MSc. thesis topics
Multiobjective Optimization Group

Many decision-making problems arising from real-world applications can be expressed as multiobjective optimization problems, where several, typically conflicting, perspectives need to be considered simultaneously. All these MSc thesis topics are related to supporting decision making with multiobjective optimization. Decision supporting skills are needed in all fields of life and, thus, completing a MSc thesis based on any of these topics increases your employability in the industry and offers an opportunity to pursue an academic career as well, if you so wish.

If you find any of the topics listed in this document interesting or want to know more, please contact one of the supervisors listed at the beginning of each topic. The emails of these members of the Multiobjective Optimization Group are in Table 1. Note that many of the topics have a lot of possibilities to customize the topic to better meet your own interests. The list of topics is directional. You may also propose a topic of your own related to any of the listed ones!

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Table 1: Contact information of the supervisors.

We have divided the topics into five categories: new methods for decision making, artificial intelligence in decision making, software development for decision making (DESDEO), cognition and decision making and real-life applications.

Collaboration: possibility to collaborate with the DESIDES, HYDRA, or UTOPIA projects and companies as a member of the Multiobjective Optimization Group (http://www.mit.jyu.fi/optgroup/)

Language options for supervision and completing the thesis: English (all supervisors) or Finnish (Kaisa Miettinen, Johanna Silvennoinen, Juuso Pajasmaa, Juho Roponen, and Giovanni Misitano)

Requirements: If the focus is on software development, programming skills are required (object-oriented programming, Python); if on empirical studies, experience in conducting empirical research is beneficial. For method development a strong mathematical/statistical background is beneficial. Optimization courses are also beneficial.

Introduction

When making decisions, the decision maker must typically balance among multiple conflicting perspectives. Simultaneous optimization of multiple conflicting objectives is known as multiobjective optimization. These problems have so-called Pareto optimal solutions (or compromises) representing different trade-offs and to find the best solution, it is necessary to involve a domain expert, known as a decision maker (DM), whose knowledge and preferences can be used to find preferred solution(s).

Based on how preferences are incorporated in the solution process, multiobjective optimization methods can be divided into distinct categories: a priori, a posteriori, and interactive methods. In interactive methods, the DM actively takes part in the solution process and preferences are incorporated during the optimization process. This has many advantages. For instance, interactive methods can focus on a particular subset of the Pareto optimal solutions that is interesting to the DM. This does not only save in computation costs, but also allows the DM to focus on solutions that best meet their current preferences. Our research group focuses on studying interactive methods.

The DESDEO framework (desdeo.it.jyu.fi) is an open-source Python framework for interactive multiobjective optimization developed in the Multiobjective Optimization research group. DESDEO contains interactive methods, which are implemented in a modular fashion. This allows reusing existing components when developing new methods. Most new methods are expected to be implemented as part of DESDEO as open-source software. For more information of DESDEO, see also the article Misitano, G., Saini, B. S., Afsar, B., Shavazipur, B., Miettinen, K., DESDEO: The Modular and Open Source Framework for Interactive Multiobjective Optimization, IEEE Access, 9, 148277-148295, 2021. https://doi.org/10.1109/ACCESS.2021.3123825

I - New methods for decision making

Topic 1: How to support the decision maker in switching between interactive methods? (Kaisa Miettinen, Johanna Silvennoinen and Bhupinder Singh Saini)

In interactive methods, the DM directs the solution process to find the most preferred solution. We can divide the solution process into two phases: learning and decision phases. During the learning phase, the DM explores different solutions to identify a region of interest. In the decision phase, the DM finds the most preferred solution by fine-tuning the search in the region of interest. Some interactive methods support the DM better during the learning phase, whereas others are better at exploiting the region of interest. Typically, only one interactive method is selected and applied in the solution process, and the type of preference information is specific to the method used. However, switching the method during the solution process can offer benefits. In this thesis, you will investigate approaches for switching interactive methods based on the DM's needs and preferred preference styles in distinct phases.

In other words, you find ways to enable the DM to switch the method (and the type of preference information) during the solution process. You will implement the mechanism you proposed as a part of the DESDEO framework (desdeo.it.jyu.fi).

Required skills

Prior experience in multiobjective optimization is desired. You should also be proficient in Python.

Learning outcomes

You will get first-person experience working in a research group. Your knowledge in decision support and interactive multiobjective optimization will increase significantly. You may also refine your findings as a conference or journal paper if you like.

Examples of tasks in this topic

- Studying literature to understand the need to switch between interactive methods during the solution process.
- Identifying challenges (what are needed) in switching between interactive methods.
- Implementing approaches enabling switching between interactive methods based on the preferred way of providing preferences by the DM during the solution process.

Topic 2: Ways to utilize the PAINT (PAreto front INTerpolation) approach when dealing with computationally expensive problems in DESDEO (Kaisa Miettinen, Babooshka Shavazipour and Giovanni Misitano)

The PAINT (PAreto front INTerpolation) method [1] is aimed at solving computationally expensive multiobjective optimization problems, where function evaluations are time-consuming (e.g., based on simulations). PAINT formulates a computationally inexpensive surrogate problem to replace the original one so that the Pareto optimal solutions of the surrogate problem approximate those of the original one. In practice, the method interpolates between a given set of Pareto optimal solutions to derive a mixed integer linear surrogate problem which can be solved with any interactive method to yield a preferred solution for the original problem in a faster way.

