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Assignment: 3
Course: CPSC 424/524

Modules:

[ff242@omega1 ff242_ps3_cpsc424]$ module list

Currently Loaded Modules:
1) StdEnv (S) 2) Langs/Intel/15.0.2 3) MPI/OpenMPI/2.1.1-intel15

Where:
S: Module is Sticky, requires --force to unload or purge

Environment:

[ff242@omega1 ff242_ps3_cpsc424]$ which icc
/home/apps/fas/Langs/Intel/2015_update2/composer_xe_2015.2.164/bin/intel64/icc
[ff242@omega1 ff242_ps3_cpsc424]$ icc --version
icc (ICC) 15.0.2 20150121
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Output:

See appendix at the end of this report.

Task 1 (Serial Program):

sbatch scripts/build-run.sh

N	1000	2000	4000	8000
Time (#1)	0.1826	2.8367	19.5150	154.6797
Time (#2)	0.1829	2.3156	19.6447	155.7885
Time (#3)	0.1829	2.3171	19.6353	155.5739
Average Time	0.1828	2.4898	19.5983	155.3474
F-norm (#1)	0	1	5	28
F-norm (#2)	0	1	5	28
F-norm (#3)	0	1	5	28
Average F-norm	0	1	5	28

Note: F-norm of Error in the table is in 10^{-10}.

Task 2:

Part A

sbatch scripts/mpi-blocking-2a-1.sh
sbatch scripts/mpi-blocking-2a-2.sh
sbatch scripts/mpi-blocking-2a-4.sh
sbatch scripts/mpi-blocking-2a-8.sh

p = 1

N	1000	2000	4000	8000
Total Time (#1)	0.1826	2.3173	19.4314	154.8959
Total Time (#2)	0.1845	2.3348	19.4398	154.4387
Total Time (#3)	0.1847	2.3239	19.7273	156.2725
Average Total Time	0.1839	2.3253	19.5328	155.2024
Average F-norm	0	1	5	28

Note that the result is similar to that in task 1.

p = 2

N	1000	2000	4000	8000
P0 Total Time	0.1371	1.5786	15.1353	119.6891
P1 Total Time	0.1360	1.5768	15.1343	119.6874
F-norm	0	1	5	28

p = 4

N	1000	2000	4000	8000
P0 Total Time	0.0963	0.7260	9.9975	80.4681
P1 Total Time	0.0814	0.5944	8.1787	67.1164
P2 Total Time	0.0950	0.7228	9.9849	80.4252
P3 Total Time	0.0959	0.7251	9.9955	80.4660
F-norm	0	1	5	28

p = 8

N	1000	2000	4000	8000
P0 Total Time	0.0548	0.4057	6.2991	53.1475
P1 Total Time	0.0481	0.3514	5.4492	46.7165
P2 Total Time	0.0500	0.3553	5.4609	46.7612
P3 Total Time	0.0520	0.3644	5.5821	47.8310
P4 Total Time	0.0538	0.3838	6.0574	51.3036
P5 Total Time	0.0544	0.3920	6.0650	51.5161
P6 Total Time	0.0547	0.4022	6.2920	53.1248
P7 Total Time	0.0548	0.4043	6.2971	53.1452
F-norm	0	1	5	28

To assess raw performance, one can compare the total time of process 0. As the number of processes increases, the total time decreases.

In terms of scalability, as p doubles from 1 to 2, 4, 8, performance gets closer and closer to twice as good, although it's not really possible to achieve linear improvement on performance with respect to the number of processes.

From p = 1 to p = 2, (154 - 119) / 154 = 23%.
From p = 2 to p = 4, (119 - 80) / 119 = 33%.
From p = 4 to p = 8, (80 - 53) / 80 = 34%.

As for load balance, loads are distributed pretty evenly. Although note that processes with higher rank tend to take more time than the ones with lower rank, this is because high rank processes have more non-zero elements in matrix A then lower rank processes, thus computation takes more time.

Part B

sbatch scripts/mpi-blocking-2b-p4n1.sh
sbatch scripts/mpi-blocking-2b-p4n2.sh
sbatch scripts/mpi-blocking-2b-p4n4.sh
sbatch scripts/mpi-blocking-2b-p8n1.sh
sbatch scripts/mpi-blocking-2b-p8n2.sh
sbatch scripts/mpi-blocking-2b-p8n4.sh

#node = 1, p = 4, N = 8000

Rank	Comp. Time	Comm. Time	Total Time
N = 8000			
1	43.9366	23.1260	67.0626
2	53.5871	26.7711	80.3583
3	65.0555	15.3433	80.3988
0	17.3633	63.0367	80.4000

F-norm of Error: 0.0000000028

#node = 2, p = 4, N = 8000

Rank	Comp. Time	Comm. Time	Total Time
N = 8000			
1	35.2796	22.3059	57.5855
2	49.9221	21.8894	71.8114
3	56.6813	15.1726	71.8539
0	13.6059	58.2479	71.8538

F-norm of Error: 0.0000000028

#node = 4, p = 4, N = 8000

Rank	Comp. Time	Comm. Time	Total Time
N = 8000			
1	35.4460	22.1138	57.5599
2	49.6578	22.1289	71.7867
3	56.6310	15.1986	71.8296
0	13.5286	58.3010	71.8296

F-norm of Error: 0.0000000028

#node = 1, p = 8, N = 8000

Rank	Comp. Time	Comm. Time	Total Time

N = 8000

1	17.4118	29.5162	46.9279
2	21.7068	25.2684	46.9752
3	31.9667	16.0709	48.0376
4	31.4902	20.0279	51.5181
5	38.3784	13.3140	51.6924
6	36.9487	16.3864	53.3351
7	41.8665	11.4885	53.3550
0	5.5352	47.8215	53.3567

