Heuristic Algorithms in Transport and Finance

Type:	Compulsory	Semester:	A	ECTS:	6
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General description

Course objectives

The course aims to equip students with the knowledge and skills to analyse, model, and solve complex decision-making problems in areas like transport and finance. Students will learn to identify key elements of real-world problems, including objectives, constraints, and uncertainty factors, and apply heuristic optimization, simulation, and machine learning methods to address them. Topics include vehicle routing and scheduling, portfolio optimization problems, optimization of systems under dynamic and uncertainty scenarios, and data-driven decision models. The course emphasizes the design and implementation of practical solution approaches using biased-randomized algorithms, GRASP, ILS, simheuristics, learnheuristics, discrete-event based heuristics, agile optimization algorithms, and genetic algorithms. By the end of the course, students will be able to develop and apply heuristic-based strategies to tackle large-scale, data-rich problems in dynamic business environments.

Contextualisation of the course

The course will contribute to the training of professionals capable of applying advanced analytical techniques to support decision-making in different systems, including transport and financial ones. It will provide students with practical tools to model and solve complex problems where exact methods are not feasible, using hybrid methodologies combining heuristic optimization, simulation, and machine learning. Emphasis will be placed on the role of these methods in improving efficiency, adaptability, and resilience in dynamic and uncertain environments. The course will highlight how data-driven and heuristic approaches can support sustainable operations in logistics and financial planning. It will contribute to the student's training in the following SDGs: SDG 8 (Target 8.2. Achieve higher levels of productivity through innovation), SDG 9 (Target 9.4. Upgrade infrastructure and industries for sustainability), and SDG 11 (Target 11.2. Provide access to safe, affordable, and sustainable transport systems).

Units

Unit 1: Introduction to Optimization and X-Heuristics

- Overview of Optimization Problems
- Limitations of Exact Methods in Real-World Contexts
- Classification of Heuristics and Metaheuristics
- Introduction to X-Heuristics and Their Role in Practice

Unit 2: Random Search and Vehicle Routing Problems (VRPs)

- Basics of Random Search Techniques
- Key Features of Vehicle Routing Problems
- Constructive Heuristics for VRPs
- Case Examples in Transport Planning

Unit 3: Biased-Randomized Algorithms (BRAs)

- Principles of Biased Randomization
- Use of Probability Distributions in Heuristics
- Implementation of BRAs in Routing and Scheduling
- Comparison with Classical Constructive Methods

Unit 4: GRASP and Team Orienteering Problems (TOPs)

- Structure of GRASP Algorithms
- Greedy Construction and Local Search Phases
- Introduction to TOPs and Related Constraints
- Application of GRASP to Resource-Constrained Routing

Unit 5: Iterated Local Search (ILS) and Permutation Flow Shop Problems (PFSPs)

- Iterated Local Search Framework
- Local Improvement and Perturbation Strategies
- PFSP Problem Structure and Objectives
- ILS Applications in Scheduling

Unit 6: Recent Applications of BRAs

- Advanced BRA Designs
- Integration with Domain-Specific Constraints
- Case Studies in Transport and Finance
- Performance Analysis and Benchmarking

Unit 7: Simulation and Simheuristics

- Role of Simulation in Optimization
- Stochastic Problem Settings and Uncertainty Modeling
- Simheuristic Frameworks
- Practical Examples in Logistics and Risk Assessment

Unit 8: Learnheuristics and Agile Optimization

- Combining Machine Learning and Heuristics
- Use of Machine Learning in Heuristic Design
- Applications of Learnheurstics
- Agile Decision-Making in Dynamic Systems
- Discrete-Event Heuristics for Time-Dependant Systems

Unit 9: Machine Learning and X-Heuristics

- Data-Driven Heuristics and Predictive Models
- Supervised and Unsupervised Learning in Optimization
- Integration of ML into X-Heuristic Pipelines
- Examples in Forecasting and Portfolio Optimization

Unit 10: Genetic Algorithms

- Structure of Genetic Algorithms
- Selection, Crossover, and Mutation Mechanisms
- Tuning Parameters and Avoiding Premature Convergence
- Applications in Transport Routing and Financial Scheduling

Prerequisites

Students are expected to have basic programming skills in Python or Julia and be comfortable with analytical reasoning. A foundational understanding of applied optimization and simulation is required. The course also assumes the ability to read and interpret scientific papers, identifying key ideas and methodologies. An interest in the practical application of modern optimization, simulation, and machine learning methods in areas such as transport, logistics, supply chain management, smart cities, and finance is recommended.

Course Methodology

The course will be delivered online through live sessions, where the instructor will explain the key concepts, methods, and applications. Students are expected to attend these sessions, participate actively, ask questions, and respond to instructor prompts. The course has a practical orientation, with a strong focus on hands-on problem solving. Students will be required to complete several coding assignments using Python or Julia. A rational and responsible use of generative AI tools is allowed to support learning and coding tasks, when appropriate and instructed. In addition to coding activities, students will read, understand, and analyze selected scientific papers. These readings will support the link between theory and practice and help students develop the ability to interpret and assess academic work. Some activities will be individual, while others will be done in groups, as assigned by the instructor.

Evaluation System

The course will include both individual tests and team-based practical activities. Active participation during live sessions will also be evaluated. As in other courses in this master's program, a final face-to-face exam will be part of the overall assessment.

Learning Resources

The main educational resources for this course can be found here: https://drive.google.com/drive/folders/1YMCI4Q5Cm0MV8moZXpWTLaIAtMU-GWrt?usp=sharing

Bibliography

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- Wirsansky, E. (2020). Hands-On Genetic Algorithms with Python: Applying genetic algorithms to solve real-world deep learning and artificial intelligence problems. Packt Publishing Ltd.