

CS140 HW #2

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Parallelization of Matrix-Vector Multiplication and the Power Method

This report describes the code and result of designing and implementing an algorithm for finding the highest eigenvalue of a matrix, called the Power Method. The algorithm is designed to run in parallel on N processors to enhance the performance. The Power Method can easily be described by the following Matlab code

Listing 1: Power Method algorithm implemented in Matlab (by John R. Gilbert)

```

1  function lambda = Powermethod(A)
2      [n,n] = size(A);           % number of rows and columns in A
3      x = ones(n,1);           % creates a starting n vector of all ones
4      for i = 1:1000
5          x = x / norm2(x);      % norm2(x) is sqrt(x(1)^2 + x(2)^2 + ... + x(n)^2)
6          x = A * x;            % use your parallel matrix * vector routine here
7      end;
8      lambda = norm2(x);
9  
```

Implementation in the C language

The code was implemented in C using the MPI library for parallelization. The design of the code was based on first partitioning the matrix operation between the N processors. First a matrix where generated in the function *generatematrix()*. This function generated $\frac{N}{nprocs}$ where nprocs is the number of processors. Further in the code each processors did operations on the same amount of rows. Further, following the algorithm in Listing 1, each processor generated a row column vector of dimension N with 1's in all the entries. Each processor executed the *norm2()* function on the vector. The parallelization used that helped the performance the most where implemented in the matrix-vector multiplication, in the function *matVec()*. Each processor performed a multiplication with each of the rows and the column vector, producing a column vector of dimension $\frac{N}{nprocs}$. The column vectors from all the processors where gathered in processor 0 using the *MPI_gather* library function to form the total matrix-vector product Ax . To make the total vector accessible to the other processors, *MPI_Bcast* where used. For more details the reader should look at the c-code implementations in functions.c.

Performance and timing

The c-code where tested on matrices of dimension N where N allways where the quotient $\frac{N}{nprocs}$ always was an integer. The algorithm proved successful and returned the same values as the matlab

nprocs	Execution Time (Seconds)
1	25.67
2	12.95
4	6.47
8	3.41
16	1.97

code, both using the matrix provided in the assignment text, and on an arbitrary matrix. For the timing of the code the dimension matrix dimension $N = 2400$ where used, yielding 25.67 seconds of execution time running the code on one processor. The rest of the execution times can be found in Fig. 1 and Table 1.

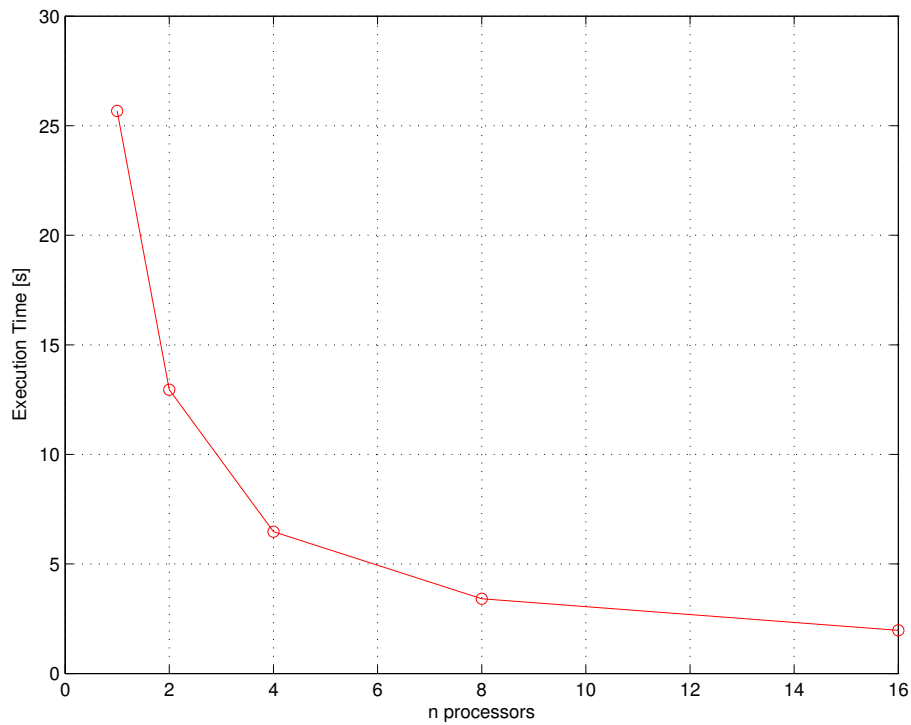


Figure 1: Plot of the execution times for the code running on 1 to 16 processors

As we can from Fig. 1 and Fig. 2 the parallelization of the code worked very well. On matrices with high dimensions the execution time where almost halved when the number of processors where doubled, for a small number of processors.

