PSA: A novel optimization algorithm based on survival rules of porcellio scaber

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Abstract—Bio-inspired algorithms have received a significant amount of attention in both academic and engineering societies. In this paper, based on the observation of two major survival rules of a species of woodlice, i.e., porcellio scaber, we design and propose an algorithm called the porcellio scaber algorithm (PSA) for solving optimization problems, including differentiable and non-differential ones as well as the case with local optima. Numerical results based on benchmark problems are presented to validate the efficacy of PSA.

I. INTRODUCTION

In recent decades, bio-inspired algorithms are widely investigated and applied. Compared with formal methods, bio-inspired algorithms are more efficient in handling complicated optimization problems, such as the NP-hard traveling salesman problem. Kennedy and Eberhart [1] developed particle swarm optimization, which is one of the well known bio-inspired algorithms. It is based on the swarm behaviour of animals, such as fish and bird schooling. Inspired by how ants find a shortest path, Dorigo and Gambardella [2] proposed an ant colony system algorithm for solving the traveling salesman problem. Based on some idealized behaviours of the flashing characteristics of fireflies, Yang et al. [3] proposed a firefly algorithm for solving non-convex economic dispatch problems with valve loading effect. The performance of these algorithms indicates that algorithms inspired by animal behaviours are feasible and promising. In this paper, based on the observation of two survival rules of a species of woodlice, i.e., porcellio scaber (PS), we propose a novel algorithm called the porcellio scaber algorithm (PSA) for solving optimization problems.

II. PORCELLIO SCABER-INSPIRED ALGORITHM DESIGN

Porcellio scaber, as shown in Fig. 1, is a species of woodlice. They prefer to live in moist, dark, and cool places and are known to live in groups. Due to the outstanding behavioral advantage of porcellio scaber, some of its varieties even can survive in extremely harsh environments, e.g., deserts around North Africa and the Middle East, where the searching of moist, dark, and cool places is usually difficult. To avoid dessication and a rapid drop in temperature, both of which can cause significant mortality, they shelter. In addition to their eyes, porcellio scaber have many sensory receptors on their body, making it possible for them to detect chemical, mechanical, and hygrometric conditions about the environment [7]. When the environment conditions are not favourable, porcellio scaber keep moving until morality or reach places with good conditions. Besides, for worse environment conditions, they move more quickly. On the other hand, when the environment condition is optimal, i.e., sufficiently good, they stay there.

For the sake of illustration, let the position of the mass center of each porcellio scaber at the kth ($k = 0, 1, 2, \cdots$) time instant be denoted by a vector $x_i^k$ and let the environmental condition at a position $x$ by described by a fitness function $f(x)$, where a minimum value of $f(x)$ corresponds to the optimal environmental condition for porcellio scaber. We consider the case that there are a group of totally N porcellio scaber, i.e., $i \in \{1, 2, \cdots, N\}$.

Many studies reveal that porcellio scaber have two behaviours, which are viewed as their survival rules. The two behaviours are depicted in Fig. 2. One is called aggregation and the other is called the propensity to explore novel environments [5], [7], [8]. Note that they aggregate at the places with

![Fig. 1. Porcellio scaber by Peter Rühr, used under the Creative Commons Attribution 3.0 Unported license](image-url)

![Fig. 2. Two behaviours of porcellio scaber. (a) Group behavior: aggregation. (b) Individual behavior: propensity to explore novel environments.](image-url)
good environment conditions \([3]\). To model the aggregation behavior, we propose to describe the movement of porcellio scaber as follows:

\[
x^{k+1}_i = x^k_i - (x^k_i - \arg \min_{x^k_j} \{ f(x^k_j) \}),
\]

which can be rewritten as

\[
x^{k+1}_i = \arg \min_{x^k_j} \{ f(x^k_j) \}.
\]

Evidently, by (1), each porcellio scaber will finally stay at the same position with the best environmental condition among all their initial positions \(x^0_i\). With only the aggregation behavior, porcellio scaber cannot live in case that they are initially placed at bad environment. Studies show that, each porcellio scaber, and view the decision variable as the position vector of porcellio scaber as follows:

\[
x^{k+1}_i = x^k_i - (1 - \lambda)(x^k_i - \arg \min_{x^k_j} \{ f(x^k_j) \}) + \lambda \tau p.
\]

where \(p\) is a function to map the fitness of a porcellio scaber to an action strength. A simple choice is \(p = f(x^k_i + \tau)\). As verified in our extensive experiments, the following normalized fitness can achieve better performance:

\[
p = \frac{f(x^k_i + \tau) - \min f(x^k_i + \tau)}{\max f(x^k_i + \tau) - \min f(x^k_i + \tau)}.\]

In the model (2), the term \(\lambda \in (0, 1)\) accounts for the weight between aggregation and the propensity to explore novel environments. The value of \(\lambda\) can be different for different porcellio scaber. The term \(\tau p\) corresponds to the propensity to explore novel environments, where \(\tau\) is a random vector that has the same dimension with that of \(x^k_i\). Specifically, \(\tau p\) means that each porcellio scaber randomly choose a direction with respect to their positions of mass centers to detect the environment condition of surroundings. In addition, the \(p\) term means movement speed requirement which indicates that the exploration for novel environments is also a result of group negotiation.

The optimization problem considered in this paper is depicted as follows:

\[
\min_{x} f(x),
\]

where function \(f\) is lower bounded and can be non-differentiable and can have multiple local minima. By the above observations about the behaviours of porcellio scaber, the PS algorithm for solving optimization problem \([3]\) is designed and depicted in Algorithm 1. The main idea is to view the function to be minimized as an evaluation of the environmental condition from the perspective of porcellio scaber, and view the decision variable as the position vector of a porcellio scaber. As the movement result of porcellio scaber is to stay at a place with the best environment condition, the algorithm design based on the observation of the movement behaviours of porcellio scaber is expected to be successful.

**Algorithm 1 PS algorithm**

**Objective function** \(f(x) = [x_1, x_2, \cdots, x_d]^T\)

**Generate initial position of porcellio scaber** \(x_i^0\) \((i = 1, 2, \cdots, N)\)

**Environment condition** \(E_x\) at position \(x\) is determined by \(f(x)\)

Set weighted parameter \(\lambda\) for decision based on aggregation and the propensity to explore novel environments

\[
\text{while } k < \text{MaxStep} \text{ do}
\]

Get the position with the best environment condition, i.e., \(x_* = \arg \min_{x^1} \{ f(x^1) \} \) at the current time among the group of porcellio scaber

Randomly chose a direction \(\tau = [\tau_1, \tau_2, \cdots, \tau_d]^T\) to detect

Detect the environment condition \(\min \{ E_x \} \) and worst environment condition \(\max \{ E_x \} \) at position \(x^k_i + \tau\) for \(i = 1 : N\) all \(N\) porcellio scaber

\[
\text{for } i = 1 : N \text{ all } N \text{ porcellio scaber do}
\]

Determine the difference with respect to the position to aggregate i.e., \(x^k_i - \arg \min_{x^k_j} \{ f(x^k_j) \}\)

Determine where to explore, i.e., \(p\tau\)

Move to a new position according to the weighted decision between aggregation and propensity to explore novel environments

\[
\text{end for}
\]

**end while**

**Output** \(x_*\) and the corresponding function value \(f(x_*)\)

**Visualization**

**III. Benchmark Validation**

To test the efficacy of the proposed PS algorithm, some benchmark problems are used.

We consider the Michalewicz function:

\[
f(x) = -\sum_{i=1}^{d} \sin(x_i) \sin\left(\frac{i x_i^2}{\pi}\right)^{2m},
\]

where \(m = 10\) and \(d = 1, 2, \cdots\). When \(d = 2\), the global minimum of the Michalewicz function is \(f_* \approx -1.801\) which occurs at \(x_* \approx (2.0232, 1.5705)\). Under the setting that each element of \(\tau\) is a zero-mean random number with the standard deviation being 0.001, with \(\lambda = 0.8\), 20 porcellio scaber, and 40 steps, i.e., \(N = 20\) and \(\text{MaxStep} = 40\), the numerical experiment result is visualized in Fig. 3. As seen from this figure, although there are some local minima, all the porcellio scaber aggregate at about the optimal one. Numerically, the solution obtained in the numerical experiment is \(x_* = [2.202847772916551, 1.570778088262819]^T\) with the corresponding minimum of the function being \(f(x_*) = -1.801303342428961 \approx -1.801\). The result validates the efficacy of the proposed method. We have tested the algorithm for many times, and the successful rate in finding the global optimizer is relatively high. In addition, when it fails to find the optimal one, the result is near optimal, i.e., it finds a local minimum.
Fig. 3. Simulation result of the proposed PS algorithm for finding the minimizer of the Michalewicz function by using 20 porcellio scaber starting from randomly generated initial positions and by taking 40 steps of movement.

Fig. 4. Visualization of the numerical result of the proposed PS algorithm for solving the Easom problem by using 20 porcellio scaber starting from randomly generated initial positions and by taking 40 steps of movement.

We also consider the Goldstein and Price problem:

\[
\min_x f(x) = [1 + (x_1 + x_2 + 1)^2(19 - 14x_1 + 3x_2^2 - 14x_2 \\
+ 6x_1x_2 + 3x_2^2)][30 + (2x_1 - 3x_2)^2(18 - 32x_1 \\
+ 12x_1^2 + 48x_2 - 36x_1x_2 + 27x_2^2)],
\]

subject to \( x_1 \geq -2, x_2 \leq 2 \)

The function has four local minima and the global minimizer is \( x^* = [0, -1]^T \) with the minimum being \( f(x^*) = 3 \). By using 20 porcellio scaber and taking 40 steps of movement, with \( \lambda = 0.6 \) and the other parameters set the same as those in the previous experiment, the numerical experiment result of the proposed PS algorithm for solving the Easom problem is visualized in Fig. 4. Note that, the initial positions of the 20 porcellio scaber are randomly set and are guaranteed to satisfy the inequality constraints.

The solution obtained in the experiment by the algorithm is \( x^* = [-0.000033275995519, -1.000060284512512]^T \) with the corresponding function value being \( f(x^*) = 3.000001145798920 \approx 3 \). The result further validates the efficacy of the proposed PS algorithm.

IV. CONCLUSION

In this paper, a novel bio-inspired algorithm called the PS algorithm has been proposed for solving optimization problems. Both the biology background and implementation of the proposed algorithm have been illustrated. Numerical experiment results on two benchmark problems have verified the efficacy of the proposed algorithm.

APPENDIX

An example of the implementation of the PSA in Matlab are available at https://cn.mathworks.com/matlabcentral/fileexchange/64574-porcellio-scaber-algorithm--psa--.

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