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A framework for evolutionary algorithms based on Charles Sanders Peirce's evolutionary semiotics

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ABSTRACT

One of the objectives of Evolutionary Computation (EC) has been to understand the processes of natural evolution and then model them algorithmically. Hans-Paul Schwefel, in his 1997 paper on the future challenges for EC argues that the more an algorithm models natural evolution at work in the universe, the better it will perform (even in terms of function optimization). There is enough data to suggest that slight differences in the understanding of the natural evolution can cause the associated Evolutionary Algorithms (EA) to change characteristically. The present paper tests Schwefel's hypothesis against Charles Sanders Peirce's theory which places semiotics, the theory of signs, at the heart of universal evolution. This course is followed because of three primary reasons. Firstly, Peirce has not been seriously tested in EC, although there have been EA based on other theories and sub-theories. Secondly, Peirce's universal theory, by not being restricted to biological evolution alone, qualifies for Schwefel's hypothesis, perhaps more than most other theories that have already been modeled algorithmically. But most importantly because, in experimental terms, it warrants an original claim that Peirce's insights are useful in improving the existing EA in computer science, as Peircean EA can potentially solve some of the major problems in this area such as the loss of diversity, stagnation, or premature convergence. This paper provides a novel framework and consequently a simple algorithm based on Peirce's theory of evolution, and tests it extensively against a benchmark set of mathematical problems of varying dimensions and complexity. Comparative results with classical and advanced EA form another significant part of the paper, and help in strengthening the viability of Schwefel–Peirce hypothesis for EC.

1. Introduction

There are many well-known lines of research within the Evolutionary Computation (EC) community such as function optimization improvements, engineering/real world applications, and mathematical foundations of Evolutionary Algorithms (EA). But many pioneering figures such as Lawrence J. Fogel, Larry J. Eshelman, Hans-Paul Schwefel, and David B. suggest in *The Handbook of Evolutionary Computation* that better modeling of natural evolution can lead to better optimization-oriented EA as well. Hans-Paul Schwefel, one of the founders of Evolution Strategies, fully understands the necessity of developing a model which is closer to natural reality. In his essay *Challenges to and Future Development of EA* [2] he says:

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> Current evolutionary algorithms are certainly better models of organic evolution. Nevertheless, they are still far from being isomorphic mappings of what happens in nature. In order to **perform better**, an appropriate model of evolution would have to comprise the full temporal and spatial development on the earth (a real global model) if not within the whole universe. We must be more modest in order to understand at least a little of what really happens – as always within natural sciences.

While the empirical reality of evolution occurring in nature is equally accessible to the entire scientific community, yet slightly different understanding and perspective in theorizing the natural processes have had different consequences. This consequential effect can be illustrated using data from EC as well. Memetic algorithms are based on the notion of cultural evolution [5,22], inspired by Richard Dawkins' proposal of meme as a unit of information that reproduces itself as people interact and exchange ideas [8]. Horizontal gene transfer that takes place in bacterial organisms has inspired the design of specialized crossover operators that have spawned a new class of evolutionary algorithms called pseudo-bacterial genetic algorithms [3,23]. Lamarckian conception of evolution and Baldwin effect on learning have been used by hybrid EA, and are reportedly more efficient than their Darwinian counterparts [12,20,37]. Island Model EA are based on Eldridge and Gould's punctuated equilibria theory [2,28,30,32], where subpopulations independently evolve while infrequent migrations take place using some communication topology. There are Diffusion Model EA as well which are based on population genetics idea of local (not global) selection and crossover. Genetic makeup spreads from individual to population levels based on the diffusion model [2,17]. They are designed for parallel processing with one individual per processor where the selection of parents is dependent on the underlying parallel architecture, usually SIMD (Single Instruction, Multiple Data streams). The Genetic Algorithms itself is John Holland's "adaptation" of Darwin's theory of evolution [15]. This brief detour serves to underscore the point that a different interpretation of natural evolution results in a different model of EA.

According to Jacques Monod, Darwin's theoretical explanation for evolution is an exquisite mix of "chance and necessity" [21]. In non-philosophical terms it is a combination of a variety of chances and a variety of laws. In order for Darwinian evolution to work it takes as a given, not only these two agents, but ironically the first batch of replicating life as well. Being a naturalist, Darwin did not make an attempt to try and relate the two apparently warring agents (chance and necessity), or how they "evolved" themselves before playing a role in the evolution of the universe and its living forms. However, there is one man that did that after Darwin.

Charles Sanders Peirce, the 20th century evolutionary pragmatist, has made major contributions to numerous fields such as logic and philosophy of science, formal and mathematical logic, topology, linguistics, epistemology and semiotics. When Peirce looked at the empirical effects of evolution, he came to the conclusion that there are three (not two) types of phenomenon, three basic categories that are operative in the universe. *First*, chance; *Second*, necessity; *Third*, habit-taking.[1] From this Peirce built a philosophically intricate system, and at its heart he installed semiosis, his theory of signs, which attempts to describe the inter-relationship of his three categories. Stressing unconditionally on the irreducibility of his semiotic triad, he said:

> ....by "semiosis" I mean, an action, or influence, which is, or involves, a cooperation of three subjects, such as a sign, its object, and its interpretant, this tri-relative influence not being in any way resolvable into actions between pairs [25, 5.484].

As far as the relation between a sign and its object is concerned, a sign, for Peirce, does not properly function or signify outside the specific context of this triadic relation. This conception is at odds with theories of signification that rely on a dyadic (or two part) relationship between signs and the objects they signify. For Peirce, semiosis of processes of signification operate only when a sign is considered in its triadic form, i.e. when a *sign* is a representation of its *object*, such that it produces or modifies its *interpretant*.[2] This effectively turns the interpretant into another sign of the same object, and thus helps enable further interpretations. This dynamic semiotic process *is* the cause for evolution and growth of meaning. It implies that organic matter learns to engage with the world, not simply by forming ideas in response to stimuli, but by forming habits of responding to non-organic material. For Peirce, habits are the ultimate interpretants of the world's signs, and he viewed habit-formation as the physiological manifestation of the sign-taking capacity [24].

Mapping Peirce's semiotic language onto his phenomenology it can be argued that evolutionary growth requires a *cooperation* of three evolutionary agencies, and for Peirce, absolute chance, mechanical necessity and tendency to take habits are a *sign* that Firstness, Secondness and Thirdness are severally operative in the cosmos. Peirce shows that in logic they are represented as beginning, end, and process. In psychology they are feelings, reaction-sensations, and thought or reason. In the case of biology Peirce extends the almost linear two step evolutionary process of random variation followed by natural selection into a non-linear triadic process. He says, First is the principle of individual variation or sporting; Second, the principle of heredity transmission; and Third, the process whereby the accidental characteristics become fixed (including, but not limited to the elimination of unfavorable characters by natural selection) [25, 6.32].

[1] Peirce's use of habits is different from its Lamarckian usage: "For Peirce, habits are not provisional adaptive responses to fluctuating environmental conditions; they are steps on the universal road from indeterminacy to law, a road traveled by objects as well as by organisms...Habit-taking is a plastic faculty. The peculiar characteristic of habit is: "not acting with exactitude" " [Louis Menand, The Metaphysical Club: A Story of Ideas in America, p. 365].

[2] For Peirce, the interpretant can mean more than one thing: (a) The context in which a Sign relates to an Object. (b) The relationship that an Object is able to establish with its context (Interpretant), because of Objects relationship with Sign. (c) The potential consequences of the relationship of Sign with Object.