Tau Profiling Tool

The Tau Profiling tool where used to analyze the performance of the code both with a text based interface and with the graphical interface *paraprof*. The program was changed to do only 10 iterations of the main loop. At first the program ran with 4 processors, and than with 16 processors. The results of the generated text profile reports, *pprof*, are in the appendix. From the profile reports it shows that all the processors, except from node 0, have very similar characteristics. They all

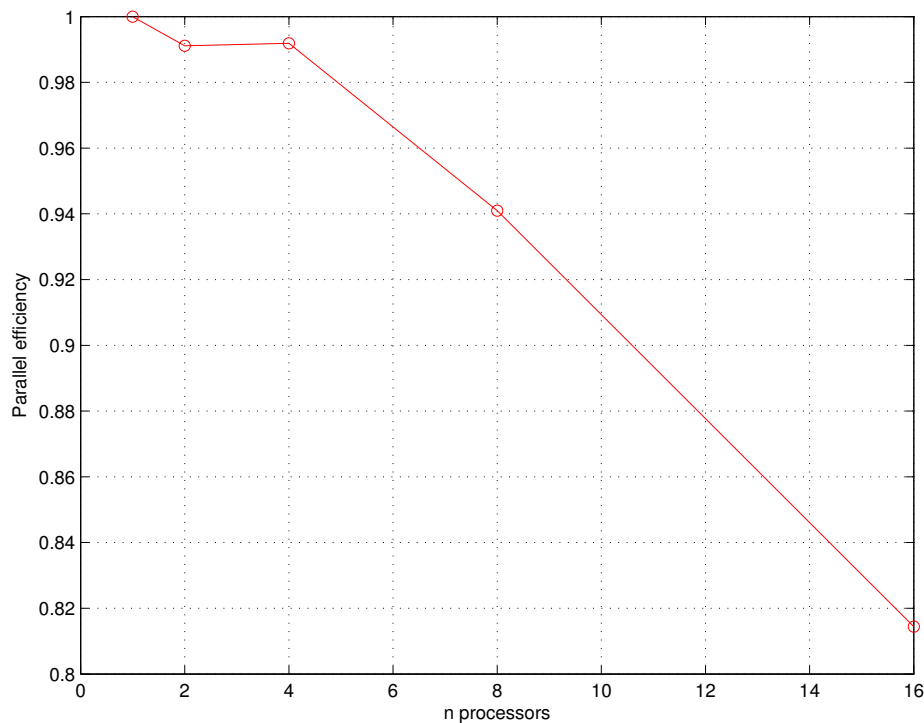


Figure 2: Plot of the parallel efficiency for the different numbers of processors

use most of their time on the initialisation, *MPI_init*. Beside this it is clear that the *matVec()* function, who is called in *powerMethod()*, uses a considerable amount of the execution time. Node 0 stands out from the other nodes with the amount of time used on the calls *MPI_Gather()* and *MPI_Bcast*. Node 0, who has to gather data from all the other nodes, uses a lot of time on *MPI_Gather()*, while all the other nodes uses almost no time on this call. This effect is more reviling with many processors, and is probably one of the main causes why the parallel efficiency goes down with more processors. The call to *MPI_Bcast* has the opposite effect. Node 0, who is broadcasting data, uses less time on this call than all the other nodes, which are on the receiving side.

Conclusion

The results we got from this assignment was pretty much as expected, but we thought the parallel efficiency was surprisingly good. It was very satisfying seeing the difference between the execution time of the power method with 1 processor versus 16 processors. With many processors, the synchronisation with *MPI_Gather()* and *MPI_Bcast* takes more time than the actual multiplication done in *matVec()*, and leads to less parallel efficiency. This is no surprise since moving data takes time.

From the figures in *paraProf* it was very quick and easy to get a first overview over the execution time for the different MPI functions. It was also easy to compare the running times between the different processors. From the text profile report, *pProf*, we got more detailed information.

■ MPI_Bcast()
 ■ MPI_Comm_rank()
 ■ MPI_Comm_size()
 ■ MPI_Finalize()
 ■ MPI_Gather()
 ■ MPI_Init()
 ■ double norm2(double *, int) C [{functions.c} {15,1}–{22,1}]
 ■ double powerMethod(double *, double *, int, int) C [{functions.c} {81,1}–{101,1}]
 ■ int main(int, char **) C [{powermethod.c} {13,1}–{76,1}]
 ■ void generateMatrix(double *, int) C [{functions.c} {51,1}–{68,1}]
 ■ void generateVec(double *, int) C [{functions.c} {72,1}–{78,1}]
 ■ void matVec(double *, double *, double *, int) C [{functions.c} {25,1}–{48,1}]

(a)

Metric: TIME
Value: Exclusive



(b)

Figure 3: The figure shows the execution time for the different MPI functions running on the different processors

Appendix

Pprof output for 4 processors

Reading Profile files in profile.*

NODE 0;CONTEXT 0;THREAD 0:

%Time	Exclusive msec	Inclusive total msec	#Call	#Subrs	Inclusive Name usec/call
100.0	2	1,115	1	7	1115667 int main(int, char **) C
92.1	1,027	1,027	1	0	1027312 MPI_Init()
6.4	0.249	71	1	23	71167 double powerMethod(double *, double *, int, int) C
6.4	68	70	10	40	7088 void matVec(double *, double *, double *, int) C
1.1	12	12	1	2	12621 void generatematrix(double *, int) C
0.2	2	2	1	0	2505 MPI_Finalize()
0.1	1	1	10	0	145 MPI_Gather()
0.1	0.61	0.61	10	0	61 MPI_Bcast()
0.0	0.041	0.041	11	0	4 double norm2(double *, int) C
0.0	0.009	0.009	13	0	1 MPI_Comm_size()
0.0	0.004	0.004	13	0	0 MPI_Comm_rank()
0.0	0.004	0.004	1	0	4 void generatevec(double *, int) C

USER EVENTS Profile :NODE 0, CONTEXT 0, THREAD 0

NumSamples	MaxValue	MinValue	MeanValue	Std. Dev.	Event Name
10	2E+04	2E+04	2E+04	0	Message size for broadcast
10	5000	5000	5000	0	Message size for gather

NODE 1;CONTEXT 0;THREAD 0:

%Time	Exclusive msec	Inclusive total msec	#Call	#Subrs	Inclusive Name usec/call
100.0	1	1,115	1	7	1115490 int main(int, char **) C
92.1	1,027	1,027	1	0	1027362 MPI_Init()
6.3	0.25	70	1	23	70733 double powerMethod(double *, double *, int, int) C
6.3	68	70	10	40	7045 void matVec(double *, double *, double *, int) C
1.2	13	13	1	2	13063 void generatematrix(double *, int) C
0.2	2	2	1	0	2332 MPI_Finalize()
0.1	1	1	10	0	128 MPI_Bcast()
0.0	0.408	0.408	10	0	41 MPI_Gather()
0.0	0.036	0.036	11	0	3 double norm2(double *, int) C
0.0	0.008	0.008	13	0	1 MPI_Comm_size()
0.0	0.004	0.004	1	0	4 void generatevec(double *, int) C
0.0	0	0	13	0	0 MPI_Comm_rank()

USER EVENTS Profile :NODE 1, CONTEXT 0, THREAD 0

NumSamples	MaxValue	MinValue	MeanValue	Std. Dev.	Event Name
10	2E+04	2E+04	2E+04	0	Message size for broadcast
0	0	0	0	0	Message size for gather

NODE 2;CONTEXT 0;THREAD 0:

%Time	Exclusive msec	Inclusive total msec	#Call	#Subrs	Inclusive Name usec/call
100.0	1	1,115	1	7	1115586 int main(int, char **) C
92.1	1,027	1,027	1	0	1027346 MPI_Init()
6.3	0.25	70	1	23	70504 double powerMethod(double *, double *, int, int) C
6.3	69	70	10	40	7022 void matVec(double *, double *, double *, int) C
1.2	13	13	1	2	13232 void generatematrix(double *, int) C
0.2	2	2	1	0	2688 MPI_Finalize()
0.1	0.868	0.868	10	0	87 MPI_Bcast()
0.0	0.309	0.309	10	0	31 MPI_Gather()
0.0	0.037	0.037	11	0	3 double norm2(double *, int) C
0.0	0.007	0.007	13	0	1 MPI_Comm_size()
0.0	0.004	0.004	1	0	4 void generatevec(double *, int) C
0.0	0.001	0.001	13	0	0 MPI_Comm_rank()

USER EVENTS Profile :NODE 2, CONTEXT 0, THREAD 0

NumSamples	MaxValue	MinValue	MeanValue	Std. Dev.	Event Name
10	2E+04	2E+04	2E+04	0	Message size for broadcast
0	0	0	0	0	Message size for gather

NODE 3;CONTEXT 0;THREAD 0:

%Time	Exclusive msec	Inclusive total msec	#Call	#Subrs	Inclusive Name usec/call
100.0	1	1,115	1	7	1115479 int main(int, char **) C
92.1	1,027	1,027	1	0	1027346 MPI_Init()
6.3	0.245	70	1	23	70319 double powerMethod(double *, double *, int, int) C
6.3	69	70	10	40	7003 void matVec(double *, double *, double *, int) C
1.2	13	13	1	2	13481 void generatematrix(double *, int) C
0.2	2	2	1	0	2545 MPI_Finalize()
0.1	0.648	0.648	10	0	65 MPI_Bcast()
0.0	0.337	0.337	10	0	34 MPI_Gather()
0.0	0.041	0.041	11	0	4 double norm2(double *, int) C
0.0	0.008	0.008	13	0	1 MPI_Comm_size()
0.0	0.005	0.005	1	0	5 void generatevec(double *, int) C
0.0	0.003	0.003	13	0	0 MPI_Comm_rank()

USER EVENTS Profile :NODE 3, CONTEXT 0, THREAD 0

NumSamples	MaxValue	MinValue	MeanValue	Std. Dev.	Event Name
10	2E+04	2E+04	2E+04	0	Message size for broadcast
0	0	0	0	0	Message size for gather

FUNCTION SUMMARY (total):

