Project 4: Problem 1

20204898 박소은

Execution environment

- Colab: GPU T4

How to compile

cuda_ray.cu

```
!nvcc cuda_ray.cu -o cuda_ray
```

openmp_ray.cpp

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

How to execute

cuda_ray.cu

```
!./cuda_ray
```

openmp_ray.cpp

```
./openmp_ray.exe [num_thread] result.ppm
```

Entire source code

cuda_ray.cu

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

#define CUDA 0
#define OPENMP 1
#define SPHERES 20

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


// Indicates 3D sphere shape: sphere location, radius, and color information
struct Sphere {
    float   r,b,g;
    float   radius;
    float   x,y,z;
};

// kernel function
__global__ void CUDA_kernel(Sphere* s, unsigned char* ptr) {
  int x = threadIdx.x + blockIdx.x * blockDim.x;
  int y = threadIdx.y + blockIdx.y * blockDim.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 dx = ox - s[i].x;
    float dy = oy - s[i].y;
    float t, n;

    // hit() function
    if (dx * dx + dy * dy < s[i].radius * s[i].radius) {
      float dz = sqrtf(s[i].radius * s[i].radius - dx * dx - dy * dy);
      n = dz / sqrtf(s[i].radius * s[i].radius);
      t = dz + s[i].z;
```

```
    } else {
      t = -INF;
    }

    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;
}

// Function to store images in PPM file format
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");
  }
  printf("[result.ppm] was generated. \n");
}

int main(int argc, char* argv[])
{
  srand(time(NULL));
  FILE* fp = fopen("result.ppm", "w");

  // temp_s: Sphere used by the CPU
  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;
  }

  // cuda_s: Sphere used by the GPU
  Sphere *cuda_s;
  cudaMalloc((void**)&cuda_s, sizeof(Sphere) * SPHERES);
  cudaMemcpy(cuda_s, temp_s, sizeof(Sphere) * SPHERES, cudaMemcpyHostToDevice);

  // bitmap: Bitmap used by CPU
  unsigned char* bitmap;
  bitmap = (unsigned char*)malloc(sizeof(unsigned char) * DIM*DIM*4);

  // cuda_bitmap: Bitmap used by GPU
  unsigned char* cuda_bitmap;
  cudaMalloc((void**)&cuda_bitmap, sizeof(unsigned char) *DIM*DIM*4);
  cudaMemcpy(cuda_bitmap, bitmap, sizeof(unsigned char)*DIM*DIM*4,
cudaMemcpyHostToDevice);

  // Execution configuration
  dim3 gridDims(DIM / 16, DIM / 16);
  dim3 blockDims(16, 16);

  clock_t start = clock();
  CUDA_kernel<<<gridDims, blockDims>>>(cuda_s, cuda_bitmap);
  clock_t end = clock();

  cudaDeviceSynchronize();   // Wait until GPU ends
  cudaMemcpy(bitmap, cuda_bitmap, sizeof(unsigned char)*DIM*DIM*4,
cudaMemcpyDeviceToHost);   // Copy the result

  clock_t exe_time = end - start;
  double exe_time_ms = ((double)exe_time / CLOCKS_PER_SEC) * 1000.0;
  printf("CUDA ray tracing: %f ms \n", exe_time_ms);

  ppm_write(bitmap,DIM,DIM,fp);   // write ppm file

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

  return 0;
}
```

openmp_ray.cpp

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

#pragma warnings(disable: 4996)
#define _CRT_SECURE_NO_WARNINGS
#define CUDA 0
#define OPENMP 1
#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);

        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");
        }
        printf("[result.ppm] was generated. \n");
}

int main(int argc, char* argv[])
{
        int no_threads, x, y;
        srand(time(NULL));

        if (argc != 2) {
                printf("> a.out [threadNum]\n");
                printf("[threadNum] 1~16: OpenMP using 1~16 threads\n");
                exit(0);
        }
        FILE* fp = fopen("result.ppm", "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;
	}

	unsigned char* bitmap;
	bitmap = (unsigned char*)malloc(sizeof(unsigned char) * DIM * DIM * 4);

	// Set the number of threads
	omp_set_num_threads(no_threads);

	clock_t start = clock();
#pragma omp parallel for default(shared) private(x, y)
	for (x = 0; x < DIM; x++) {
		for (y = 0; y < DIM; y++) {
			kernel(x, y, temp_s, bitmap);
		}
	}
	clock_t end = clock();

	clock_t exe_time = end - start;
	double exe_time_ms = ((double)exe_time / CLOCKS_PER_SEC) * 1000.0;
	printf("OpenMP (%d threads) ray tracing: %f ms \n", no_threads, 
exe_time_ms);

	ppm_write(bitmap, DIM, DIM, fp);

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

	return 0;
}
```

