Systems Analysis 2015: Conference Synthesis

11-13 November 2015, at IIASA, Laxenburg, Austria

International Institute for Applied Systems Analysis
IIASA www.iiasa.ac.at

Conference Partners

informs Institute for Operations Research and the Management Sciences

NANYANG TECHNOLOGICAL UNIVERSITY Complexity Institute

SANTA FE INSTITUTE

We have come a long way…

- Military-style operations research
- Expansion to systems analysis
- Inclusion of policy analysis
- Interfacing with complexity science
- Massive growth of computational resources and data availability

Following Roger Levien (2000)

Ten overarching methodological dimensions

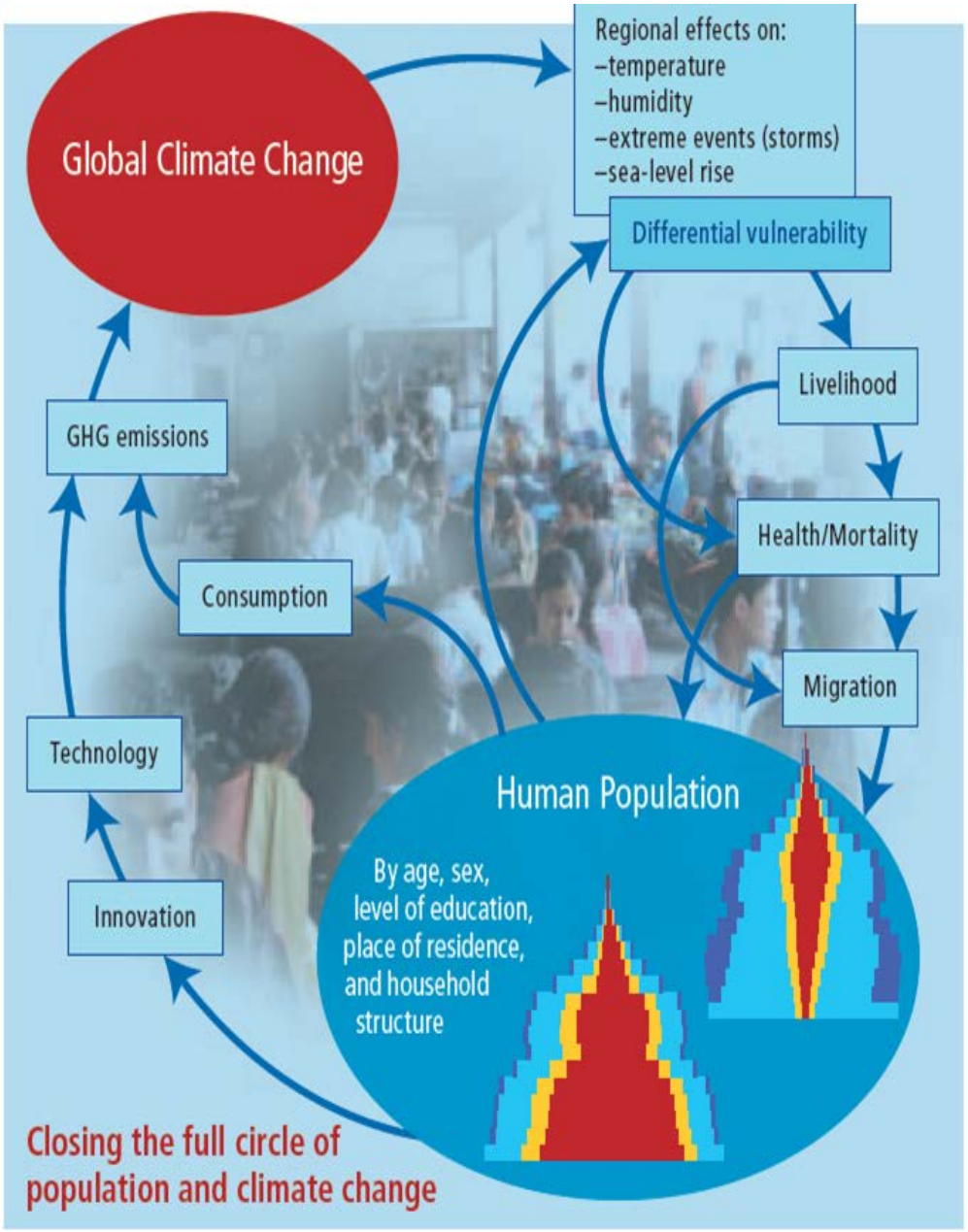
- Heterogeneity
- Optimization
- Adaptation
- Uncertainty
- Emergence
- Resilience
- Bounded rationality
- Interconnectedness and integration
- Big data
- Interfacing of science and society

Heterogeneity: major aspects

- Accounting for spatial structure
- Dealing with social diversity in incomes, education, values, religion
- Heterogeneity often requires up-scaling (aggregation) and down-scaling (disaggregation)
- Mean-based projections become inaccurate or misleading, hence variance corrections are needed

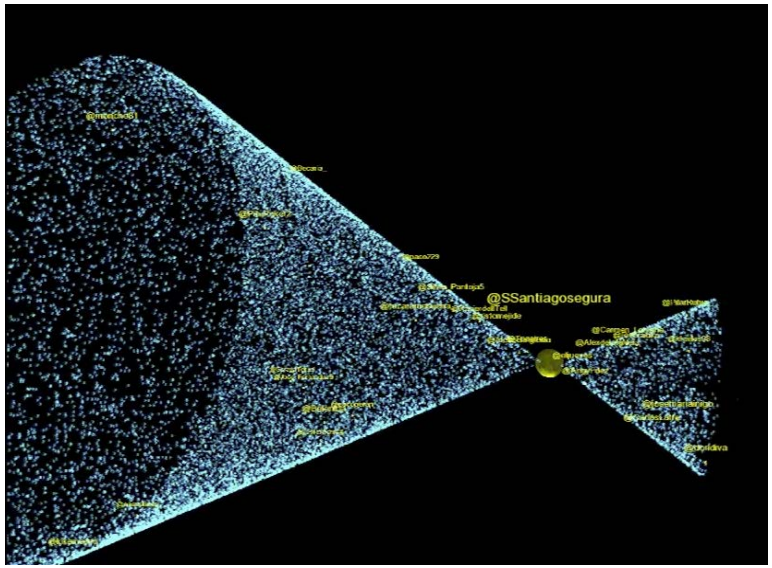
Wolfgang Lutz

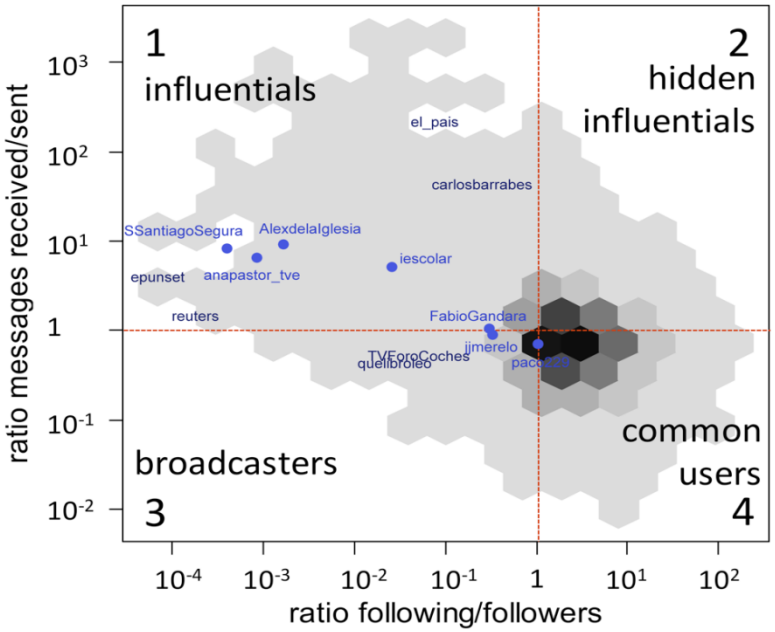
- People differ with respect to age, sex, level of education, place of residence, and household structure
- Incorporating such differences into global projections can significantly increase their accuracy and feasible time horizon



Yamir Moreno

- In the online world, the "average individual approach" does not work
- Example: Few individuals receive a lot of messages, while most are mainly senders
- This leads to a taxonomy of online users

