Investigation into the efficiency of different bionic algorithm combinations for a COBRA meta-heuristic

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Abstract. Previously, a meta-heuristic approach, called Co-Operation of Biology-Related Algorithms or COBRA, for solving real-parameter optimization problems was introduced and described. COBRA’s basic idea consists of a cooperative work of five well-known bionic algorithms such as Particle Swarm Optimization, the Wolf Pack Search, the Firefly Algorithm, the Cuckoo Search Algorithm and the Bat Algorithm, which were chosen due to the similarity of their schemes. The performance of this meta-heuristic was evaluated on a set of test functions and its workability was demonstrated. Thus it was established that the idea of the algorithms’ cooperative work is useful. However, it is unclear which bionic algorithms should be included in this cooperation and how many of them. Therefore, the five above-listed algorithms and additionally the Fish School Search algorithm were used for the development of five different modifications of COBRA by varying the number of component-algorithms. These modifications were tested on the same set of functions and the best of them was found. Ways of further improving the COBRA algorithm are then discussed.

1. Introduction
Co-Operation of Biology-Related Algorithms or COBRA is a meta-heuristic approach developed in 2013 for solving unconstrained real-parameter optimization problems [1]. Its basic idea consists in the cooperative work of different nature-inspired algorithms. In the original version of COBRA, five well-known bionic heuristics were used as component-algorithms: the Particle Swarm Optimization Algorithm (PSO) [2], the Wolf Pack Search Algorithm (WPS) [3], the Firefly Algorithm (FFA) [4], the Cuckoo Search Algorithm (CSA) [5] and the Bat Algorithm (BA) [6]. All of the mentioned heuristics are similar bionic optimization methods originally developed for continuous variable space. These algorithms mimic the collective behaviour of the corresponding animal groups which allows the global optima of real-valued functions to be found. For example, PSO was inspired by fish and bird swarm intelligence and BA was inspired by the echolocation behaviour of bats.

However, there are still various algorithms which can be used as components for COBRA. In this study additionally the Fish School Search algorithm (FSS) [7] was include. The investigation into the efficiency of these six heuristics was conducted on the set of test functions (the Rosenbrock function, the Griewank function, the Griewank function, and so on [8]). Their performance demonstrated that all of them are sufficiently effective for solving optimization problems, and their workability was established. Based on the experimental results, five different modifications of the meta-heuristic
approach COBRA were developed and their efficiency was examined on 28 test problems from the CEC'2013 competition [9].

Thus, in this paper firstly the original version of COBRA is described, and then a brief description of the FSS algorithm and comparison of the bionic algorithms are presented. In the next section, experimental results obtained using the proposed modification are discussed and finally some conclusions are given.

2. Co-Operation of Biology Related Algorithms (COBRA)
The meta-heuristic approach Co-Operation of Biology Related Algorithms or COBRA [1] was developed on the basis of five optimization methods, namely Particle Swarm Optimization (PSO) [2], the Wolf Pack Search (WPS) [3], the Firefly Algorithm (FFA) [4], the Cuckoo Search Algorithm (CSA) [5] and the Bat Algorithm (FFA) [6] (hereinafter referred to as “component-algorithms”). The main reason for the development of a new meta-heuristic was the inability to say which of the above-listed algorithms is the best one or which algorithm should be used for solving any given optimization problem [1]. Thus, the idea was to use the cooperation of these algorithms instead of any attempts to understand which one is the best for the current problem in hand.

The originally proposed approach consists in the generating of five populations (one population for each bionic algorithm) which are then executed in parallel, cooperating with each other. The algorithm COBRA is a self-tuning meta-heuristic so there is no need to choose the population size for each component-algorithm. The number of individuals in the population of each algorithm can increase or decrease depending on the fitness value: if the overall fitness value has not improved during a given number of iterations, then the size of each population increases, and vice versa, if the fitness value has constantly improved during a given number of iterations, then the size of each population decreases.

There is also one more rule for adjusting the population size, whereby each population can “grow” by accepting individuals removed from another population. The population “grows” only if its average fitness value is better than the average fitness value of all other populations. Therefore a “winner algorithm” (an algorithm whose population has the best average fitness value) can be determined on each iteration. The described competition among component-algorithms allows the largest resource (population size) to be presented to the bionic algorithm most appropriate on the current generation.

