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Homework 5

Overview:

For Part 1:

I did not see any differences in the counts of ASCII characters when producing the counts using synchronization and not using synchronization. The only noticeable difference was that calculating the counts using a mutex took much longer than it did when I re-wrote the code using a one-dimensional array as opposed to a two-dimensional array. The time difference makes sense because the threads must now wait a little bit longer to obtain the lock before they can increment the global array.

For Part 2:

The purpose of this project was to create a multithreaded solution to the consumer/producer problem using condition variables as well as a mutex. An int buffer of size 16 is declared globally. This buffer will be treated as a circular buffer. The buffer is going to be written into by the producer threads and read from by the consumer threads. A global int will also be keeping track of the size of this buffer as items are being read from and written into the buffer. A static mutex as well as 2 static condition variables are declared globally. The mutex is used to prevent race conditions when we are either reading or writing to the buffer. The condition variables (ready_to_read and ready_to_write) will be used in both the producer thread and consumer thread functions. In the producer thread function, if a producer thread writes to all of the available spots in the buffer pthread_cond_wait() is called passing in the ready_to_write condition variable. Each time an item is written to the buffer by a producer thread, we use pthread_cond_signal() and pass in the ready_to_read variable which wakes up a consumer thread because there is data available for a consumer thread to read. The concept works very similarly for the consumer thread function. If a consumer thread reads all of the data in the buffer, pthread_cond_wait() is called passing in the ready_to_read condition variable. Each time an item is read and printed from the buffer by a consumer thread, it frees up a spot in the buffer for a producer thread to write into so we use pthread_cond_signal() and pass in ready_to_write which wakes up a producer thread. The global integers totalItemsProduced and totalItemsConsumed are used to basically keep track of the grand total of items produced and consumed. Each time a thread produced or consumed an item these integers are incremented accordingly. If the program is working properly, these two integers should be the same number by the time all of the threads exit. The global integer readyIndex is used to keep track of the next index that is available to either read or write to depending on which thread method it is being used in. Lastly, each thread will have a unique thread ID and a number of items it is responsible for handling. This information will be managed using structs for each kind of thread.

In the main the arguments the user passes the command-line parameters and uses shift left logical to convert them to a power of 2. These values are assigned to integers that represent the number of producer threads, the number of consumer threads, and the number of items each producer will be producing. Arrays of structs and pthread arrays are used to keep track of the various consumer and producer threads that are being used in the program. An output message just tells the user how many producer threads, consumer threads, and how many items will be produced by each producer thread based on the arguments they passed into the command line. The rest of the main is basically just initializing all of the synchronization objects, spawning the producer and consumer threads and printing the grand total of items produced and consumed.

In the producer thread function, there is a for loop that loops from 0 to the number of items the producer thread is meant to produce. In the for loop, we lock the mutex to prevent a race condition when numbers are being written into the buffer. First, an available index is calculated, then an item is written to that calculated index.

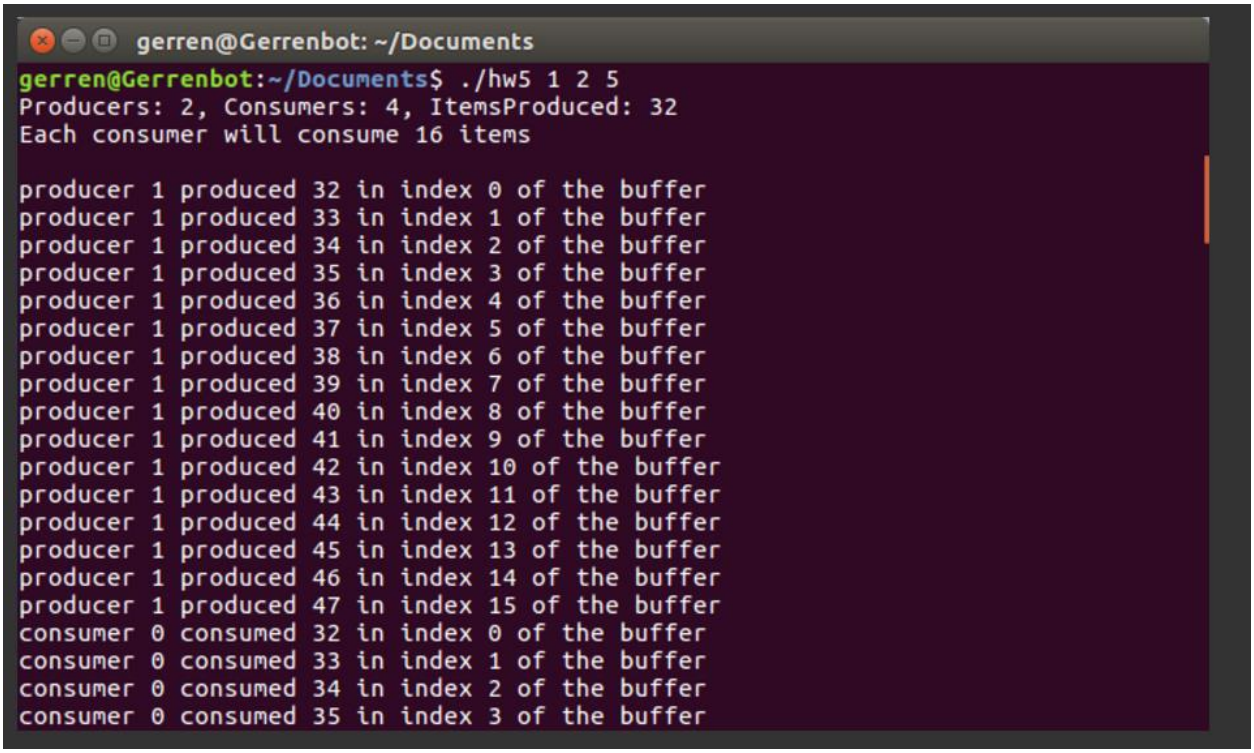
A local variable counter keeps track of how many items the current producer thread has added into the buffer is incremented. The size of the buffer is incremented as well, along with the global integer keeping track of the grand total of items produced. The mutex is then unlocked. The for loop continues until the producer thread has produced the correct number of items, then it exits.

