SIMULATION OF THE DIFFERENTIAL EVOLUTION PERFORMANCE DEPENDENCY ON SWITCHING OF THE DRIVING CHAOTIC SYSTEMS

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KEYWORDS

Deterministic chaos; Discrete chaotic maps; Evolutionary computation; Differential Evolution; Chaotic Pseudo Random Number Generators

ABSTRACT

This research deals with the deeper analysis of the novel concept of a multi-chaos-driven evolutionary algorithm Differential Evolution (DE). This paper is aimed at the embedding and alternating of set of two discrete dissipative chaotic systems in the form of chaos pseudo random number generator for DE. Repeated simulations were performed on the selected test function in higher dimensions. Finally, the obtained results are compared with canonical DE.

INTRODUCTION

These days the methods based on soft computing such as neural networks, evolutionary algorithms, fuzzy logic, and genetic programming are known as powerful tool for almost any difficult and complex optimization problem. Differential Evolution (DE) (Price 1999) is one of the most potent heuristics available.

This paper is aimed at the investigating the novel concept of multi-chaos driven DE. Although a number of DE variants have been recently developed, the focus of this paper is the embedding of chaotic systems in the form of chaos pseudo random number generator (CPRNG) into the DE (ChaosDE).

Firstly, the motivation for this research is proposed. The next sections are focused on the description of evolutionary algorithm DE, the concept of chaos driven DE and the used test function. Results and conclusion follow afterwards.

MOTIVATION

This research is an extension and continuation of the previous successful initial experiments with chaos driven DE (Senkerik et al. 2014), (Senkerik et al. 2013) with test functions in higher dimensions.

In this paper the novel initial concept of DE/rand/1/bin strategy driven alternately by two chaotic maps (systems) is more deeply studied. From the previous research, it follows that very promising results were obtained through the utilization of different chaotic maps within the ChaosDE concept. The idea was then to connect these several different influences given by different CPRNGs to the performance of DE into the one multi-chaotic concept. This paper is aimed to the deeper analysis of the novel Multi-ChaosDE concept and the performance dependency on switching of the driving chaotic systems.

Recent research in chaos driven heuristics has been fueled with the predisposition that unlike stochastic approaches, a chaotic approach is able to bypass local optima stagnation. A chaotic approach generally uses the chaotic map in the place of a pseudo random number generator (Aydin et al. 2010). This causes the heuristic to map unique regions, since the chaotic map iterates to new regions. The task is then to select a very good chaotic map as the pseudo random number generator.

The initial concept of embedding chaotic dynamics into the evolutionary algorithms is given in (Caponetto et al. 2003). Later, the initial study (Davendra et al. 2010) was focused on the simple embedding of chaotic systems into the DE in the form of chaos pseudo random number generator (CPRNG). Also the PSO (Particle Swarm Optimization) algorithm with elements of chaos was introduced as CPSO (Coelho and Mariani 2009). The chaos embedded PSO with inertia weigh strategy was closely investigated (Pluhacek et al. 2013a) afterwards, followed by the introduction of a PSO strategy driven alternately by two chaotic systems (Pluhacek et al. 2013b). The primary aim of this work is not to develop a new type of pseudo random number generator, which should pass many statistical tests, but to try to use and test the implementation of natural chaotic dynamics into evolutionary algorithm as a multi-chaotic pseudo random number generator.

DIFFERENTIAL EVOLUTION

DE is a population-based optimization method that works on real-number-coded individuals (Price 1999). For each individual $\vec{x}_{i,G}$ in the current generation G, DE generates a new trial individual $\vec{x}'_{i,G}$ by adding the

