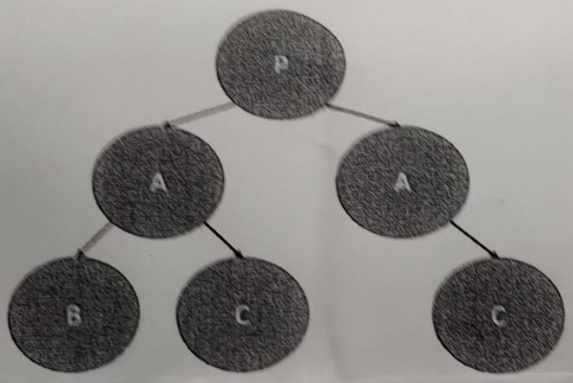
1. (10%) For operating system structures, please describe why the modular based approach is more practical than the layered approach.

2. (15%) A, B and C are three executable programs. **Please write the pseudocode of a program *P*** (with *fork()* and *exec()* system calls) to create processes such that the parent-child relationship of these processes is shown in the following figure. Assume that the prototypes of the *fork()* and *exec()* calls are as follows.

```
int fork(void);
void exec(unsigned char* name);   // name represents the program name
```



3. (10%) Please describe **RPC**, its relationship with **message passing**, and the role of **stubs** in RPC.

4. (10%) Please describe the 1-to-1 threading model. In this model, can multiple threads in a process run in parallel on multiprocessors? Why or why not?

5. (15%) About the microkernel
   (a) Please briefly describe the microkernel system structure.
   (b) Please describe two benefits and one drawback of microkernel. Please briefly **explain** your answers.

6. (15%) Assume that a process currently runs in the user mode of an x86 system. Which of the following situation(s) **always** cause a transition from the user mode to the kernel mode? (a) the process executes an integer **add** instruction (b) the process executes a memory **store** instruction and the cache hits (c) the process executes a memory **store** instruction and the cache misses (d) the process reads data from a shared memory (e) the process sends a message to a mailbox. Please briefly **explain** your answers.

7. (10%) Please briefly describe NUMA and its benefit(s).

8. (15%) About thread communication

   (a) (10%) Which of the following can be used for communication between threads in the same process? Please **explain** your answer briefly. (1) System V mailbox (2) socket (3) local variables (4) global variables (5) variables in the heap section

   (b) (5%) Which of the above 5 methods result in better performance? Please explain your answer briefly.