



**33<sup>rd</sup>** Annual **INCOSE**  
international symposium

hybrid event

Honolulu, HI, USA  
July 15 - 20, 2023



# Multi-Disciplinary Approaches to Addressing the Wicked Problems of Cyber-Physical Social Systems

- o **Prof. Javier Calvo-Amodio**, Oregon State, Systems Science
- o **Prof. Hortense Gerardo**, UCSD, Anthropology & Performance
- o **Prof. Erika Palmer**, Cornell University, Social Systems
- o **Prof. Michael Bruno**, U. of Hawai'i at Mānoa, Oceanography/Earth Science
- o **Prof. Olivier De Weck**, MIT, Engineering Systems
- o **Prof. Jon Wade**, UCSD, Moderator



Human needs have hardly changed over the centuries. Societal needs are similar throughout the world, and systems need to respond to such needs.



The Major  
Challenges of the  
21st Century

Stephen Hawking's  
advice "Embrace  
Complexity"

INCOSE, "INCOSE Systems Engineering Vision 2025.", 2014.

“The machine does not isolate man from the great problems of nature but plunges him more deeply into them.”

- Antoine de Saint-Exupéry



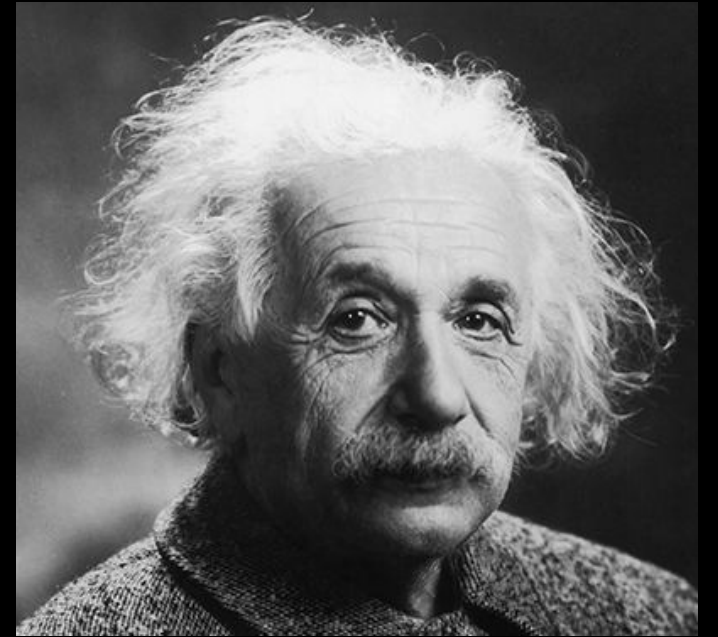
A wicked problem is a social or cultural problem that's difficult or impossible to solve because of its complex and interconnected nature. Wicked problems lack clarity in both their aims and solutions, and are subject to real-world constraints which hinder risk-free attempts to find a solution.



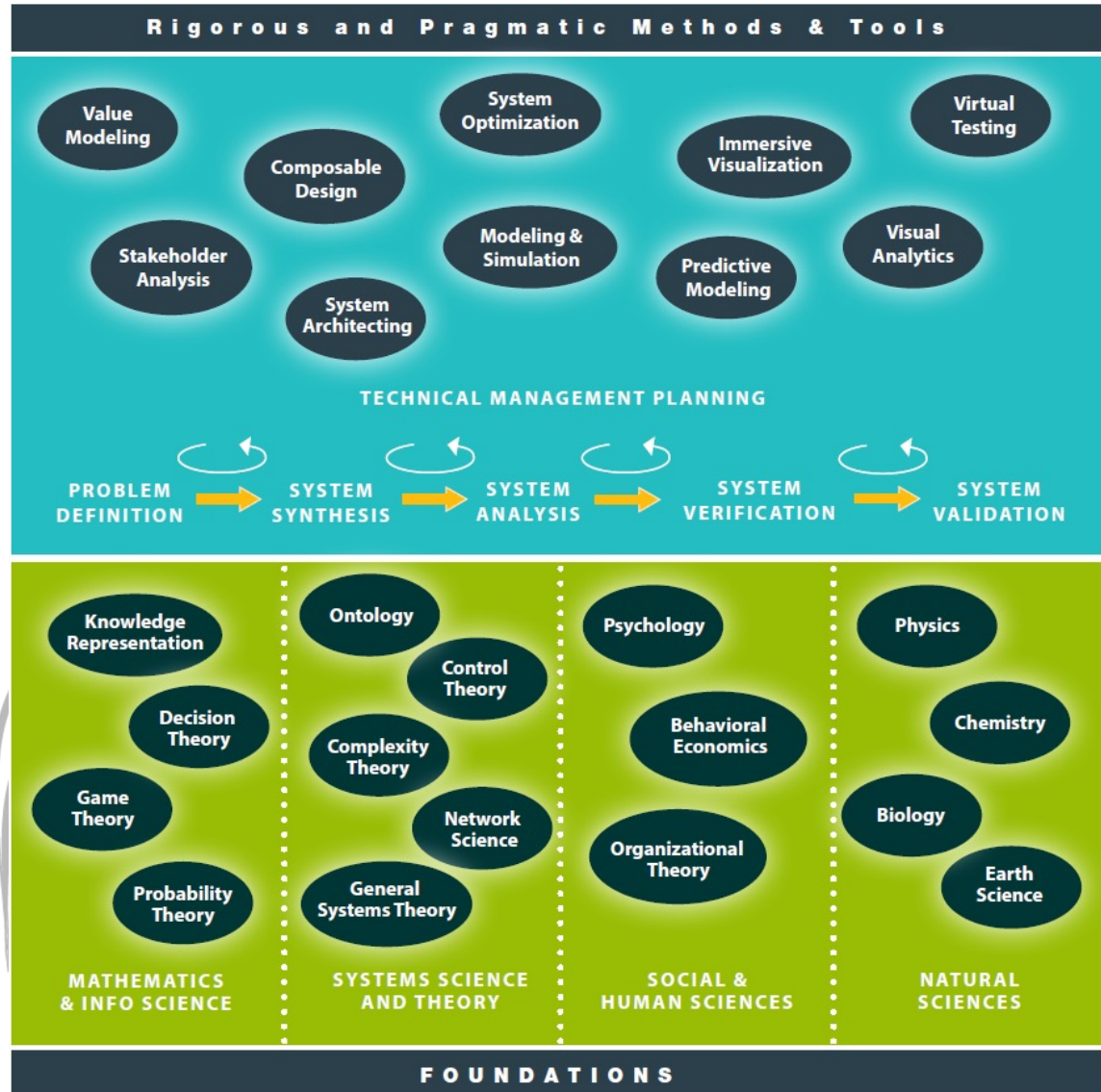


“You can never solve a problem with the same kind of thinking that created the problem in the first place.”

- Albert Einstein



# Global Warming: How can it be addressed?



- Systems Science: **Prof. Javier Calvo-Amodio**, Oregon State
- Anthropology & Performance: **Prof. Hortense Gerardo**, UCSD
- Social Systems: **Prof. Erika Palmer**, Cornell University
- Oceanography/Earth Science: **Prof. Michael Bruno**, U. of Hawai'i at Mānoa
- Engineering Systems: **Prof. Olivier De Weck**, MIT



# Global Warming: How can it be addressed?



## Systems Science

**Javier Calvo-Amodio** is an Associate Professor of Industrial Engineering at Oregon State University. He serves as the chair of the Systems Science Working Group at INCOSE and is a member of the Bridge Team. He is also a Fellow of the American Society for Engineering Management and serves as Deputy Editor of Systems Research and Behavioral Science Journal.



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How does systems science approach the problem of the  
human impact of global warming?

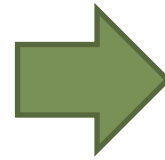
and

How to be part of the solution?

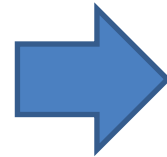
Systems science provides all and no answers at once!



**Complexity Science** deals with phenomena that are difficult to describe but eventually easy to explain. Highly scientific and widely used, but can be considered as largely dependent in systemic reductionistic arguments.



**Systems Research** deals with phenomena that are easy to describe but increasingly difficult to explain. Largely dependent in systemic holistic arguments but not widely used and mostly grounded in heuristics.





# Systems science provides all and no answers at once!

## Complexity Science

- ✓ Difficult to describe but easy to explain
- ✓ Dependent in systemic reductionistic arguments

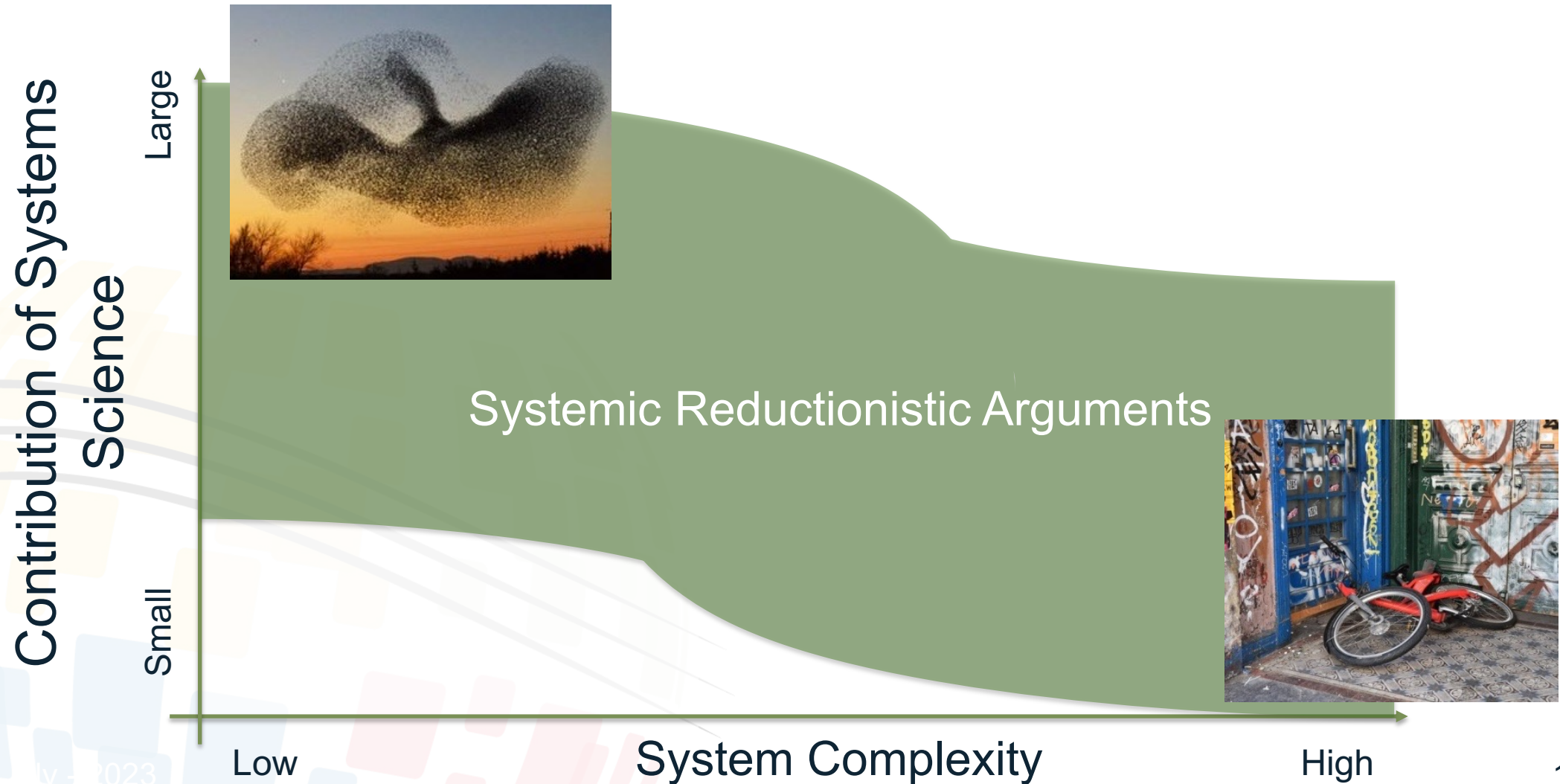


## Systems Research

- ✓ Easy to describe but increasingly difficult to explain
- ✓ Dependent on systemic holistic arguments but not widely used and mostly grounded in heuristics



