Author: Danis Alukaev Student ID: 19BS551

Assignment 2 – Report

Description of algorithm.

For Assignment 2, there was implemented program reproducing provided image using the set of symbols. This program is built based on a genetic algorithm inspired by the natural selection process. Follow the link to see how the algorithm works on the portrait of Charles Darwin.

The following sections will describe the foundation of the genetic algorithm: the chromosome representation, fitness function, selection, crossover, and mutation operators.

The algorithm was implemented in Python programming language. Images are stored as NumPy arrays. The reading and saving of images are performed using the *PIL* package. Symbols are drawn using the *PyCairo* package. To improve the performance of the program there was used *multiprocessing*, *concurrent.futures* packages that utilize all the cores of the user's machine CPU. Further instructions are described in README file.

Chromosome representation.

The set of symbols used to reproduce the image consists of Basic Latin, Latin-1 supplements, and digits. The genetic representation of each individual (chromosome) consists of genes comprising a symbol, its position, font size, and color. The size of the chromosome is a hyperparameter and could be changed by the user.

For the sake of clarity there was introduced class *Individual* having chromosome field. The chromosome is the list of genes (see Figure 1). Accordingly, the phenotype of an individual is an image built on the basis of a chromosome. This phenotype will be checked for similarity to the original image using fitness function.

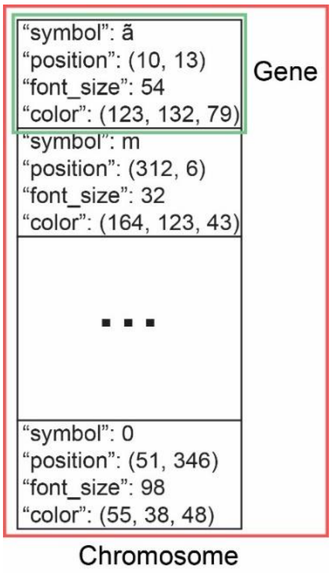

Figure 1. Chromosome representation.

Each gene is the dictionary with keys *symbol*, *position*, *font_size*, and *color*. The image is reconstructed from the chromosome by an iterative drawing of symbols. Consequently, each gene has a priority: genes closer to the end of the chromosome will display the symbols on the top of others.

Furthermore, there was introduced palette generator that can be used to define the desired color space. Reducing the search space significantly improves the performance of the algorithm (see Figure 2).

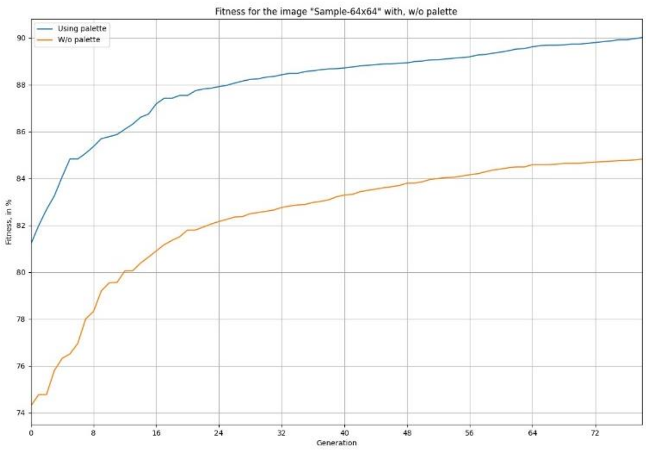

Figure 2. Comparison of the efficiency of the algorithm with and without the usage of the palette.

Selection of hyper parameters.

Three parameters do not depend on the original image and could be predefined: population size, elite unit size, and the number of mutations. However, the optimization problem of the three variable stochastic function arises. Unfortunately, I do not have enough computer resources at my disposal, so the proposed approach does not pretend to be precise and used only to assess the possibilities of using different parameters.

The performance of the program is measured by the time it takes to reach 90 % accuracy in terms of a fitness function. The program was tested on a sample 64×64 image.

Firstly, the population size was selected. The performance of the program was assessed for the population sizes in the range of [20..500]. For each population size, the algorithm was executed 100 times. Note that the other two parameters were taken at random. The idea was to explore the general impact of population size without considering fixed values of elite unit size and number of mutations. On average, the highest performance in terms of the execution time of the program was reached when the population size was 100 individuals (see Figure 3).

