CS-520-A Homework Assignment #3
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1. Shortest Job First (SJF) scheduling algorithm is optimal in that it minimizes the average waiting time.

We have already known the formula for average waiting time and the definition of Shortest Job First scheduling algorithm. Here is the formula of average waiting time:

$$\frac{1}{n}\sum_{i=1}^{n-1}(n-i)t_i$$

Where n is the number of processes, t_i is the burst time of number i process. SJF scheduling algorithm means the process that requests the shortest length of the process is allocated the CPU first.

Based on these information, we can prove that SJF scheduling algorithm minimizes the average waiting time. Here are two supposes: suppose all n processes are already in the system at the time the scheduling decision has to made, and suppose all processes have arrived at the same time.

For proving, we can use an example to help illustrate it. Here are three processes, process P_1, which has 15 milliseconds burst time, process P_2, which has 3 milliseconds burst time, and process P_3, which has 6 milliseconds burst time. Suppose that the processes arrive in the order: P_2, P_3, P_1, and are served in SJF order. We can get the waiting time is 0 milliseconds for process P_2, 3 milliseconds for process P_3, and 9 milliseconds for process P_1. Then, we can calculate the average waiting time under SJF policy is (0+3+6)/3=3 milliseconds.

For detecting whether this average waiting time is minimal. We change the order which the processes arrive into: P_1, P_2, P_3, and are served in FCFS order. Using the same method to get the waiting time of each process, we can get the average waiting time under FCFS policy is (0+15+3)/3=6 milliseconds.

According the change the order which the processes arrive, we can get different average waiting time. After comparing them, we can find that the average waiting time under SJF policy is minimal. It is because, we have move the short process before the long process, and this action decrease the waiting time of the short process. Consequently, the average waiting time also decreases.

2.
First of all, we calculate the turnaround time and waiting time by analysis, then, we design one event-driven code to achieve the FCFS (First come-First Served Scheduling), SJF (Shortest-Job-First Scheduling), Nonpreemptive Priority Scheduling and RR (Round-Robin Scheduling). At the last, we use the code to check if the code is correctly.

For solving Problem 5.3:

There are three processes in the list. Here is a table which suggests the arrival time and the burst time for each process.

Process	Arrival Time	Burst Time
P_1	0.0	8
P_2	0.4	4
P_3	1	1

If we used FCFS scheduling algorithm, the processes would arrive in the order P_1, P_2, P_3. The turnaround time is 8 milliseconds for process P_1, 11.6 milliseconds for process P_2, and 12 milliseconds for process P_3. Thus, the average turnaround time is (8+11.6+12)/3=10.53. Here is the picture for using event-driven code to solve problem.

```
Enter the number of the process: 3
Enter the Arrival Time of Process P1 : 0.0
Enter the Burst Time of Process P1 : 8
Enter the priority of Process P1 : 0
Enter the Arrival Time of Process P2 : 0.4
Enter the Burst Time of Process P2 : 4
Enter the priority of Process P2 : 0
Enter the Arrival Time of Process P3 : 1
Enter the Burst Time of Process P3 : 1
Enter the priority of Process P3 : 0
Process   Arrival Time   Burst Time   Priority
      P1            0            8          0
      P2          0.4            4          0
      P3            1            1          0
Start using Fist Come First Served scheduling algorithm.
If CPU is left idle, please input it(if not, please enter 0): 0
0 |  P1__________| 8  P2_____| 12  P3__| 13
The waiting time of Process P1 is: 0
The turnaround time of Process P1 is: 8
The waiting time of Process P2 is: 7.6
The turnaround time of Process P2 is: 11.6
The waiting time of Process P3 is: 11
The turnaround time of Process P3 is: 12
The average waiting time is: 6.2
The average turnaround time is: 10.5333
```

If we used SJF scheduling algorithm, the processes would be served in the order P_1, P_3, P_2. It is because when process P_1 is being served, both of process P_2 and P_3 have arrived. So, according to the definition of SJF algorithm, after process P_1 is being served, we need to compare process P_2 and P_3, and find out which process has the shortest burning time. Then, we have the served order. Based on the order, we can calculate the turnaround time is 8 milliseconds for process P_1, 12.6 milliseconds for process P_2, and 8 milliseconds for process P_3. Thus, the average turnaround time is (8+12.6+8)/3=9.53. Here is the picture for using event-driven code to solve problem.

```
Enter the number of the process: 3
Enter the Arrival Time of Process P1 : 0.0
Enter the Burst Time of Process P1 : 8
Enter the priority of Process P1 : 0
Enter the Arrival Time of Process P2 : 0.4
Enter the Burst Time of Process P2 : 4
Enter the priority of Process P2 : 0
Enter the Arrival Time of Process P3 : 1
Enter the Burst Time of Process P3 : 1
Enter the priority of Process P3 : 0
Process   Arrival Time   Burst Time   Priority
      P1           0            8          0
      P2         0.4            4          0
      P3           1            1          0
Start using Shortest Job First scheduling algorithm.
If CPU is left idle, please input it(if not, please enter 0): 0
0 |  P1________| 8  P3__| 9  P2_____| 13
The waiting time of Process P1 is: 0
The turnaround time of Process P1 is: 8
The waiting time of Process P2 is: 8.6
The turnaround time of Process P2 is: 12.6
The waiting time of Process P3 is: 7
The turnaround time of Process P3 is: 8
The average waiting time is: 5.2
The average turnaround time is: 9.53333
```

If the CPU is left idle time for 1 unit, and then we used SJF scheduling, the process would be served in the order P_2, P_3, P_1. It is because when the CPU has 1 unit idle time, process P_1 and process P_2 have already waited in the serving line. Comparing two processes, process P_2 has the shorter burst time. So, we run the process P_2 firstly. After process P_2 has being served, process P_3 has already coming. Then, we compare the burst time of process P_1 and process P_3, process P_3 has shorter burst time. So, we run the process P_3. At the last, we run the process P_1. According to the order, we can calculate the turnaround time is 14 milliseconds for process P_1, 4.6 milliseconds for process P_2, and 5 milliseconds for process P_3. Thus, the average turnaround time is (14+4.6+5)/3=7.87. Here is the picture for using event-driven code to solve problem.

```
Enter the number of the process: 3
Enter the Arrival Time of Process P1 : 0.0
Enter the Burst Time of Process P1 : 8
Enter the priority of Process P1 : 0
Enter the Arrival Time of Process P2 : 0.4
Enter the Burst Time of Process P2 : 4
Enter the priority of Process P2 : 0
Enter the Arrival Time of Process P3 : 1
Enter the Burst Time of Process P3 : 1
Enter the priority of Process P3 : 0
Process   Arrival Time   Burst Time   Priority
      P1           0            8          0
      P2         0.4            4          0
      P3           1            1          0
Start using Shortest Job First scheduling algorithm.
If CPU is left idle, please input it(if not, please enter 0): 1
0 |  P2_____| 4  P3__| 5  P1________| 13
The waiting time of Process P1 is: 6
The turnaround time of Process P1 is: 14
The waiting time of Process P2 is: 0.6
The turnaround time of Process P2 is: 4.6
The waiting time of Process P3 is: 4
The turnaround time of Process P3 is: 5
The average waiting time is: 3.53333
The average turnaround time is: 7.86667
```

For solving Problem 5.12:

There are five processes in the list. Here is a table which suggests the burst time and the priority for each process.

Process	Burst Time	Priority
P_1	10	3
P_2	1	1
P_3	2	3
P_4	1	4
P_5	5	2

If we used FCFS scheduling algorithm, the processes would arrive in the order P_1,P_2,P_3,P_4,P_5. The waiting time is 0 milliseconds for process P_1, 10 milliseconds for process P_2, 11 milliseconds for process P_3, 13 milliseconds for process P_4, and 14 milliseconds for process P_5. The turnaround time is 10 milliseconds for process P_1, 11 milliseconds for process P_2, 13 milliseconds for process P_3, 14 milliseconds for process P_4, and 19 milliseconds for process P_5. Thus, the average waiting time is (0+10+11+13+14)/5=9.6, the average turnaround time is (10+11+13+14+19)/5=13.4. Here is the picture for using event-driven code to solve problem.

```
Enter the number of the process: 5
Enter the Arrival Time of Process P1 : 0
Enter the Burst Time of Process P1 : 10
Enter the priority of Process P1 : 3
Enter the Arrival Time of Process P2 : 0
Enter the Burst Time of Process P2 : 1
Enter the priority of Process P2 : 1
Enter the Arrival Time of Process P3 : 0
Enter the Burst Time of Process P3 : 2
Enter the priority of Process P3 : 3
Enter the Arrival Time of Process P4 : 0
Enter the Burst Time of Process P4 : 1
Enter the priority of Process P4 : 4
Enter the Arrival Time of Process P5 : 0
Enter the Burst Time of Process P5 : 5
Enter the priority of Process P5 : 2
Process   Arrival Time   Burst Time   Priority
      P1            0          10         3
      P2            0           1         1
      P3            0           2         3
      P4            0           1         4
      P5            0           5         2
Start using Fist Come First Served scheduling algorithm.
If CPU is left idle, please input it(if not, please enter 0): 0
0 |  P1__________| 10  P2__| 11  P3___| 13  P4__| 14  P5______| 19
The waiting time of Process P1 is: 0
The turnaround time of Process P1 is: 10
The waiting time of Process P2 is: 10
The turnaround time of Process P2 is: 11
The waiting time of Process P3 is: 11
The turnaround time of Process P3 is: 13
The waiting time of Process P4 is: 13
The turnaround time of Process P4 is: 14
The waiting time of Process P5 is: 14
The turnaround time of Process P5 is: 19
The average waiting time is: 9.6
The average turnaround time is: 13.4
```

If we used SJF scheduling algorithm, the processes would be served in the order P_2,P_4,P_3,P_5,P_1. It is because the five processes are all arrive at time 0. So, we need to find out which process has the shortest burst time, and let this process run firstly. Then, we find process P_2 and process P_4 all have the shortest burst time, 1. At this situation, we let process P_2 being served firstly, because before SJF, the processes are assumed to have arrived in the order P_1,P_2,P_3,P_4,P_5. Then, after the process P_2 being served, we keep finding the process which has the shortest burst time, and we get the serving order of these processes. Next, we can calculate the turnaround time is 19 milliseconds for process P_1, 1 milliseconds for process P_2, 4 milliseconds for process P_3, 2 milliseconds for process P_4, and 9 milliseconds for process P_5. The waiting time is 9 milliseconds for process P_1, 0 milliseconds for process P_2, 2 milliseconds for process P_3, 1 milliseconds for process P_4, and 4 milliseconds for process P_5. Thus, the average turnaround time is (19+1+4+2+9)/5=7, the average waiting time is (9+0+2+1+4)/5=3.4. Here is the picture for using event-driven code to solve problem.

```
Enter the number of the process: 5
Enter the Arrival Time of Process P1 : 0
Enter the Burst Time of Process P1 : 10
Enter the priority of Process P1 : 3
Enter the Arrival Time of Process P2 : 0
Enter the Burst Time of Process P2 : 1
Enter the priority of Process P2 : 1
Enter the Arrival Time of Process P3 : 0
Enter the Burst Time of Process P3 : 2
Enter the priority of Process P3 : 3
Enter the Arrival Time of Process P4 : 0
Enter the Burst Time of Process P4 : 1
Enter the priority of Process P4 : 4
Enter the Arrival Time of Process P5 : 0
Enter the Burst Time of Process P5 : 5
Enter the priority of Process P5 : 2
Process   Arrival Time   Burst Time   Priority
      P1            0          10          3
      P2            0           1          1
      P3            0           2          3
      P4            0           1          4
      P5            0           5          2
Start using Shortest Job First scheduling algorithm.
If CPU is left idle, please input it(if not, please enter 0): 0
0 |  P2__| 1  P4__| 2  P3___| 4  P5______| 9  P1___________| 19
The waiting time of Process P1 is: 9
The turnaround time of Process P1 is: 19
The waiting time of Process P2 is: 0
The turnaround time of Process P2 is: 1
The waiting time of Process P3 is: 2
The turnaround time of Process P3 is: 4
The waiting time of Process P4 is: 1
The turnaround time of Process P4 is: 2
The waiting time of Process P5 is: 4
The turnaround time of Process P5 is: 9
The average waiting time is: 3.2
The average turnaround time is: 7
```