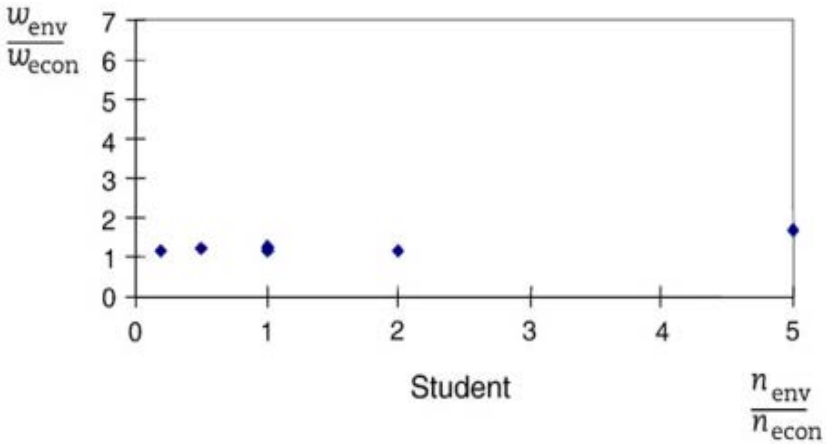




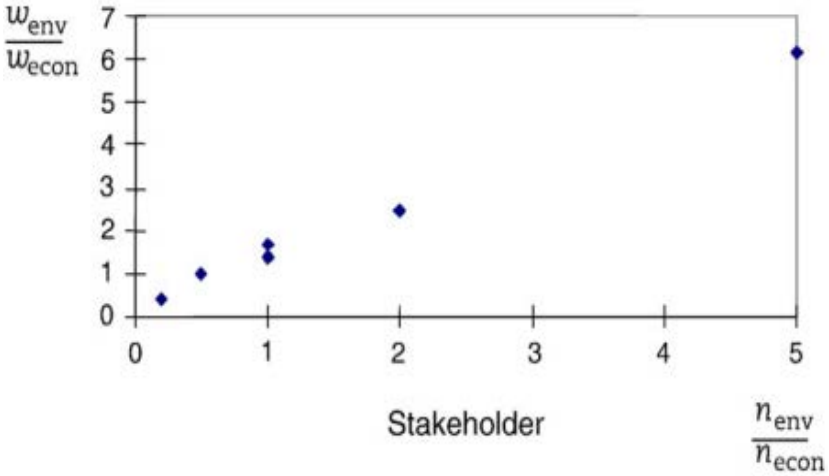
Raimo Hämäläinen

- Individuals differ in their cognitive biases
- These heterogeneities are robust, and are not easily overcome by guidance

Students with debiasing guidance: no splitting bias

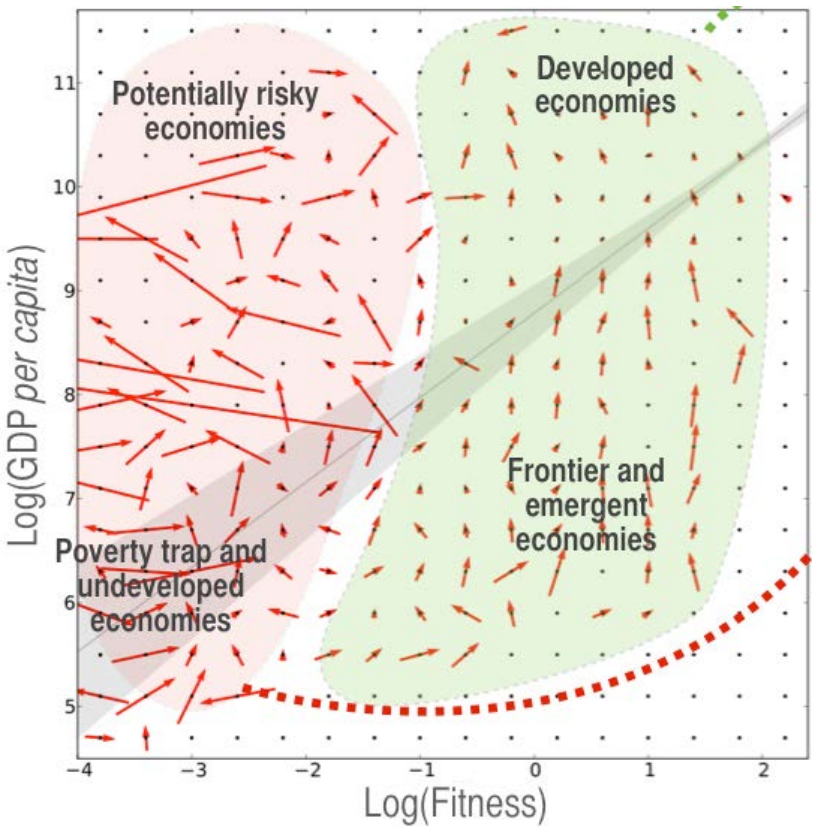


Stakeholders with debiasing guidance: systematic bias, guidance did not help



Luciano Pietronero

- The heterogeneity of countries can be captured by new metrics of economic complexity
- These reveal new patterns and thereby enable conditional forecasts



Heterogeneity: challenges and directions

On the spatial side:

- New methods for spatial down-scaling
- Model integration across GIS layers
- Multi-scale modeling

On the social side:

- Diversity matters
- New metrics for capturing salient aspects of heterogeneity
- New models for involving and predicting such metrics

Optimization: major aspects

- Descriptive, normative, and prescriptive analysis
- Choice of the objective function(s)

David Bell: Policy, Probability and Preference

- Simplified models and simplified preferences – successful in economics and finance
- Each stakeholder has different preferences
- "IIASA should be at the forefront of knowing the preferences of interest groups and be as competent at representing values as it is at representing systems"

	Rashid	Clark	Holling	Jones	Forest Industry
Rashid	1.00	.69	.40	.21	-0.52
Clark		1.00	.80	.39	-0.80
Holling			1.00	.63	-0.46
Jones				1.00	-0.34
Forest Industry					1.00

The Budworm Project

Ali Abbas: The need for a sound decision-making system in systems analysis

Uncertainty?

Generic Decision Tree for 1 Alternative

February 2nd 2014

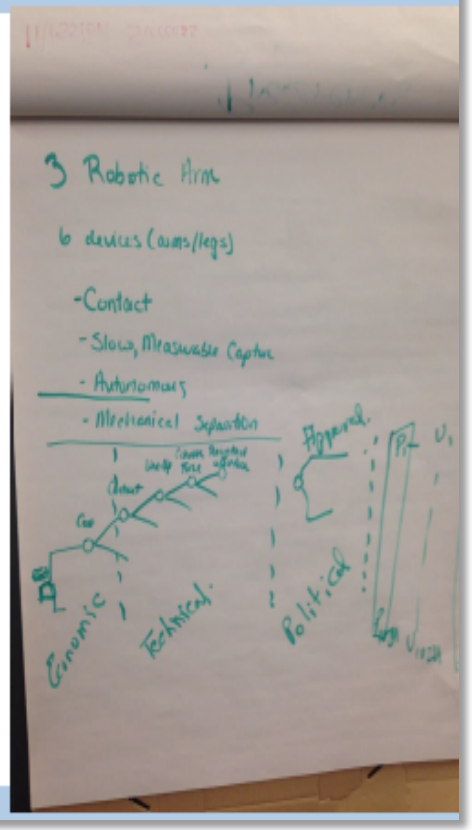
Probability of Capture

With sensitivity analysis, we showed that improving probability of capture will add significant value to the space mission.

It will help with

*Positive Public Perception/Awareness
*Advance Science (Return with rich Asteroid)
*Funding Approval (Money)
*Safety of Crew
*Allow more time for observing/ C/C
*Allow more time for deflection

Worth more than $50 million radar.



Ralph Keeney: Constructing value models for applied systems analysis

- Objective function = value model
- Approaches to construct value models
  - Preferential independence
  - Utility independence
  - Additive independence
- "The effort required to build value models is very small relative to that to build traditional systems analysis models"
- "Including policymakers in this explicit manner enhances their interest in the analysis, since it addresses their decisions and their values"
- "Such analyses provide more insight for the decisions that may be made"

Ronald Yager: Fuzzy methods for constructing multi-criteria decision functions

- How to formalize in models information expressed in natural language?
- Integrating multi-criteria decision making with fuzzy sets: criteria are represented as fuzzy sets over the set of decision alternatives
- Enables using logical operators to represent preferences
- Using different convolutions to derive an objective function

Optimization: challenges and directions

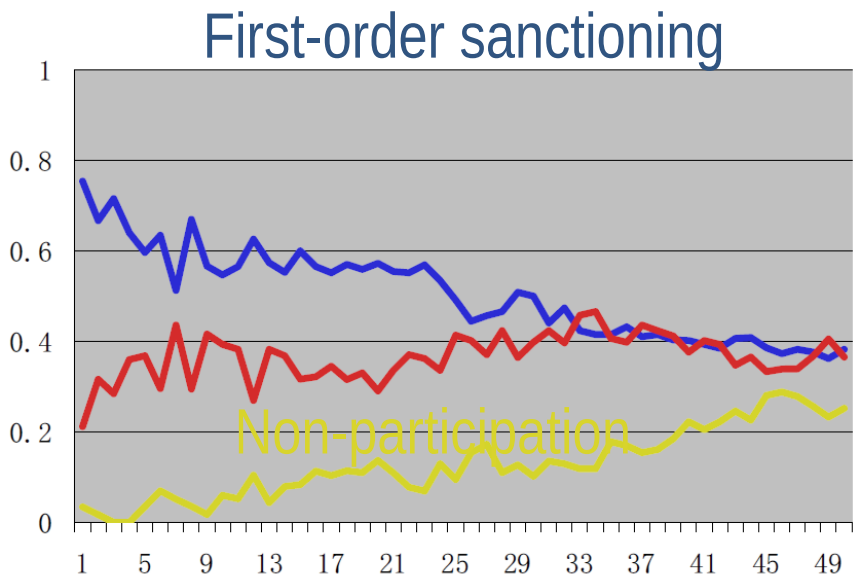
- More of prescriptive analysis – responsibility of scientists to advise on better solutions?
- Massively collect empirical data on stakeholder preferences
- Use natural language to measure stakeholder preferences
- Optimization is only possible when enough understanding has been collected on the underlying processes; if this is not the case, qualitative scenarios can complement modeling

