Decision Support for Wicked Problems

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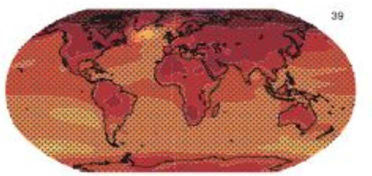
How to Use Quantitative Information to Make Good Policy Choices?

In many policy areas, quantitative information is often indispensable to making good policy choices

Energy



Climate change

Health

Defense

Economic policy

It may seem obvious that quantitative analysis can best inform policy by making predictions of the future

But predictions -- a core principle of the scientific method -- often complicate the use of quantitative information when:

- Uncertainties are deep
- People disagree

Fortunately, there is another way,

which creates new and interesting analytic challenges

Traditional Policy Analysis Begins with a Consensus Understanding of the Future

"Predict then Act"

What will future conditions be? → What is the best near-term decision? → How sensitive is the decision to the conditions?

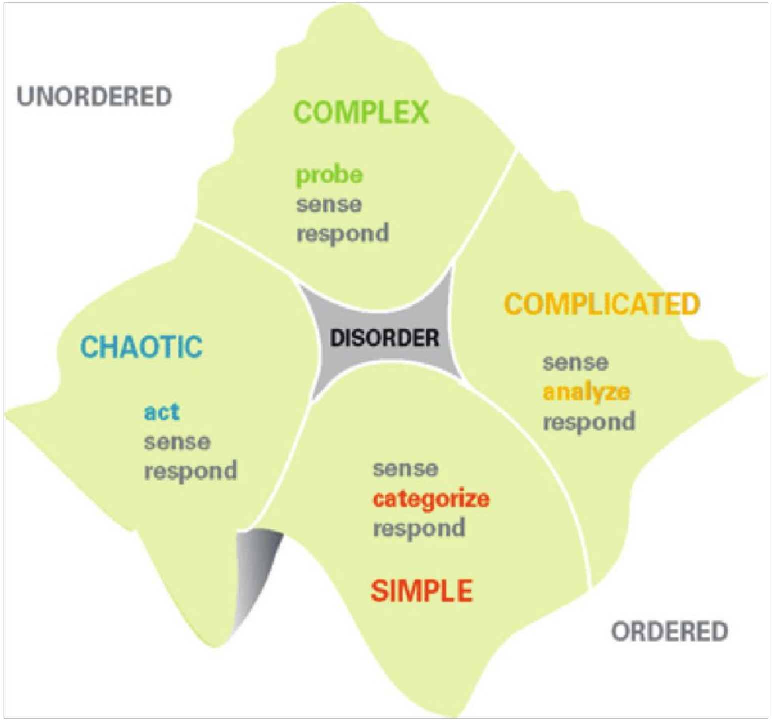
Predict

Act

Many Policy Challenges Usefully Understood as Complex and "Wicked" Problems

Characteristics of "wicked" problems include:

- Not well bounded,
- Framed differently by various groups and individuals,
- Large to existential scientific uncertainties,
- Non-linear dynamics, and
- Not well understood until after the formulation of a solution



Cynefin framework

Complex and complicated systems have different implications for understanding and acting:

- Behavior of complex systems can be understood, but difficult to predict
- Complex systems often best managed by probe and respond, rather than analyze and act

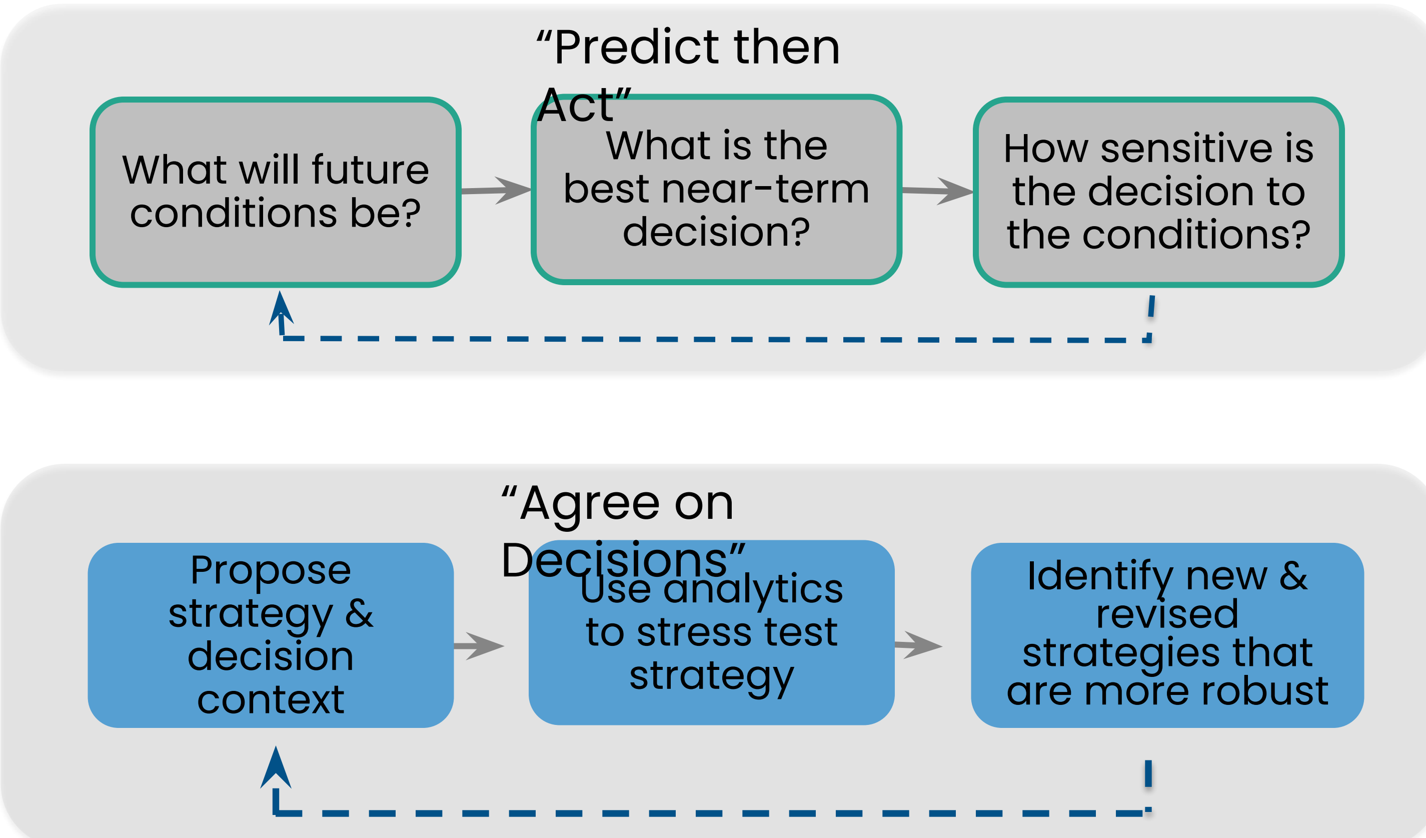
“Predict then Act” Can Break Down When Uncertainties are Deep

