- **Questions 4-6:** ***(5 points each)***

1. (*1 point*) The following sequence in 2 processes:
   P0 = {MPI_Recv, MPI_Send} P1 = {MPI_Irecv, MPI_Send}

   a. will always work b. will always fail c. will result in deadlock d. may work depending on buffer space

2. (*2 points*) Find the diameter and bisection width of:
   a. a 5-D torus b. a 7-D hypercube.

3. (*2 points*) Illustrate decomposition of a 3-D matrix of size $(m \times n \times l)$ across a 3-D process grid with $(p \times q \times r)$ processes in which the x and z dimensions of the matrix are distributed using block distribution and the y dimension is distributed using block-cyclic distribution.

4. a. Explain how you would extend the butterfly barrier algorithm for non power-of-2 processes. Explain the algorithm with 13 processes.
   b. Consider a 16-processor hypercube. Assume that the time units required for a communication between any two nodes is equal to the minimum number of hops between the nodes. Also, assume that **a link can communicate only one message at a time**. Assume that processes P1-P16 are mapped to the corresponding nodes in the hypercube. Find and explain the minimum number of time units required for all the communications of your barrier algorithm involving the processes on the hypercube.

5. Give the scope of different kinds of memory on a GPU. Explain how you would implement an efficient parallel quick sort algorithm on GPUs using CUDA.

6. Write the pseudo code for the *Solve()* function of the Shared Address Space (SAS) version of the grid solver program. Explain the need for the different barriers in the program.