CS240 Operating Systems, Communications and Concurrency – Dermot Kelly
Practical 7 – Thread Programming in Java and C
The Producer Consumer Bounded Buffer Synchronisation Problem

The Producer-Consumer problem is an example of a concurrency problem dealing with the management of a shared finite buffer structure used for exchanging data between processes which are running asynchronously. Some processes write data into the buffer (producers) and other processes remove data from the buffer (consumers). The approach to coding of a solution to the producer-consumer problem was covered in lectures and the corresponding Java code for a simulation of this problem is given below.

The solution uses semaphore operations provided by a `Semaphore` class with synchronised methods `acquire()` and `release()` which operate on a local integer `value` belonging to an instance of `Semaphore`. A thread trying to acquire the semaphore behaves as follows: - If the value of the semaphore is greater than 0, the calling thread decrements it by 1, otherwise the calling thread is blocked by invoking `wait()`. When a thread invokes `release()`, it increments the semaphore and notifies another thread on the queue that the semaphore may be available. That thread will then wake up and continue its attempt to acquire it. See if you can follow the description of these methods in the code below.

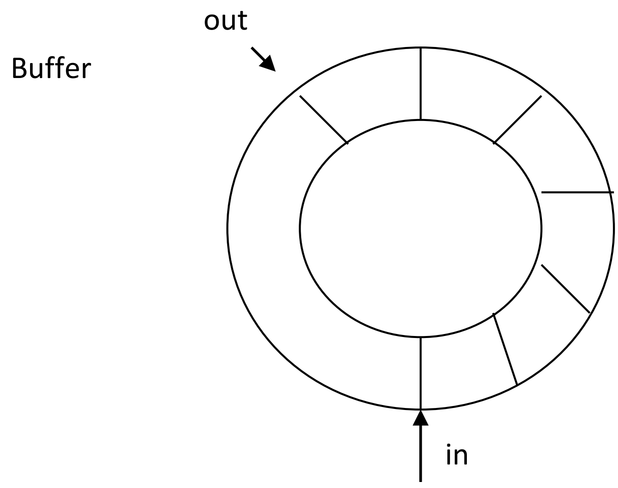
```
/* The Semaphore class below contains methods declared as
synchronized. Java's locking mechanism will ensure that access
to its methods is mutually exclusive among threads that invoke these
methods. Save the code in a file Semaphore.java */

class Semaphore {
   private int value;

   public Semaphore(int value) {
      this.value = value;
   }

   public synchronized void acquire() {
      while (value == 0) {
         try {
             // Calling thread waits until semaphore is free
             wait();
         } catch(InterruptedException e) {}
      }
   value = value - 1;
   }

   public synchronized void release() {
      value = value + 1;
      notify();
   }
}
```

Wait and Notify
Every object in Java has associated with it a wait set which is initially empty. When a thread calls the `wait()` method the following happens:- The thread releases the object lock; The thread is set to blocked; The thread is placed in the wait set for the object.
The notify() method picks an arbitrary thread from the wait set and moves it to the entry set where is can reacquire the lock. The thread is made runnable.

The following class attempts to coordinate the actions of producer and consumer processes when accessing the buffer. A producer can only write into the buffer when a space exists for its item, and a consumer can only remove an item from the buffer when one exists. At all times, there should only be at most one process actually manipulating the buffer structure itself. Three semaphores are used to control these three conditions, `full`, `empty` and `mutex`.

