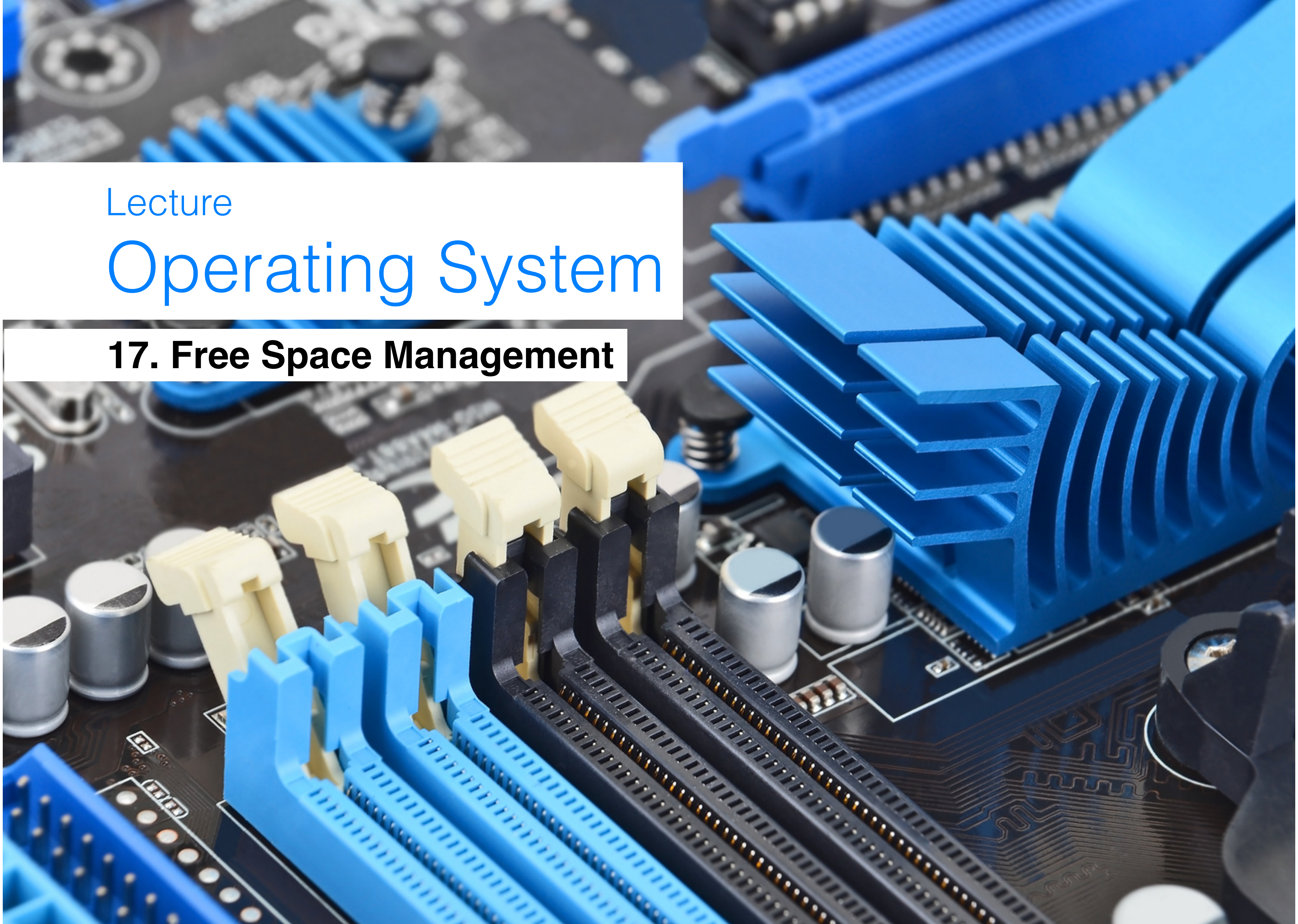
Lecture

Operating System

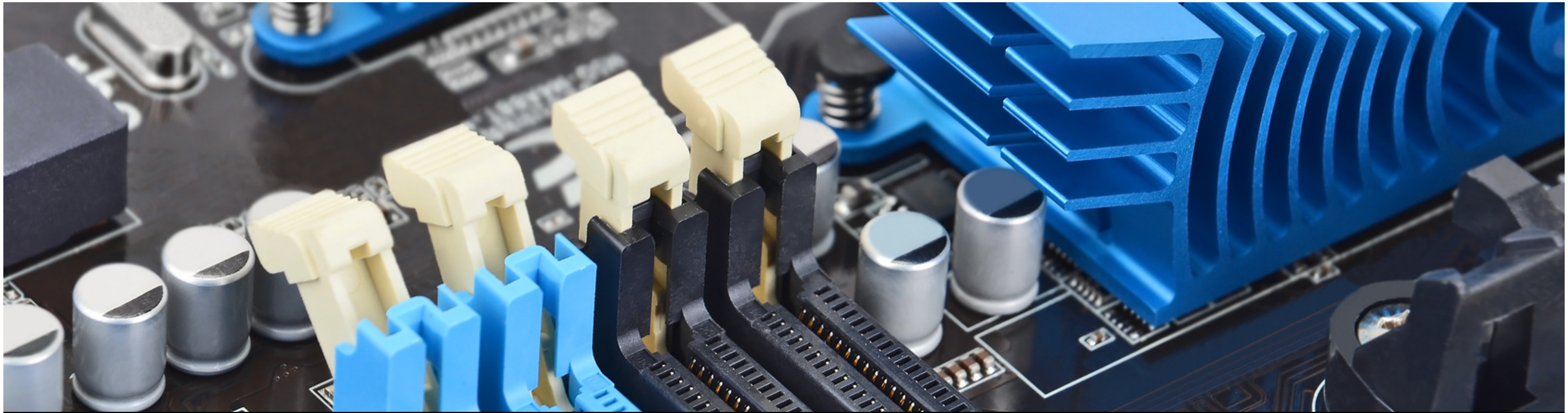
17. Free Space Management



Professor Dr. Michael Mächtel

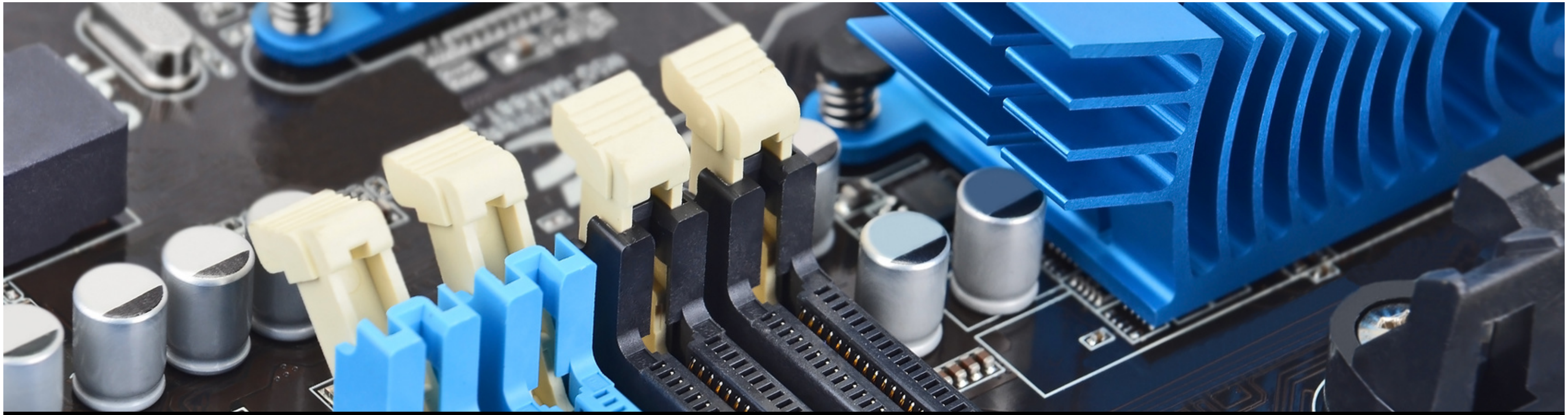
17. Free Space Management

1. **Splitting and Coalescing**
2. **malloc() and free()**
3. **Free List Management**
4. **Managing Free Space**



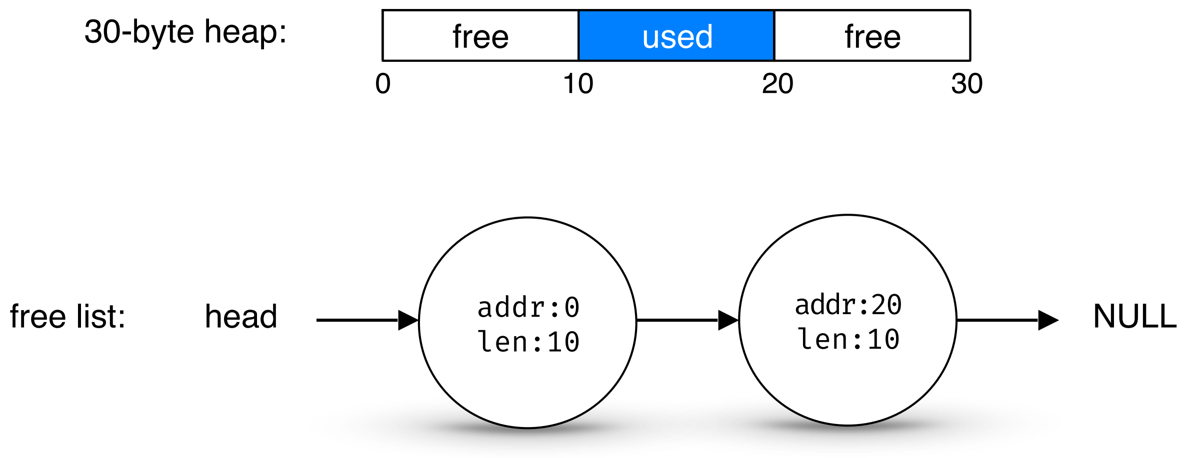
17. Free Space Management

1. **Splitting and Coalescing**
2. malloc() and free()
3. Free List Management
4. Managing Free Space

