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CLUSTERING-BASED APPROACH TO THE PLACEMENT OF VECTOR GRAPHIC OBJECTS ON A PLANE

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This article presents an approach to improving the efficiency of placing vector graphic objects on a plane by applying clustering based on object size. The proposed method groups vector figures into subsets with similar bounding rectangle areas using a configurable deviation threshold. This strategy enhances spatial utilization by reducing fragmentation and increasing the likelihood of successfully placing all objects within a single sheet. The clustering algorithm is described in detail, including its mathematical formulation and implementation as part of a placement system. Experimental results demonstrate the advantages of this approach over traditional methods that do not involve preprocessing, showing improved packing density and layout consistency. Additionally, the clustering mechanism integrates naturally into evolutionary algorithms such as genetic algorithms, where it enhances the effectiveness of mutation and crossover operations by structuring the population into logical groups. The conclusions confirm the method's potential for use in optimization tasks related to layout planning in fields such as printing, manufacturing, and digital design. Future research will explore alternative clustering metrics and evaluate the method's performance in multi-objective and real-time optimization scenarios.

Keywords: *clustering, graphic object placement, vector graphics, optimization, genetic algorithm, plane, layout, heuristic.*

Introduction. The problem of placing vector graphic objects on a plane is relevant to printing, digital manufacturing, material cutting, and related industries, where achieving a dense and rational arrangement of elements is essential. One of the main challenges in such tasks is the non-uniformity of object sizes: large shapes often cannot be placed on a partially filled plane because smaller objects placed earlier have fragmented the free space. This approach leads to reduced area utilization efficiency and an increased number of required material sheets.

Problem statement. Existing placement algorithms typically treat shapes as a sequence processed in a fixed order, without considering grouping based on their characteristics, in the context of evolutionary methods, such as genetic algorithms, the lack of object structuring limits the effectiveness of mutations and crossovers, which affects both the speed and quality of convergence toward an optimal solution.

Therefore, the problem of preliminary grouping of objects according to their dimensional characteristics before placement remains relevant. Clustering shapes enables the consideration of more consistent subsets of elements, increasing the efficiency of both deterministic placement algorithms and evolutionary optimization approaches.

Analysis of recent studies and publications. Researchers across packing, printing, computer-aided design, material cutting, and digital manufacturing actively explore how to place objects on a plane more efficiently. They propose a variety of approaches ranging from greedy heuristics to evolutionary optimization methods such as simulated annealing, genetic algorithms, and simulation modelling [1–4]. These methods aim to maximize packing density and reduce resource consumption. However, most existing approaches process objects sequentially without considering their characteristics, particularly their dimensions, which often leads to inefficient use of space.

One promising approach to preprocessing input data is clustering - a method that groups objects based on the similarity of their features [5–8]. In general, clustering divides a set of elements into subsets (clusters) where objects within the same cluster share common characteristics, while objects from different clusters differ significantly.

The main components of clustering include:

– feature selection: the characteristics used for comparison (in this work, the area of a shape's bounding rectangle);
– distance or similarity metric: a measure of how close the objects are to each other (in this case, the difference in object areas);
– threshold value (tolerance): a limit that defines whether objects belong to the same cluster;
– merging algorithm: a procedure that forms subsets according to the selected criteria.

Researchers widely apply cluster analysis in machine learning, computer vision, data segmentation, and pattern recognition. However, its use in the placement of vector objects remains insufficiently explored. Clustering has strong potential as a preprocessing stage for evolutionary algorithms, as it can improve spatial arrangement efficiency and increase variation in mutations and crossovers.

Therefore, developing a method for clustering objects by size and studying its influence on placement results remains an important research task, especially in the context of genetic algorithms.

Research objective. The goal of this study is to improve the efficiency of placing vector graphic objects on a plane by applying size-based clustering of shapes to reduce fragmentation.

Proposed method. The proposed clustering method groups vector graphic objects by size before placement, helping to avoid free-space fragmentation and improve overall placement quality. Unlike simple sorting, clustering creates logical subgroups of shapes with similar dimensions, allowing more flexible control over placement order and better adaptation to subsequent optimization procedures, such as mutations and crossovers within a genetic algorithm.

The algorithm workflow is illustrated in Figure 1.

