Northeastern University
College of Engineering
Department of Electrical & Computer Engineering

EECE7376: Operating Systems: Interface and Implementation

Homework 5

Instructions

- For programming Problems:
    1. Your code must be well commented by explaining what the lines of your program do. Have at least one comment for every 4 lines of code.
    2. At the beginning of your source code files write your full name, students ID, and any special compiling/running instruction (if any).
    3. Before submitting the source code file(s), your code must compile and tested with a standard GCC compiler (available in the CoE Linux server).
    4. Do not submit any compiled object or executable files.
- Submit the following to the homework assignment page on Canvas:
    1. Your homework report developed by a word processor (e.g., Microsoft Word) and submitted as one PDF file. The report cover page must include your full name, student ID, course/section/semester information. For answers that require drawing and if it is difficult on you to use a drawing application, which is preferred, you can neatly hand draw "only" these diagrams, scan them, and insert the scanned images in your report document. The report includes the following (depending on the assignment contents):
        a. Answers to the non-programming Problems that show all the details of the steps you follow to reach these answers.
        b. A summary of your approach to solve the programming Problems.
        c. The screen shots of the sample run(s) of your program(s)
    2. The source files (i.e., the .c, .h, or .S files) that contain your well-commented code.

Do NOT submit any files (e.g., the PDF report file and the source code files) as a compressed (zipped) package. Rather, upload each file individually.

Note: You can submit multiple attempts for this homework, however, only what you submit in the last attempt will be graded. This means all required files must be included in this last submission attempt.

Problem 1 (50 Points)

In this problem you will examine the Michael & Scott Concurrent Queue code presented in the course slides. In your code main function create one queue and initialize it. Also, in the main function create at least two threads to run the **Queue_Enqueue** function and at least two more threads to run the **Queue_Dequeue** function.

a) Test your program without using any locks. Simulate a sequence of enqueue and dequeue operations. Comments on the results and highlights the data race problem that is expected to occur.
b) Compare the performance of your program by using two locks (as in the slides) as opposed to using only one lock for both the enqueue and dequeue operations. For the comparison to be noticeable, use a system call , such as sleep(1), within the critical sections. Simulate a large number of overlapped (not sequential) enqueues and dequeues operations by all threads and use the system time (this is for simplicity as it is not the best way) to compare the performance of these two approaches. Comments on the results.
c) Why do we need a dummy node in case two locks are deployed? Support your answer by testing the code without using a dummy node.

Attach your programs as three files named `h5-p1-nolock.c`, `h5-p1-onelock.c`,and `h5-p1-twolocks.c`

A) Queue Operations Without Locks

Test Setup & Observations:

`` `make run0` runs `./h5-p1-nolock` ``

Running the queue operations without a locking mechanism led to a critical runtime error, "`double free or corruption (fasttop)`". This error was consistently reproducible when dequeue operations attempted to free memory. Conversely, by omitting the `free()` call in the dequeue process, the program could complete its execution, albeit with incorrect behavior and potential memory leaks.

Analysis:

The absence of locks in concurrent operations on the queue results in data races, where multiple threads manipulate shared data simultaneously without synchronization. This condition often leads to memory corruption as observed, since the same memory location might be freed or modified by multiple threads concurrently. The workaround of not freeing

dequeued elements only masks the underlying issue by avoiding immediate memory management conflicts but introducing memory leaks. This approach may not work in real scenarios as the object pointing from the queue's head is unprotected.

B) Performance Comparison: Dual Locks vs. Single Lock

Test Setup & Observations:

`make run1` runs `./h5-p1-onelock`

`make run2` runs `./h5-p1-twolocks`

`make test-p1` will run both test targets 10 times and save outputs to `results-test-p1.log`

Both test targets (and the previous `run0`) simulate 4 enqueue and 4 dequeue threads with 1000 R/W cycles each. `usleep(1000)` system call was added within the critical sections of both operations to observe the performance differences clearly.

