Malloc Lab - Part 2, Processes

OMET Survey

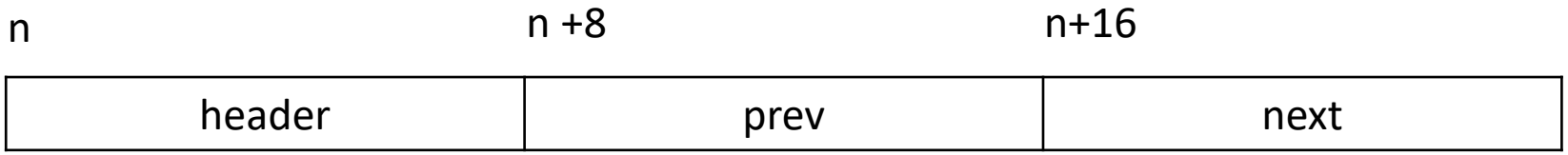
- Please take some time to complete the OMET survey.

Malloc Lab (Part 2)

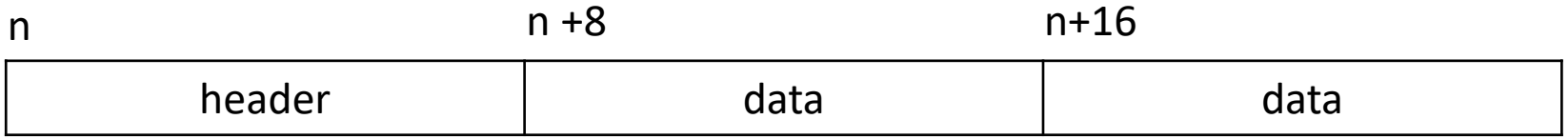
```c
struct block
{
    /* Header contains:
    *  a. size
    *  b. allocation flag
    */
    word_t header;

    union
    {
        struct
        {
            block_t *prev;
            block_t *next;
        } links;
        /*
        * We don't know what the size of the payload will be, so we will
        * declare it as a zero-length array.  This allows us to obtain a
        * pointer to the start of the payload.
        */
        unsigned char data[0];

    /*
     * Payload contains:
     * a. only data if allocated
     * b. pointers to next/previous free blocks if unallocated
     */
    } payload;

    /*
     * We can't declare the footer as part of the struct, since its starting
     * position is unknown
     */
};
```

struct block

If NOT allocated



If allocated



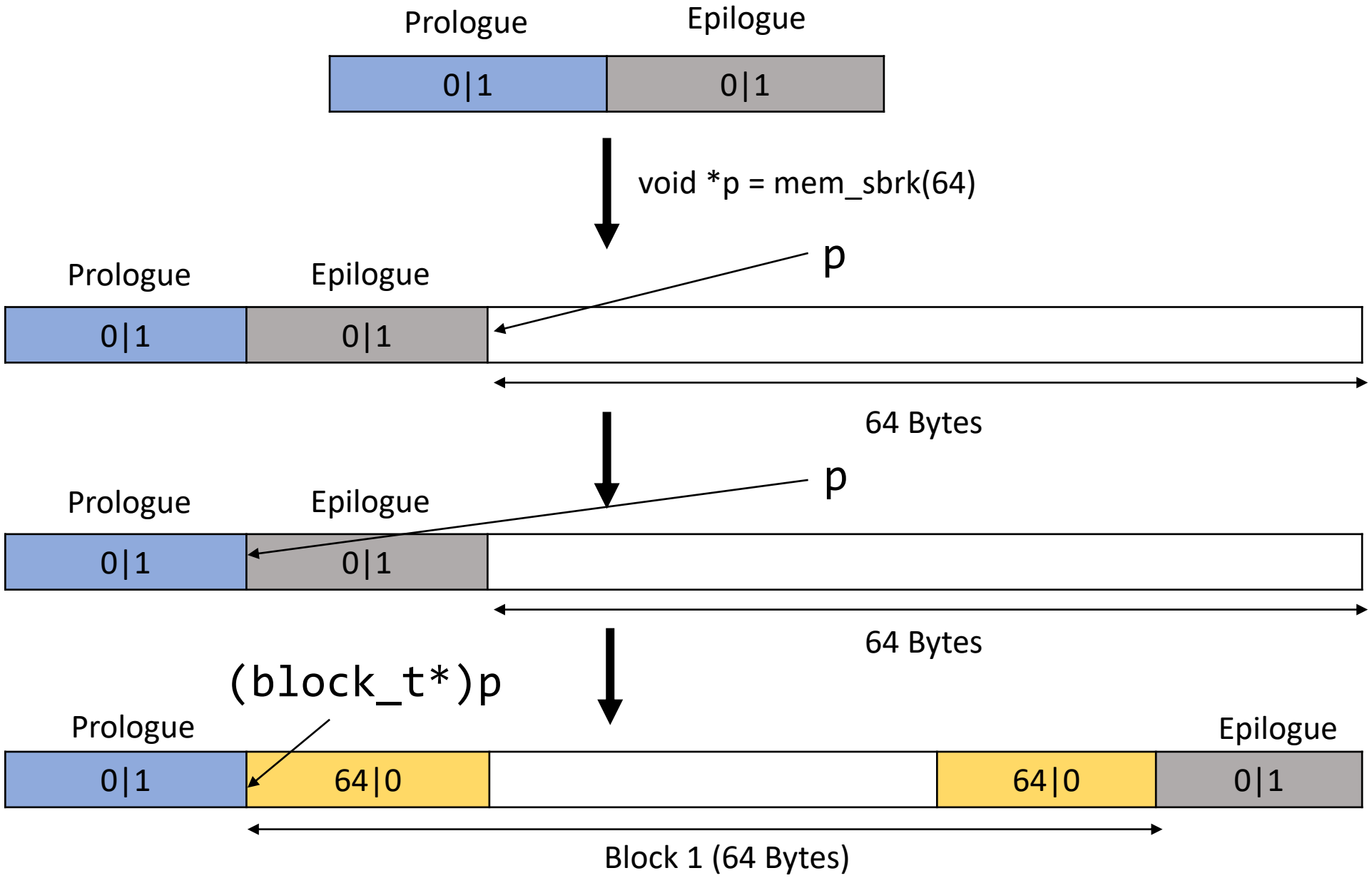
- You DO NOT need to put any data in the allocated space
  - **You just need to know the STARTING ADDRESS OF data (which is the address of header + size of a word)**
- Utilize the prev and next pointer when using explicit list traversal

Let’s See Some Code

```c
int mm_init(void)
{
    /* Create the initial empty heap */
    word_t *start = (word_t *)(mem_sbrk(2*wsize));
    if ((ssize_t)start == -1) {
        printf("ERROR: mem_sbrk failed in mm_init, returning %p\n", start);
        return -1;
    }

    /* Prologue footer */
    start[0] = pack(0, true);
    /* Epilogue header */
    start[1] = pack(0, true);

    /* Heap starts with first "block header", currently the epilogue header */
    heap_start = (block_t *) &(start[1]);

    /* Extend the empty heap with a free block of chunksize bytes */
    block_t *free_block = extend_heap(chunksize);
    if (free_block == NULL) {
        printf("ERROR: extend_heap failed in mm_init, returning");
        return -1;
    }

    /* Set the head of the free list to this new free block */
    free_list_head = free_block;
    free_list_head->payload.links.prev = NULL;
    free_list_head->payload.links.next = NULL;

    return 0;
}
```

```c
static block_t *extend_heap(size_t size)
{
    void *bp;

    // Allocate an even number of words to maintain alignment
    size = round_up(size, dsize);
    if ((bp = mem_sbrk(size)) == (void *)-1) {
        return NULL;
    }

    // bp is a pointer to the new memory block requested

    // TODO: Implement extend_heap.
    // You will want to replace this return statement...
    return NULL;
}
```