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weighted difference between two randomly selected individuals $\vec{x}_{r1,G}$ and $\vec{x}_{r2,G}$ to a randomly selected third individual $\vec{x}_{r3,G}$. The resulting individual $\vec{x}'_{i,G}$ is crossed-over with the original individual $\vec{x}_{i,G}$. The fitness of the resulting individual, referred to as a perturbed vector $\vec{u}_{i,G+1}$, is then compared with the fitness of $\vec{x}_{i,G}$. If the fitness of $\vec{u}_{i,G+1}$ is greater than the fitness of $\vec{x}_{i,G}$, then $\vec{x}_{i,G}$ is replaced with $\vec{u}_{i,G+1}$; otherwise, $\vec{x}_{i,G}$ remains in the population as $\vec{x}_{i,G+1}$. DE is quite robust, fast, and effective, with global optimization ability. It does not require the objective function to be differentiable, and it works well even with noisy and time-dependent objective functions. Please refer to (Price 1999), (Price et al. 2005) for the detailed description of the used DERand1Bin strategy (1) (both for Chaos DE and Canonical DE) as well as for the complete description of all other strategies.

$$u_{i,G+1} = x_{r1,G} + F \cdot \left(x_{r2,G} - x_{r3,G}\right) \quad (1)$$

ChaosDE AND MultiChaosDE CONCEPT

The general idea of ChaosDE and CPRNG is to replace the default PRNG with the discrete chaotic map. As the discrete chaotic map is a set of equations with a static start position, we created a random start position of the map, in order to have different start position for different experiments (runs of EA's). This random position is initialized with the default PRNG, as a one-off randomizer. Once the start position of the chaotic map has been obtained, the map generates the next sequence using its current position.
From the previous research it follows, that very promising results were obtained through the utilization of Delayed Logistic, Lozi, Burgers and Tinkerbelt chaotic maps within the (single) ChaosDE concept. The last two mentioned chaotic maps have unique properties with connection to DE: strong progress towards global extreme, but weak overall statistical results, like average CF value and std. dev., and tendency to premature stagnation. While through the utilization of the Lozi and Delayed Logistic map the continuously stable and very satisfactory performance of ChaosDE was achieved. The idea is then to connect these two different influences to the performance of DE into the one multi-chaotic concept (Multi-ChaosDe).

SELECTED DISCRETE CHAOTIC SYSTEMS

This section contains the description of discrete dissipative chaotic maps used as the chaotic pseudo random generators for DE. In this research, direct output iterations of the chaotic maps were used for the generation of real numbers in the process of crossover based on the user defined CR value and for the generation of the integer values used for the selection of individuals. Following chaotic maps were used: Burgers (2), and Lozi map (3).

The typical chaotic behavior of the utilized maps, represented by the examples of direct output iterations is depicted in Fig. 1 (Burgers map) and Fig. 3 (Lozi map). The illustrative histograms of the distribution of real numbers transferred into the range <0 - 1> generated by means of studied chaotic maps are in Figures 2 and 4.

Burgers Map

The Burgers mapping is a discretization of a pair of coupled differential equations which were used to illustrate the relevance of the concept of bifurcation to the study of hydrodynamics flows. The map equations are given in (2) with control parameters a = 0.75 and b = 1.75 as suggested in (Sprott 2003).

$$\begin{aligned} X_{n+1} &= aX_n - Y_n^2 \\ Y_{n+1} &= bY_n + X_nY_n \end{aligned} \quad (2)$$

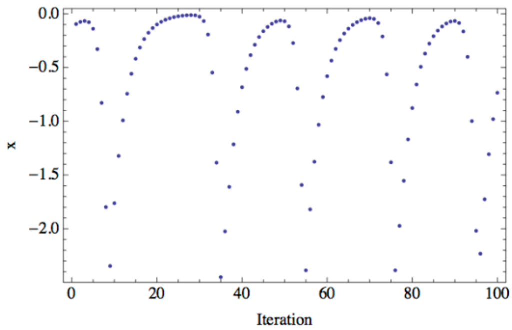

Figure 1: Iterations of the Burgers map (variable x)

