Name: Amir Yakubov
Group: BDA-2008
E-mail: 201463@astanait.edu.kz

Main part:

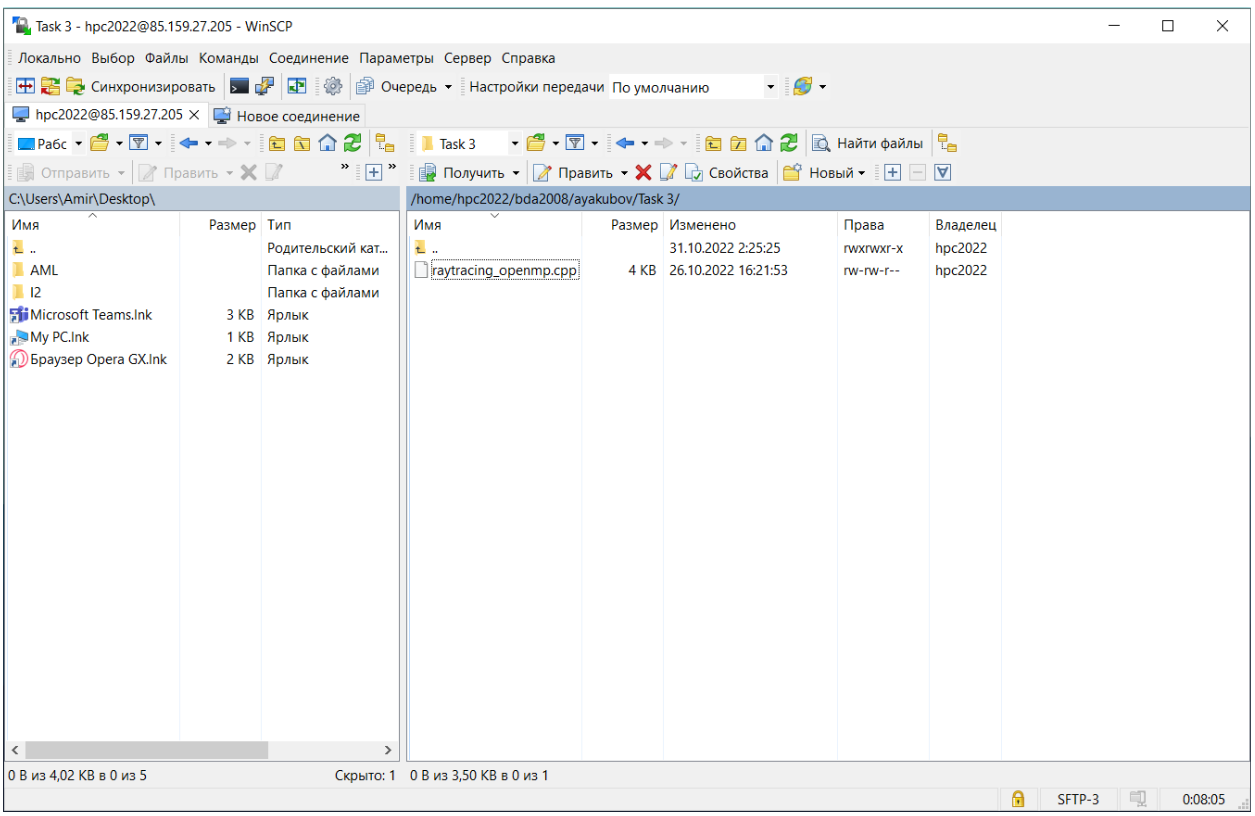
Step 0:

We will be using the sequential ray tracing program from Task 1. Download and install Mini-Rt library (https://github.com/georgy-schukin/mini-rt), if necessary.

