OS 2018

Homework 4: Memory Allocator Implementation

(Due date 01/03 23:59:59)

Lab @NCKU

Objective

- Understand how **malloc()** and **free()** work
- Understand how to **manage Heap**

Requirements

Requirements

1. Implement a **Memory Allocator Library** for user application (*slides 4-16*)

2. Write a **User Application** to test the memory allocator library (*slides 17,18*)

3. Please follow the **Input/output format** (*slides 19,20*)

1. Memory Allocator Library Requirements

- The library must provide the following **3 functions**, and you should follow the format in next slide **:**

  1. **hw_malloc()** (*slides 6-13*)
  2. **hw_free()** (*slides 14-16*)
  3. **hw_get_start_brk()**

- Use **chunk** (*slides 7,8*), **bin** (*slides 9,10*) and **sbrk()** to **manage heap**
- Use **chunk** (*slides 7,8*) to **manage every mmap-allocated memory**

Functions format

1. **void *hw_malloc(size_t bytes)**

- bytes : the required memory size in bytes
- Return = $\begin{cases} \text{the valid virtual address (starting address of the data part)} & , \ if\ success \\ \text{NULL} & , \ otherwise \end{cases}$

2. **int hw_free(void *mem)**

- mem : starting address of the data part
- Return = $\begin{cases} 1 & , \ if\ success \\ 0 & , \ otherwise \end{cases}$

3. **void *hw_get_start_brk()**

- Return the starting address of the heap

hw_malloc( ) requirements

- Use **mmap_threshold** to decide the memory allocate method. If **the allocated size(data size + chunk header size)** > **mmap_threshold** , use mmap allocation method ; else use Heap allocation method.
  - mmap_threshold is **initial** : **32 KiB** (32 * 1024)

mmap allocation method :

- Use **mmap() system call** to allocate the space
- Use **chunk** (slides 7,8) to manage the allocated space

The allocate size = request size (data size) + chunk header size

- Use **mmap_alloc_list** (slide 11) to manage allocated mmap chunks

Heap allocation method:

- Use **chunk** (slides 7,8) and **bin** (slides 9,10) to manage heap
- Should follow the rules of **Heap initialization** (*slide 12*)
- Should follow the rules of **Split** (*slide 13*)
- The allocated size **(data size + chunk header size)** should be **the best fit size**

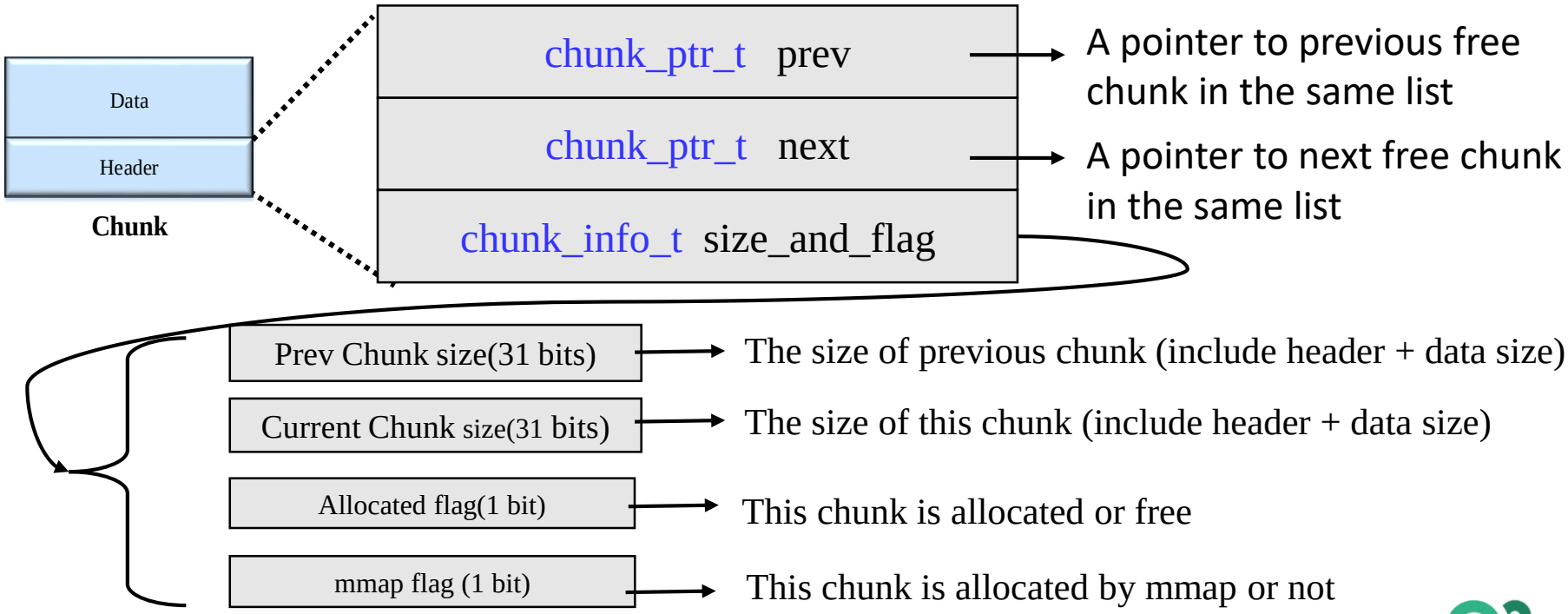
Chunk requirements

- The continuous heap space is split into chunk(s) for management

- Each chunk contains two parts, header and data (*in next slide*)
  - Header (lower address)
  - Data (higher address), the actual memory space return to caller

Chunk header format

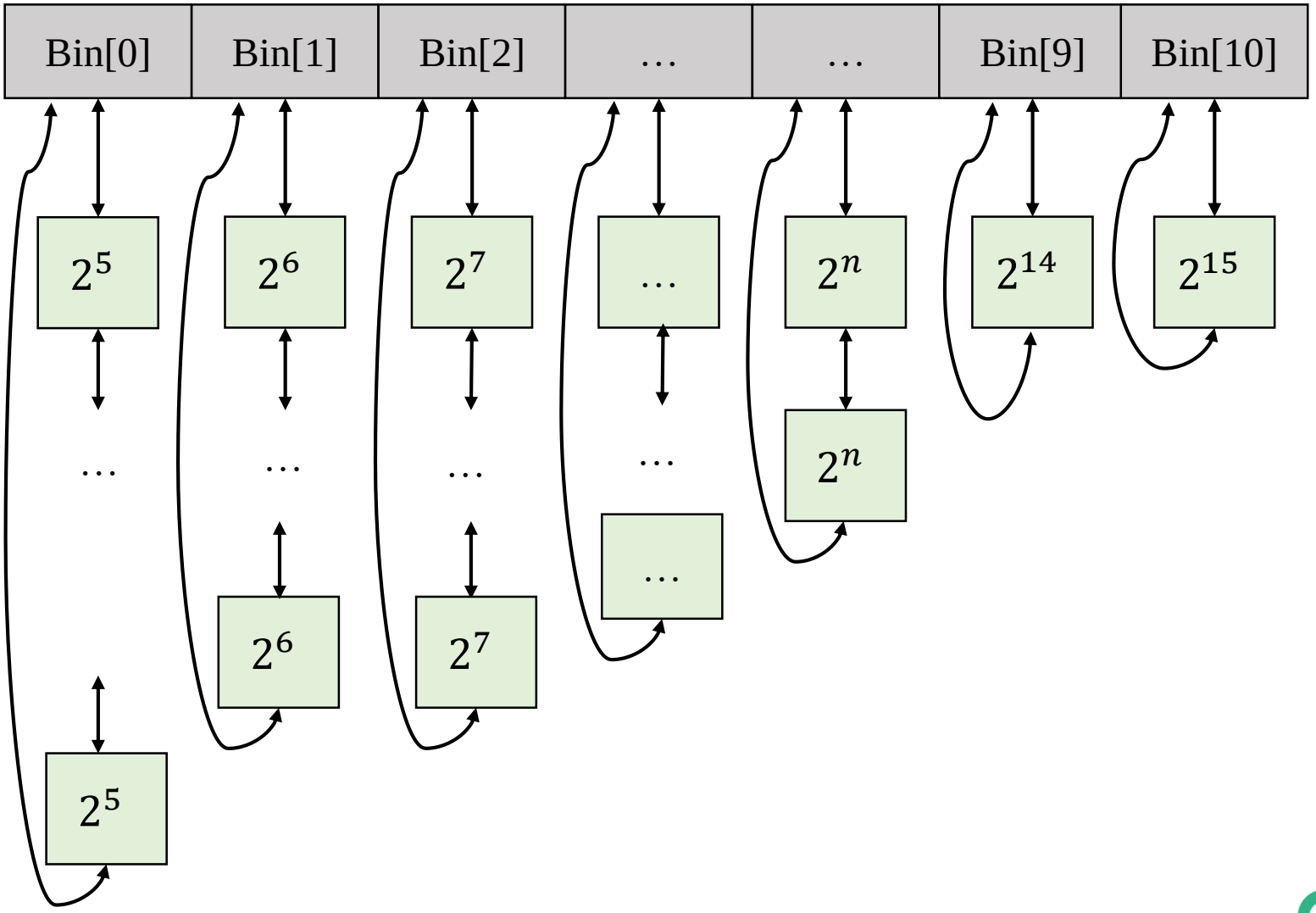
- Chuck header (24 bytes)
  - There are 3 members in the header
    - chunk_ptr_t, chunk_size_t, and chunk_sizeandflag_t can be defined by yourself, but each of them should be 8 bytes
    - chunk_info_t should include 4 information (Prev Chunk size, Current Chunk size, Allocates flag and mmap flag)



