Problem1

Environment

Os	Pop!_OS 22.04 LTS x86
CPU	Intel i7-8665U (8) @ 1.900GHz
Memory	16Gb
GCC version	14.0.0
GNU Make version	4.3
GPU	Google Colab

Build

openmp_ray.cpp

```
make
```

or

```
g++ -o openmp_ray ./openmp_ray.cpp -fopenmp
```

cuda_ray.cu

```
nvcc ./test_cuda.cu -o cuda_ray
```

Run

openmp_ray

```
openmp_ray < number of threads >
```

cuda_ray

```
cuda_ray
```

Source code

openmp_ray.cpp

```
#include <stdio.h>
#include <string.h>
#include <stdlib.h>
#include <time.h>
#include <math.h>
#include <omp.h>

#define SPHERES 20

#define rnd(x) (x * rand() / RAND_MAX)
#define INF 2e10f
#define DIM 2048

struct Sphere
{
    float r, b, g;
    float radius;
    float x, y, z;
    float hit(float ox, float oy, float *n)
    {
        float dx = ox - x;
        float dy = oy - y;
        if (dx * dx + dy * dy < radius * radius)
        {
            float dz = sqrtf(radius * radius - dx * dx - dy * dy);
            *n = dz / sqrtf(radius * radius);
            return dz + z;
        }
        return -INF;
    }
};

void kernel(int x, int y, Sphere *s, unsigned char *ptr)
{
    int offset = x + y * DIM;
    float ox = (x - DIM / 2);
    float oy = (y - DIM / 2);

    //    printf("x:%d, y:%d, ox:%f, oy:%f\n",x,y,ox,oy);
    float r = 0, g = 0, b = 0;
    float maxz = -INF;
    for (int i = 0; i < SPHERES; i++)
    {
        float n;
        float t = s[i].hit(ox, oy, &n);
        if (t > maxz)
        {
            float fscale = n;
```

```
            r = s[i].r * fscale;
            g = s[i].g * fscale;
            b = s[i].b * fscale;
            maxz = t;
        }
    }

    ptr[offset * 4 + 0] = (int)(r * 255);
    ptr[offset * 4 + 1] = (int)(g * 255);
    ptr[offset * 4 + 2] = (int)(b * 255);
    ptr[offset * 4 + 3] = 255;
}

void ppm_write(unsigned char *bitmap, int xdim, int ydim, FILE *fp)
{
    int i, x, y;
    fprintf(fp, "P3\n");
    fprintf(fp, "%d %d\n", xdim, ydim);
    fprintf(fp, "255\n");
    for (y = 0; y < ydim; y++)
    {
        for (x = 0; x < xdim; x++)
        {
            i = x + y * xdim;
            fprintf(fp, "%d %d %d ", bitmap[4 * i], bitmap[4 * i + 1],
bitmap[4 * i + 2]);
        }
        fprintf(fp, "\n");
    }
}

int main(int argc, char *argv[])
{
    int no_threads;
    int x, y;
    unsigned char *bitmap;
    double start_time = 0;
    double end_time = 0;
    const char *output_file = "result.ppm";

    srand(time(NULL));

    if (argc != 2)
    {
        printf("> openmp_ray [option]\n");
        printf("[option] 1~16: OpenMP using 1~16 threads\n");
        printf("for example, '> openmp_ray 8' means executing OpenMP with 8
threads\n");
        return EXIT_FAILURE;
    }
    FILE *fp = fopen(output_file, "w");

    no_threads = atoi(argv[1]);
```

```
    Sphere *temp_s = (Sphere *)malloc(sizeof(Sphere) * SPHERES);
    for (int i = 0; i < SPHERES; i++)
    {
        temp_s[i].r = rnd(1.0f);
        temp_s[i].g = rnd(1.0f);
        temp_s[i].b = rnd(1.0f);
        temp_s[i].x = rnd(2000.0f) - 1000;
        temp_s[i].y = rnd(2000.0f) - 1000;
        temp_s[i].z = rnd(2000.0f) - 1000;
        temp_s[i].radius = rnd(200.0f) + 40;
    }

    bitmap = (unsigned char *)malloc(sizeof(unsigned char) * DIM * DIM *
4);
    start_time = omp_get_wtime();
#pragma omp parallel for schedule(dynamic) num_threads(no_threads)
    for (y = 0; y < DIM; y++)
    {
        for (x = 0; x < DIM; x++)
        {
            kernel(x, y, temp_s, bitmap);
        }
    }
    end_time = omp_get_wtime();
    ppm_write(bitmap, DIM, DIM, fp);

    fclose(fp);
    free(bitmap);
    free(temp_s);

    printf("OpenMP (%d threads) ray tracing :%.3lf sec\n", no_threads,
(end_time - start_time));
    printf("[%s] was generated\n", output_file);
    return EXIT_SUCCESS;
}
```