Step 1: Prepare a directory for the Task 3

In your personal directory:

- Create directory "Task 3"
- Copy the sequential program to this new directory
- Rename the file to raytracing_openmp.cpp



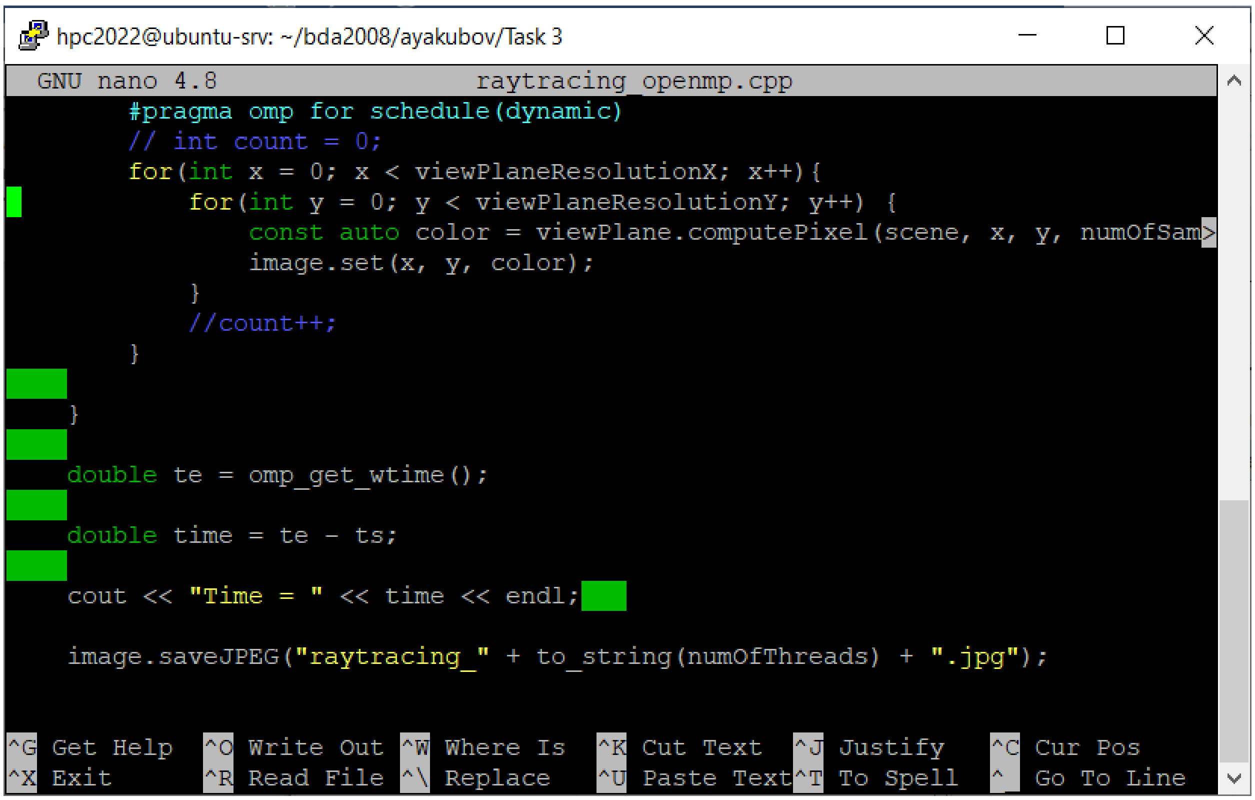
Step 2: Implement parallel program with OpenMP

Use OpenMP to parallelize the sequential ray tracing program (edit raytracing_openmp.cpp); the single image should be computed in parallel by many threads. Use **#pragma omp parallel** and **#pragma omp for** directives (or **#pragma omp parallel for** combined directive) to parallelize the main computational loop (in which image is computed pixel by pixel).

Hint: you can use [this program template] as a starting point.

