Modern Heuristic Optimization Techniques with Applications to Power Systems

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Edited by

K. Y. Lee

and

M.A. El-Sharkawi

From the Course Editors

Several heuristic tools have evolved in the last decade that facilitate solving optimization problems that were previously difficult or impossible to solve. These tools include evolutionary computation, simulated annealing, tabu search, particle swarm, etc. Reports of applications of each of these tools have been widely published. Recently, these new heuristic tools have been combined among themselves and with knowledge elements, as well as with more traditional approaches such as statistical analysis, to solve extremely challenging problems. Developing solutions with these tools offers two major advantages: 1) development time is much shorter than when using more traditional approaches, and, 2) the systems are very robust, being relatively insensitive to noisy and/or missing data.

The purpose of this course is to provide participants with basic knowledge of evolutionary computation, and other heuristic optimization techniques, and how they are combined with knowledge elements in computational intelligence systems. Applications to power problems are stressed, and example applications are presented. The tutorial is composed of two parts: The first part gives an overview of modern heuristic optimization techniques, including fundamentals of evolutionary computation, genetic algorithms, evolutionary programming and strategies, simulated annealing, tabu search, and hybrid system of evolutionary computation. It also gives an overview of power system applications.

The second part of the tutorial deals with specific applications of the heuristic approaches to power system problems, such as security assessment, operational planning, generation, transmission and distribution planning, state estimation, and power plant and power system control.

Evolutionary Computation:

Natural evolution is a hypothetical population-based optimization process. Simulating this process on a computer results in stochastic optimization techniques that can often out-perform classical methods of optimization when applied to difficult real-world problems. This tutorial will provide a background in the inspiration, history, and application of evolutionary computation and other heuristic optimization methods to system identification, automatic control, gaming, and other combinatorial problems.

The objectives are to provide an overview of how evolutionary computation and other heuristic optimization techniques may be applied to problems within your domain of expertise, to provide a good understanding of the design issues involved in tailoring heuristic algorithms to real-world problems, to compare and judge the efficacy of modern heuristic optimization techniques with other more classic methods of optimization, and to program fundamental evolutionary algorithms and other heuristic optimization routines.

Genetic Algorithms:

Genetic Algorithm (GA) is a search algorithm based on the conjecture of natural selection and genetics. The features of genetic algorithm are different from other search techniques in several aspects. First, the algorithm is a multi-path that searches many peaks in parallel, and hence reducing the possibility of local minimum trapping. Secondly, GA works with a coding of parameters instead of the parameters themselves. The coding of parameter will help the genetic operator to evolve the current state into the next state with minimum computations. Thirdly, GA evaluates the fitness of each string to guide its search instead of the optimization function. The genetic algorithm only needs to evaluate objective function (fitness) to guide its search. There is no requirement for derivatives or other auxiliary knowledge. Hence, there is no need for computation of derivatives or other auxiliary functions. Finally, GA explores the search space where the probability of finding improved performance is high.

Evolution Strategies and Evolutionary Programming:

Evolution Strategies (ES) employ real-coded variables and, in its original form, it relied on Mutation as the search operator, and a Population size of one. Since then it has evolved to share many features with GA. The major similarity between these two types of algorithms is that they both maintain populations of potential solutions and use a selection mechanism for choosing the best individuals from the population. The main differences are: ES operate directly on floating point vectors while classical GAs operate on binary strings; GAs rely mainly on recombination to explore the search space, while ES uses mutation as the dominant operator; and ES is an abstraction of evolution at individual behavior level, stressing the behavioral link between an individual and its offspring, while GAs maintain the genetic link.

Evolutionary Programming (EP) is a stochastic optimization strategy similar to GA, which places emphasis on the behavioral linkage between parents and their offspring, rather than seeking to emulate specific genetic operators as observed in nature. EP is similar to Evolutionary Strategies, although the tow approaches developed independently. Like both ES and GAs, EP is a useful method of optimization when other techniques such as gradient descent or direct analytical discovery are not possible. Combinatorial and real-valued function optimization in which the optimization surface or fitness landscape is "rugged", possessing many locally optimal solutions, are well suited for Evolutionary Programming.

