Cubic collages by an evolutionary algorithm

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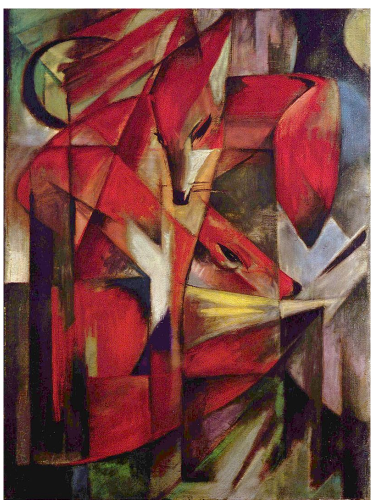
The objective was to create an evolutionary algorithm that would do something with an input picture, which might be called art.

1 Idea

The goal I set was to restore the 3-dimensional nature of sculptures in their photographs. I achieve that by adopting a method of Cubist artists: their canvas gathers fragments of an object in a weird way, showing its parts from different angles, thus making it far from naturalistic, but possessing the volume, in a sense that viewer can see the depicted object from all sides at the same time:



Fox. Franz Mark

Violin and Grapes. Pablo Picasso

So, my algorithm tries to find meaningful parts of a given picture (or pictures, it scales easily) and combines them.

2 Results

The algorithm does not converge to a particular result for some input; instead, it produces "equally attractive" pictures. The reason is that the process of choosing fragments and combining them is highly randomized. Moreover, determining "attractiveness" is not straightforward at all, even on a high level.
Here are several examples:

Winged Victory of Samothrace.
Photo by Remy de la Mauviniere.

Psyche Revived by Cupid's Kiss. Antonio Canova.
Photo by Reji via Flickr

Angel. Benjamin Victor.
Photo by Benjamin Victor

Shrine of Azura. Skyrim,
available at Elderscrolls Fandom

Green Waterfall. Erik Demaine and Martin Demaine.

The algorithm exploits several heuristics, which is the source of limitations of applications. It shows its best when applied to a picture with a relatively calm (shapeless) background of average luminosity.

3 Implementation overview

This is a generational genetic algorithm with crossover and mutation. As it turns out, 7-13 chromosomes in population and about 60 generations are sufficient to converge to an (empirically obtained) maximum of fitness. It takes from 1 to 2 minutes to run.

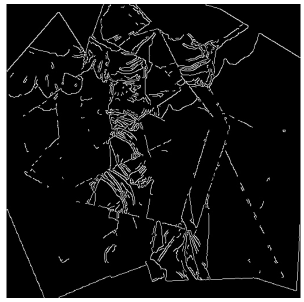
- **Gene** is a fragment of the source image together with its position on the resulting image. Namely, it contains information on the shape of the fragment to cut (as vertices of a polygon), how it is adjusted (in terms of brightness/contrast/blurring), how the fragment is shifted and rotated in the resulting image, as well as the strategy of application — either transparent superimposition or simple overlay on previously rendered fragments.

- **Chromosome** is an image (as phenotype) and a list of genes (as genotype). The heuristic here is to sort genes in a chromosome in decreasing order based on the area of fragments so that when rendered, large fragments are beyond.

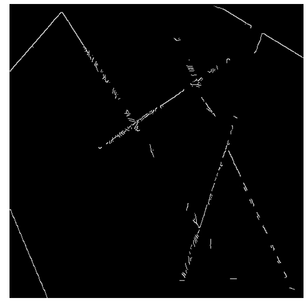
- **Population** is simply a list of chromosomes. It is initialized with random chromosomes, which in turn are essentially lists of random genes. Each of the genes' attribute is initialized randomly in respective reasonable domains, except for the application method (it depends on fragment area).

- **Fitness function** comprises three components, primary of which is the "nontriviality" of shapes in a fragment. It executes the Canny edge detection algorithm and then counts pixels of edges. Borders of fragments are also found with Canny edge detection, and it is an undesirable side effect. To ensure that evolution is not speculating on edges of polygons, I find straight lines with Hough Transform and subtract pixels from the borders of fragments from the overall pixel count.

Canny edge detection for Nike of Samothrace.



Canny edge detection for a chromosome.



Masked out borders of fragments.

Secondly, I wanted to maximize the coverage of fragments; for this reason number of non-zero (non-black) pixels in a decoded chromosome is calculated. Though detected edges and coverage of fragments are heavily correlated, I decided to add this component independently.

Thirdly, ceteris paribus, I would prefer chromosomes with higher diversity of shapes in fragments. To achieve that, the program counts the number of occurrences of each pixel from the source image in the fragments and sums up their squares (to get a weighted sum: more repetitions — more weight).

The fitness of a particular chromosome is a weighted sum of the three above described quantities (best weights were found by trial and error).

- **Selection** process of the algorithm exploits the Rank Space method. I chose it because the fitness estimate is rather vague and meaningless by itself but good enough in comparing chromosomes. So proportions of fitness as the probability of survival/reproduction would hardly make sense.

  Here is a detailed explanation: probability of the highest ranking chromosome is some chosen p_c, probability for holder of i^{th} rank is $p(1-p)^{(i-1)}$ with $i \in \{1, \ldots, N-1\}$, and the least ranked one is chosen with probability $(1-p)^{(N-1)}$, where N is population size.

  Selection for survival is made with a relatively high probability $p_c = 0.85$ to ensure an explicit bias to the fitter chromosomes. Selection for becoming a parent is less restrictive: $p_c = 0.3$. Higher values tend to destroy variety.

- **Mutation** of a chromosome is simply reinitialization of one of its genes. Properties of the chosen allele change independently from each other with a probability of 0.7.

  The mutation probability is set to 0.3.

- **Crossover** consists of shuffling genes of two parents and selecting a random subset from the obtained pool of genes to form a new chromosome.

  Each generation produces $\lfloor N/3 \rfloor$ offsprings, where N is population size.

4 Words on art

The question "what is art?" is fundamental and might have lots of nontrivial answers. Among all possible definitions, I would prefer the one following A. J. Toynbee[1], in his discussion on the growth of civilizations, telling that the creative act (and art in a most general case) is the result of the so-called Withdrawal-and-Return. It is a two-phase process of creation: the Withdrawal, the mystic transformation of an Individual caused by arrival of the Idea, is followed by the Return to the outer world of people with a goal to change it. So art is an act of bringing an Idea into reality, such that without it, an Individual to whom the Idea originally came would not be able to bear their life. Art should have the power to cause transformations inside spectators — anything from slight appreciation to rapture and worship or profound upheavals.

References

[1] Arnold J. Toynbee. *A Study of History*. Dell Publishing, 1974. Chap. 2.11.2.