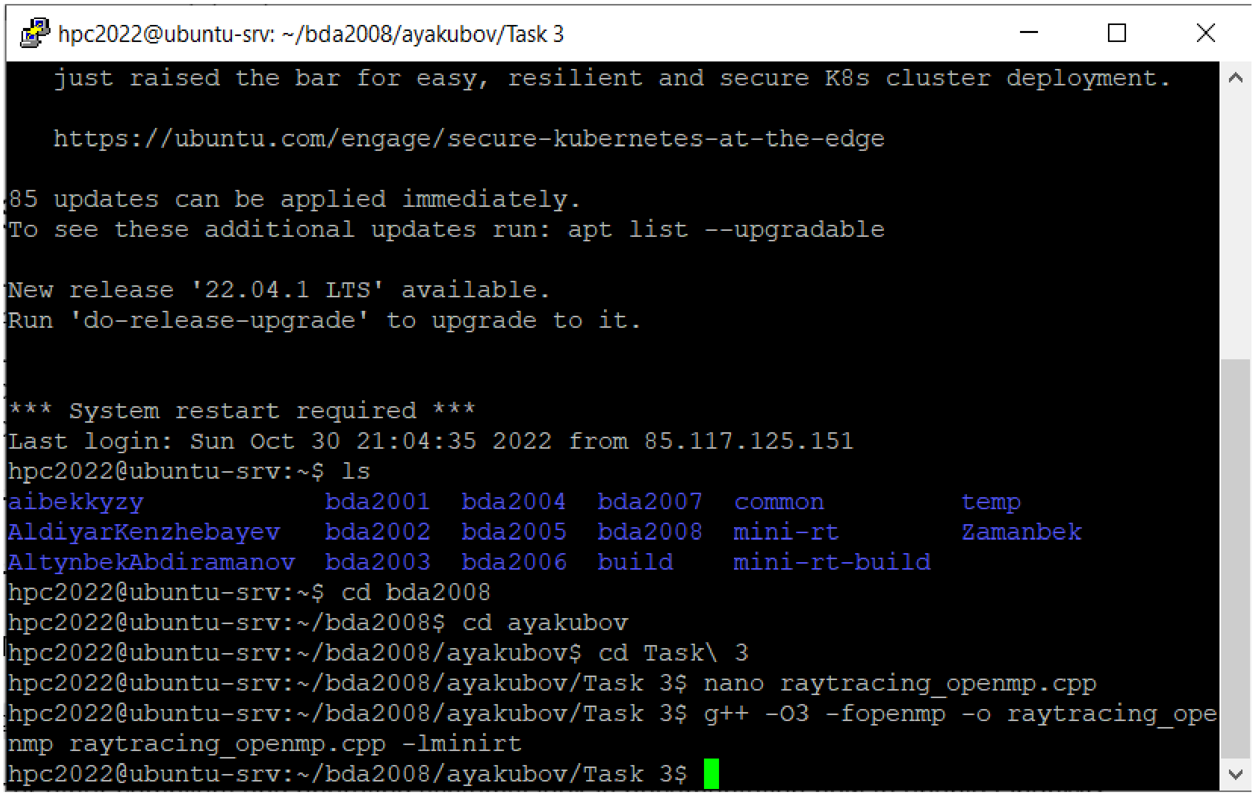
Hint: study [this program example] about parallelizing ‘for’ loop with OpenMP.

To compile your program with OpenMP support (Linux/Mac):



```
hpc2022@ubuntu-srv: ~/bda2008/ayakubov/Task 3
  GNU nano 4.8                    raytracing_openmp.cpp
        #pragma omp for schedule(dynamic)
        // int count = 0;
        for(int x = 0; x < viewPlaneResolutionX; x++){
            for(int y = 0; y < viewPlaneResolutionY; y++) {
                const auto color = viewPlane.computePixel(scene, x, y, numOfSam>
                image.set(x, y, color);
            }
            //count++;
        }

    }

    double te = omp_get_wtime();

    double time = te - ts;

    cout << "Time = " << time << endl;

    image.saveJPEG("raytracing_" + to_string(numOfThreads) + ".jpg");

^G Get Help   ^O Write Out  ^W Where Is   ^K Cut Text   ^J Justify    ^C Cur Pos
^X Exit       ^R Read File  ^\ Replace    ^U Paste Text ^T To Spell   ^_ Go To Line
```

g++ -O3 -fopenmp -o raytracing_openmp raytracing_openmp.cpp -lminirt



For other compilers and operating systems: look in documentation how to enable OpenMP.