Particle Swarm:

Particle swarm optimization (PSO) is an exciting new methodology in evolutionary computation that is somewhat similar to a genetic algorithm in that the system is initialized with a population of random solutions. Unlike other algorithms, however, each potential solution (called a particle) is also assigned a randomized velocity and then flown through the problem hyperspace. Particle swarm optimization has been found to be extremely effective in solving a wide range of engineering problems. It is very simple to implement (the algorithm comprises two lines of computer code) and solves problems very quickly.

Tabu Search:

Tabu Search (TS) is basically a gradient-descent search with memory. The memory preserves a number of previously visited states along with a number of states that might be considered unwanted. This information is stored in a Tabu List. The definition of a state, the area around it and the length of the Tabu list are critical design parameters. In addition to these Tabu parameters, two extra parameters are often used: Aspiration and Diversification. Aspiration is used when all the neighboring states of the current state are also included in the Tabu list. In that case, the Tabu obstacle is overridden by selecting a new state. Diversification adds randomness to this otherwise deterministic search. If the Tabu search is not converging, the search is reset randomly.

Simulated Annealing:

In statistical mechanics, a physical process called annealing is often performed in order to relax the system to a state with minimum free energy. In the annealing process, a solid in a heat bath is heated up by increasing the temperature of the bath until the solid is melted into liquid, then the temperature is lowered slowly. In the liquid phase all particles of the solid arrange themselves randomly. In the ground state the particles are arranged in a highly structured lattice and the energy of the system is minimum. The ground state of the solid is obtained only if the maximum temperature is sufficiently high and the cooling is done sufficiently slowly. Based on the annealing process in the statistical mechanics, the Simulated Annealing (SA) was introduced for solving complicated combinatorial optimization.

The name 'simulated annealing' originates from the analogy with the physical process of solids, and the analogy between physical system and simulated annealing is that the cost function and the solution (configuration) in the optimization process correspond to the energy function and the state of statistical physics, respectively. In a large combinatorial optimization problem, an appropriate perturbation mechanism, cost function, solution space, and cooling schedule are required in order to find an optimal solution with simulated annealing. SA is effective in network reconfiguration problems for large-scale distribution systems, and its search capability becomes more significant as the system size increases. Moreover, the cost function with a smoothing strategy enables the simulated annealing to escape more easily from local minima and to reach rapidly to the vicinity of an optimal solution.

K. Y. Lee and M. A. El-Sharkawi

For further information, please contact

K. Y. Lee

Department of Electrical Engineering
The Pennsylvania State University
University Park, PA 16802
Phone:(814) 865-2621
Fax: (814) 865-7065
e-mail: kwanglee@psu.edu

M. A. El-Sharkawi

Department of Electrical Engineering
University of Washington
Seattle, WA 98195-2500
Phone: (206) 685-2286
Fax: (206) 543-3842
e-mail: elsharkawi@ee.washington.edu

In memory of **Alcir J. Monticelli** (1946 – 2001):

Alcir José Monticelli was born on November 16, 1946 in Rio Capinzal, Santa Catarina, Brazil. He was a Fellow of the IEEE and a member of the Brazilian Academy of Sciences. He received his B.S. degree in electronic engineering from the Insituto Tecnológico de Aeronáutica (ITA) in 1970, the M.S. degree from Universidade Federal da Paraiba (UFPB) in 1972, and the Ph.D. degree from Universidade Estadual de Campinas (Unicamp) in 1975, all in Brazil. From 1982 to 1985, he was a visiting professor at the University of California Berkeley where he worked on theoretical aspects of network analysis, and from 1991 to 1992 he was with Mitsubishi Electric Corporation, Japan as a researcher of the artificial intelligence and parallel computing group. He was a professor of electrical engineering at Unicamp since 1972.

