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Hierarchical Approaches to Solve Optimization Problems

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Abstract

Optimization is the operation of finding the most appropriate solution for a particular problem or set of problems. In the literature, there are many population-based optimization algorithms for solving optimization problems. Each of these algorithms has different characteristics. Although optimization algorithms give optimum results on some problems, they become insufficient to give optimum results as the problem gets harder and more complex. Many studies have been carried out to improve optimization algorithms to overcome these difficulties in recent years. In this study, six well-known population-based optimization algorithms (artificial algae algorithm - AAA, artificial bee colony algorithm - ABC, differential evolution algorithm - DE, genetic algorithm - GA, gravitational search algorithm - GSA, and particle swarm optimization - PSO) were used. Each of these algorithms has its own advantages and disadvantages. These population-based six algorithms were tested on CEC'17 test functions and their performances were examined and so the characteristics of the algorithms were determined. Based on these results, hierarchical approaches have been proposed in order to combine the advantages of algorithms and achieve better results. The hierarchical approach refers to the successful operation of algorithms. In this study, eight approaches were proposed, and performance evaluations of these structures were made on CEC'17 test functions. When the experimental results are examined, it is concluded that some hierarchical approaches can be applied, and some hierarchical approaches surpass the base states of the algorithms.

Keywords: Optimization; Population-based Algorithm; CEC'17; Hierarchical Approaches

1. INTRODUCTION

Optimization is the operation of searching and identifying the most appropriate solution for a specific problem or set of problems. Optimization is used in almost every field, from engineering to medical, from agriculture to economics. The aim of optimization is to use the resources to a minimum, and the earnings are maximum. For the present problem, it is very critical to determine and use the most appropriate optimization method in line with this purpose [1].

The algorithms that solve optimization problems are called optimization algorithms. These algorithms are examined under two headings: deterministic and stochastic. Deterministic algorithms are algorithms that always follow the same path when the same starting points are given. Due to the disadvantages of these algorithms, such as being problem-dependent, locating them at local points in the problem, having high computational costs for large and difficult problems, researchers have turned to stochastic algorithms for the solution of optimization problems [2]. Stochastic algorithms are relied on randomness. Because these algorithms are randomness, they do not always guarantee to find the optimum, but they give close to optimum quality results with an acceptable calculation cost [1].

Stochastic algorithms are examined under two headings as heuristic and meta-heuristic. Heuristic algorithms use trial and error to find reasonable solutions for complex problems within an acceptable period of time [3]. The metaheuristic is a superior strategy that is more general than heuristics, which can easily be applied to unlike optimization problems, aiming to combine basic heuristic methods that will enable a more comprehensive investigation of the solution space [4].

Metaheuristic algorithms are classified as nature-inspired or evolutionary. Nature-inspired algorithms are one of the most studied areas in recent years. These algorithms are developed by inspiring the life of living creatures in nature. An example of these algorithms is the artificial bee colony algorithm [5]. The artificial bee colony algorithm is an algorithm inspired

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by the life behavior of bees. Artificial algae algorithm [3], particle swarm optimization algorithm [6], ant colony algorithm [7] are examples of these algorithms. Evolutionary algorithms are developed rely on the theory of evolution in biology. Genetic algorithm [8] and differential evolution algorithms [9] are examples of evolutionary algorithms.

Population-based algorithms are also used in metaheuristic algorithms. In these algorithms, the solution set is called the population [2]. In this study, six famous population-based optimization algorithms (artificial algae algorithm - AAA, artificial bee colony algorithm - ABC, differential evolution algorithm - DE, genetic algorithm - GA, gravitational search algorithm -GSA, and particle swarm optimization - PSO) were used. Each of these algorithms has its own parameters. Changing these parameters creates differences on the local and global search abilities of the algorithm. For example, one of the control parameters of the AAA is the energy loss parameter. If this parameter is low, the local search ability of the algorithm increases, and there is a risk of getting stuck to local minimums. If the energy loss parameter is high, the algorithm's global search capability increases, and thus the rate of convergence to the global best decreases [3]. Determining the most suitable values of the parameters in algorithms is an important problem.

It is necessary to well know the characteristics of the algorithms used to propose a hierarchical approach. For this purpose, a previous study was conducted to determine the characteristics of the algorithms used in this study and to compare them with each other. These six algorithms used in the previous study were tested on CEC'17 test functions [10]. Then the performances of these algorithms were examined, and their characteristics were determined. Based on these results, hierarchical approaches have been proposed in order to obtain better results than the individual results of the algorithms. In this context, eight approaches have been proposed. The performance evaluations of these structures were also made on CEC’17 test functions. When the results were examined, it was concluded that some hierarchical approaches were applicable.

The organization of the article is as follows: in the second section, related works are given. In section 3, the algorithms used in the study are introduced. In section 4, the proposed hierarchical approaches are described. In section 5, experimental setup and experimental results are given. In section 6, the results of this study were evaluated, and suggestions for future studies were given.

1.1. Main Contribution of the Study

Optimization algorithms have their own strengths and weaknesses. While some algorithms have a strong exploitation feature, some algorithms have a strong exploration feature. The aim of this study is to merge an algorithm with a strong exploitation feature and an algorithm with a strong exploration feature to obtain a stronger algorithm. For this purpose, eight different hierarchical approaches from algorithms with strong exploitation or exploration feature are proposed. As far as we know, it is the first study that presents the largest number of hierarchical approaches.

2. RELATED WORK

Metaheuristic algorithms are generally used today to resolve optimization problems. Although these algorithms are used very often, they have some disadvantages such as being stuck in local points, not being able to balance between exploration and exploitation as the problem to be solved becomes difficult and the solution space expands [11]. In order to get rid of these disadvantages and to achieve more successful results, studies have been continuing to improve the optimization algorithms in recent years. The hierarchical approach is one of these studies.

Two hierarchical approaches as PSO-GA and GA-PSO were used in antenna optimization using GA and PSO algorithms by Robinson et al. It has been observed that the PSO-GA hierarchical approach surpasses the GA-PSO hierarchical approach and the singular states of GA, PSO algorithms [12].

Bellatreche et al. (2006) [13] used the hierarchical use of GA and simulation annealing (SA) algorithms for physical data warehouse design. It was implemented as GA-SA. Experimental studies have shown that the proposed approach is feasible.

The combined GA-PSO approach was used for optimum location and sizing of distributed generation resources by Moradi and Abedini. According to the results, it has been shown that the GA-PSO approach passes GA and PSO algorithms individually and finds the most suitable solution for the system [14].

Arunachalam et al. (2014) [15] have proposed the PSO-Firefly Algorithm (FA) hierarchical approach, which they call HPSOFF, for the Combined Economic and Emission Dispatch (CEED) problem. In their proposed hierarchical approach, FA uses the population generated from the PSO algorithm. Half of the maximum number of function evaluations (MaxFES) uses the PSO and the other half the FA algorithm. In the experimental results, they saw that the method they suggested gave more successful results.

The ant colony (ACO) algorithm and the ABC algorithm are hierarchically used as ACO-ABC for the resolution of optimization problems by Kıran. As a result of experimental studies, it has been demonstrated that the ACO-ABC hierarchical approach shows superior performance compared to ACO and ABC algorithms [2].

The hierarchical approach of ACO and PSO algorithms has been applied to the traveling salesman problem by Eldem. According to the results, it has been observed that the hierarchical approach performs better than the standard ACO and standard PSO algorithm [16].

ABC, DE, and PSO algorithms were used hierarchically to solve optimization problems by Gökalp and Uğur. It was determined that the ABC-DE-PSO hierarchical structure among the combinations of these three algorithms was successful. Later, this structure was compared with the singular states of the algorithms on the test functions and it was revealed that the proposed hierarchical structure showed superior success [17].

Gaidhane and Nigam (2018) [18] have proposed the Grey Wolf Optimizer (GWO)-ABC hierarchical approach. In addition, they have proposed a new method rely on chaotic mapping and opposition-based learning to begin the population. In their paper, to evaluate the performance of the GWO-ABC, they tested on 27 synthesis comparison functions with distinct features; and they compared the results with 5 algorithms. According to the results, they showed that his overall performance improved.

Lin et al. (2018) [19] have proposed the PSO-DE hierarchical approach for numerical benchmark problems and optimization of active disturbance rejection controller (ADRC) parameters. In their study, they used the DE algorithm to get rid of PSO stagnation. They tested it on CEC2005 and CEC2011 test functions to assess the performance of the proposed algorithm. In the results, they presented that the proposed approach performed well.

Jiang et al. (2020) [20] have presented the PSO-GSA hierarchical approach, which they called HPSO-GSA. In their proposed approach, the PSO algorithm begins. Then, when the swarm reaches the optimum level and cannot develop fitness, it is included in the GSA PSO. In order to assess the effectiveness of their proposed HPSO-GSA, simulations were carried out on comparison test functions. In their results, they showed that HPSO-GSA outperformed PSO, GSA, and other recently developed hybrid variants.

Sharma and Ghosh (2020) [21] proposed a hybrid ABC-PSO algorithm to determine the optimum capacitor size. The ABC algorithm consists of three stages: worker bees, onlooker bees and scout bees. In this work, each phase updates the capacitors size and the worst solution results at the end of the last phase are optimized using the PSO algorithm. In this study, they designed and used the ABC-PSO algorithm to minimize the total power loss and energy loss.