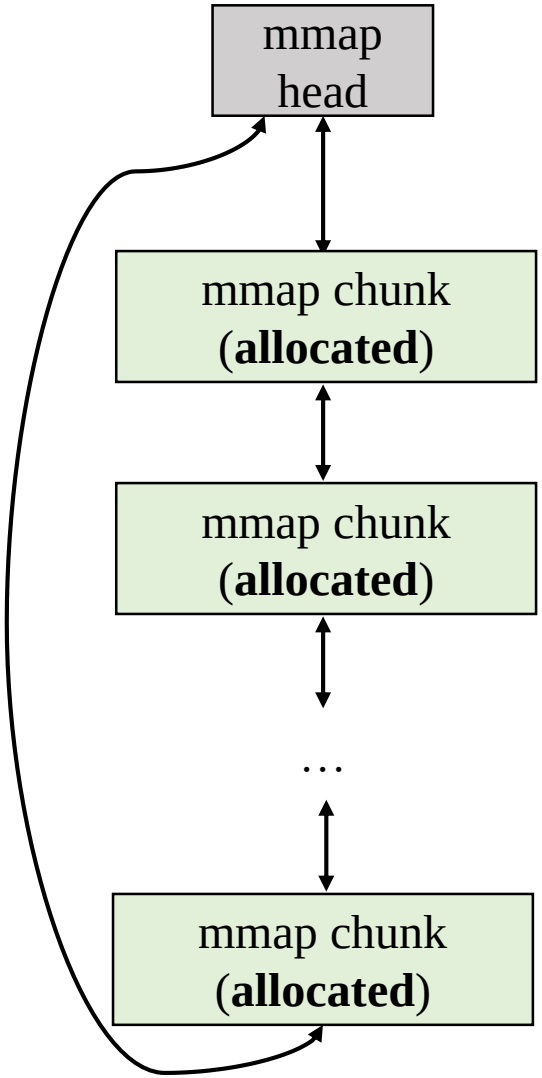
Bins requirements

- Bins are use to manage free chunks of Heap's segment.
- A bin is a circular doubly-linked list of free chunk(s) (*next slide*)
- Add the chunk to rear of the bin.
- You should manage 11 bins
  - bin[0]-bin[10] hold chunks with fixed size (*next slide*)
  - Every chunk size should be the nth power of 2 (n is a number of 5 to 15)
- Use the best fit size to select a chunk during memory allocation
  - If there are multiple chunks with the same size, **select the one with the lowest address**

Bin example



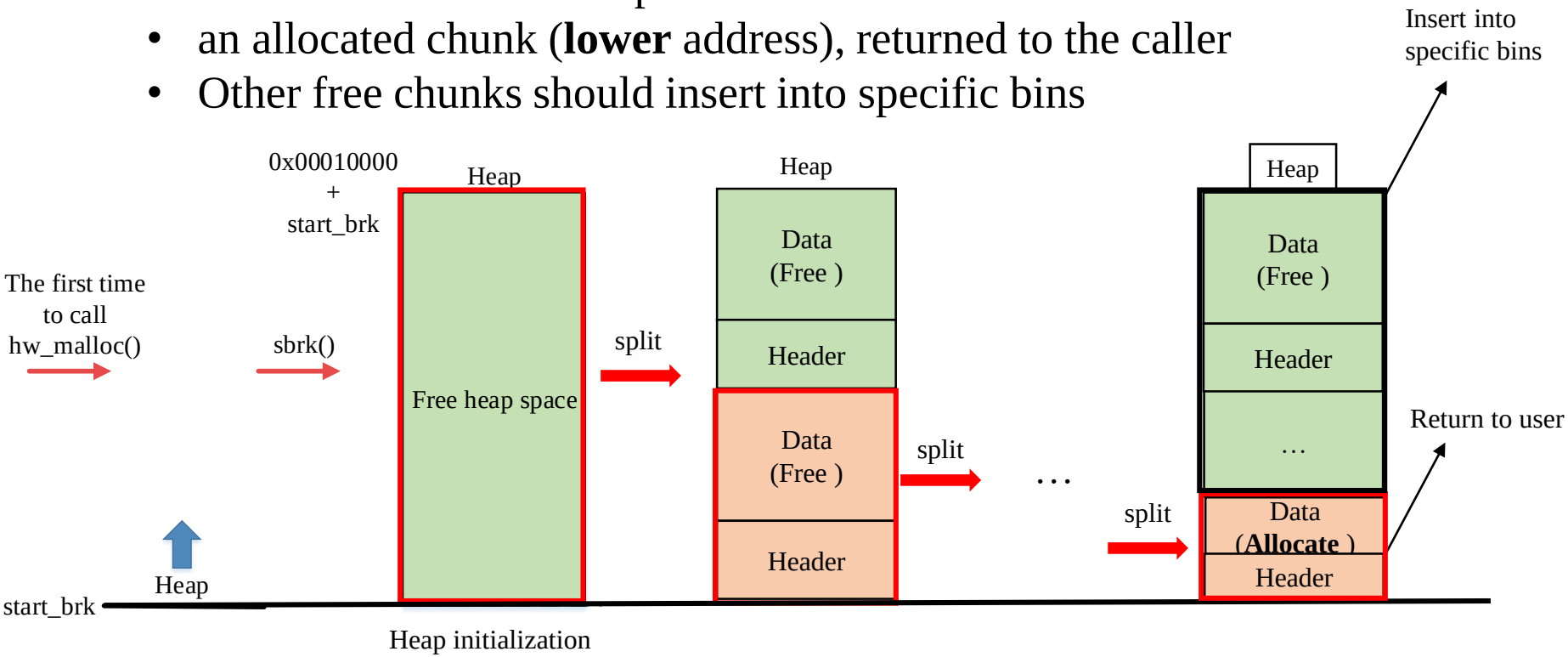
mmap_alloc_list



- mmap_alloc_list is a circular doubly-linked list of mmap allocated chunk(s)
- mmap chunk header is same as slide 8 (use chunk_ptr_t)
- mmap_alloc_list should be ordered by size (ascending)
- If there is/are multiple chunk(s) of the same size, add new chunk after it/them.

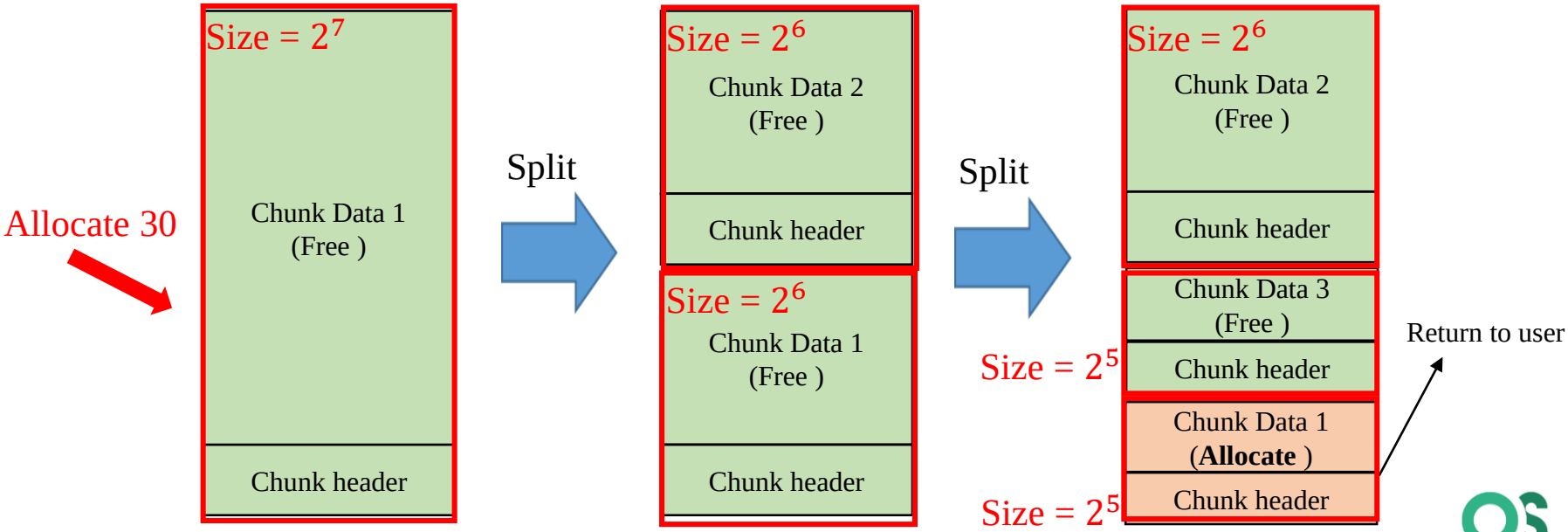
Heap initialization & First-time Heap allocation

- Initialize the Heap before its first use :
  - Use sbrk() to allocate a **64KiB** heap
- After the heap initialization, Split (*next slide*) until the allocated size match the best fit of the nth power of 2
  - an allocated chunk (**lower** address), returned to the caller
  - Other free chunks should insert into specific bins



Split

- When Heap allocation method is used, *split* may be performed :
  - If chunk size is too large (not the best fit for the allocation size), they must be split into two equal-sized chunks
  - Should split the lowest address chunk
  - Chunk size should always be the nth power of the 2
  - Must be **split until it reach the best fit for the allocation size**
- Example : (hw_malloc(6), allocation size =30 , Chunk1 =2^7)



hw_free( ) requirements

- Use Chunk header information (*slides 7, 8*) to check the address was allocated by mmap or Heap allocation method.

mmap free method :

- Use **munmap()** system call to free the space
- **The chunk header should be free too**.
- This free chunk **do not need to be added into bin.**
  (bin is not used in mmap allocation method)

Heap free method :

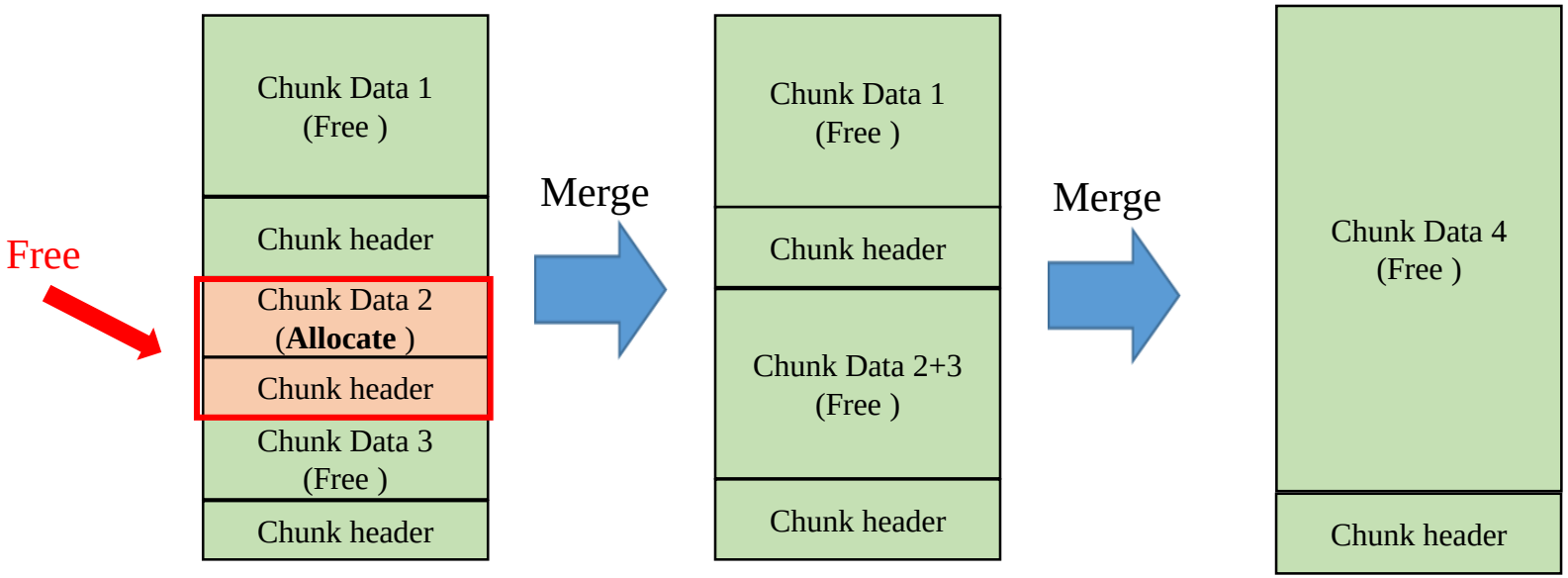
- Use bin (*slides 9,10*) to manage free chunks
- Should follow the rules of **Merge** (*slides 15,16*)

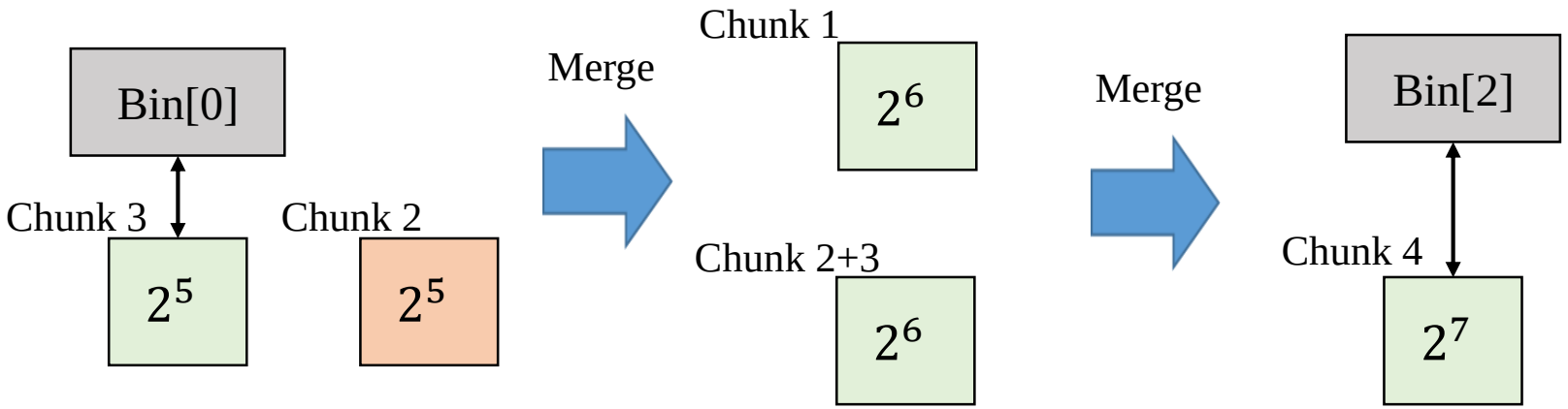
Merge

- When Heap free method is called , adjacent free chunks must be merged into one if they have the same size :
  - **Merge operations should be repeated until the two adjacent free chunks do not have the same size**

Merge Example

- Example: (Chunk 1 size =2^6, Chunk 2 size = Chunk 3 size =2^5)





2. User Application Requirements

Write a user application to test the memory allocator library

- Should receive **4 kinds of commands :**

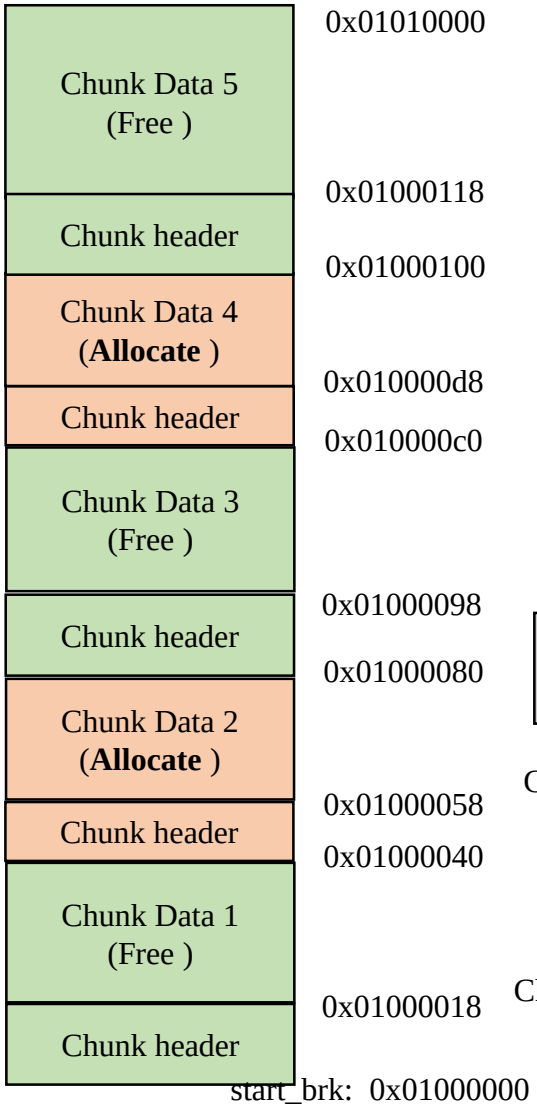
    1. **alloc *N***
    2. **free *ADDR***
    3. **print *BIN***
    4. **print mmap_alloc_list**

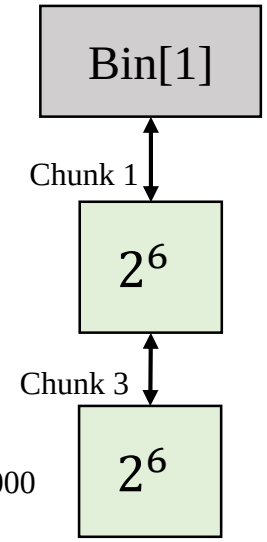
- Continuously receive commands from stdin until ***EOF*** (***Ctrl+D***)
    - Should successfully run
      “cat testfile.txt | hw4_mm_test > outputfile.txt”

Commands format

1. **alloc N**
   - Call hw_malloc(N) to allocate N bytes of data memory
   - Print relative data address (i.e., offset between start_brk and the address returned by hw_malloc())
2. **free ADDR**
   - Call hw_free() to free the memory at (start_brk + ADDR)
   - Print either “success” or “fail”
3. **print bin[i]**
   - Print relative data address and size information of a given bin
     - bin[i] can be bin[0], bin[1] …... bin[10]
4. **print mmap_alloc_list**
   - Print data address and size information.

