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Survey Paper

A review of opposition-based learning from 2005 to 2012

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ABSTRACT

Diverse forms of opposition are already existent virtually everywhere around us, and utilizing opposite numbers to accelerate an optimization method is a new idea. Since 2005, opposition-based learning is a fast growing research field in which a variety of new theoretical models and technical methods have been studied for dealing with complex and significant problems. As a result, an increasing number of works have thus proposed. This paper provides a survey on the state-of-the-art of research, reported in the specialized literature to date, related to this framework. This overview covers basic concepts, theoretical foundation, combinations with intelligent algorithms, and typical application fields. A number of challenges that can be undertaken to help move the field forward are discussed according to the current state of the opposition-based learning.

1. Introduction

This paper is inspired in part by the observation that opposites permeate everything around us, in some form or another. In the last 2500 years, its study has already attracted the attention of countless experts in the field. In a sense, the interplay between entities and opposite entities is fundamental for maintaining universal balance and harmony. Sometimes we unconsciously or consciously apply the opposition concept in our regular life. However, due to the lack of an accepted mathematical or computational model for opposition, until recently it has not been explicitly studied to any great length in fields outside of philosophy and logic (Tizhoosh and Ventresca, 2008).

Many machine intelligence algorithms inspired by different natural systems consider finding the solution of a given problem as function approximation. In many cases, the starting points are chosen randomly, such as weights of a neural network, initial population of soft computing algorithms, and action policy of reinforcement agents. If the starting point is close to the optimal solution, this results a faster convergence. On the other hand, if it is very far from the optimal solution, such as opposite location in worst case, the convergence will take much more time or even the solution can be intractable. Looking simultaneously for a better candidate solution in both current and opposite directions may help us to solve the present problem quickly and efficiently.

The basic concept of Opposition-Based Learning (OBL) was originally introduced by Tizhoosh (2005a). The main idea of this optimization is, for finding a better candidate solution, the simultaneous consideration of an estimate and its corresponding opposite estimate which is closer to the global optimum. In a very short period of time, it has been utilized in different soft computing areas. These efficient meta-heuristic methods mainly include Differential Evolution (DE), Particle Swarm Optimization (PSO), Reinforcement Learning (RL), Biogeography-Based Optimization (BBO), Artificial Neural Network (ANN), Harmony Search (HS), Ant Colony System (ACS) and Artificial Bee Colony (ABC). However, the comprehensive surveys published in the technical literature about opposition-based learning with other natural computation methods, especially in future trends and challenges, are relatively scarce (Al-Qunaieer et al., 2010a; Ergezer and Sikder, 2011; Imran et al., 2010). But they do not discuss further researches and challenges thoroughly, and several other approaches have arisen since the publication of those papers. The intention of the present work is to provide researchers an updated survey and the future research trends of theoretical and practical areas on OBL.

The review of the literature in this paper consists of 138 articles concerned with the theory and application of opposition-based learning. These papers are listed in the bibliography and are drawn from the period 2005–2012. The articles in this literature review have been from refereed journal articles and conferences proceedings from across a broad range of disciplines. Books (Rahnamayan, 2009; Tizhoosh and Ventresca, 2008) and dissertations (Malisia, 2007; Rahnamayan, 2007; Salama, 2007; Shokri, 2008) have generally not been included, although the tendency is to be inclusive when dealing with borderline cases. One of the major

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concerns here is that, these results and key contributions with rarely novel idea are usually the collection of previous results published in journal or conference. But it is undeniable that, as classics, two books authored by Rahnamayan and Tizhoosh have discussed the genuine beginning of thought, evolution and definition of the concept, variation of typical algorithms and their applications.

The remaining of this paper is organized as follows: some basic concepts and description of opposition-based learning are introduced briefly in Section 2. In Section 3, its mathematical analysis is provided which takes into consideration various performance metrics. Then, opposition-based computing with natural computation methods is summarized in Section 4, with special emphasis on the different ways of employing the opposition concept. In Section 5, a review of the applications of opposition-based learning in soft computing is conducted. Finally, the trends and challenges for further research are discussed in Section 6.

2. Basic concepts

2.1. The concept of opposition

The footprints of the opposition concept can be observed in many areas around us (Rahnamayan et al., 2012). This concept has sometimes been labeled with different names. Following are just some examples of opposition concept often mentioned in relevant research: opposite particles in physics, absolute or relative complement of an event in set theory, antithetic variables in simulation, antonyms in languages, opposite proverbs in culture, opposition parties in politics, subject and object in philosophy of science, theses and antitheses in dialectic and “Yin” and “Yang” in Chinese philosophy and Taoist religion.

