HPC: High-Performance Computing
Academic Year: 2024 - 25

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High-Performance Computing: Course Objectives

1. Learn the abstractions of parallel and concurrent programming.
2. Use of multiple and many cores while developing a solution.
3. How to explore a solution space and reduce the response time.
4. Know the usage different synchronization techniques.
5. Understand the limitations of architectures, operating systems, and programming languages

References:

1. "The Art of Multiprocessor Programming" by Maurice Herlihy and Nir Shavit, Morgan Kaufmman Publishers.
2. https://www.openmp.org/

Evaluation Scheme

All exams are open-book exams.

Submission Guide Lines:

- Mail-ID: hpc.mu.2023@gmail.com
- Sub:ROLLNUM_ASSIGN_NUM
- Attach.Name and Type: (ROLLNUM_ASSIGN_NUM).zip
- Late Submission<=3-Days:50%.
- Write a readme file to understand your solutions.
- Submit source files only (C).

Learn the art of multi-core and many-core programming

Assignment2: Due Date September 22, 2024

Develop parallel codes for the following problems:

1. **Minimum, Maximum, and Mean:** We have an array of size 2^{28}, and all elements of the array are initialized with random integers from the set $\{0, 1, \ldots, 10^9\}$. Find the minimum, maximum, and mean of all.
2. **Prime Numbers:** Generate all the prime numbers between 2^{40} and 2^{41}.
3. **Dot Product:** Calculate the dot product of two vectors. Assume that the length of each vector is 10^9 and the vectors are initialized with random integers from the set $\{$ -1, 0, 1$\}$.

Verify all your results by using sequential code. If the results are the same, then only we consider the code (or testcase is passed).

Assignment2: Due Date September 22, 2024

4. **Compute X^{15} of a matrix X**: Assume that X is a complex-valued matrix of order 2048 X 2048. It is represented by a pair of matrices (A, B) where A and B contain values from the set {-1, 0, 1}. Write a multi-threaded code to compute X^{15}.
5. Develop a program to create a **Sorted Linked List** with 1000 nodes (assume that the nodes consist of fields: key and next) and the range of keys from the set $\{-2^{10} \ldots 2^{10}\}$. Consider the workload (x,y,z) (x%-contains(), y%-insert(), and z%-remove()) and perform 100 million operations on this list **by varying the number of threads**. Assume that (x,y,z)$\in$\{ (100,0,0), (50,25,25), (0, 50, 50)\}.
6. **Multi-threaded Sorting:** Sort 10^9 integers in the range 0 to 10^3 using the following sorting techniques:
   a. Merge Sort
   b. Quick Sort
   c. Counting Sort

Assignment2: Due Date September 22, 2024

7. **Sorting and Merging Subsequences:** You are given a sequence of 10^9 elements to sort. The input sequence consists of 10^3 subsequences, each of which contains 10^6 elements. The elements in a given subsequence are all smaller than the elements in the succeeding subsequence and larger than the elements in the preceding subsequence. Sort the input sequence by varying the number of threads.
8. **Find a median of 10^9 elements using the median-of-medians.** Assume that the elements from the set $\{-2^{30} \ldots 2^{30}\}$.

Verify all your results by using sequential code. If the results are the same, then only we consider the code (or testcase is passed).

Assignment 1 (Due Date September 22, 2024, 11:59 pm)

Develop a parallel code for the following problems using OpenMP. Report the speedup of your implementations by varying the number of threads from 2 to 16 (i.e., 2, 4, 6, 8, 10, 12, 14, and 16). Use *gettimeofday*() for calculating runtime and consider the average of 5 runs. Draw appropriate plots using the GNU plot. For example, when we consider a problem square of a square matrix, we can draw the following graphs for each implementation technique.

- Runtime vs. Matrix Sizes for different number of threads
- Runtime vs. Threads for different implementations

1. **Square of Square Matrix:**
   Consider a square matrix A. The goal of the problem is to find the square of A as efficiently as possible. Fill the matrix A with random entries ranging from 0 to 1. Vary the size of the matrices from 8x8 to 4096x4096, in powers of 2. Assume that the matrices are given in row-major order. If you perform any transformation, that also has to be accounted for in the runtime as well. Try with the different implementations and measure the speedup.

Assignment 1 (Due Date: September 22, 2024, 11:59 pm)

2. **Game of Life:**
Conway's game of life is a cellular automaton where the game depends on the initial configuration and nothing else. The initial configuration is a two-dimensional grid of cells, each of which is either dead or alive (represented as 0's and 1's respectively). The game proceeds in steps where every cell interacts with the vertical, horizontal, or diagonal neighbors and decides on its status in the next step. At each step, the following rules are used:

   - Any live cell with fewer than two live neighbors dies as if caused by underpopulation.
   - Any live cell with two or three live neighbors lives on to the next generation.
   - Any live cell with more than three live neighbors dies, as if by overcrowding.
   - Any dead cell with exactly three live neighbors becomes a live cell, as if by reproduction.

   The initial configuration is called the seed and starting from this all the cells take steps in tandem. The grid size is fixed with a number of rows $= 10000$ and the number of columns $= 10000$.

Game of Life:

Input: The first 10000 lines of input with each line containing 10000 space-separated binary values ('0' for dead and '1' for alive) representing the seed, starting with the first row. The cells within a row are presented from left to right. The next line of input contains steps, the number of steps the game has to proceed.

Output: The output should contain exactly 10000 lines with each line containing 10000 binary values representing the configuration of the board after steps starting from the seed.

Constraints:

- $0 \leq \#steps \leq 10000$
- Seed should have not more than 10% of cells that are alive.

Assignment 1 (Due Date: September 22, 2024, 11:59 pm)

3. **N-Queens Problem:**
   Given an $N \times N$ chessboard and N-Queens. Place N-Queens on the chessboard in non-attackable positions. Consider the different values of N =8, 12, 16, 20, 24, and 32. Store all the solutions in a file.

4. **Volume of the Graph** $X^2 + Y^2 + Z^2 = 1$.
   Assume that X, Y, and Z belong to the set of Real Numbers and the step size is 10^{-8}.

All the best ☺