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Research paper

Kidney-inspired algorithm for optimization problems

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ABSTRACT

In this paper, a population-based algorithm inspired by the kidney process in the human body is proposed. In this algorithm the solutions are filtered in a rate that is calculated based on the mean of objective functions of all solutions in the current population of each iteration. The filtered solutions as the better solutions are moved to filtered blood and the rest are transferred to waste representing the worse solutions. This is a simulation of the glomerular filtration process in the kidney. The waste solutions are reconsidered in the iterations if after applying a defined movement operator they satisfy the filtration rate, otherwise it is expelled from the waste solutions, simulating the reabsorption and excretion functions of the kidney. In addition, a solution assigned as better solution is secreted if it is not better than the worst solutions simulating the secreting process of blood in the kidney. After placement of all the solutions in the population, the best of them is ranked, the waste and filtered blood are merged to become a new population and the filtration rate is updated. Filtration provides the required exploitation while generating a new solution and reabsorption gives the necessary exploration for the algorithm. The algorithm is assessed by applying it on eight well-known benchmark test functions and compares the results with other algorithms in the literature. The performance of the proposed algorithm is better on seven out of eight test functions when it is compared with the most recent researches in literature. The proposed kidney-inspired algorithm is able to find the global optimum with less function evaluations on six out of eight test functions. A statistical analysis further confirms the ability of this algorithm to produce good-quality results.

1. Introduction

In recent years, the researchers are trying to imitate nature in technology due to the nature is the best trainer for technology and its designs and capabilities are enormous. In addition, these two fields have much stronger connection since a lot of new problems in computer science are categorized as nature problems. Therefore, easy mapping is possible between nature and technology in real world. Although, there are many nature-inspired algorithms in the literature in recent years, we still believe that there is room to improve this mapping between nature and computer science by both enhancement of the existing nature- inspired algorithms and introducing new ones. This can be as motivation of introducing kidney- inspired algorithm in this study.

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Table 1
Examples of nature-inspired algorithms in the literature.

Nature-inspired algorithm	Imitation	Reference
Simulated annealing (SA)	simulates the steel annealing process	[2]
Great deluge (GD)	imitates the process whereby a person in a great deluge climbing a hill	[3]
Gravitational search algorithm (GSA)	Imitates the law of gravity and the idea of mass interactions	[4]
Genetic algorithm (GA)	Imitates natural selection operators and natural genetic variation	[5]
Ant colony optimization (ACO)	stimulates finding shortest path to the food sources of ants	[6]
Intelligent water drops (IWDs)	imitates destination finding behavior of natural rivers	[7]
Particle swarm optimization (PSO)	Imitates the swarm behavior	[8]
Bat algorithm (BA)	Simulates echolocation behavior of bats	[9]
Honey bee optimization (HBO)	Mimics the food-foraging behavior of honey bee colonies	[10]
Honey bee mating optimization (HBMO)	Imitates self-explanatory honey bee mating	[11]
Firefly algorithm (FA)	imitates the flashing light emitted by fireflies in the natural world	[12]
Cuckoo search (CS)	inspires reproduction behavior of the cuckoo	[13]
Harmony search (HS)	simulates finding the harmony in music	[14]
Black hole (BH)	Imitates the black hole phenomenon	[15]
Imperialist competitive (IC)	Simulates competition among empires	[16]

In computer science, a meta-heuristic is a higher level heuristic that may offer a suitably high-quality solution for a given optimization problem. Among all the meta-heuristic algorithms in the literature, nature-inspired algorithms have become particularly attractive over the past few decades for solving various optimization problems [1]. The nature-inspired algorithms are derived from the activities of physical or biological systems in the natural world. Some examples of nature-inspired algorithms in the literature are shown in Table 1.

Nature-inspired algorithms have found application in many fields such as data mining [17-26], timetabling and scheduling [27-29], pattern recognition [30-33], industry [34-36], engineering [37-39] and economics [40, 41]. The balance between exploration and exploitation has a considerable effect on the efficiency of a meta-heuristic [42]. This paper proposes a new optimization algorithm inspired by the kidney process in the human body exploration and exploitation capabilities.

In the kidney process, there are four steps in urine formation. The first step, filtration, involves the transfer of solutes and water from the blood to the tubules in the kidneys. The second step, reabsorption, is the movement of useful water and solutes from the tubules back into the blood. In the third step, secretion, the tubules continue to secrete extra and harmful substances into the tubular. The end result of the above three steps leaves the body via urine in the fourth step, excretion. These four steps of the kidney process are simulated in the proposed kidney-inspired algorithm (KA). The KA starts with an initial population of water and solutes particles (solutions). At each iteration, the solutes are filtered depending on a filtration rate that is calculated based on mean of objective functions (MOF) of all solutes. The filtered solutes are moved to filtered blood (FB) and the rest are transferred to waste (W). These steps imitate the glomerular filtration process in the kidneys. Reabsorption, secretion and excretion are the other three functions of a kidney that are considered and imitated in the KA. A solute allocated to W is reabsorbed if it can become part of FB after applying the reabsorption operator, otherwise it is excreted from W. In addition, a solution in FB is secreted if it is not better than the worst solution in FB. After treating all the solutions in the population, all the solutions are ranked, W and FB are merged to be the new population and the filtration rate is updated. In this algorithm, the generation of a new solution and reabsoption operator is calculated based on the quality of the current solution and the best solution found so far. In this algorithm, exploitation is achieved by the filtration process and exploration is provided by the new solution generation and reabsorption process.

The rest of the paper is structured as follows: an overview of the overall kidney process in the human body is provided in Section 2. The details of the proposed KA are specified and explained in Section 3. The four simulated components of the KA and its pseudocode are also given in this section. The experimental results of the assessment of the proposed algorithm based on eight standard test functions and a statistical analysis are presented in Section 4. The conclusion is provided in Section 5 in which potential extensions are also discussed.

2. The biological kidney process

The kidneys are the main biological structure of the urinary system in the human body. They generally filter blood in order to eliminate excess water and wastes through the urine. They also handle the amount of ions in the blood.

The kidney's primary functional component is called the nephron. In each kidney there are about one million nephrons. Each nephron has a filtering system called a glomerulus, and a tubule, through which the filtered fluid passes. Urine formation starts in the glomerular capillaries. In glomerular capillaries, the dissolved substances are passed into the tubule as an effect of the force of blood pressure and the pressure in Bowman's capsule. The tubule in the kidney is responsible for reabsorption and secretion. Reabsorption is the procedure of transferring solutes from the tubules and returning them to the bloodstream. Some substances such as sodium and glucose are reabsorbed when the plasma level reaches a specific threshold. The process of moving solutes toward the renal tubule so that they can be excreted in the urine is defined as secretion. Secretion permits substances such as hydrogen ions to be eliminated. The kidney function has effects on the general state of health, including blood pressure, blood chemistry and fluid balance. The kidney process can be summarized as follows: