CS 451

Assignment-2

Intro. To Parallel And Distributed Computing

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Question Given:

In this problem you are asked to write two parallel algorithms (one in Pthreads and the other in openMP) for solving a dense linear equations of the form A*x=b, where A is an n*n matrix and b is a vector. You will use Gaussian elimination without pivoting.

Abstract:

In linear algebra, Gaussian elimination (also known as row reduction) is an algorithm for solving systems of linear equations. It is usually understood as a sequence of operations performed on the corresponding matrix of coefficients. This method can also be used to find the rank of a matrix, to calculate the determinant of a matrix, and to calculate the inverse of an invertible square matrix. The method is named after Carl Friedrich Gauss (1777–1855), although it was known to Chinese mathematicians as early as 179 CE

Solution:

Given Gaussian Elimination Code for the assignment is an algorithm for solving linear matrices of equal sizes.

The Equation Given is A*X = B and A and B is given and then we use Gaussian Elimination to find X.

The Given Sequential Code for the Assignment is as Follows

Sequential Code Structure:

The Code can be broken down into following

- The Maximum Size for the matrix is given as 2000 with MAXN 2000
- Gauss() function is initiated
- The Function parameters() takes in the values given during execution for initializing matrix size
- Function initializematrix is responsible for initializng the matrix and fill in random numbers into matrix
- Function printInput prints the given input matrix
- The Main() function initializes the time counter and gauss() function is called
- The Gauss function is the function which performs gauss elimination.

Gauss Elimination Using Pthreads:

The Code was analyzed and found that whole gauss function was not good to be parallelized because function like back substitution was difficult to be parallelized Hence the solution was to parallelize the loop of the gauss elimination which did not have loop carried dependencies.

The Second loop did not carried any loop dependencies hence the second loop was parallelized and the number of pthreads were taken as arguments during the execution of the program.

The loop execution was divided into the threads and executed.

Gauss Elimination Using OpenMP:

The Code was analyzed and found that whole gauss function was not good to be parallelized because function like back substitution was difficult to be parallelized Hence the solution was to parallelize the loop of the gauss elimination which did not have loop carried dependencies.

The Second loop did not carried any loop dependencies hence the second loop was parallelized Using OpenMP

Execution Steps

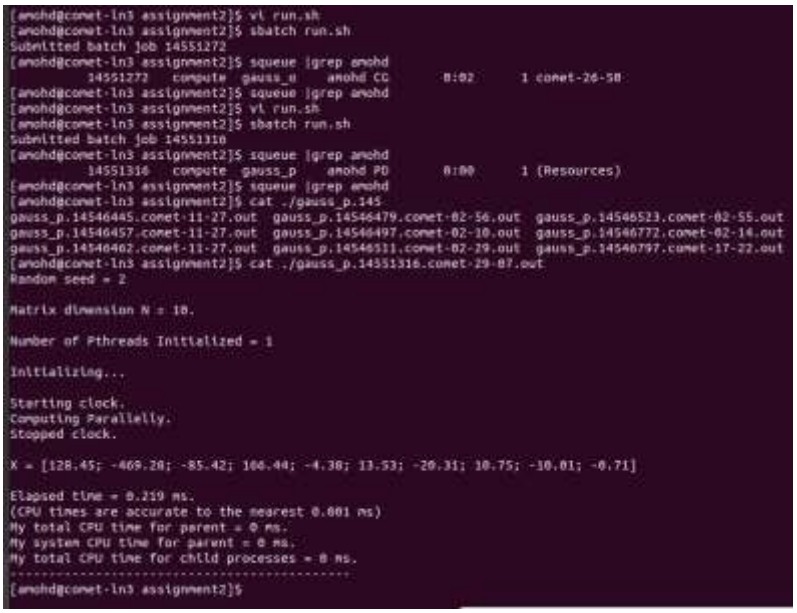
Pthread & OpenMP:

- The Parametres are taken as follows
  - Arg[1] = N = Size of the matrix
  - Arg[2] = Random Seed
  - Arg[3] = Number of threads
- The Main() is executed and timer is started
- Gauss function is called
- Pthreads are created
- Pthreads parallelize the given task using Function parloop
- The Back Substitution is made
- Matrix X is made
- The Timer is stopped .
- The Results are announced

Execution Manual:

Pthread:

Compile : gcc gauss_pthread.c –o gauss_p –lpthread
Run: ./gauss_p 10 1 10
Run.sh



OpenMP:

Compile : gcc gauss_opneMP.c –o gauss_o –lpthread
Run: ./gauss_p 10 1 10

```
[amohd@comet-ln3 assignment2]$ vi run.sh
[amohd@comet-ln3 assignment2]$ sbatch run.sh
Submitted batch job 14552054
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14552003   compute  gauss_o    amohd PD       0:00      1 (Resources)
          14552054   compute  gauss_o    amohd PD       0:00      1 (Resources)
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14552003   compute  gauss_o    amohd PD       0:00      1 (Resources)
          14552054   compute  gauss_o    amohd PD       0:00      1 (Resources)
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
[amohd@comet-ln3 assignment2]$ cat ./gauss_o.14552003.comet-21-03.out

Matrix dimension N = 10.

Number of OpenMP threads Initialized = 1

Initializing...

Starting clock.
Computing Parallelly Using OpenMP.
Stopped clock.

X = [-1.56;  3.11;  1.89; -1.64; -4.38; -0.65;  1.67; -2.05; -0.47;  5.53]

Elapsed time = 0.016 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0 ms.
My system CPU time for parent = 0 ms.
My total CPU time for child processes = 0 ms.
-----------------------------------------
[amohd@comet-ln3 assignment2]$ cat ./gauss_o.14552003.comet-21-03.out
```

