Operating Systems (CSE1603)
Continuous Evaluation Examination
Apr 2025

Marks : 10

Assessment Criteria :

- **Complete any three of the following project headings.**
- **Have complete conceptual understanding of the project heading that you choose**
- **Deadline : 12th March 2025**

Project One Heading : Process Synchronization

Assume that a finite number of resources of a single resource type must be managed. Processes may ask for a number of these resources and will return them once finished. As an example, many commercial software packages provide a given number of ***licenses***, indicating the number of applications that may run concurrently. When the application is started, the license count is decremented. When the application is terminated, the license count is incremented. If all licenses are in use, requests to start the application are denied. Such a request will be granted only when an existing license holder terminates the application and a license is returned.

The following program segment is used to manage a finite number of instances of an available resource. The maximum number of resources and the number of available resources are declared as follows:

```
#define MAX_RESOURCES 5
int available_resources = MAX_RESOURCES;
```

When a process wishes to obtain a number of resources, it invokes the decrease_count() function:

```
/* decrease available_resources by count resources */
/* return 0 if sufficient resources available, */
/* otherwise return -1 */
int decrease_count(int count) {
  if (available_resources < count)
    return -1;
  else {
    available_resources -= count;

    return 0;
  }
}
```

When a process wants to return a number of resources, it calls the increase_count() function:

```
/* increase available_resources by count */
int increase_count(int count) {
  available_resources += count;

  return 0;
}
```

(PTO)

The preceding program segment produces a race condition. Do the following:

a. Identify the data involved in the race condition.

b. Identify the location (or locations) in the code where the race condition occurs.

c. Using a semaphore or mutex lock, fix the race condition. It is permissible to modify the `decrease_count()` function so that the calling process is blocked until sufficient resources are available.

6.34 The `decrease_count()` function in the previous exercise currently returns 0 if sufficient resources are available and -1 otherwise. This leads to awkward programming for a process that wishes to obtain a number of resources:

```
while (decrease_count(count) == -1)
  ;
```

Rewrite the resource-manager code segment using a monitor and condition variables so that the `decrease_count()` function suspends the process until sufficient resources are available. This will allow a process to invoke `decrease_count()` by simply calling

```
decrease_count(count);
```

The process will return from this function call only when sufficient resources are available.

(PTO)

Project Two Heading : Deadlocks

Banker's Algorithm

For this project, you will write a program that implements the banker's algorithm discussed in Section 8.6.3. Customers request and release resources from the bank. The banker will grant a request only if it leaves the system in a safe state. A request that leaves the system in an unsafe state will be denied. Although the code examples that describe this project are illustrated in C, you may also develop a solution using Java.

The Banker

The banker will consider requests from n customers for m resources types, as outlined in Section 8.6.3. The banker will keep track of the resources using the following data structures:

```
#define NUMBER_OF_CUSTOMERS 5
#define NUMBER_OF_RESOURCES 4

/* the available amount of each resource */
int available[NUMBER_OF_RESOURCES];

/*the maximum demand of each customer */
int maximum[NUMBER_OF_CUSTOMERS][NUMBER_OF_RESOURCES];

/* the amount currently allocated to each customer */
int allocation[NUMBER_OF_CUSTOMERS][NUMBER_OF_RESOURCES];

/* the remaining need of each customer */
int need[NUMBER_OF_CUSTOMERS][NUMBER_OF_RESOURCES];
```

(PTO)

The banker will grant a request if it satisfies the safety algorithm outlined in Section 8.6.3.1. If a request does not leave the system in a safe state, the banker will deny it. Function prototypes for requesting and releasing resources are as follows:

```
int request_resources(int customer_num, int request[]);

void release_resources(int customer_num, int release[]);
```

The `request_resources()` function should return 0 if successful and −1 if unsuccessful.

Testing Your Implementation

Design a program that allows the user to interactively enter a request for resources, to release resources, or to output the values of the different data structures (`available`, `maximum`, `allocation`, and `need`) used with the banker's algorithm.