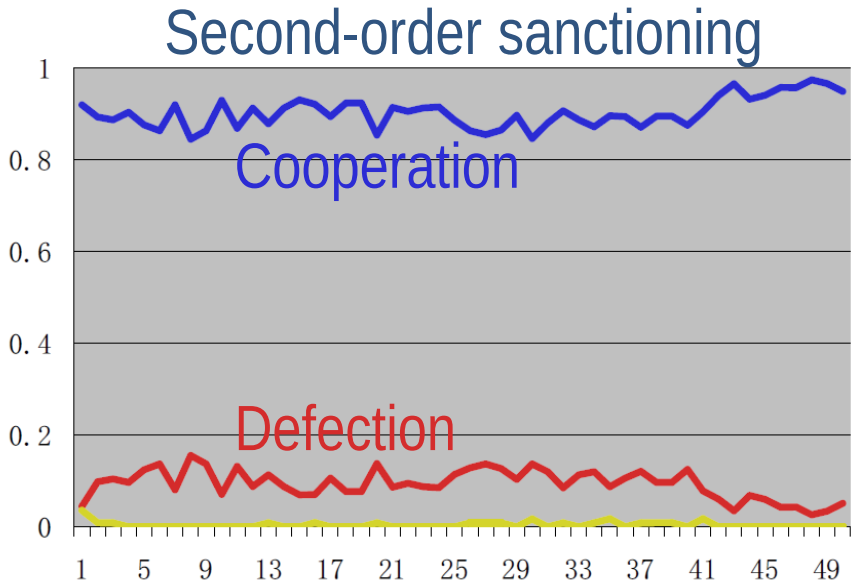
Adaptation: major aspects

- Adaptation is more complex, and often also more realistic, than optimization
- Different perspectives: social planning vs. agent interactions
- Crucial for understanding human behavior and living systems
- In complex adaptive systems, not only abundances change, but strategies and traits adapt too
- Such systems thus come to embody their history
- Adaptations can undermine a system's resilience or productivity

Karl Sigmund

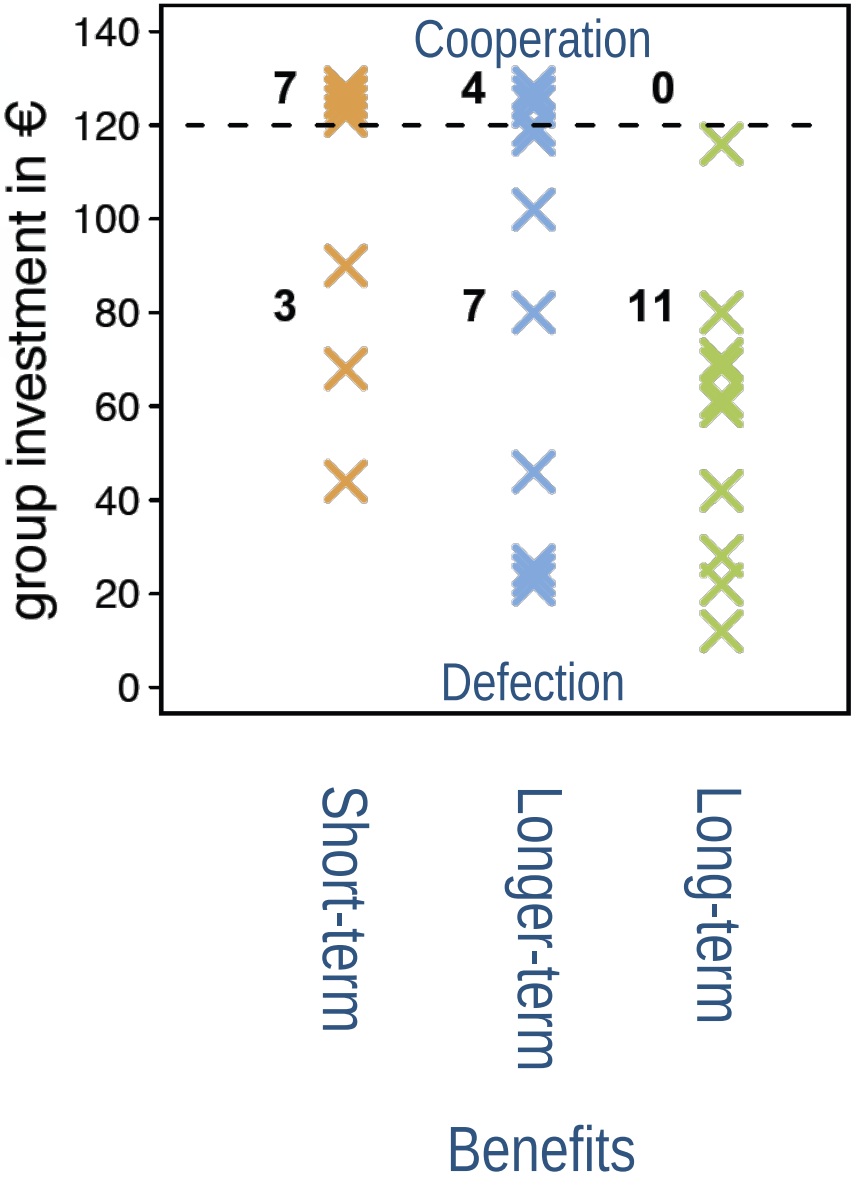
- Agents adapt strategies for cooperation and sanctioning
- When second-order free-riders are sanctioned, cooperation is stabilized
- Through such adaptation, social institutions can become established (here: pool punishment)





Christoph Hauert

- Public goods game, 6 players, 10 rounds
- Benefits are delayed by one day, seven weeks, or a generation (planting oak trees)
- The selfish adaptations of players jeopardize the public good, even more so when benefits are delayed



Adaptation: challenges and directions

On the social side:

- Emergence of social institutions for the governance of common goods
- Understanding the origins of cognitive biases

On the ecological side:

- Eco-evolutionary models of functional biodiversity
- Evolutionary impact assessments and evolutionarily informed management of living resources

Uncertainty: Major aspects

- Uncertainty and risks are not the same
- Parameter uncertainty, process uncertainty, structural uncertainty
- Sensitivity analyses
- Learning: a way to decrease uncertainty?
- Decisions under uncertainty: Need for robust decisions
- Various risk measures – may imply different solutions

Andrzej Ruszczynski: Risk quantification and control: challenges and opportunities

Probabilistic approaches:

- Utility models (inclusion of risk measures in utility function)
- Chance constraints (individual and systemic risks)
- Stochastic dominance constraints (rely on entire distribution)

Risk measures:

- Mean-semideviation
- Average value at risk
- Entropy-based metrics

Issues:

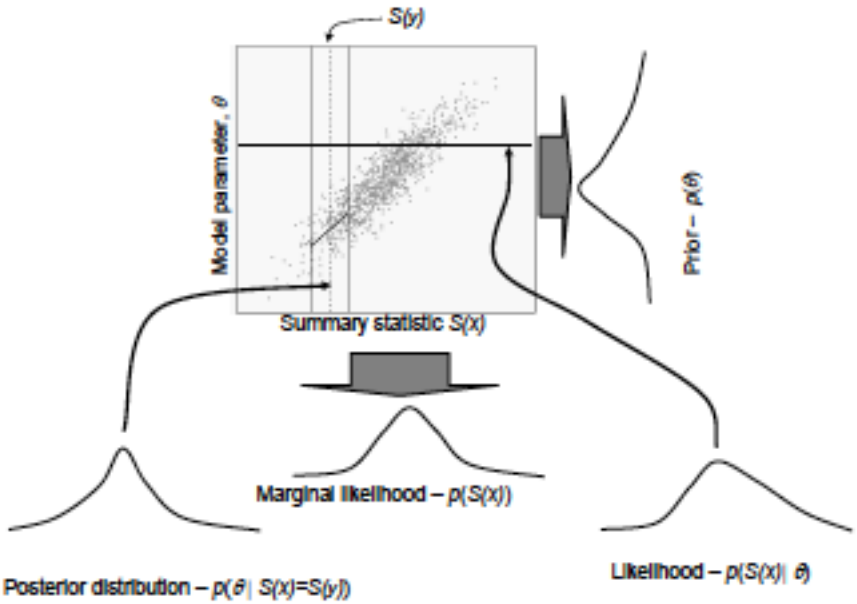
- Time consistency of dynamic risk measures
- Inclusion of big data, learning, and artifical intellingence

Werner Römisch: Energy systems under uncertainty: modeling and computations

- (Quasi-)Monte-Carlo samples from the empirically derived distribution of uncertainty to be used in optimization problem
- Optimization aims to maximize expected revenue and minimize risks
- Average value at risk as a risk measure
- In the presented example of the German gas transportation network, risk aversion costs less than 1% of expected revenue

Mark Beaumont: Approximate Bayesian computation: methods and applications for complex systems

- Enables dealing with high-dimensional data by operating with distance functions and summary-statistic functions
- Allows comparing posterior probabilities in different models