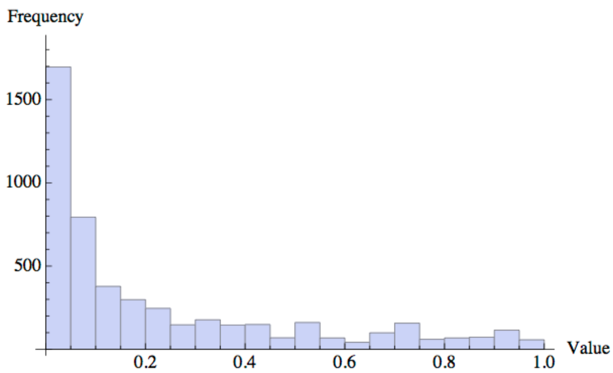

Figure 2: Histogram of the distribution of real numbers transferred into the range <0 - 1> generated by means of the chaotic Burgers map – 5000 samples

Lozi map

The Lozi map is a discrete two-dimensional chaotic map. The map equations are given in (3). The parameters used in this work are: a = 1.7 and b = 0.5 as suggested in (Sprott 2003). For these values, the system exhibits typical chaotic behavior and with this parameter setting it is used in the most research papers and other literature sources.

$$\begin{aligned} X_{n+1} &= 1 - a\left|X_n\right| + bY_n \\ Y_{n+1} &= X_n \end{aligned} \quad (3)$$

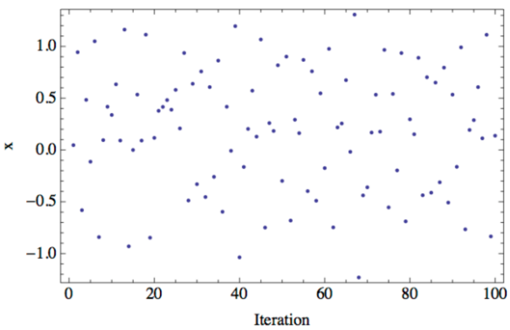

Figure 3: Iterations of the Lozi map (variable *x*)

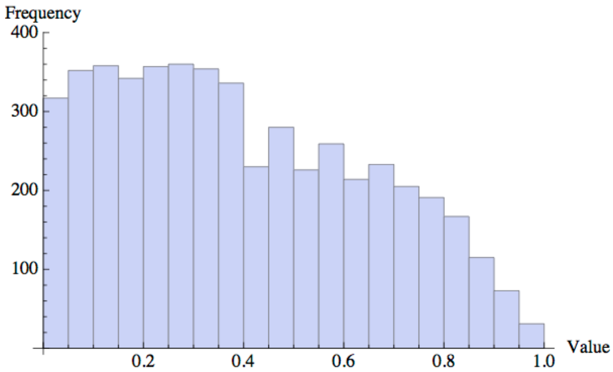

Figure 4: Histogram of the distribution of real numbers transferred into the range <0 - 1> generated by means of the chaotic Lozi map – 5000 samples

EXPERIMENT DESIGN

For the purpose of evolutionary algorithm performance comparison within this initial research, the multimodal Schwefel's test function (4) was selected.

$$f(x) = \sum_{i=1}^{D} -x_i \sin\left(\sqrt{|x_i|}\right) \quad (4)$$

Function minimum: Position for E_n:
$(x_1, x_2 \ldots x_n) = (420.969, 420.969, \ldots, 420.969)$
Value for E_n: $y = -418.983 \cdot \mathit{Dimension}$

The novelty of this research represents the simulation of the DE performance dependency on switching of the driving chaotic systems.

In this paper, the canonical DE strategy DERand1Bin and the Multi-Chaos DERand1Bin strategy driven alternately by two different chaotic maps (ChaosDE) were used.

The parameter settings for both canonical DE and ChaosDE were obtained analytically based on numerous experiments and simulations (see Table 1).

Table 2: DE settings for meta-evolution

DE Parameter	Value
PopSize	75
F	0.8
CR	0.8
Generations	3000
Max. CF Evaluations (CFE)	225000

Investigation on the moment of manual switching over between two chaotic maps represents the main aim of this paper.

