OTTO VON GUERICKE UNIVERSITÄT MAGDEBURG

INF FAKULTÄT FÜR INFORMATIK

SwarmLab

# Course

# Evolutionary Multi-Objective Optimization

Sanaz Mostaghim
Chair of Computational Intelligence

Faculty of Computer Science
Otto von Guericke University Magdeburg

# Team

**Lectures**

Prof. Dr.-Ing. habil. Sanaz Mostaghim

Office hours: Only by Email request

Email: Sanaz.Mostaghim@ovgu.de

Office: G29-008

**Tutorials**

Julia Heise, M.Sc.

Office hours: Only by Email request

Email: Julia.heise@ovgu.de

Office: G29-013

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

# 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.

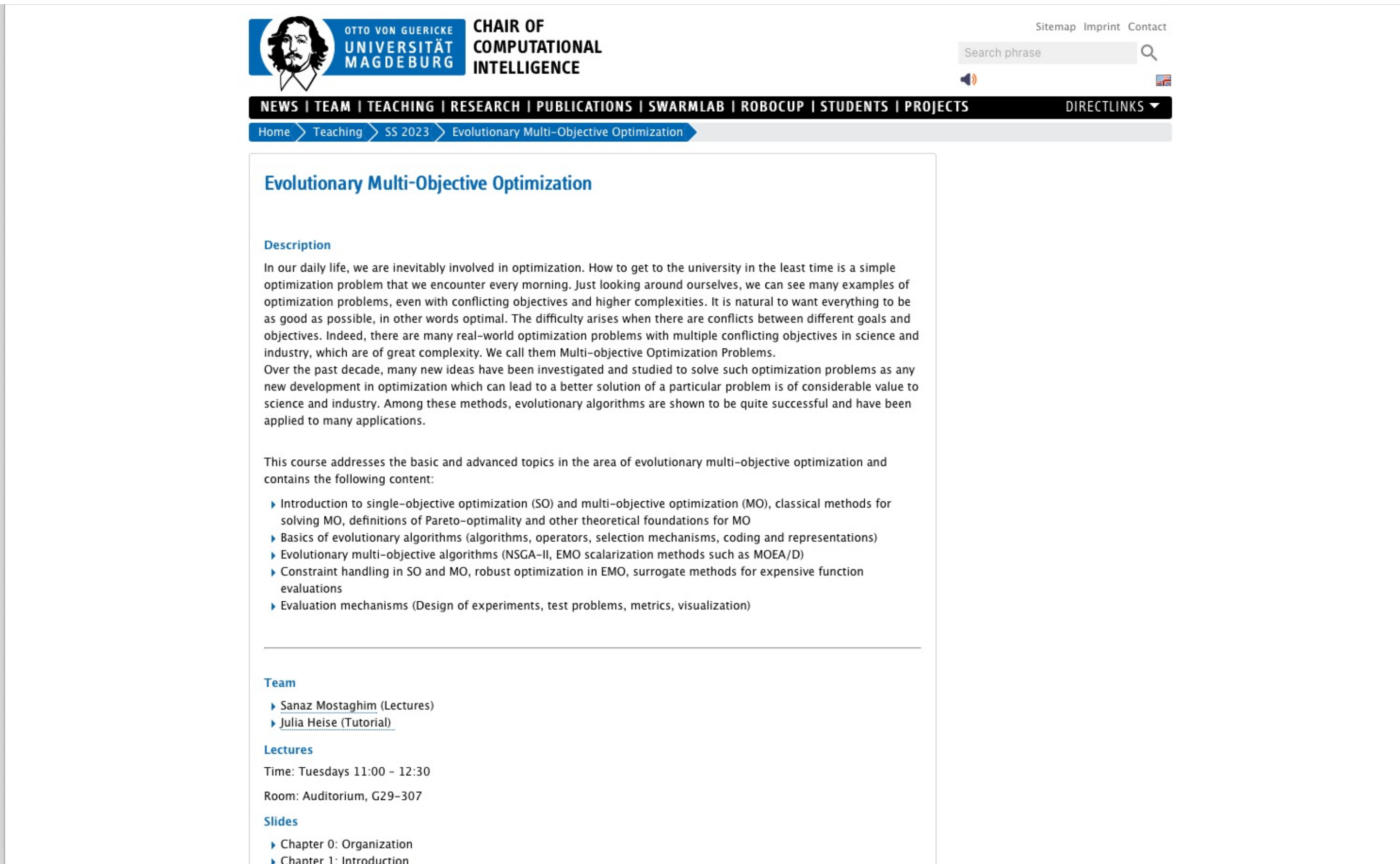
**Tutorials:**

- **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



# Exam

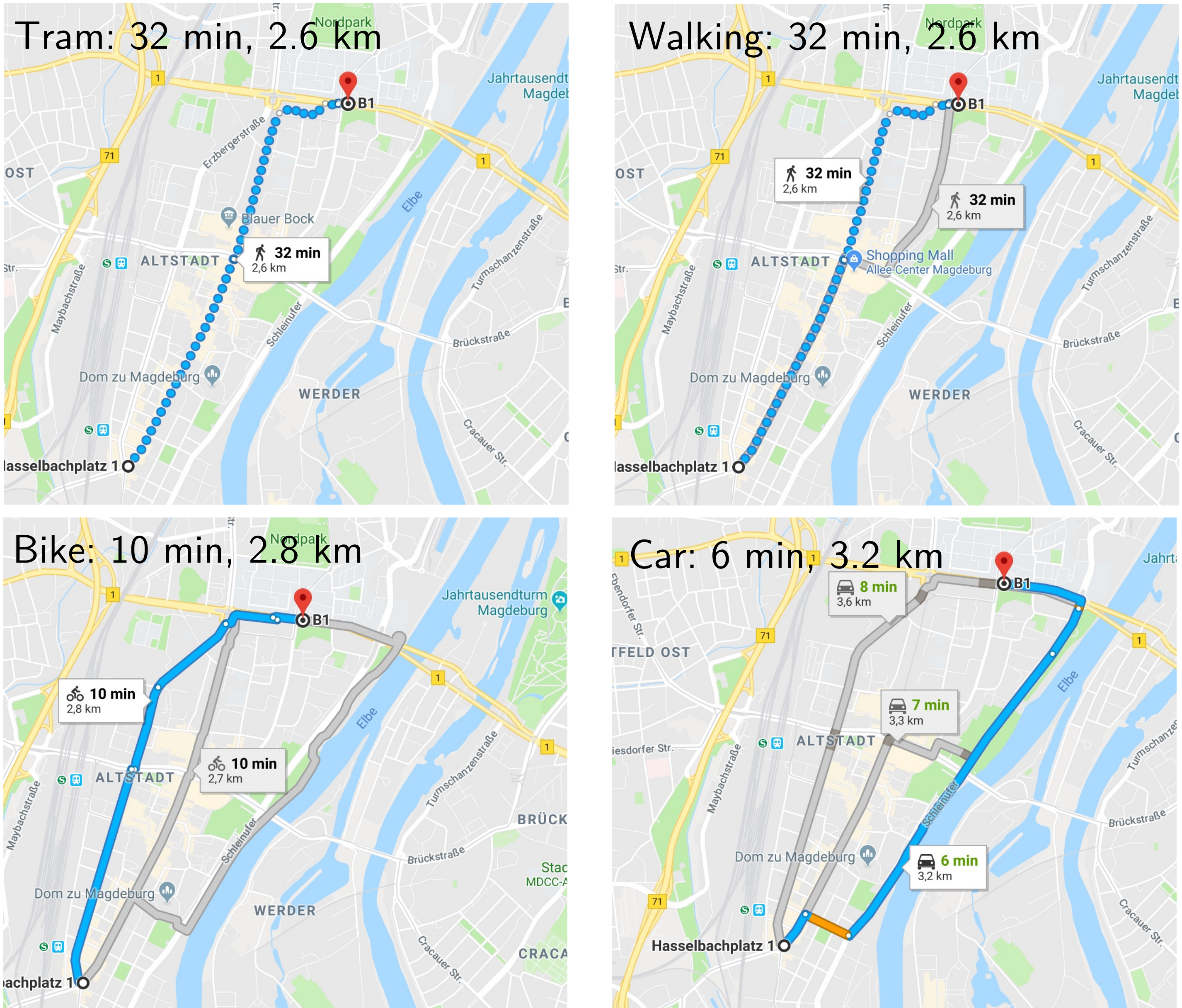
- There will be a written exam of 120 minutes. Details on the format of the exam will be announced later.
- You can only attend the exam if you passed **the midterm exam**.
- The exam questions will be in English. You may answer in English or German.