Example: extend_heap by 64 Bytes

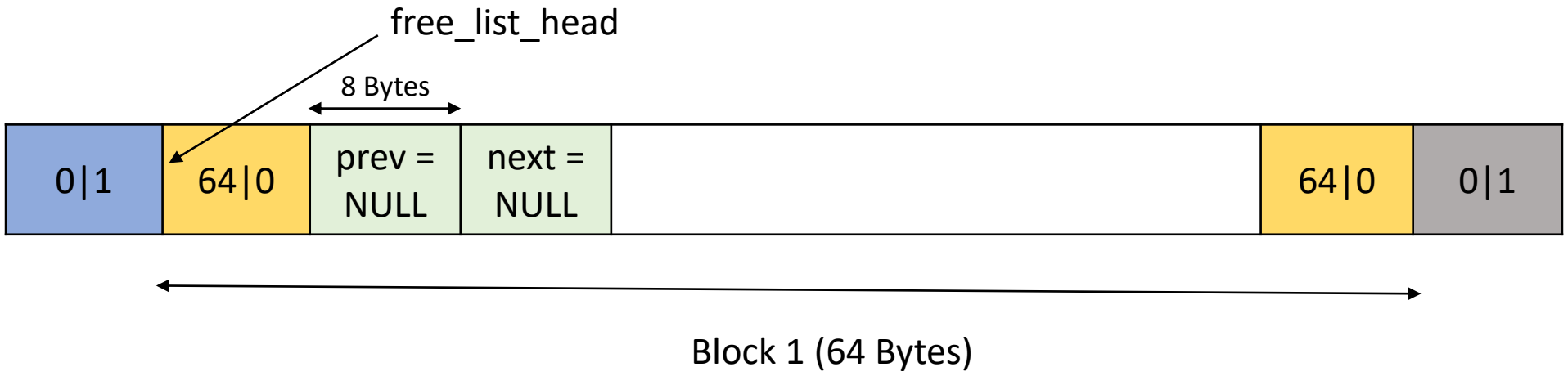


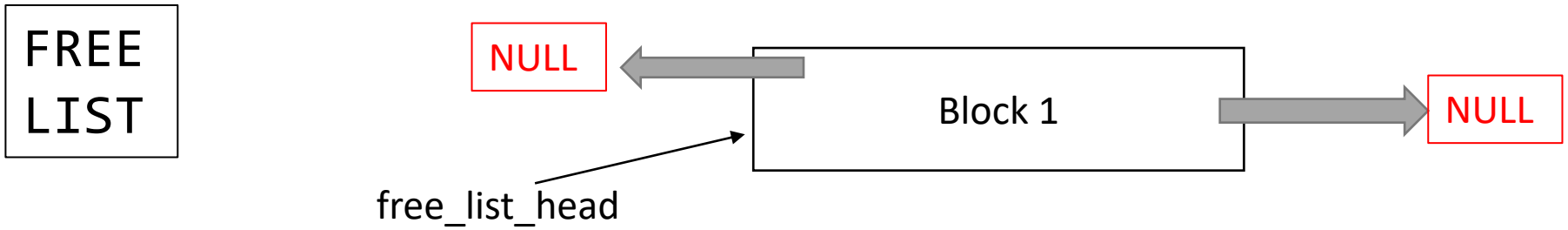
Let’s See Some Code

```
int mm_init(void)
{
    /* Create the initial empty heap */
    word_t *start = (word_t *)(mem_sbrk(2*wsize));
    if ((ssize_t)start == -1) {
        printf("ERROR: mem_sbrk failed in mm_init, returning %p\n", start);
        return -1;
    }

    /* Prologue footer */
    start[0] = pack(0, true);
    /* Epilogue header */
    start[1] = pack(0, true);

    /* Heap starts with first "block header", currently the epilogue header */
    heap_start = (block_t *) &(start[1]);

    /* Extend the empty heap with a free block of chunksize bytes */
    block_t *free_block = extend_heap(chunksize);
    if (free_block == NULL) {
        printf("ERROR: extend_heap failed in mm_init, returning");
        return -1;
    }

    /* Set the head of the free list to this new free block */
    free_list_head = free_block;
    free_list_head->payload.links.prev = NULL;
    free_list_head->payload.links.next = NULL;

    return 0;
}
```

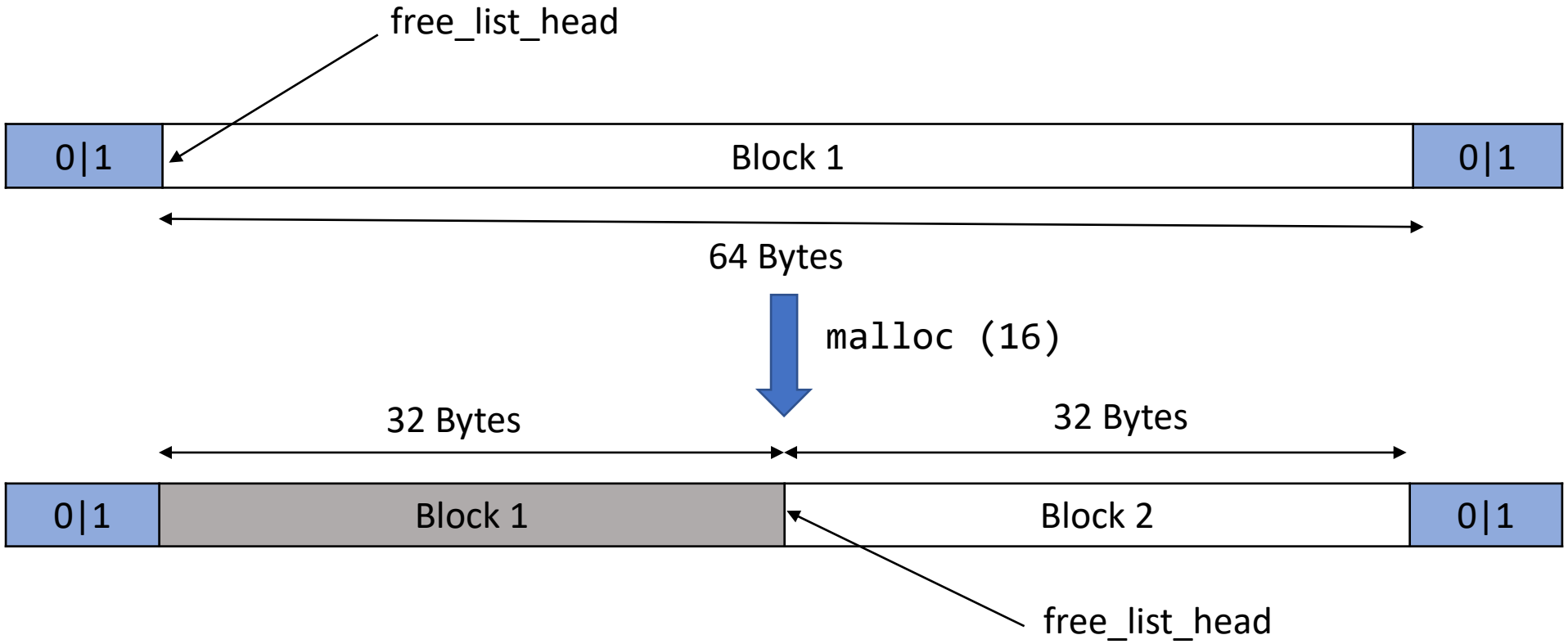
```
// Pointer to the first block in the free list
static block_t *free_list_head = NULL;
```

Visualizing the Heap

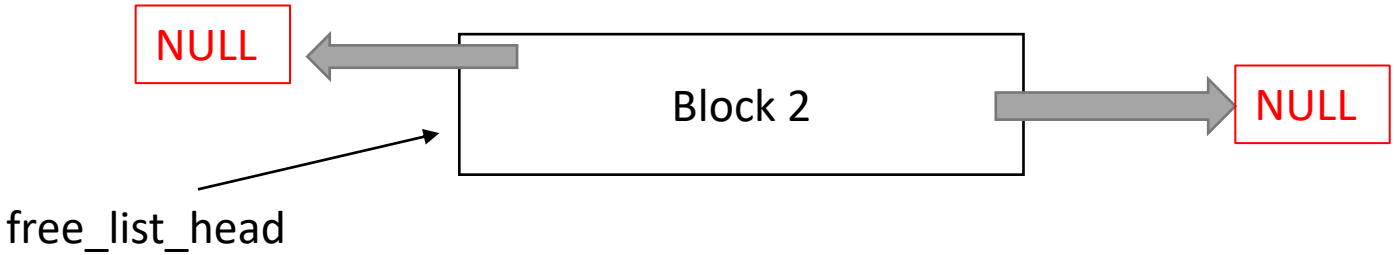




Allocating in the Heap



FREE LIST



- Step 1: Remove Block 1 from Free List
- Step 2: Add Block 2 to Free List

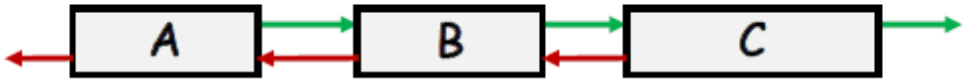
Free List

- The Free List is conceptually a doubly Linked List.

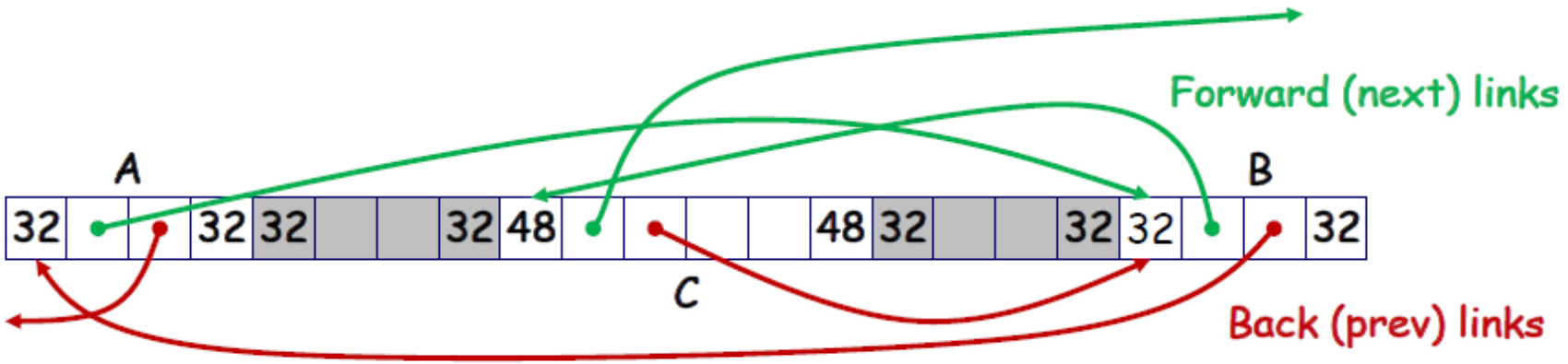
- A node (essentially a free block) in the Free list
  - Has pointer (prev) pointing to the previous free block
  - Has pointer (next) pointing to the next free block

Explicit Free Lists

- Logically:

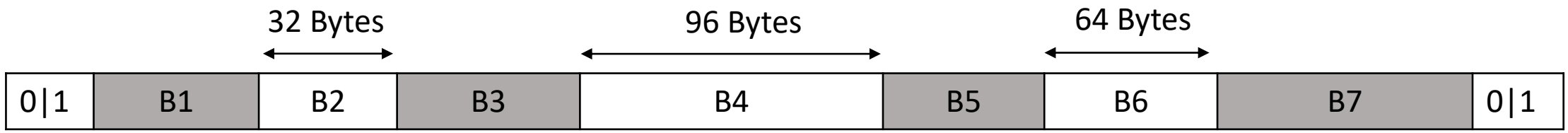


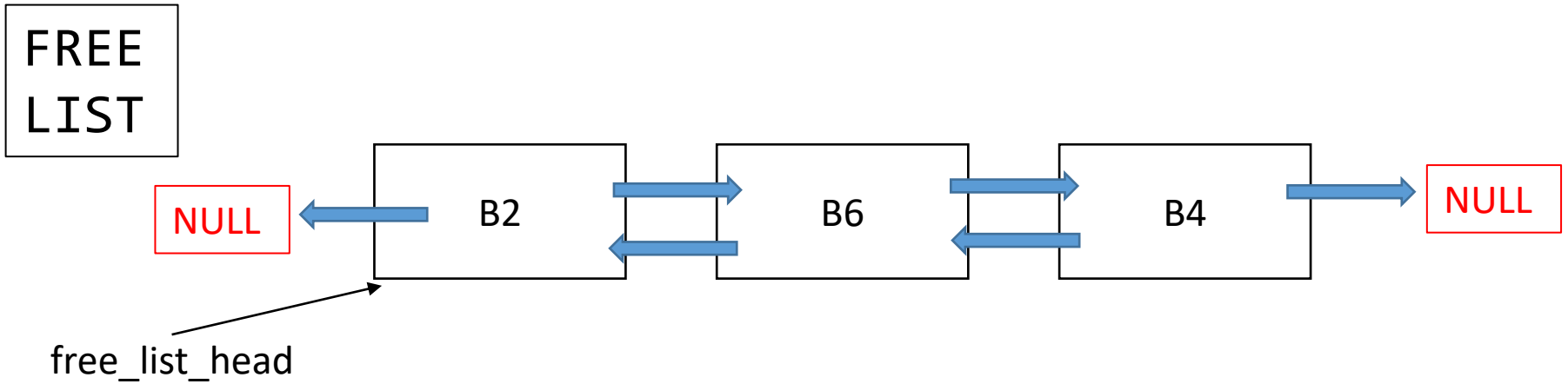
- Physically: blocks can be in any order



Updating Free List During Allocation

Consider this Scenario



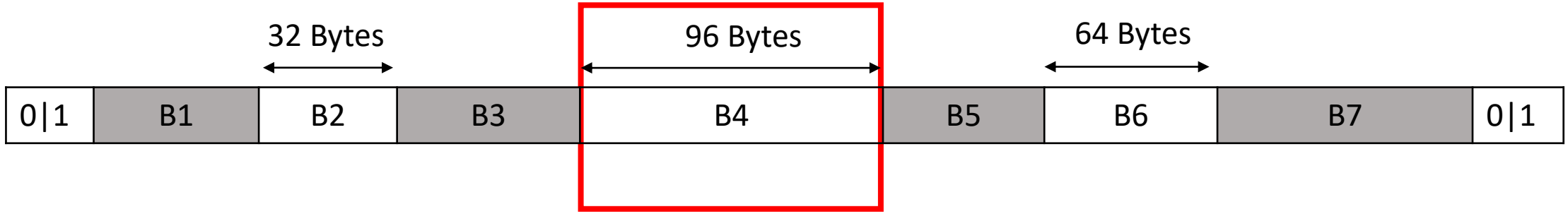


CASE 1 (with Splitting)

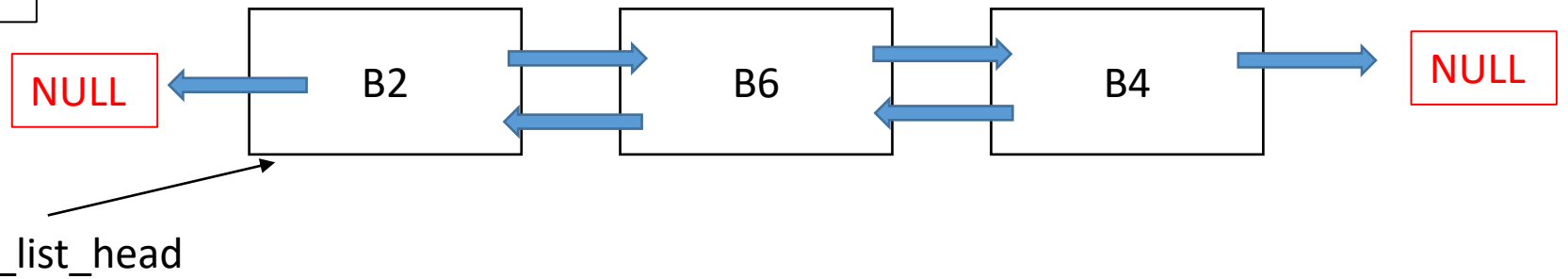
Which free block will you allocate in??

malloc(32)

Will depend on the Allocation Policy. Let's assume **Worst Fit** for this example

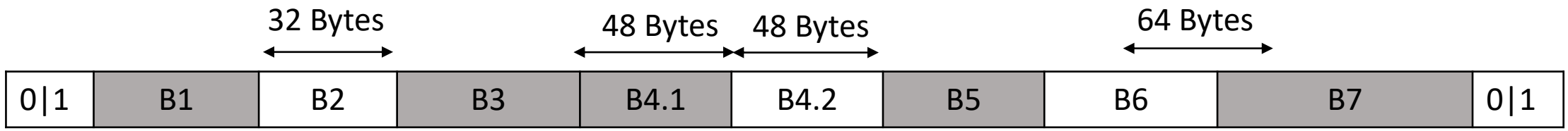


FREE LIST

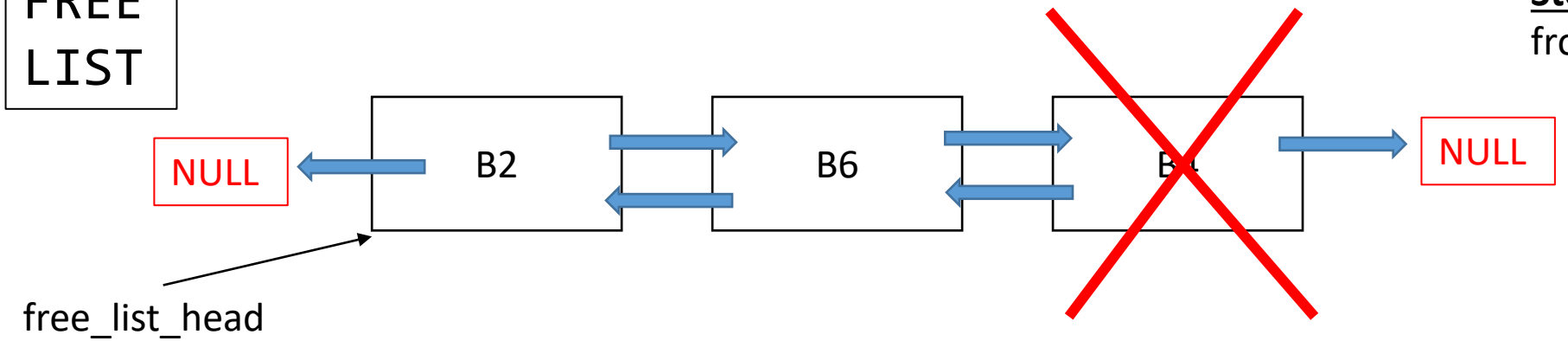


malloc(32)

Splitting!!



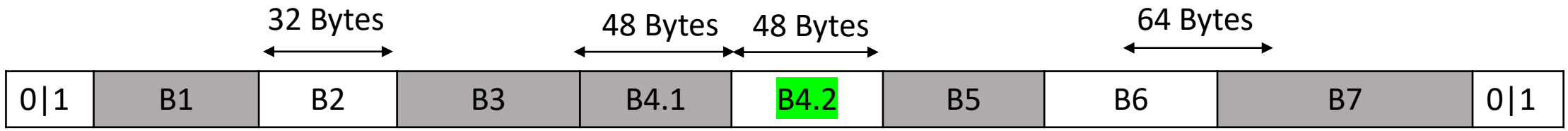
FREE LIST



Step 1: Remove Block 4 from FREE LIST

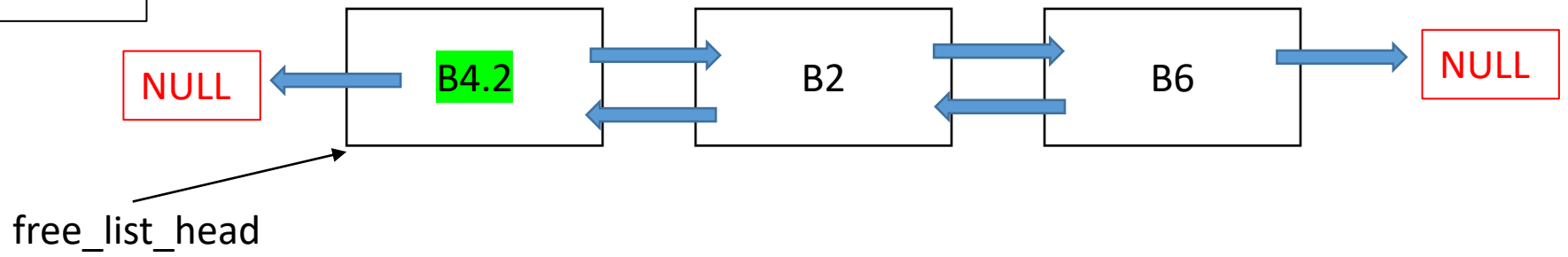
malloc(32)

Splitting!!