Karakoyun et al. (2020) [22] proposed a new algorithm based on gray wolf optimizer (GWO) and shuffled frog leaping (SFLA) algorithms for multi-objective optimization problems. They named it MOSG. They applied some modifications to improve the performance of the proposed algorithm and to use the GWO algorithm effectively. The results show that the proposed algorithm gives successful results in solving multi-objective problems.

Dixit et al. (2021) [23] proposed a hybrid DE-PSO-based COVID-19 prediction model using support vector machine (SVM) from chest X-ray images. They initially performed feature extraction and data preprocessing steps. Then, the selected features were optimized with the hybrid DE-PSO algorithm as a new feature optimization approach. These optimized attributes are sent to the SVM. In the results, they showed that their proposed model achieved 99.34% accuracy.

Kisengeu et al. (2021) [24] proposed the hybrid ABC-PSO algorithm. With the algorithm they proposed in this study, they made under-voltage load shedding (UVLS) to increase voltage stability. They solved the UVLS problem by incorporating the PSO's velocity and position finding capability into the ABC algorithm. They compared their proposed hybrid ABC-PSO algorithm with GA, ABC-ANN (artificial neural networks), PSO-ANN. As a result, they show that the proposed algorithm throws an optimal amount of load.

Parouha and Verma (2021) [25] proposed a new hybrid algorithm based on PSO-DE for unlimited optimization problems and applications. They named this algorithm ihPSODE. They have integrated the ihPSODE algorithm with the proposed new PSO (nPSO) and DE (nDE). In ihPSODE, they initially ranked the entire population by fitness function value and applied nPSO to half. They then administered nDE to the offspring generated by nPSO. Then they combined the two populations. They demonstrated the superiority of the proposed algorithms in the results.

Zhang et al. (2022) [26] proposed a new GSA-PSO algorithm for multi-purpose load distribution for microgrid with electric vehicles. They named it MGSA-PSO. They integrated the global memory capacity of the PSO into the GSA to improve the global search performance of the GSA in the MGSA-PSO structure. In the results, they demonstrated the success of the proposed MGSA-PSO algorithm by analyzing it on different numbers of electric vehicles.

Li et al. (2022) [27] proposed ABC-PSO algorithm for mobile robot path planning. They added the search process and optimization process in the ABC algorithm to the optimized PSO algorithm. Thus, they developed ABC-PSO algorithm, which has good global search capabilities and fast convergence. They show in the results that the proposed algorithm finds the optimal path of the robot quickly and efficiently, with short search time and less iteration.

3. MATERIALS AND METHODS

In this section, metaheuristic algorithms used in the study are defined.

3.1. Artificial Algae Algorithm – AAA

Artificial algae algorithm (AAA) is an optimization algorithm presented in 2015 rely on the characteristics and life behavior of moving micro-algae. AAA consists of three main stages. These; evolutional process, helical movement process, and adaptation process. The helical movement process is based on the helical movements of algae in the liquid and their attitude towards approaching the light. The evolutionary process is based on the proliferation of algae by mitosis. The adaptation process is based on the adaptation of the algae to their environment. In the algorithm, algae is the main component, and all population contain of algae colonies. The number of algae cells in each algae colony is equal to the problem size. Thus, each solution in the resolution space corresponds to an artificial algae colony [3]. Due to its success in many problems, AAA is used in many areas such as feature selection [28], clustering analysis [29], uncapacitated facility location problems [30].

3.2. Artificial Bee Colony – ABC

The artificial bee colony (ABC) algorithm is a population-based optimization algorithm developed in 2005 by modeling the intelligent behavior of bees with swarm intelligence during the food search process. There are two types of bees in the artificial bee colony. The first type of bees is employed bees. Other types of bees are unemployed bees. Onlooker bees are unemployed bees. The ABC algorithm makes some assumptions. The first is that only one bee receives the nectar of each resource. Thus, the number of employed bees equals the total number of food sources. Another assumption is that the number of employed bees is the same to the number of onlooker bees [2, 5].

3.3. Differential Evolution Algorithm – DE

Differential evolution algorithm was put forward by Price and Storn in 1995. Differential evolution algorithm is one of population-based optimization algorithms rely on genetic algorithms in general [9]. Crossover, mutation, and natural selection operators in GA are also included in DE. In DE, chromosomes are handled one by one, and a new individual is formed using three randomly selected chromosomes. These operations are performed with mutation and crossover operators [31, 32].

3.4. Genetic Algorithm – GA

Genetic algorithms are evolutionary algorithms that optimize optimization problems modeled by biological processes [8]. Genetic algorithms are optimization methods based on natural selection principles. The algorithm was set up by John Holland. Later, many studies on genetic algorithms were published [33]. GA parameters represent genes. The aggregate set of parameters constitutes the chromosome. Each chromosome represents a solution [8].

In the algorithm, firstly, the initial population is randomly generated, and the suitability values of this population are calculated. Then, with the natural selection process, crossover and mutation are used to produce solutions in the next generation. The fitness evaluation process is applied to each individual to perform the selection process. A simple genetic algorithm consists of five basic components. These; representations of solutions, the method of forming the initial population, the fitness evaluation function, using the genetic operators and control parameters [32].

3.5. Gravitational Search Algorithm – GSA

The gravitational search algorithm (GSA) is an optimization algorithm presented in 2009 inspired by Newton's laws of gravity and motion. GSA tries to find the optimal solution according to Newton's laws of gravity and motion by using a series of agents called masses. Each possible solution corresponds to an agent in the GSA. The mass of each agent is represented by its fitness value. According to the fitness function, the best and worst agent of the population is detected and used in the algorithm [34].

3.6. Particle Swarm Optimization – PSO

Particle Swarm Optimization (PSO) is an optimization algorithm improved in 1995 inspired by fish and birds traveling in the swarm [6]. The algorithm is basically based on swarm intelligence. Social information sharing among individuals is important in PSO. In the algorithm, each individual is called a particle. The population formed by the combination of these particles is called a swarm. When determining the position of each particle, it takes advantage of its previous experience and adjusts it to the best position in the swarm [35]. In PSO, each particle has its best position vector called *pbest* (personal best) and passed down from generation to generation. The vector called *gbest* (global best) shows the best position information that the particle swarm has so far [36].

4. PROPOSED HIERARCHICAL APPROACHES

The six algorithms used in the study were tested on CEC'17 test functions[10]. After examining the performance of these algorithms on CEC'17 test functions and determining the characteristics of their algorithms, binary hierarchical structures were created. Hierarchical structure means that the methods work consecutively.

The first algorithm in the hierarchical approach was determined as one of the AAA, ABC, and DE algorithms. Because the global search success of these algorithms is better than other algorithms. The second hierarchical algorithm is the use of one of the ABC, GSA, and PSO algorithms whose local search capabilities are successful. The flow chart of the designed hierarchical structures is presented in Figure 1.

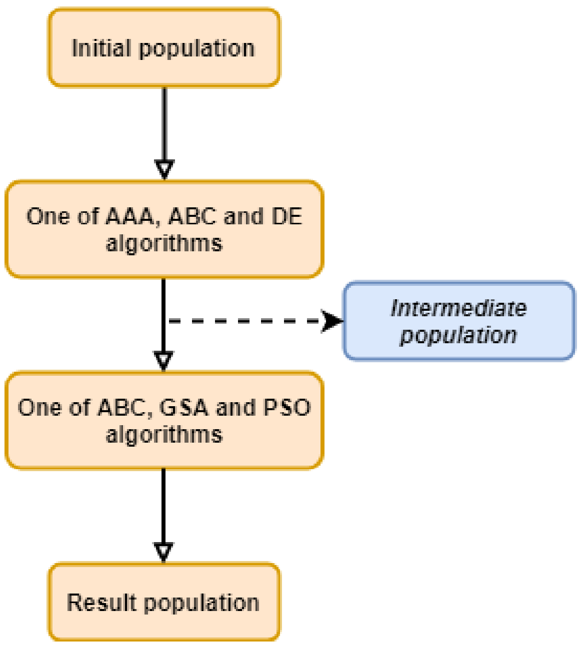

Figure 1. Flow chart of hierarchical approaches

As shown in the diagram in Figure 1, the algorithms were used successively in the hierarchical structures tested. The population developed by the first algorithm is called the intermediate population. This population is given as input to the second algorithm. In the first attempts of hierarchical approaches, the maximum number of function evaluations was equally distributed between the two algorithms as 50% -50%, and the results were examined. Then, 70% of the maximum number of function evaluations was determined to be the first algorithm and 30% to the second algorithm. This structure was compared with the structures where the maximum number of function evaluations was 50% - 50%. It was seen that the maximum number of function evaluations was 70% -30%, and the hierarchical structures gave more successful results. Therefore, the maximum number of function evaluations was taken as 70%- 30%. The results obtained after the completion of the second algorithm are the final results.

