Tradeoffs, Vulnerabilities, & Robustness

Problem framing challenges for water systems planning under change

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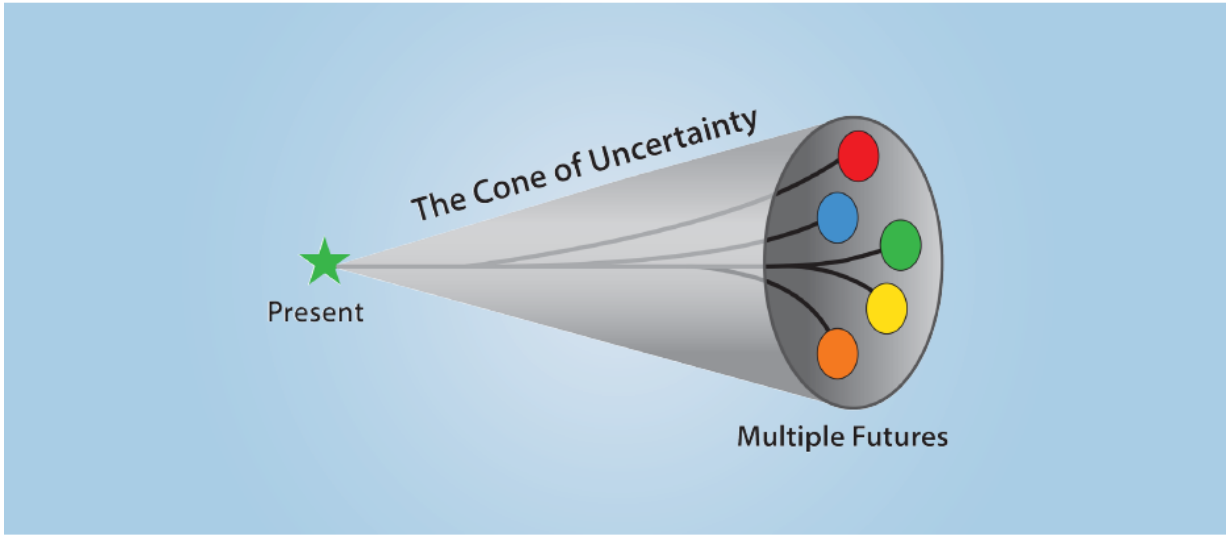
A qualitative starting point…

EMBRACING UNCERTAINTY

A Case Study Examination of How Climate Change is Shifting Water Utility Planning



Prepared for:

Water Utility Climate Alliance (WUCA)
American Water Works Association (AWWA)
Water Research Foundation (WRF)
Association of Metropolitan Water Agencies (AMWA)

Project Manager: Laurna Kaatz, Denver Water

13 Case Studies

-UK & Australia
-Denver Water
-Bureau of Rec.
-CA DWR
-MWD
-many more

Seeking robustness across possible futures

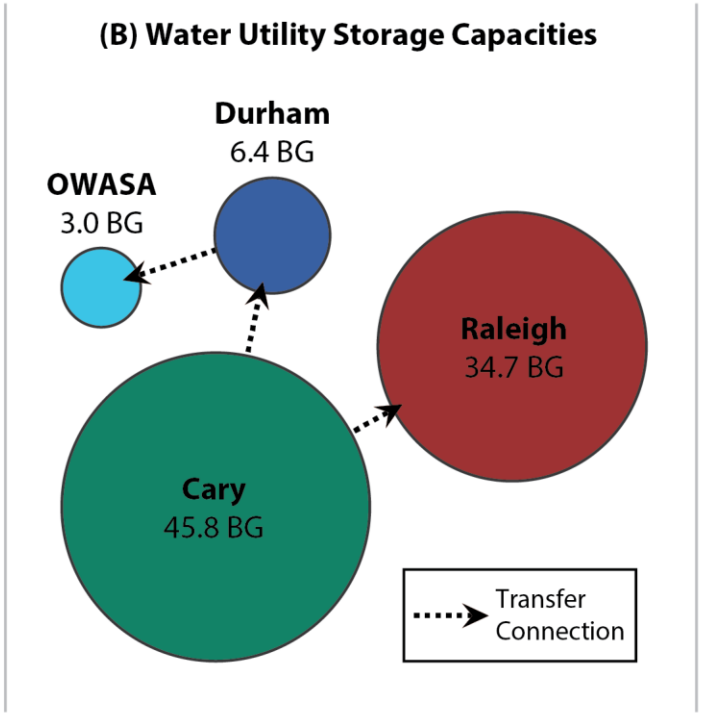
"Bottom-up" decision frameworks

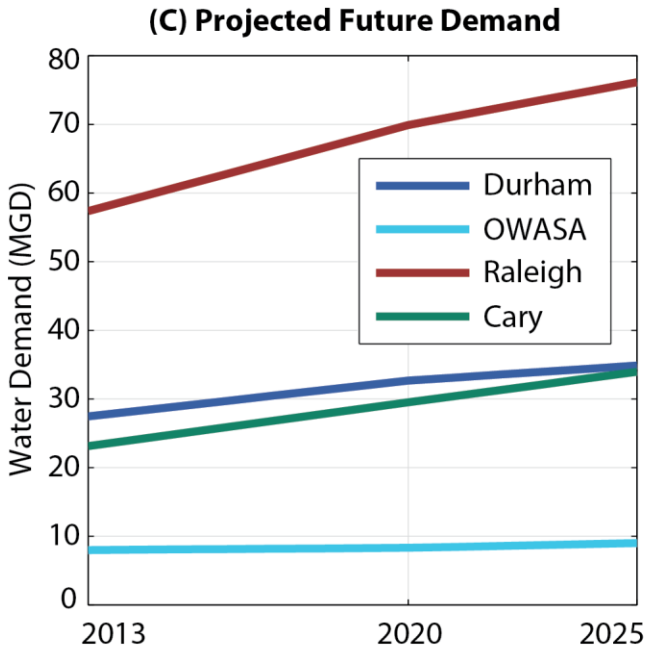
(Decision Scaling, Info-Gap, RDM, MORDM, Dynamic Adaptive Policy Pathways …)

> Shift from asking the *prediction question* –
> 'how likely is this scenario?'
> to asking the *decision impact question* –
> 'how likely would this scenario need to be to affect one's choice of strategy?'

— Bryant and Lempert (2010)

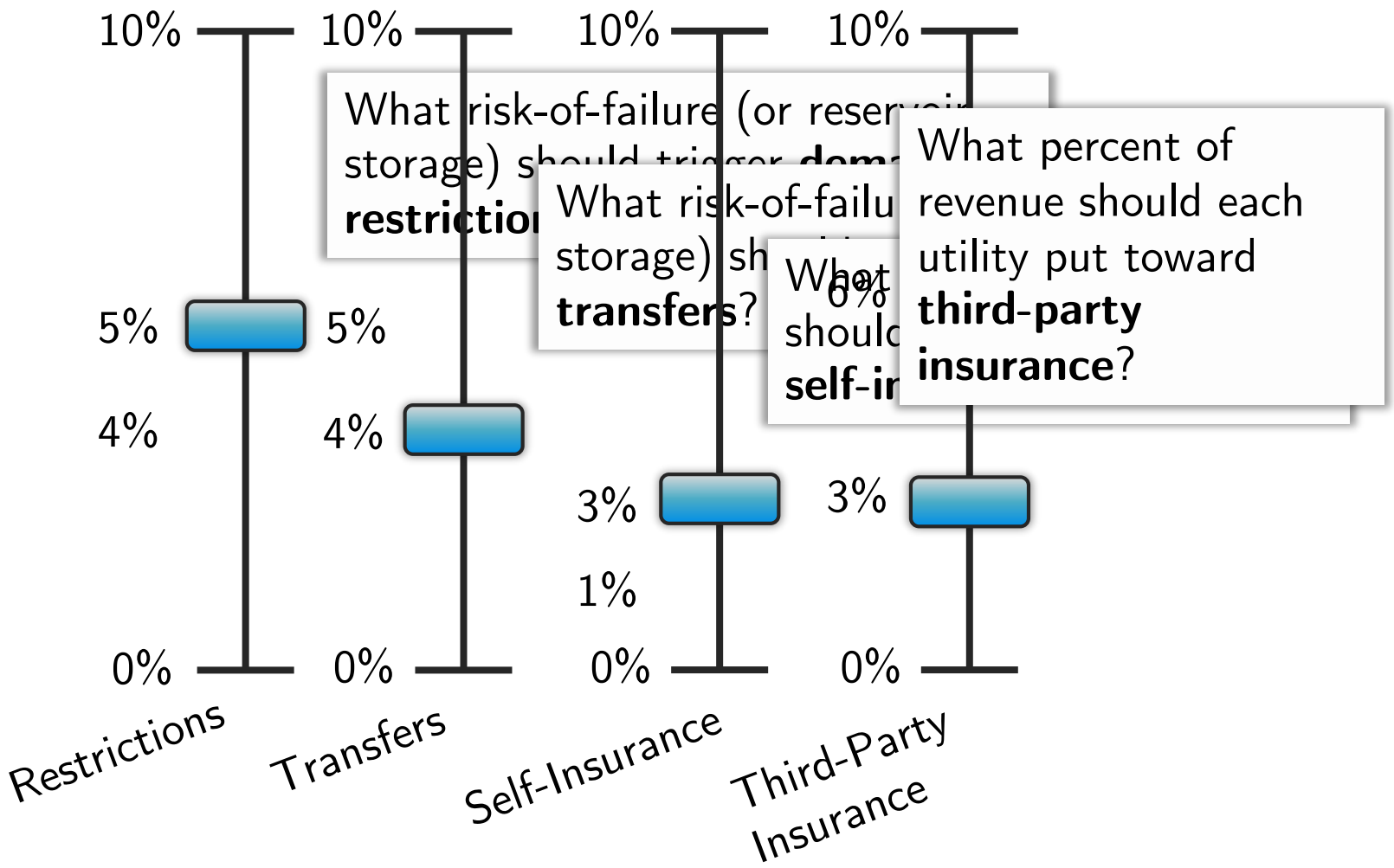
Overview of 'Research Triangle' Water Utilities: North Carolina, USA