# 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.

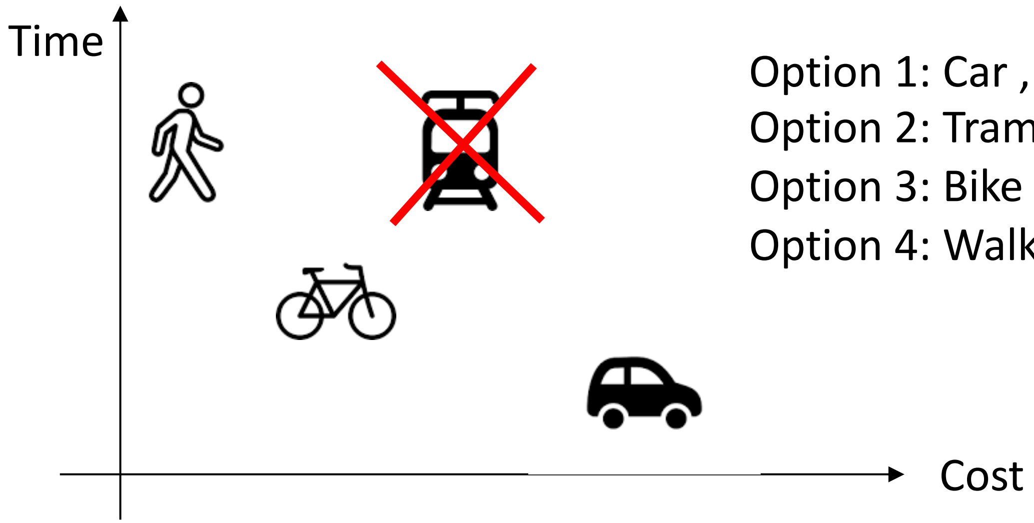
**Example 1:** Suppose that you want to find the optimal way from home to the university. Now you can specify your objectives such as time (find the way which is fastest) and cost (find the way which costs as low as possible).
These functions are in conflict with each other, the fastest way requires 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
32 min
2,6 km
B1
Hasselbachplatz 1
Walking: 32 min, 2.6 km
32 min
2,6 km
32 min
2,6 km
Bike: 10 min, 2.8 km
10 min
2,8 km
10 min
2,7 km
Car: 6 min, 3.2 km
8 min
3,6 km
7 min
3,3 km
6 min
3,2 km