3. Input/output format





- alloc
  - print **(relative) data address** in a line
- free
  - print success/fail in a line
- print bin[i]
  - print **(relative) chunk address** and **size** of each free chunk in the given bin, from the front to the rear
  - print a line for each chunk; pad 8 dash signs between the address and size

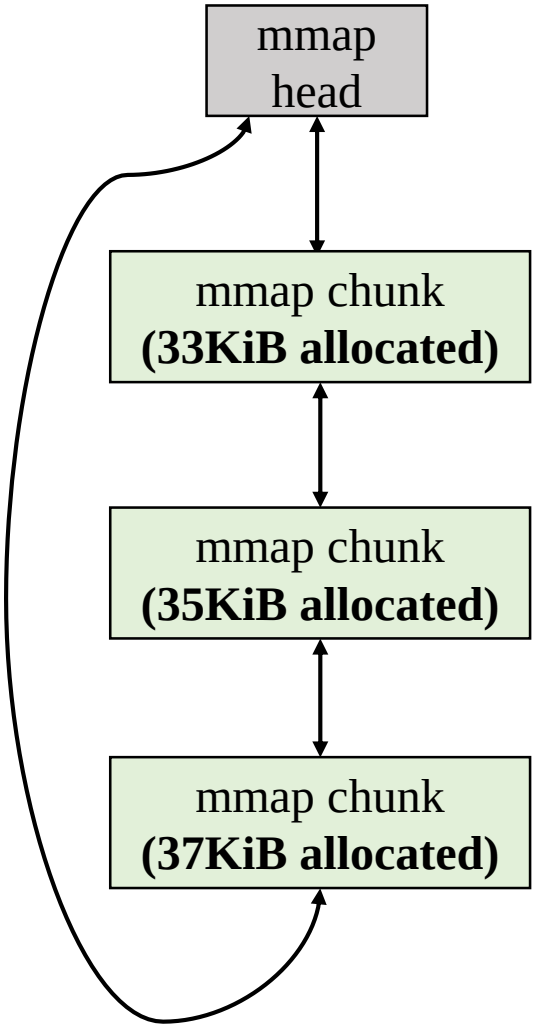
Input example

```
alloc 16
alloc 16
alloc 16
alloc 16
free 0x00000018
free 0x00000098
print bin[1]
```

Output example

```
0x00000018
0x00000058
0x000000d8
0x000000d0
success
success
0x00000000--------64
0x00000080--------64
```

3. Input/output format



- print mmap_alloc_list
  - print **chunk address** and **size** of each free chunk in the list, from the front to the rear
  - print a line for each chunk; pad 8 dash signs between the address and size

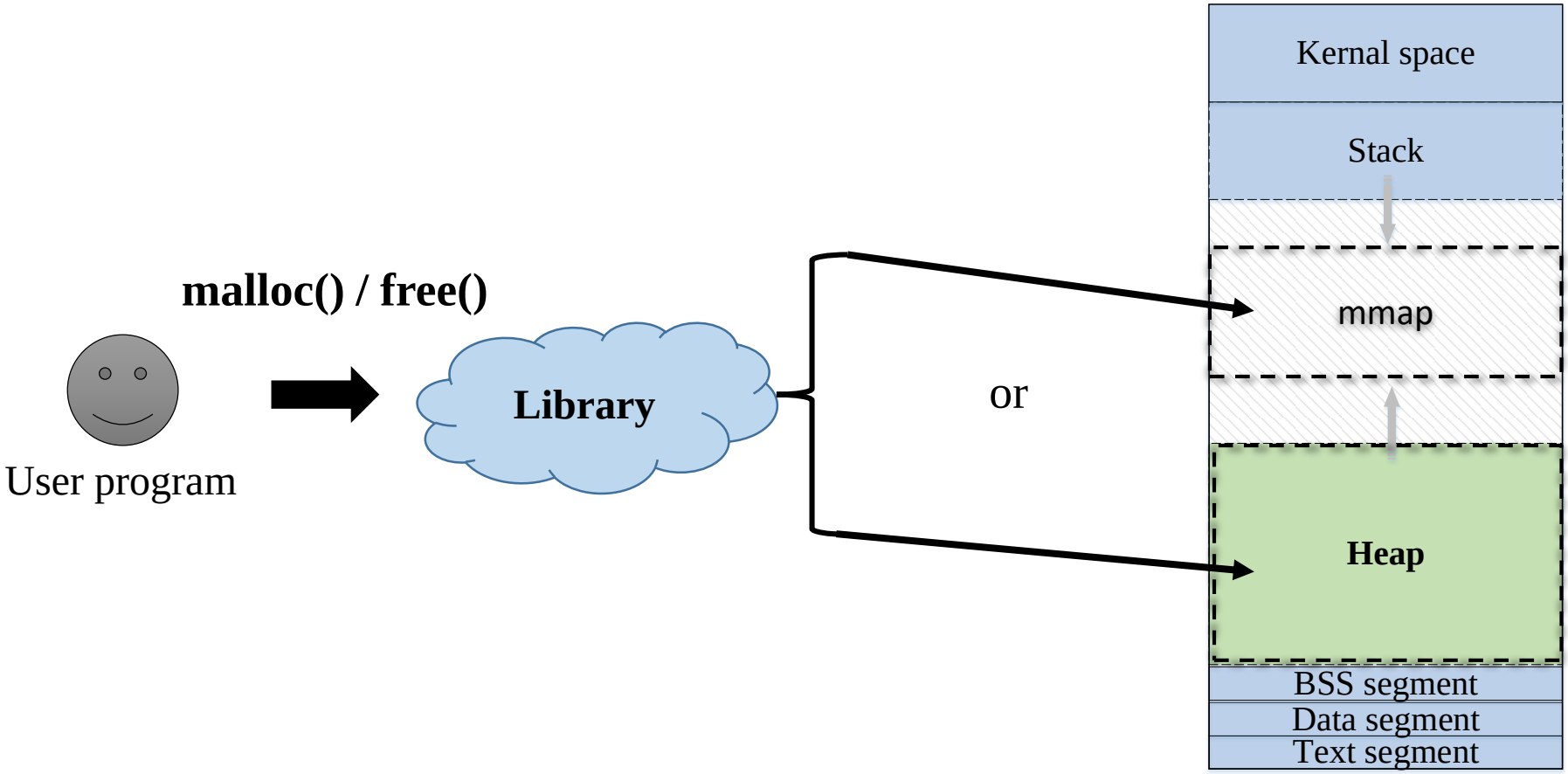
Input example

```
alloc 33768
alloc 37864
alloc 35816
print mmap_alloc_list
```

Output example

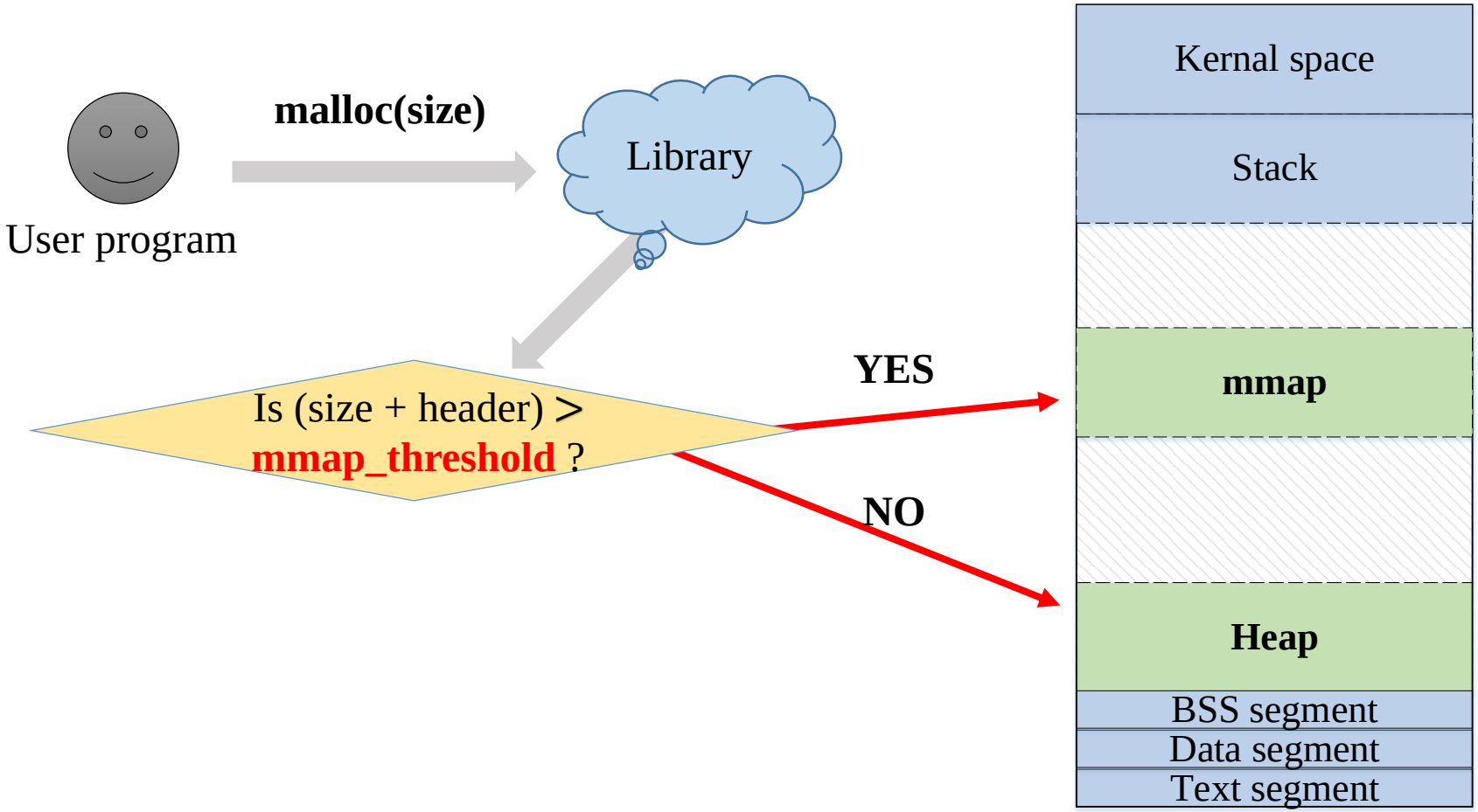
```
0xfdcf00018
0xfecff0f018
0xffcff0f018
0xfdcf00000--------33792
0xffcff0f000--------35840
0xfecff0f000--------37888
```