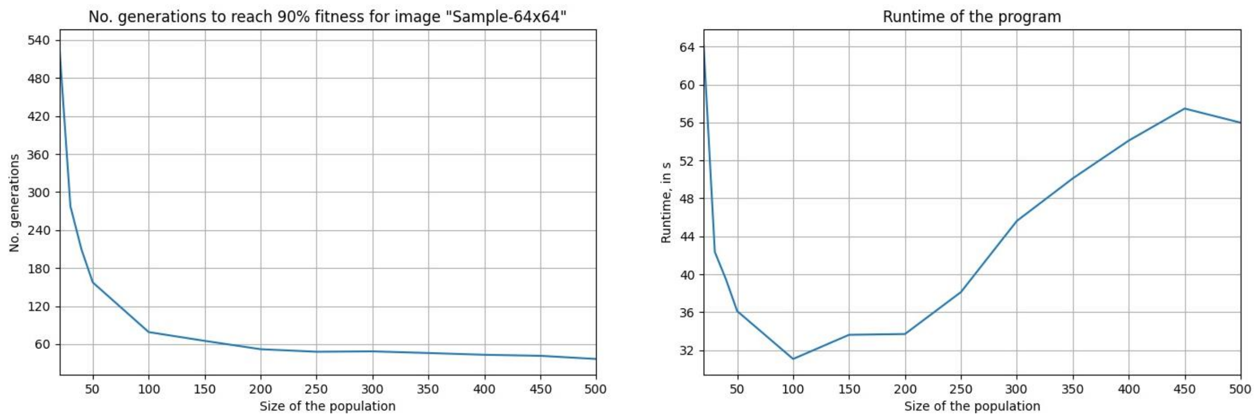

Figure 3. Population size examination.

Furthermore, the elite unit size was selected. The performance of the program was assessed for the elite unit sizes in the range of [4, 97]. For each elite unit size, the algorithm was executed 100 times. The population did not evolve when the elite unit size was 2, 3, 97, 98, and 99, so measurements for them were not included in the plot. Similar to the previous examination, the number of mutations was taken at random. On average, the highest performance in terms of the execution time of the program was reached when the elite unit size was 24 individuals (see Figure 4).

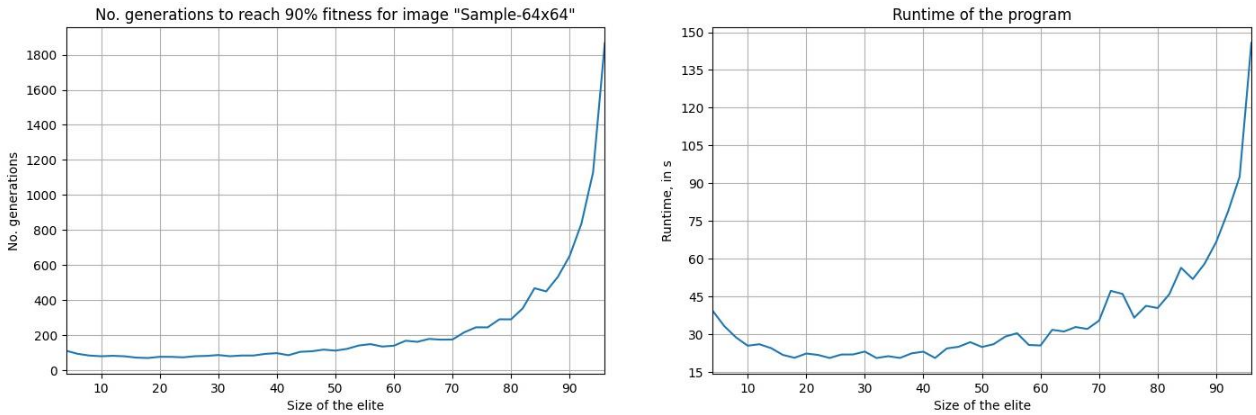

Figure 4. Elite unit size examination.

Finally, there was observed the effect of the number of mutations on the efficiency of the algorithm. On average, the highest performance in terms of the execution time of the program was reached when the mutation number was 2 (see Figure 5).

