UNIVERSITY OF WISCONSIN-MADISON
Computer Sciences Department

CS 537
Fall 2018

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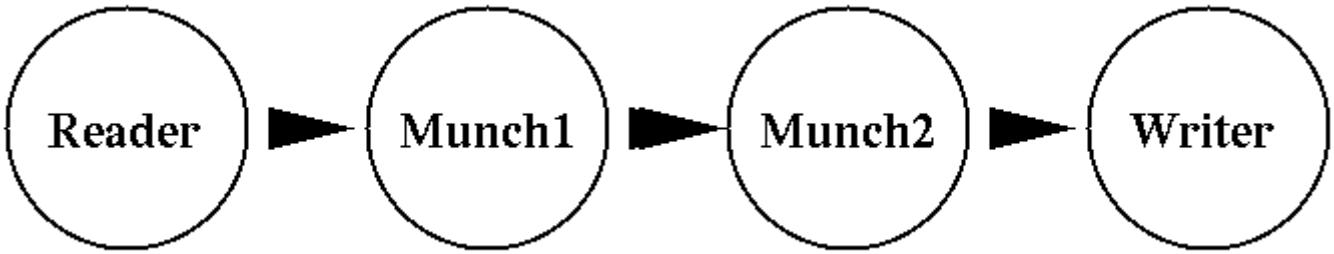
Programming Assignment #2
(Due Friday, October 19, at 5pm)

Shared Memory Producer/Consumer Program

The goal of this assignment is to get experience in writing a program that actually runs in parallel on Linux using threads (pthreads) and synchronization. You will write a program with four threads, structured like:



- The `Reader` thread will read from standard input, one line at a time. `Reader` will take the each line of the input and pass it to thread `Munch1` through a queue of character strings.
- `Munch1` will scan the line and replace each space character (not tabs or newlines) with an asterisk ("*") character. It will then pass the line to thread `Munch2` through another queue of character strings.
- `Munch2` will scan the line and convert all lower case letters to upper case (e.g., convert "a" to "A"). It will then pass the line to thread `Writer` though yet another queue of character strings.
- `Writer` will write the line to standard output.

Memory Allocation of Strings

Each time that the `Reader` thread is going to read a string from standard input, it will first `malloc` memory for that string. The pointer to that string will then be passed down the queues between the threads until it finally arrives at the `Writer` thread. After `Writer` writes out the string pointed to by the pointer, it will then `free` the memory that holds the string.

The Queue Module

One of the most important parts of your code is going to be the module (.c file) that implements synchronized queue. Since your program is reading in strings of characters

and passing them from thread to thread, your queue will be a queue of pointers to strings (`char *`).

Queues are dynamically created. So, for this assignment, you will need one between each pair of threads (so you'll need three queues).

Queues will be represented by a structure of type `Queue`.

The main external functions for this module should be:

`Queue *CreateStringQueue(int size)`

> Dynamically allocate a new `Queue` structure and initialize it with an array of character points of length `size`. That means you'll `malloc` the queue structure and then malloc the `char **` array pointed to from that structure. Also remember to any state and synchronization variables used in this structure.
>
> The function returns a pointer to the new queue structure.
>
> For testing purposes, create your Queue's with a size of 10.

`void EnqueueString(Queue *q, char *string)`

> This function places the pointer to the string at the end of queue `q`. If the queue is full, then this function blocks until there is space available.

`char * DequeueString(Queue *q)`

> This function removes a pointer to a string from the beginning of queue `q`. If the queue is empty, then this function blocks until there is a string placed into the queue. This function returns the pointer that was removed from the queue.

`void PrintQueueStats(Queue *q)`

> This function prints the statistics for this queue (see the next section for details).

Keeping Queue Statistics

Each `Queue` structure will also contain some extra fields for statistics-keeping. These fields will include:

`enqueueCount`

> A count of the number of strings enqueued on this queue.

`dequeueCount`

> A count of the number of strings dequeued on this queue. We would expect that when the program exits, the two count values are equal.

`enqueueBlockCount`

> A count of the number of times that an enqueue was attempted but blocked.

`dequeueBlockCount`

A count of the number of times that a dequeue was attempted but blocked.