Table 1. Algorithm steps of AAA [3], ABC, DE [32], GA [32], GSA [34] and PSO [35]

AAA	ABC	DE
Step 1: Determination of parameters and initiation of algae colonies **REPEAT** **Step 2**: Helical movement stage **Step 3**: Evolutionary process **Step 4**: Adaptation process **Step 5**: Keep the best algae colony **UNTIL (number of iterations = Maximum number of iterations)**	**Step 1**: Determination of initial food sources **REPEAT** **Step 2**: Sending employed bees to food sources **Step 3**: Calculation of probability values **Step 4**: Selection of food source by onlooker bees **Step 5**: Resource release and explorer bee production **UNTIL (number of iterations = Maximum number of iterations)**	**Step 1**: Creating the initial population **REPEAT** **Step 2**: Mutation and regeneration **Step 3**: Crossover **Step 4**: Selection **UNTIL (number of iterations = Maximum number of iterations)**

GA	GSA	PSO
Step 1: Creating the initial population **REPEAT** **Step 2**: Calculation of the fitness values **Step 3**: Natural selection **Step 4**: Crossover **Step 5**: Mutation **UNTIL (number of iterations = Maximum number of iterations)**	**Step 1**: Creating the initial population **REPEAT** **Step 2**: Calculation of the fitness values **Step 3**: Finding the best and worst agent and updating the gravity value **Step 4**: Calculation of mass and acceleration of each agent **Step 5**: Updating speeds and locations **UNTIL (number of iterations = Maximum number of iterations)**	**Step 1**: Creating the initial population **REPEAT** **Step 2**: Calculation of the fitness values **Step 3**: The local best (pbest) is found for each particle. **Step 4**: Global best (gbest) is found **Step 5**: Positions and velocities are updated **UNTIL (number of iterations = Maximum number of iterations)**

In hierarchical trials, the CEC'17 test functions and their evaluation criteria were used. In this study, eight structures were tested. These eight structures are given in Table 2.

Table 2. Proposed structures

No	Proposed structures
1	AAA-ABC
2	AAA-GSA
3	AAA-PSO
4	ABC-GSA
5	ABC-PSO
6	DE-ABC
7	DE-GSA
8	DE-PSO

Hierarchical structures and singularities of algorithms were compared according to their average values over 20 independent runs in CEC'17 test functions.

5. EXPERIMENTAL STUDY

5.1. Experimental Setup

All tests in this study were made on CEC'17 test functions. The CEC'17 function set consists of 30 functions presented at the IEEE Evolutionary Computing Congress in 2017 and used to evaluate the performance of algorithms under equal conditions. The function is shown in Table 3. These functions have function groups defined in four different classes, single-mode (F1-F3), multi-mode (F4-F10), hybrid (F11-F20), and joined (F21-F30), and all functions are minimization problems. The search range [-100,100] is defined for all functions [37].

All algorithms were tested according to CEC'17 evaluation criteria. These criteria are given in Table 4. The specific parameters of each algorithm used in the algorithms are given in Table 5.

Table 3. CEC'17 test functions

Function Class	No	Function	F_i
Single mode	F1	Shifted and Rotated Bent Cigar Function	100
	F2*	Shifted and Rotated Sum of Different Power Function	200
	F3	Scrolled and Rotated Zakharov Function	300
Basic Multi-mode	F4	Scrolled and Rotated Rosenbrock Function	400
	F5	Shifted and Rotated Rastrigin Function	500
	F6	Scrolled and Rotated Extended Scaffer Function	600
	F7	Scrolled and Rotated Lunacek Bi_Rastrigin Function	700
	F8	Shifted and Rotated Discontinuous Rastrigin Function	800
	F9	Shifted and Rotated Levy Function	900
	F10	Shifted and Rotated Schwefel Function	1000
Hybrid	F11	Hybrid Function 1 (*N*=3)	1100
	F12	Hybrid Function 2 (*N*=3)	1200
	F13	Hybrid Function 3 (*N*=3)	1300
	F14	Hybrid Function 4 (*N*=4)	1400
	F15	Hybrid Function 5 (*N*=4)	1500
	F16	Hybrid Function 6 (*N*=4)	1600
	F17	Hybrid Function 7 (*N*=5)	1700
	F18	Hybrid Function 8 (*N*=5)	1800
	F19	Hybrid Function 9 (*N*=5)	1900
	F20	Hybrid Function 10 (*N*=6)	2000
Combined	F21	Combined Function 1 (*N*=3)	2100
	F22	Combined Function 2 (*N*=3)	2200
	F23	Combined Function 3 (*N*=4)	2300
	F24	Combined Function 4 (*N*=4)	2400
	F25	Combined Function 5 (*N*=5)	2500
	F26	Combined Function 6 (*N*=5)	2600
	F27	Combined Function 7 (*N*=6)	2700
	F28	Combined Function 8 (*N*=6)	2800
	F29	Combined Function 9 (*N*=3)	2900
	F30	Combined Function 10 (*N*=3)	3000
Search Range: [-100,100]			

* The function F2 has been omitted because it exhibits large instability.

Table 4. Evaluation criteria of CEC'17 functions

Population size (*N*)	50
Dimension (*D*)	10, 30, 50, 100
Maximum function evaluation number (*MaxFES*)	10000 * D
Lower limit	-100
Upper limit	100
The number of runs (*run*)	20

Table 5. Parameters of algorithms

Algorithm	Parameters
AAA	Loss of energy (e) = 0.3 Shear force (K) = 2 Adaptation coefficient (A_p) = 0.2
ABC	Limit=100
DE	Step size (F_weight) = 1 Crossover probability constant (F_CR) = 0.9
GA	Crossover probability (p_c) = 0.9 Mutation probability (p_m) = 0.1 Stochastic Universal Sampling in Selection (SUS)
GSA	α parameter = 20 Gravity constant initial value (G_0) = 100
PSO	Inertia weight (w) = 1 Inertia Weight reduction ratio (wdamp) = 0.99 Learning Constants (c_1, c_2) = 2

The statistical results such as mean and standard deviation were used in all studies to evaluate the quality of the solutions. When comparing, the hierarchical approaches were compared according to their mean and standard deviation values, and the best hierarchical approach and the basic states of the algorithms were compared according to their mean values.

5.2. Experimental Results

In this study, hierarchical approaches are proposed for continuous optimization problems. First, these proposed hierarchical approaches were compared on the CEC'17 test functions in 10, 30, 50 and 100 dimensions. Then, according to the results obtained from this comparison, the hierarchical approach, which was found to be the most successful, and the basic states of the art algorithms used in the hierarchical approaches were again compared on the CEC'17 test functions in 10, 30, 50 and 100 dimensions. The results obtained in the hierarchical approaches are presented between Table 6 and Table 9. In addition, in the last row of these tables, there is the best value showing how many best results each hierarchical approach achieved.

Table 6. Results of hierarchical approaches for D = 10

F	AAA-ABC		AAA-GSA		AAA-PSO		ABC-GSA		ABC-PSO		DE-ABC	
	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
f1	1,06E+03	1,16E+03	1,20E+03	1,89E+03	6,22E+02	6,94E+02	8,92E+02	7,41E+02	3,30E+02	2,97E+02	**1,00E+02**	2,53E-0
f3	3,17E+02	3,07E+01	3,25E+02	2,78E+01	**3,00E+02**	9,83E-11	8,82E+03	3,40E+03	**3,00E+02**	1,27E-08	**3,00E+02**	2,61E-1
f4	4,04E+02	1,07E+00	4,04E+02	1,11E+00	4,03E+02	1,24E+00	4,01E+02	6,48E-01	**4,00E+02**	6,35E-01	**4,00E+02**	1,10E-0
f5	**5,05E+02**	1,51E+00	5,06E+02	2,35E+00	5,06E+02	2,05E+00	5,07E+02	2,09E+00	5,11E+02	2,61E+00	5,09E+02	2,89E+
f6	**6,00E+02**	9,76E-14	**6,00E+02**	6,39E-14	**6,00E+02**	7,82E-14	**6,00E+02**	2,89E-06	**6,00E+02**	7,94E-08	**6,00E+02**	2,79E-0
f7	**7,14E+02**	1,64E+00	7,16E+02	1,82E+00	7,15E+02	2,05E+00	7,21E+02	3,23E+00	7,20E+02	3,14E+00	7,20E+02	4,25E+
f8	8,05E+02	2,11E+00	8,05E+02	1,67E+00	**8,03E+02**	1,50E+00	8,07E+02	1,63E+00	8,11E+02	4,09E+00	8,12E+02	4,08E+
f9	**9,00E+02**	4,92E-13	**9,00E+02**	2,29E-13	**9,00E+02**	3,69E-14	**9,00E+02**	3,05E-01	**9,00E+02**	6,90E-14	9,01E+02	1,82E+
f10	1,20E+03	1,19E+02	1,27E+03	1,25E+02	**1,17E+03**	1,22E+02	1,44E+03	1,37E+02	1,38E+03	1,02E+02	1,34E+03	1,18E+
f11	**1,10E+03**	7,49E-01	**1,10E+03**	1,01E+00	**1,10E+03**	9,01E-01	1,13E+03	2,54E+01	1,11E+03	5,89E+00	1,11E+03	5,21E+
f12	1,01E+04	7,59E+03	9,32E+03	6,35E+03	8,37E+03	5,79E+03	5,80E+05	3,50E+05	1,29E+04	9,06E+03	**1,35E+03**	1,87E+
f13	2,30E+03	2,41E+03	1,49E+03	2,25E+02	1,67E+03	5,82E+02	6,63E+03	3,33E+03	4,47E+03	3,32E+03	**1,31E+03**	6,07E+
f14	1,46E+03	7,64E+01	1,44E+03	9,54E+01	1,42E+03	3,18E+01	3,18E+03	1,11E+03	1,48E+03	9,35E+01	**1,41E+03**	8,34E+
f15	1,54E+03	7,86E+01	1,54E+03	4,12E+01	1,52E+03	3,93E+01	2,05E+03	5,71E+02	1,52E+03	1,68E+01	**1,50E+03**	2,83E+
f16	**1,60E+03**	8,52E+00	**1,60E+03**	7,08E-01	**1,60E+03**	9,06E+00	1,62E+03	1,99E+01	**1,60E+03**	8,66E+00	1,62E+03	2,82E+
f17	**1,70E+03**	3,83E+00	**1,70E+03**	6,87E-01	**1,70E+03**	4,98E-01	**1,70E+03**	2,91E+00	**1,70E+03**	2,84E+00	1,71E+03	8,21E+
f18	2,92E+03	1,21E+03	2,77E+03	1,13E+03	2,49E+03	8,11E+02	4,33E+03	1,14E+03	5,01E+03	2,72E+03	1,82E+03	1,20E+
f19	1,92E+03	6,09E+01	1,94E+03	6,89E+01	1,91E+03	1,05E+01	2,36E+03	2,81E+02	1,93E+03	2,94E+01	**1,90E+03**	1,19E+
f20	**2,00E+03**	8,82E-03	**2,00E+03**	2,69E-05	**2,00E+03**	6,98E-02	**2,00E+03**	4,59E-01	**2,00E+03**	4,45E-01	**2,00E+03**	4,17E+
f21	2,21E+03	2,28E+01	2,22E+03	4,36E+01	2,22E+03	4,41E+01	2,22E+03	6,12E+00	**2,20E+03**	1,42E+00	2,22E+03	1,37E+
f22	2,28E+03	3,61E+01	**2,27E+03**	4,38E+01	**2,27E+03**	4,06E+01	2,29E+03	1,85E+01	2,28E+03	3,13E+01	2,29E+03	2,93E+
f23	2,61E+03	2,19E+00	2,61E+03	3,11E+00	2,61E+03	1,91E+00	2,61E+03	3,95E+00	**2,58E+03**	9,40E+01	2,61E+03	4,17E+
f24	2,56E+03	7,27E+01	2,61E+03	1,21E+02	2,63E+03	1,24E+02	2,51E+03	5,06E+00	**2,50E+03**	2,42E-06	2,54E+03	2,44E+
f25	2,90E+03	2,48E-01	2,90E+03	5,42E-01	2,90E+03	4,49E-01	2,88E+03	5,17E+01	2,86E+03	9,37E+01	**2,78E+03**	9,27E+
f26	2,81E+03	1,39E+02	2,84E+03	1,23E+02	2,88E+03	7,16E+01	2,80E+03	7,86E+01	**2,74E+03**	1,04E+02	2,84E+03	7,17E+
f27	**3,09E+03**	7,39E-01	**3,09E+03**	4,86E-01	**3,09E+03**	5,88E-01	3,10E+03	3,19E+00	**3,09E+03**	2,71E+00	**3,09E+03**	3,12E+
f28	3,13E+03	3,45E+01	3,13E+03	8,20E+01	3,10E+03	7,72E+01	3,12E+03	6,44E+01	3,10E+03	5,92E+00	**3,09E+03**	1,18E+
f29	**3,14E+03**	4,61E+00	3,15E+03	1,15E+01	**3,14E+03**	9,07E+00	3,19E+03	2,74E+01	3,17E+03	3,16E+01	3,15E+03	2,27E+
f30	**5,07E+03**	1,28E+03	6,42E+03	1,87E+03	7,01E+03	4,28E+03	1,69E+05	1,07E+05	1,20E+04	7,18E+03	8,62E+03	1,21E+
Best	**11**		**8**		**12**		**4**		**12**		**13**	

