What is robustness?

Problem framing challenges for water systems planning under change

Patrick Reed (Cornell) & Jon Herman (UC-Davis)

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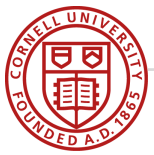
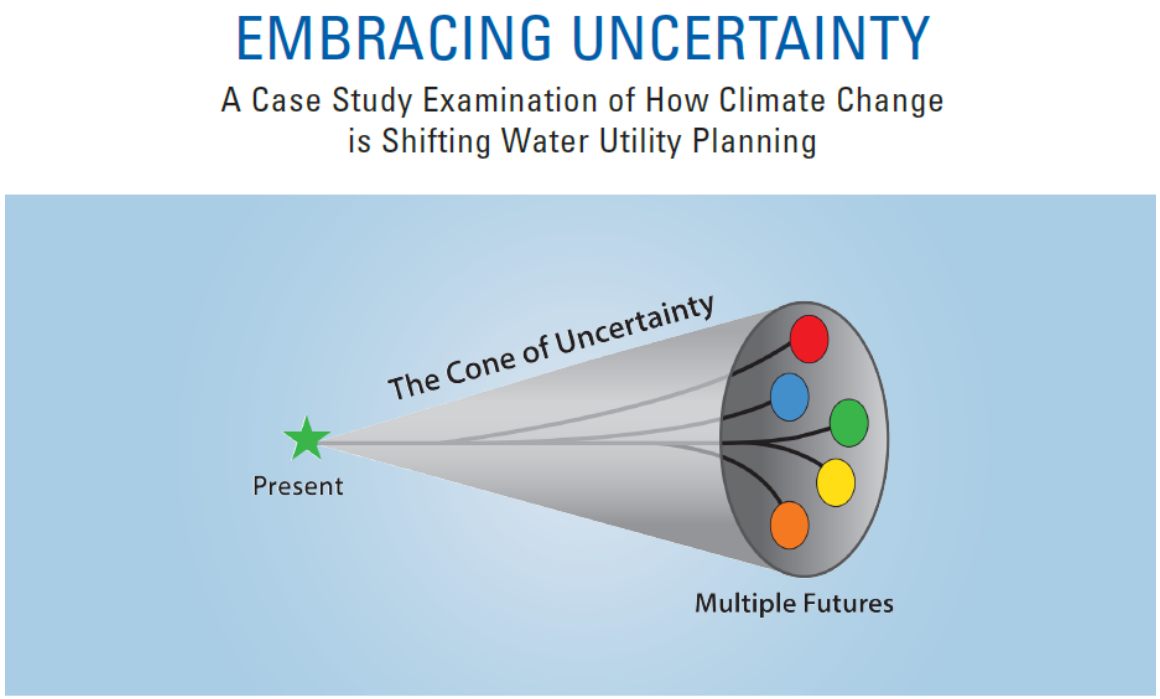
http://reed.cee.cornell.edu



Robustness: a climate risk sectoral example



13 Case Studies

-UK & Australia

-Denver Water

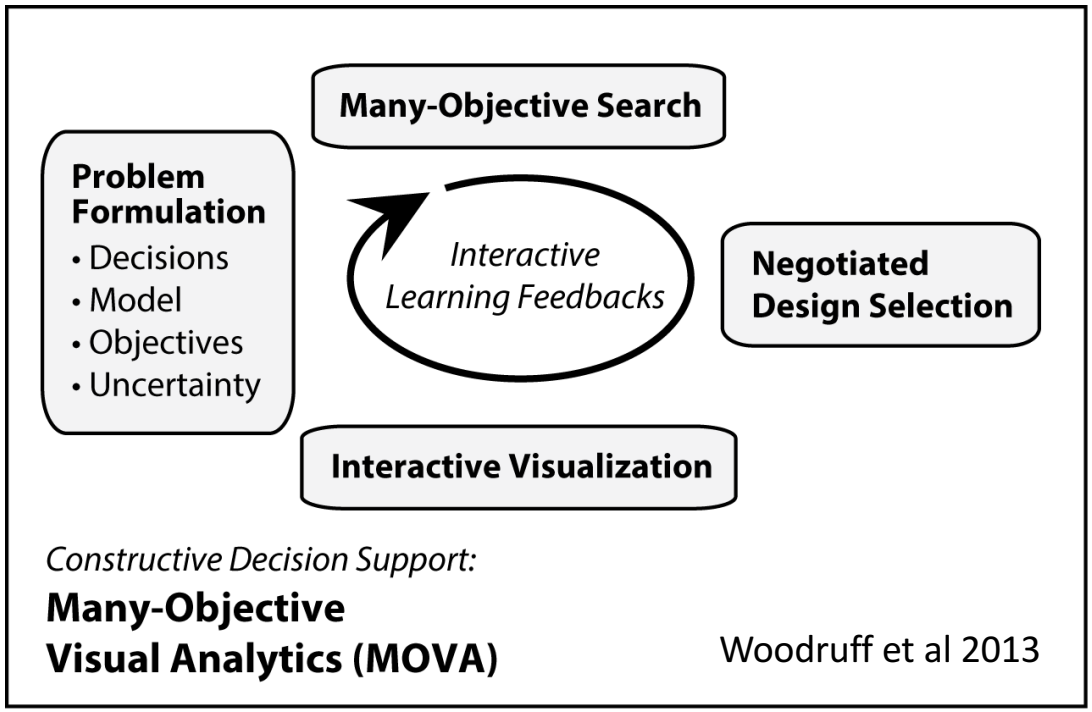
-Bureau of Rec.

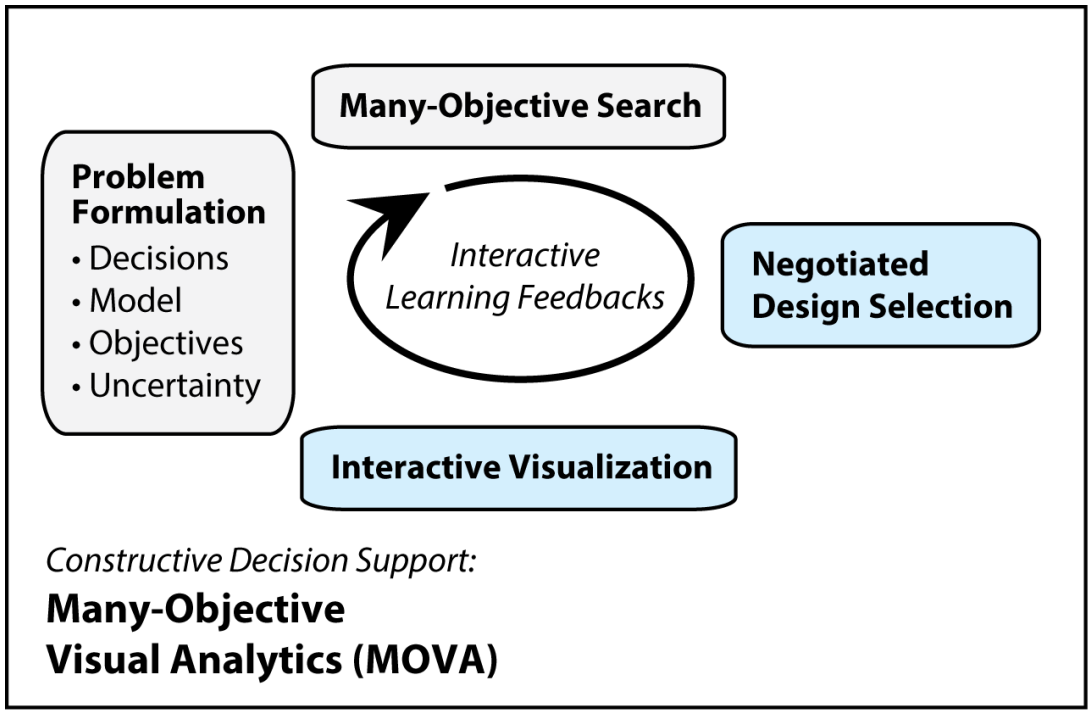
-CA DWR

-MWD

-many more

Seeking robustness across possible futures


Many-Objective Search
Problem Formulation
• Decisions
• Model
• Objectives
• Uncertainty
Interactive Learning Feedbacks
Negotiated Design Selection
Interactive Visualization
Constructive Decision Support:
Many-Objective Visual Analytics (MOVA)
Woodruff et al 2013



Many-Objective Robust Decision-Making for Multiple Stakeholders

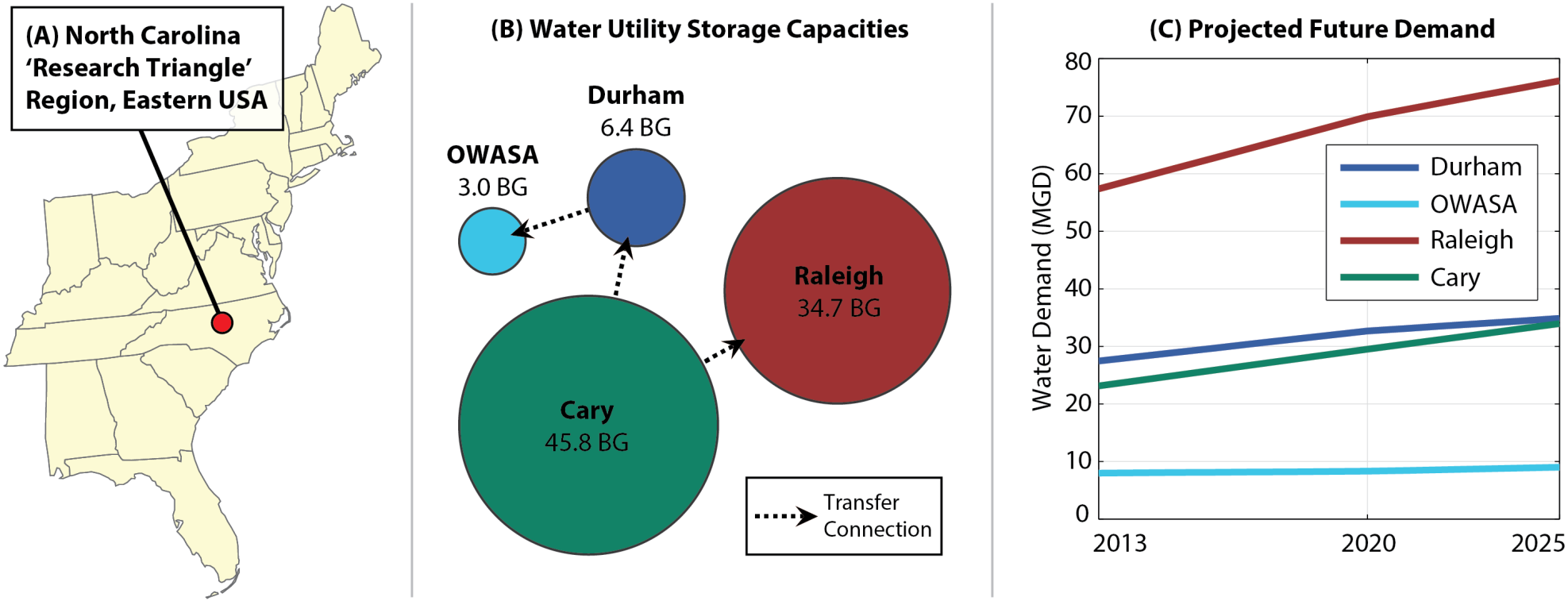
To summarize:

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

(2) Facilitate learning and visual tradeoff analysis

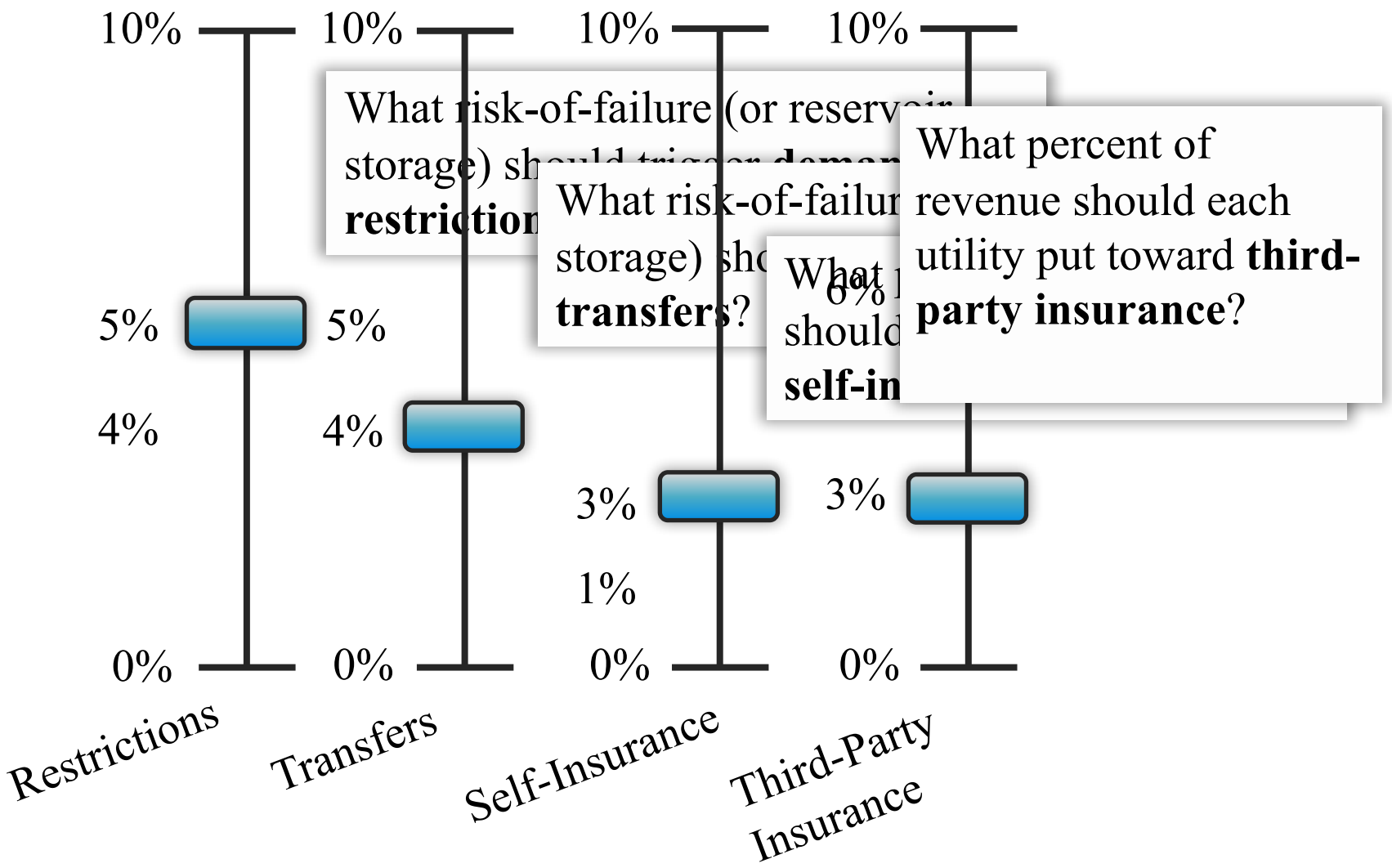
(3) Ensure decisions and monitoring recommendations are robust to many futures

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

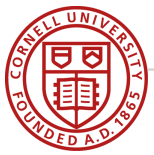
Average Financial Losses (Min):

Revenue reductions + costs due to drought management

Worst-Case Financial Losses (Min):

Financial losses in the 1% worst scenario

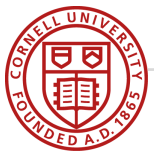
The worst-performing utility is optimized such that others will perform as well or better.



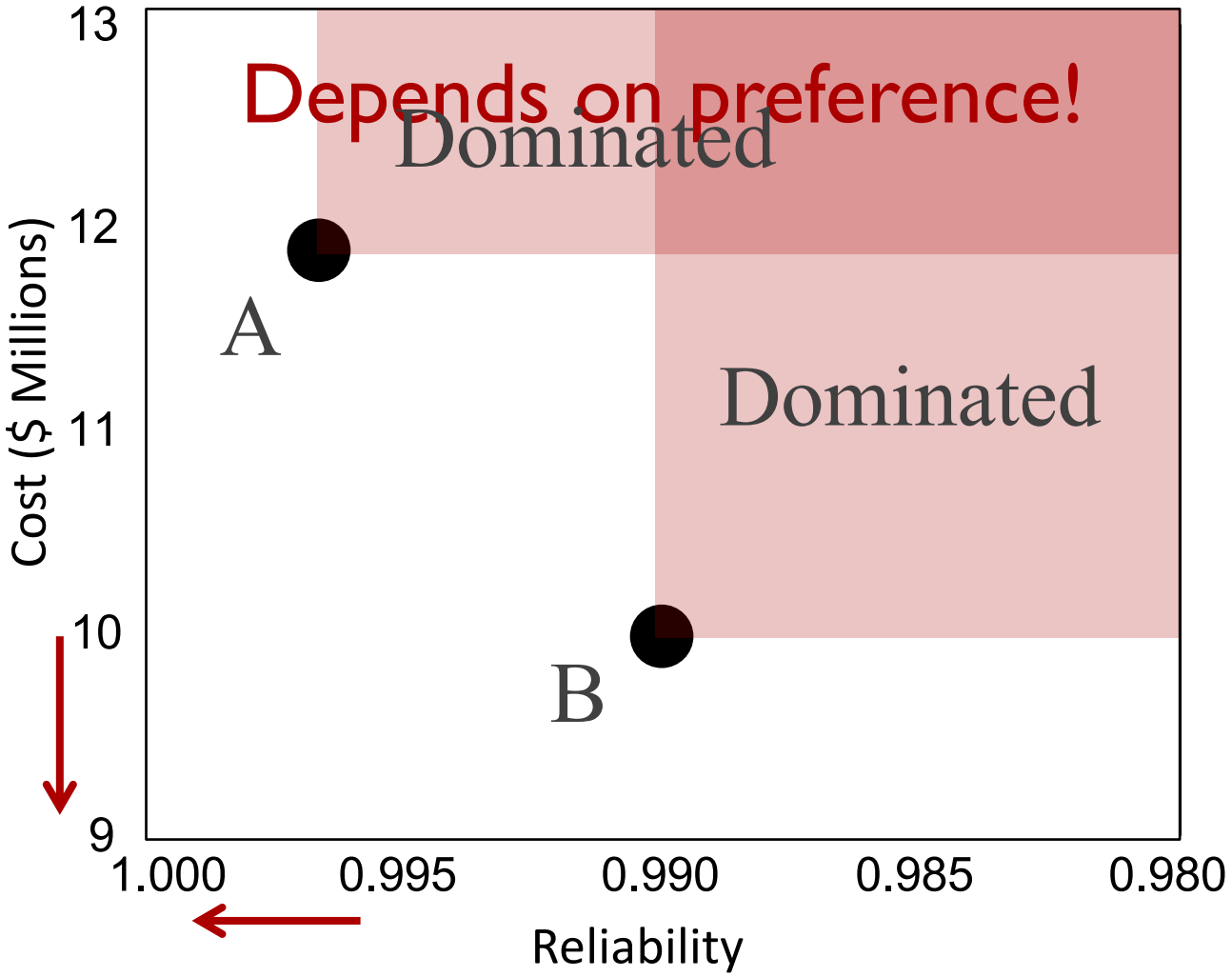
What portfolio complexity is needed?