An example implementation of the buffer class, **save as file "Buffer.java"** :-

```
public class Buffer {
   private static final int BUFFER_SIZE = 5;
   private Object[] buffer;
   private int in, out;
   private Semaphore mutex;
   private Semaphore empty;
   private Semaphore full;

   public Buffer() {
      in = 0;
      out = 0;
      buffer = new Object[BUFFER_SIZE];

      mutex = new Semaphore(1);
      empty = new Semaphore(BUFFER_SIZE);
      full = new Semaphore(0);
   }

   public void insert(Object item) {
      empty.acquire();
      mutex.acquire();

      buffer[in] = item;
      in = (in + 1) % BUFFER_SIZE;

      mutex.release();
      full.release();
   }

   public Object remove() {
      full.acquire();
      mutex.acquire();

      Object item = buffer[out];
      out = (out + 1) % BUFFER_SIZE;

      mutex.release();
      empty.release();
      return item;
   }
}
```



<u>Producer Process Behaviour</u>

```
while (true) {
   Produce Object item
   Insert item in buffer
}
```

<u>Consumer Process Behaviour</u>

```
while (true) {
   Remove item from buffer
   Consume item
}
```

<u>An example behaviour for a producer thread is given below.</u>
This class defines a runnable object, that is, an object that can be executed by a thread. The thread executing this object will execute its `run()` method where the producer behaviour is described below. The main program should create a buffer object first to be shared between producer and consumer threads and then pass a reference to this buffer to the runnable object's constructor as shown below. **Save this as "Producer.java"**

```
import java.util.Date;
public class Producer implements Runnable {
   private Buffer buffer;

   public Producer(Buffer buffer) {
      this.buffer = buffer;
   }

   public void run() {
      Date message;

      while (true) {
         message = new Date(); // produce an item
         try {
            Thread.sleep(1000); // sleep for 1000 ms
         } catch (InterruptedException e) {}
         buffer.insert(message);
         System.out.println("Inserted "+ message);
      }
   }
}
```

Producer和Consumer类的构造函数目前接受单个参数(buffer)，该参数存储在同名的局部变量中。修改构造函数，使其接受一个额外的整型参数，并具有一个相应的局部变量，该局部变量可以在创建可运行对象时存储该对象的ID。然后，生产者和消费者运行方法代码应该在每次执行循环时将这个ID写入消息的输出中，这样我们就知道哪个生产者/消费者生成了消息。

修改BounderBufferSimulation.java中的主程序代码，使其创建两个消费者线程和两个生产者线程。现在我们需要向新的构造函数传递两个参数，不仅是缓冲区，而且是一个整数，表示每个生产者的不同ID，例如1和2，以及每个消费者)。不要忘记启动所有4个线程。所有线程都应该使用相同的共享缓冲区并发执行。

An example behaviour for a consumer thread is given below, save as "Consumer.java"

```
import java.util.Date;
public class Consumer implements Runnable {
   private Buffer buffer;

   public Consumer(Buffer buffer) {
      this.buffer = buffer;
   }

   public void run() {
      Date message;

      while (true) {
         try {
            Thread.sleep(1000); // sleep for 1000 ms
         } catch (InterruptedException e) {}
         message = (Date) buffer.remove();
         // consume the item
         System.out.println("Removed "+ message);
      }
   }
}
```

The main routine of the Bounded Buffer Simulation, save as "BoundedBufferSimulation.java"

The code creates a buffer object to be shared between the producers and consumers. It then creates creates two threads. It passes a runnable object to the constructor of each thread. The first gets an instantiation of the Producer class and the second gets an instantiation of the consumer class. Invoking the start method causes each thread to execute the `run()` method of its runnable object.

```
public class BoundedBufferSimulation {
   public static void main (String args[]) {
      Buffer buffer = new Buffer();

      // Create one producer and one consumer process
      Thread producer1 = new Thread(new Producer(buffer));
      Thread consumer1 = new Thread(new Consumer(buffer));

      producer1.start();
      consumer1.start();
   }
}
```

Compile all the five code files using `javac` and run the `BoundedBufferSimulation` in a JVM with the command `java BoundedBufferSimulation`

Modify the program as follows:

The constructors for the Producer and Consumer classes currently take a single parameter (buffer) which is stored in a local variable of the same name. Modify the constructors to take an additional integer parameter and have a corresponding local variable which can store an ID for that runnable object when it is created. The Producer and Consumer run method code should then write this ID to the output in a message each time it executes its loop so we know which Producer/Consumer is generating the message.