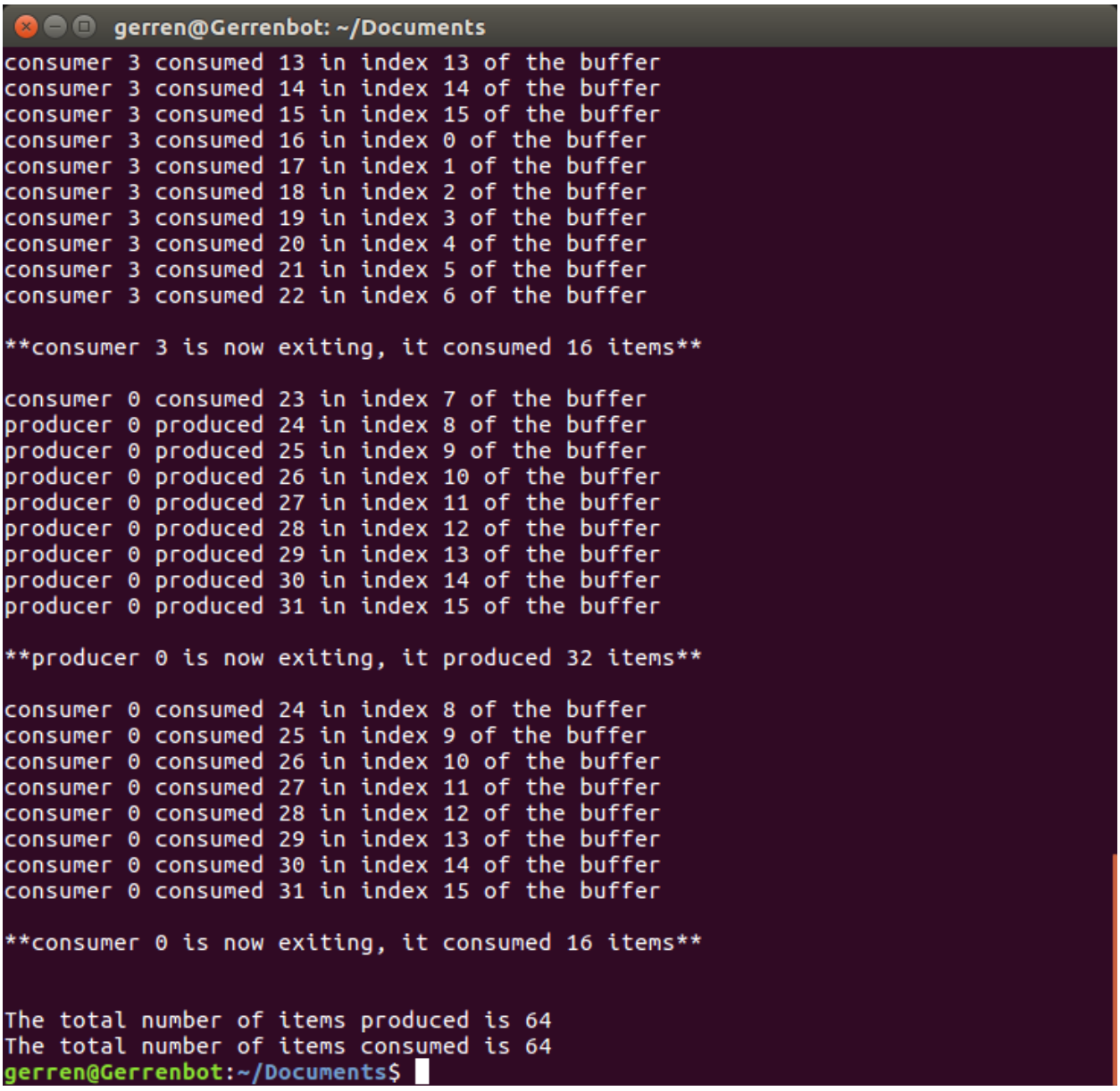
In the consumer thread function, there is a for loop that loops from 0 to the number of items the consumer thread is meant to consume. In the for loop, we again lock the mutex to prevent a race condition when the items are being read from the buffer. Once an item is consumed it is printed onto the console and the readyIndex is updated. The purpose of updating the readyIndex is so the consumer thread consumes an element at a valid index and so the producer threads write into the buffer at a proper index. The local variable counter that keeps track of how many items the thread has consumed from the buffer is incremented. The global variable that tracks the grand total of items consumed is also incremented. The global variable keeping track of the size of the buffer is decremented because once the item is read from the buffer, space frees up to write into the buffer. The mutex is then unlocked and a signal is sent to alert any waiting producer threads that space has been freed up in the buffer. The consumer thread exits once it has consumed the correct number of items.

On success, print statements will be printed onto the console that track which producer thread is writing to which index on the buffer and which consumer thread is consuming which item in the buffer. Print statements for when a producer or consumer thread exit and how many items they produced/consumed will also be printed. The last two lines will be the grand total of items produced and consumed, if the program functioned correctly, these numbers should be the same number.

