New progresses in swarm intelligence-based computation

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Abstract: Nature is a great and immense source of inspiration for solving complex problems in the real world. The well-known examples in nature for swarms are bird flocks, fish schools and the colony of social insects. Birds, ants, bees, fireflies, bats, and pigeons are all bringing us various inspirations for swarm intelligence. In 1990s, swarm intelligence algorithms based on ant colony have highly attracted the interest of researchers. During the past two decades, several new algorithms have been developed depending on different intelligent behaviours of natural swarms. This review presents a comprehensive survey of swarm intelligence-based computation algorithms, which are ant colony optimisation, particle swarm optimisation, artificial bee colony, firefly algorithm, bat algorithm, and pigeon inspired optimisation. Future orientations are also discussed thoroughly.

Keywords: swarm intelligence; SI; bio-inspired computation; ant colony optimisation; ACO; particle swarm optimisation; PSO; artificial bee colony; ABC; firefly algorithm; FA; bat algorithm; BA; pigeon inspired optimisation; PIO.

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1 Introduction

The incredible creativity of nature is an immense source of inspiration for solving real world problems. These complex problems are similar to the difficulties nature has encountered, thus the connection between these two fields is close and strong. Bio-inspired computation is roughly defined as the use of computers to model the internal mechanism of biological phenomena, and study from intelligent colony to improve the usage of computing. Swarm intelligence (SI)-based computation is an important branch of bio-inspired computation, and it mainly focus on the collective behaviour of decentralised, self-organised systems.

The history of bio-inspired computation and SI has spanned over half a century. Trace back to the emergence of evolutionary strategies in the 1960s and the development of genetic algorithms (GAs) in the 1970s. The period of the 1990s witnessed the rapid development of modern bio-inspired computation and SI. With the fast development of the SI, various SI-based computation algorithms have been presented in the past 20 years.

SI can be briefly defined as the group of natural metaheuristics inspired by the collective behaviour of decentralised and self-organised swarms. SI generally models the collective intelligence mechanism in swarms of social insects, birds or other animals. The collective intelligence of swarms is mainly based on the information exchange between each individual in the group. The environmental impact is also taken into account in swarm's interaction (Yang, 2011c). Examples of such intelligence can be observed in group of ants, birds, bees, fireflies, bats, pigeons, etc. Typically, ants interact with each other through chemical pheromone trails to find the shortest path from their nest to food sources. In the bee colony, the scouts provide information to the other individual bees, and the employed bees are organised to search for the food sources.

Many SI-based computation algorithms that simulate the natural swarm models have been invented to solve all sorts of problems. The monograph (Bonabeau et al., 1999) introduced the developments and applications of SI algorithms for solving numerous optimisation problems. After two decades of burgeoning development, many SI-based computation algorithms have been presented. These algorithms mainly include ant colony optimisation (ACO) by Dorigo (1992), particle swarm optimisation (PSO) by Kennedy and Eberhart (1995), artificial bee colony (ABC) algorithm by Basturk and Karaboga (2006), etc. Some novel SI-based computation algorithms are also emerging subsequently, including firefly algorithm (FA) (Yang, 2008), bat algorithm (BA) (Yang, 2010b) and pigeon inspired optimisation (PIO) (Duan and Qiao, 2014).

SI-based approaches related to different optimisation problems have been studied, and several new variants have been described and applied to solve real world problems in different areas (Parpinelli and Lopes, 2011). Many literatures focus on solving difficult problems, covering various areas including computer networks, security, robotics, biomedical engineering, control systems, parallel processing, data mining, power systems, and production engineering. Moreover, theoretical analysis, modifications and combinations of SI-based computation algorithms have been presented according to their different in-born characteristics. The parameter setting of these SI-based computation algorithms has also been studied by developers for better performance (Eiben and Smit, 2011).

In this paper, we survey and compare different aspects of SI-based computation algorithms, and the challenges are summarised systematically. The remainder of this paper is organised as follows: SI-based computation algorithms are overviewed in Section 2. In Section 3, PSO, ABC, FA, BA and PIO are introduced. Section 4 discusses some future research issues. Finally, and our conclusions are presented in Section 5.

