Programming Assignment 4: malloc()Replacement

Introduction to Operating Systems
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Objectives

- To replace the original libc implementation of malloc() and free() with your own version
- To evaluate the performance of Best Fit space allocation algorithm (based on the multilevel list implementation)

malloc()

- Part of the standard C library
- Linux employs the GNU implementation, glibc

Implementation details about malloc() in glibc

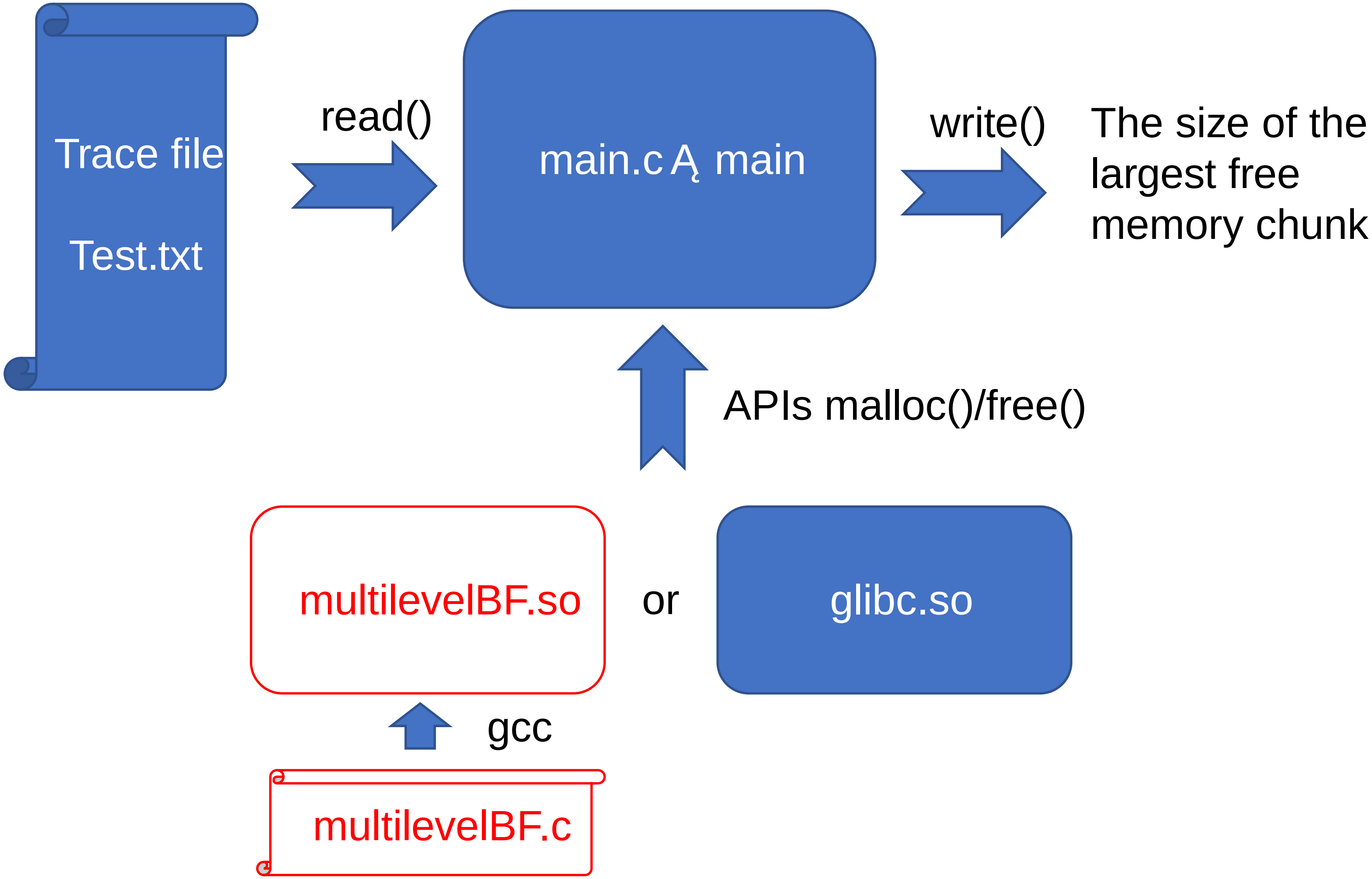
- Small requests (< M_MMAP_THRESHOLD, i.e., 128KB) are serviced using the heap. Heap is resized using brk()/sbrk() if necessary
- Large requests are serviced by asking the kernel to allocate a piece of anonymous memory using mmap()