Experiments were performed in the combined environment of *Wolfram Mathematica* and *C language*, canonical DE therefore used the built-in *C language* pseudo random number generator *Mersenne Twister C* representing traditional pseudorandom number generators in comparisons. All experiments used different initialization, i.e. different initial population was generated within the each run of Canonical or Chaos driven DE.

EXPERIMENT RESULTS

This initial research utilizes the maximum number of generations fixed at 3000 generations. This allowed the possibility to analyze the progress of DE within a limited number of generations and cost function evaluations.

The statistical results of the experiments are shown in Table 2, which represent the simple statistics for cost function (CF) values, e.g. average, median, maximum values, standard deviations and minimum values representing the best individual solution for all 50 repeated runs of canonical DE and several versions of ChaosDE and Multi-ChaosDE.

Table 3 compares the progress of several versions of ChaosDE, Multi-ChaosDE and Canonical DE. This table contains the average CF values for the generation No. 750, 1500, 2250 and 3000 from all 50 runs. The bold values within the both Tables 2 and 3 depict the best obtained results. Following versions of Multi-ChaosDE were studied:

Burgers-Lozi-Switch-500: Start with Burgers map CPRNG, switch to the Lozi map CPRNG after 500 generations.
Burgers-Lozi-Switch-1500: Start with Burgers map CPRNG, switch to the Lozi map CPRNG after 1500 generations.
Lozi-Burgers-Switch-500: Start with Lozi map CPRNG, switch to the Burgers map CPRNG after 500 generations.
Lozi-Burgers-Switch-1500: Start with Lozi map CPRNG, switch to the Burgers map CPRNG after 1500 generations.

The graphical comparison of the time evolution of average CF values for all 50 runs of ChaosDE/Multi-ChaosDE and canonical DERand1Bin strategy is depicted in Fig. 6. Finally the Figures 5 a) – 5d) confirm the robustness of Multi-ChaosDE in finding the best solutions for all 50 runs.

Obtained numerical results given in Tables 2 and 3 and graphical comparisons in Figures 5 and 6 support the claim that all Multi-Chaos/ChaosDE versions have given better overall results in comparison with the canonical DE version. From the presented data it follows, that Multi-Chaos DE versions driven by Lozi/Burgers Map have given the best overall results.

Table 2: Simple results statistics for the Schwefel's function – 30D

DE Version	Avg CF	Median CF	Max CF	Min CF	StdDev
Canonical DE	-5957.28	-5919.58	-5486.45	-6553.09	**272.7228**
Burger-Lozi-Switch-500	-11306.1	-11326.5	-9153.31	**-12387.9**	677.7153
Burger-Lozi-Switch-1500	-10982.9	-11067	-9832.01	-12153.4	530.9785
Lozi-Burger-Switch-500	-11120.7	-11188.4	-9794.39	-12208.5	515.4589
Lozi-Burger-Switch-1500	**-11480.5**	**-11619.6**	**-10384**	-12321.3	479.3151

Table 3: Comparison of progress towards the minimum for the Schwefel's function

DE Version	Generation No.: 750	Generation No.: 1500	Generation No.: 2250	Generation No.: 3000
Canonical DE	-5281.95	-5529.28	-5749.8	-5957.28
Burger-Lozi-Switch-500	-6466.86	-8660.88	-10360.7	-11306.1
Burger-Lozi-Switch-1500	**-6845.26**	**-9916.04**	-10738.9	-10982.9
Lozi-Burger-Switch-500	-5957.77	-8692.1	-10680.1	-11120.7
Lozi-Burger-Switch-1500	-5874.04	-7949.73	**-10808.9**	**-11480.5**