If we used nonpreemptive priority scheduling algorithm, with the suppose that the smaller priority number implies a higher priority, the process would be served in the order P_2, P_1, P_3, P_5, P_4. This order under the theory that the higher priority should be served at first. So, the process P_2 runs firstly because it has priority 1 which is the highest priority. Similarly, we let process P_5 runs secondly. However, process P_1 and process P_3 have the same priority, 3. We let process P_1 runs firstly, because the assumed order which from the question. Then, we assigned the order. Based on this order, the waiting time is 6 milliseconds for process P_1, 0 milliseconds for process P_2, 16 milliseconds for process P_3, 18 milliseconds for process P_4, and 1 milliseconds for process P_5. The turnaround time is 16 milliseconds for process P_1, 1 milliseconds for process P_2, 18 milliseconds for process P_3, 19 milliseconds for process P_4, and 6 milliseconds for process P_5. Thus, the average waiting time is (6+0+16+18+1)/5=8.2, the average turnaround time is (16+1+18+19+6)/5=12. Here is the picture for using event-driven code to solve problem.

```
Enter the number of the process: 5
Enter the Arrival Time of Process P1 : 0
Enter the Burst Time of Process P1 : 10
Enter the priority of Process P1 : 3
Enter the Arrival Time of Process P2 : 0
Enter the Burst Time of Process P2 : 1
Enter the priority of Process P2 : 1
Enter the Arrival Time of Process P3 : 0
Enter the Burst Time of Process P3 : 2
Enter the priority of Process P3 : 3
Enter the Arrival Time of Process P4 : 0
Enter the Burst Time of Process P4 : 1
Enter the priority of Process P4 : 4
Enter the Arrival Time of Process P5 : 0
Enter the Burst Time of Process P5 : 5
Enter the priority of Process P5 : 2
Process   Arrival Time   Burst Time   Priority
      P1            0          10          3
      P2            0           1          1
      P3            0           2          3
      P4            0           1          4
      P5            0           5          2
Start using Nonpreemptive Priority scheduling algorithm.
If CPU is left idle, please input it(if not, please enter 0): 0
0 |  P2__| 1  P5______| 6  P1___________| 16  P3___| 18  P4__| 19
The waiting time of Process P1 is: 6
The turnaround time of Process P1 is: 16
The waiting time of Process P2 is: 0
The turnaround time of Process P2 is: 1
The waiting time of Process P3 is: 16
The turnaround time of Process P3 is: 18
The waiting time of Process P4 is: 18
The turnaround time of Process P4 is: 19
The waiting time of Process P5 is: 1
The turnaround time of Process P5 is: 6
The average waiting time is: 8.2
The average turnaround time is: 12
```

If we used RR scheduling algorithm, with the quantum equals to 1, the process would be divided into pieces according to the definition of RR. And the serving order would beP_1,P_2,P_3,P_4,P_5, P_1,P_3, P_5,P_1,P_5, P_1, P_5, P_1, P_5, P_1. Since the quantum is equal to 1, the process P_2 and process P_4 are being served and finished at the first round, the process P_3 is at the second round, the process P_5 is at the fifth round, and the process P_1 is at the tenth round. Based on this order, the waiting time is 0+5+2+1+1=9 milliseconds for process P_1, 1 milliseconds for process P_2, 2+3=5 milliseconds for process P_3, 3 milliseconds for process P_4, and 4+2+1+1+1=9 milliseconds for process P_5. The turnaround time is 19 milliseconds for process P_1, 2 milliseconds for process P_2, 7 milliseconds for process P_3, 4 milliseconds for process P_4, and 14 milliseconds for process P_5. Thus, the average waiting time is (9+1+5+3+9)/5=5.4, the average turnaround time is (19+2+7+4+14)/5=9.2. Here is the picture for using event-driven code to solve problem.

```
Enter the number of the process: 5
Enter the Arrival Time of Process P1 : 0
Enter the Burst Time of Process P1 : 10
Enter the priority of Process P1 : 3
Enter the Arrival Time of Process P2 : 0
Enter the Burst Time of Process P2 : 1
Enter the priority of Process P2 : 1
Enter the Arrival Time of Process P3 : 0
Enter the Burst Time of Process P3 : 2
Enter the priority of Process P3 : 3
Enter the Arrival Time of Process P4 : 0
Enter the Burst Time of Process P4 : 1
Enter the priority of Process P4 : 4
Enter the Arrival Time of Process P5 : 0
Enter the Burst Time of Process P5 : 5
Enter the priority of Process P5 : 2
Process   Arrival Time   Burst Time   Priority
      P1            0           10          3
      P2            0            1          1
      P3            0            2          3
      P4            0            1          4
      P5            0            5          2
Please input the quantum of Round-Robin scheduing: 1
Start using Round-Robin scheduling algorithm.
If CPU is left idle, please input it(if not, please enter 0): 0
0 |  P1__| 1  P2_| 2  P3__| 3  P4_| 4  P5__| 5  P1__| 6  P3_| 7  P5__| 8  P1__| 9  P5__| 10
 P1__| 11  P5__| 12  P1__| 13  P5_| 14  P1__| 15  P1__| 16  P1__| 17  P1__| 18  P1_| 19
The waiting time of Process P1 is: 9
The turnaround time of Process P1 is: 19
The waiting time of Process P2 is: 1
The turnaround time of Process P2 is: 2
The waiting time of Process P3 is: 5
The turnaround time of Process P3 is: 7
The waiting time of Process P4 is: 3
The turnaround time of Process P4 is: 4
The waiting time of Process P5 is: 9
The turnaround time of Process P5 is: 14
The average waiting time is: 5.4
The average turnaround time is: 9.2
```

The average waiting time for FCFS is 9.4 milliseconds, for SJF is 3.4, for nonpreemptive priority is 8.2 milliseconds, for RR is 5.4 milliseconds. So, the minimum average waiting time is 3.4 milliseconds, which using the SJF scheduling algorithm.

3.

From the Figure 1 of the question, at the beginning of the simulation, each job from these 10 jobs might be at the Ready queue, or I/O waiting queue, or it is being executed by the CPU. If it is at the Ready queue, the next station of this job is being executed by the CPU. If it is at the I/O waiting queue, the next station of this job is being executed by I/O channel, then going Ready queue. If it is at the CPU, when it finished, the next station is going I/O waiting queue. During the simulation, we use the uniform distribution method for generating the length of each jobs. Here is the reference of uniform real distribution method:

```
//use uniform_int_distribution to acculate the length of jobs
//reference from http://www.cplusplus.com/reference/random/uniform_int_distribution/uniform_int_distribution/
double cpu_schd::uniform_random_length(int start, int end)
{
    // construct a trivial random generator engine from a time-based seed:
    unsigned seed = std::chrono::system_clock::now().time_since_epoch().count();
    std::default_random_engine generator(seed);

    std::uniform_int_distribution<int> distribution(start, end);

    double number_1 = distribution(generator);
    return number_1;
```

