Paleti Krishnasai
CED18I039

HPC LAB - Matrix Multiplication MPI

Name: Paleti Krishnasai
Roll No: CED18I039
Programming Environment: MPI
Problem: Matrix Multiplication
Date: 21-10-2021

Hardware Configuration:
PU NAME: Intel(R) Core(TM) i5-8300H CPU @ 2.30GHz
Number of Sockets: 1
Cores per Socket: 4
Threads per core: 2
L1d cache: 128 KiB
L1i cache: 128 KiB
L2 cache: 1 MiB
L3 cache: 8 MiB

```
paleti@paleti-Lenovo-ideapad-330-15ICH:~$ likwid-topology
--------------------------------------------------------------------------------
CPU name:       Intel(R) Core(TM) i5-8300H CPU @ 2.30GHz
CPU type:       Intel Coffeelake processor
CPU stepping:   10
********************************************************************************
Hardware Thread Topology
********************************************************************************
Sockets:                1
Cores per socket:       4
Threads per core:       2
--------------------------------------------------------------------------------
HWThread        Thread          Core            Socket          Available
0               0               0               0               *
1               0               1               0               *
2               0               2               0               *
3               0               3               0               *
4               1               0               0               *
5               1               1               0               *
6               1               2               0               *
7               1               3               0               *
--------------------------------------------------------------------------------
Socket 0:               ( 0 4 1 5 2 6 3 7 )
--------------------------------------------------------------------------------
********************************************************************************
Cache Topology
********************************************************************************
Level:                  1
Size:                   32 kB
Cache groups:           ( 0 4 ) ( 1 5 ) ( 2 6 ) ( 3 7 )
--------------------------------------------------------------------------------
Level:                  2
Size:                   256 kB
Cache groups:           ( 0 4 ) ( 1 5 ) ( 2 6 ) ( 3 7 )
--------------------------------------------------------------------------------
Level:                  3
Size:                   8 MB
Cache groups:           ( 0 4 1 5 2 6 3 7 )
--------------------------------------------------------------------------------
********************************************************************************
NUMA Topology
********************************************************************************
NUMA domains:           1
--------------------------------------------------------------------------------
Domain:                 0
Processors:             ( 0 1 2 3 4 5 6 7 )
Distances:              10
Free memory:            3546.2 MB
Total memory:           7831.84 MB
--------------------------------------------------------------------------------
```

```
**************************************************
Graphical Topology
**************************************************
Socket 0:
+-------------------------------------------------+
| +---------+ +---------+ +---------+ +---------+ |
| |  0 4    | |  1 5    | |  2 6    | |  3 7    | |
| +---------+ +---------+ +---------+ +---------+ |
| +---------+ +---------+ +---------+ +---------+ |
| |  32 kB  | |  32 kB  | |  32 kB  | |  32 kB  | |
| +---------+ +---------+ +---------+ +---------+ |
| +---------+ +---------+ +---------+ +---------+ |
| | 256 kB  | | 256 kB  | | 256 kB  | | 256 kB  | |
| +---------+ +---------+ +---------+ +---------+ |
| +-------------------------------------------+ |
| |                   8 MB                    | |
| +-------------------------------------------+ |
+-------------------------------------------------+
```

No of nodes: 12 (4 for each as written in machine file).

