HW-2A:
There are 10 questions in this Homework.

- **Edit programs in your Unix/Linux OS and show the outputs that you see along with the source codes. There are some *.txt files associated with some of the source codes. Correlate the *.txt files with the corresponding source code and run the source codes.**
- **Also provide a brief description of what each code is doing.**

Table of Content

Color and symbol specification in Terminal output of this document:

1. gcc hw1_h.c No shading color: command line;
2. Hello World Yellow shading color: program output;
3. d Blue highlight with yellow shading: (waiting) user input;
4. ← Redirect the STDOUT Red shading: author extra explanation warning
5. $ --- command prompt for NON-root account;
6. # --- command prompt for Root account.

All the source code and executable files can be found on the Github:

https://github.com/Chufeng-Jiang/SFBU-CS510-Advanced-Linux-Programming/tree/main/Homework/Week03

Q1 Sys_wait.c

hw1_sys_wait.c

This program acts as a simple shell and designed a new prompt template "% command" to execute the commands required from the user. It repeatedly prompts the user for input, reads the command entered by the user, and attempts to execute it in a child process. The program removes the trailing newline character from the user input, then uses fork to create a new process. In the child process, it uses *execlp()* to execute the command specified by the user. The parent process waits for the child process to finish using *waitpid()* before prompting the user for another command.

```
#include "apue.h"
#include <sys/wait.h>

int main(void) {
    // Declare a buffer array to hold input from the user
    char buf[MAXLINE];
    pid_t pid;
    int status;

// Print the new designed prompt
    printf("%% "); /* print prompt (printf requires %% to print %) */

// Read input from the user, and write it into the buf array
    while (fgets(buf, MAXLINE, stdin) != NULL) {
// Check if the last character in the buffer is a newline
        if (buf[strlen(buf) - 1] == '\n')
            buf[strlen(buf) - 1] = 0; /* replace newline with null */

// Fork a new process and check for errors
        if ((pid = fork()) < 0) {
            printf("fork error");
        } else if (pid == 0) {

// If in the child process, execute the command typed by the user
// int execlp(const char *file, const char *arg, ...   /* (char  *) NULL */);
// The first buf is the name of the file to be executed. In this context, buf contains the
command entered by the user.
// The second buf is the argv[0] value, which conventionally is the name of the program being
executed. By convention, this is typically the same as the first argument.
// The (char *)0 marks the end of the argument list to the new program. In C, (char *)0 is a null
pointer, equivalent to NULL, which signals the end of the arguments.
            execlp(buf, buf, (char *)0);
```

```
            printf("couldn't execute: %s\n", buf);
            exit(127);
        }

// Wait for the child process to terminate
        if ((pid = waitpid(pid, &status, 0)) < 0)
            printf("waitpid error");

        printf("%% ");
    }

    return 0;
}
```

[Terminal Coding Test]

Terminal

```
$   gcc hw1_sys_wait.c -o hw1
$   ./hw1
    % date
    Mon May 20 06:33:33 PM PDT 2024
    % who
    beza     tty2         2024-05-20 07:48 (tty2)
    beza     pts/1        2024-05-20 15:55 (192.168.80.1)
    beza     pts/2        2024-05-20 16:14 (192.168.80.1)
    beza     pts/3        2024-05-20 16:14 (192.168.80.1)
    % ls
    apue.h  file_baz    foo1.txt  hw1   hw10.c          hw3_file_open.c  sysw.c
    baz.txt  file_baz.c  foo.txt   hw10  hw1_sys_wait.c  sample.txt
    % ps
      PID TTY          TIME CMD
     3623 pts/1    00:00:00 bash
     4517 pts/1    00:00:00 hw1
     4520 pts/1    00:00:00 ps
    % ps\ aux
    couldn¡¯t execute: ps\ aux
    % ps aux
    couldn¡¯t execute: ps aux
```

[Output analysis]

When we execute the program, the "% " will automatically display in the terminal to indicate us to input our command.

The new prompt is working good will single word command such as “who”, “date”, “ls”, “ps”, however, it cannot work with command with space such as “ps -aux”, “ls -l”.

Q2 File_hole.c

hw2_file_hole.c
This program creates a file named "*file.hole*", and writes specific content into. Initially, it writes a 10-byte string buf1 *("abcdefghij")* to the file, starting at the beginning. Then, it uses *lseek()* to move the file offset to byte 16384, creating a gap between the first and second write operations. After moving the offset, it writes another 10-byte string buf2 *("ABCDEFGHIJ")* at the new offset. The gap between these writes will result in the creation of holes of “\0”.

```
#include "apue.h"
#include <fcntl.h>

char buf1[] = "abcdefghij";
char buf2[] = "ABCDEFGHIJ";

int main(void) {
    int fd;

    if ((fd = creat("file.hole", FILE_MODE)) < 0)
        printf("creat error");

// Write 10 bytes from buf1 to the file.hole
    if (write(fd, buf1, 10) != 10)
        printf("buf1 write error");

// The file offset is now 10,
// Move the file offset to 16384 bytes from the beginning of the file, and the file cursor will be at the offset 16384
    if (lseek(fd, 16384, SEEK_SET) == -1)
        printf("lseek error");

// Write 10 bytes from buf2 to the file, and the file offset is now 16394.

    if (write(fd, buf2, 10) != 10)
        printf("buf2 write error");
    return(0);
}
```

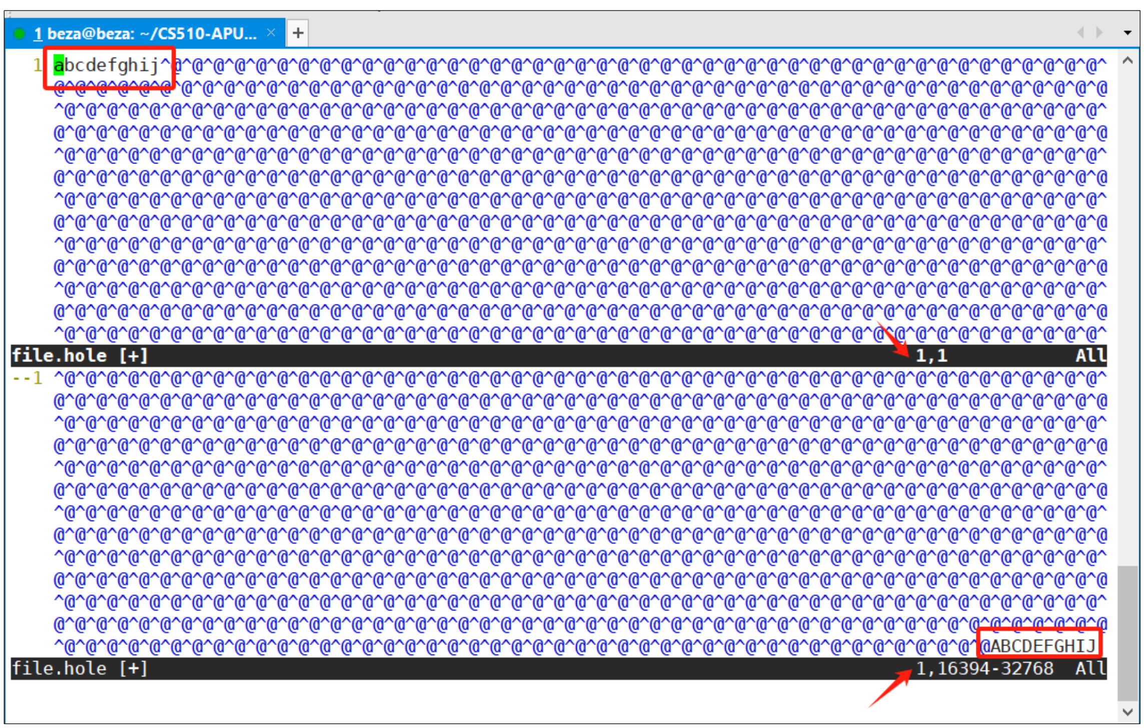
[Terminal Coding Test]

Terminal	
$	gcc hw2_file_hole.c -o hw2
$	./hw2
$	cat file.hole
	abcdefghijABCDEFGHIJ
$	ls -l file.hole
	-rw-r--r-- 1 beza beza 16394 May 20 19:49 file.hole
$	od -c file.hole
	0000000 a b c d e f g h i j \0 \0 \0 \0 \0 \0
	0000020 \0 \0 \0 \0 \0 \0 \0 \0 \0 \0 \0 \0 \0 \0 \0 \0
	*
	0040000 A B C D E F G H I J
	0040012

[Output analysis]

After compiling the code, a *file.hole* was created. When we using cat command, we can see that the contents of the two buffers are connected together “abcdefghijABCDEFGHIJ”.

If we use vim to open the *file.hole, we can see a lot of “^@”.*

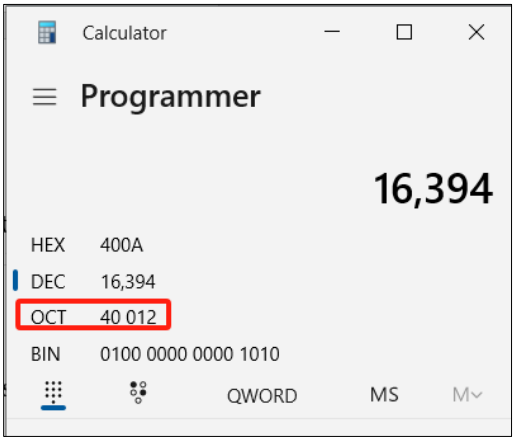


When we use the od(1) command to look at the contents of the file. The -c flag tells it to print the contents as characters. We can see that the unwritten bytes in the middle are read back as zero.

