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Visualizations and User Interfaces To Support Decision-Making

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2. Visualizations for the objective space (Sets, comparisons, preferences)
3. Visualizations for the decision space
4. GUIs to support decision-making
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6. Recommended articles

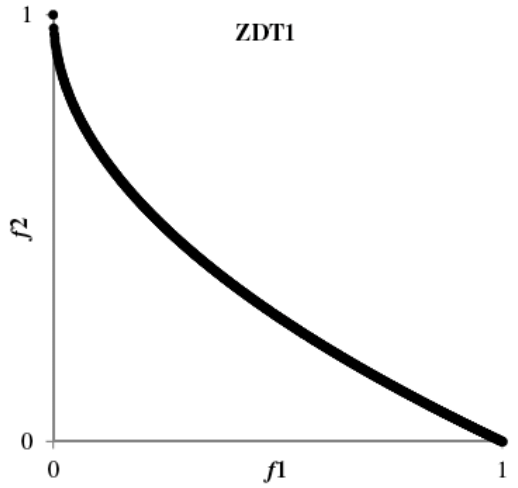
Introduction

Real-world decisions are not simple:

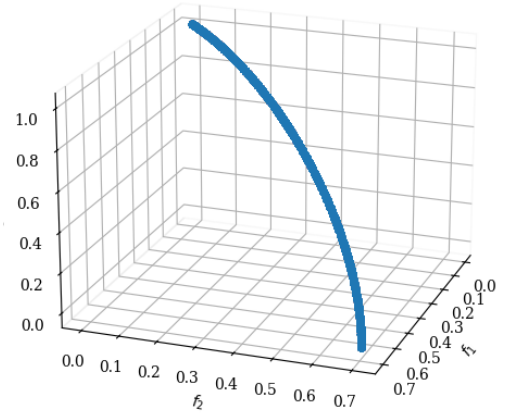
- Multiple **conflicting objectives**
- No “perfect” choice → **trade-offs are inevitable**
- We rely on **Pareto optimal solutions** (improve one, impair another)
- We need **more than numbers** → We need visuals to **explore**, **compare**, and **choose**.

Why Do We Need Visualizations?

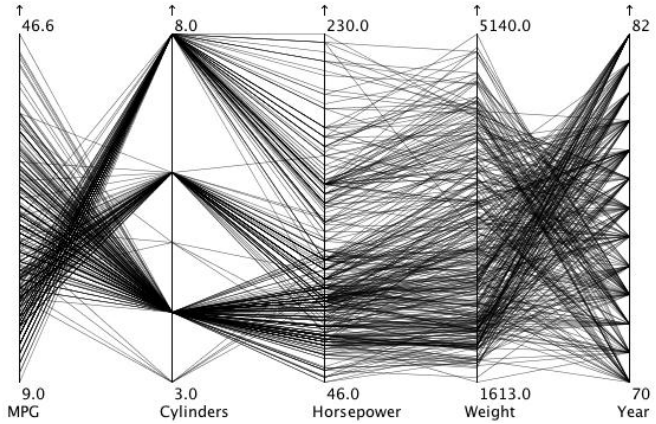
- High-dimensional problems:
  - 2 objectives → simple plot
  - 3+ → harder to imagine
  - 5+ → visuals are ***essential***
- All DMs are different



2 objective functions



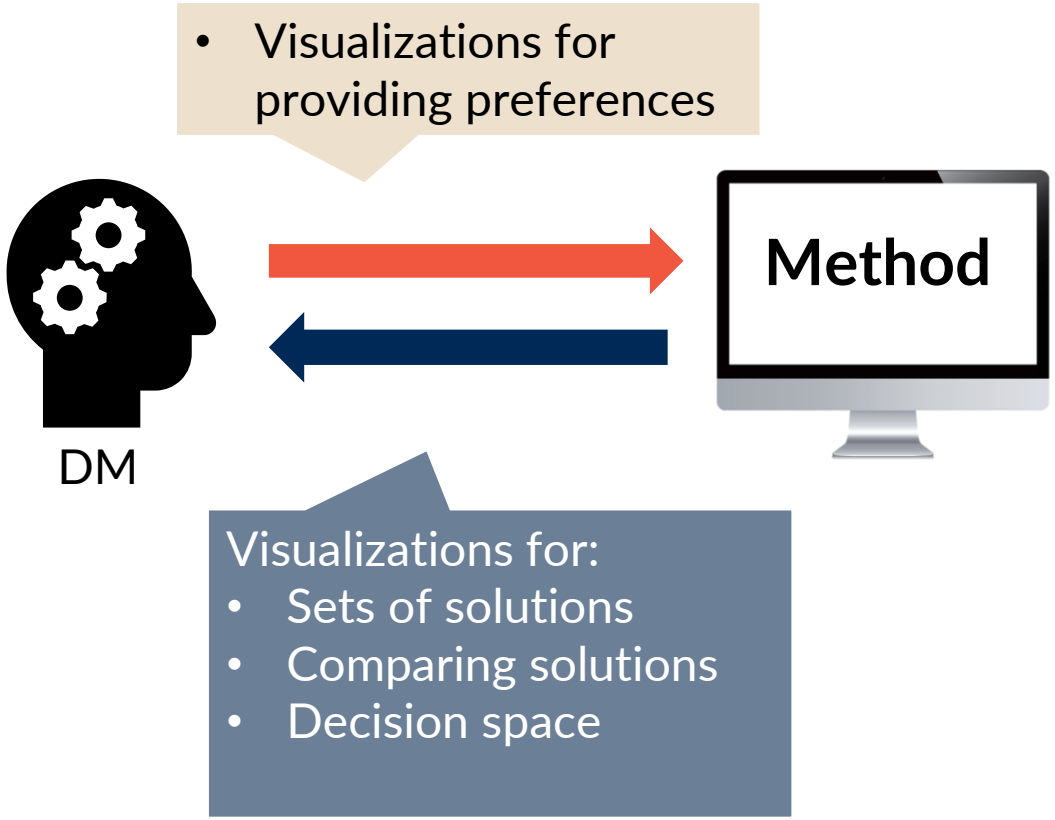
3 objective functions



5 objective functions

When Do We Need Visualizations?

- Too many objectives to mentally track
- Trade-offs are unclear
- You need to spot **patterns, clusters, or outliers**



Example: Sustainability Problem

- Assess sustainability in Spain.
- **Dimensions:** Social, economic, and environmental.
- **Formulation**:
  - Objectives: Maximize achievement in all three dimensions.
  - Decision variables: 11 sustainability indicators.

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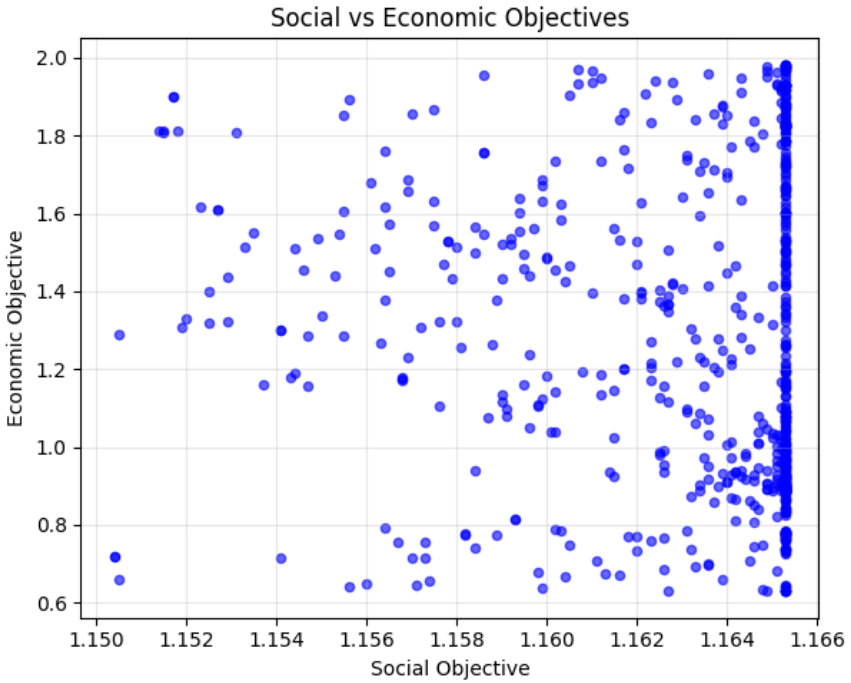
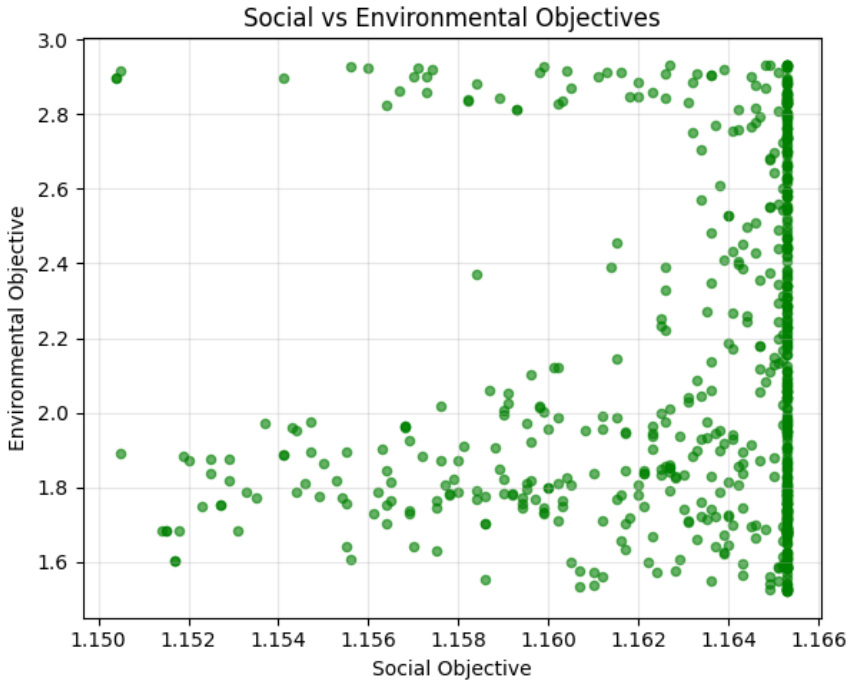
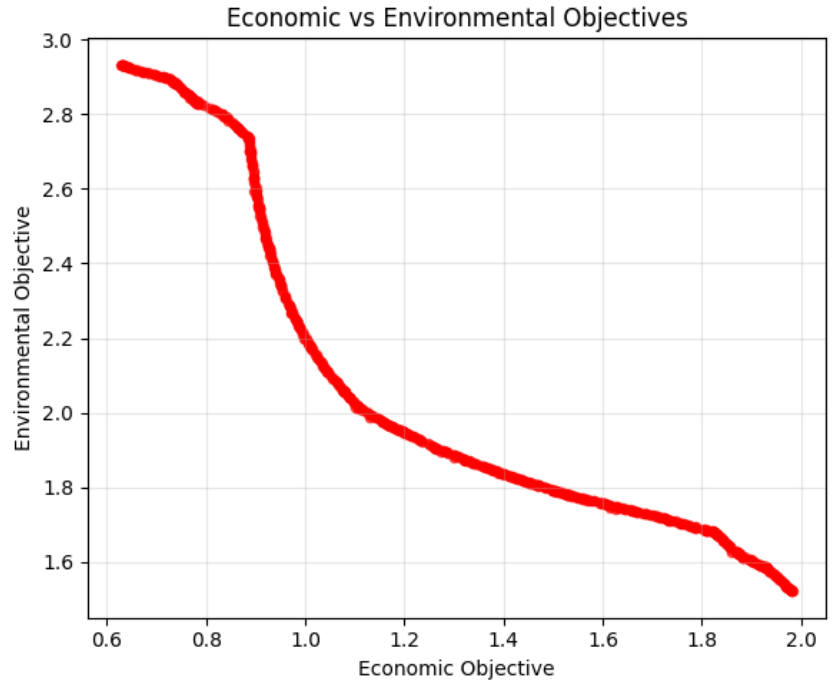
Visualizations for Sets of Solutions

***Goal:** See the **range of possible choices**.*

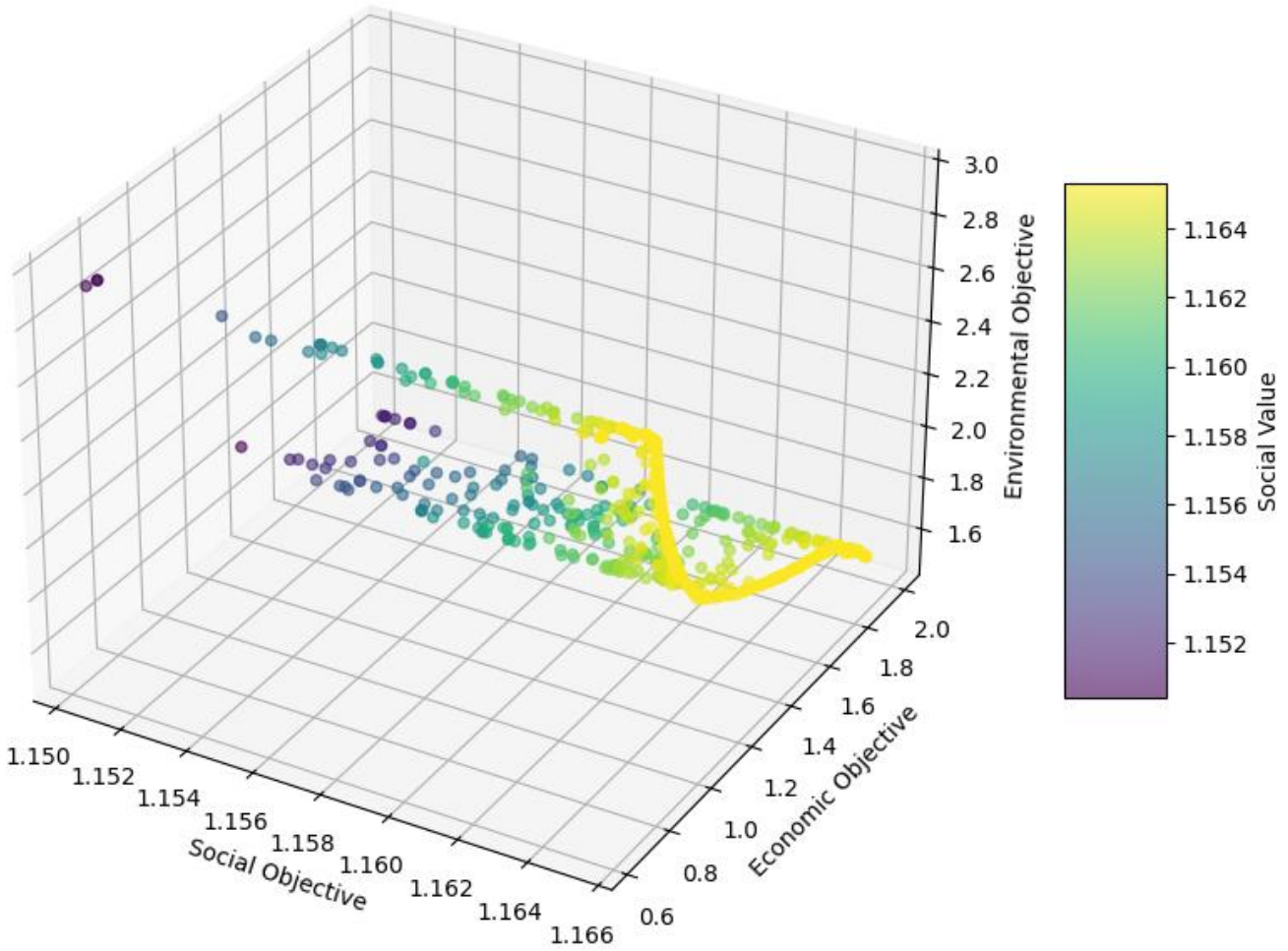
Scatter Plot 2D





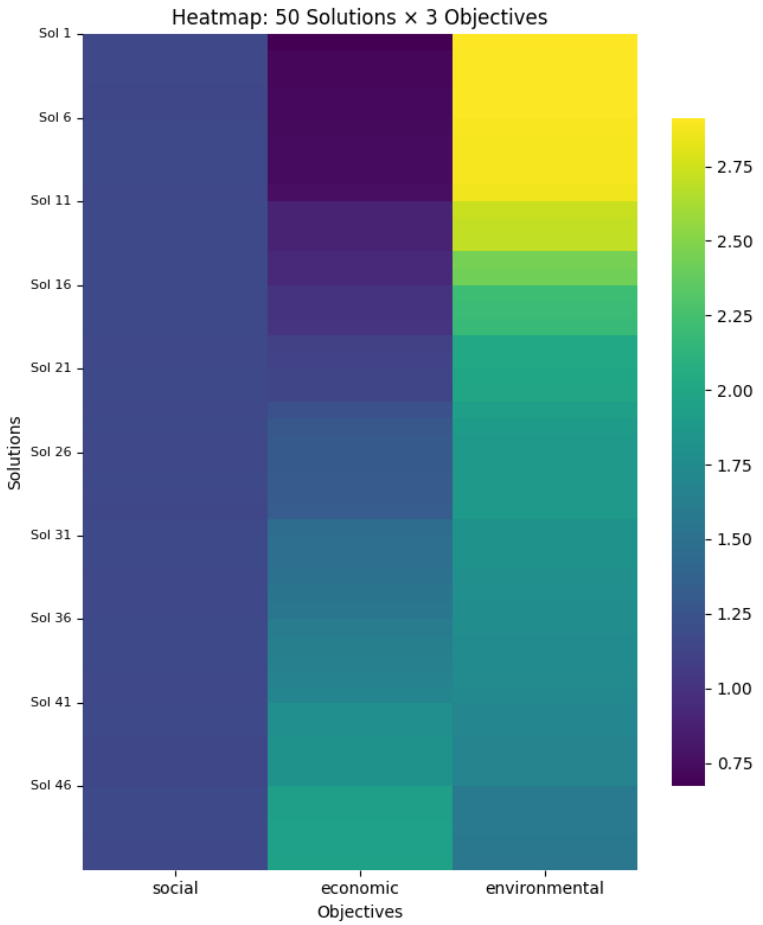


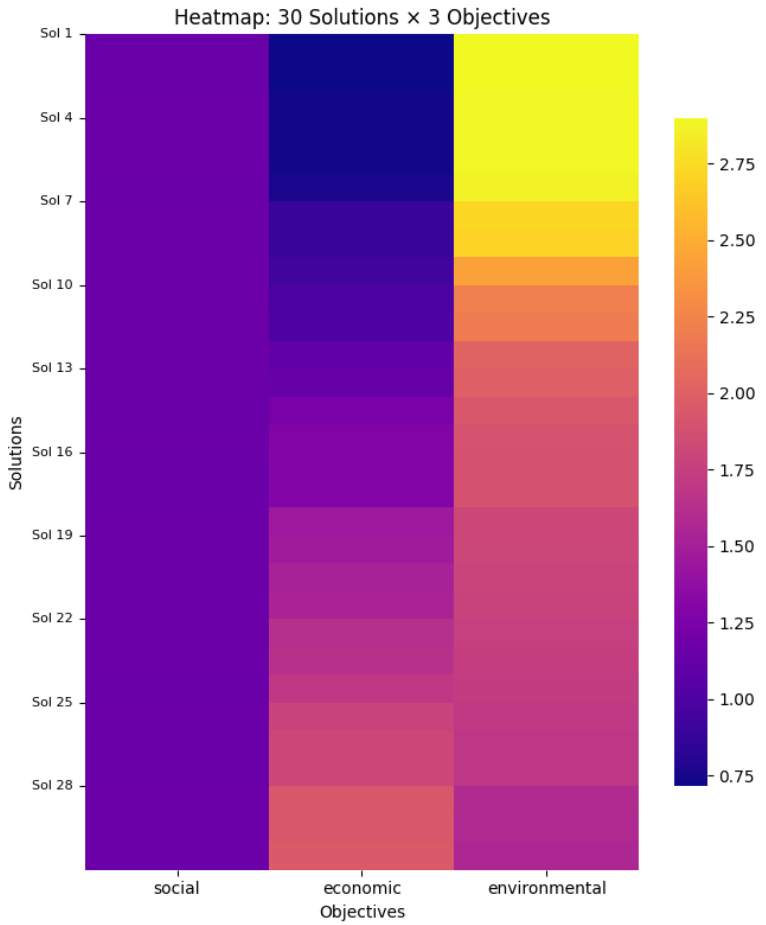
Scatter Plot 3D

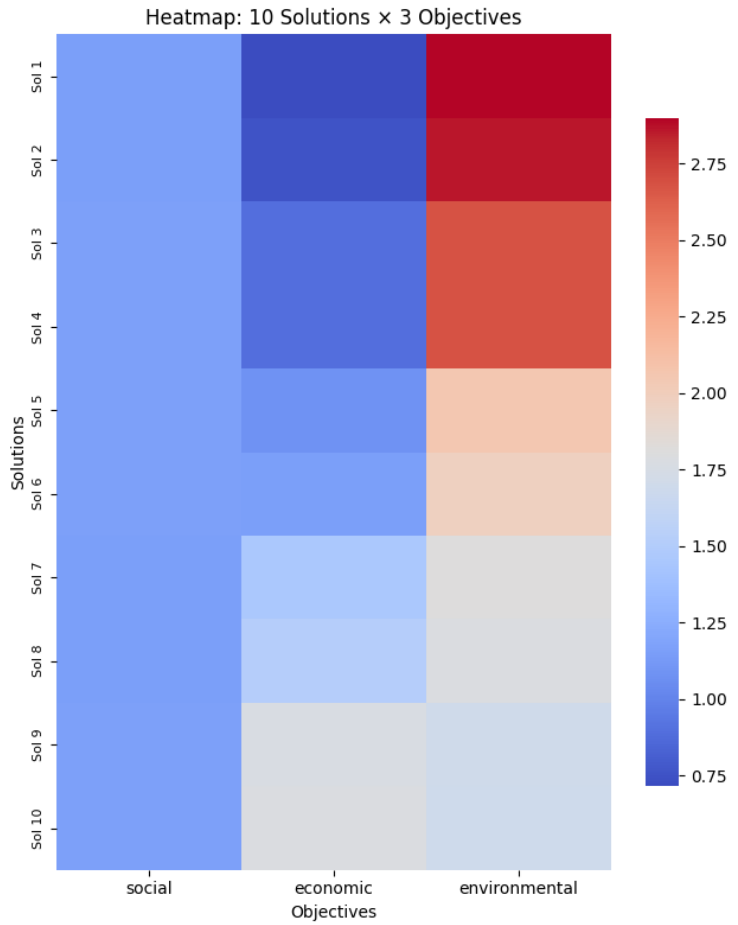


Heatmap

lluminates patterns, not trade-offs between solutions.

