Grouping Genetic Algorithms: An Exploratory Study

Michael Mutingi, *Member, IAENG*, Charles Mbohwa, and Harmony Musiyarira

***Abstract*—Grouping problems are an important class of computational problems where the objective is to group, cluster or partition members of a set into desired sub sets. The grouping genetic algorithm is an extension of genetic algorithm that is heavily modified to model the structure of grouping problems. Since its inception, grouping genetic algorithms has been applied to several types of grouping problems. This paper presents an exploratory and chronological review of the grouping genetic algorithm approach. First, a survey of articles on grouping genetic algorithm approaches and its applications is presented. Second, a chronological review and analysis of research activities on the grouping genetic algorithm approach is presented. Third and finally, future trends and further research prospects are visualized and outlined.**

***Index Terms*—Genetic algorithms, grouping, grouping genetic algorithms, exploratory study, chronological review**

I. Introduction

A significant number of combinatorial problems arising in industry consist in grouping, clustering, or partitioning a given set U of objects into a collection of mutually disjoint subsets U_i of U, such that,

$$\mathrm{U}_i = \mathrm{U} \tag{1}$$

and,

$$\mathrm{U}_i \quad \mathrm{U}_j = \varnothing,\ i \neq j \tag{2}$$

This can also be visualized as problems where the objective is to group the members of the set U into one or more groups of objects, where each object is exactly in one group [1] [2]. In most cases, not all possible groupings are allowable, and the solution to the problem should satisfy all the hard constraints [1] [2] [3]. However, it is generally assumed that the order of groups is not relevant [2] [3]. Usually, the objective of the grouping is to optimize a specific cost function that is defined over the set of all the valid groups. Some of the well-known combinatorial grouping problems are graph coloring problem [4], line-balancing problem [5], cell formation problem [6] [7] [9] [10] [11] [12], bin packing problem [8], equal piles problem[13], batch–machine scheduling problem [3], packing/partitioning problems [3], timetabling problem [4], pickup and delivery problem [14], home healthcare scheduling [15] [16] [17], flexible job shop scheduling [18], team formation [19], modular product design [20] [21] [22], among others [2] [3] [5] [23] [24-48].

These grouping problems are characterized by objective functions that are a function of the composition of the groups, rather than individual members of the group. In other words, when one object is taken in isolation, this has no significance.

Grouping problems can be classified in various forms. For example, these problems may be grouped into constant and variable grouping problems [3] [5]:

1) Constant grouping problems, where the number of groups is a constant input to the problem, such as the identical or non-identical parallel-machine scheduling problem; and,
2) Variable grouping problems, where the number of groups is not known a priori and the algorithm has to determine the optimum number members in the groups, such as bin packing and graph coloring problems.

In addition to the above, grouping problems can be classified into those with identical groups and those with non-identical groups [3]. For identical groups, all groups have similar characteristics, and swapping of groups does not change anything. For non-identical groups, different groups are identified by different features, where swapping of groups results in a grouping different from the original one [3] [5].

Since its inception in the early 90s [1] [2], the grouping genetic algorithms approach has received significant attention. Several extensions to the algorithms have appeared in the literature, and have been applied to several types of problems [5]. It will be interesting to make a chronological literature survey of the algorithm, beginning from the 90s.

In light of the above discussions, the purpose of this research was to make an explorative and chronological review of the grouping genetic algorithm approach and its applications. Therefore, the research focuses on the

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following specific objectives:

1) To make a survey of the articles on grouping genetic algorithms and its applications;
2) To make a chronological review analysis of research on the grouping genetic algorithm approach; and,
3) To visualize and derive future trends and further research prospects.

The rest of the paper is structured as follows: Section II presents an overview of the grouping genetic algorithms. Section III outlines the research methodology followed in this research. Section IV presents the results and discussions. Section V discusses future research trends. Finally, Section VI concludes the paper.

II. Grouping Genetic Algorithms: An Overview

In 1993, Falkenauer [1] originated the grouping genetic algorithm, the term coined to refer to a genetic algorithm that applies the group encoding and the associated genetic operators for solving grouping problems. This development was motivated by the need to improve the performance of genetic algorithms on grouping problems. In their classical representation (coding) schemes, classical genetic algorithms suffer from high redundancy among chromosomes and context insensitivity [1] [2]. The algorithm can primarily be described in terms of its group encoding, group crossover, mutation and inversion operators.

A. Group encoding

The encoding scheme for grouping problems can be illustrated as in Fig. 1. Three groups 1, 2, 3, contain items {4,5}, {2,3,6}, and {1,7}, respectively. According to Falkenauer [1], each group represents a gene, and the order of items in a group is insignificant. Unlike the classical approach, the group encoding scheme does not suffer from redundancy [1] [2].

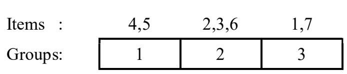

Fig. 1. Group encoding scheme

Following the group encoding step, the group crossover operator is executed.