Outputs

Pthread:

N = 10 thread =1

```
[amohd@comet-ln3 assignment2]$ vi run.sh
[amohd@comet-ln3 assignment2]$ sbatch run.sh
Submitted batch job 14551392
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14551392   compute  gauss_p    amohd CG       0:04      1 comet-07-09
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
[amohd@comet-ln3 assignment2]$ cat ./gauss_p.14551392.comet-07-09.out
Random seed = 2

Matrix dimension N = 10.

Number of Pthreads Initialized = 1

Initializing...

Starting clock.
Computing Parallelly.
Stopped clock.

X = [128.45; -469.28; -85.42; 166.44; -4.38; 13.53; -20.31; 10.75; -10.01; -0.71]

Elapsed time = 0.232 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0 ms.
My system CPU time for parent = 0 ms.
My total CPU time for child processes = 0 ms.
----------------------------------------
[amohd@comet-ln3 assignment2]$ .
```

N = 100 thread =1

```
[amohd@comet-ln3 assignment2]$ vi run.sh
[amohd@comet-ln3 assignment2]$ sbatch run.sh
Submitted batch job 14551347
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14551347   compute  gauss_p    amohd PD       0:00      1 (Resources)
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
[amohd@comet-ln3 assignment2]$ cat ./gauss_p.1455137
cat: ./gauss_p.1455137: No such file or directory
[amohd@comet-ln3 assignment2]$ cat ./gauss_p.145513
gauss_p.14551316.comet-29-07.out  gauss_p.14551347.comet-04-64.out
[amohd@comet-ln3 assignment2]$ cat ./gauss_p.14551347.comet-04-64.out
Random seed = 2

Matrix dimension N = 100.

Number of Pthreads Initialized = 1

Initializing...

Starting clock.
Computing Parallelly.
Stopped clock.

Elapsed time = 2.928 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0 ms.
My system CPU time for parent = 0 ms.
My total CPU time for child processes = 0 ms.
----------------------------------------
[amohd@comet-ln3 assignment2]$
```

N = 1000 thread =1

```
[amohd@comet-ln3 assignment2]$ vi run.sh
[amohd@comet-ln3 assignment2]$ sbatch run.sh
Submitted batch job 14551401
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14551401   compute  gauss_p    amohd PD       0:00      1 (Resources)
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14551401   compute  gauss_p    amohd CG       0:04      1 comet-07-02
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
[amohd@comet-ln3 assignment2]$ cat ./gauss_p.14551401.comet-07-02.out
Random seed = 2

Matrix dimension N = 1000.

Number of Pthreads Initialized = 1

Initializing...

Starting clock.
Computing Parallelly.
Stopped clock.

Elapsed time = 1155.33 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0.116 ms.
My system CPU time for parent = 0.002 ms.
My total CPU time for child processes = 0 ms.
------------------------------------------
[amohd@comet-ln3 assignment2]$
```

N = 1000 thread =2

```
[amohd@comet-ln3 assignment2]$ vi run.sh
[amohd@comet-ln3 assignment2]$ sbatch run.sh
Submitted batch job 14551446
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14551446   compute  gauss_p    amohd PD       0:00      1 (Resources)
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14551446   compute  gauss_p    amohd CG       0:04      1 comet-14-51
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
[amohd@comet-ln3 assignment2]$ cat ./gauss_p.14551446.comet-14-51.out
Random seed = 2

Matrix dimension N = 1000.

Number of Pthreads Initialized = 2

Initializing...

Starting clock.
Computing Parallelly.
Stopped clock.

Elapsed time = 605.543 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0.12 ms.
My system CPU time for parent = 0.002 ms.
My total CPU time for child processes = 0 ms.
------------------------------------------
[amohd@comet-ln3 assignment2]$
```

N = 1000 thread = 3

```
[amohd@comet-ln3 assignment2]$ vi run.sh
[amohd@comet-ln3 assignment2]$ sbatch run.sh
Submitted batch job 14551461
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14551461   compute  gauss_p    amohd PD       0:00      1 (Resources)
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14551461   compute  gauss_p    amohd PD       0:00      1 (Resources)
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
[amohd@comet-ln3 assignment2]$ cat ./gauss_p.14551461.comet-20-20.out
Random seed = 2

Matrix dimension N = 1000.

Number of Pthreads Initialized = 3

Initializing...

Starting clock.
Computing Parallelly.
Stopped clock.

Elapsed time = 421.498 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0.123 ms.
My system CPU time for parent = 0.004 ms.
My total CPU time for child processes = 0 ms.
----------------------------------------
[amohd@comet-ln3 assignment2]$
```

N = 1000 thread = 4

```
[amohd@comet-ln3 assignment2]$ vi run.sh
[amohd@comet-ln3 assignment2]$ sbatch run.sh
Submitted batch job 14551470
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14551470   compute  gauss_p    amohd PD       0:00      1 (Resources)
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14551470   compute  gauss_p    amohd PD       0:00      1 (Resources)
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
[amohd@comet-ln3 assignment2]$ cat ./gauss_p.14551470.comet-19-60.out
Random seed = 2

Matrix dimension N = 1000.

Number of Pthreads Initialized = 4

Initializing...

Starting clock.
Computing Parallelly.
Stopped clock.

Elapsed time = 328.759 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0.124 ms.
My system CPU time for parent = 0.005 ms.
My total CPU time for child processes = 0 ms.
----------------------------------------
[amohd@comet-ln3 assignment2]$
```

N = 1000 thread =5

```
[amohd@comet-ln3 assignment2]$ vi run.sh
[amohd@comet-ln3 assignment2]$ sbatch run.sh
Submitted batch job 14551483
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
[amohd@comet-ln3 assignment2]$ cat ./gauss_p.14551483.comet-14-65.out
gauss.c                          gauss_p                          gauss_p.14546772.comet-02-14.out
gauss_o                          gauss_p.14546445.comet-11-27.out  gauss_p.14546797.comet-17-22.out
gauss_o.14550595.comet-04-25.out  gauss_p.14546457.comet-11-27.out  gauss_p.14546839.comet-03-61.out
gauss_o.14550596.comet-22-32.out  gauss_p.14546462.comet-11-27.out  gauss_p.14546885.comet-14-13.out
gauss_o.14550918.comet-22-33.out  gauss_p.14546479.comet-02-56.out  gauss_p.14550592.comet-04-25.out
gauss_o.14551111.comet-22-33.out  gauss_p.14546497.comet-02-10.out  gauss_p.14551316.comet-29-07.out
gauss_o.14551272.comet-26-50.out  gauss_p.14546511.comet-02-29.out  gauss_p.14551347.comet-04-64.out
gauss_openMP.c                   gauss_p.14546523.comet-02-55.out  gauss_p.14551353.comet-22-32.out
[amohd@comet-ln3 assignment2]$ cat ./gauss_p.14551483.comet-14-65.out
Random seed = 2

Matrix dimension N = 1000.

Number of Pthreads Initialized = 5

Initializing...

Starting clock.
Computing Parallelly.
Stopped clock.

Elapsed time = 277.252 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0.125 ms.
My system CPU time for parent = 0.007 ms.
My total CPU time for child processes = 0 ms.
------------------------------------------
[amohd@comet-ln3 assignment2]$
```

N = 1000 thread =6

```
[amohd@comet-ln3 assignment2]$ vi run.sh
[amohd@comet-ln3 assignment2]$ sbatch run.sh
Submitted batch job 14551487
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14551487   compute  gauss_p    amohd PD       0:00      1 (Resources)
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
[amohd@comet-ln3 assignment2]$ cat ./gauss_p.14551487.comet-20-01.out
gauss.c                          gauss_p                          gauss_p.14546772.comet-02-14.out
gauss_o                          gauss_p.14546445.comet-11-27.out  gauss_p.14546797.comet-17-22.out
gauss_o.14550595.comet-04-25.out  gauss_p.14546457.comet-11-27.out  gauss_p.14546839.comet-03-61.out
gauss_o.14550596.comet-22-32.out  gauss_p.14546462.comet-11-27.out  gauss_p.14546885.comet-14-13.out
gauss_o.14550918.comet-22-33.out  gauss_p.14546479.comet-02-56.out  gauss_p.14550592.comet-04-25.out
gauss_o.14551111.comet-22-33.out  gauss_p.14546497.comet-02-10.out  gauss_p.14551316.comet-29-07.out
gauss_o.14551272.comet-26-50.out  gauss_p.14546511.comet-02-29.out  gauss_p.14551347.comet-04-64.out
gauss_openMP.c                   gauss_p.14546523.comet-02-55.out  gauss_p.14551353.comet-22-32.out
[amohd@comet-ln3 assignment2]$ cat ./gauss_p.14551487.comet-20-01.out
Random seed = 2

Matrix dimension N = 1000.

Number of Pthreads Initialized = 6

Initializing...

Starting clock.
Computing Parallelly.
Stopped clock.

Elapsed time = 243.802 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0.128 ms.
My system CPU time for parent = 0.009 ms.
My total CPU time for child processes = 0 ms.
------------------------------------------
[amohd@comet-ln3 assignment2]$
```

N = 1000 thread = 7

```
[amohd@comet-ln3 assignment2]$ vi run.sh
[amohd@comet-ln3 assignment2]$ sbatch run.sh
Submitted batch job 14551494
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
[amohd@comet-ln3 assignment2]$ cat ./gauss_p.14551494.comet-14-59.out
Random seed = 2

Matrix dimension N = 1000.

Number of Pthreads Initialized = 7

Initializing...

Starting clock.
Computing Parallelly.
Stopped clock.

Elapsed time = 223.008 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0.131 ms.
My system CPU time for parent = 0.012 ms.
My total CPU time for child processes = 0 ms.
----------------------------------------
[amohd@comet-ln3 assignment2]$
```

N = 1000 thread =8

```
[amohd@comet-ln3 assignment2]$ vi run.sh
[amohd@comet-ln3 assignment2]$ sbatch run.sh
Submitted batch job 14551497
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14551497   compute  gauss_p    amohd  R       0:01      1 comet-04-32
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
[amohd@comet-ln3 assignment2]$ cat ./gauss_p.14551497.comet-04-32.out
Random seed = 2

Matrix dimension N = 1000.

Number of Pthreads Initialized = 8

Initializing...

Starting clock.
Computing Parallelly.
Stopped clock.

Elapsed time = 205.237 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0.13 ms.
My system CPU time for parent = 0.011 ms.
My total CPU time for child processes = 0 ms.
----------------------------------------
[amohd@comet-ln3 assignment2]$
```