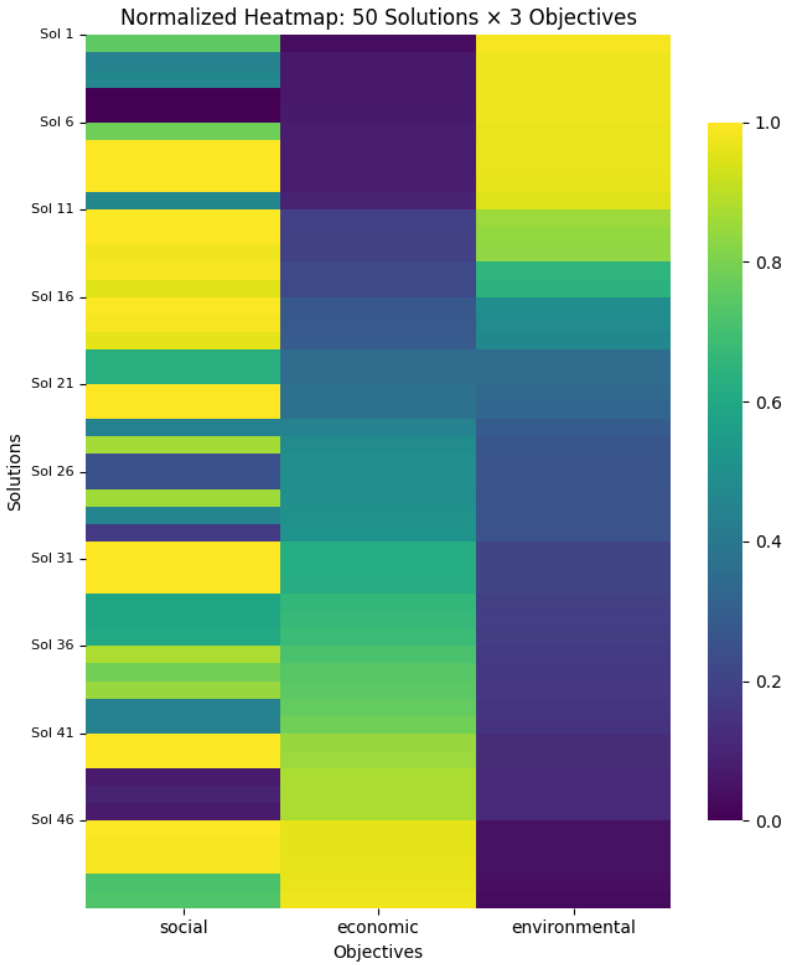


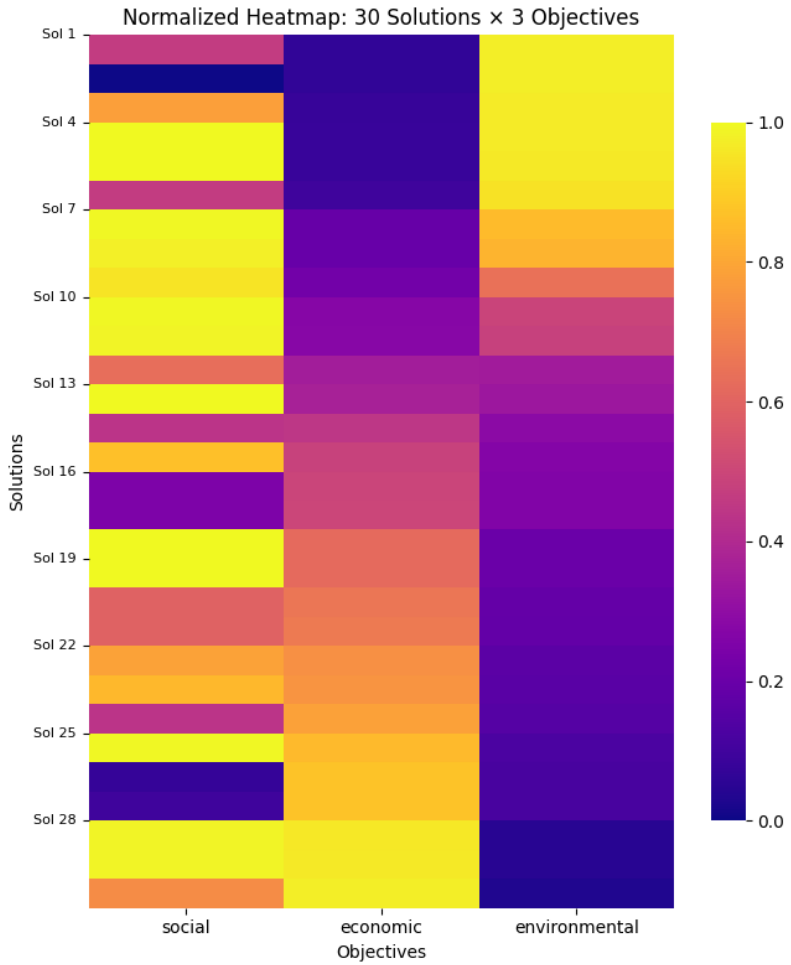


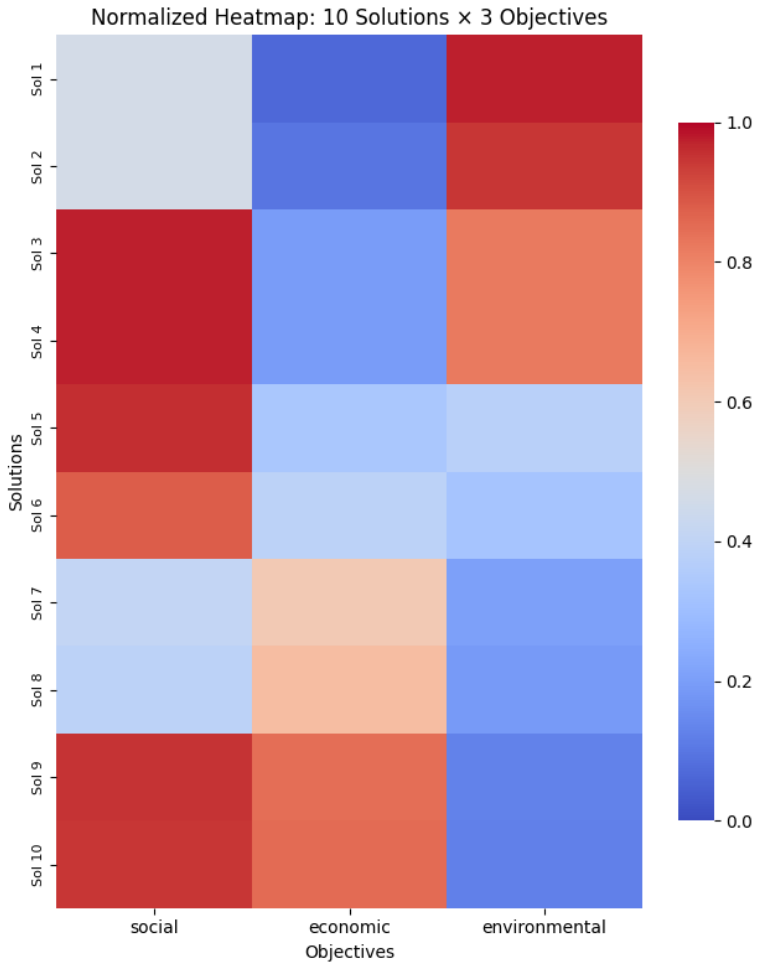


Heatmap

Normalizing the values is useful when the ranges of the objectives are different.

