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IMAGE VECTORIZATION AND COLORS REDUCTION WITH ANT COLONY OPTIMIZATION

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ABSTRACT. In some industrial visualization tasks an image should be represented as a set of identical geometric shapes (image simplification) such as pattern recognition, cartography, molecular biology and computer animation, see [6]. In this study an Ant Colony based geometric shape optimization is proposed, so that it is capable to vectorize two dimensional bitmap images. Shapes, such as ellipses or strokes, can be arranged in particular order and orientation in which image approximation can be achieved. That source images are full-colored (24-bits colors), while derived images are limited to 16 colors (indexed colors). The scope of this paper is focused on the shapes drawn on the 2D surface in such way that a common goal to be satisfied - the produced image to be as close as possible to the source image with relatively good colors reduction.

1. INTRODUCTION

In Geometry there is a class of optimization problems called packing problems. It is an attempt to pack objects together into containers. In the most common case the goal is to pack a single container as densely as possible, see [7]. For each packing problem there is a dual covering problem. In the covering problem it is asked how many of the same objects are required to completely cover every region of the container when, in the common case, objects are allowed to overlap. In two dimensional space the most popular packing problems are: circle packing in a circle [8], circle packing in a square [12], circle packing in an isosceles right triangle [1], circle packing in an equilateral triangle [5] and square packing in a square, see [9]. In this study a covering problem is presented where an image should be covered with regular ellipses with different colors and overlapping is allowed. The optimization objective function is strongly related to the composite picture and it is not so strongly related to the optimal packing. The criteria for good optimization is the Euclidean distance between the original image and the approximated image. The images are compared in HSV color space.

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FIGURE 1. Mona Lisa - polygonal approximation:
https://rogeralsing.files.wordpress.com/2008/12/evolutionofmonalisa1.gif

2. Problem Formulation

Some drawing devices (like plotters) are not capable to represent the visual information as pixels. For such devices the visual information, represented in the raster image, should be transformed in a group of simple geometric shapes. This process of image data transformation is related to information reduction. The process is transformation of true colors image in a set of simple geometric shapes.

This problem is very well known in literature and one of the most impressive implementations has been done with the image of Mona Lisa (Fig. 1). The goal of this project [13] was to approximate the picture of Mona Lisa by no more than 50 polygons. The colors and the points of the polygons were optimized by GAs.

3. The Model Proposed

The model proposed is based on Ant Colony Optimization (ACO). ACO is applied over a graph of shapes, represented by position and orientation. It is an unsupervised system which takes digital photographs as input and generates simplified, stylized vector data as output.

3.1. **Image Simplification and Vectorization.** A raster image usually contains many details that are not relevant for a visual query and increase the cost of manipulations. Simplification of raster images is a process to eliminate the most useless elements, while retaining the perceptually dominant elements and shape, see [10]. Simplification of raster images is a widely used process in the area of document analysis and recognition as a preprocessing step for high-level object recognition, such as optical character recognition (OCR) and graphic objects recognition, [3].

Until now no methods devised can be considered as sufficiently stable and robust to work as standalone, [4]. In image simplification and vectorization digital photographs are the input when generates simplified, stylized vector data are the output. The objective of image simplification by vectorization is to split the original image into simple geometric regions. In this process color reduction is also applied.

3.2. **Ant Colony Optimization.** ACO is a search heuristic inspired by the ant animals in the real natural, see [14, 11]. ACO are routinely used to optimize path in graph (candidate solutions). By application of techniques for ant moving and pheromone update paths can get closer to the optimums. ACO is classified also as a population based algorithms, because artifficial ants explore the solution space. Each ant investigates different paths and distribution of pheromone is done. Traditional representation of the solutions is a graph with nodes and edges, [2].