Under conditions of deep uncertainty:

- Uncertainties are often underestimated
- Competing analyses can contribute to gridlock
- Misplaced concreteness can blind decision makers to surprise

<u>Deep uncertainty</u> occurs
when the parties to a decision do not know or do not agree on the likelihood of alternative futures
or how actions are related to consequences

To Inform Decisions Under Deep Uncertainty, Invert the Order of Traditional Analysis

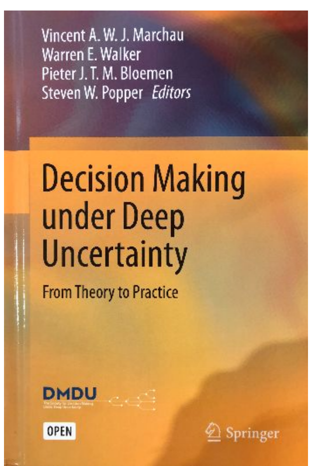


Kalra, N., S. Hallegatte, R. Lempert, C. Brown, A. Fozzard, S. Gill and A. Shah (2014). Agreeing on Robust Decisions: A New Process for Decision Making Under Deep Uncertainty. WPS-6906, World Bank.

Robust Decision Making (RDM) Provides Such an “Agree on Decision” Approach

- **Robust decision-making** (RDM) is an iterative, **multi-scenario, multi-objective** decision analytic framework that aims to:
  - Help identify potential **robust** strategies,
  - Characterize the **vulnerabilities** of such strategies, and
  - Display the **tradeoffs** among them.

- RDM rests on a **simple concept**
  - Rather than use computer models and data as predictive tools,
  - RDM runs model thousands to millions of times to:
    - Stress test proposed policies against a wide range of futures, and
    - Uses the results to help decision identify policy-relevant scenarios and strategies robust across those scenarios.



Robust Decision Making (RDM) is one common approach for decision making under deep uncertainty (DMDU)

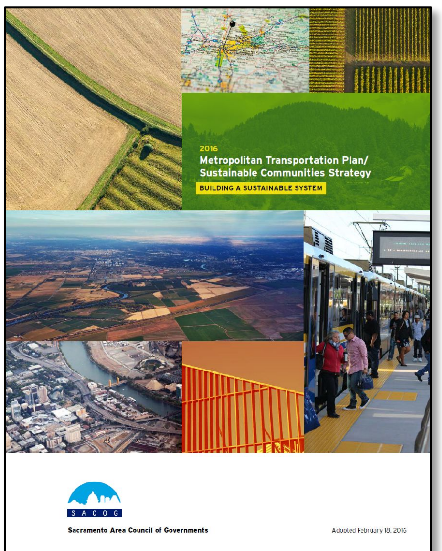
Outline

- Robust Decision Making (RDM)
- Stress Tests
- Supporting Deliberation
- Observations

"Scenario Discovery" Algorithms Illuminate Vulnerabilities of Proposed Plans

Sacramento Council of Governments (SACOG) aims to improve mobility and equity while meeting stringent greenhouse reduction requirements

SACOG's 2016
Regional Transportation Plan
Sustainable Community Strategy

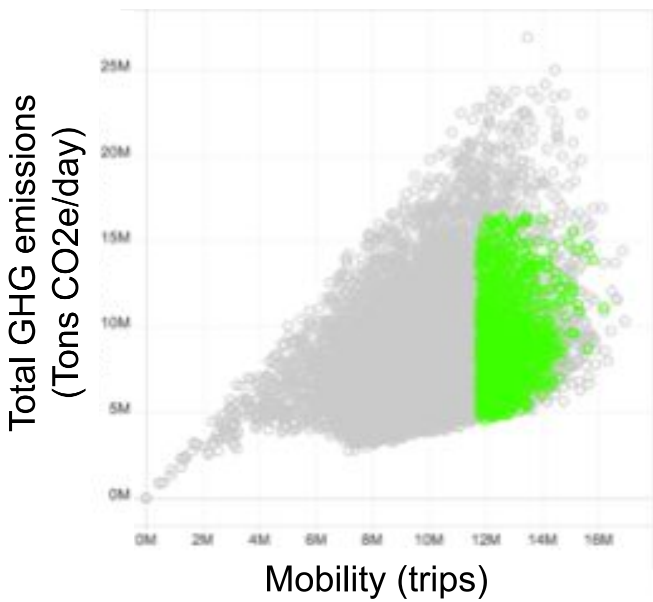


- SACOG's 2016 plan aims to meet these goals by 2035 with:
  - Targeted transportation investments and
  - More compact growth
- Used RDM to stress test this plan over many futures
  - Used simple model fit to agencies travel demand model
  - Results helped to identify key vulnerabilities and potential responses

Lempert, R., J. Syme, G. Mazur, D. Knopman, G. Ballard-Rosa, K. Lizon and I. Edochie (2020)
Meeting Climate, Mobility, and Equity Goals in Transportation Planning Under Wide-Ranging Scenarios: A Demonstration of Robust Decision Making. Journal of the American Planning Association

Under What Conditions Would SACOG Meet Its Mobility, Equity, and Climate Goals for 2035?

Run model over many plausible futures



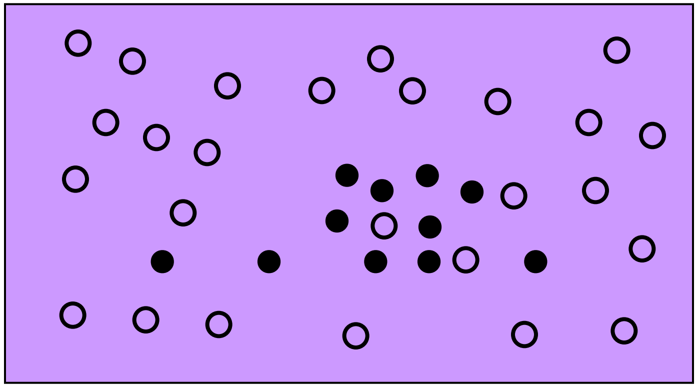
SACOG meets goals when mobility is high and emissions are low

Green = case meets all SACOG goals
Grey = case misses some SACOG goals

What combination of factors best distinguish the green and grey cases?