You should invoke your program by passing the number of resources of each type on the command line. For example, if there were four resource types, with ten instances of the first type, five of the second type, seven of the third type, and eight of the fourth type, you would invoke your program as follows:

```
./a.out 10 5 7 8
```

The `available` array would be initialized to these values.

Your program will initially read in a file containing the maximum number of requests for each customer. For example, if there are five customers and four resources, the input file would appear as follows:

```
6,4,7,3
4,2,3,2
2,5,3,3
6,3,3,2
5,6,7,5
```

where each line in the input file represents the maximum request of each resource type for each customer. Your program will initialize the `maximum` array to these values.

Your program will then have the user enter commands responding to a request of resources, a release of resources, or the current values of the different data structures. Use the command '`RQ`' for requesting resources, '`RL`' for releasing resources, and '`*`' to output the values of the different data structures. For example, if customer 0 were to request the resources $(3, 1, 2, 1)$, the following command would be entered:

```
RQ 0 3 1 2 1
```

Your program would then output whether the request would be satisfied or denied using the safety algorithm outlined in Section 8.6.3.1.

(PTO)

Similarly, if customer 4 were to release the resources (1, 2, 3, 1), the user would enter the following command:

```
RL 4 1 2 3 1
```

Finally, if the command '*' is entered, your program would output the values of the `available`, `maximum`, `allocation`, and `need` arrays.

Project Three Heading : Multithreading

A ***Sudoku*** puzzle uses a 9×9 grid in which each column and row, as well as each of the nine 3×3 subgrids, must contain all of the digits $1 \cdots 9$. Figure 4.26 presents an example of a valid Sudoku puzzle. This project consists of designing a multithreaded application that determines whether the solution to a Sudoku puzzle is valid.

There are several different ways of multithreading this application. One suggested strategy is to create threads that check the following criteria:

- A thread to check that each column contains the digits 1 through 9
- A thread to check that each row contains the digits 1 through 9

6	2	4	5	3	9	1	8	7
5	1	9	7	2	8	6	3	4
8	3	7	6	1	4	2	9	5
1	4	3	8	6	5	7	2	9
9	5	8	2	4	7	3	6	1
7	6	2	3	9	1	4	5	8
3	7	1	9	5	6	8	4	2
4	9	6	1	8	2	5	7	3
2	8	5	4	7	3	9	1	6

(PTO)

- Nine threads to check that each of the 3×3 subgrids contains the digits 1 through 9

This would result in a total of eleven separate threads for validating a Sudoku puzzle. However, you are welcome to create even more threads for this project. For example, rather than creating one thread that checks all nine columns, you could create nine separate threads and have each of them check one column.

I. Passing Parameters to Each Thread

The parent thread will create the worker threads, passing each worker the location that it must check in the Sudoku grid. This step will require passing several parameters to each thread. The easiest approach is to create a data structure using a `struct`. For example, a structure to pass the row and column where a thread must begin validating would appear as follows:

```
/* structure for passing data to threads */
typedef struct
{
  int row;
  int column;
} parameters;
```

Both Pthreads and Windows programs will create worker threads using a strategy similar to that shown below:

```
parameters *data = (parameters *) malloc(sizeof(parameters));
data->row = 1;
data->column = 1;
/* Now create the thread passing it data as a parameter */
```

The `data` pointer will be passed to either the `pthread_create()` (Pthreads) function or the `CreateThread()` (Windows) function, which in turn will pass it as a parameter to the function that is to run as a separate thread.

II. Returning Results to the Parent Thread

Each worker thread is assigned the task of determining the validity of a particular region of the Sudoku puzzle. Once a worker has performed this check, it must pass its results back to the parent. One good way to handle this is to create an array of integer values that is visible to each thread. The i^{th} index in this array corresponds to the i^{th} worker thread. If a worker sets its corresponding value to 1, it is indicating that its region of the Sudoku puzzle is valid. A value of 0 indicates otherwise. When all worker threads have completed, the parent thread checks each entry in the result array to determine if the Sudoku puzzle is valid.

(PTO)

Project Four Heading : IPC

This project consists of designing a C program to serve as a shell interface that accepts user commands and then executes each command in a separate process. Your implementation will support input and output redirection, as well as pipes as a form of IPC between a pair of commands. Completing this project will involve using the UNIX `fork()`, `exec()`, `wait()`, `dup2()`, and `pipe()` system calls and can be completed on any Linux, UNIX, or macOS system.