Table 7. Results of hierarchical approaches for D = 30

F	AAA-ABC		AAA-GSA		AAA-PSO		ABC-GSA		ABC-PSO		DE-ABC	
	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
f1	6,35E+02	9,60E+02	**4,24E+02**	4,72E+02	7,80E+02	1,11E+03	1,04E+03	7,61E+02	6,61E+02	5,48E+02	8,74E+02	1,32E+
f3	2,01E+04	7,35E+03	2,42E+04	1,01E+04	1,38E+03	1,56E+02	8,13E+04	8,66E+03	2,20E+03	5,34E+02	4,60E+02	2,40E+
f4	4,74E+02	2,02E+01	4,59E+02	3,08E+01	4,66E+02	2,27E+01	4,43E+02	2,66E+01	**4,35E+02**	2,72E+01	4,75E+02	2,47E+
f5	5,53E+02	1,31E+01	**5,46E+02**	9,56E+00	**5,46E+02**	1,20E+01	5,59E+02	8,67E+00	6,02E+02	1,80E+01	5,73E+02	1,54E+
f6	**6,00E+02**	1,17E-13	**6,00E+02**	1,25E-13	**6,00E+02**	1,45E-13	**6,00E+02**	3,28E-06	**6,00E+02**	2,48E-07	6,10E+02	3,68E+
f7	7,75E+02	8,54E+00	**7,74E+02**	1,08E+01	7,79E+02	1,20E+01	8,31E+02	1,56E+01	8,15E+02	1,71E+01	8,19E+02	1,51E+
f8	8,60E+02	1,99E+01	8,51E+02	1,24E+01	**8,49E+02**	1,15E+01	8,52E+02	5,14E+00	9,07E+02	1,69E+01	8,79E+02	1,78E+
f9	**9,01E+02**	6,58E-01	**9,01E+02**	1,83E+00	9,02E+02	2,15E+00	9,07E+02	9,66E-01	2,25E+03	1,05E+03	2,02E+03	7,14E+
f10	**2,97E+03**	4,62E+02	3,03E+03	4,19E+02	2,99E+03	4,45E+02	4,00E+03	2,55E+02	4,14E+03	3,00E+02	3,91E+03	5,73E+
f11	**1,13E+03**	9,37E+00	1,14E+03	1,55E+01	**1,13E+03**	9,14E+00	2,40E+03	6,68E+02	1,18E+03	4,04E+01	1,21E+03	4,92E+
f12	3,75E+05	2,78E+05	4,79E+05	2,62E+05	3,13E+05	2,20E+05	2,78E+06	7,64E+05	5,04E+05	4,81E+05	**3,23E+04**	1,70E+
f13	7,38E+03	6,98E+03	6,62E+03	7,66E+03	5,00E+03	6,05E+03	1,66E+05	9,32E+04	1,27E+04	8,30E+03	5,83E+03	1,37E+
f14	2,99E+04	2,99E+04	1,63E+04	1,64E+04	1,45E+04	1,07E+04	5,26E+05	1,89E+05	2,56E+04	3,32E+04	1,48E+03	3,23E+
f15	2,40E+03	1,54E+03	2,87E+03	1,62E+03	2,25E+03	9,23E+02	3,19E+04	1,28E+04	5,16E+03	5,38E+03	1,65E+03	1,22E+
f16	**2,12E+03**	1,50E+02	2,25E+03	1,06E+02	2,15E+03	1,44E+02	2,47E+03	1,70E+02	2,31E+03	1,81E+02	2,58E+03	2,39E+
f17	**1,84E+03**	9,87E+01	**1,84E+03**	8,67E+01	**1,84E+03**	7,26E+01	2,08E+03	1,57E+02	1,95E+03	1,16E+02	2,10E+03	1,64E+
f18	1,32E+05	6,54E+04	1,31E+05	9,05E+04	1,24E+05	5,67E+04	7,46E+05	5,27E+05	3,07E+05	2,52E+05	3,27E+03	1,34E+
f19	2,60E+03	9,66E+02	3,20E+03	2,97E+03	3,48E+03	2,13E+03	4,91E+04	1,86E+04	6,56E+03	5,04E+03	1,95E+03	6,20E+
f20	**2,15E+03**	7,58E+01	2,17E+03	7,20E+01	2,19E+03	9,79E+01	2,47E+03	1,18E+02	2,35E+03	1,32E+02	2,27E+03	1,01E+
f21	2,34E+03	2,66E+01	2,35E+03	3,63E+01	2,34E+03	3,49E+01	**2,33E+03**	3,29E+01	2,38E+03	6,74E+01	2,35E+03	5,74E+
f22	2,46E+03	5,13E+02	**2,43E+03**	5,93E+02	2,61E+03	7,66E+02	3,12E+03	1,43E+03	2,46E+03	6,95E+02	2,88E+03	1,18E+
f23	**2,68E+03**	9,65E+01	**2,68E+03**	8,60E+01	2,69E+03	6,98E+01	2,71E+03	1,22E+01	2,75E+03	2,01E+01	2,72E+03	1,53E+
f24	2,88E+03	8,89E+01	2,90E+03	1,66E+01	2,90E+03	1,86E+01	**2,85E+03**	1,48E+02	2,97E+03	1,36E+02	2,87E+03	1,08E+
f25	2,89E+03	1,50E+00	2,89E+03	1,26E+00	2,89E+03	1,58E+00	2,89E+03	1,44E+00	**2,88E+03**	1,62E+00	2,89E+03	7,14E+
f26	3,40E+03	6,78E+02	3,19E+03	5,49E+02	3,86E+03	6,74E+02	3,10E+03	3,20E+02	**2,92E+03**	1,07E+02	3,42E+03	6,25E+
f27	**3,20E+03**	6,41E+00	**3,20E+03**	5,76E+00	**3,20E+03**	8,97E+00	3,22E+03	6,01E+00	3,22E+03	7,49E+00	3,21E+03	1,47E+
f28	3,21E+03	6,57E+00	3,20E+03	1,43E+01	3,21E+03	5,76E+00	3,21E+03	4,56E+00	3,21E+03	4,98E+00	**3,19E+03**	5,70E+
f29	3,40E+03	8,69E+01	3,41E+03	8,40E+01	**3,38E+03**	6,71E+01	3,68E+03	8,84E+01	3,58E+03	7,93E+01	3,68E+03	1,76E+
f30	7,88E+03	2,10E+03	7,25E+03	1,26E+03	7,92E+03	3,11E+03	8,12E+04	5,39E+04	1,18E+04	3,48E+03	**5,17E+03**	1,79E+
Best	**9**		**9**		**7**		**3**		**4**		**3**	

