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Differential Big Bang - Big Crunch algorithm for construction-engineering design optimization

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ABSTRACT

The present study proposes the Differential Big Bang - Big Crunch (DBB-BC) algorithm. This new hybrid metaheuristic is designed to enhance the performance of the Big Bang-Big Crunch (BB-BC) algorithm. DBB-BC uses collaborative-combination hybridization to combine the BB-BC algorithm, Differential Evolution algorithm, and Neighborhood Search in order to improve the exploration and exploitation capabilities of the original BB-BC in finding global solutions. Subsequently, a number of unconstrained mathematical benchmark problems and seven practical design problems from the construction-engineering field are used to investigate the effectiveness and efficiency of DBB-BC. The results of this investigation confirm that the DBB-BC performs significantly better than the other algorithms that were tested in terms of optimal solution (efficacy) and required function evaluations (efficiency).

1. Introduction

Construction design optimization is a challenging activity that has become increasingly important in the field of construction engineering. Minimizing the overall cost of a construction project is one of the principal responsibilities of designers. Optimization allows designers to create designs that use the minimum amount of materials and financial resources to accomplish a project within a reasonable amount of time. However, modern engineering design problems have increased tremendously in complexity, and now frequently address complicated, objective functions with large numbers of design variables and constraints. This complexity has inspired numerous studies worldwide with the shared goal of developing a model that is capable of optimizing current construction-engineering problems effectively.

Many optimization methods have been introduced over the past four decades. Gradient-based methods were the first of these methods to be widely used in solving construction-decision-making problems [39]. These methods are often inadequate to deal with the complexities that are inherent in many of today's optimization problems due to their poor handling of large-scale variables and constraints. Additionally, these methods use analyses that require gradient information to improve initial solutions. However, designers often face difficulties in identifying an initial solution, as they have no way to identify the most promising area for the global optimum of the current problem. Therefore, these gradient-based methods frequently fail to converge on the global optimum because of failed guesswork in defining the area of the global optimum. The above concerns have encouraged researchers to work to develop better optimization models.

In recent years, researchers have explored the capability of metaheuristics to solve complex optimization problems and to provide solutions that are significantly superior in terms of quality and effectiveness to those obtained using classic heuristic or gradient-based optimization methods [44]. Researchers have developed numerous powerful, effective, efficient, and easy-to-use metaheuristic algorithms since the inception of this class of algorithms in the early 1980s. Nearly all metaheuristic algorithms are inspired by nature. For example, Genetic Algorithm (GA) mimics the theory of evolution [26]; Particle Swarm Optimization (PSO) simulates in-flight flocking behavior of birds [32]; the Firefly Algorithm (FA) is an algorithm inspired by firefly behavior, which produces flashes of light [60]; the Bees Algorithm (BA) simulates the natural foraging behavior of honeybees [18]; and Symbiosis Organisms Search (SOS) adopts the interactive relationships of organisms in nature [9].

Numerous studies have proposed metaheuristic approaches for solving construction-engineering problems. In construction management, metaheuristic algorithms have been used to solve problems such as project site layout [55,56], time-cost tradeoff [57], time-cost-quality tradeoff [42], time-cost-labor utilization tradeoff [52], resource leveling [10,24], bridge maintenance [4,6], and optimizing the location of a tower crane [40]. Moreover, metaheuristic algorithms have been

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used to handle problems related to structural design [8,9,12,58], water distribution network design [61], geotechnical issues [13,14], concrete mix design [5,11], and traffic engineering [49]. Furthermore, new metaheuristic algorithms may be expected to emerge as construction-engineering problems become more complex.

The Big Bang theory and the Big Crunch theory are two theories that are currently widely used to describe the evolution of our universe. The former depicts the creation of the universe in an initial singularity that has since expanded outward. The latter depicts the reverse, with gravitational energy pulling all of space toward a singularity in a process that destroys the universe. These theories inspired Erol and Eksin to propose a metaheuristic optimization method entitled the Big Bang - Big Crunch (BB-BC) algorithm [21]. In BB-BC, random candidates are generated in the Big Bang phase. Then, those candidates are pulled into a single converge point that is named the “center of mass” in the Big Crunch phase. The advantages of BB-BC include: fast convergence characteristic, easy to use, and a relatively small number of tuning parameters. Furthermore, BB-BC incorporates a unique mechanism for group interaction that improves the process of searching for the optimal solution [51].

Although BB-BC offers good intensification (exploitation), this algorithm lacks diversification (exploration) [29]. The present study proposes Differential Big Bang - Big Crunch (DBB-BC), a new hybrid metaheuristic, to resolve this diversification problem. DBB-BC uses collaborative-combination hybridization to hybridize BB-BC, Neighborhood Search (NS), and Differential Evolution (DE) in order to improve both the diversification and intensification of the BB-BC algorithm. The performance of DBB-BC is validated and evaluated using 26 benchmark functions. Furthermore, the performance of DBB-BC is compared with that of standard DE, standard BB-BC, and the other algorithms. Finally, seven construction-engineering design problems are used to verify the performance of the proposed metaheuristic algorithm.