Concepts (malloc / free)

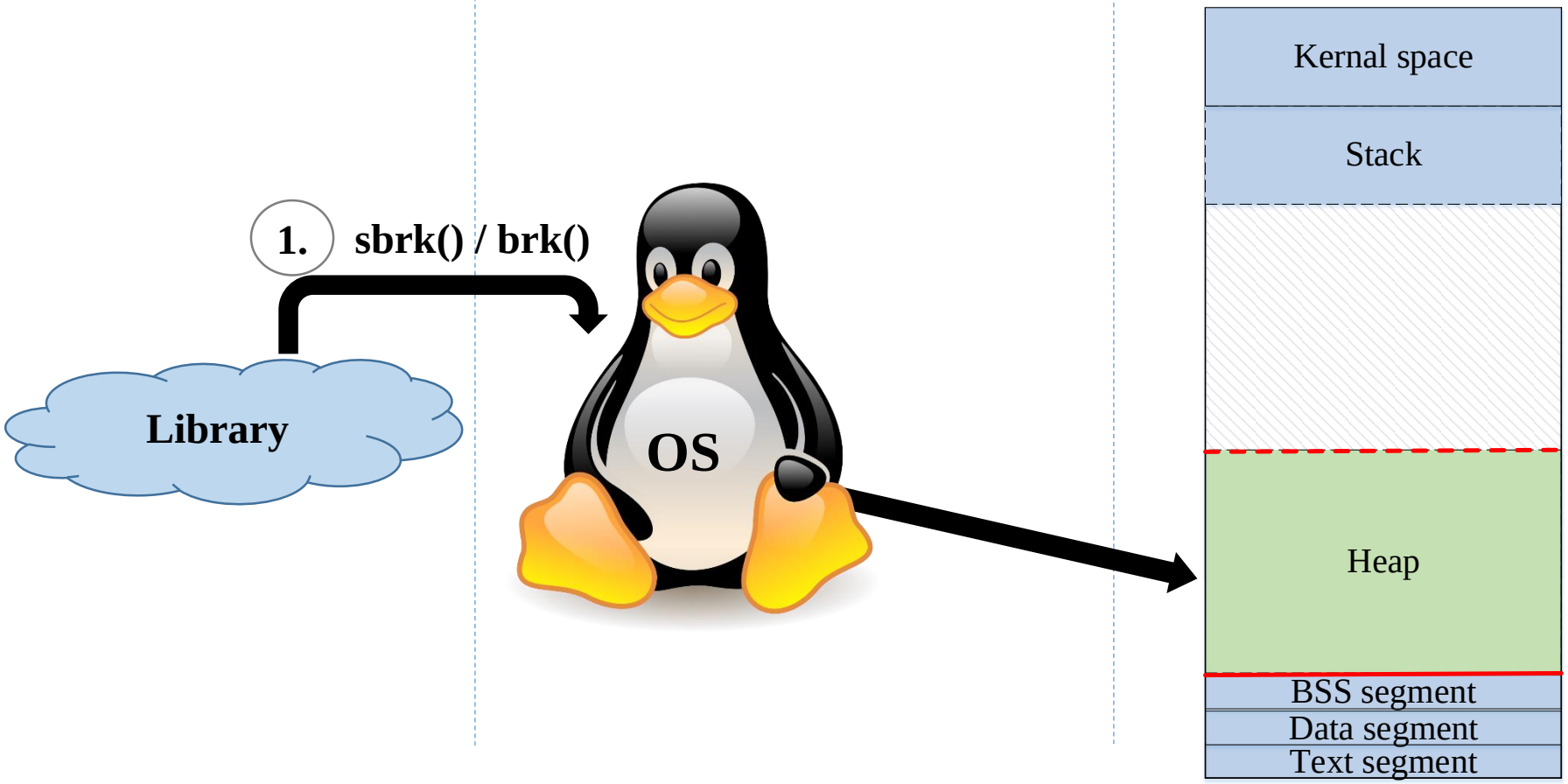


Concepts (mmap_threshold)

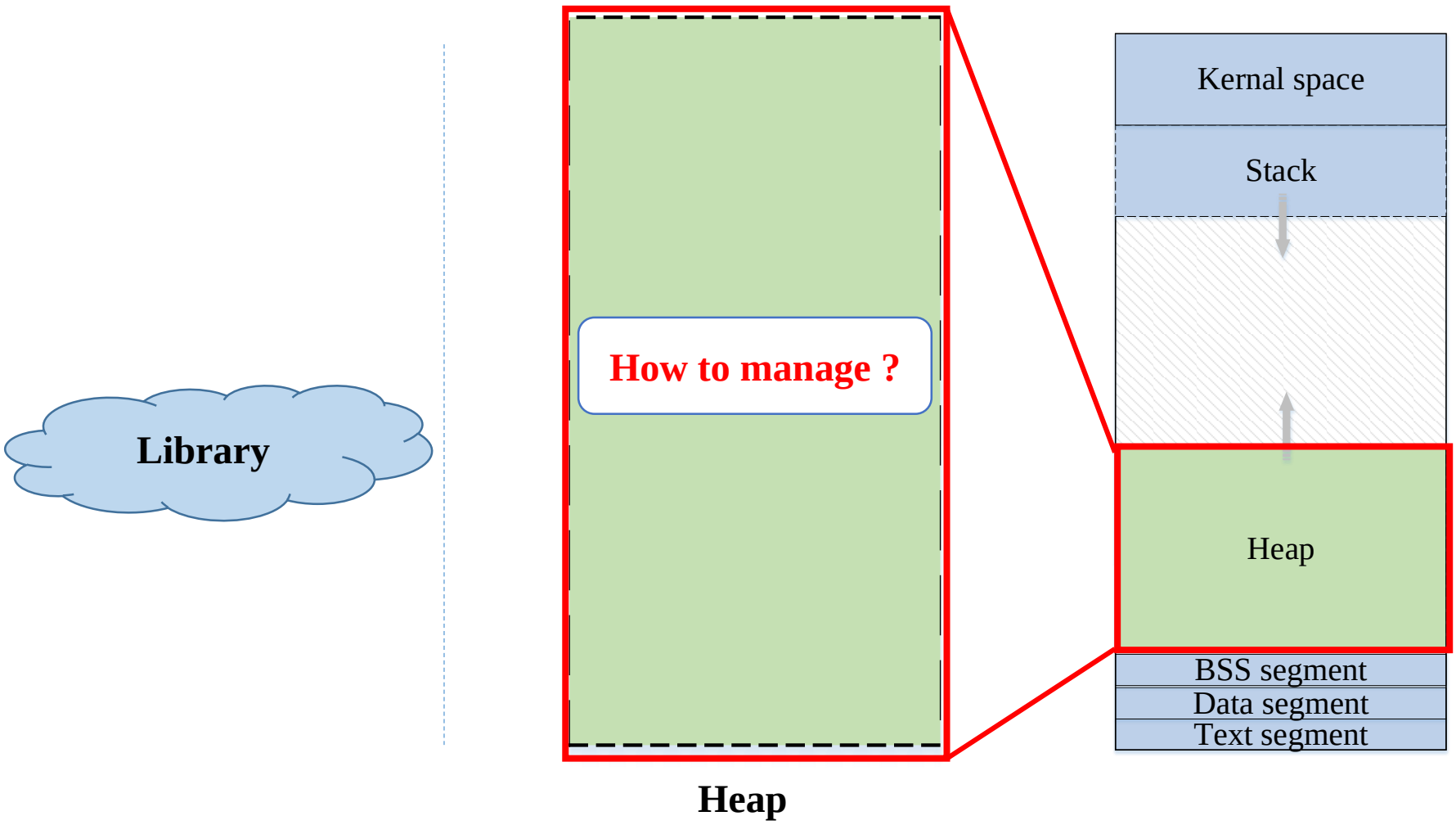
- Use mmap_threshold to decide the memory allocate method