N = 2000 thread = 1

```
[amohd@comet-ln3 assignment2]$ vi run.sh
[amohd@comet-ln3 assignment2]$ sbatch run.sh
Submitted batch job 14551508
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14551508   compute  gauss_p    amohd  R       0:05      1 comet-04-32
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14551508   compute  gauss_p    amohd  R       0:08      1 comet-04-32
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
[amohd@comet-ln3 assignment2]$ cat ./gauss_p.14551508.comet-04-32.out
Random seed = 2

Matrix dimension N = 2000.

Number of Pthreads Initialized = 1

Initializing...

Starting clock.
Computing Parallelly.
Stopped clock.

Elapsed time = 9110.12 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0.913 ms.
My system CPU time for parent = 0.004 ms.
My total CPU time for child processes = 0 ms.
------------------------------------------
[amohd@comet-ln3 assignment2]$
```

N = 2000 thread =2

```
[amohd@comet-ln3 assignment2]$ vi run.sh
[amohd@comet-ln3 assignment2]$ sbatch run.sh
Submitted batch job 14551504
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14551504   compute  gauss_p    amohd  R       0:01      1 comet-04-32
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
[amohd@comet-ln3 assignment2]$ cat ./gauss_p.14551504.comet-04-32.out
Random seed = 2

Matrix dimension N = 2000.

Number of Pthreads Initialized = 2

Initializing...

Starting clock.
Computing Parallelly.
Stopped clock.

Elapsed time = 4788.12 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0.94 ms.
My system CPU time for parent = 0.006 ms.
My total CPU time for child processes = 0 ms.
------------------------------------------
[amohd@comet-ln3 assignment2]$
```

N = 2000 thread = 4

```
[amohd@comet-ln3 assignment2]$ vi run.sh
[amohd@comet-ln3 assignment2]$ sbatch run.sh
Submitted batch job 14551512
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14551512   compute  gauss_p    amohd CG       0:05      1 comet-10-06
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
[amohd@comet-ln3 assignment2]$ cat ./gauss_p.14551512.comet-10-06.out
Random seed = 2

Matrix dimension N = 2000.

Number of Pthreads Initialized = 4

Initializing...

Starting clock.
Computing Parallelly.
Stopped clock.

Elapsed time = 2454.24 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0.948 ms.
My system CPU time for parent = 0.011 ms.
My total CPU time for child processes = 0 ms.
------------------------------------------
[amohd@comet-ln3 assignment2]$
```

N = 2000 thread = 8

```
[amohd@comet-ln3 assignment2]$ vi run.sh
[amohd@comet-ln3 assignment2]$ sbatch run.sh
Submitted batch job 14551517
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
[amohd@comet-ln3 assignment2]$ cat ./gauss_p.14551517.comet-10-06.out
Random seed = 2

Matrix dimension N = 2000.

Number of Pthreads Initialized = 8

Initializing...

Starting clock.
Computing Parallelly.
Stopped clock.

Elapsed time = 1320.62 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0.966 ms.
My system CPU time for parent = 0.023 ms.
My total CPU time for child processes = 0 ms.
------------------------------------------
[amohd@comet-ln3 assignment2]$
```

OpenMP:

N = 10 thread =1

```
[amohd@comet-ln3 assignment2]$ vi run.sh
[amohd@comet-ln3 assignment2]$ sbatch run.sh
Submitted batch job 14552054
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14552003   compute  gauss_o    amohd PD       0:00      1 (Resources)
          14552054   compute  gauss_o    amohd PD       0:00      1 (Resources)
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14552003   compute  gauss_o    amohd PD       0:00      1 (Resources)
          14552054   compute  gauss_o    amohd PD       0:00      1 (Resources)
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
[amohd@comet-ln3 assignment2]$ cat ./gauss_o.14552003.comet-21-03.out

Matrix dimension N = 10.

Number of OpenMP threads Initialized = 1

Initializing...

Starting clock.
Computing Parallelly Using OpenMP.
Stopped clock.

X = [-1.56;  3.11;  1.89; -1.64; -4.38; -0.65;  1.67; -2.05; -0.47;  5.53]

Elapsed time = 0.016 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0 ms.
My system CPU time for parent = 0 ms.
My total CPU time for child processes = 0 ms.
----------------------------------------
[amohd@comet-ln3 assignment2]$ cat ./gauss_o.14552003.comet-21-03.out
```

N = 100 thread =1

```
[amohd@comet-ln2 assignment2]$ vi run.sh
[amohd@comet-ln2 assignment2]$ sbatch run.sh
Submitted batch job 14552117
[amohd@comet-ln2 assignment2]$ squeue |grep amohd
[amohd@comet-ln2 assignment2]$ cat ./gauss_o.14552117.comet-10-52.out

Matrix dimension N = 100.

Number of OpenMP threads Initialized = 1

Initializing...

Starting clock.
Computing Parallelly Using OpenMP.
Stopped clock.

Elapsed time = 1.223 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0 ms.
My system CPU time for parent = 0 ms.
My total CPU time for child processes = 0 ms.
----------------------------------------
[amohd@comet-ln2 assignment2]$ vi run.sh
```