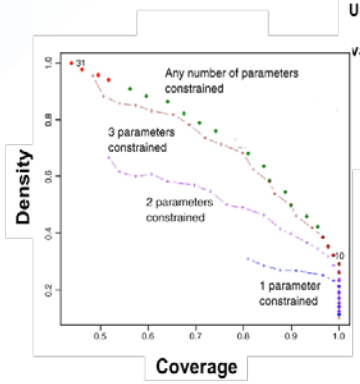
Robert Lempert: A new decision science for complex systems: a decade of enabling tools

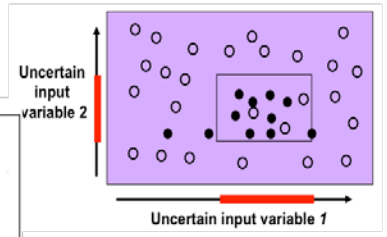
With Scenario Discovery, Policy-Relevant Scenarios Emerge From Analysis

1. Generate large, multi-dimensional database of simulation model runs

2. Use classification algorithms to find interpretable (low dimensional) clusters of policy-relevant cases

Maximize coverage, density, and interpretability



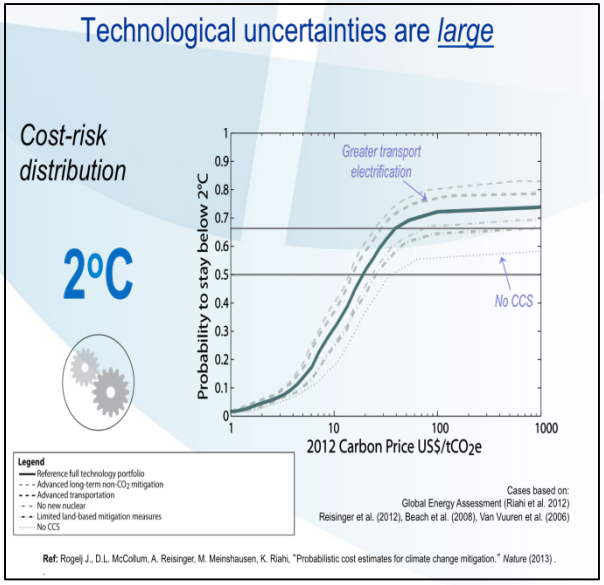


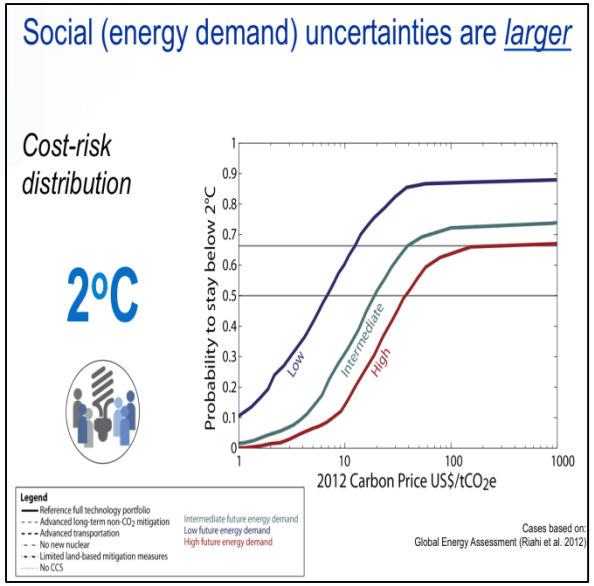
3. Resulting scenarios often provide effective decision support

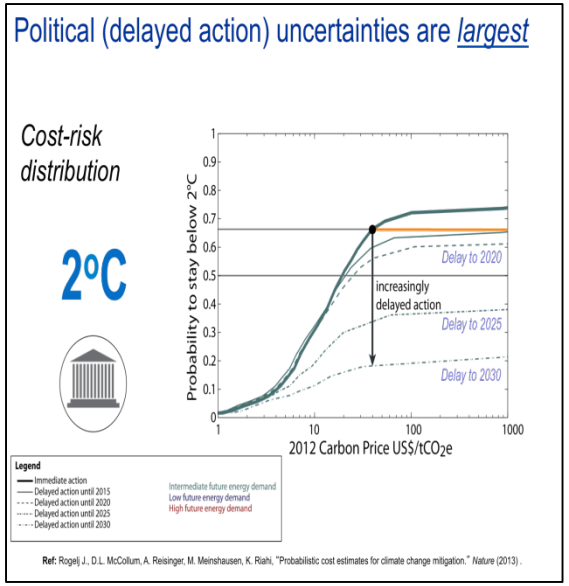
See IQ SCENE workshop (http://www.wholesem.ac.uk/iq-scene/iq-scene) and forthcoming special issue of Environmental Modeling and Software

David McCollum: Harnessing systems-analytical tools to develop sustainable energy scenarios for the 21st century

- Integrating uncertainties for climate change mitigation







Uncertainty: challenges and directions

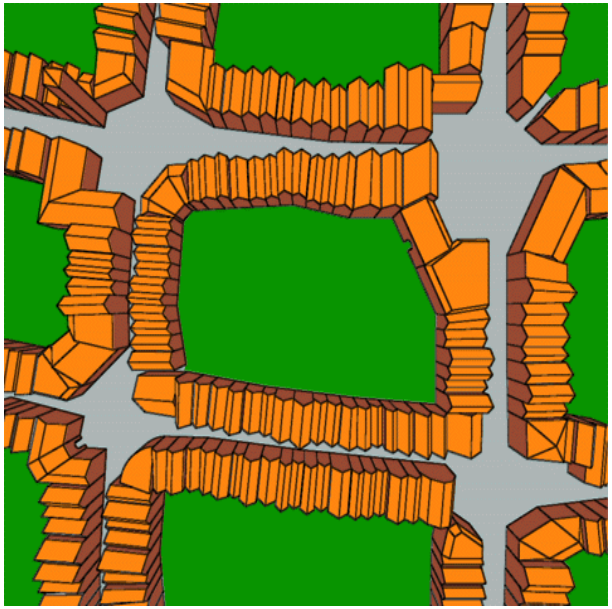
- Multi-stage stochastic optimization, robust solutions with respect to input uncertainty
- Sensitivity analysis with respect to model assumptions, in particular to risk measures
- Complexities are increasing – efficient computational approaches needed

Emergence: major aspects

- Macroscopic features emerge from microscopic processes
- Examples: crowd patterns, incipient social ordering, meme trends
- Often associated with surprises, tipping points, and regime shifts
- Fundamental for capturing complexity formation in system models
- Two main sources: self-organization and adaptation
- Transcends simple reductionism, as new levels of systems organization can emerge
- Important for understanding network dynamics, contagion, collapse, resilience, systemic risk

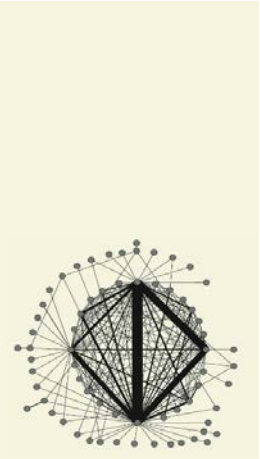
Brian Fath

- Spatial pattern formation is a typical emergent phenomenon
- Example: A center is a spatial zone of coherence that recursively depends on other centers
- Philosophical connection: autopoiesis and structural coupling



Simon Levin

- Cascading failures across networks of interacting agents
- Systemic risk as a macro-level emergent phenomenon
- Implies universality across many applied domains



Emergence: challenges and directions

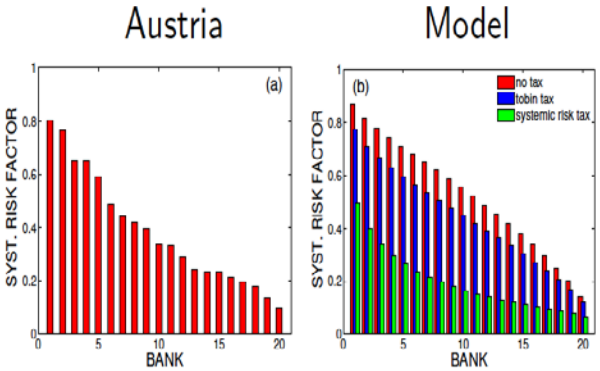
- Automatic identification of order parameters for measuring emergent properties
- Contributions to early-warning systems
- Joint integration of self-organization and adaptation into models

Resilience: major aspects

- Definition and measures
- Shock- and stress-type of disturbances
- Anticipation, mitigation, adaptation, and repairing

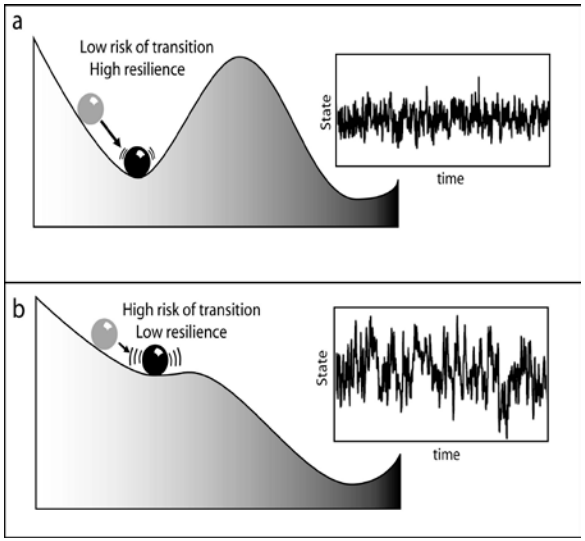
Stefan Thurner: Managing systemic risk

- Financial systemic risk: system stops functioning due to local defaults and subsequent cascading reaching out large part of the system
- Origins: synchronization of behavior and networks of contacts
- Bank have no means to manage systemic risk => regulator's role => incentivize banks to think of systemic risk
- Manage systemic risk: re-structure financial networks to minimize cascading effects => tax transactions that increase systemic risk