Testing:

To test the program I passed in different values for the producers and consumers, but kept the items being produced at a constant 32. The tests were for 1 producer/2 consumers, 2 producers/1 consumer, 2 producers/4 consumers, and 4 producers/2 consumers.




gerren@Gerrenbot: ~/Documents
consumer 3 consumed 13 in index 13 of the buffer
consumer 3 consumed 14 in index 14 of the buffer
consumer 3 consumed 15 in index 15 of the buffer
consumer 3 consumed 16 in index 0 of the buffer
consumer 3 consumed 17 in index 1 of the buffer
consumer 3 consumed 18 in index 2 of the buffer
consumer 3 consumed 19 in index 3 of the buffer
consumer 3 consumed 20 in index 4 of the buffer
consumer 3 consumed 21 in index 5 of the buffer
consumer 3 consumed 22 in index 6 of the buffer
consumer 3 is now exiting, it consumed 16 items
consumer 0 consumed 23 in index 7 of the buffer
producer 0 produced 24 in index 8 of the buffer
producer 0 produced 25 in index 9 of the buffer
producer 0 produced 26 in index 10 of the buffer
producer 0 produced 27 in index 11 of the buffer
producer 0 produced 28 in index 12 of the buffer
producer 0 produced 29 in index 13 of the buffer
producer 0 produced 30 in index 14 of the buffer
producer 0 produced 31 in index 15 of the buffer
producer 0 is now exiting, it produced 32 items
consumer 0 consumed 24 in index 8 of the buffer
consumer 0 consumed 25 in index 9 of the buffer
consumer 0 consumed 26 in index 10 of the buffer
consumer 0 consumed 27 in index 11 of the buffer
consumer 0 consumed 28 in index 12 of the buffer
consumer 0 consumed 29 in index 13 of the buffer
consumer 0 consumed 30 in index 14 of the buffer
consumer 0 consumed 31 in index 15 of the buffer
consumer 0 is now exiting, it consumed 16 items
The total number of items produced is 64
The total number of items consumed is 64
gerren@Gerrenbot:~/Documents$
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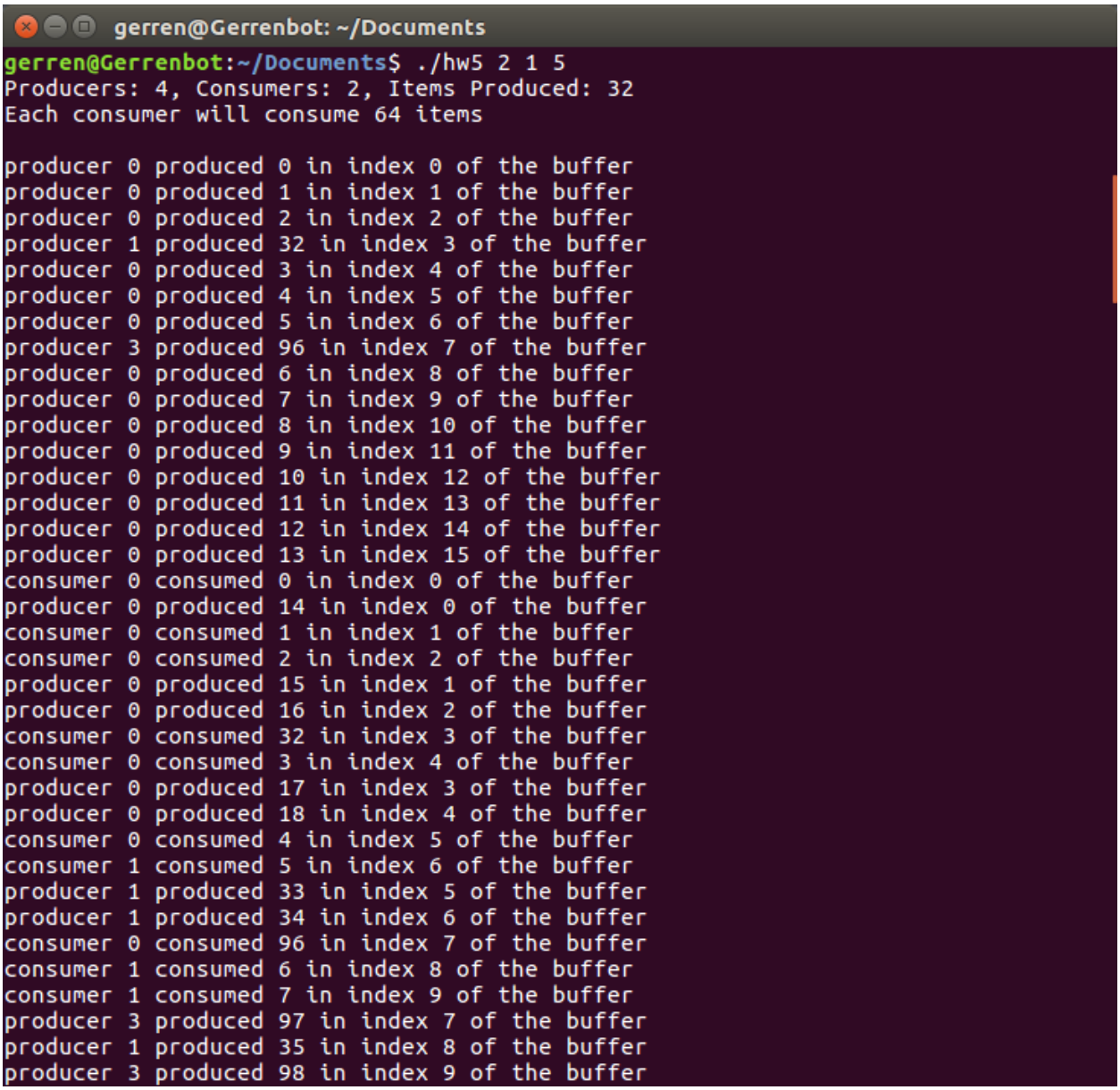
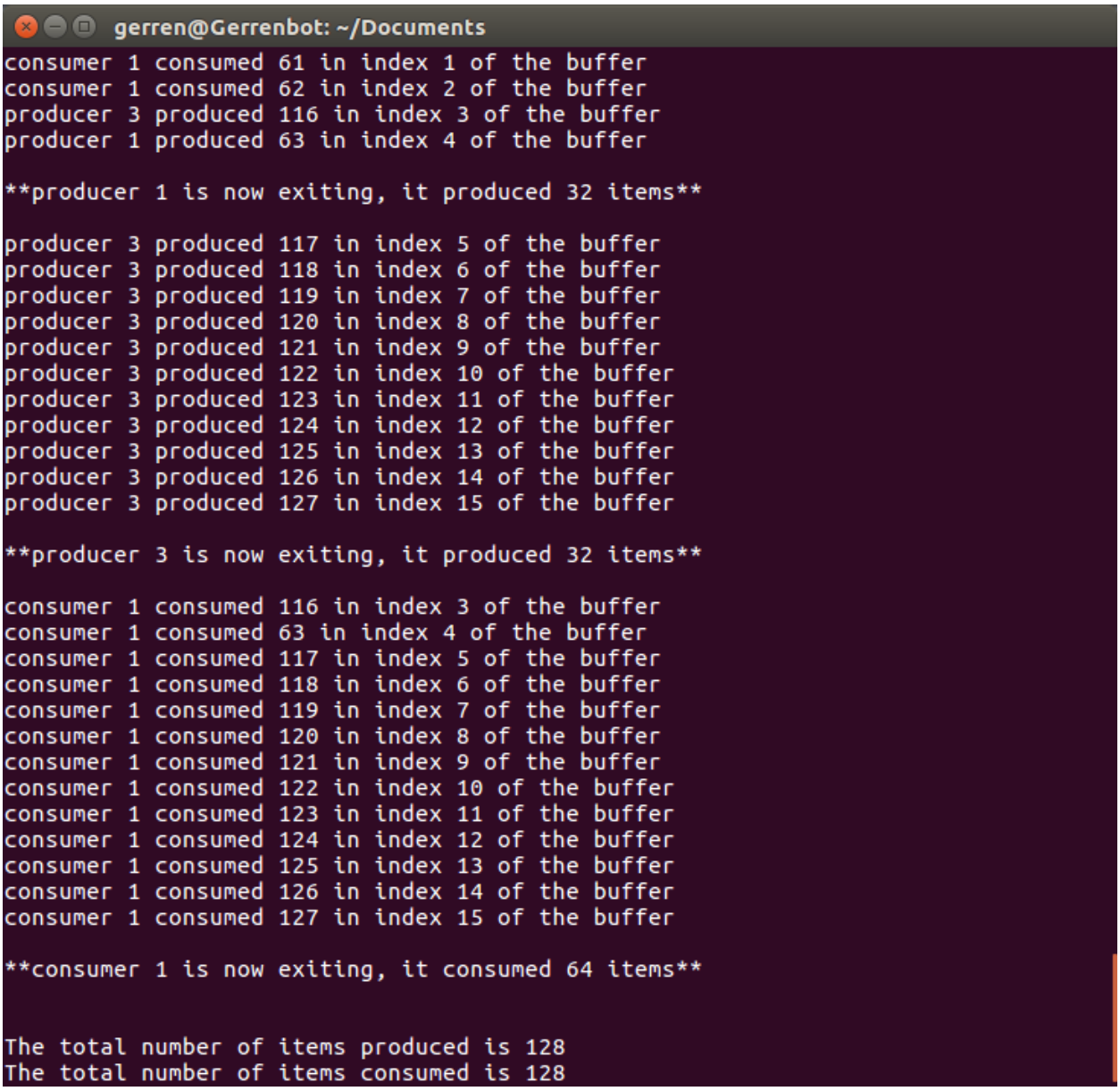
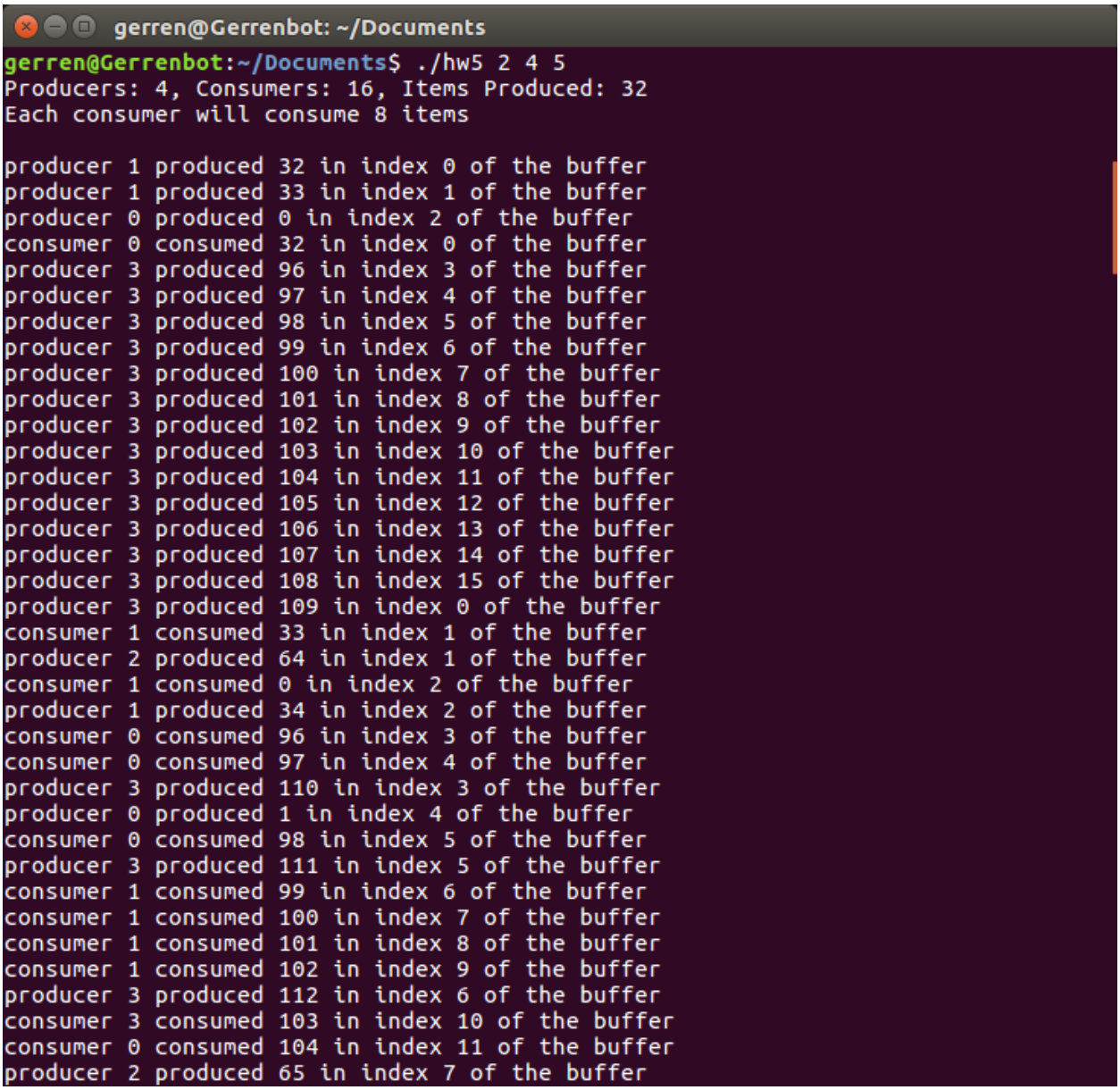
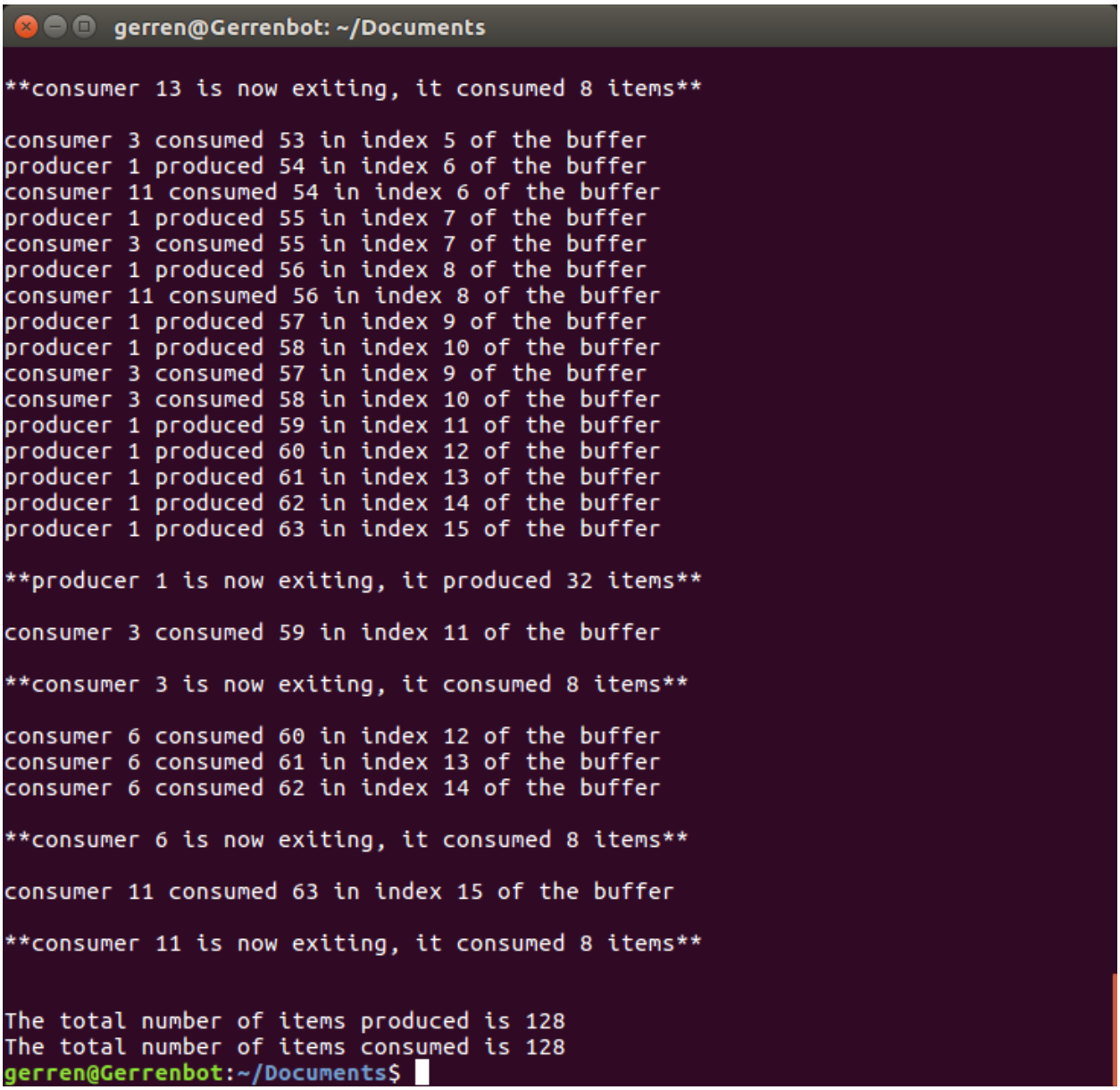
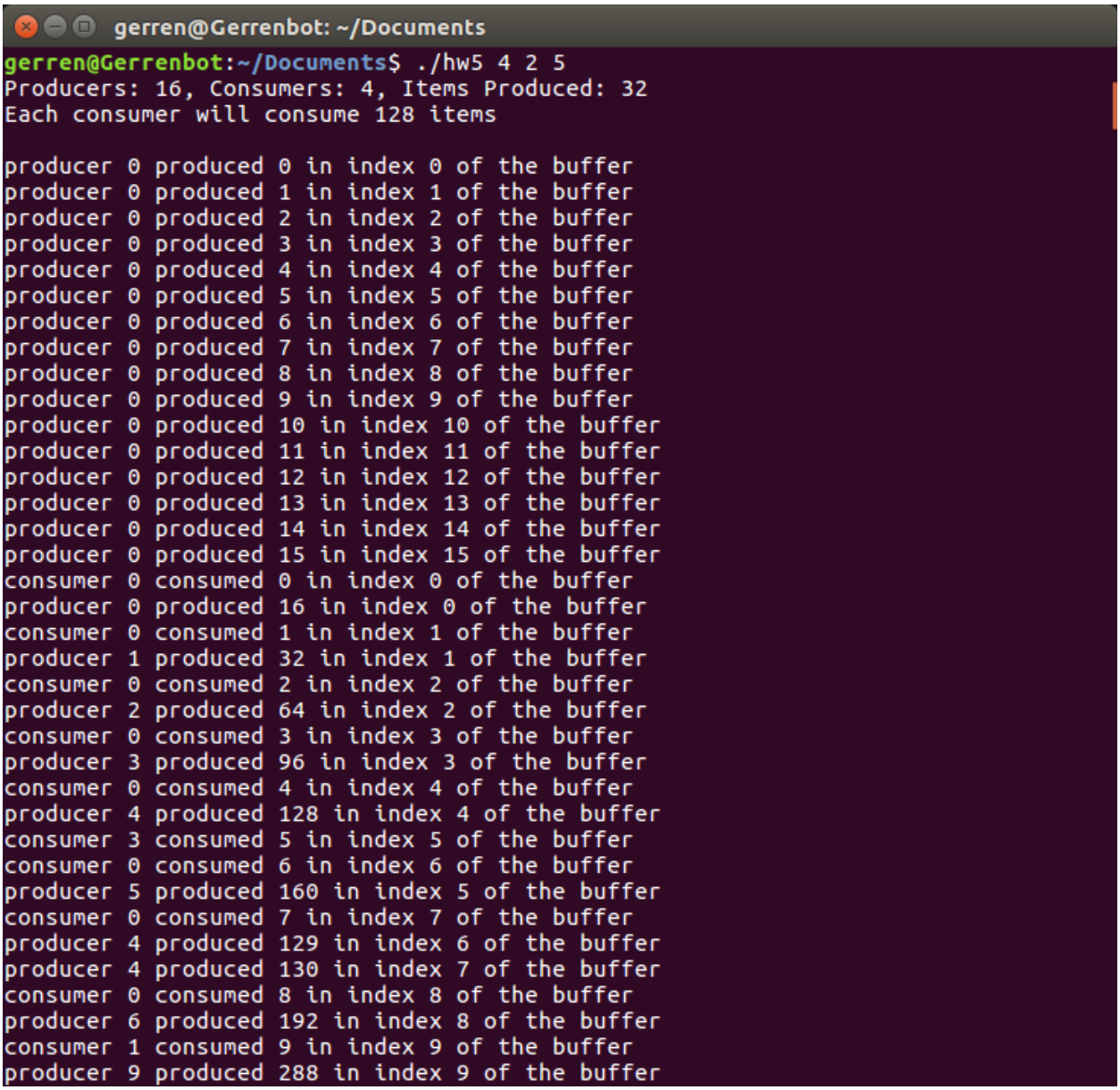
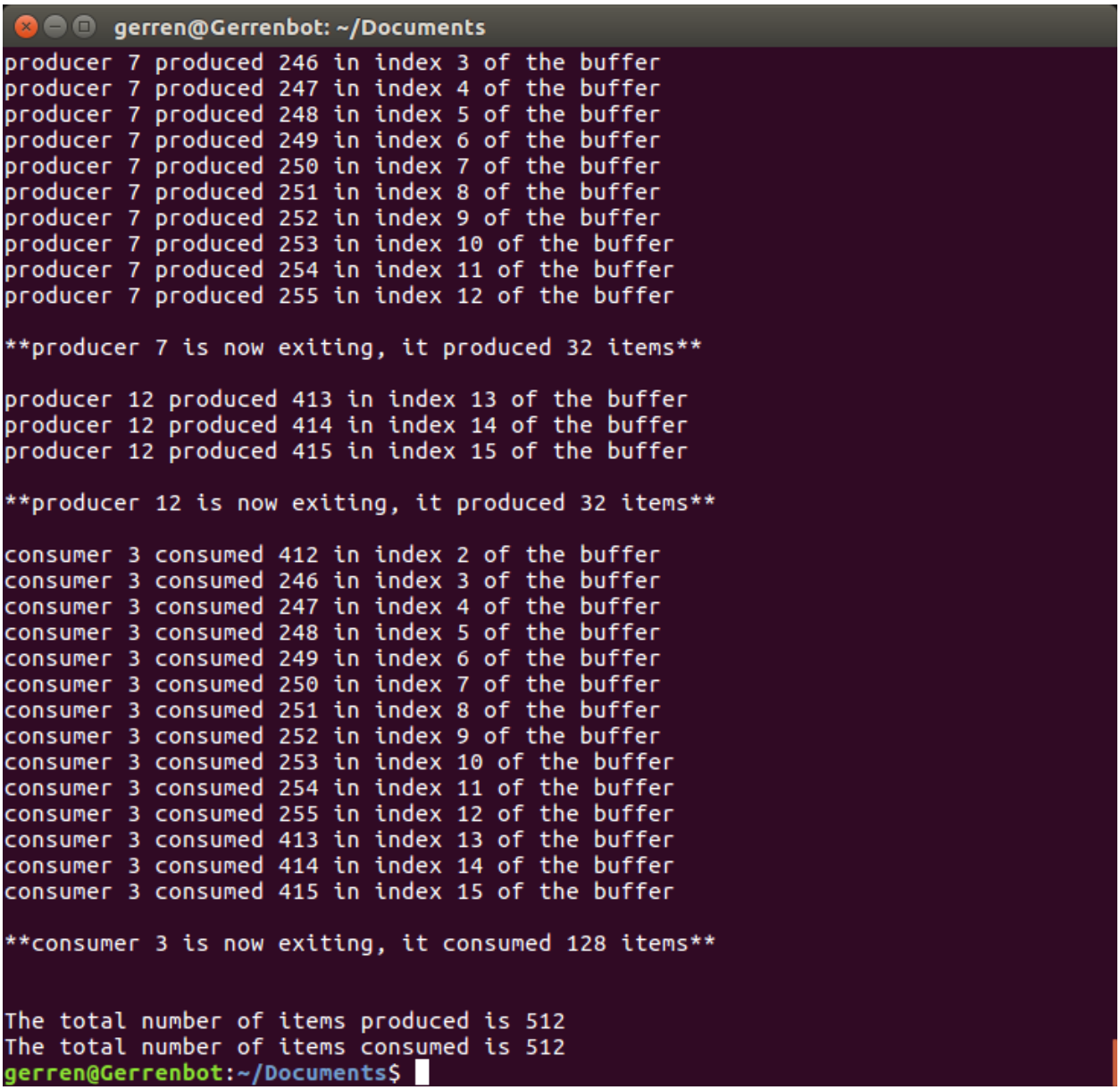

