Final Year B.Tech. (CSE) – VII [2024-25]

6CS452: High Performance Computing Lab

Assignment No: 10

Analysis of MPI Programs

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Title: Analysis of MPI Programs

Problem Statement 1:

Execute the MPI program (Program A) with a fixed size broadcast. Plot the performance of the broadcast with varying numbers of processes (with constant message size). Explain the performance observed.

Code for Creation of Sample Files:

```
import numpy as np
import os

def create_matrix_file(filename, rows=512, cols=512):
    # Create the directory if it doesn't exist
    directory = os.path.dirname(filename)
    if not os.path.exists(directory):
        os.makedirs(directory)

    # Generate a matrix of random floating-point numbers
    matrix = np.random.rand(rows, cols)

    # Write the matrix to the file
    with open(filename, 'w') as f:
        for row in matrix:
            row_str = ' '.join(f'{val:.6f}' for val in row)
            f.write(row_str + '\n')

# Create sample/in1 and sample/in2 files
create_matrix_file('sample/in1')
create_matrix_file('sample/in2')

print("Files sample/in1 and sample/in2 have been created if they did not exist.")
```

Corrected Code:

```
#include <assert.h>
#include <math.h>
#include <string.h>
#include <stdio.h>
#include <stdlib.h>
#include <mpi.h>

typedef struct
{
   float r;
   float i;
} complex;

static complex ctmp;

#define C_SWAP(a, b) \
   {            \
      ctmp = (a);  \
      (a) = (b);   \
      (b) = ctmp;  \
   }

#define N 512

void c_fft1d(complex *r, int n, int isign)
{
   int m, i, i1, j, k, i2, l, l1, l2;
   float c1, c2, z;
   complex t, u;

   if (isign == 0)
      return;

   /* Do the bit reversal */
   i2 = n >> 1;
   j = 0;
   for (i = 0; i < n - 1; i++)
   {
      if (i < j)
         C_SWAP(r[i], r[j]);
      k = i2;
      while (k <= j)
      {
         j -= k;
         k >>= 1;
      }
      j += k;
   }
```

```
/* m = (int) log2((double)n); */
for (i = n, m = 0; i > 1; m++, i /= 2)
   ;

/* Compute the FFT */
c1 = -1.0;
c2 = 0.0;
l2 = 1;
for (l = 0; l < m; l++)
{
   l1 = l2;
   l2 <<= 1;
   u.r = 1.0;
   u.i = 0.0;
   for (j = 0; j < l1; j++)
   {
      for (i = j; i < n; i += l2)
      {
         i1 = i + l1;

         /* t = u * r[i1] */
         t.r = u.r * r[i1].r - u.i * r[i1].i;
         t.i = u.r * r[i1].i + u.i * r[i1].r;

         /* r[i1] = r[i] - t */
         r[i1].r = r[i].r - t.r;
         r[i1].i = r[i].i - t.i;

         /* r[i] = r[i] + t */
         r[i].r += t.r;
         r[i].i += t.i;
      }
      z = u.r * c1 - u.i * c2;

      u.i = u.r * c2 + u.i * c1;
      u.r = z;
   }
   c2 = sqrt((1.0 - c1) / 2.0);
   if (isign == -1) /* FWD FFT */
      c2 = -c2;
   c1 = sqrt((1.0 + c1) / 2.0);
}

/* Scaling for inverse transform */
if (isign == 1)
{ /* IFFT*/
   for (i = 0; i < n; i++)
   {
      r[i].r /= n;
      r[i].i /= n;
```

```
      }
   }
}

void getData(char fileName[15], complex **data)