Assignment Overview

- TA provides two files
  - test.txt: Ainput file that defines operations of memory allocation and de-allocation
  - main.c: A program that calls malloc() and free() using the operations in test.txt

- You write one file
  - multilevelBF.c: your malloc() & free() using Best Fit with multilevel free list

Assignment Overview



Trace file

Test.txt

read()

main.c Ą main

write()

The size of the largest free memory chunk

APIs malloc()/free()

multilevelBF.so

or

glibc.so

gcc

multilevelBF.c

Test Flow

1) Compile main.c into main and put test.txt in the same dir.
2) Run $ ./main
   - Should be no problem
3) Compile multilevelBF.c into multilevelBF.so

```
$ gcc -shared -fPIC multilevelBF.c -o multilevelBF.so
```

4) Run $ LD_PRELOAD=/path/to/your/multilevelBF.so ./main
   - Print a result on the screen

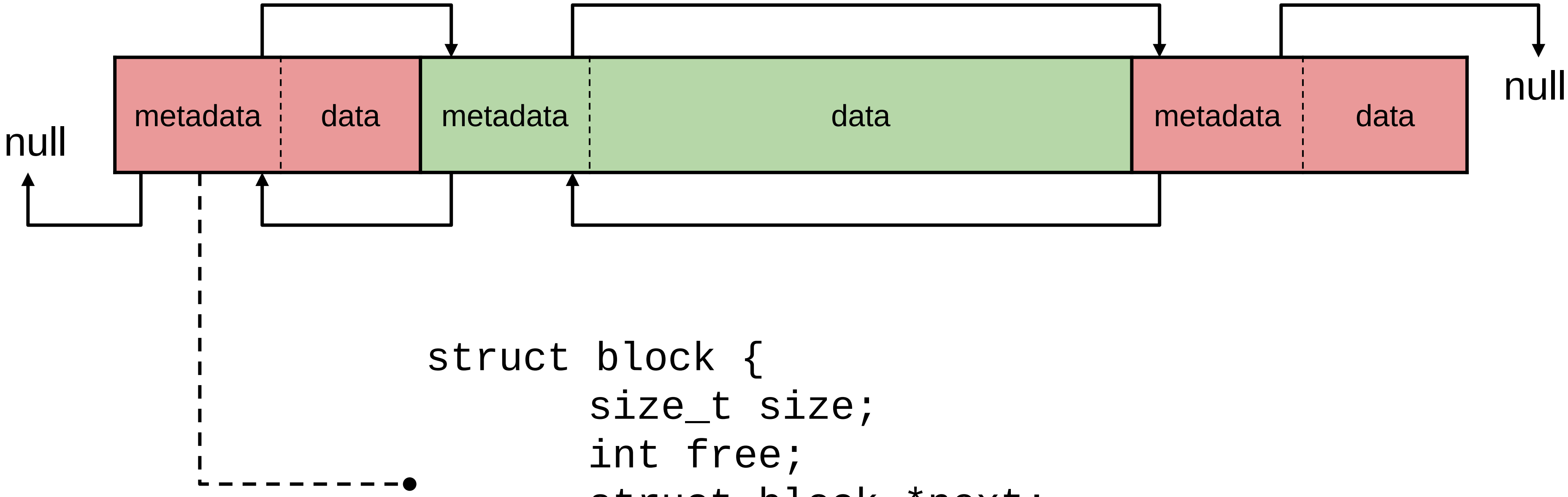
Remark: environment variable: LD_PRELOAD

