Operating System Labs

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Announcement

- Project 1 due
  - 21:00, Oct. 9

- xv6 warm-up
  - target
    - install qemu
    - run xv6 in qemu
  - https://github.com/ecnu-oslab/ecnu-oslab-up/blob/main/22-Fall/index.md#xv6-lab-environments

Operating System Labs

- Introduction of I/O operations

Operating System Labs

- Manipulate I/O
  - System call
    - File descriptor
    - No buffering
  - Standard library
    - FILE object
    - Buffering

Operating System Labs

- Manipulate I/O
  - System call
    - **File descriptor**
  - Standard library
    - FILE object
    - Buffer/non-buffer

I/O System Calls

- 5 basic system calls
  - open(), read(), write(), lseek(), close()
- I/O without buffering
- File sharing
  - understand file descriptor
  - dup() dup2()
- Other
  - fcntl(), sync(), fsync(), ioctl()

File Descriptor

- File descriptor
  - Allocated when a process open a file
  - “ID” of the file in the process (unsigned int)
- Default
  - 0 (STDIN_FILENO): standard input
  - 1 (STDOUT_FILENO): standard output
  - 2 (STDERR_FILENO): standard error

I/O System Calls

- Open files:

```
# include <fcntl.h>

int open(const char *pathname, int o_flag, …  );
// man 2 open
```

- Return value
  - Success: file descriptor
  - Failed: -1
- o_flag:
  - O_RDONLY, O_WRONLY, O_RWWR
  - Options:
    - O_APPEND, O_CREAT, O_TRUNC, ...

I/O System Calls

- Open files
  - File descriptors: the smallest one available
  - Examples

```
int main (int argc, char **argv)
{
        int fd = open("foo", O_RDONLY);
        printf("%d", fd);
}
```

```
int main (int argc, char **argv)
{
        close(0);
        int fd = open("foo", O_RDONLY);
        printf("%d", fd);
}
```

I/O System Calls

- Open files
  - STDIN_FILENO, STDOUT_FILENO, STDERR_FILENO
  - opened by the OS when creating a process

I/O System Calls

- Close files

```
# include <unistd.h>

int close(int filedes);
```

- Return
  - Success: 0
  - Failed: -1

I/O System Calls

- File Position

```
# include <unistd.h>

off_t lseek(int filedes, off_t offset, int whence);
```

- An offset (in byte) to the “whence” of the file
- whence:
  - SEEK_SET, SEEK_CUR, SEEK_END

- concept: “current file offset”

I/O System Calls

- Read files

```
# include <unistd.h>

int read(int filedes, void *buf, size_t nbytes);
```

- Start reading at “file offset”
- Return:
  - Success: number of bytes read (0, if EOF)
  - Failed: -1
- Return < size
  - EOF
  - Read from terminal (stdin), one line
  - ...

I/O System Calls

- Write files

```
# include <unistd.h>

int write(int filedes, const void *buf, size_t nbytes);
```