Marten Scheffer: Foreseeing critical transitions

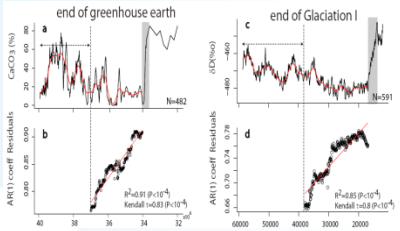
- Early-warning signals based on slowing-down effect: found in models, empirical data, and lab experiments (both temporal and spatial)



Ocean Dynamics (2003) 53: 53–63
DOI 10.1007/s10236-002-0023-6

Thomas Kleinen · Hermann Held
Gerhard Petschel-Held

The potential role of spectral properties in detecting thresholds in the Earth system: application to the thermohaline circulation



Dakos et al PNAS 2008

LETTER

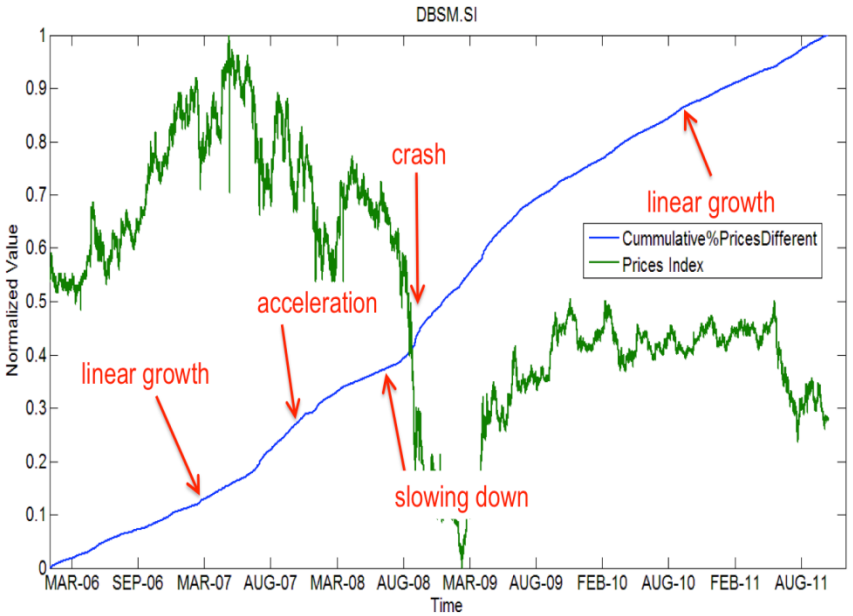
doi:10.1038/nature10723

Recovery rates reflect distance to a tipping point in a living system

Annelies J. Veraart[1], Elisabeth J. Faassen[1], Vasilis Dakos[1], Egbert H. van Nes[1], Miquel Lürling[1,2] & Marten Scheffer[1]

Siew Ann Cheong: Critical transitions in markets and societies

- Critical Transitions in Socioeconomic Systems
  - Critical slowing down + Slow recovery
- US Housing Market
  - Critical slowing down detected = Subprime Loans Transition
- Singapore Housing Market
  - Critical slowing down detected = housing bubble
  - Slow recovery detected
- SOG Forecasting
  - Sep 1999 Chi-Chi earthquake, Taiwan
  - October 2008 SGX market crash

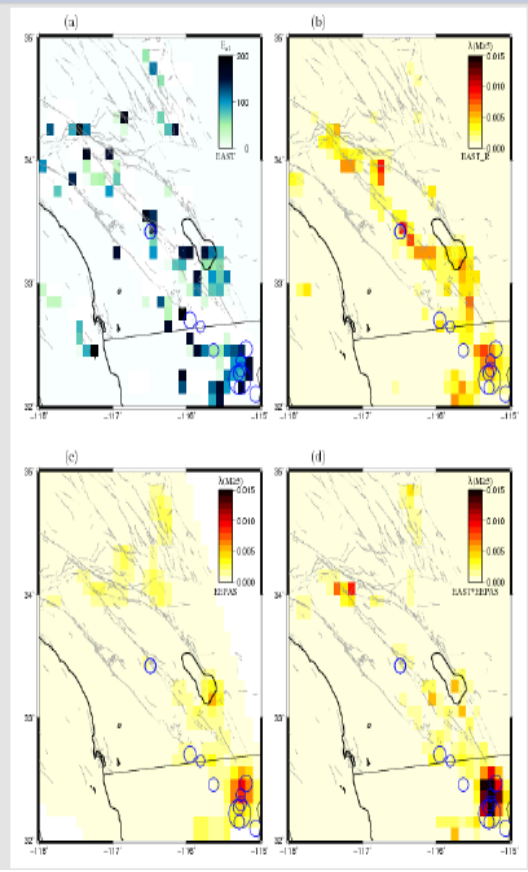


Petr Shebalin: Linking probabilistic and deterministic forecast methods: systems analysis for predicting earthquakes

10 costliest:	Total losses, in US $ m	Insured losses, In US $ m	%
Earthquakes (tsunamis)	565 000	86 000	15
Storms (hurricanes, tornadoes)	366 000	188 000	51
Floods	115 000	37 000	32

Source: Munich Re, NatCatSERVICE, 2015

- Alarm-based (deterministic) vs. rate-based (stochastic) methods
- Problem of small probabilities – how to interpret?
- Combining methods increases predictive power (differential probability-gain approach)



Shebalin, P., Narteau, C., Holschneider, M., Zechar J. Combining earthquake forecast models using differential probability gains. ***Earth, Planets and Space,*** 2014, 66:37, 1-14.

Resilience: challenges and directions

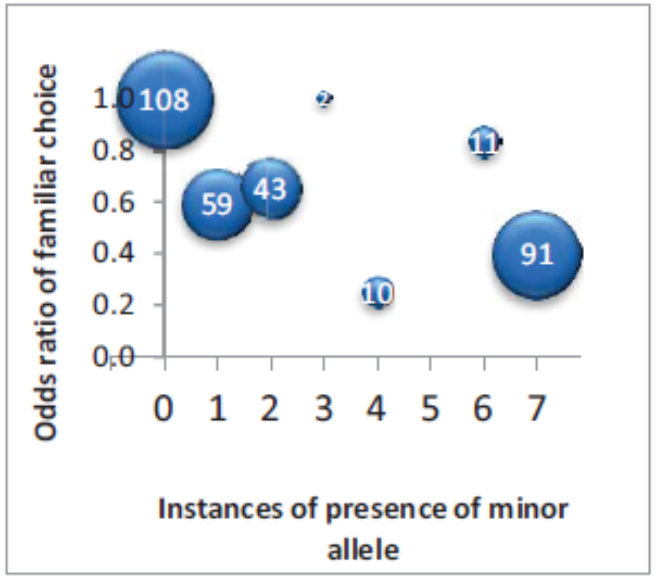
- Early-warning signals: theory-based vs. learning from the historical data
- Forecasting and predicting: combining models
- New type of risk due to increasing interconnectedness – systemic risk – measuring, modeling, managing

Bounded rationality: major aspects

- Growing skepticism toward rational-actor assumptions
- Ubiquitous cognitive biases and limitations
- Importance of heuristic thinking

Soo Hong Chew

- People tend to choose investments they consider familiar
- This familiarity bias appears to have a genetic basis
- Minor alleles seem to be associated with a lessened bias