Table 8. Results of hierarchical approaches for D = 50

F	AAA-ABC		AAA-GSA		AAA-PSO		ABC-GSA		ABC-PSO		DE-ABC	
	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
f1	3,03E+03	3,60E+03	**2,19E+03**	1,93E+03	2,93E+03	3,34E+03	1,23E+04	6,04E+03	3,39E+03	3,03E+03	1,17E+04	1,28E+
f3	7,83E+04	1,77E+04	7,11E+04	1,49E+04	7,98E+03	1,98E+03	1,78E+05	1,03E+04	1,09E+04	2,10E+03	4,69E+04	1,84E+
f4	4,55E+02	2,79E+01	**4,47E+02**	2,46E+01	4,54E+02	2,82E+01	4,57E+02	2,01E+01	4,55E+02	2,30E+01	5,33E+02	5,35E+
f5	6,19E+02	2,13E+01	6,17E+02	2,38E+01	6,22E+02	2,65E+01	**6,07E+02**	1,14E+01	7,49E+02	3,23E+01	6,82E+02	2,72E+
f6	**6,00E+02**	1,22E-13	**6,00E+02**	1,17E-13	**6,00E+02**	1,79E-13	**6,00E+02**	3,51E-06	**6,00E+02**	1,11E-06	6,17E+02	3,65E+
f7	8,68E+02	2,38E+01	**8,66E+02**	2,19E+01	8,73E+02	2,56E+01	9,70E+02	1,55E+01	9,58E+02	2,77E+01	1,07E+03	1,05E+
f8	9,22E+02	3,04E+01	**9,11E+02**	2,40E+01	9,23E+02	2,73E+01	9,15E+02	1,06E+01	1,03E+03	2,21E+01	9,80E+02	2,93E+
f9	1,57E+03	6,27E+02	**9,15E+02**	1,39E+00	1,25E+03	4,00E+02	**9,15E+02**	1,72E+00	1,60E+04	4,24E+03	4,76E+03	1,31E+
f10	**4,85E+03**	3,94E+02	4,87E+03	5,75E+02	4,99E+03	4,46E+02	6,41E+03	4,21E+02	6,60E+03	4,13E+02	6,17E+03	8,68E+
f11	1,22E+03	5,71E+01	1,21E+03	3,76E+01	**1,20E+03**	2,61E+01	5,21E+03	1,27E+03	1,26E+03	4,83E+01	1,33E+03	6,44E+
f12	3,25E+06	1,87E+06	3,06E+06	2,17E+06	2,47E+06	1,35E+06	1,07E+07	3,02E+06	3,42E+06	1,79E+06	3,64E+05	2,80E+
f13	5,43E+03	5,92E+03	**3,65E+03**	2,88E+03	4,15E+03	4,74E+03	2,34E+05	2,31E+05	6,11E+03	6,70E+03	2,04E+04	1,43E+
f14	2,87E+05	2,38E+05	1,32E+05	1,08E+05	8,53E+04	7,63E+04	6,67E+05	2,86E+05	6,80E+04	3,92E+04	3,26E+03	1,63E+
f15	6,66E+03	5,11E+03	6,85E+03	5,37E+03	**6,12E+03**	5,08E+03	7,09E+04	4,35E+04	1,55E+04	5,46E+03	2,41E+04	1,11E+
f16	**2,80E+03**	2,82E+02	**2,80E+03**	2,51E+02	2,81E+03	1,71E+02	3,12E+03	1,95E+02	3,02E+03	2,92E+02	3,37E+03	4,82E+
f17	**2,41E+03**	1,95E+02	2,43E+03	1,96E+02	2,47E+03	2,12E+02	3,00E+03	2,43E+02	2,87E+03	2,10E+02	2,96E+03	3,86E+
f18	6,17E+05	3,12E+05	6,20E+05	5,23E+05	6,38E+05	4,08E+05	1,65E+06	5,96E+05	1,42E+06	9,34E+05	1,23E+04	7,42E+
f19	6,71E+03	4,98E+03	7,82E+03	4,17E+03	5,35E+03	2,48E+03	8,72E+04	2,74E+04	2,38E+04	1,03E+04	4,12E+03	4,25E+
f20	2,62E+03	1,47E+02	**2,59E+03**	2,20E+02	2,61E+03	2,02E+02	3,07E+03	1,83E+02	3,01E+03	2,38E+02	2,90E+03	2,28E+
f21	2,43E+03	2,10E+01	2,42E+03	1,82E+01	2,42E+03	2,15E+01	**2,40E+03**	1,62E+01	2,54E+03	3,27E+01	2,49E+03	3,84E+
f22	6,32E+03	1,50E+03	**6,23E+03**	1,42E+03	6,61E+03	8,15E+02	8,67E+03	5,23E+02	8,27E+03	1,46E+03	8,69E+03	6,62E+
f23	2,87E+03	3,19E+01	2,87E+03	2,76E+01	2,87E+03	2,44E+01	**2,86E+03**	1,70E+01	3,00E+03	2,66E+01	2,92E+03	3,52E+
f24	3,12E+03	6,01E+01	3,12E+03	4,09E+01	3,11E+03	5,25E+01	3,24E+03	2,84E+01	3,43E+03	1,79E+02	**3,05E+03**	8,46E+
f25	**3,00E+03**	2,86E+01	3,01E+03	1,90E+01	3,01E+03	2,52E+01	3,02E+03	1,47E+01	3,02E+03	1,00E+01	3,03E+03	4,77E+
f26	4,41E+03	1,05E+03	4,77E+03	6,74E+02	5,14E+03	5,77E+02	**4,23E+03**	8,66E+02	4,96E+03	1,61E+03	5,35E+03	6,81E+
f27	**3,26E+03**	2,77E+01	3,27E+03	2,19E+01	3,27E+03	2,45E+01	3,39E+03	2,84E+01	3,39E+03	3,06E+01	3,40E+03	9,25E+
f28	**3,26E+03**	1,05E+01	3,27E+03	1,42E+01	3,28E+03	1,64E+01	3,29E+03	1,13E+01	3,28E+03	1,49E+01	3,30E+03	2,22E+
f29	3,58E+03	1,31E+02	3,64E+03	1,50E+02	**3,57E+03**	1,77E+02	4,29E+03	1,86E+02	4,26E+03	1,86E+02	4,40E+03	3,43E+
f30	6,97E+05	7,12E+04	6,91E+05	6,80E+04	6,94E+05	5,75E+04	1,49E+06	4,43E+05	8,80E+05	9,34E+04	**6,62E+05**	8,93E+
Best	**7**		**10**		**4**		**6**		**1**		**2**	