"Being a professor wasn't just a profession for him. It was a way of life: he used to observe everything and teach all the time. He had a great pleasure living that way". - *Isadora Monticelli*

Everyone that had worked with him corroborates the words of Alcir's daughter. He was the author of three books on power systems and had more than 40 articles published in international journals, transactions and proceedings with more than 500 citations according to the Science Citation Index. He was a collaborator of National Science Foundation and a member of most conferences in the power engineering area.

"Alcir Monticelli was a very important academic leader" - words of Carlos Henrique de Brito Cruz, president of FAPESP (Fundação de Amparo à Pesquisa do Estado de São Paulo) – the State of São Paulo Research Foundation. Alcir was an active collaborator with several projects, and he was the mentor of Small Business Innovation Research program in the State of São Paulo by FAPESP. His creativity and intelligence is present in the way the power system is treated nowadays. Load flow, state estimation, security analysis, and network planning, had undergone great advances with his contributions. The recognition for his contributions came with the honor of IEEE Fellow (1996), Engineer of the Year in Latin America (1997) and with the IEEE Third Millennium Medal (2000). As a professor, researcher, writer and a man engaged with technological innovation, he never neglected his family, which was the source of constant strength and joy to him. With his wife, Maria Stella he left three lovely daughters, Viridiana, Isadora, and Eleonora, who are all successful. He will always be remembered and when problems arise in power systems we will deeply miss his discussions.

List of Contributors

- Theory of Evolutionary Computation
  By Russell C. Eberhart, Indiana University Purdue University Indianapolis

- Overview of Applications in Power Systems
  By Alexandre P. Alves da Silva, Federal Engineering School at Itajuba

- Fundamentals of Genetic Algorithms
  By Alexandre P. Alves da Silva, Federal Engineering School at Itajuba

- Fundamentals of Evolution Strategies and Evolutionary Programming
  By Vladimiro Miranda, University of Porto

- Fundamentals of Particle Swarm Techniques
  By Yoshikazu Fukuyama, Fuji Electric Co. R&D

- Fundamentals of Simulated Annealing
  By Alcir J. Monticelli, Universidade Estaduial de Campinas; Ruben Romero, Universidade Estadual Paulista Julio de Mesquita Filho

- Fundamentals of Tabu Search
  By Alcir J. Monticelli, Universidade Estaduial de Campinas; Ruben Romero, Universidade Estadual Paulista Julio de Mesquita Filho

- Hybrid Systems: An Example with Fuzzy Systems
  By Germano Lambert-Torres, Federal Engineering School at Itajuba

- Application of Evolutionary Technique to Power System Security Assessment
  By Mohamed A. El-Sharkawi, University of Washington

- Generation Expansion and Reactive Power Planning
  By Kwang Y. Lee, Pennsylvania State University

- Network Planning
  By Alcir J. Monticelli, Universidade Estaduial de Campinas; Ruben Romero, Universidade Estadual Paulista Julio de Mesquita Filho

- Operational Planning: Unit Commitment and Economic Dispatch
  By Vladimiro Miranda, University of Porto

- Power System Controls: Particle Swarm Technique
  By Yoshikazu Fukuyama, Fuji Electric Co. R&D

- Power Plant Controls: Feedforward and Feedback Controller Design for Wide Range Operation Using Genetic Algorithm
  By Kwang Y. Lee, Pennsylvania State University

- State Estimation
  By Eduardo Nobuhiro Asada, Universidade Estaduial de Campinas; Ruben Romero, Universidade Estadual Paulista Julio de Mesquita Filho; Alcir J. Monticelli, Universidade Estaduial de Campinas

- Hybrid Models and Shade of Lamarckism
  By Vladimiro Miranda, University of Porto

- Additional References on Modern Heuristic Optimization Techniques
  By Kwang Y. Lee, Pennsylvania State University

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