Swarm and Evolutionary Computation 25 (2015) 2–14

Contents lists available at ScienceDirect

Swarm and Evolutionary Computation

journal homepage: www.elsevier.com/locate/swevo

Survey Paper

A survey on evolutionary algorithms dynamics and its complexity – Mutual relations, past, present and future

Ivan Zelinka [a,b,*]

[a] Division of MERLIN, Ton Duc Thang University, Ho Chi Minh City, Vietnam
[b] Department of Computer Science Faculty of Electrical Engineering and Computer Science, VSB-Technical University of Ostrava, Czech Republic

ARTICLE INFO

Article history:
Received 10 December 2014
Received in revised form
22 June 2015
Accepted 27 June 2015
Available online 6 July 2015

Keywords:
Swarm algorithms
Complex systems
Deterministic chaos
Control
Synthesis
Evolutionary algorithms

ABSTRACT

Swarm and evolutionary based algorithms represent a class of search methods that can be used for solving optimization problems. They mimic natural principles of evolution and swarm based societies like ants, bees, by employing a population-based approach in mutual communication and information sharing and processing, including randomness. In this paper, history of swarm and evolutionary algorithms are discussed in general as well as their dynamics, structure and behavior. The core of this paper is an overview of an alternative way how dynamics of arbitrary swarm and evolutionary algorithms can be visualized, analyzed and controlled. Also selected representative applications are discussed at the end. Both subtopics are based on interdisciplinary intersection of two interesting research areas: swarm and evolutionary algorithms and complex dynamics of nonlinear systems that usually exhibit very complex behavior.

1. An introduction into a few historical facts and relations

Swarm based algorithms can be understand as a special edge class of wider class of the so-called evolutionary algorithms (EAs), that are based on principles of evolution which have been observed in nature long time before they were applied and transformed into algorithms to be executed on computers. In fact, firstly EAs have been developed and then, in last 10–15 years swarm based algorithms were introduced by different researchers, as reported in [26] and shortly mentioned here. From the deepest historical point of view there are four most significant personalities whose research on evolution and genetics has the biggest impact on modern understanding of evolution and its use for computational purposes. They are Gregor Johann Mendel, Charles Darwin, Turing and Barricelli. Because historical facts are very often misinterpreted and ignored, it is better to mention few important milestones now in order to clarify background of swarm and evolutionary algorithms (SEA, let us use this abbreviation for the rest of this paper despite the fact that swarm algorithms were "discovered" later than classical evolutionary algorithms and can be considered as a "non-evolutionary" class of algorithms. It is clear from the context whether we are talking about swarm or evolutionary algorithms.

Gregor Johann Mendel (July 20, 1822—January 6, 1884) was an Augustinian priest and a scientist, and is often called the father of genetics for his study of the inheritance of certain traits in pea plants. He was born in the family of farmers in Hyncice (Heinzendorf bei Odrau) in the Czech Republic (at that era part of Austrian–Hungary empire). The most significant contribution of Mendel for science was his discovery of genetic laws which showed that the inheritance of these traits follows particular laws (published in [1]), which were later named after him. All his discoveries were done in Abbey of St. Thomas in Brno city. Mendel published his research at two meetings of the Natural History Society of Brünn in Moravia (eastern part of the Czech Republic) in 1865 [1]. When Mendel's paper was published in 1866 in Proceedings of the Natural History Society of Brünn, it had surprisingly little impact and was cited only about three times over the next 35 years. The significance of Mendel's work was not recognized until the turn of the 20th century. Its rediscovery (thanks to Hugo de Vries, Carl Correns and Erich von Tschermak) prompted the foundation of the discipline of genetics. Very peculiar historical fact about Mendel's research is also that his letters about his discovery, sent to many of scientific societies, have been found after many years in their libraries unopened. Mendel died on January 6, 1884, at age 61, soon after his death the succeeding abbot burned all papers in Mendel's collection, to mark an end to the disputes over taxation [2].

The other important (and better known – therefore here only briefly introduced) researcher whose discoveries found the theory of evolution was the British scientist Charles Darwin. Darwin published [3] the main ideas of the evolutionary theory in his work. The full and original title was "*On the Origin of Species by Means of Natural Selection,*

* Correspondence address: Department of Computer Science Faculty of Electrical Engineering and Computer Science, VSB-Technical University of Ostrava, Czech Republic.
E-mail address: ivan.zelinka@vsb.cz

http://dx.doi.org/10.1016/j.swevo.2015.06.002
2210-6502/

or the Preservation of Favored Races in the Struggle for Life". The word "*races*" refers to biological varieties. The title has been changed to [3] for the 6th edition in 1872. In Darwin's book On the Origin of Species (1859) he established evolutionary descent with modification as the dominant scientific explanation of diversification in the nature.

The above-mentioned ideas of genetics and evolution have been formulated long before the first computer experiments with evolutionary principles have been done. Officially the beginning of the EAs is dated to the 1970s of the 20th century, when famous genetic algorithms were introduced by Holland [4,5] or to the late 1960s with evolutionary strategies, introduced by Schwefel [6] and Rechenberg [7] and evolutionary programming by Fogel [8].

However, when certain historical facts are taken into consideration, then one can see that the main principles and ideas of SEA as well as their computer simulations had been done earlier than mentioned above. Conceptionally, SEA can be traced back to the famous British mathematician and scientist Turing and first numerical experiments (based on Turing ideas) to the (far less famous) Barricelli and others later on. Their understanding and formulation of basic ideas of ECT was remarkably clear and in full coincidence with modern understanding of EAs, see e.g. Turing in his essay "Intelligent machinery" (1948) [9] where he introduced the modern concept of EAs, for more see [26].

