CSE 344 System Programming

Homework 5

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1-Producer & Consumer

This project was about the producer-consumer problem. For this reason, one producer and a number of consumer threads, determined by the user input, were created. The tasks of each are as follows:

Producer:

- Takes the source and destination folders as arguments. It opens these folders using the opendir() function. If the destination folder doesn't exist, it creates it using the mkdir() function.
- Checks if the folders are successfully opened, and returns NULL if any folder fails to open.
- Reads each file and folder in the source folder using the readdir() function. It retrieves the stats of each entry using the stat() function and stores them in the fileStat structure.
- Determines whether the read entry is a regular file or a directory based on its stat values. It performs the copying operation only on regular files. Files within a source directory are also recursively copied by calling the function again.
- If the entry is a regular file, it opens the source and destination file descriptors. If a file with the same name already exists in the destination folder, it is truncated. This operation is performed using open(dest_filepath, O_WRONLY | O_CREAT | O_TRUNC). It checks for errors in file opening and returns NULL if any occur.
- If the source and destination files are successfully opened, it puts their file descriptors into a Task object. Then it puts this task into the taskQueue array. In this project, the buffer is represented by the taskQueue.
- Access to the taskQueue (buffer) is managed using two semaphores. One is semEmpty (checks if the buffer is empty), and the other is semFull (checks if the buffer is full). These two semaphores ensure synchronization between the producer and consumer for the taskQueue (buffer).
- If the producer thread has finished recursively processing all directories and there are no more files to read, it sets the "done" flag to 1 and notifies the consumers.
- At the end of the function, the opened folders are closed.

Consumer:

- Runs in an infinite while loop. After a task is added to the taskQueue (buffer) by the producer, a consumer thread from the thread pool is assigned to that task.
- While waiting for a new task, the consumer continuously checks the "done" flag.
- If the "done" flag is set to 1 and there is a task in the taskQueue (buffer), the consumer takes and completes the task, and then exits the while loop by returning NULL.
- If the "done" flag is set to 1 and there are no tasks in the taskQueue (buffer), the consumer directly exits the while loop by returning NULL.
- After retrieving a task from the taskQueue (buffer), the consumer reads the source file using the read() function. It then writes each byte value it reads to the destination file using the write() function.
- During the read and write operations, the read byte values are accumulated, and at the end of the program, they are printed as statistics.
- After each copying operation, a message is printed to the standard output indicating the number of bytes copied from which file to which file.
- All opened files (file descriptors opened by the producer) are closed by the consumer at the end.

2-Thread Pool

For the consumer threads, a thread pool implementation was required. Therefore, I created a pthread* array called "consumers." I allocated memory for this array based on the value provided by the user. Then, using pthread_create(), I made each consumer active within the main(). The consumer threads execute the consumerFunction() function. After each task is added by the producer, an idle thread without a task in the pool is awakened, and the given task is performed. The synchronization of the threads within the thread pool is achieved using "pthread_cond_t condQueue." Each consumer thread waits in a sleep state using pthread_cond_wait() as long as taskCount == 0 and done == 0. When a task is added to the taskQueue (buffer) by the producer, an asleep thread is awakened using pthread_cond_signal() to perform the task. If the program encounters any error or if the done flag is set to 1, all sleeping threads are awakened using pthread_cond_broadcast().

3-Handling Race Conditions

To prevent race conditions between threads, pthread_mutex_t was used. Two different mutexes were used to ensure synchronization for both the taskQueue (buffer) and the standard output. Before accessing the taskQueue, lock() is applied using mutexQueue, then necessary operations are performed (such as retrieving a task, decreasing/increasing the task count, deleting a task, adding a task, etc.), and mutexQueue is unlocked using unlock(). This process ensures synchronization among threads while accessing the taskQueue.

Additionally, both consumer and producer threads print to the standard output using printf(). To prevent potential race conditions that may arise during printing, lock() and unlock() operations were performed using mutexSTDOUT.

4- Buffer

In this project, the buffer is referred to as the taskQueue. It is an array of Task objects. Each Task object contains the source file descriptor, destination file descriptor, source filename, and destination filename. In the producer, when file information is read from the source folder, a new Task is created and added to the taskQueue. Then, consumers retrieve the first element from the taskQueue (FIFO) and perform the given task. The buffer operates based on the First In - First Out (FIFO) principle.

```
typedef struct Task{
    int source_fd;
    int dest_fd;
    char * source_filename;
    char * dest_filename;
}Task;
```

5-Signal Handling

In this project, only the SIGINT signal is handled. The SIGCHLD signal is not handled since there are no child processes involved. The handling of the SIGINT signal is as follows:

- The user sends the SIGINT signal to the program.
- The program receives the SIGINT signal and goes to the sigIntHandler() function.
- In this function, the "done" flag is first set to 1, and pthread_cond_broadcast() is used to wake up the sleeping threads in the thread pool and wait for them to shut themselves down.
- If a consumer thread is currently in the process of copying a file when the SIGINT signal is received, that thread continues its operation. After completing its task, it closes itself.

