Computationally Complex Multiobjective Problems: Experiences on Industrial Optimization

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Outline

- Background
- Experiences on Industrial Optimization
- IND-NIMBUS Optimization Framework
- Future Directions

Background

- I've been involved with industrial optimization since 1999
- MSc, Information Technology, University of Jyväskylä, 2008
- Currently as Researcher
  - *Strategic Development of Multiobjective Optimization: Theory and Software*, Academy of Finland
  - 2009–2012

PhD Thesis

- *Optimization framework for computationally complex multiobjective problems*
  - Collection of papers
- Supervisor: prof. Kaisa Miettinen
- Area: Multiobjective optimization
- One published article
  - Laukkanen, T.; Tveit, T.-M.; Ojalehto, V.; Miettinen, K. & Fogelholm, C.-J. *An interactive multi-objective approach to heat exchanger network synthesis* Computers & Chemical Engineering, 2010 , 34 , 943-952
- Four articles under progress
  - *GAMS-NIMBUS Tool for Multiobjective Optimization in the GAMS Modeling Environment* Ojalehto, V. et al
  - *Solving a Computationally Expensive Multiobjective Wastewater Treatment Plant Desing and Operation Problem with a Novel PAINT Method and the Interactive Method NIMBUS* Hartikainen, M.; Ojalehto, V.
- Two articles under consideration
  - *Testing framework for multi/single objective optimization*

Multiobjective Optimization

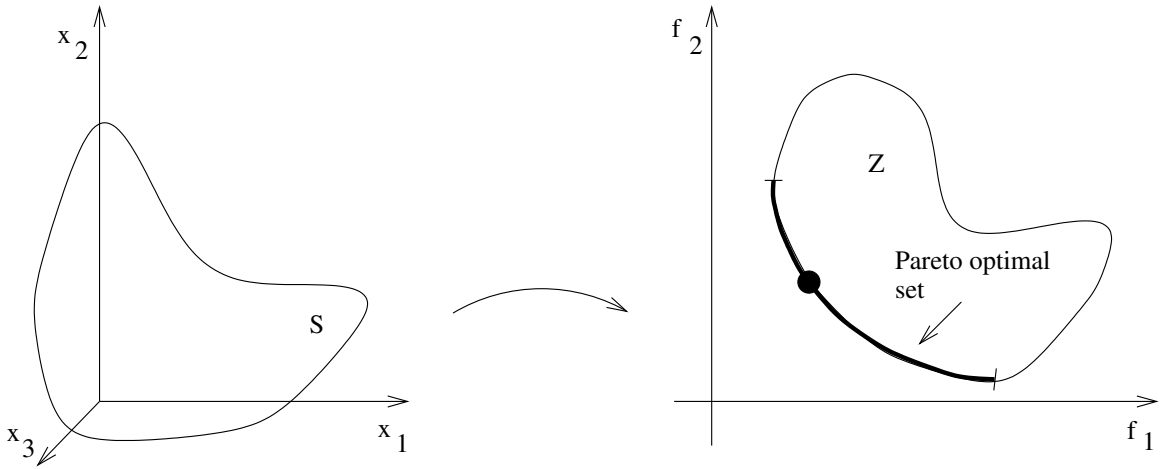
- In multiobjective Optimization we consider a problem of the form

$$
\begin{array}{lll}
\text{minimize} & \{f_1(x), ..., f_k(x)\} & \\
 & Ax \leq b \;\} & \text{linear constraints} \\
 & g_1(\mathbf{x}) \leq 0 & \\
\text{subject to} & \vdots & \text{nonlinear constraints} \\
 & g_m(\mathbf{x}) \leq 0 & \\
 & x^l \leq \mathbf{x} \leq x^u \;\} & \text{box constraints}
\end{array}
\quad \mathbf{x} \in S.
$$

- (Objective functions f can be either minimized or maximized)

Pareto Optimality

- We consider several *conflicting* objective functions
- Concept of optimality – *Pareto optimality*



- Other concepts:
  ideal vector $(\mathbf{z}^{\star})$,
  nadir vector $(\mathbf{z}^{\mathrm{nad}})$,
  objective vector $(\mathbf{z}^{\star\star})$.