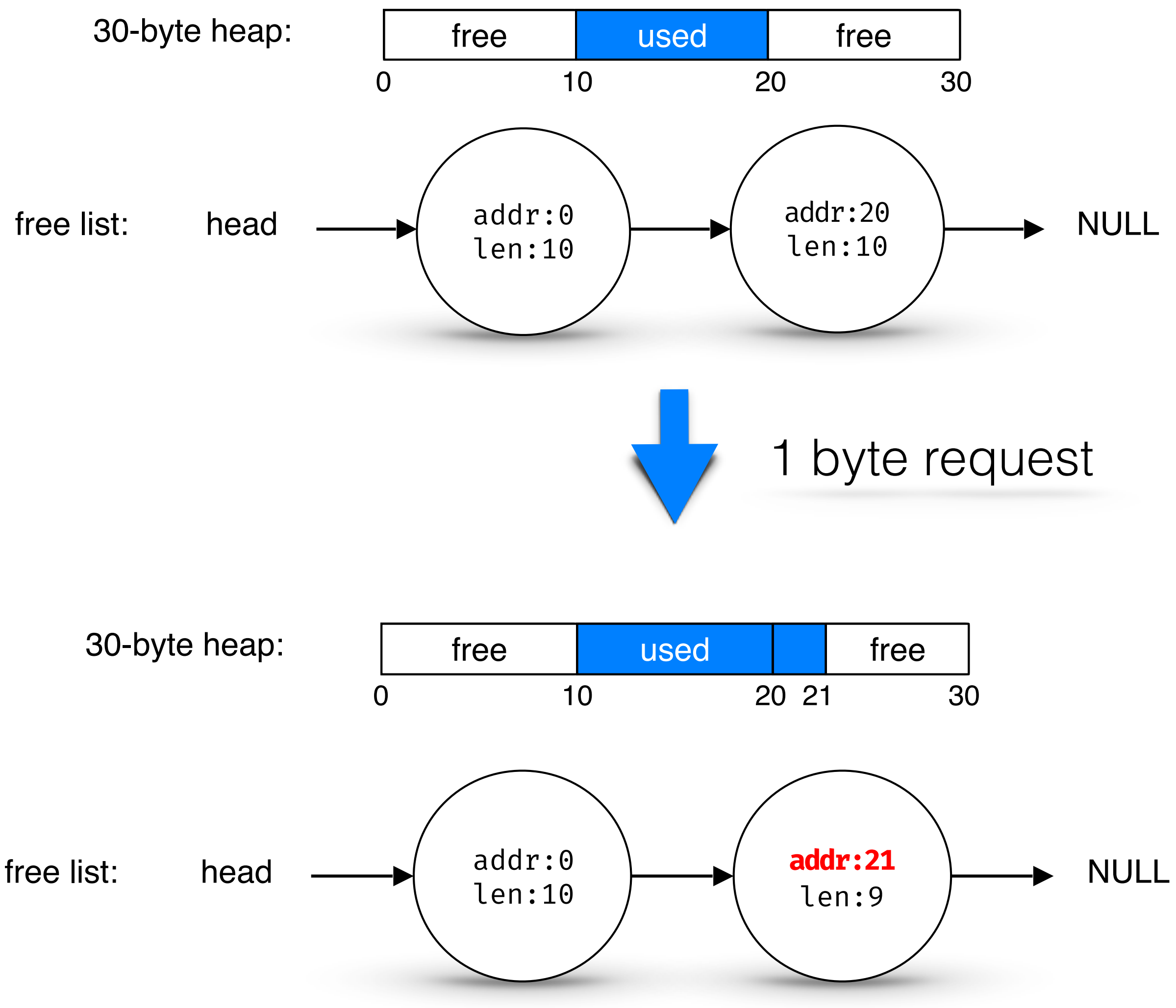


Splitting

- 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.

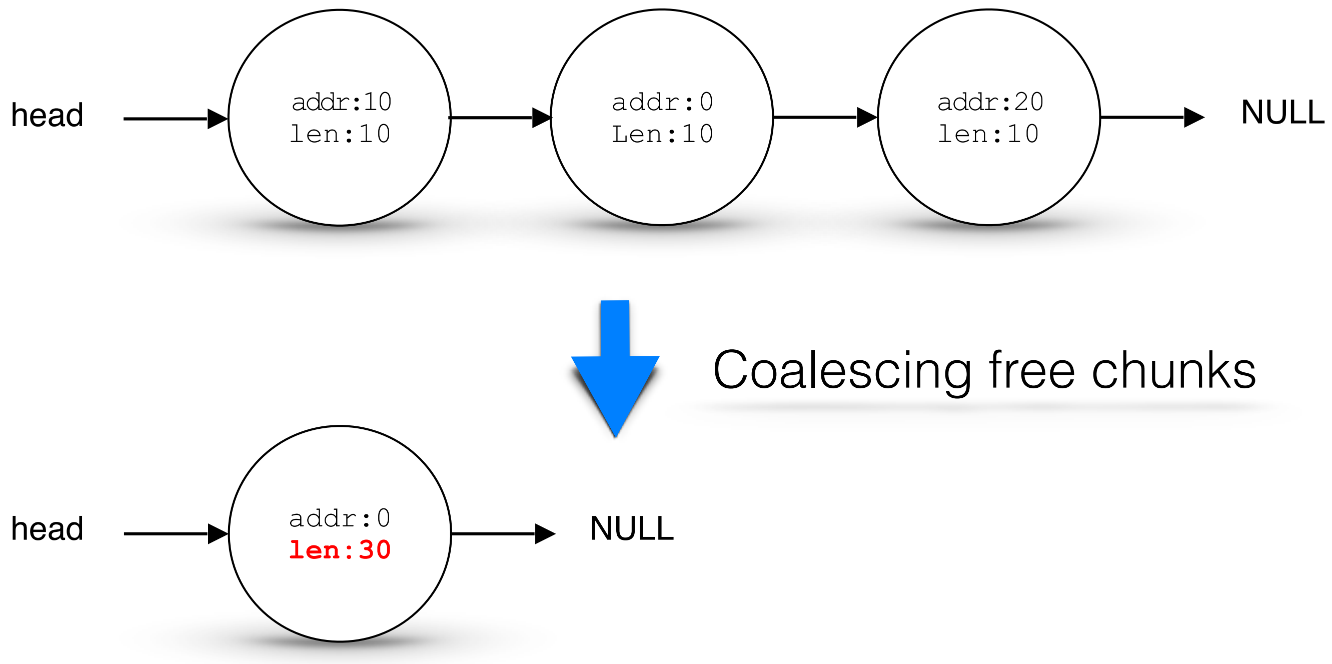


Splitting (1-byte request)



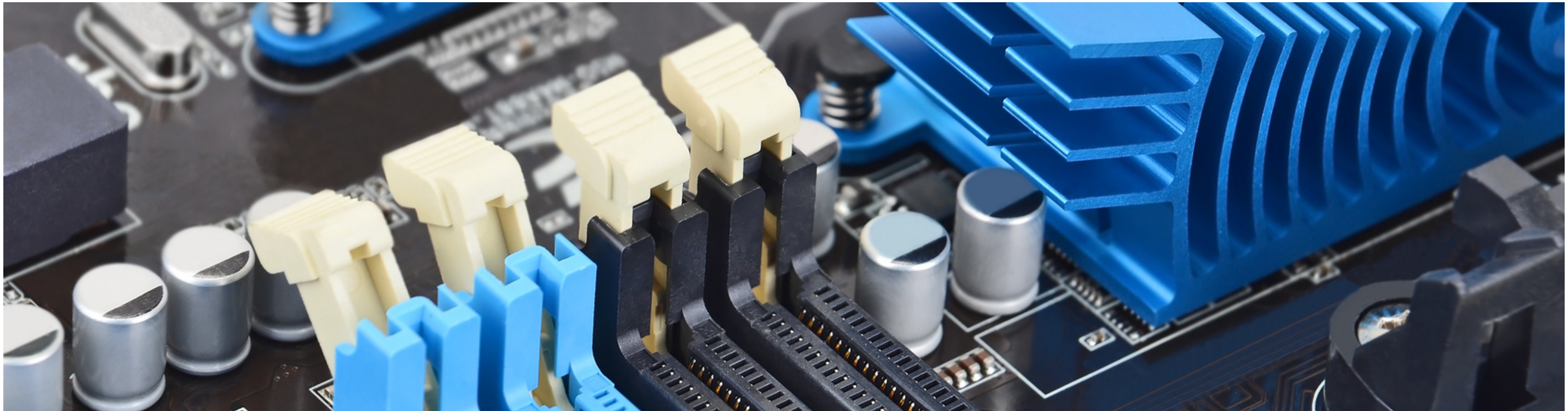
Coalescing

- 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**.