# Multi-Objective Optimization (MO)

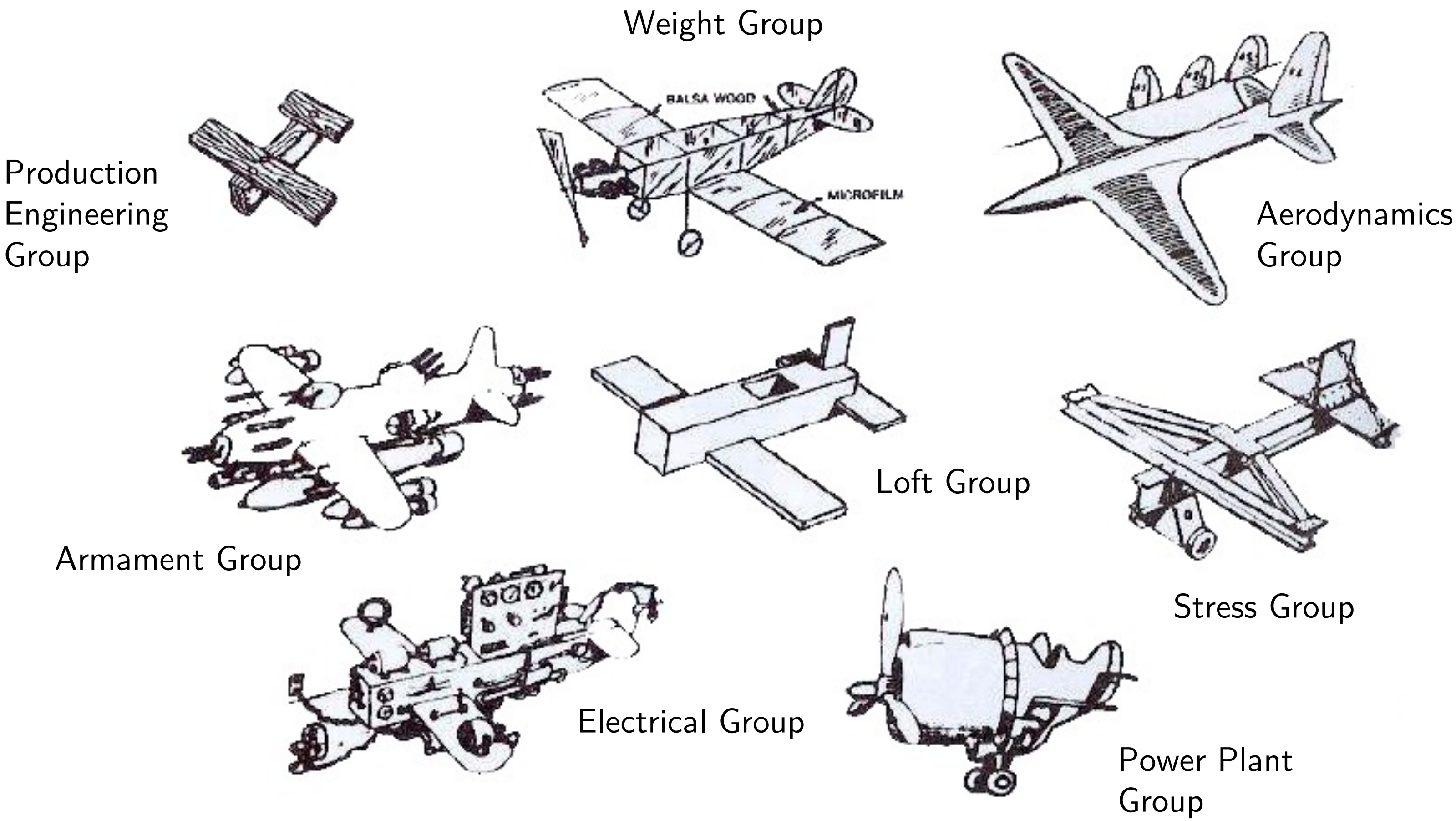
The solution of a multi-objective problem is a set of solutions from which a user can select one according to his/her preferences:




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

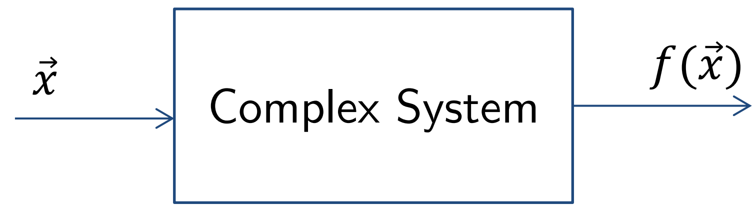
# MO in inter- and multi-disciplinary research



