Editorial
Special Issue: Swarm Intelligence

THIS special issue contains seven papers describing recent research developments in the swarm intelligence (SI) field. Swarm intelligence is an artificial intelligence technique involving the study of collective behavior in decentralized systems [1]–[3]. Such systems are made up by a population of simple individuals interacting locally with one another and with their environment. Although there is typically no centralized control dictating the behavior of the individuals, local interactions among the individuals often cause a global pattern to emerge. Examples of systems like this can be found abundant in nature, including ant colonies, bird flocking, animal herding, honey bees, bacteria, and many more. SI refers to the problem-solving behavior that emerges from the interaction between individuals of such systems, and computational SI refers to algorithmic models of such behaviors. These algorithmic models have shown to be able to adapt well in changing environments, and are immensely flexible and robust. As traditional algorithms, which emphasize more on centralization, become increasingly inadequate in handling today's more complex problems, SI algorithms offer an attractive alternative to problem-solving. The last decade has shown rapid growing research interests in SI, as demonstrated by the significant increase of the number of research publications on SI, especially on two popular SI paradigms, namely particle swarm optimization (PSO) and ant colony optimization (ACO).

PSO is a population-based stochastic optimization technique modeled on the social behaviors observed in flocking birds. It was originally proposed by James Kennedy and Russell Eberhart in 1995 [4], [5]. Since its inception, PSO has gained increasing popularity among researchers and practitioners as a robust and efficient technique for solving difficult optimization problems. In PSO, individual particles of a swarm represent potential solutions, which move through the problem search space seeking an optimal, or good enough, solution. The particles broadcast their current positions to neighboring particles. The position of each particle is adjusted according to its velocity (i.e., rate of change) and the difference between its current position, respectively, to the best position found by its neighbors and the best position it has found so far. As the model is iterated, the swarm focuses more and more on an area of the search space containing high-quality solutions.

ACO, which was introduced by Marco Dorigo in 1992 [6], is inspired by the food foraging behavior of ant colonies. ACO algorithms are especially effective for problems where the goal is to find the shortest path. Just like real ants dropping chemical pheromone in order to inform other ants, ACO uses this as a means of indirect communication to guide the search toward more promising regions.

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Both PSO and ACO algorithms have been applied to a wide range of optimization problems including scheduling problems, the traveling salesman problem, task assignment, graph coloring problems, vehicle routing problems, etc. In recent years, they are also the popular choices of many researchers for handling multiobjective optimization and dynamic optimization problems.

Swarm robotics is another popular research topic where SI principles are applied to physical robots [7], [8]. Swarm robotics emphasizes studying the emergent behaviors of a large number of mostly simple physical robots. Relatively simple rules governing the interactions among these robots and their environment may produce complex swarm behaviors. It is expected that such SI systems will scale better since only local communications are used. Potential swarm robotics applications may include robots involving a search-and-rescue operation for survivors in a collapsed building, and robots involving mining or foraging tasks.

In the paper "A Swarm Algorithm for a Self-Structured P2P Information System" by Forestiero and Mastroianni, a novel bio-inspired algorithm is developed to resolve the issue of resource organization and discovery in a peer-to-peer (P2P) system in grid environments. Inspired by the behaviors of ants, the proposed algorithm, *Antares* (ANT-based Algorithm for RESource management in Grids), is designed to more effectively disseminate and reorganize resources (or descriptors), thereby facilitating and speeding up resource discovery operations in a dynamically changing environment. The *emergence* of resource organization at the system level is a result of many ant-like agents performing simple operations at the local level. Through a carefully designed simulation study, the authors demonstrate that *Antares* is able to achieve effective information reorganization for a P2P system as the algorithm is *self-structured*. Furthermore, this information reorganization is adaptive to a dynamically changing environment.

Another appplication of ant algorithms can be found in "Using a Local Discovery Ant Algorithm for Bayesian Network Structure Learning" by Pinto *et al*. An ACO algorithm, hybridized with a local heuristic, is applied as a Bayesian network learning algorithm. The local heuristic is used to construct the skeleton of the Bayesian network, while the ACO algorithm is used to orient the edges of the network. It is shown that this ACO-based Bayesian network learning algorithm outperforms greedy search and simulated annealing algorithms.

While simulation study is useful in validating a new SI algorithm, physical implementation of an SI algorithm will pose additional challenges such as the coordination among robots. In the paper "Teamwork in Self-Organized Robot Colonies" by Nouyan *et al.*, an experimental study is carried out using a team of physical robots to perform a foraging task.

This task requires a series of subtasks such as exploring the environment, forming a path, recruitment, self-assembly, and group transport. These robots execute a copy of an identical decentralized control algorithm, and they do not require any explicit knowledge of the environment beyond their local perceptual range. A recovery mechanism proving to be critical for the performance of the system is applied to the subtasks including path formation, self-assembly, and group transport. What sets this paper apart from other similar swarm robotic studies is that it demonstrates compellingly that complex forms of *division of labor* can indeed emerge as a consequence from the interactions among robots following relatively simple and local rules.

In the paper "Self-Organizing Sync in a Robotic Swarm: A Dynamical System View" by Trianni and Nolfi, a systematic study is carried out on self-organizing synchronization in a group of robots based on minimal behavioral and communication strategies. An analysis of the evolutionary behavior of the robot system from a dynamic systems viewpoint is provided. Furthermore, a description of the building blocks necessary to produce synchronized behaviors is presented. The scalability of the self-organizing synchronization is also examined.

In swarm robotic systems, it is important to be able to detect non-operational robots. Such knowledge is important so that mechanisms can be implemented to either repair failed robots or to arrange for other robots to take over the tasks of failed robots. In the paper, "From Fireflies to Fault Tolerant Swarm of Robots" by Christensen *et al.*, the synchronized flashing behavior observed in certain species of fireflies is used to derive a decentralized algorithm to detect non-operational robots in a swarm robotic system. It is shown that this algorithm correctly and timely detects failed robots, and that a swarm robotic system, in a simulation environment where the robots exhibit self-repair capabilities, can survive relatively high failuer rates.

In the paper "Mean and Variance of the Sampling Distribution of Particle Swarm Optimizers during Stagnation" by Poli, a theoretical study on the sampling distribution of particles in a particle swarm optimizer is presented. Most theoretical studies of the dynamics of PSO to date are largely dependent on substantial simplifications and the assumption that particles are deterministic. This has severely limited the usefulness of these studies, since they are far from representative of the true characterization of the sampling distribution of the PSO. This paper for the first time presents a novel method to exactly determine the characteristics of a PSO's sampling distribution, without these unrealistic assumptions. The only assumption made is *stagnation*. Since particles behave independently in stagnation, it is possible to analyze each particle's behavior in isolation. Experimental runs have been carried out which further confirm the accuracy of the proposed model.

In the paper "Using an Ant Colony Metaheuristic to Optimise Automatic Word Segmentation for Ancient Greek" by Tambouratzis, an application of ACO to morphological segmentation of ancient Greek word forms is presented. This task of segmenting words into stems and endings is in particular challenging for highly inflectional languages (e.g., ancient Greek), where each stem may be associated with a large number of different endings. ACO is used here to optimize a set of weights associated with the proposed system AMP (automated morphological processing). The experimental results show that the automated segmentation achieved by ACO is equal to or better than the case where manually tuned weights are adopted.

We received 70 submissions for this special issue. After at least three rounds of rigorous reviews, only seven have been accepted and included in this special issue, representing an acceptance rate of 10.0%. We hope papers included in this special issue will be seen as important contributions to the field of SI in the years to come.

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