FREE LIST

Step 2: Insert Block 4.2 to the **beginning of the FREE LIST (LIFO)**

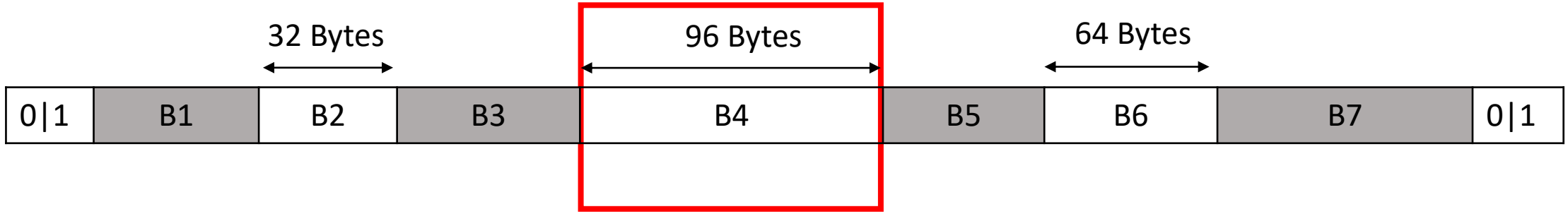


CASE 2 (without Splitting)

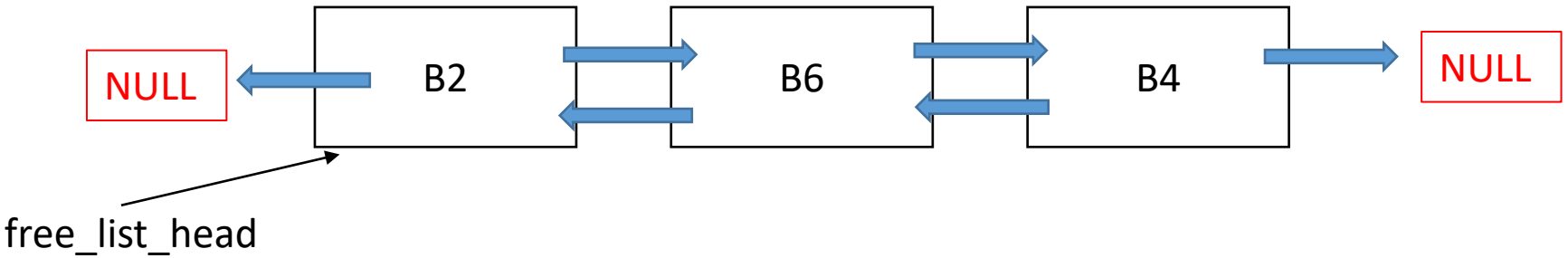
Which free block will you allocate in??

malloc(80)

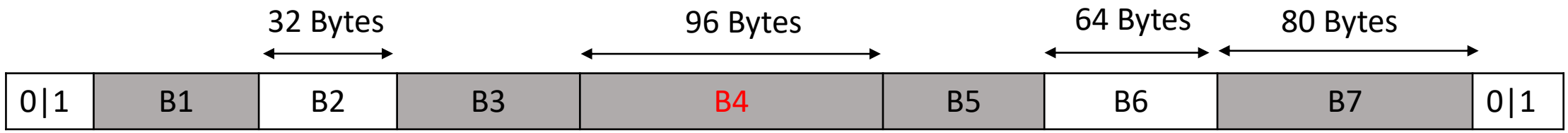
Will depend on the Allocation Policy. Let's assume **First Fit** for this example



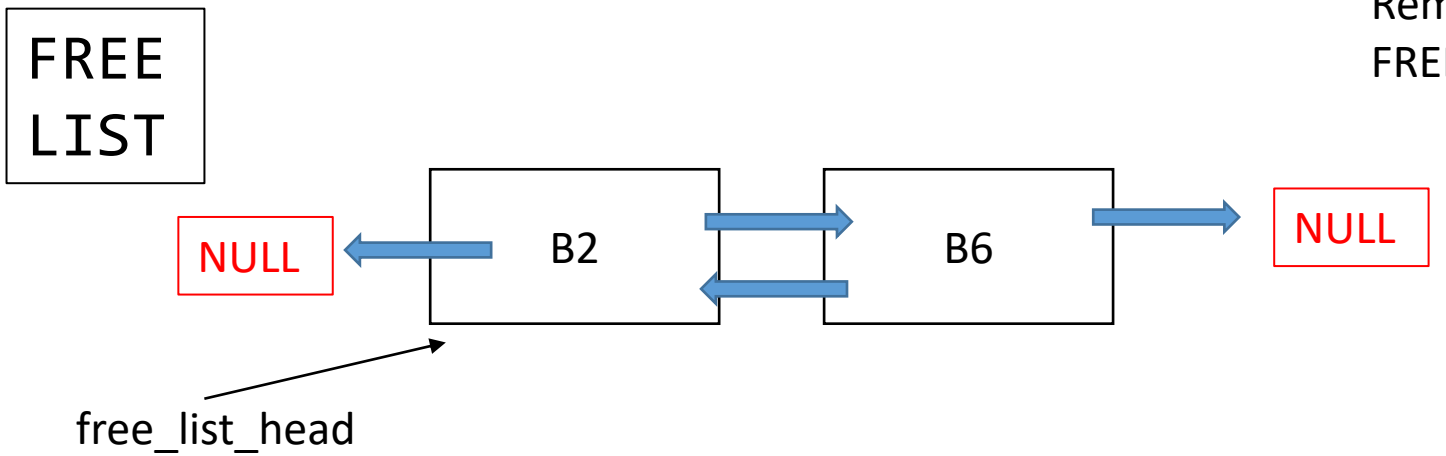
FREE LIST



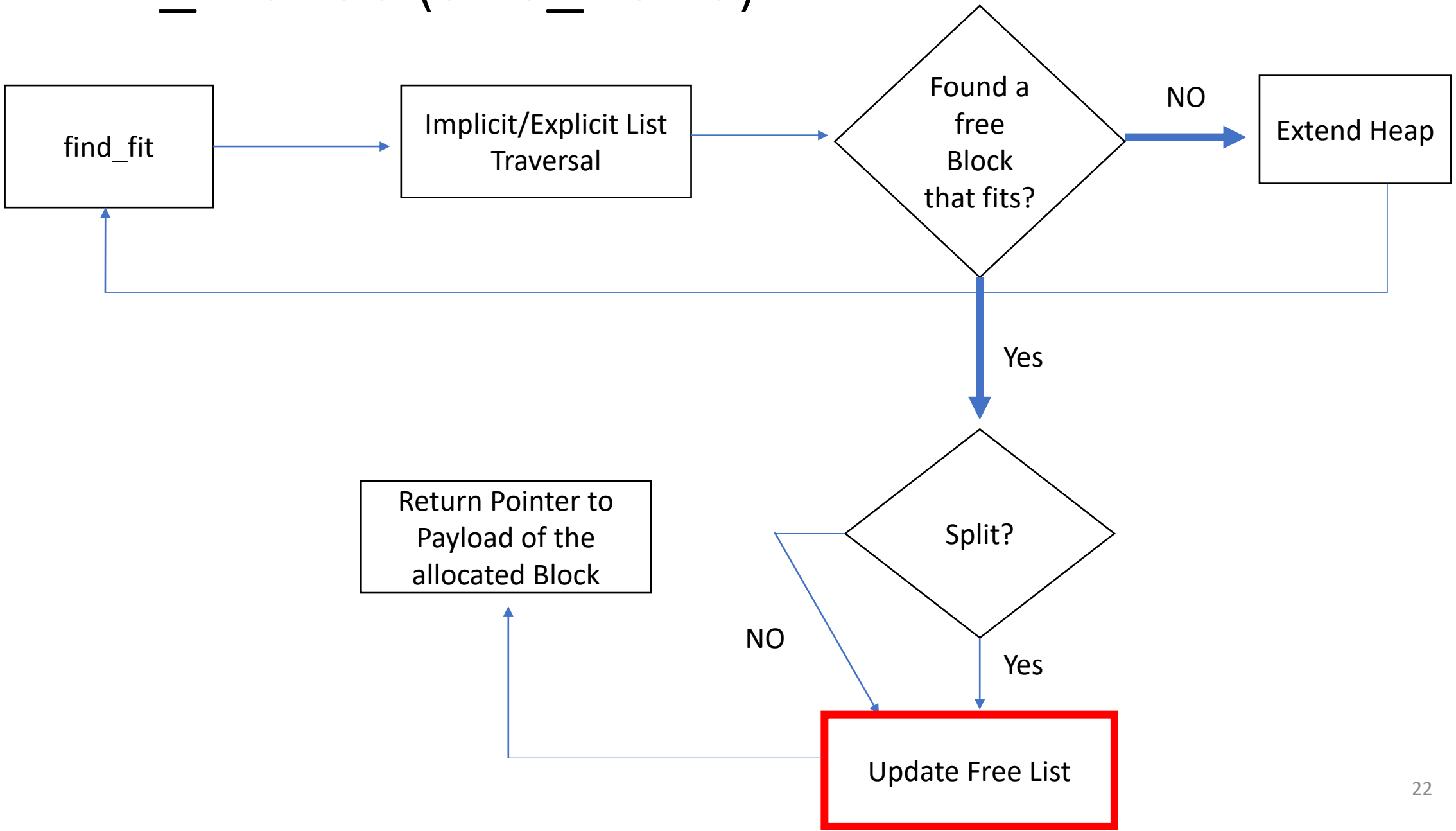
malloc(80)