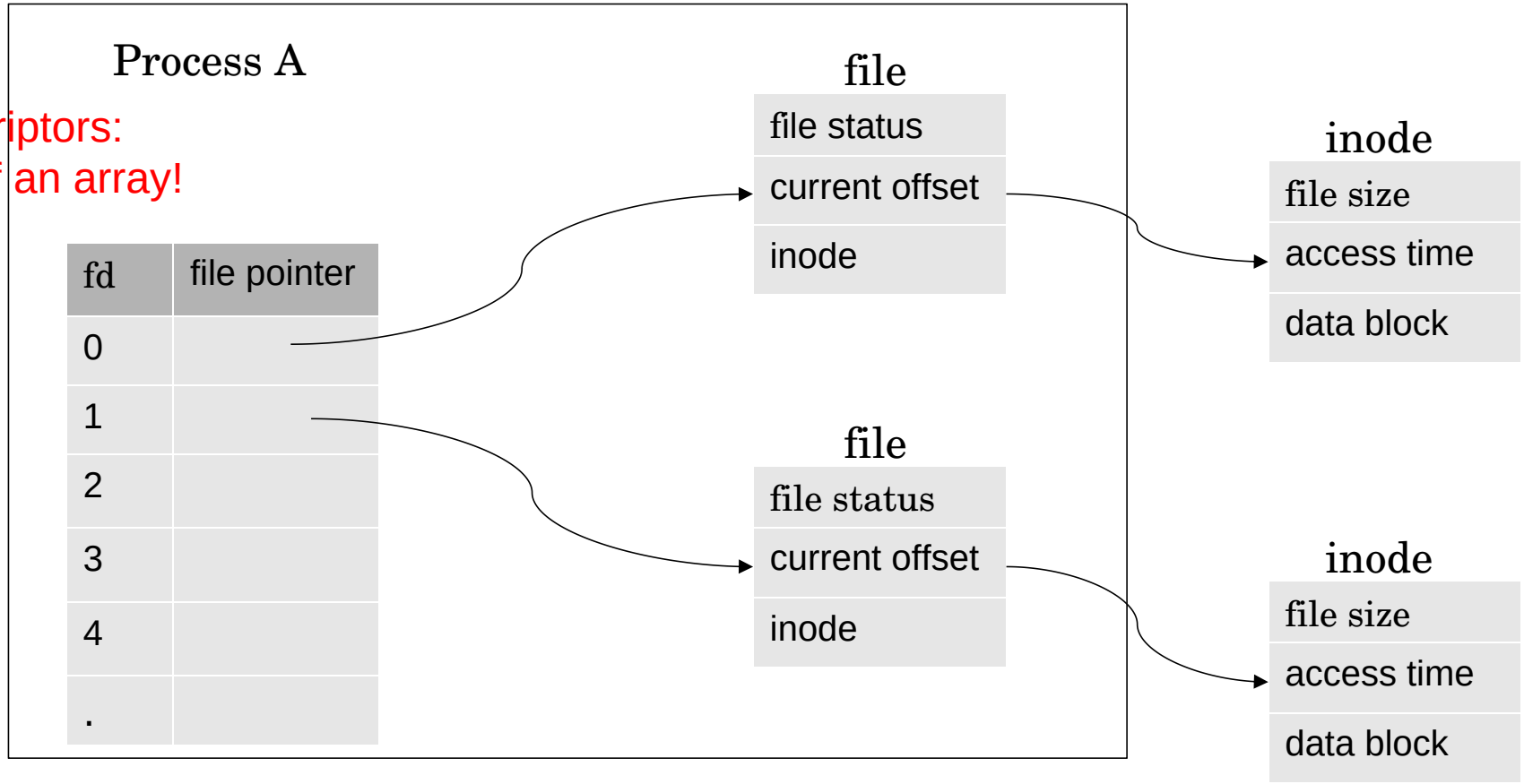
- Return:
  - Success: number of bytes write
  - Failed: -1

An Example: I/O and Buffers

- I/O without buffer
  - No (user space) buffer
    - read(), write(): system calls
    - Do have buffer in kernel space (by file system)
  - Let's do some coding
  - Buffering do matter!
    - printf, scanf in standard I/O library are buffered

Revisit File Descriptors

File descriptors:
indices of an array!



1. Each process has its own array of “struct file*”
2. Each file associates with only one “struct inode”
3. The “inode number” is a low-level id of a file