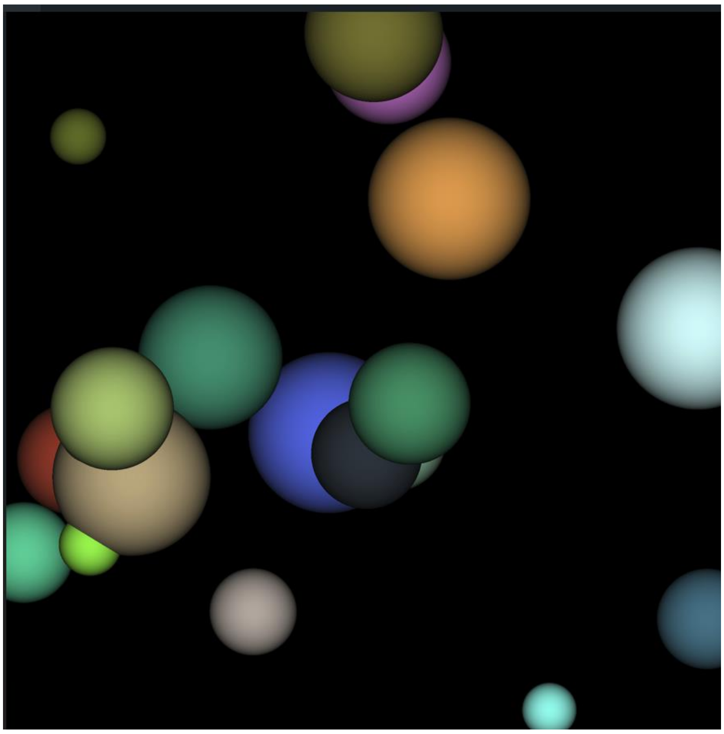
Program output results, Ray-tracing result pictures

cuda_ray.cu

```
[10] !nvcc cuda_ray.cu -o cuda_ray

[11] !./cuda_ray

CUDA ray tracing: 0.027000 ms
[result.ppm] was generated.
```



openmp_ray.c

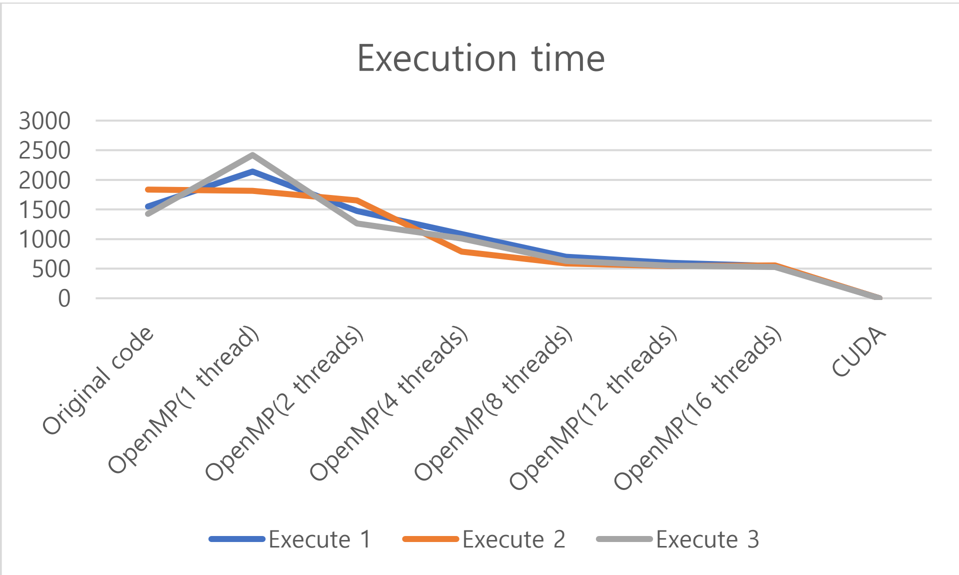
```
Microsoft Visual Studio 디버그

OpenMP (8 threads) ray tracing: 605.000000 ms
[result.ppm] was generated.
```