In this thesis, you will explore the existing literature on approximation methods (literature review) and the implementation of the PAINT method in the DESDEO framework to connect PAINT to the functionalities of DESDEO. Your thesis can also consist of a real-life case study using PAINT to approximate the Pareto optimal solutions and solve the problem with an interactive method. In this case, you may contribute to literature that can lead to a scientific publication.

Required skills

Prior knowledge of multiobjective optimization is desired. You should also be proficient in Python. A prior background in mathematics (approximation methods and numerical analysis) is also beneficial.

Learning outcomes

You will get first-person experience working in a research group. Your knowledge in decision support in general and in interactive multiobjective optimization and approximation methods for handling computationally expensive problems will increase significantly, and you can make significant contributions to open-source software development.

Examples of tasks in this topic

- Accomplishing a literature review on approximation methods for multiobjective optimization.
- Connecting the current implementation of the PAINT method to the functionalities of the DESDEO framework.
- Conducting a real-life case study using PAINT (your implementation) to approximate the Pareto optimal solutions and solve the problem with an interactive method. Otherwise, you can show the applicability of your implemented version in a hypothetical example (e.g., from the literature).

[1] Hartikainen, M., Miettinen, K., Wiecek, M. M., PAINT: Pareto front interpolation for nonlinear multiobjective optimization. Computational Optimization and Applications, 52(3), 845-867, 2012. https://doi.org/10.1007/s10589-011-9441-z

Topic 3: A systematic review on multiobjective robust decision making (MORDM) and its applications (Babooshka Shavazipour, Giovanni Misitano)

Many real-life decision-making problems involve multiple conflicting objective functions and various sources of uncertainty. In complex decision contexts, decision makers need decision-support tools that reveal trade-offs between conflicting objectives, identify potential sources of vulnerability, and help decision-makers select a robust policy that aligns with their preferences. A decade ago, a so-called manyobjective robust decision-making (MORDM) framework extended the robust decision-making (RDM) framework to facilitate the exploration of complex planning problems. (Here, manyobjective means multiobjective optimization.) A distinguishing feature of MORDM is using multiobjective optimization to simultaneously consider multiple objective functions and generate a broad range of alternative policies. Since its introduction, different versions of MORDM have been developed, improving its performance, usability, and robustness. They have also been applied to various real-life applications.

The primary purpose of this thesis is to review the advancements made in this field over the past decade, highlight remaining practical and theoretical challenges, and identify crucial areas for future research.

Required skills

Prior knowledge of multiobjective optimization and deep uncertainty or willingness to learn are needed as well as critical thinking and intendency to explore.

Learning outcomes

You will get first-person experience working in a research group. Your knowledge of decision support in complex real problems with multiple conflicting objective functions under deep uncertainty in general and MORDM will increase significantly. Assuming covering all relevant publications, giving a good overview of them, and identifying literature gaps and potential future research direction, your thesis research could also lead to a scientific publication as a conference or journal article. If you are interested, you can continue to doctoral studies to follow the identified research directions in related topics.

Examples of tasks in this topic

- Performing a literature review on one of the hot topics in complex decision-making.
- Reviewing various real-life applications of the complex decision-making process.

II - Artificial intelligence in decision making

Topic 4: Smart evolutionary algorithms for multiobjective optimization (Bhupinder Saini, Juuso Pajasmaa)

The use of evolutionary algorithms to solve real-world optimization problems has been getting increasing attention. Typically, evolutionary algorithms have several parameters that need to be set according to each problem. However, setting the right values for these parameters is a challenging task and sometimes we do not even know the effect of these parameters on the performance of the algorithm for a specific problem very well.

This thesis project aims to develop an AI-driven approach for optimizing evolutionary algorithms. You will study various evolutionary methods and create an AI (Artificial Intelligence) system that analyzes these methods and their target problems. The AI will automatically set and dynamically fine-tune parameters to maximize algorithm performance. If results are promising, you may co-author a scientific paper. You will also have the opportunity to implement your method in the DESDEO framework as part of our software development team.

Required skills

Expertise in Python, basics of multiobjective optimization or willingness to learn, algorithmic thinking and familiarity with basic concepts of machine learning.

Learning outcomes

You will get first-person experience working in a research group. Your knowledge in artificial intelligence and algorithm development will increase significantly. You may also expect your master's thesis to be eligible to be extended into a conference or journal article.

Examples of tasks in this topic

- Learning more about evolutionary multiobjective optimization methods and how to modify them to be applicable to real-world problems.

- Exploring diverse ways of making evolutionary methods self-adaptive based on the problem that is being solved.
- Building and training AI models that explore various aspects of multiobjective optimization problems being solved and making a connection between the problem domain and the parameters of the evolutionary algorithms to increase the algorithms' performance.

Topic 5: Modeling decision maker's preferences with belief-desire-intention agents (Bekir Afsar, Giovanni Misitano and Juho Roponen)

Eliciting and modeling the preferences of a DM is a challenging task. Many methods exist to accomplish this. However, they often leave much to be desired. One interesting approach is to look at agents able to support the DM to express and model their preferences. Agents adhering to a belief-desire-intention (BDI) architecture, a software model that can accommodate for qualitative knowledge, are a promising kind of agent that can address this issue.