gerren@Gerrenbot: ~/Documents
gerren@Gerrenbot:~/Documents$ ./hw5 2 1 5
Producers: 4, Consumers: 2, Items Produced: 32
Each consumer will consume 64 items
producer 0 produced 0 in index 0 of the buffer
producer 0 produced 1 in index 1 of the buffer
producer 0 produced 2 in index 2 of the buffer
producer 1 produced 32 in index 3 of the buffer
producer 0 produced 3 in index 4 of the buffer
producer 0 produced 4 in index 5 of the buffer
producer 0 produced 5 in index 6 of the buffer
producer 3 produced 96 in index 7 of the buffer
producer 0 produced 6 in index 8 of the buffer
producer 0 produced 7 in index 9 of the buffer
producer 0 produced 8 in index 10 of the buffer
producer 0 produced 9 in index 11 of the buffer
producer 0 produced 10 in index 12 of the buffer
producer 0 produced 11 in index 13 of the buffer
producer 0 produced 12 in index 14 of the buffer
producer 0 produced 13 in index 15 of the buffer
consumer 0 consumed 0 in index 0 of the buffer
producer 0 produced 14 in index 0 of the buffer
consumer 0 consumed 1 in index 1 of the buffer
consumer 0 consumed 2 in index 2 of the buffer
producer 0 produced 15 in index 1 of the buffer
producer 0 produced 16 in index 2 of the buffer
consumer 0 consumed 32 in index 3 of the buffer
consumer 0 consumed 3 in index 4 of the buffer
producer 0 produced 17 in index 3 of the buffer
producer 0 produced 18 in index 4 of the buffer
consumer 0 consumed 4 in index 5 of the buffer
consumer 1 consumed 5 in index 6 of the buffer
producer 1 produced 33 in index 5 of the buffer
producer 1 produced 34 in index 6 of the buffer
consumer 0 consumed 96 in index 7 of the buffer
consumer 1 consumed 6 in index 8 of the buffer
consumer 1 consumed 7 in index 9 of the buffer
producer 3 produced 97 in index 7 of the buffer
producer 1 produced 35 in index 8 of the buffer
producer 3 produced 98 in index 9 of the buffer


