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RGB Images Histogram Equalization

Francesco Lombardi
Alessandro Minervini

Introduction

Histogram Equalization is an image's histogram based technique used in image processing to improve an image. Given a greyscale one, we have to:

1. Compute its histogram;

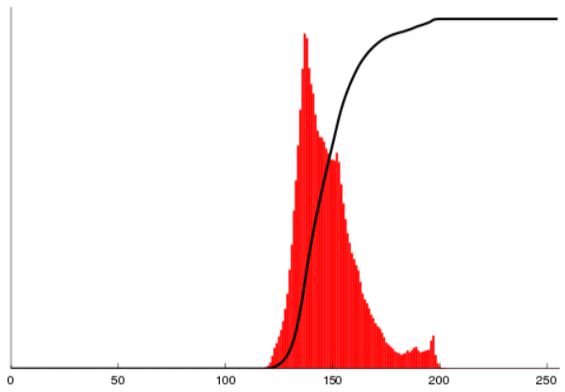
2. Apply the following rule to compute equalization:

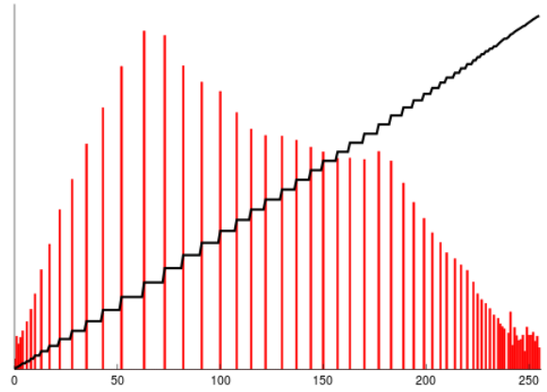
$$h_{eq}(hist) = round(\frac{cdf(hist) - cdf(0)}{(N * M) - 1} * (L - 1))$$

where cdf is the cumulative distribution function, $N * M$ is image size and $L - 1$ is the maximum value for a pixel.

3. Update image histogram with the computed values.

An example of greyscale image histogram equalization:





Histogram Equalization can be realized also with RGB images. In order to do this we have followed the steps below:

1. Switch to a different color space having a Y channel (YUV in our case);

2. Compute the histogram of Y channel values;

3. Equalize the histogram and map old values with the new ones;

4. Turn back to RGB color space.

An example of RGB image histogram equalization:

Languages

We have implemented the task using different technologies:

- **C++** for the sequential version;
- **OpenMP** for the first parallel version;
- **CUDA/C++** for the second parallel version.

Implementation

Sequential version is made by 3 main functions:

```
function Make_Histogram
Data: image, histogram, YUV_image;
initialize histogram;
for i = 0, i<image.cols, i ++ do
    for j = 0, j<image.cols, j ++ do
        R, G, B = image(i,j);
        Y = R * 0.299 + G * 0.587 + B * 0.114;
        U = R * -0.168736 + G * -0.331264 + B * 0.5
          + 128;
        V = R * 0.5 + G * -0.418688 + B * -0.081312
          + 128;
        histogram[Y]++;
        YUV_image(i,j) = Y, U, V;
    end
end
```

Algorithm 1: Make_histogram

Implementation

```
function Cumulative_Histogram
Data: histogram, equalized_histogram, image.cols,
      image.rows;
cumulative_histogram[256];
for i = 0, i<256, i ++ do
    cumulative_histogram[i] = histogram[i] +
     cumulative_histogram[i-1];
    equalized_histogram[i] = (cumulative_histogram[i]
     - histogram[0])/(cols * rows - 1)*255);
end
```

Algorithm 2: Cumulative_histogram

```
function Equalize
Data: image, equalized_histogram, YUV_image;
initialize histogram;
for i = 0, i < image.cols, i ++ do
    for j = 0, j < image.cols, j ++ do
        Y = equalized_histogram[YUV_image(i,j)];
        U = YUV_image(i,j);
        V = YUV_image(i,j);
        R = max(0, min(255,(int)(Y + 1.4075 * (V -
         128))));
        G = max(0, min(255,(int)(Y - 0.3455 * (U -
         128) - (0.7169 * (V - 128)))));
        B = max(0, min(255,(int)(Y + 1.7790 * (U -
         128))));
        image(i,j) = R, G, B;
    end
end
```