And we use poisson random to promise the mean inter-I/O intervals. Here is the reference of poisson random:

```
//use possion distribution to acculate the possibility of random
//reference from http://www.cplusplus.com/reference/random/poisson_distribution/
double cpu_schd::possion_random(double mean)
{
    // construct a trivial random generator engine from a time-based seed:
    unsigned seed = std::chrono::system_clock::now().time_since_epoch().count();
    std::default_random_engine generator(seed);
    std::poisson_distribution<int> distribution(mean);
    return distribution(generator);
}
```

a) Here is the pictures of FCFS simulation.

```
Process   Arrival Time   Burst Time   Priority   Length   Burst_Control
     P1              0           33          0     2164               1
     P2              0           36          0     3443               3
     P3              0           42          0     3011               3
     P4              0           40          0     3085               3
     P5              0           36          0     3429               3
     P6              0           52          0     3185               2
     P7              0           70          0     3315               2
     P8              0           73          0     3755               3
     P9              0           75          0     3036               3
     P10              0           70          0     3570               2
The CPU utilization is: 0.867272
The waiting time of Process P1 is: 2225
The turnaround time of Process P1 is: 3001
The waiting time of Process P2 is: 16119
The turnaround time of Process P2 is: 17220
The waiting time of Process P3 is: 15545
The turnaround time of Process P3 is: 16860
The waiting time of Process P4 is: 14938
The turnaround time of Process P4 is: 16380
The waiting time of Process P5 is: 15336
The turnaround time of Process P5 is: 16920
The waiting time of Process P6 is: 14583
The turnaround time of Process P6 is: 15840
The waiting time of Process P7 is: 14149
The turnaround time of Process P7 is: 15900
The waiting time of Process P8 is: 14727
The turnaround time of Process P8 is: 16740
The waiting time of Process P9 is: 12372
The turnaround time of Process P9 is: 13897
The waiting time of Process P10 is: 13610
The turnaround time of Process P10 is: 15507
The throughput is: 0.58072
The average waiting time is: 13360
The average turnaround time is: 14826
```

From this picture, we can that the CPU utilization is about 86.7%, the throughput is about 0.58072. And the average waiting time is 13360, average turnaround time is 14826. Besides that, cause we let the first process has the shortest burst time, and go to the CPU firstly, this process has the shortest waiting time.

Here is the pictures of SJF simulation with α values of 0.9, 0.5, and 0.33.

α values of 0.9

```
Process   Arrival Time   Burst Time   Priority   Length   Burst_Control
    P1          0             29          0       3950           2
    P2          0             41          0       2994           3
    P3          0             41          0       2944           1
    P4          0             38          0       3969           2
    P5          0             47          0       3497           3
    P6          0             65          0       2253           2
    P7          0             59          0       2457           3
    P8          0             53          0       2915           2
    P9          0             65          0       3618           2
    P10          0             81          0       2731           2
Please input the a values: 0.9
The CPU utilization is: 0.695861
The waiting time of Process P1 is: 1760.65
The turnaround time of Process P1 is: 3060
The waiting time of Process P2 is: 16750.7
The turnaround time of Process P2 is: 17880
The waiting time of Process P3 is: 15929
The turnaround time of Process P3 is: 17040
The waiting time of Process P4 is: 16915.2
The turnaround time of Process P4 is: 18544.2
The waiting time of Process P5 is: 17111.1
The turnaround time of Process P5 is: 18420
The waiting time of Process P6 is: 12020.9
The turnaround time of Process P6 is: 13140
The waiting time of Process P7 is: 13882.6
The turnaround time of Process P7 is: 15000
The waiting time of Process P8 is: 14554.9
The turnaround time of Process P8 is: 15909.9
The waiting time of Process P9 is: 16020.3
The turnaround time of Process P9 is: 17760
The waiting time of Process P10 is: 15181.9
The turnaround time of Process P10 is: 16440
The throughput is: 0.539253
The average waiting time is: 14012
The average turnaround time is: 15319
```

α values of 0.5

```
Process   Arrival Time   Burst Time   Priority   Length   Burst_Control
    P1          0             32          0       3277           3
    P2          0             33          0       2984           2
    P3          0             53          0       2068           3
    P4          0             51          0       3702           3
    P5          0             47          0       3476           3
    P6          0             75          0       3354           3
    P7          0             64          0       2588           2
    P8          0             61          0       3491           3
    P9          0             61          0       2698           2
    P10          0             78          0       3279           2
Please input the a values: 0.5
The CPU utilization is: 0.741511
The waiting time of Process P1 is: 1744.36
The turnaround time of Process P1 is: 2880
The waiting time of Process P2 is: 16057.1
The turnaround time of Process P2 is: 17160
The waiting time of Process P3 is: 12510.2
The turnaround time of Process P3 is: 13380
The waiting time of Process P4 is: 16284.5
The turnaround time of Process P4 is: 17880
The waiting time of Process P5 is: 15961.6
The turnaround time of Process P5 is: 17462.6
The waiting time of Process P6 is: 15805
The turnaround time of Process P6 is: 17400
The waiting time of Process P7 is: 13013.8
The turnaround time of Process P7 is: 14280
The waiting time of Process P8 is: 16157.7
The turnaround time of Process P8 is: 17700
The waiting time of Process P9 is: 13799
The turnaround time of Process P9 is: 15060
The waiting time of Process P10 is: 15229
The turnaround time of Process P10 is: 16800
The throughput is: 0.559284
The average waiting time is: 13656
The average turnaround time is: 15000
```

α values of 0.33

```
Process   Arrival Time   Burst Time   Priority   Length   Burst_Control
    P1          0             23          0       2720           2
    P2          0             25          0       2581           1
    P3          0             47          0       2444           3
    P4          0             38          0       2164           2
    P5          0             63          0       3565           3
    P6          0             56          0       3053           2
    P7          0             58          0       2685           2
    P8          0             59          0       3421           3
    P9          0             72          0       3968           2
    P10          0             68          0       3600           2
Please input the a values: 0.33
The CPU utilization is: 0.759805
The waiting time of Process P1 is: 1320.17
The turnaround time of Process P1 is: 2220
The waiting time of Process P2 is: 14551.4
The turnaround time of Process P2 is: 15540
The waiting time of Process P3 is: 13560.6
The turnaround time of Process P3 is: 14552.6
The waiting time of Process P4 is: 11675.8
The turnaround time of Process P4 is: 12600
The waiting time of Process P5 is: 15699.7
The turnaround time of Process P5 is: 17100
The waiting time of Process P6 is: 14597.6
The turnaround time of Process P6 is: 15960
The waiting time of Process P7 is: 12932.9
The turnaround time of Process P7 is: 14220
The waiting time of Process P8 is: 15138.6
The turnaround time of Process P8 is: 16740
The waiting time of Process P9 is: 15305.5
The turnaround time of Process P9 is: 17236
The waiting time of Process P10 is: 15059.5
The turnaround time of Process P10 is: 16860
The throughput is: 0.580181
The average waiting time is: 12984
The average turnaround time is: 14302
```

Compared the CPU utilization and average waiting time with different α values, we can find that with the decreasing of α values, the CPU utilization is increased, and the throughput is decreased, the waiting time is decreased. It is because SJF simulation need to find out which job has the shortest burst time, and the α values help control the predict burst time of the jobs.