# Systems science provides all and no answers at once!





# Systems science provides all and no answers at once!

Contribution of Systems Science

Large

Small

Systemic Holistic Arguments



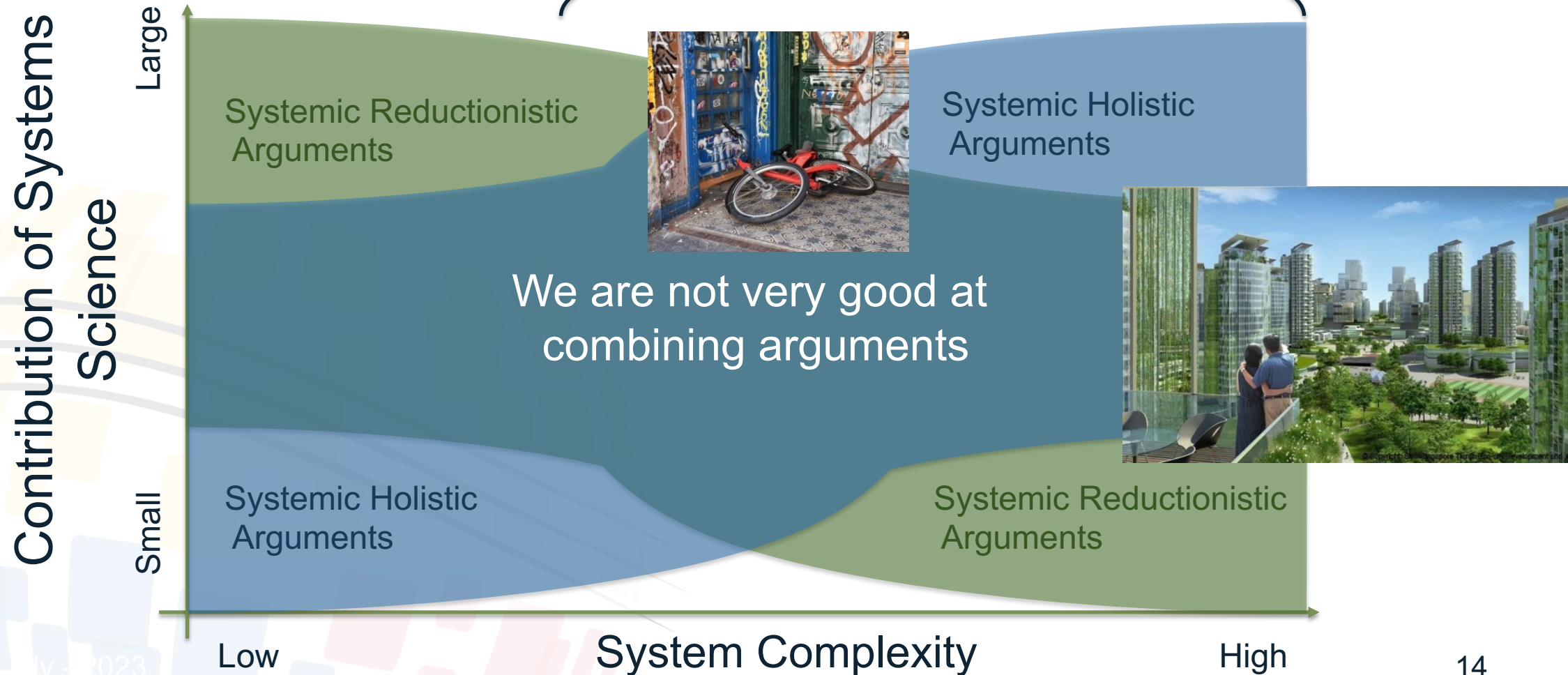
Low

System Complexity

High

# Systems science provides all and no answers at once!

Transdisciplinarity Must be Present





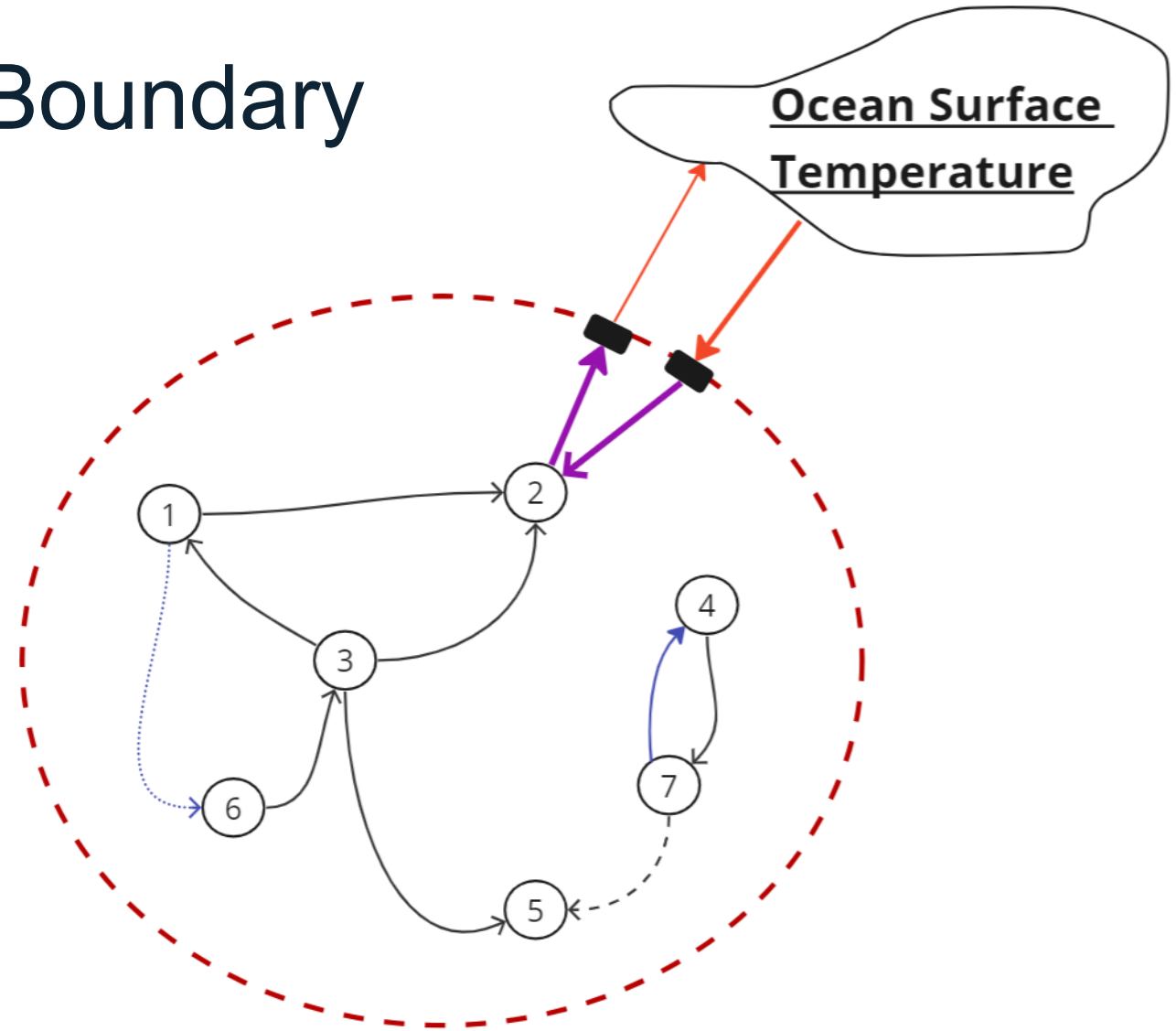
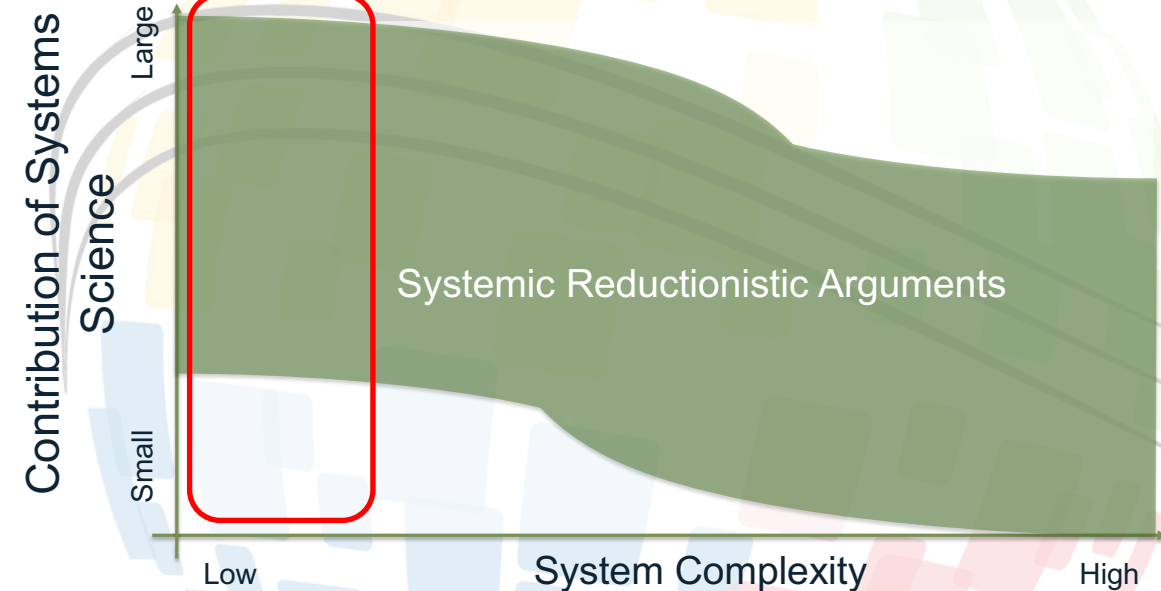
Systems science provides all and no answers at once!

Utilizing a systems approach assists us in developing self-awareness



# Systemic Reductionist Argument

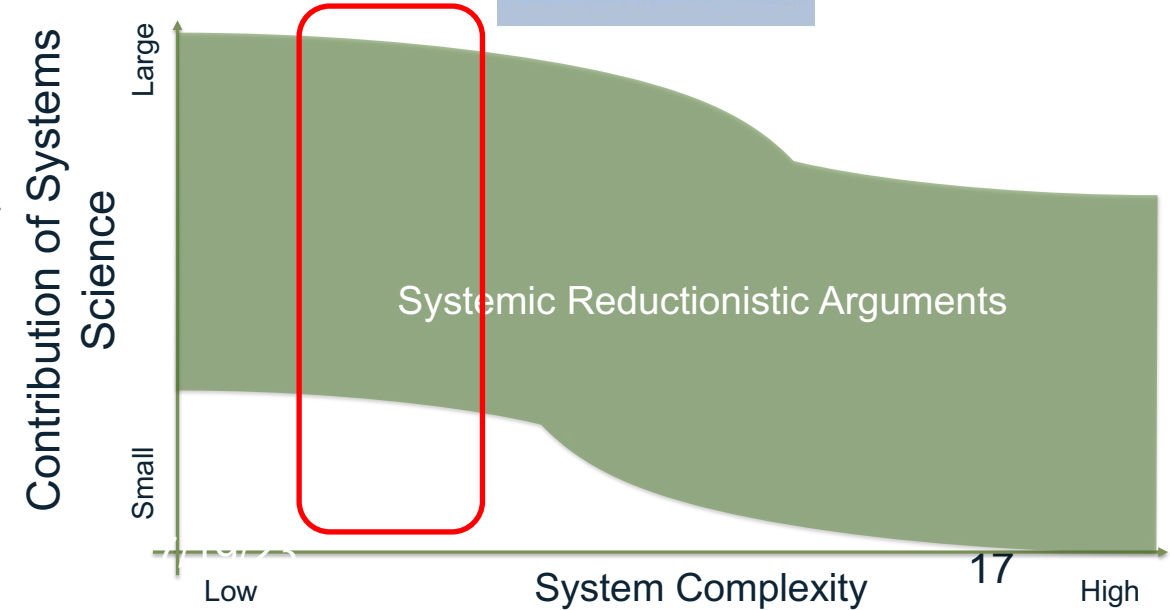
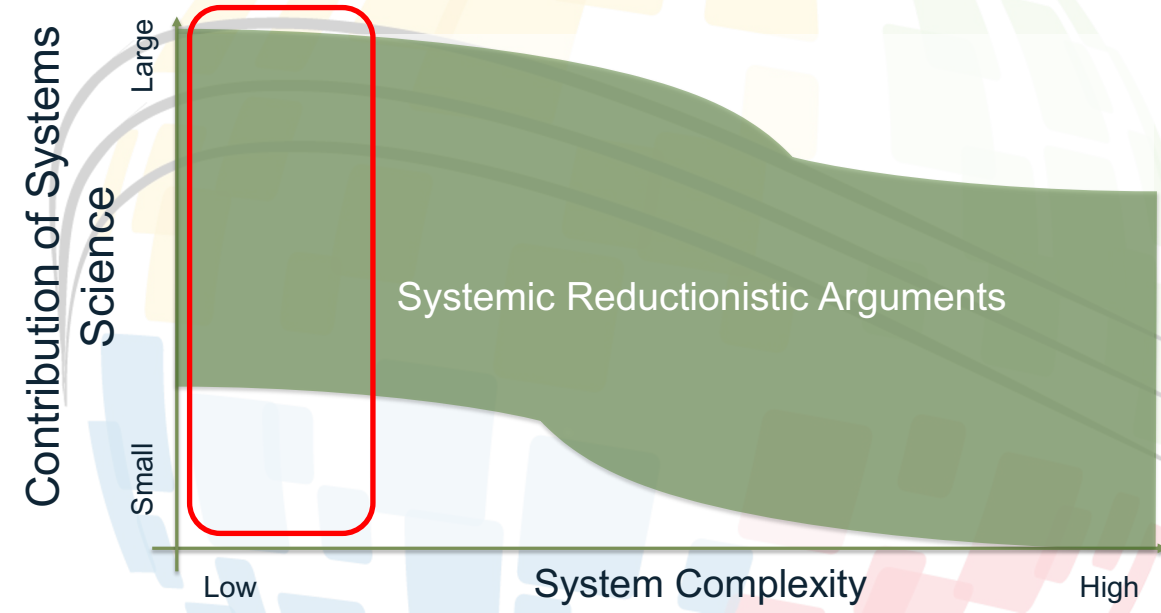
## One Experience at the Boundary



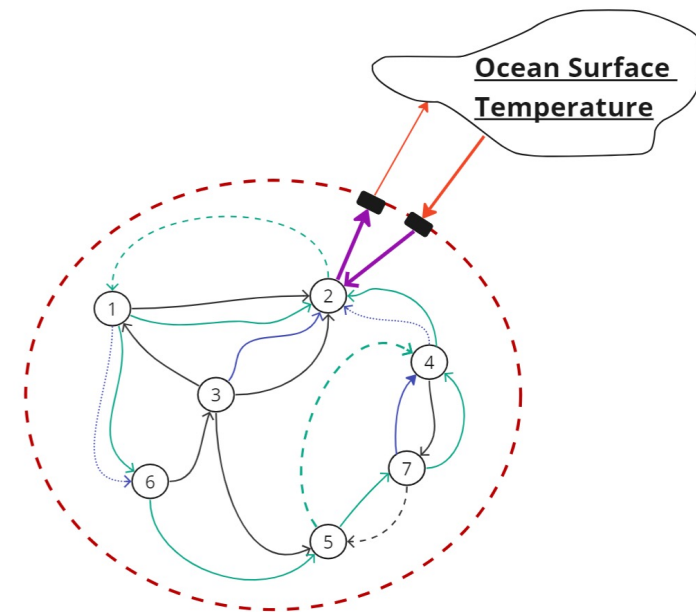
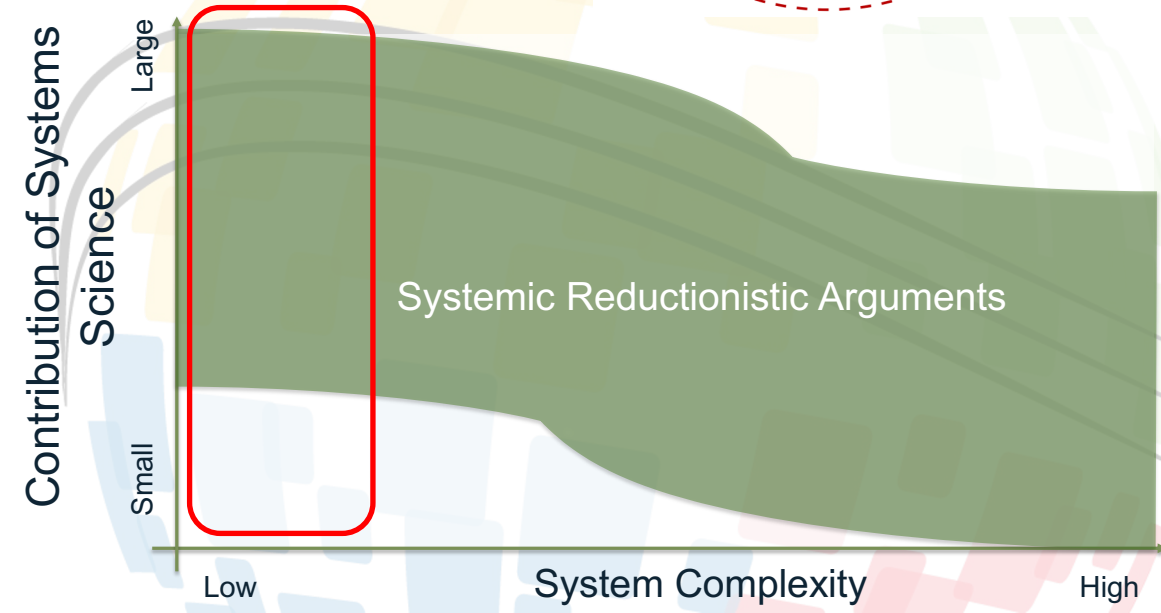
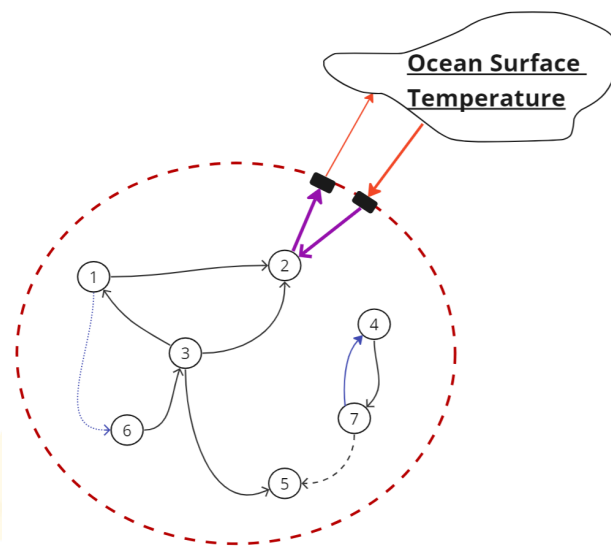