N = 1000 thread =1

```
[amohd@comet-ln2 assignment2]$ vi run.sh
[amohd@comet-ln2 assignment2]$ sbatch run.sh
Submitted batch job 14552145
[amohd@comet-ln2 assignment2]$ squeue |grep amohd
          14552145   compute  gauss_o    amohd PD       0:00      1 (Resources)
[amohd@comet-ln2 assignment2]$ squeue |grep amohd
[amohd@comet-ln2 assignment2]$ cat ./gauss_o.14552145.comet-19-19.out

Matrix dimension N = 1000.

Number of OpenMP threads Initialized = 1

Initializing...

Starting clock.
Computing Parallelly Using OpenMP.
Stopped clock.

Elapsed time = 1053.85 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0.105 ms.
My system CPU time for parent = 0 ms.
My total CPU time for child processes = 0 ms.
------------------------------------------
[amohd@comet-ln2 assignment2]$
```

N = 1000 thread =2

```
[amohd@comet-ln2 assignment2]$ vi run.sh
[amohd@comet-ln2 assignment2]$ sbatch run.sh
Submitted batch job 14552154
[amohd@comet-ln2 assignment2]$ squeue |grep amohd
[amohd@comet-ln2 assignment2]$ cat ./gauss_o.14552154.comet-07-65.out

Matrix dimension N = 1000.

Number of OpenMP threads Initialized = 2

Initializing...

Starting clock.
Computing Parallelly Using OpenMP.
Stopped clock.

Elapsed time = 532.46 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0.106 ms.
My system CPU time for parent = 0 ms.
My total CPU time for child processes = 0 ms.
------------------------------------------
[amohd@comet-ln2 assignment2]$
```

N = 1000 thread = 3

```
[amohd@comet-ln2 assignment2]$ vi run.sh
[amohd@comet-ln2 assignment2]$ sbatch run.sh
Submitted batch job 14552157
[amohd@comet-ln2 assignment2]$ squeue |grep amohd
[amohd@comet-ln2 assignment2]$ cat ./gauss_o.14552157.comet-17-26.out

Matrix dimension N = 1000.

Number of OpenMP threads Initialized = 3

Initializing...

Starting clock.
Computing Parallelly Using OpenMP.
Stopped clock.

Elapsed time = 357.393 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0.107 ms.
My system CPU time for parent = 0 ms.
My total CPU time for child processes = 0 ms.
------------------------------------------
[amohd@comet-ln2 assignment2]$
```

N = 1000 thread =4

```
[amohd@comet-ln2 assignment2]$ vi run.sh
[amohd@comet-ln2 assignment2]$ sbatch run.sh
Submitted batch job 14552161
[amohd@comet-ln2 assignment2]$ squeue |grep amohd
[amohd@comet-ln2 assignment2]$ cat ./gauss_o.14552161.comet-16-38.out

Matrix dimension N = 1000.

Number of OpenMP threads Initialized = 4

Initializing...

Starting clock.
Computing Parallelly Using OpenMP.
Stopped clock.

Elapsed time = 269.429 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0.107 ms.
My system CPU time for parent = 0 ms.
My total CPU time for child processes = 0 ms.
------------------------------------------
[amohd@comet-ln2 assignment2]$
```

N = 1000 thread =5

```
[amohd@comet-ln2 assignment2]$ vi run.sh
[amohd@comet-ln2 assignment2]$ sbatch run.sh
Submitted batch job 14552164
[amohd@comet-ln2 assignment2]$ squeue |grep amohd
          14552164   compute  gauss_o    amohd  R       0:01      1 comet-19-60
[amohd@comet-ln2 assignment2]$ squeue |grep amohd
[amohd@comet-ln2 assignment2]$ cat ./gauss_o.14552164.comet-19-60.out

Matrix dimension N = 1000.

Number of OpenMP threads Initialized = 5

Initializing...

Starting clock.
Computing Parallelly Using OpenMP.
Stopped clock.

Elapsed time = 217.487 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0.109 ms.
My system CPU time for parent = 0 ms.
My total CPU time for child processes = 0 ms.
------------------------------------------
[amohd@comet-ln2 assignment2]$
```

N = 1000 thread =6

```
[amohd@comet-ln2 assignment2]$ vi run.sh
[amohd@comet-ln2 assignment2]$ sbatch run.sh
^[[ASubmitted batch job 14552166
[amohd@comet-ln2 assignment2]$ squeue |grep amohd
          14552166   compute  gauss_o    amohd CG       0:02      1 comet-04-61
[amohd@comet-ln2 assignment2]$ squeue |grep amohd
[amohd@comet-ln2 assignment2]$ cat ./gauss_o.1455216
gauss_o.14552161.comet-16-38.out  gauss_o.14552164.comet-19-60.out  gauss_o.14552166.comet-04-61.out
[amohd@comet-ln2 assignment2]$ cat ./gauss_o.14552166.comet-04-61.out

Matrix dimension N = 1000.

Number of OpenMP threads Initialized = 6

Initializing...

Starting clock.
Computing Parallelly Using OpenMP.
Stopped clock.

Elapsed time = 182.037 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0.11 ms.
My system CPU time for parent = 0 ms.
My total CPU time for child processes = 0 ms.
------------------------------------------
[amohd@comet-ln2 assignment2]$
```

N = 1000 thread =7

```
[amohd@comet-ln2 assignment2]$ vi run.sh
[amohd@comet-ln2 assignment2]$ sbatch run.sh
Submitted batch job 14552170
[amohd@comet-ln2 assignment2]$ squeue |grep amohd
          14552170   compute  gauss_o    amohd PD       0:00      1 (None)
[amohd@comet-ln2 assignment2]$ squeue |grep amohd
[amohd@comet-ln2 assignment2]$ cat ./gauss_o.14552170.comet-10-32.out

Matrix dimension N = 1000.

Number of OpenMP threads Initialized = 7

Initializing...

Starting clock.
Computing Parallelly Using OpenMP.
Stopped clock.

Elapsed time = 157.792 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0.11 ms.
My system CPU time for parent = 0 ms.
My total CPU time for child processes = 0 ms.
------------------------------------------
[amohd@comet-ln2 assignment2]$
```