NIMBUS method

- Classification is the central idea of the NIMBUS method
- The decision maker is asked to divide the functions *into up to five different classes:*
  - $<$ objective value should be improved,
  - $\leq$ objective value should be improved till some aspiration level,
  - $=$ objective value is satisfactory at the moment,
  - $\geq$ objective value is allowed to impair up till some bound,
  - $\diamond$ objective value is allowed to change freely.
- Upto four single objective subproblems

Experiences on Industrial Optimization

- **1997 – 2001:** *DECISION*, EU
  - Heterogeneous optimization oriented integration platform
  - Participants
    - **End User:** Dassault Aviation, Messet, Nokka Tume
    - **Software Developer:** NAG
    - **Researchers:** Inria, University of Jyväskylä, VTT
  - Main results
    - DEEP Platform – IRIS Explorer with PBEXPE
    - Optimal Design of the Structure of Grapple Loader
- **2001 – 2002:** *Methodological and Implementational Challenges in Nonlinear Multiobjective Optimization and Decision Support*, Academy of Finland
  - WWW-NIMBUS Development

Experiences on Industrial Optimization with TEKES, I

- **2002 – 2005:** *Multiobjective Optimization in Product Development*
  - The NIMBUS method for industry, that is, for non-academic use
  - Participants
    - **End User:** Metso Paper, Jyväskylän Teknologiakeskus Oy,(Liqum Oy,)
    - **Software Developer:** Numerola Oy
    - **Researchers:** University of Jyväskylä, VTT Prosessit
  - Results
    - IND-NIMBUS – Software for multiobjective optimization
    - NIMBalas – multiobjective optimization for BALAS Process Simulation Software
    - MOP – Multiobjective process line optimization for paper making

Experiences on Industrial Optimization with TEKES, II

- **2005–2008:** *Multiobjective Optimization and Multidisciplinary Decision Support*
  - Developing a new intelligent decision support system and apply it to new application areas
  - Participants
    - **End User:** Andritz Oy, Foster Wheeler Energia Oy, Kuopio University Hospital, Kvaerner Power Oy, M-real Oyj, Patria Aerostructures Oy, Varian Medical Systems Finland Oy, Wärtsilä Finland Oy
    - **Researchers:** University of Jyväskylä, Helsinki School of Economics, Helsinki University of Technology, Tampere University of Technology,University of Kuopio
  - Results:
    - Pareto Navigator – Interactive approximation method for nonlinear multiobjective optimization
    - SynHEAT – Multiobjective optimization of heat exchanger network synthesis

And Others

- MCDM Cases
  - *Continuous Casting of Steel*, Timo Männikkö
  - *Heuristic Solution Methods for Housing Location Models*, Michael P. Johnson
  - *Multiobjective Optimization of an Ultrasonic Transducer using NIMBUS*, Paavo Nieminen et al.
  - *Optimization of Internal Combustion Engine*, Timo Aittokoski
  - *Simulated moving bed processes*, Jussi Hakanen
  - *Engine control system optimization*, Markus Inkeroinen et al.
  - *Wastewater Treatment*, Kristian Sahlstedt
  - *Multi-criteria model for intensity modeled radiotherapy planning*, Henri Ruotsalainen
  - And more
- Coworkers
  Tommi Ronkainen, Tommi Myöhänen, Jari Huikari, Ville Tirronen, Timo Tarvainen, Antoine Le Hyaric, Juha-Pekka Koskinen, Aki Järvinen, Kirsi Holopainen, Heikki Maaranen, Tero Oravasaari, and many more

