CS399 Operating System
Project 2

April 3, 2019

The goal of the project is to build a program in parallel and to solve inter-process communication problems.

Objectives

- Complete all the code files
- Provide a simple **Makefile** that can generate an executable file named **express**, The project will be examined by only two commands:

```
$ make
$ ./express
```

- Provide your running results
- Compress all the materials into **PRJ2_studentID.tar.gz** and upload to moodle
- the deadline is 2019/05/14 Tuesday at 23:59

Problem statement

The problem is a simulation of the express center in our campus.

There are three types of people in the center: customer, producer and cashier. Each is characterized by a type of thread. Besides, there two types of resources: shelf and counter. They are represented by mutex variables. The problem is divided into two parts.

Part I

In this part, you have to implement the customer thread and half of the producer thread.

Customer does the following three things.

1. Finding the package at target shelf whose id is given.
2. Finding the cashier counter with least customers.

3. Checking out at the cashier counter.
   A counter allows one customer checking out at a time.

Producer does one thing. He checks the shelves regularly. If a shelf is empty, he fills the shelf to its maximum capacity.

Explanation of **shelf**:

1. The shelf accepts one operation at a time, either a customer is searching his package, either the producer is refilling it.
2. The shelves are full of packages at the beginning. The maximum capacity is 5 by default.
3. The amount of packages reduces by 1 every time a package is taken.
4. When a shelf is empty, customers can't find the package in it. It should wait to be filled by the producer.

Part II

In this part, you have to implement the cashier thread and the other half of producer thread.

In fact, **cashier** is not always at the counter. When there's no customer waiting at the cashier counter, he will leave the counter and play for a while.

1. When the cashier leaves his counter, no customers can check out there.
2. He can be recalled back to work by the producer.
3. He should also get back to work spontaneously after playing for enough time. Because the producer may be busy maintaining the shelves and too many customers are crowded at the counter.

So the **producer** supervises the cashiers. When a cashier leaves the counter and there appears a customer in the queue, he calls the cashier back to work.

Explanation and tips 

1. There are five code files: *main.c params.h customer.c producer.c cashier.c.*
   In *params.h* we define the necessary variables.
   main.c is the main entrance of our program and it's complete, in which all the threads are created.
   You have to complete three functions in *customer.c, producer.c*, and *cashier.c.*
2. After you finish part I, you can already run the program to see an intermediate result.
3. Add function *sleep()* for situations where the operation needs time to be done, for example finding a package or checking out.
4. Add **-lpthread** flag for **gcc** while compiling