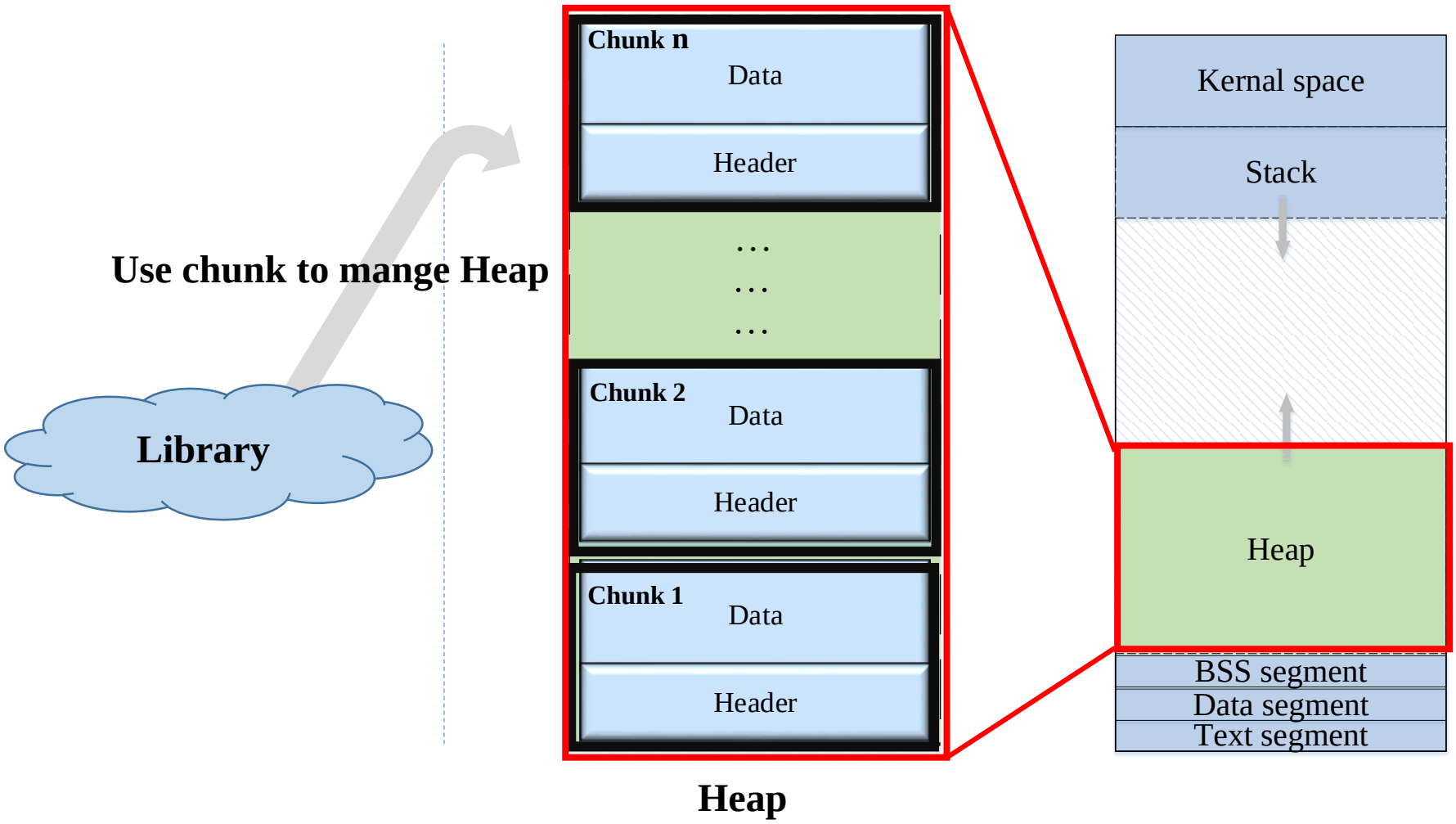
Concepts (Heap initialization)



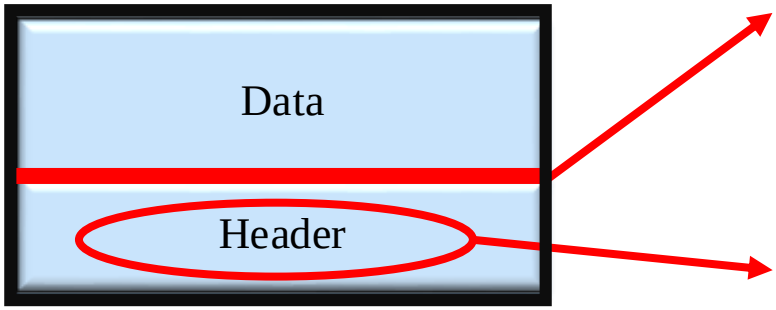
Concepts (heap)



Concepts (heap segment)



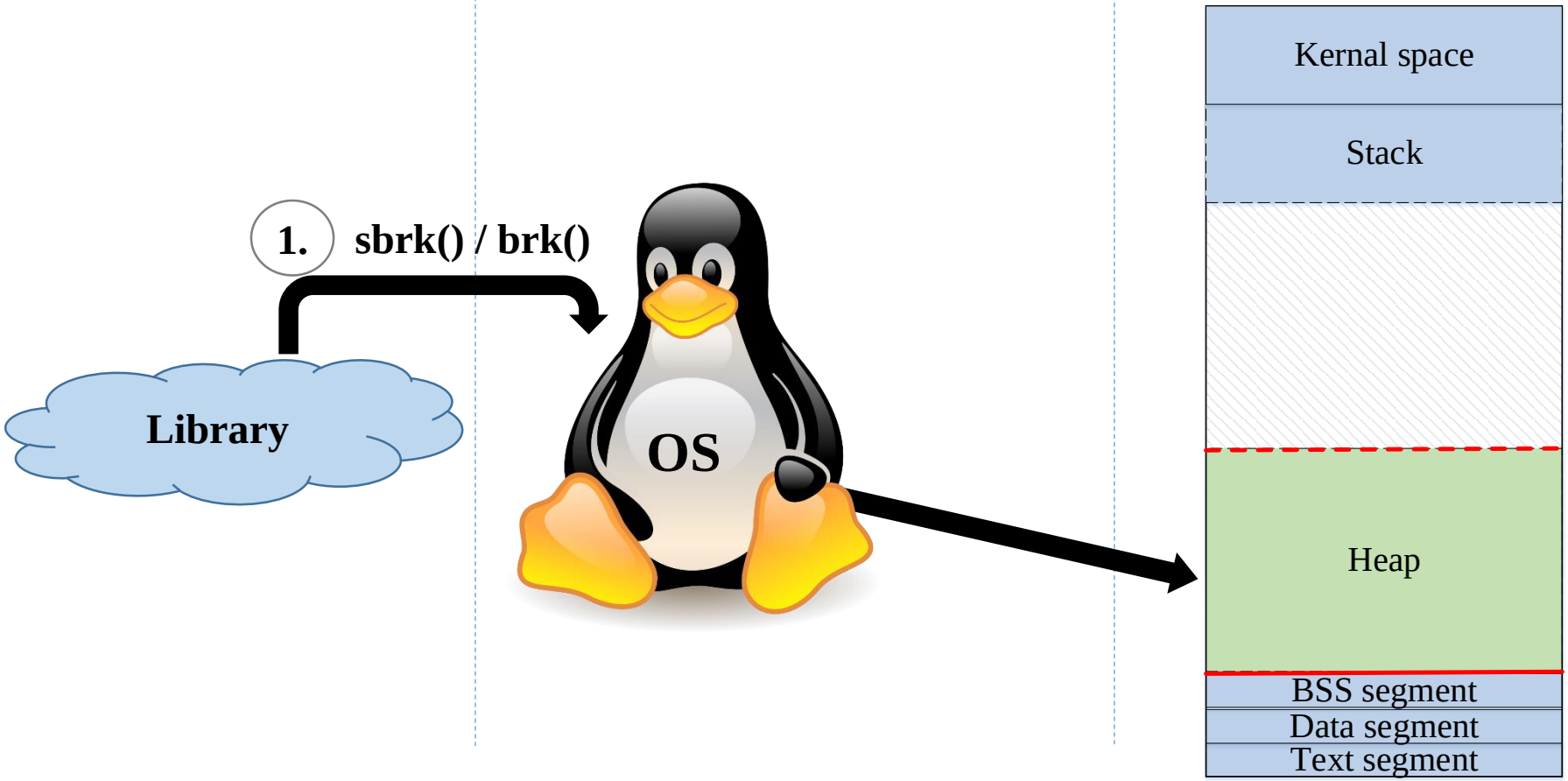
Concepts (chunk)