F-norm of Error: 0.0000000028

#node = 2, p = 8, N = 8000

Rank	Comp. Time	Comm. Time	Total Time

N = 8000

1	11.2412	25.7872	37.0284
2	15.6892	21.3634	37.0526
3	21.2794	17.1515	38.4309
4	27.4727	14.1689	41.6415
5	30.1916	11.4710	41.6626
6	31.8071	11.6271	43.4342
7	32.7451	10.7103	43.4554
0	2.9059	40.5496	43.4555

F-norm of Error: 0.0000000028

#node = 4, p = 8, N = 8000

Rank	Comp. Time	Comm. Time	Total Time

N = 8000

1	9.3058	22.7280	32.0338
2	15.3551	16.8338	32.1888
3	19.7139	14.3199	34.0338
4	23.4236	12.4263	35.8499
5	25.9124	10.8562	36.7685
6	27.8797	9.7825	37.6622
7	28.7091	8.9741	37.6833
0	2.4276	35.2558	37.6833

F-norm of Error: 0.0000000028

In terms of raw performance, total time of p = 8 is less than that of p = 4, as seen in part A. For the same number of processes with different

number of nodes, performance improves as the number of nodes increases.

In terms of computation time vs. communication time, as rank increases, the computation time increases, due to the fact that matrix A is triangular. With total time being roughly the same, the communication time decreases as rank increases.

As for load balance, similar to part A, loads are distributed pretty evenly, although there are notable differences between processes with lower rank and ones with higher rank.

Possible improvements include:

1. Using collectives, I tried using collectives initially, but had various problems, thus ended up using blocking non-collective send and recv only. Collectives can potentially reduce the overhead of the for loop by scattering and gathering, therefore can perhaps improve performance.

2. Using non-blocking communication. This can improve performance since send and recv operations return immediately so that computations don't have to wait until communication is finished.

3. To achieve better load balance across processes, one possible approach is to split matrix A and B by the number of elements, instead of by number of rows. This can achieve better load balance since computation time will be closer to each other, although this does make it more complex to implement.

Task 3:

Part A

sbatch scripts/mpi-non-blocking-3a-1.sh
sbatch scripts/mpi-non-blocking-3a-2.sh

sbatch scripts/mpi-non-blocking-3a-4.sh
sbatch scripts/mpi-non-blocking-3a-8.sh

p = 1

N	1000	2000	4000	8000
Total Time (#1)	0.1766	2.2575	19.3389	153.3338
F-norm	0	1	5	28

p = 2

N	1000	2000	4000	8000
P0 Total Time	0.1289	1.5393	14.8599	117.5159
P1 Total Time	0.1289	1.5384	14.8592	117.5150
F-norm	0	1	5	28

p = 4

N	1000	2000	4000	8000
P0 Total Time	0.0897	0.6895	8.7717	79.7506
P1 Total Time	0.0763	0.5662	8.1115	66.6237
P2 Total Time	0.0896	0.6793	8.7710	79.7496
P3 Total Time	0.0734	0.5619	8.0905	65.3819
F-norm	0	1	5	28

p = 8

N	1000	2000	4000	8000
P0 Total Time	0.0497	0.3544	6.1669	51.5719
P1 Total Time	0.0419	0.3039	4.9550	43.7540
P2 Total Time	0.0432	0.3041	4.8305	43.3229
P3 Total Time	0.0451	0.3058	5.2417	46.2949
P4 Total Time	0.0473	0.3099	5.9386	49.7890
P5 Total Time	0.0484	0.3408	5.8917	50.0115
P6 Total Time	0.0496	0.3544	6.1660	51.5711
P7 Total Time	0.0410	0.2986	4.8499	43.3100

F-norm	0	1	5	28

Comparing Task 2 with Task 3, the raw performance in Task 3 is better, although the improvement is not significant (approximately by a few percent).

In terms of scalability, Task 3 has similar behaviors to Task 2.

As for load balance, again loads are distributed pretty evenly, and the distribution is arguably better than that in Task 2.

Part B

sbatch scripts/mpi-non-blocking-3b-p4n1.sh
sbatch scripts/mpi-non-blocking-3b-p4n2.sh
sbatch scripts/mpi-non-blocking-3b-p4n4.sh
sbatch scripts/mpi-non-blocking-3b-p8n1.sh
sbatch scripts/mpi-non-blocking-3b-p8n2.sh
sbatch scripts/mpi-non-blocking-3b-p8n4.sh

#node = 1, p = 4, N = 8000

```
Rank     Comp. Time    Comm. Time    Total Time
-------  ----------    ----------    ----------
N = 8000
   3      65.1012       0.6742       65.7754
   1      43.9436      23.1609       67.1045
   2      53.7825      26.6072       80.3898
   0      17.4252      62.9656       80.3908
F-norm of Error:    0.0000000028
```

#node = 2, p = 4, N = 8000

```
Rank     Comp. Time    Comm. Time    Total Time
-------  ----------    ----------    ----------
N = 8000
   1      35.3305       7.9969       43.3274
   3      56.8282       0.2226       57.0508
   2      50.0478      11.1964       61.2442
```

0	13.6601	47.5842	61.2442

F-norm of Error: 0.0000000028

#node = 4, p = 4, N = 8000

Rank	Comp. Time	Comm. Time	Total Time
N = 8000			
1	35.4480	7.7223	43.1703
3	56.6842	0.1935	56.8776
2	49.5883	11.2227	60.8109
0	13.5497	47.2613	60.8110