Compared the FCFS simulation and the SJF simulation, we can find that the SJF simulation has the shorter CPU utilization. However, the FCFS has the shorter throughput. It is because SJF need to find out which job has the shortest burst time, and FCFS do not need to do so. Thus, the FCFS has the shorter throughput.

However, when α values is less than 0.5, the simulation might more easily cause starvation. The simulation is easily cause starvation in my code. It is because the mean inter-I/O intervals for these jobs is fixed. There always exist one job which has 30ms mean interval, and this job might always has the shortest burst time, and it should be run at the first. However, there also exist one job which has 75ms mean interval, and this job might always has the largest burst time, and it also need to wait for other jobs. So, it cause the starvation. When the α values is less than 0.5, the predict burst time is changed a little, at the first, the predict burst time is always around 35ms, and it increases gradually. If the last predict burst time is 70ms, then the job which has the largest mean intervals might not be run, so, it causes the starvation.

b) When quantum in Round Robin is decreasing, the waiting time increases:

From the question, we can know that the I/O burst time is 60ms. So, when the quantum under the 60ms, the waiting time is increases. It is because the quantum might just have influence on Ready queue, and when the quantum is less than 60ms which is the burst time of I/O, the job will spend more time on I/O, and spend less time on CPU. So, all of the jobs need to wait for the I/O burst, then execute CPU. Thus, the waiting time of these jobs increases, because they have to increase the waiting time one more time.

When quantum in Round Robin is decreasing, the waiting time decreases:

Based on the analysis of the increasing waiting time, the decreasing waiting time is also having been influenced by the I/O burst time. When the quantum upper than 60ms, the waiting time is unstable. We cannot make sure that the waiting time is decreasing of increasing with the decreasing quantum. It is because the different job has different burst time, the job which has the larger burst time than the quantum, might decreasing the time they spend on CPU than before. For example, if one job has the 75ms burst in CPU, and the quantum is 65ms. Under this situation, this job can only burst 65ms in CPU. If there is no quantum, it should burst 75ms. So, when the quantum is larger than the I/O burst, 60ms, the job which actually have more burst time, might need to wait for one I/O burst, then executing CPU again. So, we cannot make sure the average waiting time of all jobs. However, during this situation, the average waiting time might decrease under some quantum.

c) Here are the pictures for increasing the waiting time with decreasing quantum

waiting time increase with decreasing quantum

quantum = 60

```
Process   Arrival Time   Burst Time   Priority   Length   Burst_Control
    P1           0            30           0      2000               1
    P2           0            35           0      2200               2
    P3           0            40           0      2400               2
    P4           0            45           0      2600               2
    P5           0            50           0      2800               2
    P6           0            55           0      3000               2
    P7           0            60           0      3200               3
    P8           0            65           0      3400               3
    P9           0            70           0      3600               3
    P10          0            75           0      3800               3
Please input the quantum: 60
The CPU utilization is: 0.834223
The waiting time of Process P1 is: 1290
The turnaround time of Process P1 is: 1980
The waiting time of Process P2 is: 12610
The turnaround time of Process P2 is: 13440
The waiting time of Process P3 is: 13005
The turnaround time of Process P3 is: 13980
The waiting time of Process P4 is: 13065
The turnaround time of Process P4 is: 14165
The waiting time of Process P5 is: 13320
The turnaround time of Process P5 is: 14580
The waiting time of Process P6 is: 13495
The turnaround time of Process P6 is: 14940
The waiting time of Process P7 is: 13560
The turnaround time of Process P7 is: 15180
The waiting time of Process P8 is: 13800
The turnaround time of Process P8 is: 15505
The waiting time of Process P9 is: 13945
The turnaround time of Process P9 is: 15780
The waiting time of Process P10 is: 14005
The turnaround time of Process P10 is: 15960
The throughput is: 0.626566
The average waiting time is: 12209
The average turnaround time is: 13551
```

quantum = 55

```
Process   Arrival Time   Burst Time   Priority   Length   Burst_Control
    P1           0            30           0      2000               1
    P2           0            35           0      2200               2
    P3           0            40           0      2400               2
    P4           0            45           0      2600               2
    P5           0            50           0      2800               2
    P6           0            55           0      3000               2
    P7           0            60           0      3200               3
    P8           0            65           0      3400               3
    P9           0            70           0      3600               3
    P10          0            75           0      3800               3
Please input the quantum: 55
The CPU utilization is: 0.800185
The waiting time of Process P1 is: 1265
The turnaround time of Process P1 is: 1980
The waiting time of Process P2 is: 12580
The turnaround time of Process P2 is: 13440
The waiting time of Process P3 is: 13015
The turnaround time of Process P3 is: 13980
The waiting time of Process P4 is: 13065
The turnaround time of Process P4 is: 14165
The waiting time of Process P5 is: 13300
The turnaround time of Process P5 is: 14580
The waiting time of Process P6 is: 13455
The turnaround time of Process P6 is: 14940
The waiting time of Process P7 is: 13865
The turnaround time of Process P7 is: 15420
The waiting time of Process P8 is: 14265
The turnaround time of Process P8 is: 15900
The waiting time of Process P9 is: 14370
The turnaround time of Process P9 is: 16100
The waiting time of Process P10 is: 14415
The turnaround time of Process P10 is: 16260
The throughput is: 0.615006
The average waiting time is: 12359
The average turnaround time is: 13676
```