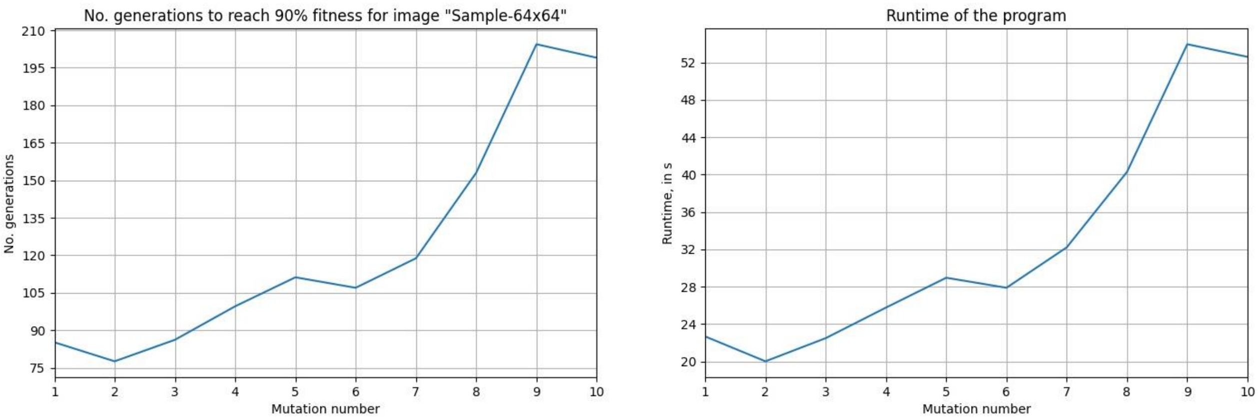

Figure 5. Mutation number examination.

Population size and selection technique.

In the previous section, there was described the examination process of different populations and elite unit sizes. Since the lowest execution time of the program is reached when the population size is 100 individuals and the elite unit size is 24 individuals, it does make sense to select them as hyperparameters.

The successive generations are composed of the 24 fittest individuals of the current generation (elite unit) and 76 of their offsprings. There was implemented the concept of fitness proportionate selection, i.e., each of the fittest individuals can be selected as a parent with a certain probability. This probability is assigned accordingly to the fitness of the individual: individuals with a greater probability are likely to be selected and have higher chances to pass their genes. Overall 76 pairs of parents were composed to mate them on the crossover stage.

Fitness function.

The fitness function is based on the Manhattan norm (ℓ_2-norm) performed on each channel of both pictures.

Essentially, there could be distinguished 3 steps:

1. Compute difference of original and produced images. Assume that original image has size of $N \times M$. Then, the resultant difference will be array of size $N \times M \times 3$ and each element is the number in range $[0..255]$.

2. Compute the absolute value of difference for each channel of each pixel. Accordingly, take the absolute value of each element in array obtained in the previous step.

3. Aggregate the total difference between images by summing all elements of the array.

For the sake of simplicity denote original image as an array $A_{N \times M \times 3}$ and resultant as $B_{N \times M \times 3}$. Thus, the fitness of individual can be found as follows:

$$\ell_2(A,B) = \sum_{i=0}^{N}\sum_{j=0}^{M}\sum_{k=0}^{2}\left|A[i][j][k] - B[i][j][k]\right|$$

$$fitness = N \times M \times 3 \times 255 - \frac{\ell_2(A,B)}{N \times M \times 3 \times 255}$$

In order not to be constrained by the precision of numbers with floating point, the fitness normalized only in the output of the program, i.e. all the comparisons performed on the numbers in range $[0..N \times M \times 3 \times 255]$.

Crossover stage.

At the selection stage, there were composed pairs of fittest individuals that will pass their genes to the next generation. Each pair produces only one offspring. At the crossover stage, the genetic information of both parents is combined.

The offspring's chromosome is composed of the randomly taken either from the first or second parent genes. The illustration of this operation can be seen in Figure 6. The operator is similar to the uniform crossover but produces only one chromosome.