In the terminal, the first number in each line is using octal, Octal (20) = Decimal (16) indicating how many bytes for each line in the terminal, therefore, there are 16 bytes in each line.

```
beza@beza:~/CS510-APUE/Homework/week03$ od -c file.hole
0000000   a   b   c   d   e   f   g   h   i   j  \0  \0  \0  \0  \0  \0
0000020  \0  \0  \0  \0  \0  \0  \0  \0  \0  \0  \0  \0  \0  \0  \0  \0
*
0040000   A   B   C   D   E   F   G   H   I   J
0040012
```

The last line number 0040012 indicates the files size in Octal (0040012) = Decimal (16394).



Q3 File_open.c

This program is originally to test the file status flag [O_RDONLY] for a *foo.txt* which is pre-existing in the directory. However, since the code doesn't contain the access permission bits in the *open()* function, some bugs were found out.

I have rewritten the code, and try to open or create files in different ways. Then I printed out the txt files' permissions to observe the bugs.

- To better see the bug, we need to delete the created files in advance of running the main program. And no any other operation executed before we get the file descriptors for the "*hw3_foo_no.txt*". We should let the stack keep empty to get some arbitrary bytes. Other wise the mode will be set to a same number every time we execute the program. (Don't know why and how.)

hw3_file_open_no.c

The program opens files and reads their permission bits, showing how *open()* behaves with different permissions and file existence scenarios.

(1) a txt file "*hw3_foo_no.txt*" was created, without access permission bits, the file descriptor number and the access permission bits after created were printed;
(2) a txt file "*hw3_foo_0444.txt*" was created, with access permission bits "0444", the file descriptor number and the access permission bits after created were printed;
(3) a pre-existing txt file "*hw3_existed_foo.txt*" was opened, the file descriptor number and the access permission bits after created were printed;
(4) a pipe is created to help execute "*ls -l hw3*.txt*" command to long list the directory file with name starting with "hw3" and end with ".txt".

```
#include <errno.h>
#include <fcntl.h>
#include <stdio.h>
#include <unistd.h>
#include <sys/types.h>
#include <sys/stat.h>
#include <dirent.h>

// Define the maximum number of lines to get from the terminal
#define MAX_RESULT_LENGTH 1000

extern int errno;

int main() {
    struct stat file_stat; // variable to get the file status
    int fd1, fd2, fd3;
    const char *command; // command to be executed
    FILE *fp; // file pointer for reading command output
```

```
    char cmd_result[MAX_RESULT_LENGTH];    // Buffer to store the command result

// open or create a file without specifying access permissions
    fd1 = open("hw3_foo_no.txt", O_RDONLY | O_CREAT);

    printf("------Testing O_CREAT Mode WITHOUT Permission Bit------\n");
    printf("Creating File: hw3_foo_no.txt ==> fd = %d\n", fd1);

// check if there was an error opening the file
    if (fd1 == -1) {
        printf("Error Number %d\n", errno);
        perror("Program");
    }

// get the file status
    if (fstat(fd1, &file_stat) == -1) {
        perror("Error in fstat");
        close(fd1);
        return 1;
    }

// print the permission bits of the created file
    printf("Creating File: hw3_foo_no.txt, Permission Bits: %o\n", file_stat.st_mode &
(S_IRWXU | S_IRWXG | S_IRWXO));

// create a file with 0444 access permissions
    fd2 = open("hw3_foo_0444.txt", O_RDONLY | O_CREAT, 0444);

    printf("\n------Testing O_CREAT Mode with 0444------\n");
    printf("Creating File with 0444: hw3_foo_0444.txt ==> fd = %d\n", fd2);

    if (fd2 == -1) {
        printf("Error Number %d\n", errno);
        perror("Program");
    }

    if (fstat(fd2, &file_stat) == -1) {
        perror("Error in fstat");
        close(fd2);
        return 1;
    }

    printf("Creating File: hw3_foo_0444.txt, Permission Bits: %o\n", file_stat.st_mode &
(S_IRWXU | S_IRWXG | S_IRWXO));

    printf("\n------Testing O_CREAT Mode with existing file------\n");
```

```
// open an existing file
    fd3 = open("hw3_existed_foo.txt", O_RDONLY | O_CREAT);
    printf("Open Existed File: hw3_foo_existed.txt ==> fd = %d\n", fd3);

    if (fd3 == -1) {
        printf("Error Number %d\n", errno);
        perror("Program");
    }

    if (fstat(fd3, &file_stat) == -1) {
        perror("Error in fstat");
        close(fd3);
        return 1;
    }

    printf("File: hw3_foo_existed.txt, Permission Bits: %o\n", file_stat.st_mode & (S_IRWXU |
S_IRWXG | S_IRWXO));

    printf("\n\n=======================================\n");

// command to list files matching the pattern
    command = "ls -l hw3*.txt";

// print the command being executed
    printf("Executing command $: %s\n", command);

// execute the command and open a pipe to read the output
    fp = popen(command, "r");
    if (fp == NULL) {
        printf("Failed to execute the command.\n");
        return 1;
    }

// read the command output line by line
    while (fgets(cmd_result, sizeof(cmd_result), fp) != NULL) {
        // Print each line of the command output
        printf("%s", cmd_result);
    }

// close the pipe
    pclose(fp);

// close file descriptors
    close(fd1);
    close(fd2);
    close(fd3);
```

```
    return 0;
}
```

hw3_delete_files.c

This program is to delete the txt files created by the above program.

```
#include <fcntl.h>
#include <unistd.h>
#include <stdio.h>
#include <string.h>
#include <dirent.h>
// function to delete files matching specific pattern
void delete_files() {
    DIR *d; // pointer to directory stream
    struct dirent *dir; // pointer to directory entry

// open the current directory
    d = opendir(".");
    if (d) {
// read each entry in the directory
        while ((dir = readdir(d)) != NULL) {
// check if the file name starts with "hw3_foo" and ends with ".txt"
            if (strncmp(dir->d_name, "hw3_foo", 7) == 0 && strstr(dir->d_name, ".txt")) {
// delete the file
                if (unlink(dir->d_name) == -1) {
                    perror("unlink");
                } else {
// print the name of the deleted file
                    printf("Deleted: %s\n", dir->d_name);
                }
            }
        }
// close the directory stream
        closedir(d);
    } else {
        perror("opendir");
    }
}

int main() {
    delete_files();
    return 0;
}
```

[Terminal Coding Test]

(1) **Terminal**

```
$ cat hw3_existed_foo.txt
hello world

$ gcc hw3_file_open_no.c -o hw3
$ ./hw3
------Testing O_CREAT Mode WITHOUT Permission Bit------
Creating File: hw3_foo_no.txt ==> fd = 3
Creating File: hw3_foo_no.txt, Permission Bits: 130

------Testing O_CREAT Mode with 0444------
Creating File with 0444: hw3_foo_0444.txt ==> fd = 4
Creating File: hw3_foo_0444.txt, Permission Bits: 444

------Testing O_CREAT Mode with existing file------
Open Existed File: hw3_foo_existed.txt ==> fd = 5
File: hw3_foo_existed.txt, Permission Bits: 664


==========================================
Executing command $: ls -l hw3*.txt
-rw-rw-r-- 1 beza beza 13 May 21 18:07 hw3_existed_foo.txt
-r--r--r-- 1 beza beza  0 May 21 18:46 hw3_foo_0444.txt
---s-ws--- 1 beza beza  0 May 21 18:46 hw3_foo_no.txt

$ echo "hello world" > hw3_foo_no.txt
-bash: hw3_foo_no.txt: Permission denied

$ echo "hello world" > hw3_foo_0444.txt
-bash: hw3_foo_0444.txt: Permission denied

$ echo "hello SFBU + 1" > hw3_existed_foo.txt
$ cat hw3_existed_foo.txt
hello SFBU + 1

$ ./hw3_del
Deleted: hw3_foo_no.txt
Deleted: hw3_foo_0444.txt

$ ./hw3
------Testing O_CREAT Mode WITHOUT Permission Bit------
Creating File: hw3_foo_no.txt ==> fd = 3
Creating File: hw3_foo_no.txt, Permission Bits: 710

------Testing O_CREAT Mode with 0444------
```

```
Creating File with 0444: hw3_foo_0444.txt ==> fd = 4
Creating File: hw3_foo_0444.txt, Permission Bits: 444

------Testing O_CREAT Mode with existing file------
Open Existed File: hw3_foo_existed.txt ==> fd = 5
File: hw3_foo_existed.txt, Permission Bits: 664



=======================================
Executing command $: ls -l hw3*.txt
-rw-rw-r-- 1 beza beza 15 May 21 18:47 hw3_existed_foo.txt
-r--r--r-- 1 beza beza  0 May 21 18:48 hw3_foo_0444.txt
-rwx--s--- 1 beza beza  0 May 21 18:48 hw3_foo_no.txt

$ echo "Bugs with this program?" > hw3_foo_no.txt
$ cat hw3_foo_no.txt
Bugs with this program?
```

[Output analysis]

Click to go to Appendix A1 - Q3 to see the full testing output.