Appendix

Sample output for part I

```
Customer 1 is searching the package in shelf <3>.
Customer 1 has found the the package.
Customer 1 is checking out at cashier 1.
Customer 2 needs to go to shelf <3>.
Customer 2 is searching the package in shelf <3>.
Customer 3 needs to go to shelf <3>.
Customer 4 needs to go to shelf <1>.
Customer 4 is searching the package in shelf <1>.
Customer 1 leaves.
Customer 5 needs to go to shelf <1>.
Customer 2 has found the the package.
Customer 2 is checking out at cashier 1.
Customer 3 is searching the package in shelf <3>.
Customer 6 needs to go to shelf <2>.
Customer 6 is searching the package in shelf <2>.
Customer 2 leaves.
Customer 7 needs to go to shelf <5>.
Customer 7 is searching the package in shelf <5>.
Customer 8 needs to go to shelf <3>.
Customer 3 has found the the package.
Customer 3 is checking out at cashier 1.
Customer 5 is searching the package in shelf <1>.
Customer 4 has found the the package.
Customer 4 is checking out at cashier 2.
Customer 8 is searching the package in shelf <3>.
Customer 4 leaves.
Customer 6 has found the the package.
Customer 6 is checking out at cashier 2.
Customer 9 needs to go to shelf <3>.
Customer 7 has found the the package.
Customer 10 needs to go to shelf <3>.
Customer 5 has found the the package.
Customer 3 leaves.
Customer 7 is checking out at cashier 1.
Customer 11 needs to go to shelf <3>.
Customer 7 leaves.
Customer 8 has found the the package.
Customer 8 is checking out at cashier 1.
Customer 9 is searching the package in shelf <3>.
Customer 6 leaves.
Customer 5 is checking out at cashier 2.
Customer 12 needs to go to shelf <3>.
Customer 9 has found the the package.
Customer 13 needs to go to shelf <1>.
Customer 13 is searching the package in shelf <1>.
Customer 13 has found the the package.
```

```
Customer 8 leaves.
Customer 9 is checking out at cashier 1.
Customer 5 leaves.
Customer 13 is checking out at cashier 2.
Customer 14 needs to go to shelf <1>.
Customer 14 is searching the package in shelf <1>.
Customer 13 leaves.
Customer 14 has found the the package.
Customer 14 is checking out at cashier 2.
Customer 15 needs to go to shelf <3>.
Customer 14 leaves.
Customer 16 needs to go to shelf <2>.
Customer 16 is searching the package in shelf <2>.
Customer 16 has found the the package.
Customer 16 is checking out at cashier 2.
Customer 16 leaves.
Customer 9 leaves.
Customer 17 needs to go to shelf <3>.
The producer is maintaining shelf <3>.
The producer has filled shelf <3> and decides to relax awhile.
Customer 10 is searching the package in shelf <3>.
Customer 18 needs to go to shelf <4>.
Customer 18 is searching the package in shelf <4>.
Customer 19 needs to go to shelf <1>.
Customer 19 is searching the package in shelf <1>.
Customer 20 needs to go to shelf <5>.
Customer 20 is searching the package in shelf <5>.
Customer 21 needs to go to shelf <5>.
Customer 10 has found the the package.
Customer 10 is checking out at cashier 1.
Customer 11 is searching the package in shelf <3>.
Customer 11 has found the the package.
Customer 11 is checking out at cashier 2.
Customer 12 is searching the package in shelf <3>.
Customer 18 has found the the package.
Customer 19 has found the the package.
Customer 20 has found the the package.
Customer 21 is searching the package in shelf <5>.
Customer 22 needs to go to shelf <4>.
Customer 22 is searching the package in shelf <4>.
Customer 23 needs to go to shelf <2>.
Customer 23 is searching the package in shelf <2>.
Customer 24 needs to go to shelf <5>.
Customer 11 leaves.
Customer 19 is checking out at cashier 2.
Customer 19 leaves.
Customer 10 leaves.
Customer 18 is checking out at cashier 1.
Customer 12 has found the the package.
Customer 12 is checking out at cashier 2.
```

```
Customer 15 is searching the package in shelf <3>.
Customer 23 has found the the package.
Customer 25 needs to go to shelf <2>.
Customer 25 is searching the package in shelf <2>.
Customer 18 leaves.
Customer 20 is checking out at cashier 1.
Customer 21 has found the the package.
Customer 24 is searching the package in shelf <5>.
Customer 24 has found the the package.
Customer 25 has found the the package.
Customer 26 needs to go to shelf <5>.
Customer 26 is searching the package in shelf <5>.
Customer 22 has found the the package.
Customer 27 needs to go to shelf <2>.
Customer 27 is searching the package in shelf <2>.
Customer 12 leaves.
Customer 23 is checking out at cashier 2.
Customer 15 has found the the package.
Customer 17 is searching the package in shelf <3>.
Customer 26 has found the the package.
Customer 28 needs to go to shelf <3>.
Customer 27 has found the the package.
Customer 29 needs to go to shelf <2>.
The producer is maintaining shelf <1>.
The producer has filled shelf <1> and decides to relax awhile.
Customer 20 leaves.
Customer 21 is checking out at cashier 1.
Customer 23 leaves.
Customer 25 is checking out at cashier 2.
Customer 25 leaves.
Customer 15 is checking out at cashier 2.
Customer 17 has found the the package.
Customer 21 leaves.
Customer 24 is checking out at cashier 1.
Customer 30 needs to go to shelf <1>.
Customer 30 is searching the package in shelf <1>.
Customer 15 leaves.
Customer 26 is checking out at cashier 2.
Customer 24 leaves.
Customer 26 leaves.
Customer 22 is checking out at cashier 1.
Customer 17 is checking out at cashier 2.
Customer 30 has found the the package.
The producer is maintaining shelf <2>.
The producer has filled shelf <2> and decides to relax awhile.
Customer 29 is searching the package in shelf <2>.
Customer 29 has found the the package.
Customer 22 leaves.
Customer 30 is checking out at cashier 2.
Customer 27 is checking out at cashier 1.
```

```
Customer 17 leaves.
Customer 27 leaves.
Customer 29 is checking out at cashier 1.
The producer is maintaining shelf <3>.
The producer has filled shelf <3> and decides to relax awhile.
Customer 28 is searching the package in shelf <3>.
Customer 30 leaves.
Customer 29 leaves.
Customer 28 has found the the package.
Customer 28 is checking out at cashier 1.
Customer 28 leaves.
The producer is maintaining shelf <5>.
The producer has filled shelf <5> and decides to relax awhile.
```