gerren@Gerrenbot: ~/Documents
consumer 1 consumed 61 in index 1 of the buffer
consumer 1 consumed 62 in index 2 of the buffer
producer 3 produced 116 in index 3 of the buffer
producer 1 produced 63 in index 4 of the buffer
producer 1 is now exiting, it produced 32 items
producer 3 produced 117 in index 5 of the buffer
producer 3 produced 118 in index 6 of the buffer
producer 3 produced 119 in index 7 of the buffer
producer 3 produced 120 in index 8 of the buffer
producer 3 produced 121 in index 9 of the buffer
producer 3 produced 122 in index 10 of the buffer
producer 3 produced 123 in index 11 of the buffer
producer 3 produced 124 in index 12 of the buffer
producer 3 produced 125 in index 13 of the buffer
producer 3 produced 126 in index 14 of the buffer
producer 3 produced 127 in index 15 of the buffer
producer 3 is now exiting, it produced 32 items
consumer 1 consumed 116 in index 3 of the buffer
consumer 1 consumed 63 in index 4 of the buffer
consumer 1 consumed 117 in index 5 of the buffer
consumer 1 consumed 118 in index 6 of the buffer
consumer 1 consumed 119 in index 7 of the buffer
consumer 1 consumed 120 in index 8 of the buffer
consumer 1 consumed 121 in index 9 of the buffer
consumer 1 consumed 122 in index 10 of the buffer
consumer 1 consumed 123 in index 11 of the buffer
consumer 1 consumed 124 in index 12 of the buffer
consumer 1 consumed 125 in index 13 of the buffer
consumer 1 consumed 126 in index 14 of the buffer
consumer 1 consumed 127 in index 15 of the buffer
consumer 1 is now exiting, it consumed 64 items
The total number of items produced is 128
The total number of items consumed is 128