2 Overview of SI-based computation algorithms

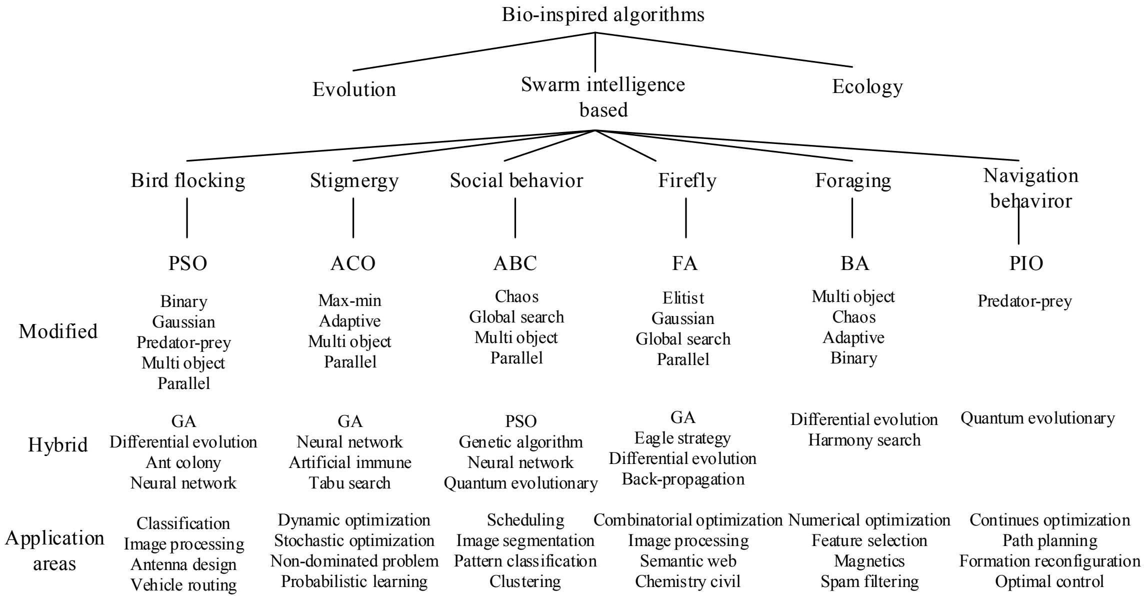
This survey attempts to categorise and introduce the works in the field of SI-based computation algorithms. Typical SI-based computation algorithms including ACO, PSO, ABC, FA, BA, and PIO are analysed, and their characteristics are shown in Table 1. These algorithms have different operators and control parameters. However, the basic operations of SI-based computation algorithms generally include initialisation, update, evaluation and selection.

The modification, hybridisation, and application areas of these algorithms are discussed according to Figure 1. The modifications of these SI-based computation algorithms are based on the methods of binary, Gaussian, predator-prey, adaptive, parallel and chaos. Furthermore, various hybrid algorithms have been presented based on these typical algorithms and other evolutionary algorithms, such as differential evolution (DE) and GA. The areas where these algorithms have been successfully applied include classification, image processing, path planning, spam filtering, chemistry, and clustering.

Table 1 Characteristics of SI-based computation algorithms

SI-based computation algorithm	*Operators*	*Inventor(s)*	*Control parameters*
ACO	Pheromone update, pheromone measure, and trail evaporation	Colorni et al. (1991)	Number of ants, iterations, pheromone evaporation rate, amount of reinforcement
PSO	Initialiser, updater and evaluator.	Kennedy and Eberhart (1995)	Number of particles, dimension of particles, range of particles, Vmax, learning factors, inertia weight, maximum number of iterations
ABC	Reproduction, replacement of bee, and selection	Teodorovic and Dell'Orco (2005), Karaboga (2005)	Number of employed and onlooker bees, the value of limit, the maximum cycle number
FA	Initialiser, attractiveness updater, and evaluator	Yang (2008)	Number of fireflies, randomisation parameter, attractiveness, absorption coefficient
BA	Initialiser, local search operator, and evaluator	Yang (2010b)	Number of bats, loudness and rate, loudness update parameters
PIO	Map and compass, landmark	Duan and Qiao (2014)	Number of pigeons, number of iterations for two operators, map and compass factor

Figure 1 Taxonomy of SI-based computation algorithms



SI has attracted more and more attention from both academia and industry, and a substantial corpus of exact applications and theoretical results is becoming available.