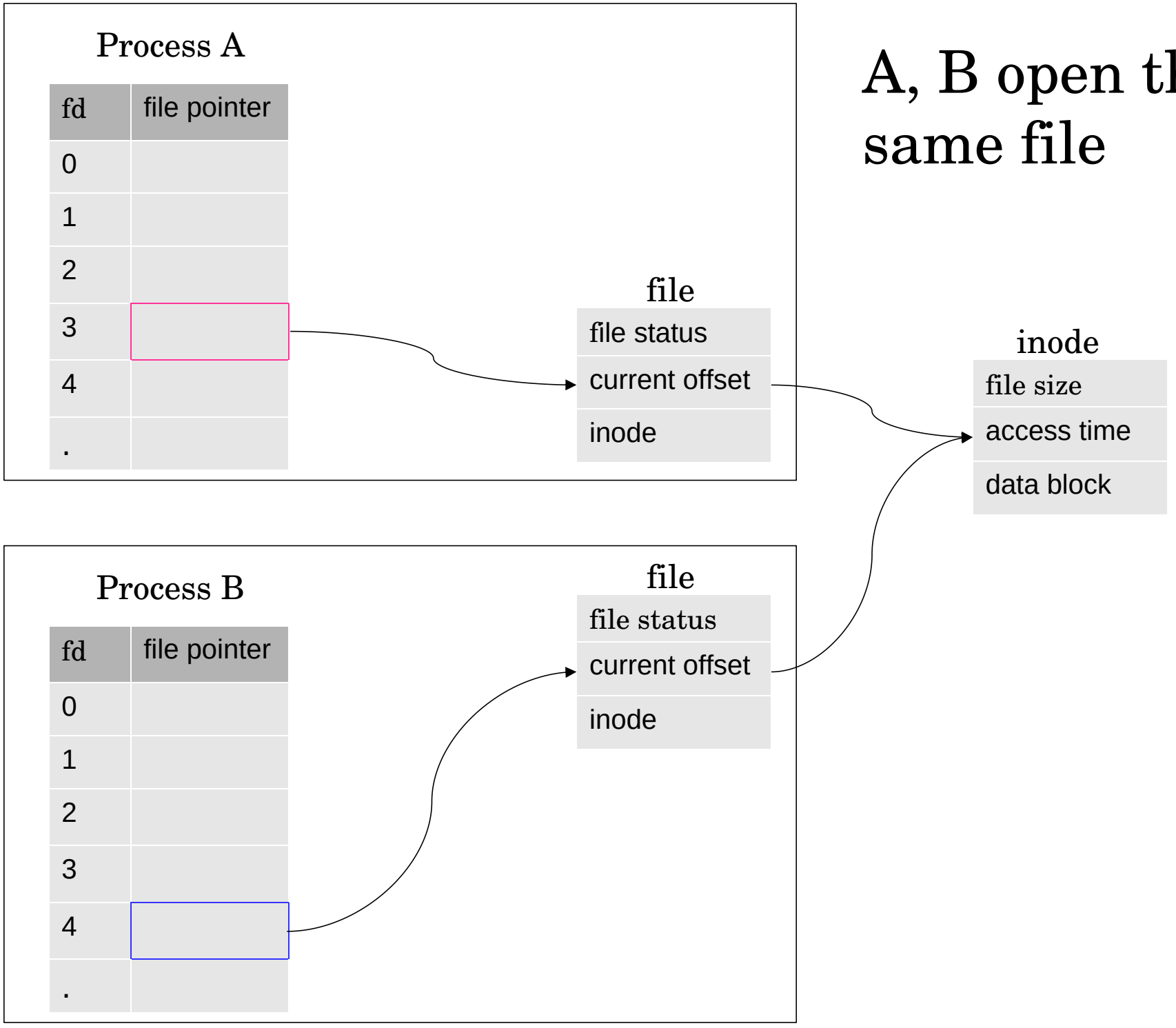
```
struct files_struct {
  int count;
  fd_set close_on_exec;
  fd_set open_fds;
  struct file * fd[NR_OPEN];
};
struct file {
  mode_t f_mode;
  loff_t f_pos;
  unsigned short f_flags;
  unsigned short f_count;
  unsigned long f_reada, f_ramax, f_raend, f_ralen, f_rawin;
  struct file *f_next, *f_prev;
  int f_owner;
  struct inode * f_inode;
  struct file_operations * f_op;
  unsigned long f_version;
  void *private_data;
};
struct ext2_inode {
        __u16   i_mode;         /* File type and access rights */
        __u16   i_uid;          /* Low 16 bits of Owner Uid */
        __u32   i_size;         /* Size in bytes */
        __u32   i_atime;        /* Access time */
        __u32   i_ctime;        /* Creation time */
        __u32   i_mtime;        /* Modification time */
        __u32   i_dtime;        /* Deletion Time */
        __u16   i_gid;          /* Low 16 bits of Group Id */
        __u16   i_links_count;  /* Links count */
        __u32   i_blocks;       /* Blocks count */
        __u32   i_flags;        /* File flags */
                ...
        __u32   i_block[EXT2_N_BLOCKS];  /* Pointers to blocks */
                ...
};
```

Quiz

- What happen when we open a file with a text editor?