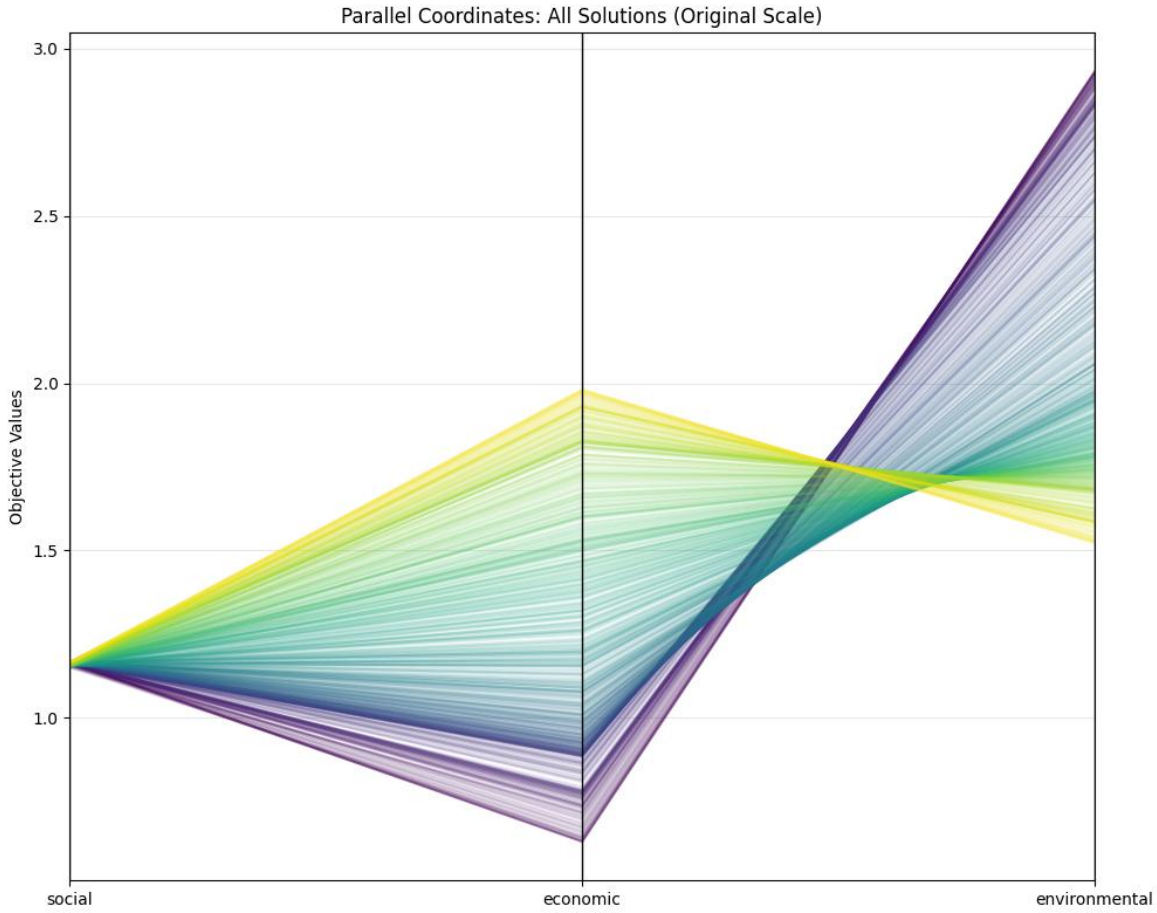


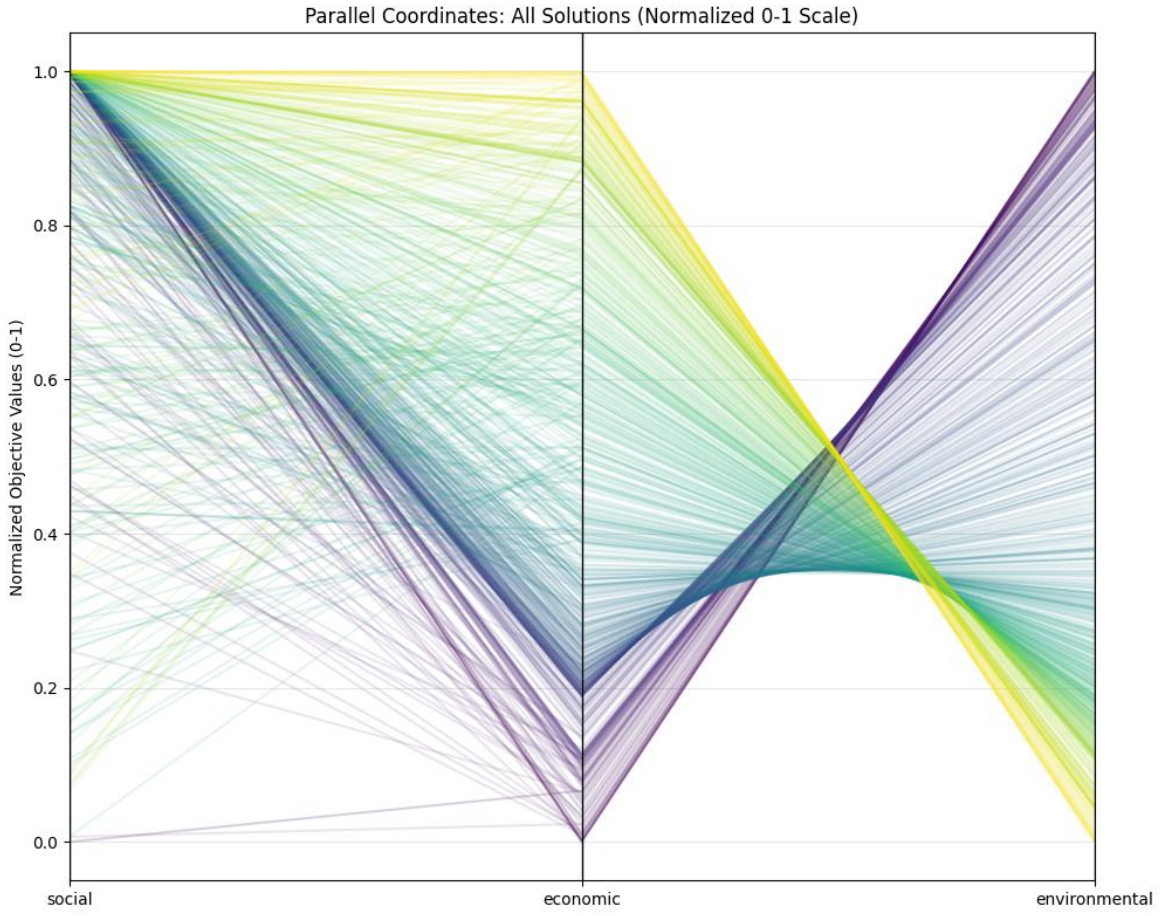




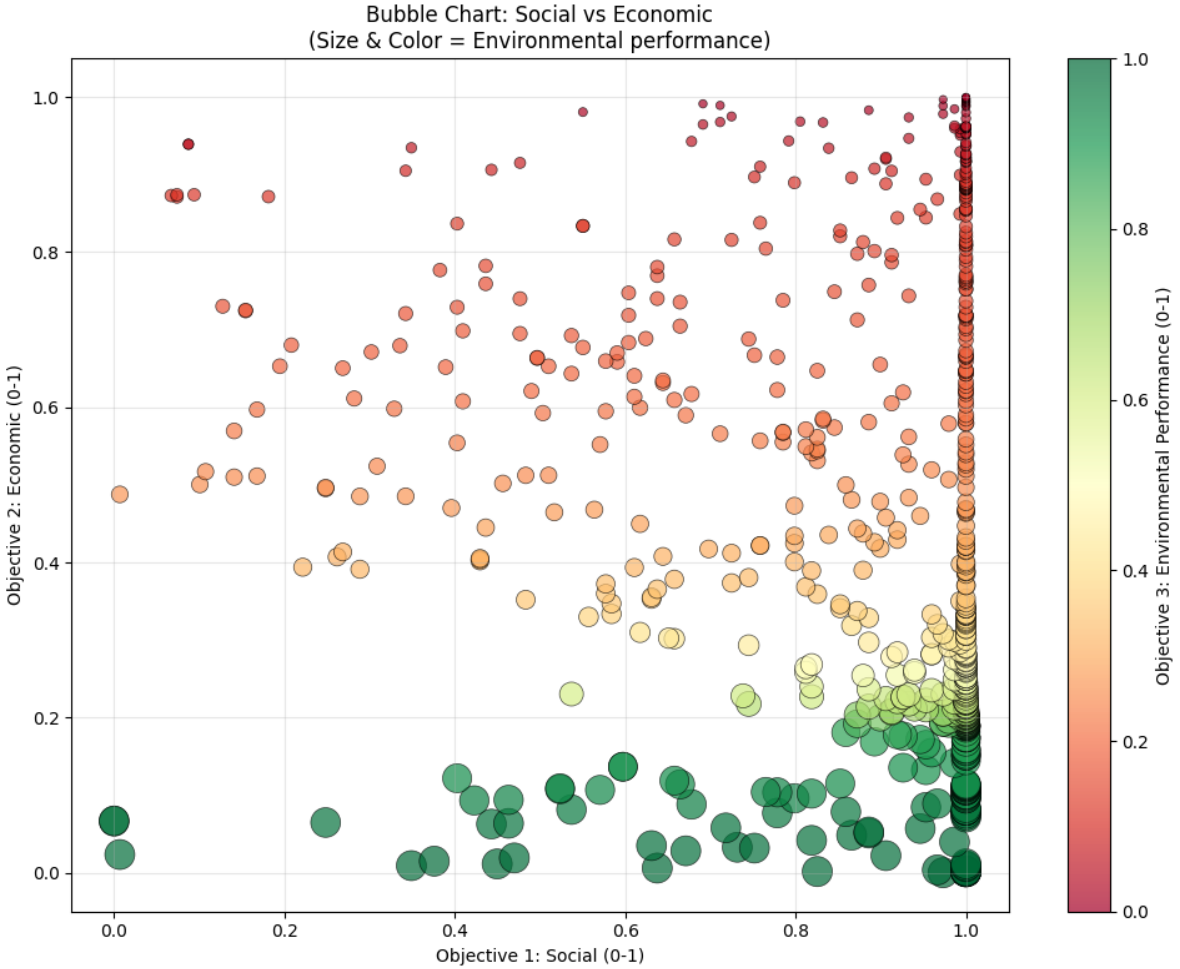
Parallel Coordinates Plot

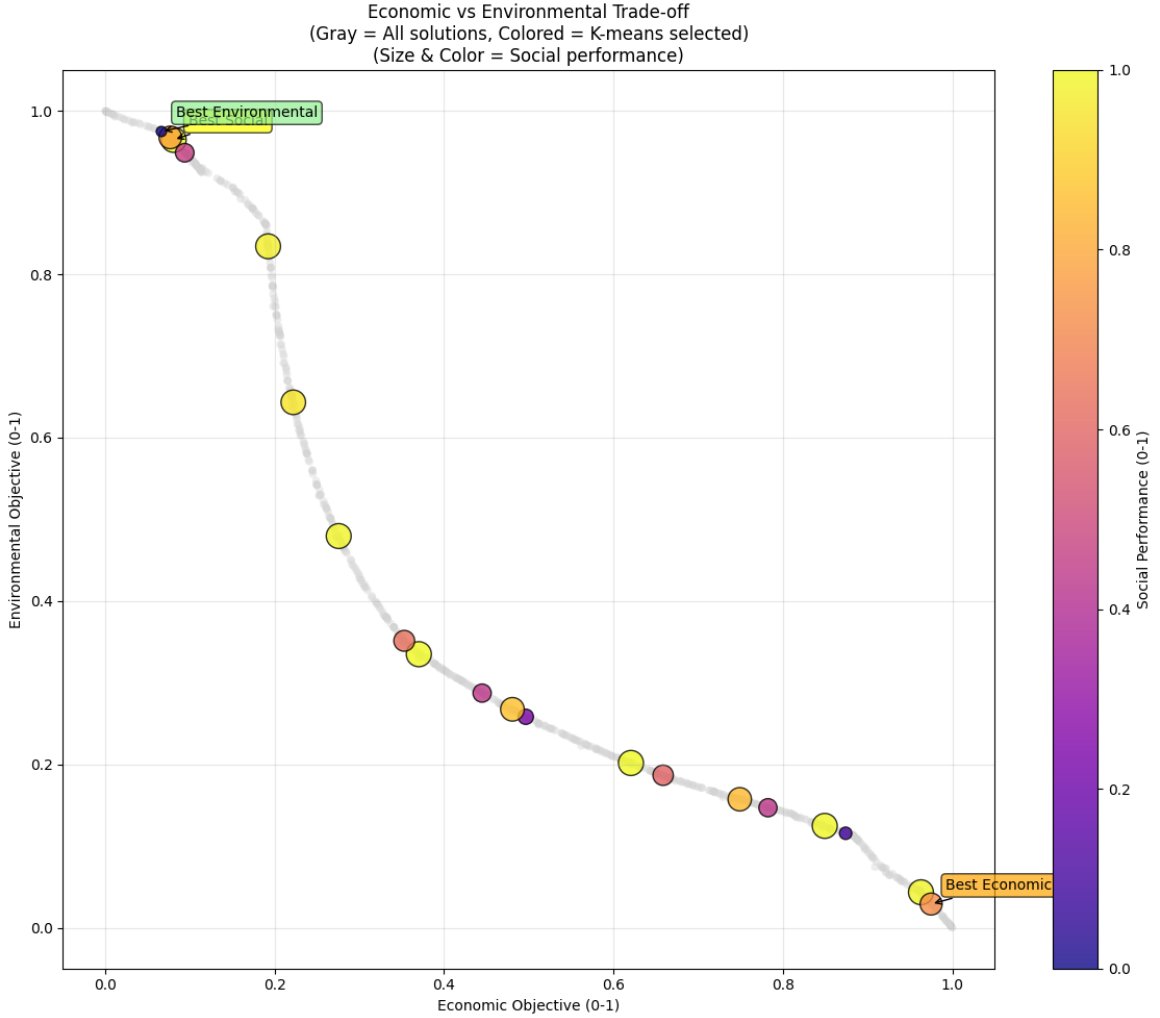
- Useful for navigating trade-offs





Bubble Chart





Visualizations for comparing solutions

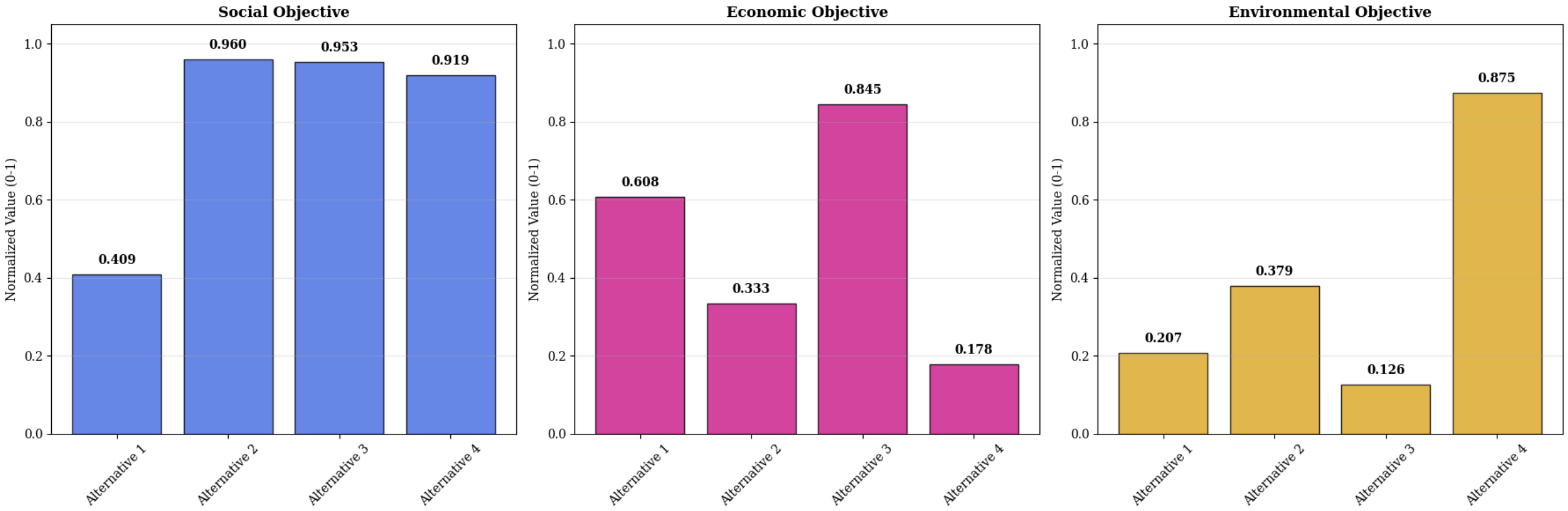
***Goal:** Decide **which option is better**.*

Example of Solutions Shown to the DM

Id	Social	Economic	Environmental
Alternative 1	1.1565	1.4513	1.8131
Alternative 2	1.1647	1.0796	2.0555
Alternative 3	1.1646	1.7718	1.6996
Alternative 4	1.1641	0.8698	2.7556

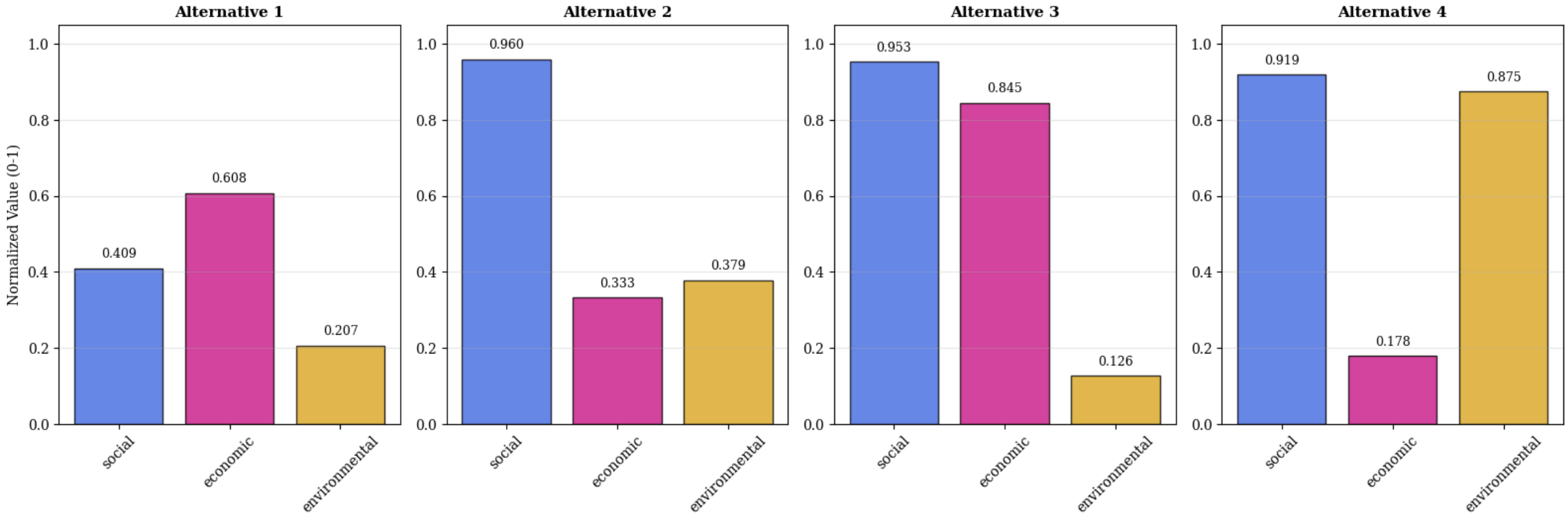
Bar Charts

- A group of bars represents the alternative values of a single objective
- Each color represents one objective



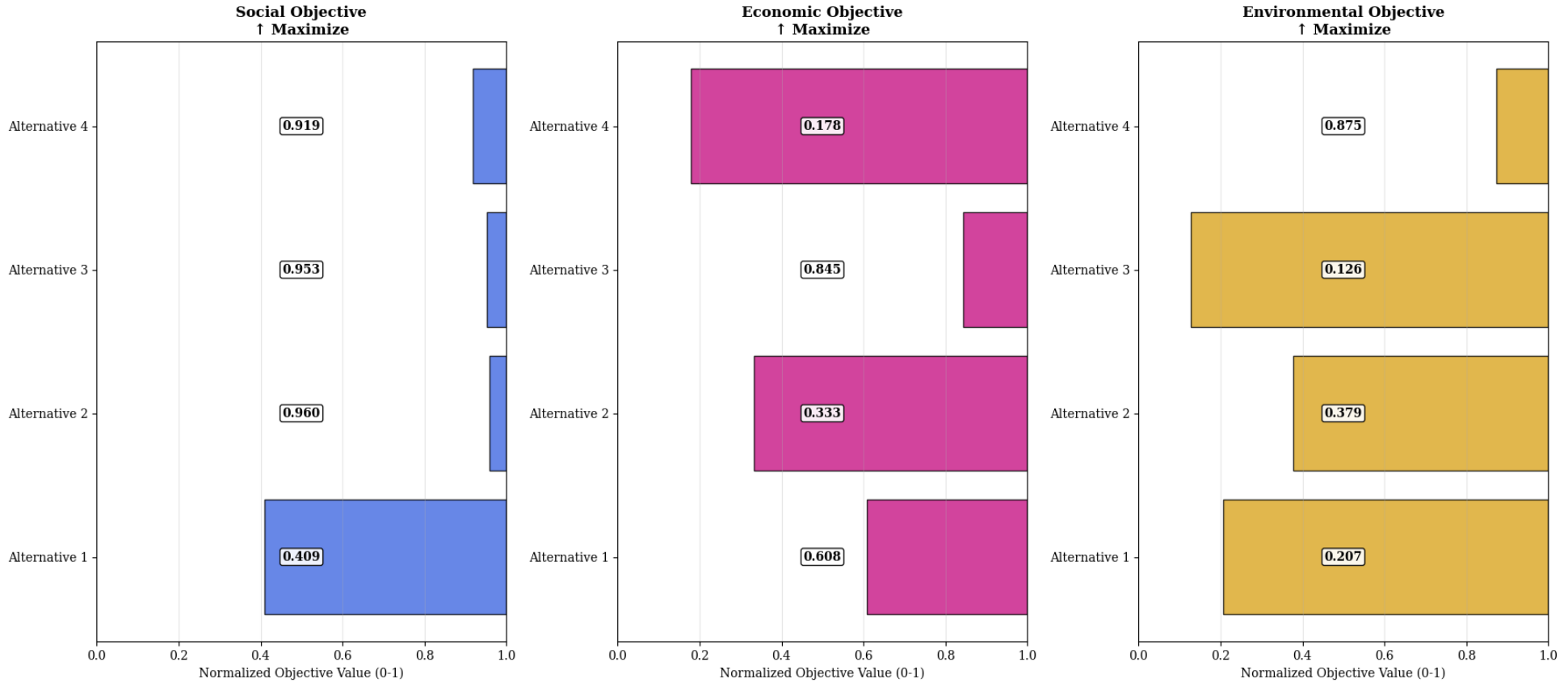
Bar Charts

- Each group of bars represent an alternative.
- The bars of the same color are related to one objective.



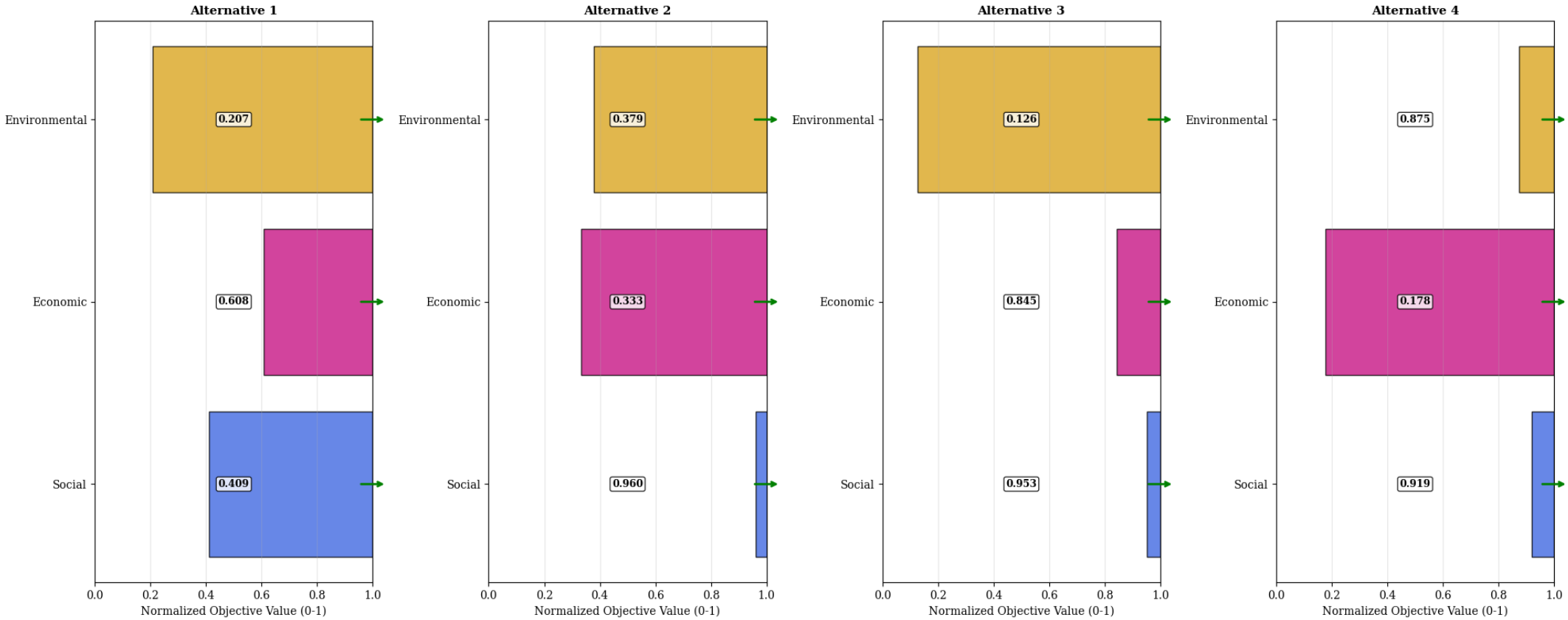
Bar Charts

- **Shorter bars = better objective function values**, regardless of minimization or maximization.
  - Minimize → bars rooted on the left
  - Maximize → bars rooted on the right



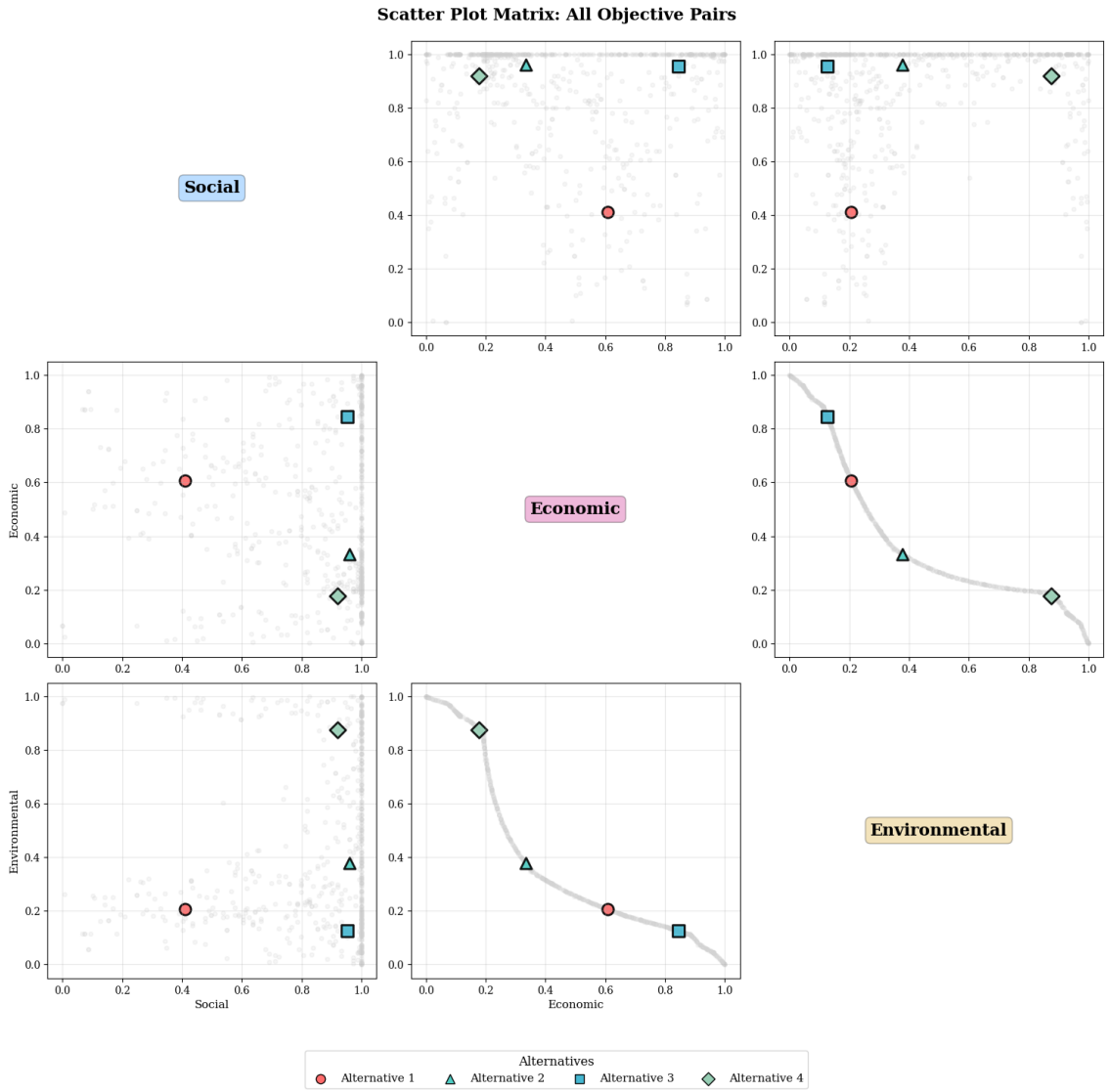
Bar Charts

- The **order of the objectives** affects the general appearance of the chart.
- Letting the decision maker **adjust the order** of alternatives improves flexibility.