- Transition from water abundance to scarcity
- Storage/demand ratios allow intra-regional transfers

Each utility has four decision variables to model drought management actions



Four objectives defined by the utilities

Reliability (Max): # years where reservoir storage > 20%

Restriction Frequency (Min):

years with drought conservation measures enacted

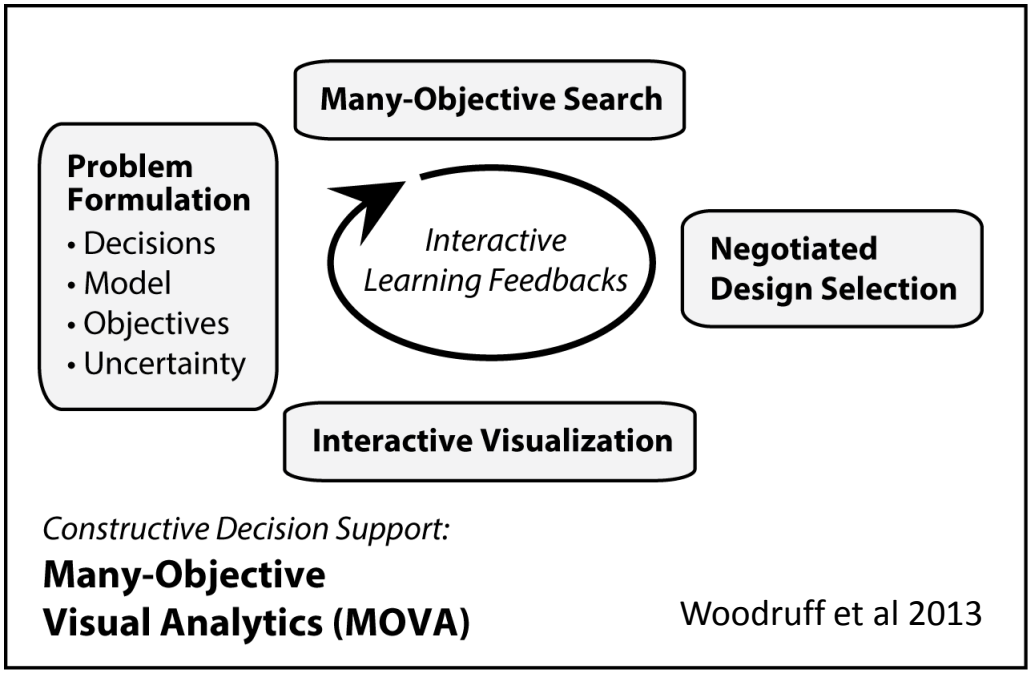
Average Financial Losses (Min):

Revenue reductions + costs due to drought management

Worst-Case Financial Losses (Min):

Financial losses in the 1% worst scenario

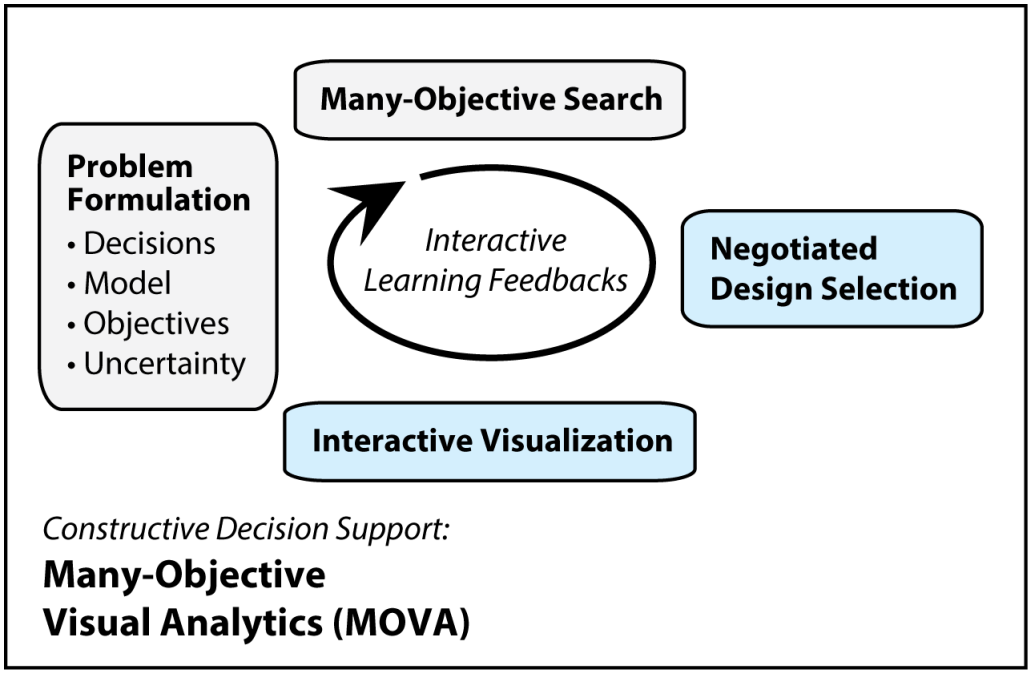
The worst-performing utility is optimized such that others will perform as well or better.



Constructive Decision Support:

Many-Objective Visual Analytics (MOVA)

Woodruff et al 2013



Many-Objective Robust Decision-Making for Multiple Stakeholders

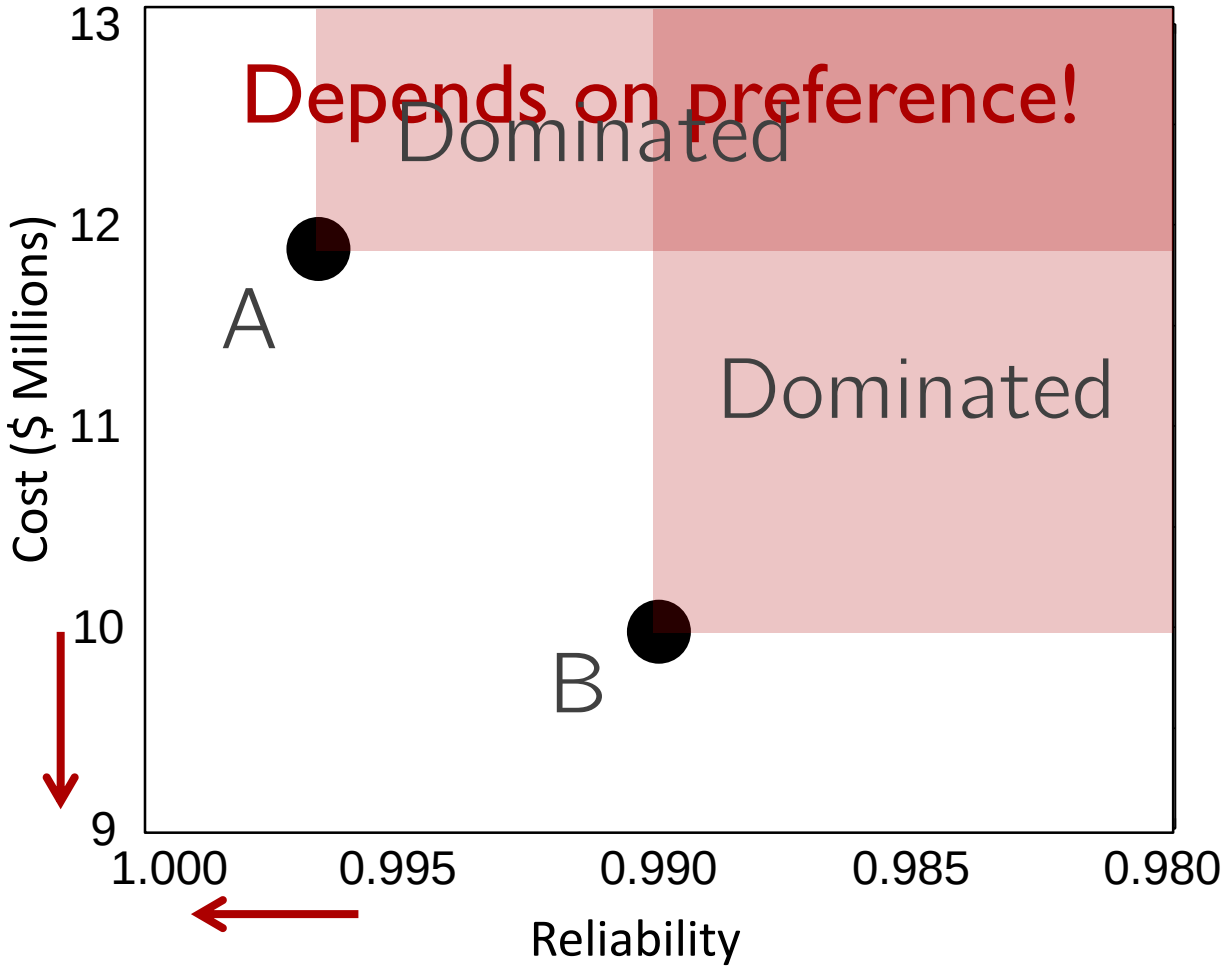
To summarize:

(1) Rapidly explore multiple competing problem formulations (hypotheses)