- What happen when we open a file with two different text editors?

A, B open the same file



File Sharing

- Simple? … emmm …
- Example: how to implement
  - open(“file”, O_WRONLY | O_APPEND)
- Two process (A and B) run the same code, what will happen?

```
if (lseek(fd, 0, SEEK_END) < 0)
        perror(“lseek”);

if (write(fd, buf, 100) < 100)
    perro(“write”);
```

Atomic operations

File Sharing

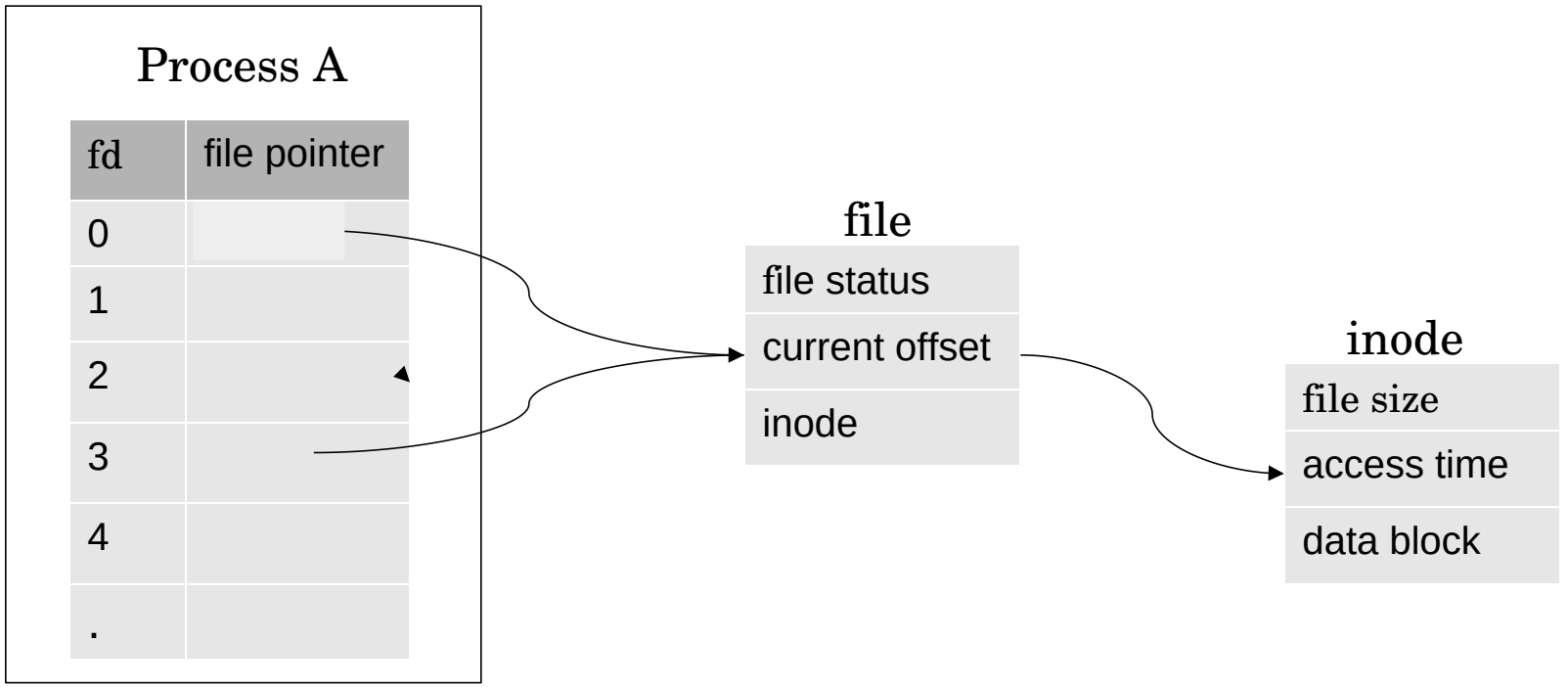
- Duplicate a file descriptor

```
# include <unistd.h>

int dup2(int fd, int fd2);
```