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

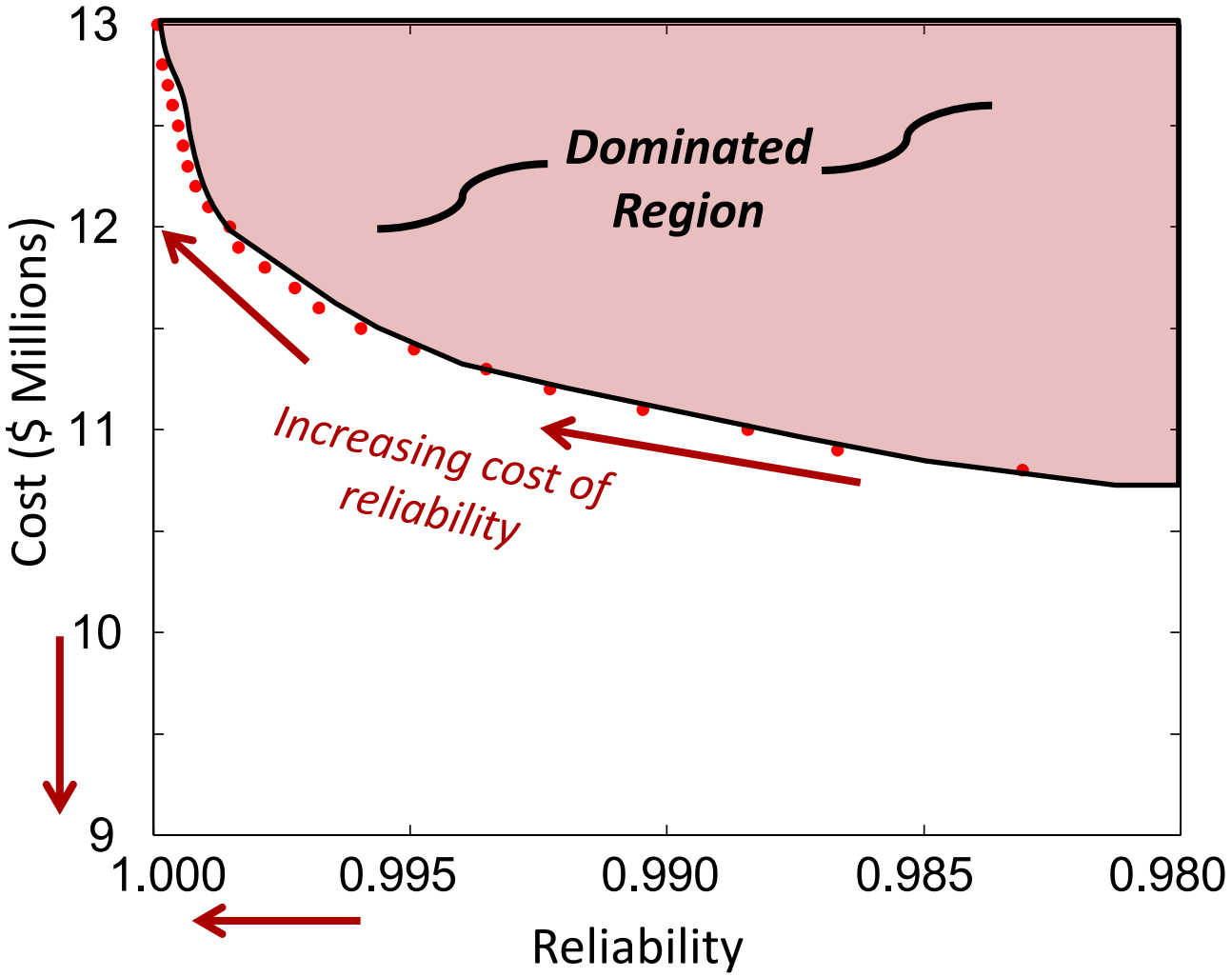


Multi-objective: which solution is better?



Kasprzyk et al. 2009

Looking for non-dominated solutions (tradeoff)

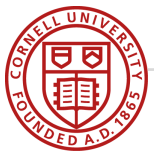


Kasprzyk et al. 2009

Multi-Objective Evolutionary Optimization

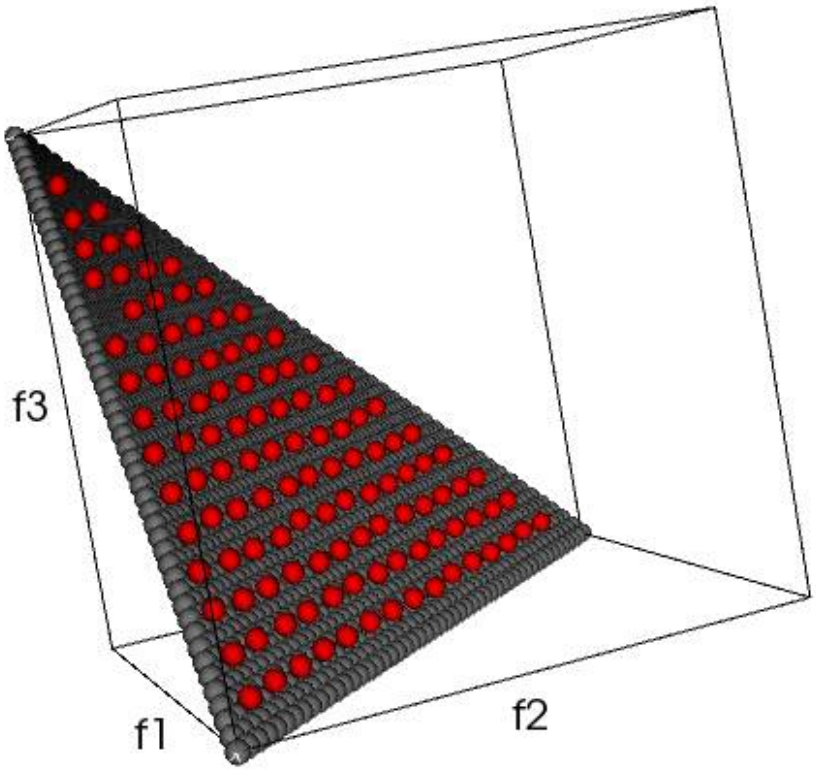
Heuristic method: flexibility for stochastic problems with unknown gradients

Search balances convergence and diversity



Multi-Objective Evolutionary Optimization

Three-objective Test Problem



Heuristic method: flexibility for stochastic problems with unknown gradients

Search balances convergence and diversity

Borg MOEA: efficient, reliable broad range of applications

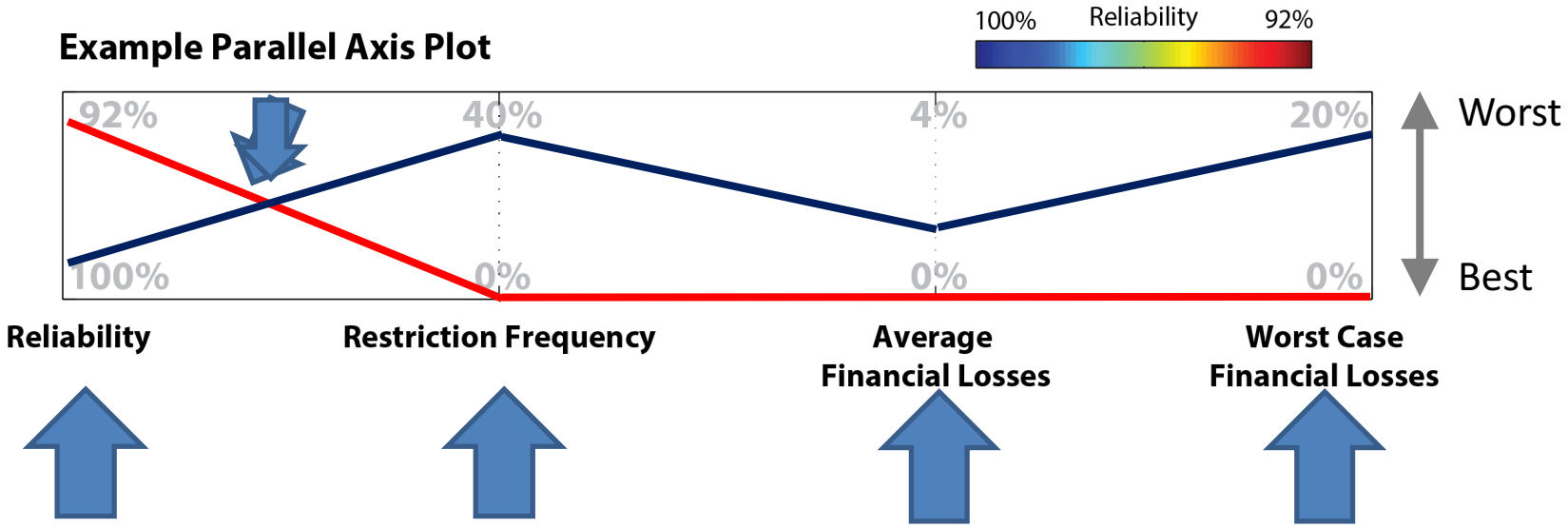
Reed, P.M., D. Hadka, J.D. Herman, J.R. Kasprzyk, and J.B. Kollat. 2013. Evolutionary Multiobjective Optimization in Water Resources: The Past, Present, and Future. *Advances in Water Resources*, 51, 438–456. [Invited Submission for 35th Anniversary Issue].

High-Performance Computing (HPC) lets us answer questions in minutes instead of days

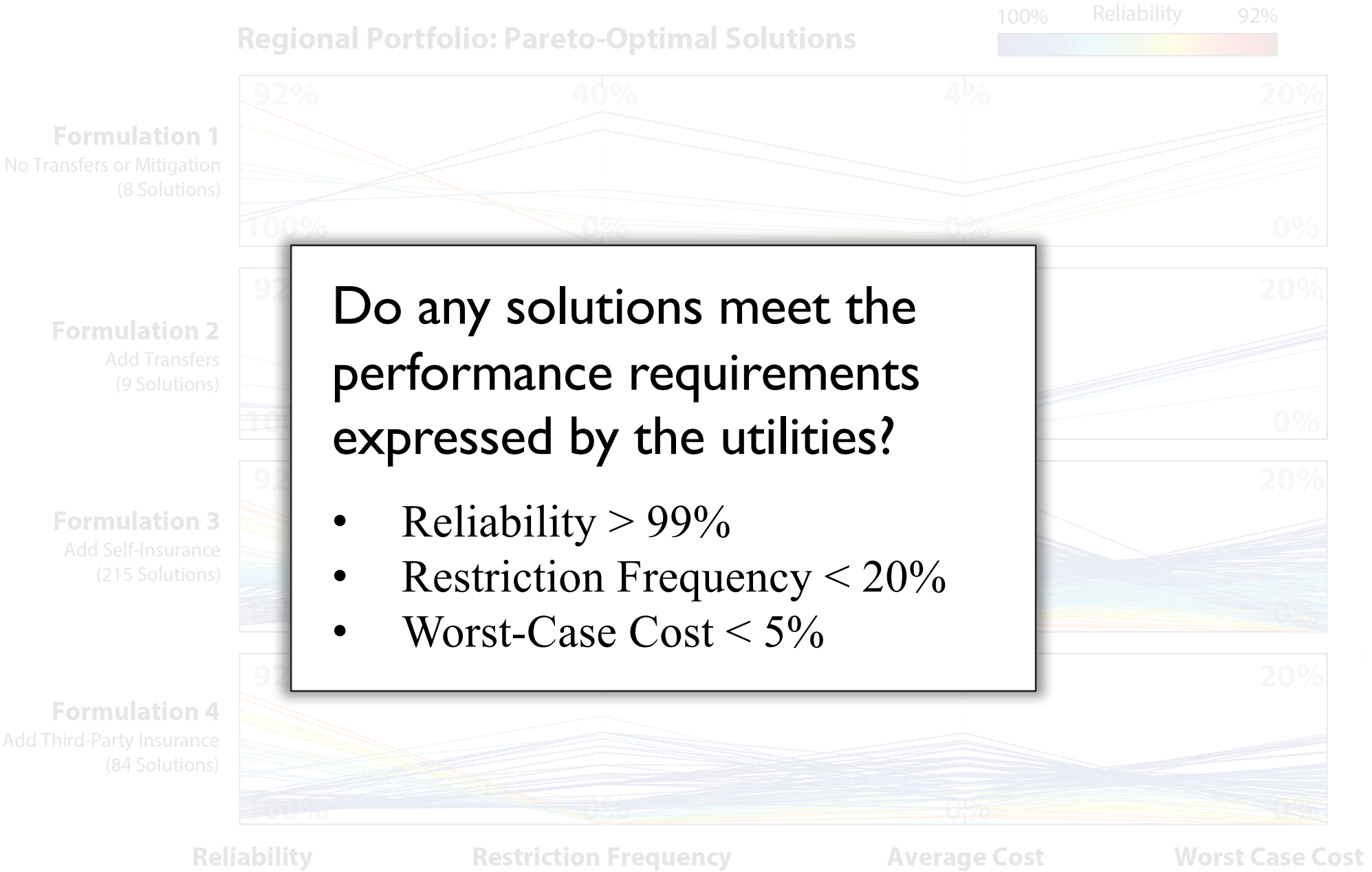
Reed, P. and Hadka, D., "Evolving Many-Objective Water Management to Exploit Exascale Computing", Water Resources Research, In-Press.

XSEDE
Extreme Science and Engineering Discovery Environment

Parallel axis plots help stakeholders visualize tradeoffs between conflicting objectives

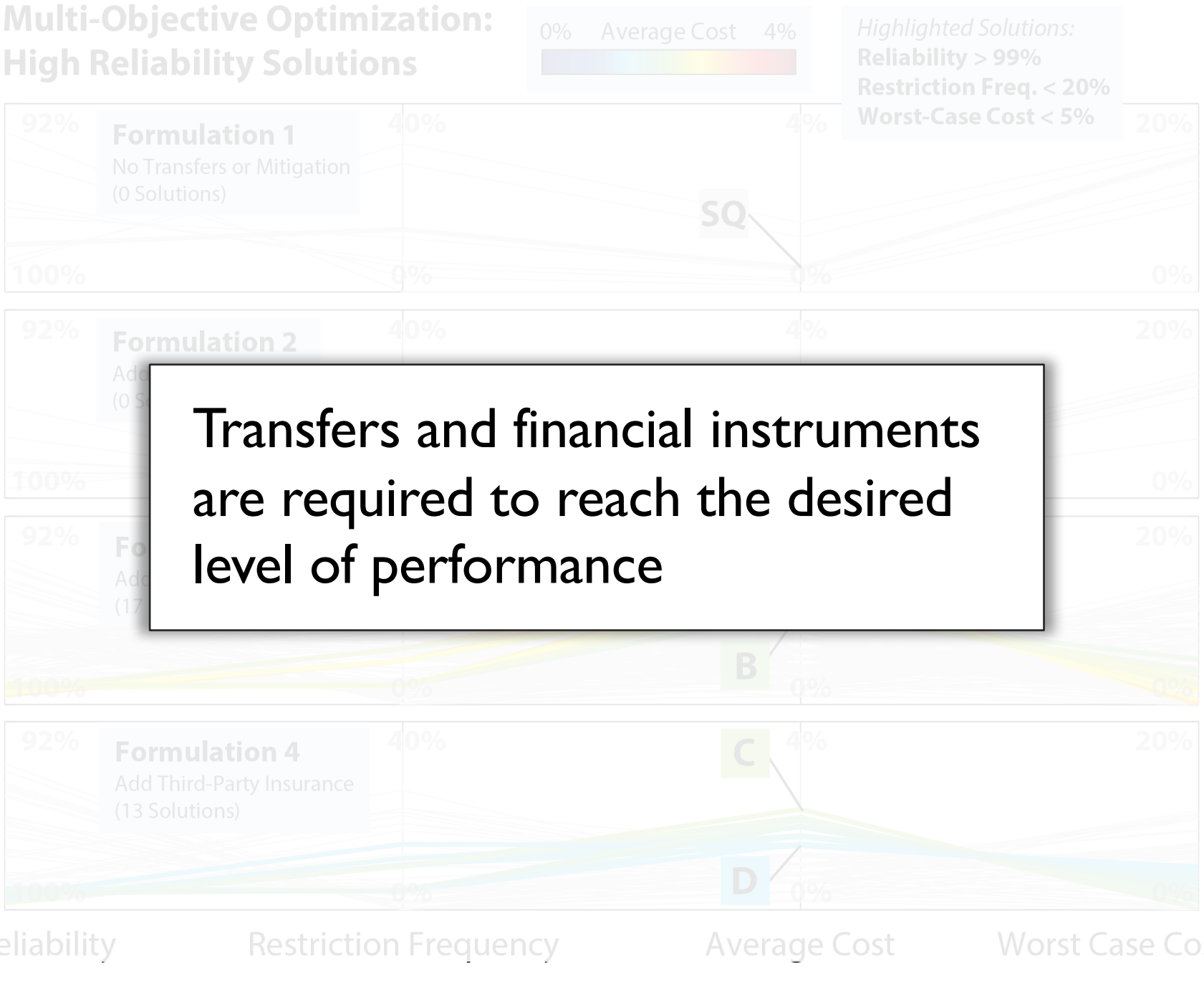


- Each line represents one solution
- X-Axis shows the four objectives to be optimized
- Y-Axis shows the objective value (performance)
- Crossing lines indicate tradeoffs



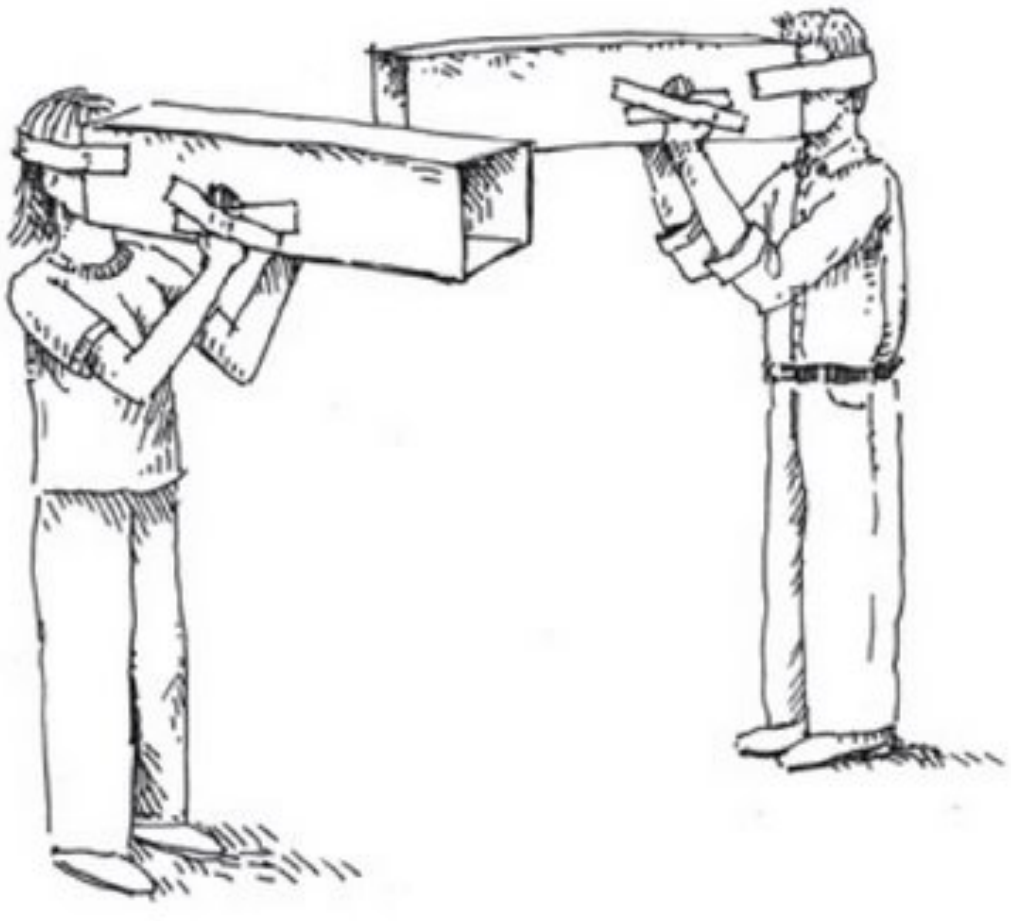
Do any solutions meet the performance requirements expressed by the utilities?