F-norm of Error: 0.0000000028

#node = 1, p = 8, N = 8000

Rank	Comp. Time	Comm. Time	Total Time
N = 8000			
7	43.1209	0.3683	43.4891
2	21.6303	21.9607	43.5910
1	17.3946	26.6430	44.0376
3	32.1015	14.5316	46.6330
4	31.5812	18.4714	50.0526
5	39.5601	10.7574	50.3174
6	36.2497	15.6158	51.8655
0	5.6463	46.2202	51.8666

F-norm of Error: 0.0000000028

#node = 2, p = 8, N = 8000

Rank	Comp. Time	Comm. Time	Total Time
N = 8000			
2	15.8147	17.4663	33.2810
1	11.0187	22.2701	33.2889
3	21.1312	12.1620	33.2932
4	27.9032	5.4257	33.3290
7	34.3601	0.2296	34.5897
5	31.6402	6.1593	37.7995
6	32.2975	6.3359	38.6334
0	3.2352	35.3983	38.6335

F-norm of Error: 0.0000000028

#node = 4, p = 8, N = 8000

Rank	Comp. Time	Comm. Time	Total Time
N = 8000			
2	15.3636	12.4946	27.8582
3	19.7776	8.1232	27.9007
1	9.3208	18.7995	28.1203
4	23.4455	4.7024	28.1480
7	28.7278	0.2096	28.9374
5	26.0403	6.5530	32.5933
6	27.8907	5.4294	33.3201
0	2.4828	30.8375	33.3202

F-norm of Error: 0.0000000028

Again, overall performance is better than that in Task 2, although only by a small margin. Similar to Task 2B, performance improves as the number of nodes increases.

For scalability, the same conclusion can be drawn as in Task 3A.

In terms of computation time vs. communication time, the root process has the minimum computation time and the maximum communication time. Unlike Task 2B, the positive relationship between rank and computation time is much less obvious in Task 3B. Also, the difference of computation time or communication time between different processes are less significant than in Task 2B.

As for load balance, a better distribution can be observed in Task 3B than that in Task 2B, although still not perfect. It is more obvious when observing computation and/or communication time, in a sense that different processes now have closer computation and/or communication time than they do in Task 2B.

Task 4:

sbatch scripts/mpi-load-balance-4-p4n1.sh
sbatch scripts/mpi-load-balance-4-p4n2.sh
sbatch scripts/mpi-load-balance-4-p4n4.sh

sbatch scripts/mpi-load-balance-4-p8n1.sh
sbatch scripts/mpi-load-balance-4-p8n2.sh
sbatch scripts/mpi-load-balance-4-p8n4.sh

Load balance improves from Task 2 to Task 3, although not achieving perfect distribution.

One possible approach to further improve load balance is to distribute elements in both triangular matrices evenly, rather than distributing rows and columns evenly.

The intuition is that although each process performs exactly p multiplication of blocks, the number of operations between processes is different. Since we only rotate matrix B not A, processes with lower ranks have less computation to do than ones with higher ranks. Distributing elements rather than rows and/or columns will ideally fix this issue and result in better load balance.

#node = 1, p = 4, N = 8000

Rank	Comp. Time	Comm. Time	Total Time
N = 8000			
3	35.7390	31.3485	67.0876
1	45.4326	21.6711	67.1037
2	42.6000	25.3603	67.9604
0	56.8059	11.1555	67.9614

F-norm of Error: 0.0000000028

#node = 2, p = 4, N = 8000

Rank	Comp. Time	Comm. Time	Total Time
N = 8000			
3	31.1711	4.9254	36.0966
2	35.3526	2.8196	38.1722
1	40.7482	0.4001	41.1483
0	49.4325	0.1286	49.5610

F-norm of Error: 0.0000000028

#node = 4, p = 4, N = 8000

Rank	Comp. Time	Comm. Time	Total Time
N = 8000			
3	30.8890	4.9952	35.8842
2	35.0674	2.7993	37.8667
1	40.4260	0.1827	40.6088
0	49.0441	0.1364	49.1805

F-norm of Error: 0.0000000028

#node = 1, p = 8, N = 8000

Rank	Comp. Time	Comm. Time	Total Time
N = 8000			
7	23.6555	22.0014	45.6570
5	26.4975	19.1908	45.6883
3	30.0559	15.6549	45.7108
1	34.1343	11.5990	45.7334
2	33.4359	12.5005	45.9365
6	25.5985	20.8575	46.4560
4	29.9081	16.5929	46.5009
0	40.2060	6.2959	46.5019

F-norm of Error: 0.0000000028

#node = 2, p = 8, N = 8000

Rank	Comp. Time	Comm. Time	Total Time
N = 8000			
2	20.9752	1.0726	22.0479
3	19.4235	2.6567	22.0802
4	18.1091	3.9944	22.1035
5	16.9903	5.1390	22.1293
6	15.9353	6.2204	22.1557
7	15.0224	7.2026	22.2250
1	22.8530	0.5827	23.4357
0	24.3120	0.1514	24.4634

F-norm of Error: 0.0000000028

#node = 4, p = 8, N = 8000

Rank	Comp. Time	Comm. Time	Total Time

```
N = 8000
   2      20.9752       1.0726      22.0479
   3      19.4235       2.6567      22.0802
   4      18.1091       3.9944      22.1035
   5      16.9903       5.1390      22.1293
   6      15.9353       6.2204      22.1557
   7      15.0224       7.2026      22.2250
   1      22.8530       0.5827      23.4357
   0      24.3120       0.1514      24.4634
F-norm of Error:    0.0000000028
```

The load balance is much better than in previous tasks, leading to an improvement on raw performance. Note that when p = 4, n = 2 and p = 4, n = 4, the load balance is not perfect, which is probably due to some communication overhead between nodes.

