first feasible node

Free Memory Management

- Example
  - 

  - Best fit

  - Worst fit

Free Memory Management

- Other approaches
  - Segregated List
    - Slab allocator
  - Buddy Allocation
    - Binary search tree