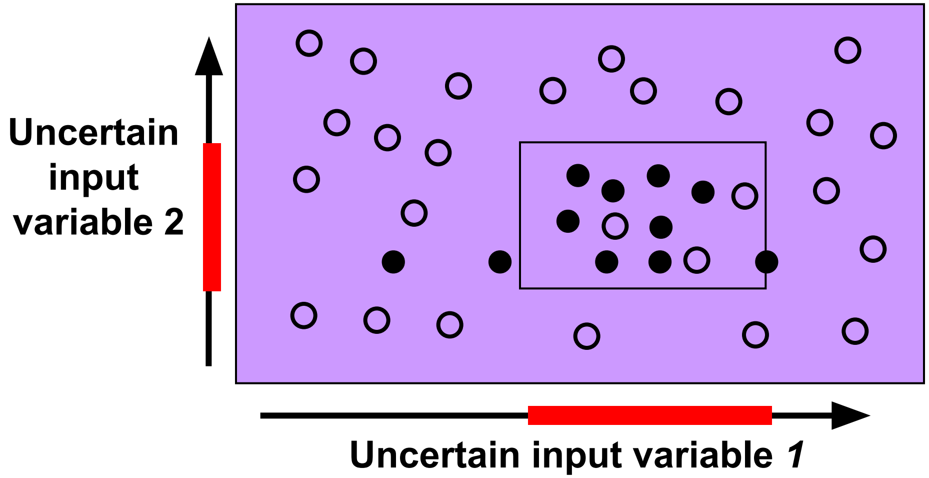
Scenario Discovery Provides an Approach for Computer-Assisted Scenario Development

1. *Indicate policy-relevant cases in database of simulation results*



Scenario Discovery Provides an Approach for Computer-Assisted Scenario Development

1. ***Indicate policy-relevant cases in database of simulation results***
2. ***Statistical analysis finds*** *low-dimensional* ***clusters with high density of these cases***



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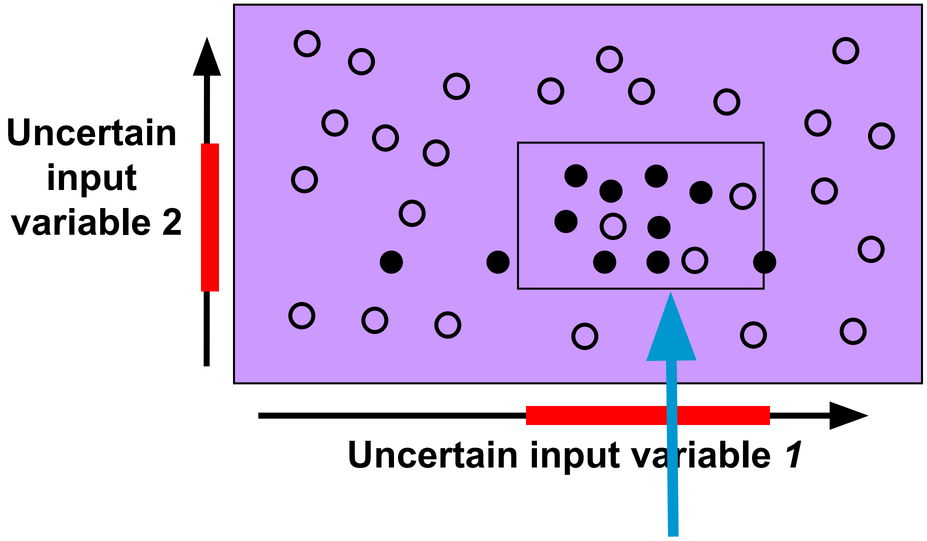

3. *Clusters represent scenarios and driving forces of interest to decision makers*

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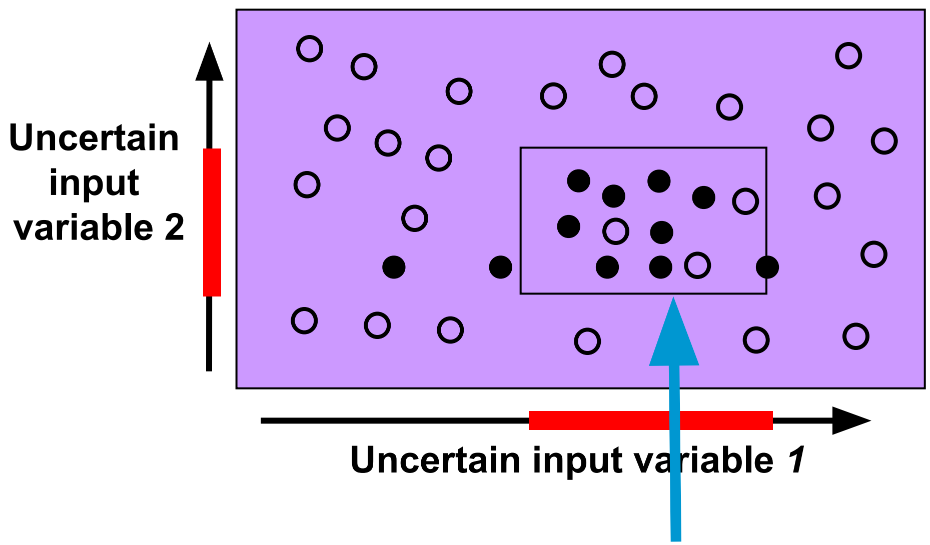


3. *Clusters represent scenarios and driving forces of interest to decision makers*

Approach provides measures of merit for scenario quality

Density:

- How many cases inside the scenario are *policy-relevant?* (e.g. 75%)

Coverage:

- How many of all the *policy-relevant* cases do the scenarios include? (e.g. 82%)

Interpretability:

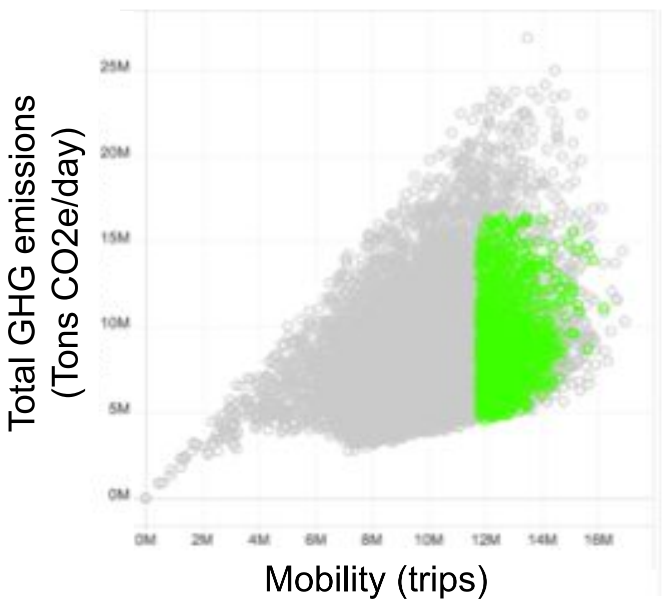
- Is the number of scenarios and driving forces sufficiently small to understand? (e.g. 1 scenario with two driving forces)

On scenario discovery: Bryant & Lempert (2010). Thinking inside the box: a participatory, computer-assisted approach to scenario discovery *Technological Forecasting and Social Change*

Kwakkel (2017) "The Exploratory Modeling Workbench: An open-source toolkit for exploratory modeling, scenario discovery, and (multi-objective) robust decision making." Environmental Modelling & Software

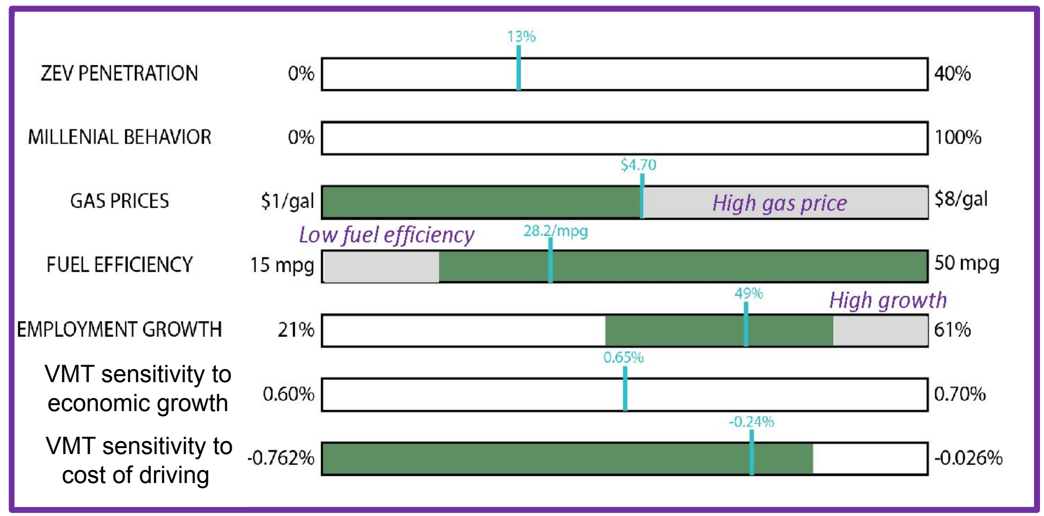
Under What Conditions Would SACOG Meet Its Mobility, Equity, and Climate Goals for 2035?

Run model over many plausible futures



Green = case meets all SACOG goals
Grey = case misses some SACOG goals

"Scenario discovery" classification algorithms show key drivers of success



- Green bars show parameter variation ranges that best differentiate futures that meet and miss goals
- Variables without green bars are not a key driver/differentiator for meeting or missing goals

Scenario discovery generates scenarios that can be used in stakeholder engagements

Outline

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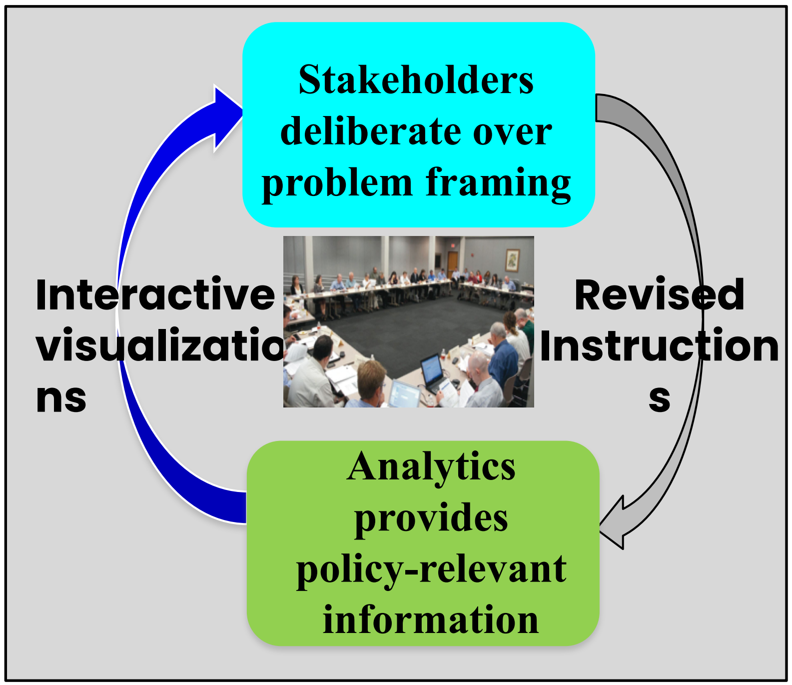
Participatory Processes Can Prove Important to Effective Policy Action

Participatory process:

- Can enhance legitimacy and inclusion
- Combine scientific and local knowledge
- Connect estimates of consequences with participants' values



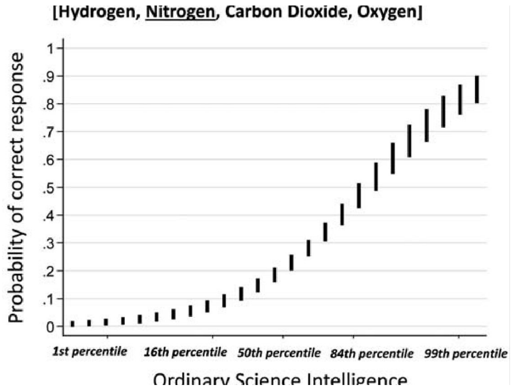
Deliberation with analysis is:

- A participatory learning process in which stakeholders deliberate over problem framings supported by analytic products responsive to those framings
- Useful when new problem framings emerge through stakeholder interactions with analytics and each other
- Useful for the "frame reflection' often needed to address wicked problems

NRC (2009) Informing Decisions in a Changing Climate

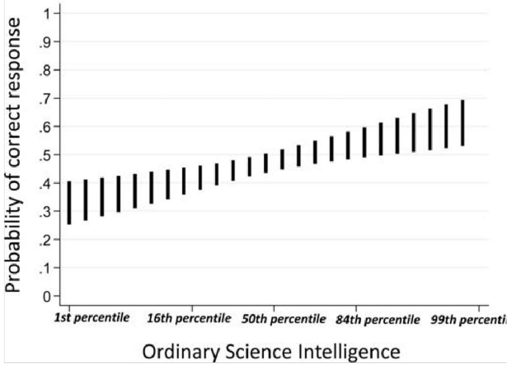
Disagreements Over Values Often Become Disagreements Over Facts

What gas makes up the majority of Earth's atmosphere?