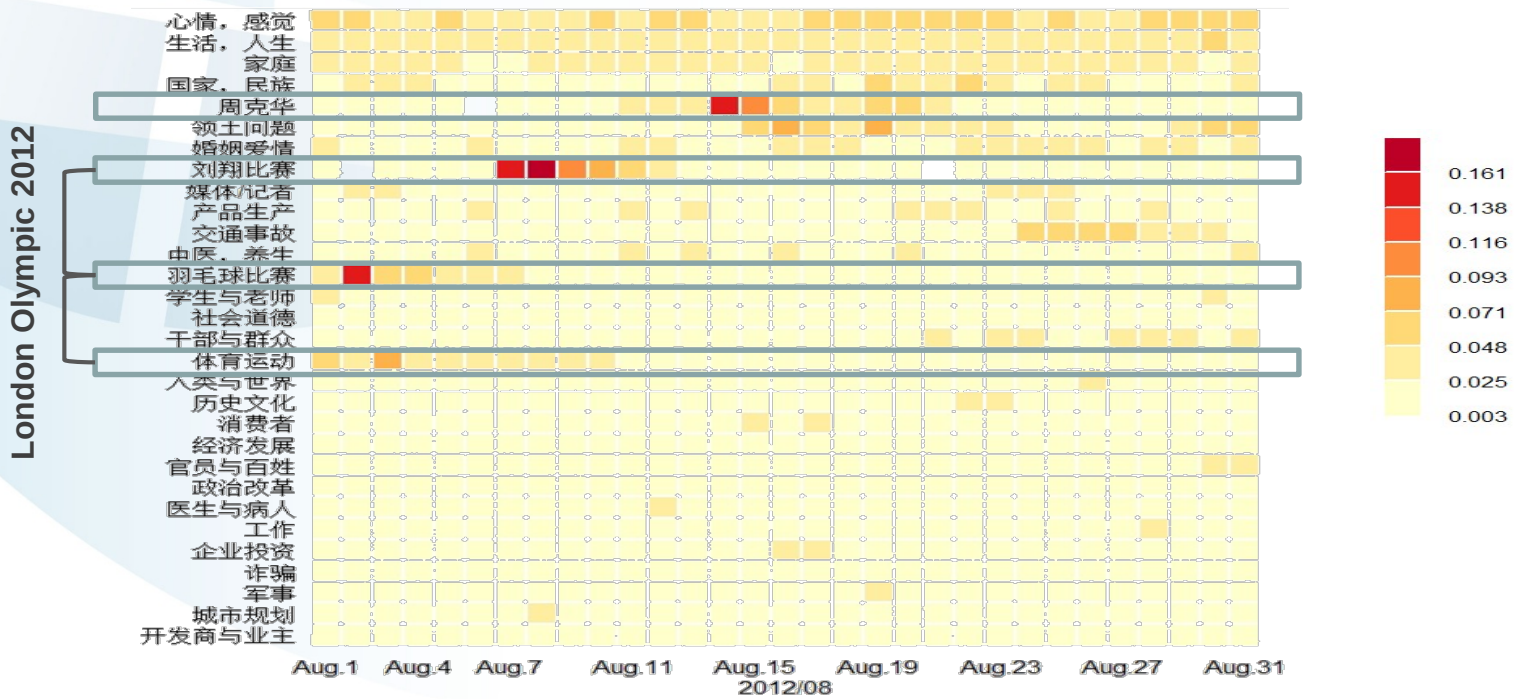
Robin Keller

- Bounded rationality can arise from myopic decision making
- This can be revealed by eliciting objectives hierarchies
- Example: Tuna fishing fleet of San Diego facing new customer preferences

Objectives Hierarchy	Decision Alternatives		
	Keep Status Quo	Reduce Dolphin Mortality	Go Dolphin Safe
MAINTAIN VIABLE BUSINESS	+	+	-
F1. Maintain Profitability			
F1.1. Maintain Lucrative Fishing Grounds	+	+	-
F1.2. Maintain Lucrative Fishing Methods	+	?	-
F1.3. Avoid Foreign Competition	+	?	-
F2. Maintain Livelihood			
F2.1. Maintain Fishing Grounds in East. Tropical Pacific	+	+	-
F2.2. Protect Large Investments in Boats	+	+	-
F2.3. Prevent Fishing Grounds from Depletion	?	+	-
F3. Maintain Quality of Life in Local Community			
F3.1. Protect Family-Owned Small Businesses & Heritage	+	+	-
F3.2. Maintain Positive Image in Community	?	+	+
F4. Protect Positive Image as Good Global Citizen			
F4.1. Legitimate Fishing Methods involving Dolphins	?	0	-
F4.2. Publicize Successes in Reducing Dolphin Mortality	0	+	+

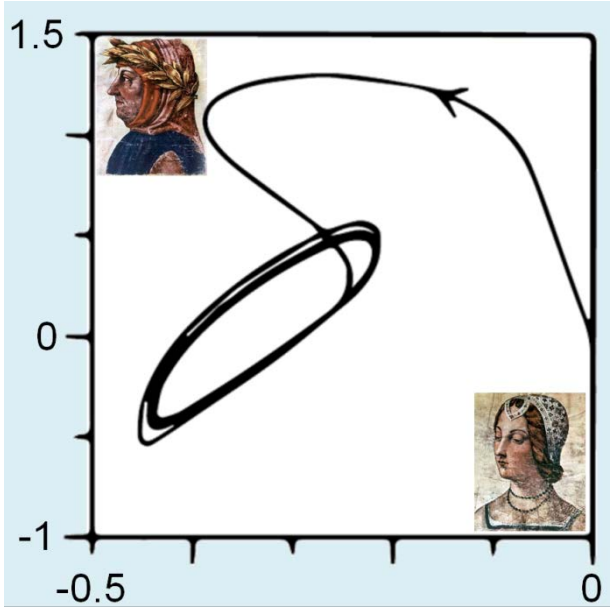
Xijin Tang

- At the collective level, bounded rationality may be involved in spontaneous social dynamics and collective actions
- Combined with machine learning, monitoring word frequencies in online communication can facilitate anticipation



Sergio Rinaldi

- Love dynamics seem to follow from irrational behavioral processes
- Yet, such dynamics are amenable to systematic analyses and rough predictions based on simple models
- Accounting for the heterogeneity of personality types is key



Bounded rationality: challenges and directions

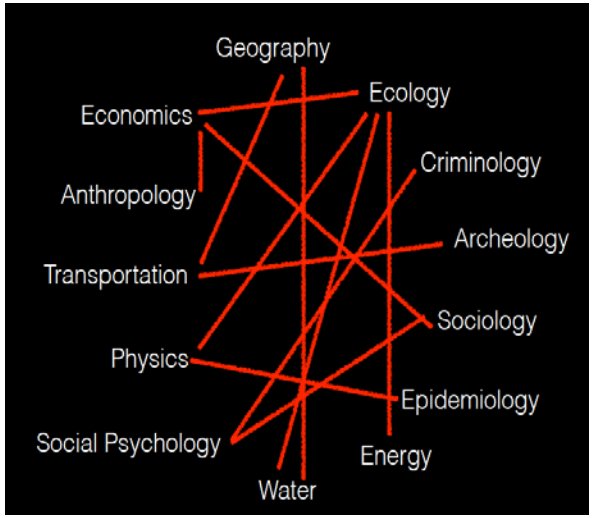
- Emerging taxonomy of cognitive biases and limitations
- Need for more realistic descriptions of human behavior
- Need for integrating these into scenarios and forecasts

Interconnectedness and integration: major aspects

- Interface between conceptual and mathematical models
- Interconnectedness of regions and sectors: linking regional and sectorial models
- Inclusion of people and institutions into models
- Compare and integrate alternative models

Luís Bettencourt: Cities as systems

- Cities are important examples of interconnected systems
- Cities are networked systems (people, infrastructure, etc.)
- Linking different sectors is needed
- Integration of people and economy



Social Interaction Types

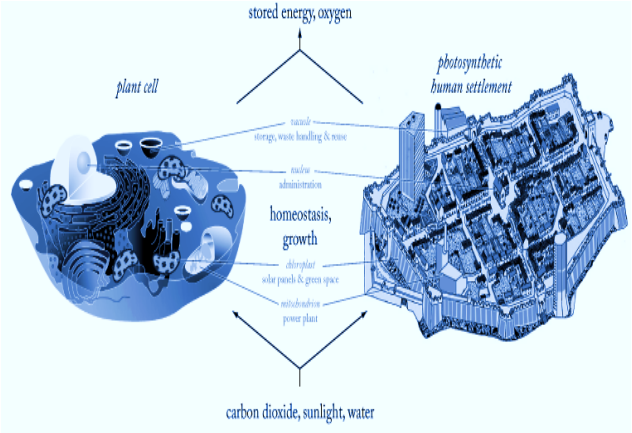
$$Y = \sum_{i,j;k} g_k F_{ij}^k,$$

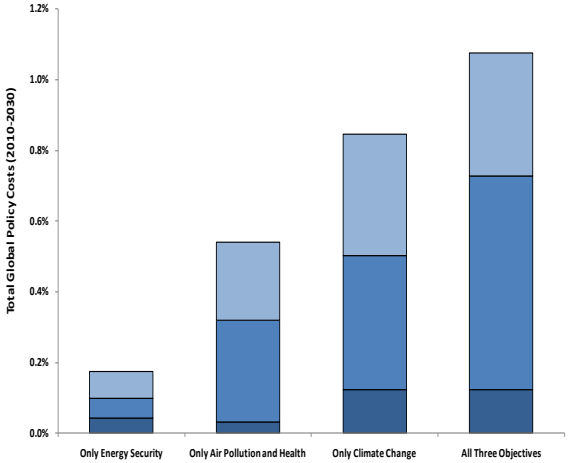
Social Network

City "Production Function"

Nebojsa Nakicenovic: Recent applications of systems analysis for achieving sustainable futures for all in a safe planet

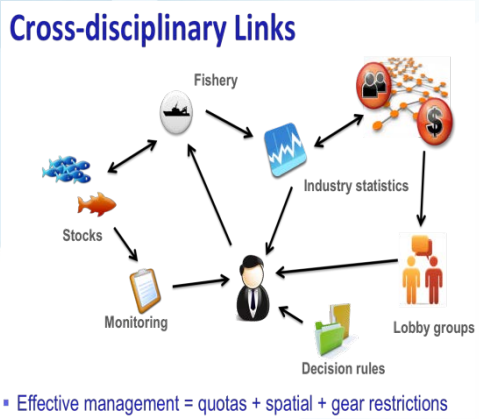
- 17 Sustainability Development Goals (SDGs): poverty, hunger, health, education, water, energy, economic growth, infrastructures and innovation, inequality, cities, climate change, consumption and production, ecosystems, justice, sustainable development
- Urban metabolism
- Synergies and tradeoffs
- Integrated policies as steps towards sustainability