17. Free Space Management

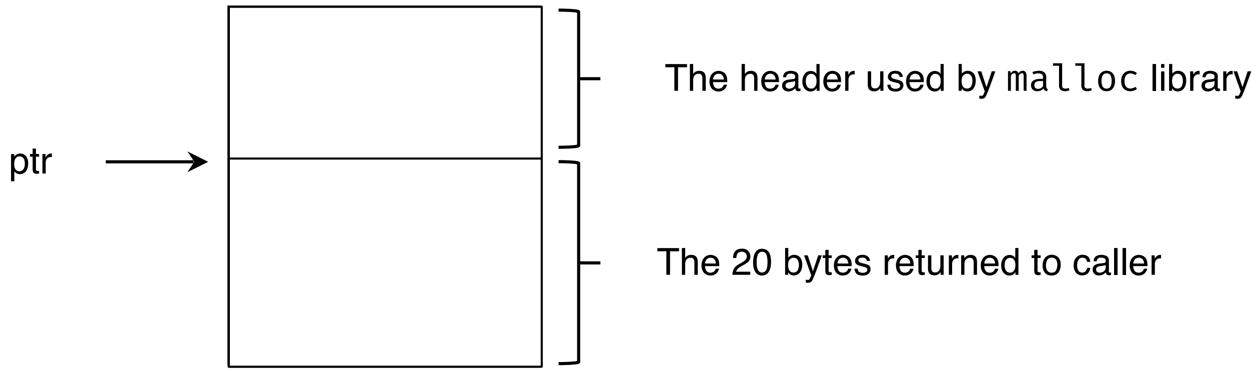
1. Splitting and Coalescing
2. **malloc() and free()**
3. Free List Management
4. Managing Free Space



Tracking 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);
```



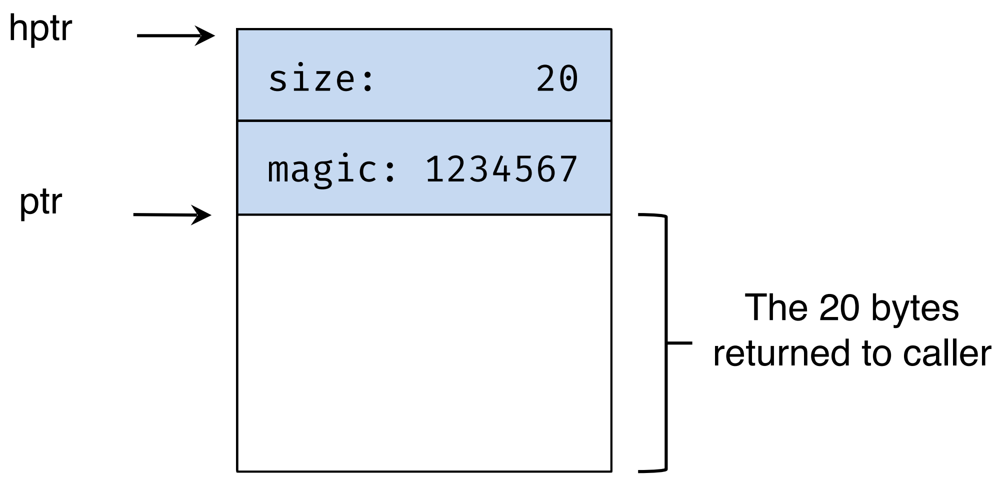
An Allocated Region Plus Header

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
- 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 (`hptr`).

Header: Example

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

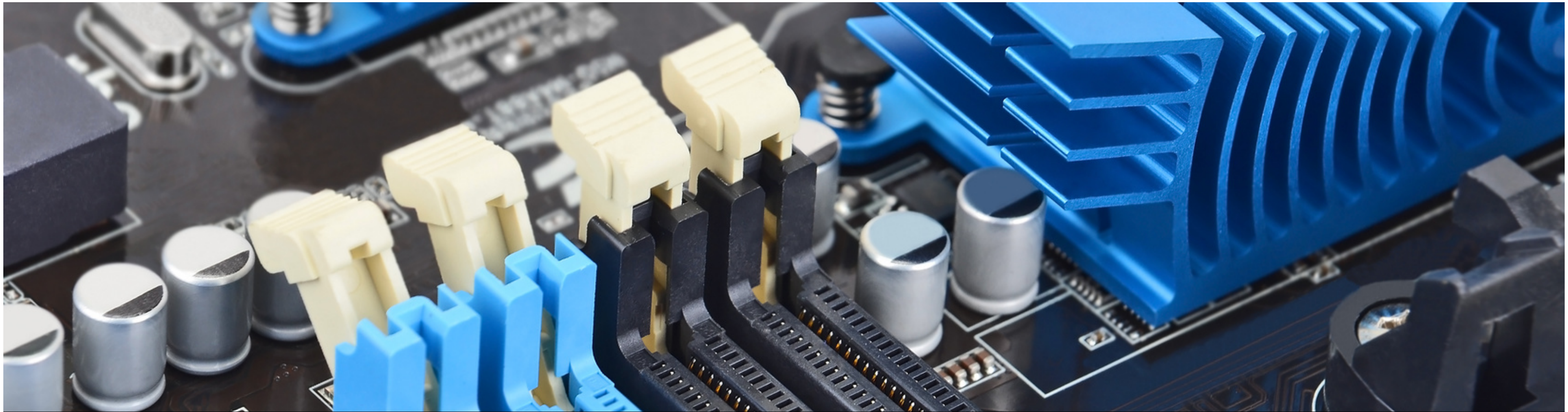


Specific Contents Of The Header

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

17. Free Space Management

1. Splitting and Coalescing
2. malloc() and free()
3. **Free List Management**
4. Managing Free Space



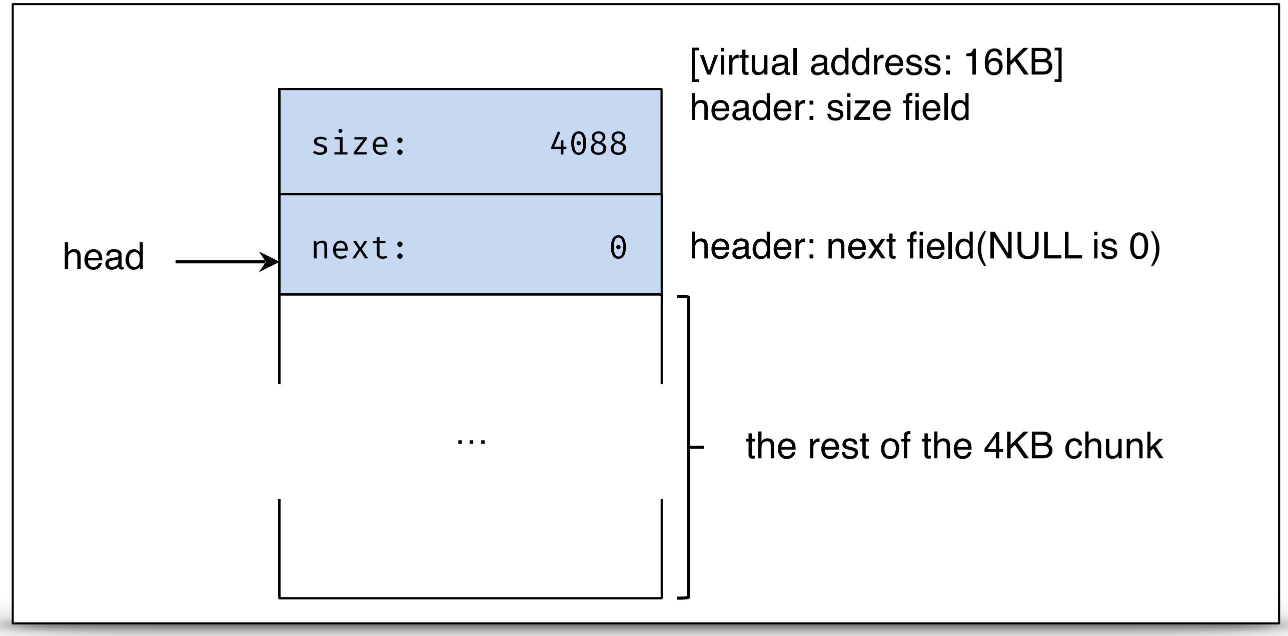
Embedding A Free List

- 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**.
- Build a heap and put a free list into it.
  - Assume that the heap is built via `mmap()` system call.

A Heap With One Free Chunk