cuda_ray.cu

```
#include <stdio.h>
#include <string.h>
#include <stdlib.h>
#include <time.h>
#include <math.h>

#define SPHERES 20

#define rnd(x) (x * rand() / RAND_MAX)
#define INF 2e10f
#define DIM 2048

struct Sphere
```

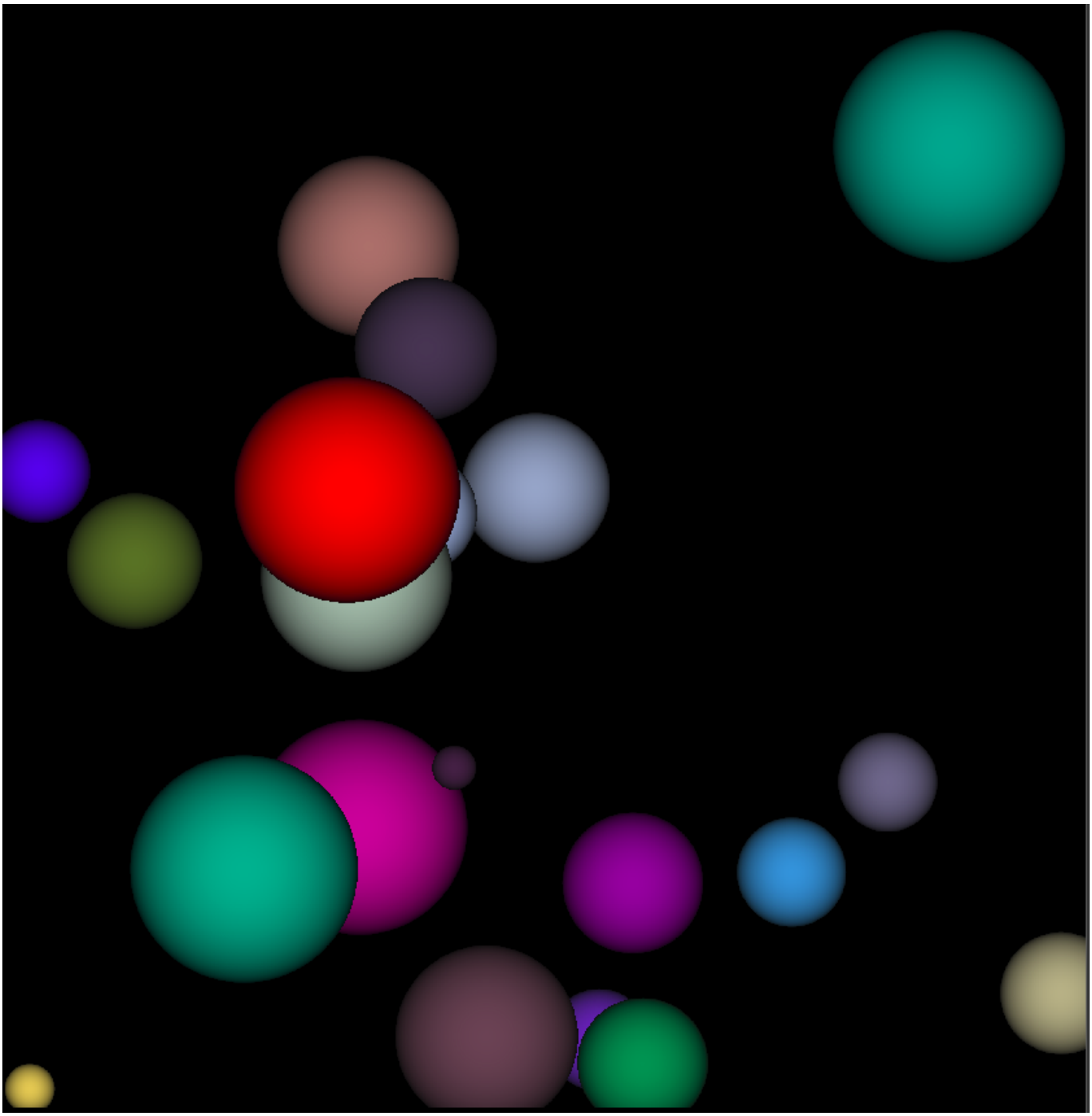
```
{
    float r, b, g;
    float radius;
    float x, y, z;
    __device__ float hit(float ox, float oy, float *n)
    {
        float dx = ox - x;
        float dy = oy - y;
        if (dx * dx + dy * dy < radius * radius)
        {
            float dz = sqrtf(radius * radius - dx * dx - dy * dy);
            *n = dz / sqrtf(radius * radius);
            return dz + z;
        }
        return -INF;
    }
};

__global__ void kernel(Sphere *s, unsigned char *ptr)
{
    int x = blockIdx.x * blockDim.x + threadIdx.x;
    int y = blockIdx.y * blockDim.y + threadIdx.y;
    int offset = x + y * DIM;
    float ox = (x - DIM / 2);
    float oy = (y - DIM / 2);

    float r = 0, g = 0, b = 0;
    float maxz = -INF;
    for (int i = 0; i < SPHERES; i++)
    {
        float n;
        float t = s[i].hit(ox, oy, &n);
        if (t > maxz)
        {
            float fscale = n;
            r = s[i].r * fscale;
            g = s[i].g * fscale;
            b = s[i].b * fscale;
            maxz = t;
        }
    }

    ptr[offset * 4 + 0] = (int)(r * 255);
    ptr[offset * 4 + 1] = (int)(g * 255);
    ptr[offset * 4 + 2] = (int)(b * 255);
    ptr[offset * 4 + 3] = 255;
}

void ppm_write(unsigned char *bitmap, int xdim, int ydim, FILE *fp)
{
    int i, x, y;
    fprintf(fp, "P3\n");
    fprintf(fp, "%d %d\n", xdim, ydim);
    fprintf(fp, "255\n");
```

```
    for (y = 0; y < ydim; y++)
    {
        for (x = 0; x < xdim; x++)
        {
            i = x + y * xdim;