- A list of additional, user-specified, ELF shared objects to be loaded before all others
- malloc() & free() in multilevelBF.so override the original ones

Your Implementation (multilevelBF.c)

- On the first malloc()
  - Pre-allocate a memory pool of 20,000 bytes from the kernel using mmap()
  - Initialize metadata for your memory pool
- On subsequent malloc() and free()
  - Process malloc() and free() within the memory pool
- On malloc(0)
  - A fake request that indicates end-of-test
  - Print the size of the largest free chunk
  - Call munmap() to release the memory pool

Metadataand Layout



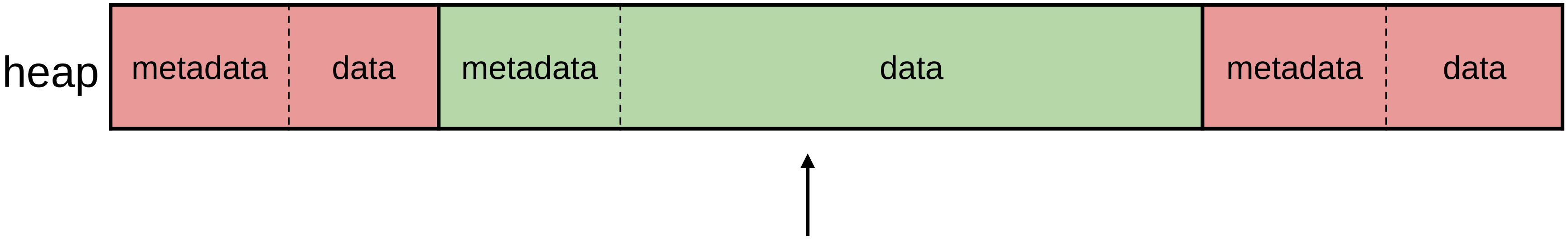
```
struct block {
        size_t size;
        int free;
        struct block *next;
        struct block *prev;
};
```

Notice that your header must exactly use 32 bytes.
Usesizeof() and padding if necessary.

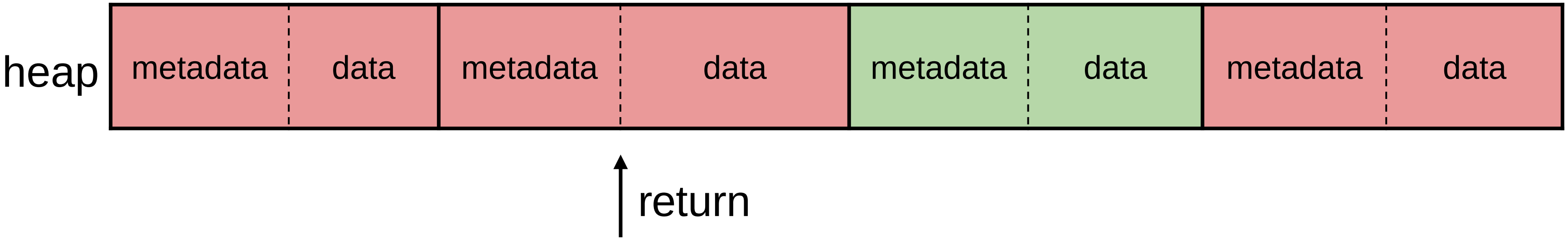
Memory Pool Management

- void *malloc(size_t size);