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

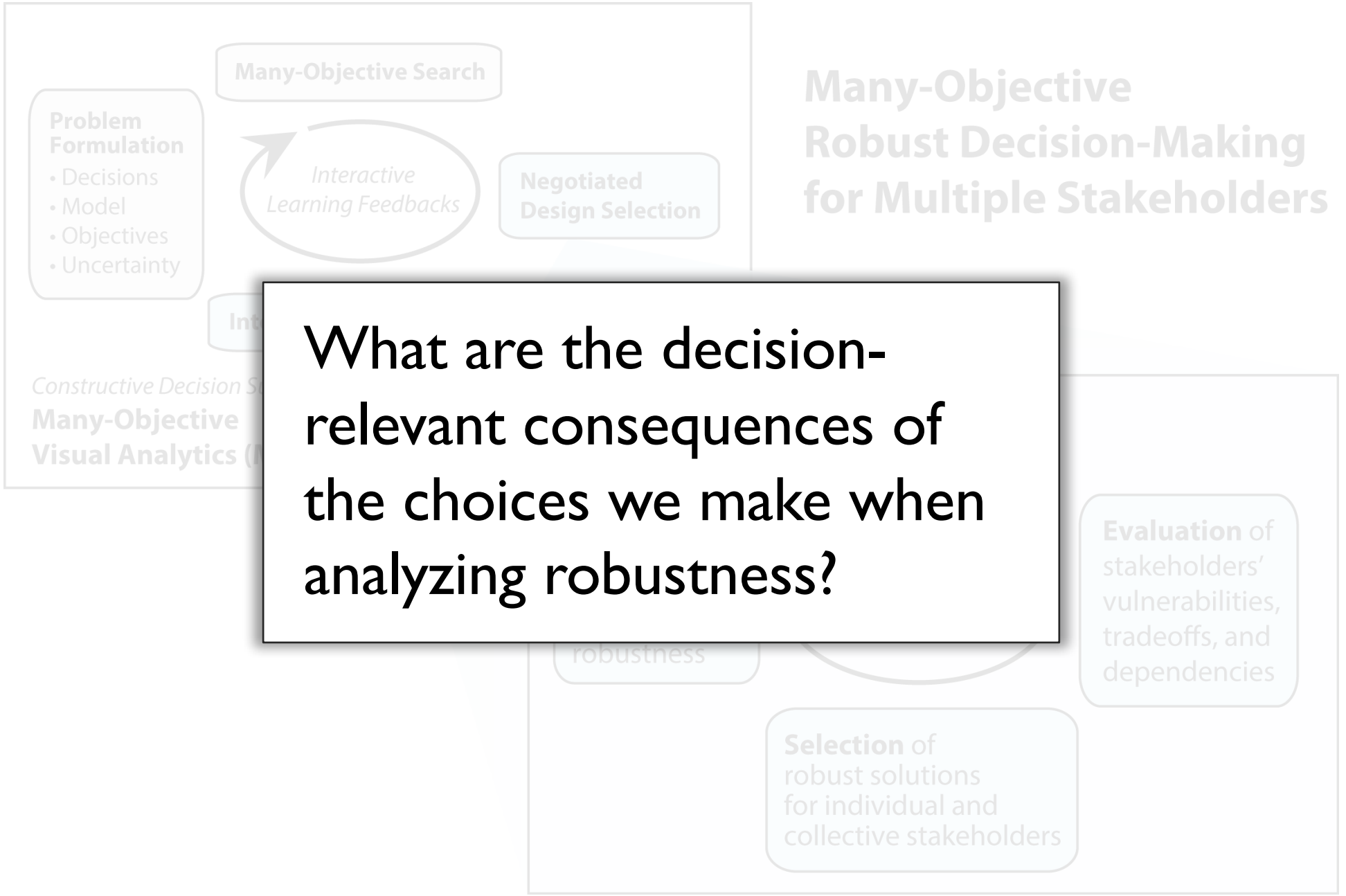


Transfers and financial instruments are required to reach the desired level of performance

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



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

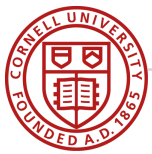


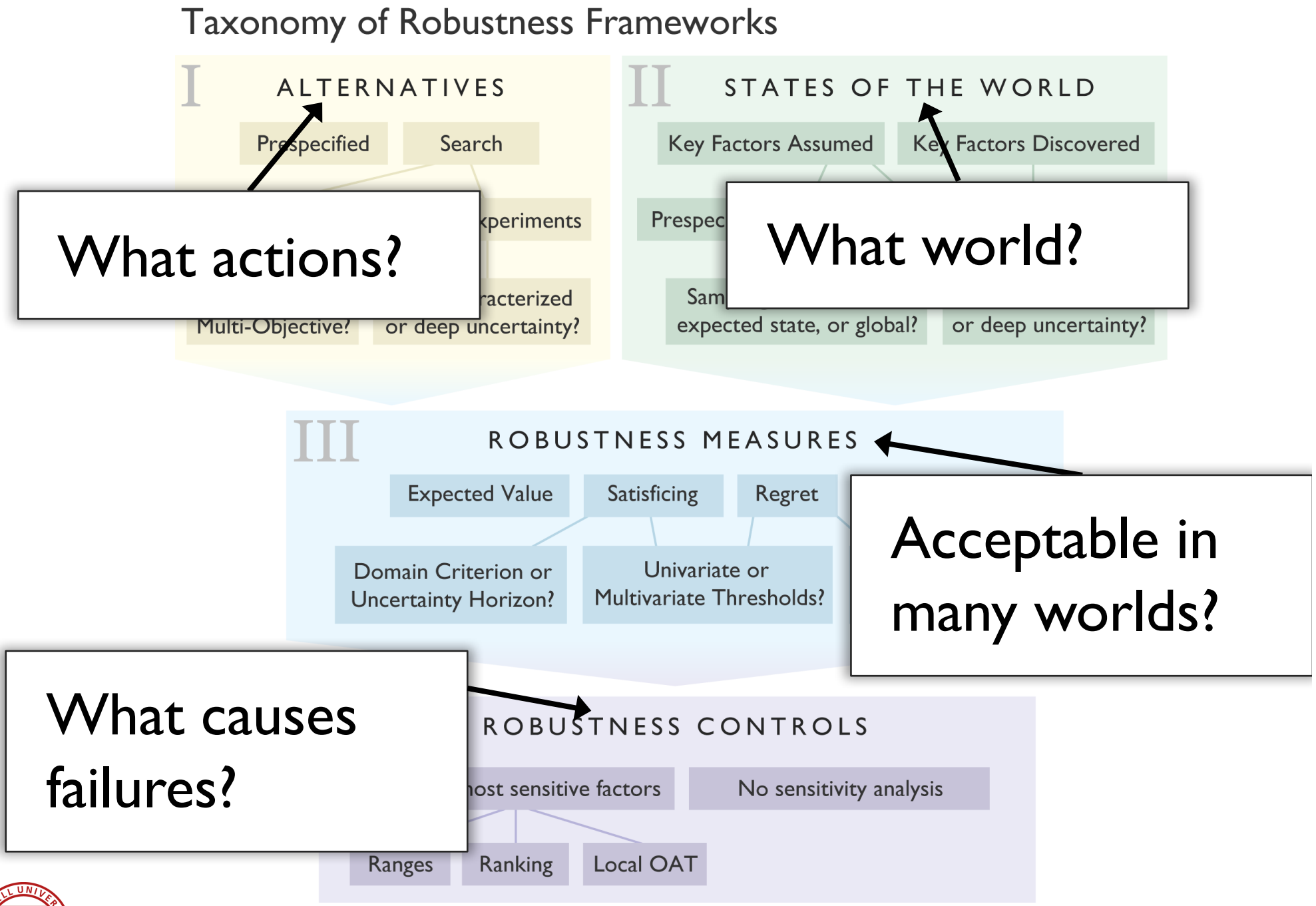
What are the decision-relevant consequences of the choices we make when analyzing robustness?

What do robustness analyses have in common?

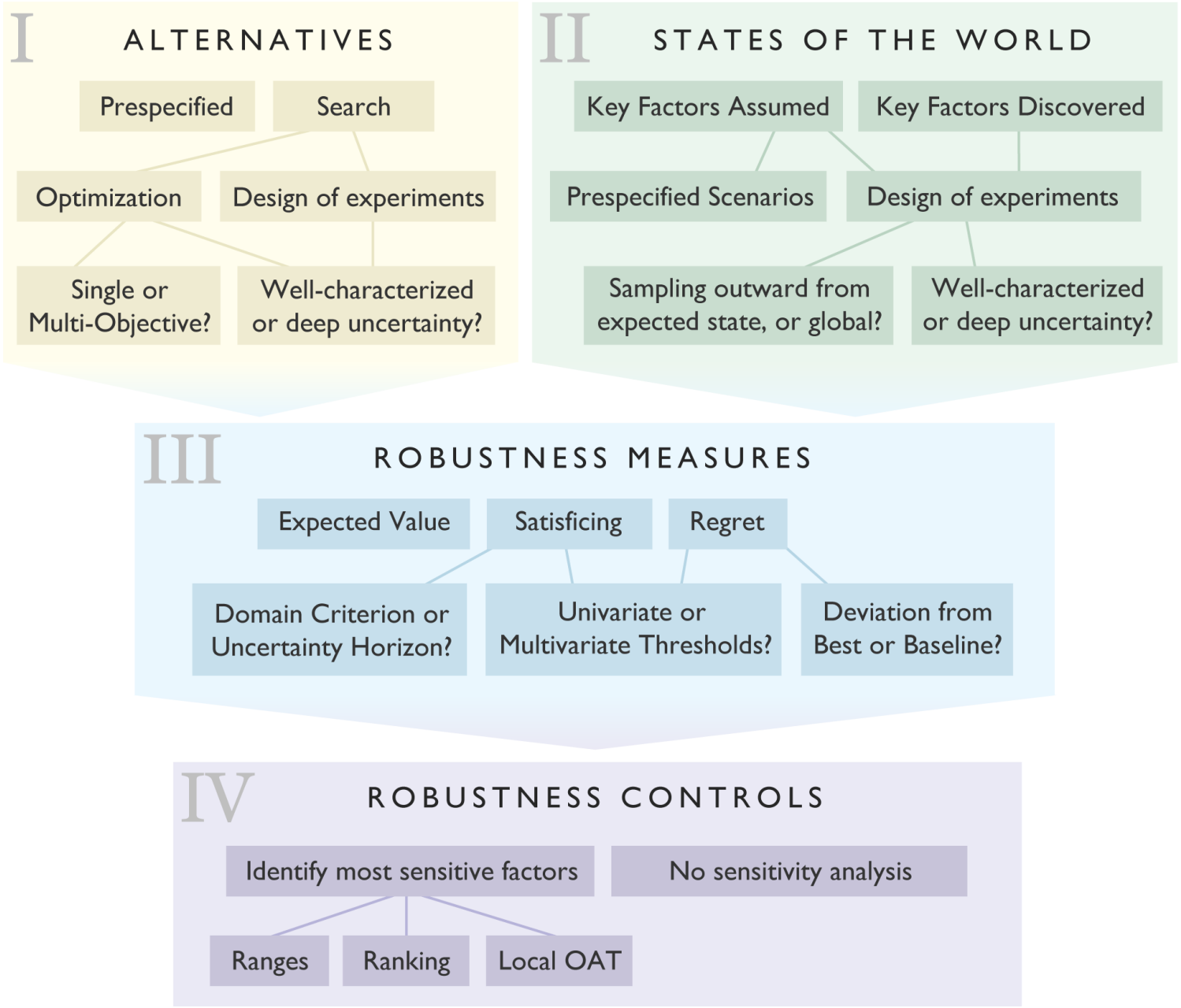
Evaluate alternatives in multiple states of the world…

Quantify robustness measures and determine sensitive uncertainties




Taxonomy of Robustness Frameworks
I ALTERNATIVES
Prespecified
Search
Multi-Objective?
or deep uncertainty?
II STATES OF THE WORLD
Key Factors Assumed
Key Factors Discovered
expected state, or global?
or deep uncertainty?
III ROBUSTNESS MEASURES
Expected Value
Satisficing
Regret
Domain Criterion or Uncertainty Horizon?
Univariate or Multivariate Thresholds?
ROBUSTNESS CONTROLS
No sensitivity analysis
Ranges
Ranking
Local OAT
What actions?
What world?
Acceptable in many worlds?
What causes failures?

Taxonomy of Robustness Frameworks



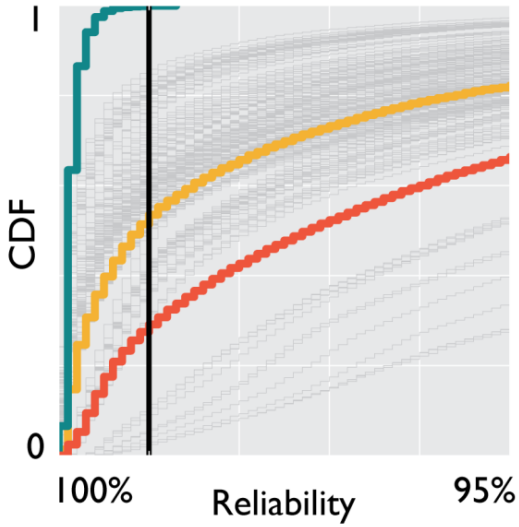
Taxonomy of Robustness Frameworks

Discovering solutions through search improves robustness relative to prespecified alternatives

