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Artificial infectious disease optimization: A SEIQR epidemic dynamic model-based function optimization algorithm

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ABSTRACT

To solve some complicated function optimization problems, an artificial infectious disease optimization algorithm based on the SEIQR epidemic model is constructed, it is called as the SEIQR algorithm, or SEIQRA in short. The algorithm supposes that some human individuals exist in an ecosystem; each individual is characterized by a number of features; an infectious disease (SARS) exists in the ecosystem and spreads among individuals, the disease attacks only a part of features of an individual. Each infected individual may pass through such states as susceptibility (S), exposure (E), infection (I), quarantine (Q) and recovery (R). State S, E, I, Q and R can automatically and dynamically divide all people in the ecosystem into five classes, it provides the diversity for SEIQRA; that people can be attacked by the infectious disease and then transfer it to other people can cause information exchange among people, information exchange can make a person to transit from one state to another; state transitions can be transformed into operators of SEIQRA; the algorithm has 13 legal state transitions, which corresponds to 13 operators; the transmission rules of the infectious disease among people is just the logic to control state transitions of individuals among S, E, I, Q and R, it is just the synergy of SEIQRA, the synergy can be transformed into the logic structure of the algorithm. The 13 operators in the algorithm provide a native opportunity to integrate many operations with different purposes; these operations include average, differential, expansion, chevy, reflection and crossover. The 13 operators are executed equi-probably; a stable heart rhythm of the algorithm is realized. Because the infectious disease can only attack a small part of organs of a person when it spreads among people, the part variables iteration strategy (PVI) can be ingeniously applied, thus enabling the algorithm to possess of high performance of computation, high suitability for solving some kinds of complicated optimization problems, especially high dimensional optimization problems. Results show that SEIQRA has characteristics of strong search capability and global convergence, and has a high convergence speed for some complicated functions optimization problems.

1. Introduction

Infectious diseases can transmit from a person or any other species to another person or other species through various channels. Usually susceptible individuals can be infected with infectious diseases by directly contacting with infected individuals, body fluids and excreta of infected individuals, or materials polluted by infected individuals; infectious diseases can spread through air, water, food, skin contact, soil, blood, and etc [1]. In nature, there exist a large number of infectious viruses, humans, animals and plants are subjected to their threat all the time. Behind almost every infectious disease, a sad story is always implied. Ebola, outbreak in early 2014, and still raging in Africa, has made thousands of Africans died [2–4]; in early 2002, outbreak of SARS had made tens of thousands of Chinese people died, more Chinese people disabled [5–8]; H7N9 [9–12] or H5N6 [13–14], which visits southern regions of China every year, makes a lot of poultry slaughtered.

However, the purpose of this article is not to introduce a model to describe an infectious disease, but reveals an important application hiding in the spreading mechanism of each infectious disease, namely behind each infectious disease, even it hides an optimization algorithm which can solve some complicated function optimization problems! In other words, an infectious disease actually corresponds to an optimization algorithm. The task of this article is to reveal how this correspondence happens.

Suppose the optimization problem we want to solve is as follows:

$$\min f(\boldsymbol{X})$$
$$\text{s.t.} \quad \begin{cases} g_i(\boldsymbol{X}) \geq 0, i \in I \\ \boldsymbol{X} \in S \subset R^n \end{cases} \tag{1}$$

where R^n is a n-dimensional Euclidean space; $\boldsymbol{X}=(x_1,x_2,\ldots,x_n)$ is an n-dimensional decision vector; S is a search space; $f(\boldsymbol{X})$ is an objective function; $g_i(\boldsymbol{X}) \geq 0$ is the ith inequality constraint, $i \in I$, I is the set of inequality constraints.

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If $f(\boldsymbol{X})$ is neither a concave function nor a convex function, or $f(\boldsymbol{X})$ and $g_i(\boldsymbol{X})$ are discontinuous or non-differentiable, or even their mathematical expressions don't know, then optimization problem (1) can only be solved by heuristic search methods [15–20], one of which is the population-based intelligence optimization method [21–24]. For a population-based intelligence optimization algorithm, we always assume that for given $\boldsymbol{X}$, $f(\boldsymbol{X})$ and $g_i(\boldsymbol{X})$ can be calculated, while $f(\boldsymbol{X})$ and $g_i(\boldsymbol{X})$ are always without any restrictions [25–27].

Up to now, many population-based intelligence optimization algorithms have been developed, for example, genetic algorithm (GA) [21,22,25,28–32], ant colony algorithm (ACA) [33,34], particle swarm optimization (PSO) [35–41], biogeography-based optimization (BBO) [42], differential evolution (DE) [43–45], artificial bee colony (ABC) [46–49], artificial immunity algorithm (AIA) [50–56] and evolutionary strategy (ES) [57,58] and so on.

Because a population-based intelligence optimization algorithm generally doesn't require special restrictions on objective function and constraints of an optimization problem, they have broad suitability and applicability [35]. A common feature of these algorithms is that evolutionary scene is very simple and corresponding operators are very few [35].

