Applied Nature Inspired System: Preliminary Investigation

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ABSTRACT: Biological processes and methods have been influencing science and technology for many decades. The ideas of feedback and control processes Norbert Wiener used in his cybernetics were based on observation of these phenomena in biological systems. Artificial intelligence and intelligent systems have been fundamentally interested in the phenomenology of living systems, namely perception, decision-making, action, and learning. Natural systems exhibit many properties that form fundamentals for a number of nature inspired applications – dynamics, flexibility, robustness, self-organisation, simplicity of basic elements, and decentralization. This paper reviews examples of nature inspired software applications, mostly drawing inspiration from collective behaviour of social colonies.

KEYWORDS: nature inspired systems, ant colony optimization, particle swarm optimization, swarm intelligence, artificial immune system

INTRODUCTION

Nature has served as inspiration in a number of different areas of human activity for centuries. In recent decades it has attracted the attention of researchers in computer science, artificial intelligence and related disciplines because most of the modern technological systems that have been and are being developed have become very complex, often distributed, and interconnected to a very high degree. Thus they depend on effective communication; they require high flexibility, adaptability, and ability to cope with changing demands. However, these systems are often designed and constructed as inflexible and centralized. There are several reasons for this approach: need for clear control of the operation of the system (easier in a centralised system than in a distributed one); requirement for an exact specification of what needs to be built on the first place; traditional routinely used way of design. It is obvious that such approach results in a number of technical problems, often due to the failure to adapt to changing circumstances.

When we inspect natural systems more closely, we can find that they are typically characterized by a great degree of complexity, at various levels of description. This complexity means that the behaviour of natural systems may appear unpredictable and imprecise, but at the same time living organisms, and the ecosystems in which they are found, show a substantial degree of resilience. Examples of such resilient systems include social insect colonies, mammalian nervous systems, and temperate woodland communities [1]. This resilience arises from several sources: large number of elements in each system, each of which may be interchangeable for another; loose but flexible interconnections between elements; differences between elements in the system, allowing a diversity of responses to a changing environment; resulting complex environment that all the interacting parts produce, which stimulates diverse responses from living organisms. Natural organisms have proved by their existence that they have the ability to deal with complex and dynamic situations in the world. They adapt to the changing environment by learning during their lifetime (development of an individual) and by evolving over the course of many generations (development of the species).

From these facts it follows that natural systems possess several properties that form fundamentals for many nature inspired applications, namely dynamics, flexibility, robustness, self-organisation, simplicity of basic elements, and decentralisation. Another important aspect of living organisms is that they always live under conditions of limited resources. Therefore they may be subject to disruptions that destroy or damage individuals or even larger populations. But despite some losses, natural systems can frequently recover. Ability to recover comes from diversity of mechanisms – immune system of individuals, or interactions within and between populations. Resource limitation represents one of the selection criteria that ultimately can lead to more effective self-organisation and recovery.

The sources of inspiration for design of both hardware and software systems come from many aspects of natural systems – evolution [2], ecology [3], development [4], cell and molecular phenomena [5], behaviour [6], cognition and neurosystems [7], and other areas. The developed techniques have led to applications in many different areas including networks [8], [9], data mining [10], [11], optimization [12], robotics [13], automatic control [14] , [15], and many others.

NATURE INSPIRED SYSTEMS

Biologically or nature inspired systems, methods and technologies represent a very broad area covering many interesting topics. We can divide them into several groups according to the stage of research and development. First group is composed of methods that are studied theoretically and till now have no practical application. Second group is represented by methods that are subject of applied research or development of laboratory prototypes. Third group consists of methods that are being implemented and tested on artificial and real data. Fourth group is represented by those methods that are already used for solving practical problems.

Before we decided about the focus of our interest we tried to identify a list of topics and keywords that are closely related to the topic of the NiSIS project. Here there is the list of searched keywords:

- adaptive system
- learning system
- nature inspired information system technology
- nature inspired computational paradigms
- developmental morphology
- self-adjusting system
- nature inspired data technology
- nature inspired networks
- nature inspired modelling
- nature inspired optimization
- nature inspired control
- nature inspired monitoring
- nature inspired optimal design
- visualisation of high dimensional data
- visualisation of high dimensional structures
- large scale emergent systems
- artificial immune systems
- swarm intelligence
- swarm robotics
- cellular automata
- cellular mechanisms
- evolvable hardware systems
- immunotronics
- fly-phones
- systems biology
- smart dust
- parsimonious systems
- behaviour of animal colonies (bees, ants) – societies possessing fault and damage tolerance.