{
   FILE *fp = fopen(fileName, "r");

   int i, j, result;

   for (i = 0; i < N; i++)
   {
      for (j = 0; j < N; j++)
      {
         result = fscanf(fp, "%g", &data[i][j].r);
         data[i][j].i = 0.00;
      }
   }

   fclose(fp);
}

void transpose(complex **data, complex **transp)
{
   int i, j;
   for (i = 0; i < N; i++)
      for (j = 0; j < N; j++)
         transp[j][i] = data[i][j];
}

void mmpoint(complex **data1, complex **data2, complex **data3)
{

   int i, j;

   float real, imag;

   for (i = 0; i < N; i++)
   {
      for (j = 0; j < N; j++)
      {
         data3[i][j].r = (data1[i][j].r * data2[i][j].r) - (data1[i][j].i * data2[i][j].i);
         data3[i][j].i = (data1[i][j].r * data2[i][j].i) + (data1[i][j].i * data2[i][j].r);
      }
   }
}

void printfile(char fileName[15], complex **data)
{

   FILE *fp = fopen(fileName, "w");
```

```
    int i, j;

    for (i = 0; i < N; i++)
    {
        for (j = 0; j < N; j++)
        {
            fprintf(fp, "   %.7e", data[i][j].r);
        }
        fprintf(fp, "\n");
    }

    fclose(fp);
}

int main(int argc, char **argv)
{
    int my_rank, p, source = 0, dest, x;

    complex **data1, **data2, **data3, **data4;

    data1 = malloc(N * sizeof(complex *));
    data2 = malloc(N * sizeof(complex *));
    data3 = malloc(N * sizeof(complex *));
    data4 = malloc(N * sizeof(complex *));

    for (x = 0; x < N; x++)
    {
        data1[x] = malloc(N * sizeof(complex));
        data2[x] = malloc(N * sizeof(complex));
        data3[x] = malloc(N * sizeof(complex));
        data4[x] = malloc(N * sizeof(complex));
    }

    complex *vec;

    char fileName1[15] = "sample/in1";
    char fileName2[15] = "sample/in2";
    char fileName3[15] = "mpi_out_test";

    MPI_Status status;

    MPI_Init(&argc, &argv);

    MPI_Comm_rank(MPI_COMM_WORLD, &my_rank);

    MPI_Comm_size(MPI_COMM_WORLD, &p);

    /* Setup description of the 4 MPI_FLOAT fields x, y, z, velocity */
    int blocklens[2] = {1, 1};
```

```
MPI_Aint indices[2] = {0, sizeof(float)};
MPI_Datatype old_types[2] = {MPI_FLOAT, MPI_FLOAT};

MPI_Datatype mystruct;

/* Make relative */
// MPI_Type_struct(2, blocklens, indices, old_types, &mystruct);
MPI_Type_create_struct(2, blocklens, indices, old_types, &mystruct);

MPI_Type_commit(&mystruct);

int i, j;

double startTime, stopTime;

// Starting and send rows of data1, data2

int offset;

int tag = 345;

int rows = N / p;

int lb = my_rank * rows;
int hb = lb + rows;

printf("%d have lb = %d and hb = %d\n", my_rank, lb, hb);

// Starting and send rows of data1, data2

if (my_rank == 0)
{
   getData(fileName1, data1);
   getData(fileName2, data2);

   /* Start Clock */
   printf("\nStarting clock.\n");
   startTime = MPI_Wtime();

   for (i = 1; i < p; i++)
   {
      offset = i * rows;
      for (j = offset; j < (offset + rows); j++)
      {
         MPI_Send(&data1[j][0], N, mystruct, i, tag, MPI_COMM_WORLD);
         MPI_Send(&data2[j][0], N, mystruct, i, tag, MPI_COMM_WORLD);