Sample output for part II

```
Cashier 1 leaves the counter since no one waits there.
Customer 1 needs to go to shelf <3>.
Customer 1 is searching the package in shelf <3>.
Cashier 2 leaves the counter since no one waits there.
Customer 1 has found the the package.
The producer has called cashier 1 back to work.
Cashier 1 goes back to work.
Customer 1 is checking out at cashier 1.
Customer 2 needs to go to shelf <5>.
Customer 2 is searching the package in shelf <5>.
Customer 3 needs to go to shelf <3>.
Customer 3 is searching the package in shelf <3>.
Customer 3 has found the the package.
The producer has called cashier 2 back to work.
Cashier 2 goes back to work.
Customer 3 is checking out at cashier 2.
Customer 1 leaves.
Customer 4 needs to go to shelf <2>.
Customer 4 is searching the package in shelf <2>.
Customer 5 needs to go to shelf <2>.
Customer 3 leaves.
Customer 2 has found the the package.
Customer 2 is checking out at cashier 1.
Customer 6 needs to go to shelf <5>.
Customer 6 is searching the package in shelf <5>.
Customer 7 needs to go to shelf <3>.
Customer 7 is searching the package in shelf <3>.
Customer 4 has found the the package.
Customer 4 is checking out at cashier 2.
Customer 5 is searching the package in shelf <2>.
Customer 4 leaves.
Customer 6 has found the the package.
```

```
Customer 6 is checking out at cashier 2.
Customer 9 needs to go to shelf <2>.
Customer 10 needs to go to shelf <2>.
Customer 8 needs to go to shelf <3>.
Customer 2 leaves.
Customer 7 has found the the package.
Customer 7 is checking out at cashier 1.
Customer 8 is searching the package in shelf <3>.
Customer 11 needs to go to shelf <5>.
Customer 11 is searching the package in shelf <5>.
Customer 8 has found the the package.
Customer 5 has found the the package.
Customer 9 is searching the package in shelf <2>.
Customer 9 has found the the package.
Customer 10 is searching the package in shelf <2>.
Customer 11 has found the the package.
Customer 12 needs to go to shelf <2>.
Customer 6 leaves.
Customer 5 is checking out at cashier 2.
Customer 7 leaves.
Customer 5 leaves.
Customer 11 is checking out at cashier 2.
Customer 8 is checking out at cashier 1.
Customer 13 needs to go to shelf <3>.
Customer 13 is searching the package in shelf <3>.
Customer 8 leaves.
Customer 9 is checking out at cashier 1.
Customer 14 needs to go to shelf <1>.
Customer 9 leaves.
Customer 14 is searching the package in shelf <1>.
Cashier 1 leaves the counter since no one waits there.
Customer 13 has found the the package.
Customer 11 leaves.
Customer 15 needs to go to shelf <1>.
Customer 10 has found the the package.
Customer 10 is checking out at cashier 2.
Customer 12 is searching the package in shelf <2>.
Customer 10 leaves.
Customer 16 needs to go to shelf <3>.
The producer is maintaining shelf <3>.
Customer 14 has found the the package.
Customer 14 is checking out at cashier 2.
Customer 15 is searching the package in shelf <1>.
Customer 14 leaves.
Customer 17 needs to go to shelf <5>.
Customer 17 is searching the package in shelf <5>.
Customer 18 needs to go to shelf <5>.
Customer 19 needs to go to shelf <1>.
Customer 20 needs to go to shelf <4>.
Customer 20 is searching the package in shelf <4>.
```

```
Customer 20 has found the the package.
Customer 20 is checking out at cashier 2.
Customer 21 needs to go to shelf <5>.
Customer 12 has found the the package.
Customer 15 has found the the package.