1. choose and split



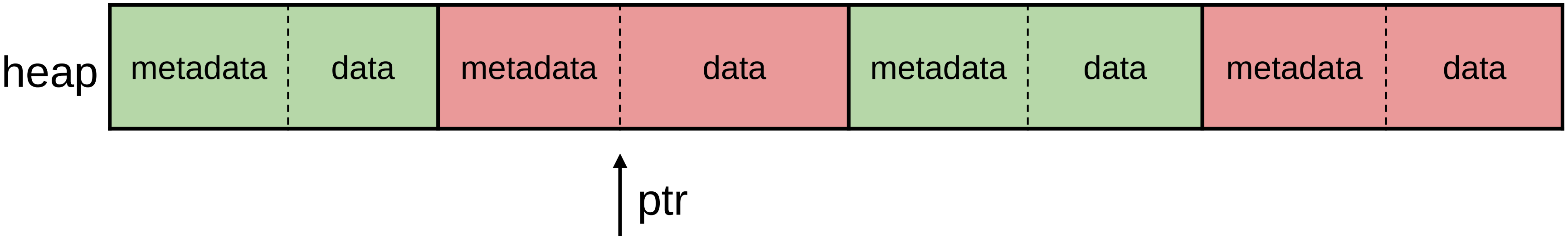
2. return the pointer



Memory Pool Management

- void free(void *ptr);

1. free thememeryblock

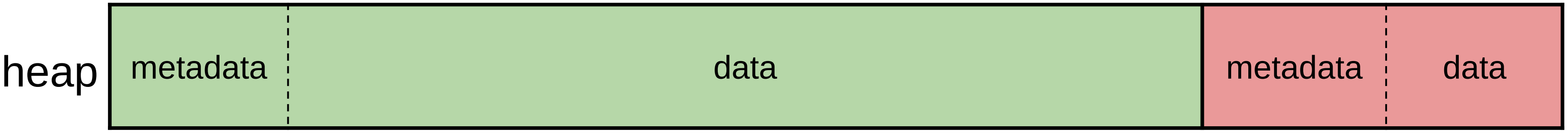


heap

metadata data metadata data metadata data metadata data

ptr

2. merge with free neighbor(s)