# 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

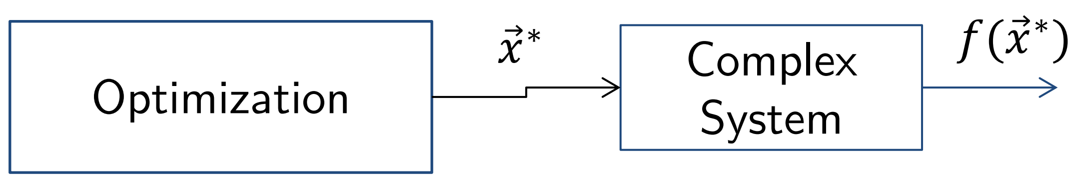



Goal of Evolutionary Algorithms: find $\vec{x}^*$, so that

$$\vec{x}^* = \arg Min\left(f(\vec{x})\right)$$

s.t. $\vec{x} \in S$

$$\vec{g}(\vec{x}) \leq 0\,, \qquad \vec{h}(\vec{x}) = 0$$

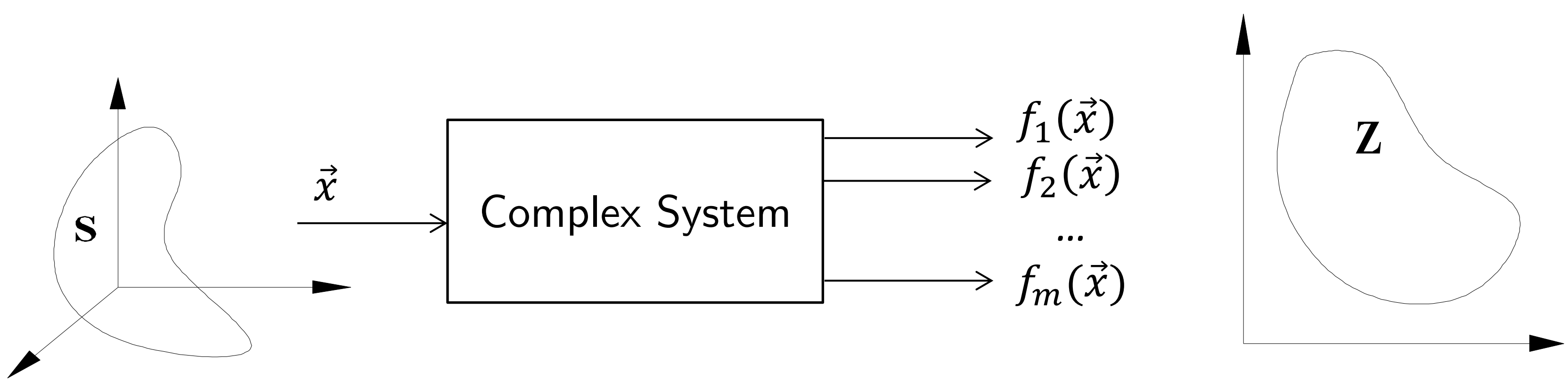


# A generic definition

Multi-objective Optimization Problem (MOP):

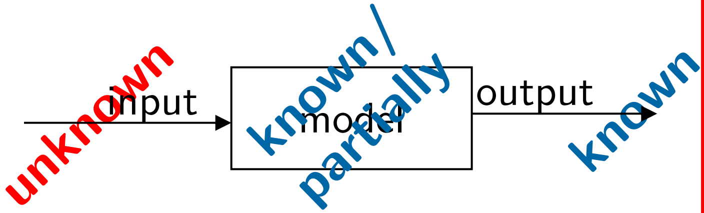
$$\text{Minimize } (f_1(\vec{x}), f_2(\vec{x}), \dots, f_m(\vec{x}))$$
$$\text{s. t. } \vec{x} \in S$$
$$\vec{g}(\vec{x}) \leq 0\,,\ \vec{h}(\vec{x}) = 0$$

where $f_i : R^n \rightarrow R$, $z_i = f_i(\vec{x})$

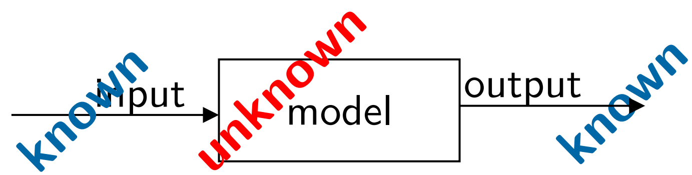


# Focus of this course

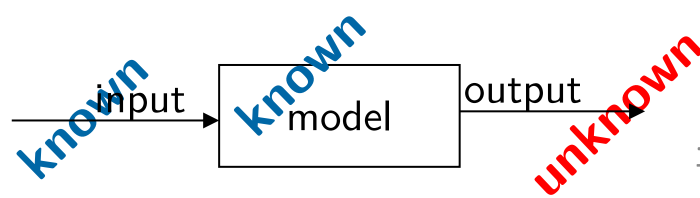
- Optimization problems
  - The model and (usually) the desired output are known.
  - The task is to find the input(s) leading to the desired output