Optimization usually starts from random generated graph, but this is also subject of implementation. The optimization process is iterative and artificial ants are moving in the graph. Each ant leave trail by leaving pheromone, according to graph nodes and edges information. Paths in the graph are the usual subject of optimization. The paths with the most pheromone accumulated are the most prefered as solution. This is used in the next iteration of the algorithm. Algorithm termination is usually achieved by reaching maximum number of repetitions or by reaching the desired level of accuracy, [2].

In order to run ACOs it is necessary to provide: 1. Graph representation of the solution space (solution domain); 2 an appropriate pheromone estimation rule to evaluate the solution domain. Once these two conditions are met ACO can proceed with population initialization and iterative population improvement by repetitive application of ants movements, [2].

3.3. **Implementation.** In this study ellipses were chosen as approximation shape, which to be used for image reconstruction. Each shape is described by its X,Y coordinates, angle of rotation and color. The graph in the ACO consists of an ordered set of shapes (as nodes) and edges (links between nodes with different color). The ordered set of shapes is chosen so that the most used color in the picture is painted first. The less used colors are painted last. The quality of approximated image is calculated as Euclidean distance between the approximate image and the original image. The approximated image is assembled by shapes (in our case ellipses) with different colors given as a colormap at the input of the program. Color reduction is done in HSV color space. Each color from the original image is matched to a color in the given colormap.

As an initial step ACO is initialized with randomly generated sets of shapes (nodes) and edges only between nodes with different colors. For each shape X,Y coordinates and rotation angle are taken randomly. The color of each shape is not taken randomly. Color reduction is done from the color on the X,Y pixel coordinates in the original image instead. Such initialization creates approximated image very close to the optimal approximation. During ACO's improvement process ellipses are selected from the graph. Selected ellipses are rotated and color correction is applied so that the image approximation is approved. In this study only ellipses with different colors are optimized. X,Y

FIGURE 2. The original source image of a flower:
https://s-media-cache-
ak0.pinimg.com/236x/6a/c9/d1/6ac9d1c995accf914fbb50fb9871485c.jpg

shifting also can be applied but is not implemented at the moment. During evaluation phase the approximated image is compared with the original image. The result of the comparison is used as a quality value of the optimization. The stopping criteria used are the total number of repetitions.

The basic algorithm is as follows:

(1) Load original image in to the memory;
(2) Initialize random ACO structure;

Parameter	Value
alpha	0.1
betha	2.0
rho	0.1
q0	0.8
number of ants	17
number of iterations	10
number of repetiotns	10

TABLE 1. ACO parameters.

(3) Optimization:
   (a) Generate solutions;
   (b) Daemon actions;
   (c) Pheromone update;
   (d) Generate image in the memory;
   (e) Compare generated and original image for quality estimation;
   (f) Stop if predefined number of generations is reached;
   (g) Repeat from (a).
(4) Report results;

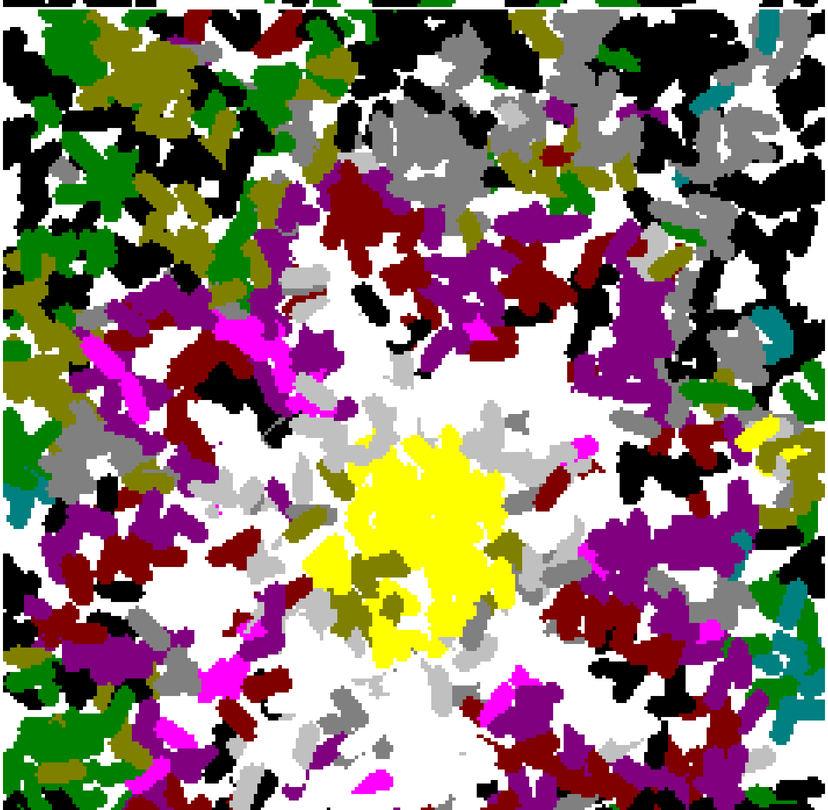
Software implementation of the model proposed is absolutely free available, as open-source project, at GitHub repository [17].

