

## HW 1: Parallel Programming on a Multicore Multiprocessor

### Part 1. Shared-Memory Programming with Threads

Compile and execute the program in the file `compute_pi.c`, which computes an estimate of  $\pi$  using the parallel algorithm discussed in class. It should be compiled and executed on `grace.hprc.tamu.edu`.

Load the Intel software stack prior to compiling and executing the code.

```
module load intel
```

To compile, use the command:

```
icc -o compute_pi.exe compute_pi.c -lpthread
```

To execute the program, use

```
./compute_pi.exe <n> <p>
```

where `<n>` represents the number of points and `<p>` represents the number of threads. The output of a sample run is shown below.

```
./compute_pi.exe 1000000 4
Trials = 1000000, Threads = 4, pi = 3.1433480000, error = 5.59e-04,
time (sec) = 0.0043
```

The run time of the code should be measured when it is executed in dedicated mode. Use the batch file `compute_pi.grace_job` to execute the code in dedicated mode using the following command on Grace:

```
sbatch compute_pi.grace_job
```

1. Execute the code for  $n=10^8$  with  $p$  chosen to be  $2^k$ , for  $k = 0, 1, \dots, 13$ . Using the experimental data obtained from these experiments, answer the following questions. For plots, use a logarithmic scale for the x-axis.
  - 1.1. (10 points) Plot execution time versus  $p$  to demonstrate how time varies with the number of threads.
  - 1.2. (10 points) Plot speedup versus  $p$  to demonstrate the change in speedup with  $p$ .
  - 1.3. (5 points) Using the definition:  $\text{efficiency} = \text{speedup}/p$ , plot efficiency versus  $p$  to demonstrate how efficiency changes as the number of threads are increased.
  - 1.4. (5 points) In your experiments, what value of  $p$  minimizes the parallel runtime?
2. Repeat the experiments with  $n=10^{10}$  to obtain the execution time for  $p=2^k$ , for  $k = 0, 1, \dots, 13$ .
  - 2.1. (5 points) In this case, what value of  $p$  minimizes the parallel runtime?
  - 2.2. (5 points) Do you expect the runtime to increase as  $p$  is increased beyond a certain value? If so, why? And is this observed in your experiments.
3. (5 points) Do you expect that there would be a difference in the number of threads needed to obtain the minimum execution time for two values of  $n$ ? Is this observed in your experiments.

4. (5 points) Plot error versus  $n$  to illustrate accuracy of the algorithm as a function of  $n$ . You may have to run experiments with different values of  $n$ ; for example  $n$  could be chosen to be  $10^k$ , for  $k = 3, \dots, 9$ . Use  $p = 48$ .

## Part 2. Distributed-Memory Programming with MPI

Compile and execute the program in the file `compute_pi_mpi.c`, which computes an estimate of  $\pi$  using the parallel algorithm discussed in class. It should be compiled and executed `grace.hprc.tamu.edu`.

Load the Intel software stack prior to compiling and executing the code.

```
module load intel
```

To compile, use the command:

```
mpiicc -o compute_pi_mpi.exe compute_pi_mpi.c
```

To execute the program, use

```
mpirun -np <p> ./compute_pi_mpi.exe <n>
```

where  $\langle n \rangle$  represents the number of intervals and  $\langle p \rangle$  represents the number of processes. The output of a sample run is shown below.

```
mpirun -np 4 compute_pi_mpi.exe 100000000
```

```
n = 100000000, p = 4, pi = 3.1415926535897749, relative error = 5.80e-15, time (sec) = 0.0608
```

The run time of the code should be measured when it is executed in dedicated mode. Use the batch file `compute_pi_mpi.grace_job`, to execute the code in dedicated mode using the following command on Grace:

```
sbatch compute_pi_mpi.grace_job
```

5. Execute the code for  $n=10^8$  with  $p$  chosen to be  $2^k$ , for  $k = 0, 1, \dots, 6$ . Specify `ntasks-per-node=4` in the job file. Using the experimental data obtained from these experiments, answer the following questions. For plots, use a logarithmic scale for the x-axis.
  - 5.1. (10 points) Plot execution time versus  $p$  to demonstrate how time varies with the number of processes.
  - 5.2. (10 points) Plot speedup versus  $p$  to demonstrate the change in speedup with  $p$ .
  - 5.3. (5 points) Using the definition:  $\text{efficiency} = \text{speedup}/p$ , plot efficiency versus  $p$  to demonstrate how efficiency changes as the number of processes is increased.
  - 5.4. (5 points) What value of  $p$  minimizes the parallel runtime?
6. (10 points) With  $n=10^{10}$  and  $p=64$ , determine the value of `ntasks-per-node` that minimizes the `total_time`. Plot time versus `ntasks-per-node` to illustrate your experimental results for this question.
7. Execute the code with  $p=64$  for  $n=10^2, 10^4, 10^6$  and  $10^8$ , with `ntasks-per-node=4`.
  - 7.1. (5 points) Plot the speedup observed as a function of  $n$  on  $p=64$  w.r.t.  $p=1$ . You will need to obtain execution time on  $p=1$  for  $n=10^2, 10^4, 10^6$  and  $10^8$ .

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- 7.2. (5 points) Plot the relative error versus  $n$  to illustrate the accuracy of the algorithm as a function of  $n$ .

**Submission:** Upload a single PDF or MSWord document with your answers to Canvas.