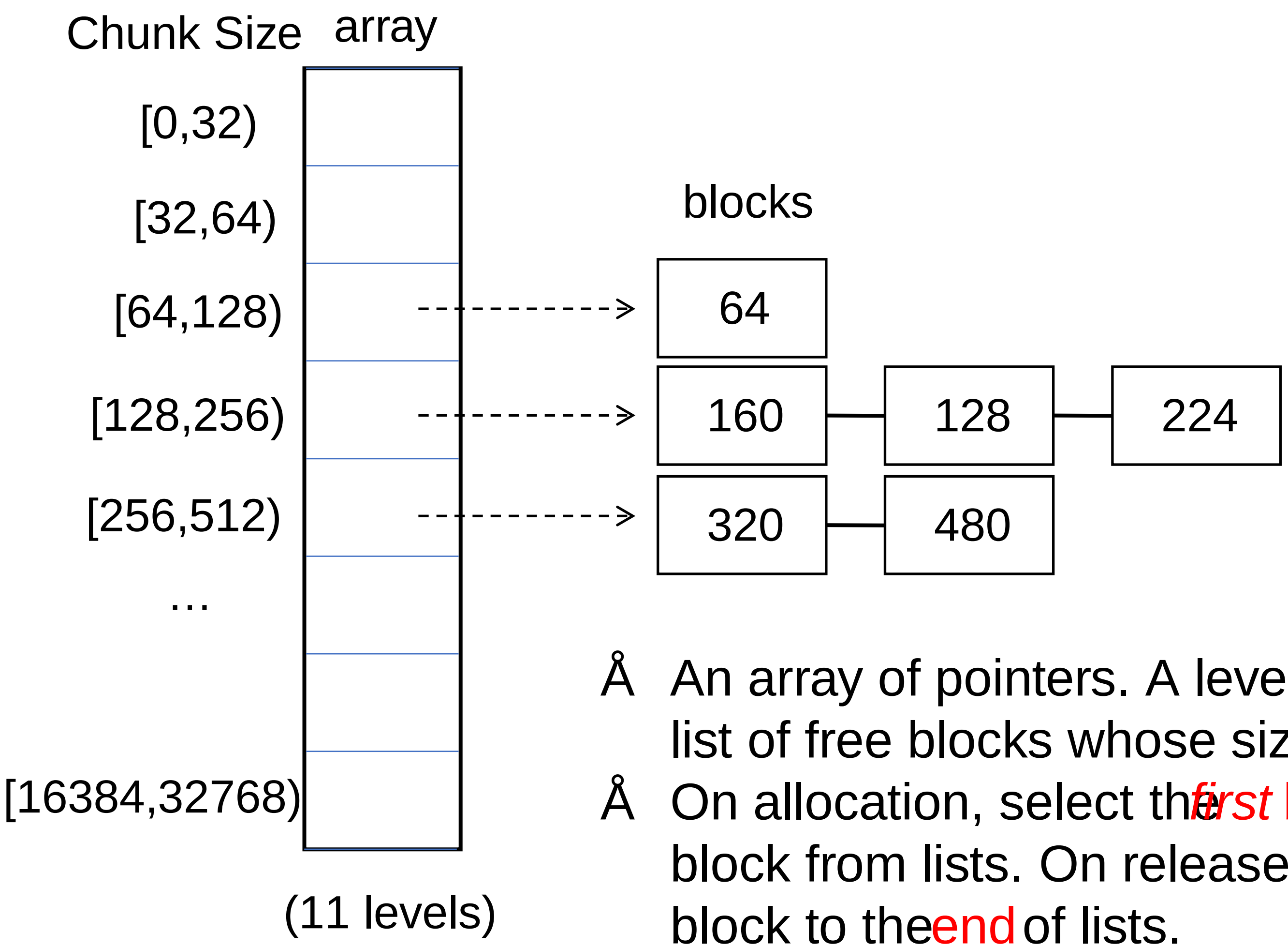
heap

metadata data metadata data

Implementation Details (!)

- Chunk list (chunk = space)
  - A list manages all memory chunks, both used and free
  - Initially has only one free memory chunk (size=20,000 bytes)
- The header of a chunk is of exactly 32 bytes
  - Including paddings (if necessary)
- Memory alignment
  - The starting address of the memory pool must be aligned to 4 KB (this is guaranteed by mmap())
  - The allocation size must be rounded to a multiple of 32
- The memory address returned by malloc() must all be aligned to 32 bytes. for example:
  - The starting memory address of the memory pool is 8192
  - The return address of the first malloc(31) is 8192 + 32
  - The return address of the second malloc() is 8192+32+32+32

Multilevel Free List



Å An array of pointers. A level has a pointer to a list of free blocks whose sizes are in [2^i, 2^{i+1})

Å On allocation, select the *first* best-fitting free block from lists. On release, append the free block to the end of lists.

Details on malloc()

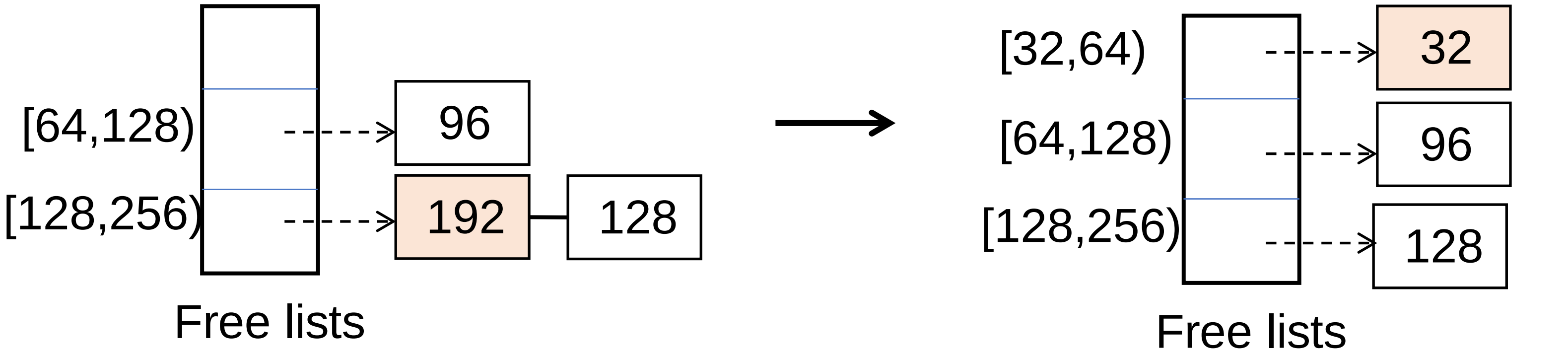
- Use the multilevel free list to find a free block
  - Find the best-fitting level (powers of 2)
  - If no free blocks, descend to the next level
  - Each level follows Best Fit (the *first* best-fitting one)
  - Get a free block and split if necessary