Task 5:

TODO: Current program breaks with N = 7644 and p = 7.

Appendix:

Task 1

```
[ff242@omega1 PS3]$ cat slurm-1193040.out
/home/fas/cpsc424/ff242/PS3
c30n01
1
rm -f serial mpi-blocking  *.o
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c serial.c
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c matmul.c
mpicc -o serial -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing serial.o
matmul.o /home/fas/cpsc424/ahs3/utils/timing/timing.o
Matrix multiplication times:
   N      TIME (secs)    F-norm of Error
 -----   -------------  -----------------
  1000       0.1831       0.0000000000
  2000       2.3240       0.0000000001
  4000      19.8099       0.0000000005
  8000     154.5914       0.0000000028
```

```
real   3m0.119s
user   2m57.547s
sys    0m0.443s
```

Task 2A

```
[ff242@omega1 PS3]$ cat slurm-1193042.out
/home/fas/cpsc424/ff242/PS3
c30n01
1
rm -f serial mpi-blocking  *.o
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c mpi-blocking.c
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c matmul-block.c
mpicc -o mpi-blocking -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing mpi-blocking.o matmul-block.o /home/fas/cpsc424/ahs3/utils/timing/timing.o
Matrix multiplication times:
 Rank      Total Time
-------    ----------
N = 1000
   0        0.1862
F-norm of Error:    0.0000000000
N = 2000
   0        2.3224
F-norm of Error:    0.0000000001
N = 4000
   0       19.6987
F-norm of Error:    0.0000000005
N = 8000
   0      156.1402
F-norm of Error:    0.0000000028

real   3m1.427s
user   2m59.857s
sys    0m0.552s
```

```
[ff242@omega1 PS3]$ cat slurm-1193050.out
/home/fas/cpsc424/ff242/PS3
```

```
c30n01
2
rm -f serial mpi-blocking  *.o
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c mpi-blocking.c
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c matmul-block.c
mpicc -o mpi-blocking -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing mpi-blocking.o matmul-block.o /home/fas/cpsc424/ahs3/utils/timing/timing.o
Matrix multiplication times:
 Rank      Total Time
-------    ----------
N = 1000
   1        0.1342
   0        0.1358
F-norm of Error:    0.0000000000
N = 2000
   1        1.5803
   0        1.5824
F-norm of Error:    0.0000000001
N = 4000
   1       15.0862
   0       15.0875
F-norm of Error:    0.0000000005
N = 8000
   1      119.4221
   0      119.4240
F-norm of Error:    0.0000000028

real   2m18.797s
user   4m12.286s
sys      0m24.151s



[ff242@omega1 PS3]$ cat slurm-1193052.out
/home/fas/cpsc424/ff242/PS3
c30n02
4
rm -f serial mpi-blocking  *.o
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c mpi-blocking.c
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c matmul-block.c
```

```
mpicc -o mpi-blocking -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing
mpi-blocking.o matmul-block.o /home/fas/cpsc424/ahs3/utils/timing/timing.o
Matrix multiplication times:
 Rank      Total Time
-------    ----------
N = 1000
   1       0.0820
   2       0.0951
   3       0.0963
   0       0.0965
F-norm of Error:    0.0000000000
N = 2000
   1       0.5899
   2       0.7171
   3       0.7193
   0       0.7215
F-norm of Error:    0.0000000001
N = 4000
   1       8.1627
   2       9.9895
   3       9.9998
   0      10.0016
F-norm of Error:    0.0000000005
N = 8000
   1      67.1136
   2      80.3886
   3      80.4289
   0      80.4311
F-norm of Error:    0.0000000028

real   1m34.456s
user   5m29.424s
sys    0m31.049s



[ff242@omega1 PS3]$ cat slurm-1193053.out
/home/fas/cpsc424/ff242/PS3
c30n02
8
rm -f serial mpi-blocking  *.o
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c mpi-
blocking.c
```

```
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c matmul-block.c
mpicc -o mpi-blocking -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing mpi-blocking.o matmul-block.o /home/fas/cpsc424/ahs3/utils/timing/timing.o
Matrix multiplication times:
 Rank      Total Time
-------    ----------
N = 1000
   1       0.0469
   2       0.0474
   3       0.0487
   4       0.0512
   5       0.0520
   6       0.0537
   7       0.0548
   0       0.0549
F-norm of Error:    0.0000000000
N = 2000
   1       0.3527
   2       0.3568
   3       0.3655
   4       0.3848
   5       0.3922
   6       0.4041
   7       0.4051
   0       0.4067
F-norm of Error:    0.0000000001
N = 4000
   1       5.4408
   2       5.4523
   3       5.5706
   4       6.0464
   5       6.0540
   6       6.2810
   7       6.2863
   0       6.2879
F-norm of Error:    0.0000000005
N = 8000
   1      46.8918
   2      46.9358
   3      48.0180
   4      51.4843
   5      51.6767
   6      53.2971
```

```
   7       53.3173
   0       53.3192
F-norm of Error:    0.0000000028

real    1m5.163s
user    7m36.350s
sys     0m25.344s
```