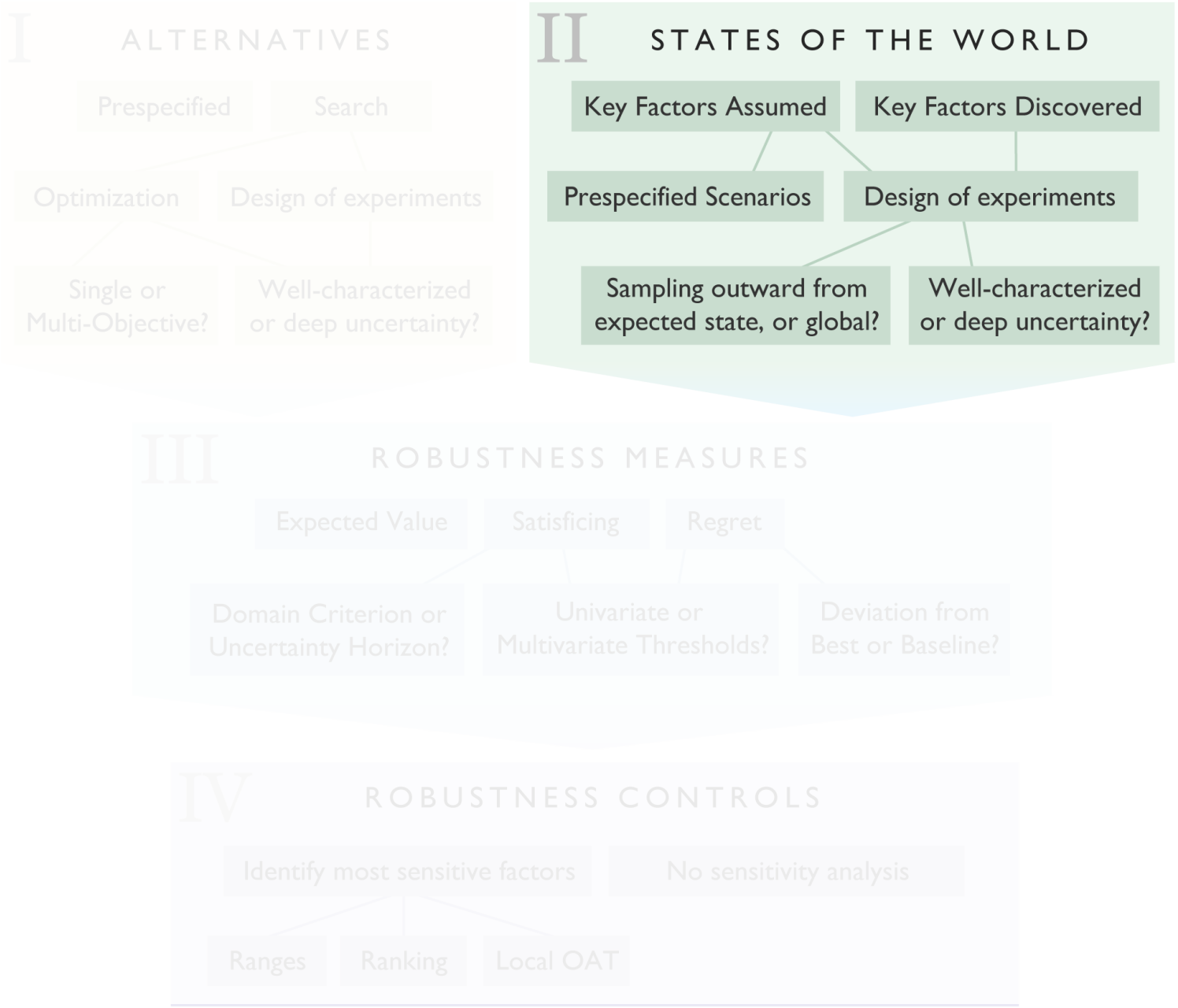
I

Performance CDFs over Uncertain States of the World

Multi-objective performance for Durham

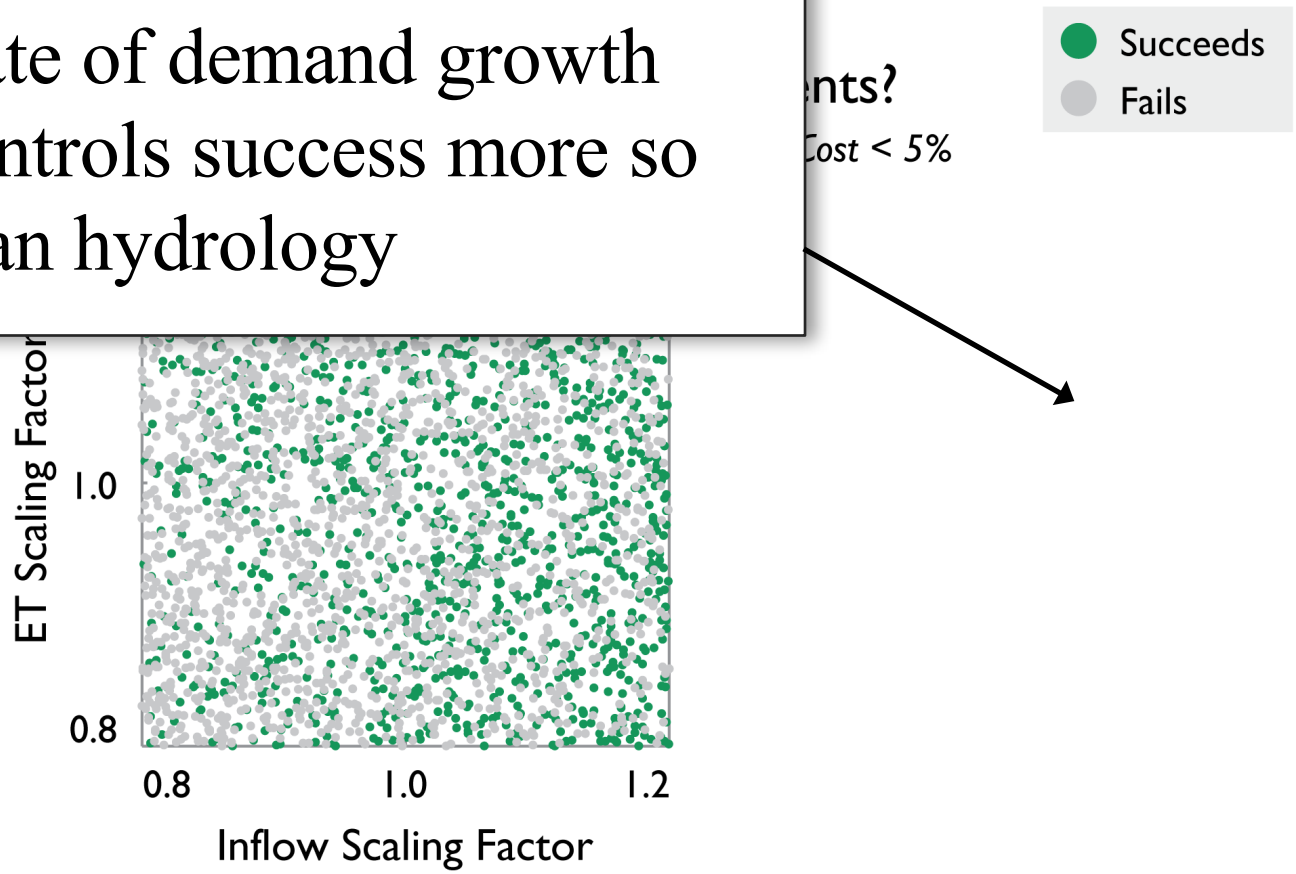


Taxonomy of Robustness Frameworks

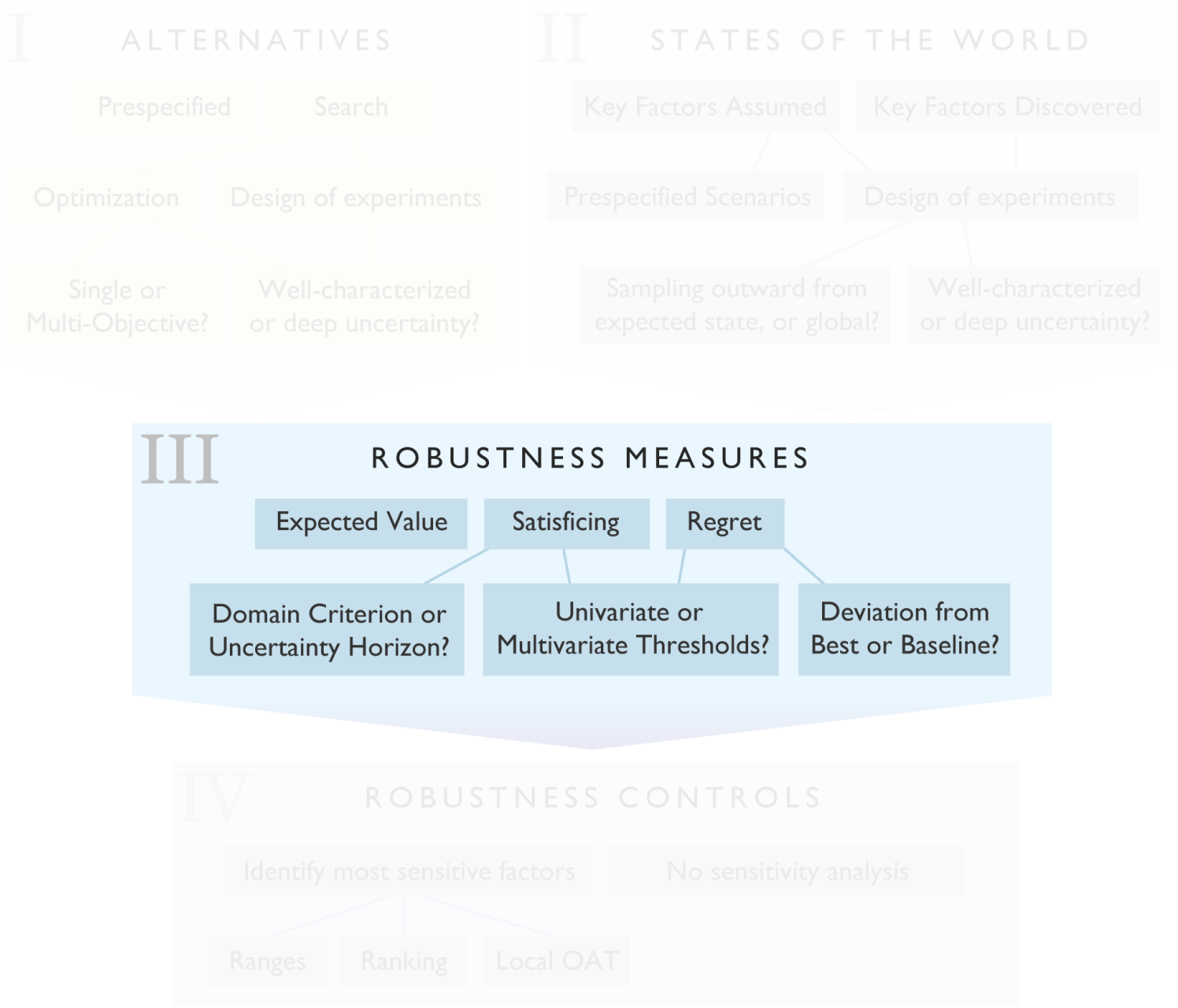


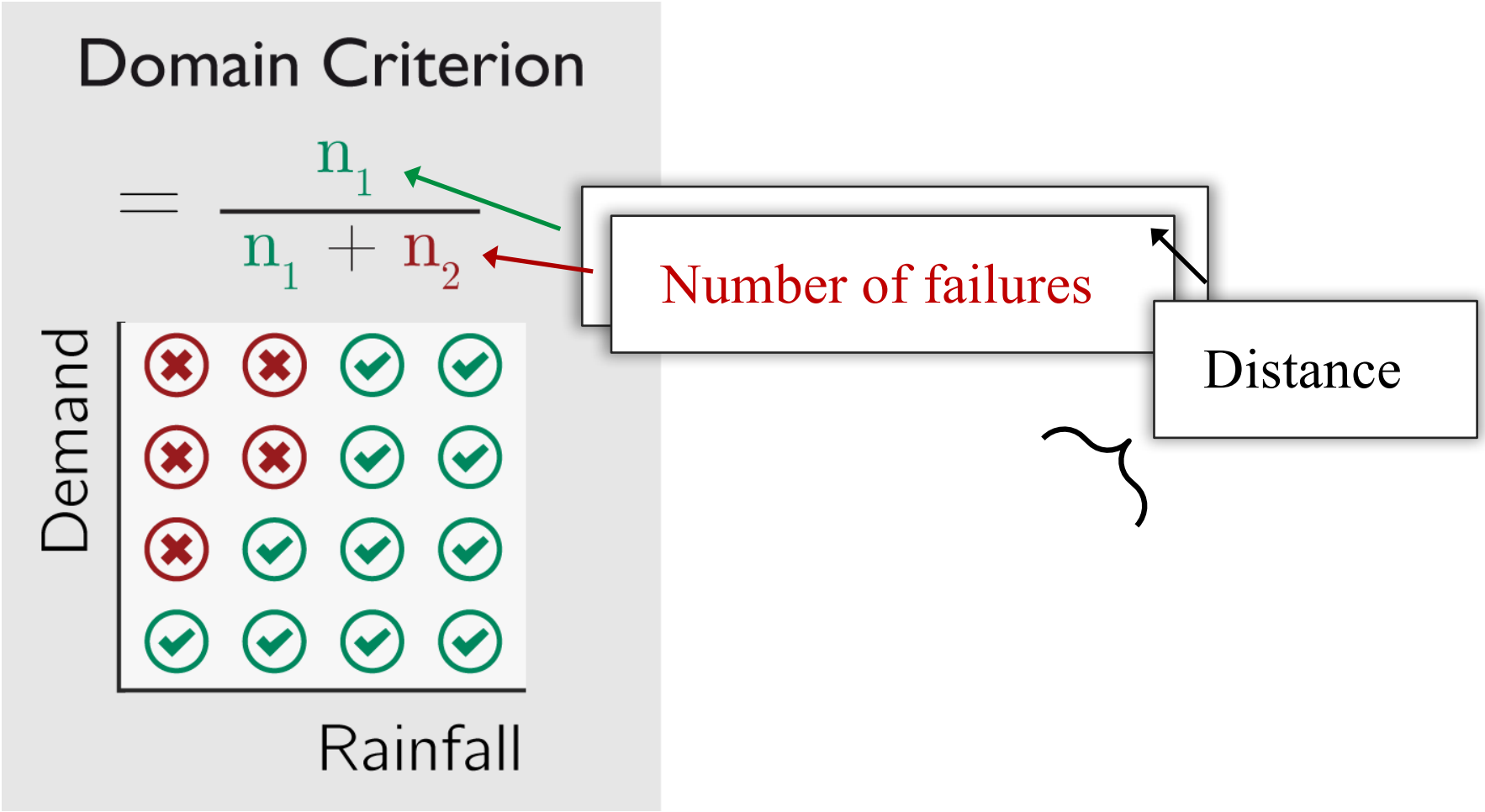
An *a priori* focus on climate/hydrologic factors may fail to capture system vulnerabilities

Rate of demand growth controls success more so than hydrology



Taxonomy of Robustness Frameworks



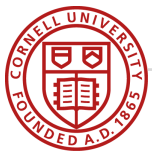


References: Lempert and Collins (2007), Schneller and Sphicas (1983), Hipel and Ben-Haim (1999)

How to measure robustness?

Which solutions would each measure choose from our Pareto front?

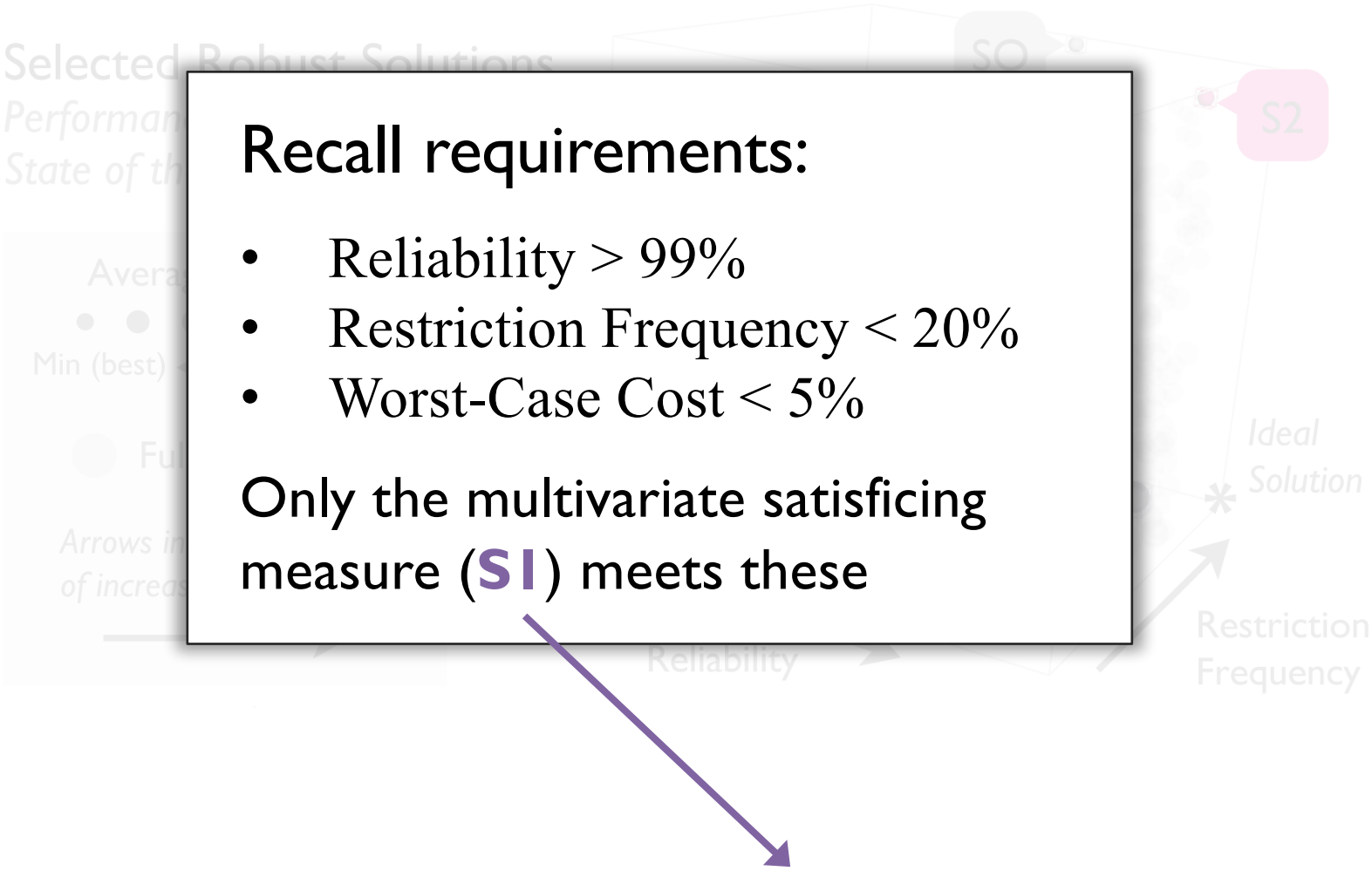
Definitions adapted from Lempert and Collins (2007)



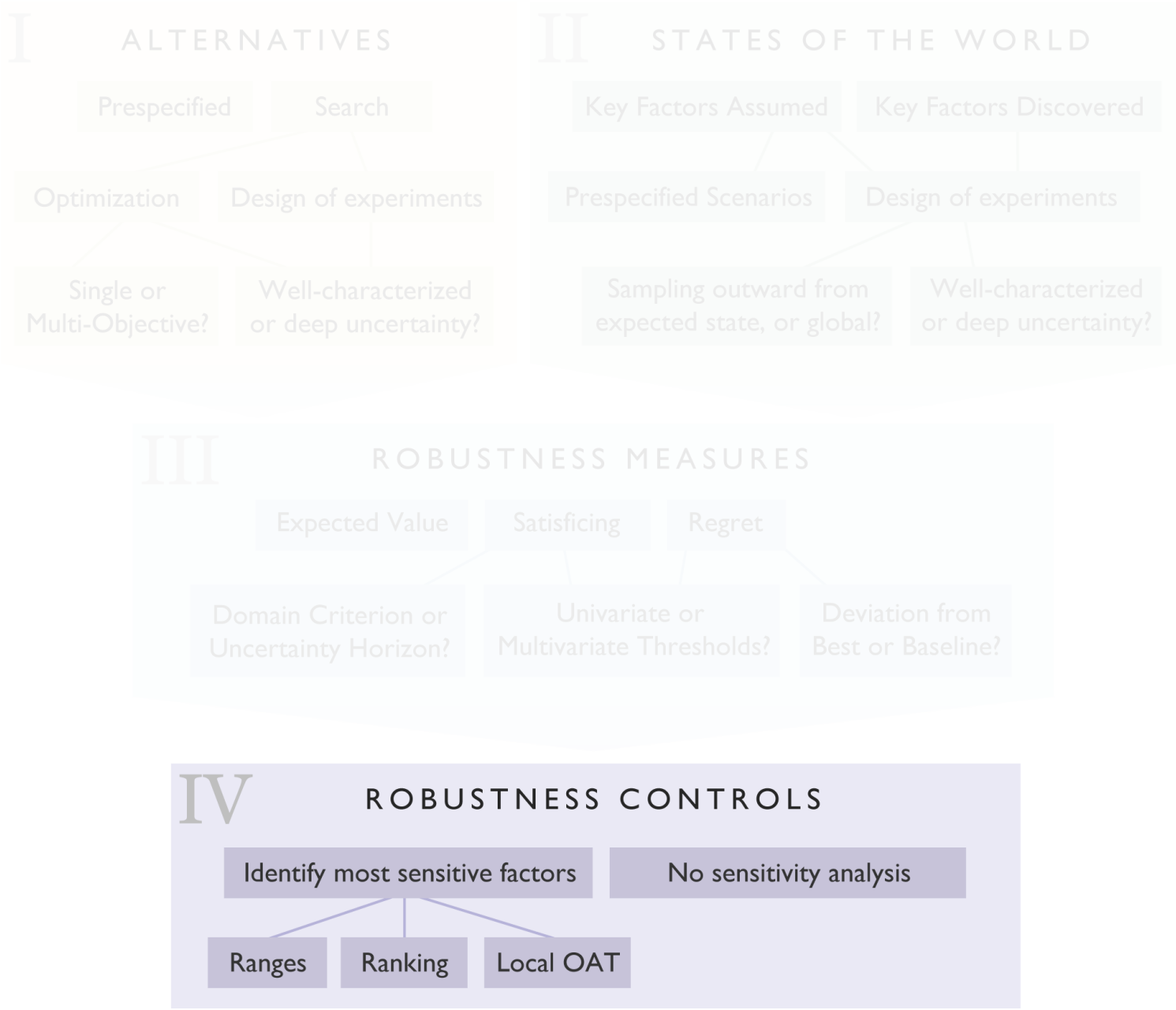
Recall requirements:

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

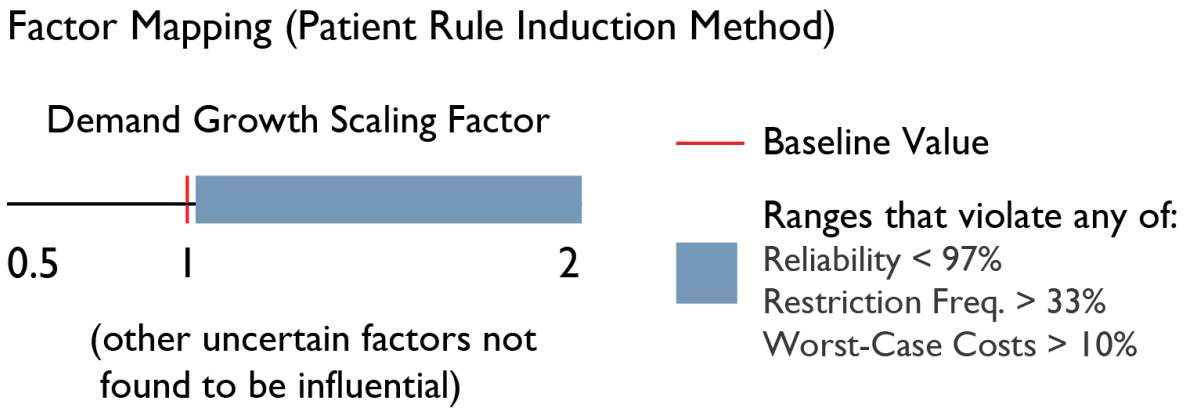
Only the multivariate satisficing measure (**S1**) meets these



Taxonomy of Robustness Frameworks



Ranges (PRIM) or ranking (Sobol)?



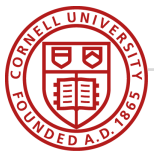
The methods complement each other, not exclusive

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



Questions on Section 1?

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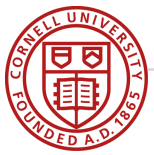
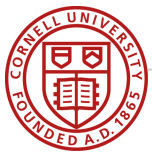


Section II: Language, Other Applications, & Tools

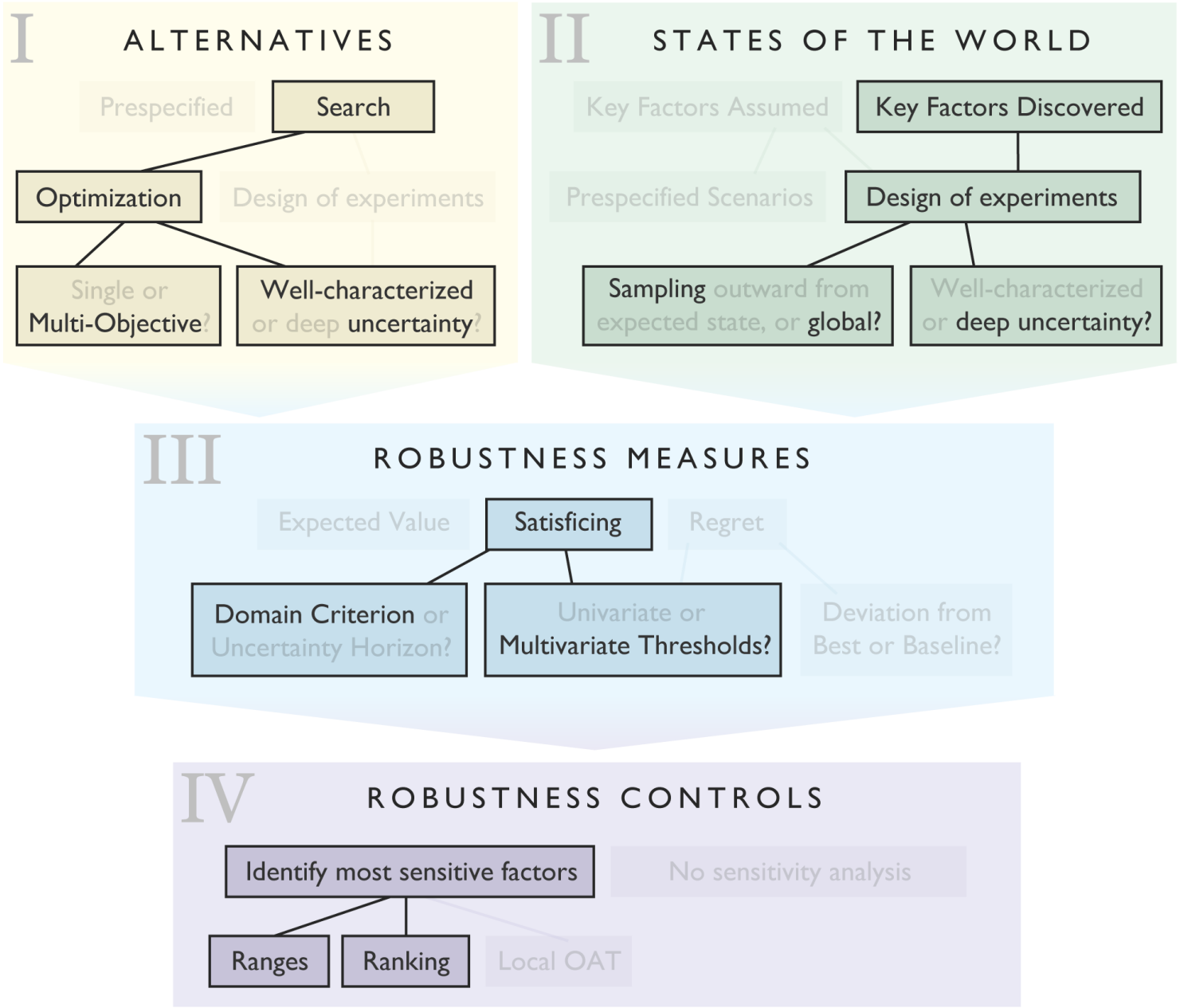
1. What do robustness-based decision frameworks have in common?

2. How do methodological choices impact decision recommendations?

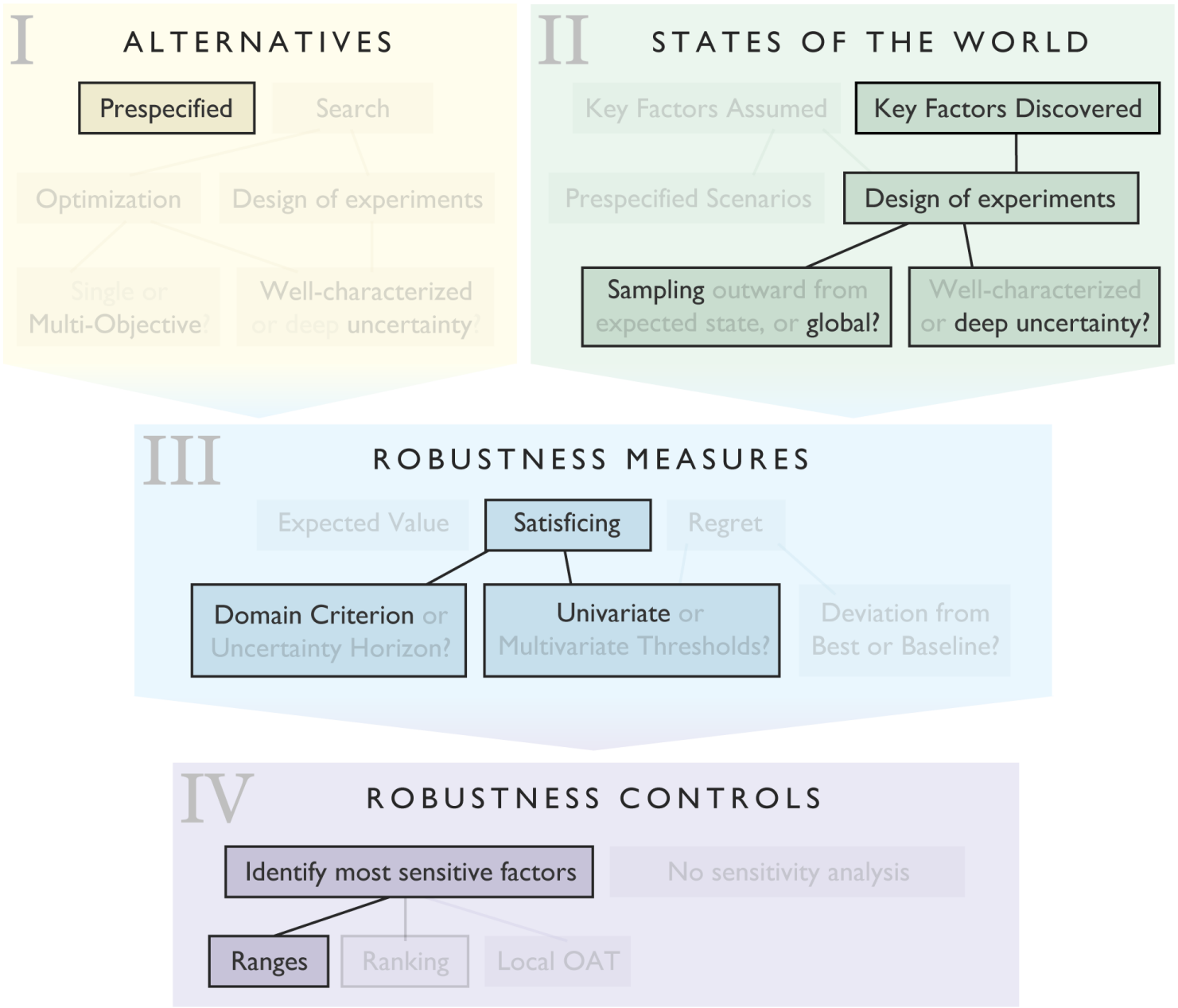
3. How can we expand the value & impacts of our advances?



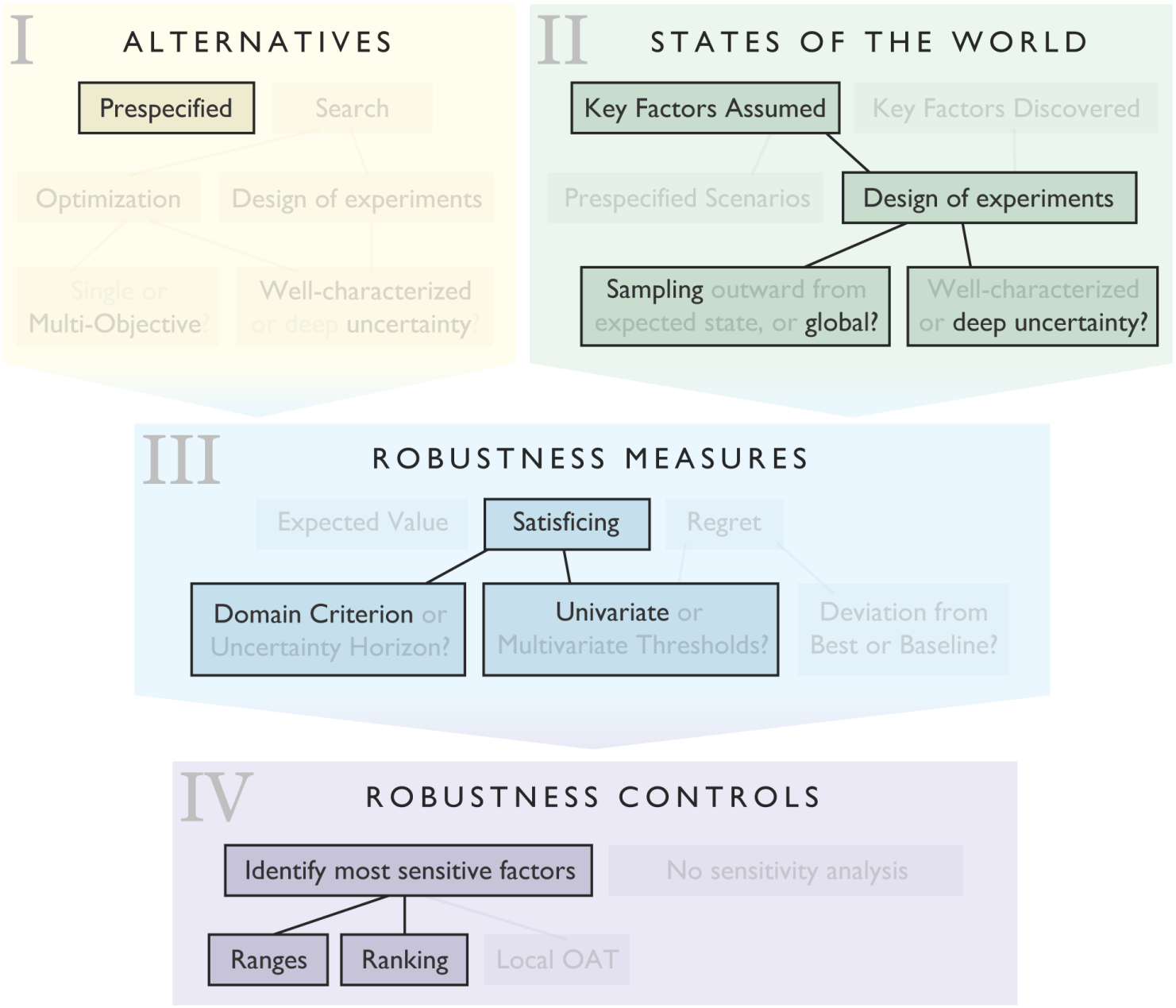
Many-Objective Robust Decision Making



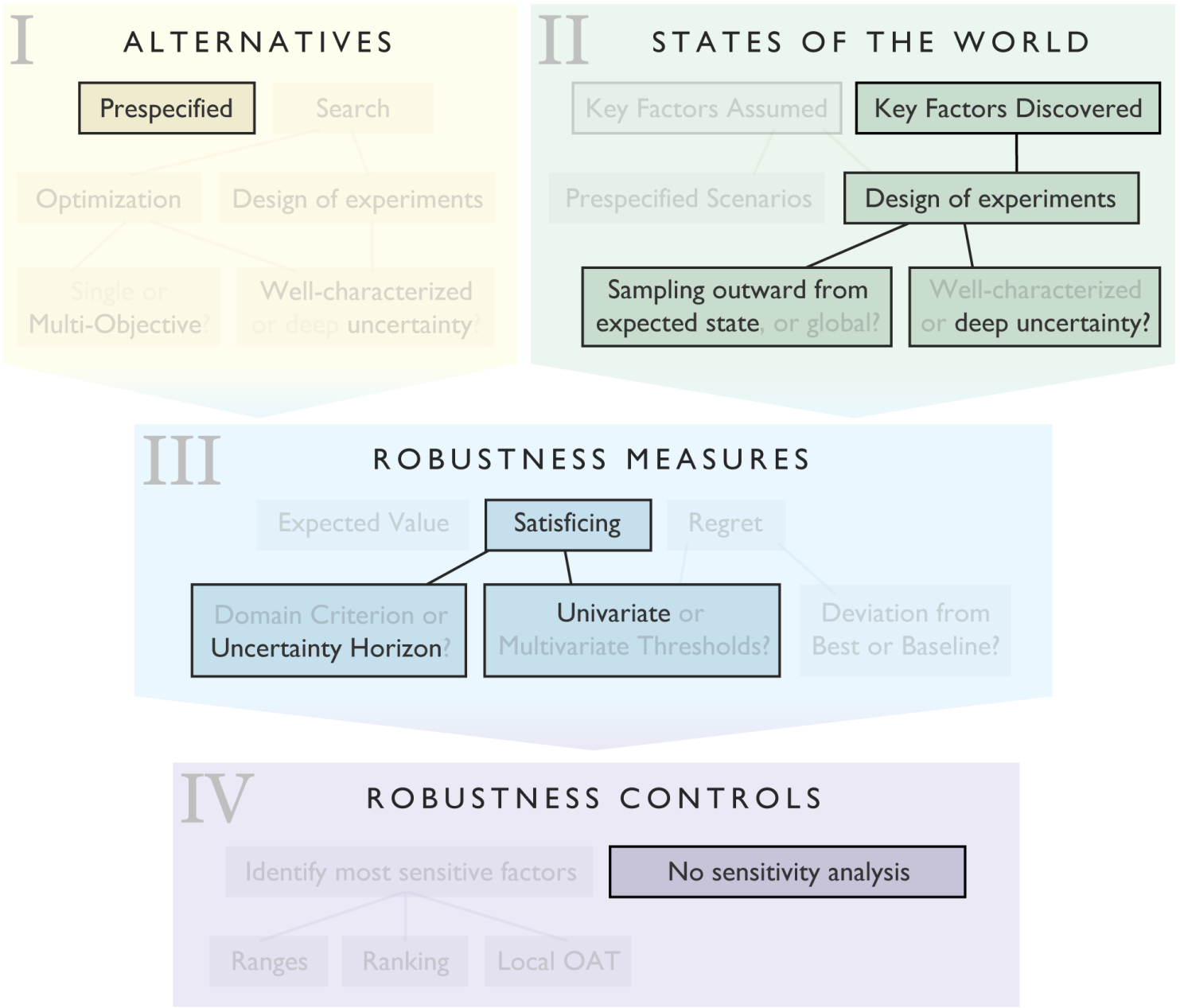
Robust Decision Making



Decision Scaling



Information-Gap



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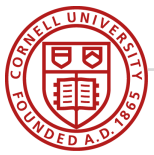
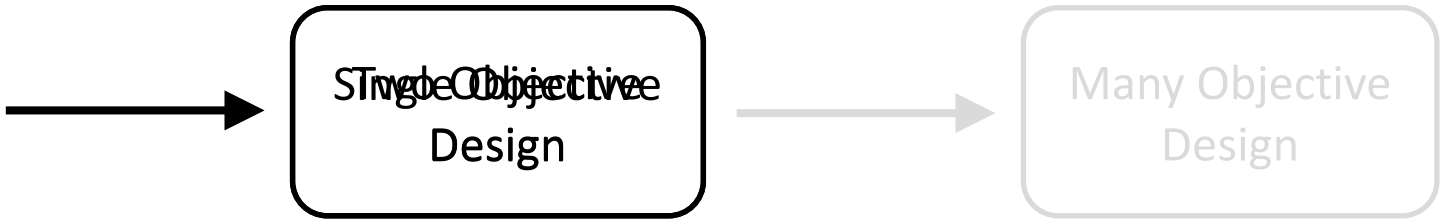
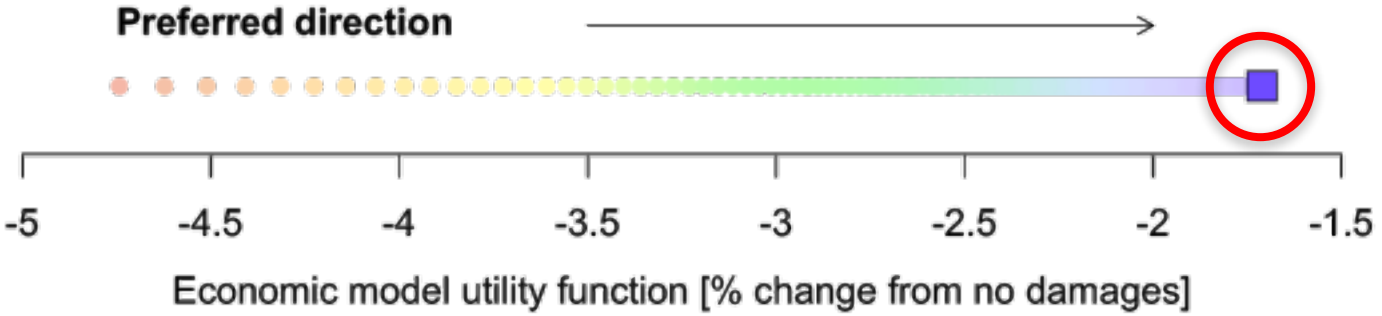