The agents should be able to model a DM's preferences in such a way that they could be used to find solutions that satisfy the DM. The agents can be implemented as standalone entities or be made part of some existing interactive methods by enhancing them. The implemented agents will be made part of the DESDEO framework. This topic has a lot of potential for novel contributions in the multiobjective optimization field of research. This topic is ideal for someone interested in pursuing doctoral studies after graduating or in a challenging MSc thesis topic.

Required skills

Prior experience in multiobjective optimization is desired. You should also be proficient in Python and Linux environments. Prior experience in agent systems is also beneficial, but not required.

Learning outcomes

You will get first-person experience working in a research group. Your knowledge in interactive multiobjective optimization will increase significantly, and you will have made significant contributions to open-source software in DESDEO. This is a good opportunity to boost your GitHub profile, if desired.

If you are interested, you can continue to doctoral studies. You may also expect your master's thesis to be eligible to be extended into a conference or journal article.

Examples of tasks in this topic

- Familiarizing yourself with the BDI architecture and its applications in the literature.
- Exploring ways for BDI agents to learn and model a DM's preferences.
- Implement a BDI agent that can learn and model preferences and validate your method either numerically or with a real DM, or both.

Topic 6: Agent-based negotiation support for group decision making in multiobjective optimization (Bekir Afsar, Kaisa Miettinen and Juuso Pajasmaa)

Existing interactive methods typically involve a single decision maker, but in many real-world applications, there exists more than one decision maker (stakeholder) in identifying the best compromise solution that should satisfy all parties involved. In such solution processes, collaborative preference elicitation and negotiation processes are necessary to find a group consensus.

Negotiation protocols are a well-studied and established research field in multi-agent systems that enable groups of agents to reach a mutual agreement in dynamic environments to carry out the tasks assigned to them. Because the agents are autonomous and can be reactive or proactive, negotiation is essential for managing such multiple intelligent agents. The negotiation process can take numerous forms, such as auctions, contract net protocols, or argumentation.

During the interactive solution process, each decision maker provides their preference information (e.g., a reference point), which may be contradictory with preferences of other decision makers due to their diverse roles. We support a group of decision makers in finding compromise preferences. In this thesis, you will explore ways of applying multi-agents and negotiation protocols to aggregate competing preferences and create compromise preference information satisfying all parties involved. By using existing agent-based negotiation protocols preference agents attempt to reach an acceptable group preference (e.g., compromise reference point), which is then incorporated in the interactive solution process. The first part of the thesis will be a review of relevant literature.

Required skills

Prior experience in multiobjective optimization and multi-agent systems is required. You should also be proficient in Python and Linux environments.

Learning outcomes

You will get first-person experience working in a research group. Your knowledge in multiobjective optimization and multi-agent systems will increase significantly. If you are interested, you can continue to doctoral studies. You may also expect your master's thesis to be eligible to be extended into a conference or journal article, if you like.

Examples of tasks in this topic

- Performing a literature review of existing agent-based negotiation support protocols.
- Constructing preference agents which model the decision maker's preferences.
- Applying one of the existing negotiation protocols on multiple preference agents to reach a group consensus when solving a multiobjective optimization problem.

Topic 7: Explainable artificial intelligence/machine learning in modeling data-driven multiobjective optimization problems (Juho Roponen, Michael Emmerich, Bhupinder Saini, Giovanni Misitano and Bekir Afsar)

Data-driven multiobjective optimization problems are based on some real-world data. Before any optimization process, the multiobjective optimization problem must be modeled to determine which decision is to be made based on the data. This involves defining the objective functions, constraints, and decision variables. Domain knowledge of the problem is therefore necessary, which is why the presence of a decision maker, or some other domain expert is crucial during the modeling process.

Machine learning (surrogates) can be used in the modeling due to the complexity of the data. Typically, machine learning models used are opaque box in nature, i.e., it is not clear to an outside observer how the model makes predictions. This can be a problem, for example, if the objective functions in a multiobjective optimization problem are modeled with black-boxes in a high-stakes domain, such as healthcare. The predictions made by the machine learning model must be justifiable and explainable.

Explainable artificial intelligence (XAI) is a research field that studies the prospect of explaining the predictions made by black-box machine learning models among other things. While machine learning has been utilized in multiobjective optimization before, the inclusion of XAI has not been studied much. XAI could help make the predictions in data-driven multiobjective optimization less oblique, justifiable, and explainable.

In this thesis, you will explore the novel prospect of utilizing XAI methods in data-driven multiobjective optimization. For example, your thesis could consist of a real-life case study where a data-driven multiobjective optimization problem is modeled using XAI. Thanks to the novelty of this research topic, this can lead to a scientific publication as well.

Required skills

Prior experience in multiobjective optimization is desired. You should also be proficient in Python and Linux environments. Prior experience in agent systems is also beneficial, but not required.

Learning outcomes

You will get first-person experience working in a research group. Your knowledge in multiobjective optimization will increase significantly. If you are interested, you can continue to doctoral studies. You may also expect your master's thesis to be eligible to be extended into a conference or journal article, if you like.

Examples of tasks in this topic

- Performing a literature review of existing XAI methods to grasp the idea of explaining machine learning models.
- Explaining a data-driven multiobjective optimization surrogate model by utilizing existing XAI methods.
- Studying the benefits of having explanations on the multiobjective optimization model.