Task 2B

```
[ff242@omega1 PS3]$ cat slurm-1193054.out
/home/fas/cpsc424/ff242/PS3
c30n02
4
rm -f serial mpi-blocking  *.o
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c mpi-
blocking.c
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c matmul-
block.c
mpicc -o mpi-blocking -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing
mpi-blocking.o matmul-block.o /home/fas/cpsc424/ahs3/utils/timing/timing.o
Matrix multiplication times:
 Rank     Comp. Time    Comm. Time    Total Time
-------    ----------    ----------    ----------
N = 8000
   1       43.9366       23.1260       67.0626
   2       53.5871       26.7711       80.3583
   3       65.0555       15.3433       80.3988
   0       17.3633       63.0367       80.4000
F-norm of Error:    0.0000000028

real    1m22.632s
user    4m44.779s
sys     0m29.976s
```

```
[ff242@omega1 PS3]$ cat slurm-1193055.out
/home/fas/cpsc424/ff242/PS3
c30n[01-02]
2
rm -f serial mpi-blocking  *.o
```

```
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c mpi-blocking.c
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c matmul-block.c
mpicc -o mpi-blocking -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing mpi-blocking.o matmul-block.o /home/fas/cpsc424/ahs3/utils/timing/timing.o
Matrix multiplication times:
 Rank     Comp. Time    Comm. Time    Total Time
-------    ----------    ----------    ----------
N = 8000
   1       35.2796       22.3059       57.5855
   2       49.9221       21.8894       71.8114
   3       56.6813       15.1726       71.8539
   0       13.6059       58.2479       71.8538
F-norm of Error:    0.0000000028

real   1m15.038s
user   2m7.713s
sys    0m7.688s



[ff242@omega1 PS3]$ cat slurm-1193056.out
/home/fas/cpsc424/ff242/PS3
c30n[01-04]
1
rm -f serial mpi-blocking  *.o
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c mpi-blocking.c
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c matmul-block.c
mpicc -o mpi-blocking -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing mpi-blocking.o matmul-block.o /home/fas/cpsc424/ahs3/utils/timing/timing.o
Matrix multiplication times:
 Rank     Comp. Time    Comm. Time    Total Time
-------    ----------    ----------    ----------
N = 8000
   1       35.4460       22.1138       57.5599
   2       49.6578       22.1289       71.7867
   3       56.6310       15.1986       71.8296
   0       13.5286       58.3010       71.8296
F-norm of Error:    0.0000000028

real   1m15.652s
```

```
user   1m12.125s
sys    0m2.513s


[ff242@omega1 PS3]$ cat slurm-1193058.out
/home/fas/cpsc424/ff242/PS3
c30n01
8
rm -f serial mpi-blocking  *.o
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c mpi-
blocking.c
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c matmul-
block.c
mpicc -o mpi-blocking -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing
mpi-blocking.o matmul-block.o /home/fas/cpsc424/ahs3/utils/timing/timing.o
Matrix multiplication times:
 Rank     Comp. Time    Comm. Time    Total Time
-------   ----------   ----------   ----------
N = 8000
   1       17.4118       29.5162       46.9279
   2       21.7068       25.2684       46.9752
   3       31.9667       16.0709       48.0376
   4       31.4902       20.0279       51.5181
   5       38.3784       13.3140       51.6924
   6       36.9487       16.3864       53.3351
   7       41.8665       11.4885       53.3550
   0        5.5352       47.8215       53.3567
F-norm of Error:    0.0000000028

real   0m55.415s
user   6m36.211s
sys    0m21.498s


[ff242@omega1 PS3]$ cat slurm-1193059.out
/home/fas/cpsc424/ff242/PS3
c30n[01-02]
4
rm -f serial mpi-blocking  *.o
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c mpi-
blocking.c
```

```
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c matmul-block.c
mpicc -o mpi-blocking -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing mpi-blocking.o matmul-block.o /home/fas/cpsc424/ahs3/utils/timing/timing.o
Matrix multiplication times:
 Rank     Comp. Time    Comm. Time    Total Time
-------    ----------    ----------    ----------
N = 8000
   1       11.2412       25.7872       37.0284
   2       15.6892       21.3634       37.0526
   3       21.2794       17.1515       38.4309
   4       27.4727       14.1689       41.6415
   5       30.1916       11.4710       41.6626
   6       31.8071       11.6271       43.4342
   7       32.7451       10.7103       43.4554
   0        2.9059       40.5496       43.4555
F-norm of Error:    0.0000000028

real   0m46.666s
user   2m42.477s
sys    0m4.474s



[ff242@omega1 PS3]$ cat slurm-1193060.out
/home/fas/cpsc424/ff242/PS3
c30n[01-04]
2
rm -f serial mpi-blocking  *.o
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c mpi-blocking.c
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c matmul-block.c
mpicc -o mpi-blocking -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing mpi-blocking.o matmul-block.o /home/fas/cpsc424/ahs3/utils/timing/timing.o
Matrix multiplication times:
 Rank     Comp. Time    Comm. Time    Total Time
-------    ----------    ----------    ----------
N = 8000
   1        9.3058       22.7280       32.0338
   2       15.3551       16.8338       32.1888
   3       19.7139       14.3199       34.0338
   4       23.4236       12.4263       35.8499
   5       25.9124       10.8562       36.7685
```

```
   6       27.8797        9.7825       37.6622
   7       28.7091        8.9741       37.6833
   0        2.4276       35.2558       37.6833
F-norm of Error:    0.0000000028

real   0m41.631s
user   1m12.500s
sys       0m2.780s
```