            fprintf(fp, "%d %d %d ", bitmap[4 * i], bitmap[4 * i + 1],
bitmap[4 * i + 2]);
        }
        fprintf(fp, "\n");
    }
}

int main(int argc, char *argv[])
{
    unsigned char *bitmap;
    const char *filename = "result.ppm";
    FILE *fp = fopen(filename, "w");
    Sphere *temp_s = (Sphere *)malloc(sizeof(Sphere) * SPHERES);
    Sphere *d_s;
    unsigned char *device_bitmap;
    cudaEvent_t start;
    cudaEvent_t end;
    float elapsedTime;

    cudaEventCreate(&start);
    cudaEventCreate(&end);
    srand(time(NULL));
    for (int i = 0; i < SPHERES; i++)
    {
        temp_s[i].r = rnd(1.0f);
        temp_s[i].g = rnd(1.0f);
        temp_s[i].b = rnd(1.0f);
        temp_s[i].x = rnd(2000.0f) - 1000;
        temp_s[i].y = rnd(2000.0f) - 1000;
        temp_s[i].z = rnd(2000.0f) - 1000;
        temp_s[i].radius = rnd(200.0f) + 40;
    }
    cudaMalloc((void **)&d_s, sizeof(Sphere) * SPHERES);
    cudaMalloc((void **)&device_bitmap, sizeof(unsigned char) * DIM * DIM *
4);
    cudaMemcpy(d_s, temp_s, sizeof(Sphere) * SPHERES,
cudaMemcpyHostToDevice);
    cudaEventRecord(start);
    kernel<<<dim3((DIM + 15) / 16, (DIM + 15) / 16), dim3(16, 16)>>>(d_s,
device_bitmap);
    cudaEventRecord(end);
    cudaEventSynchronize(end);
    cudaEventElapsedTime(&elapsedTime, start, end);
    bitmap = (unsigned char *)malloc(sizeof(unsigned char) * DIM * DIM *
4);
    cudaMemcpy(bitmap, device_bitmap, sizeof(unsigned char) * DIM * DIM *
4, cudaMemcpyDeviceToHost);
    printf("CUDA ray tracing: %.3lf sec\n", elapsedTime);
    ppm_write(bitmap, DIM, DIM, fp);
```

```
    printf("[%s] was generated.", filename);
    fclose(fp);
    free(bitmap);
    free(temp_s);
    cudaFree(d_s);
    cudaEventDestroy(start);
    cudaEventDestroy(end);
    cudaFree(device_bitmap);
    return 0;
}
```