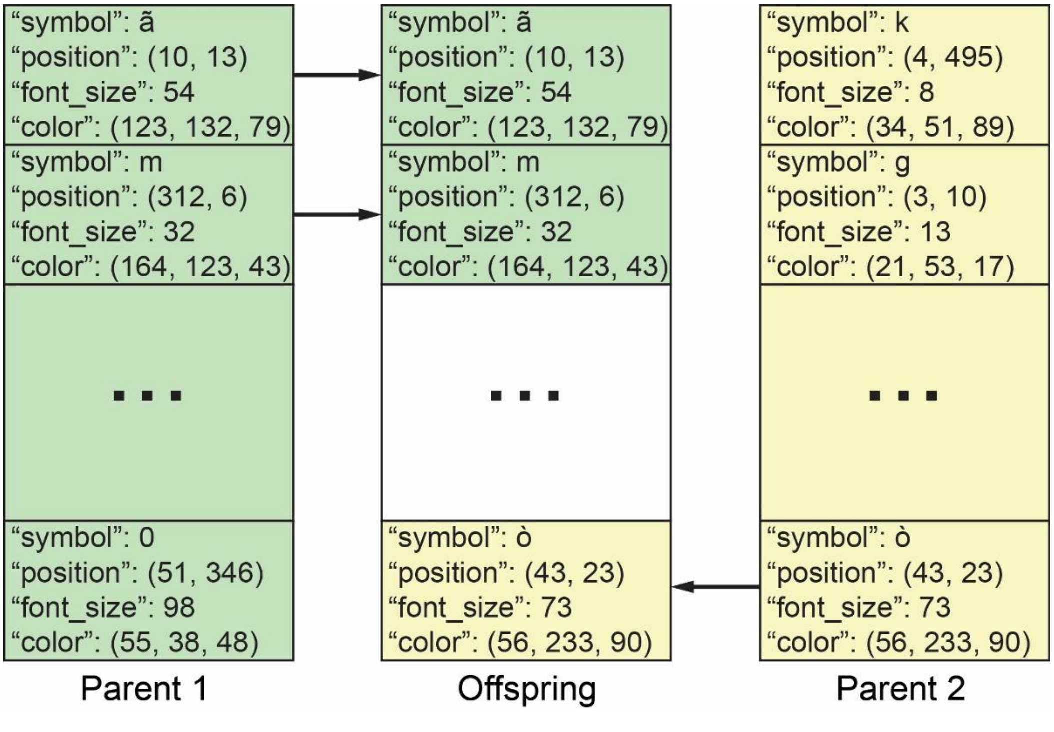

Figure 6. Crossover illustration.

In comparison with the one-point crossover and two-point crossover, the proposed method (uniform-based) ensures higher diversity in the successive population and results in the higher efficiency of the algorithm (see Figure 7).

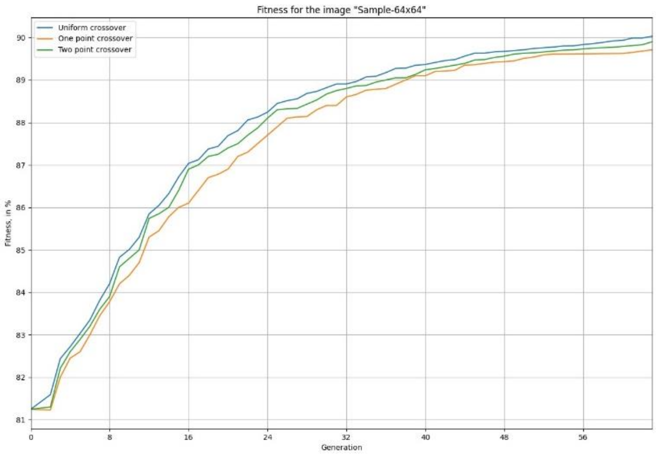

Figure 7. Assessment of different types of crossovers.

Mutation stage.

According to the examination of the mutations number the optimal parameter is 2. Thus, in the mutation stage to each individual obtained in the crossover stage, there were applied two mutations. The chromosome of each offspring could be mutated in four different ways:

1. Mutate the color parameter of the gene. The color of the symbol changes to random from the color space.

2. Mutate the priority of the gene, i.e., two random genes swapped.

3. Remove the randomly chosen gene and insert a new gene in the chromosome.

4. Mutate the entire gene by changing all the parameters. The priority stays unchanged.

Impact of genetic algorithm on sample images.

The impact of the proposed genetic algorithm was tested on five sample images provided below: portrait of Charles Darwin (see Figure 8), photo of the statue (see Figure 9), photo of Professor

Joseph Alexander Brown (see Figure 10), photo of mandrill (see Figure 11) and the Mona Lisa (see Figure 12).

Portrait of Charles Darwin.