Public understanding of science as function of "scientific intelligence"

There is "solid evidence" of recent global warming due "mostly" to human activity such as burning fossil fuels



Kahan, D.M., *Climate-Science Communcation and the Measurement Problem.* Advances in Political Psychology, 2015. 36

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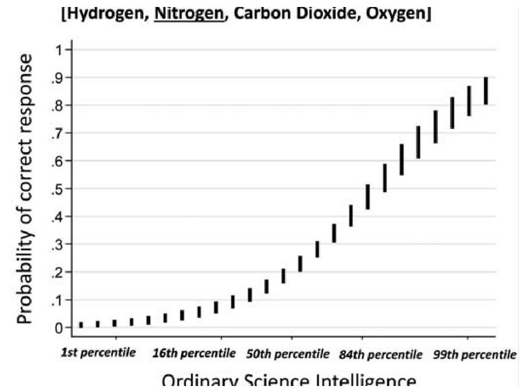

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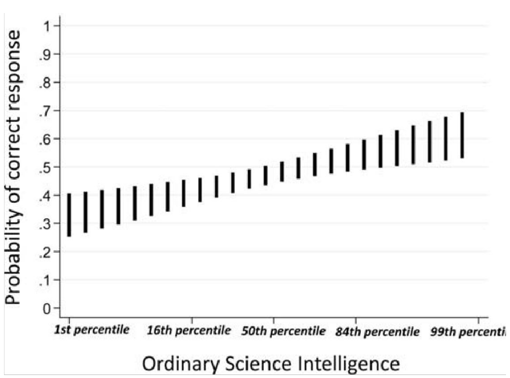
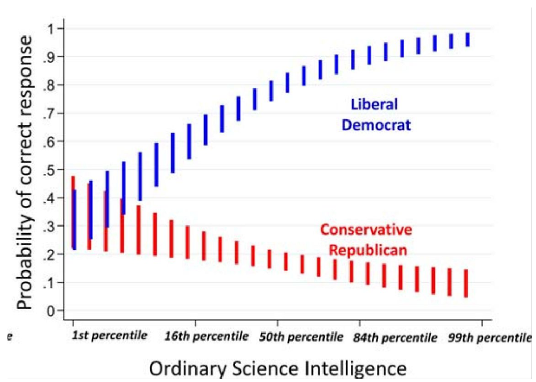
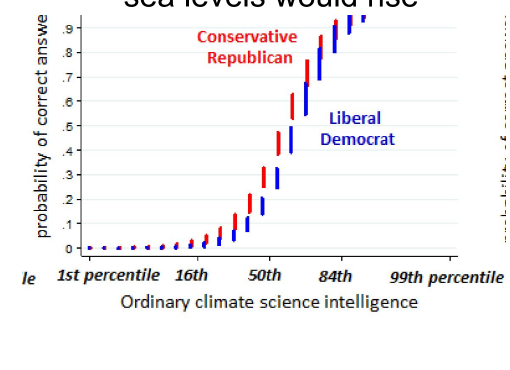




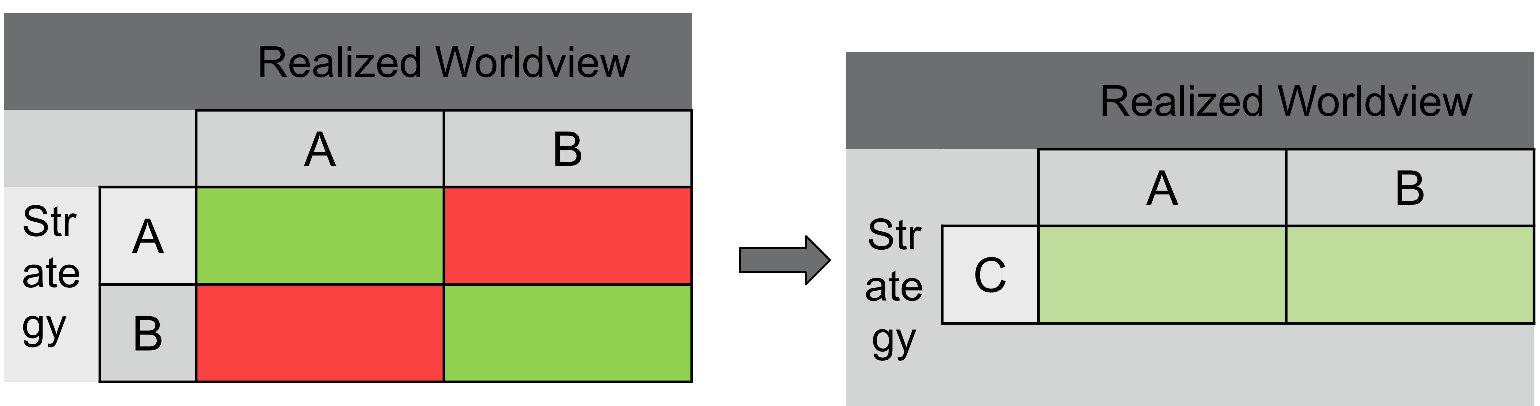
Climate scientists believe that if the North Pole icecap melted as a result of human-caused global warming, global sea levels would rise



Kahan, D.M., *Climate-Science Communication and the Measurement Problem.* Advances in Political Psychology, 2015. 36

How Can Analytics Engage Multiple Worldviews?