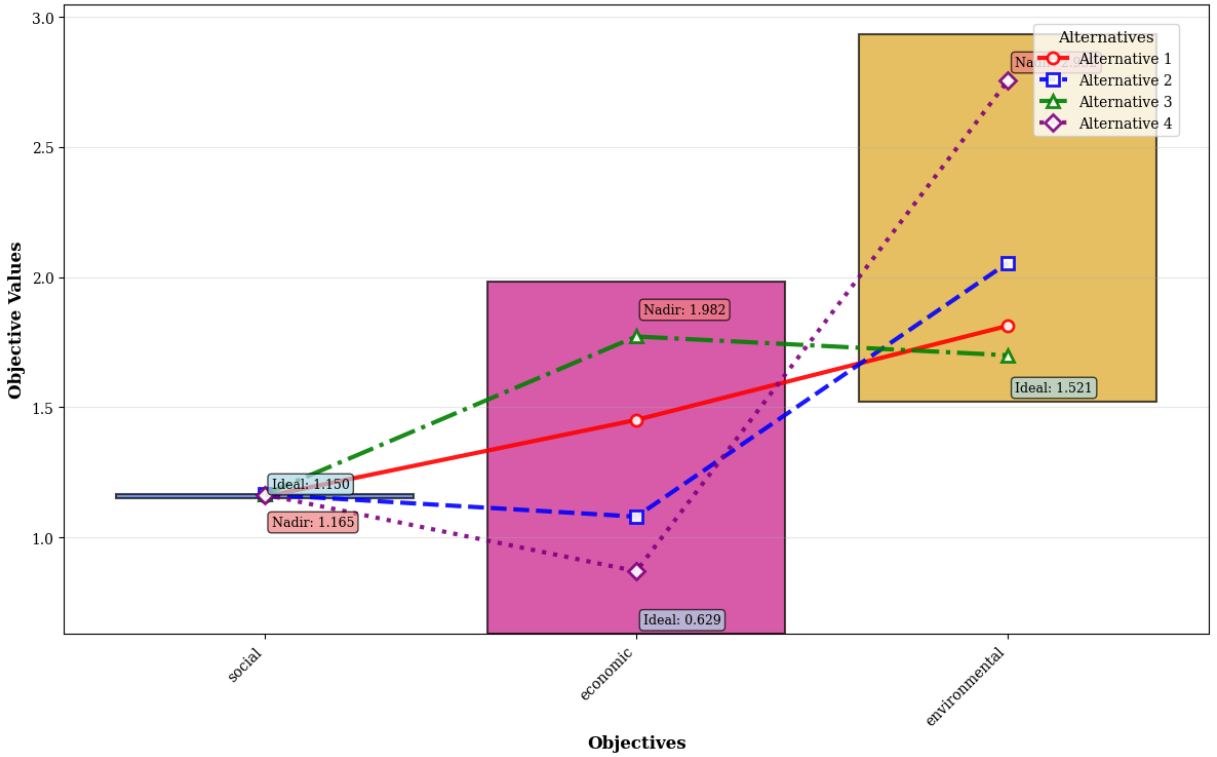
Scatter Plots

- **Scatter plot:** shows data in 2D using any two objectives as axes.
- **Scatter plot matrix**: a grid of all objective pairs, one per panel.
  - Helps compare one objective vs. all others by scanning a row or column.
  - Can become **hard to interpret** with **many objectives.**



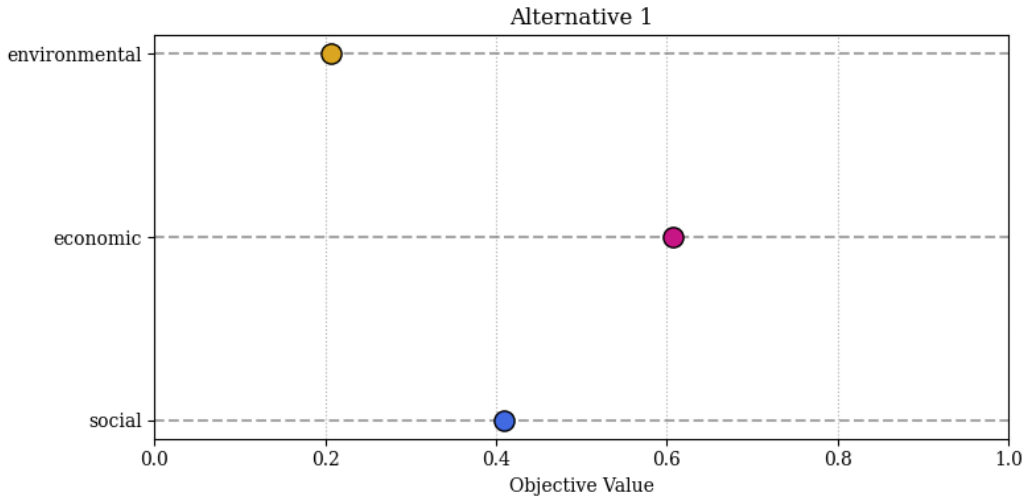
Value Paths

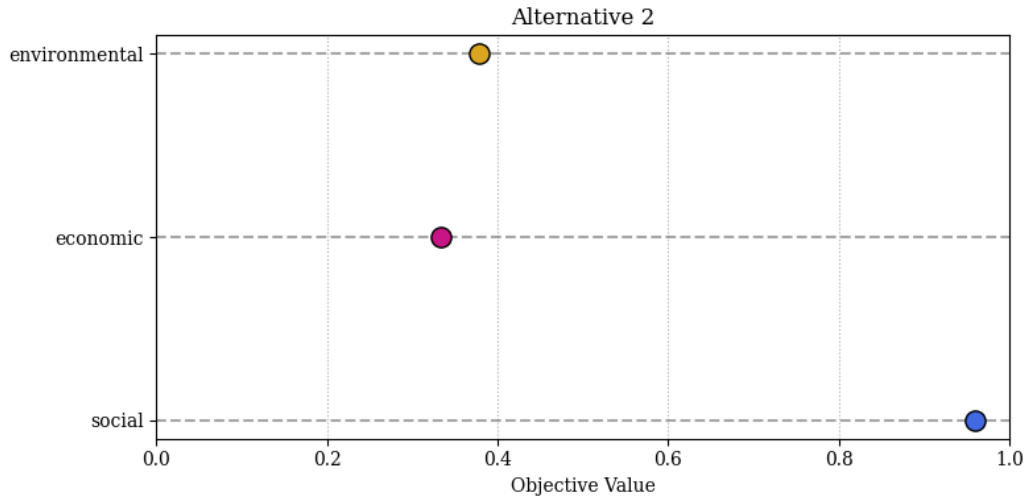
- Colored/styled lines show objective function values for different alternatives.
- Bars indicate the range of each objective in the Pareto optimal set.
- Clear and easy to interpret without overwhelming the user.
- Changing objective order affects the overall layout.

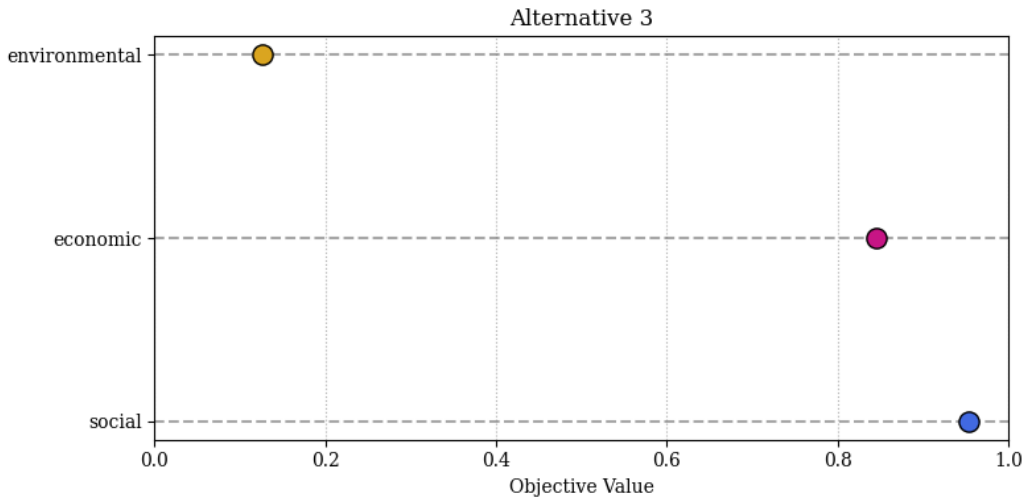


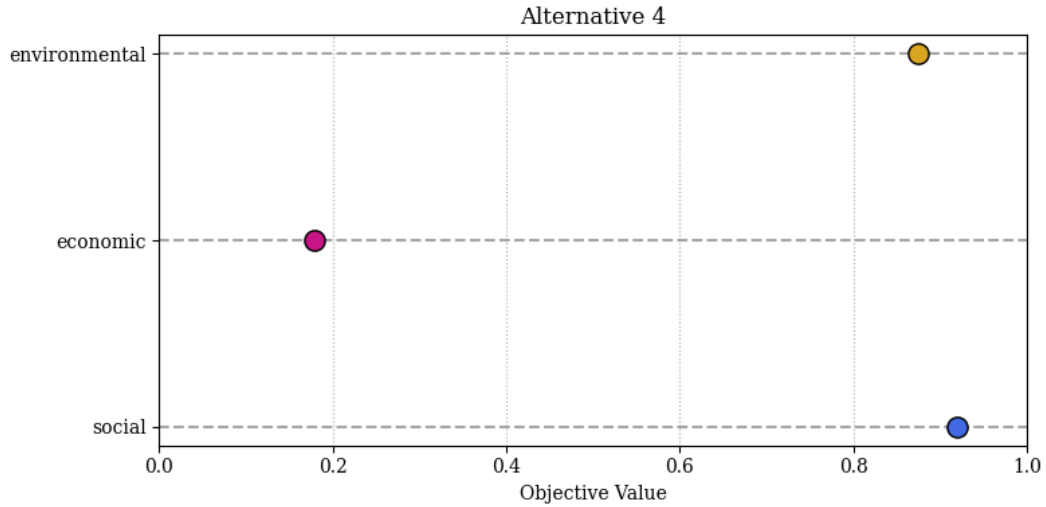
Multiway Dot Plots

- Each panel represents one alternative and the levels represent objectives.



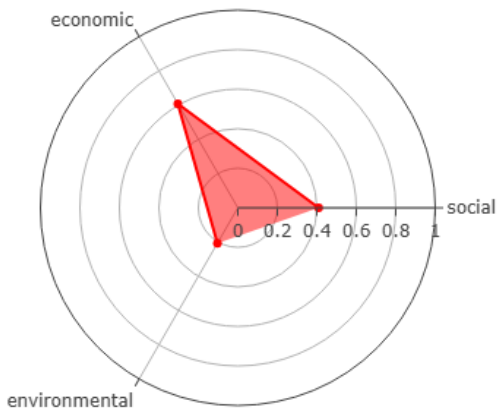


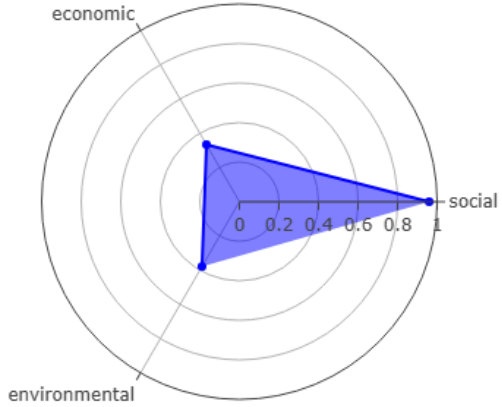


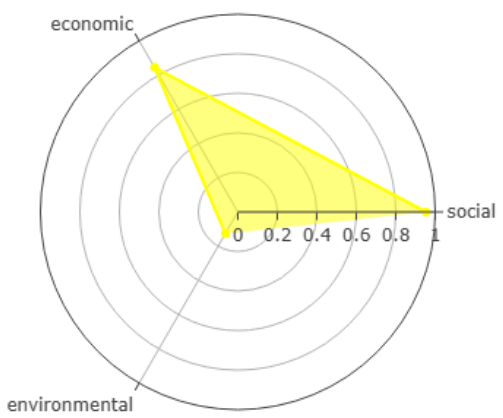


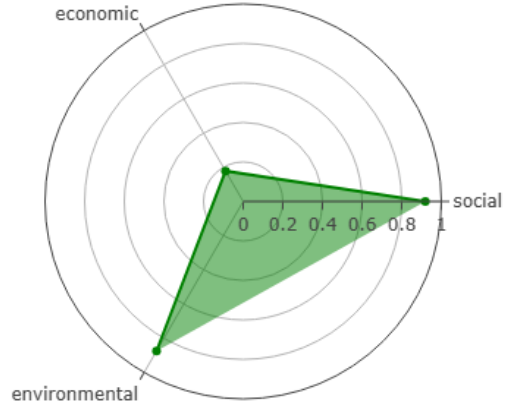
Star Coordinate Systems

- Rays from the origin represent **objectives**, the lengths of the rays depict **objective values**.
- The endpoints of the rays are connected to form **star shapes**.



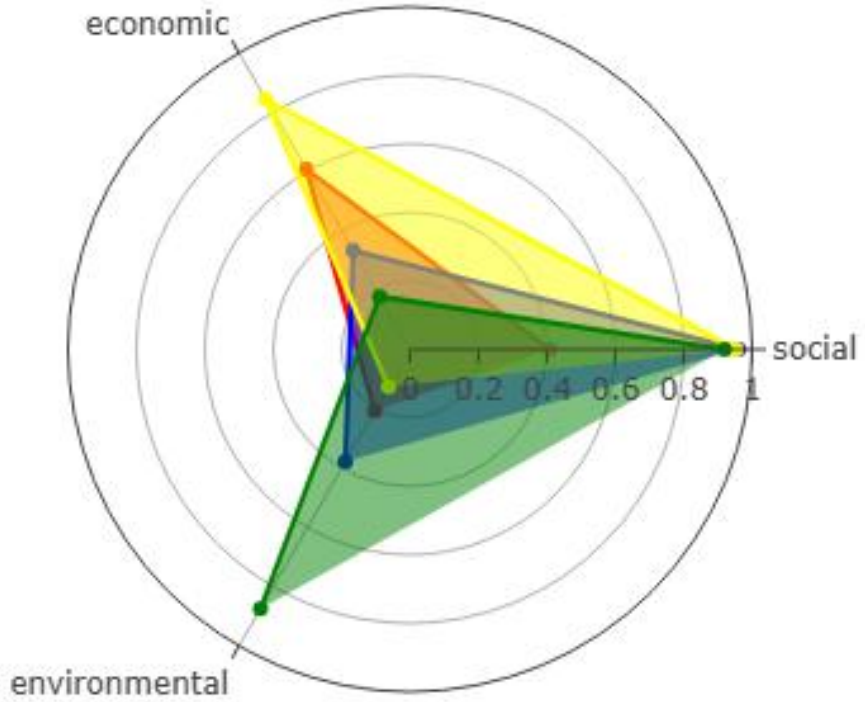






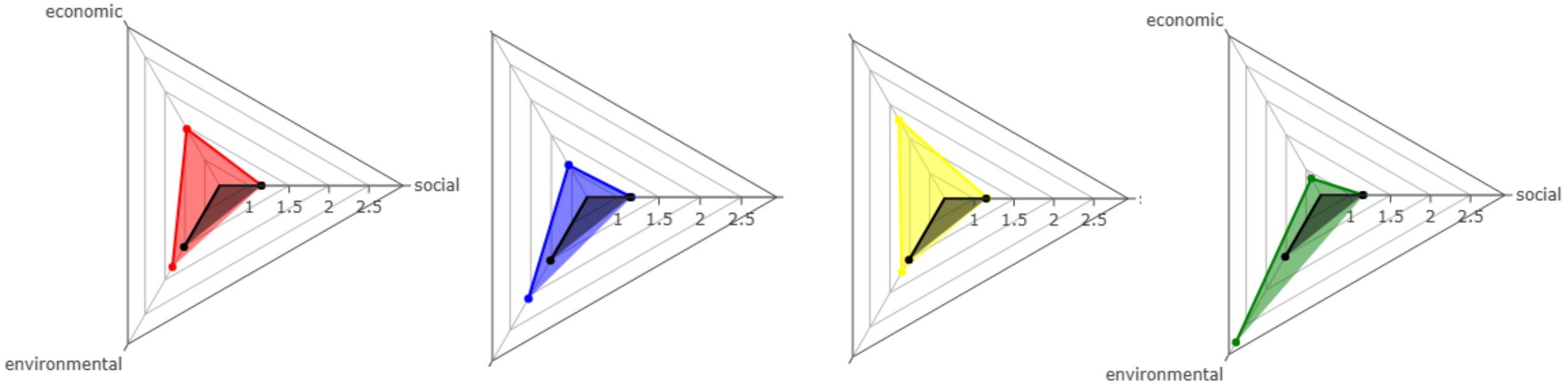
Star Coordinate Systems

- Can display **all alternatives together**.
- Works best with **up to ~10 objectives**.
- Requires the **ideal** and **nadir** objective vectors



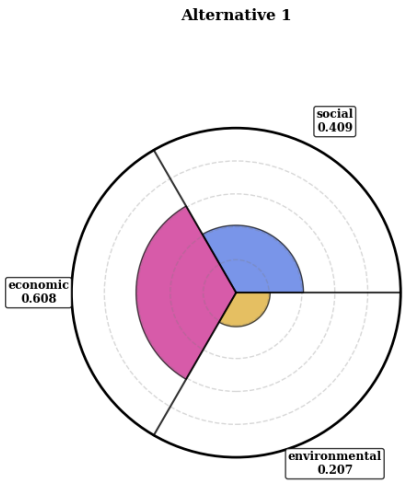
Spider-web Charts

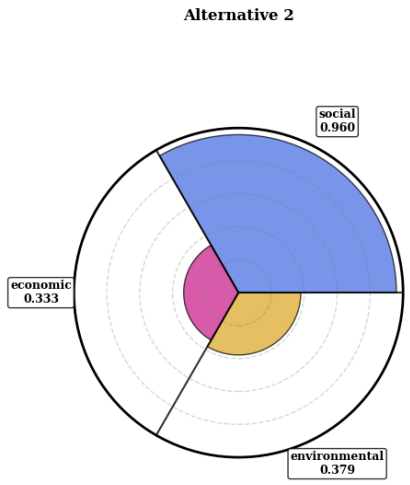
- Each apex of a polygon represents one objective.
- **For maximization: Outer polygon** = **ideal**, **inner polygon** = **nadir**, **middle polygon** = an **alternative**.
- It is also possible to include **aspiration values** of a reference point.