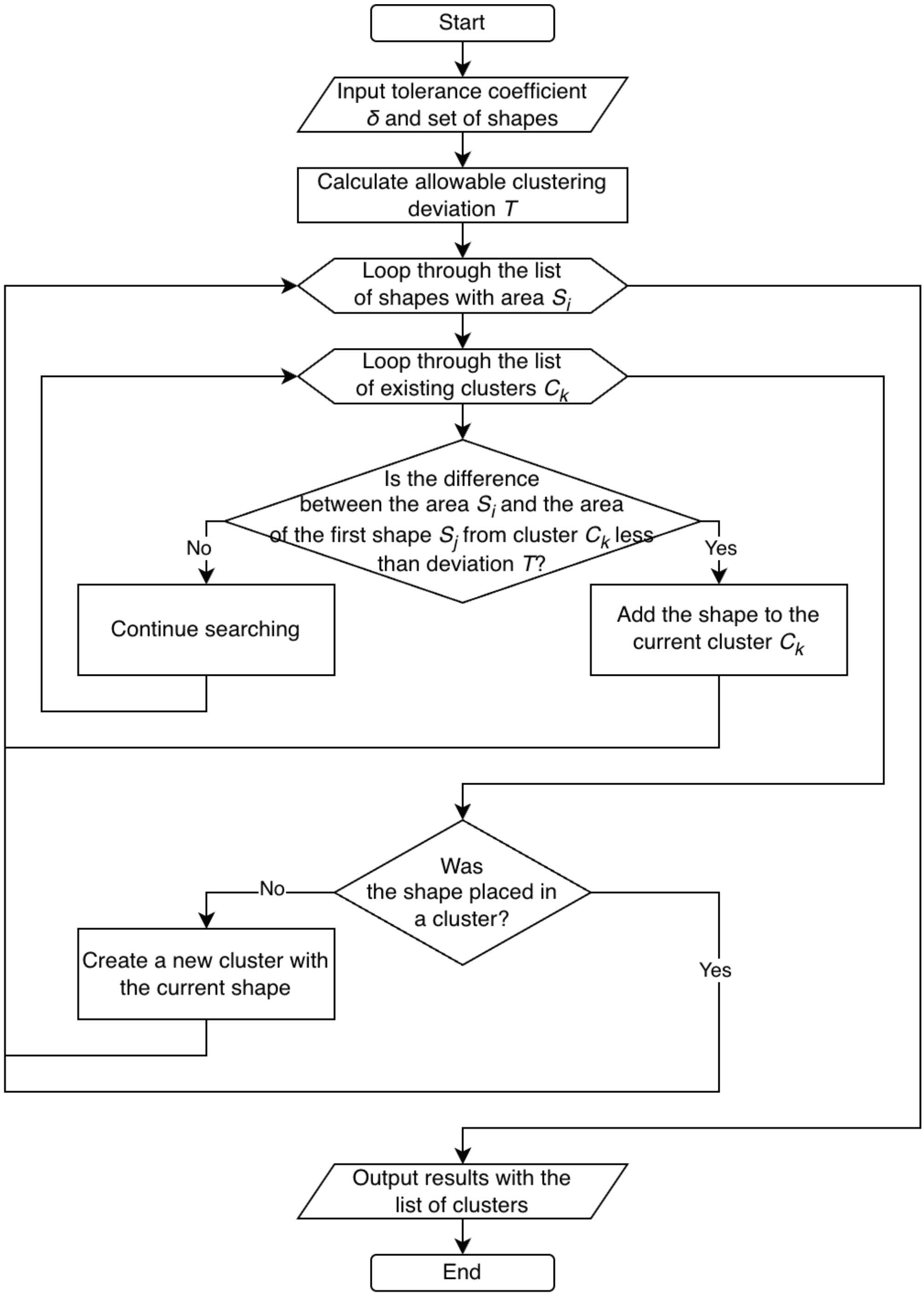

Figure 1. Block diagram of the shape clustering algorithm

The clustering process is implemented by calculating the area of the bounding rectangle for each shape using the formula:

$$S_i = w_i \cdot h_i,$$

S_i - denotes the area of the i shape; w_i and h_i - represent the width and height of its bounding rectangle.