(2) Facilitate learning and visual tradeoff analysis

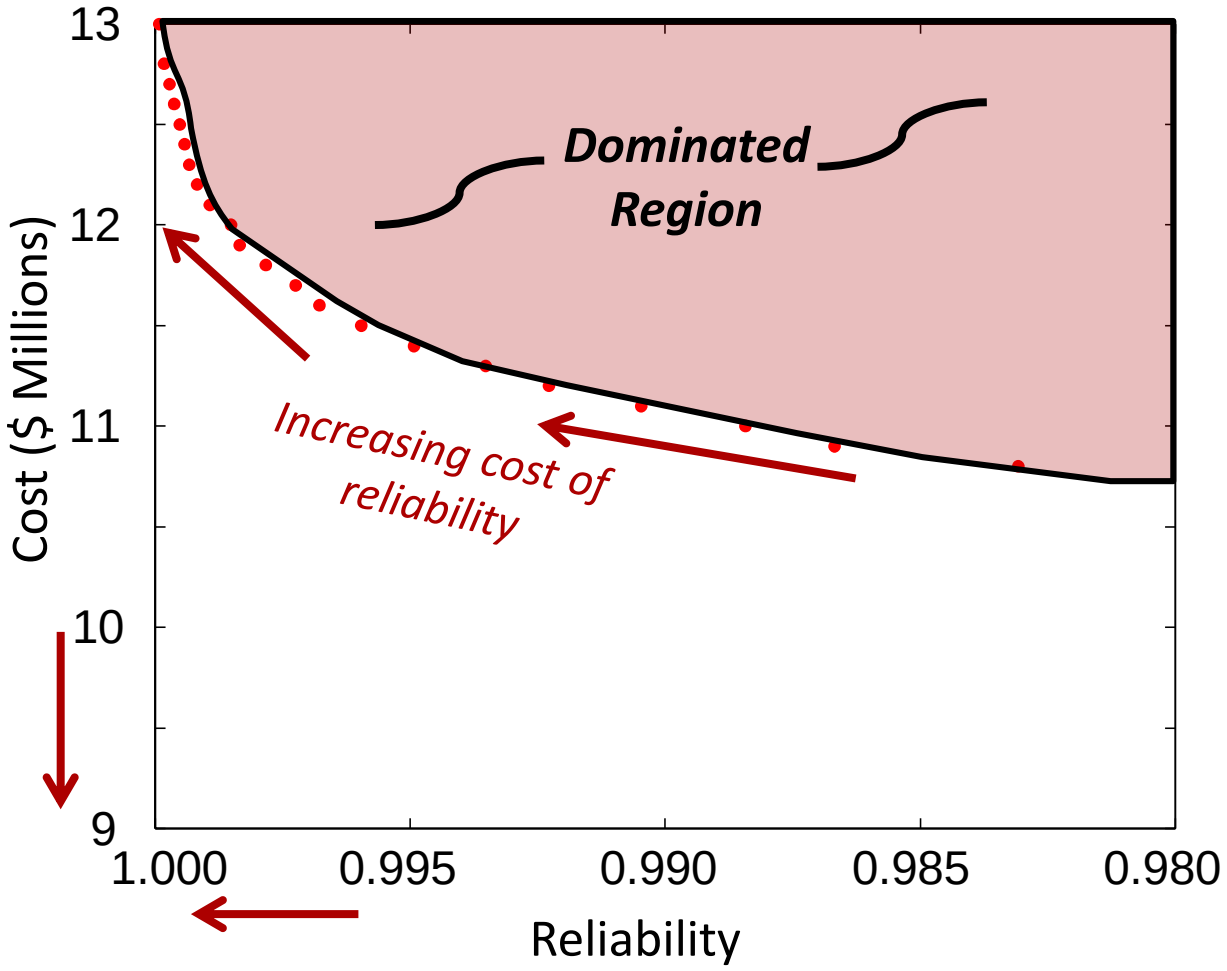
(3) Ensure decisions and monitoring recommendations are robust to many futures

Multi-objective: which solution is better?



Kasprzyk et al. 2009

Looking for non-dominated solutions (tradeoff)



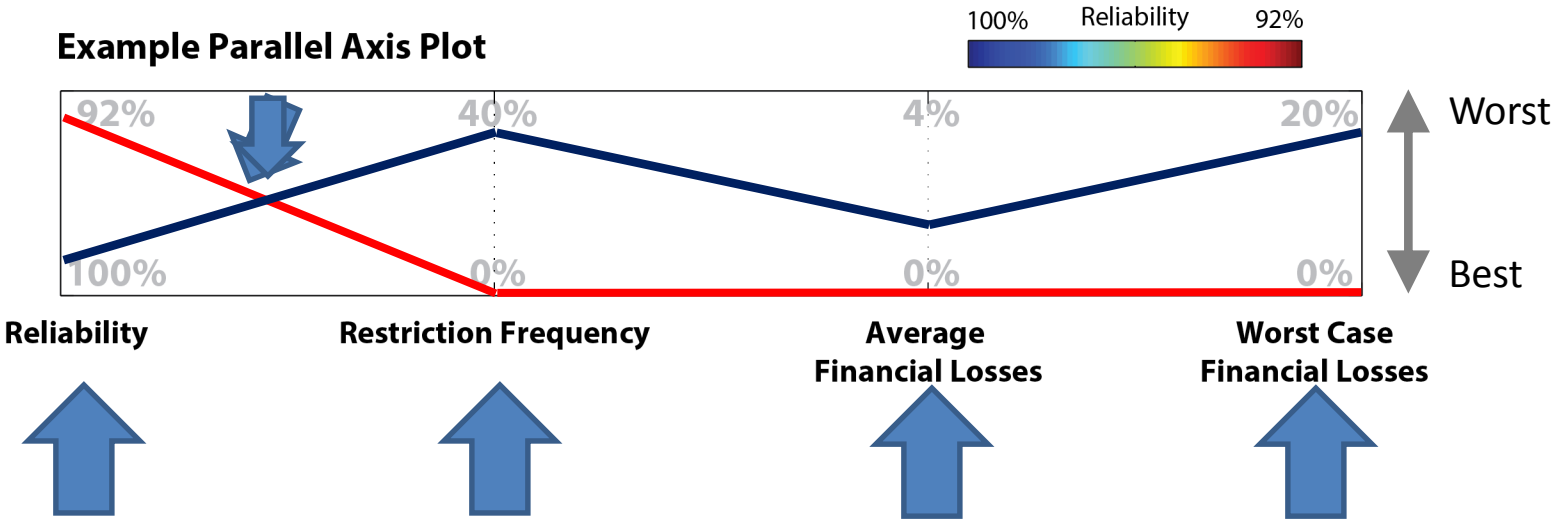
Kasprzyk et al. 2009

What portfolio complexity is needed?

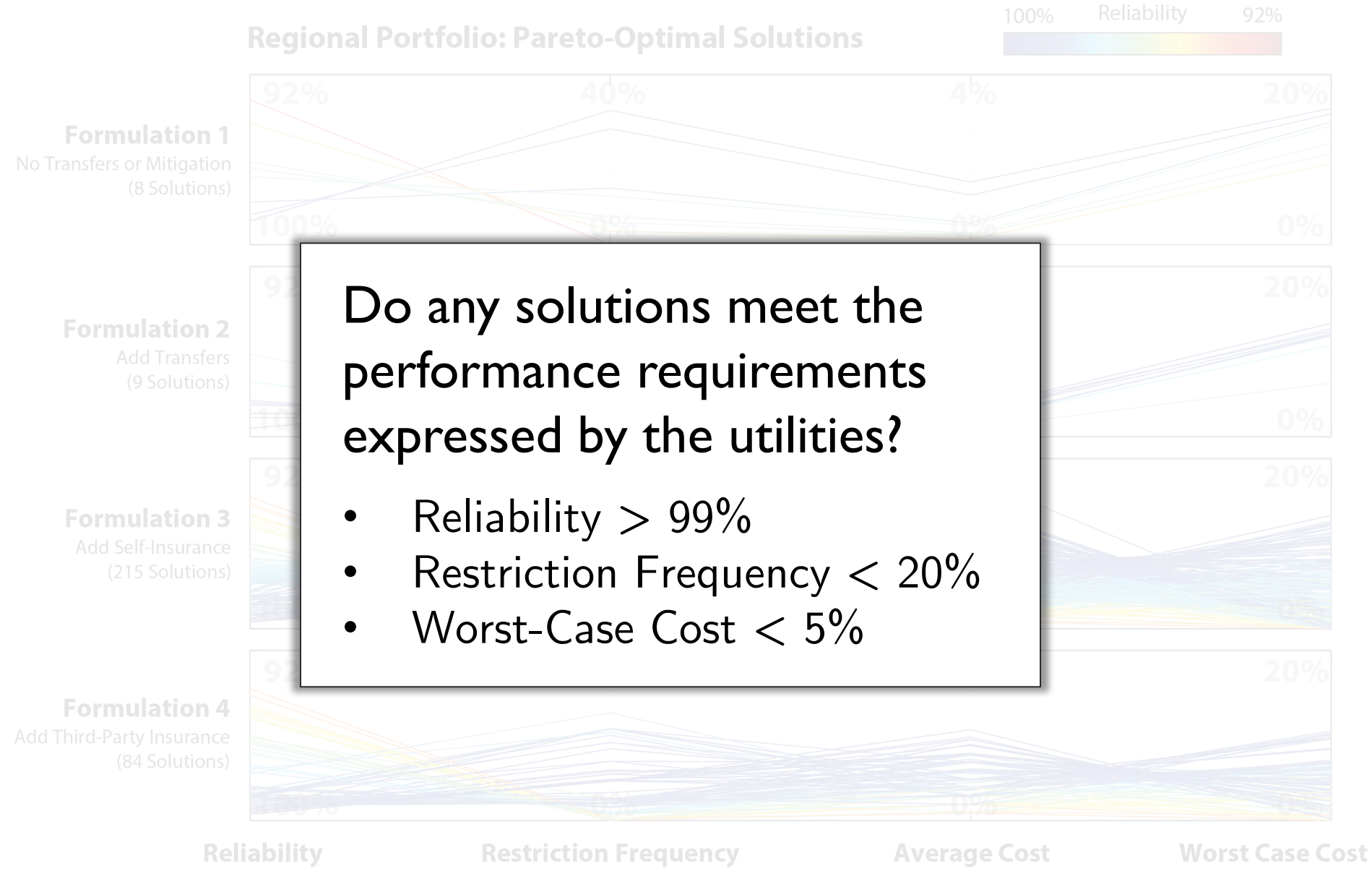
Multiple formulations tested – a "constructive" approach (Tsoukias 2008)

