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ORIGINAL STUDY

Cauchy Distribution with Cuckoo Search Algorithms for Solving Job Shop Scheduling Problem

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Abstract

This research applies the Cuckoo Search Algorithm, specifically the Original Cuckoo Search(CS), Improved Cuckoo Search(ICS), and Global Feedback cuckoo search(GFCS) with different values of parameters instead of using a fixed value of probability a banda (Pa) which equal to 0.25 by another researcher to solve the problem of Job Shop Scheduling. The goal is to modify the method to improve its effectiveness and total completion time (Makespan) using benchmark datasets for basic scheduling problems, and suggest using the Cauchy distribution, with its ability to generate random numbers from distant points, and the stronger perturbation ability of Cauchy variation compared to Gaussian variation, along with Levy flight, effectively prevent the cuckoo algorithm from falling into local optima.

Notably, when the step size is 0.1 and Pa is 0.1, with a population of 10 and 100 iterations, GFCS obtains the ideal Makespan of 140 when applied to the (20 × 20) set.

Also, the Cauchy distribution for the CS produces the best results compared levy distribution that increases the variety of the nests, enabling escape from regional extreme values and fostering global search.

Keywords: Cuckoo search, Improved cuckoo search, Global feedback, Cauchy distribution, Job shop scheduling problem

1. Introduction

Metaheuristic optimization algorithms refer to a class of optimization methods that employ heuristics or approximate techniques to discover solutions that are close to optimal for complex problems. Unlike traditional optimization algorithms, which are designed to solve specific types of problems, Meta-heuristic algorithms can be applied to a wide variety of problem domains [1].

Metaheuristics are a type of optimization algorithm that has been developed in the intersection of computer science, applied mathematics, and artificial intelligence. These algorithms are designed to find good solutions to problems that are difficult or impossible to solve with traditional methods. Over the past twenty years, many different metaheuristics have been developed, including genetic algorithms, simulated annealing, tabu search, and ant colony optimization [2].

The main advantages of meta-heuristic algorithms is the ability to search large solution spaces efficiently, without requiring a priori knowledge of the problem structure. However, due to their stochastic nature, "Metaheuristic" algorithms are not guaranteed to find the optimal result, but instead, aim to find optimal solutions in a reasonable amount of time [3].

In 2009, Yang and Deb introduced a novel optimization algorithm known as Cuckoo search, which operates at a higher level of optimization [4]. This algorithm draws inspiration from the obligate brood parasitism behavior observed in certain cuckoo species. The Cuckoo Search Algorithm draws its inspiration from the bird known as the Cuckoo, specifically from the brood parasitism behavior observed in cuckoo species. Cuckoo birds rely on suitable hosts to complete their life cycle, as they are unable to construct their own nests. Instead, they deposit their eggs in the nests of other birds [4].

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When a bird detects that an egg in its nest does not belong to it, it may respond by either eliminating the foreign egg or abandoning the nest altogether to construct a new one elsewhere. Female cuckoos possess specialized abilities in mimicry, enabling them to lay eggs that closely resemble those of their selected host bird [5].

A notable advantages of the cuckoo search algorithm is its ease and simplicity when it comes to implementation. It also highly scalable and can be parallelized to improve its performance on large-scale problems. However, like other metaheuristic algorithms, the cuckoo search does not guarantee to find the optimal solution, but instead aims to find best solutions in a reasonable amount of time [6].

The Job Shop Scheduling (JSS) is a problem in operations research and production management. It involves scheduling a set of jobs on the set of machines, A job is comprised of a series of operations that are executed on specific machines. The aim is minimize the total completion time or makespan of all jobs [7].

Job Shop Scheduling problem are used to find optimal or near-optimal solutions. There are various algorithms that have been developed for this problem, including exact algorithms such as branch and bound (BB) [7], dynamic programming, integer programming, and metaheuristic algorithms such as genetic algorithms, and simulated annealing [8].

Exact algorithms guarantee to find of the optimal solution, but they can be expensive and may not be suitable for large-scale problems. Metaheuristic algorithms, are faster and more efficient, but they may not always find the optimal solution [7].

The paper is organized as follows. Section 2 gives the Research contribution. Section 3 introduces Related work, section 4 gives information about Cuckoo search Algorithm, and section 5 provides the General proposed system method. Section 6 describes the Dataset, section 7 gives the computational results, and the conclusion and future research are presented in Section 8. Finally, the Acknowledgements in section 9.

