Programming Assignment 4: malloc() Replacement

Introduction to Operating Systems
Prof. Li-Pin Chang @ NYCU

Objectives

- To replace the original libc implementation of malloc() and free() with your own version
- To evaluate the performance of two representative space allocation algorithms, namely, Best Fit and First Fit

malloc()

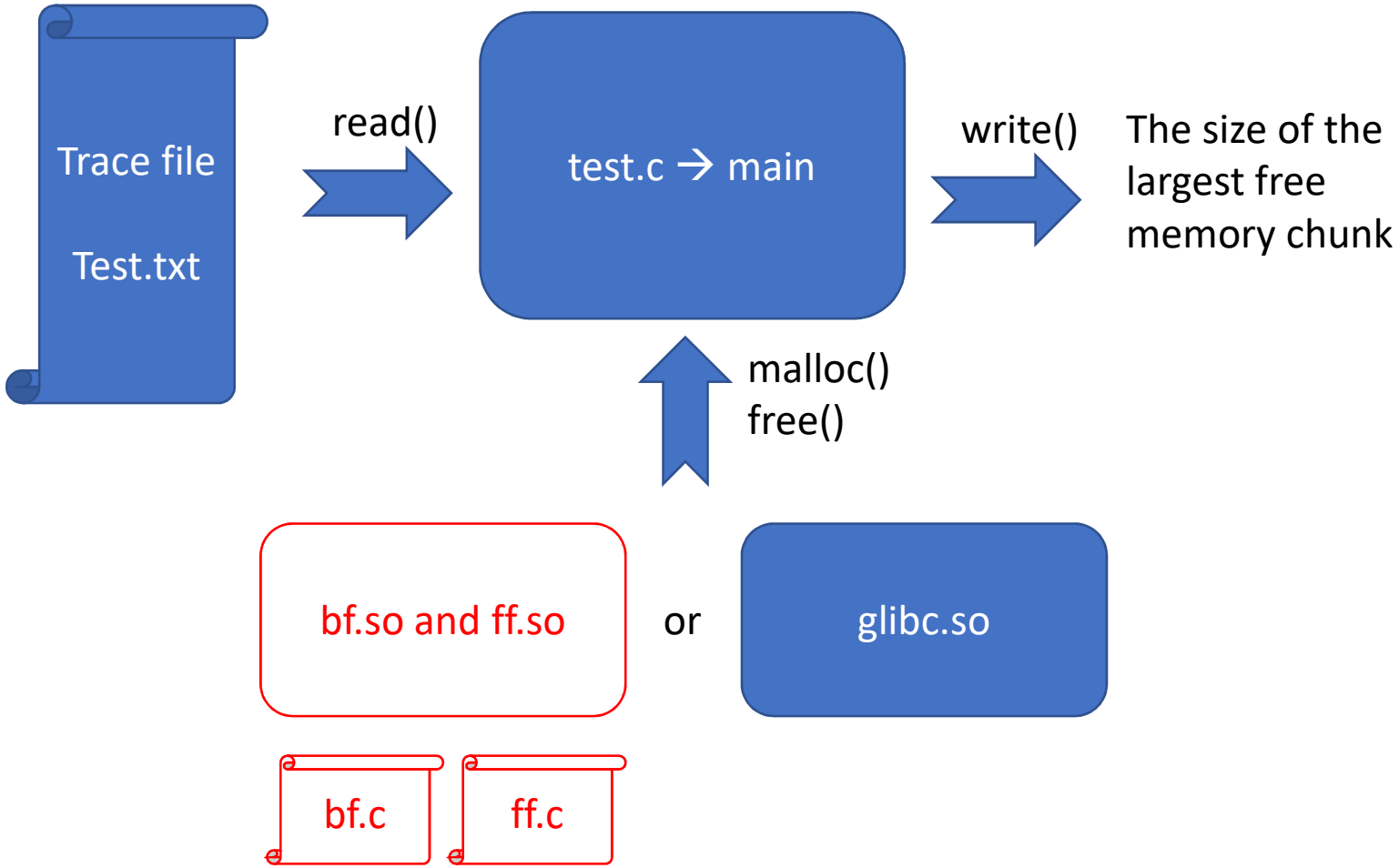
- Part of the standard C library
- Linux adopts the GNU implementation, glibc