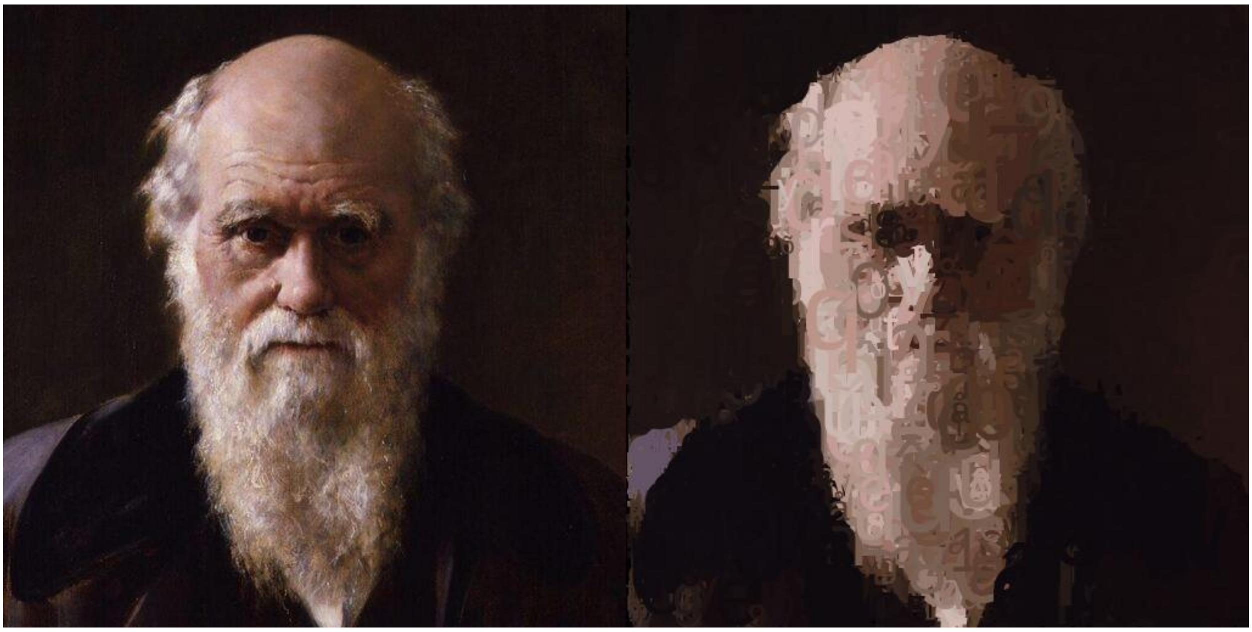

Figure 8a. Original portrait of Charles Darwin (left), result of the algorithm (right).

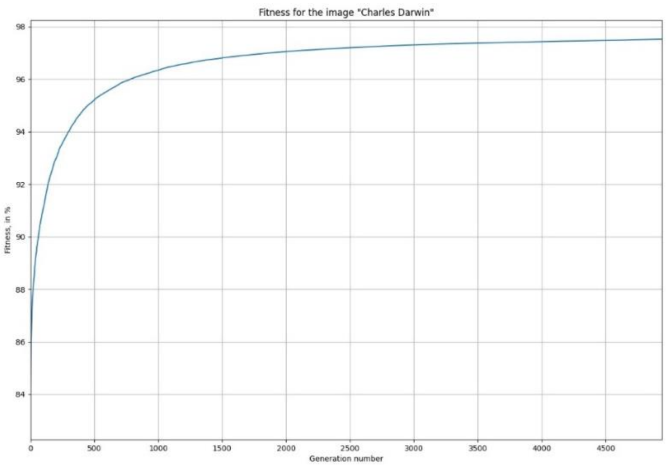

Figure 8b. Fitness plot.

The program produced 4949 generations, which took ~ 3.43 hours, to achieve the maximal ~ 97.1761% fitness of the individual in the population

Photo of the statue.

Figure 9a. Original photo of statue (left), result of the algorithm (right).

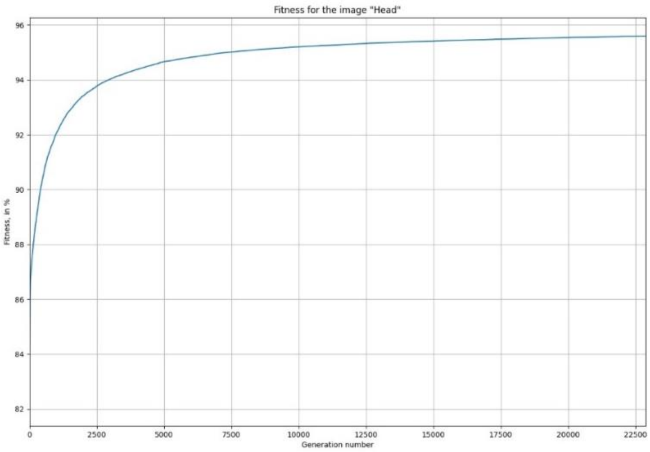

Figure 9b. Fitness plot.