To run your OpenMP program with N threads, first set value of OMP_NUM_THREADS environment variable:

export OMP_NUM_THREADS=*N* && ./raytracing_openmp <args>

Or set number of threads with omp_set_num_threads() function or num_threads() clause (setting number of threads this way will override value from OMP_NUM_THREADS variable).

Compare performance with different parameters of the **schedule** clause for 'for' directive (for example, **schedule(static)**, **schedule(static, 1)** and **schedule(dynamic)**). Don't forget to recompile the program after changing the parameters. Explain the results. Why do some parameters provide better performance? Why are the others worse?

Step 3: Study performance of your parallel program

1. Use omp_get_wtime() to measure the execution time for the main loop:

   double start = omp_get_wtime();

```
#pragma omp …
for(int x = …)
for(int y = …) {
    const auto color = viewPlane.computePixel(
                    scene, x, y, numOfSamples);
…
}
```

double end = omp_get_wtime();

double execution_time = end - start;

std::cout << "Time = " << execution_time << std::endl;

2. Select such a scene and rendering parameters (image size, number of samples, depth of recursion, etc.), that the execution time of the program, when running on 1 thread, is more than several seconds.
3. Measure the execution time for the parallel program on 1, 2, 4, 8, 16 threads. For accuracy you can do several runs (>5) on each number of threads and choose the minimal time among runs for this number of threads.
4.

Static schedule

```
hpc2022@ubuntu-srv: ~/bda2008/ayakubov/Task 3
hpc2022@ubuntu-srv:~/bda2008/ayakubov/Task 3$ g++ -O3 -fopenmp -o raytracing_ope
nmp raytracing_openmp.cpp -lminirt
hpc2022@ubuntu-srv:~/bda2008/ayakubov/Task 3$ export OMP_NUM=1 && ./raytracing_o
penmp 1 640 480 10
^[[B^[[A^[[DTime = 7.18727
hpc2022@ubuntu-srv:~/bda2008/ayakubov/Task 3$ export OMP_NUM=1 && ./raytracing_o
penmp 1 640 480 10
Time = 7.19286
hpc2022@ubuntu-srv:~/bda2008/ayakubov/Task 3$ export OMP_NUM_THREADS=1 && ./rayt
racing_openmp 1 640 480 10
Time = 7.20417
hpc2022@ubuntu-srv:~/bda2008/ayakubov/Task 3$ export OMP_NUM_THREADS=2 && ./rayt
racing_openmp 2 640 480 10
Time = 4.70045
hpc2022@ubuntu-srv:~/bda2008/ayakubov/Task 3$ export OMP_NUM_THREADS=2 && ./rayt
racing_openmp 4 640 480 10
Time = 2.55789
hpc2022@ubuntu-srv:~/bda2008/ayakubov/Task 3$ export OMP_NUM_THREADS=2 && ./rayt
racing_openmp 8 640 480 10
Time = 2.05880
hpc2022@ubuntu-srv:~/bda2008/ayakubov/Task 3$ export OMP_NUM_THREADS=2 && ./rayt
racing_openmp 16 640 480 10
Time = 1.34910
hpc2022@ubuntu-srv:~/bda2008/ayakubov/Task 3$
```

Static, 1 schedule

hpc2022@ubuntu-srv: ~/bda2008/ayakubov/Task 3

```
hpc2022@ubuntu-srv:~/bda2008/ayakubov/Task 3$ export OMP_NUM_THREADS=1 && ./rayt
racing_openmp 1 640 480 10
Time = 7.2152
hpc2022@ubuntu-srv:~/bda2008/ayakubov/Task 3$ export OMP_NUM_THREADS=1 && ./rayt
racing_openmp 2 640 480 10
Time = 3.69257
hpc2022@ubuntu-srv:~/bda2008/ayakubov/Task 3$ export OMP_NUM_THREADS=1 && ./rayt
raing_openmp 4 640 480 10
-bash: ./raytraing_openmp: No such file or directory
hpc2022@ubuntu-srv:~/bda2008/ayakubov/Task 3$ export OMP_NUM_THREADS=1 && ./rayt
racing_openmp 4 640 480 10
Time = 2.17021
hpc2022@ubuntu-srv:~/bda2008/ayakubov/Task 3$ export OMP_NUM_THREADS=1 && ./rayt
racing_openmp 8 640 480 10
Time = 1.16165
hpc2022@ubuntu-srv:~/bda2008/ayakubov/Task 3$ export OMP_NUM_THREADS=1 && ./rayt
racing_openmp 16 640 480 10
Time = 0.82552
hpc2022@ubuntu-srv:~/bda2008/ayakubov/Task 3$
```