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Serial Code:

```
#include "mpi.h"

#include <stdio.h>

#include <stdlib.h>



#define ROWS_A 500                 /* number of rows in matrix A */

#define COLUMNS_A 300                /* number of columns in matrix A */

#define COLUMNS_B 150                 /* number of columns in matrix B */

#define MASTER 0               /* taskid of first task */

#define FROM_MASTER 1          /* setting a message type */

#define FROM_WORKER 2          /* setting a message type */

int main(int argc, char *argv[])

{

   double start,end;
MPI_Init(&argc,&argv);

    start=MPI_Wtime();

    int i,j,k;

    long double   a[ROWS_A][COLUMNS_A],           /* matrix A to be
multiplied */
   b[COLUMNS_A][COLUMNS_B],           /* matrix B to be multiplied */
   c[ROWS_A][COLUMNS_B];

   //printf("Initializing arrays...\n");

    for (i=0; i<ROWS_A; i++)
```

```
        for (j=0; j<COLUMNS_A; j++)

           a[i][j]= i+j;

     for (i=0; i<COLUMNS_A; i++)

        for (j=0; j<COLUMNS_B; j++)

           b[i][j]= i*j;

   for (k=0; k<COLUMNS_B; k++)

        for (i=0; i<ROWS_A; i++)

        {

           c[i][k] = 0.0;

           for (j=0; j<COLUMNS_A; j++)

              c[i][k] = c[i][k] + a[i][j] * b[j][k];

        }

   printf("-------------------------------------------------\n");
     printf("Result Matrix:\n");
     for (i=0; i<ROWS_A; i++)
     {
        printf("\n");

        for (j=0; j<COLUMNS_B; j++)
           printf("%6.2Lf   ", c[i][j]);
     }
     printf("\n-------------------------------------------------------\n");
     printf ("Done.\n");
   end=MPI_Wtime();
   printf("\nTime= %f",end-start);
   return 0;
}
```

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Parallel Code :

```
#include "mpi.h"

#include <stdio.h>

#include <stdlib.h>



#define ROWS_A 500                  /* number of rows in matrix A */

#define COLUMNS_A 300                  /* number of columns in matrix A */

#define COLUMNS_B 150                   /* number of columns in matrix B */

#define MASTER 0               /* taskid of first task */

#define FROM_MASTER 1          /* setting a message type */

#define FROM_WORKER 2          /* setting a message type */



int main (int argc, char *argv[])

{

int   numtasks,              /* number of tasks in partition */

   taskid,                /* a task identifier */

   numworkers,            /* number of worker tasks */

   source,                /* task id of message source */

   dest,                  /* task id of message destination */

   mtype,                 /* message type */

   rows,                  /* rows of matrix A sent to each worker */
```

```
   averow, extra, offset, /* used to determine rows sent to each worker */

   i, j, k, rc;           /* misc */

   long double a[ROWS_A][COLUMNS_A],           /* matrix A to be
multiplied */

   b[COLUMNS_A][COLUMNS_B],           /* matrix B to be multiplied */

   c[ROWS_A][COLUMNS_B];           /* result matrix C */

   MPI_Status status;

   double start,end;




   MPI_Init(&argc,&argv);
   start=MPI_Wtime();

   MPI_Comm_rank(MPI_COMM_WORLD,&taskid);

   MPI_Comm_size(MPI_COMM_WORLD,&numtasks);

   if (numtasks < 2 ) {

      printf("Need at least two MPI tasks. Quitting...\n");

      MPI_Abort(MPI_COMM_WORLD, rc);