The program produced 22887 generations, which took ~ 13.3 hours, to achieve the maximal ~ 95.2152% fitness of the individual in the population. Since it was decided to upload this image for the contest, I tried to produce as many generations as possible.

Photo of Professor Joseph Alexander Brown.

Figure 10a. Original photo of Professor Joseph Alexander Brown (left), result of the algorithm (right).

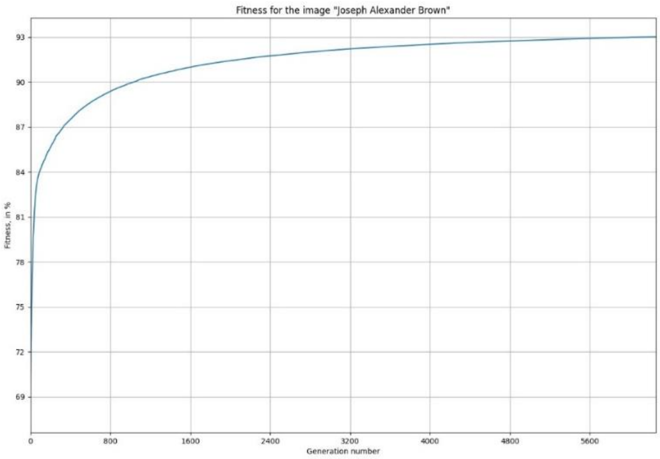

Figure 10b. Fitness plot.

The program produced 6280 generations, which took ~ 4.36 hours, to achieve the maximal ~ 93.102% fitness of the individual in the population

Photo of mandrill.

Figure 11a. Photo of Mandrill (left), result of the algorithm (right).

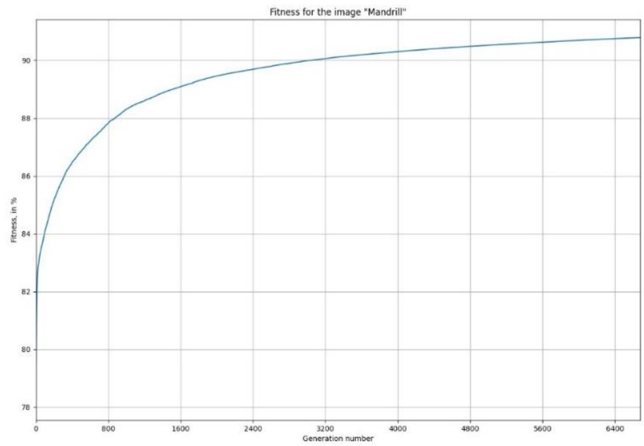

Figure 11b. Fitness plot.

The program produced 6697 generations, which took ~ 4.65 hours, to achieve the maximal ~ 93.114% fitness of the individual in the population

The Mona Lisa.