Modify the main program code in BounderBufferSimulation.java so that it creates two consumer and two producer threads. We need to pass two parameters now to the new constructor, not just buffer, but also an integer representing a different ID for each producer, e.g. 1 and 2, and each consumer). Don't forget to start all 4 threads. All threads should then execute concurrently using the same shared buffer.

The code below is an alternative multithreaded implementation of the producer/consumer bounded buffer synchronisation problem written in C and using the POSIX pthreads API.
From your understanding of the Java implementation, you should easily be able to follow the code and understand the synchronisation. If you save the file below as "boundedbuffer.c", it can be compiled using
cc boundedbuffer.c –l pthread –o boundedbuffer

```
#include <stdio.h>
#include <pthread.h>
#include <stdlib.h>
#include <unistd.h>
#include <time.h>
#include <semaphore.h>

#define BUFFER_SIZE 10
#define TRUE 1

time_t buffer[BUFFER_SIZE];
int in,out;
pthread_mutex_t mutex;
sem_t empty, full;

void init_buffer()
   {
      in = 0;
      out = 0;
      pthread_mutex_init(&mutex,NULL); /* serialise buffer modifications */
      /* 2nd parameter indicates semaphore shared between threads not processes */
      sem_init(&empty,0,BUFFER_SIZE); /* buffer has max free space */
      sem_init(&full,0,0); /* No items in buffer */
   }


void insert_item(time_t timeinseconds)
   {
      sem_wait(&empty);
      pthread_mutex_lock(&mutex);
            buffer[in] = timeinseconds;
            in = (in + 1) % BUFFER_SIZE;
      pthread_mutex_unlock(&mutex);
      sem_post(&full);
   }


time_t remove_item()
   {
      time_t item; /* item stores date as a number of seconds since Jan 1 1970. */
      sem_wait(&full);
```

```
      pthread_mutex_lock(&mutex);
            item = buffer[out];
            out = (out + 1) % BUFFER_SIZE;
      pthread_mutex_unlock(&mutex);
      sem_post(&empty);
        return item;
   }

void *consumer(void* id)
  {
      unsigned long my_id = (unsigned long) id;
      time_t timeinseconds;

      while (TRUE) {
            sleep(2);
            timeinseconds = remove_item(); /* Consume the date item */
            printf("Consumer %ld Removed %ld \n",my_id, timeinseconds);
      }
}

void *producer(void* id)
   {
      unsigned long my_id = (unsigned long) id;
      time_t timeinseconds;

      while (TRUE) {
            timeinseconds = time(NULL);  /* Produce a date item */
            insert_item(timeinseconds);
            printf("Producer %ld Inserted %ld \n",my_id, timeinseconds);
            sleep(1);
      }
}


int main(int argc, char **argv) {
      pthread_t thread1, thread2, thread3, thread4;
      unsigned long p1 = 1;
      unsigned long c1 = 1;
      unsigned long p2 = 2;
        unsigned long c2 = 2;
      init_buffer();

      /* Start 2 producer and 2 consumer threads and give them ids*/
      pthread_create(&thread1, NULL, consumer, (void *) p1);
      pthread_create(&thread2, NULL, producer, (void *) c1);
      pthread_create(&thread3, NULL, consumer, (void *) p2);
      pthread_create(&thread4, NULL, producer, (void *) c2);

      /* Execute pthread_join to prevent main thread from exiting and terminating
           program */
      pthread_join(thread1, NULL);
      pthread_join(thread2, NULL);
      pthread_join(thread3, NULL);
      pthread_join(thread4, NULL);
      printf("All threads finished\n"); /* Will never happen as threads loop
indefinitely */
```

```
    exit(0);
}
```

When the program runs, notice the rate at which output messages from the producer and consumer threads appear initially and then notice the point where this rate slows down. Can you explain this from the code?