Our students (at Czech Technical University in Prague) helped us to perform an Internet search on these topics. We tried to restrict the search because when we used more general keywords, as for example “nature inspired” we got tens of thousands of references in Google. Search for “Ant Colony Optimization” resulted in more than 30000 links. Of course, not all of them were relevant but it was impossible to check them in detail. Therefore after we collected the extensive search results from the students we decided to focus only on those topics that are more mature and have already some practical applications. So we arrived at the following topics: swarm intelligence, ant colony optimization, particle swarm optimization, artificial immune systems, and swarm robotics.

Of course, there are already well developed and well established systems using nature inspired paradigms such as neural networks, genetic algorithms, evolution strategies, and simulated annealing. Since they have been in practical use for many years we will not present them in this paper.

SWARM INTELLIGENCE

Swarm intelligence [16] can be defined as the collective intelligence that emerges from a group (usually a large one) of simple entities, mostly called agents. These entities enter into interactions, sense and change their environment locally. Furthermore, they exhibit complex, emergent behaviour that is robust with respect to the failure of individual entities. Most frequently used agent-based models are ant colonies, flocks of birds, termites, swarms of bees, or fish schools. Some of the developed algorithms are inspired by the biological swarm social behaviour, e.g. the ant colony foraging.

There are two popular swarm inspired methods in computational intelligence areas: Ant colony optimization (ACO) and particle swarm optimization (PSO). ACO was inspired by the behaviours of ants and has many successful applications in discrete optimization problems [17].

The particle swarm concept originated as a simulation of simplified social system. The original intent was to graphically simulate the choreography of a bird flock or fish school. However, it was found that particle swarm model could be used as an optimizer [18].

These algorithms have been already applied to solving problems of clustering, data mining, dynamic task allocation, and optimization.

ANT COLONY OPTIMIZATION

ACO was introduced by Marco Dorigo [19] and his colleagues in the early 1990s. The first computational paradigm appeared under the name Ant System. It is another approach to stochastic combinatorial optimization. The search activities are distributed over “ants” – agents with very simple basic capabilities that mimic the behaviour of real ants. There emerges collective behaviour that has a form of autocatalytic behaviour (positive feedback loop). The more the ants follow a trail, the more attractive that trail becomes for being followed. The main aim was not to simulate ant colonies, but to use artificial ant colonies as an optimization tool. Therefore the system exhibits several differences in comparison to the real (natural) ant colony: artificial ants have some memory; they are not completely blind; they live in an environment with discrete time.

ACO was applied to many optimization problems and nowadays it belongs to the class of metaheuristic algorithms. ACO algorithms are state-of-the-art for combinatorial optimization problems such as open shop scheduling (OSS) [20], quadratic assignment [21], and sequential ordering [22]. They can be found in other types of applications as well.

Since 1995 Dorigo, Gambardella and Stützle have been working on various extended versions of the AS paradigm. Dorigo and Gambardella have proposed Ant Colony System (ACS) [22], while Stützle and Hoos have proposed MAX-MIN Ant System (MMAS) [21]. They have both have been applied to the symmetric and asymmetric travelling salesman problem with excellent results. Dorigo, Gambardella and Stützle have also proposed new hybrid versions of ant colony optimization with local search. In problems like the quadratic assignment problem and the sequential ordering problem these ACO algorithms outperform all known algorithms on vast classes of benchmark problems.

The recent book "Ant Colony Optimization" [23] gives a full overview of the many successful applications of Ant Colony Optimization.

PARTICLE SWARM OPTIMIZATION

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Dr. Eberhart and Dr. Kennedy in 1995 [24], [25], inspired by social behaviour of bird flocking or fish schooling.

PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA). The system is initialized with a population of random solutions, has fitness values, updates the population, and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles. Particles update themselves with the internal velocity. They also have memory, which is important to the algorithm.
Compared to GA, the advantages of PSO are that PSO is easy to implement and there are few parameters to adjust. PSO has been successfully applied in many areas: function optimization, artificial neural network training, fuzzy system control, and other areas where GA can be applied.
Compared with genetic algorithms (GAs), the information sharing mechanism in PSO is significantly different. In GAs, chromosomes share information with each other. So the whole population moves like a one group towards an optimal area. In PSO, only gBest (or lBest) gives out the information to others. It is a one-way information sharing mechanism. The evolution only looks for the best solution. Compared with GA, all the particles tend to converge to the best solution quickly even in the local version in most cases.

SWARM ROBOTICS

Swarm robotics is an emerging field within collective robotics [26]. Large groups of simple robots are used to collectively solve problems that exceed the capabilities of a single robot. The swarm robotics approach is characterized by the application of swarm intelligence techniques to the control of groups of robots, emphasizing principles such as decentralization, local interactions among agents, indirect communication and the use of local information.

ARTIFICIAL IMMUNE SYSTEMS

Artificial Immune System (AIS) is a new intelligent problem solving technique, but until now hundreds of papers in this area have been published. [27] contains a review of more than 500 references in this field. The possible areas of applications are very broad [28]. AIS algorithms were successful used for the detection and characterization of intrusion in computer networks, for the implementation of learning and optimisation, for clustering and the detection of faults and anomaly in complex technological systems. Because this paper should not have a special focus on AIS we will only give a brief introduction and a relevant list. Very interesting for monitoring tasks there are immunity based change detection algorithms. They are inspired by the information-process properties of the natural immune system. Some feature of a natural immune system like uniqueness, learning and memory, novelty detection, and the capacity of a distributed detection, which is very important for very huge systems, could be implemented in AIS. Using immunological principles, different algorithms are developed which are capable of launching a specific response to an anomalous situation for diagnostic purposes [29]. In [30] some experimental results concerning fault detection in an induction motor are presented as an example illustrating how the immune-based system operates, discussing its capabilities, drawbacks and future developments.

APPLICATIONS

As we have already mentioned there have appeared many interesting applications in different areas. In principle all tasks can be viewed as optimization tasks. However, we can divide them into several groups according to the main solved problems, namely optimization (of parameters, topology), state space search (travelling salesman problem, routing in telecommunication networks), data mining and classification (clustering, feature extraction), and data visualization. Let us briefly describe several examples of applications representing the areas of telecommunication networks, data mining, design of digital circuits, optimization, and detection of objects in images.
Emission sources localization [31]. In this application, a biasing expansion swarm approach is used. It is based on swarm behaviour and utilizes its three properties: separation, cohesion and alignment. This approach is applied to multiple simple mobile agents, with limited sensing and communication capabilities. The agents search collaboratively and locate an indeterminate number of emission sources in an unknown large-scale area. Each agent considers all concentration values collected by other swarm members and determines the positive gradient direction of the whole coverage area of the swarm.
Open shop scheduling. In ACO algorithms, artificial ants construct solutions from scratch by probabilistically making a sequence of local decisions. At each construction step an ant chooses exactly one of possibly several ways of extending the current partial solution. The rules that define the solution construction mechanism in ACO implicitly map the search space of the considered problem (including the partial solutions) onto a search tree.

ACO can be combined with tree search methods with the aim to improve methods for solving combinatorial optimization problems. In [20] a combination of ACO and beam search is described. It has been applied to open shop scheduling, which is an NP-hard scheduling problem. The obtained results compared with two best approaches currently available (GA by Prins [32] and Standard-ACO-OSS) show that the Beam-ACO performs better.

Agent Coalition Problem [33]. ACO has been used for finding the optimal, task oriented agent coalition in a multi-agent system. Agent coalition mechanism is an important coordination and cooperation method in MAS. Ants incline to choose those agents who cooperated well before to form coalitions, which realizes the acquaintance mechanism. The novel "inner hormone" can avoid the algorithm getting in the local minimum area easily. It is a robust, self-adaptive and very efficient algorithm.