2 How do methodological choices impact decision recommendations?



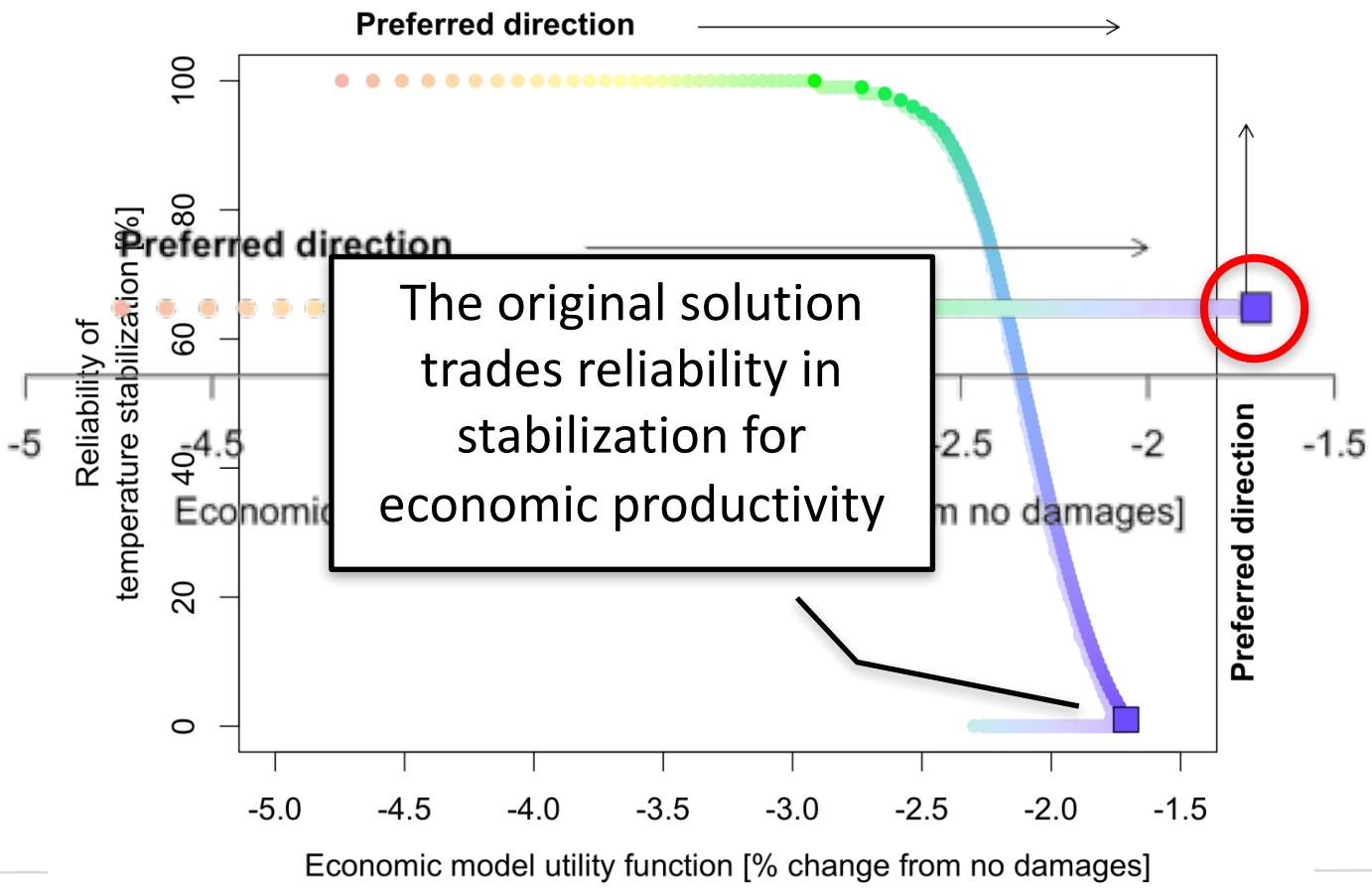


Mitigation vs Adaption Tradeoffs: DICE Integrated Assessment Model

SCRiM publication: Garner Reed Keller (2016) Climatic Change, 134(4), 713-723.

2 How do methodological choices impact decision recommendations?

Single Objective Design → Two Objective Design → Many Objective Design



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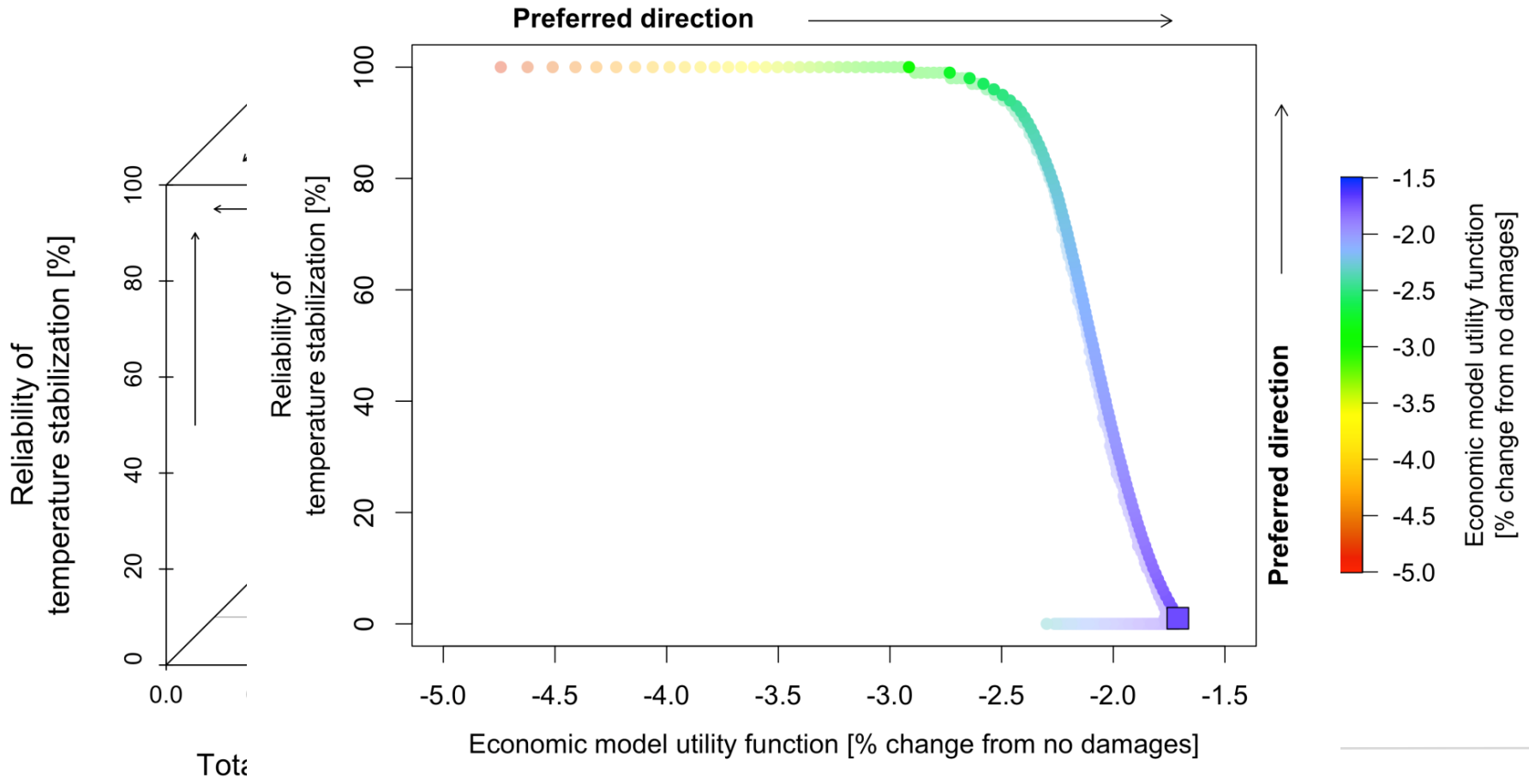


② How do methodological choices impact decision recommendations?

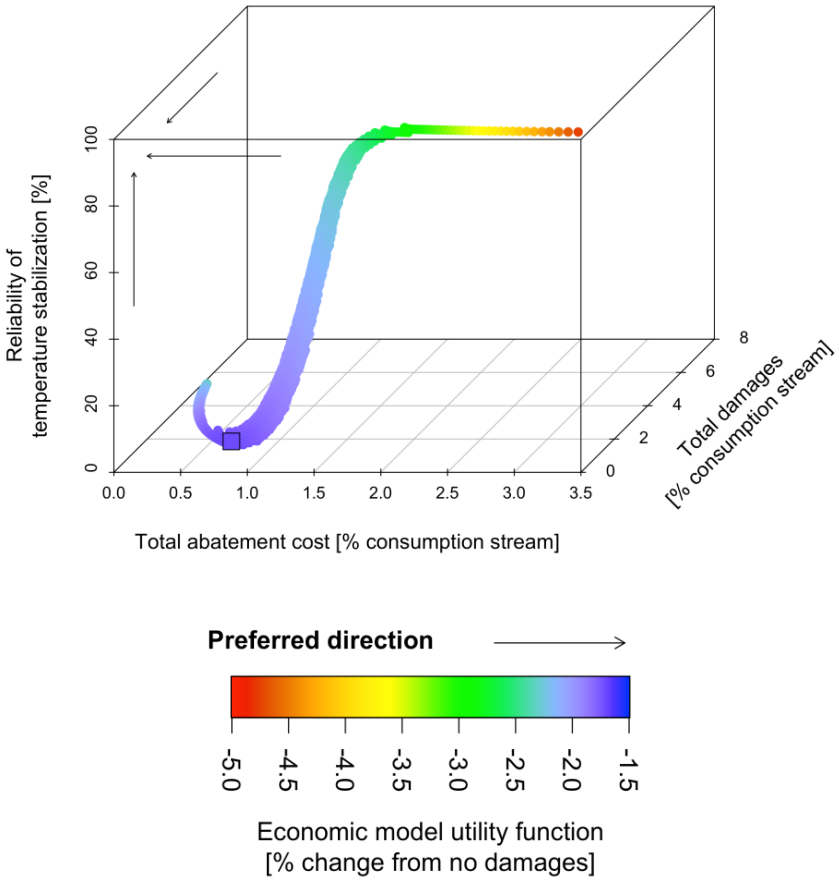
Climate risk management benefits from explicit representation of societal trade-offs

Methods: Sample uncertain distribution of climate sensitivity and quantify key trade-offs.

Findings: Reliability of geophysical stabilization not well accounted for with traditional utility representation of preference.

Relevance: Decision analysts can use the trade-offs to better inform the negotiated policies and their consequences.

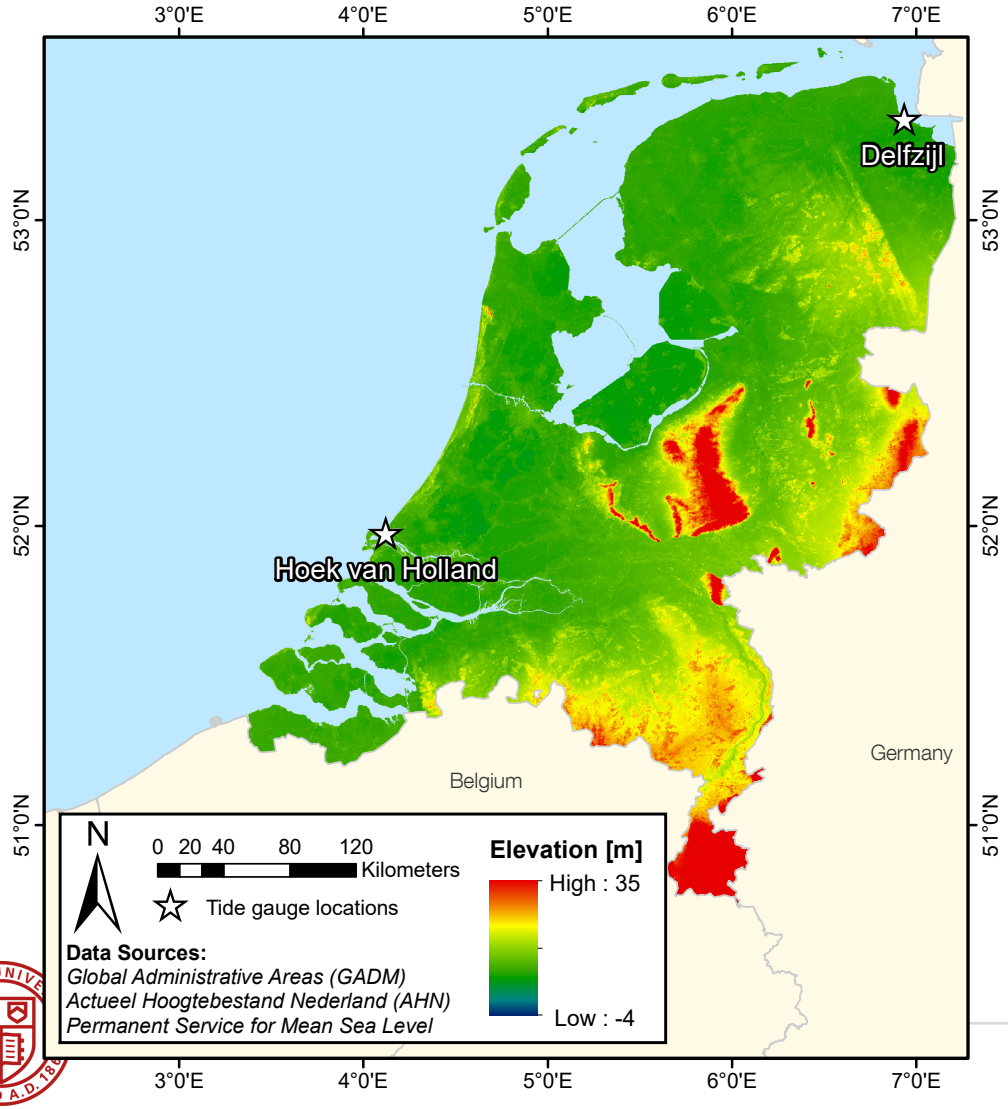
Linkages: Insights feed into (multi-objective) robust decision making framework.



***Right**: Explicit trade-offs between reliable stabilization, abatement costs, and damages given uncertainty in climate sensitivity.*

② How do methodological choices impact decision recommendations?