Task 3A

```
[ff242@omega1 PS3]$ cat slurm-1193064.out
/home/fas/cpsc424/ff242/PS3
c30n01
1
rm -f serial mpi-blocking  *.o
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c mpi-non-
blocking.c
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c matmul-
block.c
mpicc -o mpi-non-blocking -g -O3 -xHost -fno-alias -std=c99 -I
/home/fas/cpsc424/ahs3/utils/timing mpi-non-blocking.o matmul-block.o
/home/fas/cpsc424/ahs3/utils/timing/timing.o
Matrix multiplication times:
 Rank      Total Time
-------    ----------
N = 1000
   0        0.1841
F-norm of Error:    0.0000000000
N = 2000
   0        2.3218
F-norm of Error:    0.0000000001
N = 4000
   0       19.7260
F-norm of Error:    0.0000000005
N = 8000
   0      156.2173
F-norm of Error:    0.0000000028

real   3m0.975s
user   2m59.932s
sys       0m0.564s
```

```
[ff242@omega1 PS3]$ cat slurm-1193065.out
/home/fas/cpsc424/ff242/PS3
c30n01
2
rm -f serial mpi-blocking  *.o
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c mpi-non-blocking.c
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c matmul-block.c
mpicc -o mpi-non-blocking -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing mpi-non-blocking.o matmul-block.o /home/fas/cpsc424/ahs3/utils/timing/timing.o
Matrix multiplication times:
 Rank      Total Time
-------    ----------
N = 1000
   1        0.1345
   0        0.1347
F-norm of Error:    0.0000000000
N = 2000
   1        1.5795
   0        1.5804
F-norm of Error:    0.0000000001
N = 4000
   1       15.0662
   0       15.0671
F-norm of Error:    0.0000000005
N = 8000
   1      119.3976
   0      119.3987
F-norm of Error:    0.0000000028

real   2m18.722s
user   3m54.982s
sys    0m41.348s



[ff242@omega1 PS3]$ cat slurm-1193066.out
/home/fas/cpsc424/ff242/PS3
c30n01
```

```
4
rm -f serial mpi-blocking  *.o
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c mpi-non-blocking.c
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c matmul-block.c
mpicc -o mpi-non-blocking -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing mpi-non-blocking.o matmul-block.o /home/fas/cpsc424/ahs3/utils/timing/timing.o
Matrix multiplication times:
 Rank     Total Time
-------    ----------
N = 1000
   3       0.0768
   1       0.0797
   2       0.0936
   0       0.0936
F-norm of Error:    0.0000000000
N = 2000
   3       0.5793
   1       0.5845
   2       0.7118
   0       0.7119
F-norm of Error:    0.0000000001
N = 4000
   3       8.1229
   1       8.1589
   2       8.8370
   0       8.8380
F-norm of Error:    0.0000000005
N = 8000
   3      66.0220
   1      66.5430
   2      80.6018
   0      80.6027
F-norm of Error:    0.0000000028

real   1m32.800s
user   5m16.469s
sys    0m25.167s



[ff242@omega1 PS3]$ cat slurm-1193067.out
```

```
/home/fas/cpsc424/ff242/PS3
c30n01
8
rm -f serial mpi-blocking  *.o
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c mpi-non-blocking.c
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c matmul-block.c
mpicc -o mpi-non-blocking -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing mpi-non-blocking.o matmul-block.o /home/fas/cpsc424/ahs3/utils/timing/timing.o
Matrix multiplication times:
 Rank     Total Time
-------    ----------
N = 1000
   7       0.0417
   1       0.0428
   2       0.0437
   3       0.0459
   4       0.0477
   5       0.0490
   6       0.0501
   0       0.0501
F-norm of Error:    0.0000000000
N = 2000
   7       0.3090
   1       0.3138
   2       0.3147
   3       0.3185
   4       0.3192
   5       0.3520
   6       0.3663
   0       0.3663
F-norm of Error:    0.0000000001
N = 4000
   7       4.8767
   2       5.0345
   1       5.1001
   3       5.4122
   5       5.9741
   4       6.0042
   6       6.2390
   0       6.2397
F-norm of Error:    0.0000000005
```

```
N = 8000
   7       43.4901
   2       43.5769
   1       43.9001
   3       46.5254
   4       50.0358
   5       50.2882
   6       51.8515
   0       51.8525
F-norm of Error:    0.0000000028

real   1m1.118s
user   6m54.846s
sys       0m37.574s
```