Synchronization and Communication

The threads will communicate through shared memory using pthreads synchronization. For this program, the synchronization should be mainly contained in the when constructing queue module. You have two choices from which to pick

1. Semaphores: You declare semaphores with the type `sem_t`, and operate on these semaphores with `sem_init`, `sem_wait`, and `sem_post`.

   Using semaphores with the pthreads library is described in OSTEP Chapter 31. You'll want to refer to the Linux manual pages as well.

2. Monitor synchronization: Since you're programming in C, you **don't** have the compiler's help to automatically lock on entry to a monitor and unlock on exit. So you have to declare the monitor lock as type `pthread_mutex_t` and declare your condition variables as type `pthread_cond_t`.

   You lock and unlock the monitor lock with `pthread_mutex_lock` and `pthread_mutex_unlock`.

   You signal and wait on condition variables with `pthread_cond_signal` and `pthread_cond_wait`.

   (**Don't** mistakenly try to use the `lock_t` type with condition variables.)

   Using mutexs and condition variables with the pthreads library is described in OSTEP Chapters 27 and 30. You'll want to refer to the Linux manual pages as well.

Pick only **one of the above two choices** and use it consistently throughout your program. Do **not** mix them.

You cannot use busy waiting (spin locks) or somehow try to read the value of a semaphore, mutex, or condition variable.

Compiling Your Program

As in Program 1, you want to use `-Wall` and `-Wextra`.

On the link gcc command, you'll also need to specify the inclusion of the pthreads library by including the `-lpthread` option.

Your executable file should be named **`prodcomm`**.

Checking Your Code

As with Program 1-1, your code will need to scan clean of warnings from the gcc `-Wall` and `-Wextra` options **and** from the Clang Static Analyzer.

Good programmers in the real world check this *every time* that they compile their code, and then fix these warnings as they occur. Your makefile should include the commands to run Clang and view the results, as we showed you for Program 1-1.

A Few More Program Details

1. Your main program will first create the three queues.
2. Your main program will then create four pthread threads. Your main thread with create these new threads by calling `pthread_create`, and then wait for these threads to finish by calling `pthread_join`. Each thread will call `pthread_exit`. when it is done with all its work.
3. Thread `Reader` will read in each input line from stdin. You must check that the input line does not exceed the size of your buffer. If it does exceed the length, then you will reject that line by (1) printing out an error message to stderr and (2) throw away (flush to end of line) any remaining characters on that line. Note that the TA's will be testing your programs with input that contains extremely long lines.
4. See the manual page entry for the function "index" to making writing `Munch1` easier.
5. See the manual page entries for "islower" and "toupper" to making writing `Munch2` easier.
6. When there are no more strings to process, thread `Writer` will also print the number of strings processed to stdout.
7. Threads should terminate when there is no more input (end of file). Proper termination can be a bit tricky. Think about this one carefully.

   Do **not** use a global variable (or multiple global variables) to signal completion of the input for the various threads. There are all sorts of bad things that can result from this technique.

8. Before the main program exits, it should print out statistics to stderr for each queue using the `PrintQueueStats` function.

Deliverables

You will work in **groups of two** and turn in a single copy of your program, clearly labeled with the name and logins of both authors. Any exception to working in a group must be approved by Bart in advance; there must be some unusual reason for not working in a group.

You will turn in your programs, including all .c and .h files and your makefile. Also include a README file which describes a little bit about what you did for this project.

Note that you must run your programs on the Linux systems provided by the CS Department.

As you are working in pairs, you should:

1. Submit only one copy of your code.
2. Make sure that both of your names, NetIDs and CompSci login names are in comments at the top of each source file.
3. Both of you should create another file called partner.txt in **both** of your `proj2` directories, where you should have two lines that have the names, NetIDs and

CompSci logins you and your partner.

Handing in Your Assignment

Your CS537 handin directory is `~cs537-1/handin/your_login` where *your_login* is your CS login. Inside of that directory, you need to create a `proj2` subdirectory.

Copying your files to this directory is accomplished with the `cp` program, as follows:

```
shell% cp *.[ch] makefile README ~cs537-1/handin/your_login/proj2
```

You can hand files in multiple times, and later submissions will overwrite your previous ones. To check that your files have been handed in properly, you should list `~cs537-1/handin/your_login/proj2` and make sure that your files are there.

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