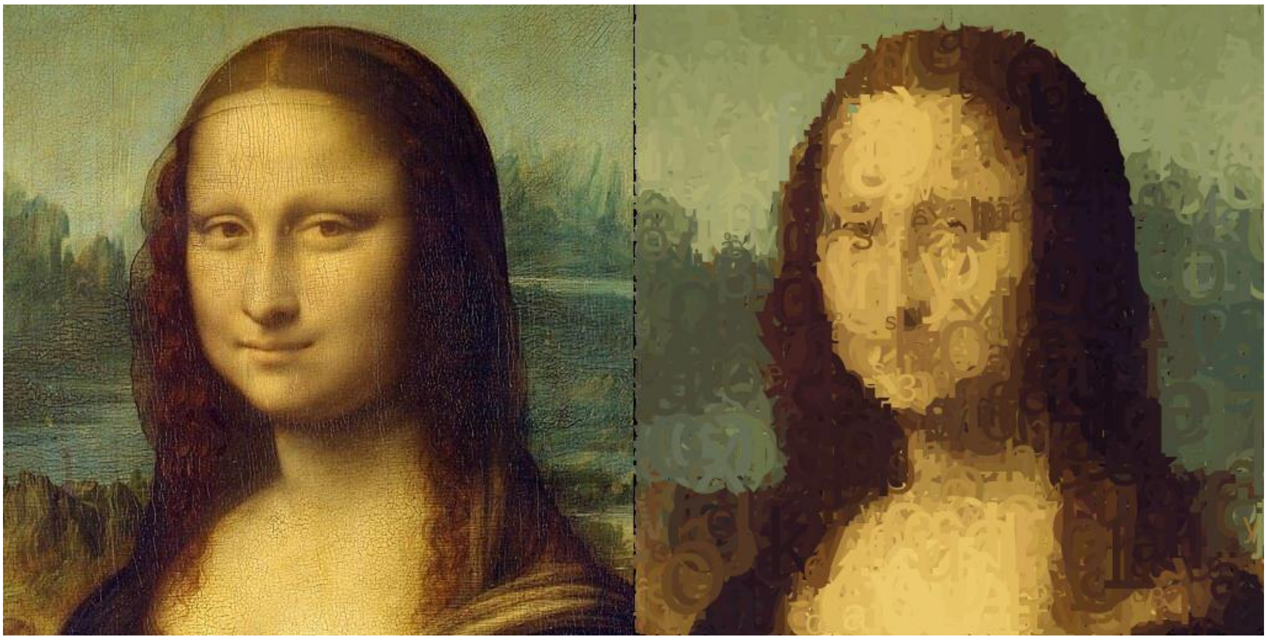

Figure 12a. The Mona Lisa (left), result of the algorithm (right).

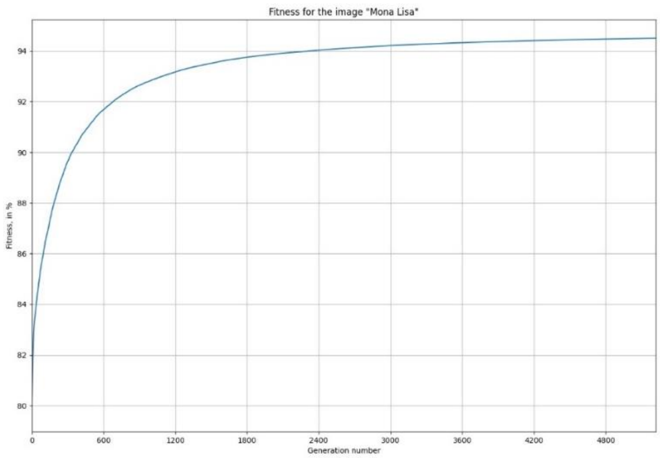

Figure 12b. Fitness plot.

The program produced 5222 generations, which took ~ 3.62 hours, to achieve the maximal ~ 94.201% fitness of the individual in the population

Author: Danis Alukaev Student ID: 19BS551

Definition of the art.

Determining the meaning of the word "art" is a complex and voluminous task. The reason is that any piece of work could be considered art. The word "art" can contain a variety of different and heterogeneous essences. This word is a kind of linguistic vessel, the meaning of which is free to change under the user's worldview.

In my opinion, the concept of art involves discussion of search and reinvention of ideas. During creativity, the author introduces new features and discovers hitherto unknown and non-obvious facts about the source.

The primary source of changes in the original piece of work is the author's experience. In a lifetime, all events, impressions, places, people are formed as a kaleidoscope constituting a system of values and a sense of beauty.

As an example, reinterpretation of ideas can occur by placing the reference in a new environment. The study of the influence of the environment on the formula of art allows the creator to discover previously unknown features. Similarly, exaggerating a specific quality of the source will lead to the creation of unknown essence.

Yet another property of the art is the emotional interaction with the observer. A work of art is a form of expressing emotions and transmitting the author's state of mind to the viewer by choice or by accident.

To conclude, any work that has introduced new features to compare with the reference and can cause certain emotions tends to be the art.

According to the derived definition, as long as the images are not identical, the produced image can be considered art. The algorithm represents images as a set of glyphs and introduces new features into the original image, thereby creating art.

Each reproduced image evokes aesthetic pleasure during contemplation. Symbolic representation of the image allows showing all the beauty of the form without going into small details. It is fascinating to imagine that a whole picture is constructed from a chaotic set of letters. It evokes thoughts about the nature of our origin. Likewise, the first RNA was synthesized non-biologically, leading to the emergence of life on earth and giving rise to our history.