Remove Block 4 from FREE LIST

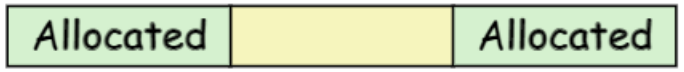


mm_malloc (size_t size)

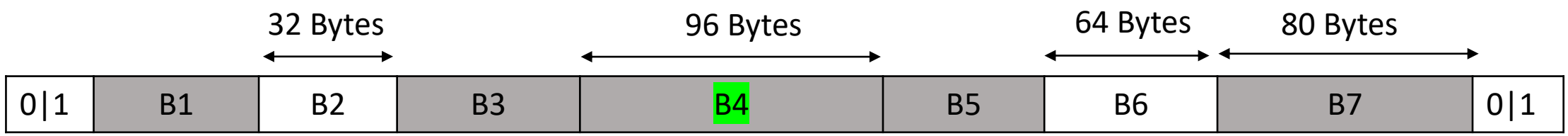


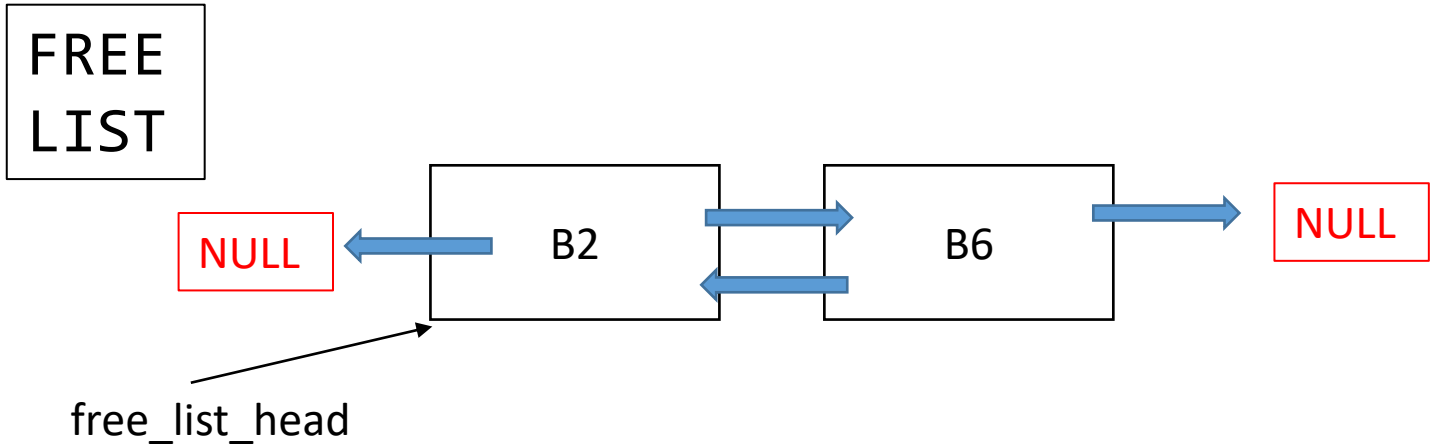
Updating Free List During De-Allocation

Freeing A Block (Case 1)

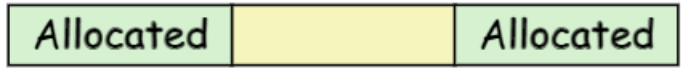


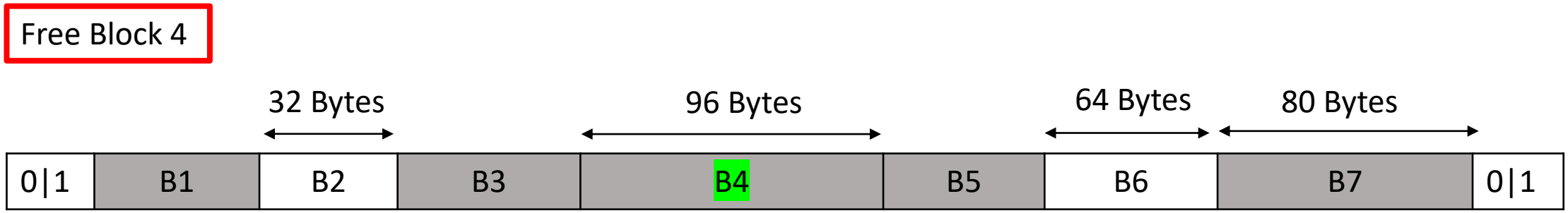
Free Block 4





Freeing A Block (Case 1)

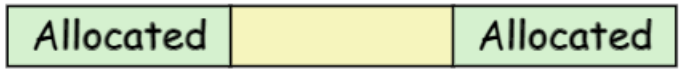




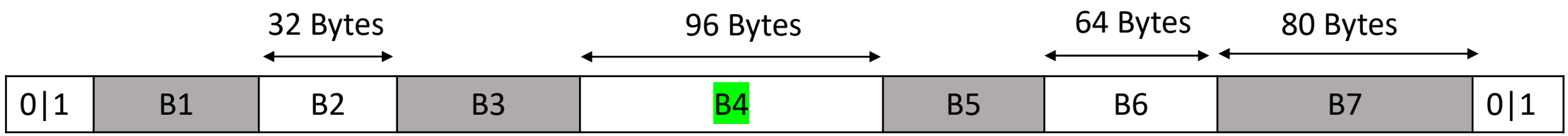
Where do you put Block 4 in the Free List?

- LIFO
- FIFO
- Address Ordered Policy

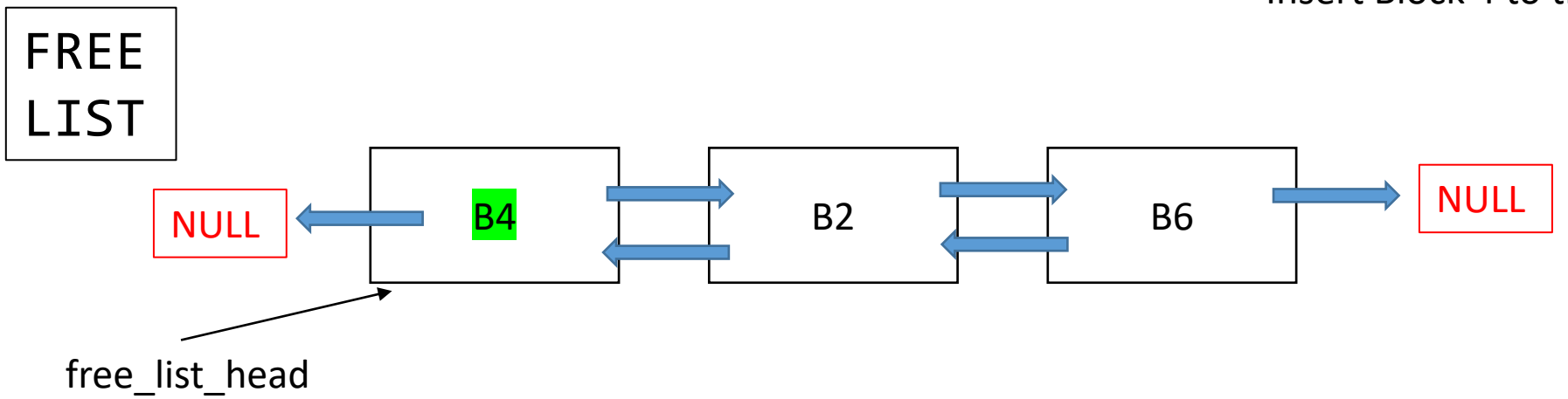
Freeing A Block (Case 1)



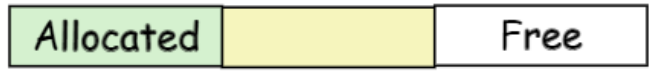
Free Block 4



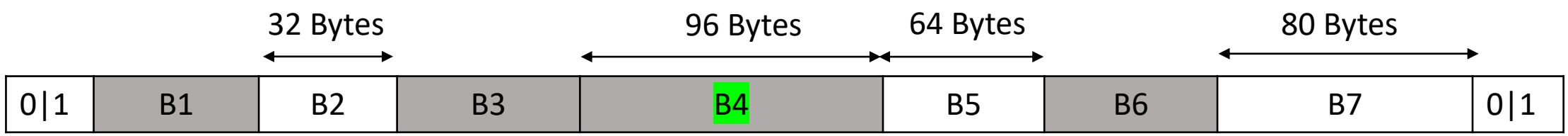
Insert Block 4 to the Free List



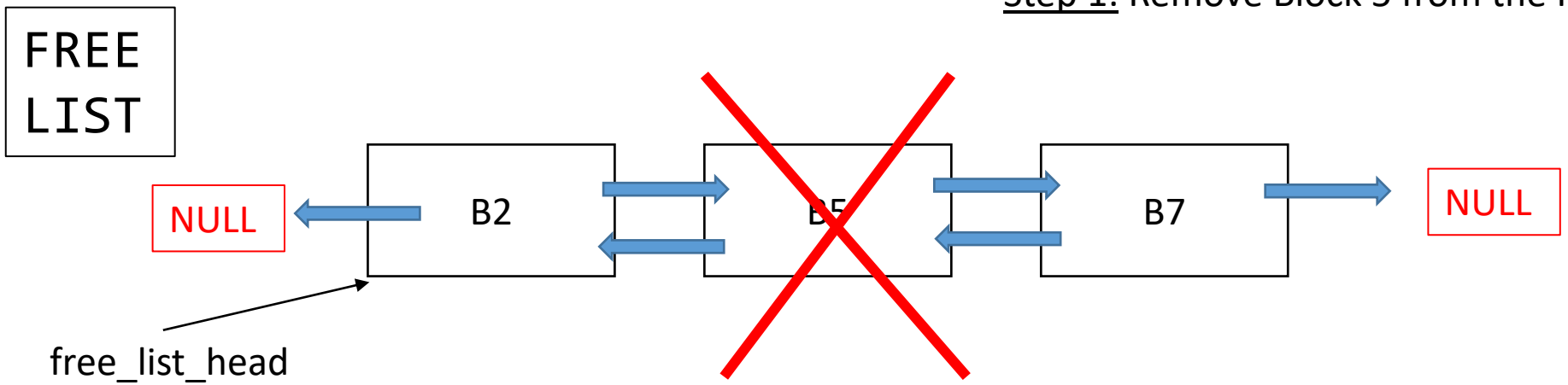
Freeing A Block (Case 2)