Dynamic schedule

hpc2022@ubuntu-srv: ~/bda2008/ayakubov/Task 3

```
hpc2022@ubuntu-srv:~/bda2008$ cd ayakubov
hpc2022@ubuntu-srv:~/bda2008/ayakubov$ cd Task\ 3
hpc2022@ubuntu-srv:~/bda2008/ayakubov/Task 3$ ls
raytracing_16.jpg  raytracing_2.jpg  raytracing_8.jpg   raytracing_openmp.cpp
raytracing_1.jpg   raytracing_4.jpg  raytracing_openmp
hpc2022@ubuntu-srv:~/bda2008/ayakubov/Task 3$ nano raytracing_openmp.cpp
hpc2022@ubuntu-srv:~/bda2008/ayakubov/Task 3$ g++ -O3 -fopenmp -o raytracing_ope
nmp raytracing_openmp.cpp -lminirt
hpc2022@ubuntu-srv:~/bda2008/ayakubov/Task 3$ export OMP_NUM_THREADS=1 && ./rayt
racing_openmp 1 640 480 10
Time = 7.19188
hpc2022@ubuntu-srv:~/bda2008/ayakubov/Task 3$ export OMP_NUM_THREADS=1 && ./rayt
racing_openmp 2 640 480 10
Time = 3.71028
hpc2022@ubuntu-srv:~/bda2008/ayakubov/Task 3$ export OMP_NUM_THREADS=1 && ./rayt
racing_openmp 4 640 480 10
Time = 1.88433
hpc2022@ubuntu-srv:~/bda2008/ayakubov/Task 3$ export OMP_NUM_THREADS=1 && ./rayt
racing_openmp 8 640 480 10
Time = 0.953725
hpc2022@ubuntu-srv:~/bda2008/ayakubov/Task 3$ export OMP_NUM_THREADS=1 && ./rayt
racing_openmp 16 640 480 10
Time = 0.591264
hpc2022@ubuntu-srv:~/bda2008/ayakubov/Task 3$
```

5. Build plots/tables for:
   a. The execution time (to demonstrate how it depends on the number of threads)
   b. Speedup: Speedup(N) = Time(1) / Time(N), N - number of threads
   c. Efficiency: Efficiency(N) = Speedup(N) / N

Static schedule

Number of threads	Execution time	Speedup(N)	Efficiency
1	7.20417	1	1
2	4.70045	1.53265	0.76632
4	2.55789	2.81645	0.63925
8	2.05880	3.49919	0.43739
16	1.34910	5.33996	0.33374