Table 9. Results of hierarchical approaches for D = 100

F	AAA-ABC		AAA-GSA		AAA-PSO		ABC-GSA		ABC-PSO		DE-ABC	
	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
f1	2,89E+03	3,61E+03	**2,14E+03**	2,05E+03	2,79E+03	4,42E+03	1,69E+04	8,43E+03	7,46E+03	7,43E+03	4,09E+08	8,15E+08
f3	2,95E+05	5,45E+04	2,92E+05	3,52E+04	**8,47E+04**	1,99E+04	3,62E+05	1,97E+04	1,00E+05	1,03E+04	4,78E+05	6,68E+04
f4	**6,14E+02**	2,02E+01	6,18E+02	2,32E+01	6,22E+02	2,47E+01	6,26E+02	2,70E+01	6,28E+02	2,84E+01	7,09E+02	5,79E+01
f5	9,08E+02	6,14E+01	9,10E+02	4,70E+01	9,18E+02	6,46E+01	**8,32E+02**	1,87E+01	1,23E+03	8,20E+01	1,02E+03	7,18E+01
f6	**6,00E+02**	2,17E-13	**6,00E+02**	2,39E-13	**6,00E+02**	2,60E-13	**6,00E+02**	3,41E-06	**6,00E+02**	3,15E-06	6,36E+02	6,27E+00
f7	**1,18E+03**	5,35E+01	**1,18E+03**	5,59E+01	**1,18E+03**	4,10E+01	1,23E+03	1,50E+01	1,47E+03	6,08E+01	3,07E+03	4,13E+02
f8	1,22E+03	7,01E+01	1,22E+03	7,28E+01	1,20E+03	6,85E+01	**1,15E+03**	2,57E+01	1,57E+03	7,62E+01	1,32E+03	6,96E+01
f9	1,82E+04	4,23E+03	7,13E+03	3,83E+03	1,86E+04	7,48E+03	**3,09E+03**	1,03E+03	7,42E+04	8,30E+03	1,58E+04	5,02E+03
f10	1,15E+04	1,10E+03	**1,12E+04**	8,51E+02	1,14E+04	9,47E+02	1,37E+04	8,34E+02	1,52E+04	9,74E+02	1,41E+04	1,25E+03
f11	1,77E+04	6,20E+03	1,72E+04	5,29E+03	2,16E+03	2,27E+02	6,48E+04	8,27E+03	2,59E+03	3,67E+02	1,90E+03	2,98E+02
f12	1,09E+07	4,05E+06	1,21E+07	8,28E+06	1,07E+07	4,14E+06	3,67E+07	7,09E+06	2,45E+07	7,58E+06	**5,81E+06**	3,53E+06
f13	**2,97E+03**	1,75E+03	3,38E+03	2,13E+03	3,15E+03	2,64E+03	7,67E+04	5,74E+04	5,57E+03	2,04E+03	1,99E+04	1,25E+04
f14	1,66E+06	1,21E+06	9,58E+05	5,01E+05	1,38E+06	7,54E+05	9,57E+05	2,51E+05	1,53E+06	8,71E+05	**2,94E+04**	1,63E+04
f15	2,36E+03	7,28E+02	**2,00E+03**	4,28E+02	2,15E+03	4,79E+02	1,41E+05	8,14E+04	2,86E+03	1,19E+03	1,48E+04	1,15E+04
f16	4,77E+03	3,62E+02	**4,65E+03**	4,52E+02	4,78E+03	3,54E+02	5,66E+03	3,95E+02	5,07E+03	4,64E+02	5,56E+03	3,58E+02
f17	4,09E+03	2,76E+02	**3,99E+03**	3,72E+02	4,06E+03	2,98E+02	4,88E+03	5,40E+02	4,89E+03	4,48E+02	5,00E+03	4,97E+02
f18	2,22E+06	1,02E+06	1,63E+06	7,84E+05	1,73E+06	8,45E+05	1,09E+06	2,40E+05	4,22E+06	2,06E+06	2,40E+05	1,04E+05
f19	**2,33E+03**	4,53E+02	2,40E+03	5,31E+02	2,82E+03	8,42E+02	2,20E+05	8,88E+04	3,23E+03	1,10E+03	2,20E+04	1,40E+04
f20	4,20E+03	3,77E+02	**4,08E+03**	3,53E+02	4,32E+03	2,73E+02	5,48E+03	4,48E+02	4,86E+03	3,74E+02	4,67E+03	4,81E+02
f21	2,74E+03	5,25E+01	2,71E+03	6,45E+01	2,73E+03	6,47E+01	**2,67E+03**	2,15E+01	3,06E+03	7,28E+01	2,86E+03	7,83E+01
f22	**1,37E+04**	9,05E+02	**1,37E+04**	1,19E+03	1,39E+04	1,15E+03	1,80E+04	7,94E+02	1,83E+04	8,64E+02	1,64E+04	9,55E+02
f23	**3,08E+03**	3,92E+01	**3,08E+03**	3,81E+01	3,10E+03	4,90E+01	3,17E+03	2,23E+01	3,23E+03	3,35E+01	3,32E+03	8,38E+01
f24	**3,67E+03**	5,22E+01	3,68E+03	6,27E+01	3,68E+03	5,13E+01	3,68E+03	4,02E+01	3,90E+03	4,53E+01	3,88E+03	1,09E+02
f25	**3,19E+03**	4,32E+01	3,21E+03	4,64E+01	3,23E+03	4,52E+01	3,24E+03	2,53E+01	3,25E+03	2,97E+01	3,36E+03	9,27E+01
f26	1,01E+04	1,13E+03	9,84E+03	6,06E+02	1,02E+04	4,71E+02	**9,44E+03**	3,54E+02	1,33E+04	5,09E+02	1,27E+04	1,17E+03
f27	**3,36E+03**	3,58E+01	3,38E+03	2,98E+01	3,39E+03	2,20E+01	3,52E+03	3,86E+01	3,48E+03	3,12E+01	3,51E+03	7,81E+01
f28	3,37E+03	1,82E+01	**3,36E+03**	1,69E+01	3,37E+03	1,98E+01	3,41E+03	1,48E+01	3,40E+03	2,00E+01	3,62E+03	3,01E+02
f29	**5,52E+03**	2,91E+02	5,53E+03	3,56E+02	5,54E+03	2,78E+02	7,39E+03	2,74E+02	7,37E+03	3,69E+02	6,54E+03	5,97E+02
f30	9,47E+03	2,40E+03	1,02E+04	3,94E+03	**9,41E+03**	2,74E+03	4,64E+04	3,92E+04	1,97E+04	3,65E+03	1,49E+04	1,42E+04
Best	**11**		**11**		**4**		**6**		**1**		**2**	

Table 10. Friedman test results of all hierarchical approaches

			AAA-ABC	AAA-GSA	AAA-PSO	ABC-GSA	ABC-PSO	DE-ABC	DE-GSA	DE-PSO
D = 10		***Best***	11	8	12	4	12	**13**	9	7
	Friedman Test	***Mean Rank***	3.9310	4.2759	**3.5000**	5.5517	4.0690	3.6207	5.5172	5.5345
		Final Rank	3	5	**1**	8	4	2	6	7
		p-Value	**7.1387e-05**							
D = 30		***Best***	**9**	**9**	7	3	4	3	4	5
	Friedman Test	***Mean Rank***	3.4483	**3.3448**	3.4483	5.7586	5.5172	4.4655	4.6552	5.3621
		Final Rank	2.5	**1**	2.5	8	7	4	5	6
		p-Value	**9.9017e-06**							
D = 50		***Best***	7	**10**	4	6	**1**	2	0	5
	Friedman Test	***Mean Rank***	3.1552	**2.6897**	3.0000	5.5690	5.6207	5.5690	4.8966	5.5000
		Final Rank	3	**1**	2	6.5	8	6.5	4	5
		p-Value	**2.1195e-10**							
D = 100		***Best***	**11**	**11**	4	6	1	2	1	1
	Friedman Test	***Mean Rank***	2.9828	**2.5517**	3.0517	5.0345	5.8103	5.6897	5.1897	5.6897
		Final Rank	2	**1**	3	4	8	6.5	5	6.5
		p-Value	**8.2196e-12**							

Looking at the comparison of hierarchical approaches in 10 dimensions in Table 6, has become the most successful DE-ABC hierarchical structure. Here, the DE-ABC hierarchical approach has been the most successful due to the low-dimensional global search ability of DE and the low-dimensional local search ability of ABC. Then, the hierarchical structures AAA-PSO and ABC-PSO were the most successful. In Table 7, the comparison of hierarchical approaches in 30 dimensions, has become the most successful AAA-ABC and AAA-GSA hierarchical structures. Here, the AAA-ABC and AAA-GSA hierarchical approaches were most successful, with the global search capabilities of the AAA algorithm combined with the local search capabilities of the ABC and GSA. In 50 dimensions the comparison of hierarchical approaches in Table 8, has become the most successful AAA-GSA hierarchical structure. In Table 9 for 100 dimensions; has become the most successful AAA-ABC and AAA-GSA hierarchical structures. As the size of CEC'17 test functions increases, the problem becomes more difficult and algorithms have difficulty in solving these problems. It can be seen from these tables that the AAA-GSA hierarchical approach has managed to maintain its success even if the problem becomes difficult. For the AAA-GSA hierarchical approach, the combination of AAA's strong global search capability and GSA's strong local search resulted in a more powerful approach. This approach proved to be powerful by achieving success as the problem size increased.

When the results between Table 6 and Table 9 are examined, it is observed that some results are close to each other. For this reason, it is necessary to determine whether the results obtained by the methods have a statistically significant difference. At this point, the Friedman test is widely used in the literature. The Friedman test is a non-parametric statistical test used to rank the results of multiple methods [38]. In this study, the Friedman test was used both when ordering hierarchical approaches among themselves and when ordering the most successful hierarchical approach and the basic states of algorithms. The significance level (p-value) for the Friedman test was determined as 0.05. If this p-Value is less than 0.05, there is a statistically significant difference between the results. If the p-Value is not less than 0.05, there is no significant difference. Mean rank, final rank, and p-Value values obtained in Friedman rank test results of hierarchical approaches are given in Table 10. As seen in Table 10, the method with the lowest mean rank value is the most successful method. Looking at the Friedman test results in Table 10, while the AAA-PSO hierarchical approach in 10 dimensions was the first in the ranking with the lowest mean rank, the AAA-GSA hierarchical approach in 30, 50, and 100 dimensions were the first in the ranking with the lowest mean rank. As seen in the Table 10, each p-Value is less than 0.05. This indicates that there is a statistically significant difference between the results. Here, among the hierarchical approaches, the AAA-GSA hierarchical approach was found to be the most successful and powerful.

AAA-GSA, which is the most successful hierarchical approach determined in the first part of the experimental study, was compared with the basic algorithms on CEC'17 test functions. The results of this comparison are given in Table 11 and Table 14 for the 10, 30, 50, and 100 dimensions, respectively.