I. Overview

A shell interface gives the user a prompt, after which the next command is entered. The example below illustrates the prompt `osh>` and the user's next command: `cat prog.c`. (This command displays the file `prog.c` on the terminal using the UNIX `cat` command.)

```
osh>cat prog.c
```

One technique for implementing a shell interface is to have the parent process first read what the user enters on the command line (in this case, `cat prog.c`) and then create a separate child process that performs the command. Unless otherwise specified, the parent process waits for the child to exit before continuing. This is similar in functionality to the new process creation illustrated in Figure 3.9. However, UNIX shells typically also allow the child process to run in the background, or concurrently. To accomplish this, we add an ampersand (`&`) at the end of the command. Thus, if we rewrite the above command as

```
osh>cat prog.c &
```

the parent and child processes will run concurrently.

The separate child process is created using the `fork()` system call, and the user's command is executed using one of the system calls in the `exec()` family (as described in Section 3.3.1).

A C program that provides the general operations of a command-line shell is supplied in Figure 3.36. The `main()` function presents the prompt `osh->` and outlines the steps to be taken after input from the user has been read. The `main()` function continually loops as long as `should_run` equals 1; when the user enters `exit` at the prompt, your program will set `should_run` to 0 and terminate.

This project is organized into several parts:

1. Creating the child process and executing the command in the child
2. Providing a history feature
3. Adding support of input and output redirection
4. Allowing the parent and child processes to communicate via a pipe

(PTO)

```c
#include <stdio.h>
#include <unistd.h>

#define MAX_LINE 80 /* The maximum length command */

int main(void)
{
char *args[MAX_LINE/2 + 1]; /* command line arguments */
int should_run = 1; /* flag to determine when to exit program */

   while (should_run) {
      printf("osh>");
      fflush(stdout);

      /**
       * After reading user input, the steps are:
       * (1) fork a child process using fork()
       * (2) the child process will invoke execvp()
       * (3) parent will invoke wait() unless command included &
       */
   }

    return 0;
}
```

II. Executing Command in a Child Process

The first task is to modify the `main()` function in Figure 3.36 so that a child process is forked and executes the command specified by the user. This will require parsing what the user has entered into separate tokens and storing the tokens in an array of character strings (`args` in Figure 3.36). For example, if the user enters the command `ps -ael` at the `osh>` prompt, the values stored in the `args` array are:

```
args[0] = "ps"
args[1] = "-ael"
args[2] = NULL
```

This `args` array will be passed to the `execvp()` function, which has the following prototype:

```
execvp(char *command, char *params[])
```

Here, `command` represents the command to be performed and `params` stores the parameters to this command. For this project, the `execvp()` function should be invoked as `execvp(args[0], args)`. Be sure to check whether the user included & to determine whether or not the parent process is to wait for the child to exit.

(PTO)

III. Creating a History Feature

The next task is to modify the shell interface program so that it provides a ***history*** feature to allow a user to execute the most recent command by entering `!!`. For example, if a user enters the command `ls -l`, she can then execute that command again by entering `!!` at the prompt. Any command executed in this fashion should be echoed on the user's screen, and the command should also be placed in the history buffer as the next command.

Your program should also manage basic error handling. If there is no recent command in the history, entering `!!` should result in a message "`No commands in history.`"

IV. Redirecting Input and Output

Your shell should then be modified to support the '>' and '<' redirection operators, where '>' redirects the output of a command to a file and '<' redirects the input to a command from a file. For example, if a user enters

```
osh>ls > out.txt
```

the output from the `ls` command will be redirected to the file `out.txt`. Similarly, input can be redirected as well. For example, if the user enters

```
osh>sort < in.txt
```

the file `in.txt` will serve as input to the `sort` command.

Managing the redirection of both input and output will involve using the `dup2()` function, which duplicates an existing file descriptor to another file descriptor. For example, if `fd` is a file descriptor to the file `out.txt`, the call

```
dup2(fd, STDOUT_FILENO);
```

duplicates `fd` to standard output (the terminal). This means that any writes to standard output will in fact be sent to the `out.txt` file.