The clustering threshold is computed using the minimum and maximum area values according to:

$$T = \left(S_{\max} - S_{\min}\right) \cdot \delta,$$

T - allowable deviation within a cluster; S_{min}, S_{max} - minimum and maximum areas among all shapes; δ - the tolerance coefficient (ranging from 0 to 1, e.g., 0.05).

The shapes are sorted by size and then grouped into clusters according to the condition:

$$\left|S_i - S_j\right| \leq T \quad \Rightarrow \quad S_i, S_j \in C_k.$$

Two shapes belong to the same cluster C_k if the difference between their areas does not exceed the threshold T.

The clustering results allow us to develop a strategy where the placement process starts with the largest shapes in each cluster. This approach allows for more efficient filling of the available plane and minimizes residual space fragments that could otherwise prevent the placement of larger objects. Within evolutionary algorithms, clusters can act as building blocks for generating new individuals, where groups of similar shapes combine and evolve together. This approach enhances both the quality and stability of the search for the optimal solution. Overall, clustering in the placement problem functions is not only as an auxiliary tool for improving spatial packing but also as an integral component of a broader optimization framework. It helps balance variability processes (mutations and crossovers) with stability processes (local improvement) within genetic algorithms.

Experiments. To conduct the study, we used a custom software application designed to place vector shapes on a plane. The placement algorithm sequentially adds objects from top to bottom and left to right. The application was developed in the Kotlin programming language using the Java Swing graphical library within the IntelliJ IDEA Community Edition environment.

At the first stage, we examined how the clustering tolerance coefficient (δ) affects the number of clusters formed. Three values were selected: 0.03, 0.05, 0.15. The input data consisted of a set of vector graphic objects generated from letters of the Ukrainian alphabet and digits, with sizes ranging from 20 to 120 mm. This setup modelled a realistic scenario involving the placement of large objects among many smaller ones. The placement area measured 200×300 mm.

In the results, we can see that when δ = 0.03, seven clusters were formed (Figure 2); when δ = 0.05, four clusters (Figure 3); and when δ = 0.15, three clusters (Figure 4). Thus, increasing the allowable deviation merges shapes into fewer groups.