Topic 8: Advancements in evolutionary algorithms for computationally expensive multiobjective optimization problems (Kaisa Miettinen and Bhupinder Saini)

Evolutionary algorithms are population-based methods, and they can be used to solve various real-world multiobjective optimization problems. When the problem is computationally expensive, that is, objective function value evaluations take time, we need ways to speed up calculations. One approach is to fit computationally less expensive surrogate models to data available and use the surrogates instead of the computationally expensive functions. We use different machine learning models as surrogate models.

In this thesis, you will work closely with several types of evolutionary methods and machine learning models. The first part of the thesis is to conduct a literature review of approaches developed for

computationally expensive problems applying evolutionary multiobjective optimization problems. One example of such methods is presented in [2]. You are also expected to implement the method described in [2] as a part of the DESDEO framework utilizing its existing modular element as much as possible. Therefore, you can be a part of our software development team.

Required skills

Expertise in Python, basics of multiobjective optimization or willingness to learn, algorithmic thinking and familiarity with basic concepts of machine learning are expected.

Learning outcomes

You will get first-person experience working in a research group. Your knowledge of multiobjective optimization, artificial intelligence and algorithm development will increase significantly. You will learn about evolutionary multiobjective optimization methods, machine learning models as surrogate models and model management to create methods that are applicable to real-world problems.

Examples of tasks in this topic

- Conducting a literature review of surrogate-based evolutionary methods for multiobjective optimization to have an understanding of the state-of-the-art.
- Implementing the HSMEA method proposed in [2] as a part of the DESDEO framework.

[2] Habib, A., Singh, H.K., Chugh, T., Ray, T., Miettinen, K., A Multiple Surrogate Assisted Decomposition Based Evolutionary Algorithm for Expensive Multi/Many-Objective Optimization, IEEE Transactions on Evolutionary Computation, 23(6), 1000-1014, 2019. ttps://doi.org/10.1109/TEVC.2019.2899030

III - Software development for decision making (DESDEO)

Topic 9: Developing advanced, user-friendly interfaces for interactive multiobjective optimization methods (Bhupinder Singh Saini, Giovanni Misitano, Johanna Silvennoinen, Kaisa Miettinen and Giomara Larraga)

Developing interfaces for interactive multiobjective optimization methods has various challenges. The data being visualized is often multidimensional (more than three dimensions, that is, objective functions) and the interface must support the DM in expressing their preferences in diverse ways. Moreover, different DMs may prefer the same data to be visualized in different ways or express their preferences in varying ways.

DESDEO already has user interfaces for some methods, but this thesis project focuses on developing the usability and understandability of the user interfaces for decision makers interacting with interactive multiobjective optimization methods in DESDEO. From the technical side, your work on developing user interfaces would focus on certain aspects like visualization or general navigation in the solution process. Like DESDEO in general, user interfaces should also be modular so that developing user interfaces for new methods could utilize existing modules as much as possible.

Required skills

Prior experience in multiobjective optimization is useful, but not required. You should be proficient in Python and TypeScript. Particularly, you should have at least some prior experiences in developing Svelte apps. Knowledge of Apache Echarts, D3.js, or similar frameworks, is also an advantage. The focus in this thesis is on practical software (frontend) development.

Learning outcomes

You will get first-person experience working in a research group. Your knowledge in interactive multiobjective optimization will increase significantly. You will be making contributions to open-source software DESDEO, which can boost your GitHub profile to the next level. You will also gain considerable experience in web development.

Examples of tasks in this topic

- Working with the various components found in the DESDEO framework.
- Extending the existing web-based interface with a dynamic layout for some existing interactive methods.
- Doing full-stack web development with a particular focus on the front-end.

Topic 10: Physical interfaces for interactive multiobjective optimization (Bhupinder Singh Saini, Johanna Silvennoinen, Juuso Pajasmaa and Juho Roponen)

In this thesis, you will work on the development of fully modular physical user interfaces for interactive multiobjective optimization methods. This work will be done as an extension to the DESDEO framework (desdeo.it.jyu.fi), which has implementations of interactive multiobjective optimization methods and supports the use of physical interfaces (such as buttons and sliders) built using microcontrollers such as Arduinos.

Additionally, you can integrate haptic feedback and braille script modules. Your work will include creating new ways of physically interfacing with interactive methods, creating custom hardware to try out and test these new interfaces, and implementing software connecting the hardware to the methods. This is a novel field where you are expected to mix engineering and design mindsets.

Your work may also include examinations of how humans represent actual information and how this kind of knowledge can be incorporated into tactual design of components within physical user interfaces. Further investigation can be conducted with brain interface devices to understand the effect of using physical interfaces. You will be able to write a publication based on your work if you wish.

Required skills

Knowledge of multiobjective optimization is useful but not required. You should be comfortable with Python and JavaScript/TypeScript programming (for working with the DESDEO framework). Experience in working with Arduinos (ATmega series, STM32, ESP32 etc.) and other electronic components, and hence C/C++ programming is also required. Prototyping circuits on breadboards, basic soldering skills and PCB designing will be helpful.