gerren@Gerrenbot: ~/Documents
gerren@Gerrenbot:~/Documents$ ./hw5 2 4 5
Producers: 4, Consumers: 16, Items Produced: 32
Each consumer will consume 8 items
producer 1 produced 32 in index 0 of the buffer
producer 1 produced 33 in index 1 of the buffer
producer 0 produced 0 in index 2 of the buffer
consumer 0 consumed 32 in index 0 of the buffer
producer 3 produced 96 in index 3 of the buffer
producer 3 produced 97 in index 4 of the buffer
producer 3 produced 98 in index 5 of the buffer
producer 3 produced 99 in index 6 of the buffer
producer 3 produced 100 in index 7 of the buffer
producer 3 produced 101 in index 8 of the buffer
producer 3 produced 102 in index 9 of the buffer
producer 3 produced 103 in index 10 of the buffer
producer 3 produced 104 in index 11 of the buffer
producer 3 produced 105 in index 12 of the buffer
producer 3 produced 106 in index 13 of the buffer
producer 3 produced 107 in index 14 of the buffer
producer 3 produced 108 in index 15 of the buffer
producer 3 produced 109 in index 0 of the buffer
consumer 1 consumed 33 in index 1 of the buffer
producer 2 produced 64 in index 1 of the buffer
consumer 1 consumed 0 in index 2 of the buffer
producer 1 produced 34 in index 2 of the buffer
consumer 0 consumed 96 in index 3 of the buffer
consumer 0 consumed 97 in index 4 of the buffer
producer 3 produced 110 in index 3 of the buffer
producer 0 produced 1 in index 4 of the buffer
consumer 0 consumed 98 in index 5 of the buffer
producer 3 produced 111 in index 5 of the buffer
consumer 1 consumed 99 in index 6 of the buffer
consumer 1 consumed 100 in index 7 of the buffer
consumer 1 consumed 101 in index 8 of the buffer
consumer 1 consumed 102 in index 9 of the buffer
producer 3 produced 112 in index 6 of the buffer
consumer 3 consumed 103 in index 10 of the buffer
consumer 0 consumed 104 in index 11 of the buffer
producer 2 produced 65 in index 7 of the buffer