Algorithm 3: Equalize

Implementation

OpenMP version has been implemented reusing the sequential code and entrusting the **for loop** computation to an OMP specific structure:

```
#pragma omp parallel default(shared)
    {
#pragma omp for schedule(static)
        for (int i = 0; i < image.rows; i++) {
            for (int j = 0; j < image.cols; j++) {
                */ code here /*
            }
        }
    }
```

Implementation

To implement CUDA version some characteristic functions have been used:

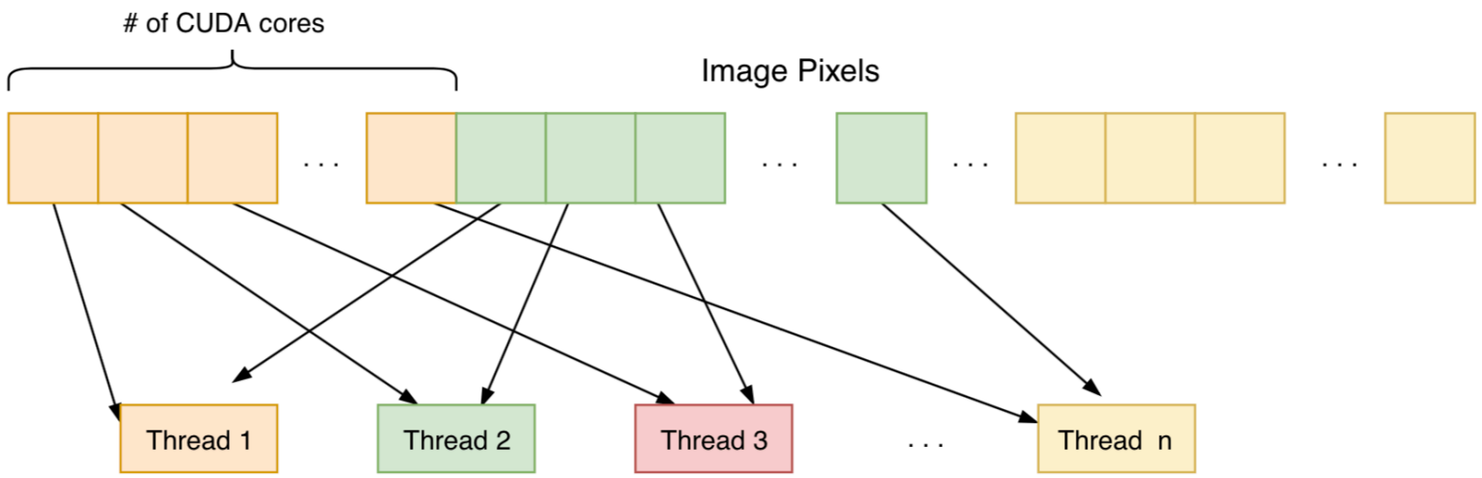
- *cudaMalloc()* to allocate arrays in the GPU;
- *cudaMemcpy()* to copy arrays from CPU to GPU and vice versa;
- *cudaFree()* to free GPU.

Moreover CUDA kernels *make_histogram()*, *equalize()* and *YUV2RGB()* have been implemented to execute the functions shown before.

In order to implement CUDA version we have paid special attention on image's pixels management:

- Images have been computed assigning one CUDA core to each pixel (as long as it was possible)

- Otherwise CUDA cores follow the pattern below:

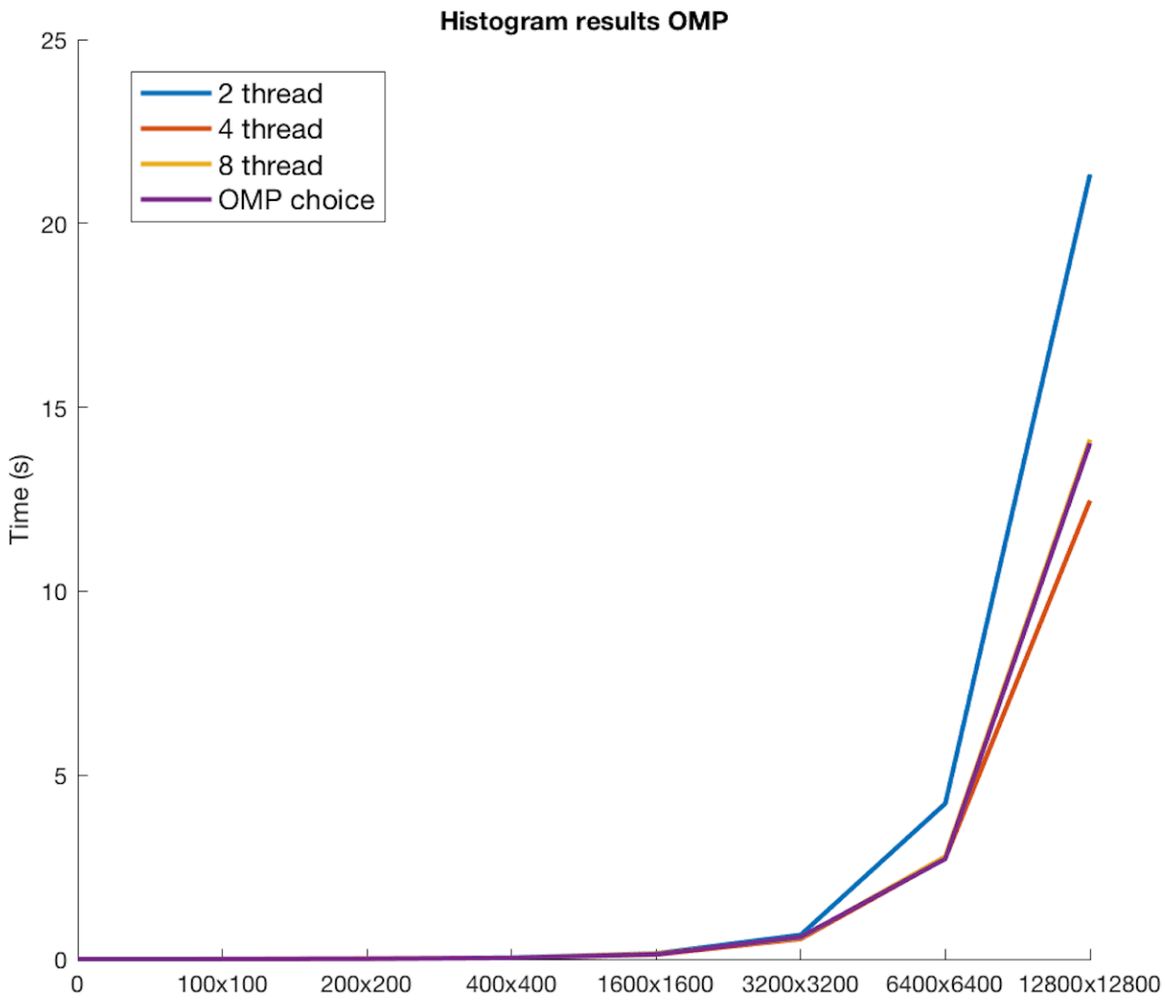


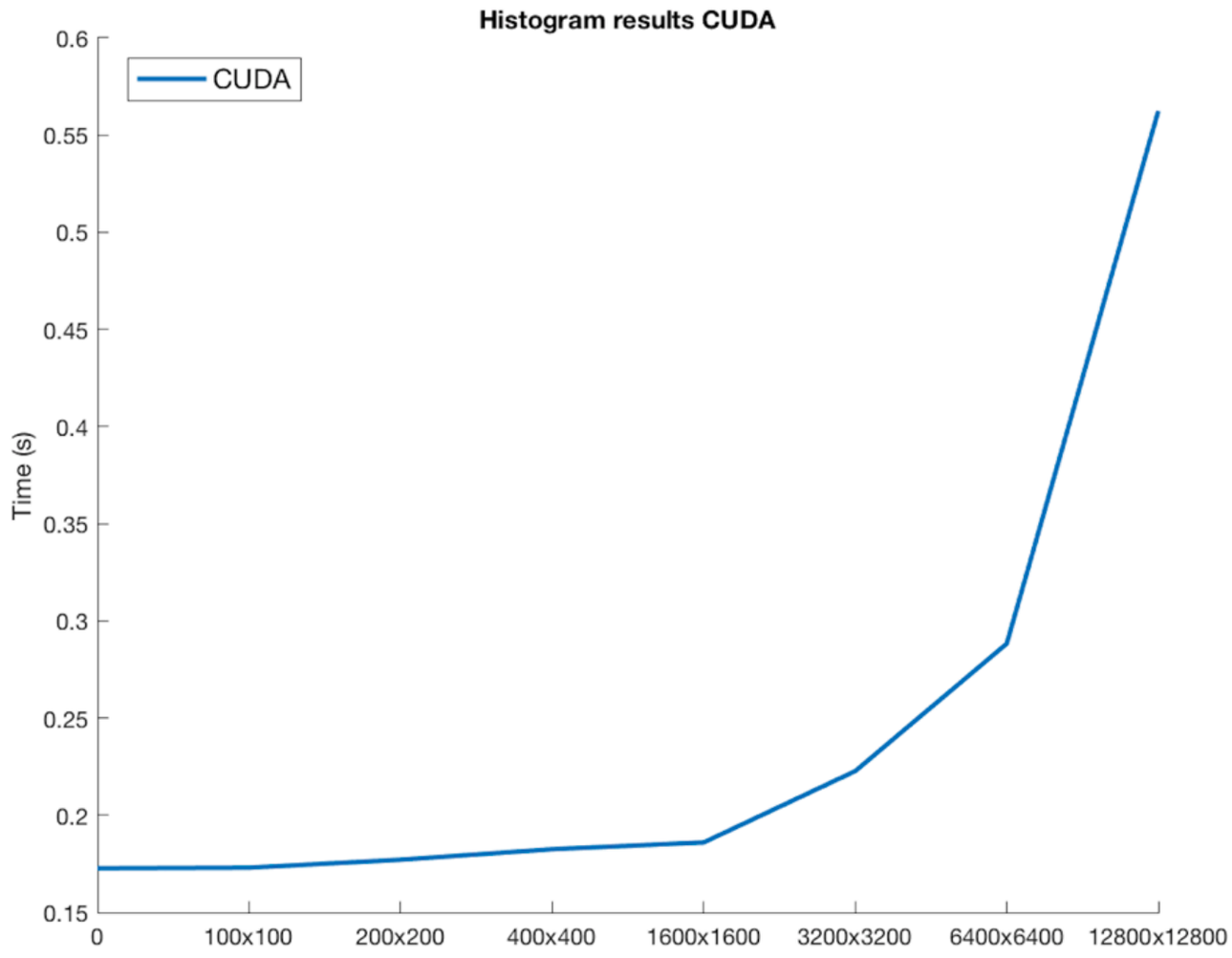
Results

The following results have been obtained:

- when varying image dimensions (100x100, 200x200, … , 12800x12800);
- when varying the number of threads (until saturation);
- mediating between 10 runs of the same task.