6- Experiments with different buffer size and consumer threads

Buffer Size = 5
Consumer Threads = 3

Copied files = 7

Total time for copying = 4.74 seconds

Buffer Size = 5
Consumer Threads = 5

Copied files = 7

Total time for copying = 5.12 seconds

Buffer Size = 3
Consumer Threads = 5

Copied files = 7

Total time for copying = 4.81 seconds

Buffer Size = 7
Consumer Threads = 7

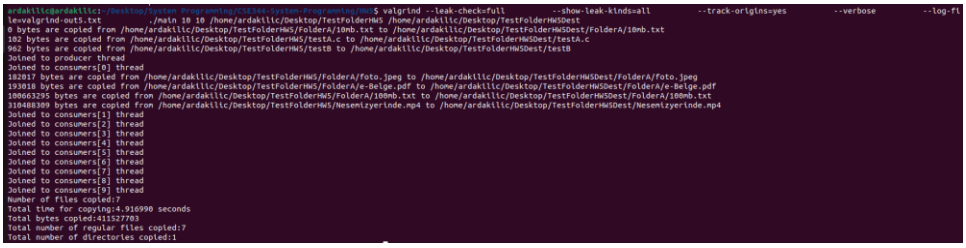
Copied files = 7

Total time for copying = 4.68 seconds (Best case)

Buffer Size = 10
Consumer Threads = 10

Copied files = 7

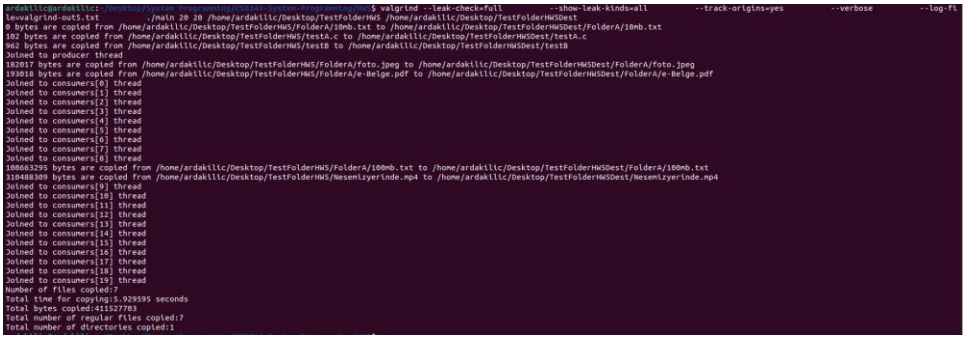
Total time for copying = 4.91 seconds



Buffer Size = 20
Consumer Threads = 20

Copied files = 7

Total time for copying = 5.92 seconds (Worst case)



7-Per-process limit on the number of open file descriptors

Each process has a limited number of file opening rights at the same time. If this number is reached, a new file cannot be opened without closing an already open file. If the open() function tries to open a file and the file descriptor limit has been reached, the file cannot be opened and the errno value is set to EMFILE. By using this errno value, it can be determined within the program whether there is an error due to reaching the limit.