Outputs

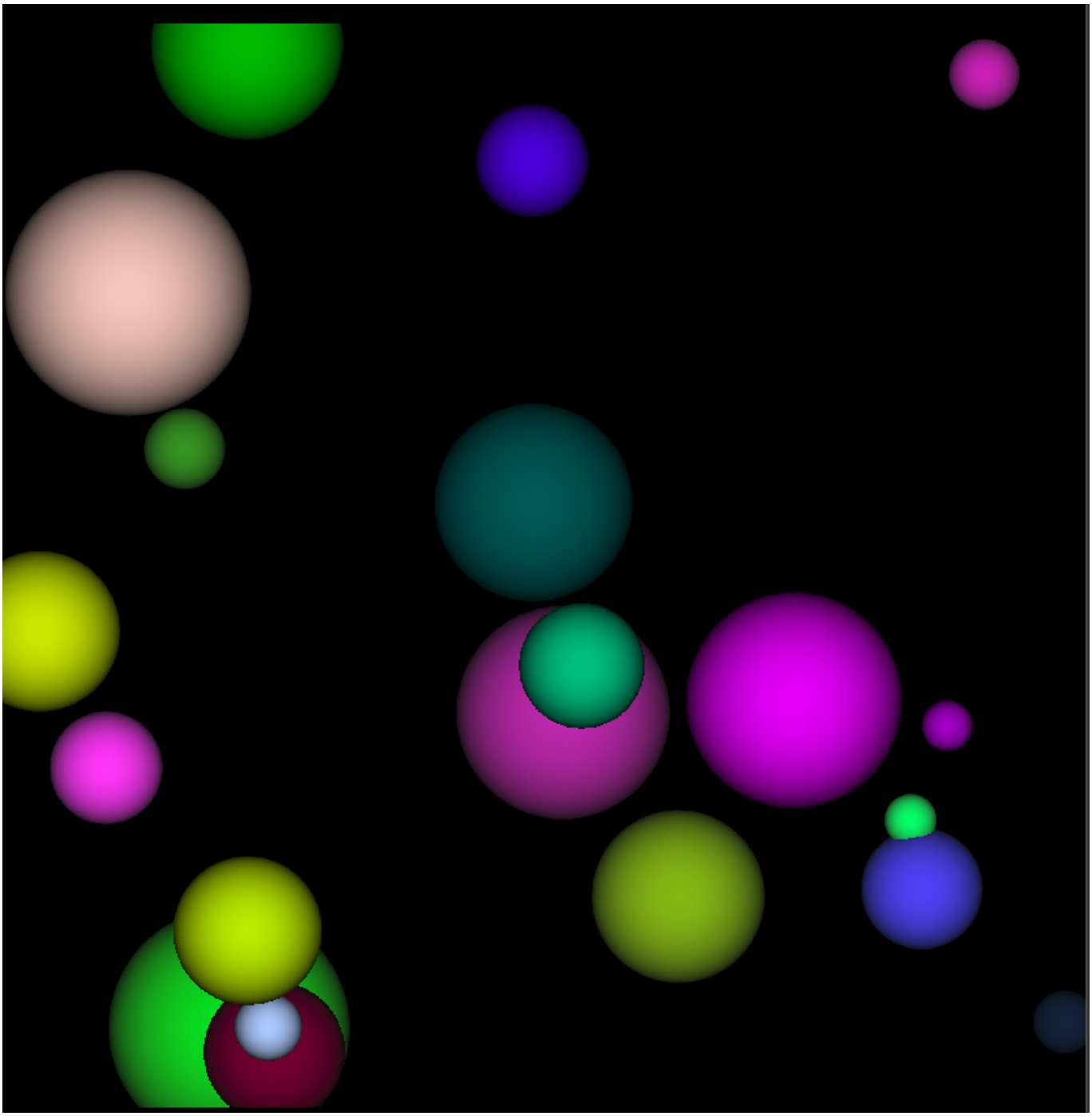
Open MP



Cuda

```
[3]  !./cuda_ray
```

```
CUDA ray tracing: 0.001 sec
[result.ppm] was generated.
```