Learning outcomes

You will get experience in working in a research group on an open-source project under active development. You will learn about the current state-of-the-art in interactive multiobjective optimization. You will gain experience in creating custom hardware using microelectronics and learn about how to create good user interface designs.

Examples of tasks in this topic

- Building novel physical interfaces to interact with various multiobjective optimization methods developed in the Multiobjective Optimization Group.
- Exploring previously uncharted research areas in our field, such as how humans represent tactual information.
- Possibility to even develop tools to support visually impaired people to operate our methods.

Topic 11: Interactive visualizations for multiobjective optimization under uncertainty (Babooshka Shavazipour and Juho Roponen)

Besides multiple conflicting objective functions, real-life problems are characterized by uncertainty. It is desirable to make robust decisions that are not too sensitive to the consequences of uncertainty, i.e., they perform well in a wide range of future states or events (scenarios).

In scenario-based multiobjective optimization problems, the performance of a decision should be evaluated regarding each objective function in different scenarios, bringing an additional dimension to the performance evaluation and complicating the decision maker's task. Visualization supports are needed to help the decision maker understand and compare trade-offs between different objective functions and evaluate and analyze trade-offs between the performances of a solution in various scenarios (called trade-offs between scenarios). Recently, two visualization methods: a novel extension of empirical attainment functions for scenarios and an adapted version of heatmaps, have been proposed [3] to help decision makers gain insight into realizations of trade-offs and comparisons between objective functions in different scenarios.

In this thesis, you will implement an interactive version of these visualizations in the DESDEO-components library and connect them to the DESDEO user interface. Note that the static version of the codes is available in the R programming language and some elements already also exist in Python. Your thesis can also consist of designing an experimental study (e.g., with some students) to test the utility of these visualizations compared to some others. In this case, you may contribute to literature that can lead to a scientific publication.

Required skills

You should be proficient in Python. Prior background in mathematics/statistics and R is also beneficial.

Learning outcomes

You will get first-person experience working in a research group. Your knowledge in decision support in general and in scenario-based multiobjective optimization will increase significantly, and you can make significant contributions to open-source software development.

Examples of tasks in this topic

- A literature review of interactive visualizations.
- Implementing (coding) interactive visualizations in the DESDEO framework and testing them by reproducing the figures of the paper.
- Performing an experimental study with human participants.

[3] Shavazipour, B., López-Ibáñez, M., Miettinen. K., Visualizations for decision support in scenario-based multiobjective optimization. Information Sciences, 578, 1–21, 2021.
https://doi.org/10.1016/j.ins.2021.07.025

Topic 12: Showcasing the modularity of DESDEO (Kaisa Miettinen, Giovanni Misitano, Giomara Larraga and Bhupinder Saini)

By choosing this topic, you will be embarking on a journey during which you will learn about different interactive multiobjective optimization methods. You will delve into the practicalities of each method and will get hands-on experience on solving multiobjective optimization problems based on real-life cases. You will also experience collaboration on an open-source project, which is a seldom taught but ever needed skill; both in industry and in the academic world.

In this thesis, we expect that you will combine pieces of existing multiobjective optimization methods creating new composite methods using DESDEO. These new methods should be tested on real-life problems and mutually compared. We expect a sound scientific analysis in the comparison of the methods. We also expect you to contribute to the DESDEO software framework during your thesis work.

These contributions should be related to combining existing methods, for example, contributions to easing the combination process are more than welcome. To our knowledge, this kind of “mix and matching” of interactive multiobjective optimization methods has not been studied much in the current literature. Therefore, you can also expect to be able to write a publication based on your master’s thesis.

Required skills

Prior experience in multiobjective optimization is desired. You should also be proficient in Python and Linux environments.

Learning outcomes

You will get first-person experience working in a research group. Your knowledge in decision support and interactive multiobjective optimization will increase significantly. You may also expect your master’s thesis to be eligible to be extended into a conference or journal article.

Examples of tasks in this topic

- Combining pieces of existing methods for interactive multiobjective optimization into new methods.
- Testing your newly implemented methods with problems based on real-life cases. You also have the possibility to test your methods with human decision makers.
- Implementing the new methods as a part of the DESDEO framework as open-source software.

IV - Cognition and decision making

Here are some of the possible topics. They can have different research approaches, for example, empirical studies with decision makers, more theoretically oriented reviews focusing for example on method development or implementing visualization elements to interactive methods.

Supporting decision making with visualizations

- Fitting to the cognitive styles of the decision maker. What visualizations best support decision makers in different decision contexts?
- Going to the element level. How the information is presented to the decision maker. How visualizations can be enhanced by examining the constructing elements in detail.
- How different visualization methods affect the decision process. Looking into more visualization methods in the literature and examine how final solutions are affected by the utilized visualizations

Cognitive and affective de-biasing in multiobjective decision making with interactive methods

1. Examining different heuristics and biases essential in multiobjective decision making with interactive methods from expert decision-making perspective. What are the central ones, and which phase of the decision process do these occur (positive and negative aspects).
2. What de-biasing methods are suitable for this decision-making context. What other methods could be utilized and developed? Can the most suitable de-biasing methods be implemented to interactive methods?

Topic 13: Cognitive biases in interactive multiobjective optimization (Kaisa Miettinen and Johanna Silvennoinen)

Decision making with multiple conflicting objective functions is a complex cognitive-affective process. Interactive multiobjective optimization methods are in a vital role in aiding decision makers to solve complex problems. Research is required to understand what kind of cognitive biases occur and affect decision making processes and how interactive multiobjective optimization methods could be designed to inform decision makers of cognitive biases enabling making better decisions.

