ATLA: A novel metaheuristic optimization algorithm inspired by the mating search behavior of longicorn beetles in the nature

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Abstract. Compared with the traditional optimization algorithms, metaheuristic optimization algorithm has more powerful performance in the optimization problem, which has attracted more and more scholars' attention. In this paper, a novel metaheuristic optimization algorithm, named artificial transgender longicorn algorithm (ATLA), is proposed, which is inspired by the mating search behavior of longicorn in the nature. ATLA simulates the mechanism of sex pheromone emission and attraction between female and male longicorn beetles, and realizes the process of local search and global search of an optimization problem. Simulation results based on three standard benchmark functions show the good search performance of optimal solution and the effectiveness of the proposed ATLA.

1. Introduction
In the past few decades, heuristic algorithm has developed rapidly. Different from the certainty of traditional algorithms, heuristic approaches have the performance characteristics of simplicity, flexibility and excellent global search ability to avoiding local optimization. In solving nonlinear and multi model optimization problems with complex characteristics, they can show better performance. Therefore, they have been widely used in theoretical optimization and many practical engineering fields [1-3].

Metaheuristic optimization algorithms are usually inspired by the behaviors of animals and plants or natural phenomena, such as I) the particle swarm optimization (PSO) algorithm [4] is inspired by the social behavior of birds, II) the artificial bee colony (ABC) algorithm [5] is designed according to the cooperative behavior of bees in foraging, III) the cuckoo search (CS) algorithm [6,7] simulates the parasitic feeding behavior of cuckoo, IV) the firefly algorithm (FA) [8,9] comes out based on the fluorescent absorption behaviors of fireflies, V) the bat algorithm (BA) [10,11] is according to the principle of ultrasonic predator, VI) the simulated annealing (SA) algorithm [12] is proposed to simulate the annealing process of metal, and VII) the artificial immune algorithm [13] is designed inspired by biological immune system, etc. These mature metaheuristic algorithms have become effective methods to solve many complex optimization problems.

However, although metaheuristic algorithm has achieved satisfactory results in many complex problems, no metaheuristic algorithm can achieve better performance than other algorithms in all
optimization problems. Therefore, it is still significant to get new inspiration from nature and provide new ideas for solving optimization problems.

In this paper, a new metaheuristic algorithm, named artificial denaturing longicorn algorithm (ATLA), is proposed inspired by the mating search behavior of longicorn beetles in the nature. The phenomenon that the male longicorn beetles will be attracted to move to the female one is the main idea of ATLA. In ATLA, solutions of the problem is represented as the positions of the female and male ones and they are adjusted according to the fitness to find the optimal position/solution.

2. Materials and Methods

2.1. Inspiration

The instinct and primary task of living things is to reproduce offspring, so the courtship and mating are the most important processes for them. There is a common phenomenon that males chase females to complete mating of insects in nature, in which the sex pheromone plays an important role. Sex pheromones are different from aggregation pheromones, which are intraspecific and will not be copied by other species in nature. They only attract intraspecific individuals and thus play a role of reproductive isolation. In the study of insect sex pheromones, the research on longicorn insects is the earliest and more detailed [14].

In the mating season, in order to attract males to mate, female longicorn beetles will release unique sex pheromones to transmit information. Males in the range of sex pheromone concentration will be affected by the sex pheromones of female and move to search for the source of sex pheromone distribution to achieve the purpose of mating, while males outside of the concentration range will continue to walk freely. It is illustrated in Figure 1.

ATLA can be constructed by associating the male's mating search behavior with the objective function of the optimization problem.

![Figure 1. Sex pheromone released by the femina and the directly attraction movement of male longicorn individuals in concentration range, while the male ones outside the range are taking random search in the space.](image-url)
2.2. Artificial transgender longicorn algorithm (ATLA)

Before all work, the following rules are assumed for ideal the characteristics of the mating behavior of the longicorn population:

In a fixed longicorn population, there will be one and only one female longicorn, and the rest of the population are male longicorn individuals.

Only the female longicorn can release sex pheromone, while the male longicorn does not have the ability.

The concentration of sex pheromone released by female longicorn has a certain range. The male longicorn individuals are affected and attracted by sex pheromone only when they are walking in the range, and try to approach the female longicorn directly. Otherwise, they carry out Lévy flight searching movement in the space.

When the sex pheromone is released, the female longicorn waits in place for mating.

According to the above four rules, ATLA can be summarized into two main stages, the stage of heterosexual attraction movement and the stage of random search movement. The main ideas of ATLA are expressed as follows,

Initializing the longicorn population to make the whole group individuals be male gender;

Apply one step random search after initializing, select the male longicorn individual with the highest fitness according to the fitness function, and change the gender of it. Then the transgendered longicorn stay in place and release the sex pheromone to attract the male ones around “her” come to mate.

At the stage of heterosexual attraction movement, once the male individuals affected by the sex pheromone, they will walk directly to the female along the direction of the concentration source which is shown in (1).

\[ d_i = \frac{x_{best}^j - x_i^j}{\|x_{best} - x_i^j\|}, \quad i = 1, 2, \ldots, m \]  

(1)

Where, \( x_i \) is the position of the \( i \)th male; \( t \) is the current number of iterations; \( x_{best} \) is the position of the female, which represents the position with the highest fitness in the current herd; and \( m \) is the number of male longicorn within the concentration range.