Communications. A number of applications have appeared quite naturally in the area of communications. There can be identified many optimization tasks. One of them is *routing in mobile ad hoc networks* [34]. Mobile ad hoc networks are wireless mobile networks formed spontaneously. Communication in such a decentralized network typically involves temporary multi-hop relays, with the nodes using each other as the relay routers without any fixed infrastructure. This kind of network is very flexible and suitable for applications such as temporary information sharing in conferences, military actions and disaster rescues. However, multi-hop routing, random movement of mobile nodes and other features lead to enormous overhead for route discovery and maintenance. Furthermore, this problem is worsened by the resource constraints in energy, computational capacities and bandwidth. The developed algorithm is an on-demand multipath routing algorithm, inspired by the foraging intelligence. It incorporates positive feedback, negative feedback and randomness into the routing computation. Positive feedback originates from destination nodes to reinforce the existing pheromone on good paths. The negative feedback is represented by exponential pheromone decay that prevents old routing solutions from remaining in the current network status. Each node maintains a probabilistic routing table.

Ant Based Control in Telecommunication Networks. In [35] the authors propose a new migration scheme for the ant-like mobile agents and a new routing table management scheme. The main objective is to achieve better load balancing. Load balancing in a telecommunication network can provide better utilization of the available resources, which results in better services for the end users. The agents update the routing tables of nodes based on their acquired knowledge (Ant Based Control is a reinforcement learning technique.) In addition to the parameter of the shortest delay, the call capacity of the path is considered. That means if the shortest-delay path becomes congested a new path with less congestion, if it exists, will be chosen.

PSO algorithm in signal detection and blind extraction. In signal processing there are among others two important problems, namely multi-user detection and blind extraction of sources. The optimal multi-user detection is a NP-complete problem. Therefore the research effort has been focused on the development of suboptimum techniques with the aim to achieve a trade-off between complexity and performance. Binary PSO algorithm was used [36] and reached better results than genetic algorithm. Similar results were achieved in blind source separation, which is an important issue in many science and engineering scenarios as well.

Optimization of FPGA placement and routing [37]. FPGAs are becoming increasingly important implementation platforms for digital circuits. One of the necessary requirements to effectively utilize the FPGA's resources is an efficient placement and routing mechanism. Initial FPGA placement and routings generated in a standard way are then optimized by PSO. According to [37] the interconnection lengths between the configurable logic blocks and input/output blocks for a counter and an arithmetic logic unit were minimized.

PSO for Solving Travelling Salesman Problem (TSP) [38]. TSP is a well-known NP-hard problem. Modification of PSO using fuzzy matrices to represent the position and velocity of the particles in PSO was developed. The algorithm can be used for resolving common routing problems and other combinatorial optimization problems.

Discovering clusters in spatial data [39] In this application, each agent represents a simple task and the success of the method depends on the cooperative work of the agents. The algorithm combines a smart exploratory strategy based on the movements of a flock of birds with a shared nearest-neighbour clustering algorithm to discover clusters in parallel. Birds are used as agents with an exploring behaviour foraging for clusters. This strategy can be used as a data reduction technique to perform approximate clustering efficiently.

Combination of ants and cellular automata – application to clustering problem in data mining [40]. Ant Sleeping Model combines advantages of the classical cellular automata model and the swarm intelligence. The ants have two states: sleeping state and active state. The ant's state is controlled by a function of the ant's fitness to the environment it locates and a probability for the ants becoming active. The state of an ant is determined only by its local information. By moving dynamically, the ants form different subgroups adaptively. The algorithm was applied to clustering problem in data mining. Results show that the algorithm is significantly better than other clustering methods in terms of both speed and quality. It is adaptive, robust and efficient, achieving high autonomy, simplicity and efficiency.

PSO for buoys-arrangement design. In [41] PSO deals with constrained multiobjective optimization problems. In this case PSO is modified by using the bidirectional searching strategy to guide each particle to search simultaneously in its neighbourhood and the region where particles are distributed sparsely. Constrained multiobjective optimization problems are very common in engineering applications, such as structural optimization, design of complex hardware/software systems, production scheduling, etc. Buoys-arrangement problem mainly researches on how to design the longitudinal position and buoyancy value of each pair of buoys. It is the main component of submarine salvage engineering.

