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Opposition based learning: A literature review

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ABSTRACT

Opposition-based Learning (OBL) is a new concept in machine learning, inspired from the opposite relationship among entities. In 2005, for the first time the concept of opposition was introduced which has attracted a lot of research efforts in the last decade. Variety of soft computing algorithms such as, optimization methods, reinforcement learning, artificial neural networks, and fuzzy systems have already utilized the concept of OBL to improve their performance. This survey has been conducted on three classes of OBL attempts: a) theoretical, including the mathematical theorems and fundamental definitions, b) developmental, focusing on the design of the special OBL-based schemes, and c) real-world applications of OBL. More than 380 papers in a variety of disciplines are surveyed and also a comprehensive set of promising directions are discussed in detail.

1. Introduction

The concepts of opposition widely exist in the world around us, but it has sometimes been understood in different ways. For instance, opposite particles in physics, antonyms in languages, complement of an event in probability, antithetic variables in the simulation, opposite proverbs in the culture, absolute or relative complement in the set theory, subject and object in the philosophy, good and evil in animism, opposition parties in politics, theses and antitheses in dialectic, and dualism in religions and philosophies. It seems that the explanation of different entities becomes a tough task without using the concept of opposition such as the east-west, south-north, and hot-cold which cannot be described separately [216,205].

Opposition-Based Learning (OBL) is a novel research field which has already attracted a recognizable interest in the past decade. Many soft computing algorithms have been enhanced by utilizing the concept of OBL such as, Reinforcement Learning (RL), Artificial Neural Networks (ANN), Fuzzy Systems, and variant optimization methods such as Genetic Algorithms (GA) [97], Differential Evolution (DE) [202,274], Particle Swarm Optimization (PSO) [121,122], Biogeography-based Optimization (BBO) [267], Harmony Search (HS) [96], Ant Colony System (ACS) [66,67], Gravitational Search Optimization (GSO), Group Search Algorithm (GSA), Artificial Bee Colony (ABC) [116], Simulated Annealing (SA), etc. In 2005, the fundamental concept of OBL [297] was proposed which considers the current estimate (guess) and its corresponding opposite simultaneously to find a solution efficiently. When the main goal of an algorithm is finding the optimal solution for an objective function, considering an estimate and its opposite simultaneously can be beneficial to enhance the performance of the algorithm. The advantages of applying the OBL concept have been investigated to define the transfer function and weights of neural networks, creating candidate solutions of evolutionary algorithms, and action policy of reinforcement agents.

Since January 2005, more than 400 publications have been published on the OBL concept. These research works have been published in conferences, journals and books which are in machine learning or soft computing. Among these papers, 60% are journal papers, 38% are conference papers, and 2% books/thesis. Fig. 1 shows the number of publications and citations per year obtained by the website, Thomson Reuters (formerly ISI) Web of Knowledge. Two surveys on OBL have been published in [7,359] which surveyed 52 and 138 papers but they do not covered many research works which were published in the recent years. Therefore, based on the fast progress of research works on OBL and its applications in the science and engineering fields, it is motivated us to prepare an up to date comprehensive survey including the latest theoretical and developmental researches and promising future directions of OBL. This paper attempts to provide a global overview of research works on OBL from different perspectives. Some of research works focus on the mathematical proofs and theoretical definitions to investigate and use the benefits of OBL; some are on the special developments for various schemes of using OBL in the machine learning methods; and others are on the different applications of OBL in the various science and engineering applications such as power systems, pattern recognition

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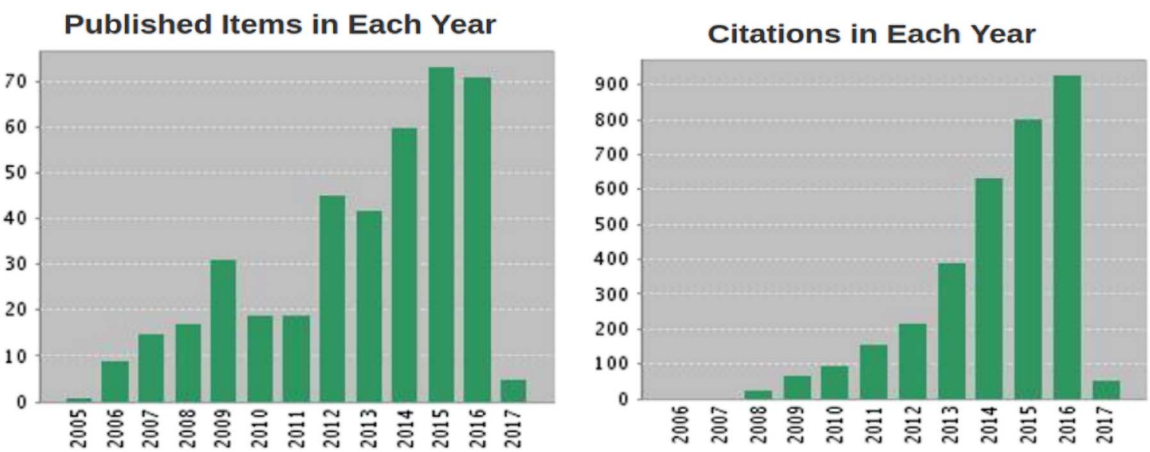