1. Restrictions only (status quo)
2. Restrictions + Transfers
3. Restrictions + Transfers + Self-insurance
4. Restrictions + Transfers + Self-insurance + Third-party Insurance

Parallel axis plots help stakeholders visualize tradeoffs between conflicting objectives



- Each line represents one solution
- X-Axis shows the four objectives to be optimized
- Y-Axis shows the objective value (performance)
- Crossing lines indicate tradeoffs

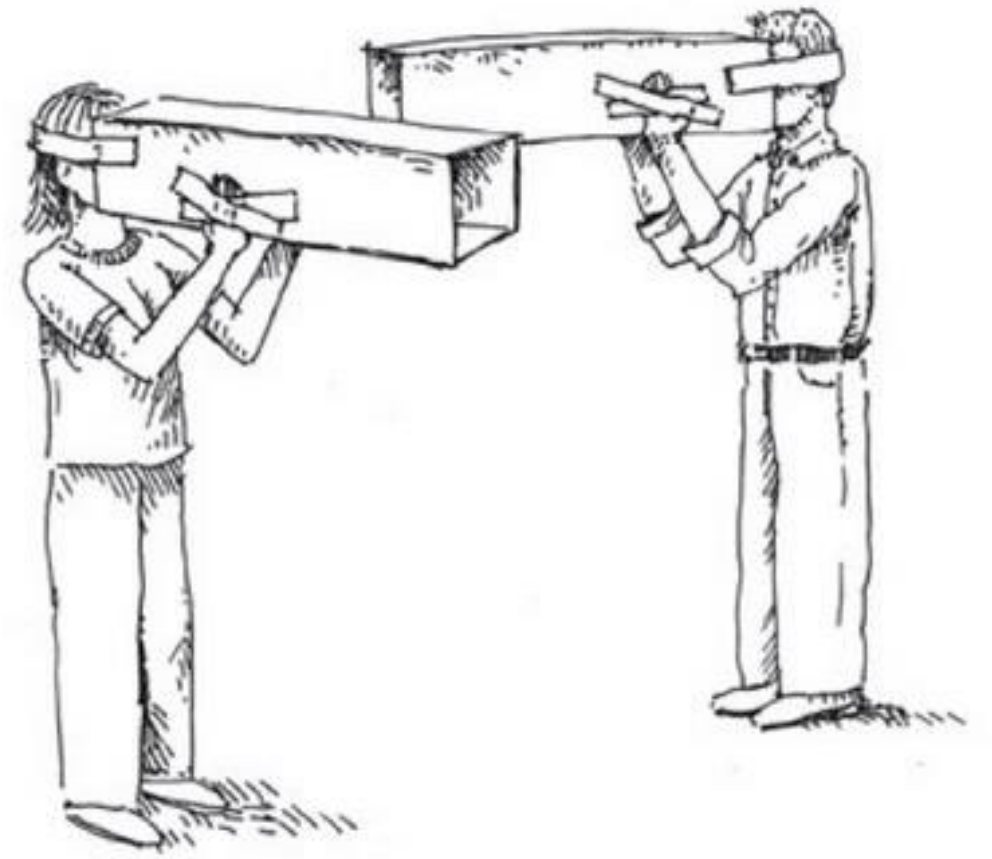


Do any solutions meet the performance requirements expressed by the utilities?

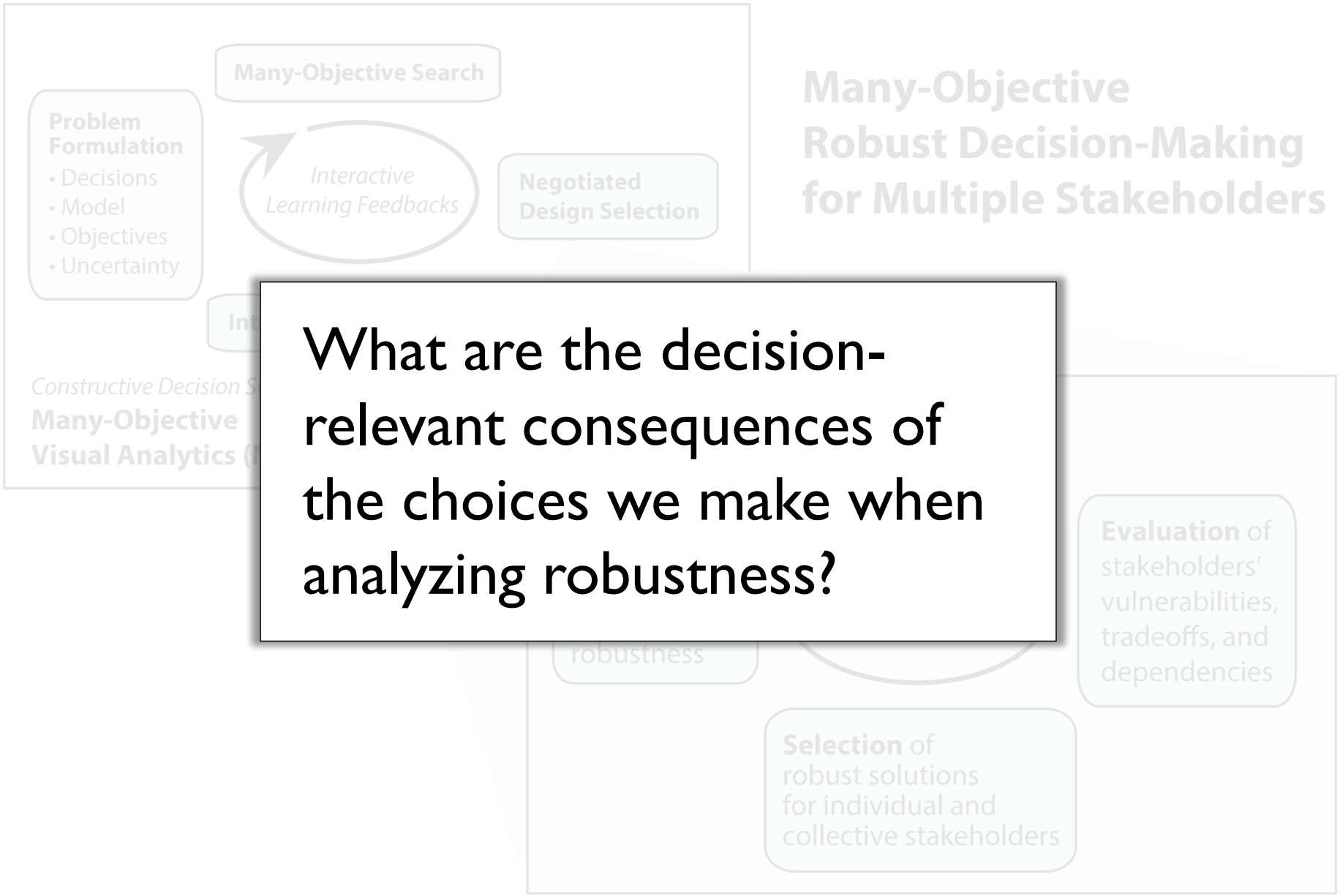
- Reliability $> 99\%$
- Restriction Frequency $< 20\%$
- Worst-Case Cost $< 5\%$

Transfers and financial instruments are required to reach the desired level of performance

Optimizing to a single future: what if we're wrong?