Task 3B

```
[ff242@omega1 PS3]$ cat slurm-1193069.out
/home/fas/cpsc424/ff242/PS3
c30n01
4
rm -f serial mpi-blocking  *.o
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c mpi-non-
blocking.c
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c matmul-
block.c
mpicc -o mpi-non-blocking -g -O3 -xHost -fno-alias -std=c99 -I
/home/fas/cpsc424/ahs3/utils/timing mpi-non-blocking.o matmul-block.o
/home/fas/cpsc424/ahs3/utils/timing/timing.o
Matrix multiplication times:
 Rank      Comp. Time    Comm. Time    Total Time
-------    ----------    ----------    ----------
N = 8000
   3       65.1012        0.6742       65.7754
   1       43.9436       23.1609       67.1045
   2       53.7825       26.6072       80.3898
   0       17.4252       62.9656       80.3908
F-norm of Error:    0.0000000028

real   1m22.403s
user   4m38.676s
sys                          0m22.224s
```

```
[ff242@omega1 PS3]$ cat slurm-1193070.out
/home/fas/cpsc424/ff242/PS3
c30n[01-02]
2
rm -f serial mpi-blocking  *.o
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c mpi-non-blocking.c
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c matmul-block.c
mpicc -o mpi-non-blocking -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing mpi-non-blocking.o matmul-block.o /home/fas/cpsc424/ahs3/utils/timing/timing.o
Matrix multiplication times:
 Rank     Comp. Time    Comm. Time    Total Time
-------   ----------   ----------   ----------
N = 8000
   1       35.3305       7.9969       43.3274
   3       56.8282       0.2226       57.0508
   2       50.0478      11.1964       61.2442
   0       13.6601      47.5842       61.2442
F-norm of Error:   0.0000000028

real   1m4.423s
user   1m48.933s
sys                         0m2.074s



[ff242@omega1 PS3]$ cat slurm-1193071.out
/home/fas/cpsc424/ff242/PS3
c30n[01-04]
1
rm -f serial mpi-blocking  *.o
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c mpi-non-blocking.c
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c matmul-block.c
mpicc -o mpi-non-blocking -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing mpi-non-blocking.o matmul-block.o /home/fas/cpsc424/ahs3/utils/timing/timing.o
Matrix multiplication times:
```

```
 Rank     Comp. Time    Comm. Time    Total Time
-------    ----------    ----------    ----------
N = 8000
   1       35.4480        7.7223       43.1703
   3       56.6842        0.1935       56.8776
   2       49.5883       11.2227       60.8109
   0       13.5497       47.2613       60.8110
F-norm of Error:    0.0000000028

real   1m3.988s
user   1m2.879s
sys                             0m0.850s



[ff242@omega1 PS3]$ cat slurm-1193072.out
/home/fas/cpsc424/ff242/PS3
c30n01
8
rm -f serial mpi-blocking  *.o
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c mpi-non-
blocking.c
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c matmul-
block.c
mpicc -o mpi-non-blocking -g -O3 -xHost -fno-alias -std=c99 -I
/home/fas/cpsc424/ahs3/utils/timing mpi-non-blocking.o matmul-block.o
/home/fas/cpsc424/ahs3/utils/timing/timing.o
Matrix multiplication times:
 Rank     Comp. Time    Comm. Time    Total Time
-------    ----------    ----------    ----------
N = 8000
   7       43.1209        0.3683       43.4891
   2       21.6303       21.9607       43.5910
   1       17.3946       26.6430       44.0376
   3       32.1015       14.5316       46.6330
   4       31.5812       18.4714       50.0526
   5       39.5601       10.7574       50.3174
   6       36.2497       15.6158       51.8655
   0        5.6463       46.2202       51.8666
F-norm of Error:    0.0000000028

real   0m53.917s
user   6m1.887s
sys                             0m33.264s
```

```
[ff242@omega1 PS3]$ cat slurm-1193073.out
/home/fas/cpsc424/ff242/PS3
c30n[01-02]
4
rm -f serial mpi-blocking  *.o
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c mpi-non-blocking.c
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c matmul-block.c
mpicc -o mpi-non-blocking -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing mpi-non-blocking.o matmul-block.o /home/fas/cpsc424/ahs3/utils/timing/timing.o
Matrix multiplication times:
 Rank      Comp. Time    Comm. Time    Total Time
-------    ----------    ----------    ----------
N = 8000
   2       15.8147       17.4663       33.2810
   1       11.0187       22.2701       33.2889
   3       21.1312       12.1620       33.2932
   4       27.9032        5.4257       33.3290
   7       34.3601        0.2296       34.5897
   5       31.6402        6.1593       37.7995
   6       32.2975        6.3359       38.6334
   0        3.2352       35.3983       38.6335
F-norm of Error:    0.0000000028

real   0m41.837s
user   2m26.056s
sys                             0m4.007s



[ff242@omega1 PS3]$ cat slurm-1193074.out
/home/fas/cpsc424/ff242/PS3
c30n[01-04]
2
rm -f serial mpi-blocking  *.o
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c mpi-non-blocking.c
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c matmul-block.c
```

```
mpicc -o mpi-non-blocking -g -O3 -xHost -fno-alias -std=c99 -I
/home/fas/cpsc424/ahs3/utils/timing mpi-non-blocking.o matmul-block.o
/home/fas/cpsc424/ahs3/utils/timing/timing.o
Matrix multiplication times:
 Rank     Comp. Time    Comm. Time    Total Time
-------    ----------    ----------    ----------
N = 8000
   2       15.3636       12.4946       27.8582
   3       19.7776        8.1232       27.9007
   1        9.3208       18.7995       28.1203
   4       23.4455        4.7024       28.1480
   7       28.7278        0.2096       28.9374
   5       26.0403        6.5530       32.5933
   6       27.8907        5.4294       33.3201
   0        2.4828       30.8375       33.3202
F-norm of Error:    0.0000000028

real   0m36.511s
user   1m5.551s
sys                         0m1.588s
```

