Evolutionary Algorithms

אלגוריתמים אבולוציוניים

89-521

(Semester A, Sunday 18:00—20:00)

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A. Introduction and Objectives

The field of evolutionary computation is a rapidly expanding field thanks to the groundbreaking practical results obtained in recent years. Specifically, genetic algorithms and genetic programming have been used successfully in a wide range of scientific and engineering problems, including optimization tasks, automatic programming, machine learning, economics, biological modeling, and military applications.

The Evolutionary Algorithms course will introduce the main concepts and applications in the field of evolutionary computation, with emphasis on genetic algorithms and genetic programming. It will also provide students with practical experience with evolutionary algorithms for search, optimization, and machine learning.

Evolutionary Algorithms is an elective course for both graduate and undergraduate students. It will be especially appropriate for the following students:

- Students looking for practical experience with the evolutionary computation techniques for problem solving and optimization in science and engineering.
- Students who are interested in pursuing evolutionary computation for their graduate research.
- Computational biology students, who would like to learn artificial evolution for modeling biological evolution.

B. Assignments

Two programming assignments will be given, each of which would constitute 25% of the final grade. The final exam would comprise the remaining 50% of the grade.

C. Detailed Syllabus

1. Introduction to Evolutionary Computation
    - Principles of Darwinian natural selection
    - Biological and artificial evolution
    - Evolutionary computation and AI
    - A basic genetic algorithm

2. Genetic Algorithms - Basic Operators
    - Reproduction and crossover (one-point, multi-point, and uniform crossover operators)
    - Mutations
    - Crossover and mutation rates
    - Bit-string vs. real-valued representations (incl. Evolution Strategy)
    - Mutations for real-valued representations (e.g., Gaussian)
    - Effect of crossover and mutation on evolution (how and why each of them work)
3. Selection Schemes
    - Fitness proportional selection
    - Tournament selection
    - Impact of selection pressure on the course of evolution
4. Search Operators and Representations
    - Combining the operators
    - Problem encoding (e.g., binary vs. gray encoding)
    - Adaptive encoding schemes
5. Theoretical Foundations of Evolutionary Algorithms
    - Schemas and the two-armed bandit problem
    - Mathematical models for simple genetic algorithms
    - Where to use evolutionary algorithms? Theoretical advantages and disadvantages of evolutionary algorithms over alternative methods (hill-climbing, simulated annealing, etc.)
6. Co-evolutionary Algorithms
    - Cooperative co-evolution
    - Competitive co-evolution
    - Swarm intelligence and ant colony optimization
7. Evolving neural networks
    - Overview of feed-forward neural networks (perceptrons, multi-layer networks, backpropagations)
    - Evolving neural networks using genetic algorithms (evolving weights, evolving network architecture)
    - Direct and grammatical encoding of neural networks
    - Comparison of conventional vs. evolutionary neural network learning
8. Advanced Applications of Genetic Algorithms
    - Data analysis and prediction
    - Genetic algorithms in financial markets
    - Additional applications of genetic algorithms in search, optimization, and machine learning
9. Genetic-Based Machine Learning
    - Genetic classifier systems
    - Applications of genetic-based machine learning
10. Genetic Algorithms in Biological Models
    - Modeling interactions between learning and evolution (Lamarckian hypothesis and Baldwin effect)
    - Modeling sexual selection
    - Modeling ecosystems
    - Measuring evolutionary activity

11. Genetic Programming
    - Evolving programs
    - Major steps of genetic programming (initialization, crossover, mutation, fitness evaluation)
    - Search operators on trees
    - Building block hypothesis in genetic programming
    - Evolution of structure and variable length genomes
    - Issues in genetic programming, e.g., bloat, scalability, etc.
12. Advanced Topics in Genetic Programming
    - Improving genetic programming with statistics
    - Genetic programming with tree genomes, linear genomes, and graph genomes
    - Implementation of genetic programming
    - Advanced applications of genetic programming (science oriented, computer science oriented, and engineering oriented applications)
13. Future of Evolutionary Computation
    - New areas of research in the field of evolutionary computation
    - Open challenges for future research
    - Summary

D. Recommended Textbooks

- An Introduction to Genetic Algorithms, M. Mitchell. MIT Press, 1998.
- Genetic Algorithms in Search, Optimization, and Machine Learning, D. Goldberg. Addison-Wesley, 1989.
- Genetic Programming: An Introduction, W. Banzhaf et al. Morgan Kaufmann, 1999.
- Genetic Programming: On the Programming of Computers by Means of Natural Selection, J.R. Koza, MIT Press, 1992.
- Evolutionary Computation 1, T. Baeck et al. Taylor & Francis, 2000.