# Systemic Reductionist Argument

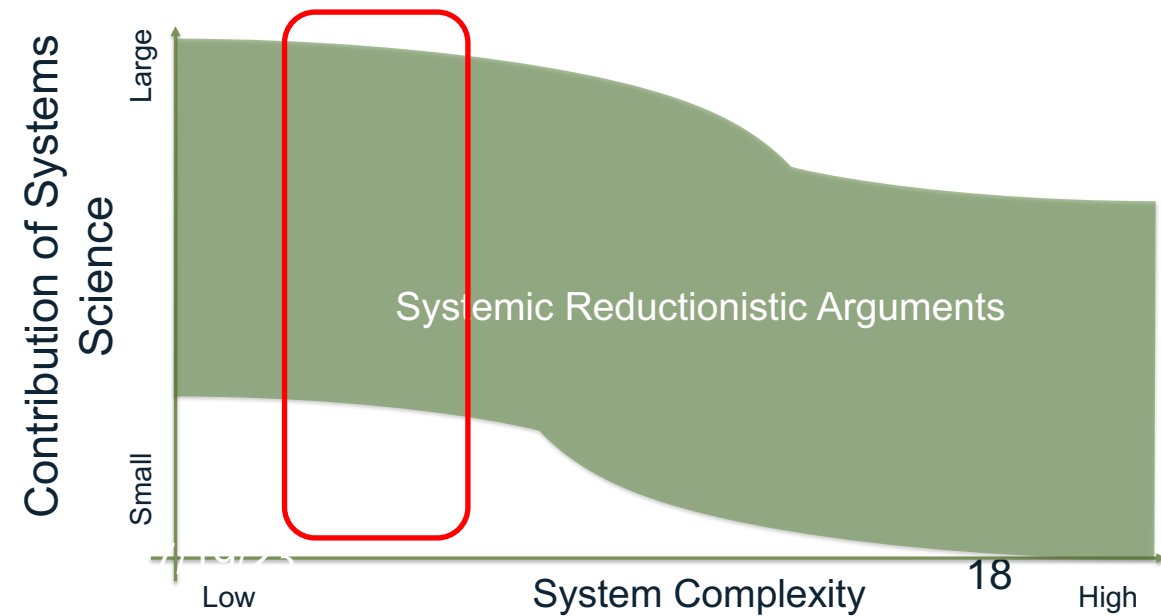
## One Experience at the Boundary



# Systemic Reductionist Argument



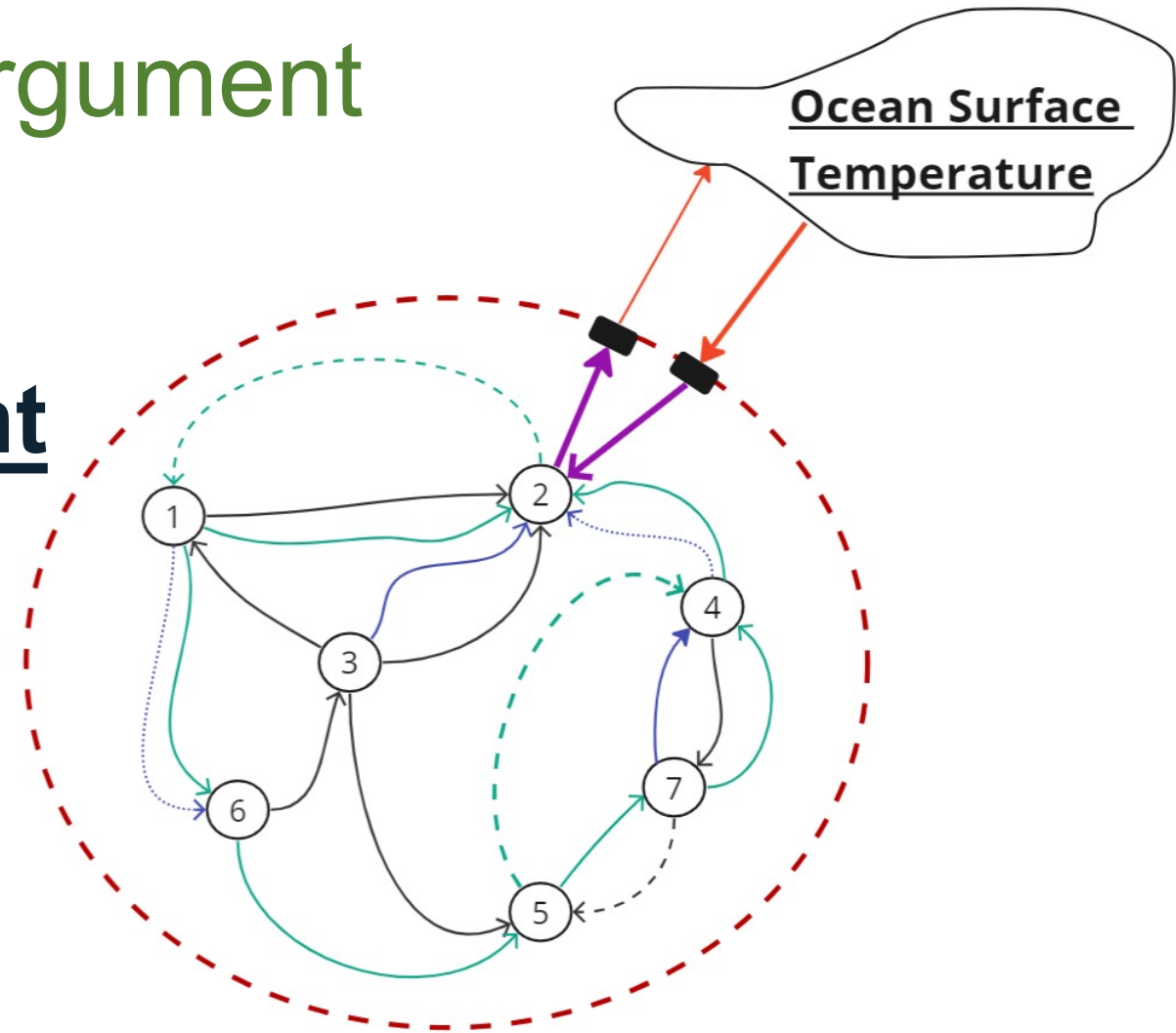
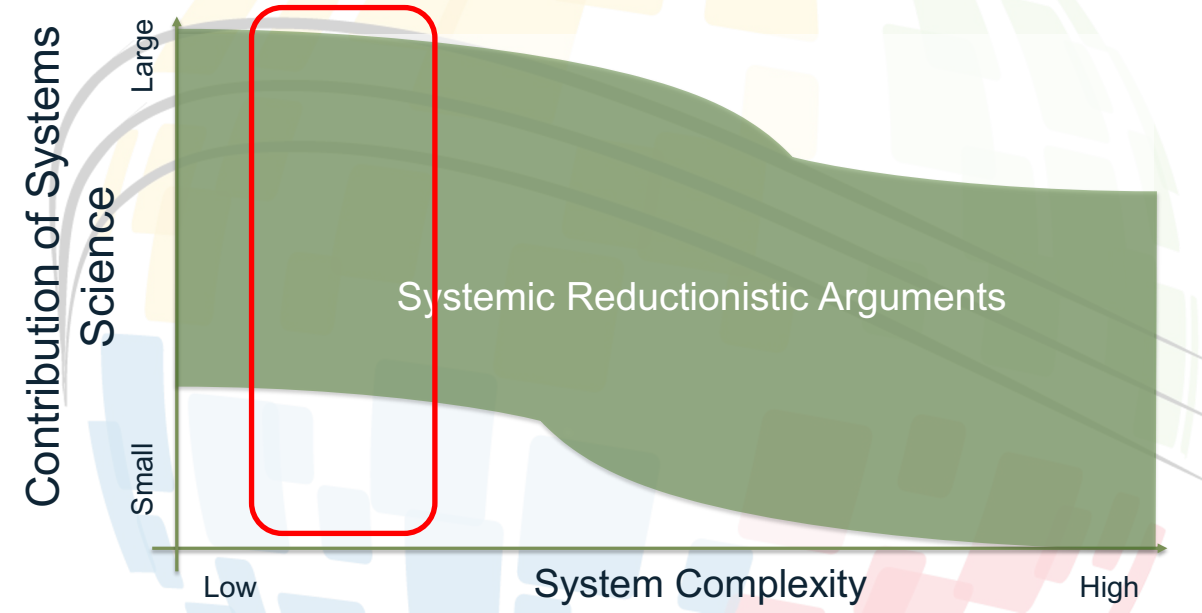
System element 2 represents the system's confluent impact of system-level properties' causal powers on the boundary experience.





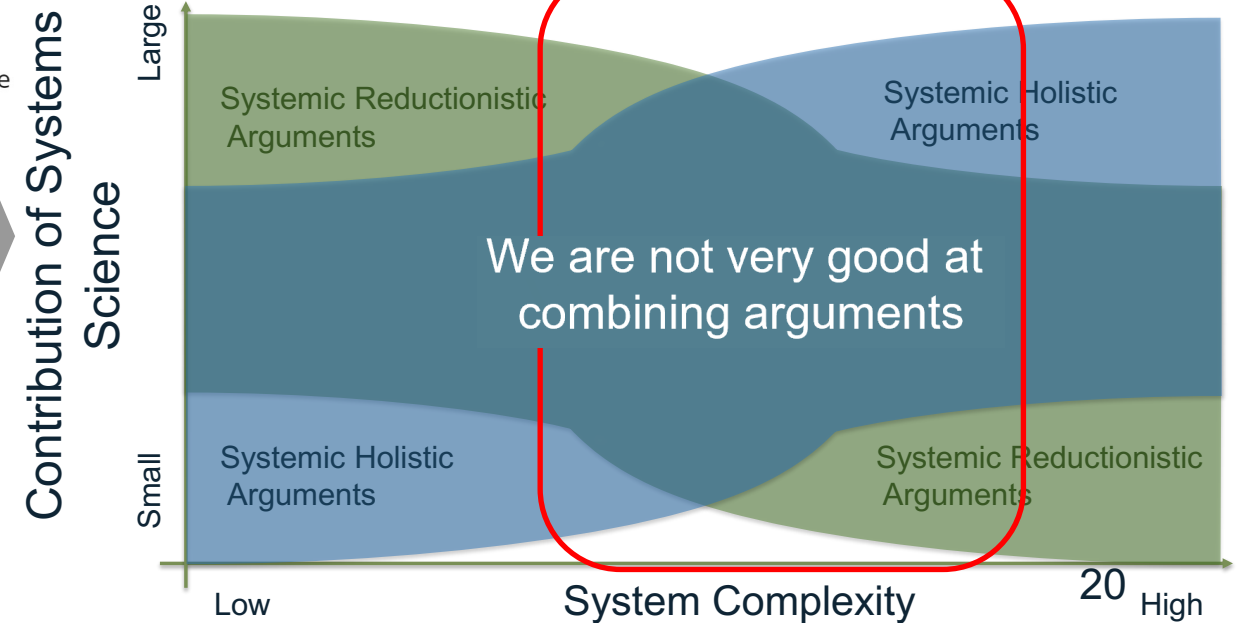
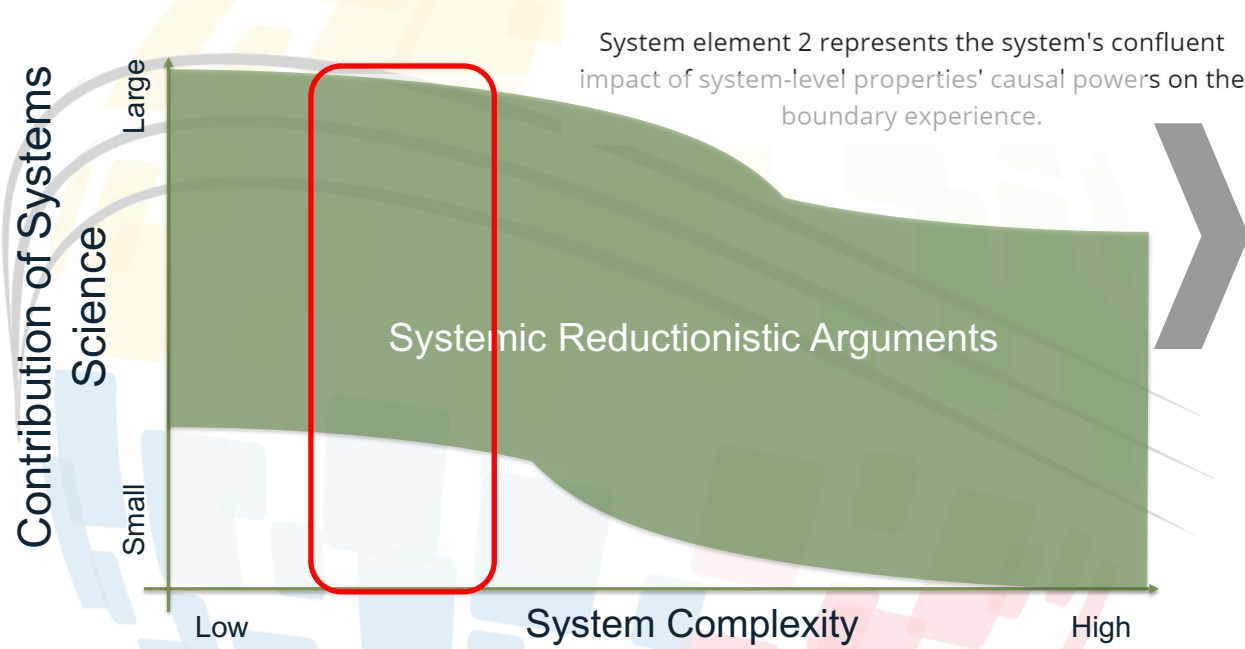
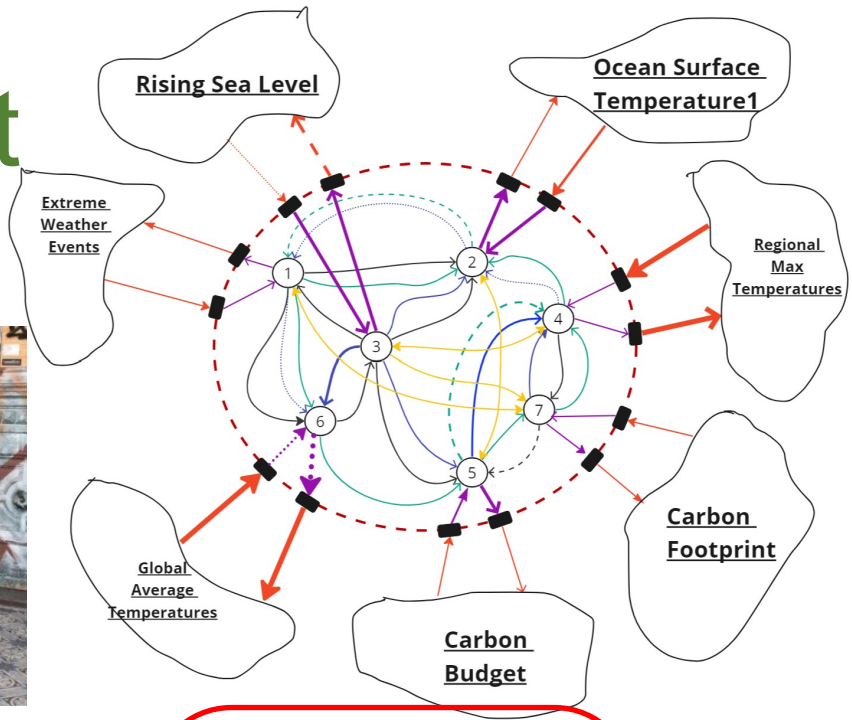
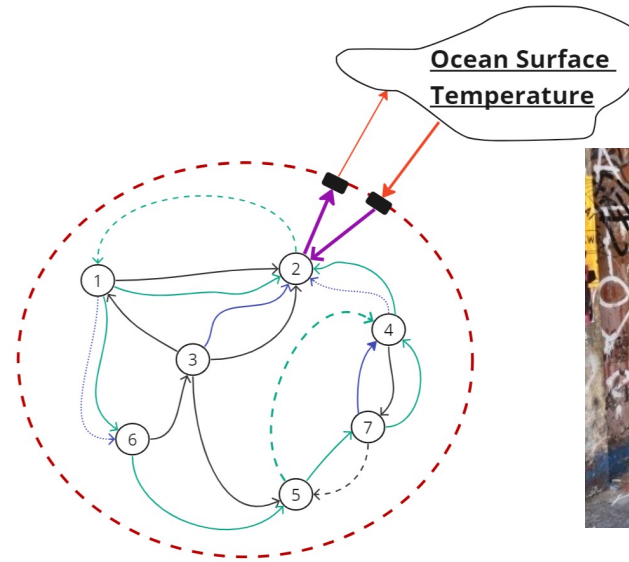
# Systemic Reductionist Argument

One Experience at the Boundary due to Confluent Influence



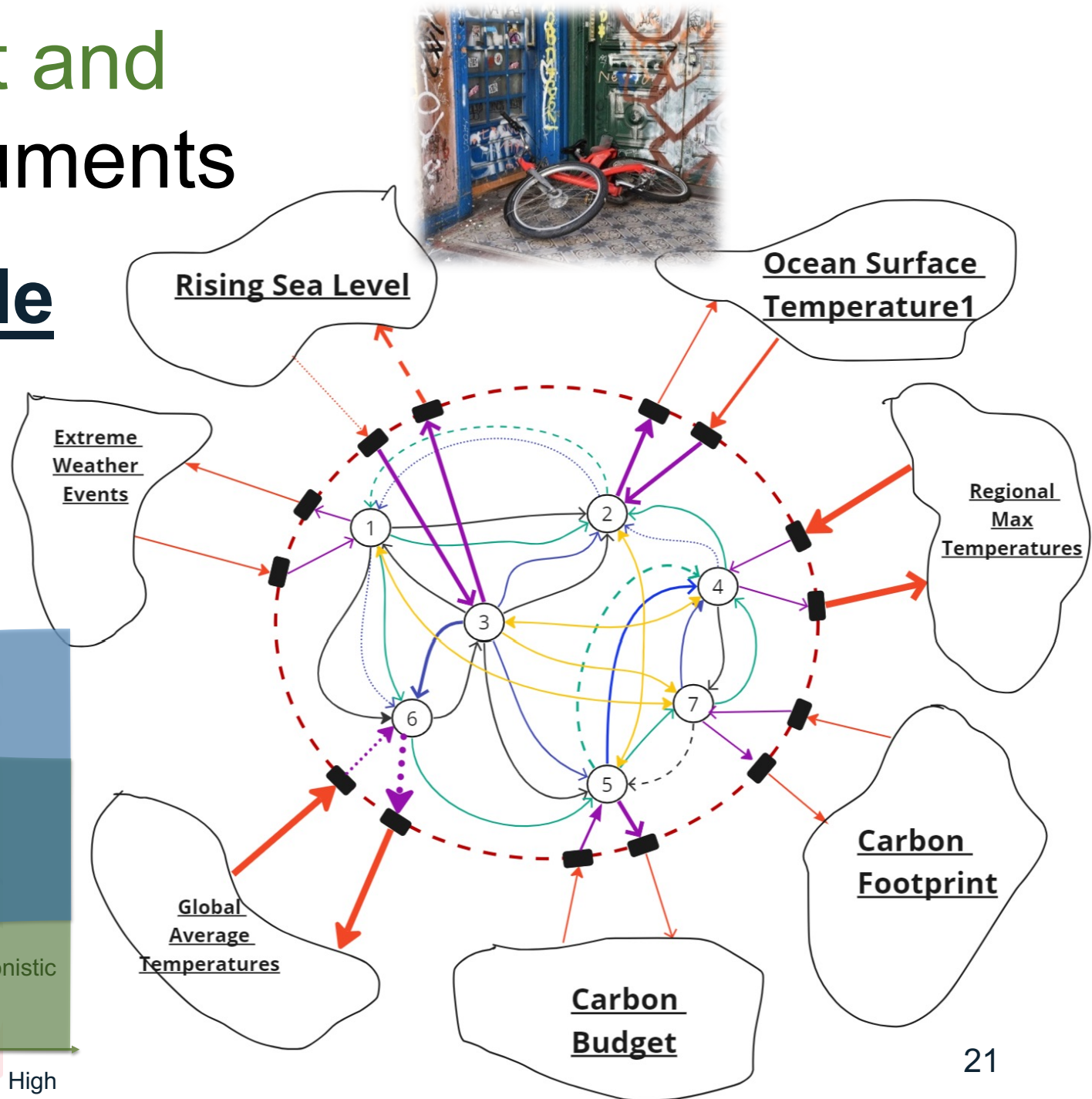
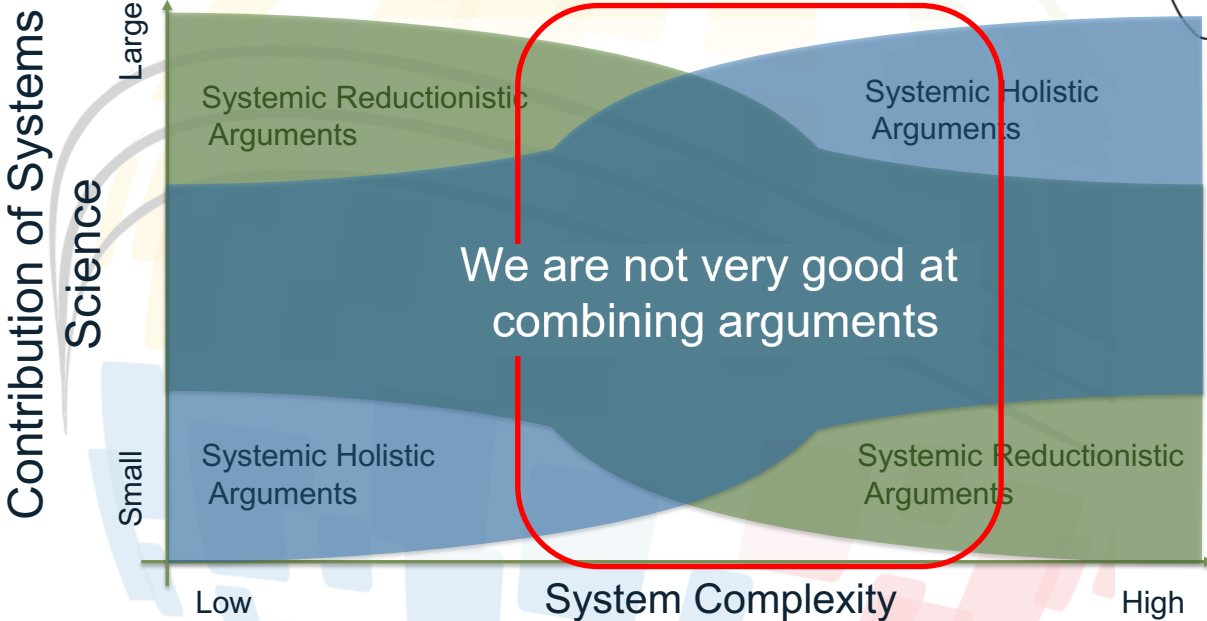
System element 2 represents the system's confluent impact of system-level properties' causal powers on the boundary experience.

# Systemic Reductionist Argument

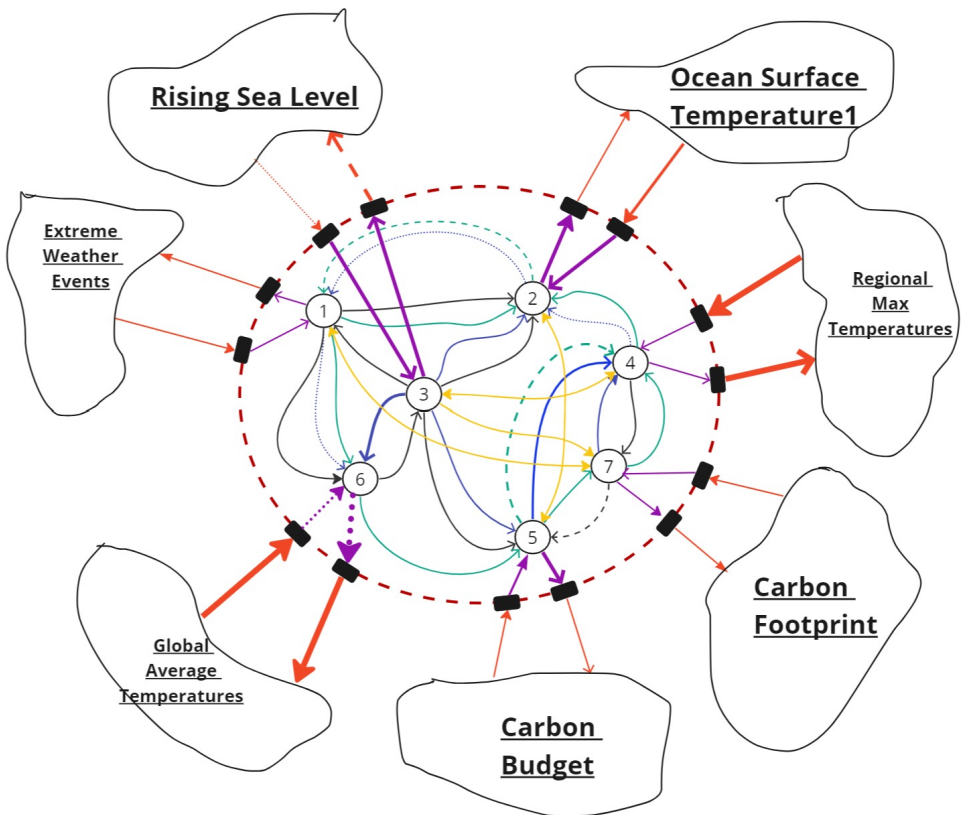


# Systemic Reductionist and Systemic Holistic Arguments

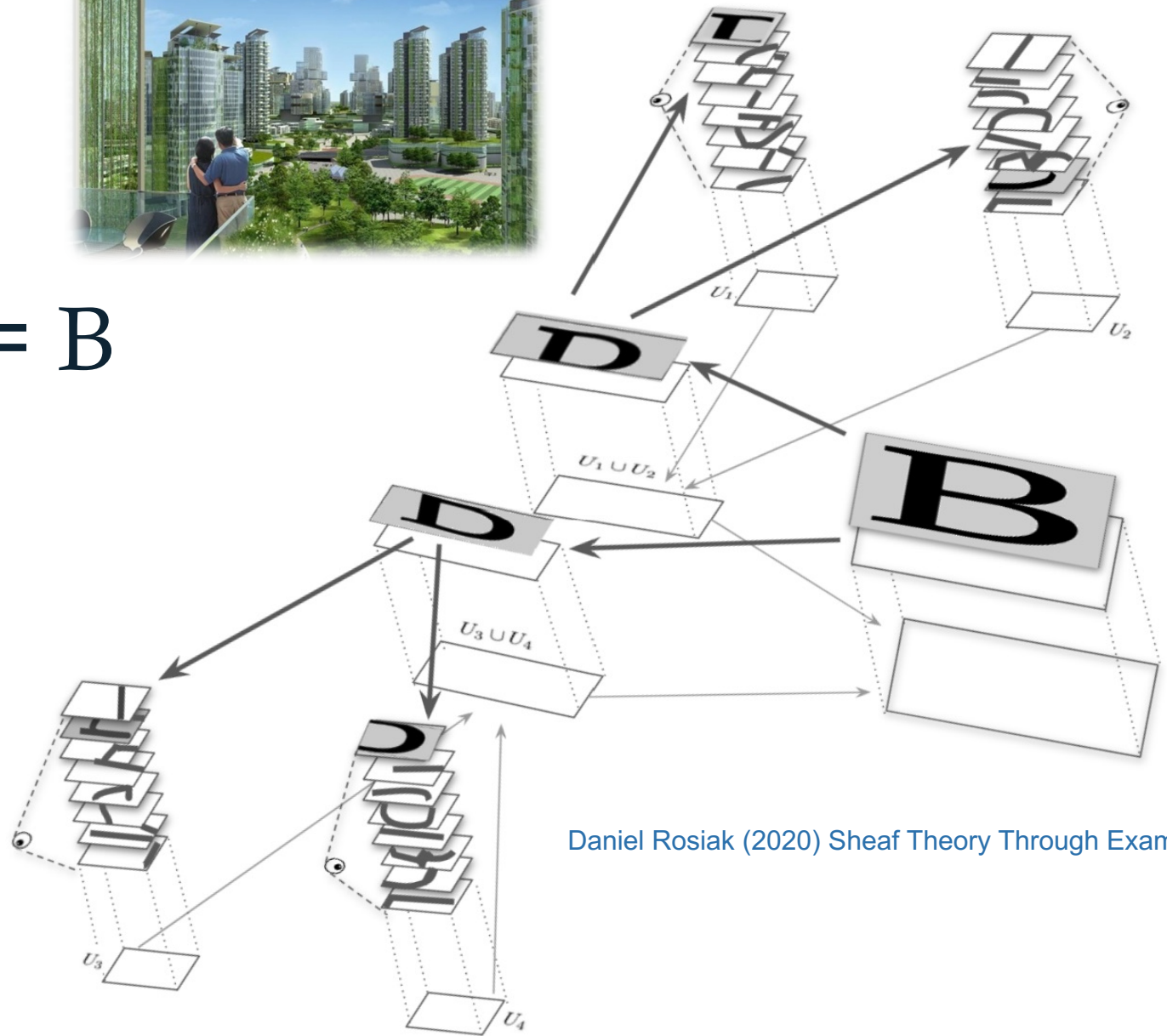
Global Warming: **Multiple**  
**Confluent** Experiences  
at many Boundaries



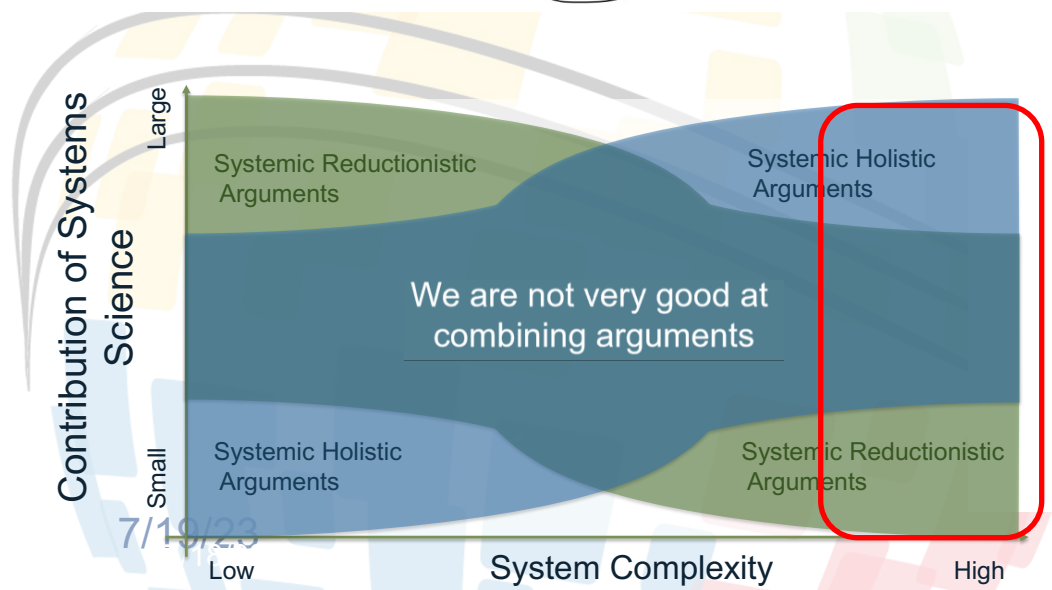




= B



Daniel Rosiak (2020) Sheaf Theory Through Examples





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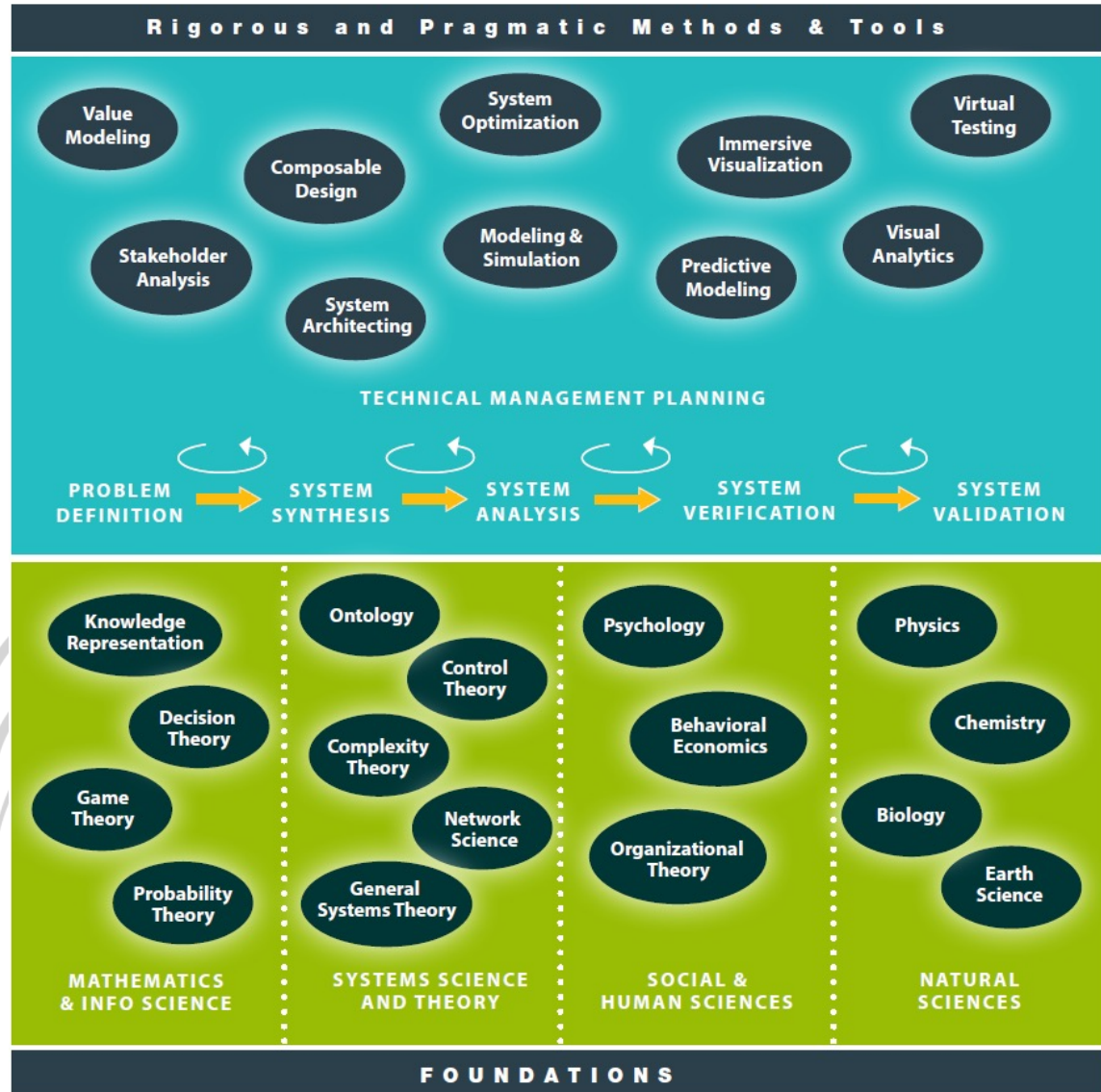
How does systems science approach the problem of the human impact of global warming, and how to be part of the solution?

Systems science provides all and no answers at once!

At present systemic reductionist, future systemic holistic



# Global Warming: How can it be addressed?



## *Anthropology & Performance*

**Hortense Gerardo** is an anthropologist, playwright, and screenwriter. She is the Director of the Anthropology, Performance, and Technology (APT) Program at the University of California, San Diego (UCSD) which she created to serve as a bridge between engineering, social sciences and the arts. Dr. Gerardo has been selected as a Teaching + Learning Commons Changemaker Anti-Racist Pedagogy Learning Community Fellow for the 2023-2024 academic year at UCSD. Her award winning works have been screened and performed nationally and internationally. She is a co-founder of the Asian American Playwright Collective (AAPC) and serves as Head of Screenwriting on the Board of the Woods Hole Film Festival.





# Anthropology and the Performing Arts: Experiential Approaches to Addressing the Wicked Problems of Cyber Physical Social Systems

INCOSE PANEL SESSION- UCSD July 19, 2023



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Hortense Gerardo, Ph.D  
the Anthropology, Performance, and Technology Program  
Jacobs School of Engineering  
University of California, San Diego





**GLOBAL PANDEMIC**



**SOCIAL INEQUALITY**



**CLIMATE CHANGE**

## **EXAMPLES OF WICKED PROBLEMS**

# WICKED PROBLEMS HAVE NO IMMEDIATE SOLUTIONS

- CULTURAL RESISTANCE
- INABILITY TO MOVE FORWARD

**ANTHROPOLOGY** ALLOWS YOU TO *FRAME THE PROBLEM* FROM THE POINT OF VIEW OF BELIEF SYSTEMS AND CULTURAL PRACTICE.

**THE ARTS** HAVE THE ABILITY TO *PROFOUNDLY MOVE PEOPLE* IN SUCH A WAY AS TO EFFECT SOCIAL CHANGE.



# AN ARTIST WALKS INTO A SYSTEMS PROBLEM...

## THE MEDFIELD STATE HOSPITAL FOR THE CRIMINALLY INSANE



**MSH IN OPERATION  
1896 - 2003**

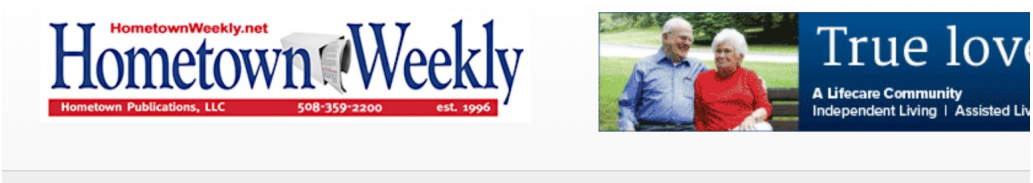


**BOUGHT BY THE TOWN OF  
MEDFIELD IN 2013**



**CREATION OF A  
POTEMPKIN VILLAGE**

# ART COMMUNICATES COMPLEX PROBLEMS IN A WAY THAT MOVES PEOPLE TO FIND SOLUTIONS



Home	Medfield	Walpole	Westwood	Dover-Sherborn	Needham
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## Medfield Anthology wows audience



H. GERARDO



## State OKs Medfield State Hospital lease

Refinance Calculator  
Today's Rate 1.90% APR

Terms & Conditions apply. NMLS#1136

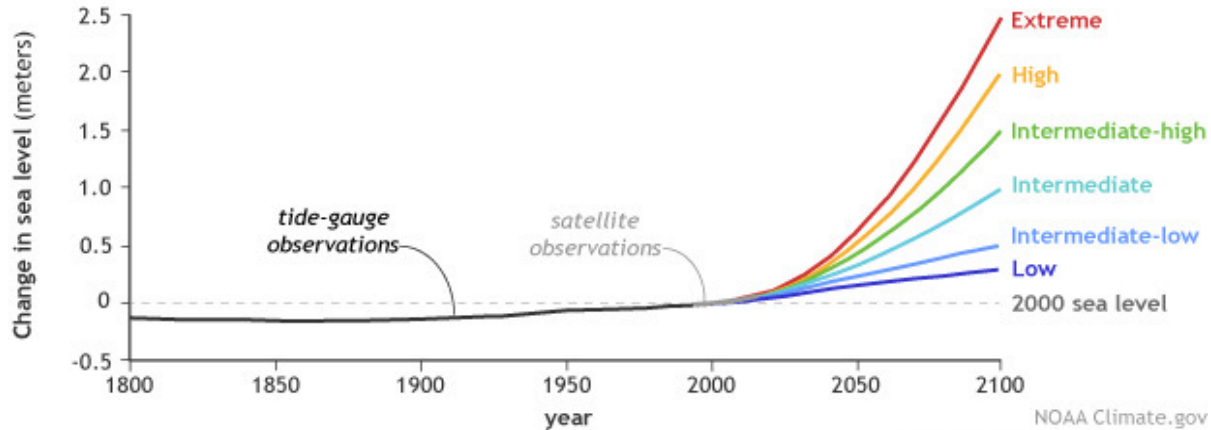
**MOST POPULAR**  
1 Famed documentarian captures City Hall and Hizzonah  
Dec 26 at 11:22 AM





# DOCUMENTARY FILM INSPIRES RESILIENCE IN THE FACE OF CLIMATE CHANGE

Possible future sea levels for different greenhouse gas pathways



NOAA Climate.gov  
Adapted from Sweet et al., 2017



## SMALL STEPS: DANCES OF RESILIENCE

A FILM BY HORTENSE GERARDO



INSPIRING HOPE IN THE FACE OF CLIMATE CHANGE



# UC San Diego

## **JACOBS SCHOOL OF ENGINEERING**

### Anthropology, Performance, and Technology Program

The program serves as an intersectional bridge  
between anthropology, performance, and  
technology, designed to nurture the creation of  
innovative solutions to socially relevant  
problems in the 21st century.

## The APT Program

# THE APT PROGRAM

BUILDING THE EXPERIENTIAL  
LANGUAGE OF ENGINEERING

## ANTHROPOLOGY

a language to provide engineering students a multicultural perspective of what the field can achieve. (teaching).

## PERFORMANCE

a language for engineers to describe the experiential sense of a system, product or service (storytelling).

## TECHNOLOGY

a language informed by social consciousness to generate innovative systems (product design and deployment).

Ethics and Professionalism

Communication

Critical Thinking

Emotional Intelligence

Negotiation

# CAP SYSTEMS ENGINEERING SURVEY ANALYSIS

CONDUCTED DECEMBER 15, 2020-  
JANUARY 15, 2021

The survey sought to learn the self-described expected and actual competencies of new graduates and mid career engineers



# Anthropology, Performance, & Technology (APT) Program

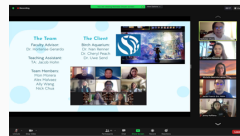
## Focus on Human & Societal Impact

## Performance as the Experiential Language of Engineering

### Education: The APT Etudes

THE FORGE VETERAN PIPELINE PROGRAM  
THE INSTITUTE OF GLOBAL ENTREPRENEURS (IGE)

Guest Workshops in Required Courses:  
ECE 140 – The Art of Product Engineering  
SE 160B – Aerospace Structural Mechanics II  
MAE 175A – Aerospace Engineering Laboratory



ENG 100L - Birch Aquarium  
Data Into Stories



ENG 100L - Memorializing the Pandemic – Ethnography and Public Art

#### COMMUNICATION

- A. Communication and Storytelling Skills
- B. Presentation of SELF in Everyday STEM Life (for Women, Underrepresented Minorities)
- C. How Art Can Effect Social Change
- D. Preparing for Interviews

#### SOCIAL SKILLS

- A. Teamship Explorations
- B. On Gender Parity in STEM
- C. Data-Informed Public Art and New Media

#### DESIGN

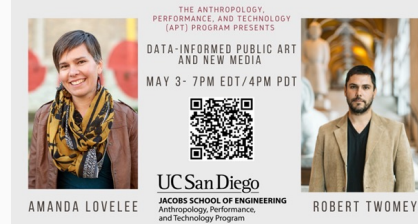
- A. Storyboarding as a Tool for Effective Design
- B. Eco-conscious Design
- C. Data-Informed Public Art and New Media
- D. Socially Engaged Art

#### ETHICS

- A. Heuristic Approach to Ethical Decision-Making [TK]
- NEW MEDIA TECHNOLOGY INTEGRATION
- AR/VR and XR Workshops
- AR/VR and XT Performance/Film/Production
- Wearable Technology for Learning and Performance

## APPLIED CREATIVE RESEARCH

### Outreach : The ARDENT Series



## EDUCATION

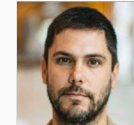
## Applied Creative Research: The INKubator Collective



Ying Wu  
Cognitive Neuroscience



Bobby McElver  
Theater and Dance



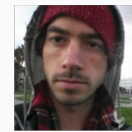
Robert Twomey  
New Media



Patrick Coleman  
Speculative Futures



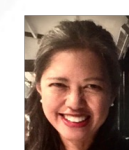
Jonathon Paden  
New Media



Timothy Wood  
Media Artist in XR



Ha Na Lee  
New Media Artist



Hortense Gerardo  
Director of APT

## COMMUNITY OUTREACH

H. GERARDO

**Science and technology revolutionize our lives, but  
memory, tradition, and myth frame our response.**

**- Arthur Schlesinger (Historian)**

# Global Warming: How can it be addressed?



## *Social Systems*

**Dr. Erika Palmer** is a Senior Lecturer in the Systems Engineering Program at Cornell University, where her research and teaching focuses on sociotechnical systems. She founded the Systems and Society Research Lab (SSRL) at Cornell, which brings together systems engineers and social scientists to develop new modeling and simulation methods for evaluating sociotechnical and policy systems. Dr. Palmer is the founding chair of the Social Systems Working Group and the incoming Deputy Technical Director of the International Council for Systems Engineering (INCOSE).



# Emergence

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- Climate change as an emergent behavior of sociotechnical systems
- Modeling and simulation of sociotechnical systems
  - Social and cultural capital
- Developing policy for sociotechnical transitions



# Global Warming: How can it be addressed?



## ***Oceanography/Earth Science***

**Michael Bruno** is the Provost and Professor of Ocean Engineering at the University of Hawai'i at Mānoa. Prior to his appointment, he was the Dean of the School of Engineering and Science, and Director of the Center for Maritime Security at Stevens Institute of Technology, Hoboken, New Jersey. His research and teaching interests include ocean observation systems, climate change, and community resilience.



An aerial photograph of a coastal city, likely Miami, showing a large body of water (Biscayne Bay) with a bridge crossing it. The city skyline is visible in the background, and the foreground shows a dense urban area with buildings and roads.

# THE URBAN OCEAN

The Interaction of Cities with Water

## **International Council of Systems Engineering International Symposium**

Michael Bruno  
University of Hawai'i at Mānoa

July 19, 2023

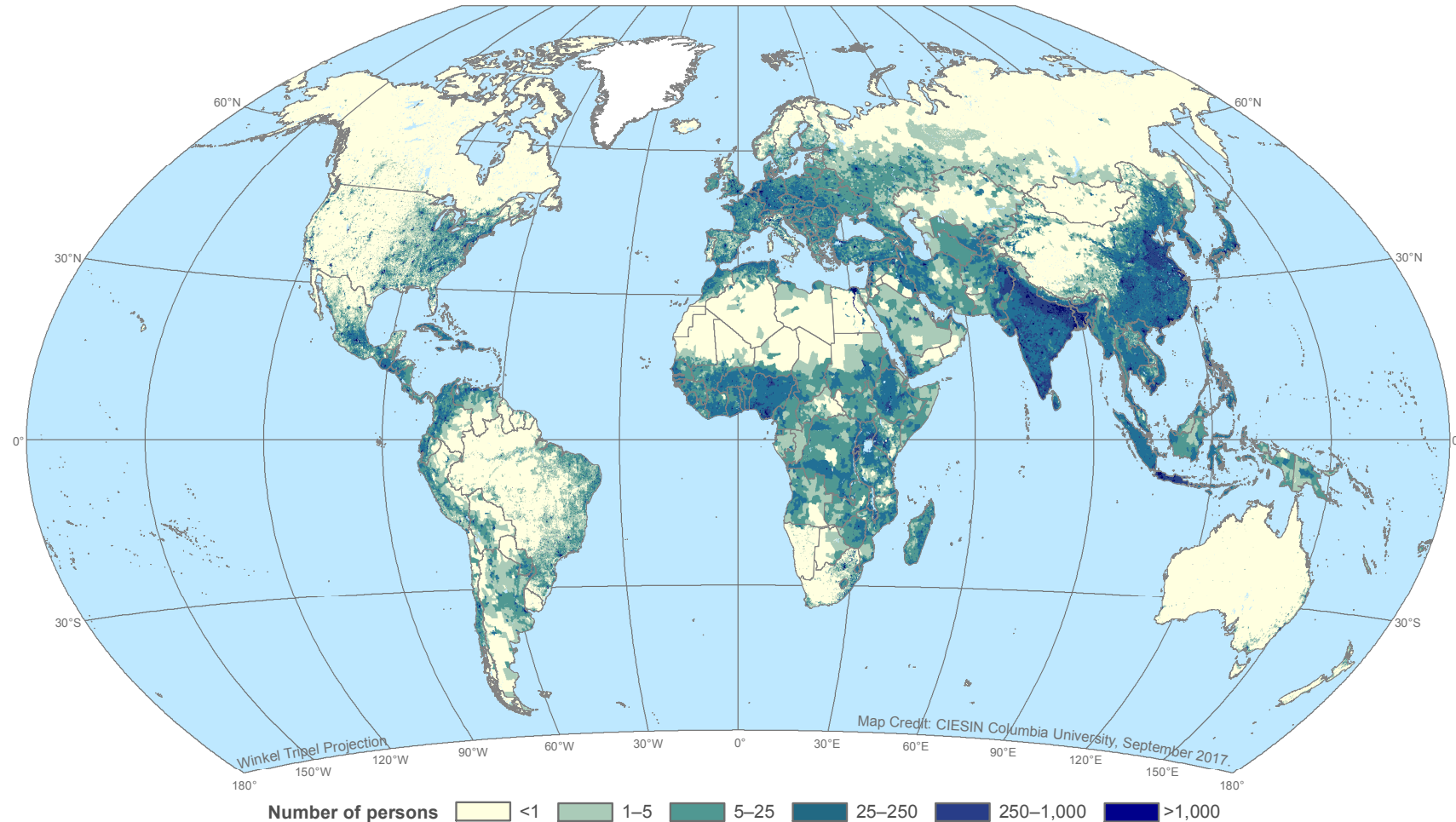


# **This is a talk about *Change***

- **The earth's population has increased, and people are migrating to urban centers, many of them located on the coast.**
- **As a result, humans are increasingly impacting the coastal ocean environment, including via climate change...**
- **and major population centers located along the coast are increasingly at risk.**  
**(risk = probability X consequence)**
- **Our understanding of the *rate* of change is limited - it is affected by both future human activities that are difficult to predict, and past human activities that we do not yet understand**
- **An additional change is needed – in our approach to complex socio-technical systems & in our behavior**

# Population Count, v4.10, 2015

## Gridded Population of the World, Version 4 (GPWv4)



Gridded Population of the World, Version 4 (GPWv4) Population Count, Revision 10 consists of estimates of human population, consistent with national censuses and population registers, for the years 2000, 2005, 2010, 2015, and 2020. A proportional allocation gridding algorithm, utilizing approximately 13.5 million national and sub-national administrative units, is used to assign population counts to 30 arc-second (approximately 1 km at the equator) pixels.

Center for International Earth  
Science Information Network  
EARTH INSTITUTE | COLUMBIA UNIVERSITY

Data Source: Center for International Earth Science Information Network - CIESIN - Columbia University. 2017. Gridded Population of the World, Version 4 (GPWv4): Population Count, Revision 10. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). <https://doi.org/10.7927/H4PG1PPM>.

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<https://creativecommons.org/licenses/by/4.0/>

RANK	CITY	NATION	REGION	POPULATION
1	Tokyo-Yokohama	Japan	Asia	37,900,000
2	Jakarta	Indonesia	Asia	31,760,000
3	Delhi	India	Asia	26,495,000
4	Manila	Philippines	Asia	24,245,000
5	Seoul-Incheon	South Korea	Asia	24,105,000
6	Karachi	Pakistan	Asia	23,545,000
7	Shanghai	China	Asia	23,390,000
8	Mumbai	India	Asia	22,885,000
9	New York City Area	United States	North America	21,445,000
10	Sao Paulo	Brazil	South America	20,850,000
11	Beijing	China	Asia	20,415,000
12	Mexico City	Mexico	North America	20,400,000
13	Guangzhou-Foshan	China	Asia	19,075,000
14	Osaka-Kobe-Kyoto	Japan	Asia	17,075,000
15	Dhaka	Bangladesh	Asia	16,820,000
16	Moscow	Russia	Europe	16,710,000
17	Cairo	Egypt	Africa	16,225,000
18	Bangkok	Thailand	Asia	15,645,000
19	Los Angeles-Riverside	United States	North America	15,500,000
20	Buenos Aires	Argentina	South America	15,355,000
21	Kolkata	India	Asia	14,950,000
22	Tehran	Iran	Asia	13,805,000
23	Istanbul	Turkey	Europe	13,755,000
24	Lagos	Nigeria	Africa	13,360,000
25	Tianjin	China	Asia	13,245,000
26	Shenzhen	China	Asia	12,775,000
27	Rio de Janeiro	Brazil	South America	11,900,000
28	Kinshasa	Congo	Africa	11,855,000
29	Lima	Peru	South America	11,150,000
30	Chengdu	China	Asia	11,050,000
31	Paris	France	Europe	10,950,000
32	Lahore	Pakistan	Asia	10,665,000
33	Bangalore	India	Asia	10,535,000
34	London	United Kingdom	Europe	10,470,000
35	Ho Chi Minh City	Vietnam	Asia	10,380,000
36	Chennai	India	Asia	10,265,000
37	Nagoya	Japan	Asia	10,070,000

The world's mega-cities, with coastal cities shaded in yellow (Cox, 2017)





# My Major Takeaways

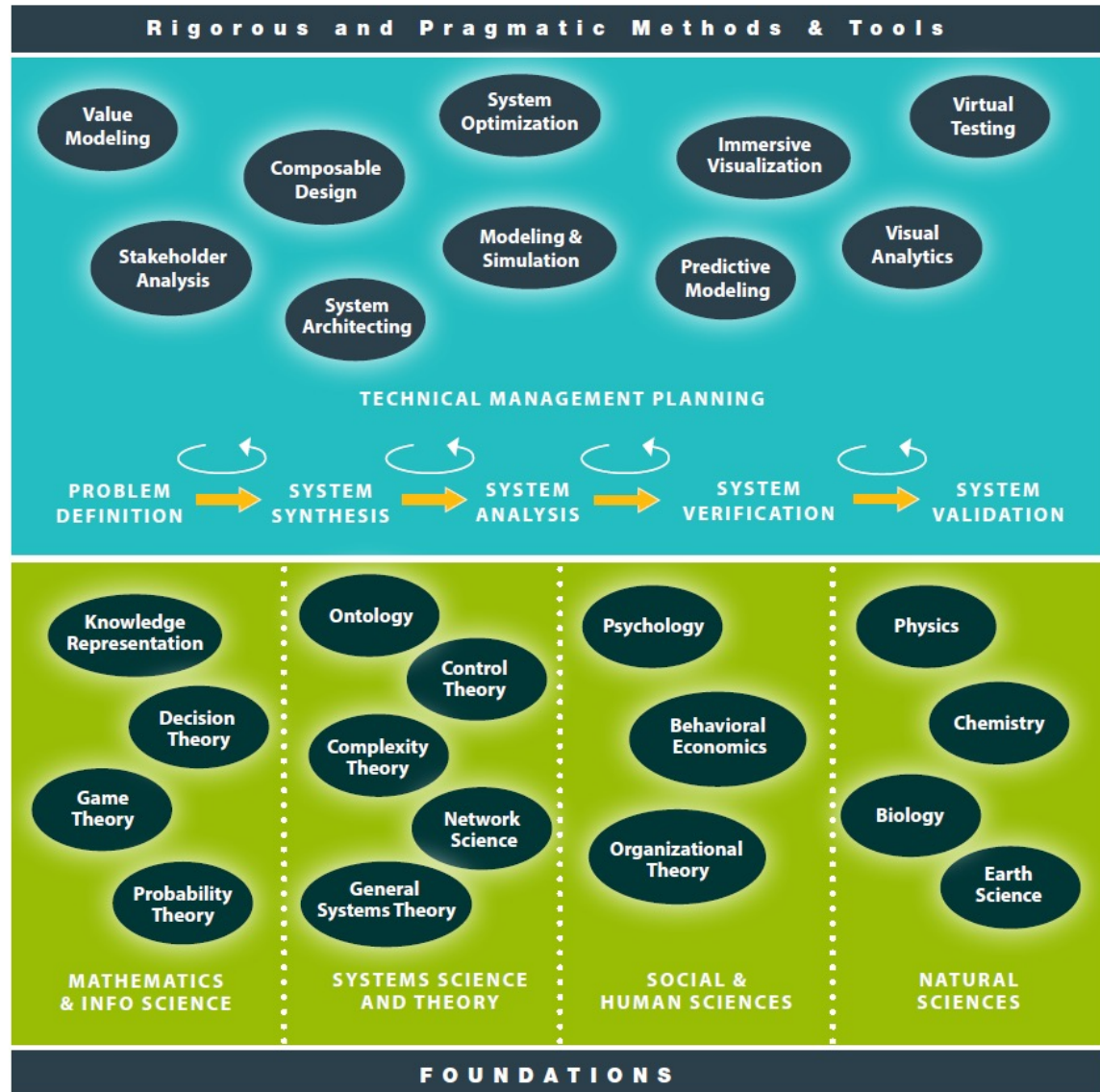
- **Socio-Technical Systems: “The future will be intensely technological and intensely human” (Woods, 2015)**
- **Prepare, Respond, Recover, *and Adapt***
- **Preserve the function, not the system**
- **It is all about people**

# The Challenges to “Designing for Resilience”

- **It is all about people** people are in most instances the source of resilience.
- **Uncertainty** - natural hazards, geopolitics, technology, and the response of the community. Difficult decisions seem only possible after an extreme event.
- **Complexity** - emerging technologies and the interactions and interdependencies that exist across different critical infrastructure systems.
- **Capacity** - The lack of capacity is often most severe in areas that are most in need but do not have the necessary human and financial resources. Need more effective technology transfer, and innovative education and training systems.
- **Globalization** - risk is increasingly shared across national boundaries and so solutions must be developed and shared across national boundaries.
- **It is all about people** – we cannot discuss measures to address resilience, in particular measures that include retreat from ancestral lands, without acknowledging the sensitivity of this issue, and without examining all possible alternatives.



# Global Warming: How can it be addressed?



## Engineering Systems

**Olivier de Weck** is the Apollo Program Professor of Astronautics at the Massachusetts Institute of Technology where he is the director of the Engineering Systems Laboratory. His research is in Systems Engineering with a focus on how complex technological systems are designed and how they evolve over time. He is a Fellow of INCOSE and a Fellow of AIAA and serves as Editor-in-Chief of the Journal of Spacecraft and Rockets.

# Multi-Disciplinary Approaches to Addressing the Wicked Problems of Cyber-Physical-Social Systems

How Systems Engineers can approach Global Change

**PROF. OLIVIER DE WECK**

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

**INCOSE IS 2023 – Honolulu, Hawai'i**

# World Scenarios 2100\*\*

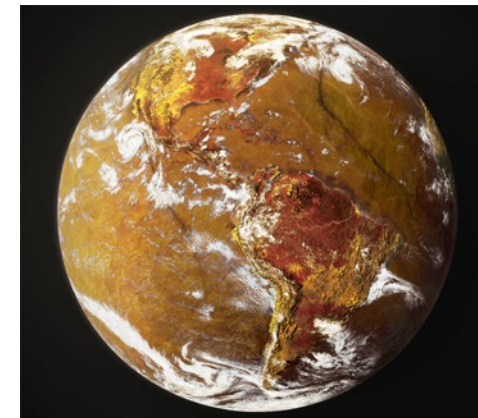
## Favorable

- Stable population and geographic distribution
- Fully renewable energy sources and consumption
- Reuse and recycle everything and close cycles
- Biodiversity maintained and natural habitats restored
- World in equilibrium



## Unfavorable

- Continued and accelerating population growth
- Climate change accelerates unabated, adaptation
- Growing Inequities nationally and worldwide
- Mass starvation and wars, depopulation
- Collapse of human civilization as we know it\*



**Systems thinking is essential in improving our odds of favorable outcome**

\*\*Olivier de Weck, Chris Magee, Dan Roos, *Engineering Systems: Meeting Human Needs in a Complex Technological World*, MIT Press, 2011

\*Jared Diamond, *Collapse: How Societies Choose to Fail or Succeed*, New York:Viking, 2005



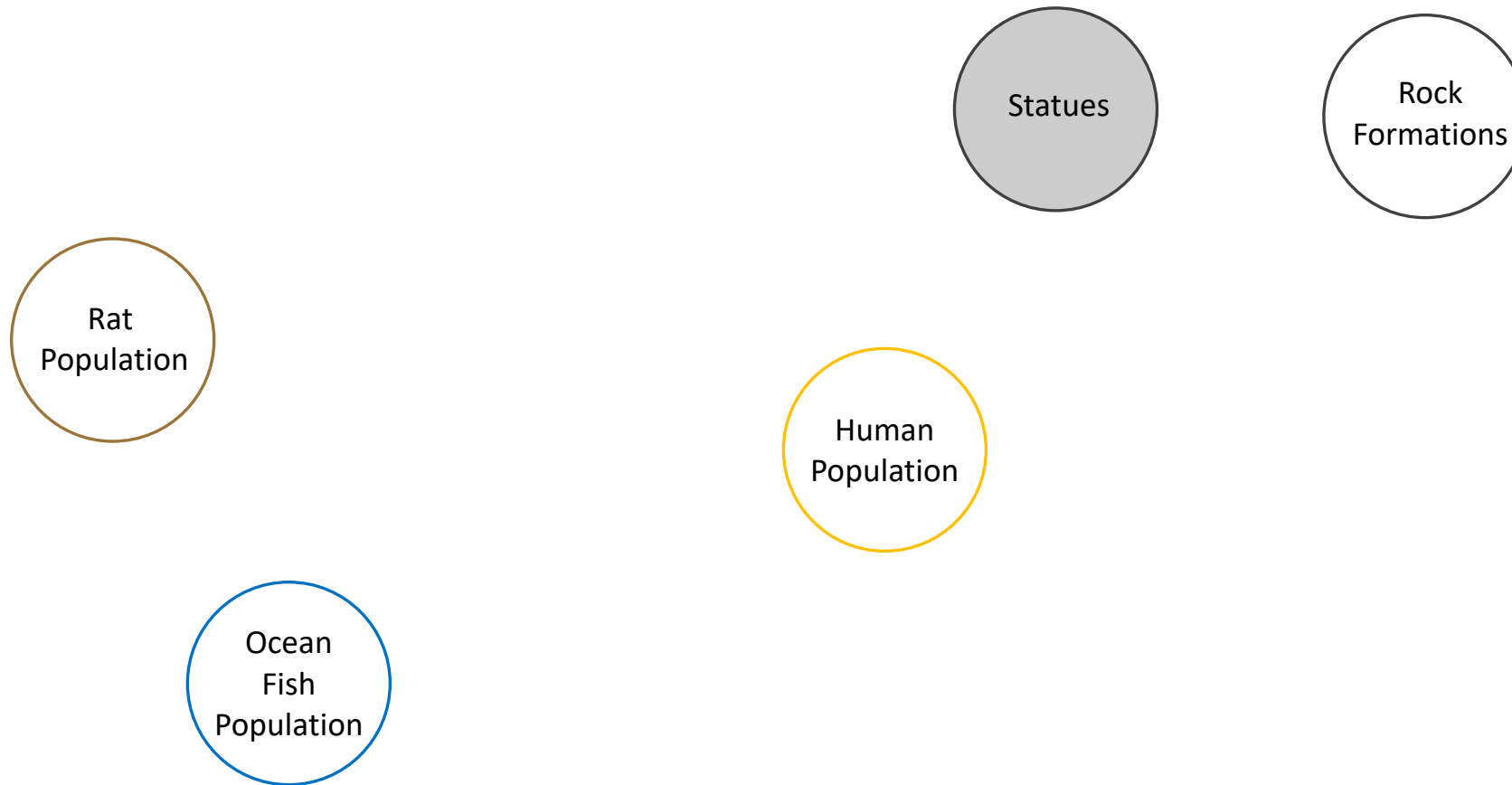
# Diamond's Opening Example: Easter Island

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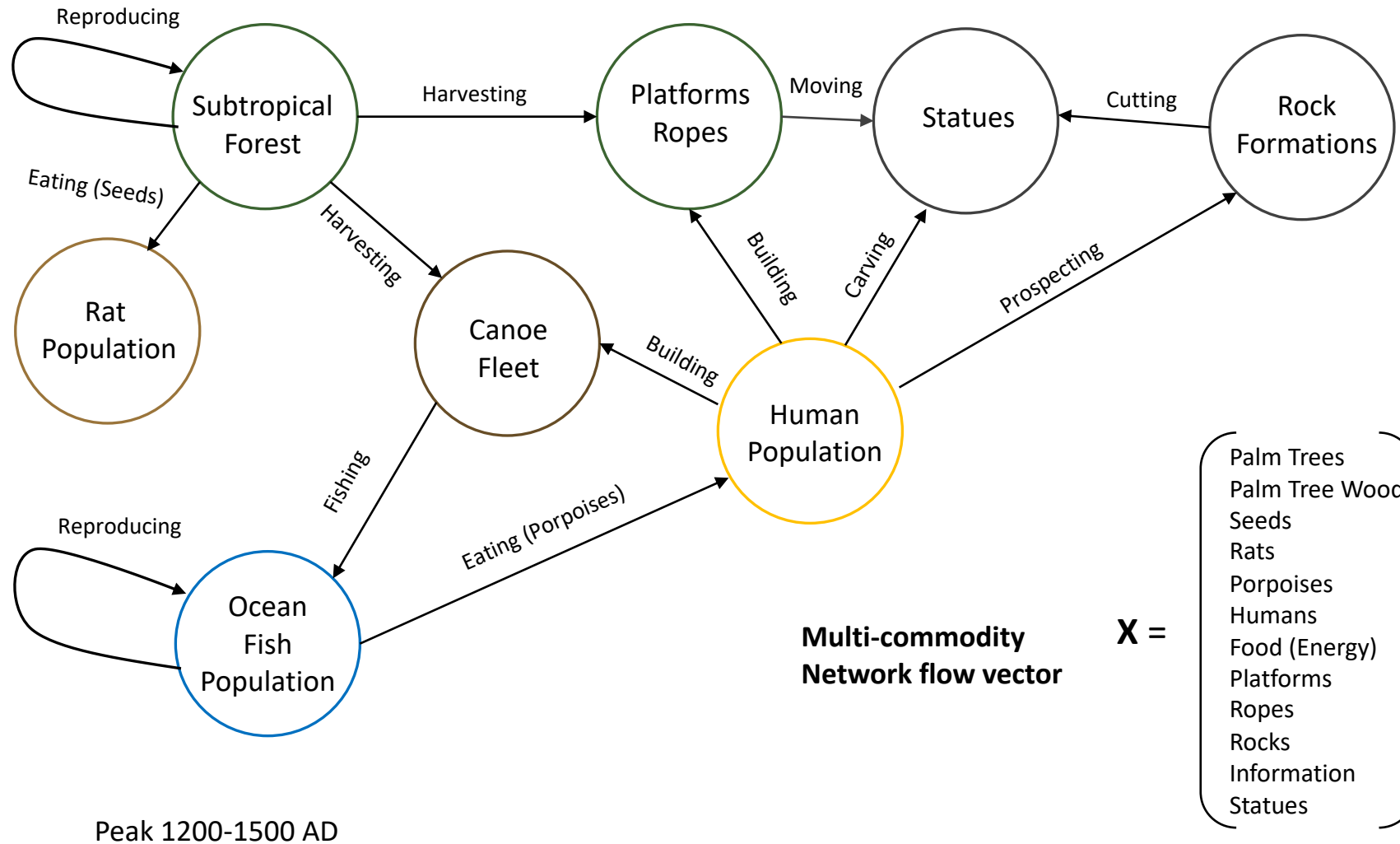
# Situation on Easter Island (post-1722)

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Post 1722

# Commodity Flows on Easter Island (pre-1722)





# What are the major challenges for a sustainable society?

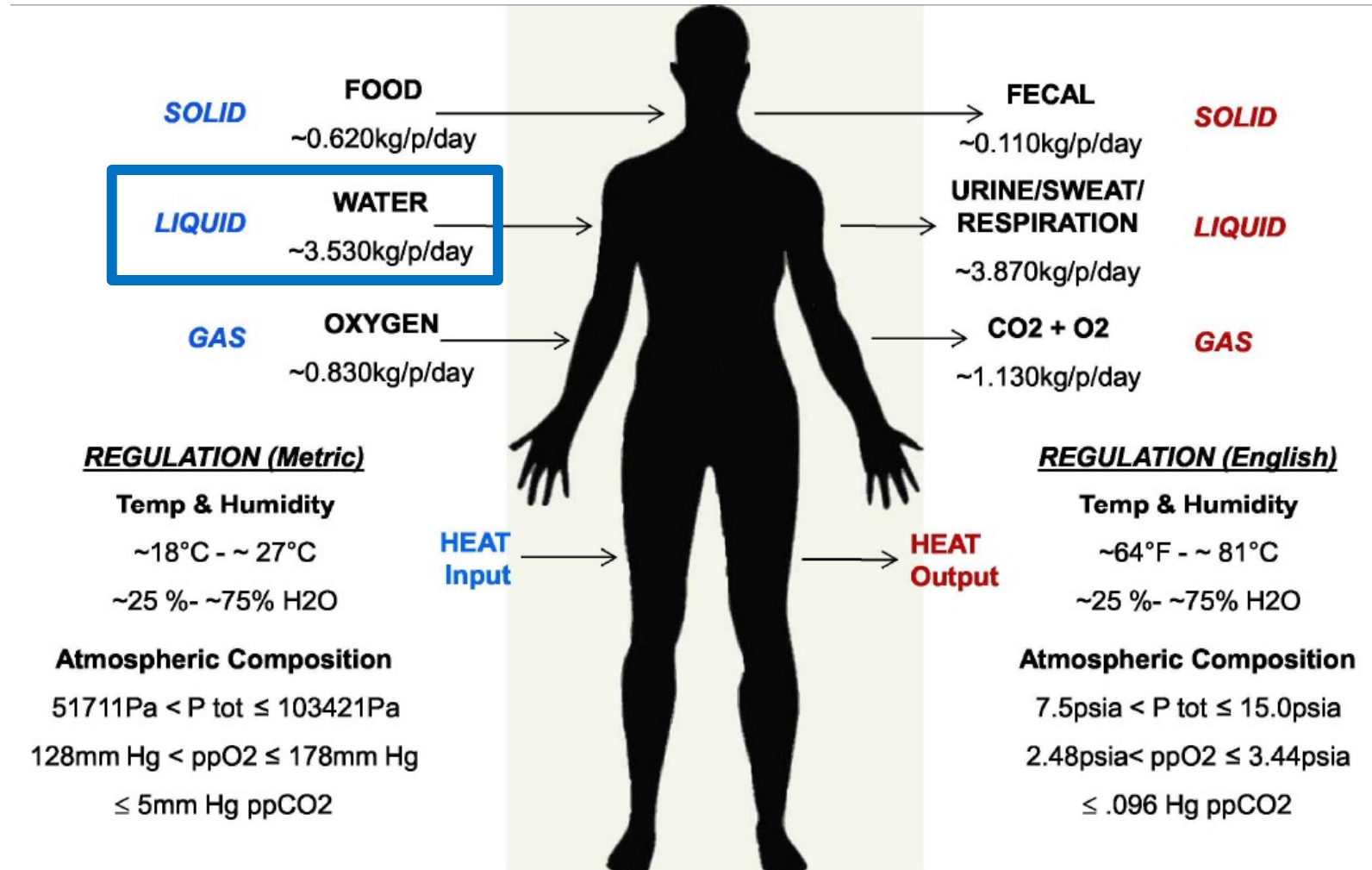
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Humans “are modifying physical, chemical, and biological systems in new ways, at faster rates, and over larger spatial scales than ever recorded on Earth.” (Lubchenko, 1998)

Sustainable Development, defined by World Commission on Environment and Development (1987): **development that meets the needs of the present, without compromising the ability of future generations to meet their own needs**

- **Economic:** production, employment, income, wealth
- **Sociopolitical:** security, liberty, justice, rule of law, education, health care, arts, civil society/culture
- **Environmental:** air, water, soils, resources, climate

# Human physiological needs

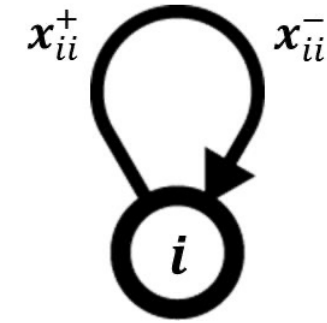
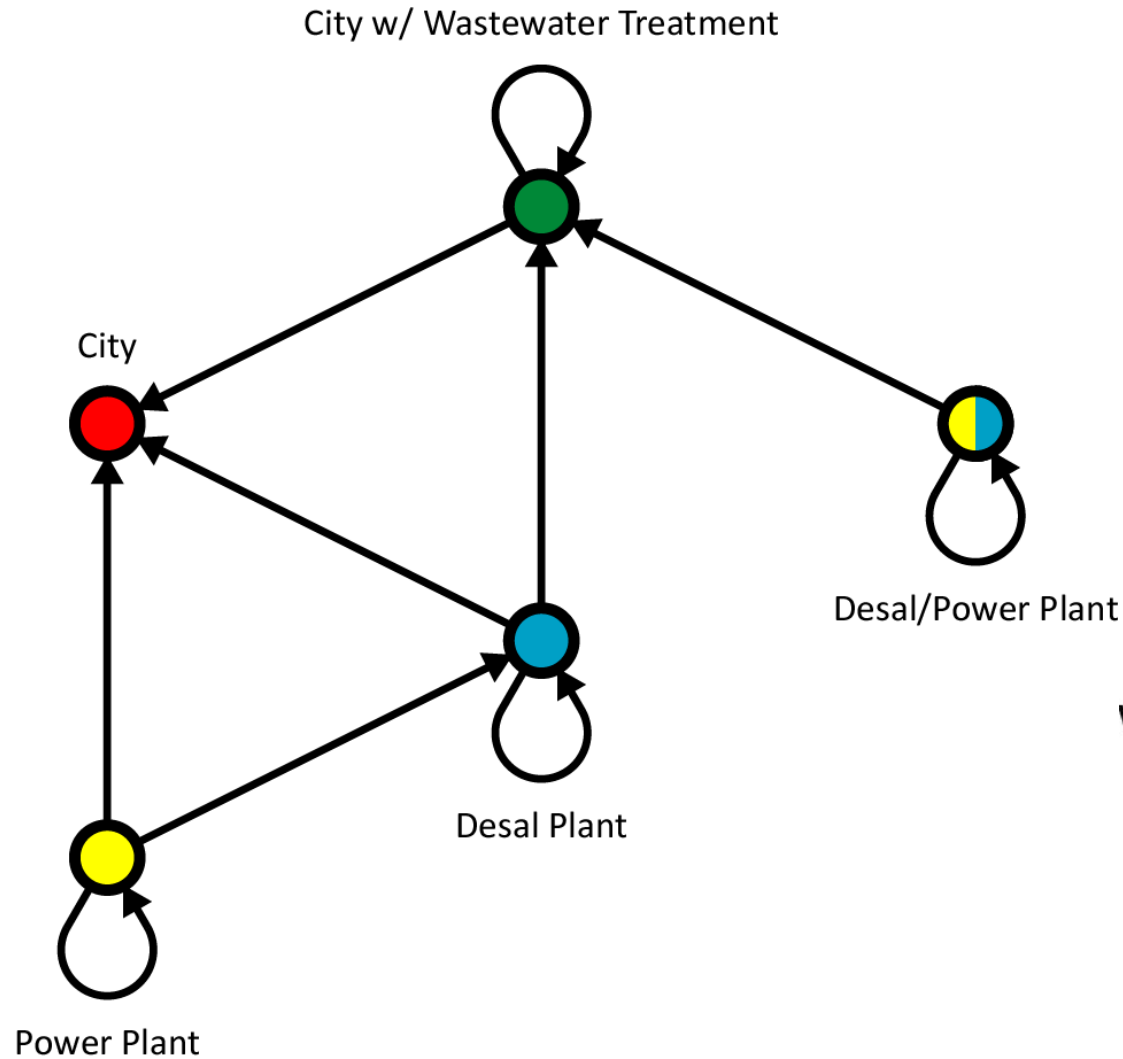


# Seawater Desalination (Fukuoka, Japan)





# Abstraction of Infrastructure Planning Problems



## Graph Loop:

An edge connecting a node to itself, modeling “facility”

## vector (decision variables):

$$x = \begin{bmatrix} \text{feed water} \\ \text{Potable water} \\ \text{non-potable water} \\ \text{wastewater} \\ \text{power resource} \\ \text{electricity} \end{bmatrix}$$