(1) fd1 = open("hw3_foo_no.txt", O_RDONLY | O_CREAT);

For this way of **creating files**, the access permission code is **randomly** set by the process which can be 130, 710, 570,250,50…

Most of the cases, the file type and permissions for *hw3_foo_no.txt* doesn't contain a write permission, such as permission bit: 130, which is ---s-ws--- in the 1st terminal output above. In this case, if we want to write something in to the file, the terminal will indicate *"-bash: hw3_foo_no.txt: Permission denied".*

There appeared a special circumstances, the file type and permissions for *hw3_foo_no.txt is 710,* which is -rwx--s--- in the 2nd terminal output above. In this case, I can write something into this file successfully, even though the read only file status flag was applied for the file descriptor.

By reading the manual, a warning was noticed that can explain the above phenomenon, that each time the permission bit is changing is due to arbitrary bytes from the stack is applied as the file mode(access permission bit).

https://man7.org/linux/man-pages/man2/open.2.html

int open(const char *_pathname_, int _flags_, ... /* mode_t _mode_ */);

> The mode argument specifies the file mode bits to be applied when a new file is created. If neither O_CREAT nor O_TMPFILE is specified in flags, then mode is ignored (and can thus be specified as 0, or simply omitted). The mode argument must be supplied if O_CREAT or O_TMPFILE is specified in flags; if it is not supplied, **some arbitrary bytes** from the stack will be applied as the file mode.

(2) fd2 = open("hw3_foo_0444.txt", O_RDONLY | O_CREAT, 0444);

With the access permission bit set to 0444, every time when the file was created, it has stable bit of access permission which is 0444, as what we have set in the function.

Under this access permission bit, we cannot write anything into the file.

(3) fd3 = open("hw3_existed_foo.txt", O_RDONLY | O_CREAT);

We have a pre-existing txt file in our directory in this case. Using this statement, each time we run this program, the file type and permissions for *hw3_existed_foo.txt* is *0664,* which is -rw-rw-r--. I can write something into this file successfully, and read the content. And this 0664 is coming from "0666 – umask(0002)", where 0666 is the default permission code set by the system, however when creating the file the umask is deducted from the default value.

Q4 File_read.c

Original code can be found on Appendix-Q4, the content for the file has changed to “hello world@@@@” for better analyzing.

hw4_file_read.c
This program demonstrates file reading and manipulation operations using the *read()* and *lseek()* functions, and how ‘\0’ affect the way of content display in the buffer.

It opens a file named *"hw4_foo.txt"* in read-only mode and then reads up to 13 bytes from the file into a dynamically allocated buffer. The program prints the current file offset before and after reading, along with the number of bytes read. It then modifies the content of the buffer by appending a character and null-terminating the string at no-continuous position.

```
#include <fcntl.h>
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <string.h>

int main() {
// declare file descriptor and size variables
    int fd, sz;

// allocate memory for 100 characters and initialize to 0
    char* c = (char*) calloc(100, sizeof(char));

// open the file "hw4_foo.txt" in read-only mode
    fd = open("hw4_foo.txt", O_RDONLY);
    if (fd < 0) {
        perror("r1");
        exit(1);
    }

// Obtain and print the current offset before reading
    off_t offset_before = lseek(fd, 0, SEEK_CUR);
    printf("Before sz = read(fd, c, 13) : current file offset: %ld\n", (long) offset_before);

// Read up to 13 bytes from the file into the buffer c
    sz = read(fd, c, 13);

// Obtain and print the current offset after reading
    off_t offset_after = lseek(fd, 0, SEEK_CUR);
    printf("After sz = read(fd, c, 13) : current file offset: %ld\n\n", (long) offset_after);
```

```
// print the number of bytes read from the file
    printf("Called read(%d, c, 13). returned that %d bytes were read.\n\n", fd, sz);
    printf("Before set c[sz] = \'p\' ===>c[sz] = [%c]\n", c[sz]);
    printf("Before set c[sz] = \'p\' ===>Those bytes in buffer c : %s, the length is: %ld\n", c,
strlen(c));

// set the character at position sz in buffer c to 'p'
    c[sz] = 'p';
    printf(" After set c[sz] = \'p\' ===>Those bytes in buffer c : %s, the length is: %ld\n\n", c,
strlen(c));

// null-terminate the string read from the file at position sz - 2
    c[sz - 2] = '\0';
    printf("After set c[sz - 2] = \'\\0\' ===>Those bytes in buffer c : %s, the length is: %ld\n\n ",
c, strlen(c));

// free allocated memory and close file descriptor
    free(c);
    close(fd);
    return 0;
}
```

hw4_foo.txt:

```
hello world@@@@
```

[Terminal Coding Test]

Terminal:

```
$ gcc hw4_file_read.c -o hw4
$ ./hw4
Before sz = read(fd, c, 13) : current file offset: 0
After sz = read(fd, c, 13) : current file offset: 13

Called read(3, c, 13). returned that 13 bytes were read.

Before set c[sz] = 'p' ===>c[sz] = []
Before set c[sz] = 'p' ===>Those bytes in buffer c : hello world@@, the length is: 13
   After set c[sz] = 'p' ===>Those bytes in buffer c : hello world@@p, the length is: 14

After set c[sz - 2] = '\0' ===>Those bytes in buffer c : hello world, the length is: 11
```

[Output analysis]

The program read 13 bytes to the buffer c, which is a char array created on the heap, because it use the *calloc()* function that allocating 100 memory for an array.

The sz is the return value for the *read()* function, which is the number of bytes read is returned (zero indicates end of file). And sz is always equal to 13.

The index for the 13 bytes should be [0, 12]. When we print the index(13), we can found that nothing is there, because there is an empty space. Then we set the c[13] = p, and print out the buffer, the 'p' is printed concatenated at the end of the original 13 bytes, resulting in length increased to 14.

If we set the index(sz -2) to be '\0', which is EOF for a string. When we print the buffer, the string will be ended at the first '\0'.

index	0	1	2	3	4	5	6	7	8	9	10	11	12	13 (sz)	14
before	h	e	l	l	o		w	o	r	l	d	@	@	p	\0
after	h	e	l	l	o		w	o	r	l	d	\0	@	p	\0

Q5 File_write.c

hw5_file_write.c

This program demonstrates file writing operations using the *write()* function. It first opens a file named "hw5_foo.txt" with write-only access, creating the file if it doesn't exist and truncating it if it does. The program then writes the string "*hello geeks*" to the file and prints the number of bytes successfully written. Subsequently, it explores whether characters like newline *('\n')* and null terminator *('\0')* affect the length of the string when written to the file.

```
#include <fcntl.h>
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <string.h>

void main()
{
   int sz; // declare file descriptor and size variables

// declare file descriptor, the file status flag is with O_TRUNC, that means:
// (1) if the file is not existed, the create it;
// (2) if the file is already there, open the file and empty the file which means truncating the file and setting the offset to 0.
   int fd = open("hw5_foo.txt", O_WRONLY | O_CREAT | O_TRUNC, 0644);

   printf("fd = %d\n", fd);
   if (fd < 0)
   {
      perror("r1");
      exit(1);
   }

// write "hello geeks " to the file "hw5_foo.txt", and sz is the return value for write function which means the number of bytes written successfully.
   sz = write(fd, "hello geeks", strlen("hello geeks"));

// print the length of "hello geeks ", and the number of bytes written into the file.
   printf("Called write(%d, \"hello geeks\", strlen(\"hello geeks\") = %ld); ===> It returned %d bytes.\n", fd, strlen("hello geeks"), sz);

// test for the length of "hello geeks\n"
   printf("\n\n====Does of \"\\n\" counts towards the length of the string? ====\n");
   sz = write(fd, "hello geeks\n", strlen("hello geeks\n"));
   printf("Called write(%d, \"hello geeks\\n\", strlen(\"hello geeks\\n\") = %ld); ===> It returned %d bytes.\n", fd, strlen("hello geeks\n"), sz);
```

```
// test the length of "hello geeks\0"
    printf("\n\n====Does of \"\\0\" counts towards the length of the string? ====\n");
    sz = write(fd, "hello geeks\0", strlen("hello geeks\0"));
    printf("Called write(%d, \"hello geeks\\0\", strlen(\"hello geeks\\0\") = %ld); ===> It
returned %d bytes.\n", fd, strlen("hello geeks\0"), sz);

    close(fd);
}
```

[Terminal Coding Test]

Terminal:

```
$ gcc hw5_file_write.c -o hw5
$ ./hw5
  fd = 3
  Called write(3, "hello geeks", strlen("hello geeks") = 11); => It returned 11 bytes.
  ====Does "\n" counts towards the length of the string? ====
  Called write(3, "hello geeks\n", strlen("hello geeks\n") = 12); => It returned 12 bytes.
  ====Does "\0" counts towards the length of the string? ====
  Called write(3, "hello geeks\0", strlen("hello geeks\0") = 11); => It returned 11 bytes.

$ cat hw5_foo.txt
  hello geekshello geeks
  hello geeks

$ echo "1111111111111111" > hw5_foo.txt
$ cat hw5_foo.txt
  1111111111111111

$ ./hw5
$ cat hw5_foo.txt
  hello geekshello geeks
  hello geeks
```

[Output analysis]

A ‘\0’ is always added to the end of a string implicitly, and it doesn’t count towards the length of the string.

A ‘\n’ explicitly write into a string will make a change of line, and this symbol is count towards the length of the string.