2. Research contribution

1. To overcome the drawback of CS which stays in the premature convergence in the levy distribution, the proposed system use the Cauchy distribution that give that asset the solution to jump from local to global optima.
2. Use the new equation by dividing the number of jobs by machines and put the value to the step-size and pa to give the effective and optimal solution of makespan for the GFCS.
3. All the researcher used fixed value of Pa = 0.25,the proposed system use the different value of Pa that give the best result especially when Pa = 0.1 for the three types of CS.

3. Related work

Ouaarab et al. [9], Focused on solving combinatorial optimization problems by using discrete cuckoo search(DCS) for resolving a JSSP to compare the effectiveness to other meta Heuristics as opposed to hybrids. In DCS, Lévy flights have control of all moves in the solution space. They perform a global random walk to explore space. In actuality, the suggested solution shows how to use Lévy flights to transition from one solution to another while still being in the same space. The proposed maximum best solution was achieved (1784) opt when applied to the La31 benchmark dataset.

Valian et al. [10], presented an improved cuckoo algorithm designed for reliability optimization problems. The algorithm incorporated the optimization of the Levy flight's step size and adjusted the probability of discovering cuckoo eggs, denoted as Pa. Additionally, they introduced a formula to progressively decrease the step size and Pa with each iteration, adapting them accordingly.

Al Daoud et al. [11], Focused on solving JSSP. The authors suggested a new hybrid algorithm that combined the (CSO) method with an Assorted Individual Enhancement Scheme. while resolving a JSSP, Initially, CSO selects a nest at random. A nest in the CSO approach consists of different solutions to the under-consideration optimization problem. Now that a nest is a set of hosts, every host stands for a potential solution to the optimization issue. The best or, to put it another way, the fittest host is the final solution to the optimization issue being solved when the method converges. The proposed maximum best solution was achieved (1,292) when applied to the la14 benchmark dataset.

Ong et al. [12], introduced an adaptive cuckoo algorithm that employed a comparison between both the average and current fitness values. Based on the outcome of this comparison, the algorithm utilized different step size algorithms. This approach aimed to achieve faster convergence in the initial stages while ensuring greater convergence accuracy in the later stages.

Several researchers have made adjustments or substitutions to the Levy flight component by incorporating novel models. These modifications include the introduction of alternative algorithms or the incorporation of Gaussian functions to expedite the optimization process.

Ashok et al. [13], focused on solving stochastic global optimization methods. The authors suggested a Gradient Based CS (GBCS). While resolving the optimization problem, The gradient was easily accessible and is able to be utilized to boost the numerical effectiveness of stochastic optimization techniques, particularly with respect to the accuracy of the optimal global solution.

Moreover, the authors applied GBCS on stochastic global optimization in order to enhance one of the more potential randomized algorithms' performance. In fact, The authors' suggested improvement is effectively applied in the technique by modifying the direction of the local random walk of cuckoos. The proposed solution achieved (7.2758E-13) Mean when applied to the Stochastic Griewank benchmark dataset [13].

4. Cuckoo search algorithm

Is an optimization algorithm used to solve optimization problem. Recently developed meta-heuristic algorithm inspired by brood parasitism of certain cuckoo species. Typically, the algorithm maintains constant parameters for a specific duration, leading to reduced efficiency. To address this issue, it is necessary to define an appropriate strategy for parameter tuning in the cuckoo search. The cuckoos are fascinating birds that captivate us with both their melodious sounds and their remarkable reproductive strategy. Certain species of cuckoos employ an aggressive reproduction tactic by laying their eggs in the nests of host birds. To enhance the chances of their own eggs hatching successfully, they may even remove the eggs of the host bird [4].

There are many types of CS, In standard CS algorithm, constant values of parameters (probabilty and step size) which are important in fine tuning of solution vector in the global solutions. In improved CS(ICS).

Lastly, in the Global feedback Cuckoo Search is obtained by performing the equation [16]:

$$X_i^{(t+1)} = X_i^t + \text{StepSize}*\text{Rand} \tag{1}$$

Where $X_i^{(t+1)}$ is the new solution, and X_i^t is the current solution [4].

5. General proposed system

To develop the CS, one needs to generate an artificial dataset, and then build the original CS followed by the ICS (Global and Local Cuckoo search), and finally, the GFCS. These algorithms can then be tested on the job shop scheduling problem to solve it. Different values of CS parameters can be applied to test their effectiveness. The proposed system was designed by using Python3.10, in a computer with processor intel®core™ 2.30 GHZ, RAM 4.00 GB.