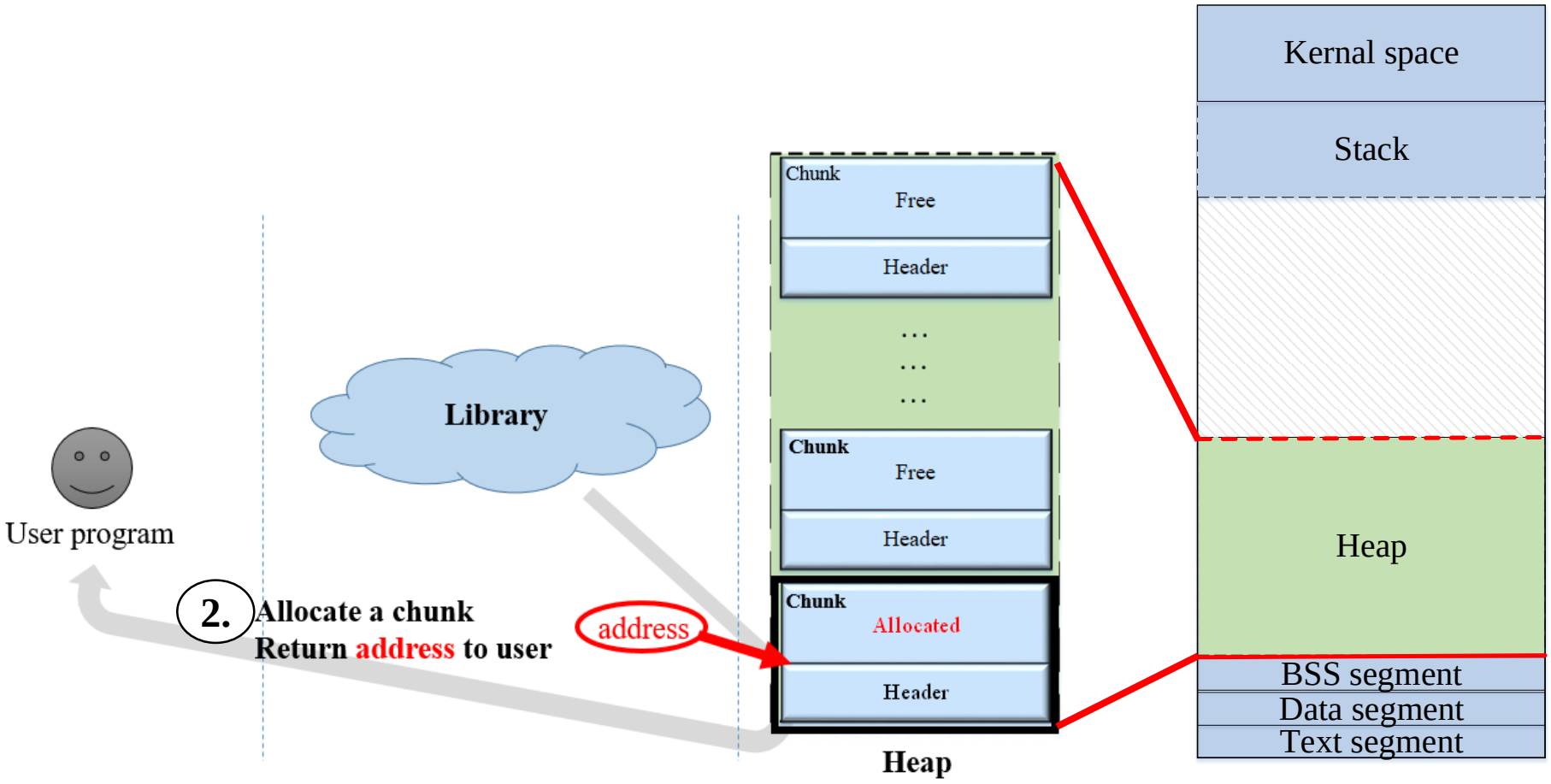
Chunk

- Return address
  (starting address of the data part)
- Chunk information
  (e.g: size, flag, prev, next…)

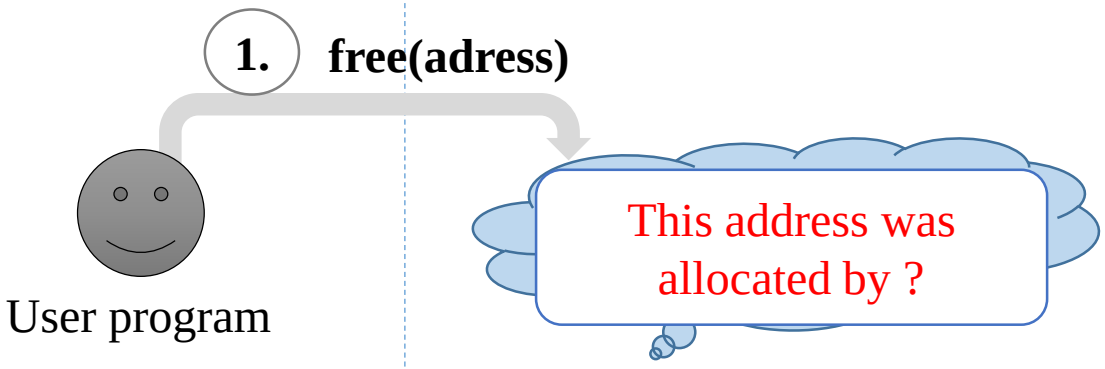
Concepts (Heap initialization)



Concepts (heap segment)

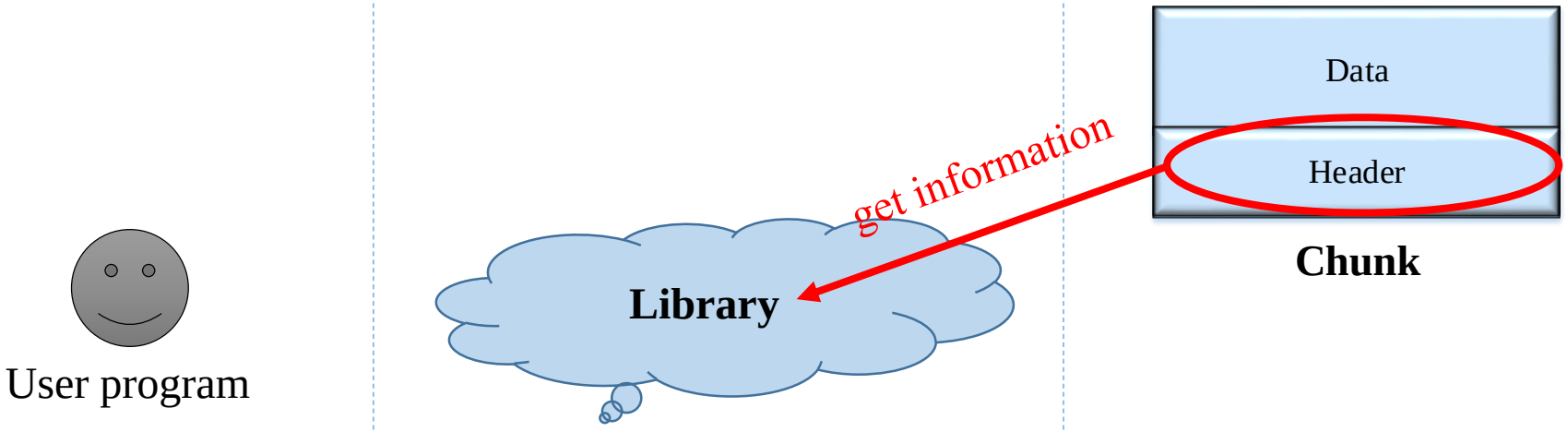


Concepts (free)