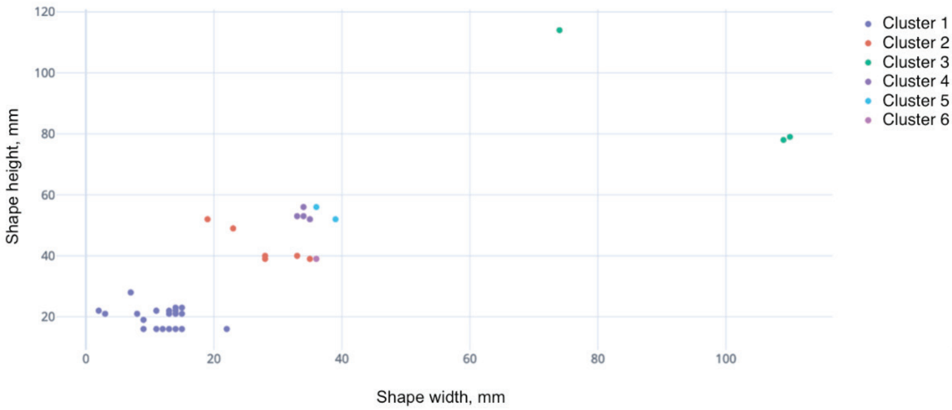

Figure 2. Clusters with a tolerance coefficient of 0.03

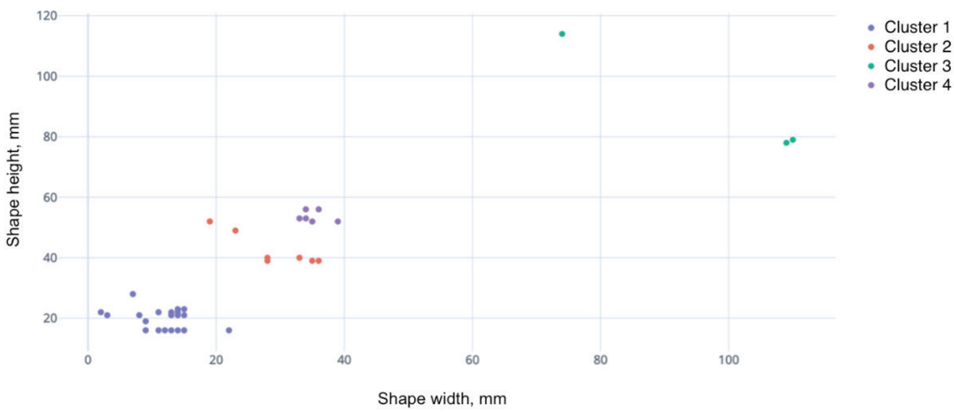

Figure 3. Clusters with a tolerance coefficient of 0.05

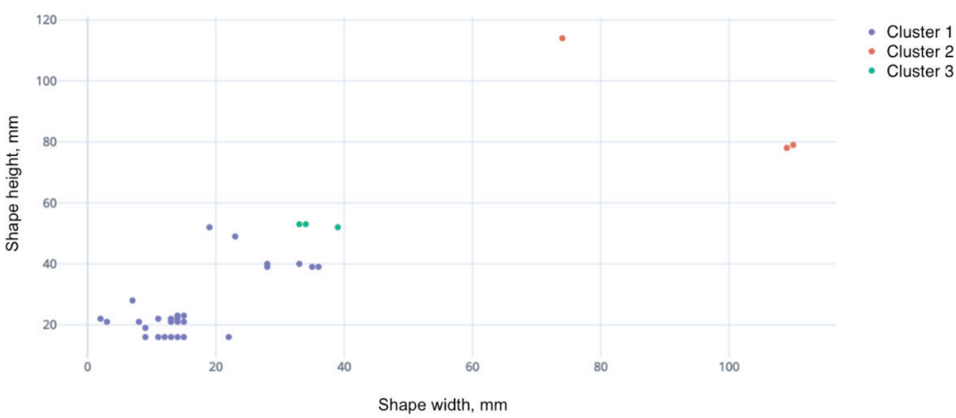

Figure 4. Clusters with a tolerance coefficient of 0.15

The next step is comparing the placement results without clustering (Figure 5) and with clustering applied (Figure 6). In the first case, one of the shapes did not fit on the plane, whereas applying clustering achieved a denser layout - all objects were successfully placed on a single page. This improvement resulted from prioritizing the placement of larger shapes within each cluster before smaller ones, which reduced the likelihood of free-space fragmentation.