Classifier Swarms for Human Detection in Infrared Imagery [42]. PSO in combination with feature-based object classification is used for visual recognition of objects in an image. PSO is extended using sequential niching methods to handle multiple minima. Each particle in the swarm is actually a self-contained classifier that “flys” through the solution space seeking the most “object-like” regions. By performing this optimization, the classifier swarm simultaneously finds objects in the scene, determines their size, and optimizes the classifier parameters.

Swarm robotics is currently one of the most important application areas for swarm intelligence. Many different swarm control models have been proposed. Beni [43] introduced the cellular robotics system, which consists of a collection of autonomous robots cooperating under distributed control. Each robot can have limited communication with its neighbour robots to accomplish predefined global tasks. Another approach is inspired by path establishment by pheromone laying [44]. It uses a chain of robots, where the robots themselves act as trail markers. A robotic chain is defined as a sequence of robots, where two neighbouring robots can sense each other and the distance between them never exceeds a certain maximum sensing range. As a sensing element, an omni-directional camera has been used. Using chains has at least two advantages. First, simple rules guide the robots when forming a chain. Second, a robotic chain can establish connections between different locations whose distance is bigger than the perceptual range of one robot. Then all robots can get to the locations simply by navigating along the chain.

PROJECTS, CONFERENCES AND OTHER RESOURCES

The fact that the topics coming from the area of nature inspired systems are becoming more and more attractive and important is reflected in already running international and national projects and in a number of conferences that are focused on these topics. In the following sections we present several examples of currently running or recently finished research projects and recently held conferences and workshops.

EXAMPLES OF RECENT PROJECTS

There have been or are running several interesting larger projects that focus on nature inspired systems or technologies.

Biology-Inspired techniques for Self-Organization in dynamic Networks (BISON) [45]is a three-year Shared-Cost RTD Project (IST-2001-38923) funded by the Future & Emerging Technologies initiative of the Information Society Technologies Programme of the European Commission. The project runs from January 2003 until December 2005. BISON proposes to draw inspiration from biological processes and develop techniques and tools for building robust, self-organizing and self-repairing Network Information Systems (NIS) as ensembles of autonomous agents that mimic the behaviour of social insects and immune networks. What renders this approach particularly attractive from a dynamic network perspective is that global properties like adaptation, self-organization and robustness are achieved without explicitly programming them into the individual artificial agents. Yet, given large enough colonies of agents, the global behaviour is surprisingly adaptive and can cope with arbitrary initial conditions, unforeseen scenarios, and variations in the environment or presence of deviant agents. This represents a radical shift from traditional algorithmic techniques to that of obtaining the desired system properties as a result of emergent behaviour that often involves evolution, adaptation, or learning.

The Complex Systems Network of Excellence, *"Exystence*", [46] is funded by the European Commission within the Future Emerging Technologies (FET) programme of the Information Society Technologies Programme (IST) of the Fifth Framework (IST-2001-32802) to develop collaboration among European researchers interested in Complex Systems, from fundamental concepts to applications, and involving academia, business and industry. The Network started in March 2002 and is funded until September 2005. The complex systems approach differs from multi-agents simulation by a constant search for paradigms complementary to numerical simulations, such as scaling, parameter reduction, simplicity of models, and interpretation of specific results in the light of more general concepts. One of the aims of the Network is not only to establish connections between national communities active in the area of complexity, but also to bridge a gap within the interested community between the existing group of talented theorists mastering very sophisticated formal methods and those concerned with concrete applications in Operational Research.