- Implementation details about malloc() in glibc
- Small requests (< M_MMAP_THRESHOLD, i.e., 128KB) are serviced using the heap, which will be enlarged if necessary through brk()/sbrk()
- 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: A input file that defines operations of memory allocation and de-allocation
  - test.c: A program tha calls malloc() and free() using the operations in test.txt
- You write two files
  - bf.c: your malloc() and free() using BEST FIT
  - ff.c: your malloc() and free() using FIRST FIT

Assignment Overview



Test Flow

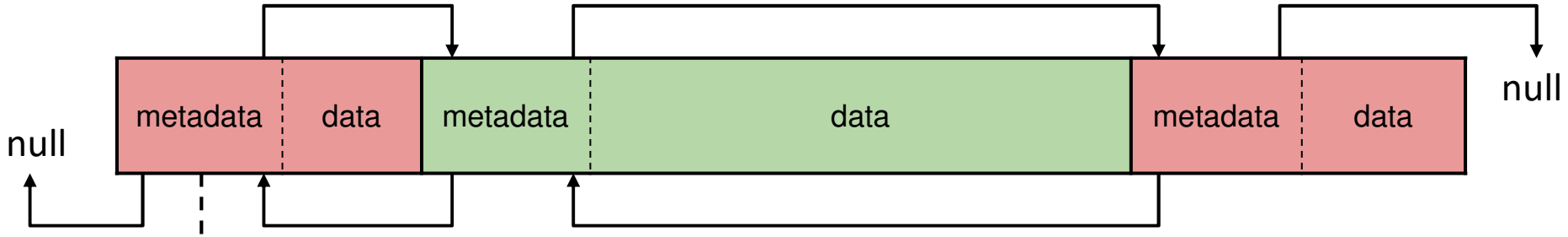
1) Compile test.c into main and put test.txt in the same dir.
2) Run $./main
    - Should be no problem
3) Compile bf.c and ff.c into bf.so and ff.so, respectively
4) Run $LD_PRELOAD=/path/to/your/bf.so ./main
    - Print a result on the screen
5) Run $LD_PRELOAD=/path/to/your/ff.so ./main
    - Print 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() and free() in bf.so and ff.so override the original ones

Your Implementation (bf.c and ff.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

Metadata and Layout



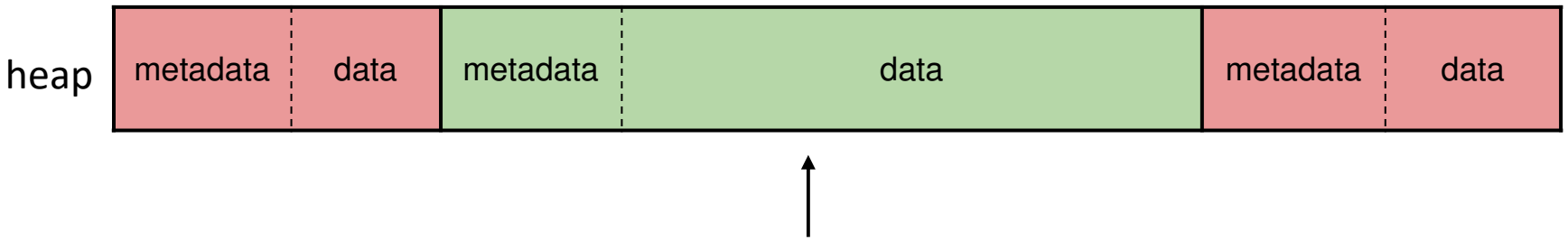

```
struct block {
        size_t size;
        int free;
        struct block *prev;
        struct block *next;
};
```