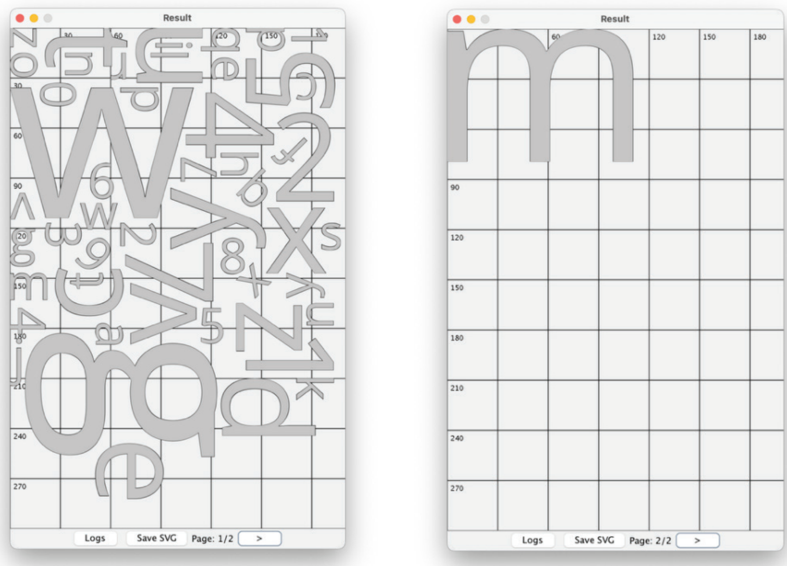

Figure 5. Placement of shapes on the plane without clustering

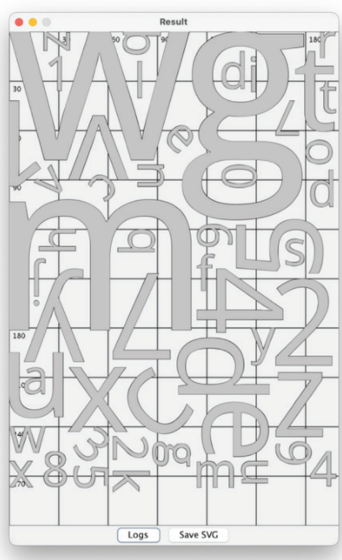

Figure 6. Placement of shapes on the plane with clustering

Results. The study confirms the effectiveness of applying clustering to optimal placement problems. Grouping shapes by size allows for more efficient use of the available area, reduces unused space, and increases the likelihood of fitting all objects on a single sheet without overflow. This is particularly relevant in printing, manufacturing, and material-cutting tasks, where packing density directly affects resource consumption.

Furthermore, the proposed approach integrates well into the structure of evolutionary algorithms, where maintaining variability in mutation and crossover processes is essential. Clustering not only orders shapes by size but also forms logical groups, improving the efficiency of combinational operations and promoting the generation of higher-quality solutions in subsequent generations.

Conclusions. This research proposes an approach to improving the efficiency of placing vector graphic objects through size-based clustering of shapes. The developed algorithm groups shapes according to the area of their bounding rectangles with a specified tolerance, which enables a denser arrangement of elements on the plane.

The experiments confirmed that applying clustering reduces fragmented space, allows more objects to be placed on a single sheet, and improves the algorithm's adaptability to input data of varying sizes. A comparison with the traditional non-clustered approach showed a noticeable improvement in both quantitative and visual aspects.

The proposed method is particularly promising for integration into evolutionary algorithms, especially genetic ones, where it enhances mutation variability and crossover efficiency. Clusters can serve as structured subsets within the population of solutions, supporting stable evolution toward the global optimum.

Future research will focus on adapting the clustering method to other similarity metrics and evaluating its effectiveness in the context of multi-objective optimization.

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ЗАСТОСУВАННЯ КЛАСТЕРИЗАЦІЇ В ЗАДАЧІ РОЗМІЩЕННЯ ВЕКТОРНИХ ГРАФІЧНИХ ОБ’ЄКТІВ НА ПЛОЩИНІ

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У статті розглянуто підхід до покращення ефективності розміщення векторних графічних об'єктів на площині шляхом кластеризації фігур за розмірними характеристиками. Існуючі алгоритми розміщення зазвичай розглядають фігури як послідовність, що обробляється у певному порядку, не враховуючи групування за характеристиками. У контексті еволюційних методів, таких як генетичні алгоритми, відсутність структуризації об'єктів обмежує ефективність мутацій і кросоверів, що впливає на швидкість і якість збіжності до оптимального рішення. Кластеризація фігур дозволяє розглядати більш узгоджені підмножини елементів та підвищує ефективність як жорстких алгоритмів розміщення, так і еволюційних підходів до оптимізації. Вибраними елементами кластеризації у даній роботі є площа обмежувального прямокутника фігури, метрика відстані або подібності, яка визначає, наскільки об'єкти близькі між собою (у нашому випадку – різниця площ фігур); порогове значення що визначає межі належності до одного кластера та алгоритм об'єднання об'єктів у підмножини.

Запропонований метод кластеризації дозволяє групувати фігури у підмножини зі схожою площею обмежувального прямокутника, що забезпечує щільніше компонування та зменшує фрагментацію вільного простору. Описано алгоритм кластеризації з використанням порогового значення, залежного від мінімальної та максимальної площ об'єктів, а також подано блок-схему його реалізації. Результати експериментів свідчать про переваги кластерного підходу у порівнянні з традиційним розміщенням без попередньої обробки: підвищується ефективність заповнення площини та зростає ймовірність повного розміщення об›єктів в межах одного носія. Крім того, метод добре інтегрується у структуру генетичного алгоритму, підвищуючи варіативність мутацій і якість комбінування рішень. Запропонований підхід має перспективу для використання в задачах оптимального розміщення у сферах поліграфії, розкрою матеріалів та цифрового виробництва.

Ключові слова: *кластеризація, розміщення графічних об'єктів, векторна графіка, оптимізація, генетичний алгоритм, площина, компонування, евристика.*

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