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Social learning optimization (SLO) algorithm paradigm and its application in QoS-aware cloud service composition

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ABSTRACT

Inspired by the evolution process of human intelligence and the social learning theory, a new swarm intelligence algorithm paradigm named the social learning optimization (SLO) algorithm is proposed. SLO consists of three co-evolution spaces: the bottom is the micro-space, where genetic evolution occurs; the middle layer is the learning space, where individuals enhance their intelligence through imitation learning and observational learning; knowledge is extracted from the middle layer and delivered to the top layer, which is called the belief space, where culture is established through knowledge accumulation and used to guide individuals' genetic evolution in the micro-space regularly. SLO is an optimization algorithm model for optimization problems, and a concrete algorithm could be generated by embodying SLO's three evolution spaces. Moreover, to demonstrate how to employ SLO and verify its superiority, this paper proposes the specific SLO (S-SLO) to solve the problem of QoS-aware cloud service composition. S-SLO is constructed by integrating the improved differential evolutionary (DE) algorithm and improved social cognitive optimization (SCO) into the micro-space and the learning space, respectively. Finally, experimental results and performance comparison show that the S-SLO is both effective and efficient. This work is expected to explore a novel swarm intelligence optimization model with better search capabilities and convergence rates, as well as to extend the theory of the swarm intelligence optimization algorithm.

1. Introduction

The human ability to understand things comes from the interaction with nature. Nature is always the source of human creativity, and many adaptive optimization phenomena of nature constantly inspire humans. Likewise, bionic intelligent computing is inspired by nature and biological rules. In recent decades, through simulating the ecosystem mechanisms, some bionic intelligent optimization algorithms have been proposed and studied for solving complex optimization problems. These algorithms are distinct from the classical mathematical programming principle and can be classified into two types: evolutionary algorithms and swarm intelligence algorithms.

Evolutionary algorithms usually begin with a population of organisms (initial solutions) and then allow them to mutate and recombine, selecting only the fittest to survive for each generation. The well-known evolutionary algorithms are the genetic algorithm (GA) [17,45,63], genetic programming (GP) [23,26], evolution strategies (ES) [2,7,8], evolution programming (EP) [6,54] and differential evolution (DE) [24,46,59,65]. Swarm intelligence (SI) [37,69] is an innovative artificial intelligence technique

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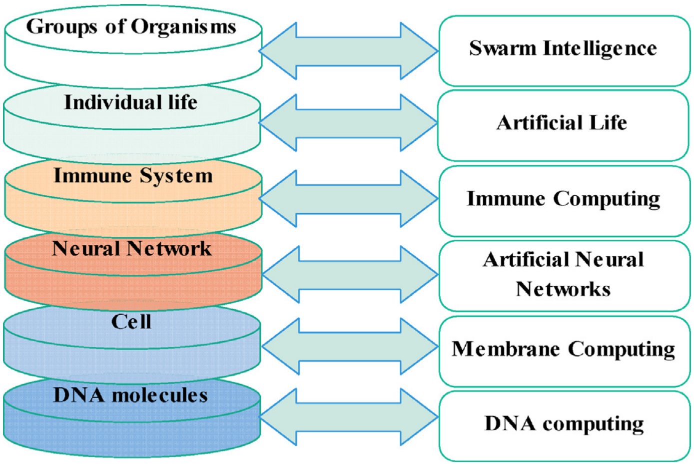

Fig. 1. Intelligence algorithms and corresponding organisms.

inspired by the intelligent behaviors of insects or animal groups in nature, such as ant colonies, bird flocks, bee colonies, bacterial swarms, etc. In recent years, several swarm intelligence algorithms have been proposed, such as ant colony optimization (ACO) [12,16], particle swarm optimization (PSO) [25,55], bacterial foraging optimization (BFO) [15,35], artificial bee colony algorithm (ABC) [22,32], social cognitive algorithm (SCO) [48,61], cultural algorithm (CA) [43,56], and so on.

With the emergence of swarm intelligence algorithms, some complex problems that cannot be processed by the traditional optimization algorithms are solved, and accordingly, humanity's ability to address optimization problems has been greatly enhanced. Swarm intelligence has become a research interest for many scientists of related fields in recent years. Bonabeau has defined swarm intelligence as "any attempt to design algorithms or distributed problem-solving devices inspired by the collective behavior of social insect colonies and other animal societies" [9]. Researchers modeled these swarm behaviors, and engineers tested the efficiency and competitiveness of these designed models on complex design problems. SI is becoming an increasingly important research area for computer scientists, engineers, economists, operational researchers, and many other disciplines, because the problems that the natural intelligent swarms can solve have important counterparts in several, real-world engineering areas.

Moreover, there are other artificial intelligence algorithms that simulate the evolution of biological internal systems, such as artificial neural networks (ANN) [10,39,53] and the immune algorithm (IA) [3,29,30]; membrane computing (MC), which simulates the evolution mechanisms inside a cell, has also been provided [1,68]. From the development of intelligence algorithms, it can be found that most of the intelligence algorithms are designed by simulating the structure or function of a living body, such as GC, ANN, IA and MC; some other intelligence algorithms are proposed by imitating the behavior of a biological population, such as ACO, PSO, ABC, etc. The relationships between intelligence algorithms and organisms are described in Fig. 1.

As seen from Fig. 1, from DNA molecules to the internal subsystems of the body, from individual life and to biological communities, the corresponding algorithm models have been designed. However, the existing intelligence algorithms are designed by simulating the behavioral mechanisms of a subsystem within a biological entity (such as DNA molecules, the immune system, neural networks) or a single biological community (such as an ant colony, bird flocks, bee colonies, bacterial swarms, and so on). However, these swarm intelligence algorithms still have some disadvantages, e.g., individuals' behaviors are unsupervised; each agent has a stochastic behavior due to its perception in the neighborhood; each individual acts independently according to certain rules; human intelligence is lacking (such as learning from others and outstanding ones).

As we know, in the entire biological system, humanity has the highest swarm intelligence. In human society, humans' intelligence is not only determined by their genes but also influenced by culture. Most importantly, humans always develop their intelligence through learning and extract knowledge from collective action. Thus, sufficient knowledge accumulation leads to the establishment of culture, whereas culture serves to accelerate the evolution speed of human intelligence. Moreover, the social learning theory, proposed by Albert Bandura, has proven that human behavior, particularly complex human behavior, is achieved mainly through learning. Achieving human behavior is subject to genetic factors as well as physiological factors and is influenced by the acquired experience environment. In short, human intelligence development mainly depends on an individual's innate constitution, learning and culture influence.

Thus, based on the analysis of the evolution process of human intelligence and the social learning theory, we believe that the evolution process of human intelligence is not limited to a single subsystem or an isolated biotic group but is, instead, a co-evolution ring that consists of individual genetic evolution, individual learning and culture influence, which is illustrated in Fig. 2.

To the best of our knowledge, a swarm intelligence algorithm that simulates the evolution process of human intelligence has not yet proposed. Therefore, inspired by the social learning theory and the evolution process of human intelligence, this paper proposes a new swarm intelligence algorithm paradigm named the social learning optimization (SLO) algorithm. SLO consists