Moreover, due to the omnipresence of opposition in the real world, regardless in what amount intensity and form we may encounter its diverse presence, the nature of entities and their opposite entities might be understood in different ways (Tizhoosh and Ventresca, 2008). A whole set of words are also invented to describe the diversity and complexity of oppositeness: antipodal, antithetical, contradictory, contrary, diametrical, polar, antipodean, adverse, disparate, negative, hostile, antagonistic, unalike, antipathetic, counter, converse, inverse, reverse, dissimilar, and divergent. All these words describe some notion of opposition and can be conveniently employed in different practical contexts to portray different relationships.

Therefore it seems that without using the opposition concept, the explanation of different entities in all cases will be very difficult, and maybe even impossible. When you are trying to explain an entity, a situation or an idea, it is sometimes easier to explain its opposite instead. In fact, opposition often manifests itself in a balance between completely different entities. For instance, the east, west, south and north cannot be defined alone, but only in terms of one another. The same is valid for many other objects, such as cold and hot, wet and dry. Imagination of the infinity is vague, but when we consider the limited, it then becomes more imaginable because its opposite is definable (Rahnamayan et al., 2012).

2.2. Opposition-based learning

In general, soft computing or, more generally, computational intelligence algorithms start from some initial solutions (initial population) and iteratively try to replace the current solutions by some better solutions toward some optimal solutions. In the absence of a priori information about the solution, starting with random guesses, generally with a uniform distribution on the entire range, is a common initialization. Many of the variables measured, such as computation time, memory usage and storage complexity, are related to the distance of these initial guesses from the optimal solution. If we simultaneously check a solution and its opposite solution, the closer (fitter) one (guess or opposite guess) can be chosen as an initial solution. In fact, according to probability theory, 50% of the time a guess is further from the solution than its opposite guess. Therefore, starting with the closer of the two guesses has the huge potential to accelerate convergence and improve the precision of the approximate methods. The same or similar approach can be applied not only to initial solutions, but also continuously to each solution in the current population as well (Rahnamayan et al., 2008b).

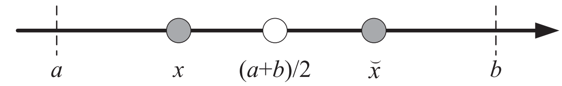

Fig. 1. Opposite point defined in domain $[a, b]$. x is a candidate solution and $\breve{x}$ is the opposite of x.

Table 1
Number of publications on opposition-based learning in the period 2005–2012.

Year	2005	2006	2007	2008	2009	2010	2011	2012*	Total
Journal	–	1	1	4	3	6	12	19	46
Conference	2	4	12	9	22	20	16	7	92
Total	2	5	13	13	25	26	28	26	138

* papers published in the print edition in 2013 and downloaded before January 2013 are also included.

In order to explain easier opposition-based learning, we need to define clearly the concept of opposite numbers. An opposition-based number can be defined as follows. Fig. 1 illustrates $\breve{x}$ (Rahnamayan et al., 2008b).

Definition 1. Let $x \in [a, b]$ be a real number. The opposition number $\breve{x}$ is defined by

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

Similarly, the opposite point in D-dimensional space can be defined as follows.

Definition 2. Let $P=(x_1, x_2,\ldots, x_D)$ be a point in D-dimensional space, where $x_1, x_2, \ldots, x_D \in R$ and $x_i \in [a_i, b_i]$, $\forall i \in \{1, 2, \ldots, D\}$. The opposite point $\breve{P}=(\breve{x}_1, \breve{x}_2, \ldots, \breve{x}_D)$ is completely defined by its coordinates

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

Now, by employing the definition of opposite point, the opposition-based optimization can be defined as follows.

Definition 3. Let $P=(x_1, x_2,\ldots, x_D)$ be a point in D-dimensional space (i.e., candidate solution). Assume $f(\cdot)$ is a fitness function which is used to measure the candidate's fitness. According to the definition of the opposite point, $\breve{P}=(\breve{x}_1, \breve{x}_2,\ldots, \breve{x}_D)$ is the opposite of $P=(x_1, x_2,\ldots, x_D)$. Now if $f(\breve{P}) \geq f(P)$, i.e., $\breve{P}$ has a better fitness than P, then point P can be replaced with $\breve{P}$; otherwise, we continue with P. Hence, the point and its opposite point are evaluated simultaneously to continue with the fitter one.

The varieties of opposition-based learning include Quasi-Opposition-Based Learning (QOBL) (Rahnamayan et al., 2007c), Quasi-Reflection Opposition-Based Learning (QROBL) (Ergezer et al., 2009), Center-based Sampling (Rahnamayan and Wang, 2009), Generalized Opposition-Based Learning (GOBL) (Wang et al., 2009a) and Opposition-Based Learning using the Current Optimum (COOBL) (Xu et al., 2011a). For further details please read the references listed above.