The position of male longicorn is updated as follows:

\[ x_i^{t+1} = x_i^t + s_i^t \times d_i, \quad i = 1, 2, \ldots, m \]  

(2)

Where, \( s_i \) is the moving step length of the \( i \)th male longicorn. In order to not only improve the search speed in the early stage, but also take into account the search accuracy in the later stage of the algorithm, the step size is set as a parameter that decays with the number of iterations (Equation (3)) to avoid the individuals falling into the local optimum.

\[ s_i^t = \frac{0.95 s_{i}^{t-1}}{r_i} \]  

(3)

Where, \( r_i \) is the fitness ranking of the \( i \)th male longicorn.

The males who do not receive the female sex pheromone, i.e. outside the concentration range, search randomly in space in the way of Lévy flight, as shown in the following (4).

\[ x_i^{t+1} = x_i^t + \alpha \oplus L(\lambda), \quad i = 1, 2, \ldots, n - m - 1 \]  

(4)
Where, “⊕” is the point-to-point multiplication operator; α equals to 1 is the step control quantity; n is the longicorn population size; \( L(\lambda) \) is a random walk whose step size \( u \) follows the Lévy distribution, which can be expressed as,

\[
L(\lambda) \sim u = t^{-\lambda}, \quad 1 \leq \lambda \leq 3
\]

(5)

Here, \( \lambda \) equals to 2. For the convenience of calculation, Mantegna algorithm is generally used to simulate the random search path.

In ATLA, the fitness value of each longicorn will be calculated according to the objective function. The male longicorn in the threshold range can receive the sex pheromone of the female longicorn and move to it, while the male longicorn outside the threshold range carries out the random search in the space. In practice, the fitness value ranking is used to determine the threshold value. Only the male longicorn in the ranking range, e.g. 90%, will be affected by the sex pheromone. This not only ensures that the optimum can be found in the threshold range of longicorn beetles, but also enables the remaining longicorn to search randomly outside the threshold range to avoid the longicorn herd falling into local optimum.

The pseudo code of the whole process of ATLA is shown in Table 1.

Table 1. Pseudo code of the proposed ATLA.

| Algorithm 1: ATLA for global minimum searching |
|------------------------------------------------|
| **Input:** Establish the objective function \( f(x') \), where \( x' = [x_1, x_2, \ldots, x_n]^T \), initialize the parameters \( n \), \( s \), \( \alpha \), \( \lambda \), \( T \), and the ranking range. |
| **Output:** \( x_{best}, f_{best} \). |
| while \( (t < T) \) or (stop criterion) do |
| Random Lévy fight search of all longicorn beetles in variable space; |
| Evaluate the fitness value of all individuals and sort them by fitness; |
| Change the gender of the best fitness one to female, and release sex pheromone; |
| if \( x_i \) is in the ranking range |
| Generate its \( \tilde{d}_i \), and move to the femina according to Equation (2); |
| else |
| Carry out random search move according to Equation (4); |
| update \( t \); |
| end while |
| return \( x_{best} \) and \( f_{best} \). |

2.3. Results and Discussion

Benchmark test functions can be used to verify the effectiveness of the optimization algorithm [15]. Therefore, the following three test functions in Table 2 are selected to verify the proposed ATLA algorithm.
Table 2. Three Test Functions

| Functions | Global extremum |
|-----------|-----------------|
| $f_{\text{Michalewicz}}(x, y) = -\sin(x)(\sin(x^2 / \pi))^20 - \sin(y)(\sin(2y^2 / \pi))^20$ | $f_{\text{min}}(2.20, 1.57) = -1.8013, 0 \leq x, y \leq 5$ |
| $f_{\text{Schaffer}}(x, y) = 0.5 - \frac{\sin^2(x^2 - y^2) - 0.5}{[1 + 0.001(x^2 + y^2)]^2}$ | $f_{\text{max}}(0, 0) = 1, -10 \leq x, y \leq 10$ |
| $f_{\text{Perm}}(x, y) = \sum_{i=1}^{2}(((1 + 0.5)(x^i - 1))^2 + ((2 + 0.5)(\frac{y^i}{2} - 1))^2)$ | $f_{\text{min}}(1, 2) = 0, -3 \leq x, y \leq 3$ |

Figure 2, 3 and 4 show the searching results and performance of the global extremum of the three selected test functions. The population size $n$ equals to 100, the initial step size length is 0.1, and the iteration stops at 100 steps. Seen from the figures, all the global extremum can be found within 30 iterations and the results are very accurate.

Actually, many other test functions are tested in the simulation study, ATLA can find the optimal solutions directly and fast, which indicates that the proposed algorithm in this paper has a good performance in optimization problems.

**Figure 2.** Test results of the Michalewicz function: (a) The optimal solution is shown in the large red dot at (2.203, 1.571); (b) Fitness curve.

**Figure 3.** Test results of the Schaffer function: (a) The optimal solution is shown in the large red dot at (-0.0000004585, 0.0000006767); (b) Fitness curve.
Figure 4. Test results of the Perm function: (a) The optimal solution is shown in the large red dot at (0.9996, 2); (b) Fitness curve

2.4. Results and Discussion

A novel metaheuristic algorithm, artificial transgender longicorn algorithm (ATLA), is proposed to in this paper solve the optimization problem. ATLA is extracted from the inspiration of the mating behavior among the populations of longicorn beetles in the nature. It has the advantages of few parameters, fast search speed and good convergence performance. The visualization results and numerical solutions verify the effectiveness of the algorithm in finding the global extremum of benchmark test functions in terms of convergence and avoiding local optimal value. It is believed that ATLA can be applied to other optimization problems in future research.

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