When using the O_TRUNC flag, once the fd open a file successfully, it will remove all the content existed, and write or read the file from the beginning.

Q6 File_close.c

hw6_file_close.c

This program demonstrates the use of the *close()* system call to close a file descriptor. It begins by opening an existing file named "*hw6_foo.txt*" in read-only mode and prints the file descriptor's value. Then, it waits for a keyboard stroke using getc(stdin), to suspend the program and open another terminal to check the file descriptor's details in the process. Finally, it attempts to close the file descriptor, and check the file descriptor's details after the program end.

```
// C program to illustrate close system Call
#include <fcntl.h>
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>

int main()
{
// open a pre-existing file using read only mode.
    int fd1 = open("hw6_foo.txt", O_RDONLY);
    if (fd1 < 0) {
        perror("c1");
        exit(1);
    }
// print the file descriptor's vale
    printf("opened the fd = % d\n", fd1);

// suspend the close of file descriptor until a keyboard stroke happened, to help check the process fds details
    int c  = getc(stdin);

// close and release the file descriptor, if not close successfully, print “c1”, otherwise print "closed the fd."
    if (close(fd1) < 0) {
        perror("c1");
        exit(1);
    }
    printf("closed the fd.\n");
}
```

hw6_foo.txt

```
hello world
```

[Terminal Coding Test]

Terminal 1		Terminal 2	
$	gcc hw6_file_close.c -o hw6		
$	./hw6		
	opened the fd = 3		
		$	ps aux | grep ./hw6
			beza 6540 0.0 0.0 2776 1408 pts/0 S+ 07:29 0:00 ./hw6
			beza 6639 0.0 0.0 9212 2432 pts/1 R+ 07:30 0:00 grep --color=auto ./hw6
		$	ls -l /proc/6540/fd/
			total 0
			lrwx------ 1 beza beza 64 May 22 07:32 0 -> /dev/pts/0
			lrwx------ 1 beza beza 64 May 22 07:32 1 -> /dev/pts/0
			lrwx------ 1 beza beza 64 May 22 07:32 2 -> /dev/pts/0
			lr-x------ 1 beza beza 64 May 22 07:32 3 -> hw6_foo.txt
		$	ls -l /proc/6540/fd/
	d		
	closed the fd.		ls: cannot access '/proc/6540/fd/': No such file or directory

[Output analysis]

We open two terminal to track the process file descriptors. When the program is running, we could see that the fd(3) is assigned to the program process and point to the pre-existing file "*hw6_foo.txt*".

After we input a char "d" and the program ended, we can no longer track the fds for the process. Because the process has been ended, with the file descriptors being closed accordingly.

Q7 File_flags.c

Copied from HW_1B_Q2

This program is to retrieves and displays the file status flags and access modes associated with a file descriptor provided as a command-line argument. It uses the fcntl() function system call with the F_GETFL command to obtain the current file status flags. The program then uses bitwise operations and a switch statement to determine and print the file's access mode. Additionally, it checks for and prints the presence of specific flags like O_APPEND, O_NONBLOCK, O_SYNC and O_FSYNC.

In the HW_1B_Q2, I have mentioned that

"// O_ACCMODE = 00000011 ***<--- This part will be discussed more in HW2A-Q7"***

Here. I am going to investigate more about the file status flags and the file descriptors.

```
#include "apue.h"
#include <fcntl.h>
#include <stdio.h>
int main(int argc, char *argv[])
{
        int val;

        if (argc != 2)
          printf("usage: a.out <descriptor#>");

// get the file descriptor from the sencond position in the cmd line, which is an integer.
// get the file status flags and access modes associated with the file descriptor.
        if ((val = fcntl(atoi(argv[1]), F_GETFL, 0)) < 0)
          printf("fcntl error for fd %d", atoi(argv[1]));

// using the switch loop to specify the types of the file status flags.
// O_ACCMODE defined in the <fcntl.h>, representing the mask for extracting the file access mode from file status flags.
// val & O_ACCMODE masks out all the bits in val except for those representing the file access mode.
// O_ACCMODE = 00000011  <-- This part will be discussed more in HW2A-Q7
        switch (val & O_ACCMODE) {
                // 00000000 (O_RDONLY) & 00000011 (O_ACCMODE) = 00000000
                 case O_RDONLY:
                   printf("read only"); // then it means the file statu is read only.
                   break;
                 // 00000001 (O_WRONLY) & 00000011 (O_ACCMODE) = 00000001
                  case O_WRONLY:
                   printf("write only");
                   break;
                 // 00000010 (O_RDWR) & 00000011 (O_ACCMODE) = 00000010
```

```
                    case O_RDWR:
                      printf("read write");
                      break;
                    default:
                      printf("unknown access mode");
        }

        // val & O_APPEND is another bitwise AND operation.
        // It's used to check whether the file status flags include the O_APPEND flag.
        if (val & O_APPEND)
          printf(", append");
        if (val & O_NONBLOCK)
          printf(", nonblocking");
        if (val & O_SYNC)
          printf(", synchronous writes");

  // This checks if the _POSIX_C_SOURCE, O_FSYNC macros are not defined
  // and if the value of O_FSYNC is different from the value of O_SYNC.
  // It's ensuring that O_FSYNC is defined and distinct from O_SYNC.
        #if !defined(_POSIX_C_SOURCE) && defined(O_FSYNC) && (O_FSYNC !=
O_SYNC)
        if (val & O_FSYNC) // This checks if the file status flags contain the O_FSYNC flag.
                printf(", synchronous writes");
        #endif

        putchar('\n');
         exit(0);
 }
```

[Terminal Coding Tests]

- ***Copied from HW_1B_Q2***

```
$   gcc hw2_print_status_flags_v1.c -o hw2
$   ./hw2 2 < /dev/tty
    read write

$   ./hw2 1 > temp.foo
$   $ cat temp.foo
    write only

$   ./hw2 2 2>>temp.foo
    write only, append

$    ./hw2 45555 2>>temp.foo
    fcntl error for fd 45555unknown access mode, append, nonblocking, synchronous writes
```

```
$   cat temp.foo
    write only

$   ./hw2 4555 1>>temp.foo
$   cat temp.foo
    write only
    fcntl error for fd 4555unknown access mode, append, nonblocking, synchronous writes

$   ./hw2 5 5<>temp.foo
    read write
```

[Output analysis] ***Copied from HW_1B_Q2***

./hw2 0 < /dev/tty
It redirected the STDIN(0) to the file /dev/tty, and pass it to the program, finding its flag status as read only.

./hw2 1 > temp.foo
We redirected the STDOUT(1) to the file temp.foo which is created automatically since it doesn't exist before, and then we pass STDOUT(1) to the program, finding its flag status as write only.

Since the STDOUT(1) has been directed to temp.foo, the result is not display in the terminal, and it has been written into the temp.foo.

By cat temp.foo, we can see the result.

```
write only
```

./hw2 2 2>>temp.foo

The program inspect STDERR(2) and redirects the Standard Error output to the file temp.foo, using append mode. Therefore, by determined the type for the file status, the results is "write only, append".

>> appends the output to a file, rather than overwriting it.

2>>temp.foo: This redirects the standard error (STDERR) stream (which is file descriptor 2) to append to the file *temp.foo* .

./hw2 45555 2>>temp.foo

I tried to create an error command, by passing the 45555 to the program, which is a number out of bound of the fd range. The terminal displayed the error message, because "2>>temp.foo" has redirect the STDERR(2) to the file *temp.foo*.

./hw2 4555 1>>temp.foo

I redirect the STDOUT (1) to the file *temp.foo*, therefore the output message will append to the *temp.foo*.

By cat temp.foo, we can see that 1 more line of error message have been appended to the *temp.foo*.

```
write only
fcntl error for fd 45555unknown access mode, append, nonblocking, synchronous writes
```

./hw2 5 5<>temp.foo

The textbook has given explanation to the result of this command line saying that "The clause 5<>temp.foo opens the file temp.foo for reading and writing on file descriptor 5."

<> with a file, it opens the file for both reading and writing

5<>: This opens the file temp.foo for both reading and writing, associating it with file descriptor 5.

- **7.1 The File Structure**

The file structure was defined at Line# 991 in the "/linux/linux/fs.h" of the source code of the linux kernel version 6.9. More specifically, the file flags were declared at Line# 997.

https://elixir.bootlin.com/linux/v6.9/source/include/linux/fs.h#L991

```
struct file {
    ……
    unsigned int        f_flags;
    ……
```

The file flags are declared as unsigned int. In the most architectures, an unsigned integer is a 32-bit (4 bytes) data that encodes a nonnegative integer in the range [0 to 4294967295].