%Time	Exclusive msec	Inclusive total msec	#Call	#Subrs	Inclusive Name usec/call
100.0	7	4,462	4	28	1115556 int main(int, char **) C
92.1	4,109	4,109	4	0	1027342 MPI_Init()
6.3	0.994	282	4	92	70681 double powerMethod(double *, double *, int, int) C
6.3	275	281	40	160	7039 void matVec(double *, double *, double *, int) C
1.2	52	52	4	8	13099 void generatematrix(double *, int) C
0.2	10	10	4	0	2518 MPI_Finalize()
0.1	3	3	40	0	85 MPI_Bcast()
0.1	2	2	40	0	63 MPI_Gather()
0.0	0.155	0.155	44	0	4 double norm2(double *, int) C
0.0	0.032	0.032	52	0	1 MPI_Comm_size()
0.0	0.017	0.017	4	0	4 void generatevec(double *, int) C
0.0	0.008	0.008	52	0	0 MPI_Comm_rank()

FUNCTION SUMMARY (mean):

%Time	Exclusive msec	Inclusive total msec	#Call	#Subrs	Inclusive Name usec/call
100.0	1	1,115	1	7	1115556 int main(int, char **) C
92.1	1,027	1,027	1	0	1027342 MPI_Init()
6.3	0.248	70	1	23	70681 double powerMethod(double *, double *, int, int) C
6.3	68	70	10	40	7039 void matVec(double *, double *, double *, int) C
1.2	13	13	1	2	13099 void generatematrix(double *, int) C
0.2	2	2	1	0	2518 MPI_Finalize()
0.1	0.853	0.853	10	0	85 MPI_Bcast()
0.1	0.626	0.626	10	0	63 MPI_Gather()
0.0	0.0387	0.0387	11	0	4 double norm2(double *, int) C
0.0	0.008	0.008	13	0	1 MPI_Comm_size()
0.0	0.00425	0.00425	1	0	4 void generatevec(double *, int) C
0.0	0.002	0.002	13	0	0 MPI_Comm_rank()

Pprof output for 16 processors

Reading Profile files in profile.*

NODE 0;CONTEXT 0;THREAD 0:

%Time	Exclusive msec	Inclusive total msec	#Call	#Subrs	Inclusive Name usec/call
100.0	1	1,109	1	7	1109381 int main(int, char **) C
96.7	1,073	1,073	1	0	1073154 MPI_Init()
2.1	0.257	23	1	23	23181 double powerMethod(double *, double *, int, int) C
2.1	17	22	10	40	2288 void matVec(double *, double *, double *, int) C
0.7	8	8	1	0	8135 MPI_Finalize()
0.3	3	3	1	2	3441 void generatematrix(double *, int) C
0.2	2	2	10	0	261 MPI_Gather()
0.2	2	2	10	0	243 MPI_Bcast()
0.0	0.039	0.039	11	0	4 double norm2(double *, int) C
0.0	0.012	0.012	1	0	12 void generatevec(double *, int) C
0.0	0.005	0.005	13	0	0 MPI_Comm_size()
0.0	0.003	0.003	13	0	0 MPI_Comm_rank()

USER EVENTS Profile :NODE 0, CONTEXT 0, THREAD 0

NumSamples	MaxValue	MinValue	MeanValue	Std. Dev.	Event Name
10	2E+04	2E+04	2E+04	0	Message size for broadcast
10	1248	1248	1248	0	Message size for gather

NODE 1;CONTEXT 0;THREAD 0:

%Time	Exclusive msec	Inclusive total msec	#Call	#Subrs	Inclusive Name usec/call
100.0	1	1,104	1	7	1104604 int main(int, char **) C
97.1	1,072	1,072	1	0	1072019 MPI_Init()
2.1	0.256	23	1	23	23029 double powerMethod(double *, double *, int, int) C
2.1	17	22	10	40	2273 void matVec(double *, double *, double *, int) C
0.5	5	5	10	0	514 MPI_Bcast()
0.4	4	4	1	0	4548 MPI_Finalize()
0.3	3	3	1	2	3424 void generatematrix(double *, int) C
0.0	0.161	0.161	10	0	16 MPI_Gather()
0.0	0.039	0.039	11	0	4 double norm2(double *, int) C
0.0	0.015	0.015	1	0	15 void generatevec(double *, int) C
0.0	0.008	0.008	13	0	1 MPI_Comm_size()
0.0	0.003	0.003	13	0	0 MPI_Comm_rank()

USER EVENTS Profile :NODE 1, CONTEXT 0, THREAD 0

NumSamples	MaxValue	MinValue	MeanValue	Std. Dev.	Event Name
10	2E+04	2E+04	2E+04	0	Message size for broadcast
0	0	0	0	0	Message size for gather

NODE 2;CONTEXT 0;THREAD 0:

%Time	Exclusive msec	Inclusive total msec	#Call	#Subrs	Inclusive Name usec/call
100.0	1	1,103	1	7	1103953 int main(int, char **) C
97.0	1,071	1,071	1	0	1071366 MPI_Init()
2.1	0.257	23	1	23	23030 double powerMethod(double *, double *, int, int) C
2.1	17	22	10	40	2273 void matVec(double *, double *, double *, int) C
0.5	5	5	10	0	511 MPI_Bcast()
0.4	4	4	1	0	4669 MPI_Finalize()
0.3	3	3	1	2	3428 void generatematrix(double *, int) C
0.0	0.146	0.146	10	0	15 MPI_Gather()
0.0	0.04	0.04	11	0	4 double norm2(double *, int) C
0.0	0.016	0.016	1	0	16 void generatevec(double *, int) C
0.0	0.012	0.012	13	0	1 MPI_Comm_rank()
0.0	0.006	0.006	13	0	0 MPI_Comm_size()

USER EVENTS Profile :NODE 2, CONTEXT 0, THREAD 0

NumSamples	MaxValue	MinValue	MeanValue	Std. Dev.	Event Name
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10	2E+04	2E+04	2E+04	0	Message size for broadcast
0	0	0	0	0	Message size for gather

NODE 3;CONTEXT 0;THREAD 0:

%Time	Exclusive msec	Inclusive total msec	#Call	#Subrs	Inclusive Name usec/call
100.0	1	1,103	1	7	1103833 int main(int, char **) C
97.1	1,071	1,071	1	0	1071370 MPI_Init()
2.1	0.259	23	1	23	23032 double powerMethod(double *, double *, int, int) C
2.1	17	22	10	40	2273 void matVec(double *, double *, double *, int) C
0.5	5	5	10	0	504 MPI_Bcast()
0.4	4	4	1	0	4730 MPI_Finalize()
0.3	3	3	1	2	3414 void generatematrix(double *, int) C
0.0	0.118	0.118	10	0	12 MPI_Gather()
0.0	0.038	0.038	11	0	3 double norm2(double *, int) C
0.0	0.014	0.014	1	0	14 void generatevec(double *, int) C
0.0	0.006	0.006	13	0	0 MPI_Comm_size()
0.0	0.002	0.002	13	0	0 MPI_Comm_rank()

USER EVENTS Profile :NODE 3, CONTEXT 0, THREAD 0

NumSamples	MaxValue	MinValue	MeanValue	Std. Dev.	Event Name
10	2E+04	2E+04	2E+04	0	Message size for broadcast
0	0	0	0	0	Message size for gather

NODE 4;CONTEXT 0;THREAD 0:

%Time	Exclusive msec	Inclusive total msec	#Call	#Subrs	Inclusive Name usec/call
100.0	1	1,103	1	7	1103954 int main(int, char **) C
97.0	1,071	1,071	1	0	1071374 MPI_Init()
2.1	0.247	23	1	23	23014 double powerMethod(double *, double *, int, int) C
2.1	17	22	10	40	2273 void matVec(double *, double *, double *, int) C
0.5	5	5	10	0	516 MPI_Bcast()
0.4	4	4	1	0	4605 MPI_Finalize()
0.3	3	3	1	2	3467 void generatematrix(double *, int) C
0.0	0.11	0.11	10	0	11 MPI_Gather()
0.0	0.038	0.038	11	0	3 double norm2(double *, int) C
0.0	0.012	0.012	1	0	12 void generatevec(double *, int) C
0.0	0.006	0.006	13	0	0 MPI_Comm_size()
0.0	0.002	0.002	13	0	0 MPI_Comm_rank()

USER EVENTS Profile :NODE 4, CONTEXT 0, THREAD 0

NumSamples	MaxValue	MinValue	MeanValue	Std. Dev.	Event Name
10	2E+04	2E+04	2E+04	0	Message size for broadcast
0	0	0	0	0	Message size for gather

NODE 5;CONTEXT 0;THREAD 0:

%Time	Exclusive msec	Inclusive total msec	#Call	#Subrs	Inclusive Name usec/call
100.0	1	1,103	1	7	1103057 int main(int, char **) C
97.0	1,070	1,070	1	0	1070183 MPI_Init()
2.1	0.253	22	1	23	22907 double powerMethod(double *, double *, int, int) C
2.1	17	22	10	40	2262 void matVec(double *, double *, double *, int) C
0.5	5	5	1	0	5036 MPI_Finalize()
0.4	4	4	10	0	492 MPI_Bcast()
0.3	3	3	1	2	3473 void generatematrix(double *, int) C
0.0	0.11	0.11	10	0	11 MPI_Gather()
0.0	0.038	0.038	11	0	3 double norm2(double *, int) C
0.0	0.014	0.014	1	0	14 void generatevec(double *, int) C
0.0	0.007	0.007	13	0	1 MPI_Comm_size()
0.0	0.005	0.005	13	0	0 MPI_Comm_rank()

USER EVENTS Profile :NODE 5, CONTEXT 0, THREAD 0

NumSamples	MaxValue	MinValue	MeanValue	Std. Dev.	Event Name
10	2E+04	2E+04	2E+04	0	Message size for broadcast
0	0	0	0	0	Message size for gather

NODE 6;CONTEXT 0;THREAD 0:

%Time	Exclusive msec	Inclusive total msec	#Call	#Subrs	Inclusive usec/call	Name
100.0	1	1,101	1	7	1101804	int main(int, char **) C
97.1	1,069	1,069	1	0	1069359	MPI_Init()
2.1	0.247	22	1	23	22967	double powerMethod(double *, double *, int, int) C
2.1	17	22	10	40	2268	void matVec(double *, double *, double *, int) C
0.5	4	4	10	0	500	MPI_Bcast()
0.4	4	4	1	0	4449	MPI_Finalize()
0.3	3	3	1	2	3501	void generatematrix(double *, int) C
0.0	0.117	0.117	10	0	12	MPI_Gather()
0.0	0.04	0.04	11	0	4	double norm2(double *, int) C
0.0	0.02	0.02	1	0	20	void generatevec(double *, int) C
0.0	0.006	0.006	13	0	0	MPI_Comm_size()
0.0	0.005	0.005	13	0	0	MPI_Comm_rank()

USER EVENTS Profile :NODE 6, CONTEXT 0, THREAD 0

NumSamples	MaxValue	MinValue	MeanValue	Std. Dev.	Event Name
10	2E+04	2E+04	2E+04	0	Message size for broadcast
0	0	0	0	0	Message size for gather

NODE 7;CONTEXT 0;THREAD 0:

%Time	Exclusive msec	Inclusive total msec	#Call	#Subrs	Inclusive usec/call	Name
100.0	1	1,108	1	7	1108454	int main(int, char **) C
96.5	1,069	1,069	1	0	1069599	MPI_Init()
2.1	0.25	23	1	23	23130	double powerMethod(double *, double *, int, int) C
2.1	17	22	10	40	2284	void matVec(double *, double *, double *, int) C
1.0	10	10	1	0	10871	MPI_Finalize()
0.5	5	5	10	0	532	MPI_Bcast()
0.3	3	3	1	2	3505	void generatematrix(double *, int) C
0.0	0.086	0.086	10	0	9	MPI_Gather()
0.0	0.035	0.035	11	0	3	double norm2(double *, int) C
0.0	0.014	0.014	1	0	14	void generatevec(double *, int) C
0.0	0.005	0.005	13	0	0	MPI_Comm_size()
0.0	0.003	0.003	13	0	0	MPI_Comm_rank()

USER EVENTS Profile :NODE 7, CONTEXT 0, THREAD 0

NumSamples	MaxValue	MinValue	MeanValue	Std. Dev.	Event Name
10	2E+04	2E+04	2E+04	0	Message size for broadcast
0	0	0	0	0	Message size for gather

NODE 8;CONTEXT 0;THREAD 0:

%Time	Exclusive msec	Inclusive total msec	#Call	#Subrs	Inclusive usec/call	Name
100.0	1	1,090	1	7	1090861	int main(int, char **) C
97.0	1,057	1,057	1	0	1057941	MPI_Init()
2.1	0.267	22	1	23	22966	double powerMethod(double *, double *, int, int) C
2.1	17	22	10	40	2266	void matVec(double *, double *, double *, int) C
0.5	4	4	1	0	4989	MPI_Finalize()
0.4	4	4	10	0	459	MPI_Bcast()
0.3	3	3	1	2	3524	void generatematrix(double *, int) C
0.0	0.206	0.206	10	0	21	MPI_Gather()
0.0	0.037	0.037	11	0	3	double norm2(double *, int) C
0.0	0.014	0.014	1	0	14	void generatevec(double *, int) C
0.0	0.005	0.005	13	0	0	MPI_Comm_size()
0.0	0.003	0.003	13	0	0	MPI_Comm_rank()

USER EVENTS Profile :NODE 8, CONTEXT 0, THREAD 0

NumSamples	MaxValue	MinValue	MeanValue	Std. Dev.	Event Name
10	2E+04	2E+04	2E+04	0	Message size for broadcast
0	0	0	0	0	Message size for gather

NODE 9;CONTEXT 0;THREAD 0:

%Time	Exclusive msec	Inclusive total msec	#Call	#Subrs	Inclusive Name usec/call
100.0	1	1,090	1	7	1090874 int main(int, char **) C
97.0	1,057	1,057	1	0	1057936 MPI_Init()
2.1	0.249	22	1	23	22947 double powerMethod(double *, double *, int, int) C
2.1	17	22	10	40	2266 void matVec(double *, double *, double *, int) C
0.5	4	4	1	0	4969 MPI_Finalize()
0.5	4	4	10	0	491 MPI_Bcast()
0.3	3	3	1	2	3513 void generatematrix(double *, int) C
0.0	0.322	0.322	10	0	32 MPI_Gather()
0.0	0.037	0.037	11	0	3 double norm2(double *, int) C
0.0	0.013	0.013	1	0	13 void generatevec(double *, int) C
0.0	0.004	0.004	13	0	0 MPI_Comm_rank()
0.0	0.003	0.003	13	0	0 MPI_Comm_size()

USER EVENTS Profile :NODE 9, CONTEXT 0, THREAD 0

NumSamples	MaxValue	MinValue	MeanValue	Std. Dev.	Event Name
10	2E+04	2E+04	2E+04	0	Message size for broadcast
0	0	0	0	0	Message size for gather