Table 11. Mean results for D=10

F	AAA	ABC	DE	GA	GSA	PSO	AAA-GSA
f1	5,48E+02	5,16E+02	**1,00E+02**	1,75E+03	3,26E+06	2,23E+03	1,20E+03
f3	3,01E+02	7,02E+03	**3,00E+02**	3,49E+03	1,24E+04	**3,00E+02**	3,25E+02
f4	4,03E+02	**4,00E+02**	**4,00E+02**	4,14E+02	4,06E+02	4,03E+02	4,04E+02
f5	**5,05E+02**	5,07E+02	5,18E+02	5,23E+02	5,13E+02	5,16E+02	5,06E+02
f6	**6,00E+02**	**6,00E+02**	6,01E+02	**6,00E+02**	6,01E+02	**6,00E+02**	**6,00E+02**
f7	**7,14E+02**	7,17E+02	7,25E+02	7,37E+02	7,29E+02	7,17E+02	7,16E+02
f8	**8,05E+02**	8,07E+02	8,17E+02	8,15E+02	8,13E+02	8,12E+02	**8,05E+02**
f9	**9,00E+02**	**9,00E+02**	9,19E+02	9,53E+02	9,01E+02	**9,00E+02**	**9,00E+02**
f10	**1,21E+03**	1,24E+03	1,49E+03	1,84E+03	1,89E+03	1,59E+03	1,27E+03
f11	**1,10E+03**	1,11E+03	1,11E+03	1,12E+03	1,39E+03	1,12E+03	**1,10E+03**
f12	9,91E+03	4,30E+04	**1,39E+03**	1,47E+06	4,31E+05	1,01E+04	9,32E+03
f13	1,51E+03	2,34E+03	**1,32E+03**	7,86E+03	9,14E+03	6,95E+03	1,49E+03
f14	1,44E+03	1,65E+03	**1,41E+03**	3,07E+03	3,73E+03	1,46E+03	1,44E+03
f15	1,54E+03	1,61E+03	**1,51E+03**	4,44E+03	9,84E+03	1,56E+03	1,54E+03
f16	**1,60E+03**	1,61E+03	1,64E+03	1,78E+03	1,96E+03	1,85E+03	**1,60E+03**
f17	**1,70E+03**	**1,70E+03**	1,73E+03	1,73E+03	1,79E+03	1,75E+03	**1,70E+03**
f18	2,84E+03	3,14E+03	**1,83E+03**	1,47E+04	4,65E+03	6,79E+03	2,77E+03
f19	1,92E+03	2,00E+03	**1,90E+03**	7,22E+03	6,11E+03	2,16E+03	1,94E+03
f20	**2,00E+03**	**2,00E+03**	2,01E+03	2,03E+03	2,16E+03	2,07E+03	**2,00E+03**
f21	2,24E+03	**2,21E+03**	2,31E+03	2,30E+03	2,32E+03	2,30E+03	2,22E+03
f22	2,28E+03	**2,25E+03**	2,29E+03	2,31E+03	2,31E+03	2,35E+03	2,27E+03
f23	2,61E+03	**2,60E+03**	2,62E+03	2,64E+03	2,62E+03	2,62E+03	2,61E+03
f24	2,68E+03	**2,50E+03**	2,71E+03	2,72E+03	2,55E+03	2,72E+03	2,61E+03
f25	2,90E+03	**2,67E+03**	2,92E+03	2,94E+03	2,93E+03	2,92E+03	2,90E+03
f26	2,86E+03	**2,66E+03**	2,92E+03	3,09E+03	2,88E+03	2,93E+03	2,84E+03
f27	3,09E+03	**3,08E+03**	3,09E+03	3,14E+03	3,10E+03	3,11E+03	3,09E+03
f28	3,13E+03	**3,07E+03**	3,30E+03	3,28E+03	3,11E+03	3,28E+03	3,13E+03
f29	**3,14E+03**	3,16E+03	3,16E+03	3,23E+03	3,22E+03	3,23E+03	3,15E+03
f30	**6,04E+03**	7,23E+03	3,95E+05	8,45E+05	2,69E+05	2,77E+05	6,42E+03
Total	**12**	**13**	**9**	**1**	**0**	**3**	**7**

Table 12. Mean results for D=30

F	AAA	ABC	DE	GA	GSA	PSO	AAA-GSA
f1	4,14E+02	2,84E+02	**1,06E+02**	3,57E+03	2,11E+07	4,97E+03	4,24E+02
f3	1,25E+04	1,13E+05	**3,01E+02**	4,02E+04	8,61E+04	7,00E+02	2,42E+04
f4	4,57E+02	**4,32E+02**	4,62E+02	4,96E+02	4,97E+02	4,91E+02	4,59E+02
f5	5,48E+02	5,83E+02	5,84E+02	6,40E+02	6,20E+02	6,04E+02	**5,46E+02**
f6	**6,00E+02**	**6,00E+02**	6,09E+02	**6,00E+02**	6,03E+02	6,05E+02	**6,00E+02**
f7	7,76E+02	8,05E+02	8,67E+02	9,08E+02	8,58E+02	8,04E+02	**7,74E+02**
f8	**8,49E+02**	8,94E+02	8,88E+02	9,11E+02	8,95E+02	8,99E+02	8,51E+02
f9	**9,01E+02**	2,22E+03	2,37E+03	2,59E+03	9,07E+02	2,04E+03	**9,01E+02**
f10	**3,01E+03**	3,45E+03	4,03E+03	4,48E+03	3,91E+03	4,37E+03	3,03E+03
f11	**1,13E+03**	1,76E+03	1,20E+03	1,23E+03	3,11E+03	1,21E+03	1,14E+03
f12	4,04E+05	8,63E+05	**3,19E+04**	1,59E+06	1,80E+06	1,84E+05	4,79E+05
f13	6,13E+03	2,89E+04	**2,42E+03**	1,80E+04	3,35E+05	2,05E+04	6,62E+03
f14	2,08E+04	1,36E+05	**1,48E+03**	9,83E+05	1,39E+05	1,67E+04	1,63E+04
f15	1,97E+03	6,75E+03	**1,64E+03**	6,87E+03	4,33E+04	7,01E+03	2,87E+03
f16	**2,17E+03**	2,18E+03	2,50E+03	2,90E+03	2,81E+03	2,48E+03	2,25E+03
f17	**1,84E+03**	1,89E+03	2,15E+03	2,43E+03	2,64E+03	2,01E+03	**1,84E+03**
f18	1,02E+05	3,13E+05	**2,68E+03**	1,70E+06	2,55E+05	2,35E+05	1,31E+05
f19	3,47E+03	1,53E+04	**1,94E+03**	7,63E+03	1,18E+05	7,51E+03	3,20E+03
f20	2,18E+03	2,25E+03	2,36E+03	2,58E+03	2,86E+03	2,42E+03	**2,17E+03**
f21	2,35E+03	**2,31E+03**	2,38E+03	2,44E+03	2,39E+03	2,40E+03	2,35E+03
f22	2,61E+03	**2,32E+03**	4,65E+03	3,69E+03	**2,32E+03**	3,93E+03	2,43E+03
f23	2,71E+03	2,72E+03	2,74E+03	2,85E+03	2,72E+03	2,81E+03	**2,68E+03**
f24	2,90E+03	**2,73E+03**	2,91E+03	3,30E+03	2,88E+03	2,95E+03	2,90E+03
f25	2,89E+03	**2,88E+03**	2,89E+03	2,90E+03	2,89E+03	2,90E+03	2,89E+03
f26	3,45E+03	**2,90E+03**	4,63E+03	5,65E+03	2,92E+03	4,22E+03	3,19E+03
f27	**3,20E+03**	3,21E+03	3,21E+03	3,27E+03	3,26E+03	3,24E+03	**3,20E+03**
f28	**3,20E+03**	**3,20E+03**	**3,20E+03**	3,21E+03	**3,20E+03**	3,21E+03	**3,20E+03**
f29	**3,41E+03**	3,54E+03	3,71E+03	3,96E+03	4,14E+03	3,67E+03	**3,41E+03**
f30	6,31E+03	2,23E+04	**5,21E+03**	9,55E+03	4,23E+05	7,99E+03	7,25E+03
Total	**10**	**8**	**10**	**1**	**2**	**0**	**10**

Table 13. Mean results for D=50

F	AAA	ABC	DE	GA	GSA	PSO	AAA-GSA
f1	**1,34E+03**	5,48E+03	1,10E+05	2,15E+03	4,11E+07	2,58E+03	2,19E+03
f3	5,17E+04	2,19E+05	**1,42E+04**	5,10E+04	1,73E+05	2,51E+03	7,11E+04
f4	4,46E+02	**4,42E+02**	5,09E+02	5,38E+02	5,82E+02	5,53E+02	4,47E+02
f5	6,21E+02	7,09E+02	6,69E+02	7,62E+02	7,40E+02	7,14E+02	**6,17E+02**
f6	**6,00E+02**	**6,00E+02**	6,19E+02	**6,00E+02**	6,06E+02	6,20E+02	**6,00E+02**
f7	8,75E+02	9,25E+02	1,23E+03	1,08E+03	9,69E+02	9,49E+02	**8,66E+02**
f8	9,29E+02	1,00E+03	9,85E+02	1,07E+03	1,05E+03	1,02E+03	**9,11E+02**
f9	1,34E+03	9,37E+03	5,00E+03	7,74E+03	**9,14E+02**	1,20E+04	9,15E+02
f10	**4,69E+03**	5,78E+03	6,42E+03	6,72E+03	5,98E+03	7,11E+03	4,87E+03
f11	**1,20E+03**	3,12E+03	1,30E+03	1,48E+03	3,66E+03	1,29E+03	1,21E+03
f12	2,32E+06	5,91E+06	**2,63E+05**	1,57E+06	1,02E+07	2,50E+06	3,06E+06
f13	**3,60E+03**	2,11E+04	2,52E+04	6,73E+03	1,19E+06	6,33E+03	3,65E+03
f14	2,35E+05	1,18E+06	**2,63E+03**	1,07E+06	1,06E+05	7,40E+04	1,32E+05
f15	**5,58E+03**	2,00E+04	1,50E+04	1,01E+04	1,47E+05	1,01E+04	6,85E+03
f16	**2,78E+03**	2,83E+03	3,31E+03	3,61E+03	3,47E+03	2,94E+03	2,80E+03
f17	2,45E+03	2,66E+03	2,89E+03	3,41E+03	3,45E+03	3,01E+03	**2,43E+03**
f18	6,35E+05	1,55E+06	**6,66E+03**	1,72E+06	7,29E+05	1,33E+06	6,20E+05
f19	7,78E+03	2,92E+04	**3,51E+03**	2,06E+04	1,96E+05	1,69E+04	7,82E+03
f20	2,98E+03	2,84E+03	2,96E+03	3,17E+03	3,22E+03	2,89E+03	**2,59E+03**
f21	2,43E+03	2,47E+03	2,47E+03	2,60E+03	2,52E+03	2,54E+03	**2,42E+03**
f22	6,73E+03	**6,16E+03**	8,24E+03	8,60E+03	9,38E+03	9,04E+03	6,23E+03
f23	**2,87E+03**	2,92E+03	2,92E+03	3,17E+03	3,08E+03	3,03E+03	**2,87E+03**
f24	3,12E+03	3,40E+03	**3,07E+03**	4,10E+03	3,17E+03	3,20E+03	3,12E+03
f25	**3,00E+03**	3,01E+03	3,04E+03	3,08E+03	3,07E+03	3,06E+03	3,01E+03
f26	5,15E+03	4,24E+03	5,90E+03	8,61E+03	**2,94E+03**	5,36E+03	4,77E+03
f27	3,29E+03	3,34E+03	3,38E+03	3,72E+03	3,72E+03	3,46E+03	**3,27E+03**
f28	3,29E+03	3,28E+03	3,29E+03	3,32E+03	3,31E+03	3,31E+03	**3,27E+03**
f29	3,65E+03	3,90E+03	4,20E+03	4,44E+03	4,65E+03	4,47E+03	**3,64E+03**
f30	**6,79E+05**	8,98E+05	7,89E+05	9,51E+05	1,18E+07	9,49E+05	6,91E+05
Total	**10**	**3**	**6**	**1**	**2**	**0**	**11**