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

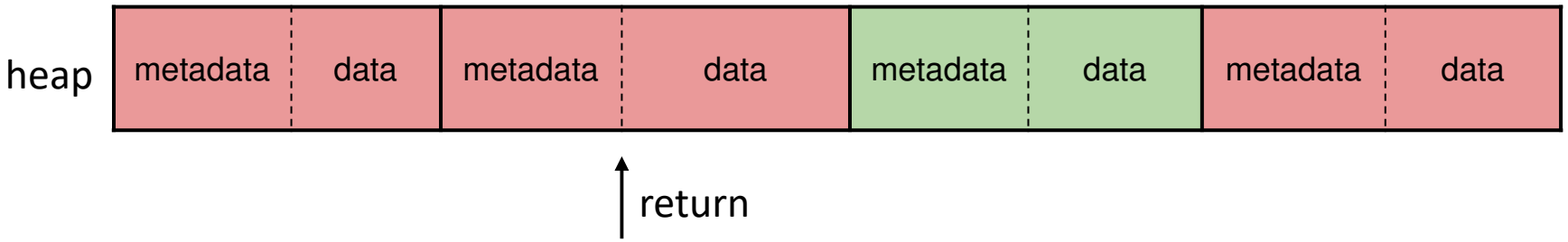
Memory Pool Management

- void *malloc(size_t size);

1. choose and split



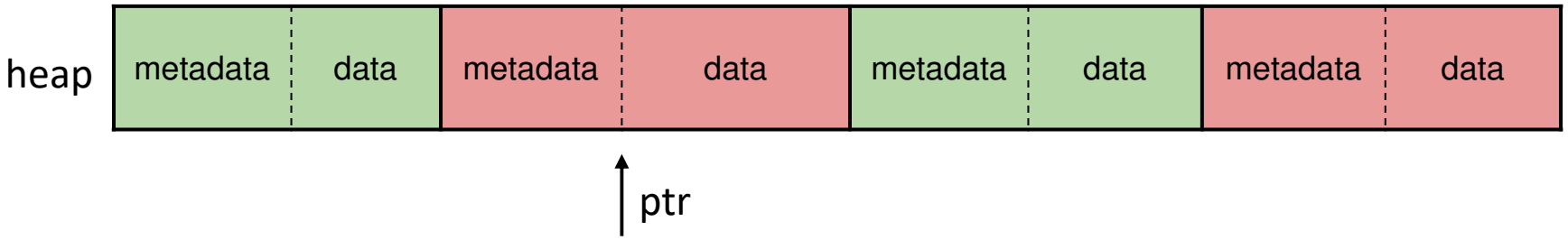
2. return the pointer



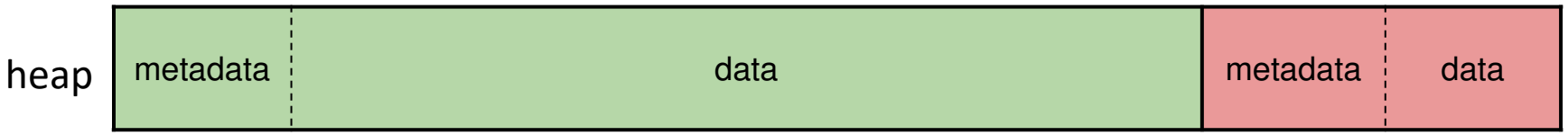
Memory Pool Management

- void free(void *ptr);

1. free the memery block



2. merge with free neighbor(s)



Implementation Details (!)

- Chunk list (chunk = space)
  - A list manages all memory chunks, both used and free
  - Initially has only one free memory chunk
- The header of a chunk is of exactly 32 bytes
  - Including paddings
- 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

Allocation Policies

- Write 2 different malloc libraries using these 2 policies:
- First Fit
- Best Fit
  - Use the first (leftmost) one if there are multiple choices

Example: calling malloc() for 100 bytes
Memory: free / allocated

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 test.c avoids using fopen(), scanf(), and printf() because these APIs call malloc() internally and will affect your result
  - fopen() -> open()
  - fread() -> read()
  - fclose() -> close()

- In your bf.c and ff.c
  - printf() -> write()

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
  - Excluding the header
- We will provide you test.c and test.txt
- Your implementation must reproduce exactly the same results shown below

```
izskon@izskon-VirtualBox:~/Code/Malloc$ LD_PRELOAD=./bf.so ./main
Max Free Chunk Size = 416
izskon@izskon-VirtualBox:~/Code/Malloc$ LD_PRELOAD=./ff.so ./main
Max Free Chunk Size = 960
```

Grading Policy

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

- Submit bf.c and ff.c to E3

Testing OS Environment

- Ubuntu 18.04
- 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.
*/
```