Classic Climate Risk Adaptation Example (van Dantzig, 1956)

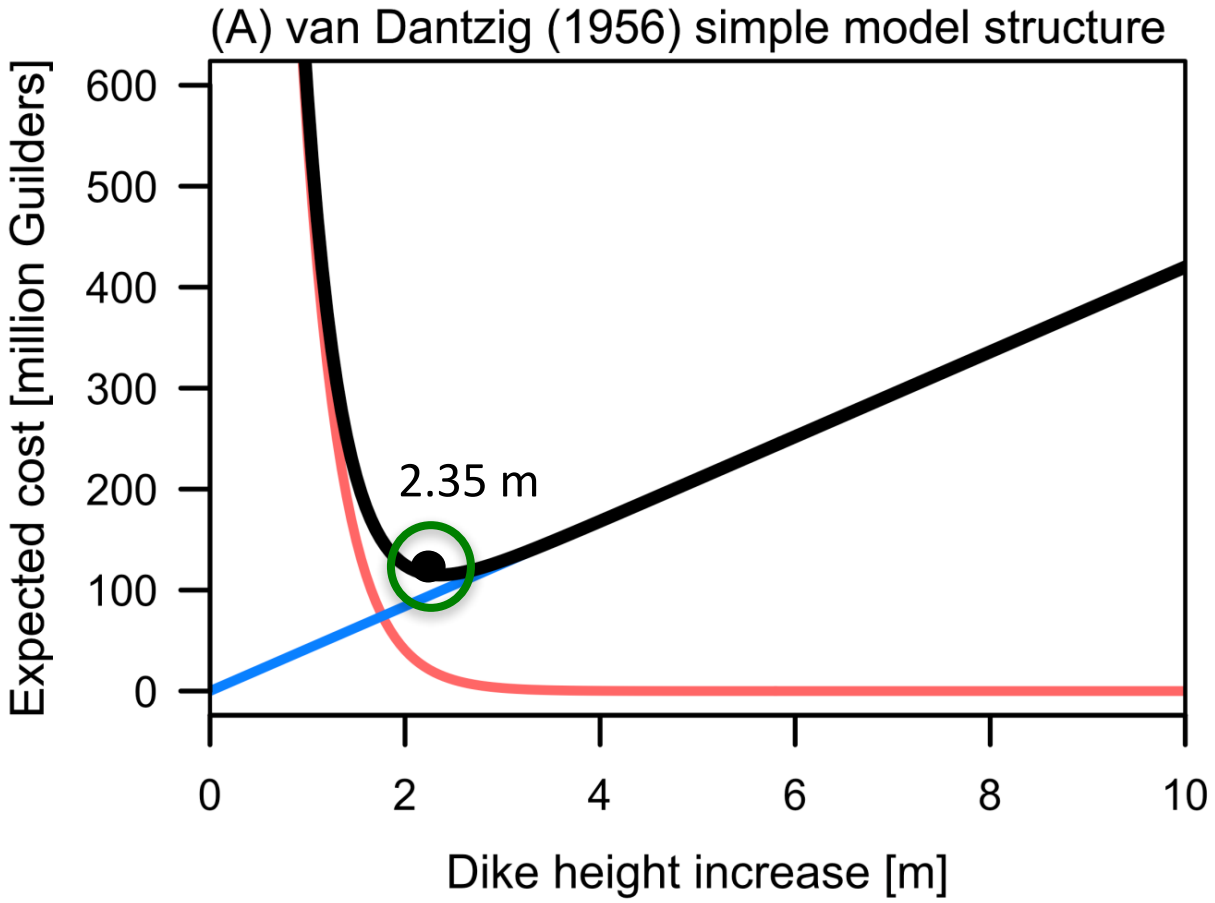


What dike height?
Global sea level rise?
Storm surge?

Economics-Engineering-Earth Science: A Synthesis Problem

***Left**: Map showing land surface elevation above mean sea level, the Netherlands.*

② How do methodological choices impact decision recommendations?

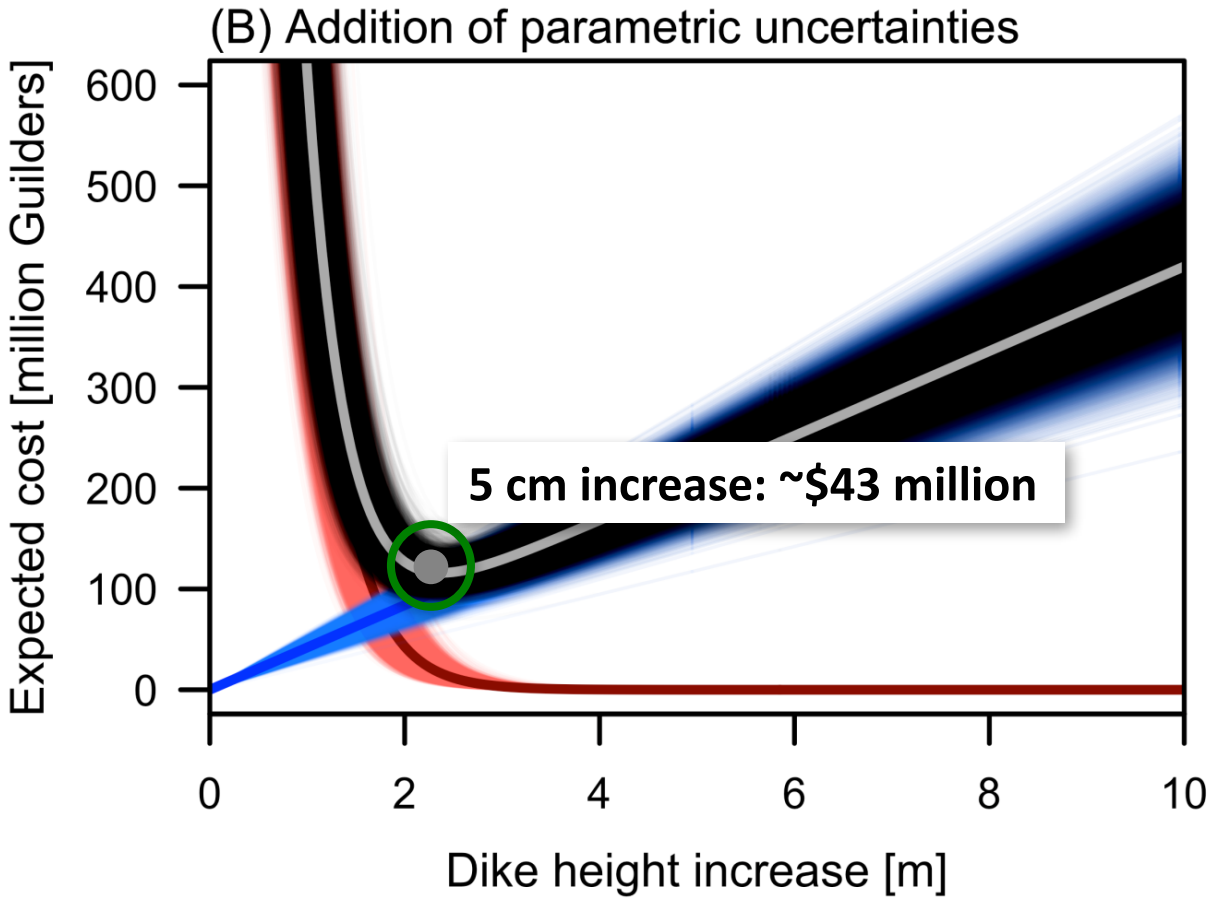


Expected Damages
Investment Costs
NPV Total Costs
Optimal strategy

Expected Outcome

SCRiM publication: Oddo et al., *Risk Analysis, In prep.* (2016)

② How do methodological choices impact decision recommendations?



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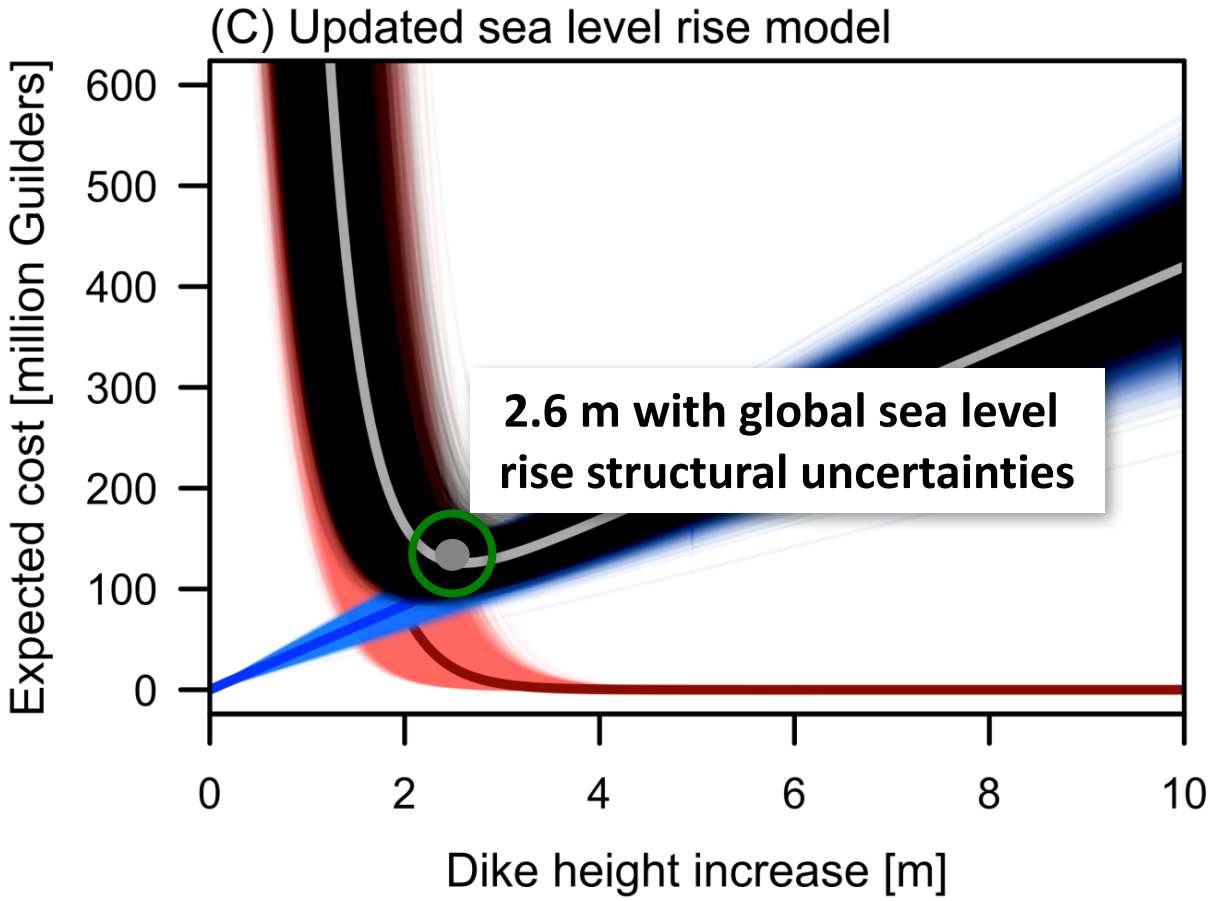

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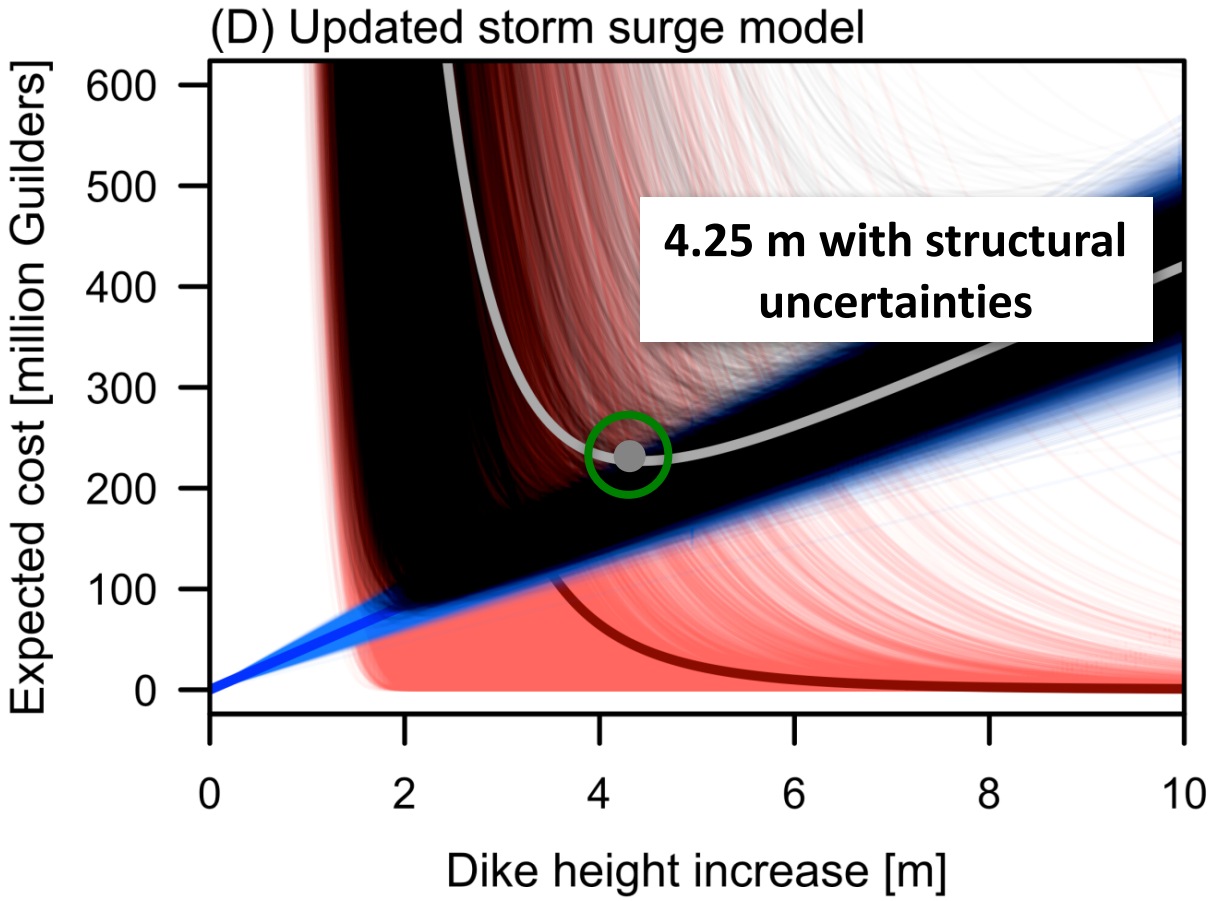
Optimal strategy

Expected Outcome

SCRiM publication: Oddo et al., *Risk Analysis, In prep.* (2016)

② How do methodological choices impact decision recommendations?



Expected Damages
Investment Costs
NPV Total Costs
Optimal strategy
Expected Outcome

SCRiM publication: Oddo et al., *Risk Analysis, In prep.* (2016)

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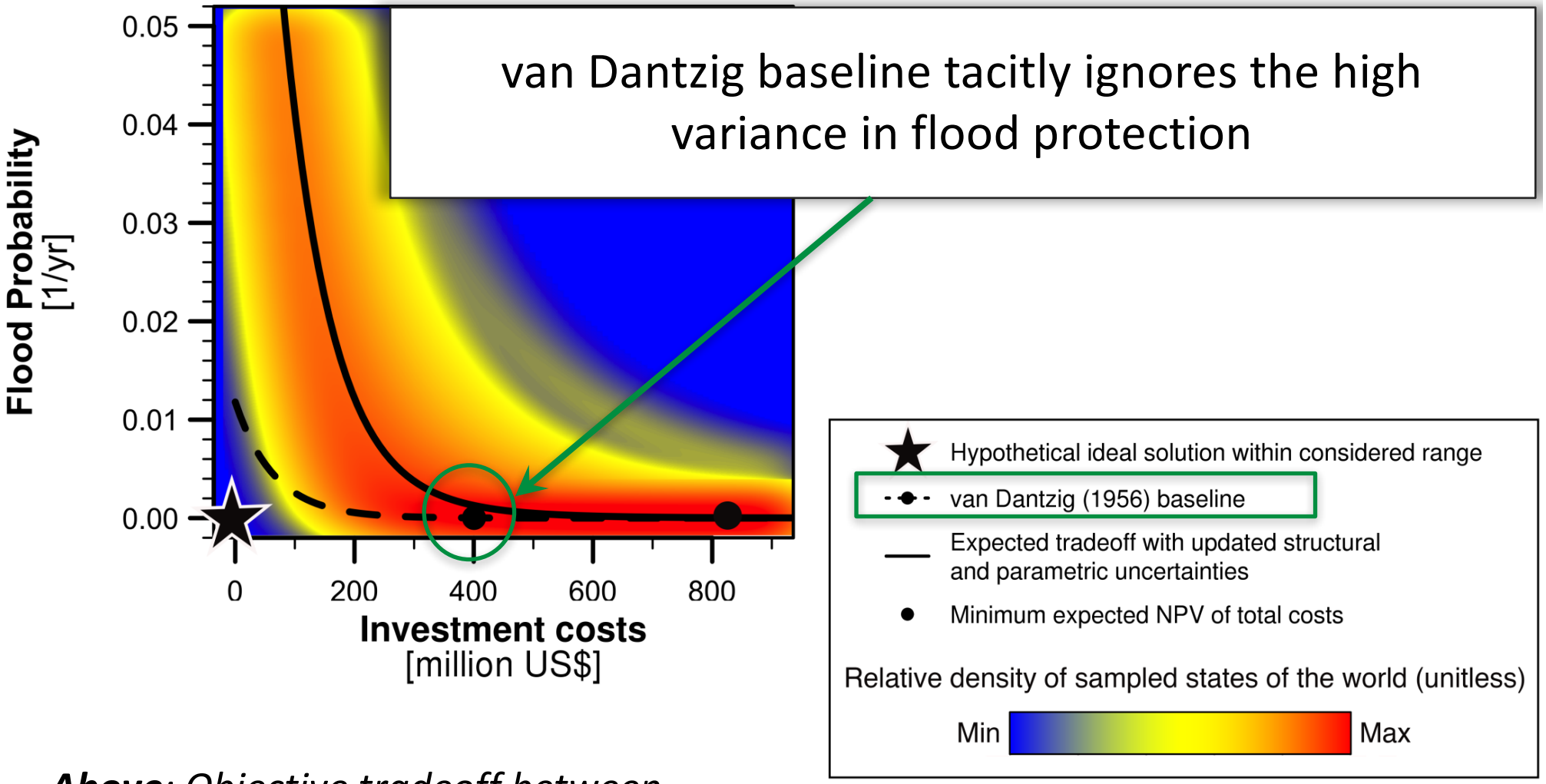
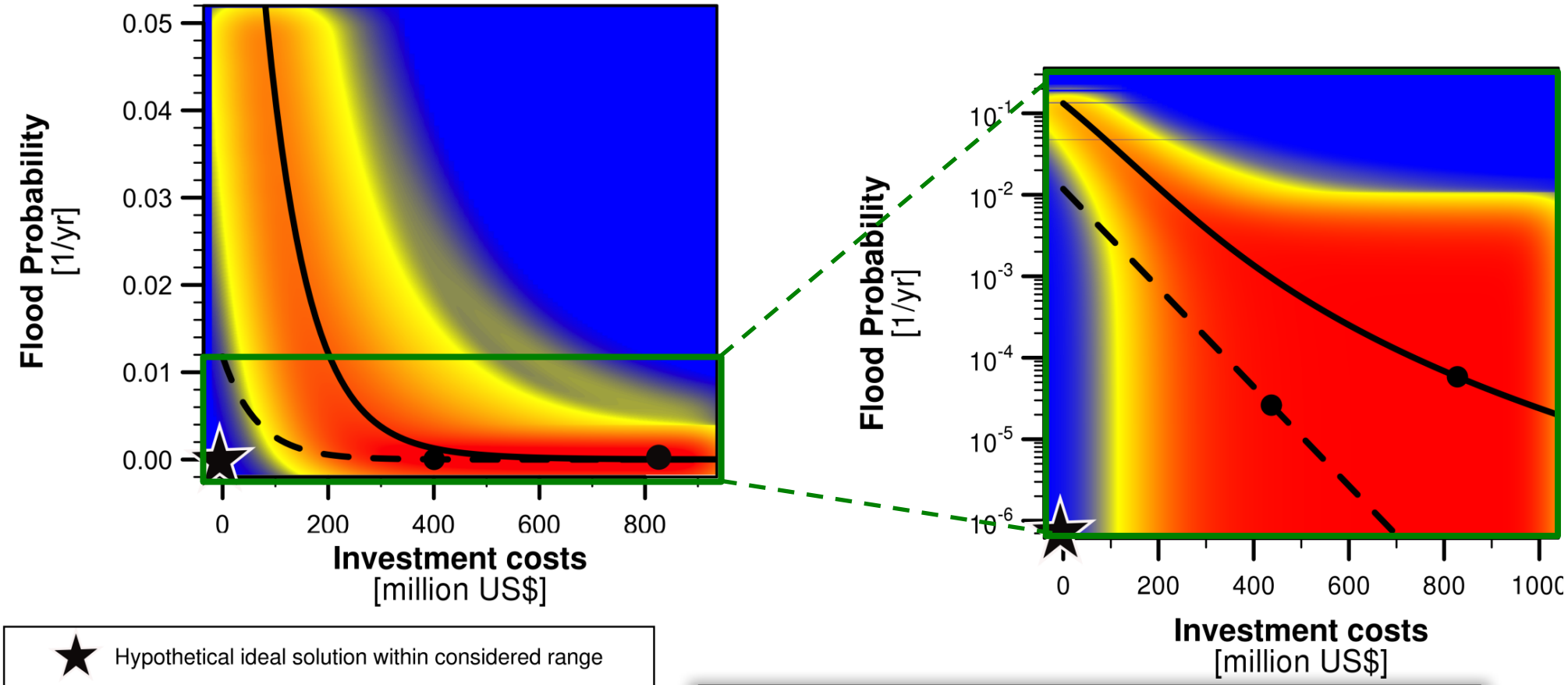


***Above**: Objective tradeoff between Flood Probability and Investment costs.*

② How do methodological choices impact decision recommendations?