The rest of the paper is structured as follows: Section 2 described briefly BB-BC, DE, and NS. Section 3 introduces the proposed hybrid metaheuristic DBB-BC algorithm. The comparison results of the proposed algorithm with the other algorithms in terms of solving the benchmark functions are investigated in Section 4. Section 5 presents seven practical construction-engineering design problems in order to validate the proposed DBB-BC. Section 6 presents the conclusion.

2. Literature review

2.1. Big Bang–Big Crunch (BB-BC) algorithm

In cosmological science, the Big Bang theory is used to explain the creation of the universe in an explosion that expanded rapidly from an original state that was extremely hot and dense, while the Big Crunch theory explains how gravitational forces may ultimately reverse the expansion of the universe, pulling everything within space back to its original state and triggering a subsequent big bang incident. Thus, from a broader perspective, the universe is eternal, proceeding through an endless cycle of big-bang expansion and big-crunch contraction phases.

Fig. 1 shows the details of the flowchart for the BB-BC algorithm which is proposed by Erol and Eksin [21]. In the Big Bang phase, the randomly distributed population are pulled into a center of mass, which is produced during the Big Crunch phase [25]. In the first iteration, similar to other evolutionary algorithms, the initial candidates are spread uniformly across the search space.

The Big Bang phase is then followed by the Big Crunch phase. In this phase, the convergence operator replaces the current positions and fitness functions of each candidate in order to produce a weighted average point, which is called the “center of mass”. The following equation calculates the center of mass:

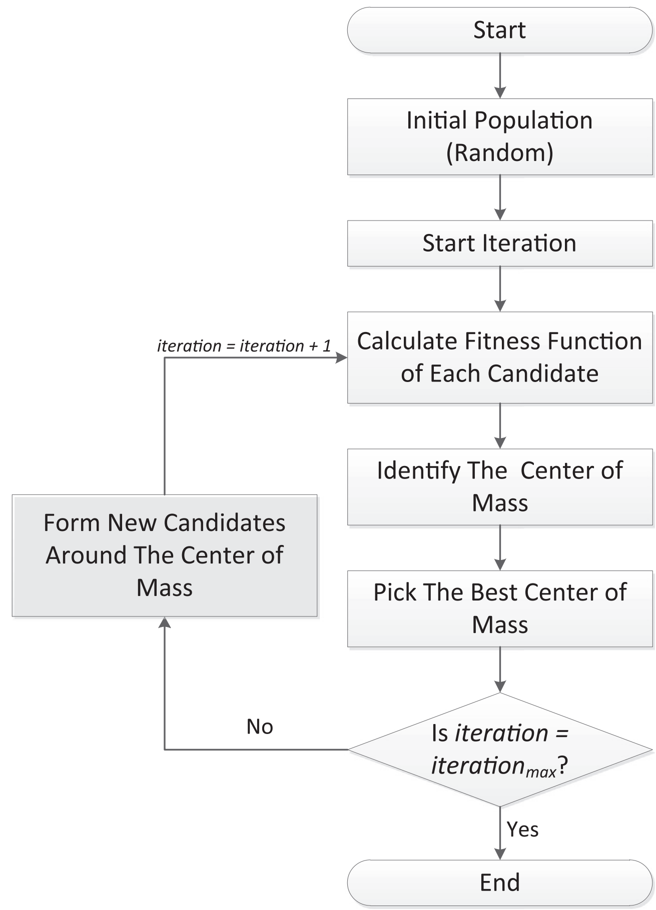

Fig. 1. Big Bang - Big Crunch algorithm flowchart.

$$x_{j,q}^{c} = \frac{\sum_{i=1}^{np} \frac{1}{f_q^i} x_{j,q}^{i}}{\sum_{i=1}^{np} \frac{1}{f_q^i}} \tag{1}$$

where j is the current dimension, i is the current candidate in the population, q is the current iteration, np is the total number of candidates in the population, $x_j^{c,q}$ is the jth component of the center of mass point at the qth iteration, $x_j^{i,q}$ is the jth component of the ith solution at the qth iteration, and $f_q^{\,i}$ is the fitness function of the ith solution at the qth iteration. In the next iteration, the current center of mass is treated as the core and subsequently exploded in the Big Bang phase. If the current position of the center of mass is inferior to the best candidate position, then the best candidate position may supplant the best candidate position as the current center of mass [1,21]. Next, the explosion produces new candidates that follow the normal distribution around the center of mass as shown in the following equation:

$$x_{j,(q+1)} = x_{j,q}^{c} + \frac{r_j \times \alpha \times (x_{max} - x_{min})}{(q+1)} \tag{2}$$

where $x_{j,(q+1)}$ is the new candidate, r_j is a random number from the standard normal distribution, α is a parameter that limits the parameters of the search space, and x_{max} and x_{min} are, respectively, the upper and lower limit. Although the standard deviation from Eq. (2) may be set to a fixed value, BB-BC will produce a better result if the standard deviation is set to decrease inversely with the current iteration [21].

The center of mass is recalculated again after the Big Bang explosion using the Big Crunch contraction phase. These explosion and contraction steps repeat continuously until the termination criterion is met.