With the aim of bringing up to date information on the best achievements to all component-algorithms and preventing their preliminary convergence to their own local optimum all populations communicate with each other. “Communication” was determined in the following way: populations exchange individuals in such a way that a part of the worst individuals of each population is replaced by the best individuals of other populations. Thus, the group performance of all algorithms can be improved.

The performance of the algorithm COBRA was evaluated on a set of benchmark problems with 5, 10 and 30 variables taken from [1] and the experiments showed that COBRA works successfully and is reliable on different benchmarks. Besides, the meta-heuristic COBRA was compared with its component-algorithms, and simulations and comparison showed that COBRA is superior to these bionic algorithms when the dimension grows and complicated problems are solved.

3. Modifications of the meta-heuristic approach COBRA
As previously noted, the original version of the COBRA approach can be described as the cooperative work of five bionic algorithms, but in this study the FSS algorithm was also used. Therefore, in this section a brief description of the FSS algorithm is presented and the idea of the proposed modifications is explained.

3.1. Fish School Search algorithm (FSS)
Fish School Search or FSS is a swarm intelligence algorithm recently developed by Carmelo J. A. Bastos Filho and Fernando Buarque de Lima Neto, based on the social behaviour of schools of fish.
[7]. FSS was first designed to simulate the process of a school of fish seeking food as an optimization problem.

The following general definitions are used for the FSS algorithm:

- the “aquarium” is the hyperdimensional search space;
- a “fish” is a candidate solution for the optimization; they each have a weight and a position;
- “food” is a metaphor for guiding fish to “good” regions of the aquarium;
- “swimming” is an operator composed of three movements that are vectorially composed before the actual move;
- “feeding” is the operator that updates the fish weight according to the quality of motion after swimming.

By living in swarms, the fish improve the survivability of the whole group due to mutual protection against enemies. Also, the fish perform collective tasks in order to find locations with lots of food. In a similar way to how real fish swim in the aquarium in order to find food, the artificial fish search (swim) the search space (aquarium) for the best solutions (locations with most food).

The FSS algorithm is simple in concept and easy to implement. The basic structure of the original FSS has the following steps:

1. initialize a population of fish with random positions on $D$ dimensions in the problem space;
2. for each fish in the swarm, update its position by applying the individual movement operator and evaluate the fitness function;
3. for each fish in the swarm, apply the feeding operator and update the fish weight;
4. for each fish in the swarm, apply the collective-instinctive movement operator and update the fish position;
5. calculate the barycentre;
6. for each fish in the swarm, apply the collective-volitive movement operator, update the fish position and evaluate the fitness function;
7. decrease the individual and volitive steps linearly;
8. continue from step 2 until a stop condition is met (usually a sufficiently good fitness value or a maximum number of iterations).

A more detailed description of the mentioned movement and feeding operators with corresponding formulas can be found in [10]. It is worth noting that the FSS algorithm is fast and is computationally inexpensive. This fact was a reason why the FSS heuristic was included as a component-algorithm of COBRA.

3.2. Efficiency examination of the bionic algorithms and proposed modifications

The performance of COBRA’s original components was evaluated on six well-known test functions, namely the Rosenbrock function, the Sphere function, the Ackley function, the Griewank function, the Hyper-Ellipsoidal function and the Rastrigin function [8] with 2, 3 and 4 variables, and was presented in [1]. Therefore, the same functions were also used for the testing of the FSS algorithm and then all the mentioned bionic algorithms were compared using the obtained results.

The minimal error, achieved within a given number of function evaluations, and the minimal number of function evaluations for obtaining the given error level were used for comparison. The observed results are given below in Table 1 where each cell contains the name of the algorithm that demonstrated the best value for the performance evaluation criteria for a given function and optimization space dimension. For each optimization problem and dimension the number of program runs was equal to 100 so the results were averaged by that number. The maximum number of function evaluations was equal to 10000; but if the obtained result differed from the known optimum by less than 0.001, calculations were stopped.