```c
// 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;
```

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



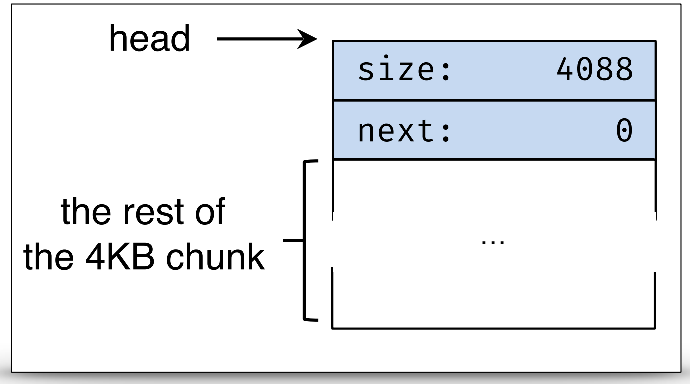
Embedding A Free List: Allocation

- 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.

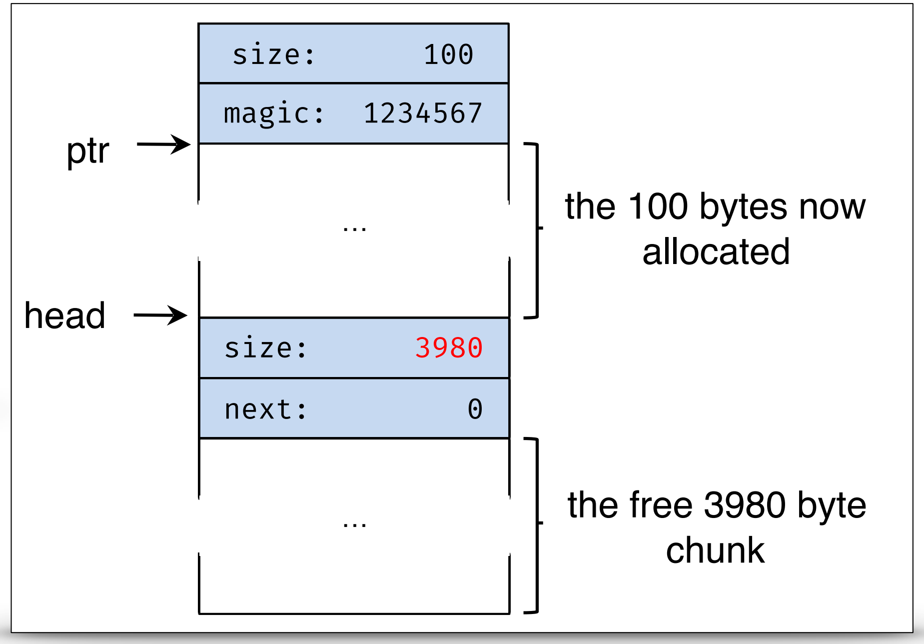
Allocation Example

- 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).

A 4KB Heap With One Free Chunk

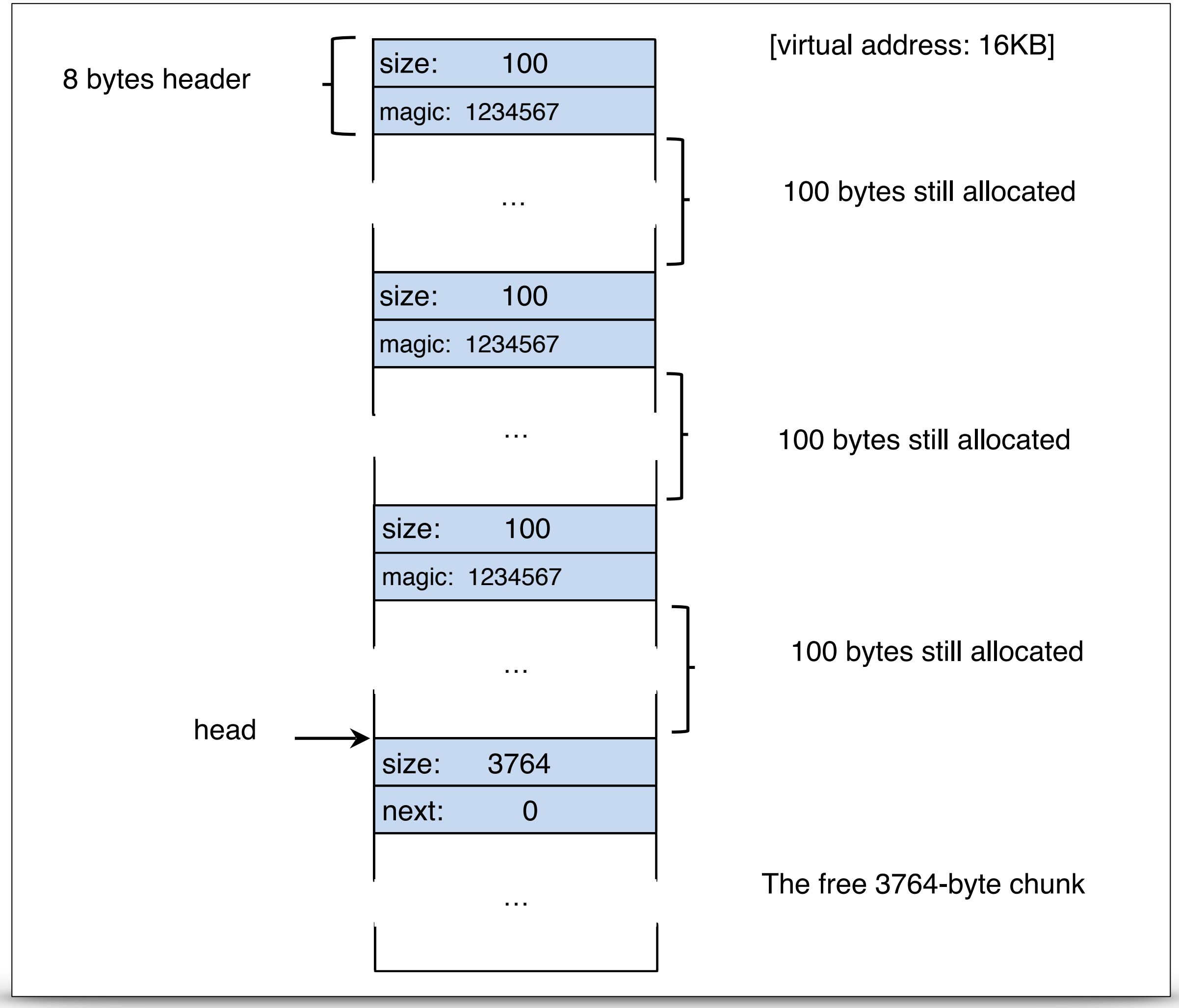


A Heap : After One Allocation



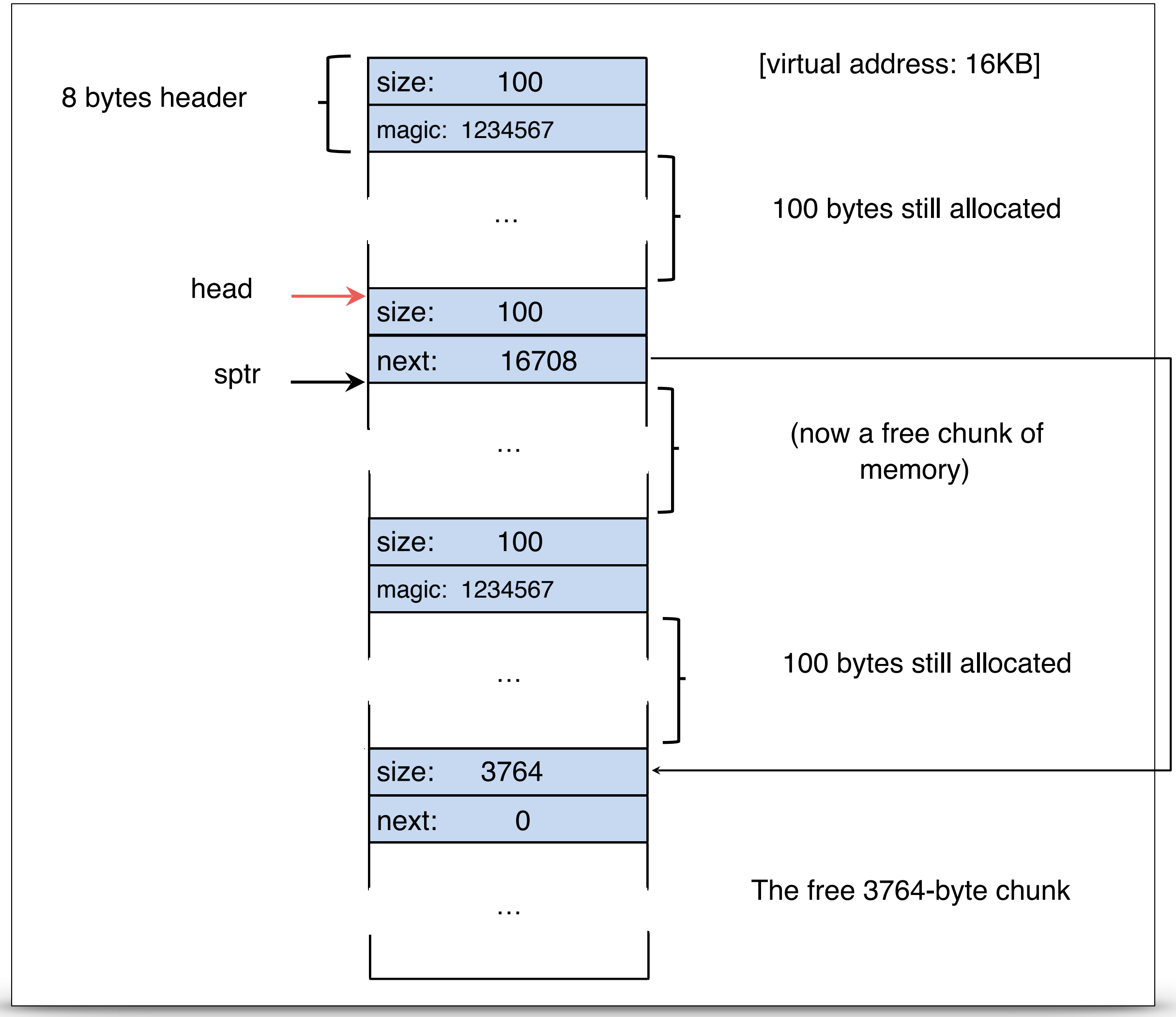
