Please submit all assignment files in a .tar, .7z, or .zip file uploaded to blackboard. The short answer portion must be submitted as a .pdf.

1. (10) Explain point-to-point communication in MPI. Try to use non engineering terms, i.e. if you had to explain it to a non engineer, how would you go about it? Carefully think about facts like; who and why are we blocking, as all processes execute the same code, how do we ensure who is sender and who is receiver, what about if one is ready to perform communication before the other is ready, what about if there are multiple messages from same source to same receiver,are they guaranteed to arrive in the correct order?

2. (10) What are the 4 functions that are used in almost every MPI program? Explain what each one does in a few words.

3. (20) Answer the following questions in one or two sentences (5 points each)

   (a) What does it mean when we say that MPI_recv() *blocks* execution?

   (b) Why does blocking reduce parallel efficiency in distributed systems?

   (c) Give an example of a system where this phenomenon might severely impact system performance.

   (d) What is one thing we can do to alleviate this issue?

4. (30) Write a parallel matrix multiplication implementation using MPI to execute on multiple processor nodes. Your program must have 3 constants: M, N, and P. The program itself will multiply an M by N with an N by P matrix (the output will be of size M x P). Run your program and record speedup and parallel efficiency for the following configurations for 1, 2, 4, 8, and 16 nodes.

   Note: Your code *must* handle an arbitrary number of execution nodes, so make sure to handle edge cases.

   - N=10, M=10, P=10
   - N=100, M=100, P=100
   - N=1000, M=1000, P=1000

5. (30) Write a program that performs a ping-pong test on the CRC. A ping-pong test is a communication in which two messages are sent, first from node A to node B, then from B back to A. Timing repeated blocks of these messages is a common way to estimate communication metrics of a system. Assume the time needed to send an n-byte message is $lambda + n/\beta$ where λ is the latency and β is the bandwidth. Your program will be designed to run on exactly two different nodes on the CRC. Process 0 will record the time and send it to process 1. Process 1 will then immediately send the message back to process 0. Process 0 will record the time and verify that it has received the correct message. The total time is divided by 2 to get the average message time.

   The requirements for this program are below:

   - MPI_Wtime() shall be used to get timing information.
   - Plot your data in Excel/Libre Office and attach as a scatter plot with Time on the Y-axis and Message Size on the X-axis
   - You must gather enough data to accurately estimate both latency and bandwidth using linear regression using the following 3 methods of communication:
     - MPI_recv() and MPI_send()
     - MPI_Isend() and MPI_Irecv()
     - MPI_sendrecv()
   - Compare the results of the three communication methods and summarize your findings.