You can assume that commands will contain either one input or one output redirection and will not contain both. In other words, you do not have to be concerned with command sequences such as `sort < in.txt > out.txt`.

(PTO)

V. Communication via a Pipe

The final modification to your shell is to allow the output of one command to serve as input to another using a pipe. For example, the following command sequence

```
osh>ls -l | less
```

has the output of the command `ls -l` serve as the input to the `less` command. Both the `ls` and `less` commands will run as separate processes and will communicate using the UNIX `pipe()` function described in Section 3.7.4. Perhaps the easiest way to create these separate processes is to have the parent process create the child process (which will execute `ls -l`). This child will also create another child process (which will execute `less`) and will establish a pipe between itself and the child process it creates. Implementing pipe functionality will also require using the `dup2()` function as described in the previous section. Finally, although several commands can be chained together using multiple pipes, you can assume that commands will contain only one pipe character and will not be combined with any redirection operators.

(PTO)

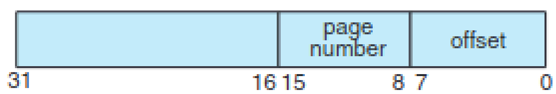
Project Five Heading : Virtual Memory and Paging

Designing a Virtual Memory Manager

This project consists of writing a program that translates logical to physical addresses for a virtual address space of size $2^{16} = 65{,}536$ bytes. Your program will read from a file containing logical addresses and, using a TLB and a page table, will translate each logical address to its corresponding physical address and output the value of the byte stored at the translated physical address. Your learning goal is to use simulation to understand the steps involved in translating logical to physical addresses. This will include resolving page faults using demand paging, managing a TLB, and implementing a page-replacement algorithm.

Specific

Your program will read a file containing several 32-bit integer numbers that represent logical addresses. However, you need only be concerned with 16-bit addresses, so you must mask the rightmost 16 bits of each logical address. These 16 bits are divided into (1) an 8-bit page number and (2) an 8-bit page offset. Hence, the addresses are structured as shown as:



Other specifics include the following:

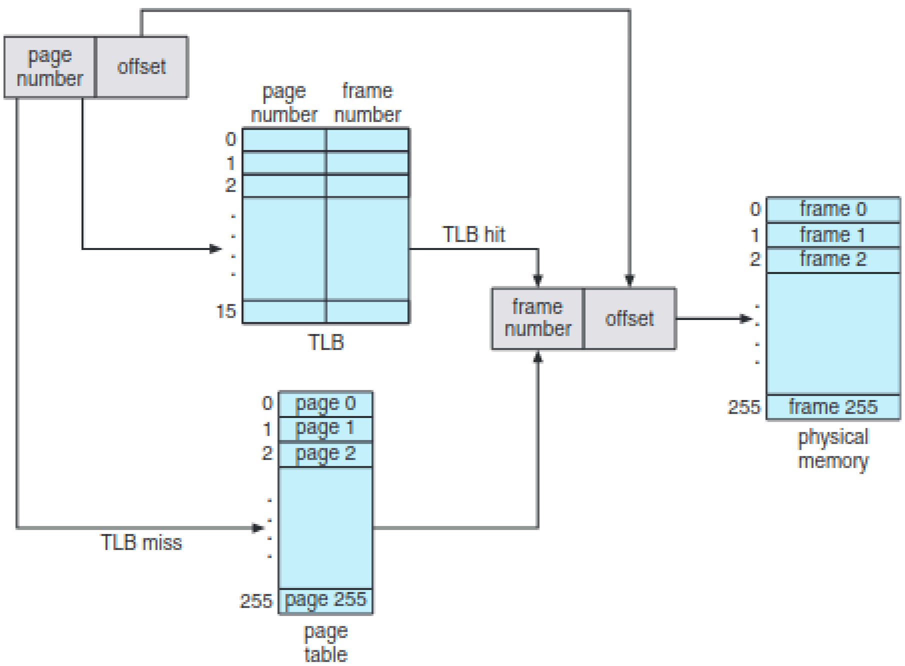
- 2^8 entries in the page table
- Page size of 2^8 bytes
- 16 entries in the TLB
- Frame size of 2^8 bytes
- 256 frames
- Physical memory of 65,536 bytes (256 frames × 256-byte frame size)

(PTO)

Additionally, your program need only be concerned with reading logical addresses and translating them to their corresponding physical addresses. You do not need to support writing to the logical address space.