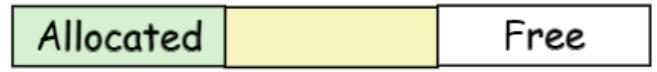
Free Block 4



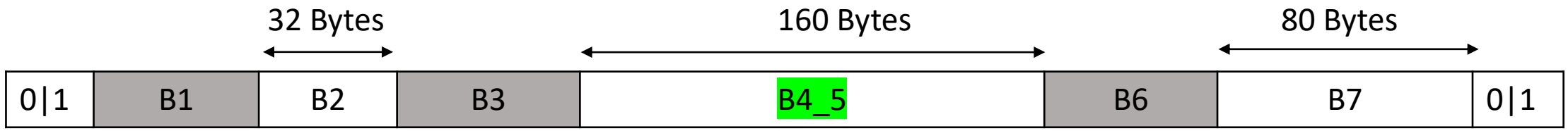
<u>Step 1:</u> Remove Block 5 from the Free List



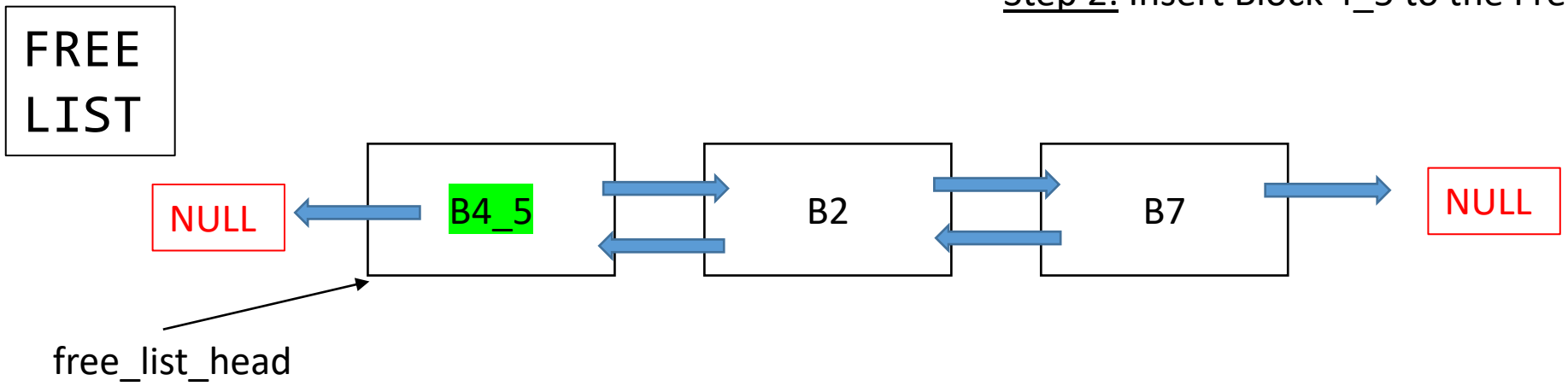
Freeing A Block (Case 2)



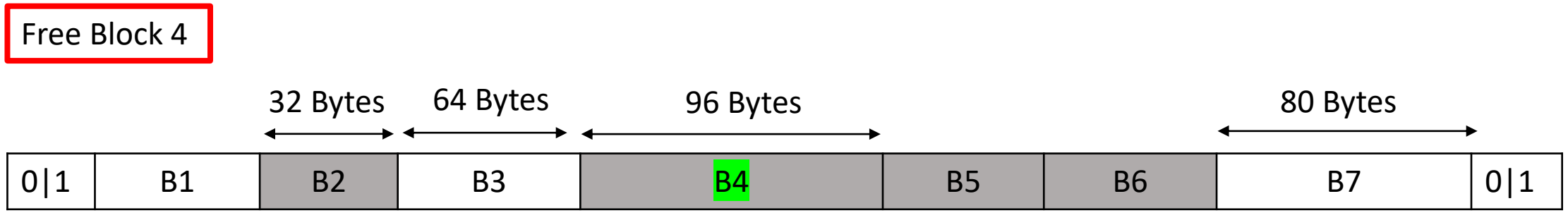
Free Block 4



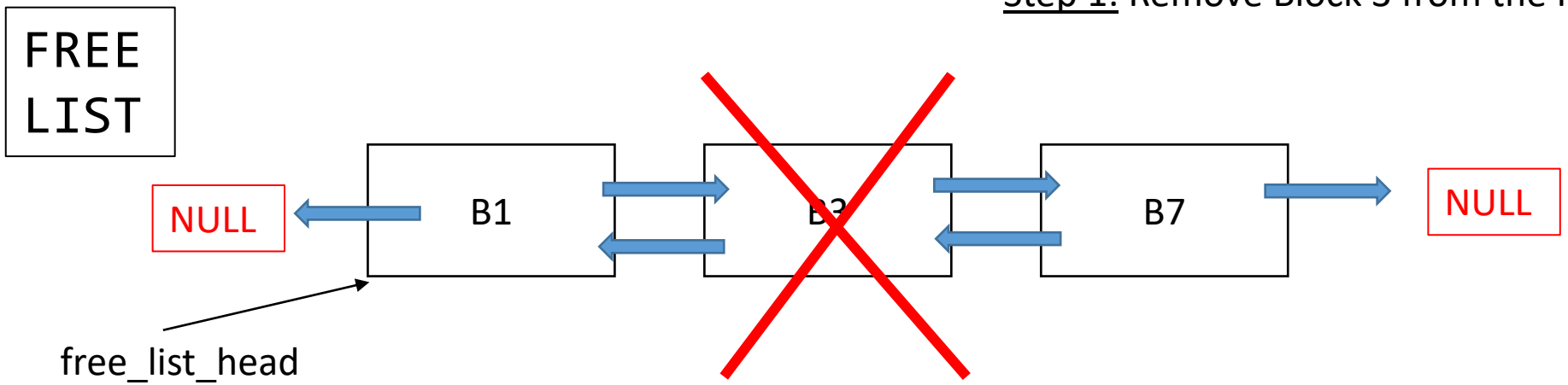
Step 2: Insert Block 4_5 to the Free List



Freeing A Block (Case 3)

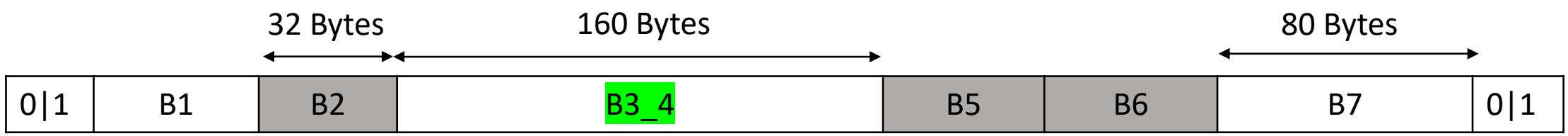


Step 1: Remove Block 3 from the Free List

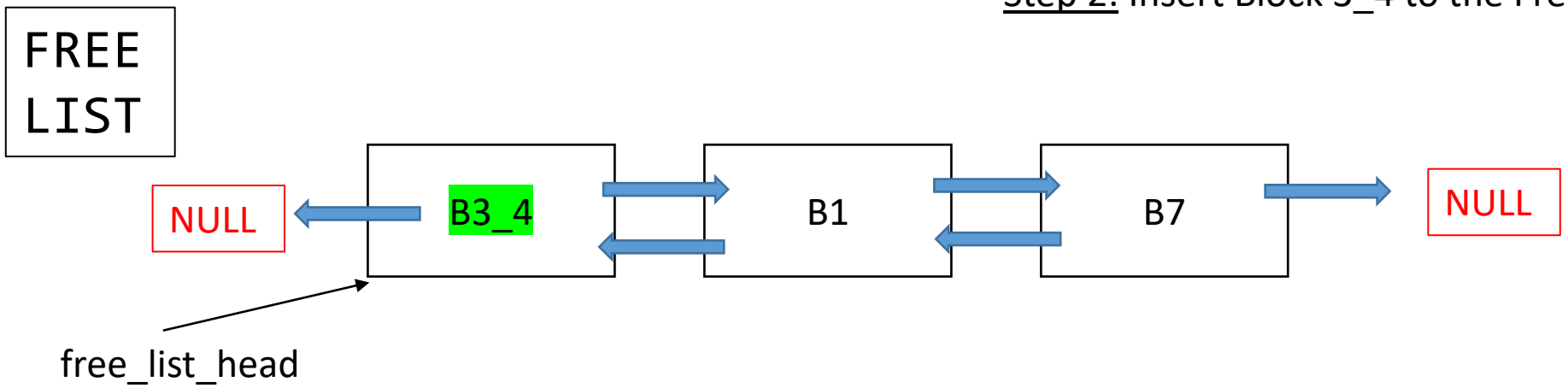


Freeing A Block (Case 3)