Overall, cognitive, and affective processes in decision making with interactive methods in multiobjective optimization is a vast research area with many research topics. This includes, for example, examinations of what cognitive and affective biases are central within this decision-making context and how to implement information of these in a manner that aids the decision makers. Multiobjective optimization with interactive methods is a unique research context for human-computer interaction, therefore other biases besides the most frequently mentioned in the judgment and decision-making literature (e.g., anchoring and availability), can have a key role. Thus, research is required to understand context-specific biases for enabling making better decisions.

In addition, efficient cognitive and affective de-biasing methods are important to be studied. These can include approaches, such as the role of metacognitive processes and possibilities of group decision making procedures towards debiased decision making, to name a few. Also, expert thinking in decision making as

its own sub-discipline is essential to be examined within this interaction context. All the issues raised above can also be examined from an expert thinking perspective.

All the research topics introduced above have a lot of potential for novel contributions in the multiobjective optimization field and within decision making research. These research topics are ideal for someone who is interested in pursuing doctoral studies after graduating but can also be conducted within a master's thesis (with a more narrowly scoped research topic).

Required skills

Prior knowledge of multiobjective optimization and cognitive science, especially regarding decision making is desired, but not mandatory for a master's thesis. For doctoral studies, a master's degree from applicable research areas is required.

Learning outcomes

You will get experience in working in an interdisciplinary research group, combining multiobjective optimization and cognitive science. This kind of knowledge and expertise is essential for current and future human-centered technology development. If the master's thesis is completed within one of these research topics, this gives you excellent capabilities of pursuing doctoral studies. There is also a possibility to extend your master's thesis into a conference or journal article with moderately little effort, if you prosper in your thesis.

Examples of tasks in this topic

- A literature review of cognitive and affective biases central in multiobjective decision making or a literature review of cognitive and affective de-biasing methods in multiobjective decision making.
- Implementation of methods and design of experimental studies (e.g., implementing de-biasing methods and conducting experimental studies on how they can aid decision makers towards better decisions.
- Performing designed experimental studies.

Topic 14: Explicating human decision makers' cognitive capacities in interacting with multiobjective optimization methods (Kaisa Miettinen, Johanna Silvennoinen and Juuso Pajasmaa)

In developing multiobjective optimization methods, what kind of design requirements are essential when the decision maker is a human? What human cognitive processes (e.g., cognitive capacity, cognitive load, and preference construction) should be acknowledged and incorporated in developing and designing multiobjective optimization methods to aid decision makers in solving complex problems with conflicting objective functions? This is an important and timely topic as often one can see in the literature that humans are assumed to be able to operate similarly to machines. *What does it mean for developing multiobjective optimization methods that the decision maker is a human* is the main question and can be further divided into more detailed problematizations. For example, how much information a decision maker can be assumed to process at a time and what kind of preference information the decision maker can be assumed to provide, and how tradeoffs should be represented to increase cognitive information processing fluency. Additionally, what other cognitive processes are relevant when considering group

decision situations? How much do well-known concepts such as information overload, coordination loss and interpersonal conflicts affect the human decision makers in group decisions? How could they be considered in interactive methods?

Required skills

Prior knowledge of cognitive science and multiobjective optimization, especially regarding decision making is desired, but not mandatory for a master's thesis. For doctoral studies, a master's degree from applicable research areas is required.

Learning outcomes

You will get experience in working in an interdisciplinary research group, combining multiobjective optimization and cognitive science. This kind of knowledge and expertise is essential for current and future human-centered technology development, especially rooting multiobjective optimization method development in sound cognitive scientific theoretical grounds. If the master's thesis is completed within one of these research topics, this gives you excellent capabilities of pursuing doctoral studies. There is also a possibility to extend your master's thesis into a conference or journal article with moderately little effort, if you prosper in your thesis.

Examples of tasks in this topic

- Research on this topic could contribute to developing user interface design guidelines for designing methods that acknowledge central human cognitive processes within this interaction context (such as, cognitive capacity and cognitive load issues).
- Conducting a literature review mapping problematic assumptions and answering to these assumptions of human cognitive processes with a developed theoretical framework
- Based on an identified problematic assumption (for example, on cognitive capacity in indicating preference information) designing an experiment to examine the capacity within the certain context and contributing the field by examining and empirically indicating the actual cognitive capacities that can be assumed and, thus should serve as the guideline in designing multiobjective optimization methods.

Topic 15: Supporting decision making with visualizations (Kaisa Miettinen, Johanna Silvennoinen, Giovanni Misitano, Bhupinder Singh Saini, Giomara Larraga and Juho Roponen

Interactive multiobjective optimization methods are based on interactive visualizations as the concrete contact points between the decision support system and the human decision maker. Thus, interactive information visualizations are in the core of this research area. Visual information can be presented in many ways. In-depth knowledge can be obtained by studying different visual elements of visualizations and the ways they are understood and how they can be designed in a way that supports decision makers. For example, knowledge of human visual information processing can be implemented as design solutions giving more predictability to the way decision makers cognize visualizations. For interactive visualizations to aid decision makers, it is important to examine how information needs to be presented.