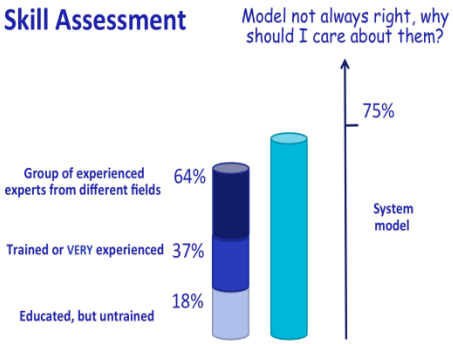


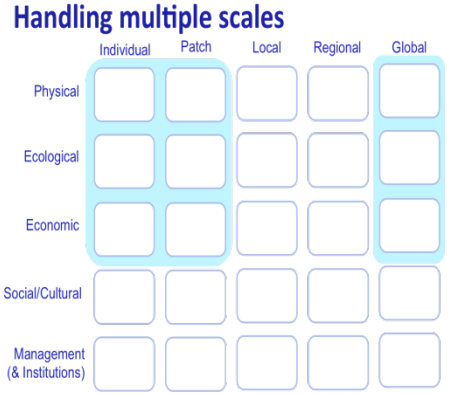


Beth Fulton: Linking scales and “I am not a modeler” – the biggest challenges in socio-ecological modeling

- Handling multiple scales – modeling is weakest at intermediate scales and for social aspects
- Trust own mental models; multiple (inconsistent) models are applied simultaneously => need to understand trust, psychology, attitudes



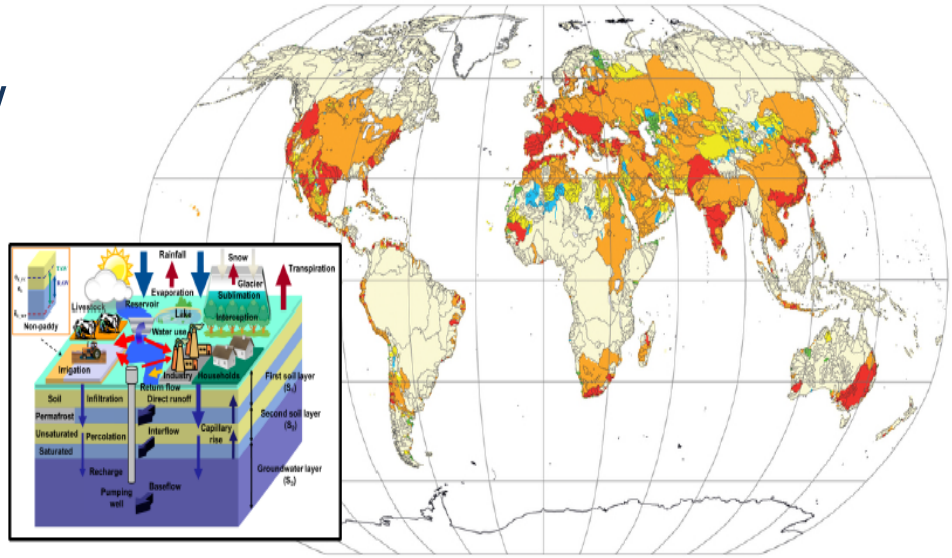




Boschetti et al (2011), Fulton et al (2007)

Yoshihide Wada: Reducing water scarcity possible by 2050: linking global assessment to policy dimensions

- Water is a truly interdisciplinary area – the scarcity problem requires linking across regions and sectors, and also include people's attitudes



The number of strategies that could be applied to each basin

No water stress 1 2 3 4 5 6

Different basins lend themselves to different measures for reducing water stress:

Agricultural water productivity, Irrigation efficiency, Improvements in domestic and industrial water-use intensity, Limiting the rate of population growth, Increasing water storage in reservoirs, Desalination of seawater

Wada et al. (2014), Nature Geoscience, doi:10.1038/ngeo2241

Interconnectedness and integration: challenges and directions

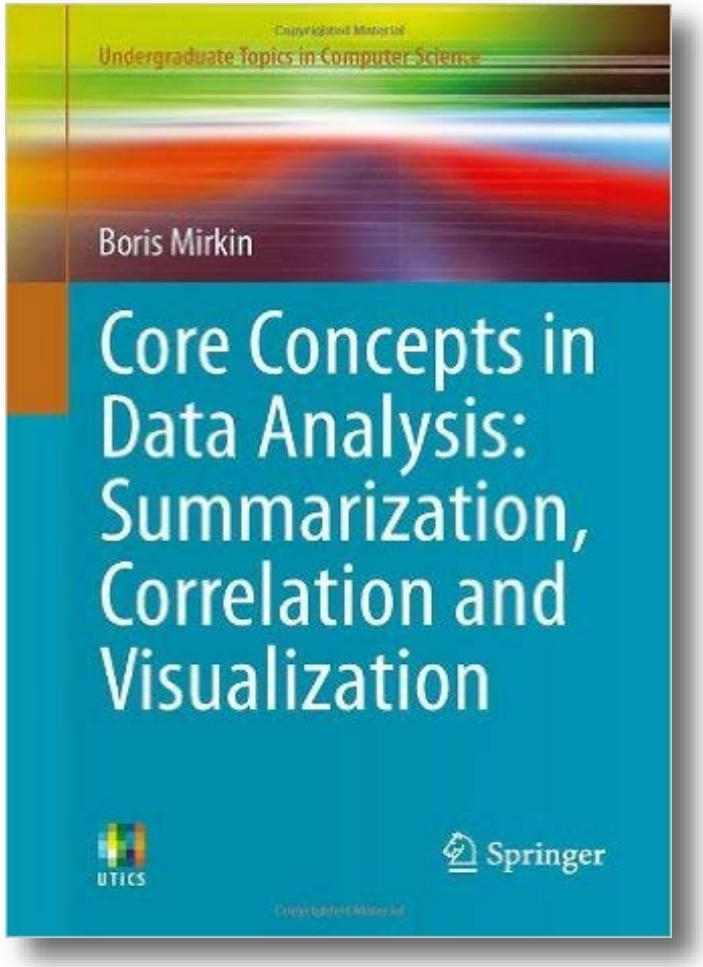
- Multi-layer networks (multiplexes)
- Nexus models
- Multi-model ensembles
- Working across scales
- Participatory involvement of stakeholders

Big data: major aspects

- Explosion of data availability: sensors, accessibility, crowd-sourcing
- Exciting promise to enable better model calibration and data-based decision making

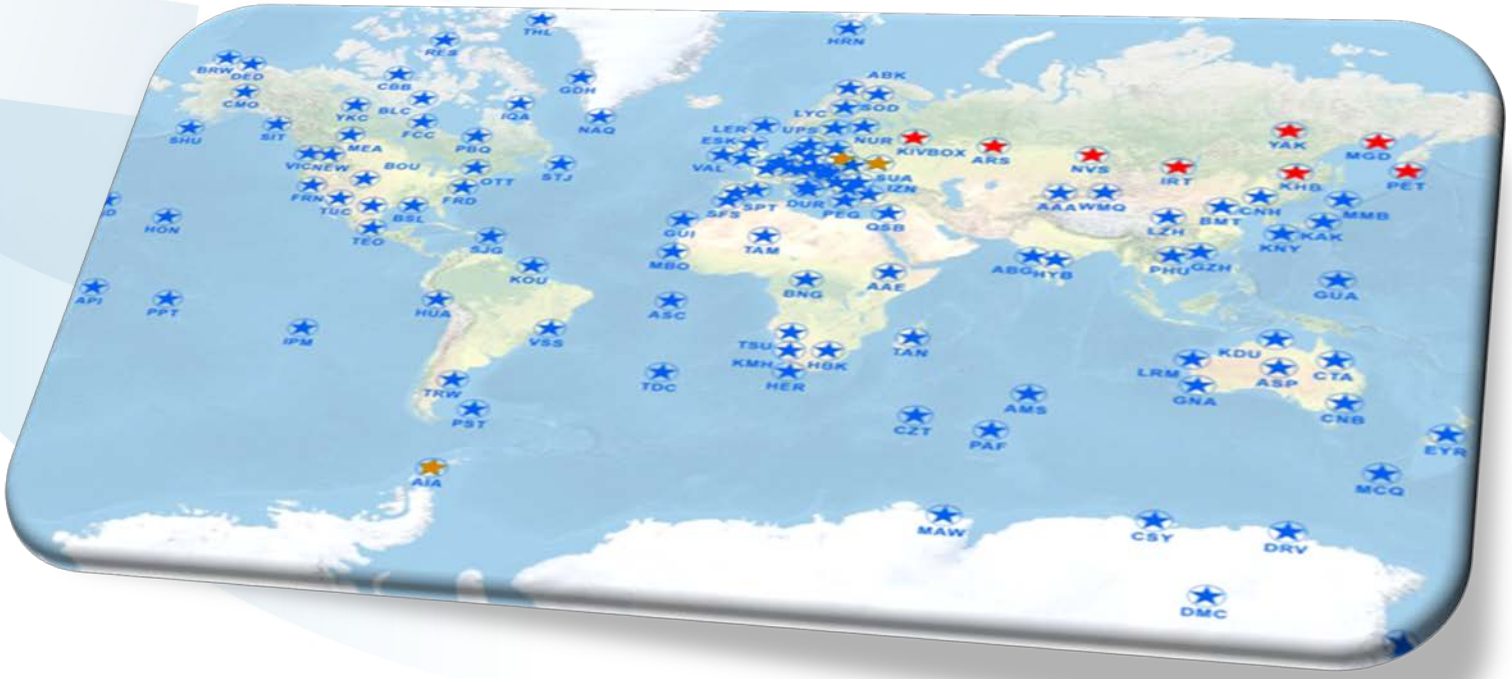
Boris Mirkin

- Processing big data requires advances in classical methods
- This applies to clustering, ranking, aggregation, tree construction, and visualization