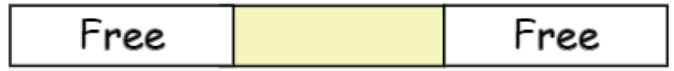
Free Block 4



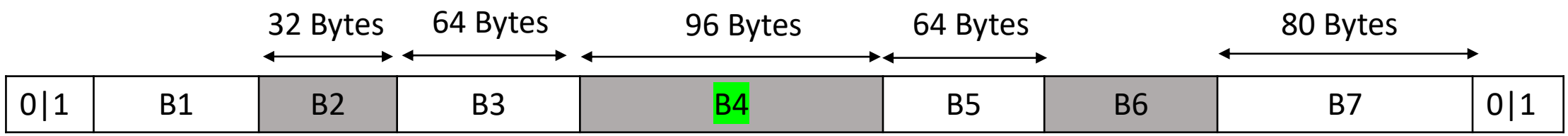
Step 2: Insert Block 3_4 to the Free List



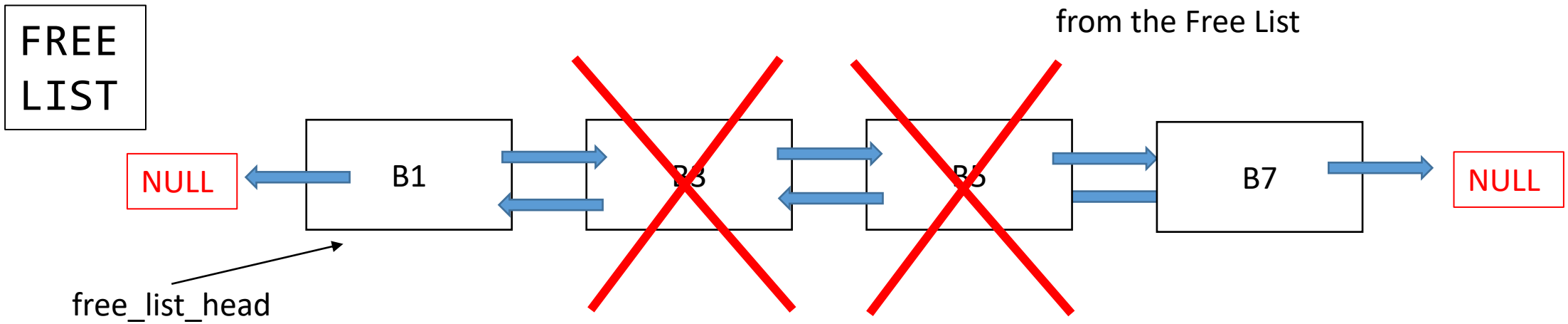
Freeing A Block (Case 4)



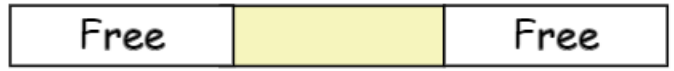
Free Block 4



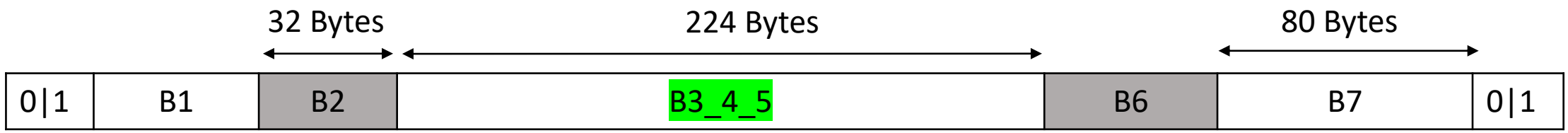
Step 1: Remove Block 3 and Block 5 from the Free List



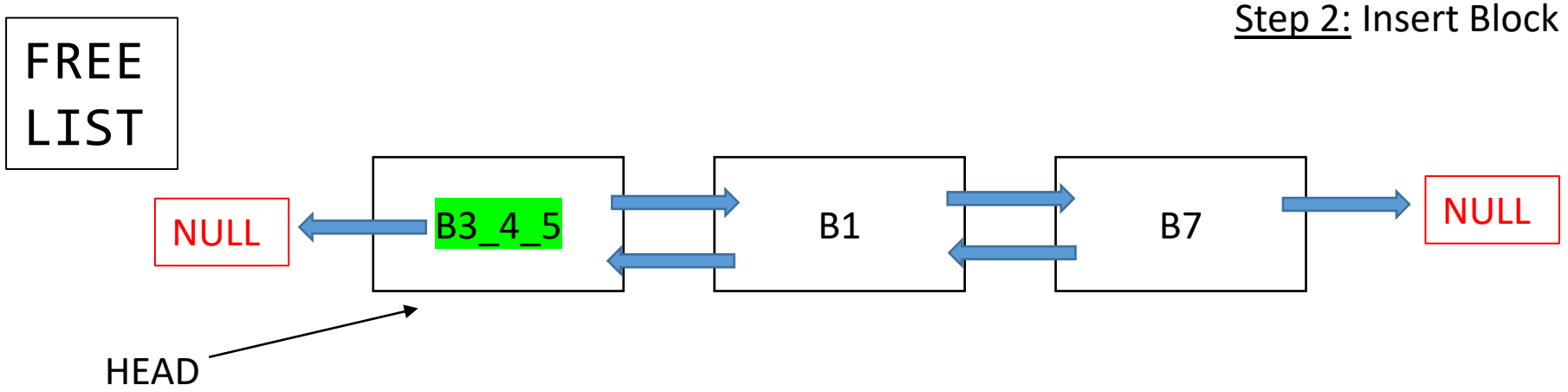
Freeing A Block (Case 4)



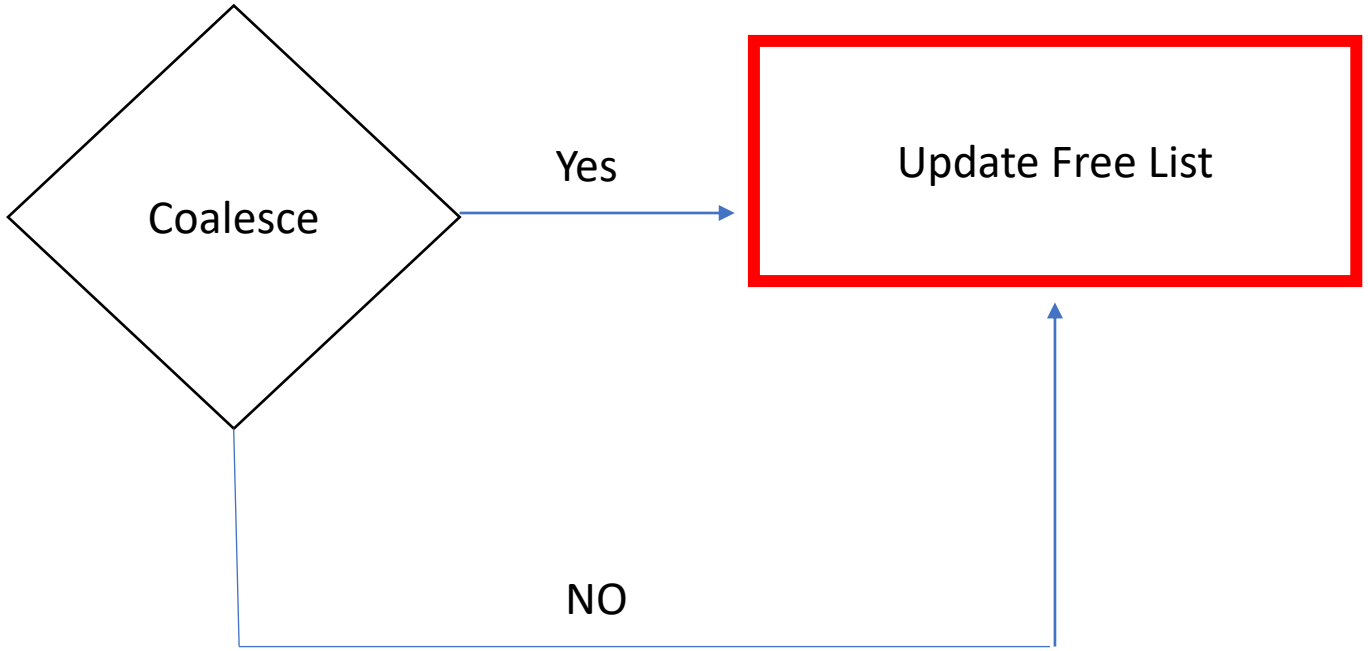
Free Block 4



Step 2: Insert Block 3_4_5 to the Free List



mm_free(void *p)



insert_block(block_t *free_block)

- Insert a Free Block to the Free List using LIFO

- Cases
  - What if the free list is empty?
  - What if the free list is Not empty?
  - Any other cases?

remove_block(block_t *free_block)

- Cases
  - What if the Free list is empty?
    - Will you ever need to check this case in this function, ideally?
  - What if the block to be removed is the head?
  - What if the block to be removed is Not the head?
    - What if it’s in the middle and what if it’s in the end of the free list?
  - Any other cases?