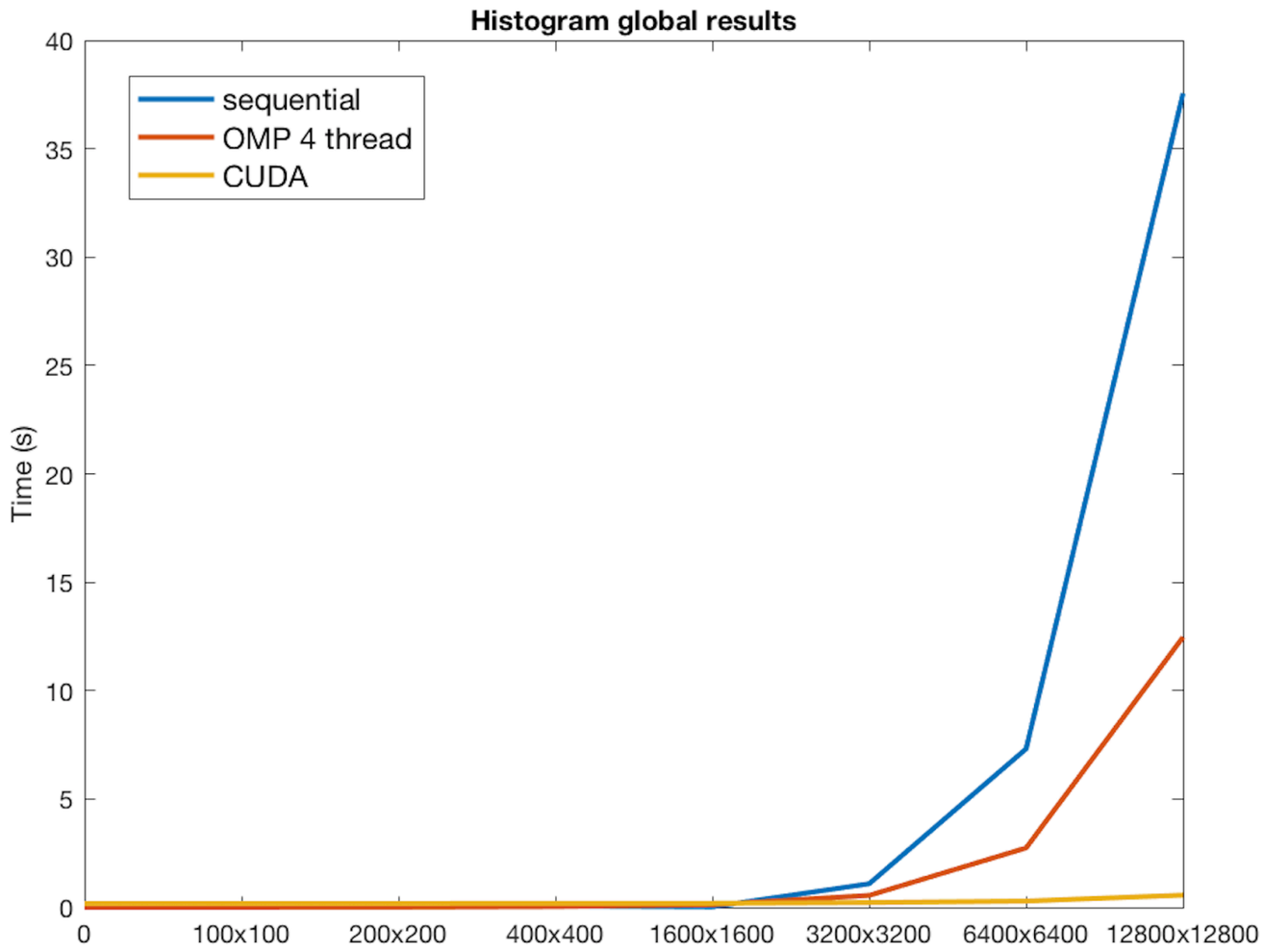
Results


Histogram results OMP
2 thread
4 thread
8 thread
OMP choice
Time (s)
0
5
10
15
20
25
0
100x100
200x200
400x400
1600x1600
3200x3200
6400x6400
12800x12800

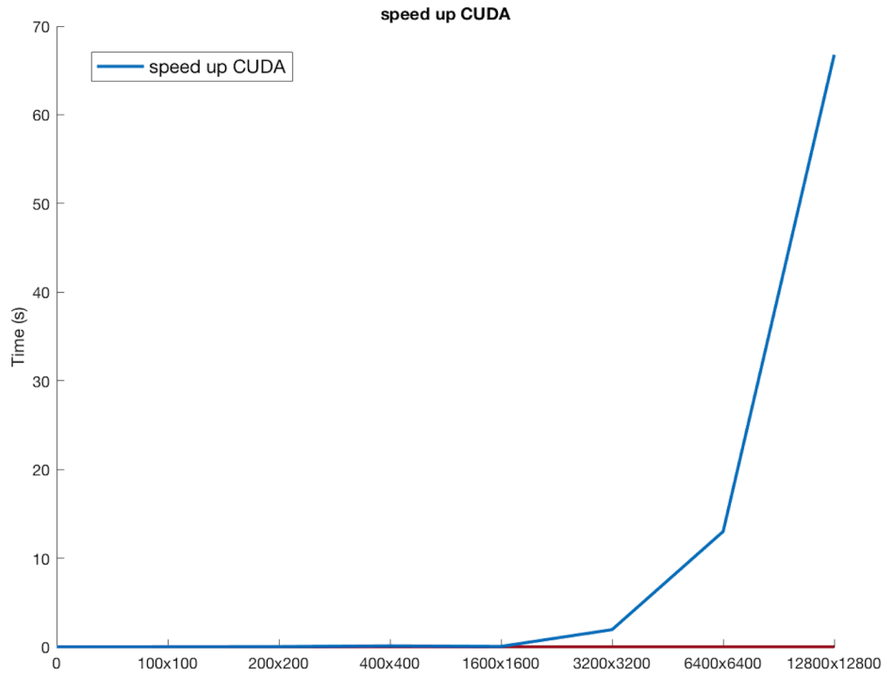

Histogram results CUDA
CUDA
Time (s)
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0
100x100
200x200
400x400
1600x1600
3200x3200
6400x6400
12800x12800