Address Translation

Your program will translate logical to physical addresses using a TLB and page table as outlined in Section 9.3. First, the page number is extracted from the logical address, and the TLB is consulted. In the case of a TLB hit, the frame number is obtained from the TLB. In the case of a TLB miss, the page table must be consulted. In the latter case, either the frame number is obtained from the page table, or a page fault occurs. A visual representation of the address-translation process is:



Handling Page Faults

Your program will implement demand paging as described in Section 10.2. The backing store is represented by the file `BACKING_STORE.bin`, a binary file of size 65,536 bytes. When a page fault occurs, you will read in a 256-byte page from the file `BACKING_STORE` and store it in an available page frame in physical memory. For example, if a logical address with page number 15 resulted in a page fault, your program would read in page 15 from `BACKING_STORE` (remember that pages begin at 0 and are 256 bytes in size) and store it in a page frame in physical memory. Once this frame is stored (and the page table and TLB are updated), subsequent accesses to page 15 will be resolved by either the TLB or the page table.

(PTO)

You will need to treat BACKING_STORE.bin as a random-access file so that you can randomly seek to certain positions of the file for reading. We suggest using the standard C library functions for performing I/O, including `fopen()`, `fread()`, `fseek()`, and `fclose()`.

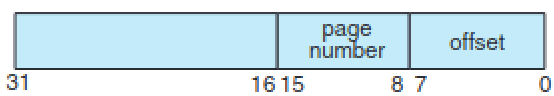
The size of physical memory is the same as the size of the virtual address space—65,536 bytes—so you do not need to be concerned about page replacements during a page fault. Later, we describe a modification to this project using a smaller amount of physical memory; at that point, a page-replacement strategy will be required.

Test File

We provide the file `addresses.txt`, which contains integer values representing logical addresses ranging from 0*to*65535 (the size of the virtual address space). Your program will open this file, read each logical address and translate it to its corresponding physical address, and output the value of the signed byte at the physical address.

How to Begin

First, write a simple program that extracts the page number and offset based on:



from the following integer numbers:

1, 256, 32768, 32769, 128, 65534, 33153

Perhaps the easiest way to do this is by using the operators for bit-masking and bit-shifting. Once you can correctly establish the page number and offset from an integer number, you are ready to begin.

Initially, we suggest that you bypass the TLB and use only a page table. You can integrate the TLB once your page table is working properly. Remember, address translation can work without a TLB; the TLB just makes it faster. When you are ready to implement the TLB, recall that it has only sixteen entries, so you will need to use a replacement strategy when you update a full TLB. You may use either a FIFO or an LRU policy for updating your TLB.

How to Run Your Program

Your program should run as follows:

```
./a.out addresses.txt
```

Your program will read in the file `addresses.txt`, which contains 1,000 logical addresses ranging from 0 to 65535. Your program is to translate each logical address to a physical address and determine the contents of the signed byte stored at the correct physical address. (Recall that in the C language, the `char` data type occupies a byte of storage, so we suggest using `char` values.)

(PTO)

Your program is to output the following values:

1. The logical address being translated (the integer value being read from `addresses.txt`).
2. The corresponding physical address (what your program translates the logical address to).
3. The signed byte value stored in physical memory at the translated physical address.

We also provide the file `correct.txt`, which contains the correct output values for the file `addresses.txt`. You should use this file to determine if your program is correctly translating logical to physical addresses.

Statistics

After completion, your program is to report the following statistics:

1. Page-fault rate—The percentage of address references that resulted in page faults.
2. TLB hit rate—The percentage of address references that were resolved in the TLB.

Since the logical addresses in `addresses.txt` were generated randomly and do not reflect any memory access locality, do not expect to have a high TLB hit rate.

—END—