http://www.hockscqc.com/articles/tunnelvision/tunnel-vision.jpg

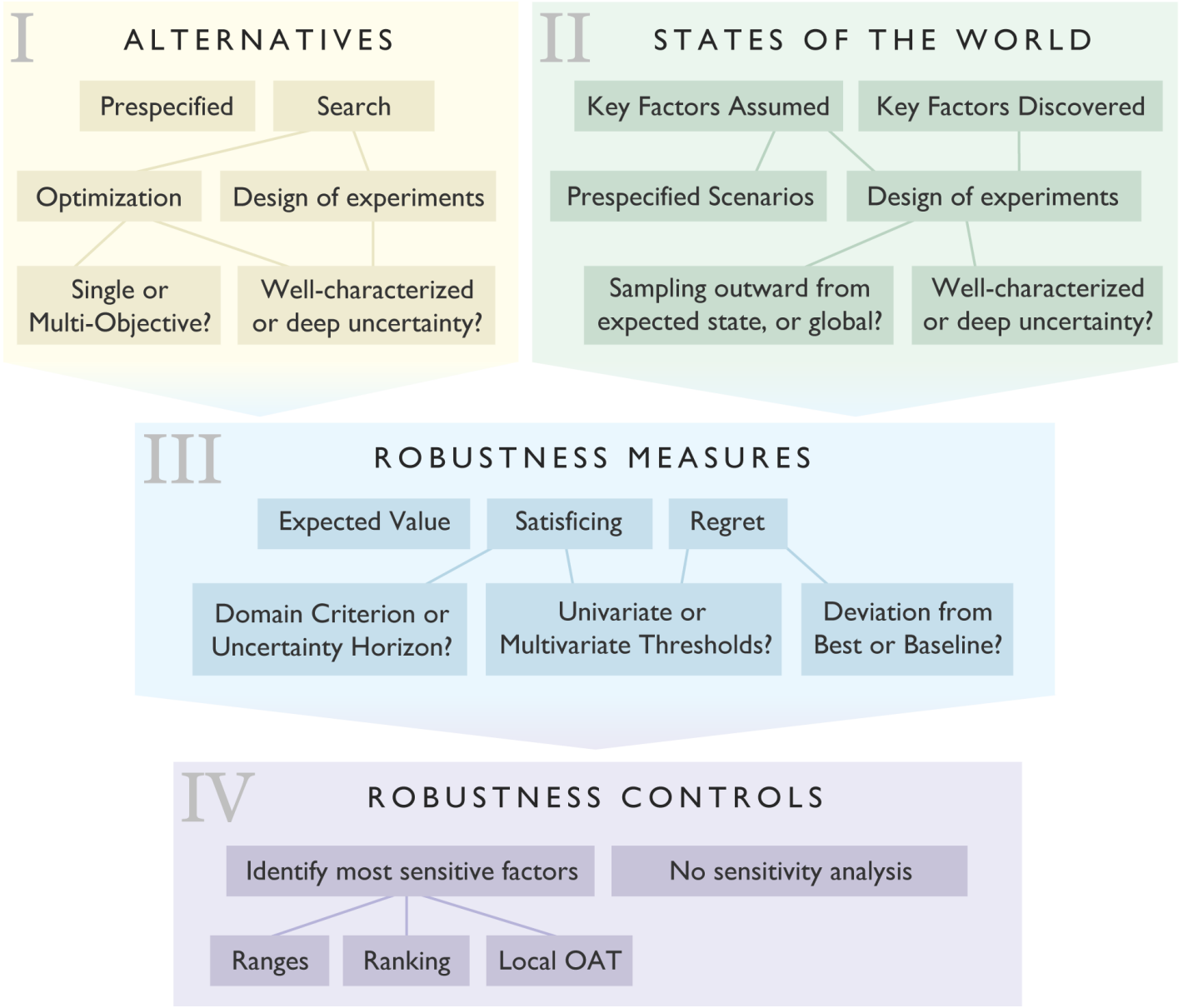

Many-Objective Search
Problem Formulation
• Decisions
• Model
• Objectives
• Uncertainty
Interactive Learning Feedbacks
Negotiated Design Selection
Many-Objective Robust Decision-Making for Multiple Stakeholders
Many-Objective Visual Analytics
What are the decision-relevant consequences of the choices we make when analyzing robustness?
Evaluation of stakeholders' vulnerabilities, tradeoffs, and dependencies
Selection of robust solutions for individual and collective stakeholders

What do robustness analyses have in common?

Evaluate alternatives in multiple states of the world…

Quantify robustness measures and determine sensitive uncertainties

Taxonomy of Robustness Frameworks



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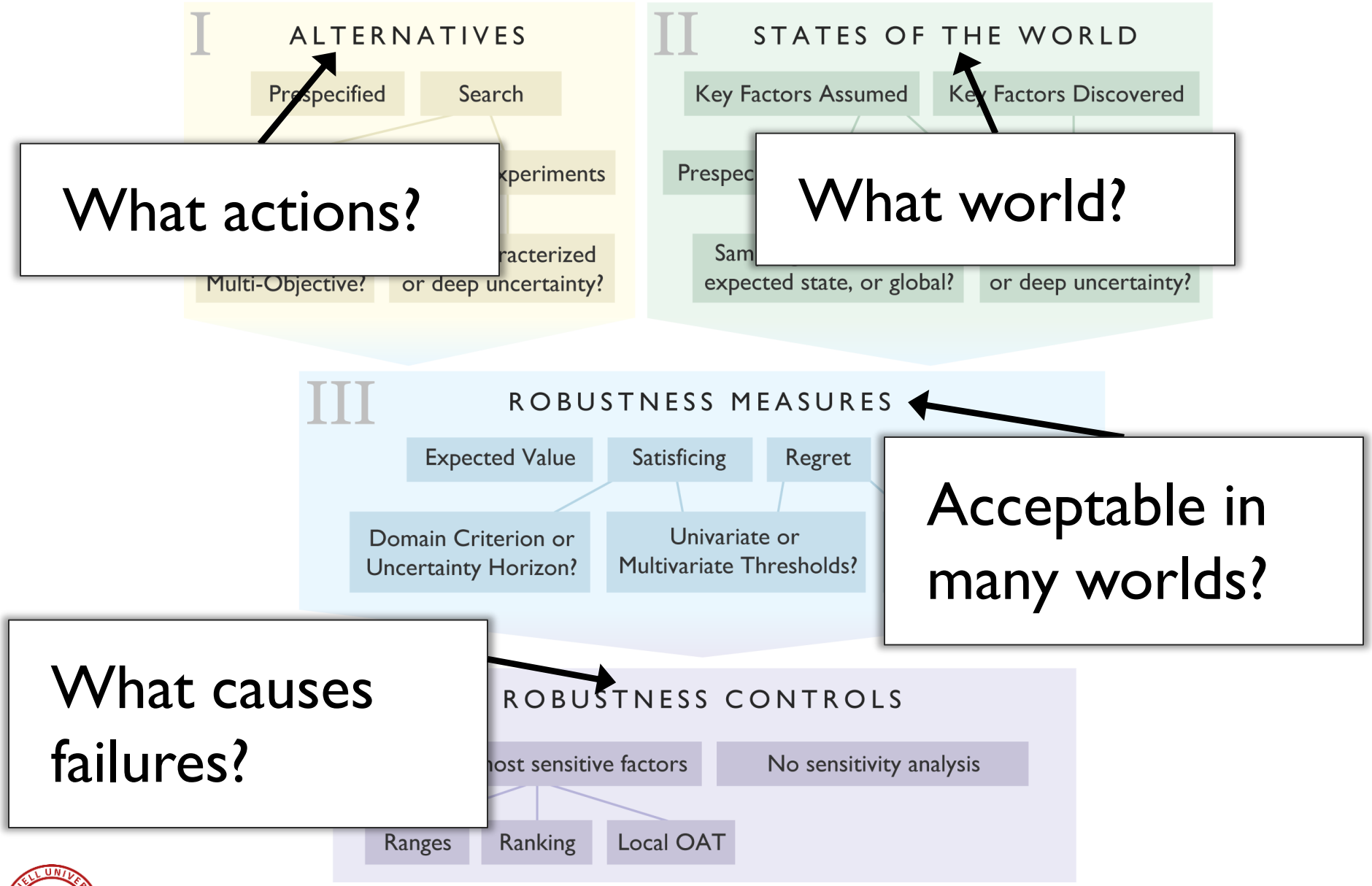

What actions?

What world?

Acceptable in many worlds?

What causes failures?

Taxonomy of Robustness Frameworks

Discovering solutions through search improves robustness relative to prespecified alternatives

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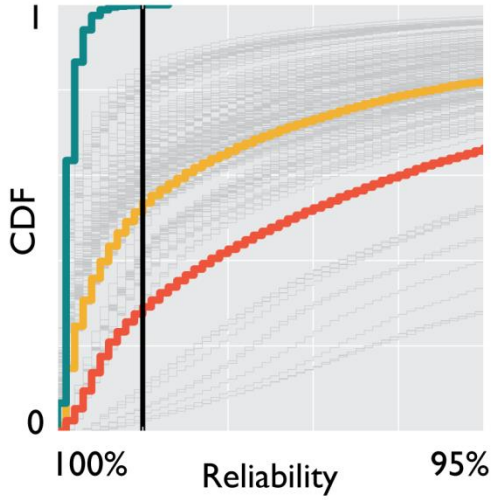
Performance CDFs over Uncertain States of the World