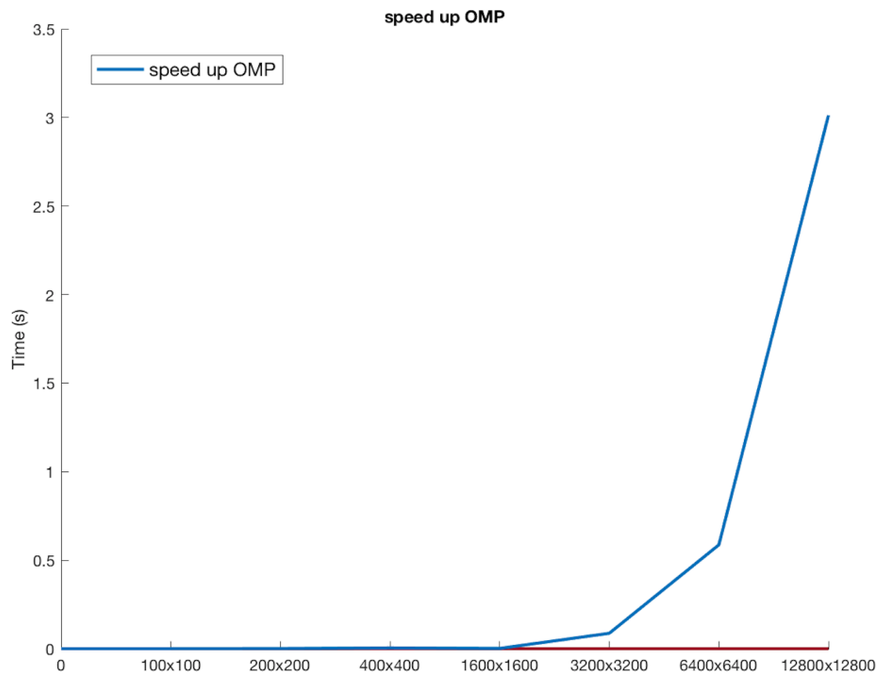
Results

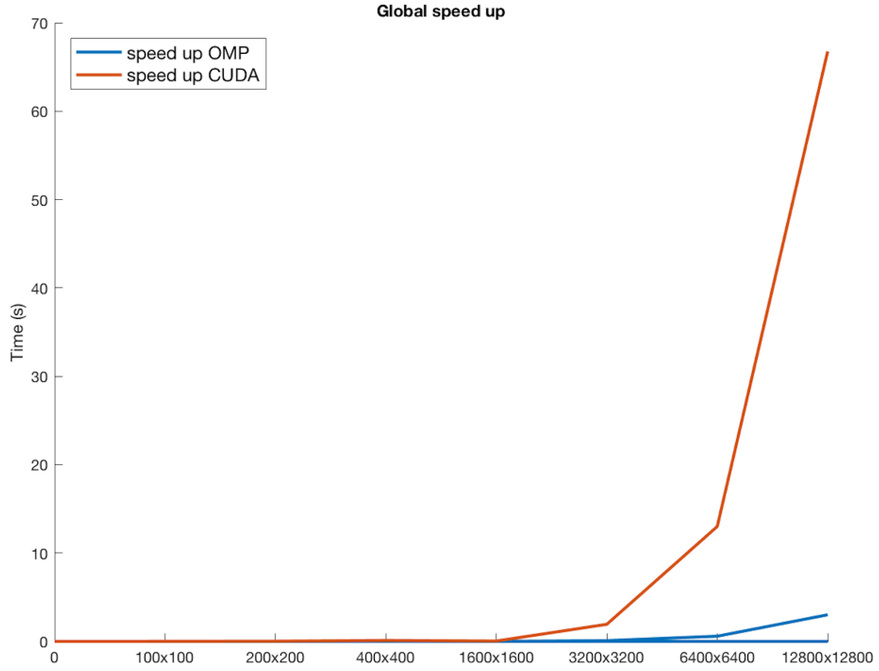
The best configurations of different implementation are compared below:



Speed Up


speed up CUDA
Time (s)
0
10
20
30
40
50
60
70
0
100x100
200x200
400x400
1600x1600
3200x3200
6400x6400
12800x12800


speed up OMP
Time (s)
0
0.5
1
1.5
2
2.5
3
3.5
0
100x100
200x200
400x400
1600x1600
3200x3200
6400x6400
12800x12800


Global speed up
speed up OMP
speed up CUDA
Time (s)
0
10
20
30
40
50
60
70
0
100x100
200x200
400x400
1600x1600
3200x3200
6400x6400
12800x12800

Notes

1. OpenCV library has been used to load, resize and (in CUDA) save images.

2. Two different time evaluators have been used to compute execution time:

   - OpenMP' s *omp_get_wtime()* for sequential and OMP;

   - *gettimeofday()* for CUDA version.

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