- set “fd2” point to the same file of “fd”
- Return
  - Success: fd
  - Failed: -1

// if fd 0 is open, close it first
dup2(3, 0);



1. a file with multiple file descriptors
2. I/O redirection

I/O System Calls

- Other system calls
  - sync() / fsync():
    - “delay write”
    - Flush kernel buffer
  - fcntl(): change file (opened) attributes
  - ioctl(): other methods

I/O System Calls

- Summary
  - File descriptor
  - open, close, read, write, lseek, dup
  - File sharing

Operating System Labs

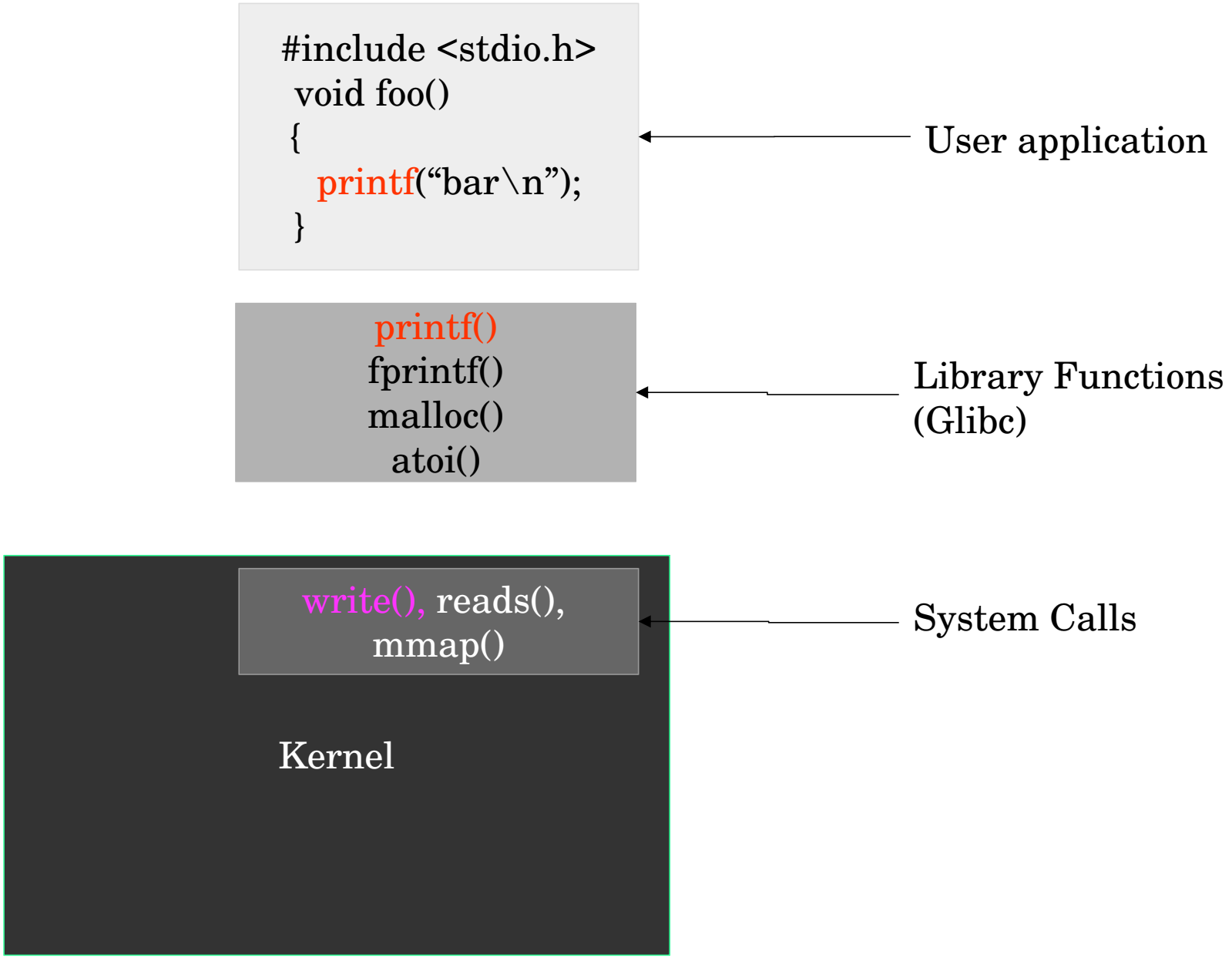
- Manipulate I/O
  - System call
    - File descriptor
    - No buffering
  - Standard library
    - FILE object
    - Buffering