Table 14. Mean results for D=100

F	AAA	ABC	DE	GA	GSA	PSO	AAA-GSA
f1	**1,55E+03**	7,09E+03	9,00E+08	5,28E+03	8,87E+07	3,72E+05	2,14E+03
f3	2,60E+05	5,45E+05	4,07E+05	2,27E+04	3,51E+05	**1,94E+04**	2,92E+05
f4	6,14E+02	**6,08E+02**	7,01E+02	6,41E+02	6,44E+02	7,52E+02	6,18E+02
f5	9,22E+02	1,19E+03	9,94E+02	1,17E+03	1,16E+03	1,11E+03	**9,10E+02**
f6	**6,00E+02**	**6,00E+02**	6,33E+02	**6,00E+02**	6,11E+02	6,50E+02	**6,00E+02**
f7	1,20E+03	1,44E+03	3,08E+03	1,85E+03	1,21E+03	1,39E+03	**1,18E+03**
f8	**1,22E+03**	1,53E+03	1,31E+03	1,50E+03	1,53E+03	1,40E+03	**1,22E+03**
f9	2,04E+04	5,00E+04	**1,44E+04**	1,93E+04	2,30E+03	5,18E+04	7,13E+03
f10	1,15E+04	1,33E+04	1,41E+04	1,39E+04	1,30E+04	1,49E+04	**1,12E+04**
f11	1,09E+04	7,14E+04	**1,82E+03**	6,61E+03	1,72E+05	2,45E+03	1,72E+04
f12	9,54E+06	3,26E+07	**2,98E+06**	4,63E+06	2,79E+07	1,80E+07	1,21E+07
f13	3,48E+03	1,52E+04	1,25E+04	8,96E+03	1,47E+06	1,01E+04	**3,38E+03**
f14	1,34E+06	1,00E+07	**2,23E+04**	9,09E+05	3,98E+05	8,10E+05	9,58E+05
f15	2,11E+03	1,62E+04	2,18E+04	3,71E+03	1,92E+05	4,88E+03	**2,00E+03**
f16	4,76E+03	4,93E+03	5,63E+03	6,01E+03	6,60E+03	5,12E+03	**4,65E+03**
f17	**3,95E+03**	4,52E+03	5,18E+03	5,43E+03	4,75E+03	4,88E+03	3,99E+03
f18	1,69E+06	6,90E+06	**1,55E+05**	7,58E+05	5,59E+05	2,71E+06	1,63E+06
f19	3,21E+03	1,06E+05	2,56E+05	4,41E+03	3,97E+05	5,35E+03	**2,40E+03**
f20	4,15E+03	4,88E+03	4,62E+03	5,23E+03	5,64E+03	5,04E+03	**4,08E+03**
f21	2,75E+03	3,00E+03	2,86E+03	3,09E+03	2,95E+03	3,01E+03	**2,71E+03**
f22	1,40E+04	1,63E+04	1,63E+04	1,69E+04	1,81E+04	1,81E+04	**1,37E+04**
f23	3,10E+03	3,17E+03	3,37E+03	3,47E+03	4,72E+03	3,73E+03	**3,08E+03**
f24	3,70E+03	3,87E+03	3,90E+03	4,27E+03	**3,54E+03**	4,17E+03	3,68E+03
f25	**3,20E+03**	3,23E+03	3,34E+03	3,32E+03	3,25E+03	3,38E+03	3,21E+03
f26	9,78E+03	1,17E+04	1,27E+04	1,90E+04	**4,38E+03**	1,25E+04	9,84E+03
f27	**3,38E+03**	3,46E+03	3,53E+03	3,73E+03	3,95E+03	3,75E+03	**3,38E+03**
f28	**3,35E+03**	3,38E+03	5,97E+03	3,37E+03	3,40E+03	3,48E+03	3,36E+03
f29	5,72E+03	6,92E+03	6,59E+03	7,07E+03	7,19E+03	6,93E+03	**5,53E+03**
f30	**8,73E+03**	2,33E+04	2,14E+04	1,17E+04	2,04E+06	1,11E+04	1,02E+04
Total	**8**	**2**	**5**	**1**	**2**	**1**	**15**

Table 15. The overall results of the hierarchical approaches

			AAA	ABC	DE	GA	GSA	PSO	AAA-GSA
D = 10		***Best***	12	13	9	1	0	3	7
	Friedman Test	***Mean Rank***	**2.3793**	2.7069	3.7759	6.0517	5.6897	4.8966	2.5000
		Final Rank	**1**	3	4	7	6	5	2
		p-Value	**4.6991e-18**						
D = 30		***Best***	10	8	10	1	2	0	10
	Friedman Test	***Mean Rank***	**2.3103**	3.5172	3.5517	6.0517	5.3276	4.7931	2.4483
		Final Rank	1	3	4	7	6	5	2
		p-Value	**6.0272e-15**						
D = 50		***Best***	10	3	6	1	2	0	11
	Friedman Test	***Mean Rank***	2.2414	4.0000	3.7414	5.5000	5.6552	4.6897	**2.1724**
		Final Rank	2	4	3	6	7	5	**1**
		p-Value	**3.4359e-14**						
D = 100		***Best***	8	2	5	1	2	1	15
	Friedman Test	***Mean Rank***	2.3276	4.6724	4.4310	4.5345	5.0000	4.9828	**2.0517**
		Final Rank	2	5	3	4	7	6	**1**
		p-Value	**5.7557e-11**						

Looking at the comparison of the AAA-GSA hierarchical approach in 10 dimensions and the basic states of the algorithms in Table 11; the AAA and ABC algorithms were the most successful. The AAA and ABC algorithms have proven their power in low dimensions. As seen in Table 12 the comparison of the AAA-GSA hierarchical approach in 30 dimensions and the basic states of the algorithms; the AAA-GSA hierarchical approach and the AAA, DE algorithms have been most successful. In Table 13 for 50 dimensions; the AAA-GSA hierarchical approach has been most successful. In 100 dimensions the comparison of the AAA-GSA hierarchical approach and the basic states of the algorithms in Table 14; the AAA-GSA hierarchical approach was again the most successful. With the increase in the size of the test functions and the difficulty of the problem, the AAA-GSA hierarchical approach has managed to maintain its success. Comparing the AAA-GSA hierarchical approach with the basic versions of the algorithms, the following conclusion can be drawn; the AAA-GSA hierarchical approach developed the AAA and GSA algorithms.

The average rank, final rank, and p-Value values obtained in the Friedman rank test results of the most successful hierarchical approaches and the basic states of the algorithms are given in Table 15. As seen in Table 15, the method with the lowest average rank is the most successful method. Looking at the Friedman test results in Table 15; while the AAA algorithm in 10 and 30 dimensions was the first in the ranking, the AAA-GSA hierarchical approach in 50 and 100 dimensions was the first in the ranking. As seen in Table 15, each p-Value is less than 0.05. This indicates that there is a statistically significant difference between the results. The fact that the AAA-GSA hierarchical approach is most successful in the dimensions where the problem becomes more difficult shows that this approach is strong and stable.

6. CONCLUSION

In this study, hierarchical structures are proposed based on the results of the AAA, ABC, DE, GA, GSA, and PSO algorithms on CEC'17 test functions. The results of the proposed hierarchical structures on the same test functions are examined, and the singular states of the algorithms are compared with these hierarchical models. When the results among the proposed hierarchical approaches are examined, the AAA-GSA hierarchical approach has been the most successful approach, keeping its success especially as the problem gets difficult. Then, since the AAA-GSA hierarchical approach was the most successful approach, the success of this approach and the basic states of the algorithms were compared. When the Friedman test results are also examined, it shows that there is a statistically significant distinction between the results. It is seen that the hierarchical structure of AAA-GSA generally has the first rank in the Friedman test results. It is seen from these results that; The AAA-GSA approach has been a very powerful approach to difficult problems. The AAA-GSA approach has improved these algorithms by surpassing the successes of AAA and GSA algorithms. The results of the proposed AAA-GSA approach are quite promising. But it is clear that all hierarchical approaches need further refinement.

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