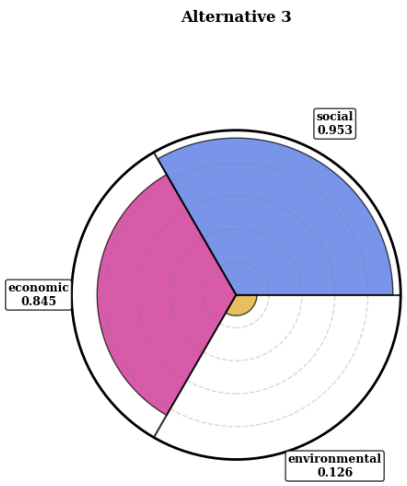


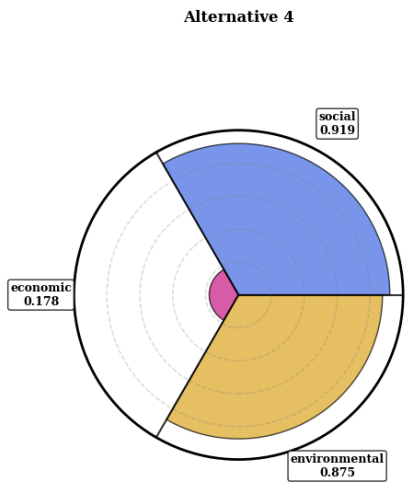
Petal Diagrams

- A **circle is split into sectors**—one per **objective**.
- The size(radius) of each slice indicates the magnitude of the objective value.
- Each sector can have a **different color** for clarity.
- The order of the objectives has no effect on the actual shape of the diagram or the total area covered by the segments.









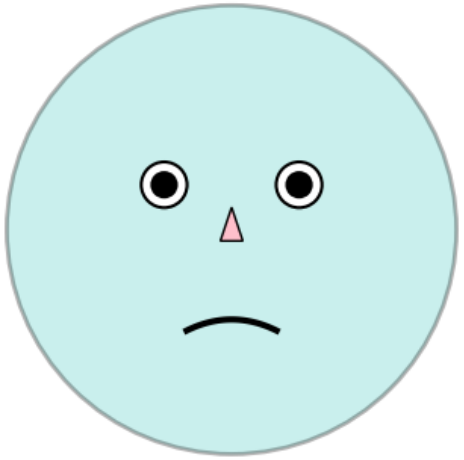
Chernoff's faces

- **Each feature of the face represents a different objective:**
  - FACE SIZE (Social): Larger face = Higher social value
  - EYE SIZE (Economic): Larger eyes = Higher economic value
  - MOUTH CURVE (Environmental): Smile ↗ = Higher environmental value

Alternative 1

S: 0.409 | E: 0.608 | En: 0.207

Alternative 2

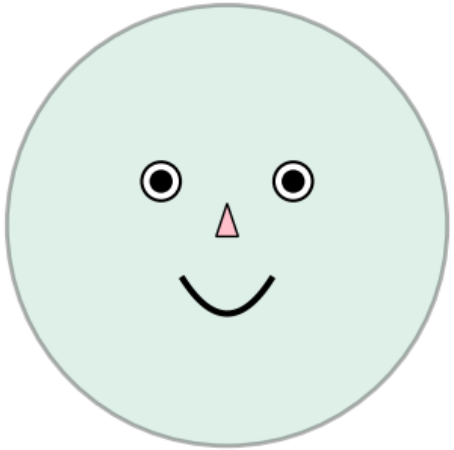


S: 0.960 | E: 0.333 | En: 0.379

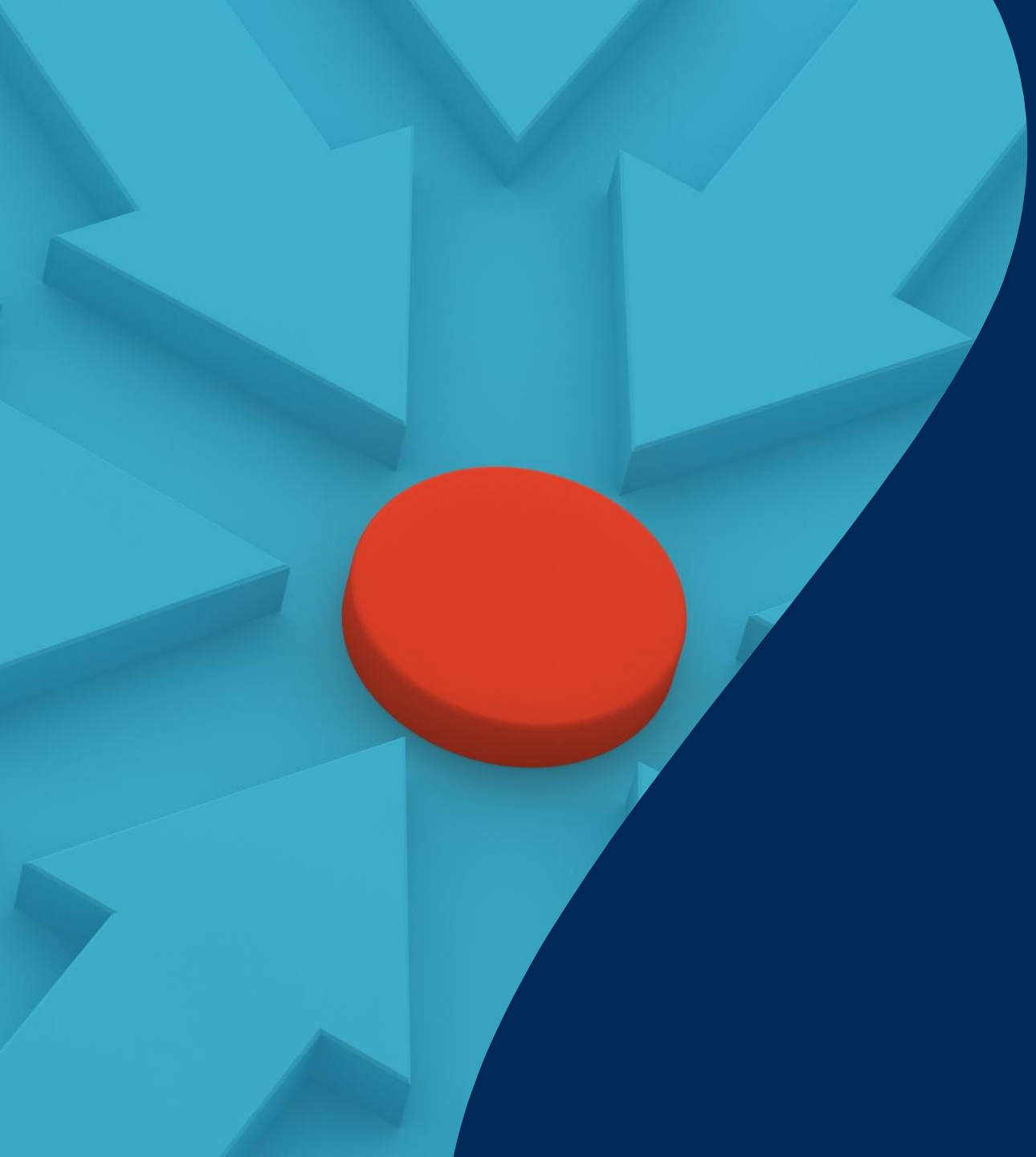
Alternative 3

S: 0.953 | E: 0.845 | En: 0.126

Alternative 4



S: 0.919 | E: 0.178 | En: 0.875

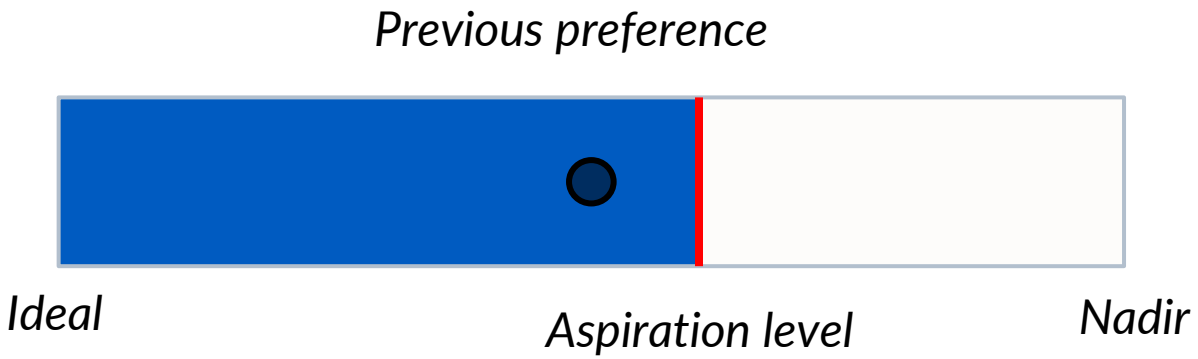


Visualizations for Providing Preferences

Goal: *Capture what matters to the decision maker.*

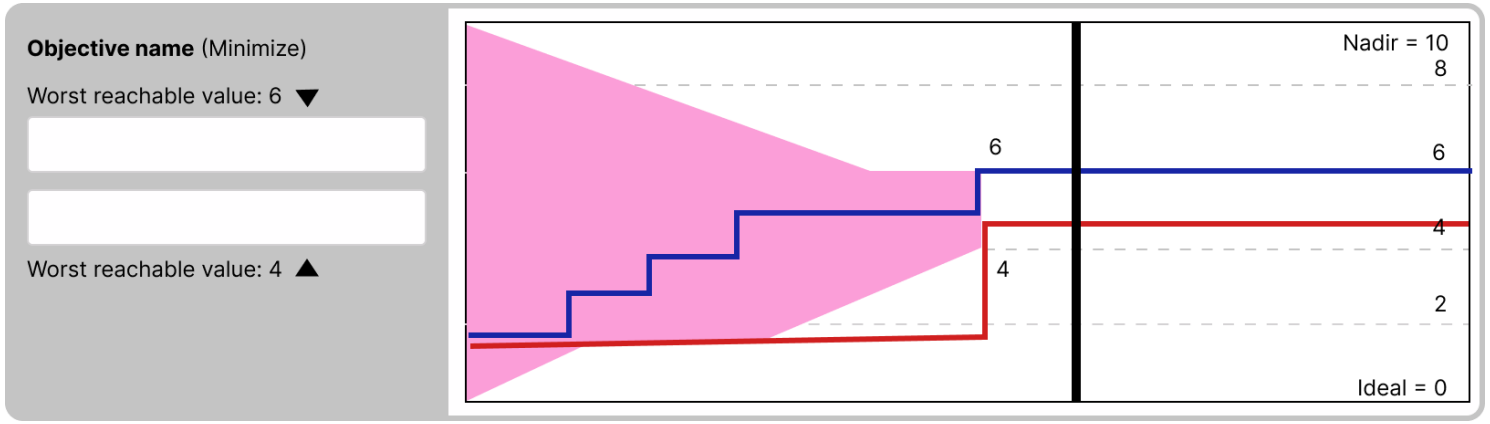
Aspiration Levels

- One bar is needed for each objective
- Utilized for the reference point method and NIMBUS
- Can also indicate the previous preference values



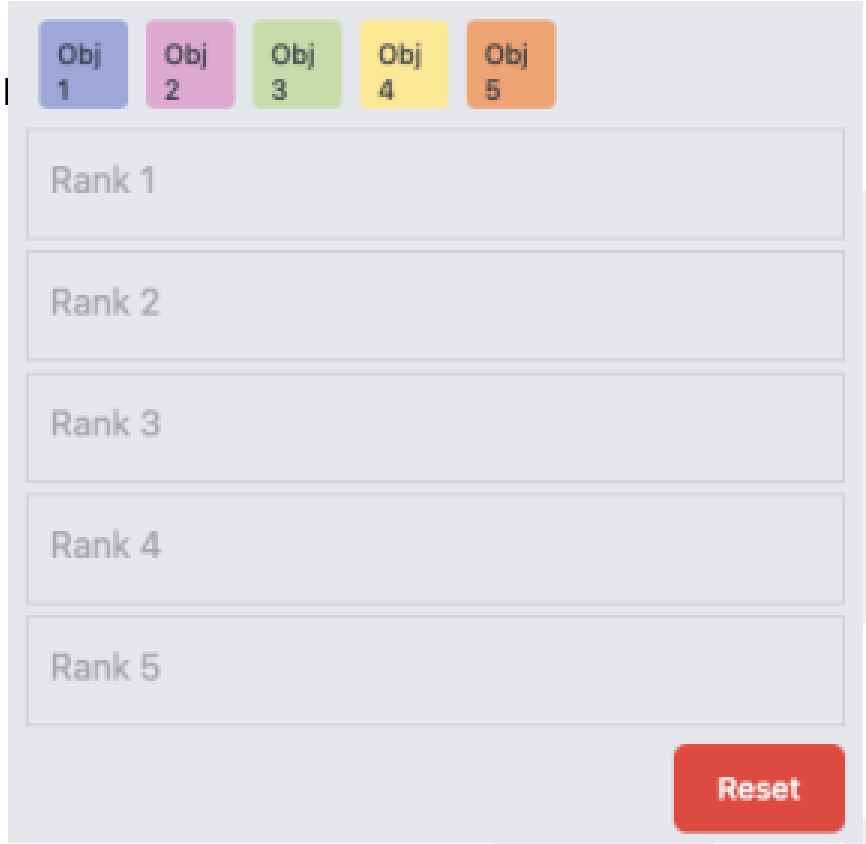
Ranges

- Utilized in Nautilus navigator
- One bar is needed for each objective



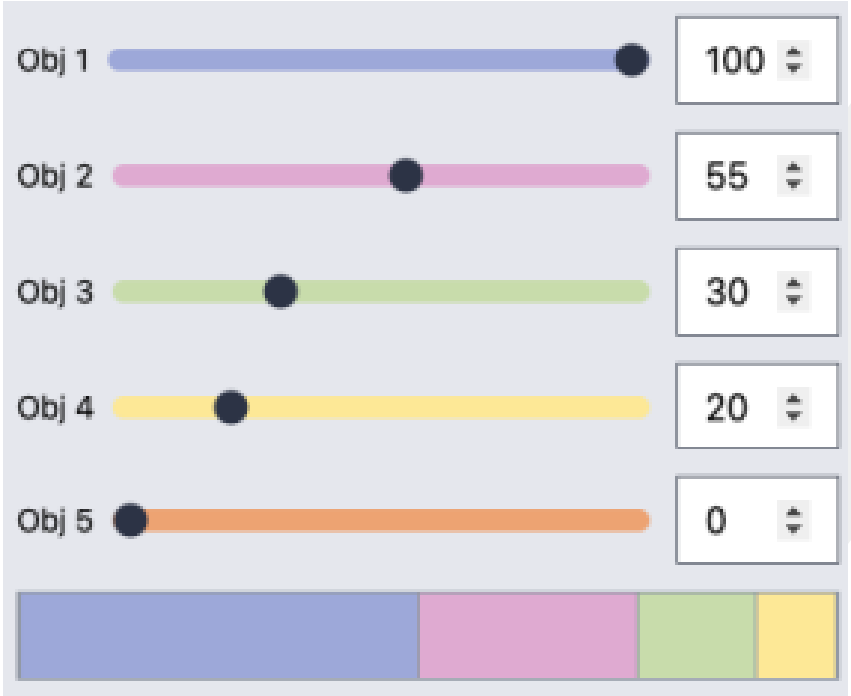
Ranking Objectives

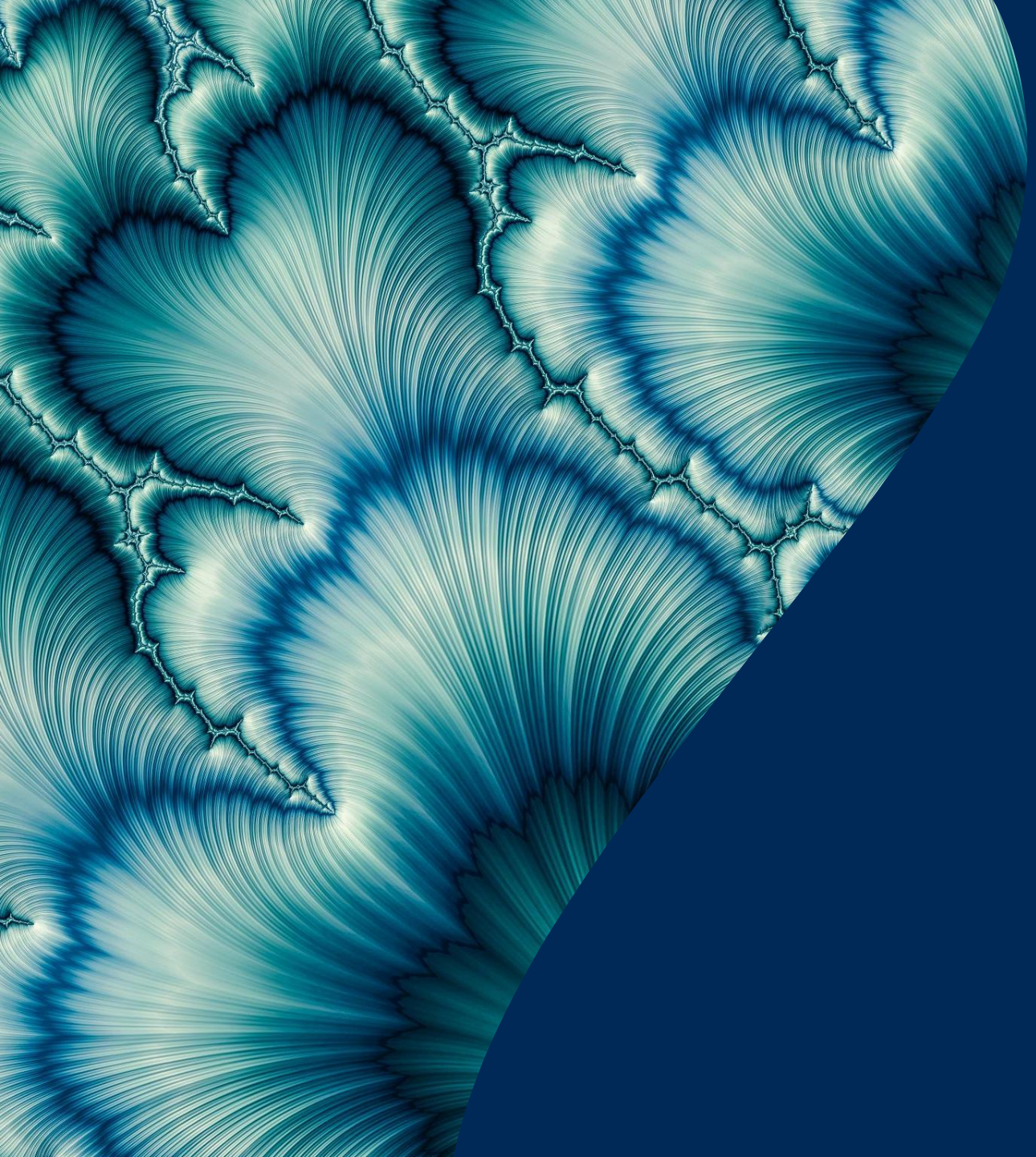
- The user can drag and drop each objective in different ra
- Multiple functions can have the same rank
- Not all ranks need to be used
- There is an option to reset the ranking



Specifying Weights

- The DM can use the sliders or the text boxes to indicate the relative importance of each objective.
- The points are internally scaled to sum up to 100.
- The color bar below reflect the distribution of the 100 points.