- 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



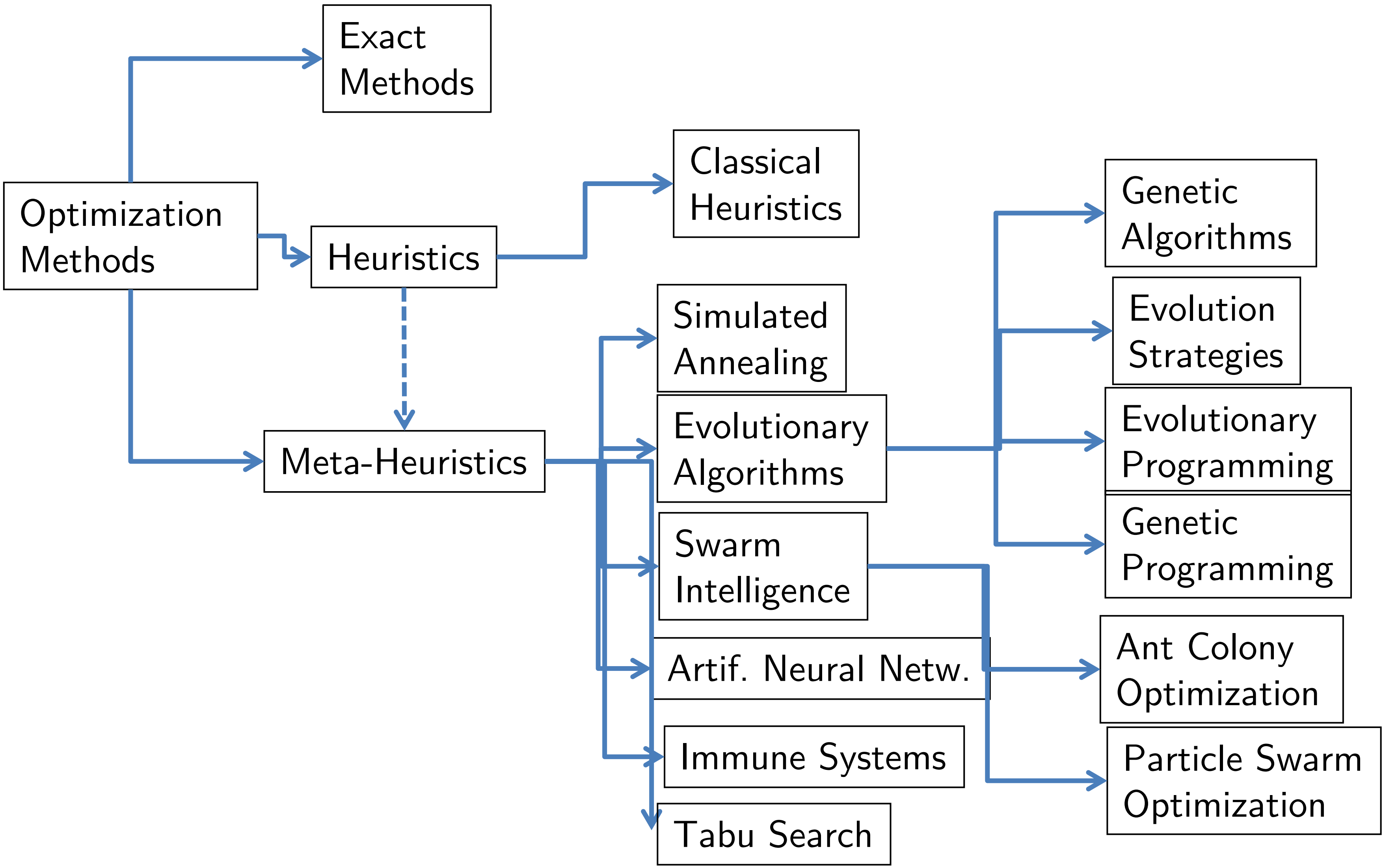
# Optimization

- 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



# 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

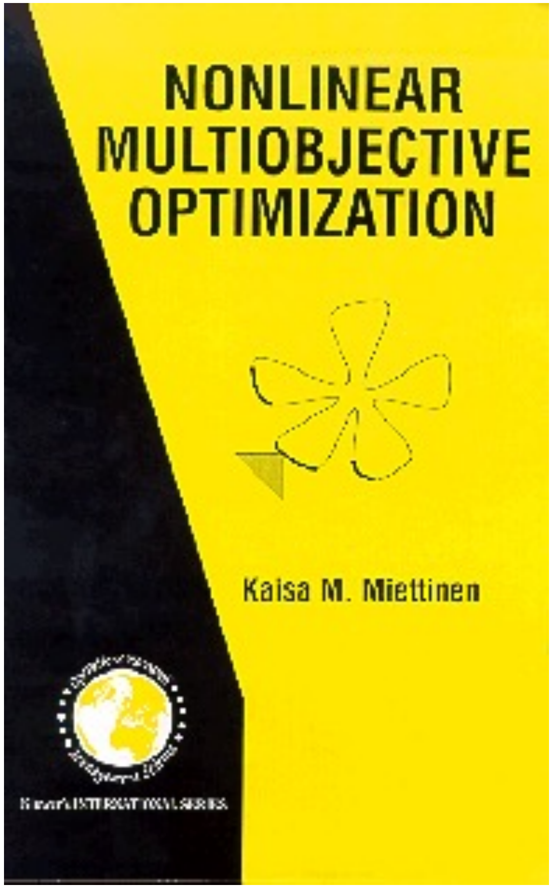
Chapter 5: Evaluation Methods

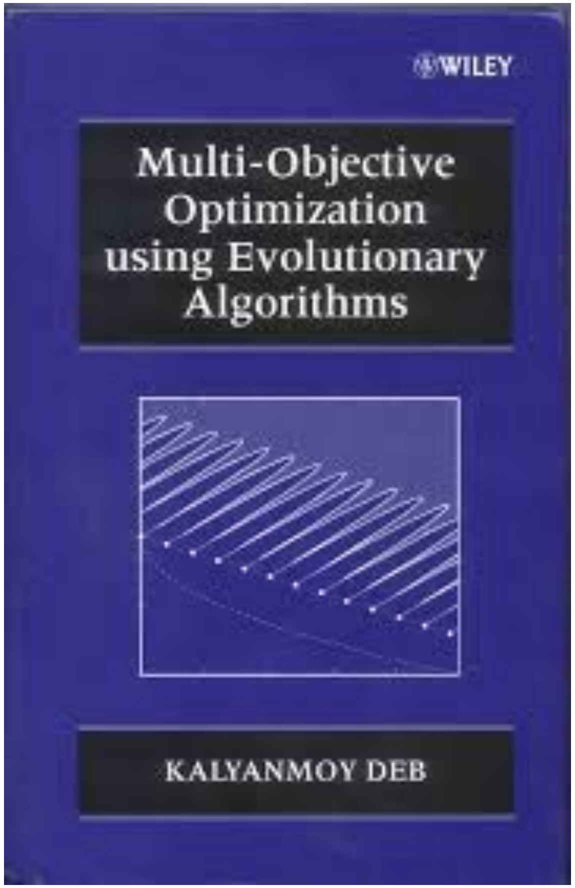
Convergence, Diversity metrics, Hypervolume, Visualization methods, Test problems

Chapter 6: Advanced topics

Constraint Handling, Robust optimization, Optimization under uncertainty

# Literature


NONLINEAR
MULTIOBJECTIVE
OPTIMIZATION
Kaisa M. Miettinen


WILEY
Multi-Objective Optimization using Evolutionary Algorithms
KALYANMOY DEB


MULTIPLE
CRITERIA
OPTIMIZATION
State of the Art
Annotated
Bibliographic
Surveys
edited by
Matthias Ehrgott
Xavier Gandibleux

# Literature

Books:


- Z. Michalewicz and D. B. Fogel: “How to solve it: modern heuristics”, Springer, 1998
- A. E. Eiben and J. E. Smith: “Introduction to evolutionary computation”, Springer, 2003
- C. Reeves (ed.): “Modern heuristic techniques for combinatorial problems”, McGraw-Hill, 1995
- Z. Michalewicz: “Genetic Algorithms + Data Structures = Evolution Programs”, Springer, 3rd edition, 1996
- E. Bonabeau, M. Dorigo, G. Theraulaz: “Swarm intelligence: from natural to artificial systems”, Oxford University Press, 1999
- K. Deb: “Multi-Objective Optimization using Evolutionary Algorithms”, John Wiley & Sons, 2001
- E.H.L. Aarts and J.K. Lenstra (eds.): “Local search in combinatorial optimization”, Wiley, 1995
- H. Hoos and T. Stützle: “Stochastic local search”, Morgan Kaufmann, 2005

# 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.**