      exit(1);

   }

   numworkers = numtasks-1;
```

```
//------------------------------------------------ master task
------------------------------------------------------//


   if (taskid == MASTER)

   {

      //printf("mpi_mm has started with %d tasks.\n",numtasks);

      //printf("Initializing arrays...\n");

      for (i=0; i<ROWS_A; i++)

         for (j=0; j<COLUMNS_A; j++)

            a[i][j]= (i+j)*2.658;

      for (i=0; i<COLUMNS_A; i++)

         for (j=0; j<COLUMNS_B; j++)

            b[i][j]= (i+j)*6.658;



      /* Send matrix data to the worker tasks */

      averow = ROWS_A/numworkers;

      extra = ROWS_A%numworkers;

      offset = 0;

      mtype = FROM_MASTER;
```

```
      for (dest=1; dest<=numworkers; dest++)

      {

         rows = (dest <= extra) ? averow+1 : averow;

         //printf("Sending %d rows to task %d
offset=%d\n",rows,dest,offset);

         MPI_Send(&offset, 1, MPI_INT, dest, mtype, MPI_COMM_WORLD);

         MPI_Send(&rows, 1, MPI_INT, dest, mtype, MPI_COMM_WORLD);

         MPI_Send(&a[offset][0], rows*COLUMNS_A, MPI_LONG_DOUBLE, dest,
mtype,

                  MPI_COMM_WORLD);

         MPI_Send(&b, COLUMNS_A*COLUMNS_B, MPI_LONG_DOUBLE, dest, mtype,
MPI_COMM_WORLD);

         offset = offset + rows;

      }



      /* Receive results from worker tasks */

      mtype = FROM_WORKER;

      for (i=1; i<=numworkers; i++)

      {

         source = i;

         MPI_Recv(&offset, 1, MPI_INT, source, mtype, MPI_COMM_WORLD,
&status);
```

```
         MPI_Recv(&rows, 1, MPI_INT, source, mtype, MPI_COMM_WORLD,
&status);

         MPI_Recv(&c[offset][0], rows*COLUMNS_B, MPI_LONG_DOUBLE, source,
mtype,

                  MPI_COMM_WORLD, &status);

         printf("Received results from task %d\n",source);

      }



      /* Print results */

      printf("-------------------------------------------------\n");

      printf("Result Matrix:\n");

      for (i=0; i<ROWS_A; i++)

      {

         printf("\n");

         for (j=0; j<COLUMNS_B; j++)

            printf("%6.2Lf   ", c[i][j]);

      }

      printf("\n-------------------------------------------------------\n");

      printf ("Done.\n");

    end=MPI_Wtime();

    printf("\nTime= %f",end-start);
```

```
   }




//------------------------------------------------ worker task
------------------------------------------------//



   if (taskid > MASTER)

   {

      mtype = FROM_MASTER;

      MPI_Recv(&offset, 1, MPI_INT, MASTER, mtype, MPI_COMM_WORLD,
&status);

      MPI_Recv(&rows, 1, MPI_INT, MASTER, mtype, MPI_COMM_WORLD, &status);

      MPI_Recv(&a, rows*COLUMNS_A, MPI_LONG_DOUBLE, MASTER, mtype,
MPI_COMM_WORLD, &status);

      MPI_Recv(&b, COLUMNS_A*COLUMNS_B, MPI_LONG_DOUBLE, MASTER, mtype,
MPI_COMM_WORLD, &status);



      for (k=0; k<COLUMNS_B; k++)

         for (i=0; i<rows; i++)

         {

            c[i][k] = 0.0;

            for (j=0; j<COLUMNS_A; j++)
```

```
                c[i][k] = c[i][k] + a[i][j] * b[j][k];

            }

        mtype = FROM_WORKER;

        MPI_Send(&offset, 1, MPI_INT, MASTER, mtype, MPI_COMM_WORLD);

        MPI_Send(&rows, 1, MPI_INT, MASTER, mtype, MPI_COMM_WORLD);

        MPI_Send(&c, rows*COLUMNS_B, MPI_LONG_DOUBLE, MASTER, mtype,
MPI_COMM_WORLD);

    }

    MPI_Finalize();

}
```