3 Typical SI-based computation algorithms

3.1 Ant colony optimisation

In analogy to the biological example, ACO is based on the indirect information exchange within a colony of ants, mediated by pheromone trails. Since 1991, different ACO algorithms have been introduced. The original of such an ant optimisation algorithm is the ant system (AS) (Colorni et al., 1991), which was presented for solving the well-known travelling salesman problem (TSP). ACO algorithm became popular after Dorigo's works were standardised in IEEE (Dorigo et al., 1996; Dorigo and Gambardella, 1997; Dorigo and DiCaro, 1999). The heuristic of ACO provides an extendable framework for the later applications and algorithmic variants. Along with some developments, Dorigo's monograph (Dorigo and Stützle, 2004) and survey paper (Dorigo and Blum, 2005) on ACO have been frequently cited. ACO has been applied extensively in many NP-hard problems such as the job-shop scheduling problem (JSP), the vehicle routing problem (VRP), the graph colouring problem (GCP), and the quadratic assignment problem (QAP).

In ACO, ants are initialised randomly for the food source around the nest. An ant encountering a previously laid trail can detect the concentration of artificial pheromone trails. An ant's movement is observed by the neighbouring ants based on the pheromone intensity. The larger amount of the pheromone is, the higher probability that an ant selects the path. At last, the ant colony collectively marks a shortest path.

After some initial works, researchers tried to carry on further theoretical analysis by building theoretical foundations. Gutjahr (2000) presented the first convergence proof for an ACO algorithm called graph-based ant system (GBAS). The convergence of basic ant colony system and MAX-MIN AS has also been proved (Dorigo and Stützle, 2004). Convergence proofs give insight into mathematically relevant properties of algorithms. Researches devoted to ACO theory mainly focus on establishing formal links between ACO and other techniques, such as the fields of optimal control, reinforcement learning and fuzzy Q-learning (Juang and Lu, 2009). A better understanding of the theoretical properties of ACO algorithm is still an important research direction.

By adjusting the search direction and following the changes of the problem, ACO algorithms have been applied to different optimisation problems, such as parameter selection in time-delay embedding (Shen et al., 2013), planar antennas design problem (Shahpari et al., 2014), and electrical load pattern clustering (Chicco et al., 2013). Other applications include portfolio optimisation and the QAP has also been presented. A number of hybrid algorithms based on ACO have been proposed by many researchers (Dorigo and Stützle, 2010). It is observed that these hybrid algorithms perform better than any of the individual algorithms in terms of efficiency and validity. ACO algorithms have shown their greatest advantages and they will be systematically applied to new problems.

3.2 Particle swarm optimisation

PSO is based on the swarming behaviour of particles searching for food in a collaborative manner. The original model of PSO was formulated based on the social and cognitive behaviour by Kennedy and Eberhart (1995). PSO simulates behaviour among bird individuals (particles) flying through a multi-dimensional search space and using memories to update their velocities and positions to find best solution. The basic idea of PSO is essentially aimed at producing computational intelligence by exploiting simple analogues of social interaction. PSO has been applied to solve various complex optimisation problems, such as image and video analysis, power generation, scheduling, neural networks, and fuzzy systems.

The most advantage of PSO is its algorithmic simplicity because it uses a relatively few parameters. The basic PSO just has two learning factors need to be decided. PSO can often achieve nearly optimal solutions with a fast convergence speed. While PSO usually fails to adjust the velocity step size in the search space, which often leads to premature convergence. As researchers have learned more about evolutionary computation and SI, new versions, new applications, and theoretical analysis of PSO have been invented.

Various PSO models have been presented in recent years. Duan and Liu (2010) developed a chaotic PSO which replaces the convergence parameters like w, c_1, c_2, r_1, r_2 with chaotic operators and applied it to multiple UAVs formation control. Sun et al. (2012) proposed a quantum-behaved particle swarm optimisation (QPSO) algorithm to solve a cluster problem related to gene expression database. Yang et al. (2014) described a modified binary PSO, in which a different transfer function and a new position updating procedure are adopted to solve the task allocation problem in a wireless sensor network. Ghamisi et al. (2014) derived a fractional-order Darwinian PSO, which has been favourably compared on the multilevel image segmentation problem. Kibria et al. (2014) presented a modified ramped convergence PSO and applied it to radio frequency identification devices (RFID) reader antenna design.