Results

Raw

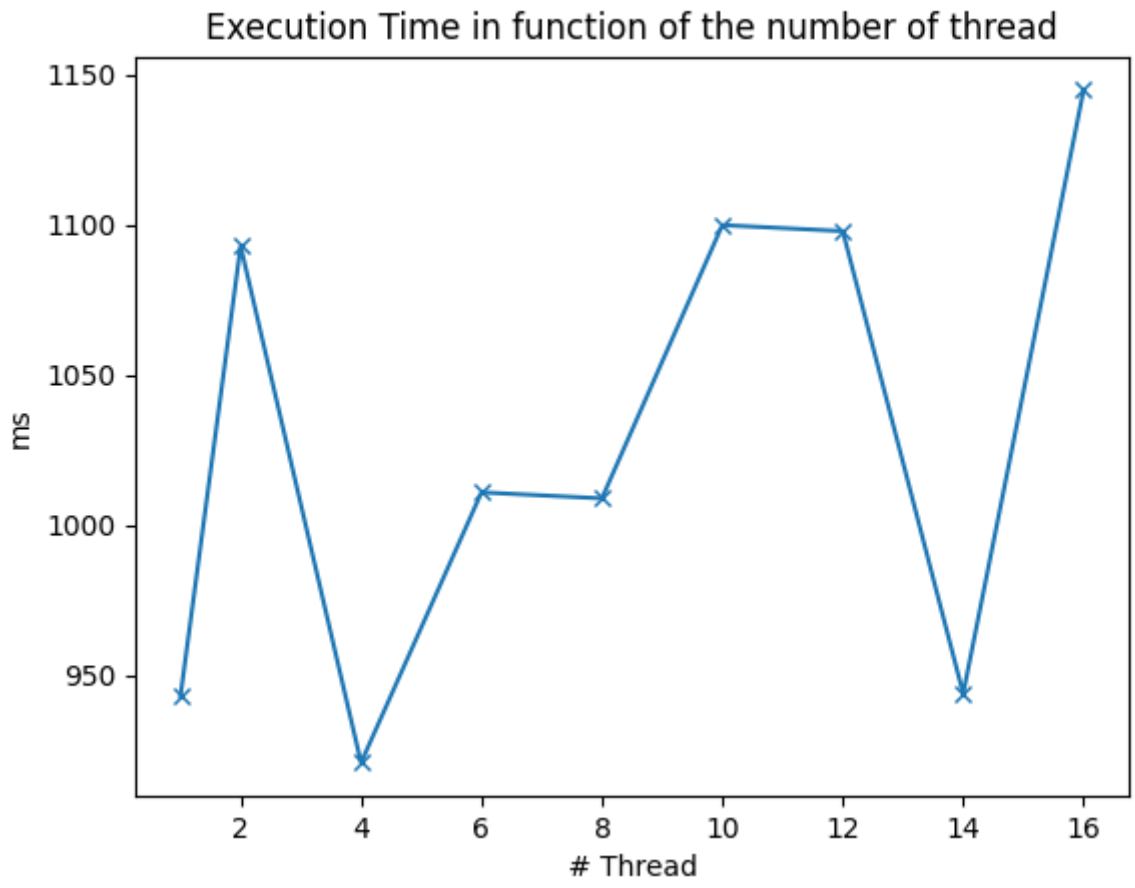
OpenMP

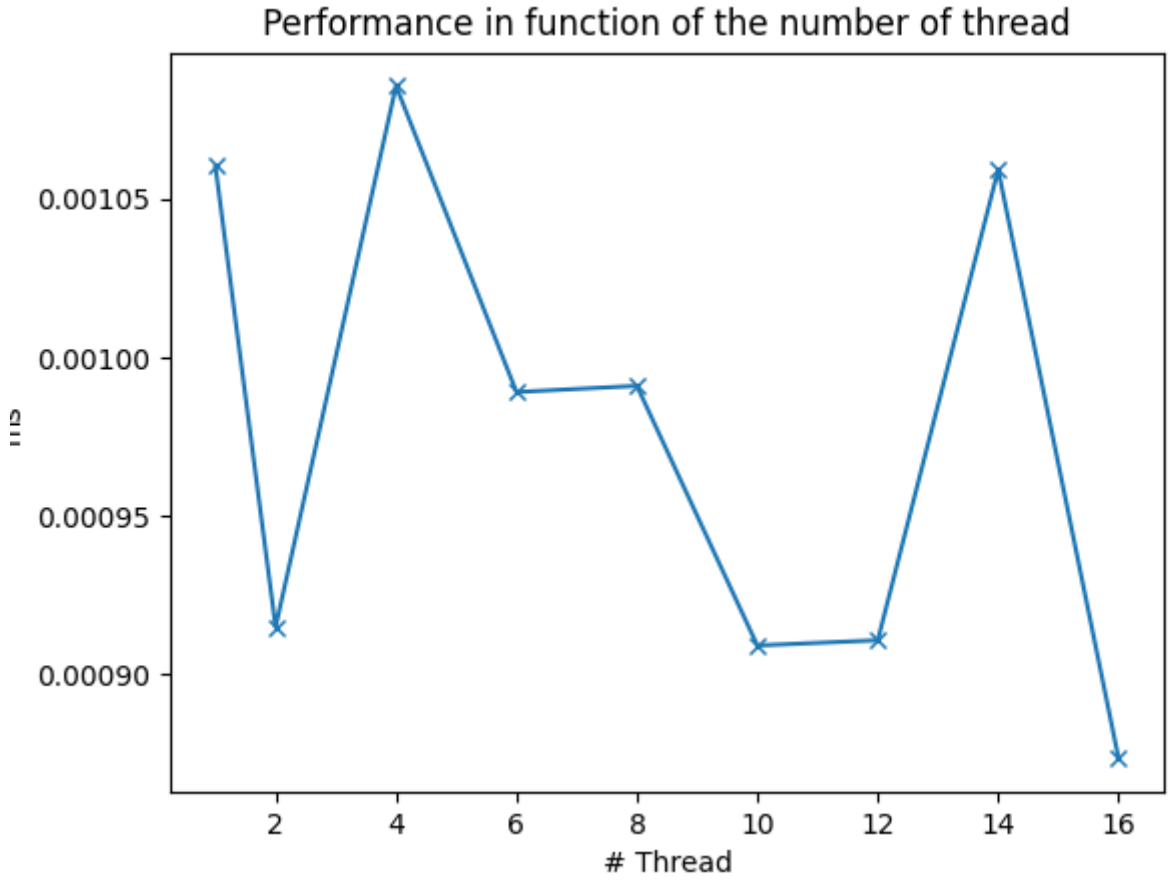
Number of thread	Execution time	Performance
1	943	0.0010604453870625664
2	1093	0.0009149130832570906
4	921	0.0010857763300760044
6	1011	0.0009891196834817012

Number of thread	Execution time	Performance
8	1009	0.0009910802775024777
10	1100	0.0009090909090909091
12	1098	0.0009107468123861566
14	944	0.001059322033898305
16	1145	0.0008733624454148472

Graphs

OpenMP





Interpretation

We can see that the GPU execution take less time that the one thread execution. So we can conclude that for this type of computation, GPU computation is better.