Customer 19 is searching the package in shelf <1>.
Customer 22 needs to go to shelf <3>.
The producer has filled shelf <3> and decides to relax awhile.
Customer 22 is searching the package in shelf <3>.
Customer 17 has found the the package.
Customer 18 is searching the package in shelf <5>.
Customer 20 leaves.
Customer 15 is checking out at cashier 2.
Customer 23 needs to go to shelf <2>.
Customer 24 needs to go to shelf <5>.
Customer 25 needs to go to shelf <1>.
Customer 26 needs to go to shelf <4>.
Customer 26 is searching the package in shelf <4>.
Customer 19 has found the the package.
Customer 25 is searching the package in shelf <1>.
Customer 15 leaves.
Customer 19 is checking out at cashier 2.
Customer 22 has found the the package.
Customer 16 is searching the package in shelf <3>.
Customer 25 has found the the package.
Customer 26 has found the the package.
Customer 27 needs to go to shelf <3>.
Customer 28 needs to go to shelf <2>.
The producer has called cashier 1 back to work.
Cashier 1 goes back to work.
Customer 13 is checking out at cashier 1.
Customer 18 has found the the package.
Customer 19 leaves.
Customer 22 is checking out at cashier 2.
Customer 29 needs to go to shelf <5>.
Customer 30 needs to go to shelf <5>.
Customer 16 has found the the package.
Customer 27 is searching the package in shelf <3>.
Customer 13 leaves.
Customer 12 is checking out at cashier 1.
Customer 22 leaves.
Customer 25 is checking out at cashier 2.
Customer 12 leaves.
Customer 17 is checking out at cashier 1.
Customer 17 leaves.
Customer 26 is checking out at cashier 1.
Customer 25 leaves.
Customer 18 is checking out at cashier 2.
Customer 18 leaves.
The producer is maintaining shelf <2>.
```

```
Customer 26 leaves.
Customer 16 is checking out at cashier 1.
Customer 27 has found the the package.
Customer 27 is checking out at cashier 2.
Customer 27 leaves.
Customer 16 leaves.
The producer has filled shelf <2> and decides to relax awhile.
Customer 23 is searching the package in shelf <2>.
Cashier 1 leaves the counter since no one waits there.
Customer 23 has found the the package.
Customer 28 is searching the package in shelf <2>.
Customer 28 has found the the package.
Customer 28 is checking out at cashier 2.
Customer 28 leaves.
Cashier 2 leaves the counter since no one waits there.
The producer is maintaining shelf <5>.
The producer has filled shelf <5> and decides to relax awhile.
Customer 21 is searching the package in shelf <5>.
The producer has called cashier 1 back to work.
Cashier 1 goes back to work.
Customer 23 is checking out at cashier 1.
Customer 21 has found the the package.
Customer 24 is searching the package in shelf <5>.
Customer 23 leaves.
Cashier 1 leaves the counter since no one waits there.
Customer 29 is searching the package in shelf <5>.
Customer 24 has found the the package.
The producer has called cashier 1 back to work.
The producer has called cashier 2 back to work.
Cashier 2 goes back to work.
Customer 21 is checking out at cashier 2.
Cashier 1 goes back to work.
Customer 24 is checking out at cashier 1.
Customer 24 leaves.
Customer 29 has found the the package.
Customer 29 is checking out at cashier 1.
Customer 21 leaves.
Customer 30 is searching the package in shelf <5>.
Customer 30 has found the the package.
Customer 30 is checking out at cashier 2.
Customer 30 leaves.
Cashier 2 leaves the counter since no one waits there.
Customer 29 leaves.
Cashier 1 leaves the counter since no one waits there.
```