quantum = 49

```
Process   Arrival Time   Burst Time   Priority   Length   Burst_Control
    P1           0            30           0      2000               1
    P2           0            35           0      2200               2
    P3           0            40           0      2400               2
    P4           0            45           0      2600               2
    P5           0            50           0      2800               2
    P6           0            55           0      3000               2
    P7           0            60           0      3200               3
    P8           0            65           0      3400               3
    P9           0            70           0      3600               3
    P10          0            75           0      3800               3
Please input the quantum: 49
The CPU utilization is: 0.747642
The waiting time of Process P1 is: 1183
The turnaround time of Process P1 is: 1863
The waiting time of Process P2 is: 12599
The turnaround time of Process P2 is: 13440
The waiting time of Process P3 is: 13052
The turnaround time of Process P3 is: 14040
The waiting time of Process P4 is: 13041
The turnaround time of Process P4 is: 14160
The waiting time of Process P5 is: 13379
The turnaround time of Process P5 is: 14640
The waiting time of Process P6 is: 13966
The turnaround time of Process P6 is: 15300
The waiting time of Process P7 is: 14297
The turnaround time of Process P7 is: 15742
The waiting time of Process P8 is: 14629
The turnaround time of Process P8 is: 16200
The waiting time of Process P9 is: 14874
The turnaround time of Process P9 is: 16500
The waiting time of Process P10 is: 14934
The turnaround time of Process P10 is: 16680
The throughput is: 0.59952
The average waiting time is: 12595
The average turnaround time is: 13856
```

quantum = 40

```
Process   Arrival Time   Burst Time   Priority   Length   Burst_Control
    P1           0            30           0      2000               1
    P2           0            35           0      2200               2
    P3           0            40           0      2400               2
    P4           0            45           0      2600               2
    P5           0            50           0      2800               2
    P6           0            55           0      3000               2
    P7           0            60           0      3200               3
    P8           0            65           0      3400               3
    P9           0            70           0      3600               3
    P10          0            75           0      3800               3
Please input the quantum: 40
The CPU utilization is: 0.646359
The waiting time of Process P1 is: 990
The turnaround time of Process P1 is: 1680
The waiting time of Process P2 is: 12680
The turnaround time of Process P2 is: 13500
The waiting time of Process P3 is: 13125
The turnaround time of Process P3 is: 14100
The waiting time of Process P4 is: 13585
The turnaround time of Process P4 is: 14640
The waiting time of Process P5 is: 14325
The turnaround time of Process P5 is: 15445
The waiting time of Process P6 is: 14965
The turnaround time of Process P6 is: 16165
The waiting time of Process P7 is: 15480
The turnaround time of Process P7 is: 16800
The waiting time of Process P8 is: 15820
The turnaround time of Process P8 is: 17220
The waiting time of Process P9 is: 16090
The turnaround time of Process P9 is: 17520
The waiting time of Process P10 is: 16135
The turnaround time of Process P10 is: 17700
The throughput is: 0.564972
The average waiting time is: 13319
The average turnaround time is: 14477
```

quantum = 35

```
Process   Arrival Time   Burst Time   Priority   Length   Burst_Control
     P1              0           30          0     2000               1
     P2              0           35          0     2200               2
     P3              0           40          0     2400               2
     P4              0           45          0     2600               2
     P5              0           50          0     2800               2
     P6              0           55          0     3000               2
     P7              0           60          0     3200               3
     P8              0           65          0     3400               3
     P9              0           70          0     3600               3
     P10              0           75          0     3800               3
Please input the quantum: 35
The CPU utilization is: 0.570159
The waiting time of Process P1 is: 915
The turnaround time of Process P1 is: 1620
The waiting time of Process P2 is: 12700
The turnaround time of Process P2 is: 13560
The waiting time of Process P3 is: 13670
The turnaround time of Process P3 is: 14580
The waiting time of Process P4 is: 14545
The turnaround time of Process P4 is: 15540
The waiting time of Process P5 is: 15350
The turnaround time of Process P5 is: 16380
The waiting time of Process P6 is: 15965
The turnaround time of Process P6 is: 17100
The waiting time of Process P7 is: 16495
The turnaround time of Process P7 is: 17700
The waiting time of Process P8 is: 16865
The turnaround time of Process P8 is: 18120
The waiting time of Process P9 is: 17045
The turnaround time of Process P9 is: 18420
The waiting time of Process P10 is: 17185
The turnaround time of Process P10 is: 18600
The throughput is: 0.537634
The average waiting time is: 14073
The average turnaround time is: 15162
```

Here are the pictures for decreasing the waiting time with decreasing quantum:

waiting time decrease with decreasing quantum

quantum = 73

```
Process   Arrival Time   Burst Time   Priority   Length   Burst_Control
     P1              0           30          0     2000               1
     P2              0           35          0     2200               2
     P3              0           40          0     2400               2
     P4              0           45          0     2600               2
     P5              0           50          0     2800               2
     P6              0           55          0     3000               2
     P7              0           60          0     3200               3
     P8              0           65          0     3400               3
     P9              0           70          0     3600               3
     P10              0           75          0     3800               3
Please input the quantum: 73
The CPU utilization is: 0.880478
The waiting time of Process P1 is: 1518
The turnaround time of Process P1 is: 2160
The waiting time of Process P2 is: 12678
The turnaround time of Process P2 is: 13380
The waiting time of Process P3 is: 13264
The turnaround time of Process P3 is: 13980
The waiting time of Process P4 is: 12994
The turnaround time of Process P4 is: 14100
The waiting time of Process P5 is: 13517
The turnaround time of Process P5 is: 14580
The waiting time of Process P6 is: 13290
The turnaround time of Process P6 is: 14940
The waiting time of Process P7 is: 13373
The turnaround time of Process P7 is: 15120
The waiting time of Process P8 is: 13568
The turnaround time of Process P8 is: 15273
The waiting time of Process P9 is: 13539
The turnaround time of Process P9 is: 15480
The waiting time of Process P10 is: 13355
The turnaround time of Process P10 is: 15600
The throughput is: 0.641026
The average waiting time is: 12109
The average turnaround time is: 13461
```

quantum = 72

```
Process   Arrival Time   Burst Time   Priority   Length   Burst_Control
     P1              0           30          0     2000               1
     P2              0           35          0     2200               2
     P3              0           40          0     2400               2
     P4              0           45          0     2600               2
     P5              0           50          0     2800               2
     P6              0           55          0     3000               2
     P7              0           60          0     3200               3
     P8              0           65          0     3400               3
     P9              0           70          0     3600               3
     P10              0           75          0     3800               3
Please input the quantum: 72
The CPU utilization is: 0.876868
The waiting time of Process P1 is: 1517
The turnaround time of Process P1 is: 2160
The waiting time of Process P2 is: 12537
The turnaround time of Process P2 is: 13380
The waiting time of Process P3 is: 13241
The turnaround time of Process P3 is: 13980
The waiting time of Process P4 is: 12971
The turnaround time of Process P4 is: 14100
The waiting time of Process P5 is: 13623
The turnaround time of Process P5 is: 14580
The waiting time of Process P6 is: 13205
The turnaround time of Process P6 is: 14940
The waiting time of Process P7 is: 13387
The turnaround time of Process P7 is: 15120
The waiting time of Process P8 is: 13482
The turnaround time of Process P8 is: 15247
The waiting time of Process P9 is: 13511
The turnaround time of Process P9 is: 15480
The waiting time of Process P10 is: 13510
The turnaround time of Process P10 is: 15600
The throughput is: 0.641026
The average waiting time is: 12098
The average turnaround time is: 13458
```