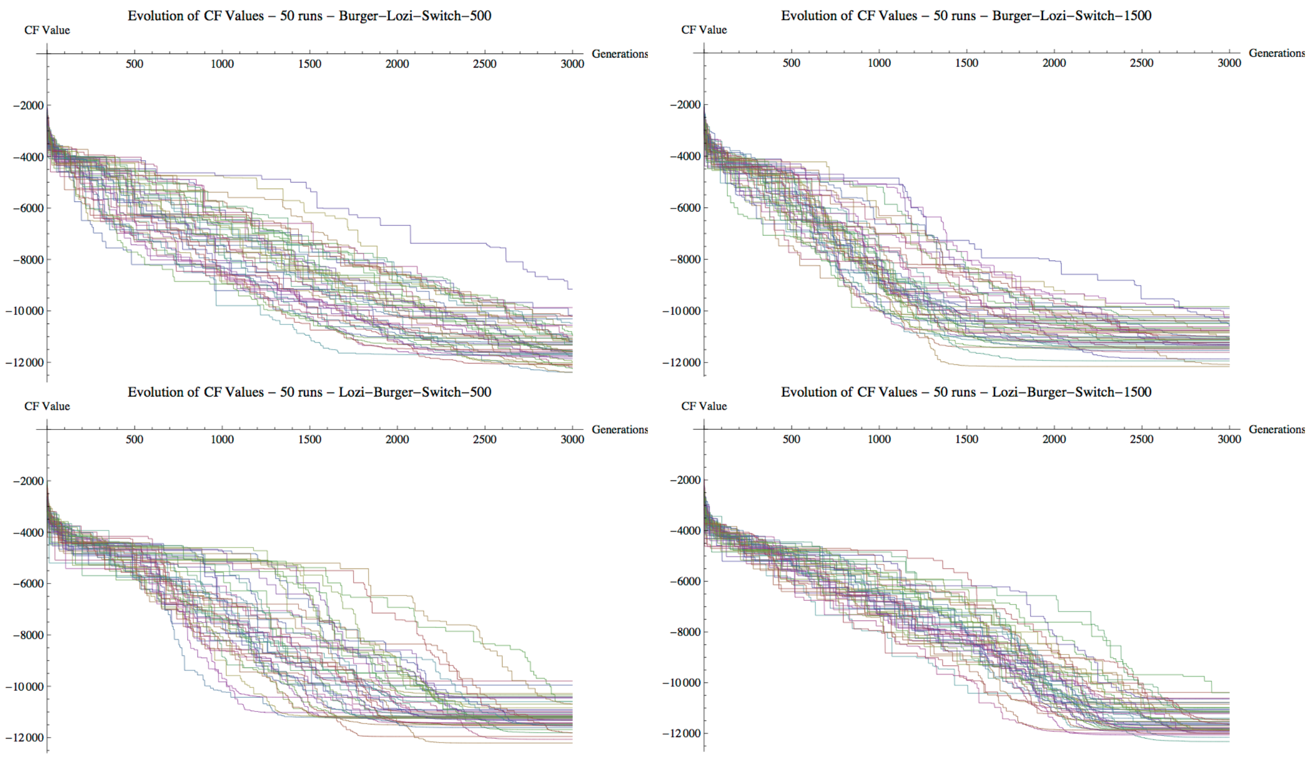

Figure 5: Comparison of the time evolution of CF values for all 50 runs of Multi-ChaosDE version:
5 a) (upper left) Burgers-Lozi-Switch-500; 5 b) (upper right) Burgers-Lozi-Switch-1500; 5 c) (below left) Lozi-Burgers-Switch-500; 5 d) (below right) Lozi-Burgers-Switch-1500

