BABEŞ-BOLYAI UNIVERSITY
Faculty of Mathematics and Computer Science

Computational Intelligence Models for Complex Problems

Camelia Chira

Habilitation Thesis

Faculty of Mathematics and Computer Science
Babes-Bolyai University of Cluj-Napoca
Romania

2018

Abstract

Computational Intelligence Models for Complex Problems

The present habilitation thesis focuses on the development of computational intelligence models and algorithms for solving complex problems from various application areas. This represents the author's major research domain after obtaining the PhD degree in 2005. The main results of recent research activity in the field of computational intelligence are presented from two perspectives: firstly, the search strategies and models that stay at the heart of the proposed methods are presented with an emphasis on the novel elements and the new computational models developed and published; secondly, the performance of the proposed algorithms in solving complex optimization problems is analysed emphasizing the computational results obtained in several experiments for both synthetic and real-world problem instances.

The main directions investigated are as follows: (i) *evolutionary computing models*, (ii) *swarm intelligence models*, and (iii) *hybrid computational models*. The common aspect of these main research directions is related to the need for developing intelligent computational solutions for complex problems which can not be easily addressed using standard algorithms and limited resources in terms of time and computational cost. For such complex problems, the identification of an approximate solution (that is near-optimal) using reasonable computational resources can be more valuable then obtaining the exact solution which can be very expensive due to the complex search space that needs to be covered by the algorithm. All computational intelligence models presented in this thesis are developed to handle complex search and optimization problems in application fields such as transportation and scheduling, clustering and classification, complex networks, bioinformatics, data analysis and prediction.

Evolutionary computing models. This direction focuses on creating evolutionary algorithms, recombination operators, fitness functions and search models to support the development of new evolutionary computing models and algorithms able to address complex problems. The most important type of evolutionary models proposed refer to collaborative asynchronous evolutionary models. The major problems addressed using these evolutionary models are Cellular Automata classification tasks, community detection in complex networks as well as the optimization of urban bicycle renting systems and electrical vehicle charging.

Swarm intelligence models. Nature-inspired metaheuristics have a great potential to identify good-quality near-optimal solutions to combinatorial optimization problems which are too complex for standard algorithms. The contributions along this research direction refer to the development of several swarm intelligence models based on Ant Colony Systems and integration with different search strategies, agent-based systems and stigmergic concepts. The proposed models have been successfully applied to combinatorial optimization problems such as the Generalized Travelling Salesman Problem, Gate Assignment Problem, Linear Ordering Problem and Matrix Bandwidth Minimization Problem.

Hybrid computational models. The development of hybrid computational models is based on models and concepts from the fields of nature-inspired computing, machine learning and multi-agent systems. The contributions along this research direction include the development of agent-based evolutionary models, hybrid hill-climbing and evolutionary model, feature selection and clustering methods. These models have been successfully applied to numerical optimization, combinatorial optimization problems and complex problems from bioinformatics including protein structure prediction, microarray cancer diagnosis, gene clustering from time-series microarrays.

The proposed models and algorithms from the above three main directions stay under the umbrella of *Computational Intelligence* using concepts and models from nature-inspired computing, genetic algorithms, machine learning and complex systems. The applications engaging the proposed models require solving search or optimization problems of high complexity. The most important specific contributions over all three directions are as follows:

- Asynchronous Evolutionary Algorithms for combinatorial optimization problems
- Collaborative Evolutionary Search Model for Cellular Automata tasks
- Evolutionary Algorithms and new fitness function for community detection in complex networks and dynamic networks
- Permutation-based Evolutionary Algorithms and search operators for optimization problems
- Sensitive Ant Model for combinatorial optimization problems
- Hybridization between agent-based systems and stigmergic agents for complex search problems
- Hybrid evolutionary and multiagent reinforcement learning system for traffic assignment
- An evolutionary model with hill-climbing operators for protein structure prediction
- Nature-inspired metaheuristics for urban bicycle renting systems
- An intelligent route management system for electric vehicle charging
- Clustering methods for time-series microarrays
- Hybrid intelligent recognition system for the early detection of strokes
- Wearable sensor system and model for fall detection

These contributions as well as the main lines of further research are detailed in the present thesis which is structured along the three main research directions identified: evolutionary computing, swarm intelligence and hybrid computational models. These three categories of contributions are complemented by the results obtained for real-world applications for which some models have been extended or proposed in order to deal with datasets and objectives corresponding to various real-world complex problems. The scientific results obtained have been facilitated by the active participation of the author in 7 research projects since 2005 (after obtaining the PhD) and several short-term collaboration projects with industrial partners. All these projects are in the area of computational intelligence and applications to real-world complex problems.

The scientific results obtained have been disseminated in more than 120 publications, including 2 books, 3 book chapters, 48 journal papers and 70 indexed conference papers. From the journal publications, 28 papers are indexed in ISI Web of Knowledge and are published in high-impact journals such as *Integrated Computer-Aided Engineering, Applied Intelligence, Soft Computing, Neurocomputing, International Journal of Neural Systems*. The main scientific events where the author has presented research results include relevant conferences in the field of computational intelligence (e.g. *IEEE Congress on Evolutionary Computation, Conference on Genetic and Evolutionary Computation, International Conference on Hybrid Artificial Intelligence Systems*). The contributions made in the area of evolutionary models and hybrid computational models for complex problems have made an impact on the scientific community and have a good international visibility. The impact of the results is confirmed by more than 350 citations obtained by the author's publications.

Future research plans include: (i) integration of learning, adaptation and evolutionary search, (ii) development of competent search methods able to deal with dynamic aspects inherent to real-world applications, (iii) evolution of evolution, (iv) development of hybrid search methods for optimization problems, and (v) exploring machine learning techniques in practical applications. Specific lines of future research will be detailed at the end of this thesis. Moreover, future work focuses on further applying and extending the proposed computational models to complex real-world problems. In particular, the problems of fall detection, traffic assignment and energy prediction still require better solutions able to handle the many interconnecting complex facets of the problem. Also, the dynamic aspects inherent to real-world applications have to be considered by future proposed methods. One line within this direction will focus on the integration of learning and evolutionary computing.

The key components of the career development plan cover teaching, research and other academic activities. From a teaching perspective, development plans focus on motivation-based education, teaching informed by research results, continuous update of subjects and study programs and involvement of students in projects. From the research and academic perspective, development plans focus on scientific contributions and generation of results in fundamental and applied research, development of proposals and implementation of research projects, creation of research team working in computational intelligence, collaboration activities with both academic and industrial partners and development of academic resources.