Multi-objective performance for Durham



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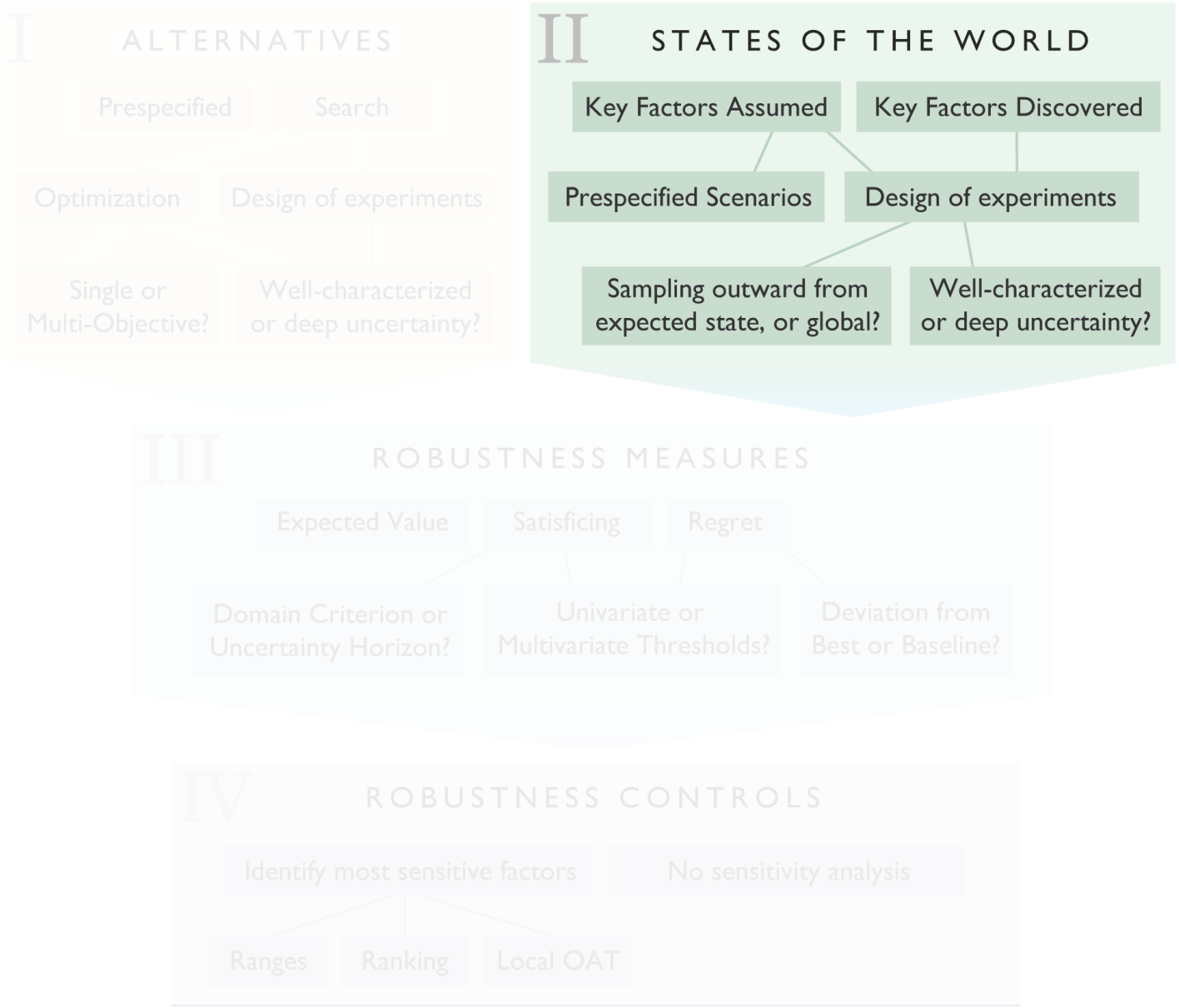
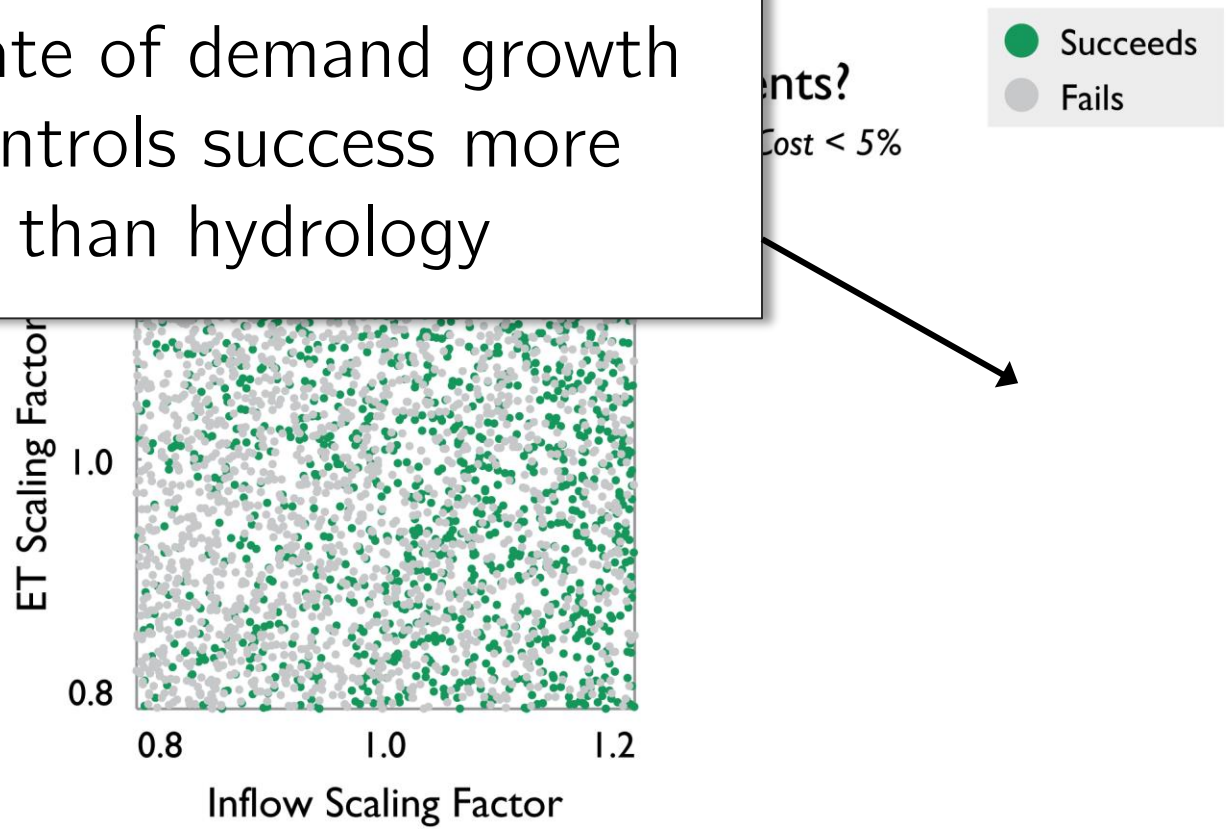


An *a priori* focus on climate/hydrologic factors may fail to capture system vulnerabilities

Rate of demand growth controls success more so than hydrology



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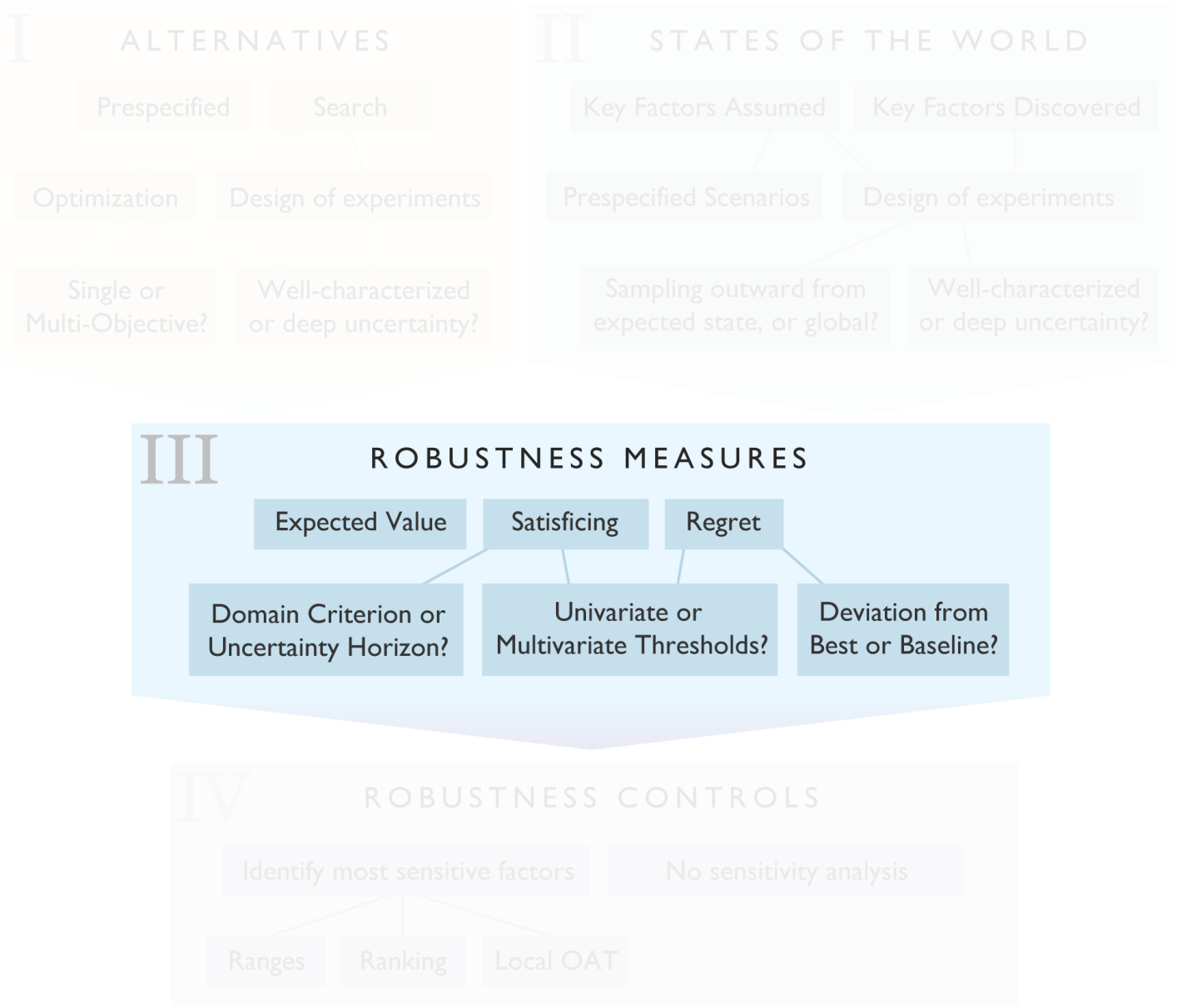
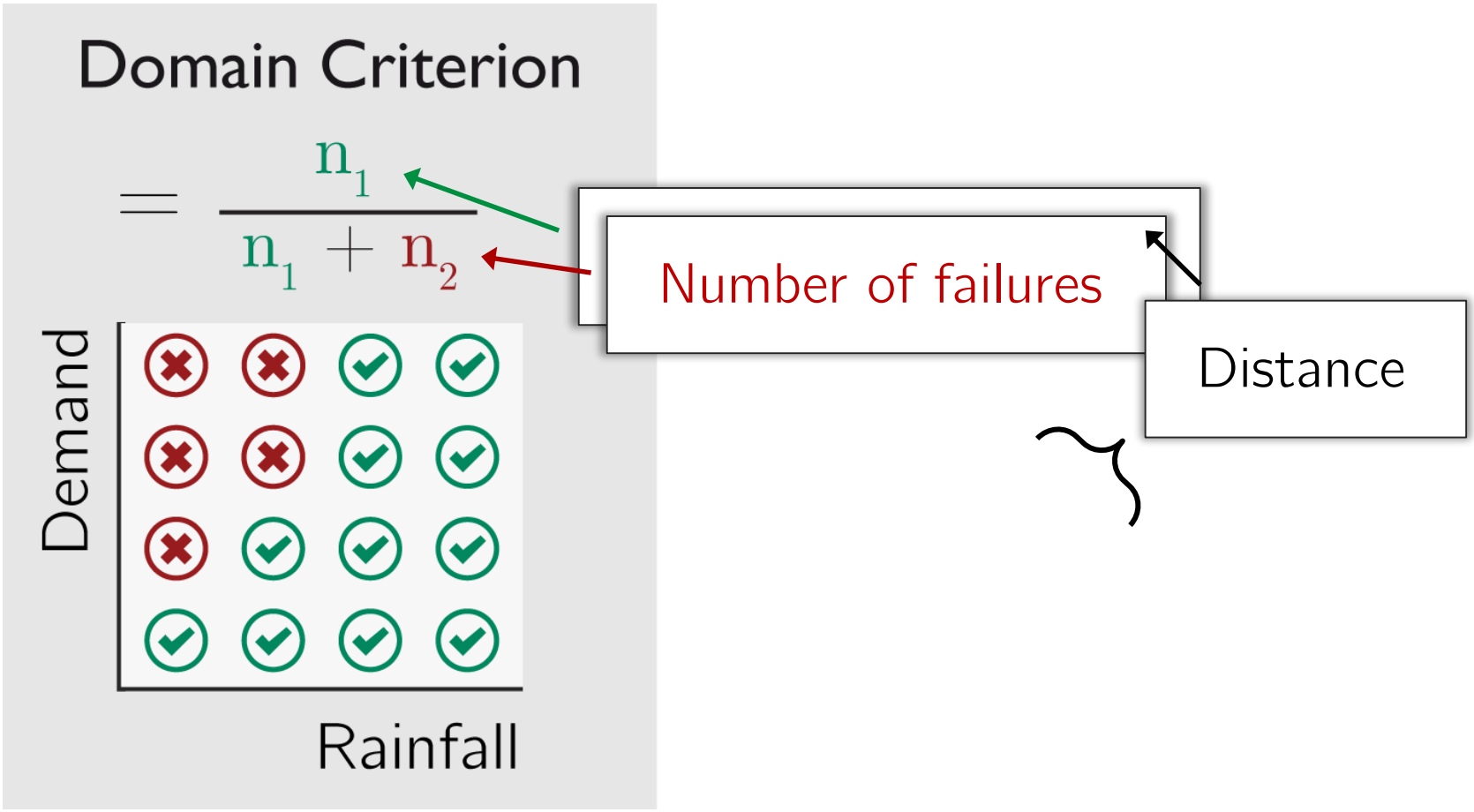