- Wicked problems engage people with different worldviews
  - A *world view is a comprehensive conception of the world, comprising a correlated set of values, beliefs, and policy preferences that shapes how one understands, judges, and acts in the world*
- Approaches for addressing wicked problems mostly envision:
  - Iterative learning processes
  - Frame reflection, in which participants are encouraged to see problem through each others' eyes
  - "Clumbsy" solutions, which contain elements of different worldviews
- Utopia-dystopia matrices help operationalize these ideas



Simple Example Introduces Analytic Tools

Imagine a Hypothetical Town on Shore of a Pristine Lake

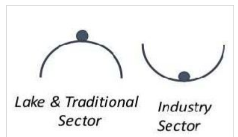
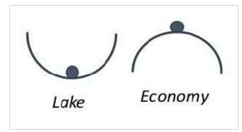
- Proposed economic development could:
  - Increase pollution into the lake
  - Enhance welfare for some current and new residents
  - Damage welfare for other current residents
- Deep uncertainties include:
  - Pollution tipping point for lake
  - Pollution intensity of development
  - Effectiveness of alternative policies

What strategy should the town pursue?

Lempert, R.J. and Turner, S. (2020): "Engaging Multiple Worldviews With Quantitative Decision Support: A Robust Decision-Making Demonstration Using the Lake Model." Risk Analysis

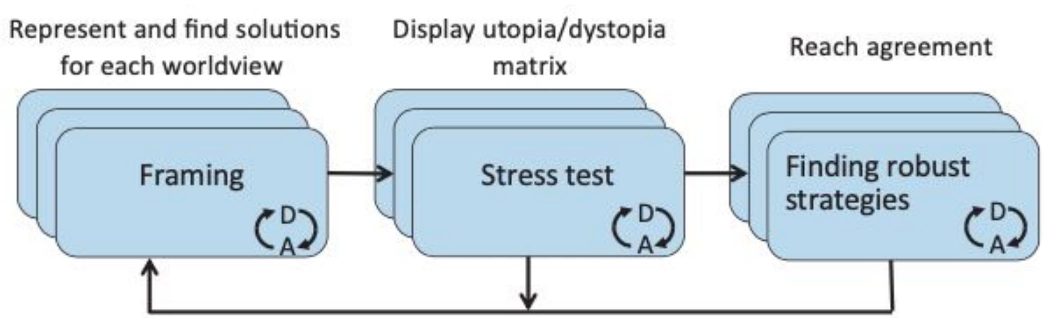
RDM Suggests Compromise Strategies Across Worldviews

Identify three worldviews from the cultural theory of risk

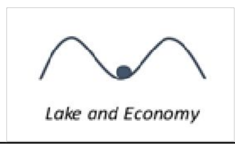
	Hierarchists	Egalitarians	Individualists
Expectations about lake and economy	• Lake and economy are benign within bounds  	• Lake is fragile, but the economy is benign  	• Like is benign, but the economy if fragile 
Appropriate actions town might take	• Favor regulation and training • Favor adaptive management	• Distrusts training • Favors regulation • Distrust adaptive management	• Distrust regulation • Favor training • Favor adaptive management
Goals	• Achieve appropriate balance among economic and environmental objectives	• Traditional sector is sacred, protect at all costs • Minimize pollution • Distrust tradeoffs	• Maximize autonomy and opportunity • Favor economy over environment

Process

1) Conduct RDM analysis for each worldview
2) Examine how solution for each world view performs from perspective of other worldviews
3) Search for solutions that perform well across worldviews



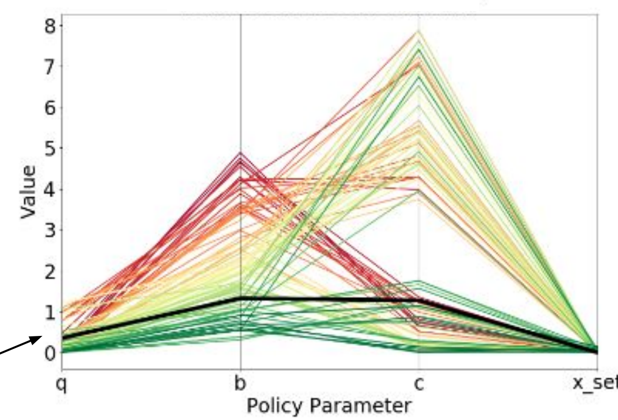
Find Policy Solutions for Hierarchist Worldview

	Hierarchical
Question	∀How can local officials best balance environmental protection and economic growth?
Expectations about lake and economy	∀Lake and economy are benign within bounds 
Appropriate actions town might take	∀Favor regulation and training ∀Favor adaptive management
Goals	∀Achieve appropriate balance among economic and environmental objectives

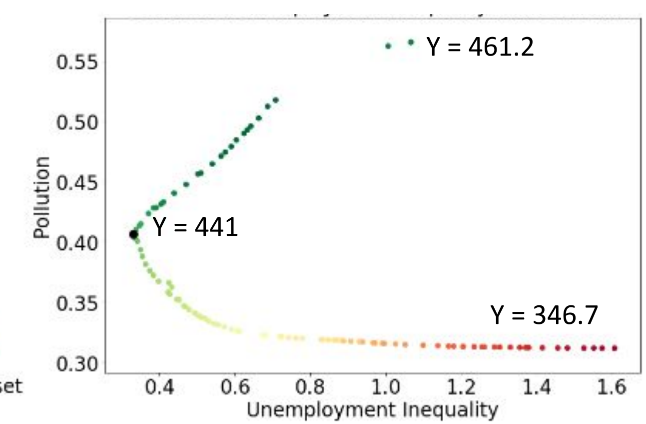
1. Express policy solutions as a controller with four parameters:
   x_{set}: Target level for pollution
   b: Amount of regulation for pollution past target level
   c: Amount of regulation for level of warning
   q: Amount of training for a given unemployment rate