Free Space With Chunks Allocated

Free Space With Three Chunks Allocated



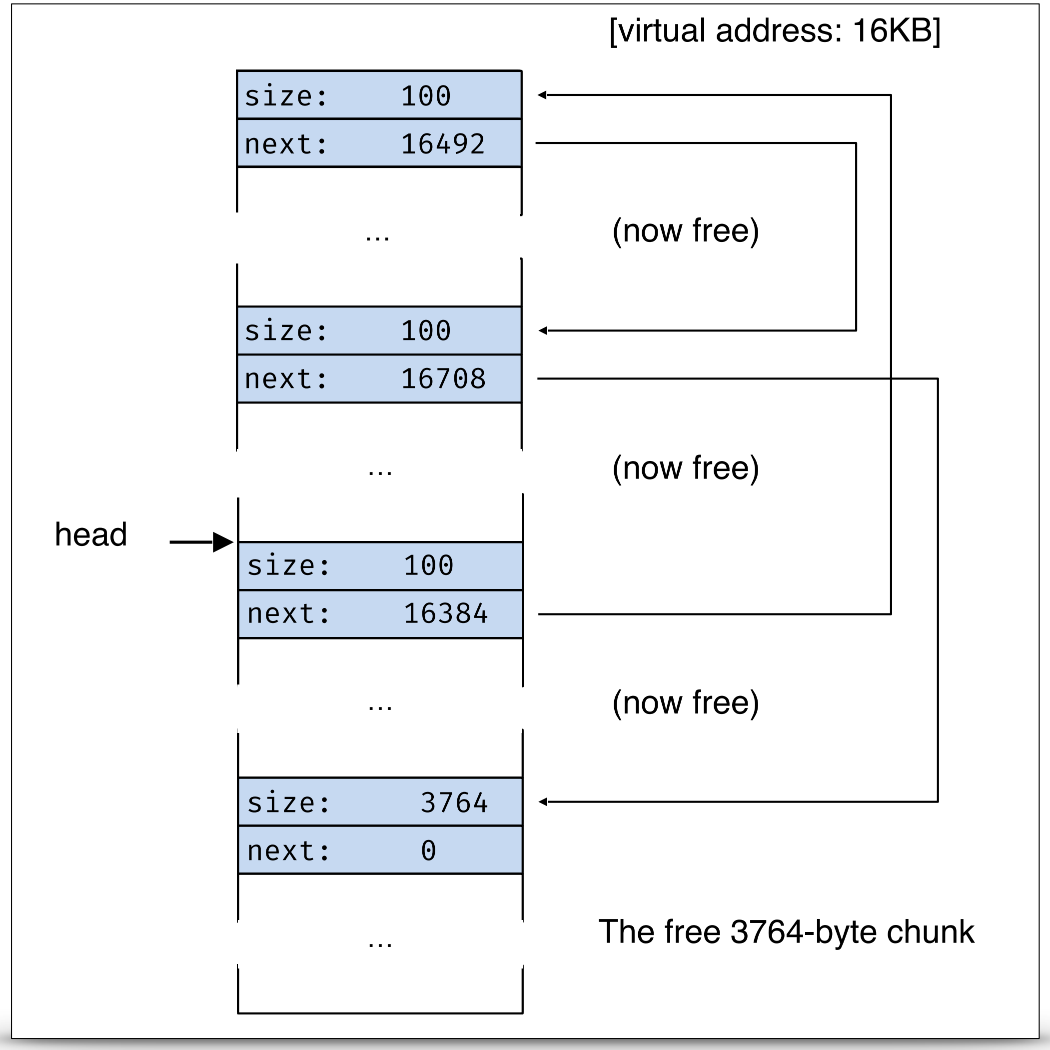
Free Space With `free()`

- 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



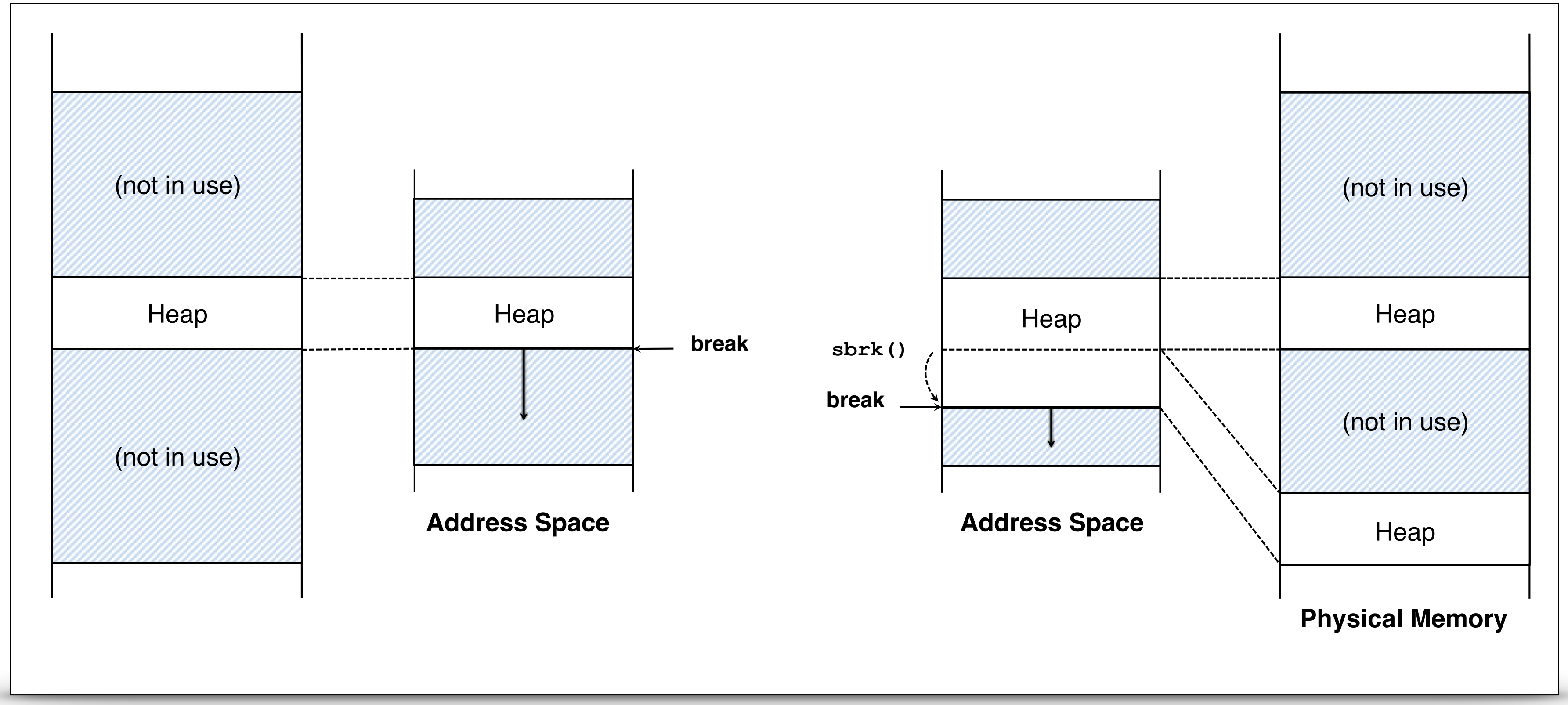
Free Space With Freed Chunks

- Let's assume that the last two in-use chunks are freed.
- **External Fragmentation** occurs.
  - **Coalescing** is needed in the list.



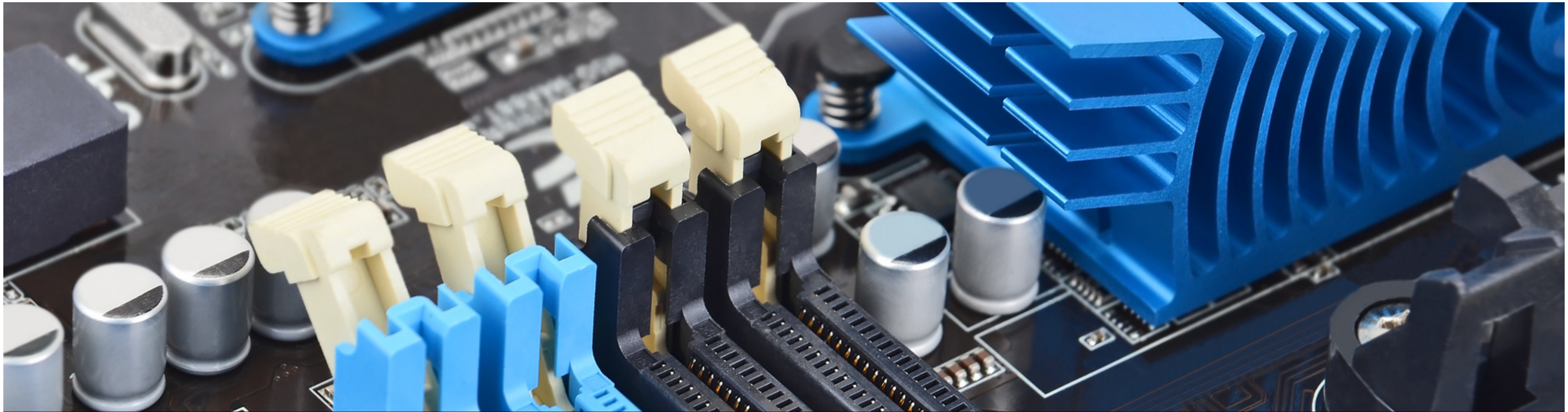
Growing The Heap