We assume no header overhead in this example!

Example: malloc(150) → round to 160

Memory: free / allocated

512	128	32	224	192	64	96

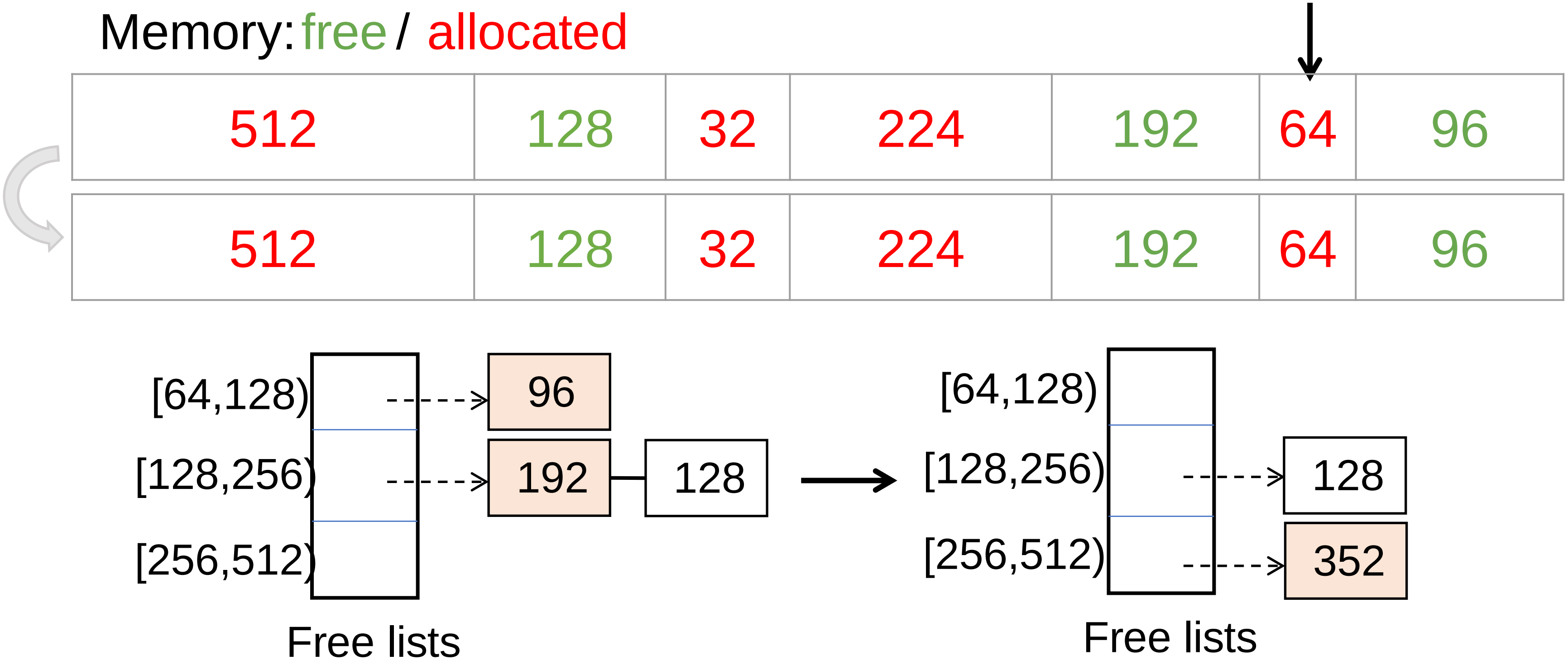


Details on free()