4. Experiments and Results

The optimization program is written in Java and can run on different computational platforms. Using of the programming language Java can be a key point for creation of a multithreading application. All experiments are done with population size of 17 ants, maximum number of interactions 10 and repetitions 10 (Tab. 1).

Initial graph is assembled by randomly taken shapes according to the color of the pixel from the original image. An image of a flower is used for the experiments (Fig. 2), but any other picture can be sent as input for the optimization program. Sixteen basic colors are used as color map as follows: Aqua (00FFFF), Black (000000), Blue (0000FF), Fuchsia (FF00FF), Gray (808080), Green (008000), Lime (00FF00), Maroon (800000), Navy (000080), Olive (808000), Purple (800080), Red (FF0000), Silver (C0C0C0), Teal (008080), White (FFFFFF), Yellow (FFFF00).

Six improvements of the initial image are shown in (Fig. 3) (upper-left). The gaps in the image are getting smaller with the progress of the optimization procedure. The orientation of the basic shapes (in this case ellipses) also gets better during the optimization process. Vectoring images can be produced by digital plotter (Fig. 4) with oil paint and can be presented as part of the concept for the digital home [15].



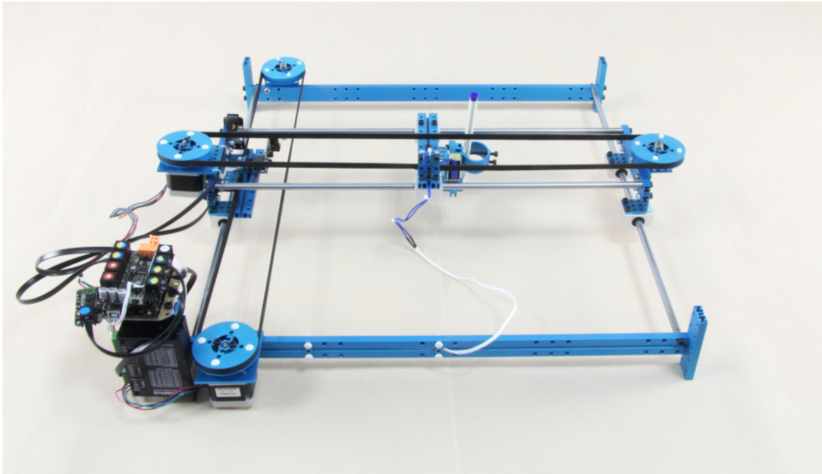


FIGURE 4. Plotter X-Y:
http://duino4projects.com/wp-content/uploads/2014/01/How-to-make-a-XY-plotter-with-Makeblock.jpg

5. Conclusions

Experiments show that using ACO may be very efficient and image approximation is pretty accurate in the limits of the color simplification. Optimization convergence is related to the probabilistic nature of ACO. Image comparison is time consuming and slows down the optimization process.

As further research, it could be interesting for ACO to be implemented as distributed computing algorithm. Such distributed implementation is efficiently applicable for the class of population based algorithms in which ACO is. Set of ellipses can be treated as a multidimensional space and optimization like Free Search [16] can provide much better results. As distributed computing implementation Incident Node Participation can be applied, as described in [18].

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References

[1] Y. Xu: *On the minimum distance determined by n ($<= 7$) points in an isosceles right triangle*, Acta Mathematicae Applicatae Sinica, **12**(2) (1996), 169–175.
[2] M. Dorigo, V. Maniezzo, A. Colorni: *Ant System: Optimization by a Colony of Cooperating Agents*, IEEE Transactions on Systems, Man, and Cybernetics-Part B, **26**(1) (1996), 29–41.
[3] L. Wenyin, D. Dori: *From Raster to Vectors: Extracting Visual Information from Line Drawings*, Pattern Analysis and Applications (PAA), 1999.

[4] K. Tombre, C. Ah-Soon, P. Dosch, G. Masini, S. Tabbone: *Stable and robust vectorization: How to make the right choices*, Proceedings of the 3rd IAPR Intlernational Workshop on Graphics Recognition, Jaipur, India, 3–16, 1999.

[5] K. Nurmela: *Conjecturally optimal coverings of an equilateral triangle with up to 36 equal circles*, Experimental Mathematics, **9**(2) (2000), 241–250.

[6] G. Xianfeng, J. Steven, H. Hugues: *Geometry images,* SIGGRAPH02 Proceedings of the 29th annual conference on Computer graphics and interactive techniques, **21**(3) (2002), 355–361.

[7] A. Lodi, S. Martello, M. Monaci: *Two-dimensional packing problems: A survey*, European Journal of Operational Research (Elsevier), **141**(2) (2002), 241–252.

[8] F. Fodor: *The Densest Packing of 13 Congruent Circles in a Circle,* Beitrage zur Algebra und Geometrie, Contributions to Algebra and Geometry, **44**(2) (2003), 431–440.

[9] W. Stromquist: *Packing 10 or 11 unit squares in a square*, Electronic Journal of Combinatorics, **10**(8) (2003), 1–11.

[10] A. Ferreira, M.J. Fonseca, J.A.Jorge, M. Ramalho: Mixing Images and Sketches for Retrieving Vector Drawings, The 7th Eurographics Workshop on Multimedia (EGMM04), China, 2004.

[11] M. Mohd Murtadha: *Articulated Robots Motion Planning Using Foraging Ant Strategy*, Journal of Information Technology - Special Issues in Artifficial Intelligence, **20**(4) (2008), 163–181.

[12] W. Huang, T. Ye: *Greedy vacancy search algorithm for packing equal circles in a square,* Operations Research Letters, **38** (2010), 378–382.

[13] R. Alsing: *Genetic programming: evolution of Mona Lisa*,
http://rogeralsing.com/2008/12/07/genetic-programming-evolution-of-mona-lisa/ , 2008.

[14] A. Kazharov, V. Kureichik: *Ant colony optimization algorithms for solving transportation problems*, Journal of Computer and Systems Sciences International, **49**(1) (2010), 30–43.

[15] T. Atanasova: *Integrated Semantic-Based Processes in Digital Home*, Informatyka Ekonomiczna Business Informatics, **3**(33) (2014), 24–33.

[16] K. Penev: *Free Search in Multidimensional Space II. - Numerical Methods and Applications*, Lecture Notes in Computer Science, **8962** (2015), 103–111.

[17] T Balabanov: *Approximate full color image with limited color ellipses*,
https://github.com/TodorBalabanov/EllipsesImageApproximator/, 2015.

[18] T. Balabanov, I. Zankinski, M. Barova: *Strategy for Individuals Distribution by Incident Nodes Participation in Star Topology of Distributed Evolutionary Algorithms*, Cybernetics and Information Technologies, **16**(1) (2016), 80–88, DOI: 10.1515/cait-2016-0006.

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