B. Group Crossover

Crossover is the main operator which facilitates guided information exchange between chromosomes. Its major purpose is to produce new chromosomes without adverse disruption of the group structure of the current chromosomes.

1) Select two cross-points in any two chromosomes, and select a crossing section from first parent, which is labelled 1 in Fig. 2.
2) Inject the crossing section into the second parent, which yields a new offspring likely to contain repeated item, called doubles.
3) Knock out repeated items, while avoiding newly-injected items. Some of the genes in the second parent are modified, e.g., genes 4 and 6 are modified to 4' and 6', respectively.
4) The modified genes are adapted using problem-specific heuristic, which yields gene 7.
5) Interchange the roles of the two parent chromosomes: parent 1 and 2.
6) Repeat steps 2 to 4 until the required number of offspring are generated.

In the actual implementation, the algorithm repeats until the desired population of new offspring is created. Consider two randomly selected parent chromosomes, (i) chromosome [1 2 3], which contains groups of items {4,5}, {2,3,6}, {1,7}, and (ii) chromosome [4 5 6] which contains groups of items {1,5}, {2,7}, {3,4,6}. The crossover operation for the two chromosomes is presented in the figure (Fig. 2). The final offspring obtained are chromosomes [4' 1 5 6'] and [1 5 7].

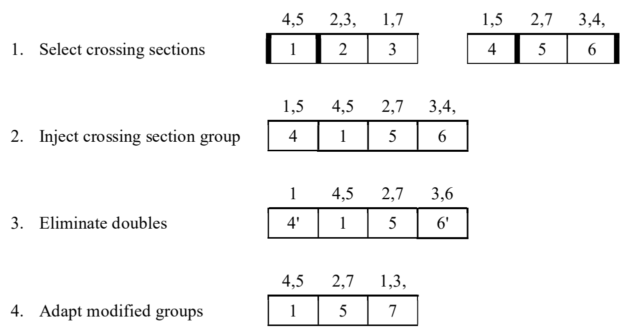

Fig. 2. An illustration of the group crossover operation

After the group crossover operator, group mutation is executed.

C. Group Mutation

Group mutation must primarily works with groups, rather than items [1]. There are three general strategies for group mutation: (i) creating new groups, (ii) eliminating selected groups, and (iii) shuffling a small number of selected items among the groups. However, this will also depend on the specific problem that is to be solved. Special constructive heuristics may be used [5].

D. Inversion

The aim of inversion is to facilitate transmission of good schemata from parents to offspring, so as to ensure increased rate of sampling of those schemata that are better performing [1] [2]. As an example, the chromosome,

[1 2 3 4],

could be inverted to:

[1 4 3 2],

Because items 1 and 4 are now closer together, this increases the probability of transmitting both genes 1 and 4 together into the next generation when the next crossover is performed.

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III. Research Methodology

The research methodology used in this study comprises three steps, which lead to the chronological exploratory analysis of peer-reviewed literature on grouping genetic algorithms and the associated application areas. The first step was to carry out an initial literature search survey to explore the GGA literature found in online databases and library resources, including EBSCO Inspec, ISI Web of Science, Ei Compendex, ScienceDirect, Google Scholar and Research Gate. To limit the range of articles, specific key words containing special terms were used, particularly, *grouping genetic algorithm(s)*, *group genetic algorithm(s)*, and *grouping problems*.

The second step was to streamline the literature to make sure that the selected articles were strictly about grouping genetic algorithms and their applications and also that the articles were published in peer-reviewed journals, conference proceedings, book chapters, and books. Only articles published from the inception of GGA in 1993 [1] to 2017 were considered.

The third and final step was to analyze the selected articles, focusing on the chronological developments in the literature, the range of articles, the associated growth of applications, and the progression of research activities over the period. Some of the results and findings of the study are presented in the next section.

IV. Research Findings

Research findings generally indicate an ever-increasing research activity. A significant number of articles were found in operations research/operations management and soft computing journals, and these areas are broadly identified with the Industrial Engineering field. More classified analyses follow.

Table I presents a classified list of articles found in the literature. Major contributions were found in journals, with a total of 34 journal articles. This was followed by conference papers and book chapters, each amounting to a total of 6 articles. In addition to these articles, 2 books were found in the literature search, whose major focus is strictly on grouping genetic algorithm [5] [24].

TABLE I
A Classified List of Articles in the Literature

Article	Count
Journal article	34
Conference proceedings	6
Book chapter	6
Books	2

Table II presents a list of identified journals, ranked according to the number or count of articles published in each of the journals, particularly those with 2 or more articles. The analysis shows that most of the journals are in soft computing and operations research, with applications in production or manufacturing industries. The leading journal is *Expert Systems with Applications*, which indicates that more specialized GGA-based expert systems are expected in the near future as more grouping problems are identified.

