Operating System Labs

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Announcement

- Project 1 due
  - 21:00, Oct. 8

Operating System Labs

- Introduction of I/O operations
- Project 1
  - Sorting

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 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);
```

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

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);
```

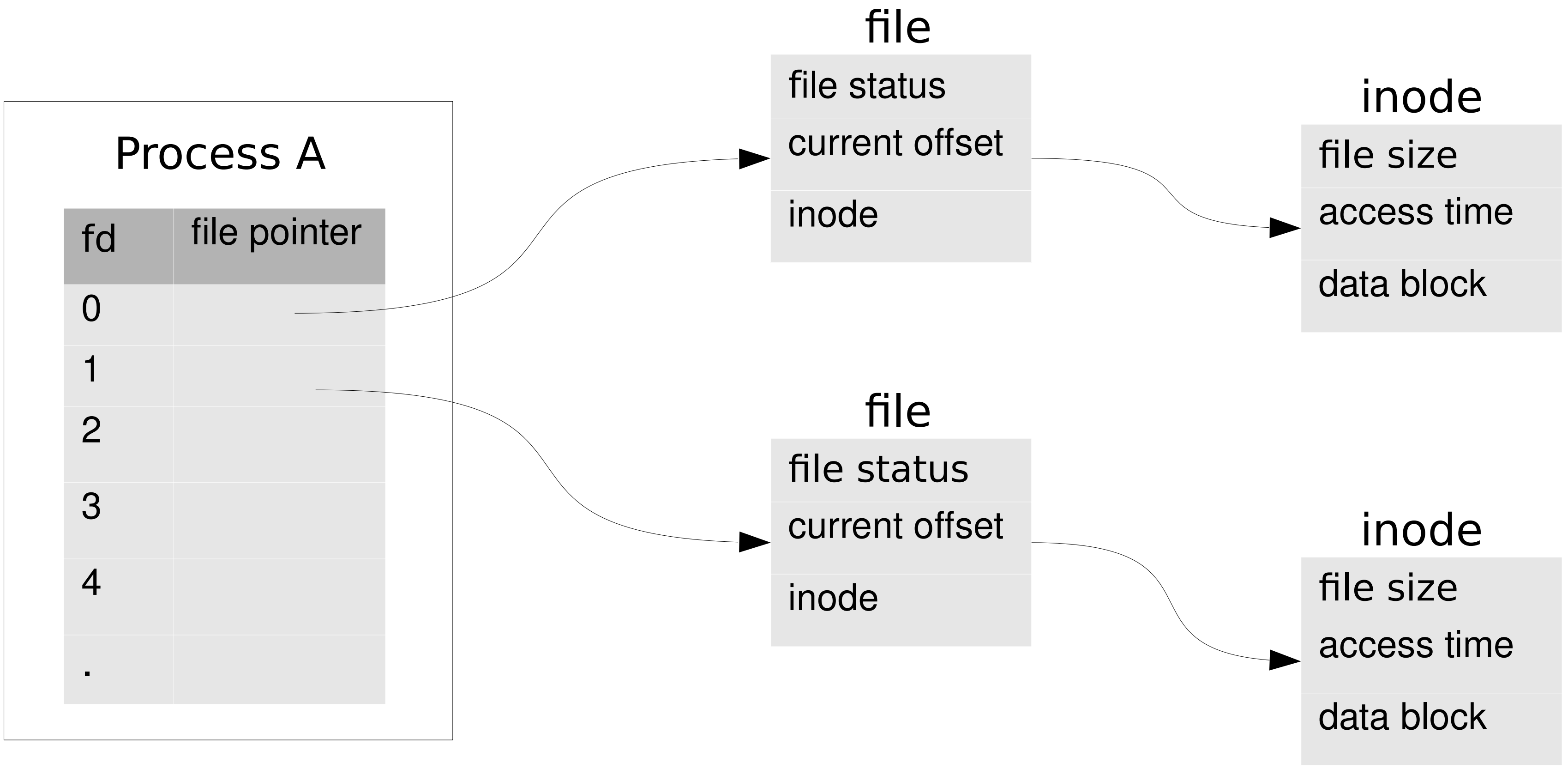
Return:

- 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



Process A

fd	file pointer
0	
1	
2	
3	
4	
.	