One of the first researchers who transformed Turing's ideas into real computer numerical experiments was N. Barricelli [10,11]. Results of his experiments were published in the journal "*Methodos*" with the title "*Esempi Numerici di processi di evoluzione*" and consequently repeated and improved in 1962 [12] when EAs numerical experiment with 500 of 8 bits strings was successfully done.

Barricelli's early computer-assisted experiments, which were focused on symbiogenesis and evolution (based on Darwin's ideas), can be accepted as pioneering experiments in artificial life and EAs research. Barricelli was working in the Institute for Advanced Study in Princeton, NJ, in 1953, 1954 and 1956. Later he worked at the University of California, LA, at Vanderbilt University, in the Department of Genetics of the University of Washington, Seattle, and then at the Mathematics Institute of the University of Oslo. Barricelli's experiments are probably some of the first historically recorded numerical EAs experiments. Another interesting tread of EA's prehistory are the works of Box [13] and Friedberg [14].

Although many of the original papers are meanwhile hardly accessible, it is in particular thanks to D.B. Fogel (son of evolutionary programming pioneer Fogel), who edited some of these works [16] and recollected some technical details and implications [15,17], that this early history of EAs can now be rediscovered. However, in some respect all these works were slightly ahead of time, as the results have clearly shown the potential of EAs methods, but lack of computing power at that time prevented solving "real problems" and hence to widespread the methods.

So the "golden era" of EAs began when original genetic algorithms were introduced by researchers like Holland [4], evolutionary strategies, by Schwefel [6] and Rechenberg [7] and evolutionary programming by Fogel [8]. Since that time other successful algorithms using SEA ideas have been developed, for instance scatter search (SS) [110], particle swarm optimization (PSO) [30,29], memetics algorithms (MA) [111], differential evolution (DE) [50], ant colony optimization (ACO) [112], self-organizing-migrating algorithms (SOMA) [52], and many others. History of SEA is of course more rich and complex than described here. For more detailed information see [26].

Later on, in [88,27,28,30] were published first pioneering papers focused on swarm algorithms and Lozi map [86,87], that become independent class of very powerful class of algorithms that are able to solve usually very hard problems. The most popular and widespread swarm algorithms are ACO, PSO, bee colony algorithm (BCA), bat algorithm (BA), SOMA for example. As reported in [43,42] SEA were used successfully on various tasks like traveling salesman or synthesis of structures [105] among the others. Swarm based algorithms can be also used in art creation, as reported in [31,32] (Swarmic Paintings and Colour Attention), or music synthesis [33] or swarm robotics [40,41] among the others.

Swarm as well as classical evolutionary algorithms have also their own visionary who had exactly predicted swarm principles and their possibilities in robotics and problem solution long time before first genetic algorithms were introduced. This "prediction" were done by famous Polish futurologist Stanislaw Lem in his novel "The Invincible" (Niezwyciezony) that describes principles of swarm based systems and consequent emergence effect in extremely high scientific correlation with today's scientific knowledge about swarm intelligence and robotics. Later this idea was repeated in novel Prey (2002), by Michael Crichton that deals with the danger of nanobots escaping from human control and developing swarm intelligence.

Based on SEA principles it can be stated that all swarm systems [42], thanks to mutual and intensive interaction between individuals and information processing inside swarm, whose communication structure needs not to be simple, exhibit qualitative and quantitative effects on "macro" level of their dynamics that belong to the emergence and self-organization domain. Such systems [34–36] usually exhibit not only cosmetic effects like nice swarm patterns and clouds that are formed in the space of possible solutions (or in our real space), but mainly the ability to solve usually hard problems and exhibit qualitative jumps in solution search, which is caused by sophisticated information processing inside swarm, that we very simply mimic in SEA. This is also observable with biological systems that inspired the first swarm based algorithms (and are still inspiring). Similar trend can be also observed in social and economical systems and its use to solve hard problems by inspiring their dynamics (gamesourcing [133,134]) or direct use in the so-called crowdsourcing.[1,2]

The aim of this paper is to discuss mutual intersections with chaotic dynamics in algorithm dynamics visualization, analysis, control and applications. Thus, the paper can be divided into two parts.

In the first part of this paper a possible novel way on how to visualize, analyze and control dynamics of (here only selected) SEA is discussed and in the second part there are possible applications/interSections of SEA with strongly nonlinear (often exhibiting chaotic dynamics) systems.

In the application part mainly applications such as deterministic chaos control, performance of selected algorithms improvement with chaotic dynamics use as well as synthesis of chaotic systems are mentioned. The mutual intersection between SEA and chaotic dynamics is not a random coincidence. It is obvious that algorithm inspired by biological systems will less or more reflect also their dynamics (even simplified) [37–39] and vice versa, SEA soon or later (that already happened) will be used to optimize, control and synthesize real dynamical systems. In fact, this is logical consequence of fact that our world is dominantly full of nonlinear systems, then it is very likely that nonlinear and complex systems will be solved by SEA and also is observable in the SEA.

During last two decades strong progress in research of both parts of science (i.e. SEA and chaos) has been done and the number of interdisciplinary research papers increased. Due to the fact that just the mentioned topics are quite wide and each of them would deserve independent article (i.e. this paper does not provide enough space here) only main ideas and results are reported here, with full references to original papers, that contain full and detail report of experiments mentioned in this survey paper.

[1] http://www.galaxyzoo.org/

[2] https://www.zooniverse.org/project/cellslider