Dual Lock Implementation: Completed in approximately 4.5 seconds.

Single Lock Implementation: Completed in approximately 9.3 seconds.

Analysis:

The performance disparity between the dual and single lock implementations is significant, with the dual lock approach nearly halving the execution time. The dual lock mechanism allows for greater concurrency by enabling enqueue and dequeue operations to proceed in parallel, provided they don't contend for the same node. The single lock strategy serializes access to the queue entirely, thereby bottlenecking the operations and doubling the time required to complete the same amount of work.

C) Necessity of a Dummy Node in Dual Lock Implementations

Test Setup & Observations:

`make run2n` runs `./h5-p1-twolocks-nodummy`

Removing the dummy node from the queue implementation while using two locks resulted in a "`Segmentation fault (core dumped)`" error. This issue manifested regardless of the locking strategy employed, therefore it is important to create a dummy node in the queue's structure.

Analysis:

The dummy node serves as a sentinel, ensuring that the head and tail pointers in an empty queue are never null but instead point to a benign, non-null node. This setup simplifies the implementation by guaranteeing that certain conditions (e.g., checking if the queue is empty) do not require special cases or additional locking to safely evaluate. Without this dummy node, the queue operations become prone to accessing null pointers or invalidated memory locations, especially in a concurrent context where the queue's state can change unpredictably between operations, leading to segmentation faults.

Problem 2 (50 Points)

The goal of this problem is designing a multithreaded reduction algorithm that calculates the sum of all elements in a vector, providing a single scalar value as a result. Use the following guidelines for your implementation:

a) Use a global variable `sum` to accumulate the partial sums calculated by each individual thread. Declare a global mutex called `sum_mutex`, which should be locked by each thread before accessing variable `sum`. Initialize the global mutex as explained in the course slides.

b) Declare a data type called `struct runner_args_t` that contains the set of arguments passed to each thread when the thread is created. The structure has the following fields:

- Field `v`, representing the base address of the array of integers to work on.
- Field `index`, representing the index of the element in array `v` that a thread will start summing from.
- Field `size`, indicating the number of elements that a thread is responsible for summing.

c) Write a `runner()` function containing the code to be executed by each thread. The function should perform the following actions:

- Cast its generic input argument of type `void *` into a pointer to a structure of type `struct runner_args_t *` and obtain its input arguments from the structure fields.
- Traverse `size` elements of vector `v` starting at position `index` and calculate their sum as a partial result in a local variable.
- Accumulate the partial result into global variable `sum`. Lock the mutex before accessing this global variable then unlock it.
- Free the thread's arguments structure as it should be allocated dynamically as explained below.

d) Write a `main()` program that creates a vector, computes its sum in parallel, and prints the result. The program should run the following intermediate actions:

- Read the number of desired elements (`num_elements`) and the number of desired threads (`num_threads`) from two arguments passed by the user when running the program. If the program was not executed with exactly two arguments, print an error and exit.

- Dynamically allocate a vector with the desired number of elements and initialize each element of the vector to a value equal to its index (i.e., `v[0]` = 0, `v[1]` = 1, etc.) This initialization guarantees predictable and verifiable results.
- Spawn the desired number of threads. For each thread, allocate a new `struct runner_args_t` dynamically, and initialize it with the appropriate arguments for that thread. The computation burden should be evenly distributed among threads.
- Wait for all child threads to complete.
- Free the vector and print the result.

This is an example of the execution of the program, in which a vector with 10,000 elements is created, and its sum is calculated with five concurrent threads:

```
$ ./main 10000 5
Sum = 49995000
```

Test your program with more examples that cover different scenarios of the possible inputs. Attach the full program in a file named `h5-p2.c`

Test Setup:

`make runq2` runs `./main`

`make test-p2` will run a sequence of tests and save outputs to `results-test-p2.log`

Observations:

COUNT	THREAD	SUM
10000	1	49995000
10000	2	49995000
10000	3	49995000
10000	4	49995000
10000	5	49995000
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