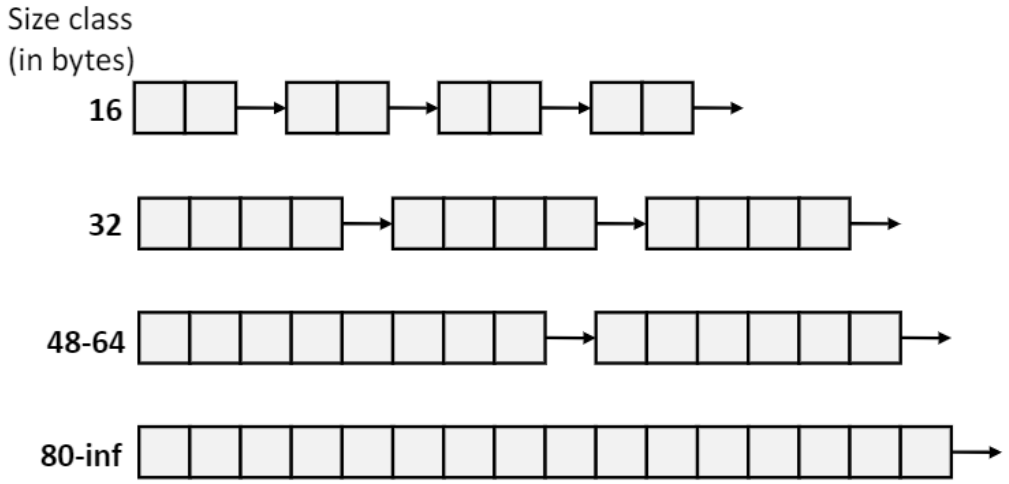
On Improving the Performance of Your Code

- Explicit Free List Implementation
- Modifying the Find_Fit algorithm
  - Traverse only the Free Blocks
  - Find a hybrid of the different Find fit algorithms, if needed.
- Turn OFF (or comment out) all calls to examine_heap() and/or check_heap()

On Improving the Performance of Your Code

Segregated List (SegList) Allocators

- Each *size class* of blocks has its own free list
- Organized as an array of free lists



- Often have separate classes for each small size
- For larger sizes: One class for each two-power size

Processes

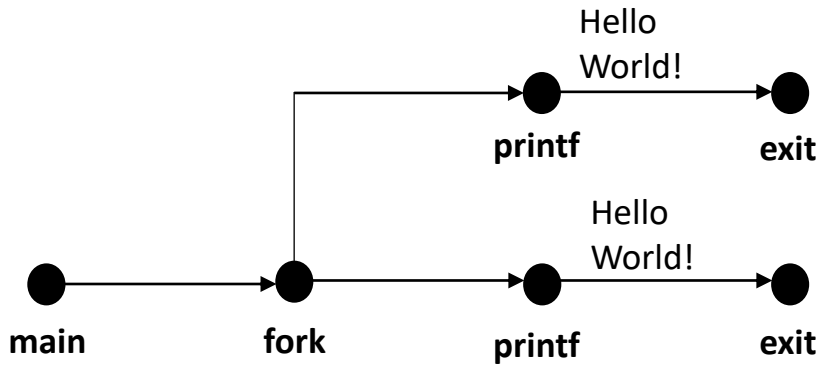
fork()

- Creates a new process by **duplicating the calling process**.

- Return value
  - On **success**, the PID of the child process is returned in the **parent**, and 0 is returned in the **child**.
  - On **failure**, -1 is returned in the **parent**, no child process is created

Example 1

```
int main()
{
  fork();

  printf("Hello world!\n");
  exit(0);
}
```



Example 1

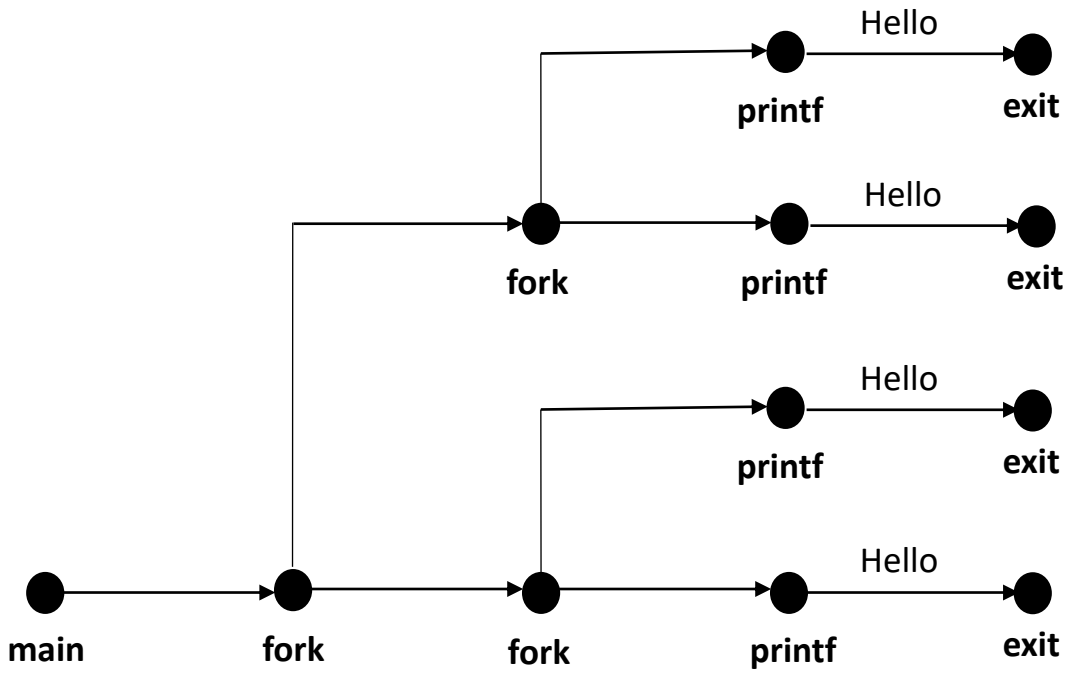
```
int main()
{
  fork();

  printf("Hello world!\n");
  exit(0);
}
```

Output

```
Hello world!
Hello world!
```

Example 2

```
int main()
{
    fork();
    fork();
    printf("Hello\n");
    exit(0);
}
```



https://csapp.cs.cmu.edu/public/waside/waside-graphs.pdf

Example 2

```
int main()
{
    fork();
    fork();
    printf(“Hello\n");
    exit(0);
}
```

Output

```
Hello
Hello
Hello
Hello
```

wait()

- A call to wait() blocks the calling process until one of its child processes exits

- Return value:
  - On success, returns the process ID of the terminated child
  - On error, -1 is returned.

Exercise

```
int main(){
        if (fork() == 0)
                printf(“a”);
        else{
                printf(“b”);
                wait(NULL);
        }
        printf(“c”);
        exit(0);
}
```

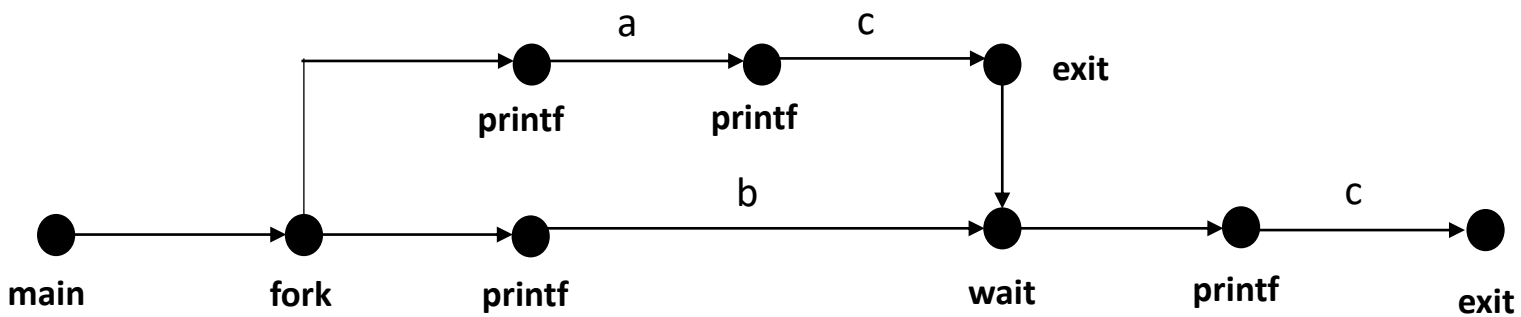
Can the following sequences be printed?

- acbc
- abcc
- bacc
- bcac
- cbca

https://csapp.cs.cmu.edu/public/waside/waside-graphs.pdf

Exercise

```
int main(){
        if (fork() == 0)
                printf(“a”);
        else{
                printf(“b”);
                wait(NULL);
        }
        printf(“c”);
        exit(0);
}
```



Exercise

```
int main(){
        if (fork() == 0)
                printf(“a”);
        else{
                printf(“b”);
                wait(NULL);
        }
        printf(“c”);
        exit(0);
}
```

Can the following sequences be printed?

- acbc - Yes
- abcc - Yes
- bacc - Yes
- bcac - No
- cbca - No

https://csapp.cs.cmu.edu/public/waside/waside-graphs.pdf

Resource on wait

- A simple example of when wait() is needed
  - https://www.youtube.com/watch?v=tcYo6hipaSA

exec()

- The exec() family of functions replaces the current process image with a **new process image**.

- The initial argument for these functions is the pathname of a file which is to be executed.

Example

ex1.c

```
int main(int argc, char *argv[])
{
      printf("PID of ex1.c = %d\n",
getpid());
      char *args = {"hello", NULL};
      execv("./ex2", args);
      printf("Next line of ex1.c");
      return 0;
}
```

ex2.c

```
int main(int argc, char *argv[])
{
      printf("Inside ex2.c\n");
      printf("PID of ex2.c: %d\n",
getpid());
      return 0;
}
```

https://www.youtube.com/watch?v=IFEFVXvjiHY

Example

Compilation

```
thoth$ gcc -o ex1 ex1.c
thoth$ gcc -o ex2 ex2.c
thoth$ ./ex1
```

Output

```
PID of ex1.c = 5551
Inside ex2.c
PID of ex2.c: 5551
```