      }
   }
}
else
{
```

```
   for (j = lb; j < hb; j++)
   {
      MPI_Recv(data1[j], N, mystruct, 0, tag, MPI_COMM_WORLD, &status);
      MPI_Recv(data2[j], N, mystruct, 0, tag, MPI_COMM_WORLD, &status);
   }
}

// Doing fft1d forward for data1 and data2 rows

vec = (complex *)malloc(N * sizeof(complex));

for (i = lb; i < hb; i++)
{
   for (j = 0; j < N; j++)
   {
      vec[j] = data1[i][j];
   }
   c_fft1d(vec, N, -1);
   for (j = 0; j < N; j++)
   {
      data1[i][j] = vec[j];
   }
}

free(vec);

vec = (complex *)malloc(N * sizeof(complex));

for (i = lb; i < hb; i++)
{
   for (j = 0; j < N; j++)
   {
      vec[j] = data2[i][j];
   }
   c_fft1d(vec, N, -1);
   for (j = 0; j < N; j++)
   {
      data2[i][j] = vec[j];
   }
}

free(vec);

// Receving rows of data1, data2

if (my_rank == 0)
{
   for (i = 1; i < p; i++)
   {
      offset = i * rows;
```

```
      for (j = offset; j < (offset + rows); j++)
      {
         MPI_Recv(data1[j], N, mystruct, i, tag, MPI_COMM_WORLD, &status);
         MPI_Recv(data2[j], N, mystruct, i, tag, MPI_COMM_WORLD, &status);
      }
   }
}
else
{

   for (j = lb; j < hb; j++)
   {
      MPI_Send(&data1[j][0], N, mystruct, 0, tag, MPI_COMM_WORLD);
      MPI_Send(&data2[j][0], N, mystruct, 0, tag, MPI_COMM_WORLD);
   }
}

// Starting and send columns of data1, data2

if (my_rank == 0)
{
   transpose(data1, data3);
   transpose(data2, data4);

   for (i = 1; i < p; i++)
   {
      offset = i * rows;
      for (j = offset; j < (offset + rows); j++)
      {
         MPI_Send(&data3[j][0], N, mystruct, i, tag, MPI_COMM_WORLD);
         MPI_Send(&data4[j][0], N, mystruct, i, tag, MPI_COMM_WORLD);
      }
   }
}
else
{
   for (j = lb; j < hb; j++)
   {
      MPI_Recv(data3[j], N, mystruct, 0, tag, MPI_COMM_WORLD, &status);
      MPI_Recv(data4[j], N, mystruct, 0, tag, MPI_COMM_WORLD, &status);
   }
}

// Doing fft1d forward for data1 and data2 columns

vec = (complex *)malloc(N * sizeof(complex));

for (i = lb; i < hb; i++)
{
   for (j = 0; j < N; j++)
   {
```

```
      vec[j] = data3[i][j];
   }
   c_fft1d(vec, N, -1);
   for (j = 0; j < N; j++)
   {
      data3[i][j] = vec[j];
   }
}

free(vec);

vec = (complex *)malloc(N * sizeof(complex));

for (i = lb; i < hb; i++)
{
   for (j = 0; j < N; j++)
   {
      vec[j] = data4[i][j];
   }
   c_fft1d(vec, N, -1);
   for (j = 0; j < N; j++)
   {
      data4[i][j] = vec[j];
   }
}

free(vec);

// Receving columns of data1, data2

if (my_rank == 0)
{
   for (i = 1; i < p; i++)
   {
      offset = i * rows;
      for (j = offset; j < (offset + rows); j++)
      {
         MPI_Recv(data3[j], N, mystruct, i, tag, MPI_COMM_WORLD, &status);
         MPI_Recv(data4[j], N, mystruct, i, tag, MPI_COMM_WORLD, &status);
      }
   }
}
else
{
   for (j = lb; j < hb; j++)
   {
      MPI_Send(&data3[j][0], N, mystruct, 0, tag, MPI_COMM_WORLD);
      MPI_Send(&data4[j][0], N, mystruct, 0, tag, MPI_COMM_WORLD);
   }
}
```

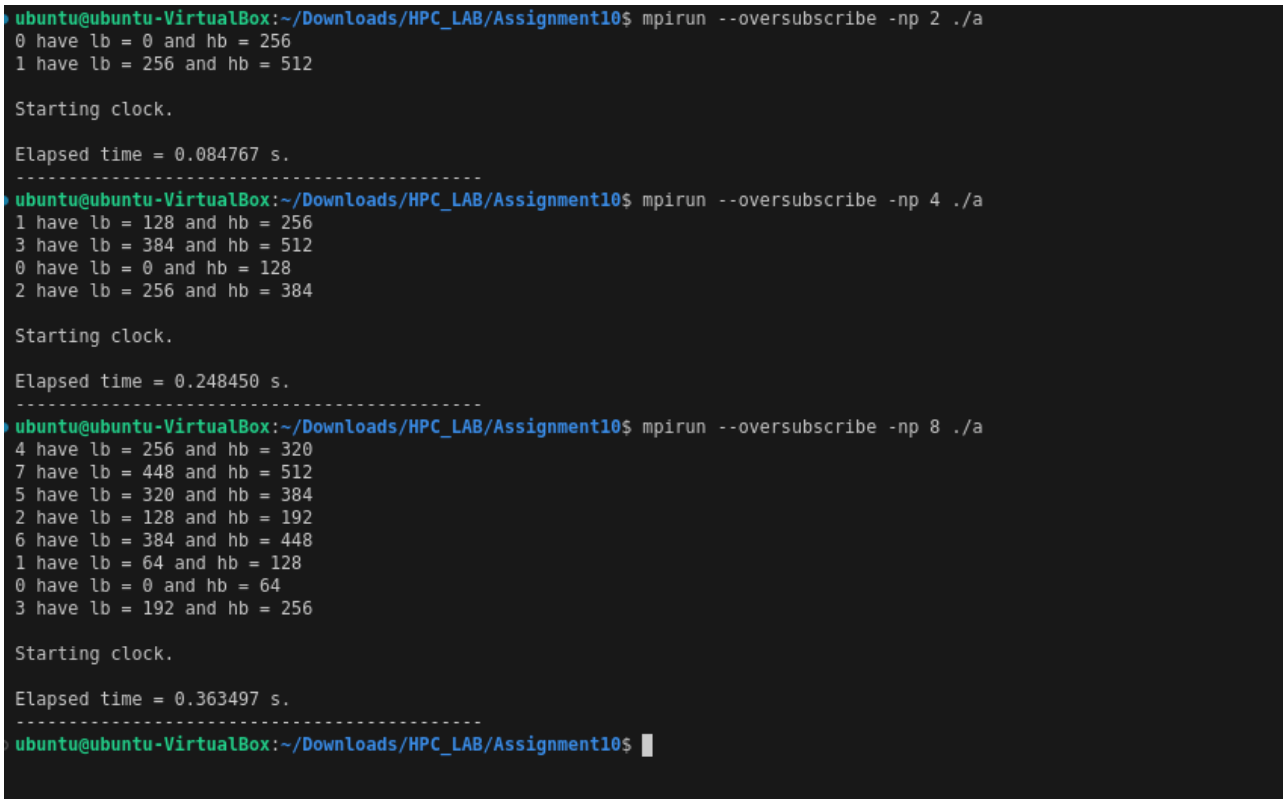
```
if (my_rank == 0)
{
   transpose(data3, data1);
   transpose(data4, data2);
   mmpoint(data1, data2, data3);
}

// Starting and send rows of data1, data2

if (my_rank == 0)
{
   for (i = 1; i < p; i++)
   {
      offset = i * rows;
      for (j = offset; j < (offset + rows); j++)
      {
         MPI_Send(&data3[j][0], N, mystruct, i, tag, MPI_COMM_WORLD);
      }
   }
}
else
{

   for (j = lb; j < hb; j++)
   {
      MPI_Recv(data3[j], N, mystruct, 0, tag, MPI_COMM_WORLD, &status);
   }
}

// Doing fft1d forward for data1 and data2 rows

vec = (complex *)malloc(N * sizeof(complex));

for (i = lb; i < hb; i++)
{
   for (j = 0; j < N; j++)
   {
      vec[j] = data3[i][j];
   }
   c_fft1d(vec, N, 1);
   for (j = 0; j < N; j++)
   {
      data3[i][j] = vec[j];
   }
}

free(vec);

// Receving rows of data1, data2

if (my_rank == 0)
```

```
{
   for (i = 1; i < p; i++)
   {
      offset = i * rows;
      for (j = offset; j < (offset + rows); j++)
      {
         MPI_Recv(data3[j], N, mystruct, i, tag, MPI_COMM_WORLD, &status);
      }
   }
}
else
{
   for (j = lb; j < hb; j++)
   {
      MPI_Send(&data3[j][0], N, mystruct, 0, tag, MPI_COMM_WORLD);
   }
}

// Starting and send columns of data1, data2

if (my_rank == 0)
{
   transpose(data3, data4);

   for (i = 1; i < p; i++)
   {
      offset = i * rows;
      for (j = offset; j < (offset + rows); j++)
      {
         MPI_Send(&data4[j][0], N, mystruct, i, tag, MPI_COMM_WORLD);
      }
   }
}
else
{
   for (j = lb; j < hb; j++)
   {
      MPI_Recv(data4[j], N, mystruct, 0, tag, MPI_COMM_WORLD, &status);
   }
}

// Doing fft1d forward for data1 and data2 columns

vec = (complex *)malloc(N * sizeof(complex));

for (i = lb; i < hb; i++)
{
   for (j = 0; j < N; j++)
   {
      vec[j] = data4[i][j];
   }
```