2. Use multi-objective robust decision making (MORDM) algorithms to find non-dominated solutions over many objectives

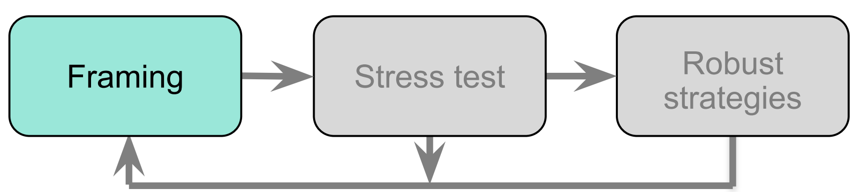
Solutions



Outcomes

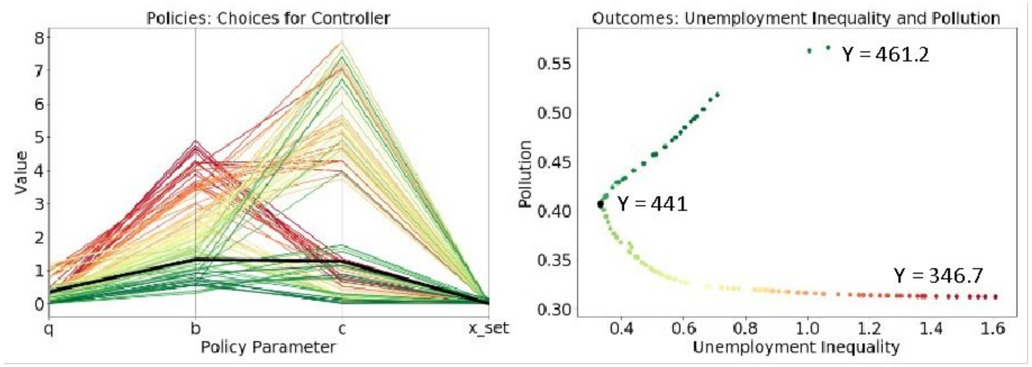


Representative strategy

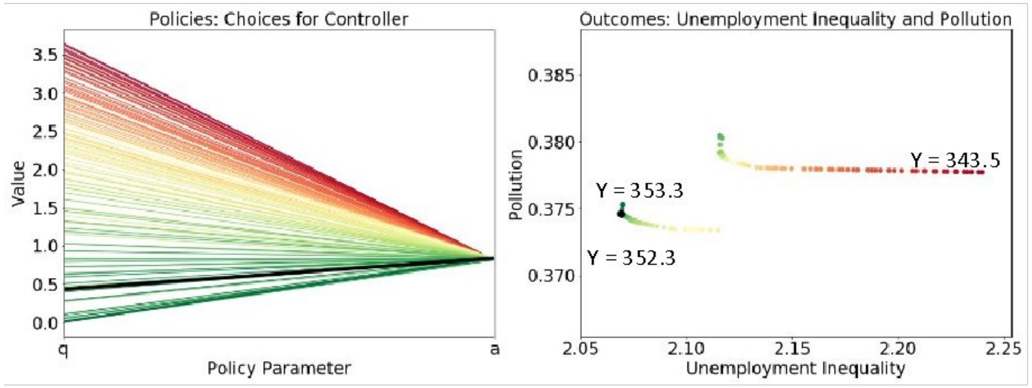


Find Solutions for All Worldviews

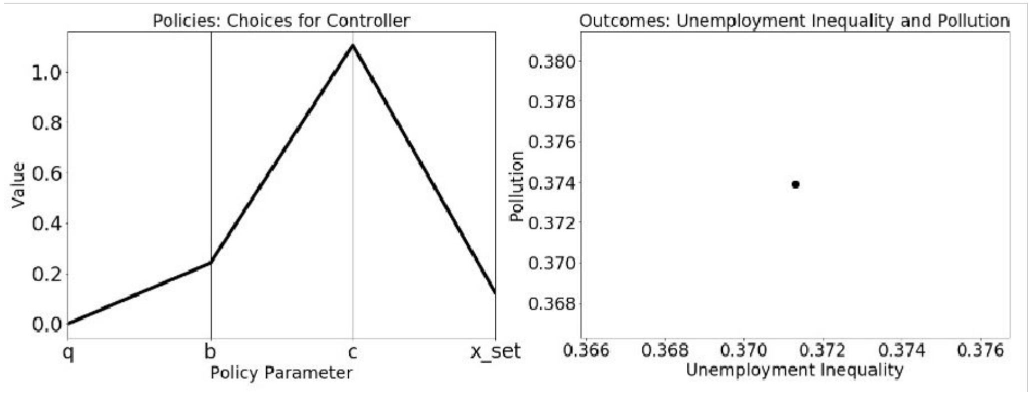
Hierarchists



Egalitarians

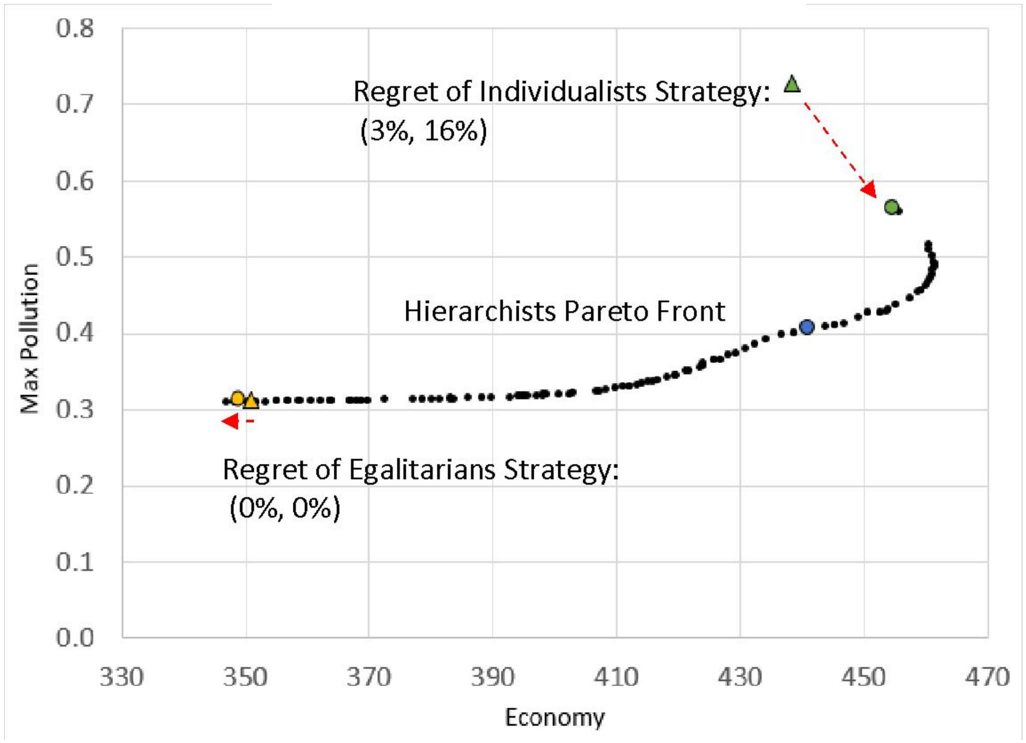


Individualists



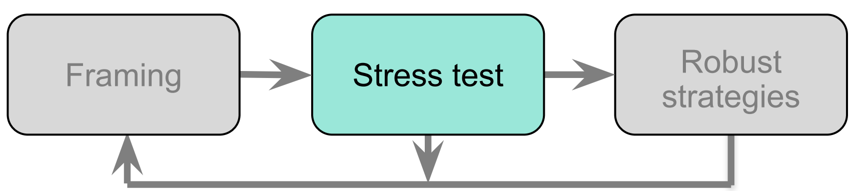
How do we compare solutions across worldviews?