Swarm-bots [47] is a project sponsored by the Future and Emerging Technologies program of the European Community (IST-2000-31010), aimed to study new approaches to the design and implementation of self-organizing and self-assembling artefacts. The project, that lasted 42 months, was successfully completed on March 31, 2005. It has been selected as one of the success stories of the Future and Emerging Technologies (FET) program of the European Commission. The main scientific objective of the *Swarm-bots* project was to study a novel approach to the design and implementation of self-organising and self-assembling artefacts. This novel approach found its theoretical roots in recent studies in swarm intelligence, that is, in studies of the self-organising and self-assembling capabilities shown by social insects and other animal societies. The main tangible objective of the project was the demonstration of the approach by means of the construction of at least one of such artefact. The intention was to construct a *swarm-bot*. That is, an artefact composed of a number of simpler, insect-like, robots (*s-bots*), built out of relatively cheap components, capable of self-assembling and self-organising to adapt to its environment.

mailto:ecands@ohm.york.ac.uk*Network for Artificial Immune Systems* [48] (funded by the British EPSRC, grant number GR S56627/01). The field of Artificial Immune Systems (AIS) is a new and exciting area of research, whose implications to the design and implementations of systems in the future are manifold. This is not limited to the obvious virus detection in computer systems, but could extend from fault-tolerant hardware design to machine learning. However, to allow this new area to develop and for the UK to continue to lead the world in such activities, a more structured approach is needed to co-ordinate and support researchers in this area. This network is designed to help bolster these researchers in the UK, stimulate and extend the community of AIS practitioners within the UK and provide the necessary infrastructure and financial support for them to pursue further interactions between themselves and international collaborators, in order to drive forward this area of research.

AIBACS: Computational Modelling of Salience Sensitive Control in Humans and in Artificial Systems (EPSRC Grant Reference: GR/S15075/01), [49]. Humans are very good at prioritising competing processing demands. In particular, perception of a salient environmental event can interrupt ongoing processing, causing attention, and accompanying processing resources, to be redirected to the new event. It is also clear that emotions, motivation and physiological state in general, play a key role in such prioritisation. In contrast, artificial systems do less well. Firstly, they are often bad at adjusting their processing to salient events, especially when assessing salience is context dependent. Secondly, when interacting with humans, artificial systems fail to fully utilise salience. Traditionally a big hindrance to constructing systems that are sensitive in this respect is that it was not understood how humans adapted their behaviour according to salience. However, through experimental paradigms such as the attentional blink, modern cognitive psychology and neuroscience is starting to clarify the underlying mechanism. In order to realise this potential there will be provided concrete computational realisations of the mechanisms being revealed. This will firstly, benefit cognitive psychology and neuroscience and secondly, act as a bridge to the construction of artificial systems.

A Novel Computing Architecture for Cognitive Systems based on the Laminar Microcircuitry of the Neocortex (EPSRC Grant Reference: EP/C010841/1), [49]. The neocortex of the brain subserves sensory perception, attention, memory and a spectrum of other perceptual and cognitive functions, which combine to provide the biological system with its outstanding powers. It is clear that the brain carries out information processing in a fundamentally different way to today's conventional computers. The computational architecture of the brain clearly involves the use of highly parallel, asynchronous, nonlinear and adaptive dynamical systems, namely the laminar neural circuits of the neocortex. The fundamental aim of this project is to create a new "brain-inspired" computing architecture, which possesses the basic properties of self-organisation, adaptation and plasticity manifest in the neural circuitry of the neocortex. The objective is a modular architecture based on a representation of a "stereotypical" cortical microcircuit. The project will focus on the laminar microcircuits of the primary visual cortex in order to build on the wealth of neurobiological knowledge concerning the behaviour and interconnectivity of neurons in this area of neocortex. However the wider objective would be to use the laminar microcircuitry of primary visual cortex as an exemplar for a stereotypical neocortically-inspired architecture. This will allow the architecture to be deployed in a wide range of perceptual tasks, and potentially also in cognitive functions such as learning and attention, with minimal changes to the basic circuitry. The aim is not simply to build a detailed, biologically-precise model of primary visual cortex, but rather the challenge is to identify and capture the key fundamental principles and mechanisms that underlie the remarkable and ubiquitous information processing power of the neocortex.

PUBLIC SOFTWARE

There are also several software packages available. Most of them provide implementation of various ACO algorithms. They have been applied to Travelling Salesman Problem or to routing problem.

The Ant_Miner software tool [50] is a data mining classification algorithm that can be used for extraction of classification rules from data.