NODE 10;CONTEXT 0;THREAD 0:

%Time	Exclusive msec	Inclusive total msec	#Call	#Subrs	Inclusive Name usec/call
100.0	1	1,090	1	7	1090315 int main(int, char **) C
97.0	1,057	1,057	1	0	1057399 MPI_Init()
2.1	0.247	22	1	23	22901 double powerMethod(double *, double *, int, int) C
2.1	17	22	10	40	2261 void matVec(double *, double *, double *, int) C
0.5	5	5	1	0	5052 MPI_Finalize()
0.5	4	4	10	0	491 MPI_Bcast()
0.3	3	3	1	2	3573 void generatematrix(double *, int) C
0.0	0.255	0.255	10	0	26 MPI_Gather()
0.0	0.039	0.039	11	0	4 double norm2(double *, int) C
0.0	0.009	0.009	1	0	9 void generatevec(double *, int) C
0.0	0.005	0.005	13	0	0 MPI_Comm_size()
0.0	0.004	0.004	13	0	0 MPI_Comm_rank()

USER EVENTS Profile :NODE 10, CONTEXT 0, THREAD 0

NumSamples	MaxValue	MinValue	MeanValue	Std. Dev.	Event Name
10	2E+04	2E+04	2E+04	0	Message size for broadcast
0	0	0	0	0	Message size for gather

NODE 11;CONTEXT 0;THREAD 0:

%Time	Exclusive msec	Inclusive total msec	#Call	#Subrs	Inclusive Name usec/call
100.0	1	1,096	1	7	1096643 int main(int, char **) C
96.4	1,057	1,057	1	0	1057706 MPI_Init()
2.1	0.255	22	1	23	22931 double powerMethod(double *, double *, int, int) C
2.1	17	22	10	40	2264 void matVec(double *, double *, double *, int) C
1.0	11	11	1	0	11130 MPI_Finalize()
0.4	4	4	10	0	482 MPI_Bcast()
0.3	3	3	1	2	3528 void generatematrix(double *, int) C
0.0	0.244	0.244	10	0	24 MPI_Gather()
0.0	0.037	0.037	11	0	3 double norm2(double *, int) C
0.0	0.012	0.012	1	0	12 void generatevec(double *, int) C
0.0	0.004	0.004	13	0	0 MPI_Comm_size()
0.0	0.001	0.001	13	0	0 MPI_Comm_rank()

USER EVENTS Profile :NODE 11, CONTEXT 0, THREAD 0

NumSamples	MaxValue	MinValue	MeanValue	Std. Dev.	Event Name
10	2E+04	2E+04	2E+04	0	Message size for broadcast
0	0	0	0	0	Message size for gather

NODE 12;CONTEXT 0;THREAD 0:

%Time	Exclusive msec	Inclusive total msec	#Call	#Subrs	Inclusive Name usec/call
100.0	1	1,090	1	7	1090713 int main(int, char **) C
97.0	1,057	1,057	1	0	1057745 MPI_Init()
2.1	0.251	22	1	23	22882 double powerMethod(double *, double *, int, int) C
2.1	17	22	10	40	2259 void matVec(double *, double *, double *, int) C
0.5	4	4	1	0	4909 MPI_Finalize()
0.4	4	4	10	0	481 MPI_Bcast()
0.3	3	3	1	2	3567 void generatematrix(double *, int) C
0.0	0.236	0.236	10	0	24 MPI_Gather()
0.0	0.036	0.036	11	0	3 double norm2(double *, int) C
0.0	0.014	0.014	1	0	14 void generatevec(double *, int) C
0.0	0.006	0.006	13	0	0 MPI_Comm_size()
0.0	0.003	0.003	13	0	0 MPI_Comm_rank()

USER EVENTS Profile :NODE 12, CONTEXT 0, THREAD 0

NumSamples	MaxValue	MinValue	MeanValue	Std. Dev.	Event Name
10	2E+04	2E+04	2E+04	0	Message size for broadcast
0	0	0	0	0	Message size for gather

NODE 13;CONTEXT 0;THREAD 0:

%Time	Exclusive msec	Inclusive total msec	#Call	#Subrs	Inclusive Name usec/call
100.0	1	1,089	1	7	1089178 int main(int, char **) C
97.0	1,056	1,056	1	0	1056270 MPI_Init()
2.1	0.247	22	1	23	22860 double powerMethod(double *, double *, int, int) C
2.1	17	22	10	40	2257 void matVec(double *, double *, double *, int) C
0.5	5	5	1	0	5299 MPI_Finalize()
0.4	4	4	10	0	481 MPI_Bcast()
0.3	3	3	1	2	3613 void generatematrix(double *, int) C
0.0	0.181	0.181	10	0	18 MPI_Gather()
0.0	0.04	0.04	11	0	4 double norm2(double *, int) C
0.0	0.012	0.012	1	0	12 void generatevec(double *, int) C
0.0	0.007	0.007	13	0	1 MPI_Comm_rank()
0.0	0.003	0.003	13	0	0 MPI_Comm_size()