- 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.



17. Free Space Management

1. Splitting and Coalescing
2. malloc() and free()
3. Free List Management
4. **Managing Free Space**



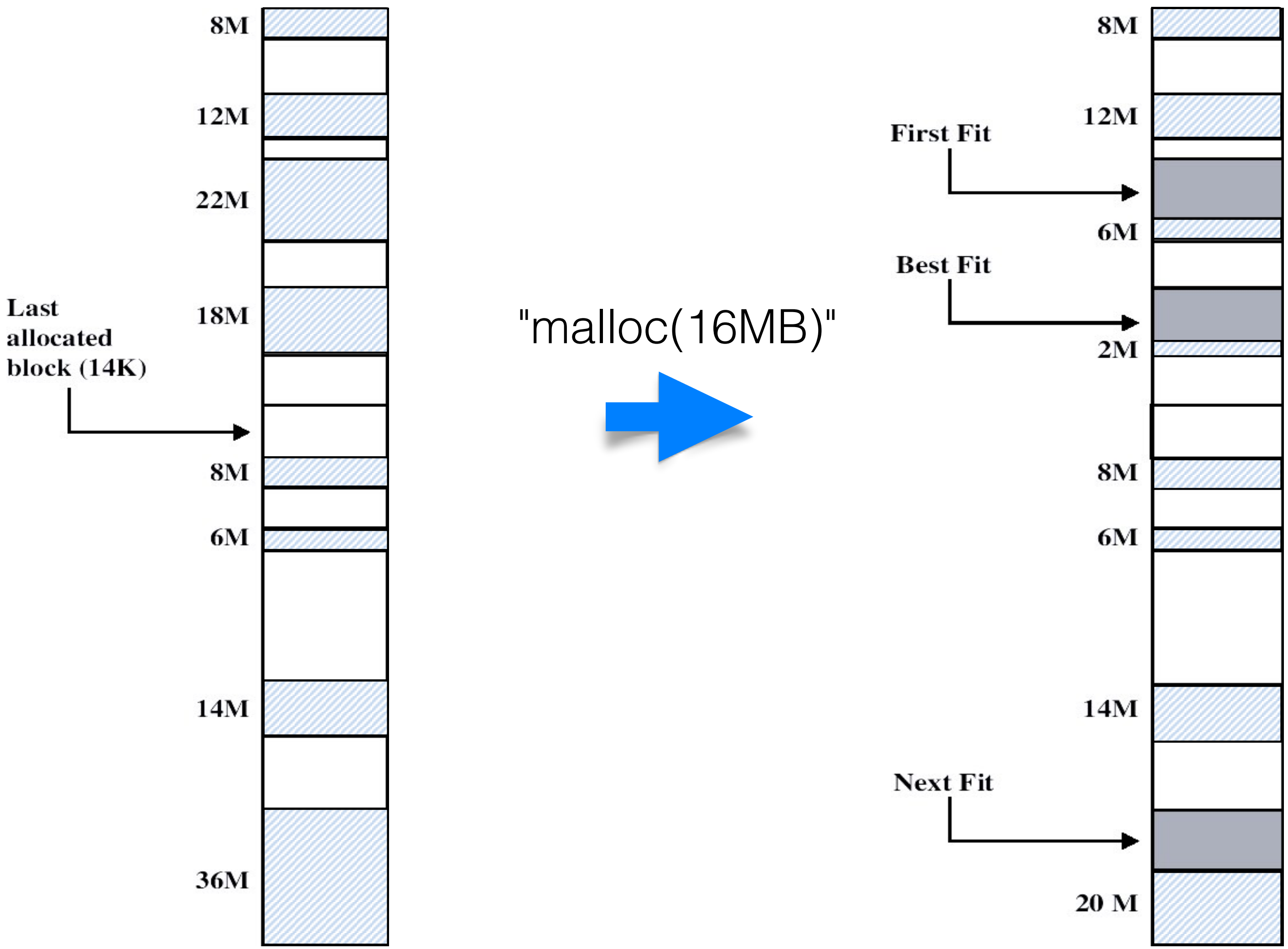
Managing Free Space: Basic Strategies

- **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

- **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.

Example: Best, First and Next Fit



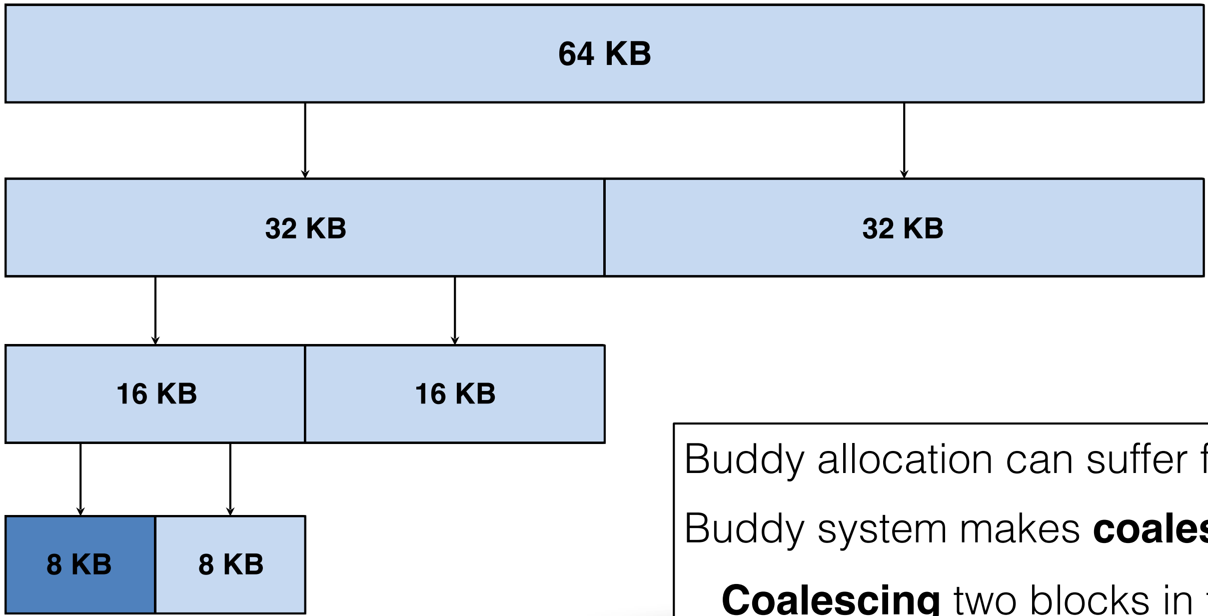
Other Approaches: Segregated List

- **Segregated List**:
  - Keeping free chunks in different size in a separate list for the size of popular request.
  - New Complication:
    - **How much** memory should dedicate to **the pool of memory** that serves **specialized requests** of a given size?
  - Slab Allocator will solve this!

Other Appr.: 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**.

64KB free space for 7KB request

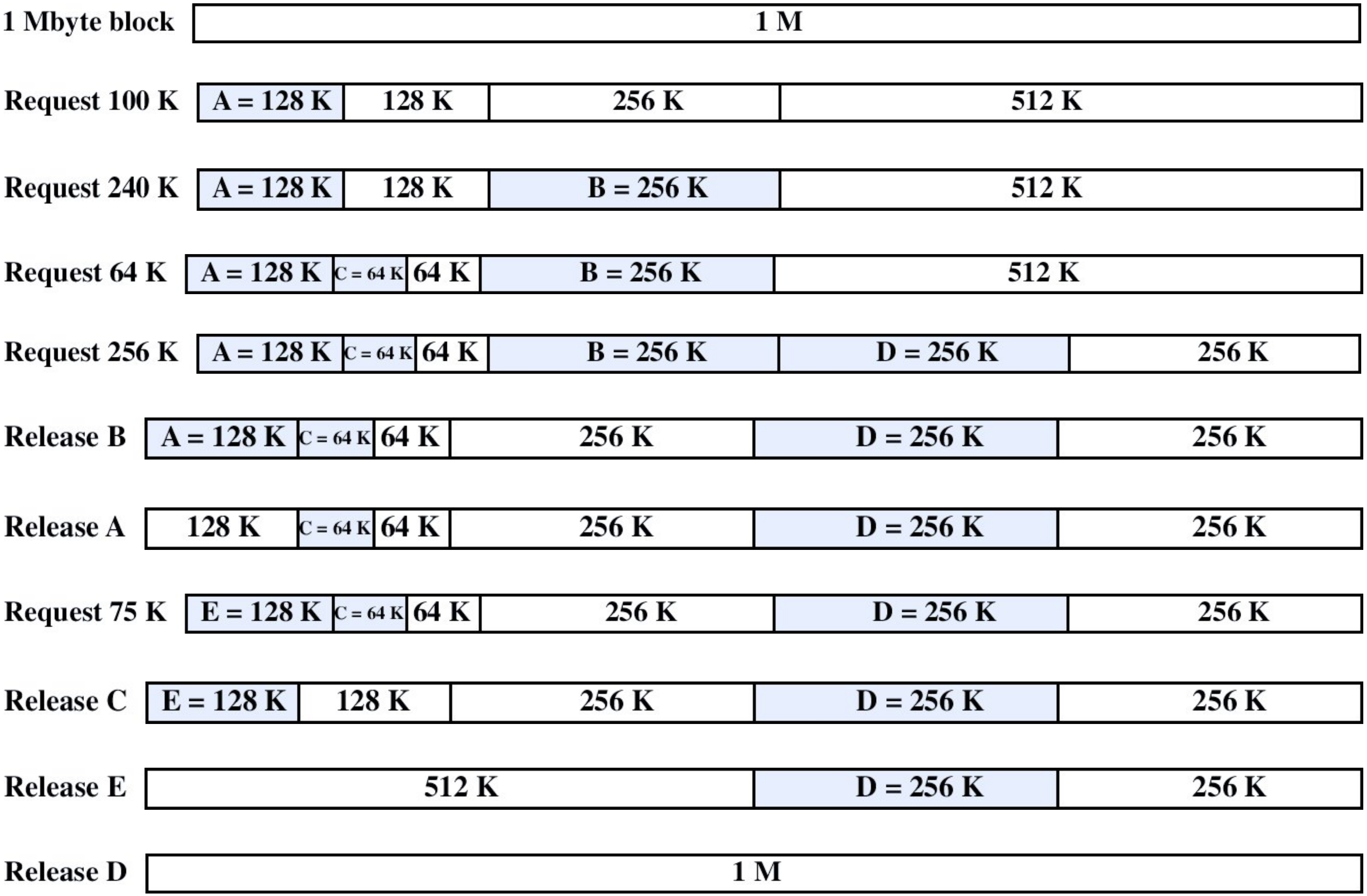


Buddy allocation can suffer from **internal fragmentation**.

Buddy system makes **coalescing** simple:

Coalescing two blocks in to the next level of block.

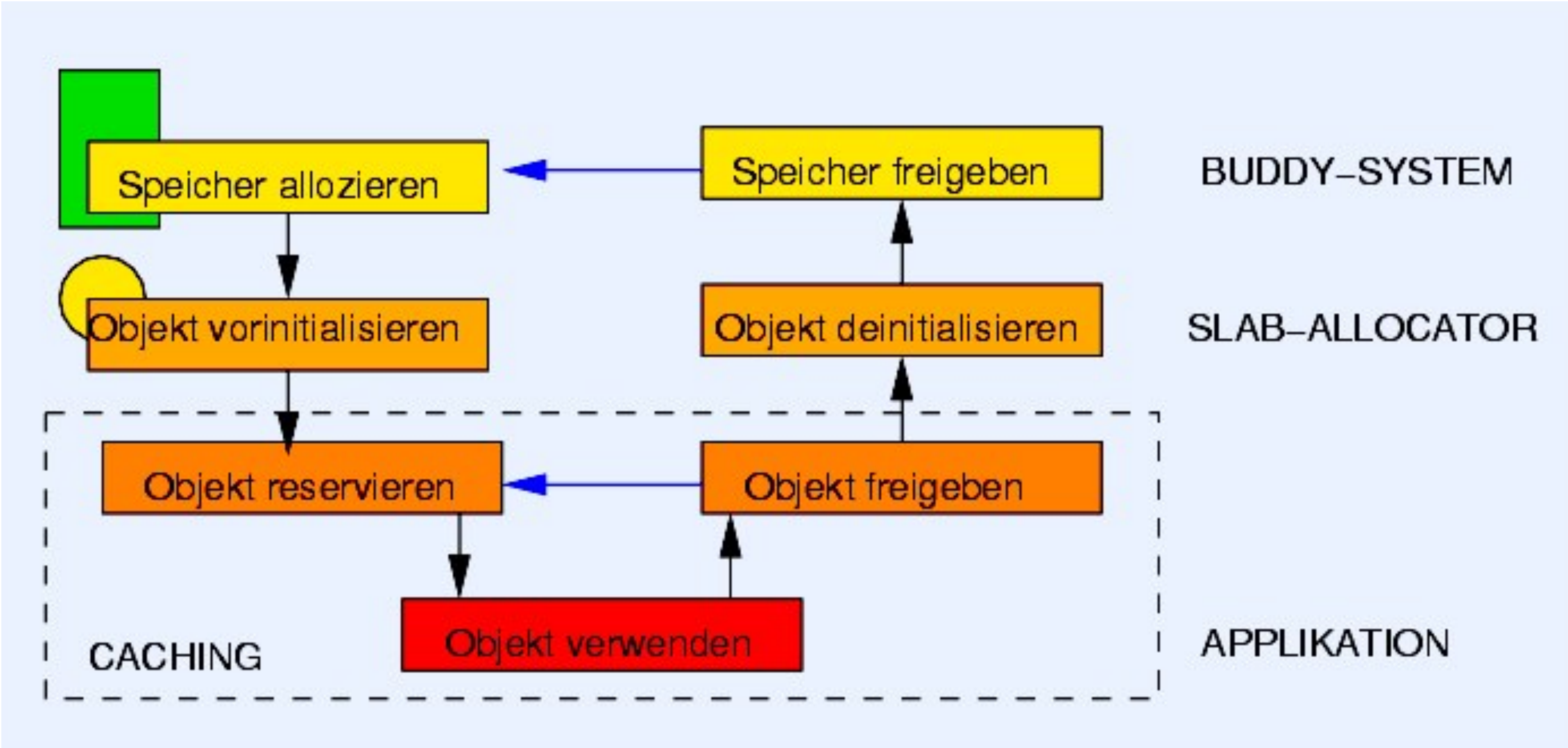
Example: Buddy Allocation



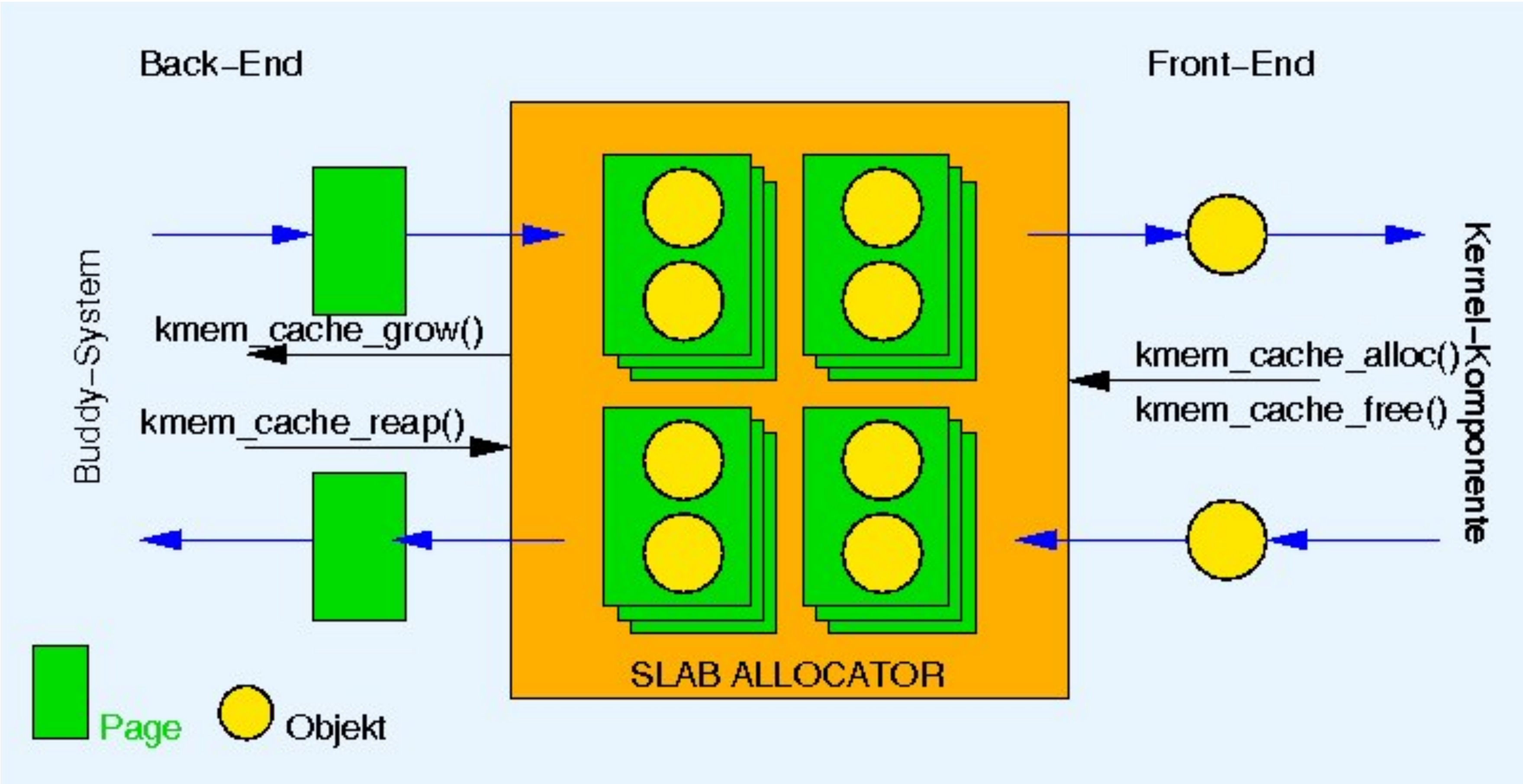
Other Approaches: SLAB Allocator

- 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.

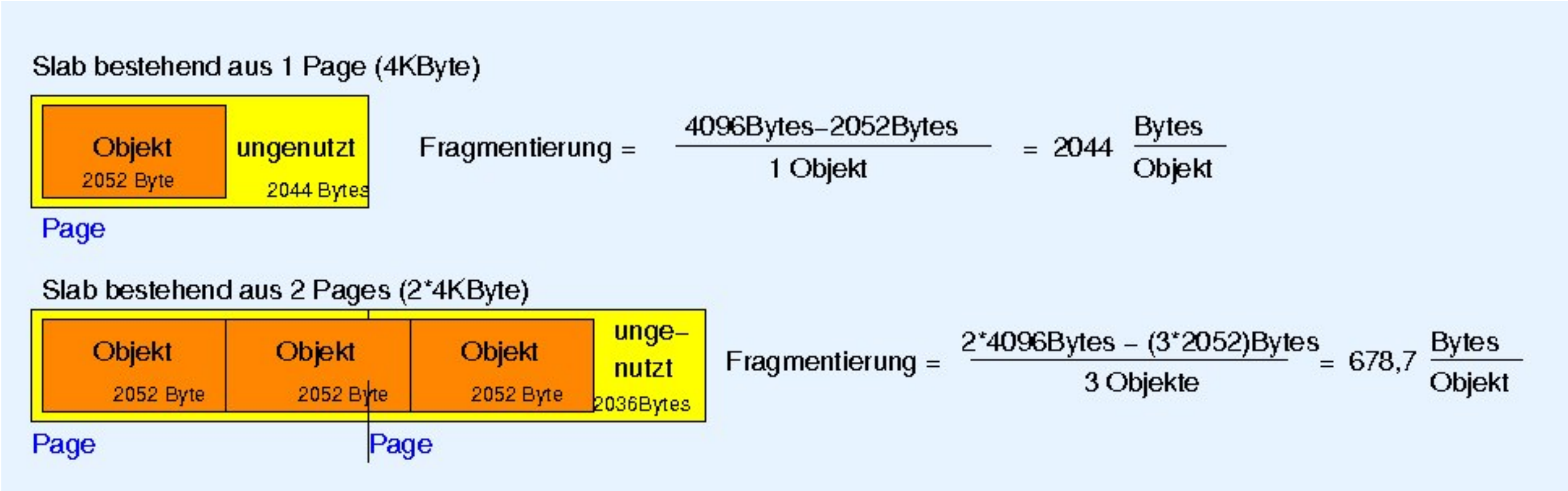
SLAB: Overview



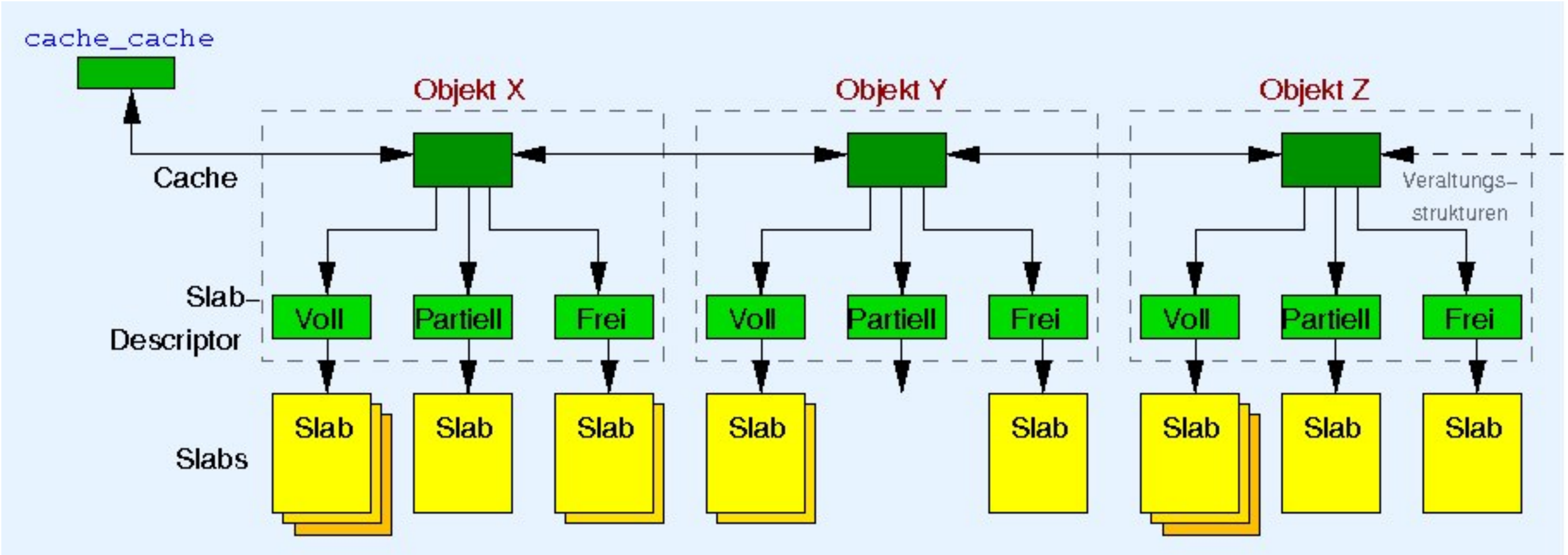
SLAB: Cache Structure

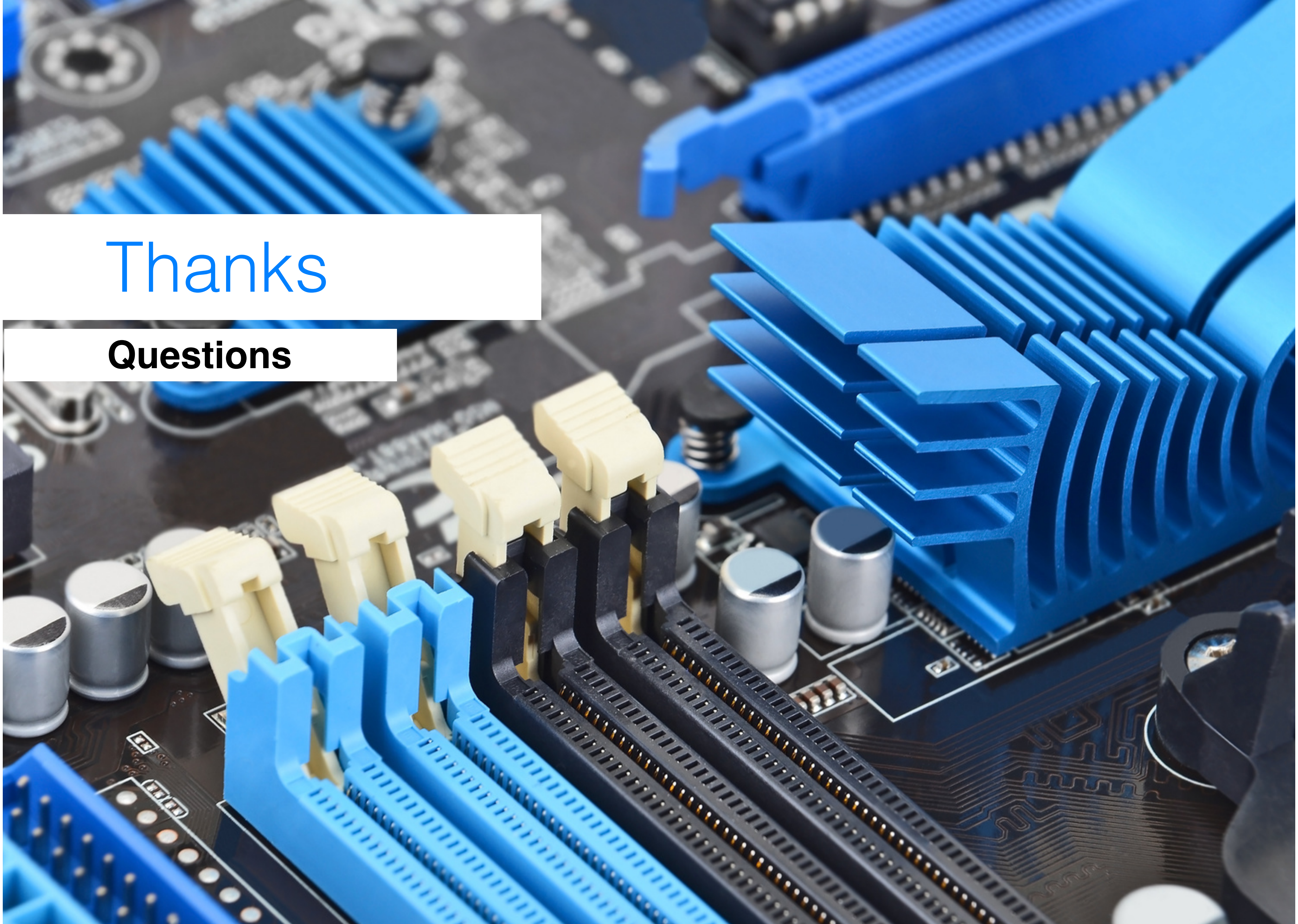


SLAB: Fragmentation



SLAB: Cache Objects





Thanks

Questions