Alexey Gvishiani

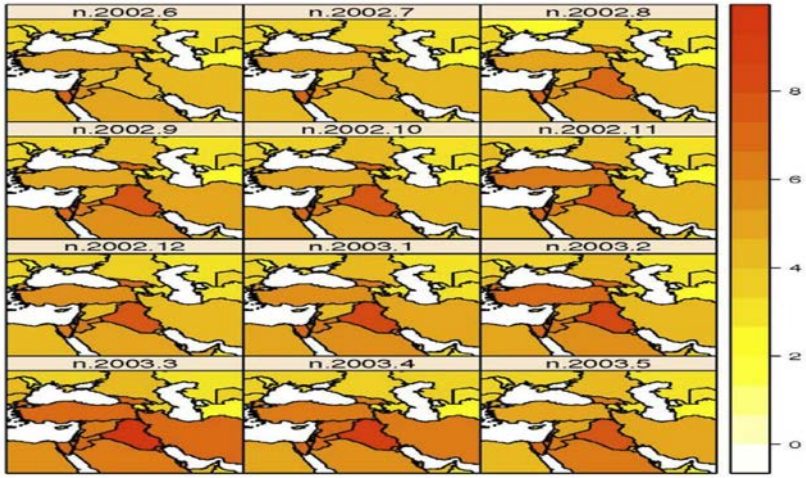
- Sensor networks can provide unprecedented volumes of location-specific real-time data
- Example: 108 observatories of the global “Intermagnet” network monitoring the Earth’s magnetic field



Dirk Helbing

- A new swath of available global data enable novel models and predictions
- Such predictions can be given better resolutions in space and time than was previously feasible

Prediction of conflict probabilities



Prediction of epidemic spreading

Mauro Martino

- Our visual system is well suited for processing data of high complexity and bandwidth, if suitably presented
- Such scientific visualizations can play a key role in enticing interest and promoting understanding among wider audiences

Big data: challenges and directions

- Democratizes access to scientific information
- Stimulates fundamentally innovative investigations and algorithms
- Promises improved understanding and forecasts
- Enables comprehensive and compelling visualizations
- On the downside, big data may
  - be only weakly structured and have low quality or representativeness,
  - need to be filtered using massive computational resources,
  - raise fundamental privacy concerns, and
  - create a deluge of false positives

Interfacing of science and society: major aspects

- Partnership between science, society, and policy
- How to involve stakeholders in research: motivation, understanding, equity
- Understanding and revealing real objectives
- Acceptance of scientific results by policy and society
- Acceptance of real stakeholder objectives by scientists

Robbert Dijkgraaf: Building bridges between science and policy

Science-Policy Interface

- Best practices in building science-policy bridges
- Organize the international field
- Plan relevant, timely, adaptive assessments
- Use right metrics
- Implement quality control
- Effective role of policy makers
- Adaptive communication

Jill Jäger: Methodological advances for transformative research

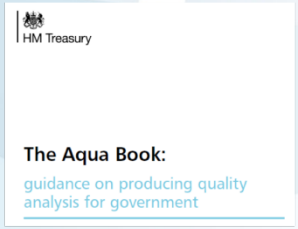
Narratives of hope

- Many results will be qualitative rather than quantitative
- Multiple narratives at multiple but linked scales – how to move towards a long-term vision of system-wide sustainability, building capacities
- Central to all of this are learning and empowerment

Markus Amann & Martin Williams: Science-policy interface in regard to air-quality and climate negotiations in Europe

Uncertainty

- Uncertainty analysis is key to policy advice
- But not often carried out
- UK Government is pushing hard for this to be done for all domestic policy analysis



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- 'Standard' Monte Carlo analysis of sensitivity/uncertainty is helpful
- But recent techniques using emulators can provide more insight into model performance

Four essential ingredients for a successful science-policy interface

- Credibility:
  - Robust science, appropriate methods, peer review
- Salience:
  - Illustrating consequences of alternative policy decisions, for diverse groups, sectors, countries
- Transparency:
  - 'Black box' models are not helpful
  - Limits to complexity
- Legitimacy:
  - Participatory process, not one-time publication
  - Institutions (IIASA serves as an impartial broker)

Paul Chatterton & Linda See: Mobilizing mass action through mobile devices: challenges and opportunities for science, policy, and governance

Applied to various global problems including

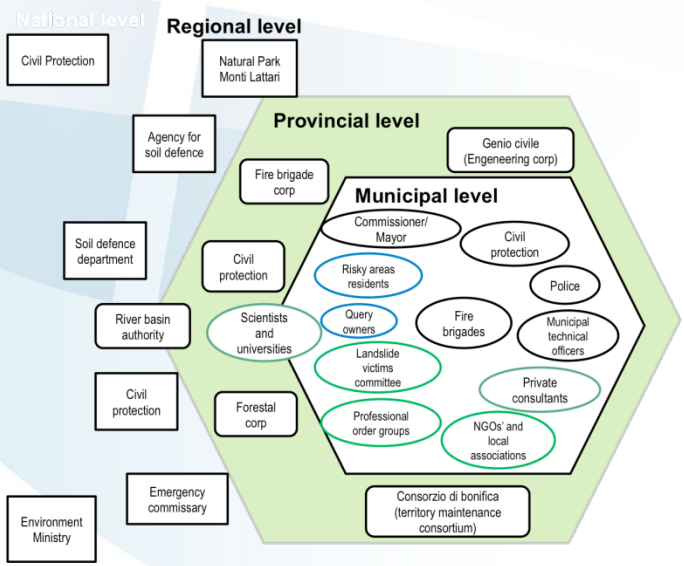
- Air pollution
- Natural disasters
- Food insecurity and malnutrition
- Deforestation
- The need for improved land cover and other new global datasets
- Locating the world's croplands

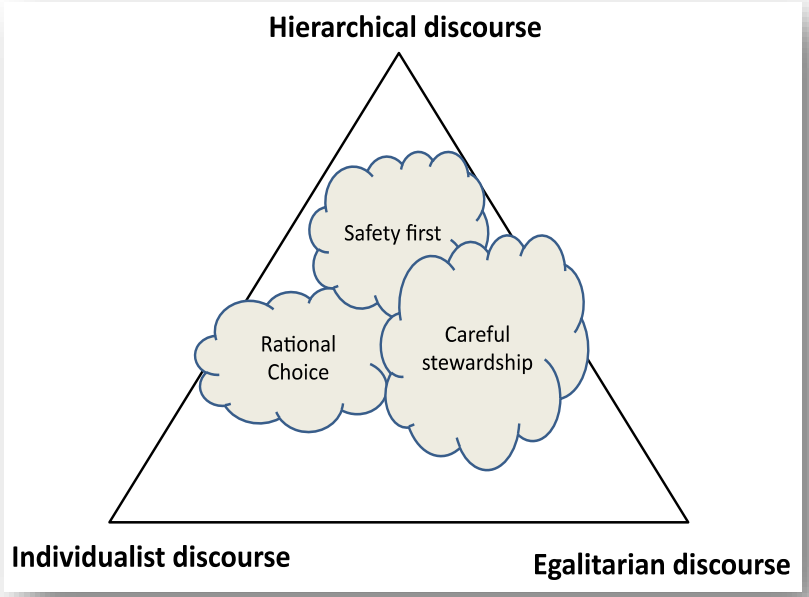
Some Lessons from Mobile Citizen Science

- Think carefully about how best to **engage citizens** – media, feedback and dialogue, gamification, incentives (sometimes)
- **Design for scaling** – pilots, stress testing
- Focus on the **big problems and the big solutions**
- **Build with business** people from the start – they know about scale!
- Build **platforms** as well as products

Anna Scolobig: From stakeholder views to policy options

- Reducing complexity: From 25 stakeholder groups to three stakeholder types by means of cultural theory





Interfacing of science and society : challenges and directions

- Involvement of stakeholders in the entire cycle of analysis, if possible
- Modeling *of* decision-makers vs. modeling *with* decision-makers
- New generation of decision-makers: education in systems analysis?
- Ethical dimension
- Trust is important – need to involve psychologists?
- Web-based tool to collect various kinds of data

A new generation of systems analysis

- Demands for systems thinking and systems analysis are on the rise
- Capabilities of systems analysis are rapidly growing, in terms of data, models, methods, and computation
- Humility and caution remain essential: overselling must be avoided, as challenges remain formidable
- Systems analysis has developed a colorful diversity of approaches
- The mobility of methods travelling to new applications along the conceptual network of systems analysis is vital for the field's cohesion and vibrancy