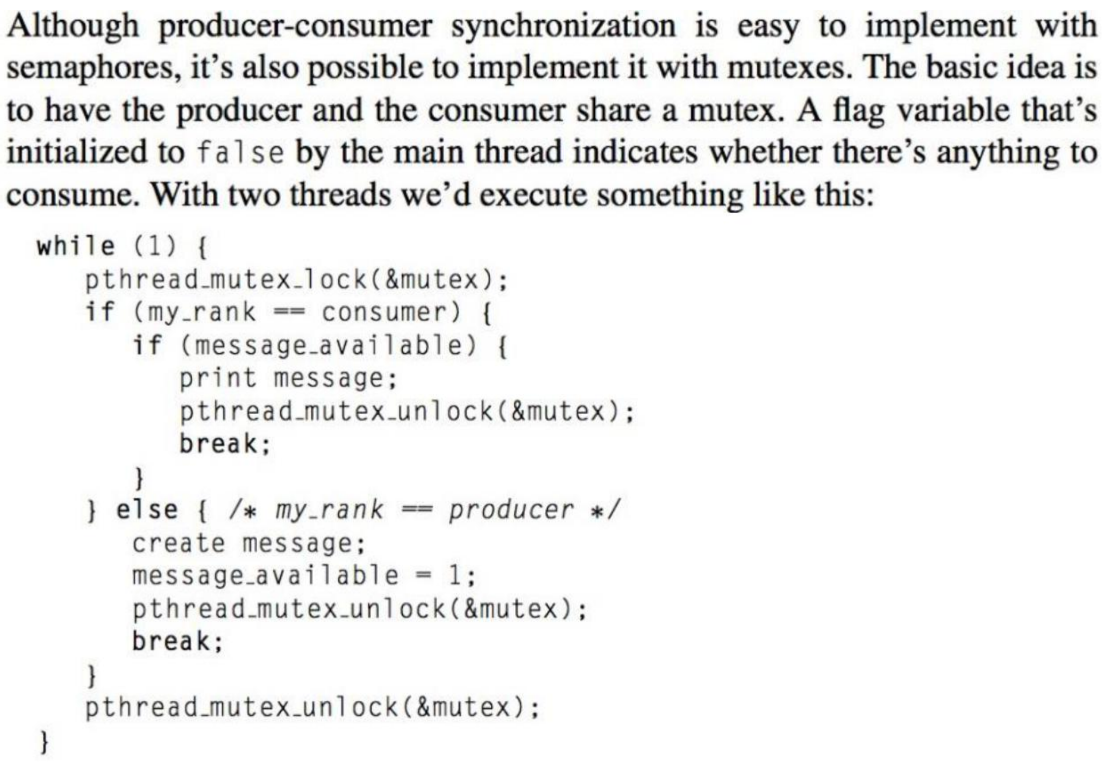
4.1.

Modify the mutex version of the calculation program so that the critical section is in the for loop. Compare the performance of your version with the serial version.

4.2.

Modify the mutex version of the calculation program so that it uses a semaphore instead of a mutex. Compare the performance of your version with the serial version.

4.3.

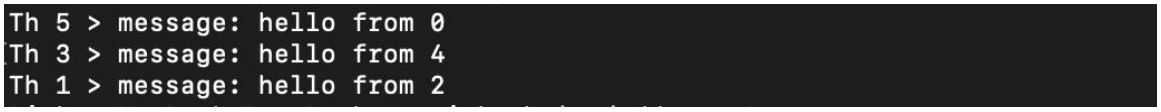


Although producer-consumer synchronization is easy to implement with semaphores, it's also possible to implement it with mutexes. The basic idea is to have the producer and the consumer share a mutex. A flag variable that's initialized to `false` by the main thread indicates whether there's anything to consume. With two threads we'd execute something like this:

```
while (1) {
   pthread_mutex_lock(&mutex);
   if (my_rank == consumer) {
      if (message_available) {
         print message;
         pthread_mutex_unlock(&mutex);
         break;
      }
   } else { /* my_rank == producer */
      create message;
      message_available = 1;
      pthread_mutex_unlock(&mutex);
      break;
   }
   pthread_mutex_unlock(&mutex);
}
```

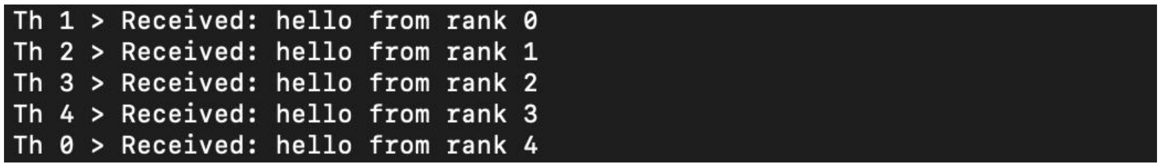
a. Write a Pthreads program that implements this version of producer-consumer synchronization with two threads. Suppose there is only at most one message at all time.

b. Generalize this so that it works with 2*k* threads – odd-ranked threads are consumers and even-ranked threads are producers. Every odd-ranked thread must indicate that it receives message and also indicate which thread sends the message.



```
Th 5 > message: hello from 0
Th 3 > message: hello from 4
Th 1 > message: hello from 2
```

Generalize this so that each thread is both a producer and a consumer. In particular, suppose that thread q "sends" a message to thread ($q + 1$) mod t and "receives" a message from thread ($q - 1 + t$) mod t, where t is the total number of threads. Every thread must indicate that it receives message and also indicate which thread sends the message.



```
Th 1 > Received: hello from rank 0
Th 2 > Received: hello from rank 1
Th 3 > Received: hello from rank 2
Th 4 > Received: hello from rank 3
Th 0 > Received: hello from rank 4
```

Templates for 4.1 and 4.2 are provided. They both use timer.h to obtain the system time, and this header file is also provided.

Note: All programs have to be presented to the instructor on the class of due date.