This topic includes, at least, the following research topics: reviewing visualizations to be implemented, examinations of how different visualizations affect decision making processes and solutions, experiments on how different visualizations are cognized with different interactive multiobjective methods, how to enhance interactivity of visualizations and, how to incorporate decision maker's cognitive styles with different visualizations. Research is required to understand what kind of visualizations are efficient in this human-computer interaction context from varying perspectives.

In addition to the topics introduced above, much research is needed in developing research methods on how to study decision maker's understandings and experiences of utilizing interactive multiobjective optimization methods. These include, for example, developing validated measurements within this research contexts for understandability of visualizations, and for example, user satisfaction. These research topics have a lot of potential for novel contributions in the multiobjective optimization and information visualization fields. The presented research topics are ideal for someone who is interested in pursuing doctoral studies after graduating but can also be conducted within a master's thesis (with a more narrowly scoped topic). These topics can also be conducted as pair-wise master's theses, combining expertise from students of cognitive science and computational sciences (e.g., mathematical information technology).

Required skills

Prior knowledge of multiobjective optimization and cognitive science, especially regarding decision making, information visualization, and method development in human sciences are desired, but not mandatory for a master's thesis. For doctoral studies, a master's degree from applicable research areas is required.

Learning outcomes

You will get first-person experience working in an interdisciplinary research group combining multiobjective optimization and information visualization design from the perspective of cognitive science. This kind of knowledge and expertise is essential for current and future human-centered technology development. If a master's thesis is completed within one of these research topics, this gives excellent capabilities for pursuing doctoral studies. There is also a possibility to extend the master's thesis into a conference or journal article with moderately little effort, if you prosper in your thesis.

Examples of tasks in this topic

- Performing a literature review on how visualizations have been used in the context of multiobjective optimization to support decision makers.
- Exploring the literature on how different visualizations have been perceived by humans in different contexts.
- Designing an experiment to measure how visualizations need to be presented to best support human decision making in the context of multiobjective optimization.
- Conducting the designed experiment(s). The experiments can also be conducted as a part of some continuation work based on your MSc thesis, such as a journal or conference article.

V - Real-life applications

Topic 16: Handling small datasets with machine learning or statistical methods in personalized medicine (Babooshka Shavazipour, Bekir Afsar)

When a clinician selects an exercise therapy for a patient, (s)he must simultaneously consider several perspectives like reducing pain, improving physical function, reducing the number of supervised sessions, increasing adherence, keeping the cost reasonable, etc. Some of them are conflicting since improving physical function may need extra supervised sessions and increase cost, and the task is to find the best balance, i.e., the best compromise. However, there are no explicit guidelines or tools available to support clinicians. Therefore, decision support tools are needed to compare several compromises with different trade-offs and confidently choose the best-fitted exercise therapy considering the characteristics of individual patients.

In the Multiobjective Optimization Group, we have started developing data-driven interactive multiobjective optimization methodology [4], which is different from the conventional meta-analyses carried out in the clinical field of research, to find a straightforward way to choose a personalized best-fitted exercise therapy for each patient based on the available research data.

As a part of it, we need prediction models for our data-driven consideration to estimate the efficiency measurements of the selected trials based on several identified objective functions. Unfortunately, most of the available trials include only a few tens of participants/samples, while state-of-the-art predictors (e.g., (deep) neural network and Gaussian regression) often need several hundred/thousand samples to provide predictions with reasonable accuracy. So, they cannot be simply applied in exercise therapy studies.

In this thesis, you will explore the existing literature on handling small datasets (with machine learning/statistical methods or both) and identify potential ways/methods to be used as prediction models in dealing with small datasets. Your thesis can also consist of testing various prediction models in a real case study (e.g., a published randomized control trial) to compare their performances. In this case, you may contribute to literature that can lead to a scientific publication.

Required skills

Prior knowledge of artificial intelligence, statistics, and multiobjective optimization is desired. You should also be proficient in programming with Python or R or both.

Learning outcomes

You will get first-person experience working in a research group. Your knowledge in decision support in general and in data-driven interactive multiobjective optimization and health-based applications will increase significantly. If you are interested, you can continue to doctoral studies.

Examples of tasks in this topic

- Performing a literature review on handling small datasets with machine learning or statistical methods.
- Identifying and testing potential methods on a real-case dataset.

[4] Shavazipour, B., Afsar, B., Multanen, J., Miettinen, K., & Kujala, U. M. (2022). Interactive multiobjective optimization for finding the most preferred exercise therapy modality in knee osteoarthritis. *Annals of Medicine*, *54*(1), 181-194. https://doi.org/10.1080/07853890.2021.2024876

Topic 17: Case study of industrial applications of multiobjective optimization (Juho Roponen, Bhupinder Saini, Kaisa Miettinen, Juuso Pajasmaa and Babooshka Shavazipour)

This topic is intended for students who wish to author their thesis about applying multiobjective optimization to support a company or a governmental organization in their decision-making. **Already before contacting us** about your thesis topic, you should have a good general idea of what the problem you are trying to solve is, and have a person inside the company who is willing to act as a point of contact and support you as a subject matter expert and by instructing you in your thesis work. If you are also employed by the company, that is even better.