Task 4

```
[ff242@omega2 PS3]$ cat slurm-1193372.out
/home/fas/cpsc424/ff242/PS3
c31n01
4
rm -f serial mpi-blocking mpi-load-balance *.o
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c mpi-load-
balance.c
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c matmul-
block-load-balance.c
mpicc -o mpi-load-balance -g -O3 -xHost -fno-alias -std=c99 -I
/home/fas/cpsc424/ahs3/utils/timing mpi-load-balance.o matmul-block-load-balance.o
/home/fas/cpsc424/ahs3/utils/timing/timing.o
Matrix multiplication times:
 Rank     Comp. Time    Comm. Time    Total Time
-------    ----------    ----------    ----------
N = 8000
   3       35.7390       31.3485       67.0876
   1       45.4326       21.6711       67.1037
   2       42.6000       25.3603       67.9604
```

```
   0       56.8059       11.1555       67.9614
F-norm of Error:    0.0000000028

real   1m9.994s
user   4m8.086s
sys                           0m27.442s



[ff242@omega2 PS3]$ cat slurm-1193375.out
/home/fas/cpsc424/ff242/PS3
c31n[01-02]
2
rm -f serial mpi-blocking mpi-load-balance *.o
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c mpi-load-
balance.c
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c matmul-
block-load-balance.c
mpicc -o mpi-load-balance -g -O3 -xHost -fno-alias -std=c99 -I
/home/fas/cpsc424/ahs3/utils/timing mpi-load-balance.o matmul-block-load-balance.o
/home/fas/cpsc424/ahs3/utils/timing/timing.o
Matrix multiplication times:
 Rank     Comp. Time    Comm. Time    Total Time
-------    ----------    ----------    ----------
N = 8000
   3       31.1711        4.9254       36.0966
   2       35.3526        2.8196       38.1722
   1       40.7482        0.4001       41.1483
   0       49.4325        0.1286       49.5610
F-norm of Error:    0.0000000028

real   0m52.725s
user   1m35.367s
sys                           0m1.454s



[ff242@omega2 PS3]$ cat slurm-1193376.out
/home/fas/cpsc424/ff242/PS3
c31n[01-04]
1
rm -f serial mpi-blocking mpi-load-balance *.o
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c mpi-load-
balance.c
```

```
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c matmul-block-load-balance.c
mpicc -o mpi-load-balance -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing mpi-load-balance.o matmul-block-load-balance.o /home/fas/cpsc424/ahs3/utils/timing/timing.o
Matrix multiplication times:
 Rank     Comp. Time    Comm. Time    Total Time
-------    ----------    ----------    ----------
N = 8000
   3       30.8890       4.9952       35.8842
   2       35.0674       2.7993       37.8667
   1       40.4260       0.1827       40.6088
   0       49.0441       0.1364       49.1805
F-norm of Error:    0.0000000028



[ff242@omega2 PS3]$ cat slurm-1193379.out
/home/fas/cpsc424/ff242/PS3
c31n01
8
rm -f serial mpi-blocking mpi-load-balance *.o
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c mpi-load-balance.c
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c matmul-block-load-balance.c
mpicc -o mpi-load-balance -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing mpi-load-balance.o matmul-block-load-balance.o /home/fas/cpsc424/ahs3/utils/timing/timing.o
Matrix multiplication times:
 Rank     Comp. Time    Comm. Time    Total Time
-------    ----------    ----------    ----------
N = 8000
   7       23.6555       22.0014       45.6570
   5       26.4975       19.1908       45.6883
   3       30.0559       15.6549       45.7108
   1       34.1343       11.5990       45.7334
   2       33.4359       12.5005       45.9365
   6       25.5985       20.8575       46.4560
   4       29.9081       16.5929       46.5009
   0       40.2060        6.2959       46.5019
F-norm of Error:    0.0000000028

real    0m48.407s
```

```
user  5m48.687s
sys                     0m29.836s


[ff242@omega2 PS3]$ cat slurm-1193384.out
/home/fas/cpsc424/ff242/PS3
c31n[01-02]
4
rm -f serial mpi-blocking mpi-load-balance *.o
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c mpi-load-
balance.c
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c matmul-
block-load-balance.c
mpicc -o mpi-load-balance -g -O3 -xHost -fno-alias -std=c99 -I
/home/fas/cpsc424/ahs3/utils/timing mpi-load-balance.o matmul-block-load-balance.o
/home/fas/cpsc424/ahs3/utils/timing/timing.o
Matrix multiplication times:
 Rank     Comp. Time    Comm. Time    Total Time
-------    ----------    ----------    ----------
N = 8000
   2       26.3034       2.3080       28.6113
   3       24.4216       4.1924       28.6140
   1       27.9289       0.6973       28.6261
   4       21.4499       7.1979       28.6477
   5       20.2554       8.5134       28.7688
   6       19.1803       9.6132       28.7936
   7       18.2902      10.5215       28.8117
   0       30.7358       0.1914       30.9272
F-norm of Error:    0.0000000028

real   0m33.983s
user   2m5.370s
sys                     0m3.095s


[ff242@omega2 PS3]$ cat slurm-1193385.out
/home/fas/cpsc424/ff242/PS3
c31n[01-04]
2
rm -f serial mpi-blocking mpi-load-balance *.o
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c mpi-load-
balance.c
```

```
mpicc -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing -c matmul-block-load-balance.c
mpicc -o mpi-load-balance -g -O3 -xHost -fno-alias -std=c99 -I /home/fas/cpsc424/ahs3/utils/timing mpi-load-balance.o matmul-block-load-balance.o /home/fas/cpsc424/ahs3/utils/timing/timing.o
Matrix multiplication times:
 Rank      Comp. Time    Comm. Time    Total Time
-------    ----------    ----------    ----------
N = 8000
   2       20.9752       1.0726       22.0479
   3       19.4235       2.6567       22.0802
   4       18.1091       3.9944       22.1035
   5       16.9903       5.1390       22.1293
   6       15.9353       6.2204       22.1557
   7       15.0224       7.2026       22.2250
   1       22.8530       0.5827       23.4357
   0       24.3120       0.1514       24.4634
F-norm of Error:    0.0000000028

real   0m28.492s
user   0m52.390s
sys                          0m1.152s
```