Course

Evolutionary Multi-Objective Optimization

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Team

Lectures
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Research topics:
• Computational Intelligence (CI)
• Evolutionary Algorithms, Multi-Objective Optimization, Decision-Making
• Swarm Intelligence, Collective Decision-Making, Artificial life, CI in computer games
• Swarm Robotics, Evolutionary Robotics

Tutorials
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Courses at the Chair of Computational Intelligence

In WS:
• Intelligente Systeme, Bachelor (5 CP)
• Swarm Intelligence, Master (6 CP)

In SS:
• Computational Intelligence in Games, Bachelor (5 CP) und Master (+ Extra Work 6 CP)
• Evolutionary Multi-Objective Optimization, Master (6 CP)
• Introduction to Robotics (6 CP)

WS und SS:
• Seminar Ethik in Computational Intelligence, B.Sc.
• Team Projects in SwarmLab – Flying Swarm, Rolling Swarm, Driving Swarm
Time and locations of this course

**Lectures:**
- **Tuesdays 11:00 to 12:30, Room G29-307**
  - Lectures are help in presence.
  - Slides and videos are available on the webpage.
  - Video recordings of the lectures are available every week.

**Tutorials:**
- **Fridays 15:00 to 17:00, Room G29-307**
  - The tutorials are held in presence.
  - Assignment sheets are available every week on the webpage.
  - The date of the first tutorial will be announced on the webpage.
Webpage

All relevant information about this course available on the Webpage:
http://www.ci.ovgu.de/Teaching

Evolutionary Multi-Objective Optimization

Description
In our daily life, we are inevitably involved in optimization. How to get to the university in the least time is a simple optimization problem that we encounter every morning. Just looking around ourselves, we can see many examples of optimization problems, even with conflicting objectives and higher complexities. It is natural to want everything to be as good as possible. In other words optimal. The difficulty arises when there are conflicts between different goals and objectives. Indeed, there are many real-world optimization problems with multiple conflicting objectives in science and industry, which are of great complexity. We call them Multi-objective Optimization Problems. Over the past decades, many new ideas have been investigated and studied to solve such optimization problems as any new development in optimization which can lead to a better solution of a particular problem is of considerable value to science and industry. Among these methods, evolutionary algorithms are shown to be quite successful and have been applied to many applications.

This course addresses the basic and advanced topics in the area of evolutionary multi-objective optimization and contains the following content:

- Introduction to single-objective optimization (SO) and multi-objective optimization (MO), classical methods for solving MO, definitions of Pareto-optimality and other theoretical foundations for MO
- Basics of evolutionary algorithms (algorithms, operators, selection mechanisms, coding and representations)
- Evolutionary multi-objective algorithms (NSGA-II, EMO scalarization methods such as NOEA/D)
- Constraint handling in SO and MO, robust optimization in EMO, surrogate methods for expensive function evaluations
- Evaluation mechanisms (Design of experiments, test problems, metrics, visualization)

Team
- Sanaz Mostaghim (Lectures)
- Julia Heise (Tutorial)

Lectures
Time: Tuesdays 11:30 – 12:30
Room: Auditorium, G29-307

Slides
- Chapter 0: Organization
- Chapter 1: Introduction
Exam

- There will be a written exam of 120 minutes. Details on the format of the exam will be announced later.

- You can only attend the exam if you passed **the midterm exam**.

- The exam questions will be in English. You may answer in English or German.
Multi-Objective Optimization (MO)

**Definition:** Multi-Objective Optimization problems have **more than one** functions (objectives) which are supposed **to be optimized at the same time.** A very important feature is that these functions are in **conflict** with each other.

**Example 1:** Suppose that you want to find the optimal way from home to the university. Now you can specify your objectives such as time (find the way which is fastest) and cost (find the way which costs as low as possible). These functions are in conflict with each other, the fastest way requires you to take the car which costs more than, if you take the way which you will walk (no cost) but is then not fast enough.

Option 1: Car, 6 min  
Option 2: Tram, 32 min  
Option 3: Bike, 10 min  
Option 4: Walking, 32 min
Tram: 32 min, 2.6 km
Walking: 32 min, 2.6 km
Bike: 10 min, 2.8 km
Car: 6 min, 3.2 km
Multi-Objective Optimization (MO)

The solution of a multi-objective problem is a set of solutions from which a user can select one according to his/her preferences:

Dealing with MO:
- Find one optimal solution from the beginning: The user has to specify the preference before optimization process
- Find all possible solutions: The user can select one of them later → The topic of this course

Option 1: Car, 6 min
Option 2: Tram, 32 min
Option 3: Bike, 10 min
Option 4: Walking, 32 min
MO in inter- and multi-disciplinary research

- Production Engineering Group
- Armament Group
- Electrical Group
- Weight Group
- Loft Group
- Aerodynamics Group
- Stress Group
- Power Plant Group

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Why Evolutionary Algorithms?

To deal with problems with following properties:

- Black-Box or simulation-based function evaluations
- Non-linear functions
- Timely-expensive function evaluations
- High dimensional search spaces
- Many constraints
- Dynamic functions and uncertainties

Goal of Evolutionary Algorithms: find \( \vec{x}^* \), so that

\[
\vec{x}^* = \arg \min \left( f(\vec{x}) \right)
\]

s.t. \( \vec{x} \in S \)

\( \vec{g}(\vec{x}) \leq 0 \), \( \vec{h}(\vec{x}) = 0 \)
A generic definition

Multi-objective Optimization Problem (MOP):

\[
\begin{align*}
\text{Minimize} & \quad (f_1(\vec{x}), f_2(\vec{x}), \ldots, f_m(\vec{x})) \\
\text{s. t.} & \quad \vec{x} \in S \\
& \quad \vec{g}(\vec{x}) \leq 0, \quad \vec{h}(\vec{x}) = 0
\end{align*}
\]

where \( f_i : \mathbb{R}^n \rightarrow \mathbb{R} \), \( z_i = f_i(\vec{x}) \)
Focus of this course

• Optimization problems
  • The model and (usually) the desired output are known.
  • The task is to find the input(s) leading to the desired output

• Modeling or system identification problems
  • Input and output are known.
  • The task is to find a model of the system that delivers the correct output for each known input.

• Simulation problems
  • We know the system model and some inputs
  • Need to compute the outputs corresponding to the known inputs
Optimization

• It simply means: “doing better”.

• Wikipedia: In mathematics, optimization refers to choosing the best element from some set of available alternatives.
• It is the process of trying to find the best possible solution to an optimization problem within (usually) a given time limit.
• …
• Examples:
  – In telecommunication, logistics: finding the shortest path
  – Factory production schedule: which gives the best throughput?
  – Molecular structures: which one has the minimal potential energy?

Any new development in optimization which leads to better results is of considerable value to Science and Industry.
Optimization Methods

• Exact methods
  • Example: Branch&Bound, Constraint Programming, Divide & Conquer
  • Guarantee the optimum
  • exponential runtime for NP-hard problems

• Heuristics
  • Example: Priority rules, nearest neighbor
  • fast but usually mediocre
  • very problem specific

• Meta-Heuristics
  • generate acceptable solutions in acceptable time frame
  • many additional advantages: broadly applicable, easy to parallelize, multiple criteria, interaction ...
Content of this course

Chapter 2: Basic Principles
Multi-Objective Optimization: Definitions
A Priori Methods, Domination criteria

Chapter 3: EA
Fundamentals of optimization Evolutionary Algorithms (Evolution Strategy)
Particle Swarm Optimization

Chapter 4: EMO algorithms
NSGA-II, SPEA-2 and Rankings, MOEA/D, MOPSO

Chapter 5: Evaluation Methods
Convergence, Diversity metrics, Hypervolume, Visualization methods, Test problems

Chapter 6: Advanced topics
Constraint Handling, Robust optimization, Optimization under uncertainty
Literature
Literature

Books:
- C. Reeves (ed.): “Modern heuristic techniques for combinatorial problems”, McGraw-Hill, 1995
Further Readings

• Journals:
  • Evolutionary Computation, MIT Press
  • IEEE Transactions on Evolutionary Computation, IEEE Press
  • Journal of Heuristics, Springer

• Conferences:
  • Genetic and Evolutionary Computation Conference (GECCO), every year
  • Congress on Evolutionary Computation (CEC), every year
  • Parallel Problem Solving from Nature (PPSN), every other year
  • Evo Star, every year
  • Evolutionary Multi-criterion Optimization (EMO), every other year

• Web-Pages:
  • Ant Colony Optimization: http://iridia.ulb.ac.be/~mdorigo/ACO/ACO.html
  • Multi-Objective Optimization: http://www.lania.mx/~ccoello/EMOO
  • Particle Swarm Optimization: http://www.particleswarm.info/
  • Traveling Salesman Problem: http://www.tsp.gatech.edu/index.html
This is a course on a very dynamic subject, so we really appreciate your feedback on contents and presentation.