USER EVENTS Profile :NODE 13, CONTEXT 0, THREAD 0

NumSamples	MaxValue	MinValue	MeanValue	Std. Dev.	Event Name
10	2E+04	2E+04	2E+04	0	Message size for broadcast
0	0	0	0	0	Message size for gather

NODE 14;CONTEXT 0;THREAD 0:

%Time	Exclusive msec	Inclusive total msec	#Call	#Subrs	Inclusive Name usec/call
100.0	1	1,089	1	7	1089593 int main(int, char **) C
97.1	1,058	1,058	1	0	1058327 MPI_Init()
1.9	0.253	21	1	23	21060 double powerMethod(double *, double *, int, int) C
1.9	17	20	10	40	2077 void matVec(double *, double *, double *, int) C
0.5	4	4	1	0	4975 MPI_Finalize()
0.3	3	3	1	2	3768 void generatematrix(double *, int) C
0.3	3	3	10	0	327 MPI_Bcast()
0.0	0.212	0.212	10	0	21 MPI_Gather()
0.0	0.036	0.036	11	0	3 double norm2(double *, int) C
0.0	0.017	0.017	1	0	17 void generatevec(double *, int) C
0.0	0.004	0.004	13	0	0 MPI_Comm_size()
0.0	0.003	0.003	13	0	0 MPI_Comm_rank()

USER EVENTS Profile :NODE 14, CONTEXT 0, THREAD 0

NumSamples	MaxValue	MinValue	MeanValue	Std. Dev.	Event Name
10	2E+04	2E+04	2E+04	0	Message size for broadcast
0	0	0	0	0	Message size for gather

NODE 15;CONTEXT 0;THREAD 0:

%Time	Exclusive msec	Inclusive total msec	#Call	#Subrs	Inclusive Name usec/call
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100.0	1	1,097	1	7	1097394 int main(int, char **) C
96.4	1,057	1,057	1	0	1057727 MPI_Init()
2.1	0.249	22	1	23	22822 double powerMethod(double *, double *, int, int) C
2.1	17	22	10	40	2253 void matVec(double *, double *, double *, int) C
1.1	11	11	1	0	11736 MPI_Finalize()
0.4	4	4	10	0	493 MPI_Bcast()
0.3	3	3	1	2	3662 void generatematrix(double *, int) C
0.0	0.181	0.181	10	0	18 MPI_Gather()
0.0	0.037	0.037	11	0	3 double norm2(double *, int) C
0.0	0.019	0.019	1	0	19 void generatevec(double *, int) C
0.0	0.006	0.006	13	0	0 MPI_Comm_rank()
0.0	0.005	0.005	13	0	0 MPI_Comm_size()

USER EVENTS Profile :NODE 15, CONTEXT 0, THREAD 0

NumSamples	MaxValue	MinValue	MeanValue	Std. Dev.	Event Name
10	2E+04	2E+04	2E+04	0	Message size for broadcast
0	0	0	0	0	Message size for gather

FUNCTION SUMMARY (total):

%Time	Exclusive msec	Inclusive total msec	#Call	#Subrs	Inclusive Name usec/call
100.0	22	17,574	16	112	1098413 int main(int, char **) C
96.9	17,029	17,029	16	0	1064342 MPI_Init()
2.1	4	365	16	368	22854 double powerMethod(double *, double *, int, int) C
2.1	280	360	160	640	2256 void matVec(double *, double *, double *, int) C
0.6	100	100	16	0	6256 MPI_Finalize()
0.4	75	75	160	0	470 MPI_Bcast()
0.3	56	56	16	32	3525 void generatematrix(double *, int) C
0.0	5	5	160	0	33 MPI_Gather()
0.0	0.606	0.606	176	0	3 double norm2(double *, int) C
0.0	0.227	0.227	16	0	14 void generatevec(double *, int) C
0.0	0.084	0.084	208	0	0 MPI_Comm_size()
0.0	0.066	0.066	208	0	0 MPI_Comm_rank()

FUNCTION SUMMARY (mean):

%Time	Exclusive msec	Inclusive total msec	#Call	#Subrs	Inclusive Name usec/call
100.0	1	1,098	1	7	1098413 int main(int, char **) C
96.9	1,064	1,064	1	0	1064342 MPI_Init()
2.1	0.253	22	1	23	22854 double powerMethod(double *, double *, int, int) C
2.1	17	22	10	40	2256 void matVec(double *, double *, double *, int) C
0.6	6	6	1	0	6256 MPI_Finalize()
0.4	4	4	10	0	470 MPI_Bcast()
0.3	3	3	1	2	3525 void generatematrix(double *, int) C
0.0	0.331	0.331	10	0	33 MPI_Gather()
0.0	0.0379	0.0379	11	0	3 double norm2(double *, int) C
0.0	0.0142	0.0142	1	0	14 void generatevec(double *, int) C
0.0	0.00525	0.00525	13	0	0 MPI_Comm_size()
0.0	0.00413	0.00413	13	0	0 MPI_Comm_rank()