quantum = 71

```
Process    Arrival Time    Burst Time    Priority    Length    Burst_Control
      P1              0            30           0      2000                1
      P2              0            35           0      2200                2
      P3              0            40           0      2400                2
      P4              0            45           0      2600                2
      P5              0            50           0      2800                2
      P6              0            55           0      3000                2
      P7              0            60           0      3200                3
      P8              0            65           0      3400                3
      P9              0            70           0      3600                3
      P10              0            75           0      3800                3
Please input the quantum: 71
The CPU utilization is: 0.876646
The waiting time of Process P1 is: 1516
The turnaround time of Process P1 is: 2160
The waiting time of Process P2 is: 12636
The turnaround time of Process P2 is: 13380
The waiting time of Process P3 is: 13218
The turnaround time of Process P3 is: 13980
The waiting time of Process P4 is: 13008
The turnaround time of Process P4 is: 14108
The waiting time of Process P5 is: 13479
The turnaround time of Process P5 is: 14580
The waiting time of Process P6 is: 13350
The turnaround time of Process P6 is: 14940
The waiting time of Process P7 is: 13361
The turnaround time of Process P7 is: 15120
The waiting time of Process P8 is: 13456
The turnaround time of Process P8 is: 15240
The waiting time of Process P9 is: 13472
The turnaround time of Process P9 is: 15480
The waiting time of Process P10 is: 13535
The turnaround time of Process P10 is: 15600
The throughput is: 0.641026
The average waiting time is: 12103
The average turnaround time is: 13458
```

quantum = 70

```
Process    Arrival Time    Burst Time    Priority    Length    Burst_Control
      P1              0            30           0      2000                1
      P2              0            35           0      2200                2
      P3              0            40           0      2400                2
      P4              0            45           0      2600                2
      P5              0            50           0      2800                2
      P6              0            55           0      3000                2
      P7              0            60           0      3200                3
      P8              0            65           0      3400                3
      P9              0            70           0      3600                3
      P10              0            75           0      3800                3
Please input the quantum: 70
The CPU utilization is: 0.87328
The waiting time of Process P1 is: 1515
The turnaround time of Process P1 is: 2160
The waiting time of Process P2 is: 12555
The turnaround time of Process P2 is: 13380
The waiting time of Process P3 is: 13195
The turnaround time of Process P3 is: 13980
The waiting time of Process P4 is: 12985
The turnaround time of Process P4 is: 14100
The waiting time of Process P5 is: 13515
The turnaround time of Process P5 is: 14580
The waiting time of Process P6 is: 13315
The turnaround time of Process P6 is: 14940
The waiting time of Process P7 is: 13265
The turnaround time of Process P7 is: 15060
The waiting time of Process P8 is: 13490
The turnaround time of Process P8 is: 15255
The waiting time of Process P9 is: 13445
The turnaround time of Process P9 is: 15420
The waiting time of Process P10 is: 13620
The turnaround time of Process P10 is: 15625
The throughput is: 0.64
The average waiting time is: 12090
The average turnaround time is: 13450
```

quantum = 69

```
Process    Arrival Time    Burst Time    Priority    Length    Burst_Control
      P1              0            30           0      2000                1
      P2              0            35           0      2200                2
      P3              0            40           0      2400                2
      P4              0            45           0      2600                2
      P5              0            50           0      2800                2
      P6              0            55           0      3000                2
      P7              0            60           0      3200                3
      P8              0            65           0      3400                3
      P9              0            70           0      3600                3
      P10              0            75           0      3800                3
Please input the quantum: 69
The CPU utilization is: 0.869707
The waiting time of Process P1 is: 1513
The turnaround time of Process P1 is: 2160
The waiting time of Process P2 is: 12692
The turnaround time of Process P2 is: 13380
The waiting time of Process P3 is: 13329
The turnaround time of Process P3 is: 13980
The waiting time of Process P4 is: 12999
The turnaround time of Process P4 is: 14100
The waiting time of Process P5 is: 13517
The turnaround time of Process P5 is: 14580
The waiting time of Process P6 is: 13284
The turnaround time of Process P6 is: 14940
The waiting time of Process P7 is: 13323
The turnaround time of Process P7 is: 15120
The waiting time of Process P8 is: 13497
The turnaround time of Process P8 is: 15262
The waiting time of Process P9 is: 13547
The turnaround time of Process P9 is: 15480
The waiting time of Process P10 is: 13533
The turnaround time of Process P10 is: 15657
The throughput is: 0.638692
The average waiting time is: 12123
The average turnaround time is: 13465
```

quantum = 68

```
Process    Arrival Time    Burst Time    Priority    Length    Burst_Control
      P1              0            30           0      2000                1
      P2              0            35           0      2200                2
      P3              0            40           0      2400                2
      P4              0            45           0      2600                2
      P5              0            50           0      2800                2
      P6              0            55           0      3000                2
      P7              0            60           0      3200                3
      P8              0            65           0      3400                3
      P9              0            70           0      3600                3
      P10              0            75           0      3800                3
Please input the quantum: 68
The CPU utilization is: 0.86944
The waiting time of Process P1 is: 1511
The turnaround time of Process P1 is: 2160
The waiting time of Process P2 is: 12649
The turnaround time of Process P2 is: 13380
The waiting time of Process P3 is: 13103
The turnaround time of Process P3 is: 13980
The waiting time of Process P4 is: 13013
The turnaround time of Process P4 is: 14113
The waiting time of Process P5 is: 13417
The turnaround time of Process P5 is: 14580
The waiting time of Process P6 is: 13393
The turnaround time of Process P6 is: 14940
The waiting time of Process P7 is: 13431
The turnaround time of Process P7 is: 15120
The waiting time of Process P8 is: 13564
The turnaround time of Process P8 is: 15269
The waiting time of Process P9 is: 13579
The turnaround time of Process P9 is: 15489
The waiting time of Process P10 is: 13497
The turnaround time of Process P10 is: 15660
The throughput is: 0.63857
The average waiting time is: 12115
The average turnaround time is: 13469
```