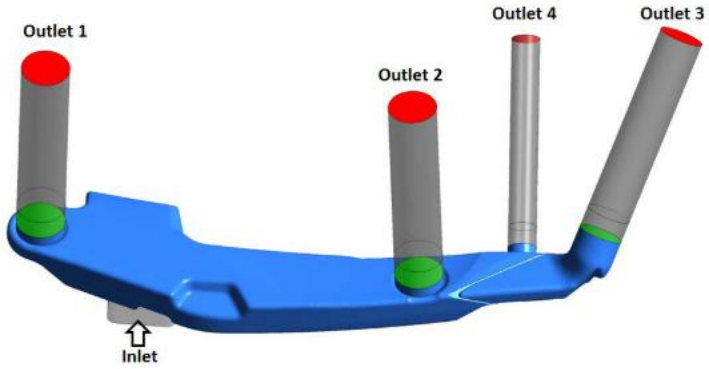




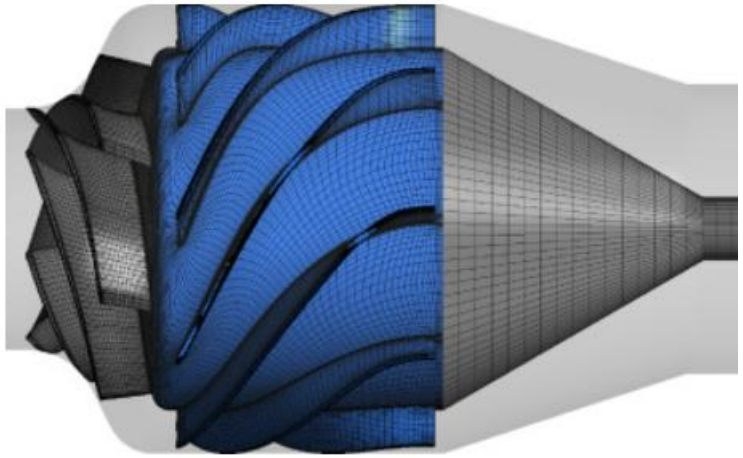
Visualizations for the Decision Space

Product design *– shape, dimensions*
Engineering *– flow, efficiency*
Geography *– spatial layouts*

Visualizations for the Decision Space



Chugh, T., Kratky, T., Miettinen, K., Jin, Y., & Makonen, P. **Multiobjective shape design in a ventilation system with a preference-driven surrogate-assisted evolutionary algorithm.** Proceedings of the 2019 Genetic and Evolutionary Computation Conference, 1147–1155 (2019).



Mazumdar A., Burkotová J., Krátký T., Chugh, T.,& Miettinen, K. **Handling simulation failures of a computationally expensive multiobjective optimization problem in pump design,** Engineering Applications of Artificial Intelligence, Volume 136, Part A, (2024)

Summary

- Data visualization helps people analyze data quickly and efficiently
- Good visualization enables visual exploration of the problem

Visualizations are not intended only to display data
but also to retrieve information from the DM

Visualizations should be interactive, allowing the DM to:

→ Compare solutions

→ Update preference information

→ Select preferred solutions

GUIs to Support Decision-Making

GUIs to Support Decision-Making

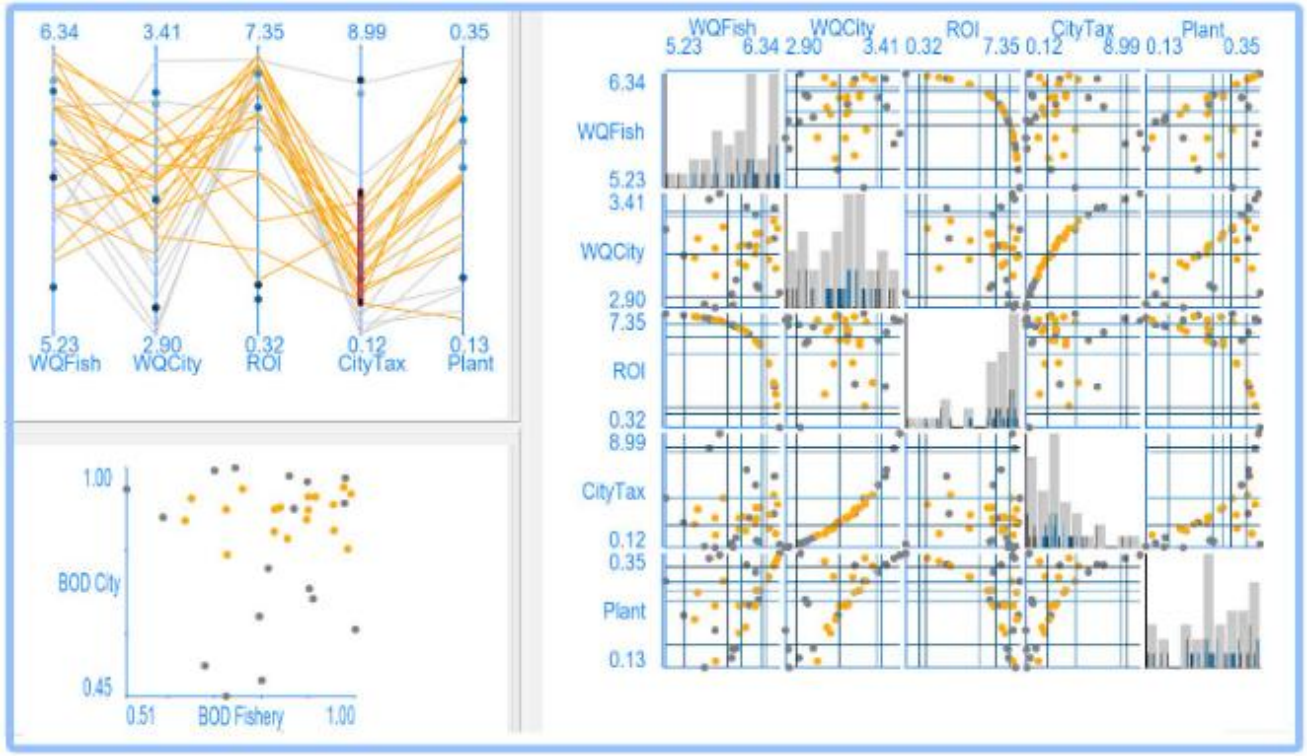
- When implementing any method, a user interface **facilitating the interaction between the method and the DM** plays a crucial role
- For example, a badly implemented user interface can **hinder a DM from using the method** regardless of how good the method itself is.
- On the other hand, a well-implemented user interface **can make a 'not so good' method popular** if it is easy and intuitive to use.
- Therefore, well-implemented methods are needed in order **to enable wider use of methods** in practical decision making.
- **Essential for interactive methods.**

Desirable Characteristics of a GUI for Decision-Support

- **Intuitive:** the steps to follow are clear for the DM in the entire process
- **Clear:** all UI elements have a clear purpose
- **Reliable:** information presented to the DM to be correct
- **Adaptable:** different visualization types are utilized in the GUI according to the needs of the method and the DM's preferences

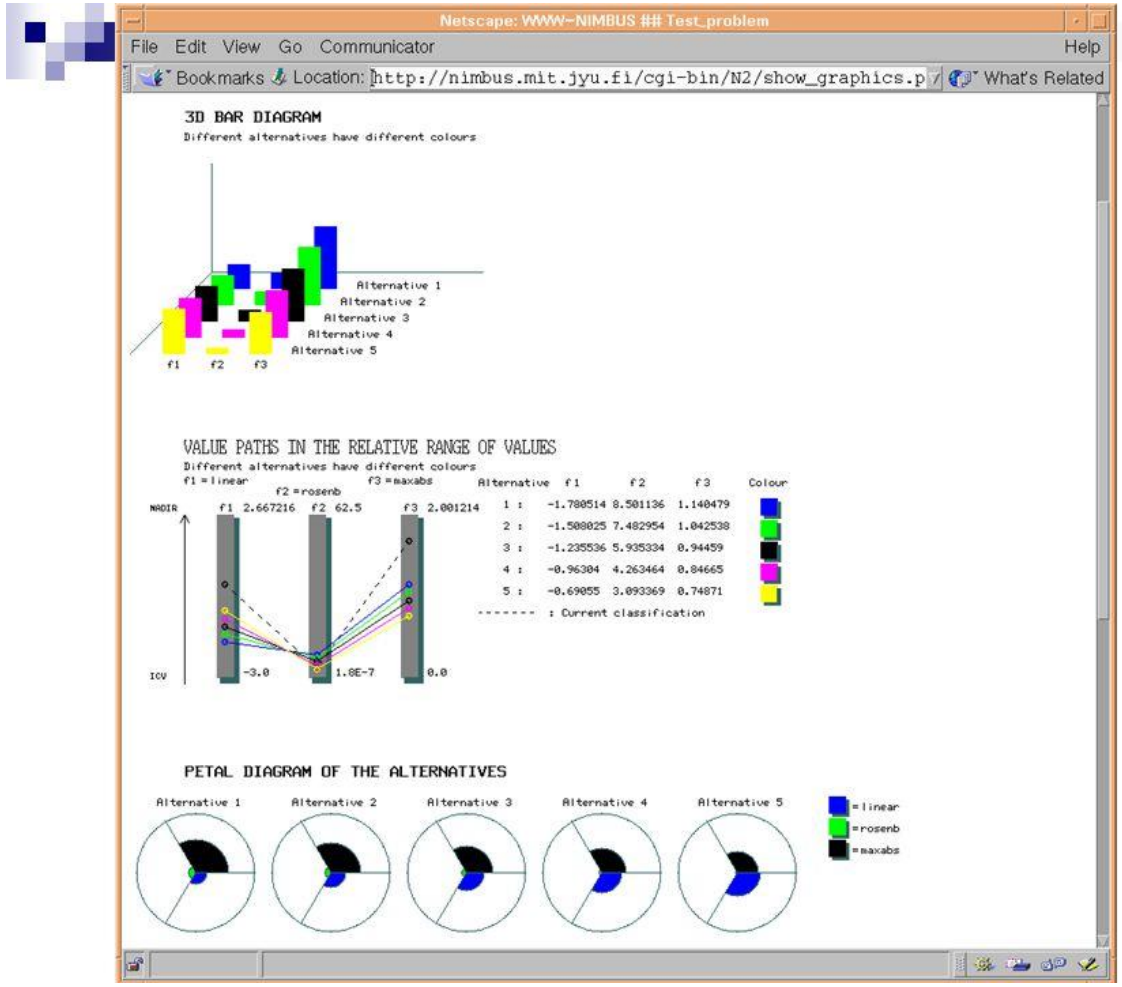
Interactive Visualizations

- **Brushing** – highlight points
- **Linking** – same points across all views
- **Coordinated views** – see the problem from multiple angles



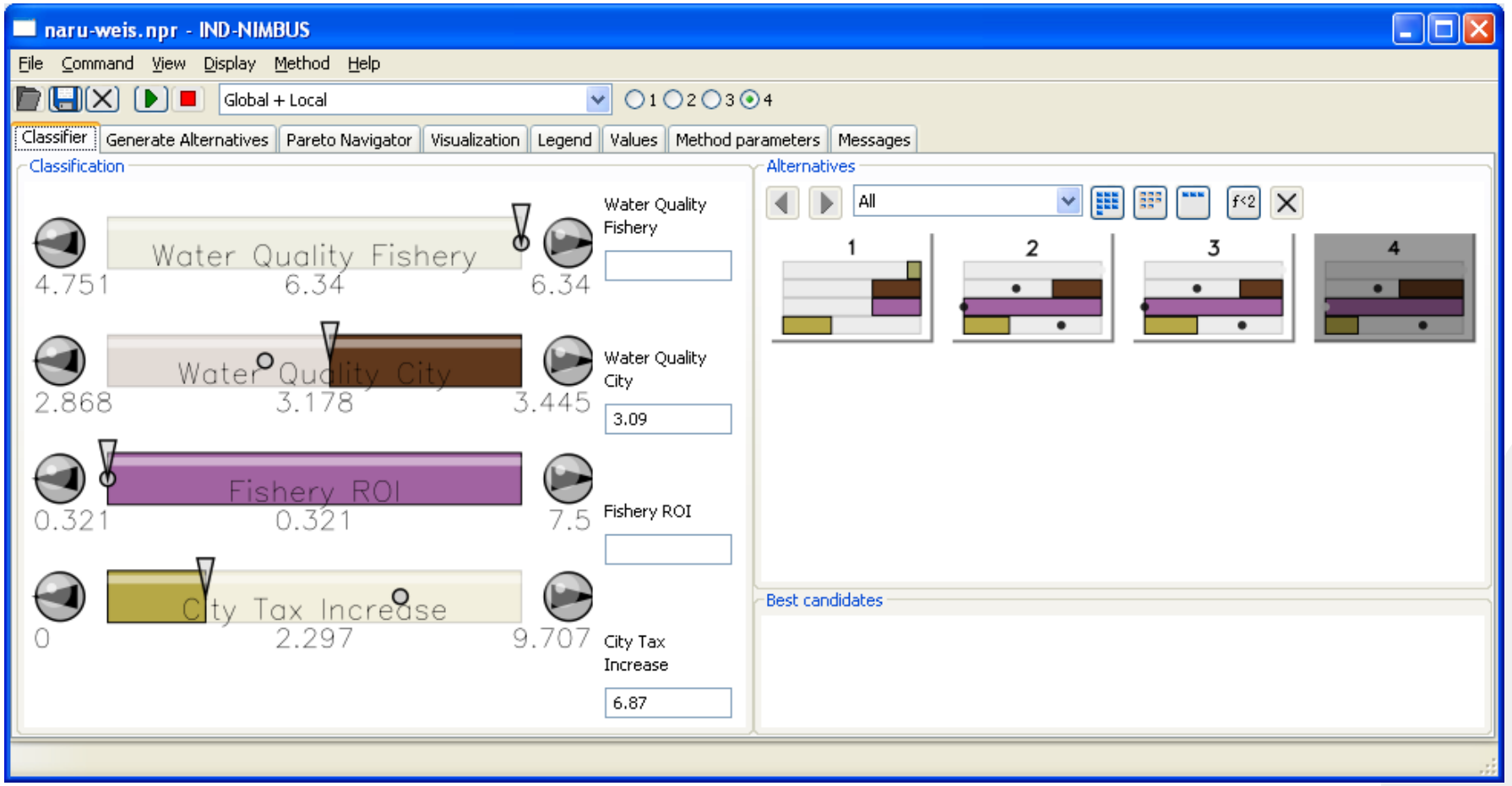
Graphical UIs: WWW-NIMBUS

https://wwwnimbus.it.jyu.fi/N4/index.html



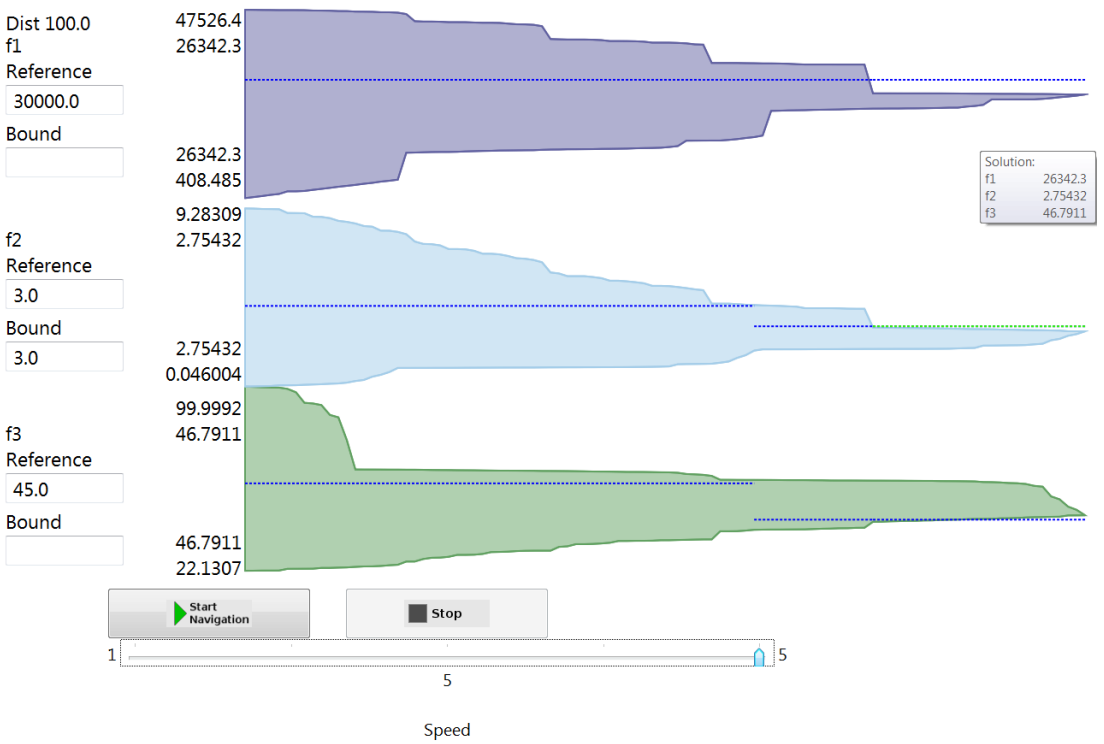
Miettinen, K. and Mäkelä, M. M., Interactive Multiobjective Optimization System WWW-NIMBUS on the Internet, Computers & Operations Research, Vol. 27 (7-8), pp. 709-723, 2000.

Graphical UIs: IND-NIMBUS



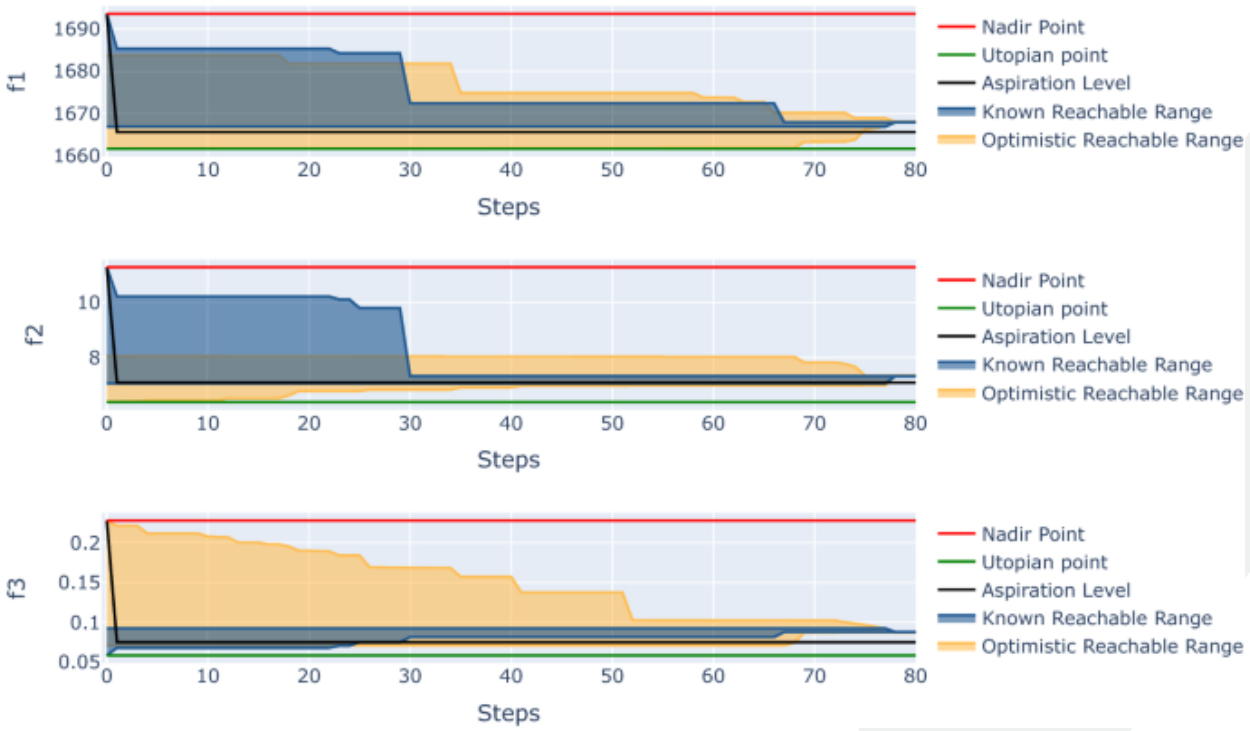
Miettinen, K., IND-NIMBUS for Demanding Interactive Multiobjective Optimization, Trzaskalik, T.(ed.), Multiple Criteria Decision Making '05, , pp. 137-150, 2006.

Graphical UIs: NAUTILUS



NAUTILUS Navigator

Ruiz, A. B., Ruiz, F., Miettinen, K., Delgado-Antequera, L., & Ojalehto, V. (2019). NAUTILUS Navigator : free search interactive multiobjective optimization without trading-off. Journal of Global Optimization, 74 (2), 213-231.