This research proposed the All the researcher used levy or Gaussian distribution, in this research proposed using Cauchy distribution with three types of CS to evaluate the results and specify the best distribution. The general block diagram of the system by using three types of CS for solving JSSP are shown in Fig. 1.

In the simple CS, a new solution is generated using Levy Flight and Cauchy distribution, while in the ICS and FCS, a new solution is generated using Random Walk.

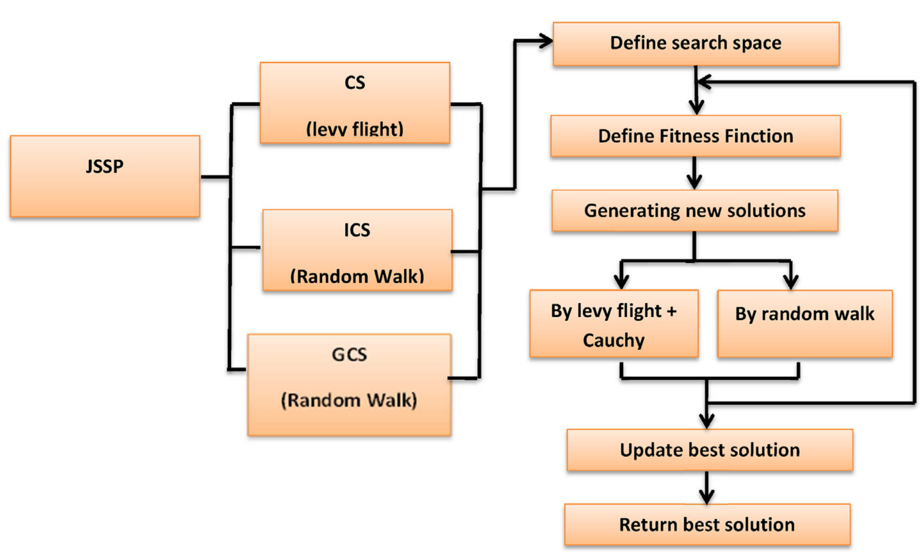

Fig. 1. General Diagram of the proposed system.

The first step involves defining the search space, followed by defining the fitness function. Then, new solutions are generated. After that, the best solution and its objective function are updated. Finally, the best solution is returned as shown below.

The key distinction between a Levy flight and a random walk lies in the nature of their step sizes or displacements.

In a random walk, the step sizes are typically drawn from a symmetric distribution with a finite mean and variance, such as a Gaussian or Cauchy distribution [14]. Each step taken in a random walk is independent of the previous steps, and the direction and magnitude of the displacement are determined randomly.

On the other hand, a Levy flight is a type of random walk characterized by step sizes drawn from a heavy-tailed distribution, known as a Levy distribution. The Levy distribution allows for occasional large step sizes, which means that Levy flights can have infrequent but significant jumps in comparison to random walks. These rare long-range jumps enable Levy flights to explore the search space more efficiently and cover a larger area compared to random walks, making them particularly useful for applications that involve exploring vast or complex environments.

Metric Makespan, best fitness, best objective function has been computed for the suggested ‘model evaluation. Makespan is the most frequently utilized parameter in the classification process as a predictive metric.

6. Dataset description

In this research, the Benchmarks for basic scheduling problems dataset [15] is the most common way to describe the Job shop scheduling. It consists of 260 randomly generated scheduling problems, The types of problems propose in the dataset: are the flow shop, the job shop, and the open shop scheduling problems. the objective of this dataset is the minimization of the makespan. The dataset has 3 sets. Each set specifies the Time seed, upper bound (UB), lower bound (LB).

Table 1 explains the instances of jobs and machines that takes in this study.

7. Results

All the researchers used the Levy distribution, and some of them also used the Gaussian distribution due to the lack of results for the CS, ICS, and GCS. This research suggests considering the use of the Cauchy distribution in most experiments. The Cauchy distribution is shown below [13]:

$$f_c^{(x)} = \frac{\sigma}{[\pi(\sigma^2 + x^2)]} \tag{2}$$

Where, σ = 1 is the standard Cauchy distribution.

Since Cauchy perturbation has better performance in global search, the Cauchy perturbation operator carries out external intervention and perturbation and mutation on the bird's nest in the local optimal state. The system built in python ver.10.The basic original CS only achieves an ideal Makespan of 210 and requires a population of 10 and 100 iterations. Although ICS achieves an ideal Makespan of 162, it also requires a population of 10 and 100 iterations, as shown in Table (2). Therefore, the proposed Global CS is highly efficient for solving JSSP.