Several hybrid algorithms have been presented by suitably combining PSO with ACO (Holden and Freitas, 2005), DE (Xu et al., 2010b), GA (Duan et al., 2013), and bacterial chemotaxis algorithm (Laudani et al., 2014).

3.3 Artificial bee colony

ABC algorithm was originally presented by Karaboga and Basturk (2007), and it has become popular after a sequence of publications (Karaboga and Basturk, 2008; Karaboga and Akay, 2009). In nature, waggle dance of the bees deliver detailed information about the food sources such as distance and direction. Through this information exchanging and learning mechanism, the whole colony would always find relatively prominent nectar source. The ABC algorithm mimics the collective foraging behaviour of honey bees on searching food source. Compared with the other SI inspired computation algorithms, the prominent advantage of ABC algorithm is that it combines global search and local search in each iteration. As a result, it has been proved that ABC has a better performance in solving optimisation problem. The ABC algorithm has been widely used in data clustering, signal processing, neural networks training, economic dispatch, path planning, multi-formation reconfiguration and multi-vehicle coordination problems, etc.

In order to accommodate the different optimisation problems, various improved ABC models have been presented. The modifications of ABC for tackling continuous, combinatorial, constrained, multi-objective, and large-scale optimisation problems lead to many engineering applications. Akay and Karaboga (2012) introduced modified versions of ABC algorithm and applied them for efficiently solving real-parameter optimisation problems. The modification is often related to the ratio of variance operator and the frequency of perturbation. Wu et al. (2012) presented an improved ABC algorithm to enhance the global search ability of basic ABC. Singh (2009) extended ABC algorithm for solving a constrained optimisation problem in graphics. Pan et al. (2011) presented a discrete version of ABC for the lot-streaming flow shop scheduling problem. Omkar et al. (2011) introduced a generic method/model based on the ABC for multi-objective design optimisation. Zhang et al. (2014a) improved a modified ABC algorithm by changing the employed bee stage and onlooker bee stage to promote the convergence rate. Xu et al. (2010a) described a chaotic ABC approach and applied this algorithm for path planning of uninhabited combat air vehicle (UCAV) in various combat fields.

ABC has also been combined with some traditional SI algorithms. Duan et al. (2010a) introduced a hybrid quantum evolutionary algorithm based on ABC for solving continuous optimisation problems. Shi et al. (2010) proposed a novel hybrid ABC and PSO algorithm. Ganesh Kumar et al. (2014) presented a hybrid approach combining ABC with ACO to solve the fuzzy expert system classification problem.

3.4 Firefly algorithm

FA is a novel SI-based computation algorithm presented by Yang (2008), and it has been applied to many optimisation and engineering problems. FA is inspired by the main characteristic of fireflies: flashing lights. These lights are used to attract mating partners and to warn potential predators. The light intensity decreases as the distance between fireflies increases according to a physical rule, and the firefly acts as an oscillator that charges and discharges the light at regular intervals. The flashing light behaviour for developing the algorithm is closely connected to the two features of SI: self-organisation and decentralised decision-making.

In FA, the population of fireflies is initialised randomly, and the initial value of the randomisation parameter is modified by an exponential function. The quality of the solution is evaluated by implementing a fitness function. The population of fireflies is sorted according to their fitness values, and the best individual in population is selected. Finally, a movement of the firefly positions in the search space is performed based on the more attractive individuals (Yang, 2010a).

The original FA has been modified or hybridised to solve different optimisation problems. Some complex optimisation problems related to different areas have been successfully solved by using the basic FA and its variants. Two important issues: the variation of light intensity and the formulation of attractiveness enable developers to tailor different FAs. Fister et al. (2013) modified the random movement of the brightest firefly by decreasing its brightness in case that the current best position does not improve. Palit et al. (2011) adopted the Merkle-Hellman knapsack cipher algorithm to construct a binary FA for cryptanalysis in order to solve the cipher text problem. Farahani et al. (2011) proposed an accelerated FA that increases convergence speed by using Gaussian distribution to attract all fireflies to the global best position in each iteration. Marichelvam et al. (2014) presented a discrete FA to solve hybrid flowshop scheduling problems.

Some hybrid FA models can improve the effectiveness when solving the special problems. Abdullah et al. (2012) proposed a hybrid evolutionary firefly algorithm (HEFA) that combined the classical FA with DE to enhance the local search. Nandy et al. (2012) combined the firefly meta-heuristic with back-propagation algorithm to achieve a faster convergence rate in training a feed-forward neural network. Huang et al. (2013) proposed a hybrid FA by mimicking a bionic random process, and applied it to solve the decision-making problem in underground cable transmission systems.