TABLE II
Identified Articles in Selected Journals

No.	Journal Title	Count
1	Expert Systems with Applications	4
2	International Journal of Production Research	3
3	Computers & Industrial Engineering	3
4	Computers & Operations Research	2
5	Engineering Applications of Artificial Intelligence	2
6	Journal of Intelligent Manufacturing	2

Table III presents a classified list of application areas of the GGA approach. About 80% of the publications are in the first 10 application areas. Major areas include cell formation, bin packing, grouping partners for cooperative learning, home healthcare scheduling, and modular product design, with 4 or more articles. The cell formation problem emerged as the most popular problem that attracted the most attention of researchers. Interesting areas in healthcare scheduling are emerging, including home healthcare [15] [17] [45] [46], care task assignment [16], and handicapped person transportation [41]. These trends show that further specific problem areas are expected to come up in the near future.

TABLE III
A Classified List of Application Areas of GGA in the Literature

No.	Application Area	Reference	Total
1	Cell formation problem	[6] [7] [9] [10] [11] [12] [32] [47] [48]	8
2	Bin packing problem	[8] [9] [10] [24] [28] [38] [42]	7
3	Grouping partners in cooperative learning	[25] [30] [31] [35] [5]	5
4	Home healthcare scheduling	[15] [17] [45] [46]	4
5	Modular product design	[5][20] [21] [22]	4
6	Line Balancing	[5] [24] [40]	3
7	Time tabling	[4] [5]	2
8	Team formation	[5] [19]	2
9	Economies of scale	[23] [24]	2
10	Material cutting	[37] [39]	2
11	Graph coloring	[4]	1
12	Equal piles problems	[13]	1
13	Pickup and delivery	[14]	1
14	Care task assignment	[16]	1
15	Flexible job scheduling	[18]	1
16	Reviewer group construction	[26]	1
17	Estimating discretionary accruals	[27]	1
18	Facility location	[29]	1
19	Registration area planning	[33]	1
20	Multiprocessor scheduling	[34]	1
21	Microcell sectorization problem	[36]	1
22	Handicapped person transportation	[41]	1
23	Travelling salesperson	[43]	1
24	Order batching	[5]	1
25	Fleet size and mix vehicle routing	[5]	1
26	Supplier selection	[5]	1

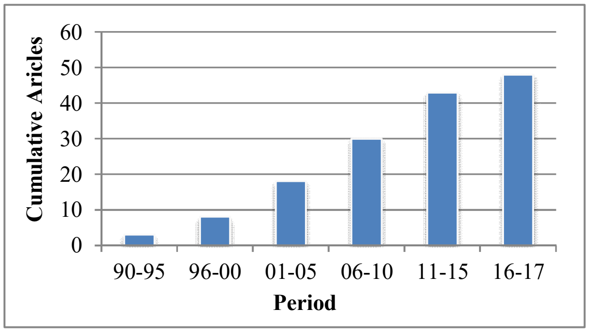

Fig. 3. Cumulative articles on grouping genetic algorithms till 2017

Fig. 3 presents research trends in terms of the cumulative articles on GGA, beginning from its conception in 1993 [1] till the year 2017. It can be seen from the graphical analysis that there is a significant ever-increasing trend in the research activities in the field. The graph reflects that the growth rate of the research activity is generally exponential, which highlights the importance of the algorithm and its applications. Based on the observed trends, research activities are expected to intensify in the future.

Following the first research book on genetic algorithms for grouping problems published in 1998 [24], a remarkable research book on advances in and applications of grouping genetic algorithms was published in 2017 [5]. These research reference books contain resourceful techniques for the algorithm.

V. Future Research Directions

From this review, it was realized that research activities in the field continue to increase. The areas of application of the algorithm continue to expand across various sectors, from manufacturing to service systems. With increasing number of application areas, and the complexity of the problems, researchers in the field are expected to focus on the following:

1) Develop better ways of exploiting the grouping structure of specific problems to improve efficient encoding schemes;
2) Develop advanced fine-tuning, dynamic and self-adaptive techniques to enhance computational efficiency of the genetic operators;
3) Develop genetic operators that are equipped with fuzzy theoretic techniques that can handle imprecise grouping problems; and,
4) Develop domain-specific constructive heuristics that can help to improve the efficiency and effectiveness of the algorithm.

It is hoped that these research directions will take the grouping genetic algorithms a step further in the near future.

VI. Conclusions

Grouping genetic algorithm is a development from classical genetic algorithms for solving an important class of computational problems where the objective is to group members of a set into desired sub sets. Designed to exploit the group structure of the problems, the algorithm can address grouping problems without suffering redundancy and context insensitivity problems. Literature search survey has shown that the grouping algorithm has been applied to several grouping problems. Most of the articles in the literature are in the areas of operations research and soft computing with applications in production and manufacturing problems. Research trends indicated an ever-increasing growth in the research activities, and more research applications are expected in the field. Prospective future research directions should focus on enhancing computational efficiency of the algorithm through improved methods of exploiting grouping structures of specific problems, design of dynamic and self-adaptive genetic operators, and hybridizing with domain-specific constructive heuristics. Further research on grouping genetic algorithms and its applications is quite promising.

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