N = 1000 thread =8

```
[amohd@comet-ln2 assignment2]$ vi run.sh
[amohd@comet-ln2 assignment2]$ sbatch run.sh
Submitted batch job 14552172
[amohd@comet-ln2 assignment2]$ squeue |grep amohd
          14552172   compute  gauss_o    amohd PD       0:00      1 (None)
[amohd@comet-ln2 assignment2]$ squeue |grep amohd
          14552172   compute  gauss_o    amohd  R       0:02      1 comet-10-52
[amohd@comet-ln2 assignment2]$ squeue |grep amohd
[amohd@comet-ln2 assignment2]$ cat ./gauss_o.14552172
cat: ./gauss_o.14552172: No such file or directory
[amohd@comet-ln2 assignment2]$ cat ./gauss_o.14552172.comet-10-52.out

Matrix dimension N = 1000.

Number of OpenMP threads Initialized = 8

Initializing...

Starting clock.
Computing Parallelly Using OpenMP.
Stopped clock.

Elapsed time = 138.936 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0.111 ms.
My system CPU time for parent = 0 ms.
My total CPU time for child processes = 0 ms.
------------------------------------------
[amohd@comet-ln2 assignment2]$
```

N = 1000 thread =9

```
[amohd@comet-ln3 assignment2]$ vi run.sh
[amohd@comet-ln3 assignment2]$ sbatch run.sh
Submitted batch job 14552182
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14552182   compute  gauss_o    amohd CG       0:02      1 comet-05-62
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14552182   compute  gauss_o    amohd CG       0:02      1 comet-05-62
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
[amohd@comet-ln3 assignment2]$ cat ./gauss_o.14552182.comet-05-62.out

Matrix dimension N = 1000.

Number of OpenMP threads Initialized = 9

Initializing...

Starting clock.
Computing Parallelly Using OpenMP.
Stopped clock.

Elapsed time = 125.083 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0.112 ms.
My system CPU time for parent = 0 ms.
My total CPU time for child processes = 0 ms.
------------------------------------------
[amohd@comet-ln3 assignment2]$
```

N = 1000 thread =10

```
[amohd@comet-ln3 assignment2]$ vi run.sh
[amohd@comet-ln3 assignment2]$ sbatch run.sh
Submitted batch job 14552184
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14552184   compute  gauss_o    amohd CG       0:02      1 comet-05-62
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
[amohd@comet-ln3 assignment2]$ cat ./gauss_o.14552184.comet-05-62.out

Matrix dimension N = 1000.

Number of OpenMP threads Initialized = 10

Initializing...

Starting clock.
Computing Parallelly Using OpenMP.
Stopped clock.

Elapsed time = 113.722 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0.113 ms.
My system CPU time for parent = 0 ms.
My total CPU time for child processes = 0 ms.
------------------------------------------
[amohd@comet-ln3 assignment2]$
```

N = 2000 thread =1

```
[amohd@comet-ln3 assignment2]$ vi run.sh
[amohd@comet-ln3 assignment2]$ sbatch run.sh
Submitted batch job 14552206
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14552206   compute  gauss_o    amohd  R       0:07      1 comet-16-49
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14552206   compute  gauss_o    amohd  R       0:09      1 comet-16-49
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14552206   compute  gauss_o    amohd  R       0:10      1 comet-16-49
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14552206   compute  gauss_o    amohd CG       0:11      1 comet-16-49
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
[amohd@comet-ln3 assignment2]$ cat ./gauss_o.14552206.comet-16-49.out

Matrix dimension N = 2000.

Number of OpenMP threads Initialized = 1

Initializing...

Starting clock.
Computing Parallelly Using OpenMP.
Stopped clock.

Elapsed time = 8361.22 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0.834 ms.
My system CPU time for parent = 0 ms.
My total CPU time for child processes = 0 ms.
----------------------------------------
[amohd@comet-ln3 assignment2]$
```

N = 2000 thread =2

```
[amohd@comet-ln3 assignment2]$ vi run.sh
[amohd@comet-ln3 assignment2]$ sbatch run.sh
Submitted batch job 14552207
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14552207   compute  gauss_o    amohd PD       0:00      1 (Resources)
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14552207   compute  gauss_o    amohd PD       0:00      1 (Resources)
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14552207   compute  gauss_o    amohd PD       0:00      1 (Resources)
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14552207   compute  gauss_o    amohd PD       0:00      1 (Resources)
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
[amohd@comet-ln3 assignment2]$ cat ./gauss_o.14552207.comet-04-34.out

Matrix dimension N = 2000.

Number of OpenMP threads Initialized = 2

Initializing...

Starting clock.
Computing Parallelly Using OpenMP.
Stopped clock.

Elapsed time = 4190.27 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0.838 ms.
My system CPU time for parent = 0.001 ms.
My total CPU time for child processes = 0 ms.
----------------------------------------
[amohd@comet-ln3 assignment2]$
```

