1. Given the declaration in a computer program
   ```c
   int i[100][200];
   ```
   which represents a matrix with 100 rows and 200 columns of integers. Suppose the compiler adopts the column-major strategy to store the matrix in computer memory. Write the pseudo codes to show how the sum of the integers in the entire matrix can be computed without resorting to strided memory access.

   (10 marks)

2. The following synchronization protocol is used by the producer and consumer threads to handle their concurrent access to a piece of shared data used for High Performance Computing.

   ```c
   Global flag: Turn  // Turn has only two values – Producer or Consumer
   Turn = Producer;
   ```

   - (i) Can deadlock occur in the protocol? If yes, write down the execution sequence. If no, justify.
   - (ii) If the Producer thread halts when it access its non-shared data, what will be the behaviour from the Consumer thread?
   - (iii) If Producer thread runs at speed v_1 and Consumer thread at speed v_2, with v_1 > v_2, what will be the final outcome of the concurrent execution?

   (20 marks)

3. Given p numbers n_0, n_1, ..., n_{p-1} (assume one number is placed in each node for the ideal case, i.e., there are p nodes), the prefix sums problem is to compute the sums s_k = \sum_{i=0}^{k} n_i for all k between 0 and p - 1. For example, if the original sequence of numbers is {3, 1, 4, 0, 2}, then the sequence of prefix sums is {3, 4, 8, 8, 10} where each prefix sum is placed in a node. Given n numbers and p nodes where n > p, and n is a multiple of p, there are altogether n prefix sums where each node contains n/p such sums. Give a hypercube
algorithm to compute prefix sums of \( n \) numbers if \( p \) is the number of nodes and \( n/p \) is an integer greater than 1. Assuming that it takes time \( t_{\text{add}} \) to add two numbers and time \( t_s \) to send a message of unit length between two directly-connected nodes, give an exact expression for the total time taken by the algorithm.

\[ \text{(20 marks)} \]

4. The volume of a cone can be approximated by random dots. Let \( h_0 \) and \( r_0 \) be the height of the cone and its base radius respectively. The front-view projection or the side-view projection of the cone is a triangle as shown in the following figures.

If a circle with origin at \((0, 0)\) and radius \( r_0 \) is drawn on the base of the triangle, all the points \((x_0, y_0)\) positioned in the base circle will fulfill the following condition:

\[ x_0^2 + y_0^2 \leq r_0^2 \quad \text{...... (1)} \]

Let \( r \) be the radius of a circle positioned at a vertical distance \( h \) from the tip of the cone as shown in the following figure. Similarly, all points \((x, y)\) positioned in the circle will fulfill the following condition:

\[ x^2 + y^2 \leq r^2 \quad \text{...... (2)} \]
Suppose 1,000,000 uniformly distributed random dots are positioned in a cylinder of height $h_0$ and radius $r_0$, and $n$ dots (out of the 1,000,000 dots) fulfill the condition (2).

![Cylinder diagram]

The volume of the cone can be approximated by $\frac{n}{1000000} \times \pi r_0^2 \times h_0$.

Write a MPI program (you need to edit it, compile it, debug it and run it before you hand in the source file) that makes use of 4 processors to compute the volume of a cone based on 1,000,000 uniformly distributed random dots where the height and the base radius of the cone are command-line arguments.

(50 marks)

Hand in your source codes named as volume.c for questions 4 by email attachment to scitaysc@nus.edu.sg. Comment your name on the first line of source files. Also print the source codes in hardcopies together with the answers to Questions 1 to 3.

(This individual assignment carries 30% of the final score. Please hand in your work on time. We practice the honour system.)