Standard I/O Library

- #include <stdio.h>
  - FILE object (structure)
  - Buffering
  - Formatted I/O

System Calls vs Library Functions

- Recall:



Standard I/O Library

```
# include <fcntl.h>

int main (int argc, char **argv)
{
    int fd = open("foo", O_RDONLY);
}
```

```
# include <stdio.h>

int main (int argc, char **argv)
{
    FILE* fp = fopen("foo", "r");
}
```

- Stream and FILE object
  - A wrapper of file descriptor
  - More information:
    - buffer
    - error info
    - single-byte or multi-byte

FILE Object

- Opaque pointer
  - The implementation is hidden
  - Access the struct member through functions
- Operations on FILE objects
  - Get file descriptor: fileno(FILE* f)
  - Set buffer: setbuf(FILE* f, char* buf)

Standard I/O Library

- Buffering
  - stdio provide a “standard I/O buffer” (user space)
- Three types of buffering
  - Full buffered
    - Performs I/O when the buffer is full
  - Line buffered
    - Performs I/O when encounter a newline
  - Unbuffered
    - Performs I/O immediately, no buffer

Standard I/O Library

- Three types of buffering
  - Standard error is unbuffered
  - A stream is line buffered if it refers to terminal device, otherwise full buffered

- Write “standard I/O buffer” to disc:

```
# include <stdio.h>

int fflush(FILE *fp);
```

Standard I/O Library

- Open/Close streams

```
# include <stdio.h>

FILE *fopen(const char* path, const char * type);
FILE *fdopen(int fd, const char * type);

int fclose(FILE* fp);
```

- Type: “r”, “w”, “a”, “r+”.. .
- Return
  - Failed: NULL

Standard I/O Library

- Character-at-a-time I/O

```
# include <stdio.h>

int getc(FILE *fp);
int fgetc(FILE *fp);

int putc(FILE *fp);
int fputc(FILE *fp);
```

Standard I/O Library

- Line-at-a-time I/O

```
# include <stdio.h>

char* fgets(char *buf, int n, FILE *fp);
char* gets(char *buf);       // should never be used

int fputs(char *str, FILE *fp);
int puts(char *str);
```

Standard I/O Library

- Direct I/O

```
# include <stdio.h>

size_t fread(void *ptr, size_t size, size_t, nobj, FILE *fp);
size_t fwrite(void *ptr, size_t size, size_t, nobj, FILE *fp);
```

Standard I/O Library

- Standard I/O efficiency
  - Recall: buffering in system calls
  - Let's do some coding

Standard I/O Library

- Formatted I/O
  - printf, fprintf, scanf

Standard I/O Library

- Summary
- #include <stdio.h>
  - FILE object (structure)
  - Buffering
  - Formatted I/O

Introduction of I/O Operations

- Summary
  - System call
    - File descriptor
    - No buffering
  - Standard library
    - FILE object
    - Buffering

Project 0b

- a simple key-value store
- with the standard I/O library

- Project 0 due
  - 21:00, Sep. 19