NFL [59,60] has pointed out, there is not an algorithm that can solve all optimization problems within finite time, but there is an algorithm that can solve some classes of optimization problems, for example, the simplex method can solve all linear programming problems [61]. Though operators contained in a population-based intelligence optimization algorithm are very simple, they are widely researched and applied in the wake of the corresponding algorithm [35].

Each algorithm can solve some kinds of optimization problems. If cores of these algorithms are extracted and combined into some new operators, then these new operators may have better suitability and wider application. For example, suppose we extract A cores from A algorithms, each core is called as an operation, if we select randomly a operations from the A cores to combine a new operator, then we can obtain C_A^a new operators. Obviously, the suitability of a new algorithm that possesses of the C_A^a new operators may be better than that of anyone of the A algorithms; applicable scope of the new algorithm may be wider than that of anyone of the A algorithms.

The above-mentioned strategy is called as integration in the article.

When a population-based intelligence optimization algorithm makes iteration, all variables in an individual, which is the biological explanation of an alternative solution of optimization problem (1), take part in computation simultaneously, we call the iteration strategy as all variables iteration (AVI). AVI means all dimensions of an optimization problem take part in computation simultaneously. The algorithms applying AVI include: GA, PSO, AFSA [62], BAT [63], Cuckoo Search (CS) [64–66], Glowworm-inspired Agent Swarms [67–68], AIA and its variations [50–56], ES [57,58], and so on. Because all variables of each alternative solution take part in computation during iteration, a population-based intelligence algorithm applying AVI may consume more CPU time, its efficiency of computation may be low relatively. Therefore it is not suitable to solve high dimensional optimization problems.

When a population-based intelligence optimization algorithm makes iteration, only a very small part of variables in an individual take part in computation simultaneously, we call the iteration strategy as part variables iteration (PVI). PVI means only a few of dimensions of an optimization problem take part in computation simultaneously. The algorithms applying PVI include: DE, BBO, ABC and so on. Because only a small part of variables of an alternative solution during iteration take part in computation, a population-based intelligence algorithm applying PVI may consume a little of CPU time, its efficiency of computation may be high comparatively, consequently it is suitable to solve some high dimensional optimization problems.

Therefore, developing a PVI-based population-based intelligence algorithm may be a good developing direction.

If a population-based intelligence optimization algorithm has its heart rhythm, then the algorithm may behave like a live animal. If the heart rhythm of the algorithm is stable, then it means that all operators contained in the algorithm are executed equi-probably; if the heart rhythm throbs (heart palpitation), then it means that a special operator is executed with higher probability under special conditions, a targeted exploration may be realized.

In a population-based intelligence optimization algorithm, many individuals work together, it is the basic property that a population-based intelligence optimization algorithm differs from a traditional optimization algorithm. In the article, we call the property as synergy, but we assign it much wider implications: synergy may be cooperation, competition, interaction, role changing, state transition and so on [35,86–88].

Information exchange among individuals is always carried out during iteration in a population-based intelligence optimization algorithm. By information exchange a new search strategy is formed. If information exchange of an algorithm is very sufficient, then the algorithm's performance may be good [35,46,57,62–64,87,88].

Diversity of individuals in a population-based intelligence optimization algorithm can make individuals to evolve vividly, and then reducing the probability that evolution drops into local pitfalls [69,70,87,88].

Evolution of population with the survival of the fittest is always the basis of a population-based intelligence optimization algorithm. If there exists evolution in a population, each individual has instincts to make itself to grow better or become stronger [25,71–74], then it means that the algorithm can converge to global optima of optimization problem (1) with higher probability [26,35,51,61,83,86–88].

Synergy can be transferred into the logic structure of a population-based intelligent optimization algorithm; information exchange can be described into operators of the algorithm; diversity can make search to develop along different directions; while the evolution and instincts of each individual will enable each individual to evolve toward better fitness so as to arrive at global optima at higher probability [26,35,51,61,74,83,86–88].

In nature, is there a scenario which can reflect the above-mentioned 8 properties simultaneously, namely integration, PVI, heart rhythm and heart palpitation, synergy, information exchange, diversity, and evolution? The answer is YES.

In the article, we introduce a new population-based intelligence optimization algorithm by telling the following sad story.

There are many people in an ecosystem; people always like to eat wild animals. One day, SARS (severe acute respiratory syndromes, SARS [5–8]) broke out suddenly within the ecosystem. At first, the SARS virus attacked some people because these people ate some wild animals that had infected with the SARS virus; hence these people were exposed, but did not come on.

Because SARS can spread by air, and people have the habitual nature of living together in the ecosystem, so the exposed people can easily transmit their diseases to other people. After a period of latency, the exposed people became ill. Because people did not know SRAS at that time, it provided a good opportunity for the virus to spread among people easily and widely. Through closely