N = 2000 thread =4

```
[amohd@comet-ln3 assignment2]$ vi run.sh
[amohd@comet-ln3 assignment2]$ sbatch run.sh
Submitted batch job 14552210
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14552210   compute  gauss_o    amohd PD       0:00      1 (Resources)
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14552210   compute  gauss_o    amohd PD       0:00      1 (Resources)
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
[amohd@comet-ln3 assignment2]$ cat ./gauss_o.14552210.comet-27-01.out

Matrix dimension N = 2000.

Number of OpenMP threads Initialized = 4

Initializing...

Starting clock.
Computing Parallelly Using OpenMP.
Stopped clock.

Elapsed time = 2104.14 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0.841 ms.
My system CPU time for parent = 0 ms.
My total CPU time for child processes = 0 ms.
------------------------------------------
[amohd@comet-ln3 assignment2]$
```

N = 2000 thread =8

```
[amohd@comet-ln3 assignment2]$ vi run.sh
[amohd@comet-ln3 assignment2]$ sbatch run.sh
Submitted batch job 14552219
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14552219   compute  gauss_o    amohd PD       0:00      1 (None)
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
[amohd@comet-ln3 assignment2]$ cat ./gauss_o.1455221
gauss_o.14552210.comet-27-01.out  gauss_o.14552219.comet-27-01.out
[amohd@comet-ln3 assignment2]$ cat ./gauss_o.1455221
gauss_o.14552210.comet-27-01.out  gauss_o.14552219.comet-27-01.out
[amohd@comet-ln3 assignment2]$ cat ./gauss_o.14552219.comet-27-01.out

Matrix dimension N = 2000.

Number of OpenMP threads Initialized = 8

Initializing...

Starting clock.
Computing Parallelly Using OpenMP.
Stopped clock.

Elapsed time = 1064.12 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0.848 ms.
My system CPU time for parent = 0 ms.
My total CPU time for child processes = 0 ms.
------------------------------------------
[amohd@comet-ln3 assignment2]$
```

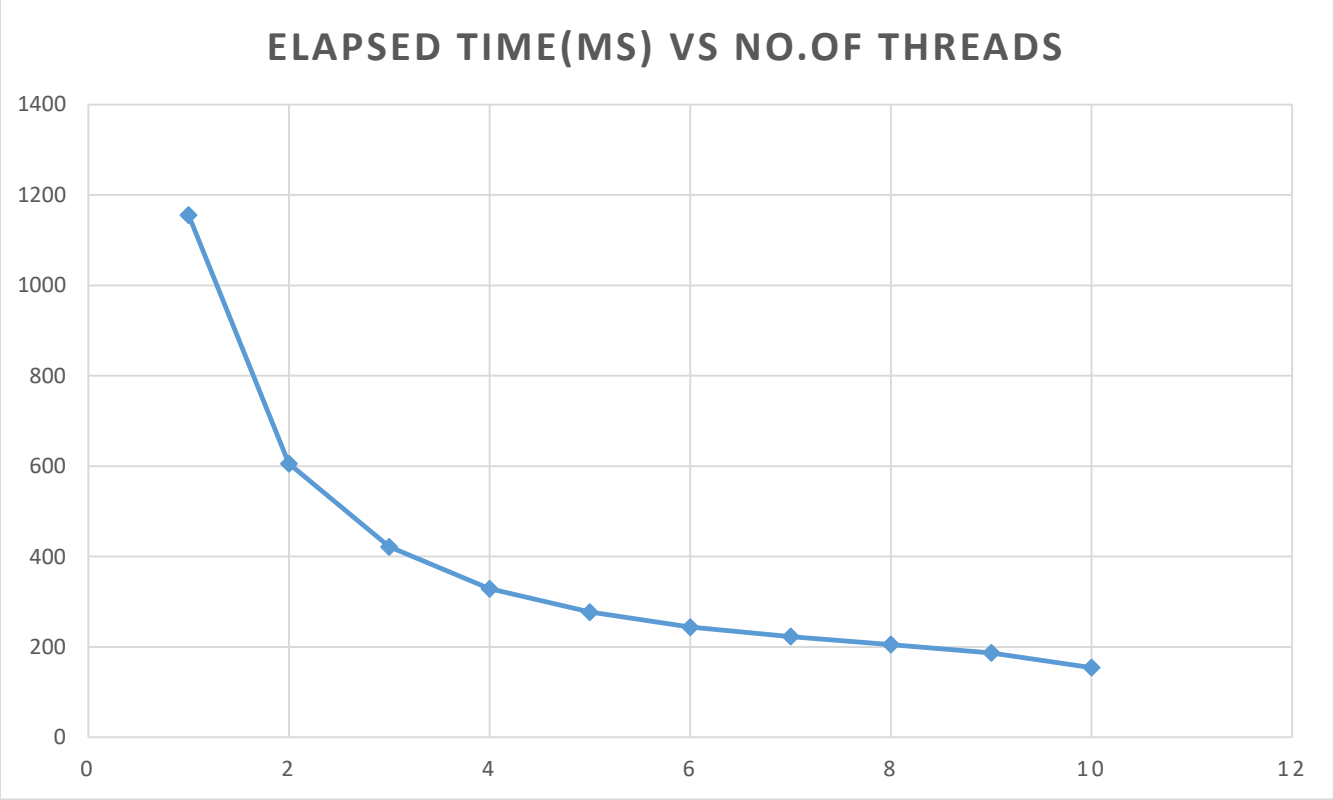
N = 2000 thread =16

```
[amohd@comet-ln3 assignment2]$ vi run.sh
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
          14552236   compute  gauss_o    amohd PD       0:00      1 (None)
[amohd@comet-ln3 assignment2]$ squeue |grep amohd
[amohd@comet-ln3 assignment2]$ cat ./gauss_o.14552236.comet-26-50.out

Matrix dimension N = 2000.

Number of OpenMP threads Initialized = 16

Initializing...

Starting clock.
Computing Parallelly Using OpenMP.
Stopped clock.

Elapsed time = 549.163 ms.
(CPU times are accurate to the nearest 0.001 ms)
My total CPU time for parent = 0.871 ms.
My system CPU time for parent = 0 ms.
My total CPU time for child processes = 0 ms.
----------------------------------------
[amohd@comet-ln3 assignment2]$
```