(a) Publications (b) Citations

Fig. 1. The number of publications and citations by year.

and image processing, identification problem, bioinformatics, and medicine, etc.

The remainder of this paper is organized as follows: Section 2 is described the basic concepts of OBL. Section 3 is theoretical research works on opposition schemes. Developmental research works conducted on OBL is described in Section 4. In Section 5, the applications of OBL is presented. Finally, the paper is concluded in Section 6.

2. Opposition-based learning: basic concepts and pioneering research works

In this section, first we summarize the basic concepts of OBL. Then, pioneering research works on using OBL concept in the machine learning algorithms such as EA, RL, ANN, and Fuzzy Systems are explained.

2.1. Basic concepts

The primary opposition concept first was expressed in the Yin-Yang symbol (Fig. 2) in the ancient Chinese philosophy [205]. This symbol indicates the duality concept in which black and white are Yin (receptive, feminine, dark, passive force) and Yang (creative, masculine, bright, active force), respectively. Also, Greek classical elements of nature patterns (Fig. 3) described the opposition concepts such as fire (hot and dry) vs. water (cold and wet), earth (cold and dry) vs. air (hot and wet). Cold, hot, wet, and dry indicate nature entities and their opposite entities [205]. It seems that the concept of many entities or situations in the real-world is described by using the opposition concept. In fact, using the opposition concept makes the explanation of different entities much easier. Pair-wised opposites such as the east, west, south, and north cannot be defined alone and only they can explain in terms of one another. Therefore, the computational

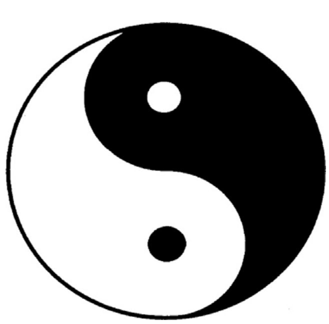

Fig. 2. Early opposite concept was mentioned in the Yin-Yang symbol [205].

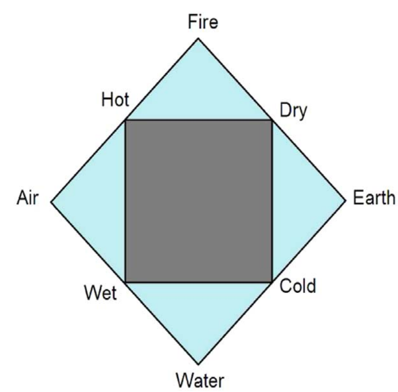

Fig. 3. The Greek classical elements to explain patterns in the nature [205].

opposition concept [297] was inspired from the opposition concept in the real-world and the opposite numbers were simply defined in [297] as follows.

Definition 1 (*Opposite number*). [297] Let $x \in [a, b]$ be a real number. Its opposite, $\breve{x}$, is defined as follow:

$$\breve{x} = a + b - x, \tag{1}$$

The extended definition for the higher dimension is defined in [296,297] as follows.

Definition 2 (*Opposite point in the D space*). [297] Let $x(x_1, \ldots, x_D)$ be a point in D-dimensional space and $x_i \in [a_i, b_i]$, $i = 1, 2, \ldots, D$. The opposite of x is defined by $\breve{x}(\breve{x}_1, \ldots, \breve{x}_D)$ as follow:

$$\breve{x}_i = a_i + b_i - x_i \tag{2}$$

In fact, they indicate that for finding the unknown optimal solution, searching both a random direction and its opposite simultaneously gives a higher chance to find the promising regions. It is reasonable that if the current estimates (guesses) are far away from the unknown optimal solution, computing their opposites leads to the opposite direction toward to the unknown optimal solution. Note that the basic opposite point is computed same as a reflected point when it is calculated through the center point $((x_1 + x_2 + \ldots + x_D)/2)$ [1].

The above definition of the opposite point is called as Type-I opposite. The Type-I opposite is defined according to the relationship between points in the search space without considering their objective values. Fig. 4 indicates x and its opposite, $\breve{x}$, in one, two, and three-dimensional spaces.