Regret relative to
Hierarchist world view



1. Measure comparative performance using regret
2. Calculate regret as the Euclidean distance between:
   - Solution from one world view and
   - closest point on pareto surface for another world view

$$Distance_s(f) = \sqrt{\sum_j^J [O_{s,j}(f) - O_{r,j}(f)]^2}$$

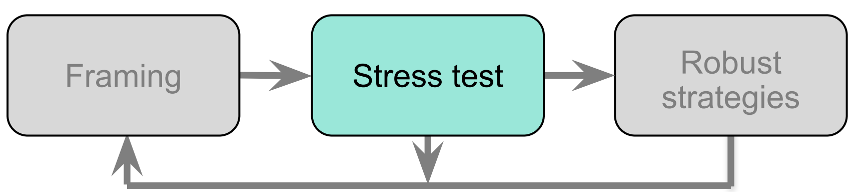


Display Comparisons in Utopia-Dystopia Matrices

		Regret using Strategy's World View							
		Environment		Economy		Unemployment		Inequality	
Strategy	World View	Rel	Poll	Econ	Employ	Trad	New	Unemp	Inc
H	E	82%	41%	5%		88%	17%	74%	
H	I	0%	-1%	14%		0%	2%	-1%	
E	H	0%	-1%	0%	0%			2%	0%
E	I	0%	-6%	33%	-7%			14%	-42%
I	H	21%		3%					
I	E	83%		26%					

LEGEND

- Relative Regret ≤ 5%
- 5% < Relative Regret ≤ 20%
- Relative Regret > 20%
- High relative regret with small base value



Seeking Robust Compromise Strategies

1. Identify new controller, more acceptable to Egalitarians:
   - Regulate pollution at constant level until pollution intensity drops below a threshold level

2. Find strategies that simultaneously perform well in multiple world views

		Relative Regret using Realized World View's objectives							
		Environment		Economy		Unemployment		Inequality	
Strategy	World View	Rel	Poll	Econ	Employ	Trad	New	Unemp	Inc
H/E	E	0%	-2%	3%	0%			11%	0%
	H	0%	-23%	18%		-98%	499%	424%	
H/I	I	0%		2%					
	H	0%	21%	-2%		45%	-24%	64%	

LEGEND

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- 5% < Relative Regret ≤ 20%
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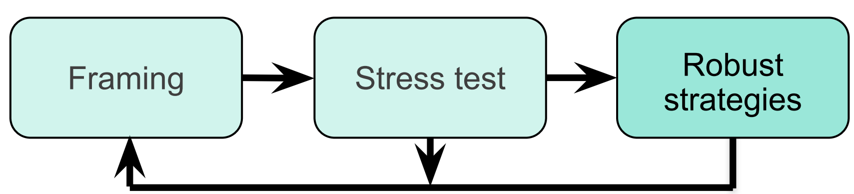

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RDM Uses Models as Exploratory, Not Predictive Tools

Consider two fundamentally different ways to use computer simulation models

Consolidative models:

- Gather all relevant knowledge into a single package which, once validated, can be used as a surrogate for the real world
- Used for prediction

Exploratory models:

- Map assumptions onto consequences, without privileging any one set of assumptions
- Supports iterative problem-solving

Exploratory modeling can:

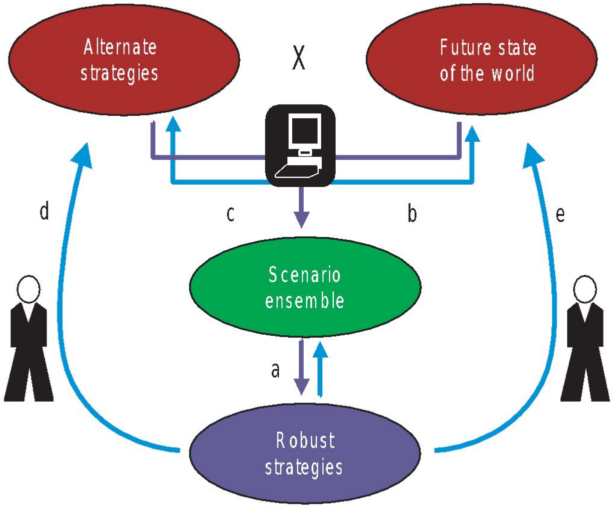
- Help generate hypotheses
- Identify special cases
- Assess common properties across many cases -- in particular identify robust strategies

Weaver, C.P., Lempert, R.J., Brown, C., Hall, J.A., Revell, D. and Sarewitz, D., 2013. *Improving the contribution of climate model information to decision making: the value and demands of robust decision frameworks*. WIREs Climate Change,

Emerging Computational Tools Facilitate RDM and DMDU

- Classification algorithms help extract decision-relevant information from large ensembles of model runs
  - Opportunities for machine learning and other algorithm development?
- Robust optimization algorithms help identify strategies robust across scenarios
- Visualization, often interactive, helps users navigate among multiple futures
- High performance computing makes each of these steps possible

Potential for an interesting approach to human-machine collaboration



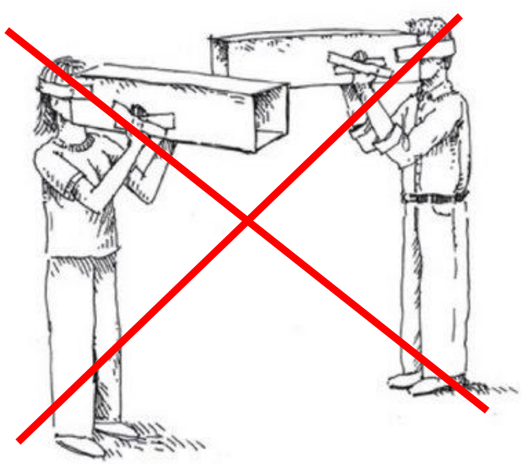
Lempert, Popper, Bankes (2003)

RDM Helps People Make Better Decisions, Not Better Predictions

Basic principles

1. Consider multiple futures, not one single future, in your planning. Choose these futures to stress test your organization's plans
2. Seek robust plans that perform well over many futures, not optimal plans designed for a single, best-estimate future
3. Make your plans flexible and adaptive, which often makes them more robust

Plan over multiple



Some DMDU aphorisms:

- Premature aggregation is the root of all evil in decision support (J. Kwakkel)
- Seek certainty in your decisions, not in your predictions

QUESTIONS?

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