quantum = 65

```
Process   Arrival Time   Burst Time   Priority   Length   Burst_Control
   P1          0             30           0        2000              1
   P2          0             35           0        2200              2
   P3          0             40           0        2400              2
   P4          0             45           0        2600              2
   P5          0             50           0        2800              2
   P6          0             55           0        3000              2
   P7          0             60           0        3200              3
   P8          0             65           0        3400              3
   P9          0             70           0        3600              3
   P10          0             75           0        3800              3
Please input the quantum: 65
The CPU utilization is: 0.858868
The waiting time of Process P1 is: 1405
The turnaround time of Process P1 is: 2100
The waiting time of Process P2 is: 13780
The turnaround time of Process P2 is: 13380
The waiting time of Process P3 is: 12995
The turnaround time of Process P3 is: 13980
The waiting time of Process P4 is: 12995
The turnaround time of Process P4 is: 14100
The waiting time of Process P5 is: 13330
The turnaround time of Process P5 is: 14580
The waiting time of Process P6 is: 13455
The turnaround time of Process P6 is: 14940
The waiting time of Process P7 is: 13535
The turnaround time of Process P7 is: 15120
The waiting time of Process P8 is: 13465
The turnaround time of Process P8 is: 15240
The waiting time of Process P9 is: 13735
The turnaround time of Process P9 is: 15600
The waiting time of Process P10 is: 13035
The turnaround time of Process P10 is: 15730
The throughput is: 0.635728
The average waiting time is: 12173
The average turnaround time is: 13477
```

quantum = 64

```
Process   Arrival Time   Burst Time   Priority   Length   Burst_Control
   P1          0             30           0        2000              1
   P2          0             35           0        2200              2
   P3          0             40           0        2400              2
   P4          0             45           0        2600              2
   P5          0             50           0        2800              2
   P6          0             55           0        3000              2
   P7          0             60           0        3200              3
   P8          0             65           0        3400              3
   P9          0             70           0        3600              3
   P10          0             75           0        3800              3
Please input the quantum: 64
The CPU utilization is: 0.855229
The waiting time of Process P1 is: 1401
The turnaround time of Process P1 is: 2100
The waiting time of Process P2 is: 12634
The turnaround time of Process P2 is: 13380
The waiting time of Process P3 is: 13105
The turnaround time of Process P3 is: 13980
The waiting time of Process P4 is: 12985
The turnaround time of Process P4 is: 14100
The waiting time of Process P5 is: 13436
The turnaround time of Process P5 is: 14580
The waiting time of Process P6 is: 13403
The turnaround time of Process P6 is: 14940
The waiting time of Process P7 is: 13436
The turnaround time of Process P7 is: 15120
The waiting time of Process P8 is: 13472
The turnaround time of Process P8 is: 15240
The waiting time of Process P9 is: 13704
The turnaround time of Process P9 is: 15540
The waiting time of Process P10 is: 13731
The turnaround time of Process P10 is: 15780
The throughput is: 0.633714
The average waiting time is: 12130
The average turnaround time is: 13476
```

quantum = 63

```
Process   Arrival Time   Burst Time   Priority   Length   Burst_Control
   P1          0             30           0        2000              1
   P2          0             35           0        2200              2
   P3          0             40           0        2400              2
   P4          0             45           0        2600              2
   P5          0             50           0        2800              2
   P6          0             55           0        3000              2
   P7          0             60           0        3200              3
   P8          0             65           0        3400              3
   P9          0             70           0        3600              3
   P10          0             75           0        3800              3
Please input the quantum: 63
The CPU utilization is: 0.848312
The waiting time of Process P1 is: 1397
The turnaround time of Process P1 is: 2100
The waiting time of Process P2 is: 12568
The turnaround time of Process P2 is: 13380
The waiting time of Process P3 is: 13095
The turnaround time of Process P3 is: 13980
The waiting time of Process P4 is: 12975
The turnaround time of Process P4 is: 14100
The waiting time of Process P5 is: 13302
The turnaround time of Process P5 is: 14580
The waiting time of Process P6 is: 13486
The turnaround time of Process P6 is: 14940
The waiting time of Process P7 is: 13417
The turnaround time of Process P7 is: 15120
The waiting time of Process P8 is: 13665
The turnaround time of Process P8 is: 15420
The waiting time of Process P9 is: 13908
The turnaround time of Process P9 is: 15696
The waiting time of Process P10 is: 13852
The turnaround time of Process P10 is: 15840
The throughput is: 0.631313
The average waiting time is: 12166
The average turnaround time is: 13515
```

quantum = 62

```
Process   Arrival Time   Burst Time   Priority   Length   Burst_Control
   P1          0             30           0        2000              1
   P2          0             35           0        2200              2
   P3          0             40           0        2400              2
   P4          0             45           0        2600              2
   P5          0             50           0        2800              2
   P6          0             55           0        3000              2
   P7          0             60           0        3200              3
   P8          0             65           0        3400              3
   P9          0             70           0        3600              3
   P10          0             75           0        3800              3
Please input the quantum: 62
The CPU utilization is: 0.844707
The waiting time of Process P1 is: 1393
The turnaround time of Process P1 is: 2100
The waiting time of Process P2 is: 12622
The turnaround time of Process P2 is: 13380
The waiting time of Process P3 is: 12965
The turnaround time of Process P3 is: 13980
The waiting time of Process P4 is: 12965
The turnaround time of Process P4 is: 14100
The waiting time of Process P5 is: 13288
The turnaround time of Process P5 is: 14580
The waiting time of Process P6 is: 13469
The turnaround time of Process P6 is: 14940
The waiting time of Process P7 is: 13478
The turnaround time of Process P7 is: 15120
The waiting time of Process P8 is: 13670
The turnaround time of Process P8 is: 15420
The waiting time of Process P9 is: 13852
The turnaround time of Process P9 is: 15699
The waiting time of Process P10 is: 13885
The turnaround time of Process P10 is: 15841
The throughput is: 0.631273
The average waiting time is: 12158
The average turnaround time is: 13516
```

The form above suggest the decrease waiting time with decreasing quantum. From the left picture to the right picture, the waiting time is decreased. Since the unstable of the waiting time, we just pick these pictures to illustrate the problem b.

During these experiments, we fixed the burst time, the length and the state of each process. The only difference is the quantum.

Based on the analysis of the experiment, we also find that there are some situation cannot suggest the waiting information, such as quantum=58, 51, 50, 48, 47, 45, 44, 41, 36, 34, 33, 31, 30. These quantum might cause starvation of the simulation, since the quantum might equal to the burst time of some jobs.