- **7.2 Flags in *fcntl.h***

In the header file "fcntl.h", we can find that the flags are defined in macro using 8 bits. And there are total 18 macros defined of which 17 status flags for files and 1 extra O_ACCMODE.

```
#ifndef _ASM_GENERIC_FCNTL_H
#define _ASM_GENERIC_FCNTL_H

#include <linux/types.h>
```

```
/* open/fcntl - O_SYNC is only implemented on blocks devices and on files
   located on an ext2 file system */
#define O_ACCMODE       00000003
#define O_RDONLY        00000000
#define O_WRONLY        00000001
#define O_RDWR          00000002
#ifndef O_CREAT
#define O_CREAT         00000100        /* not fcntl */
#endif
#ifndef O_EXCL
#define O_EXCL          00000200        /* not fcntl */
#endif
#ifndef O_NOCTTY
#define O_NOCTTY        00000400        /* not fcntl */
#endif
#ifndef O_TRUNC
#define O_TRUNC         00001000        /* not fcntl */
#endif
#ifndef O_APPEND
#define O_APPEND        00002000
#endif
#ifndef O_NONBLOCK
#define O_NONBLOCK      00004000
#endif
#ifndef O_SYNC
#define O_SYNC          00010000
#endif
#ifndef FASYNC
#define FASYNC          00020000        /* fcntl, for BSD compatibility */
#endif
#ifndef O_DIRECT
#define O_DIRECT        00040000        /* direct disk access hint */
#endif
#ifndef O_LARGEFILE
#define O_LARGEFILE     00100000
#endif
#ifndef O_DIRECTORY
#define O_DIRECTORY     00200000        /* must be a directory */
#endif
#ifndef O_NOFOLLOW
#define O_NOFOLLOW      00400000        /* don't follow links */
#endif
#ifndef O_NOATIME
#define O_NOATIME       01000000
#endif
#ifndef O_CLOEXEC
#define O_CLOEXEC       02000000        /* set close_on_exec */
#endif
#ifndef O_NDELAY
#define O_NDELAY        O_NONBLOCK
#endif
  ...
```

- **7.3 Relationship with Flags in *fcntl.h***

The *unsigned int 'f_flags'* in the file structure is used to store various flags related to file access and status. This field, typically 32 bits in size, ensures there is enough space to accommodate all possible combinations of these flags. When a file is opened using the *open* system call, the flags specified as arguments (defined in '*fcntl.h'*) are stored in the '*f_flags'* field of the file structure. The 32-bit *unsigned int* type of '*f_flags'* allows it to handle all the various 8-bit flags defined in '*fcntl.h'*.

- **7.4 Visualization of File Status Flags**

I run the program from https://github.com/Cyborg117/File-Descriptors-C

It can visualize the decimal and bit representation for the status flags well.

Terminal cd /hw7_file-descriptors-c/	
$ $	gcc fcntl_flags.c -o hw7_vis ./hw7_vis

```
================================================
                    fcntl.h flags
================================================

0_RDONLY                : 0       : 00000000 00000000 00000000 00000000
0_WRONLY                : 1       : 00000000 00000000 00000000 00000001
0_RDWR                  : 2       : 00000000 00000000 00000000 00000010

O_APPEND                : 1024    : 00000000 00000000 00000100 00000000
O_TRUNC                 : 512     : 00000000 00000000 00000010 00000000
O_CREAT                 : 64      : 00000000 00000000 00000000 01000000

O_WRONLY|O_APPEND|O_CREAT: 1089 : 00000000 00000000 00000100 01000001
```

Q8 File_baz.c

hw8_file_baz.c

This program showcases file opening, reading, and closing operations using the *open*(), read(), and *close()* functions. It first opens an existing file named "*hw8_foo.txt*" in read-only mode, printing the file descriptor assigned to it and then printing out its content character by character. Following a similar pattern, it opens another existing file named "*hw8_baz.txt*", prints its file descriptor, reads and prints its content, and finally closes its file descriptor.

Throughout the process, the program suspends execution many times and I open another terminal to allow inspection of file descriptor details. This program also points out that "*when a file descriptor (fd) is assigned using the open() system call, it typically returns the lowest available integer that is not currently being used as a file descriptor*."

```
#include<stdio.h>
#include<fcntl.h>
#include <stdlib.h>
#include <unistd.h>

int main()
{
// declare a char variable to help suspend the program and print the file content.
        char ch;

        printf("-------open hw8_foo.txt------\n");
// assume that foo.txt is already created
       int fd1 = open("hw8_foo.txt", O_RDONLY, 0);

// print the fd assigned to "hw8_foo.txt".
        printf("fd1 = %d\n", fd1);

// print out the content that the fd direct to.
        while ((read(fd1, &ch, 1)) != 0) {
           putchar(ch);
        }
// suspend the program to check the process fds details
        ch = getchar();

// close the current fd, to test the fd integer used for the next open() function.
         close(fd1);
        printf("-------fd1 closed------\n\n");

// suspend the program to check the process fds details
        ch = getchar();

        printf("-------open hw8_baz.txt------\n");
```

```
        // assume that baz.tzt is already created
         int fd2 = open("hw8_baz.txt", O_RDONLY, 0);
         printf("fd2 = %d\n", fd2);
        while ((read(fd2, &ch, 1)) != 0) {
              putchar(ch);
          }
// suspend the program to check the process fds details
        ch = getchar();
          close(fd2);
        printf("-------fd2 closed------\n\n");
// suspend the program to check the process fds details after close the fd.
        ch = getchar();
   exit(0);
}
```

Pre-existing txt files
hw8_baz.txt: Hello, its Baz!
hw8_foo.txt: hello world

[Terminal Coding Tests]

Terminal 1		**Terminal 2**	
$	gcc hw8_file_baz.c -o hw8		
$	./hw8	$	ps aux | grep ./hw8
	---open hw8_foo.txt---		beza 3241 0.0 0.0 2776 1408 pts/0 S+ 10:25 0:00 ./hw8
	fd1 = 3		beza 3243 0.0 0.0 9212 2432 pts/2 S+ 10:25 0:00 grep --color=auto ./hw8
	hello world		
		$	ls -l /proc/3241/fd
			total 0
			lrwx------ 1 beza beza 64 May 22 10:25 0 -> /dev/pts/0
			lrwx------ 1 beza beza 64 May 22 10:25 1 -> /dev/pts/0
			lrwx------ 1 beza beza 64 May 22 10:25 2 -> /dev/pts/0
			lr-x------ 1 beza beza 64 May 22 10:25 3 -> hw8_foo.txt
	(press ENTER)	$	$ ls -l /proc/3241/fd
	---fd1 closed---		total 0
			lrwx------ 1 beza beza 64 May 22 10:25 0 -> /dev/pts/0
			lrwx------ 1 beza beza 64 May 22 10:25 1 -> /dev/pts/0
			lrwx------ 1 beza beza 64 May 22 10:25 2 -> /dev/pts/0
	(press ENTER)		
	---open hw8_baz.txt---	$	ls -l /proc/3241/fd
	fd2 = 3		total 0
	Hello, its Baz!		lrwx------ 1 beza beza 64 May 22 10:25 0 -> /dev/pts/0
			lrwx------ 1 beza beza 64 May 22 10:25 1 -> /dev/pts/0
			lrwx------ 1 beza beza 64 May 22 10:25 2 -> /dev/pts/0

			lr-x------ 1 beza beza 64 May 22 10:25 3 -> hw8_baz.txt
		$	ls -l /proc/3241/fd
	(press ENTER) ---fd2 closed---		total 0 lrwx------ 1 beza beza 64 May 22 10:25 0 -> /dev/pts/0 lrwx------ 1 beza beza 64 May 22 10:25 1 -> /dev/pts/0 lrwx------ 1 beza beza 64 May 22 10:25 2 -> /dev/pts/0
	(press ENTER)	$	ls -l /proc/3241/fd
			ls: cannot access '/proc/3241/fd': No such file or directory

[Output analysis]

From the output we could know that, when the fd1 open the file *hw8_foo.txt, fd1(3) ->hw8_foo.txt,* the system returns the 3 which is the most minimum number in the file descriptor table to the fd1.After, we close fd1, and 3 is unconnected to the file, when checking with the fd files in the system, 3 is no longer there.

We then use fd2 to open the hw8_baz.txt, and then the system returns the 3 to fd2 again, and fd2(3) -> hw8_baz.txt.

That means in the same process, once the fd is closed and released, it will be applied to another variable if it is the current available minimum fd value in the fd table.

After the program ended, the fd table is destroyed, and we can no longer check the status for that process including the fds.

Q. How file descriptor value is assigned?

From the Linux kernel source code, the process to find the smallest available file descriptor involves using the *find_next_fd*() function, which operates on the fdtable structure.

Initially, the *alloc_fd*()function [R1] sets the starting point fd to the greater of the given start value or *files->next_fd*.[R2] It then utilizes the *find_next_zero_bit()* function [R3] to locate the next zero bit in the *full_fds_bits* bitmap, starting from the calculated bit position. This determines the next available slot in the bitmap, which is then compared to *maxfd* to ensure it is within bounds. If necessary, start is updated to this new position. Finally, the *find_next_zero_bit()* function searches the *open_fds* bitmap [R4] from this updated starting point to find the next zero bit, ensuring it identifies the smallest available fd. This systematic search through the bitmap ensures that the function always returns the smallest unused fd.