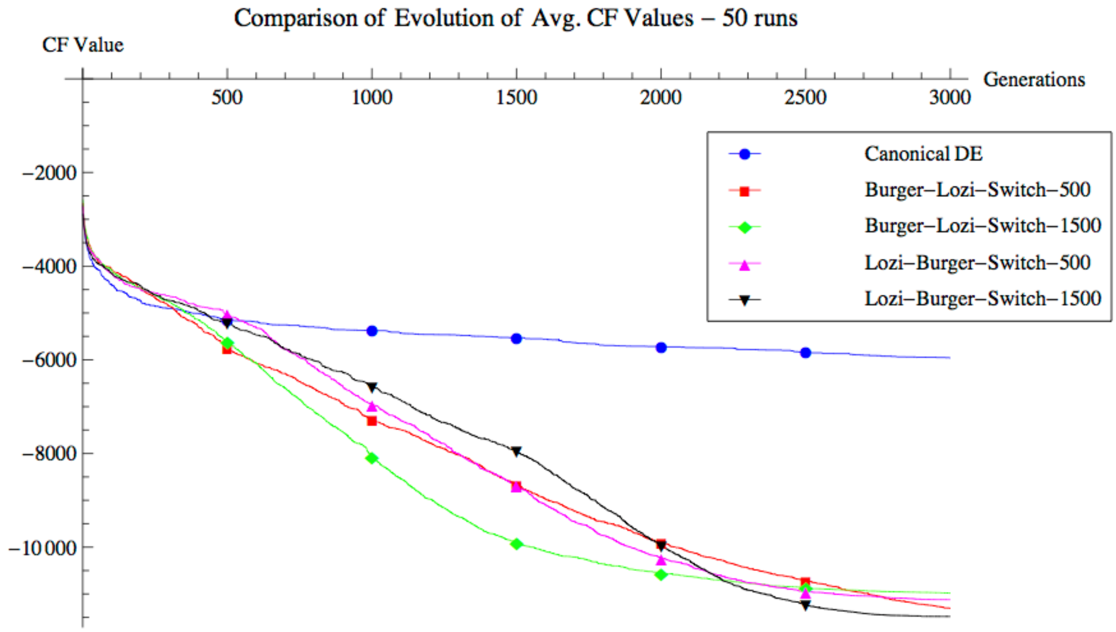

Figure 6: Comparison of the time evolution of avg. CF values for the all 50 runs of Canonical DE, ChaosDE and Multi-ChaosDE. Schwefel's function, $D = 30$.

RESULTS ANALYSIS

For the both *Burgers-Lozi-Switch* versions the progressive Burgers map CPRNG secured the faster approaching towards the global extreme from the very beginning of evolutionary process. The very fast switch over to the Lozi map based CPRNG (*Burgers-Lozi-Switch-500 version*) helped to avoid the Burgers map based CPRNG weak spots, which are the weak overall statistical results, like average CF value and std. dev.; and tendency to stagnation. This version was able to reach the best individual minimum CF value. The aforementioned weak spots of the Burgers map based CPRNG have fully revealed in the case of later alternating of both maps. The initial faster convergence (starting of evolutionary process) and subsequent continuously stable searching process without premature stagnation issues are visible from Fig. 6 (red and green lines).

Through the utilization of *Lozi-Burgers-Switch* versions, the strong progress towards global extreme given by Burgers map CPRNG helped to the evolutionary process driven moderately from the start by mans of Lozi map CPRNG to achieve the best avg. CF and median CF values. The moment of switch (at 500 and 1500 generations) is clearly visible from Fig. 6 (magenta and black lines). From the results, it seems that it is better to keep the Lozi map based CPRNG for more generations to ensure the stable searching process.

CONCLUSION

In this paper, the novel concept of multi-chaos driven DERand1Bin strategy was more deeply analyzed and compared with the canonical DERand1Bin strategy on the selected benchmark function in higher dimension. Based on obtained results, it may be claimed, that the developed Multi-ChaosDE gives considerably better results than other compared heuristics.

The novelty of this research represents the deeper investigation and simulation of the DE performance dependency on switching of the two driving chaotic systems.

Future plans are including the testing of combination of different chaotic systems as well as the adaptive switching and obtaining a large number of results to perform statistical tests.

Furthermore chaotic systems have additional parameters, which can by tuned. This issue opens up the possibility of examining the impact of these parameters to generation of random numbers, and thus influence on the results obtained by means of ChaosDE.

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