3 problems. 45 points total. Closed book, closed notes, no electronic devices

1. [15 points] This question concerns the projects.

a. What are refcounts used for?

Solution [5 points]
To determine when a thread's memory can be reaped.
3 points for saying what refcounts are (i.e., the number of interested threads) but not what they are used for.

b. In project 2 what is the purpose of the trampoline function?

Solution [5 points]
To initiate restoring of a user thread's stack at the end of of a user signal handler so that the user resumes execution from the point where it was previously switched out.

c. Why do we need WaitNoPID if there is already a Wait function?

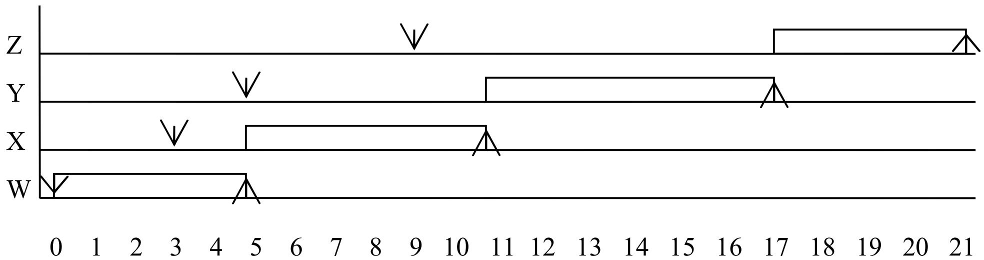
Solution [5 points]
To kill dead child processes with non-zero refcounts without knowing their pids.
(If the parent knows the pid, it can use Wait (without blocking).)

2. [15 points] Jobs W, X, Y, Z have the following arrival times and service durations (in seconds):

- W: arrival time 0; service duration 5. (So if no other job arrives, W leaves at time 5.)
- X: arrival time 3; service duration 6.
- Y: arrival time 5.; service duration 6.
- Z: arrival time 9; service duration 4.

a. Assuming fifo scheduling, obtain the departure time and response time of each job. (The response time of a job is the time it stays in the system.)

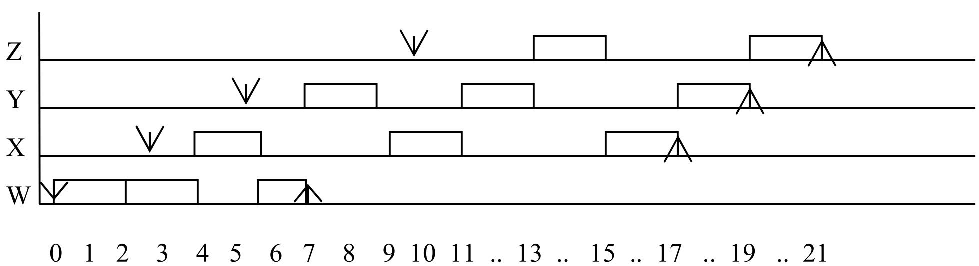
Solution [6 points]



W: arrival 0; service 5; departure 5; response 5
X: arrival 3; service 6; departure 11; response 8
Y: arrival 5; service 6; departure 17; response 12
Z: arrival 9; service 4; departure 21; response 12

b. Repeat part a assuming fifo queueing with round-robin scheduling using quantum of 2 seconds.

Solution [9 points]
Below solution assumes Z joins behind Y at 9. It's also possible for Y to rejoin behind Z.



Interval	Fifo queue at end of interval (job being served at left)	
0 to 3	W 2	
3+	W 2, X 6	
4+	X 6, W 1	
5+	X 5, W 1, Y 6	
6+	W 1, Y 6, X 4	
7+	Y 6, X 4	W departs
9+	X 4, Y 4, Z 4 (assuming Z joins behind Y)	
11+	Y 4, Z 4, X 2	
13+	Z 4, X 2, Y 2	
15+	X 2, Y 2, Z 2	
17+	Y 2, Z 2	X departs
19+	Z 2	Y departs
21+		Z departs

3. [15 points]
Here is a skeleton of a program that starts threads t_1, …, t_n executing functions F_1, …, F_N. Each part below states a synchronization constraint. Fill in **W**, X_i, Y_i, Z_i to satisfy the constraint. The only synchronization construct you can use are semaphores. No busy waiting. Elegance and brevity count. The solution to part a is given below to illustrate.

```
// global variables; initialization
W    // you supply this
spawn thread t1 executing F1 ;
spawn thread t2 executing F2 ;
  ....
spawn thread tN executing FN ;
```

```
Fi
  Xi;      // you supply this
  while true {
     Ai;
     Yi;    // you supply this
     Bi;
     Zi;    // you supply this
}
```

a. At any time at most one thread is in any B_i.
W: Semaphore s = 1; X_i: <nothing>; Y_i: P(s); Z_i: V(s);

b. At any time at most 4 threads are in any B_i.

Solution [5 points]

W: Semaphore s = 4; X_i: <nothing>; Y_i: P(s); Z_i: V(s);

c. Assume there are only two threads, t_1 and t_2. Assume that B_1 and B_2 are atomically executed by the hardware. Ensure that the executions of B_1 and B_2 alternate, starting with B_1. That is, in any evolution of the program, the subsequence of executions of B_1 and B_2 has the form B_1, B_2, B_1, B_2, ….

Solution [5 points]

W: Semaphore s1 = 1;
Semaphore s2 = 0;

X_1: <nothing>	X_2: <nothing>
Y_1: P(s1);	Y_2: P(s2);
Z_1: V(s2);	Z_2: V(s1);

Other than semaphores, the only atomicity you can assume is atomic reads and writes of integers; e.g., cannot assume that x++ is atomic.

Cannot have t_1 or t_2 skip an execution of B_1 or B_2; e.g., cannot have t_1 execute A_1, A_1, B_1, A_1, ….

d. Repeat part c but now allow B_1 and B_2 to be code chunks that are not atomically executed by the hardware. Ensure also that there is no overlap in the executions of B_1 and B_2.

Solution [5 points]
Part b solution also works here.