The analysis of results shows how many times each bionic algorithm demonstrates the best result for a given problem. For example, it was established that the FSS algorithm works more slowly than most of the examined heuristics but frequently it found the best minimal error.
Table 1. Comparison of the bionic algorithm performance.

| Function          | D | Minimal number of function evaluations | Minimal error |
|-------------------|---|---------------------------------------|---------------|
| Sphere function   | 2 | CSA                                   | CSA           |
|                   | 3 | BA                                    | BA            |
|                   | 4 | BA                                    | BA            |
| Griewank’s function | 2 | CSA                                   | FSS           |
|                   | 3 | WPS                                   | BA            |
|                   | 4 | CSA                                   | BA            |
| Ackley’s function | 2 | FFA                                   | PSO           |
|                   | 3 | WPS                                   | CSA           |
|                   | 4 | CSA                                   | CSA           |
| Hyper-Ellipsoidal function | 2 | CSA                                   | FSS           |
|                   | 3 | FFA                                   | FSS           |
|                   | 4 | CSA                                   | BA            |
| Rosenbrock’s function | 2 | BA                                    | BA            |
|                   | 3 | FFA                                   | FSS           |
|                   | 4 | CSA                                   | FSS           |
| Rastrigin’s function | 2 | BA                                    | CSA           |
|                   | 3 | CSA                                   | FFA           |
|                   | 4 | WPS                                   | FFA           |

Thus, the idea was proposed to vary the number of component-algorithms. More specifically, the following five new versions of the meta-heuristic approach COBRA were developed:

1. COBRA-2 (cooperative work of the CSA and the BA algorithms);
2. COBRA-3 (cooperative work of the CSA, the BA and the FFA algorithms);
3. COBRA-4 (cooperative work of the CSA, the BA, the FFA and the WPS algorithms);
4. COBRA-5 (cooperative work of the CSA, the BA, the FFA, the WPS and the FSS algorithms);
5. COBRA-6 (cooperative work of all six bionic algorithms).

Moreover, inclusion of certain algorithms was based on their successfulness during the experiments described above.

4. Experimental results
The modifications of the meta-heuristic approach COBRA proposed in the previous section were validated by using test functions with analytical or known solutions and then the obtained results were compared. The examination into the efficiency of the algorithms was conducted on the set of 28 benchmark functions that were submitted for the CEC 2013 Special Session on Real-Parameter Optimization [9].

All these functions are minimization problems; also they all are shifted and scalable. The same search ranges are defined for all test functions: the search range for each variable was [-100, 100]. So, the algorithm was tested by using 5 unimodal functions, 15 basic multimodal functions and 8 composition functions. The error values achieved after maximal function evaluations over 51 runs were sorted from the smallest (best) to the largest (worst) and then the best, worst, mean, median and standard variance values of the function error values over 51 runs were presented.

The performance of the algorithms was evaluated on functions with 5, 10 and 30 dimensions. In Table 2 the number of “wins” for each modification is presented, where “win” denotes the best obtained mean value of function error for a given number of variables.

As examples, the results for test optimization problems with 5 dimensions obtained by COBRA-6 and COBRA-4 are summarized in Table 3 and Table 4 respectively. In these Tables the standard variance is denoted as “STD”.
Table 2. Comparison of the proposed modifications.

| $D$ | COBRA-2 | COBRA-3 | COBRA-4 | COBRA-5 | COBRA-6 |
|-----|---------|---------|---------|---------|---------|
| 5   | 2       | 6       | 8       | 2       | 10      |
| 10  | 0       | 8       | 9       | 3       | 8       |
| 30  | 1       | 9       | 6       | 7       | 5       |
|     | 3       | 23      | 23      | 12      | 23      |

Table 3. Results for dimension $D = 5$ obtained by COBRA-6.