Hypothetical ideal solution within considered range

van Dantzig (1956) baseline

Expected tradeoff with updated structural and parametric uncertainties

Minimum expected NPV of total costs

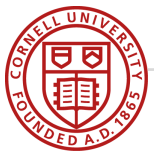
Relative density of sampled states of the world (unitless)

Min — Max

Tail-area behavior yields a severe variance in the reliability of a given investment

Section II: Language, Other Applications, & Tools

1. What do robustness-based decision frameworks have in common?
2. How do methodological choices impact decision recommendations?
3. How can we expand the value & impacts of our advances?



3 How can we exploit the SCRiM SRN to expand the value & impacts of our advances?

OpenMORDM

Multiobjective Robust Decision Making in R

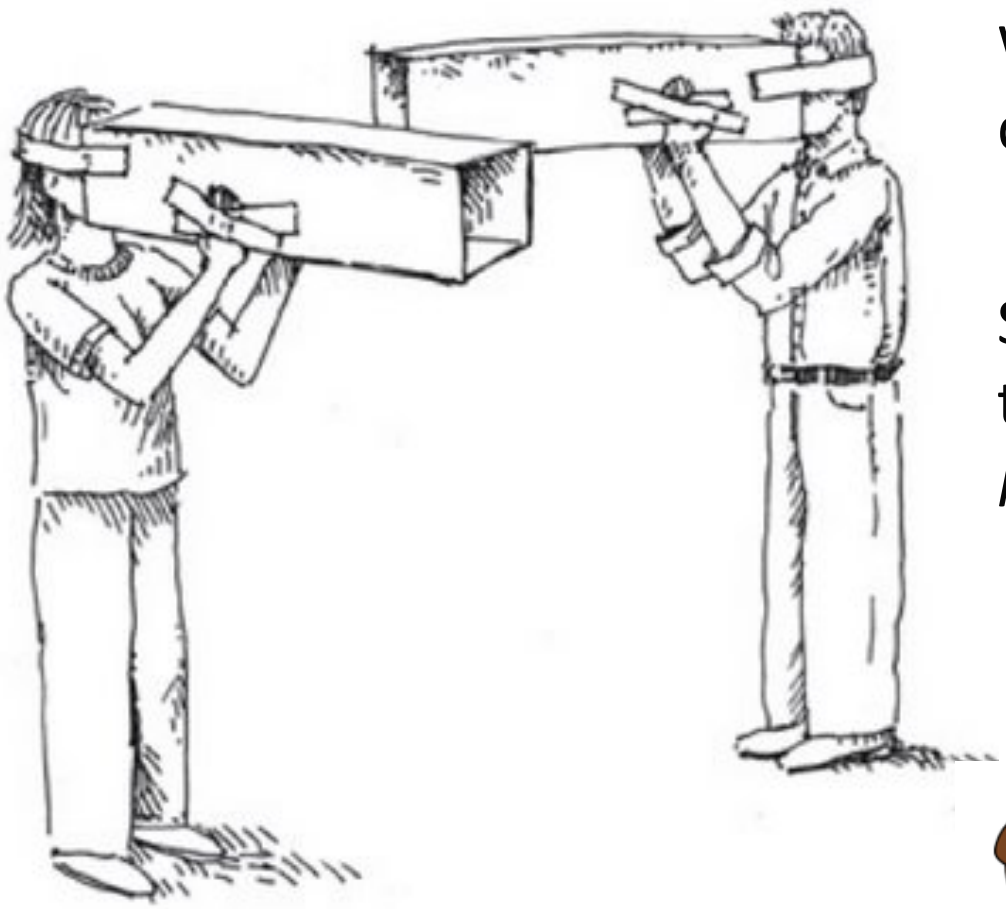
Developed by Penn State (David Hadka, Klaus Keller) and Cornell (Jon Herman, Patrick Reed)

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

3 How can we exploit the SCRiM SRN to expand the value & impacts of our advances?



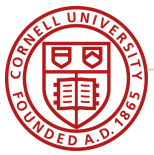
Which actions are robust? How to decide?

Sample deeply uncertain states of the world (*climate sensitivity, sea-level rise, etc.)*

OpenMORDM

Multiobjective Robust Decision Making in R

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



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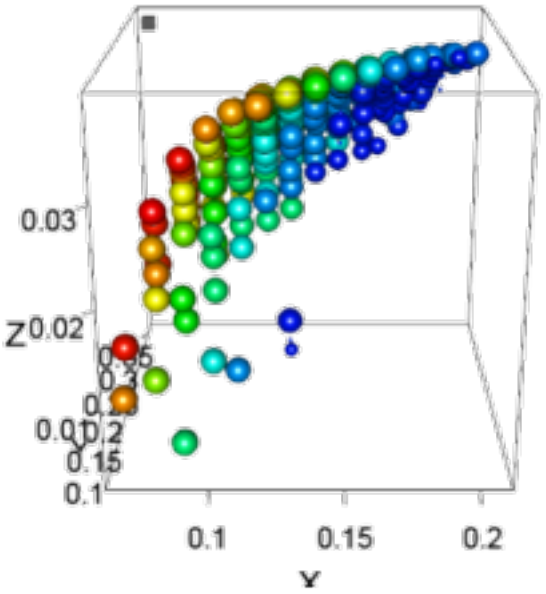
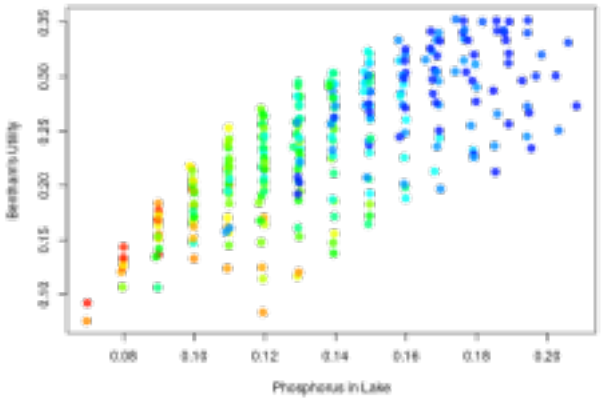
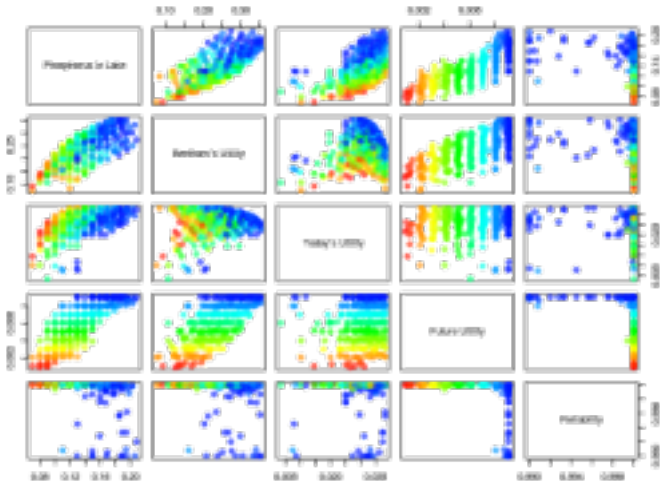
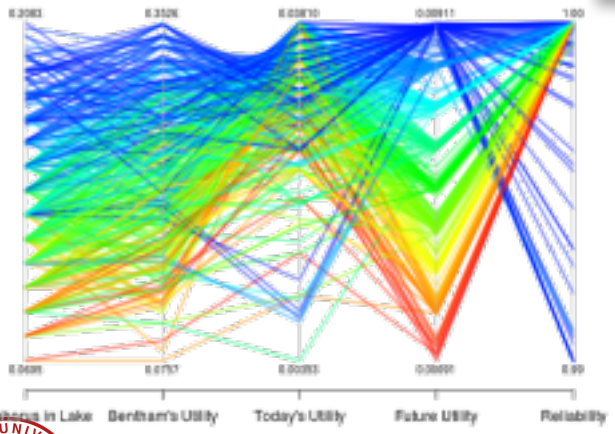
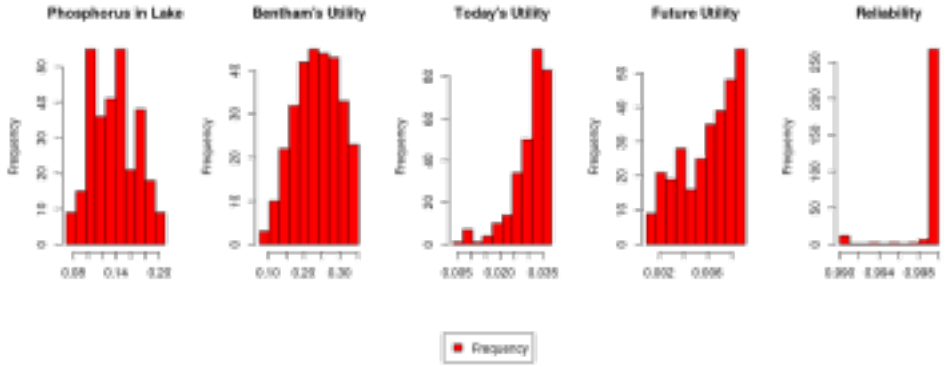






Interactive, high-dimensional visualization of datasets





SCRiM publication: Hadka Herman Reed Keller (2016) Env. Modelling & Software, 74, 114-129

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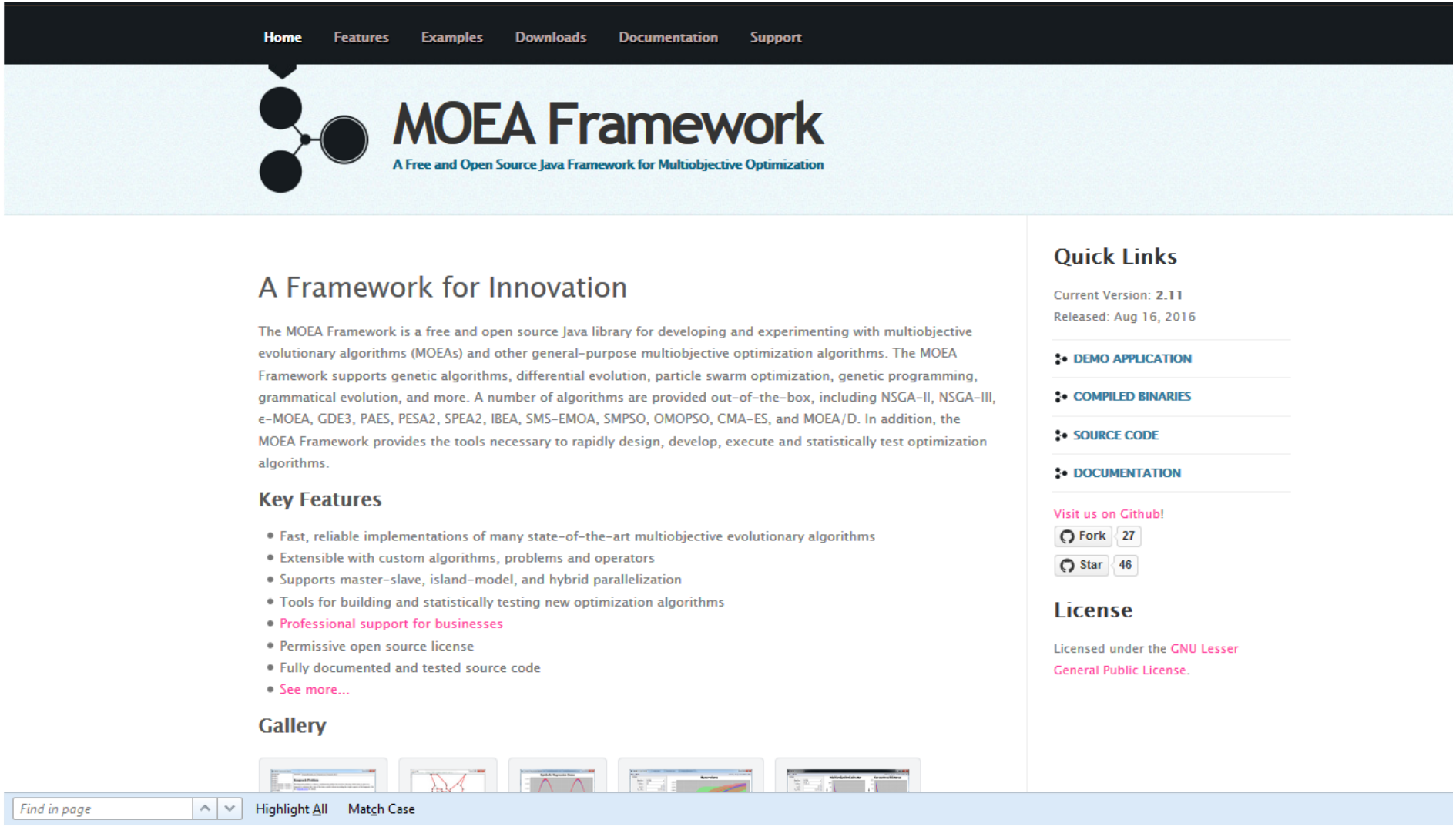

http://moeaframework.org/

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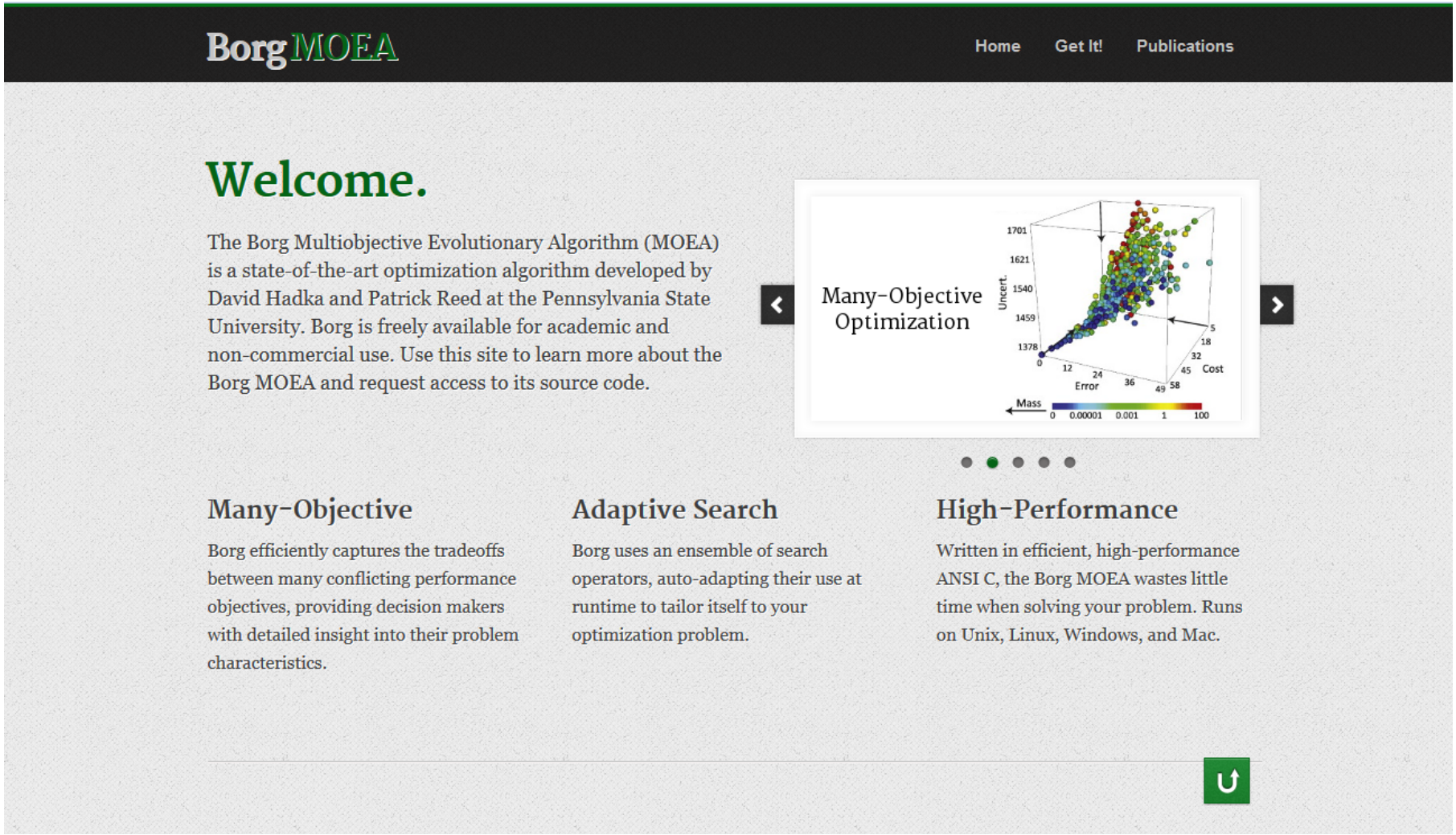

http://BorgMOEA.org/

Thank you & any questions?

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