FA has been used to solve unconstrained stochastic functions and applied to solve the pressure vessel design optimisation. Applications of FAs are very diverse, and it would be more fruitful to be applied in areas such as: machine learning, bioinformatics, scheduling and assignment, image processing, and large-scale applications. On the other hand, it also encourages new researchers and algorithm developers to use this simple and efficient mechanism for creating new algorithms.

3.5 Bat algorithm

In recent years, some novel metaheuristic algorithms have been proposed. Such algorithms can increase the computational efficiency, solve larger problems, and implement robust optimisation codes. Yang (2010b) recently developed a bat-inspired metaheuristic algorithm, namely BA, which is based on the echolocation characteristics of microbats. The BA has three idealised rules: bats use echolocation to sense distance, bats fly randomly and adjust the wavelength depending on the proximity of their target, and the loudness of bat varies from a large value to a minimum constant value.

Preliminary studies show that BA can have superior performance over GAs and PSO (Yang and Gandomi, 2012), and it can be applied to solve real world and engineering optimisation problems (Gandomi et al., 2013). BA is a very promising algorithm according to its implementation and comparison. The primary reason may be that BA uses a nice combination of major advantages of classical algorithms in the formulation. BA has been validated through several benchmark engineering optimisation problems, and it is found that it is very efficient (Tsai et al., 2012). Yang (2011b) also proposed multi-objective bat algorithm (MOBA) to solve multi-objective optimisation problems, such as welded beam design. BA has come into a wider use in many fields, such as numerical optimisation (Wang and Guo, 2013), feature selection (Nakamura et al., 2012), magnetics (Bora et al., 2012), spam filtering (Natarajan et al., 2012), and constrained dynamic environmental dispatch (Niknam et al., 2013).

3.6 Pigeon inspired optimisation

Recently, inspired by the homing behaviours of pigeons, a novel bio-inspired SI algorithm: pigeon inspired optimisation (PIO) (Duan and Qiao, 2014) has been proposed. Pigeon is a kind of common and wise bird and it is widely used in the military and civil society for their homing behaviour. Pigeons have the special homing ability by using a combination navigation method based on the sun position, the earth's magnetic field and landmarks. Guilford et al. (2004) found that pigeons probably use different navigational tools during different parts of their journey. A mathematical model has been developed by Guilford et al. (2004), which reveals how pigeons swap the navigation techniques. In this newly introduced algorithm, map and search model is constructed based on the homing pigeons' navigation mechanism, which is related to magnetic field, sun and landmarks.

Two operators in PIO: map and compass operator and landmark operator are designed to idealise the homing characteristics of pigeons. In the map and compass operator, the position and the velocity of pigeon are updated according to the map and compass factor. The global best position's information can be exchanged by comparing all the positions among all the pigeons through this operator. Each pigeon can adjust its flying direction by following the global best pigeon's position. In the landmark operator, the pigeons' positions will be updated based on the landmarks in order to fly straight to the destination. For each individual pigeon, the optimal position can be guaranteed through this update rule after the iteration.

PIO can be implemented in various ways by changing some parameters, and some modifications have been presented to improve its performance. Predator-prey pigeon inspired optimisation (PPPIO) is proposed to solve the three-dimensional path planning and PID controller design problem (Zhang and Duan, 2014a; Sun and Duan, 2014). A novel bloch quantum-behaved pigeon inspired optimisation (BQPIO) is presented by combining the basic PIO with quantum theory (Li and Duan, 2014).

PIO algorithm has been successfully applied to solving air robot path planning problem and its feasibility and effectiveness has been investigated by conducting some comparative experiments (Hao et al., 2014). Zhang and Duan, (2014b) also combined PIO with control parameterisation and time discretisation (CPTD) method to solve multiple UAVs formation reconfiguration problem. As a newly proposed SI-based computation algorithm, PIO is very promising in solving complicated optimisation problems.

4 Hot issues and future work

The field of SI is relatively young, fascinating, and emerging with new concepts and applications. With the expanding area of SI, traditional and novel SI-based computation algorithms have been applied to various optimisation problems. However, there are some important and essential topics need to be further investigated.