Optimistic NAUTILUS

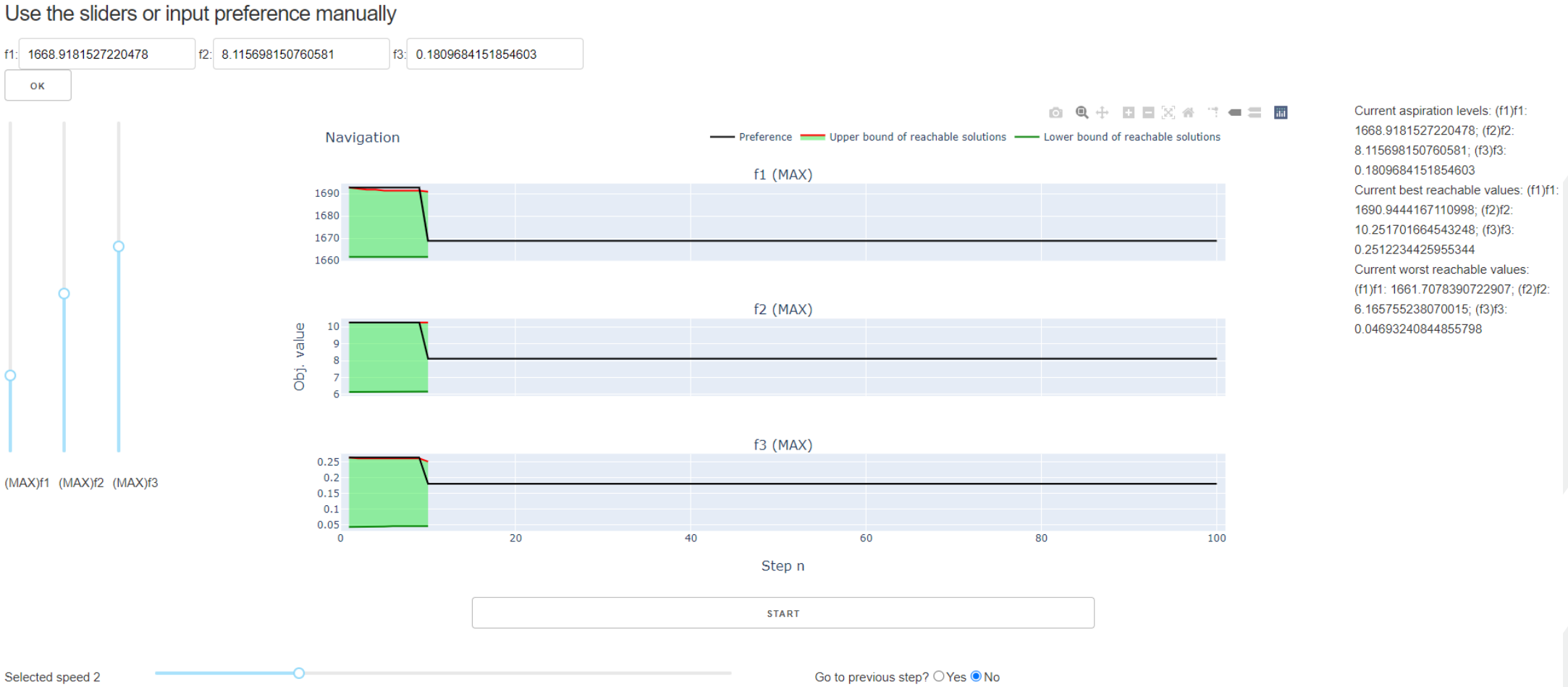
Saini, B.S., Emmerich, M., Mazumdar, A. et al. Optimistic NAUTILUS navigator for multiobjective optimization with costly function evaluations. J Glob Optim (2022).

How to Generalize These Interfaces?

- Each of the software tools presented so far are related to a specific method.
- However, the methods (and UIs) have elements in common.
- That is the main idea of DESDEO: having a modular implementation of interactive methods available as open-source software.