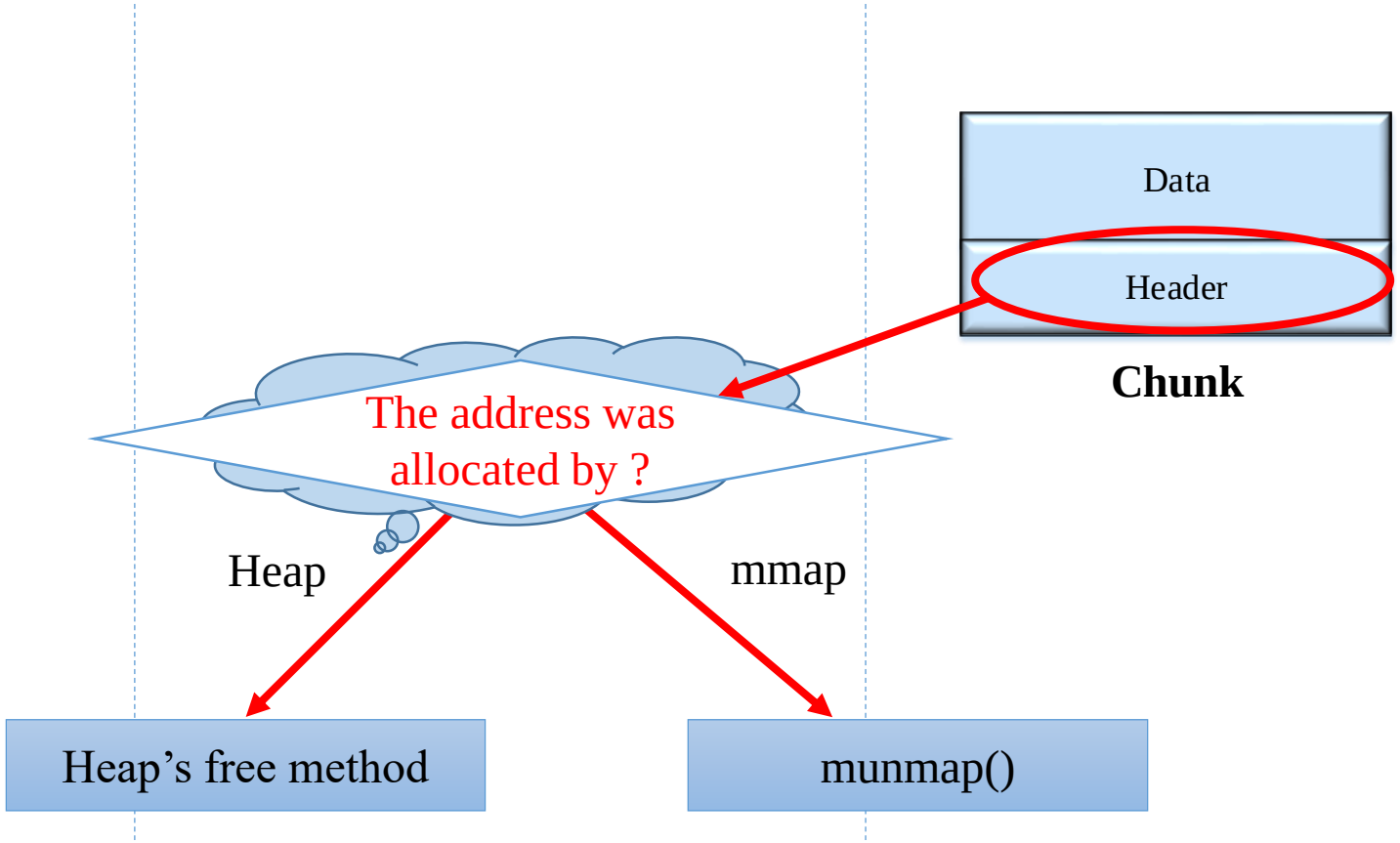


Concepts (free)

- Get information from Chunk header to know which memory allocate method was use

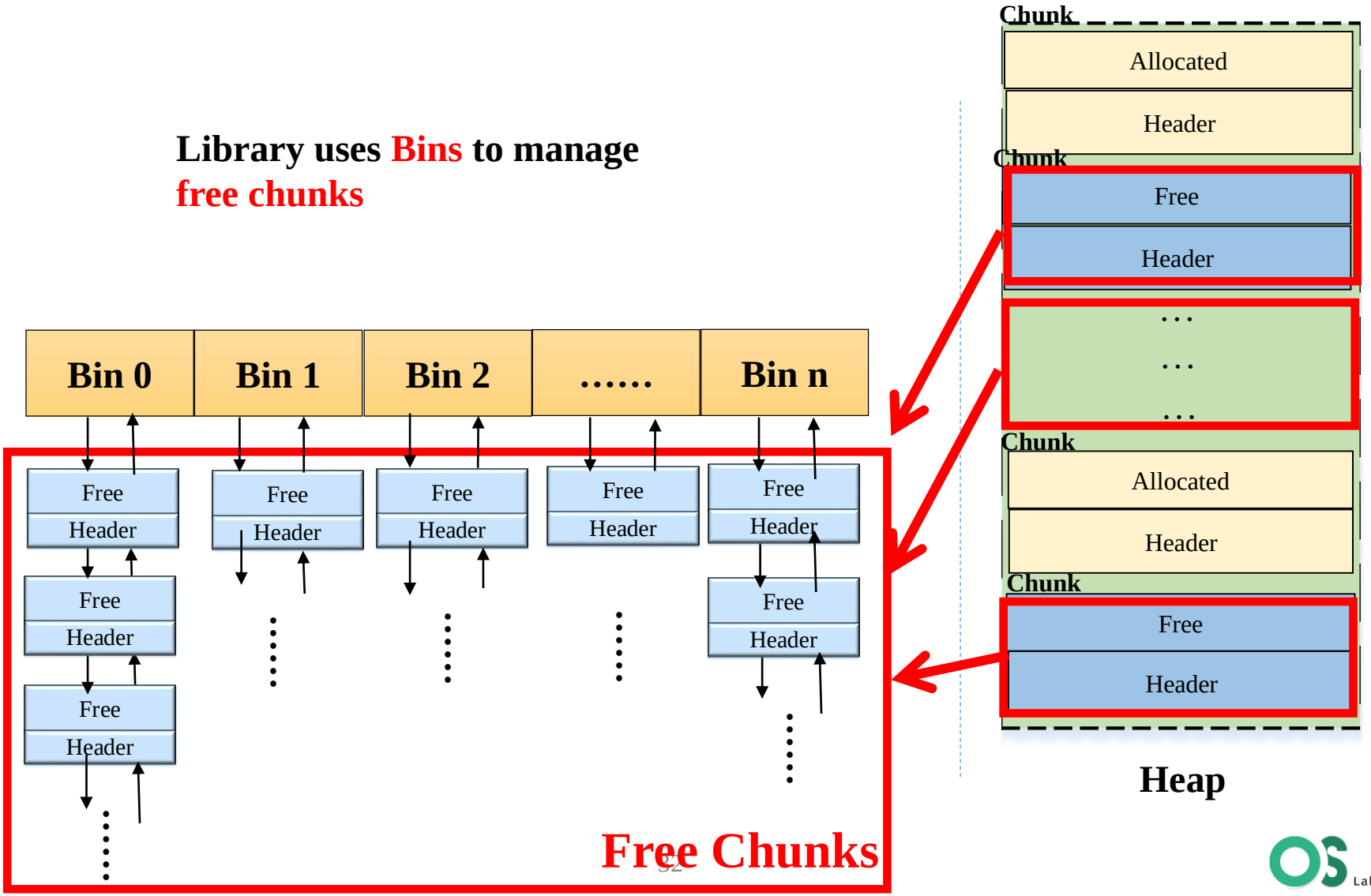


Concepts (free)

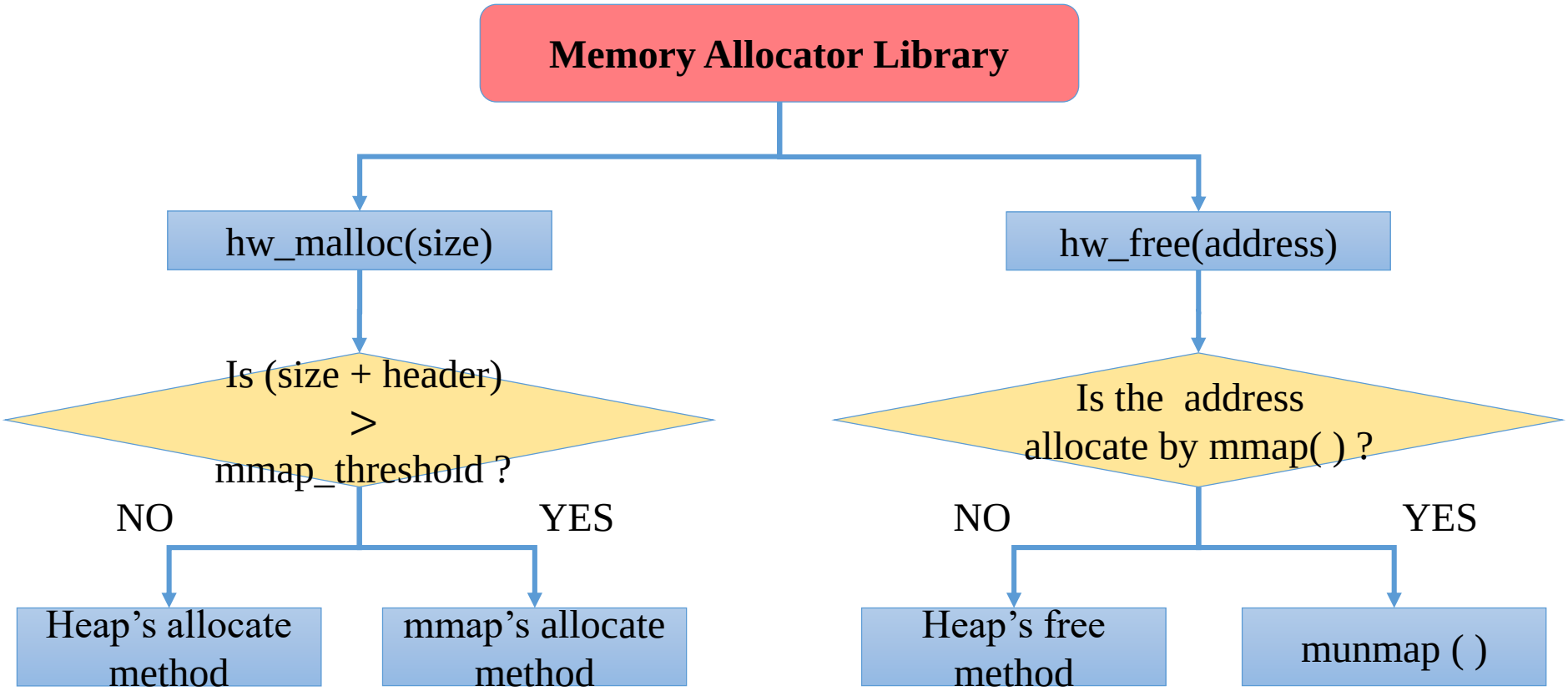


Concepts (Heap's free method)

Library uses Bins to manage free chunks



Concepts (Architecture)



References

- sbrk()
  - Linux man page

- Streams, pipes, and redirects
  - IBM