4.1 Complex optimisation problems and applications

Nowadays, many researchers are applying SI-based computation algorithms to solve various optimisation problems. Problems from the following domains have been successfully solved: continuous optimisation, combinatorial optimisation, and constraint optimisation. These problems are widely exist in computer networks, control systems, bioinformatics, data mining, game theory, biometrics, image processing, parallel computing, robotics, economics and finance, network system design, forecasting problems, etc. Generally, some existing or newly proposed SI-based computation algorithms can be combined with traditional methods to carry out the optimisation problems. Various studies have revealed that the usage of SI-based computation algorithms to solve some complex optimisation problems is very suitable (Rubio-Largo et al., 2012). However, only a few works concern complicated problems that include dynamic and stochastic aspects as well as noisy environments. The study of how to appropriately apply these algorithms to complex and difficult problems will certainly be one of the major research problems in the future.

Recently, increasing attention is given to even more challenging problems. Researches on SI-based computation algorithms are concerned with new applications. More extensive comparison studies with test functions in higher dimensions will pose more challenges to SI-based computation algorithms (Jia et al., 2014). Further research can also emphasise the performance comparison of these algorithms with other popular methods for different optimisation problems (Xu et al., 2012). We should investigate that in which particular problem the usage of SI is especially advisable.

In real world, complex optimisation problems have to be carried out with diverse and stringent constrains, while the major constrain handling in SI-based computation algorithms is far from perfect. In order to solve different optimisation problems, SI-based computation algorithms require to be specifically designed, including encoding scheme, search operators, and set of parameters (Chetty and Adewumi, 2014). Therefore, for different optimisation problems the design process of the algorithm should be theoretically analysed before the simulation and implementation.

As we have reviewed, current works on swarm inspired algorithm are mainly focus on algorithmic and application aspects, it should be mentioned that theoretical studies can greatly promote the development of the algorithms. Generally, different problems (fitness function) have different impacts on the dynamics of an algorithm. Some research have been conducted to find out on which classes of problems a particular algorithm should be expected to provide good or bad performance. The fitness landscapes and dynamics of an algorithm related to different optimisation problems is a very attractive theoretical research topic.

4.2 Theoretical analysis

The convergence analysis of SI-based computation algorithms is primary, and a better theoretical framework is also required. As shown in several studies, a mathematical model of such general framework for theoretical analysis is difficult to establish. Convergence proofs of most existing SI-based computation algorithms have not been conducted systematically, which limits their further applications.

When an algorithm is applied to solve a new problem, investigations on determining all possible configurations and select the best option is important. On the other hand, some existing results suggest that more studies should be conducted to analyse the sensitivity of SI-based computation algorithms (Li et al., 2013). More research should be dedicated to studying the details of dynamics in SI-based computation algorithms (Hu et al., 2013). Fortunately, various studies started to propose a feasible measure for comparing algorithm performance.

Obviously, more comparison studies are highly needed to identify the strength and weakness of current metaheuristic algorithms. Furthermore, many algorithms internally need very high number of iterations to achieve reasonable results. Therefore, it is necessary to develop a standard complexity analysis model. For example, ACO has been demonstrated as a well-established heuristic. The complexity analysis of the ACO in solving dynamic, stochastic, and multiple objective problems remains incomplete. The study of applying ACO to such variations will certainly be one of the major research directions in the near future (Dorigo and Stützle, 2010). When promoting the real world application of ACO, a better understanding of ACO algorithm is a challenging direction.

Despite the rapid developments of applications, theoretical analysis of SI-based computation algorithm is relatively weak. Theoretical analysis can help us understand the mechanisms of SI-based computation algorithms in-depth. Stability and convergence analysis of SI-based computation algorithms are useful for further developments. Some studies have intended to address the theoretical and mathematical analysis of recently presented algorithms (Xiao and Chen, 2013). However, many algorithms still remain to be further analysed.

Further analysis of the parallel and distributed implementation of SI-based computation algorithms is very important. Since most of the algorithms relay or could be implemented with the information network of individuals, it is obvious that highly distributed architectures may be created. The theoretical analytic expressions of an algorithm could determine whether the parallelisation and distribution is efficient for its architecture.