ACOTSP software package [51] provides an implementation of various Ant Colony Optimization (ACO) algorithms applied to the symmetric Travelling Salesman Problem (TSP). The ACO algorithms implemented are

Ant System, Elitist Ant System, MAX-MIN Ant System, Rank-based version of Ant System, Best-Worst Ant System, and Ant Colony System.
Swarm [52] is a software package for multi-agent simulation of complex systems, originally developed at the Santa Fe Institute. Swarm is intended to be a useful tool for researchers in the study of agent-based models. Swarm software comprises a set of code libraries, which enable simulations of agent-based models to be written in the Objective-C or Java computer languages. The basic architecture of Swarm is the simulation of collections of concurrently interacting agents: with this architecture, we can implement a large variety of agent-based models.

CONFERENCES AND JOURNALS

During the 1990ies and early 2000s there appeared a number of conferences that focused on ACO and PSO. Other conferences had and still have special sessions or tracks on ACO, PSO, swarm intelligence and applications. We present a list of the most important conferences and workshops focusing on this and similar topics (links are available via [53] and [54]). Let us mention the most important conferences and workshops:

- IEEE Swarm Intelligence Symposium (2003, 2005, 2006)
- IEEE Congress/Conference on Evolutionary Computation CEC (1999, 2000, 2001, 2002, 2003, 2004, 2005)
    - Special sessions on Swarm Intelligence and PSO
- Genetic and Evolutionary Computation Conference GECCO (1999, 2001, 2003, 2005)
    - Special tracks on ACO
- Parallel Problem Solving from Nature PPSN (1990, 1992, 1994, 1996, 1998, 2000, 2002, 2004)
- European Conference on Artificial Life ECAL (1991, 1993, 1995, 1997, 1999, 2001, 2003, 2005)
- ANTS 2004: Fourth International Workshop on Ant Colony Optimization and Swarm Intelligence
- ANTS 2002: From Ant Colonies to Artificial Ants: Third International Workshop on Ant Algorithms
- ANTS 2000: From Ant Colonies to Artificial Ants: Second International Workshop on Ant Algorithms
- ANTS'98: From Ant Colonies to Artificial Ants: First International Workshop on Ant Algorithms
- Ant Colony Optimization Session at INFORMS Tel Aviv 1998
- International Conference on Simulation of Adaptive Behaviour: From Animals to Animats 1994 (Diversity and adaptation in populations of clustering ants)
- Special ACO session at MIC-2001
- International Parallel and Distributed Processing Symposium
    - Workshop on bio-inspired solutions to parallel processing problems
    - Workshop on nature inspired distributed computing

Fast development in the area is reflected in increasing number of articles in many different journals. Recently there have appeared special issues or sections of journals devoted to nature inspired systems: Special Issue on Ant Algorithms - Future Generation Computer Systems Journal (Vol. 16, No. 8, 2000); Special Section on Ant Colony Optimization - IEEE Transactions on Evolutionary Computation (Vol. 6, No. 4, 2002); Parallel Computing (Vol. 30, 2004); Journal of Artificial Societies and Social Simulations; Special Issue on Swarm Robotics - Autonomous Robots, 17 (2-3); Special Issue on Learning Autonomous Robots - IEEE Trans. on Systems, Man, and Cybernetics - Part B, 26 (3). Individual articles can be found in journals devoted to different application areas, which shows the diversity of applications, fox example Computers & Operation Research; European Journal of Operational Research; International Journal of Production Research; Mathematical Methods of Operations Research; IEEE Transactions on System, Man and Cybernetics; Control: Theory and Applications; IEEE Transactions on Power Systems; Process Biochemistry; Robotics and Computer-Integrated Manufacturing; International Journal of Machine Tools and Manufacture; IEEE Transactions on Magnetics; Journal of Medicinal Chemistry; IEEE Transactions on Energy Conversion; Applied Optics; IEEE Transactions on Antennas and Propagation.

CONCLUSIONS

This paper has tried to show using few examples that nature inspired systems are still at the beginning of promising future development. Nature inspired computing as a subset of these systems is already active in a number of different application areas. We can see that especially computing and telecommunication systems tend to become more complicated. They will require adequate solutions for which the use of nature inspired techniques promises substantial benefits.
However, many areas still require further investigation before they will be used in real-world applications. Therefore nature inspired systems remain an active area of research.

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