Reference for the above R1-R4 in the source code.	
	https://elixir.bootlin.com/linux/latest/source/fs/file.c#L499

```
//Line 468
struct files_struct init_files = {
        ……
        .fdt            = &init_files.fdtab,
        .fdtab          = {
                .max_fds        = NR_OPEN_DEFAULT,
// array of file pointers
                .fd             = &init_files.fd_array[0],
                .close_on_exec          = init_files.close_on_exec_init,
// a bitmap that contains the file descriptors of currently opened files.
R4              .open_fds       = init_files.open_fds_init,
    ……
};

//Line 482
// this function use bitmap to search the opened fds and then get the next unused fd.
static unsigned int find_next_fd(struct fdtable *fdt, unsigned int start)
{
        unsigned int maxfd = fdt->max_fds;
        unsigned int maxbit = maxfd / BITS_PER_LONG;
        unsigned int bitbit = start / BITS_PER_LONG;

// this function is defined at "include/linux/find.h" line 173
        bitbit = find_next_zero_bit(fdt->full_fds_bits, maxbit, bitbit) *
BITS_PER_LONG;
        if (bitbit > maxfd)
                return maxfd;
        if (bitbit > start)
                start = bitbit;

// find the next zero bit in the open_fds bitmap starting from start, and ensures that the
smallest available fd is found and returned.
        return find_next_zero_bit(fdt->open_fds, maxfd, start);
}

//Line 499
R1  static int alloc_fd(unsigned start, unsigned end, unsigned flags)
{
        ……
        // Line 509 Search Start
R2      fd = start;   // it firstly set it as start value, usually to be 0 because the fd array will
be initialized
        // if current value lower than the file's next fd value, set it to be the next fd value
        if (fd < files->next_fd) // if the current fd value lower than the
                fd = files->next_fd;
```

R3	// if current value is greater then the file's next fd value, we use the find *find_next_fd(fdt, fd);* function to find the next available value.
	
	if (fd < fdt->max_fds)
	fd = find_next_fd(fdt, fd);
	
	/* https://elixir.bootlin.com/linux/latest/source/include/linux/find.h#L173 */
	
	//find_next_zero_bit searches for the next zero bit in the open_fds bitmap, which represents the smallest available fd starting from the given offset. If it finds an available fd, it returns that value.
	// find the next zero bit in the open_fds bitmap starting from start.
	unsigned long find_next_zero_bit(const unsigned long *addr, unsigned long size,
	unsigned long offset)
	{
	if (small_const_nbits(size)) {
	unsigned long val;
	
	if (unlikely(offset >= size))
	return size;
	
	val = *addr | ~GENMASK(size - 1, offset);
	return val == ~0UL ? size : ffz(val);
	}
	
	return _find_next_zero_bit(addr, size, offset);
	}

Q9 File_system_call.c

hw9_file_sys_call.c
This program demonstrates how file descriptors maintain ***separate file offsets*** even when they reference the same file. It opens the file "*hw9_sample.txt*" twice, resulting in two different file descriptors (fd1 and fd2).

The program reads one byte from each file descriptor and prints the byte and the current file offset for each. It then reads another byte using fd1 and shows that the file offset for fd2 remains unchanged, highlighting that each file descriptor has its own independent offset. This illustrates the isolation of file offsets in concurrent file operations.

```
#include <fcntl.h>
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>

int main()
{
    char c[10], ch;

// to record the fd offset after each read.
    off_t position1, position2;

// using fd1 and fd2 open the same file
    printf("==Read 1 byte for fd1 and fd2==\n");
    int fd1 = open("hw9_sample.txt", O_RDONLY, 0);
    int fd2 = open("hw9_sample.txt", O_RDONLY, 0);

// read 1 byte of data to buffer c, and print it.
    read(fd1, &c, 1);
    printf("fd1: c = %s\n", c);

// get the current offset for fd1
    position1 = lseek(fd1, 0, SEEK_CUR);
    if (position1 == -1) {
            perror("lseek");
            exit(EXIT_FAILURE);
    }
    printf("fd1: current position1: %ld\n\n", (long)position1);

// read 1 byte of data to buffer c, and print it.
    read(fd2, &c, 1);
    printf("fd2: c = %s\n", c);

// get the current offset for fd2
```

```
    position2 = lseek(fd2, 0, SEEK_CUR);
    if (position2 == -1) {
            perror("lseek");
            exit(EXIT_FAILURE);
    }
    printf("fd2: current position2: %ld\n\n", (long)position2);

// suspend the program to check the fds details
    ch = getchar();

// using fd1, read 1 byte of data to buffer c, and print it.
// but fd2 keep no change.
     printf("==Read 1 more byte for fd1, NOT fd2==\n");
     read(fd1, &c, 1);
     printf("fd1: c = %s\n", c);
     position1 = lseek(fd1, 0, SEEK_CUR);
     if (position1 == -1) {
            perror("lseek");
            exit(EXIT_FAILURE);
     }
     printf("fd1: current position1: %ld\n", (long)position1);
     printf("fd2: current position2: %ld\n", (long)position2);

     close(fd1);
     close(fd2);
    exit(0);
}
```

Pre-existing *hw9_sample.txt*: This is a sample file.

[Terminal Coding Tests]

Terminal 1			**Terminal 2**
$	gcc hw9_file_sys_call.c -o hw9		
$	./hw9		
	==Read 1 byte for fd1 and fd2==	$	ls -l /proc/3334/fd
	fd1: c = T		total 0
	fd1: current position1: 1		lrwx------ 1 beza beza 64 May 22 11:29 0 -> /dev/pts/0
			lrwx------ 1 beza beza 64 May 22 11:29 1 -> /dev/pts/0
	fd2: c = T		lrwx------ 1 beza beza 64 May 22 11:29 2 -> /dev/pts/0
	fd2: current position2: 1		lr-x------ 1 beza beza 64 May 22 11:29 3 -> hw9_sample.txt
	d		lr-x------ 1 beza beza 64 May 22 11:29 4 -> hw9_sample.txt
	==Read 1 more byte for fd1, not fd2==		
	fd1: c = h		
	fd1: current position1: 2		
	fd2: current position2: 1		

[Output analysis]

When we using different file descriptor to open() then same file, different value will assigned to the different file descriptors.

Apart from that, the fds direct to the same file, what they read from the content are working separately. Thant means the offset for the fds after read are moving individually, and they don't affect each other.

Q10 Printing_without_printf.c

hw10_print_wo_printf.c
This program demonstrates file operations and cursor position handling using two file descriptors and buffers.

It opens two files, writes "hello world" to the first file, and prints the buffer contents and cursor positions for both file descriptors.

It then reads 12 bytes from the first file into a buffer and writes the buffer content to standard output (STDOUT), effectively displaying the content of the first file.

Cursor positions for both file descriptors are displayed again, showing that operations on one file descriptor do not affect the other. And the *read()* and *write()* function are sharing the same fd offset when using the same fd.

```
#include <fcntl.h>
#include <stdio.h>
#include <string.h>
#include <unistd.h>
#include <stdlib.h>

int main(void)
{
   int fd[2]; // using a integer array to store the value for 2 file descriptors.
   off_t cursorPos1, cursorPos2; // to record the offset for the fds
   FILE *file; // a pointer that points to a file, to help print the content for a file
   char character;

   char buf1[12] = "hello world"; // buffer1 with initialized content.
   char buf2[12];
```

```
    // assume foo1.txt and sample.txt are already created
    fd[0] = open("hw10_foo.txt", O_RDWR);
    fd[1] = open("hw10_sample.txt", O_RDWR);

    if (fd[0] == -1 || fd[1] == -1) {
        perror("Error opening files");
        exit(1);
    }
    printf("===1. after write(fd[0], buf1, strlen(buf1))====");

// writing [strlen(buf1)] bytes of the content from bu1 to file fd[0].
    write(fd[0], buf1, strlen(buf1));
// print the content in buf1 and buf2
    printf("\nbuf1: %s", buf1);
    printf("\nbuf2: %s", buf2);

// get the offset of fd[0] after the write function
    cursorPos1 = lseek(fd[0], 0, SEEK_CUR);
    if (cursorPos1 == -1) {
        perror("Error getting cursor position");
        close(fd[0]);
        close(fd[1]);
        exit(1);
    }

// get the offset of fd[1] after the write function
    printf("\nfd[0]: Current cursor1 position: %ld\n", (long)cursorPos1);

    cursorPos2 = lseek(fd[1], 0, SEEK_CUR);
    if (cursorPos2 == -1) {
        perror("Error getting cursor position");
        close(fd[0]);
        close(fd[1]);
        exit(1);
    }
    printf("fd[1]: Current cursor2 position: %ld\n", (long)cursorPos2);

    printf("\n>>>>>> Print File content in fd[0]: hw10_foo.txt<<<<<<\n");
// open "hw10_foo.txt" in read mode
    file = fopen("hw10_foo.txt", "r");
    if (file == NULL) {
        perror("Error opening file");
        return 1;
    }

// print the content in "hw10_foo.txt" of which the file descriptor is fd[0]
```

```
   while ((character = fgetc(file)) != EOF) {
       printf("%c", character);
    }

// close the file
    fclose(file);

    printf("\n\n\n===2. write(1, buf2, read(fd[0], buf2, 12))====\n");

/*
This function is write the content in buffer2 to the file descriptor 1(STDOUT);
However, the third parameter is a read() function, and the return value is the number of bytes
read from fd[0] to the buffer2. Therefore, is successfully read, the third parameter would be
12.

In summary, this statement was executed as the following sequence:
      1. read(fd[0], buf2, 12)): read 12 bytes of date from the file directed by fd[0] , and put
         the content to the buf2;
      2.  write(1, buf2, 12)): write 12 bytes of date from buf2, them direct to the file descriptor
         1 (STDOUT).
      3. In this case, the terminal STDOUT will display the content.

fd[0] ---read---->"hw10_foo.txt"                    read(fd[0], buf2, 12))
 |
 |----(write)----->buf2----(write)-- > STDOUT       write(1, buf2, read(fd[0], buf2, 12))

 in this way, write(1, buf2, read(fd[0], buf2, 12)) is equal to printf() .

*/
    write(1, buf2, read(fd[0], buf2, 12));
    printf("\nbuf1: %s", buf1);
    printf("\nbuf2: %s", buf2);

    cursorPos1 = lseek(fd[0], 0, SEEK_CUR);
    if (cursorPos1 == -1) {
        perror("Error getting cursor position");
        close(fd[0]);
        close(fd[1]);
        exit(1);
    }

    // Print the current cursor position
    printf("\nfd[0]: current cursor1 position: %ld\n", (long)cursorPos1);

    cursorPos2 = lseek(fd[1], 0, SEEK_CUR);
    if (cursorPos2 == -1) {
```

```
        perror("Error getting cursor position");
        close(fd[0]);
        close(fd[1]);
        exit(1);
    }

    // Print the current cursor position
    printf("fd[1]: current cursor2 position: %ld\n", (long)cursorPos2);
    close(fd[0]);
    close(fd[1]);

    return 0;
}
```