4.3 Internal principles of SI

More and more SI-based computation algorithms have been invented recently. In particular, there are great opportunities to explore a new algorithm based on an unusual SI model. Although some algorithms have achieved great success, it is clear that some modifications to the original structure are still necessary to significantly improve their performance (de Oca et al., 2011). Some SI-based computation algorithms have obvious drawbacks. If an algorithm does not use an operator like crossover as employed in GA and DE, the distribution of profitable solutions is not at a good level. This results in remarkable differences in the quality of the solutions between the swarm proposals and the standard GA. Moreover, the convergence rate of some algorithms should be further improved.

The SI-based searching mechanism with an effective population initialisation and an adaptive search strategy is helpful to perform exploration for promising solutions (Pehlivanoglu, 2013). Some algorithms, such as BA, FA and PIO are good SI frameworks into which different traditional or modern heuristic algorithmic components can be integrated. Hybridisation between SI-based computation algorithms and other computation methods may be fruitful.

The main biological insight of present algorithms is using simple and effective mechanisms to obtain complex and adaptive systems. Generally, the SI-based computation algorithms have some disadvantages related to the local prematurity of the individuals, which leads to local optimum. In fact, individuals in some SI-based computation algorithms act in a purely reactive way and do not have any explicit knowledge about the actions of the other entities. This feature obviously exists in ACO. This problem has been solved partly by combining different methods that introduce the global perspective.

Investigation of the SI principles is also a key issue, which includes convergence, quality, diversity, stability, and adaptability. The coordinative mechanism in individuals' decision-making should be further developed by investigating new and better interactive swarm behaviour models (Yang and Cui, 2014). What is more, there is a need to develop truly intelligent algorithms with more powerful generation, self-regulating, self-evolving, and truly intelligence.

4.4 SI inspired hardware and network

In recent years, many researchers suggest the establishment of a new field called SI inspired hardware, which refers to hardware that can change dynamically and autonomously by interacting with the environment. Adaptive ACO based hardware has made great progress in the past years, but there still has some fundamental and interesting issues need to be further investigated. In most SI-based computation algorithms, the computational resources are allocated to a set of relatively simple agents. These agents exploit a form of indirect communication mediated by the environment to find an optimal solution (Duan et al., 2010b). Therefore, the typical challenges for the SI-based hardware can be generalised as: online realisation, robustness, generalisation, disaster problems, and implementation.

Comparing current artificial systems with those found in nature, there is a need to devise a sophisticated scheme, involving a set of comparison criteria and measures. Distributed system design can be improved with a combination of multi-agent theory and SI (Suri et al., 2013). SI models and structures can be an immense source for improving hardware systems. SI inspired hardware systems is becoming a reality, and it will be endowed with evolutionary, reproductive, regenerative, and learning capabilities. The availability of these systems opens long-term opportunities for the applications able to take profit of evolution, development, self-replication, and self-repair.

With increasing complexity, difficulties in the configuration and management of large-scale networks constantly appear. Recently, the artificial self-organised networking systems inspired by SI have caught much attention for their good flexibility and robustness (Kim et al., 2013). A combination of SI and network technology consequently leads to the development of complex and heterogeneous networks. Self-organisation, existing in many swarm groups, has brought remarkable benefits in terms of cost reduction in network configuration.

The essential properties of modern network systems are systematism, complexity, cohesion, nonlinearity, distributed control, sub-optimum, and adaptivity. By associating the network system with collective behaviours in swarm activities, self-organised networks with SI have already exhibited their advantages over other techniques. The existing SI-based computation algorithm has been extended to the optimisation of inter-nodes communications in presence of time delay, link failures and random noise (Di Lorenzo et al., 2012). Compared to the conventional methods, SI-based computation algorithms are based on distributed information sharing, which has a high adaptivity to the complex and dynamic environment.

Some SI-based computation algorithms have already exhibited enormous advantages in improving the network security, robustness, adaptiveness and load balancing capabilities. It shows that the SI inspired mechanism is indeed a powerful source of innovative technique for artificial self-organised networking systems. On the other hand, this field is very young, and there still remain significantly challenging tasks in the emerging artificial network architectures (Zhang et al., 2014b). Some more complicated real world problems need to be further investigated and modelled. Theoretical analysis of SI in constructing a massively distributed network for various environments is also a rather challenging topic.

5 Conclusions

In this paper, we have reviewed the current studies on SI-based computation algorithms, and discussed the main challenges. We believe that SI-based computation algorithms will continue to show their prominent advantages when they are systematically applied to more sophisticated real world problems.

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