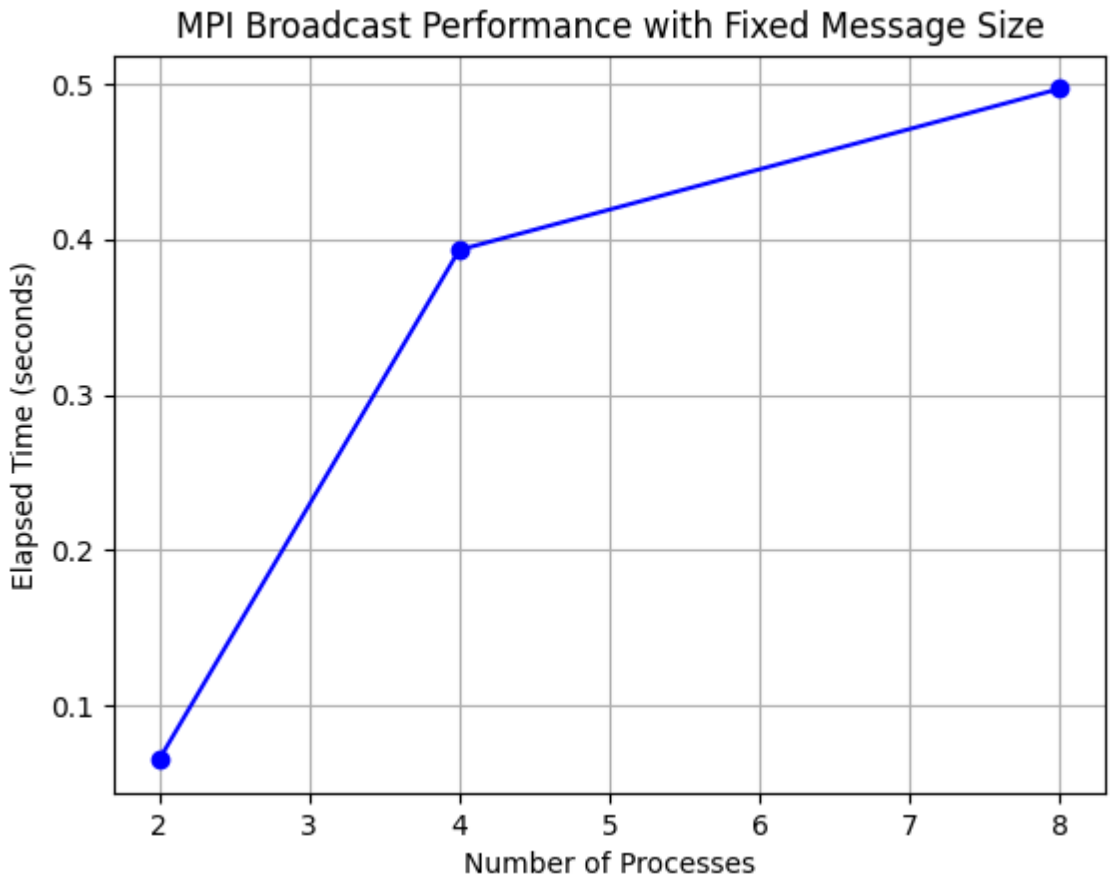
```
    c_fft1d(vec, N, 1);
    for (j = 0; j < N; j++)
    {
      data4[i][j] = vec[j];
    }
  }

  free(vec);

  // Receving columns of data1, data2

  if (my_rank == 0)
  {
    for (i = 1; i < p; i++)
    {
      offset = i * rows;
      for (j = offset; j < (offset + rows); j++)
      {
        MPI_Recv(data4[j], N, mystruct, i, tag, MPI_COMM_WORLD, &status);
      }
    }
  }
  else
  {
    for (j = lb; j < hb; j++)
    {
      MPI_Send(&data4[j][0], N, mystruct, 0, tag, MPI_COMM_WORLD);
    }
  }

  if (my_rank == 0)
  {
    transpose(data4, data3);
    /* Stop Clock */
    stopTime = MPI_Wtime();

    printf("\nElapsed time = %lf s.\n", (stopTime - startTime));
    printf("-----------------------------------------\n");
  }

  MPI_Finalize();

  if (my_rank == 0)
  {
    printfile(fileName3, data3);
  }

  free(data1);
  free(data2);
  free(data3);
  free(data4);
```

```
    return 0;
}
```