References: Lempert and Collins (2007), Schneller and Sphicas (1983), Hipel and Ben-Haim (1999)

How to measure robustness?

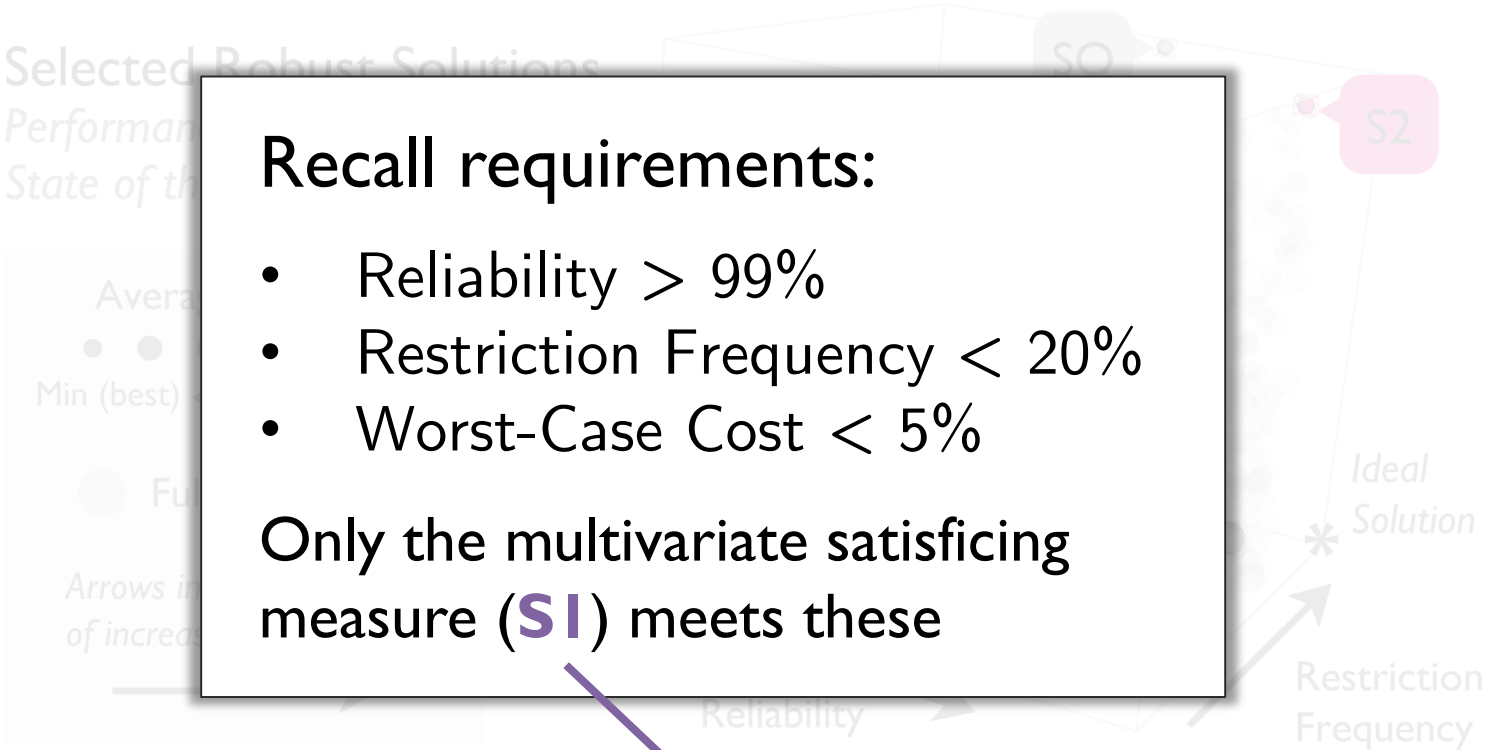
Which solutions would each measure choose from our Pareto front?

Definitions adapted from Lempert and Collins (2007)

Recall requirements:

- Reliability $> 99\%$
- Restriction Frequency $< 20\%$
- Worst-Case Cost $< 5\%$