|   | Best value  | Worst value | Mean value  | STD  |
|---|-------------|-------------|-------------|------|
| 1 | 2.60E-07    | 2.90E-06    | 5.63E-07    | 4.66E-07 |
| 2 | 2.26E-04    | 7.72E-04    | 5.57E-04    | 1.86E-04 |
| 3 | 3.89E-03    | 4.72E-05    | 1.62E-05    | 6.61E-06 |
| 4 | 1.78E-06    | 1.05E-04    | 2.55E-05    | 2.30E-05 |
| 5 | 3.33E-02    | 7.82E-01    | 3.24E-01    | 2.20E-01 |
| 6 | 9.31E-04    | 1.67E-03    | 1.67E-03    | 1.03E-03 |
| 7 | 9.31E-04    | 4.31E-03    | 1.67E-03    | 1.03E-03 |
| 8 | 4.37E-03    | 2.00E+01    | 1.34E+01    | 9.35E+00 |
| 9 | 1.67E+00    | 1.67E+00    | 1.67E+00    | 1.27E+04 |
|10 | 9.37E-02    | 9.40E-02    | 9.40E-02    | 1.51E-03 |
|11 | 9.46E-05    | 1.44E-01    | 1.44E-01    | 3.20E-01 |
|12 | 9.95E-01    | 9.95E-01    | 9.95E-01    | 6.66E-08 |
|13 | 3.69E+00    | 4.05E+00    | 4.05E+00    | 1.06E+00 |
|14 | 3.49E-06    | 1.16E-03    | 1.16E-03    | 8.00E-03 |
|15 | 2.35E+01    | 3.26E+01    | 3.26E+01    | 4.48E+01 |
|16 | 6.88E-02    | 6.88E-02    | 6.88E-02    | 4.01E-05 |
|17 | 5.00E+00    | 5.00E+00    | 5.00E+00    | 5.78E-06 |
|18 | 5.00E+00    | 5.00E+00    | 5.00E+00    | 1.02E-03 |
|19 | 9.89E-03    | 1.40E-02    | 1.40E-02    | 1.18E-02 |
|20 | 3.89E-02    | 1.13E-01    | 1.13E-01    | 6.54E-02 |
|21 | 2.89E-03    | 4.79E-03    | 4.79E-03    | 1.62E-03 |
|22 | 2.27E-04    | 3.14E-04    | 3.14E-04    | 1.18E-04 |
|23 | 2.17E-04    | 3.03E-04    | 3.03E-04    | 1.16E-04 |
|24 | 3.85E+01    | 3.85E+01    | 3.85E+01    | 1.62E-05 |
|25 | 1.51E-03    | 2.60E-03    | 2.60E-03    | 7.10E-03 |
|26 | 1.86E-01    | 5.02E+00    | 5.02E+00    | 3.88E+00 |
|27 | 1.86E-01    | 5.02E+00    | 5.02E+00    | 3.88E+00 |
|28 | 5.56E-03    | 5.84E-03    | 5.84E-03    | 1.07E-03 |

Table 4. Results for dimension $D = 5$ obtained by COBRA-4.

|   | Best value  | Worst value | Mean value  | STD  |
|---|-------------|-------------|-------------|------|
| 1 | 2.03E-08    | 2.29E-06    | 1.51E-07    | 3.17E-07 |
| 2 | 1.26E-03    | 8.06E-03    | 3.43E-03    | 2.32E-03 |
| 3 | 7.14E-03    | 2.49E-01    | 2.75E-02    | 4.17E-02 |
| 4 | 9.31E-07    | 8.39E-06    | 1.69E-06    | 1.41E-06 |
| 5 | 8.21E-07    | 7.16E-05    | 1.70E-05    | 1.72E-05 |
| 6 | 1.42E-04    | 1.50E-04    | 1.44E-04    | 2.52E-06 |
One can observe that the best combination differs if the dimension varies and it is clear that COBRA should have at least three component-algorithms, otherwise it will not work efficiently. Experimental results demonstrated that the number of component-algorithms can be adjusted by a fuzzy controller, for example. In this case, the number of component-algorithms and the process of varying the population size will be controlled by some rule base.

5. Conclusions
In this paper new modifications of the meta-heuristic called COBRA (Co-Operation of Biology Related Algorithms), which was originally based on five nature-inspired algorithms (the Particle Swarm Optimization Algorithm, the Wolf Pack Search Algorithm, the Firefly Algorithm, the Cuckoo Search Algorithm and the Bat Algorithm), have been introduced. The proposed modifications involve variation of the number of component-algorithms and consequently variation of the whole composition of COBRA. Besides, the Fish School Search algorithm was added as a potential component of the COBRA approach. These modifications were validated and compared. Simulations and comparison showed that the COBRA-6 algorithm is superior to other modifications when the dimension is equal to 5, the COBRA-4 algorithm is superior to the others when the dimension is equal to 10 and the COBRA-3 algorithm is superior to the others when the dimension is equal to 30.

Experimental results showed that there is a necessity for some structure, for example, a fuzzy controller, which can be used to adjust the number of component-algorithms in an automated way. Although some modifications of the component algorithms that improve their performance are known, we used the original design of these algorithms, bearing in mind the aim of our investigation. Thus, in further work their modifications will also be included in COBRA.

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