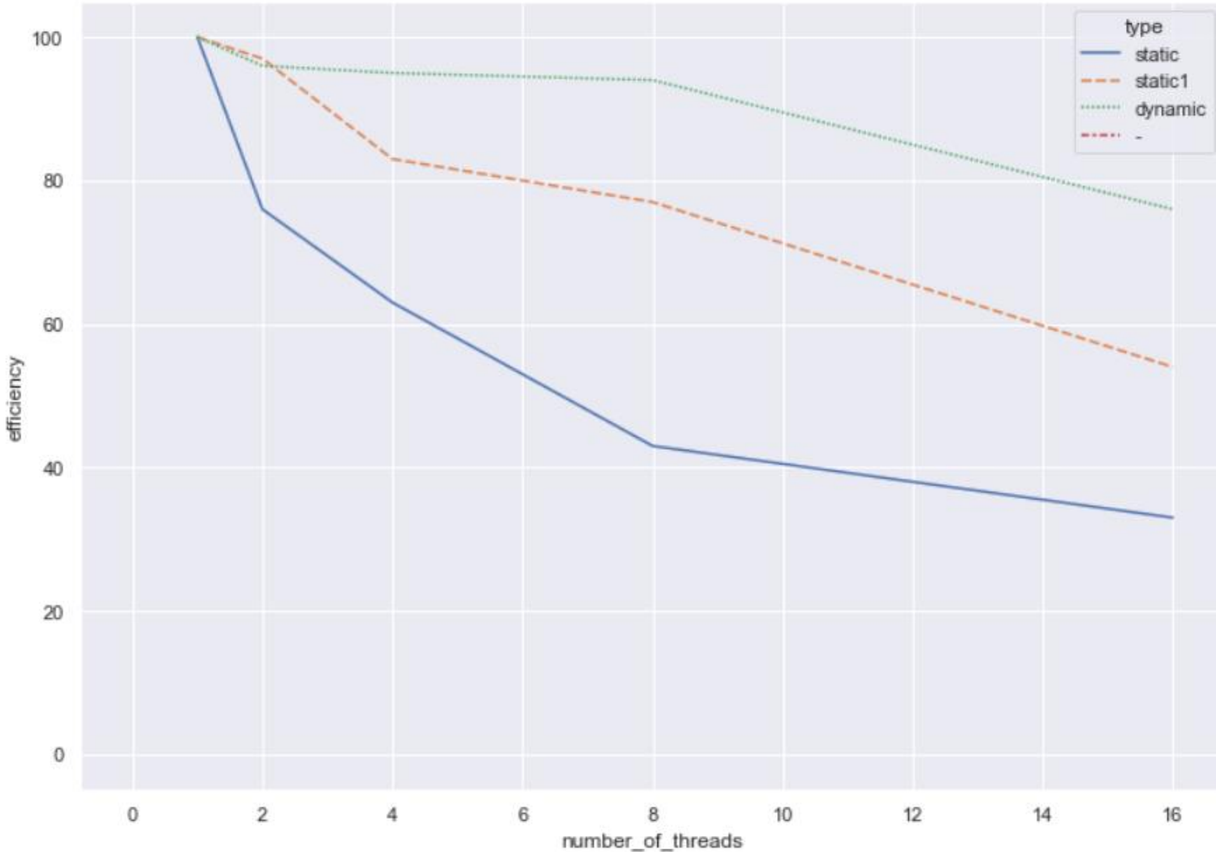
Static, 1 schedule

Number of threads	Execution time	Speedup(N)	Efficiency
1	7.2152	1	1
2	3.69257	1.95397	0.97397
4	2.17021	3.32464	0.83116
8	1.16165	6.21115	0.77639
16	0.82552	8.74013	0.54625

Dynamic schedule

Number of threads	Execution time	Speedup(N)	Efficiency
1	7.19188	1	1
2	3.71028	1.93836	0.96918
4	1.88433	3.81667	0.95416
8	0.953725	7.54074	0.94259
16	0.591264	12.16393	0.76024

Remember that you have to compare performance of the program with different parameters of the **schedule** clause. So, you will have multiple lines on your plots for different versions of parameters.



Efficieny in procents.

Step 4: Commit and push your changes to the Gitlab server

Upload your source code files in Task 3 directory to your Github repository, include a link to it in the report.
https://github.com/Am1rrr/hpc/tree/main/Task%203

Step 5: Conclusion in a free form

Dynamic scheduling is acceptable when varied computing expenses are needed at various iterations. This suggests that there isn't a good enough balance between iterations and static methods. However, because it distributes the iterations dynamically while the program is running, the dynamic scheduling type has more overhead than the static scheduling type. The sole reason why dynamic scheduling is not much more efficient than static scheduling is that the time required to create an image is too brief to serve as an accurate comparison. It was probably worthwhile to do this in order to increase the picture's resolution or the sample count.