file

file status

current offset

inode

inode

file size

access time

data block

file

file status

current offset

inode

inode

file size

access time

data block

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

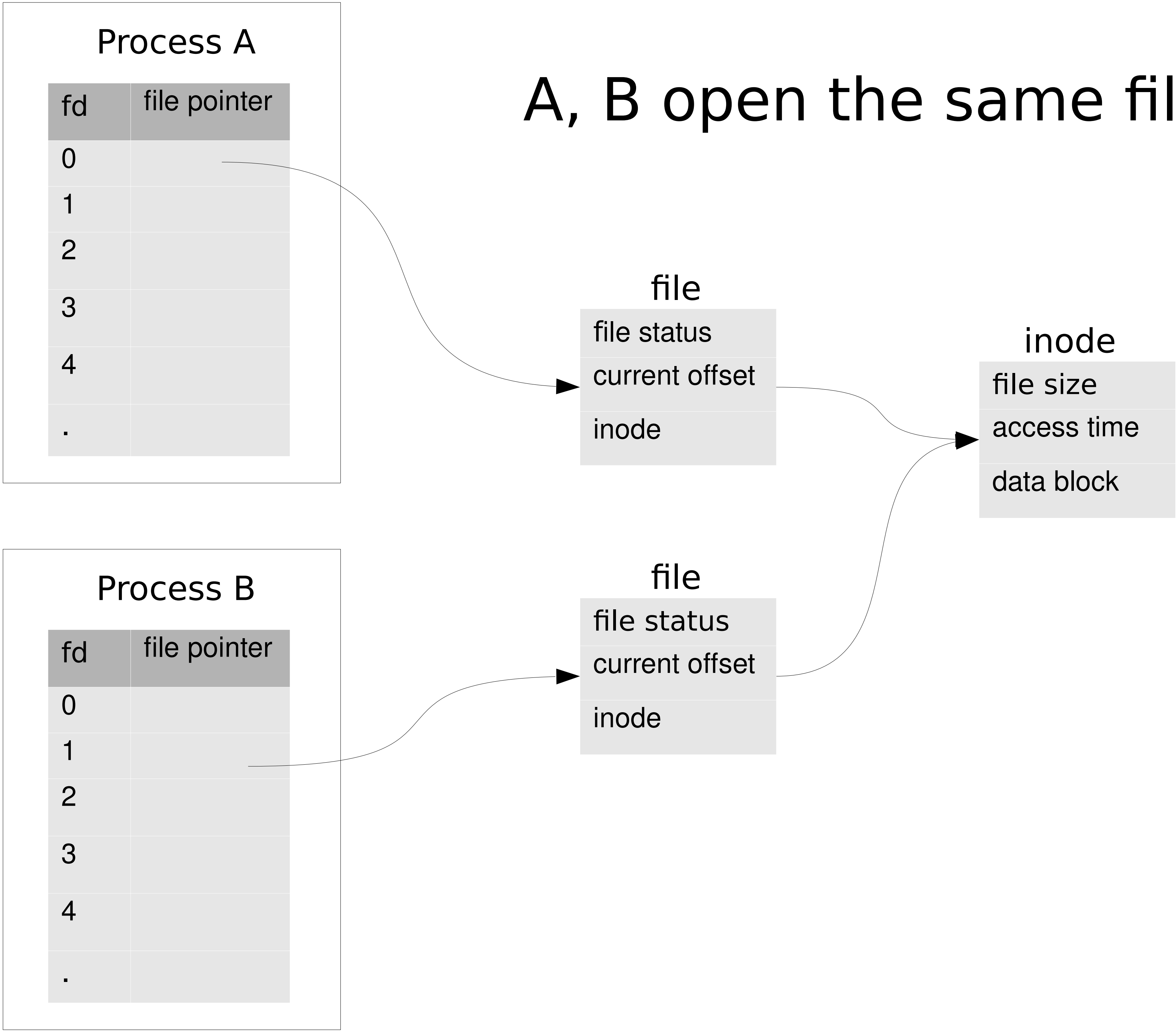
```
struct files_struct {
  int count;
  fd_set close_on_exec;
  fd_set open_fds;
  struct file * fd[NR_OPEN];
};

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



Process A

fd	file pointer
0	
1	
2	
3	
4	
.	

Process B

fd	file pointer
0	
1	
2	
3	
4	
.	

file

- file status
- current offset
- inode

file

- file status
- current offset
- inode

inode

- file size