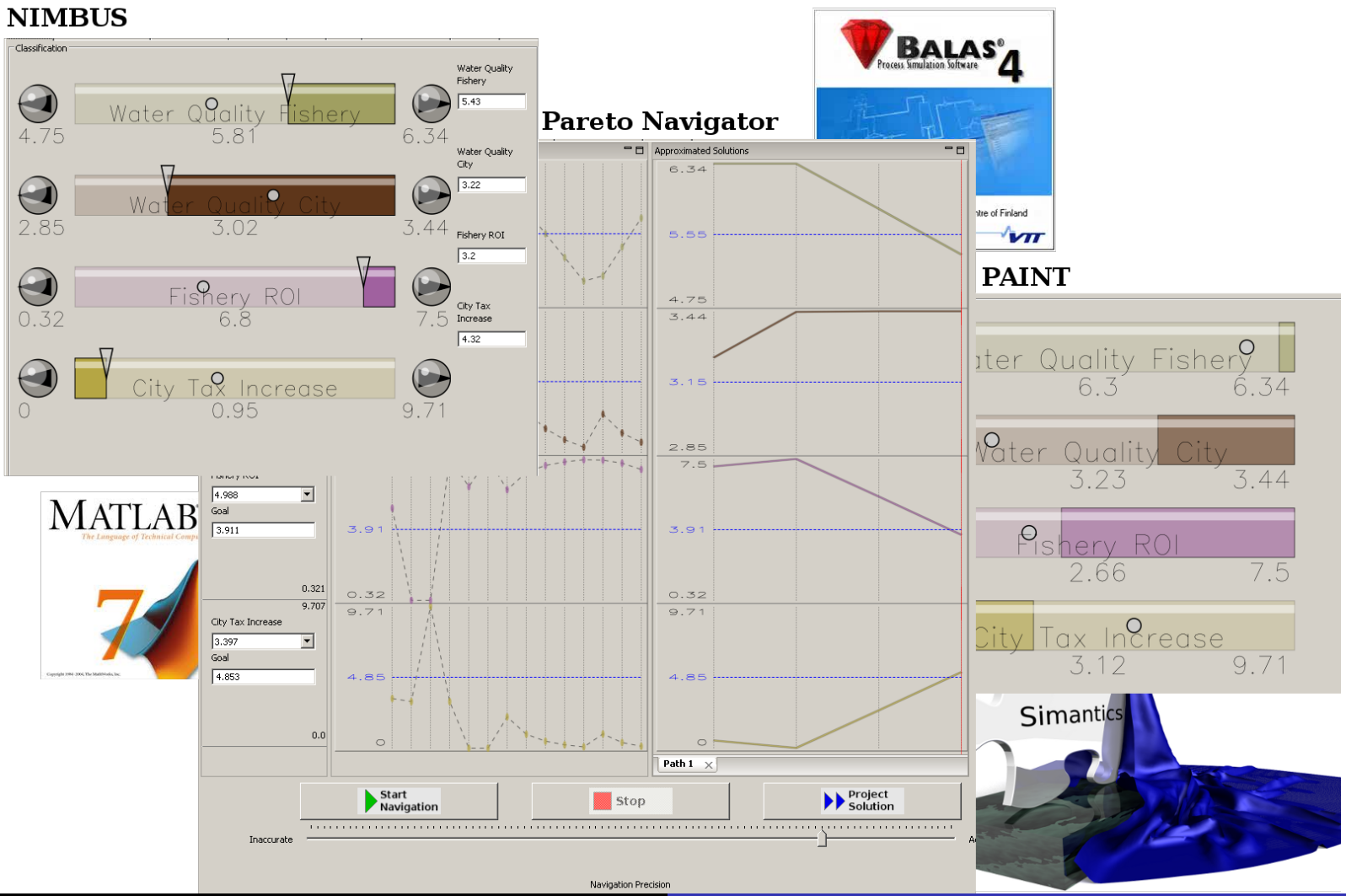
Major obstacles encountered

- Research project buy-in
  - Management – engineer
- Black-box optimization
  - Are current methods sufficiently robust?
  - Wider set of methods
  - Testing
- Computationally demanding problems
  - Parallel computing
  - Methods based on Pareto Frontier approximation
- Problem formulation
  - Different formulation for different methods
  - Not difficult, but time consuming
- Knowledge domain differences

Proposed Solution

- Software framework for multiobjective optimization: IND-NIMBUS
- Different multiobjective methods
  - Interactive methods: NIMBUS, Nautilus
  - Approximation Methods: Pareto Navigator, PAINT
  - EMO Methods: Hybrid NSGAII, UPS-EMO
- General interface for problem formulation
  - Programming languages
  - Simulator: Matlab, Balas
  - Problem Modelling: GAMS, CPLEX
  - Simulator Platforms: Simantics, CapeOpen

IND-NIMBUS Software framework



Future Challenges

- Closed source NIMBUS development
  - Set restrictions on usable tool set
  - Framework future?
- Black-box problem pre-analysis
  - DM Agent with an utility function?
- Platform implementation
  - Resources?
  - Motivation?

Thank You!

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References

Miettinen, K., Mäkelä, M.M., *Synchronous Approach in Interactive Multiobjective Optimization*, European Journal of Operational Research, 170(3), 909-922, 2006.

Eskelinen, P., Miettinen, K., Klamroth, K., Hakanen, J., *Pareto Navigator for Interactive Nonlinear Multiobjective Optimization*, OR Spectrum, 23, 211-227, 2010.

Laukkanen, T.; Tveit, T.-M.; Ojalehto, V.; Miettinen, K. & Fogelholm, C.-J. *An interactive multi-objective approach to heat exchanger network synthesis* Computers & Chemical Engineering, 2010 , 34 , 943-952

Hartikainen, M., Miettinen, K., Wiecek, M.M., *Constructing a Pareto Front Approximation for Decision Making*, Mathematical Methods of Operations Reserach, 73(2), 209-234, 2011.