- Return a block to the multilevel list
  - If neighbor(s) are also free blocks, merge them
  - Delete old free blocks on merge
  - Append the new free block to the end of a list

Example: free(64)

Memory: free / allocated



Design Problem

- How do you squeeze the following into a 32B header?
  - Free flag
  - Size
  - Two list pointers (prev next) for neighbors
  - Two list pointers (prev next) for free blocks

APIs

- <sys/mman.h>
- mmap() - creates a new mapping in the virtual address space of the calling process
- munmap() - deletes the mappings

- https://man7.org/linux/man-pages/man2/mmap.2.html
- https://man7.org/linux/man-pages/man8/ld.so.8.html

mmap()

- void *mmap(void *addr, size_t length, int prot, int flags, int fd, off_t offset);
  - addr : NULL for system to choose suitable address
  - length : the length of the mapping
  - prot : PROT_READ | PROT_WRITE for read and write
  - flags: MAP_ANON since our mapping is not backed by any file, MAP_PRIVATE let updates invisible to other processes
  - fd : -1 for ignored (in conjunction with MAP_ANON)
  - offset : 0

munmap()

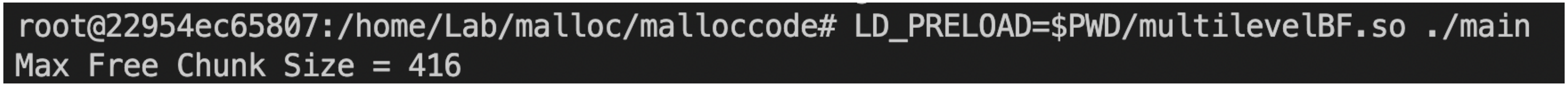
- int munmap(void *addr, size_t length);
  - addr : The starting address to be unmap(must be a multiple of the page size)
  - length : the length to be unmap

Remark: malloc() called within glibc APIs

- You may notice that main.c avoids using fopen(), scanf(), and printf() because these APIs call malloc() internally and will affect your result (or deadlock your program)
  - fopen() -> open()
  - fread() -> read()
  - fclose() -> close()
- To print out a string
  - Use a local variable string array
  - Use sprinf() to format your string
  - Use wrtie(stdout, **) to output your string

Input and Output

- Input filename: test.txt
- Input line format: [A or D] [id] [size]\n
    - A: Allocate, D: Deallocate
    - id: an integer identifier
    - size: bytes
- Output: size of the largest free space
    - Format: Max Free Chunk Size = $size in bytes$\n
    - Exclude the header
- We will provide you main.c and test.txt
- Your implementation must reproduce exactly the same results shown below



```
root@22954ec65807:/home/Lab/malloc/malloccode# LD_PRELOAD=$PWD/multilevelBF.so ./main
Max Free Chunk Size = 416
```

Grading Policy

- Produce correct answers for
  - The test.txt that TA give to you
  - Some other input files prepared by TA

- Submit your multilevelBF.c to E3
  - Filename : hw4_<student_ID>.c
  - Example: hw4_111550999.c

- Notice: It is recommended to write some testcases yourself to ensure there are no other issues (should be take care about how to free and merge) since the provided testcase is the simplest.

Testing OS Environment

- Ubuntu 22.04
- Install as a VM or on a physical machine

Header of your .c or .cpp

```
/*
Student No.:31415926
Student Name:John Doe
Email:xxx@yyy.zzz
SE tag:xnxcxtxuxoxsx
Statement: I am fully aware that this program is not
supposed to be posted to a public server, such as a
public GitHub repository or a public web page.
*/
```

Credits

- Ḛ ῞Ω ȳ Ể đ ԓ ȳ ضمٔ help design this project
- Direct all questions to the current TAs