Performance
Using Pthreads:

Performance is calculated on Comet. Based on the above screen shots given in the document.
Matrix Size N = 1000

No Of Threads	Time (ms)
1	1155.33
2	605.543
3	421.498
4	328.759
5	277.253
6	243.802
7	223.008
8	205.237
9	186.866
10	154.321

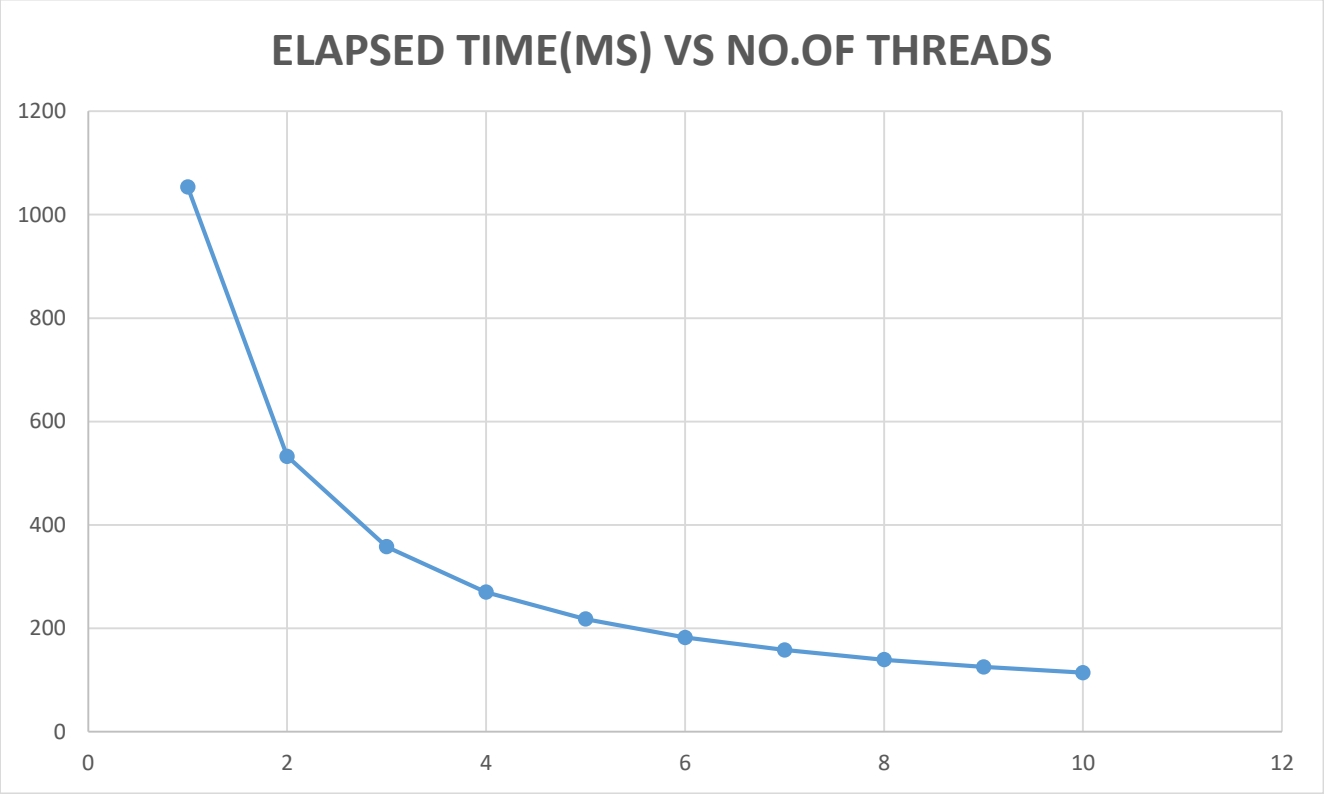


Using OpenMP:

Performance is calculated on Comet. Based on the above screen shots given in the document.

Matrix Size N = 1000

No Of Threads	Time (ms)
1	1053.85
2	532.46
3	357.393
4	269.429
5	217.487
6	182.037
7	157.792
8	138.936
9	125.083
10	113.722



Conclusion and Previous Versions Made:

Pthreads:

Version 1:

Tried to Parallelize only the loop and found the elapsed time was increasing with number of Pthreads. This was happening because the loop was not getting executed according to the loop number.

Version 2:

In this version, I tried to use static variable for passing data to loop function which we were using in the pthread_create(). I also implemented an pointer to the variable which is getting passed in pthread_create(), It was saving a lot of memory because instead of a variable , pointer to the variable was getting passed.

OpenMP:

Version 1:

Tried to Parallelize only the loop by using a single static variable and passing variable using OpenMP.

Version 2:

Used 2 variables through OpenMP for Optimum results.