Graphical UIs : DESDEO-DASH

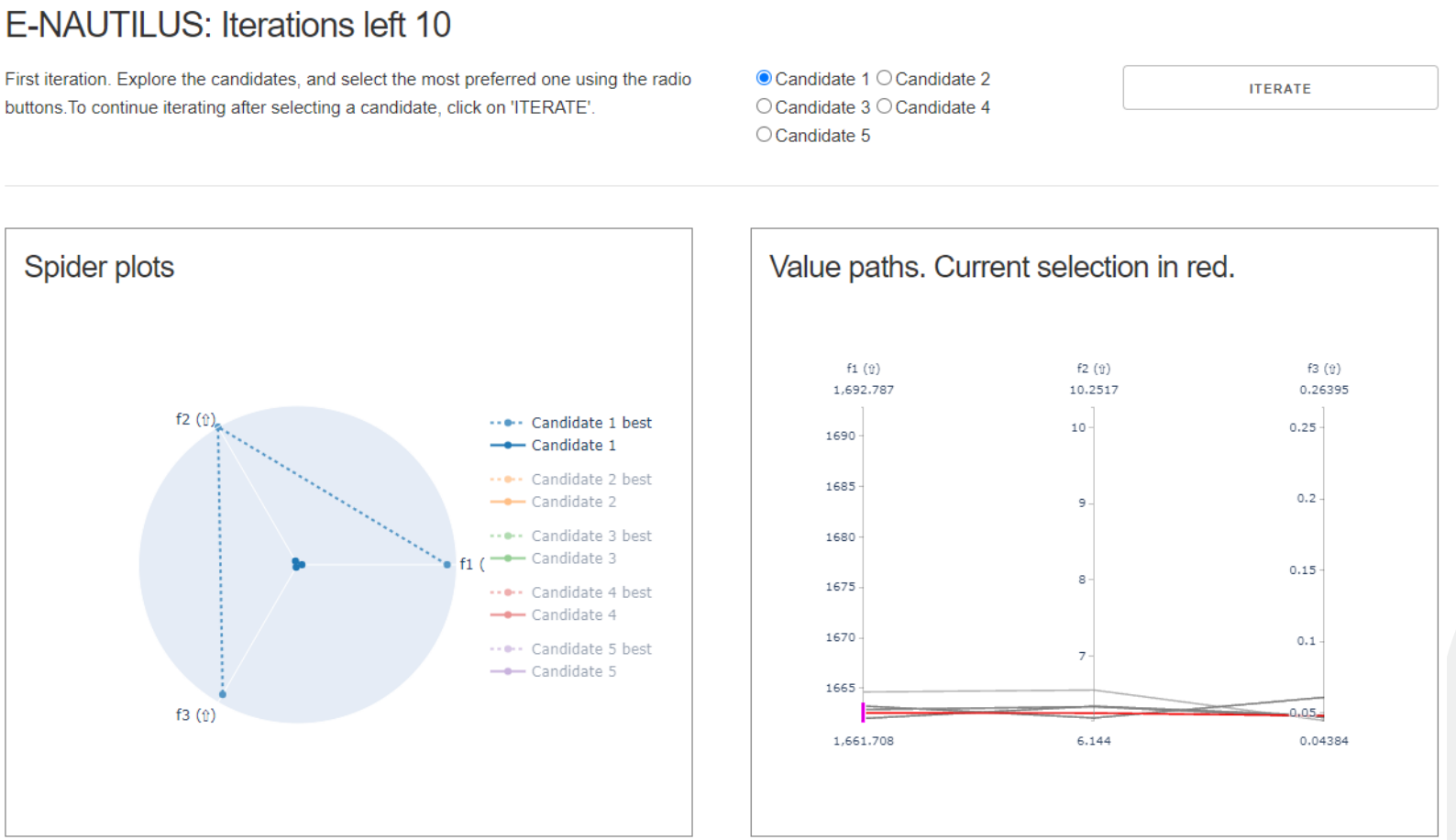
NAUTILUS navigator



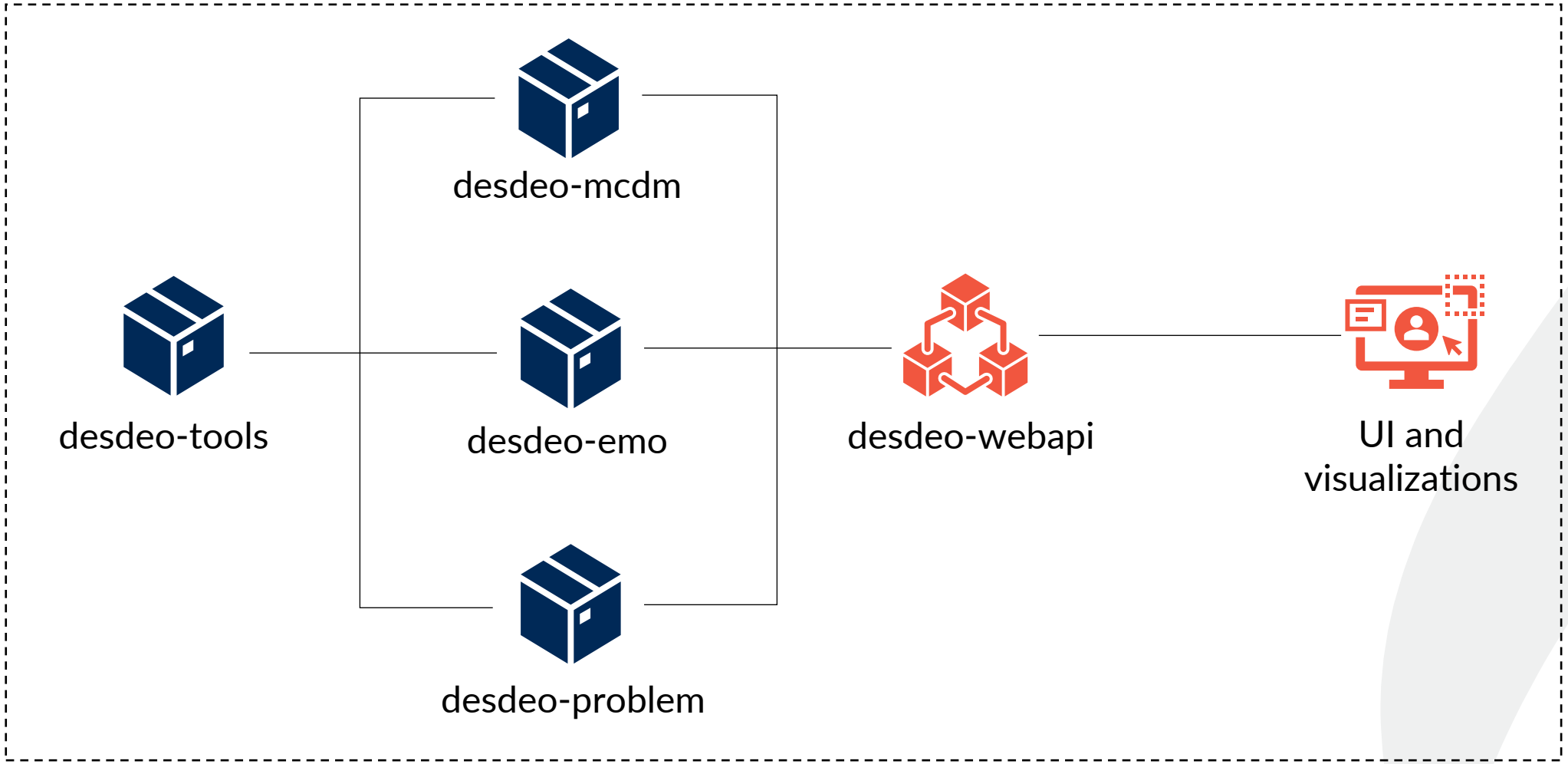
https://dash.misitano.xyz/

Graphical UIs : DESDEO-DASH

E-NAUTILUS

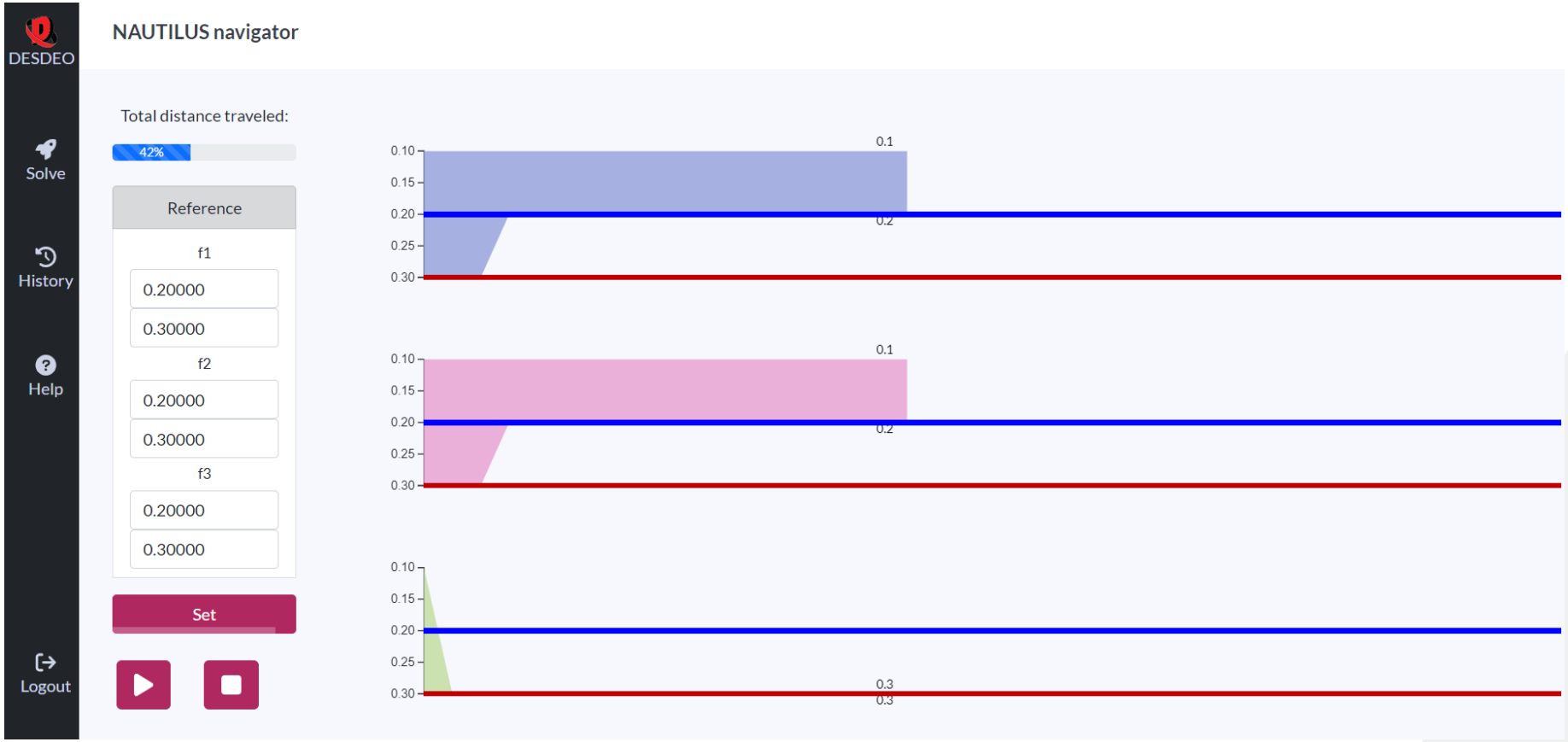


Graphical UIs: DESDEO 1 and 2



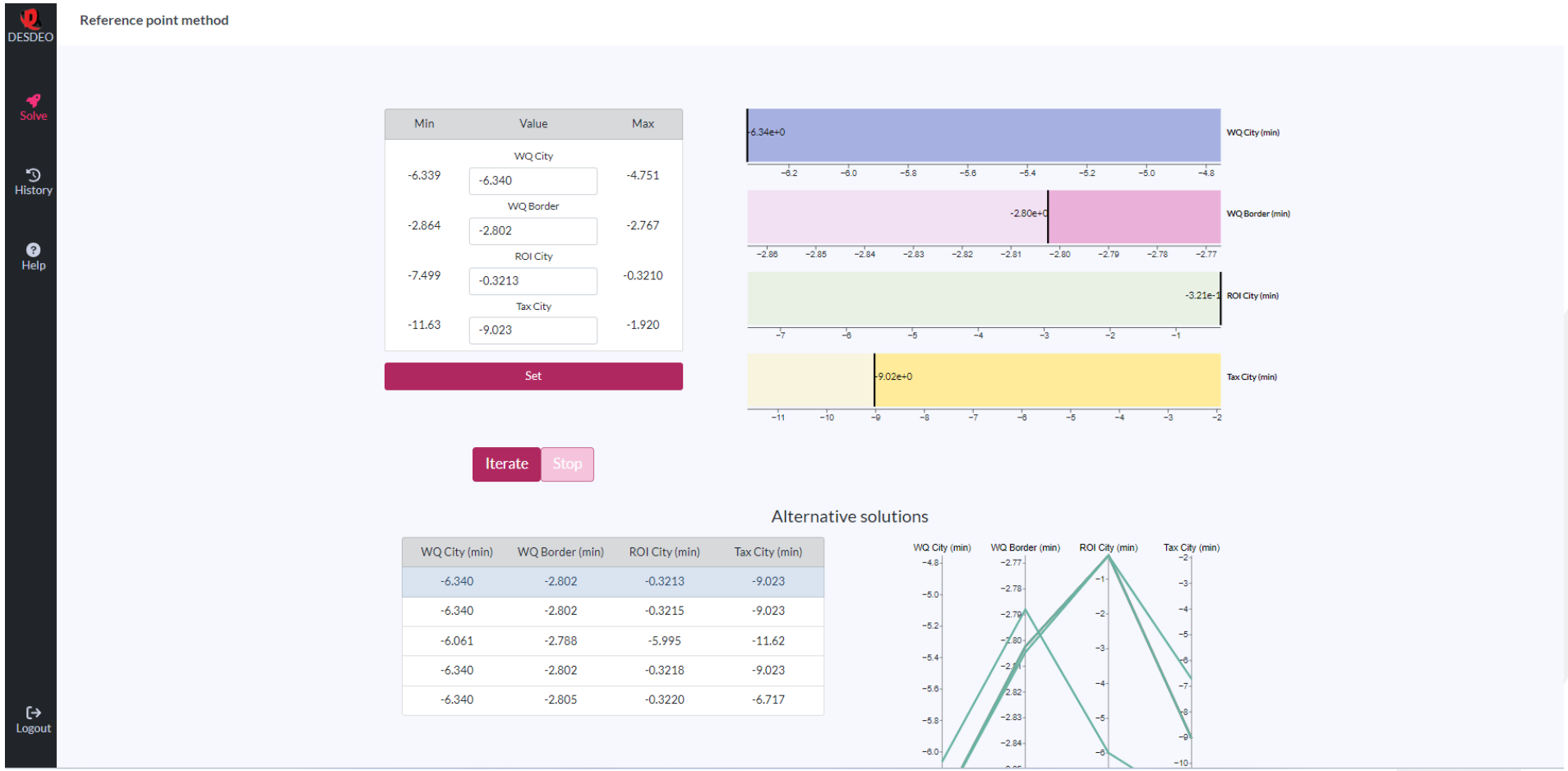
Graphical UIs: DESDEO 1

NAUTILUS navigator



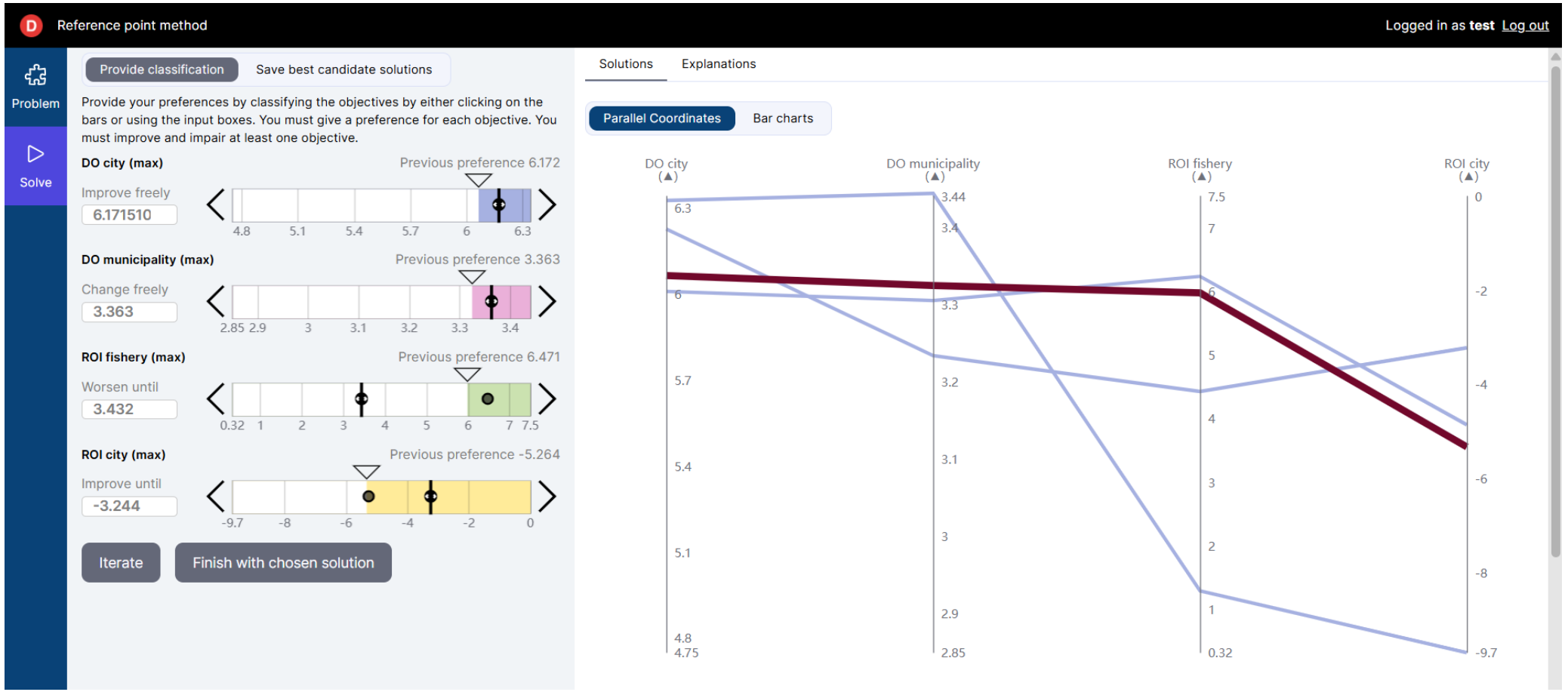
Graphical UIs: DESDEO 1

Reference point method



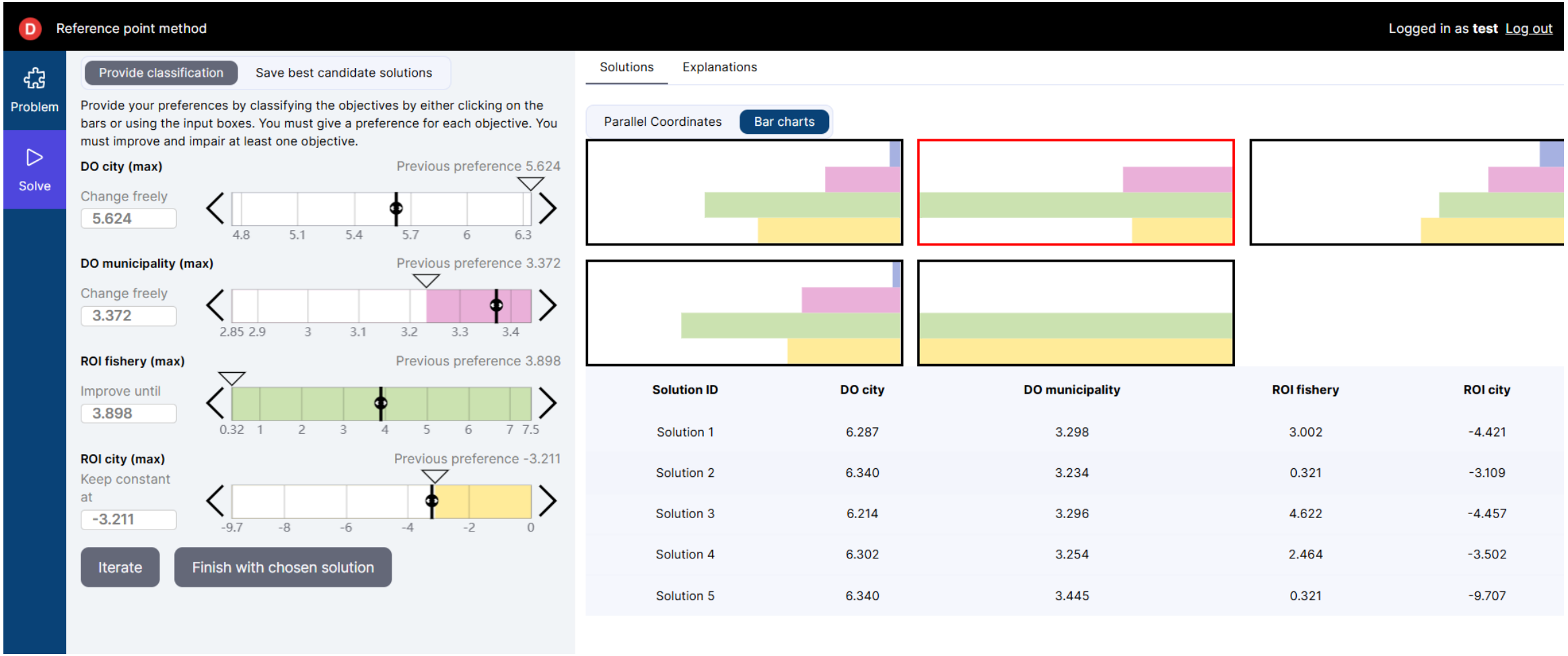
Graphical UIs: DESDEO 2

NIMBUS



Graphical UIs: DESDEO 2

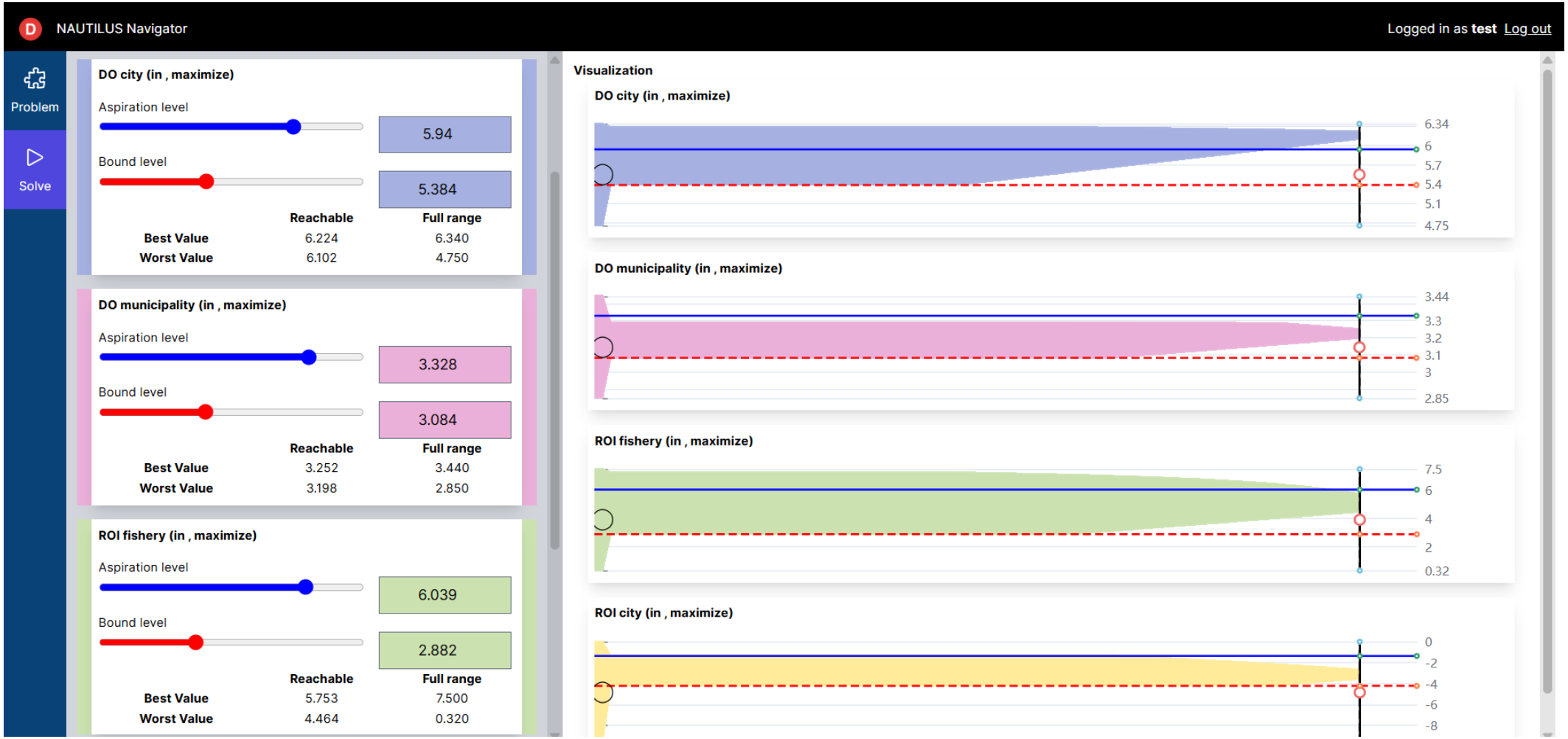
NIMBUS



Solution ID	DO city	DO municipality	ROI fishery	ROI city
Solution 1	6.287	3.298	3.002	-4.421
Solution 2	6.340	3.234	0.321	-3.109
Solution 3	6.214	3.296	4.622	-4.457
Solution 4	6.302	3.254	2.464	-3.502
Solution 5	6.340	3.445	0.321	-9.707

Graphical UIs: DESDEO 2

NAUTILUS navigator



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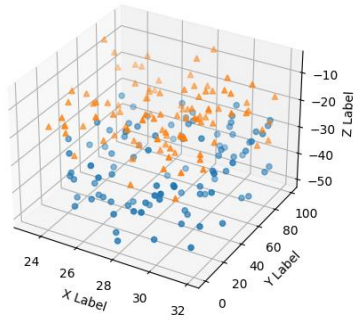
Online Version of the DESDEO 2 UI

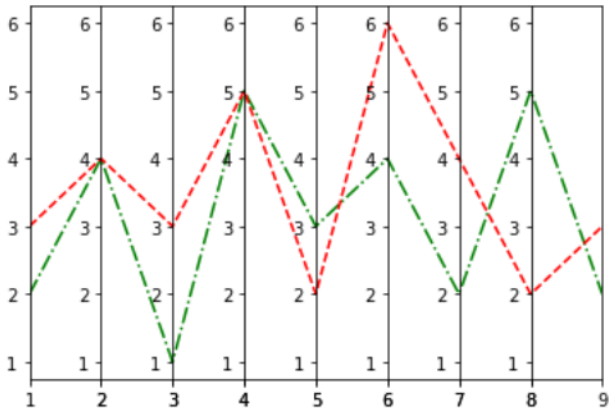
https://webui-utopia.2.rahtiapp.fi/login

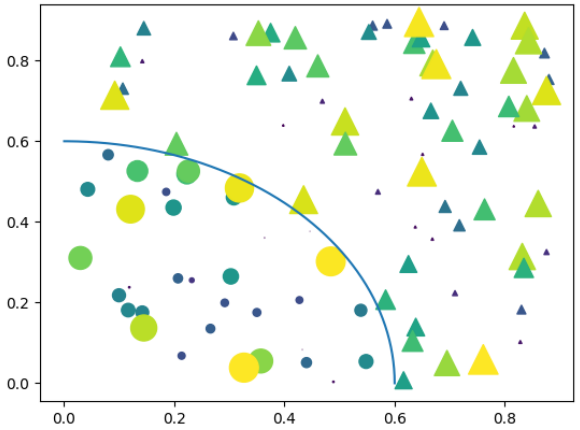
Tools for Implementing Visualizations and GUIs

Matplotlib

- Matplotlib is a comprehensive library for creating static, animated, and interactive visualizations in Python.
  - Make interactive figures that can zoom, pan, update.
  - Customize visual style and layout.
  - Export to many file formats.
  - It is a great place to start developing visualizations

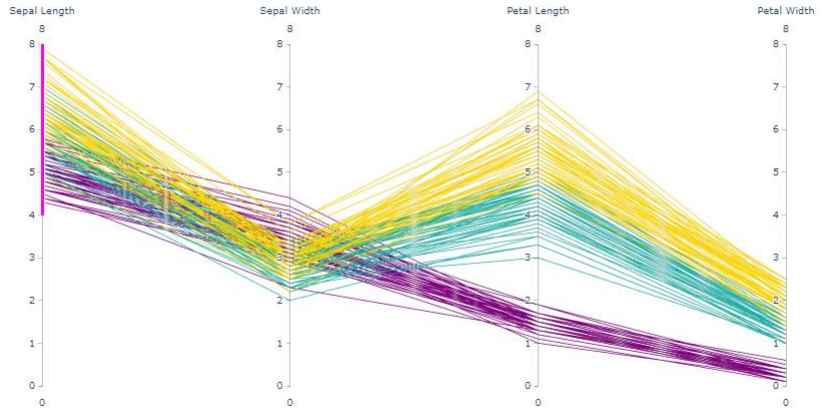


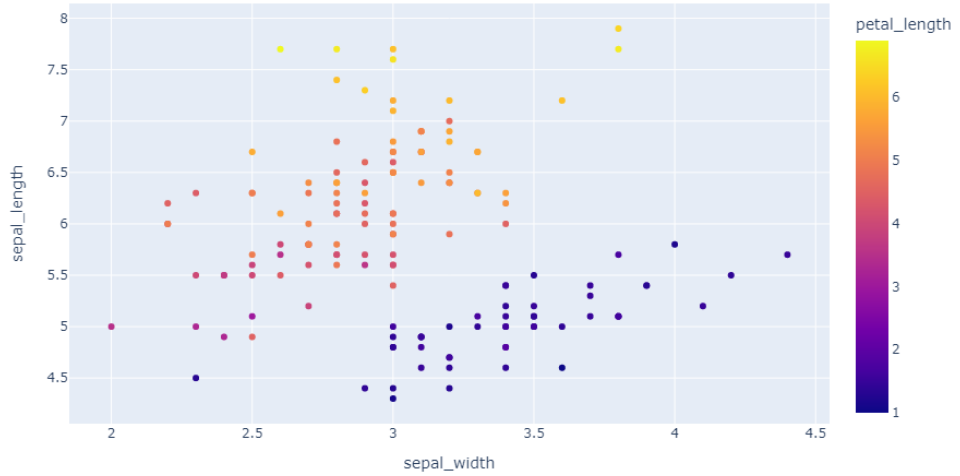




Plotly

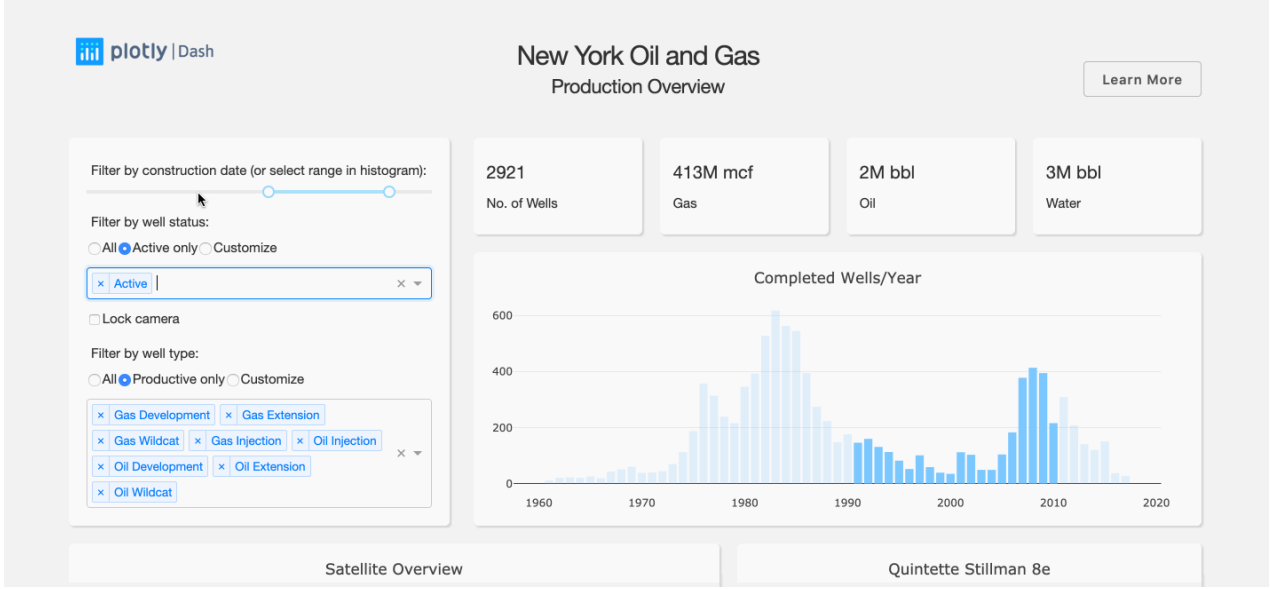
- Plotly is an interactive, open-source, and browser-based graphing library for Python
- Built on top of the Plotly JavaScript library (plotly.js),
- Plotly graphs can be viewed in Jupyter notebooks, standalone HTML files, or integrated into **Dash applications**.





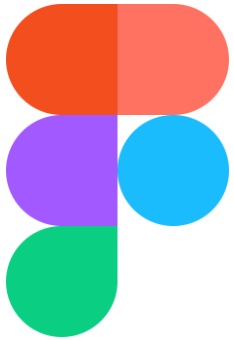
Plotly Dash

- Dash is the best way to build **analytical apps** in Python using Plotly figures.
- Dash is written on the top of **Flask, Plotly.js** and **React.js**
- With Dash, you **don't have to learn HTML, CSS and Javascript** in order to create interactive dashboards, you only need Python.



Prototyping tools

- **Figma:** Collaborative design tool
  - Drawing components
  - Drafting UIs
  - Simulate some interactions
- **Just in mind:** Design and prototyping tool for web and mobile apps
  - Simulation of the general UI
  - Events
  - Reviews



Challenges and future developments

- UIs and visualizations for **group decision-making**
- **Explainability** to help DMs to update their preferences
- Create **new methods** through the UI
- **Switching between methods** during the solution process

Recommended articles

- Miettinen, K. ***Survey of methods to visualize alternatives in multiple criteria decision making problems***. OR Spectrum 36, 3–37 (2014). https://doi.org/10.1007/s00291-012-0297-0
- Hakanen, J., Radoš, S., Misitano, G., Saini, B. S., Miettinen, K., & Matković, K. ***Interactivized : Visual Interaction for Better Decisions with Interactive Multiobjective Optimization***. *IEEE Access*, *10*, 33661-33678 (2022). https://doi.org/10.1109/access.2022.3161465
- Saini, B. S., Miettinen, K., Klamroth, K., Steuer, R. E., & Dächert, K. ***SCORE Band Visualizations : Supporting Decision Makers in Comparing High-Dimensional Outcome Vectors in Multiobjective Optimization***. *IEEE Access*, *12*, 164371-164388 (2024). https://doi.org/10.1109/access.2024.3491423
- Silvennoinen, J., Larraga, G., Ruiz, A. B., Ruiz, F., Misitano, G., & Miettinen, K. ***Icons for Software Implementations of Interactive Multiobjective Optimization Methods : A Semantic Distance Study***. *Journal of Multi-Criteria Decision Analysis*, *32*(1), Article e70010 (2025). https://doi.org/10.1002/mcda.70010

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