Pre-existing files:
hw10_foo.txt: Hello, how are you.
hw10_sample.txt: This is a sample

[Terminal Coding Tests]

Terminal

```
$ gcc hw10_print_wo_printf.c -o hw10_wo
$ ./hw10_wo
===1. after write(fd[0], buf1, strlen(buf1))====
buf1: hello world
buf2:
fd[0]: Current cursor1 position: 11
fd[1]: Current cursor2 position: 0

>>>>>> Print File content in fd[0]: hw10_foo.txt<<<<<<
hello worldare you.


===2. write(1, buf2, read(fd[0], buf2, 12))====
are you.
buf1: hello world
buf2: are you.
fd[0]: current cursor1 position: 19
fd[1]: current cursor2 position: 0
```

[Output analysis]

The original buf1, buf2 , and the file content in foo.txt is as follows:

index	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
buf1	h	e	l	l	o		w	o	r	l	d	\0								
buf2																				
fd[0]	H	e	l	l	o	,		h	o	w		a	r	e		y	o	u	.	\0

After the program execute the 1st write statement: write(fd[0], buf1, strlen(buf1))

buf1, buf2 , the file content in foo.txt, and the offset of the fd[0] is as follows:

index	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
buf1	h	e	l	l	o		w	o	r	l	d	\0								
buf2																				
fd[0]	h	~~e~~	~~l~~	~~l~~	~~o~~	~~,~~		~~h~~	~~o~~	~~w~~		a	r	e		y	o	u	.	\0
after write(fd[0], buf1, strlen(buf1))																				
fd[0]	h	e	l	l	o		w	o	r	l	d	a	r	e		y	o	u	.	\0
↑ fd[0] offset_1																				

Here we got the output in the terminal as what we expected:

```
beza@beza:~/CS510-APUE/Homework/week03$ ./hw10_wo
===1. after write(fd[0], buf1, strlen(buf1))====
buf1: hello world
buf2:
fd[0]: Current cursor1 position: 11
fd[1]: Current cursor2 position: 0

>>>>>> Print File content in fd[0]: hw10_foo.txt<<<<<<
hello worldare you.
```

Then the program reach the statement of *write(1, buf2, read(fd[0], buf2, 12))*, we split this statement into 2 steps to analyze:

1. *read(fd[0], buf2, 12)):* read 12 bytes of date from the file directed by fd[0] , and put the content to the buf2;
2. *write(1, buf2, 12)):* write 12 bytes of date from buf2, them direct to the file descriptor 1 (STDOUT).

Step1: *read(fd[0], buf2, 12)):*

index	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
buf1	h	e	l	l	o		w	o	r	l	d	\0								
buf2																				
fd[0]	h	e	l	l	o		w	o	r	l	d	a	r	e		y	o	u	.	\0
											⬆ fd[0] offset_1									
read(fd[0], buf2, 12)):																				
fd[0]	h	e	l	l	o		w	o	r	l	d	a	r	e		y	o	u	.	\0
											⬆ fd[0] offset_1					fd[0] offset_2 ⬆				
buf2	a	r	e		y	o	u	.												

Step2: *write(1, buf2, 12)):*

index	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
buf1	h	e	l	l	o		w	o	r	l	d	\0								
buf2	a	r	e		y	o	u	.	\0											
fd[0]	h	e	l	l	o		w	o	r	l	d	a	r	e		y	o	u	.	\0
																			fd[0] offset_2 ⬆	
write(1, buf2, 12)):																				
STDOUT	a	r	e		y	o	u	.												

After the second write() operation statement of *write(1, buf2, read(fd[0], buf2, 12))*, we also got the results as expected.

```
>>>>>> Print File content in fd[0]: hw10_foo.txt<<<<<<
hello worldare you.


===2. write(1, buf2, read(fd[0], buf2, 12))====
are you.
buf1: hello world
buf2: are you.
fd[0]: current cursor1 position: 19
fd[1]: current cursor2 position: 0
beza@beza:~/CS510-APUE/Homework/week03$ cat hw10_foo.txt
hello worldare you.beza@beza:~/CS510-APUE/Homework/week03$
```

By revieving the source code for the file structure at the "fs.h" Line# 1008, we can find that the structure of file contains a filed of f_pos for each file, and the f_pos is a pointer to the current file position. It keeps track of where the next read operation should start.:

https://elixir.bootlin.com/linux/v6.9/source/include/linux/fs.h#L1008

```
struct file {
```

```
        ……
// a pointer to the current file position.
// it keeps track of where the next read operation should start.
        loff_t      f_pos; // <---- current offset is defined here
        unsigned int   f_flags;
        ……}
```

In the book "*Linux Device Drivers*", a more detailed explanation is there. It says that:

https://www.oreilly.com/library/view/linux-device-drivers/0596000081/ch03s04.html

"loff_t f_pos;

The current reading or writing position. loff_t is a 64-bit value (long long in gcc terminology). The driver can read this value if it needs to know the current position in the file, but should never change it (read and write should update a position using the pointer they receive as the last argument instead of acting on filp->f_pos directly)."

By reviewing the Linux manual page for *read()* and write*()*, we could have a better understanding of how the offset effect the *read()* and *write()* function resulting in the content change in the "*hw10_foo.txt*". Whether *read()*or *write()* function, as long as they share the same file descriptor, then they share the same file offset information.

https://man7.org/linux/man-pages/man2/read.2.html

ssize_t read(int *fd*, void *buf* [.*count*], size_t *count*);

DESCRIPTION

read() attempts to read up to *count* bytes from file descriptor *fd* into the buffer starting at *buf*. On files that support seeking, the read operation commences at the file offset, and the file offset is incremented by the number of bytes read. If the file offset is at or past the end of file, no bytes are read, and read() returns zero.

RETURN VALUE

On success, the number of bytes read is returned (zero indicates end of file), and the file position is advanced by this number. It is not an error if this number is smaller than the number of bytes requested……

https://man7.org/linux/man-pages/man2/write.2.html

ssize_t write(int *fd*, const void *buf* [.*count*], size_t *count*);

DESCRIPTION

write() writes up to *count* bytes from the buffer starting at *buf* to the file referred to by the file descriptor *fd* ……

For a seekable file (i.e., one to which lseek(2) may be applied, for example, a regular file) writing takes place at the file offset, and the file offset is incremented by the number of bytes actually written……

APPENDIX

A1 - Q3 Original Code:

Original file_open.c

```
#include <errno.h>
#include <fcntl.h>
#include <stdio.h>
#include <unistd.h>

extern int errno;

int main()
{
   // if file does not have in directory
   // then foo.txt is created.
// open or created the file of which the type is ready only.
   int fd = open("foo.txt ", O_RDONLY | O_CREAT);
   printf("fd = %d\n", fd);

   if (fd == -1) {
      // print which type of error have in a code
      printf("Error Number % d\n", errno);

      // print program detail "Success or failure"
      perror("Program");
   }
   return 0;
}
```