- access time
- data block

File Sharing

- Simple? … emmm …
- Example: how to implement

  open(“file”, O_WRONLY | O_APPEND)

- Two process A, 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

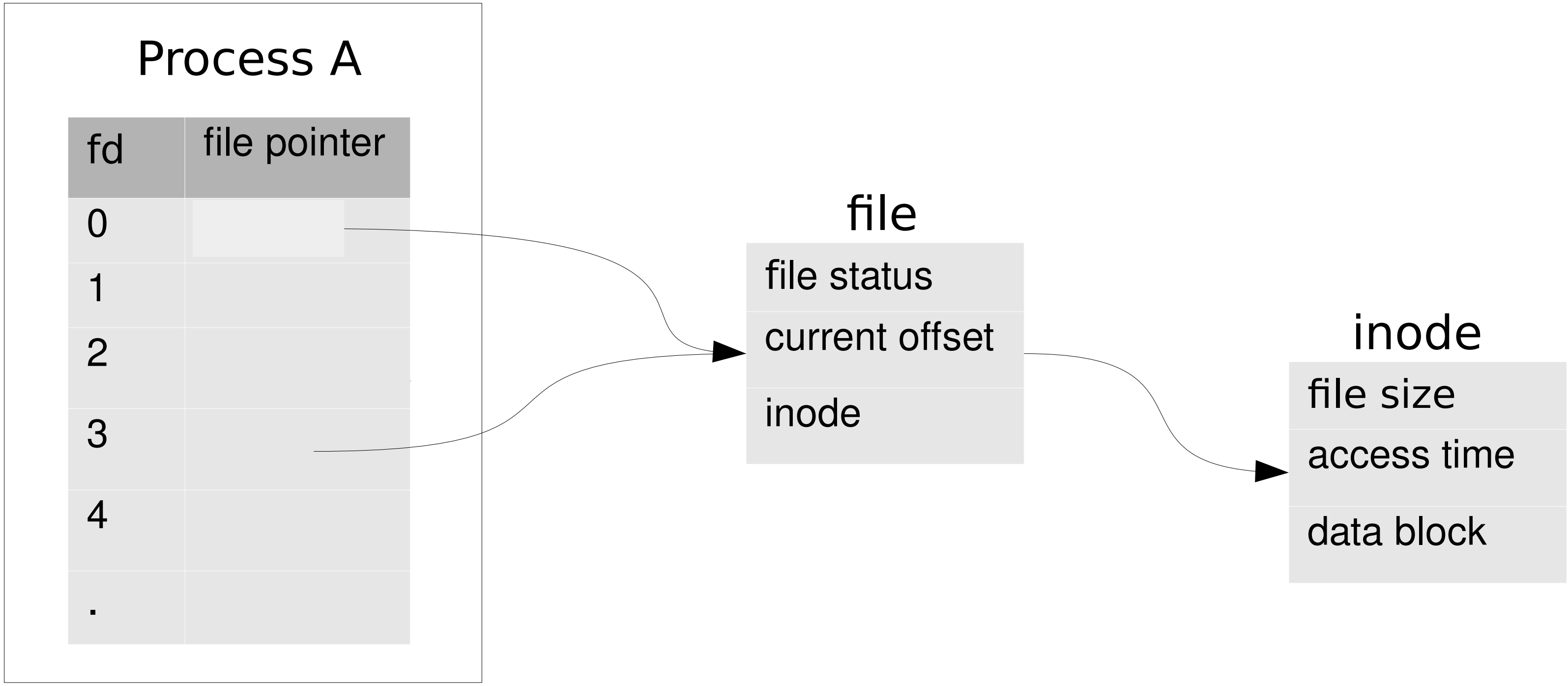
File Sharing

- 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

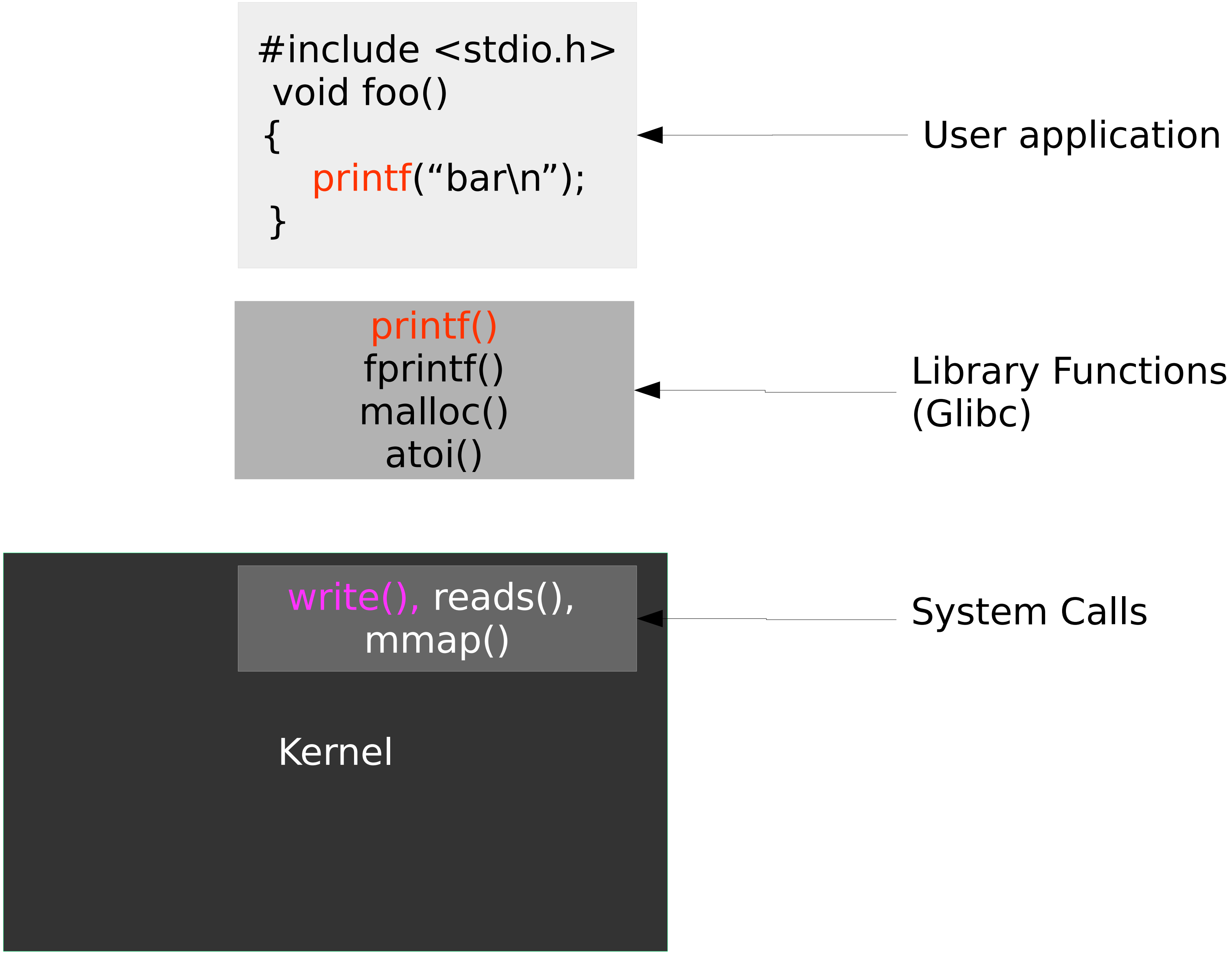
- Manipulate I/O
  - System call
    - File descriptor
    - No buffering
  - Standard library
    - FILE object
    - Buffering

Standard I/O Library

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

System Calls vs Library Functions

- Recall:



```
#include <stdio.h>
 void foo()
{
    printf(“bar\n”);
 }
```

User application

printf()
fprintf()
malloc()
atoi()

Library Functions
(Glibc)

write(), reads(),
mmap()

System Calls

Kernel

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 object
    - 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: cases
  - 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 again

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
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    - No buffering
  - Standard library
    - FILE object
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Project 1

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