Only the multivariate satisficing measure (**SI**) meets these



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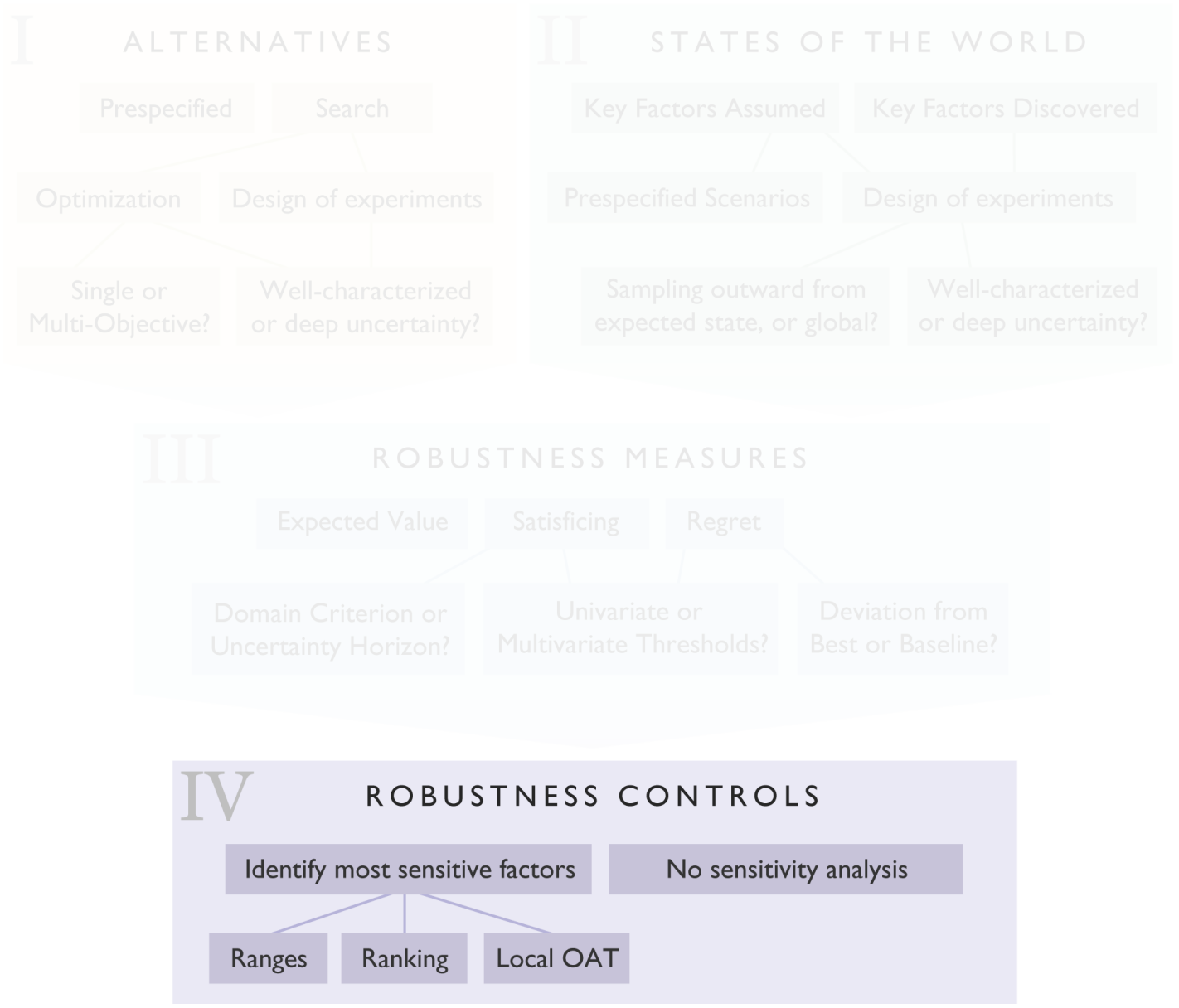
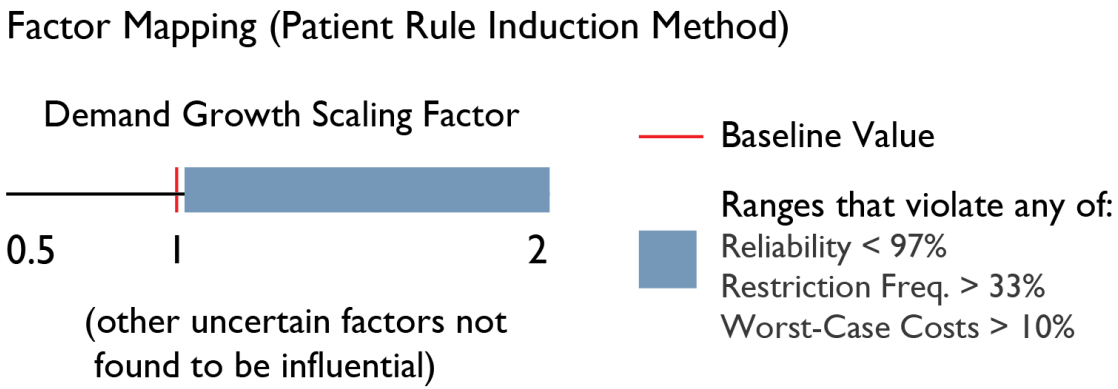
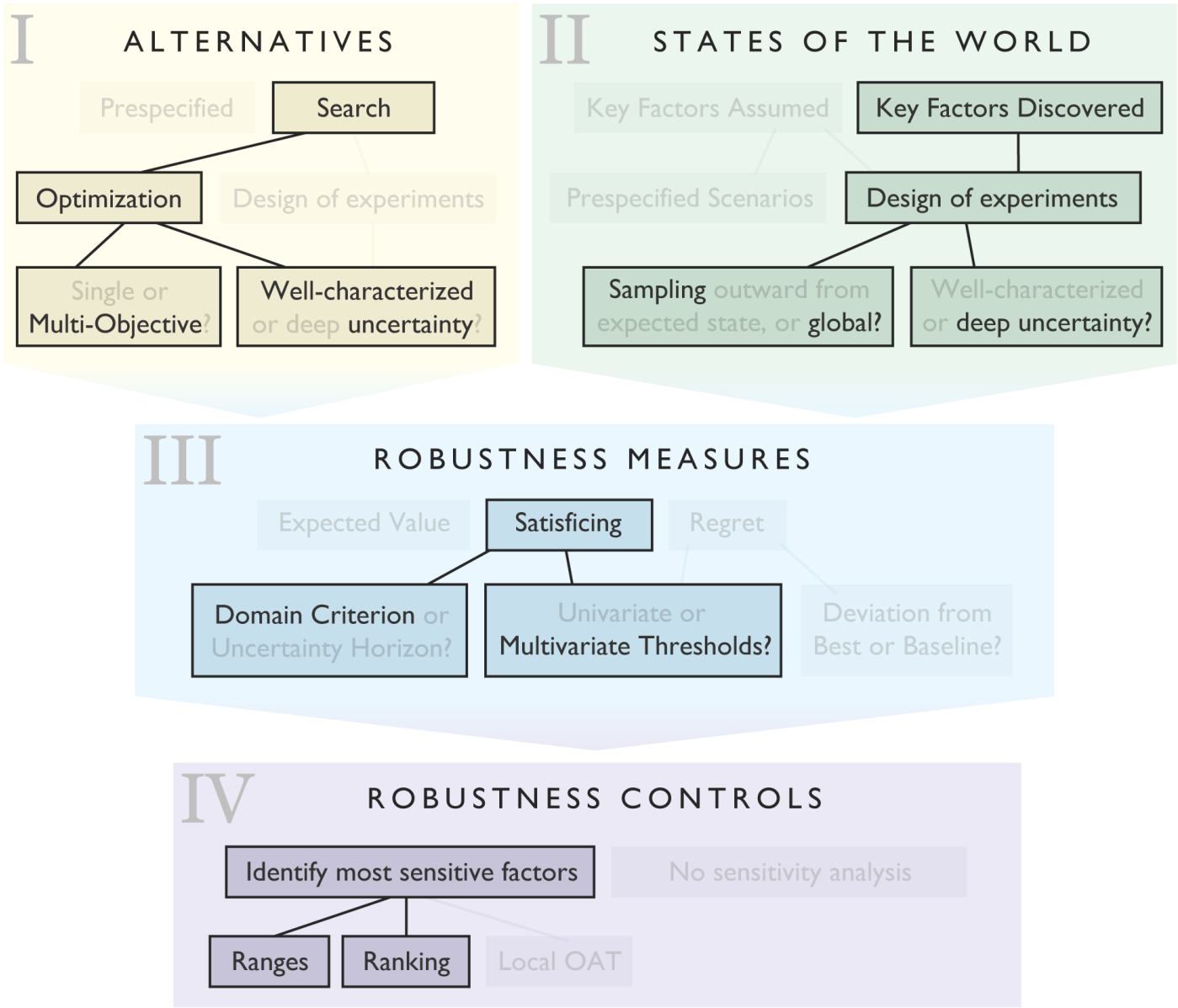


Ranges (PRIM) or ranking (Sobol)?



The methods complement each other, not exclusive

Many-Objective Robust Decision Making



Key Points

(1) Pre-specified decision alternatives can suffer from a status quo bias, ignore full tradeoff context, and may fail to meet performance requirements (e.g., high reliability)

(2) Robustness-based decision frameworks can be classified according to several interchangeable ideas

(3) We need to better understand how methodological choices impact the selection of a "robust" solution, including the quantification of robustness and sensitivity analysis approaches

OpenMORDM

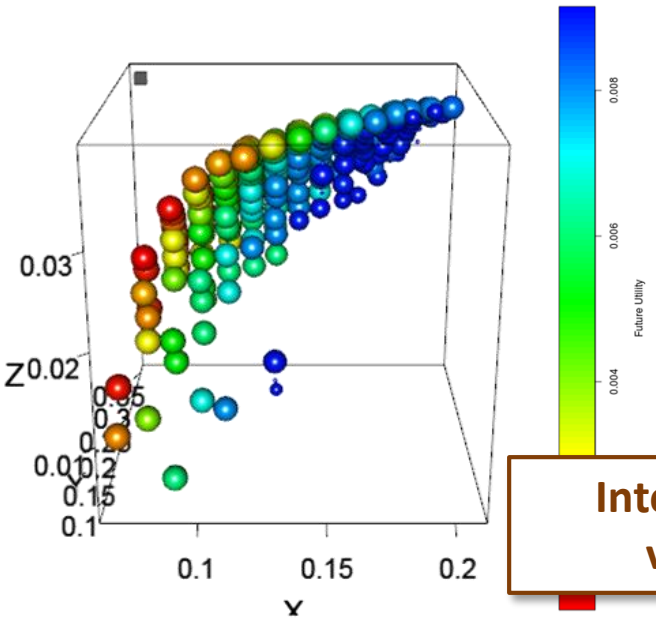
Multiobjective Robust Decision Making in R

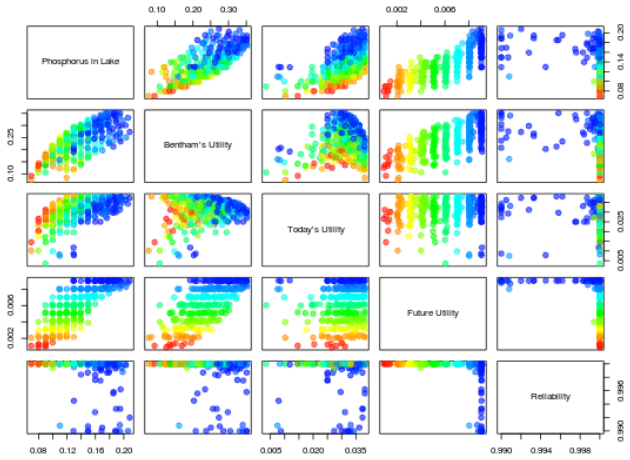
Developed by Penn State SCRiM (David Hadka, Klaus Keller) and Cornell (Jon Herman, Patrick Reed)

What is OpenMORDM?

- R library for Multiobjective Robust Decision Making (MORDM)
- Exploring systems with deep uncertainties, identify vulnerabilities, understand tradeoffs between competing goals

Free and Open Source - http://github.com/OpenMORDM





Interactive, high-dimensional visualization of datasets