The content in pre-existing foo.txt: hello world

A1 - Q3 Full Terminal Outputs

Click here to return to Q3 Terminal Output

```
$ cat hw3_existed_foo.txt
hello world
```

```
$ gcc hw3_file_open_no.c -o hw3
$ ./hw3
------Testing O_CREAT Mode WITHOUT Permission Bit------
Creating File: hw3_foo_no.txt ==> fd = 3
Creating File: hw3_foo_no.txt, Permission Bits: 570

------Testing O_CREAT Mode with 0444------
Creating File with 0444: hw3_foo_0444.txt ==> fd = 4
Creating File: hw3_foo_0444.txt, Permission Bits: 444

------Testing O_CREAT Mode with existing file------
Open Existed File: hw3_foo_existed.txt ==> fd = 5
File: hw3_foo_existed.txt, Permission Bits: 664


========================================
Executing command $: ls -l hw3*.txt
-rw-rw-r-- 1 beza beza 13 May 21 18:07 hw3_existed_foo.txt
-r--r--r-- 1 beza beza  0 May 21 18:46 hw3_foo_0444.txt
-r-xrwx--T 1 beza beza  0 May 21 18:46 hw3_foo_no.txt
$ ./hw3_del
Deleted: hw3_foo_no.txt
Deleted: hw3_foo_0444.txt
$ ./hw3
------Testing O_CREAT Mode WITHOUT Permission Bit------
Creating File: hw3_foo_no.txt ==> fd = 3
Creating File: hw3_foo_no.txt, Permission Bits: 130

------Testing O_CREAT Mode with 0444------
Creating File with 0444: hw3_foo_0444.txt ==> fd = 4
Creating File: hw3_foo_0444.txt, Permission Bits: 444

------Testing O_CREAT Mode with existing file------
Open Existed File: hw3_foo_existed.txt ==> fd = 5
File: hw3_foo_existed.txt, Permission Bits: 664


========================================
Executing command $: ls -l hw3*.txt
-rw-rw-r-- 1 beza beza 13 May 21 18:07 hw3_existed_foo.txt
-r--r--r-- 1 beza beza  0 May 21 18:46 hw3_foo_0444.txt
---s-ws--- 1 beza beza  0 May 21 18:46 hw3_foo_no.txt
$ echo "hello world" > hw3_foo_no.txt
-bash: hw3_foo_no.txt: Permission denied
$ echo "hello world" > hw3_foo_0444.txt
-bash: hw3_foo_0444.txt: Permission denied
```

```
$ echo "hello SFBU + 1" > hw3_existed_foo.txt
$ cat hw3_existed_foo.txt
hello SFBU + 1
$ ./hw3_del
Deleted: hw3_foo_no.txt
Deleted: hw3_foo_0444.txt
$ ./hw3
------Testing O_CREAT Mode WITHOUT Permission Bit------
Creating File: hw3_foo_no.txt ==> fd = 3
Creating File: hw3_foo_no.txt, Permission Bits: 150

------Testing O_CREAT Mode with 0444------
Creating File with 0444: hw3_foo_0444.txt ==> fd = 4
Creating File: hw3_foo_0444.txt, Permission Bits: 444

------Testing O_CREAT Mode with existing file------
Open Existed File: hw3_foo_existed.txt ==> fd = 5
File: hw3_foo_existed.txt, Permission Bits: 664


========================================
Executing command $: ls -l hw3*.txt
-rw-rw-r-- 1 beza beza 15 May 21 18:47 hw3_existed_foo.txt
-r--r--r-- 1 beza beza  0 May 21 18:47 hw3_foo_0444.txt
---xr-x--T 1 beza beza  0 May 21 18:47 hw3_foo_no.txt
$ ./hw3_del
Deleted: hw3_foo_no.txt
Deleted: hw3_foo_0444.txt
$ ./hw3
------Testing O_CREAT Mode WITHOUT Permission Bit------
Creating File: hw3_foo_no.txt ==> fd = 3
Creating File: hw3_foo_no.txt, Permission Bits: 170

------Testing O_CREAT Mode with 0444------
Creating File with 0444: hw3_foo_0444.txt ==> fd = 4
Creating File: hw3_foo_0444.txt, Permission Bits: 444

------Testing O_CREAT Mode with existing file------
Open Existed File: hw3_foo_existed.txt ==> fd = 5
File: hw3_foo_existed.txt, Permission Bits: 664


========================================
Executing command $: ls -l hw3*.txt
-rw-rw-r-- 1 beza beza 15 May 21 18:47 hw3_existed_foo.txt
-r--r--r-- 1 beza beza  0 May 21 18:48 hw3_foo_0444.txt
```

```
---srws--- 1 beza beza  0 May 21 18:48 hw3_foo_no.txt
$ ./hw3_del
Deleted: hw3_foo_no.txt
Deleted: hw3_foo_0444.txt
$ ./hw3
------Testing O_CREAT Mode WITHOUT Permission Bit------
Creating File: hw3_foo_no.txt ==> fd = 3
Creating File: hw3_foo_no.txt, Permission Bits: 250

------Testing O_CREAT Mode with 0444------
Creating File with 0444: hw3_foo_0444.txt ==> fd = 4
Creating File: hw3_foo_0444.txt, Permission Bits: 444

------Testing O_CREAT Mode with existing file------
Open Existed File: hw3_foo_existed.txt ==> fd = 5
File: hw3_foo_existed.txt, Permission Bits: 664


========================================
Executing command $: ls -l hw3*.txt
-rw-rw-r-- 1 beza beza 15 May 21 18:47 hw3_existed_foo.txt
-r--r--r-- 1 beza beza  0 May 21 18:48 hw3_foo_0444.txt
--w-r-x--- 1 beza beza  0 May 21 18:48 hw3_foo_no.txt
$ ./hw3_del
Deleted: hw3_foo_no.txt
Deleted: hw3_foo_0444.txt
$ ./hw3
------Testing O_CREAT Mode WITHOUT Permission Bit------
Creating File: hw3_foo_no.txt ==> fd = 3
Creating File: hw3_foo_no.txt, Permission Bits: 50

------Testing O_CREAT Mode with 0444------
Creating File with 0444: hw3_foo_0444.txt ==> fd = 4
Creating File: hw3_foo_0444.txt, Permission Bits: 444

------Testing O_CREAT Mode with existing file------
Open Existed File: hw3_foo_existed.txt ==> fd = 5
File: hw3_foo_existed.txt, Permission Bits: 664


========================================
Executing command $: ls -l hw3*.txt
-rw-rw-r-- 1 beza beza 15 May 21 18:47 hw3_existed_foo.txt
-r--r--r-- 1 beza beza  0 May 21 18:48 hw3_foo_0444.txt
---Sr-x--T 1 beza beza  0 May 21 18:48 hw3_foo_no.txt
$ ./hw3_del
```

```
Deleted: hw3_foo_no.txt
Deleted: hw3_foo_0444.txt
$ ./hw3
------Testing O_CREAT Mode WITHOUT Permission Bit------
Creating File: hw3_foo_no.txt ==> fd = 3
Creating File: hw3_foo_no.txt, Permission Bits: 710

------Testing O_CREAT Mode with 0444------
Creating File with 0444: hw3_foo_0444.txt ==> fd = 4
Creating File: hw3_foo_0444.txt, Permission Bits: 444

------Testing O_CREAT Mode with existing file------
Open Existed File: hw3_foo_existed.txt ==> fd = 5
File: hw3_foo_existed.txt, Permission Bits: 664


========================================
Executing command $: ls -l hw3*.txt
-rw-rw-r-- 1 beza beza 15 May 21 18:47 hw3_existed_foo.txt
-r--r--r-- 1 beza beza  0 May 21 18:48 hw3_foo_0444.txt
-rwx--s--- 1 beza beza  0 May 21 18:48 hw3_foo_no.txt
$ echo "Bugs with this program?" > hw3_foo_no.txt
$ cat hw3_foo_no.txt
Bugs with this program?
```

Click here to return to Q3 Terminal Output

A2 - Q4 Original Code

```
// C program to illustrate
// read system Call
#include <fcntl.h>
#include <stdio.h>
#include <unistd.h>

int main()
{
    int fd, sz;
    char* c = (char*) calloc(100, sizeof(char));

    fd = open("hw4_foo.txt", O_RDONLY);
    if (fd < 0) {
        perror("r1");
```

```
        exit(1);
    }

    sz = read(fd, c, 13); //
    printf("called read(% d, c, 13). returned that %d bytes were read.\n", fd, sz);

    c[sz] = '\0';
    printf("Those bytes are as follows: % s\n", c);

    return 0;
}
```

Foo.txt

```
hello world@@@@@
```

Q5 Original Code

```
// C program to illustrate
// write system Call
#include<stdio.h>
#include <fcntl.h>
main()
{
int sz;

int fd = open("foo.txt", O_WRONLY | O_CREAT | O_TRUNC, 0644);
printf("fd = %d\n", fd);
if (fd < 0)
{
    perror("r1");
    exit(1);
}

sz = write(fd, "hello geeks\n", strlen("hello geeks\n"));

printf("called write(%d, \"hello geeks\\n\", %d)."
    " It returned %d\n", fd, strlen("hello geeks\n"), sz);

close(fd);
}
```

Foo1.txt

```
hello geeks
~
```

A3 - Q8 Original Code

```
// C program to illustrate close system Call
#include<stdio.h>
#include<fcntl.h>
int main()
{
    // assume that foo.txt is already created
    int fd1 = open("hw8_foo.txt", O_RDONLY, 0);
    close(fd1);

    // assume that baz.tzt is already created
    int fd2 = open("hw8_baz.txt", O_RDONLY, 0);

    printf("fd2 = % d\n", fd2);
    exit(0);
}
~ Foo.txt
hello world

Baz.txt
Hello, its Baz!
~
```

A4 - Q9 Original Code

```
#include <fcntl.h>
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>

int main()
{
    char c;
    int fd1 = open("sample.txt", O_RDONLY, 0);
    int fd2 = open("sample.txt", O_RDONLY, 0);
    read(fd1, &c, 1);
    printf("c = %c\n", c);
    read(fd2, &c, 1);
    printf("c = %c\n", c);
    exit(0);
```

```
}
Output:
Sample.txt

This is a sample file.
```

A5 - Q10 Original Code

```
// C program to illustrate
// I/O system Calls
#include <fcntl.h>
#include <stdio.h>
#include <string.h>
#include <unistd.h>

int main(void)
{
   int fd[2];
   char buf1[12] = "hello world";
   char buf2[12];

   // assume foobar.txt is already created
   fd[0] = open("foo1.txt", O_RDWR);
   fd[1] = open("sample.txt", O_RDWR);

   write(fd[0], buf1, strlen(buf1));
   write(1, buf2, read(fd[1], buf2, 12));

   close(fd[0]);
   close(fd[1]);

   return 0;
}
~
foo1.txt: Hello, how are you.
sample.txt : This is a sample.
```