Output:



Analysis:



Problem Statement 2:

Repeat problem 2 above with varying message sizes for reduction (Program B). Explain the observed performance of the reduction operation.

Code:

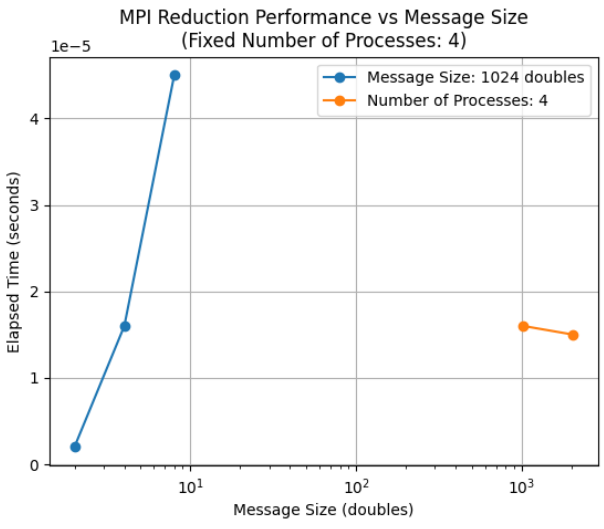
```
#include <stdio.h>
#include <stdlib.h>
#include <time.h>
#include <mpi.h>


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

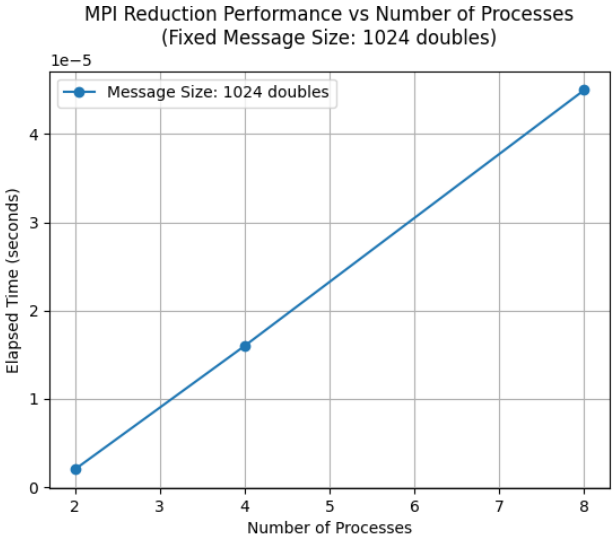
```
{
if (argc != 2)
{
printf("Usage : reduce message_size\n");
return 1;
}

int rank;
int size = atoi(argv[1]);

char input_buffer[size];
char output_buffer[size];

MPI_Init(&argc, &argv);

MPI_Comm_rank(MPI_COMM_WORLD, &rank);

int i;
srand(time(NULL));

for (i = 0; i < size; i++)
input_buffer[i] = rand() % 256;

double total_time = 0.0;
double start_time = 0.0;

for (i = 0; i < 100; i++)
{
MPI_Barrier(MPI_COMM_WORLD);
start_time = MPI_Wtime();

MPI_Reduce(input_buffer, output_buffer, size, MPI_BYTE, MPI_BOR, 0, MPI_COMM_WORLD);

MPI_Barrier(MPI_COMM_WORLD);
total_time += (MPI_Wtime() - start_time);
}

if (rank == 0)
{
printf("Average time for reduce : %f secs\n", total_time / 100);
}

MPI_Finalize();
return 0;
}
```

Output:

```
ubuntu@ubuntu-VirtualBox:~/Downloads/HPC_LAB/Assignment10$ mpirun --oversubscribe -np 2 ./a 1048
Average time for reduce : 0.000002 secs
ubuntu@ubuntu-VirtualBox:~/Downloads/HPC_LAB/Assignment10$ mpirun --oversubscribe -np 4 ./a 2048
Average time for reduce : 0.000012 secs
ubuntu@ubuntu-VirtualBox:~/Downloads/HPC_LAB/Assignment10$ mpirun --oversubscribe -np 8 ./a 2048
Average time for reduce : 0.000124 secs
ubuntu@ubuntu-VirtualBox:~/Downloads/HPC_LAB/Assignment10$ mpirun --oversubscribe -np 4 ./a 1048
Average time for reduce : 0.000010 secs
ubuntu@ubuntu-VirtualBox:~/Downloads/HPC_LAB/Assignment10$ mpirun --oversubscribe -np 8 ./a 1048
Average time for reduce : 0.000031 secs
ubuntu@ubuntu-VirtualBox:~/Downloads/HPC_LAB/Assignment10$ mpirun --oversubscribe -np 2 ./a 2048
Average time for reduce : 0.000002 secs
ubuntu@ubuntu-VirtualBox:~/Downloads/HPC_LAB/Assignment10$
```

Analysis:




MPI Reduction Performance vs Number of Processes
(Fixed Message Size: 1024 doubles)
1e−5
Message Size: 1024 doubles
Elapsed Time (seconds)
0
1
2
3
4
2
3
4
5
6
7
8
Number of Processes