Table 1. Explains the benchmarks for basic scheduling problems dataset.

Nb. Jobs	Nb. Machines	Nb. Instances	LB reached(%)	Nb. Iterations	Nb. resolutions
15	15	50	0	7.10^5	4
20	15	50	4	10^6	3
20	20	50	0	10^7	4
30	15	50	26	3.10^6	4
30	20	50	0	2.10^6	4
50	15	100	78	3.10^6	4
50	20	26	27	5.10^5	4
100	20	100	97	5.10^5	3

Where.
Nb jobs: The number of jobs.jl
Nb machines: The number of machines.
Nb instances: The total number of problems generated.
LB reached: The proportion of problems for which found a solution for which the makespan was equal to the lower bound (or equal to the lower bound augmented by 2% for the 500-job 20-machine problems).
Nb iterations: The maximum number of iterations.
Nb resolutions: The number of attempts to solve the problem from various initial solutions (long resolution).

In Table 2 below show the changes in the value of the Pa and step-size in the proposed system model.

In Table 3, In the table below, displays the comparison between Cauchy and levy distribution for the CS with different values of step size and P_a for the population size = 10 with 100 iterations. The drawback of CS when using levy distribution is stay in the premature convergence (local optima) and not to jump to global optima.

To overcome this lake, perform the proposed system by using Cauchy distribution instead of levy to jump from local to global optima with fixing the value of step size and P_a.

From the above table, deduce that the Cauchy distribution is better than levy distribution with different values of all parameters of the algorithms.

8. Conclusion

The suggested study shows how to solve the JSSP using the Original Cuckoo Search (CS), Improved Cuckoo Search (ICS), and Global Feedback algorithms. In the JSSP setting, the study shows how these algorithms have a favorable effect on the overall completion time (Makespan).

1. Using just the Global Feedback algorithm, the best scheduling is accomplished.
2. When the step size is 0.1, Pa (probability of accepting poorer solutions) is 0.1, population size is 10, and iteration count is 100, the best result is obtained with a set size of 20 × 20. It has been shown that in this situation, a high iteration count yields the greatest results by using the new equation dividing the size of population by number of iteration.

Furthermore, the result of using the Cauchy distribution in the Original Cuckoo Search (CS) algorithm is better than that of the Levy flight mechanism. This improvement is attributed to the utilization of the global variation and discrete distribution characteristics of the Cauchy distribution in searching for a single nest. By applying Cauchy variation to a single nest, the diversity of the nests is increased, facilitating the escape from local extreme values and promoting global search. As a result, the search speed and quality are enhanced, leading to superior results compared to the Levy flight mechanism.

The future work could involve the Exploring the hybridization of the cuckoo search with other metaheuristic algorithms might be an interesting direction. Cuckoo search may perform better and more quickly approach optimal or nearly optimal solutions when combined with strategies like

Table 2. The result of CS,ICS and global feedback with varying step size and Pa with (20 × 20), and (20 × 10) job shop problems.

Jobs No.	Machines No.	Step_Size	Pa	Population	iteration	Makespan_Cuckoo	Makespan_ICS	Makespan_Global
20	20	0.1	0.2	10	100	210	164	169
20	20	0.1	0.25	10	100	216	166	162
20	20	0.1	0.1	10	100	236	162	140
20	20	0.1	0.01	10	100	244	210	158
20	20	0.1	0.5	10	100	235	201	212
20	10	0.1	0.1	10	100	1019	807	870
20	10	0.1	0.2	10	100	1029	885	884
20	10	0.1	0.25	10	100	1035	911	886
20	10	0.1	0.01	10	100	1015	960	980
20	10	0.1	0.5	10	100	1074	1020	988

Table 3. The result of CS with cauchy distribution and levy flight distribution for (20 × 20), and (20 × 10).

						Cauchy distribution	Levy Flight distribution
Jobs No.	Machines No.	Step_Size	Pa	population	Iteration	CS	CS
20	20	1.5	0.25	10	100	210	790
20	20	1.5	0.2	10	100	216	916
20	20	1.5	0.1	10	100	236	929
20	20	0.1	0.01	10	100	219	385
20	20	0.1	0.5	10	100	237	359
20	10	0.01	0.25	10	100	1019	6554
20	10	0.01	0.2	10	100	1029	8502
20	10	0.01	0.1	10	100	1035	9969
20	10	0.1	0.01	10	100	1015	3856
20	10	0.1	0.5	10	100	1074	3006

genetic algorithms, particle swarm optimization, or ant colony optimization.

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