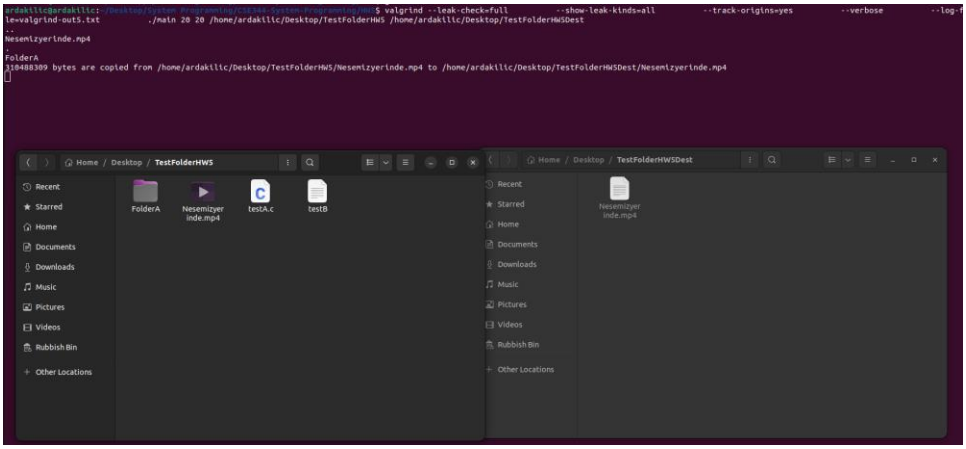
```
source_fd = open(source_filepath,O_RDONLY,0666);
dest_fd = open(dest_filepath, O_WRONLY | O_CREAT | O_TRUNC, 0666);

/* If there is an error at opening file, then print it. */
if(source_fd == -1 || dest_fd == -1){
    if(errno == EMFILE){
        perror("Exceeded the per-process limit on open file descriptors.\n");
    }
    else{
        pthread_mutex_lock(&mutexSTDOUT);
        printf("Error at opening file\n");
        pthread_mutex_unlock(&mutexSTDOUT);
    }
    pthread_mutex_lock(&mutexQueue);
    done = 1; // Set done flag
    pthread_mutex_unlock(&mutexQueue);
    pthread_cond_broadcast(&condQueue);
    closedir(SOURCE_DIR);
    closedir(DEST_DIR);
    return NULL;
}
```

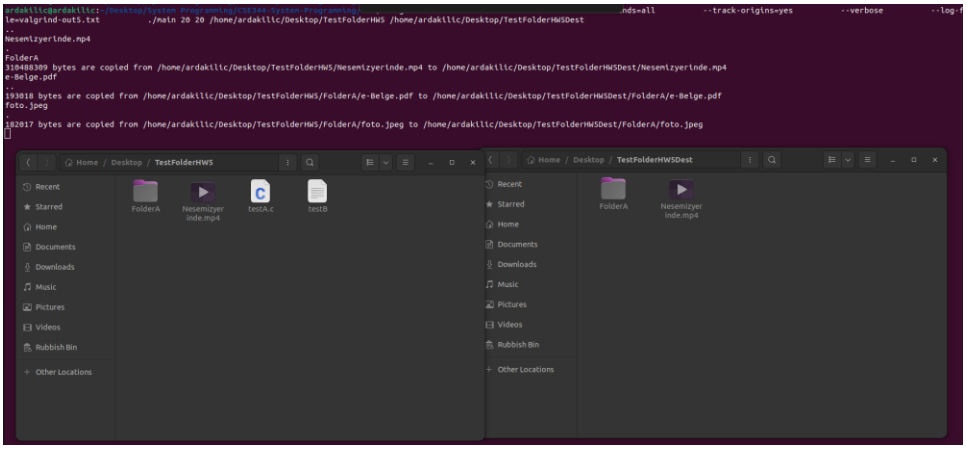
8- Tests

The program is started. Copy process will be from /Desktop/TestFolderHW5 to /Desktop/TestFolderHW5Dest folder. (Sleep operation is used only for taking screenshots before program termination. It is removed afterwards.)

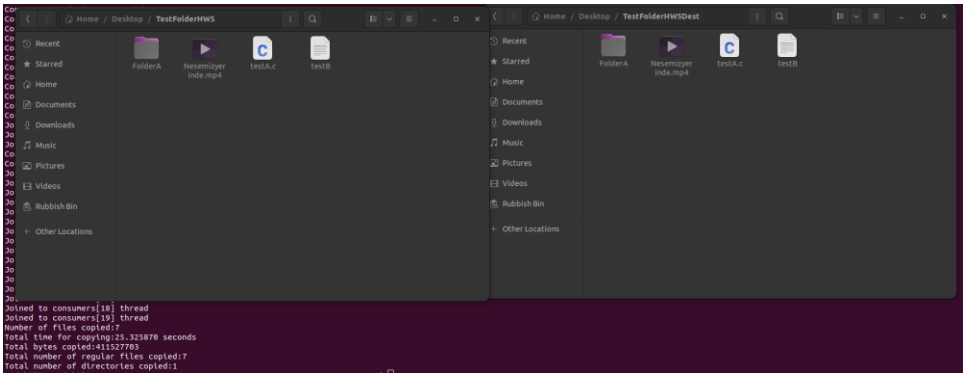
The first file is being written to the destination file.



The directory is created in the destination folder.



The program is finished. Both folders have 411 MB at the end of the program.



The SIGINT signal is sent to the program during its execution. Only one file is written to the destination folder. During this test, sleep() is used to prevent producer thread to set done flag before SIGINT handler.