gerren@Gerrenbot: ~/Documents
consumer 13 is now exiting, it consumed 8 items
consumer 3 consumed 53 in index 5 of the buffer
producer 1 produced 54 in index 6 of the buffer
consumer 11 consumed 54 in index 6 of the buffer
producer 1 produced 55 in index 7 of the buffer
consumer 3 consumed 55 in index 7 of the buffer
producer 1 produced 56 in index 8 of the buffer
consumer 11 consumed 56 in index 8 of the buffer
producer 1 produced 57 in index 9 of the buffer
producer 1 produced 58 in index 10 of the buffer
consumer 3 consumed 57 in index 9 of the buffer
consumer 3 consumed 58 in index 10 of the buffer
producer 1 produced 59 in index 11 of the buffer
producer 1 produced 60 in index 12 of the buffer
producer 1 produced 61 in index 13 of the buffer
producer 1 produced 62 in index 14 of the buffer
producer 1 produced 63 in index 15 of the buffer
producer 1 is now exiting, it produced 32 items
consumer 3 consumed 59 in index 11 of the buffer
consumer 3 is now exiting, it consumed 8 items
consumer 6 consumed 60 in index 12 of the buffer
consumer 6 consumed 61 in index 13 of the buffer
consumer 6 consumed 62 in index 14 of the buffer
consumer 6 is now exiting, it consumed 8 items
consumer 11 consumed 63 in index 15 of the buffer
consumer 11 is now exiting, it consumed 8 items
The total number of items produced is 128
The total number of items consumed is 128
gerren@Gerrenbot:~/Documents$


gerren@Gerrenbot: ~/Documents
gerren@Gerrenbot:~/Documents$ ./hw5 4 2 5
Producers: 16, Consumers: 4, Items Produced: 32
Each consumer will consume 128 items
producer 0 produced 0 in index 0 of the buffer
producer 0 produced 1 in index 1 of the buffer
producer 0 produced 2 in index 2 of the buffer
producer 0 produced 3 in index 3 of the buffer
producer 0 produced 4 in index 4 of the buffer
producer 0 produced 5 in index 5 of the buffer
producer 0 produced 6 in index 6 of the buffer
producer 0 produced 7 in index 7 of the buffer
producer 0 produced 8 in index 8 of the buffer
producer 0 produced 9 in index 9 of the buffer
producer 0 produced 10 in index 10 of the buffer
producer 0 produced 11 in index 11 of the buffer
producer 0 produced 12 in index 12 of the buffer
producer 0 produced 13 in index 13 of the buffer
producer 0 produced 14 in index 14 of the buffer
producer 0 produced 15 in index 15 of the buffer
consumer 0 consumed 0 in index 0 of the buffer
producer 0 produced 16 in index 0 of the buffer
consumer 0 consumed 1 in index 1 of the buffer
producer 1 produced 32 in index 1 of the buffer
consumer 0 consumed 2 in index 2 of the buffer
producer 2 produced 64 in index 2 of the buffer
consumer 0 consumed 3 in index 3 of the buffer
producer 3 produced 96 in index 3 of the buffer
consumer 0 consumed 4 in index 4 of the buffer
producer 4 produced 128 in index 4 of the buffer
consumer 3 consumed 5 in index 5 of the buffer
consumer 0 consumed 6 in index 6 of the buffer
producer 5 produced 160 in index 5 of the buffer
consumer 0 consumed 7 in index 7 of the buffer
producer 4 produced 129 in index 6 of the buffer
producer 4 produced 130 in index 7 of the buffer
consumer 0 consumed 8 in index 8 of the buffer
producer 6 produced 192 in index 8 of the buffer
consumer 1 consumed 9 in index 9 of the buffer
producer 9 produced 288 in index 9 of the buffer


gerren@Gerrenbot: ~/Documents
producer 7 produced 246 in index 3 of the buffer
producer 7 produced 247 in index 4 of the buffer
producer 7 produced 248 in index 5 of the buffer
producer 7 produced 249 in index 6 of the buffer
producer 7 produced 250 in index 7 of the buffer
producer 7 produced 251 in index 8 of the buffer
producer 7 produced 252 in index 9 of the buffer
producer 7 produced 253 in index 10 of the buffer
producer 7 produced 254 in index 11 of the buffer
producer 7 produced 255 in index 12 of the buffer
producer 7 is now exiting, it produced 32 items
producer 12 produced 413 in index 13 of the buffer
producer 12 produced 414 in index 14 of the buffer
producer 12 produced 415 in index 15 of the buffer
producer 12 is now exiting, it produced 32 items
consumer 3 consumed 412 in index 2 of the buffer
consumer 3 consumed 246 in index 3 of the buffer
consumer 3 consumed 247 in index 4 of the buffer
consumer 3 consumed 248 in index 5 of the buffer
consumer 3 consumed 249 in index 6 of the buffer
consumer 3 consumed 250 in index 7 of the buffer
consumer 3 consumed 251 in index 8 of the buffer
consumer 3 consumed 252 in index 9 of the buffer
consumer 3 consumed 253 in index 10 of the buffer
consumer 3 consumed 254 in index 11 of the buffer
consumer 3 consumed 255 in index 12 of the buffer
consumer 3 consumed 413 in index 13 of the buffer
consumer 3 consumed 414 in index 14 of the buffer
consumer 3 consumed 415 in index 15 of the buffer
consumer 3 is now exiting, it consumed 128 items
The total number of items produced is 512
The total number of items consumed is 512
gerren@Gerrenbot:~/Documents$