Observations :

Processes(n)	Runtime	Speedup (s)
1	0.727793	1
2	1.173708	0.6200801221
4	1.625658	0.4476913348
6	1.558417	0.4670078676
8	1.795315	0.4053845704
10	1.772297	0.4106495695
12	1.78564	0.4075810354
16	3.73724	0.1947407713
32	8.186064	0.08890634131
64	23.777508	0.0306084641
128	91.022718	0.007995729154

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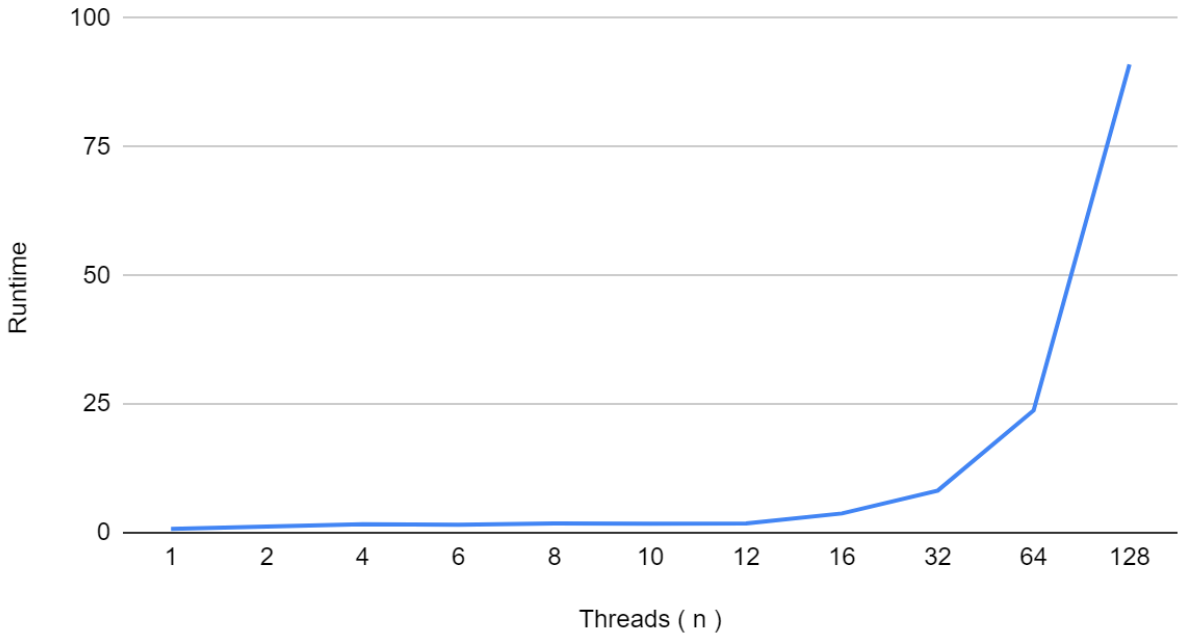
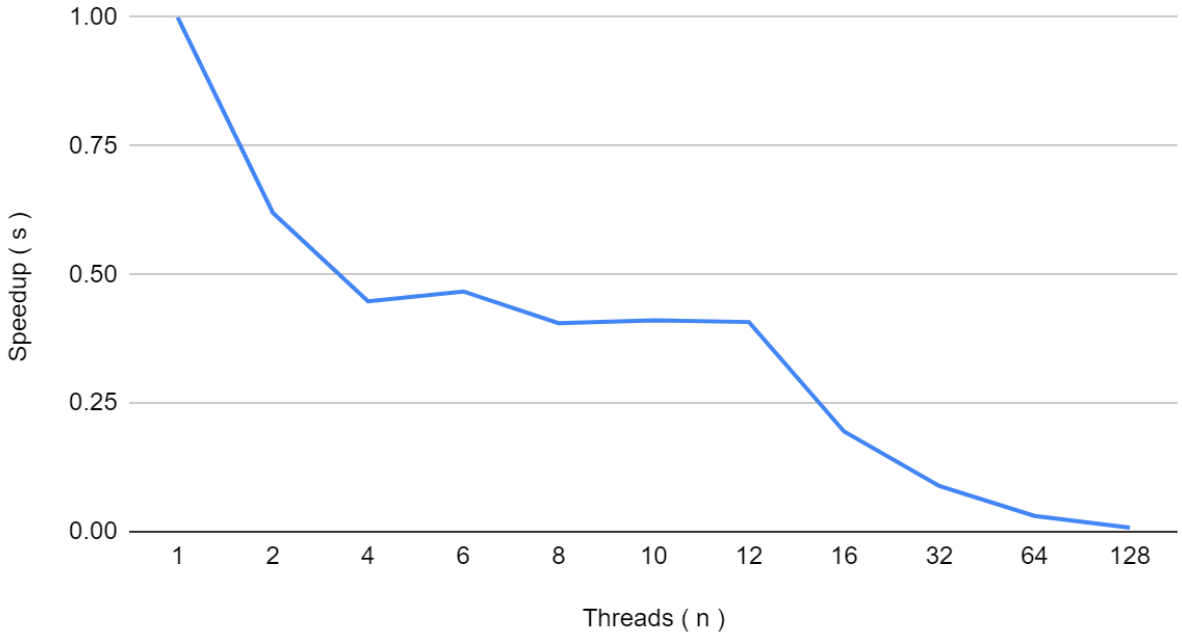
Runtime vs. Processes(n)



Speedup (s) vs. Processes(n)



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Inference: (**Note**: Execution time, graph, and inference will be based on hardware configuration)

- Since MPI is a distributed memory architecture, the communication overhead between nodes causes the parallel code to run slower compared to serial code (running in 1 node or only in master).