Experimental results

As a result of executing each code three times, each execution time and the average are as follows.

	Execute 1	Execute 2	Execute 3	Average(ms)
Original code	1547	1835	1424	**1602**
OpenMP(1 thread)	2140	1816	2419	**2125**
OpenMP(2 threads)	1476	1652	1262	**1463.33333**
OpenMP(4 threads)	1086	789	1009	**961.333333**
OpenMP(8 threads)	699	587	633	**639.666667**
OpenMP(12 threads)	599	542	549	**563.333333**
OpenMP(16 threads)	542	555	530	**542.333333**
CUDA	0.037	0.022	0.02	**0.02633333**



The original code had an average execution time of 1602ms.

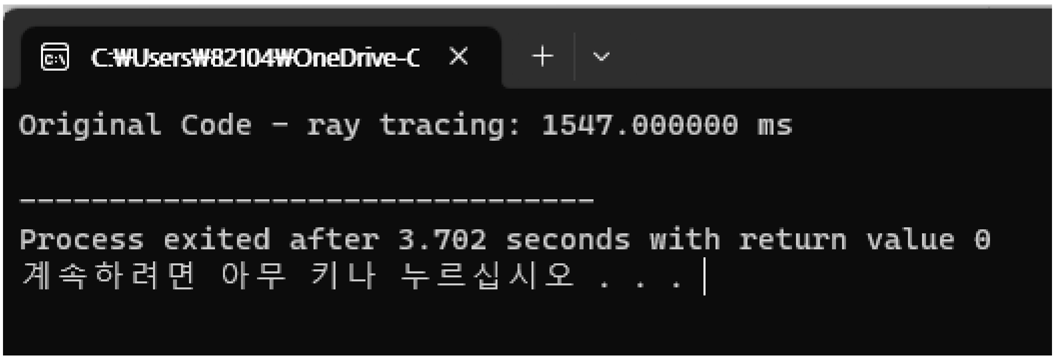
In the case of OpenMP, as the number of threads increases, the execution time decreases. This is due to the improved calculation by parallel processing. The performance can be improved as it takes advantage of the physical CPU cores.

CUDA uses GPU for parallel processing, which allows high degree of parallelism by a large number of cores. Also, CUDA is specifically designed for vector operations, and this example is advantageous for GPU processing in that the sphere calculations can be processed in parallel(One thread can calculate one pixel). Therefore, this example has better performance when it is processed by GPU.

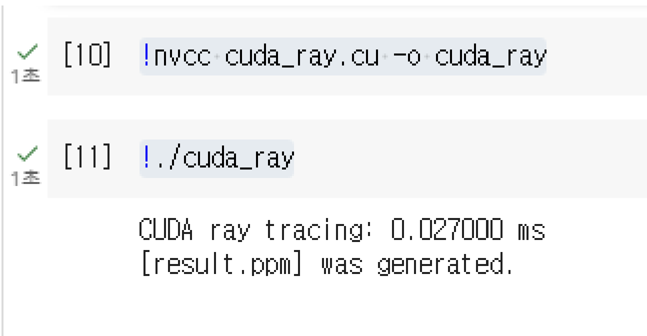
Compared to GPU, the OpenMP uses fewer cores(threads) and has limit on memory hierarchy. In CUDA, 128 blocks are created, and each block has 256 threads. The total number of threads is 1,048,576. CUDA has 8192 times more threads than OpenMP(16 threads), and perform 20,000 times more faster.

Screen captures of output result.

- Original code



- CUDA



- OpenMP