Multiobjective optimization is a mathematical and computational approach used to solve problems with multiple conflicting objective functions. It is a valuable tool in various fields and can be used for a wide range of applications, including but not limited to:

- Designing products or systems that need to optimize multiple criteria, such as cost, performance, and durability.
- Portfolio optimization to balance risk and return and possible other perspectives (like sustainability) in investment strategies.
- Determining an optimal resource allocation in conservation efforts, considering factors like biodiversity, cost, and land use.
- Route planning and vehicle scheduling minimize both travel time and fuel consumption.
- Supply chain optimization, considering factors like cost, delivery time and inventory levels.
- Treatment planning in healthcare optimizes multiple patient-specific objectives, such as maximizing treatment effectiveness while minimizing side effects.
- Policymaking and governance, where decisions need to consider multiple conflicting objective functions.

The exact methods to be used in your thesis will depend on the problem you are solving. We should discuss the goals and scope of your research and the methods to apply with your company contact. If you want a general idea what the methods might look like, you can browse the other topics provided here.

Required skills

Prior knowledge of multiobjective optimization or related topics is desirable. The exact skills required will also depend on the problem you intend to solve.

Learning outcomes

You will get first-hand experience in working in a research group and in applying optimization methods in practical real-life problems, giving you valuable experience in both multiobjective optimization and

the subject field. Assuming relevant and novel methods are used, your thesis research could also lead to a scientific publication in a conference or journal article.

Examples of tasks in this topic

- Supporting a company in their product or process planning.
- Creating a tool to aid some decision-making or planning process.
- Finding novel applications to existing multiobjective optimization methods.

Topic 18: Solving truck loading problem with interactive multiobjective optimization (Michael Emmerich, Giomara Larraga and Babooshka Shavazipour)

The problem of loading trucks is closely related to the more abstract 3D bin packing problem, which has received considerable attention in the literature. Like its easier variant, the 2D bin packing problem, this problem is NP-hard and the best-known exact algorithms scale exponentially with the problem size. Therefore, smart algorithms are needed to find optimal or close-to optimal solutions for realistic problem sizes. Most of the existing problems only consider one objective function and ignore some practical requirements and limitations.

There are some models and implementation of simple cases are available but needs improvement and consideration of additional practical requirements. The topic of the thesis is to study the literature, identify and implement solution methods for truck loading problems with the help of interactive multiobjective optimization methods.

Required skills

Prior knowledge of multiobjective optimization or related topics is desirable. You should also be proficient in programming with Python.

Learning outcomes

You will get first-person experience working in a research group. and in applying optimization methods in practical real-life problems

Examples of tasks in this topic

- Identification and implementation of solution methods.
- Creating a tool to aid some decision-making or planning process.

Topic 19: Portfolio management under deep uncertainty (Babooshka Shavazipour)

Typical portfolio management approaches are based on stochastic models and rely mostly on perfect predictions. However, most of the predictions failed to some extent. In the absence of reliable predictions, robustness analysis may be more efficient and provide a more realistic view of the possibilities and vulnerabilities. The aim is to develop a decision support tool by integrating multiobjective optimization, forecasting, and decision-making under deep uncertainty for portfolio selection.

Required skills

Prior knowledge of multiobjective optimization or related topics, scenario planning, portfolio management is desirable. You should also be familiar with programming with Python.

Learning outcomes

You will get first-person experience working in a research group. Your knowledge in decision support in complex real problems with multiple conflicting objectives under deep uncertainty in general and portfolio management will increase significantly. Assuming relevant and novel methods are used, your thesis research could also lead to a scientific publication in a conference or journal article. If you are interested, you can continue to doctoral studies.

Examples of tasks in this topic

- Performing a literature review on portfolio management under deep uncertainty.
- Formulating a multi-scenario multiobjective optimization problem for portfolio management based on some available models in the literature.
- Extracting real data from some open resources.
- Creating a tool to aid some decision-making or planning process.

Topic 20: Supply management under disruptions (Babooshka Shavazipour)

Recent worldwide crises highlighted the vulnerability of our previous decisions to trust unreliable but cheap supply options. Thus, there is an essential need for considering potential disruptions and finding robust solutions to avoid collapses in such an unpredictable situation. However, Decision-making in this crucial issue involves long-term planning, multiple stockholders with conflicting objectives, and handling various sources of deep uncertainty. This thesis paves the way for addressing the abovementioned challenges by developing a decision-support tool based on multiobjective optimization for sustainable and resilient planning in supply chain management. The aim is to develop a decision support tool by integrating multiobjective optimization, forecasting, and decision-making under deep uncertainty for supply chain management.

Required skills

Prior knowledge of multiobjective optimization or related topics, scenario planning, and supply chain management is desirable. You should also be familiar with programming with Python.

Learning outcomes

You will get first-person experience working in a research group. Your knowledge of decision support in complex real problems with multiple conflicting objectives under deep uncertainty in general and supply chain management will increase significantly. Assuming relevant and novel methods are used, your thesis research could also lead to a scientific publication in a conference or journal article. If you are interested, you can continue to doctoral studies.

Examples of tasks in this topic

- Performing a literature review on supply chain management under disruptions.

- Formulating a multi-scenario multiobjective optimization problem for supply chain management based on some available models in the literature.
- Extracting/generating data.
- Creating a tool to aid some decision-making or planning process.