# Generalized Multi-Commodity Network Flow (GMCNF) Model

Minimize:

$$\sum_{a \in \mathcal{A}} (c^{a+T} x^{a+} + c^{a-T} x^{a-})$$

subject to:

$$\sum_{a \in \mathcal{A}_{i+}} A^{a+} x^{a+} - \sum_{a \in \mathcal{A}_{i-}} A^{a-} x^{a-} \leq b^i \quad \forall i \in \mathcal{N}$$

Mass Balance

$$B^a x^{a+} = x^{a-} \quad \forall a \in \mathcal{A}$$

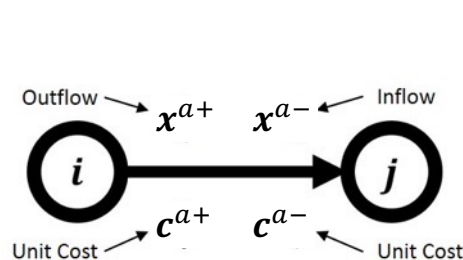
Flow Transformation

$$C^{a\pm} x^{a\pm} \leq d^{a\pm} \quad \forall a \in \mathcal{A}$$

Flow Concurrency

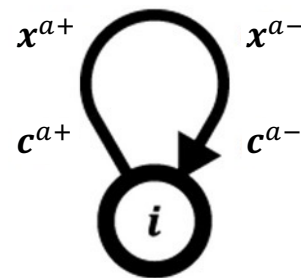
$$l^{a\pm} \leq x^{a\pm} \leq u^{a\pm} \quad \forall a \in \mathcal{A}$$

Flow Bound



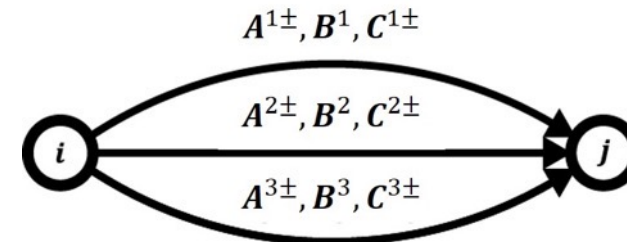
**Arc (normal):**

Modeling transport/movement



**Graph Loop:**

Modeling a resource processing facility/event



**Multigraph:**

Allowing multiple (parallel) arcs between the same end nodes

\*Each arc has a different set of  $ABC$  matrices

**$A^{a\pm}$ : Flow Equilibrium Matrix**

Outflow  $x^{a+}$  requires sending out  $A^{a+} x^{a+}$  at node  $i$   
Inflow  $x^{a-}$  requires receiving  $A^{a-} x^{a-}$  at node  $j$

**$B^a$ : Flow Transformation Matrix**

$x^{a+}$  is transformed into  $x^{a-}$  on arc  $a$   
 $x^{a-} = B^{a(e)} \dots B^{a(3)} B^{a(2)} B^{a(1)} x^{a+}$

**$C^{a\pm}$ : Flow Concurrency Matrix**

$x^{a\pm}$  satisfies concurrent flow constraints on arc  $a$





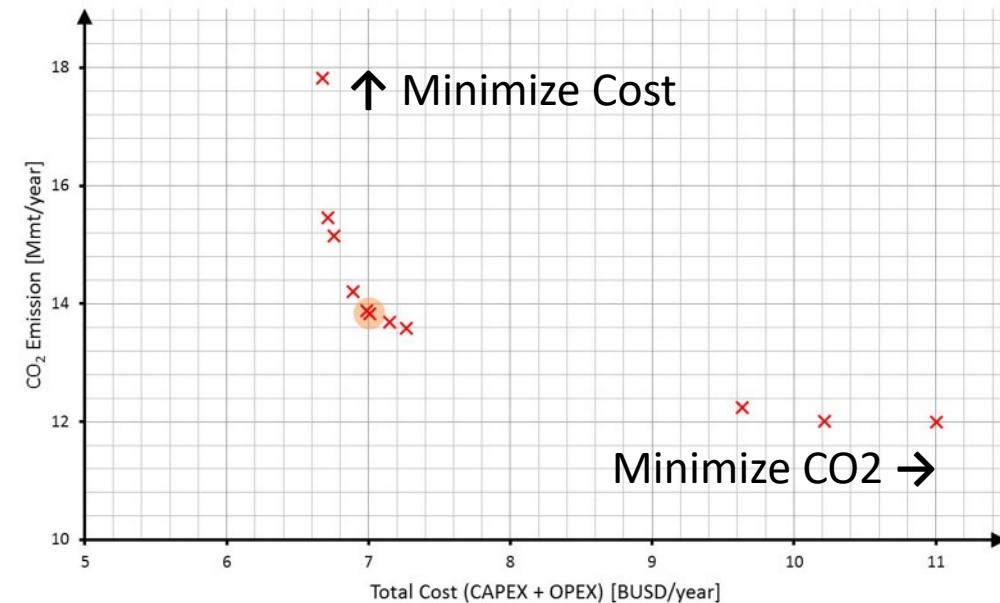
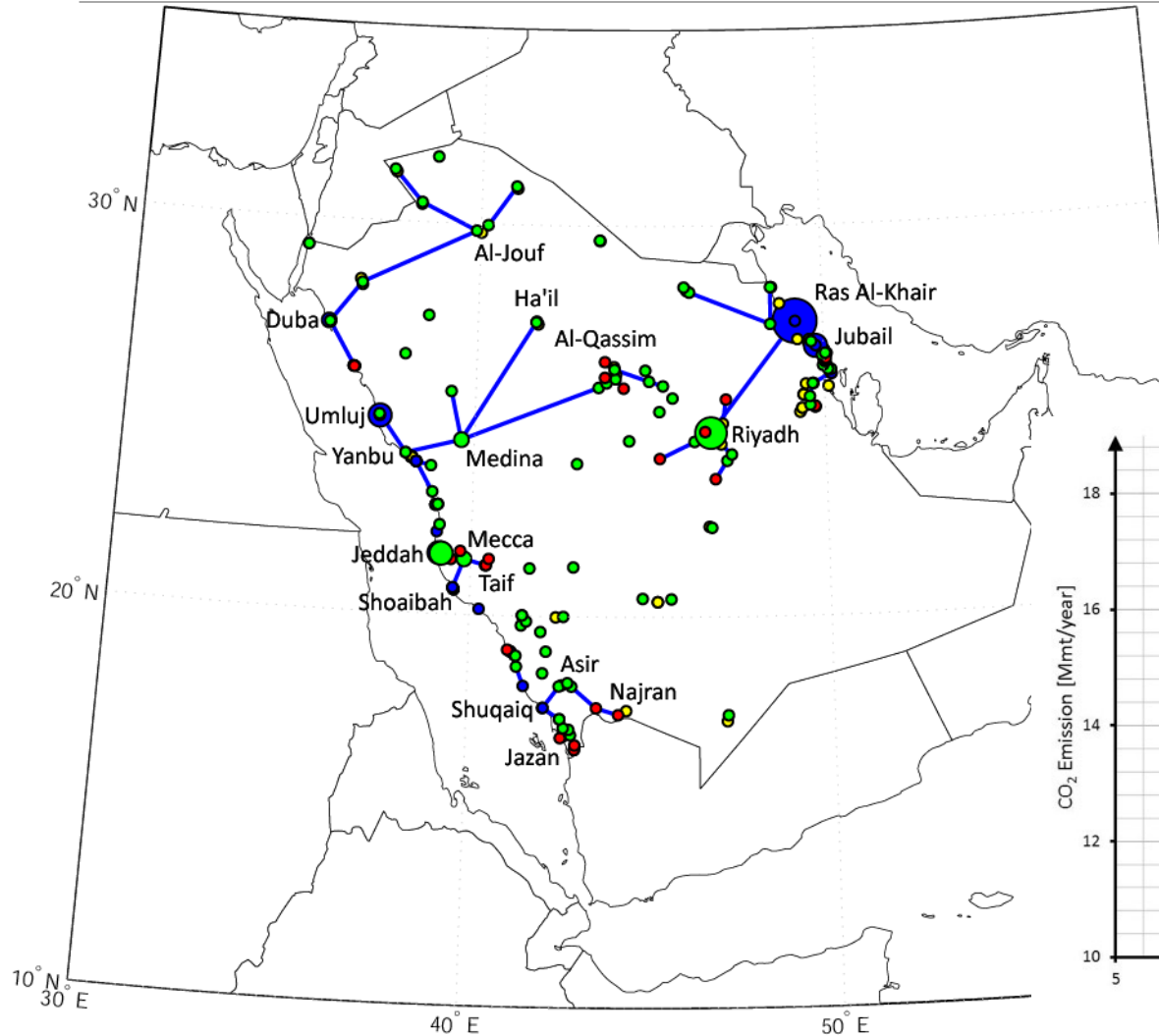
# KSA Water/Energy Infrastructure 2010 → 2030

## Multi-objective optimization

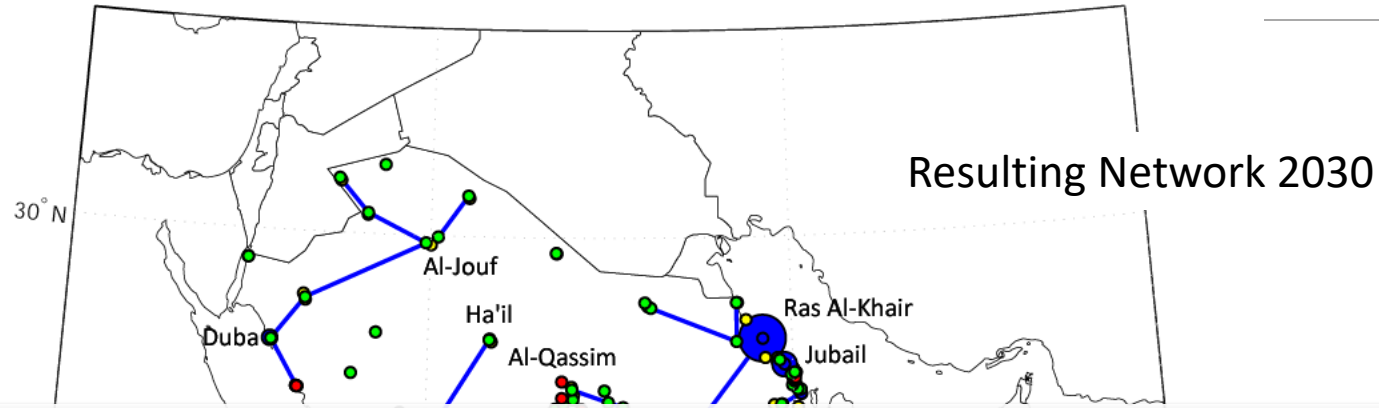
Minimize:

- **Cost (= CAPEX + OPEX)**
- **CO<sub>2</sub> emission**

**Pareto-optimal solutions with different network topology**

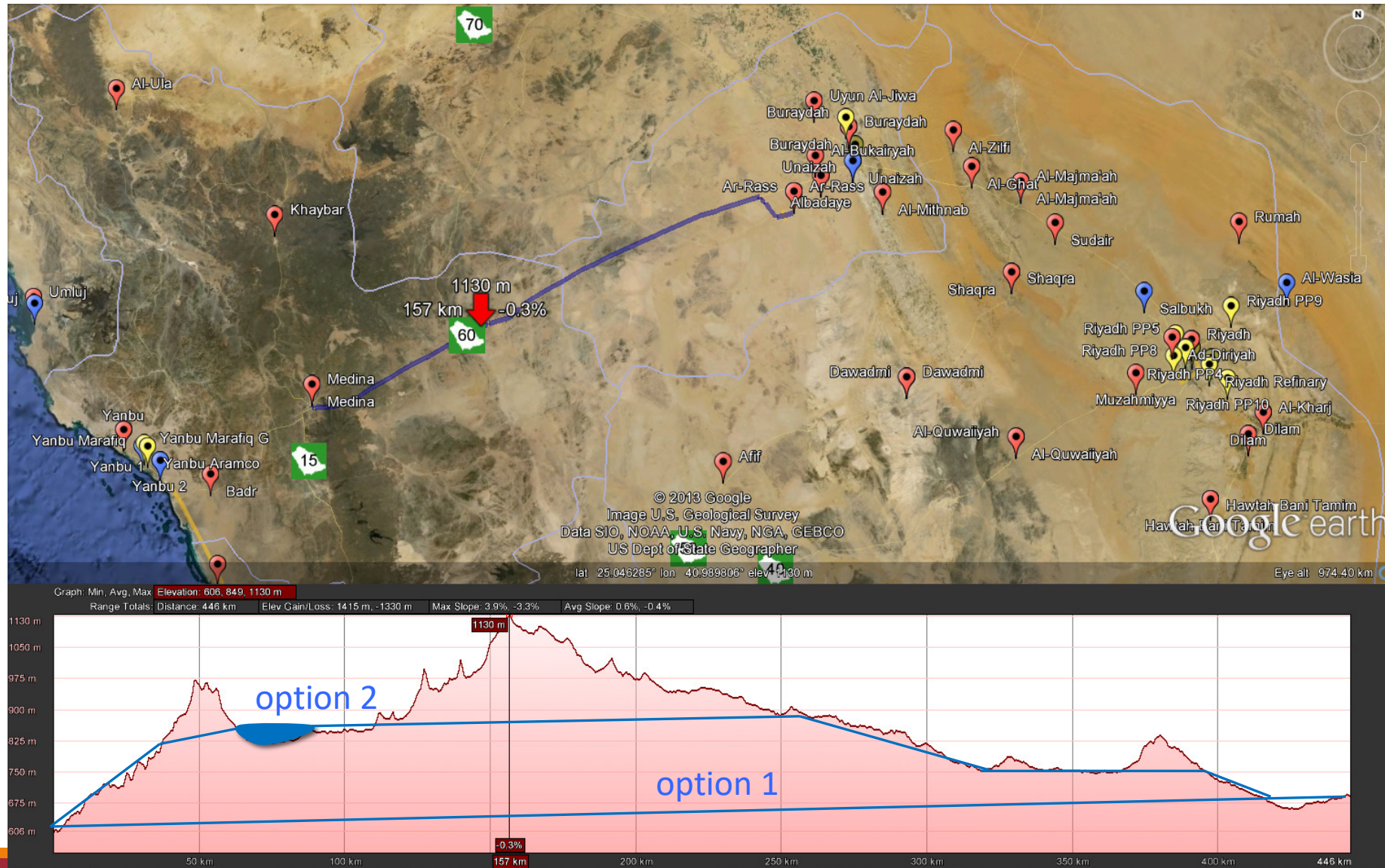


# Ranked List of Top 10 Capital Projects



Rank	CAPEX [MUSD/year]	Investment Purpose	Location	Technology	Capacity	Distance [km]
1	201.0	Desal Plant Construction	Ras Al-Khair	SWRO	2512300 [m <sup>3</sup> /day]	
2	87.7	Desal Plant Capacity Expansion	Jeddah	SWRO	1096600 [m <sup>3</sup> /day]	
3	74.5	Desal Plant Capacity Expansion	Jubail	SWRO	931300 [m <sup>3</sup> /day]	
4	73.1	Desal Plant Capacity Expansion	Umluj	BWRO	914090 [m <sup>3</sup> /day]	
5	21.9	Desal Plant Capacity Expansion	Duba	BWRO	273230 [m <sup>3</sup> /day]	
6	19.2	Pipeline Construction	Ras Al-Khair - Riyadh			479
7	18.4	Pipeline Construction	Medina - Ha'il			460
8	17.8	Pipeline Construction	Medina - Ar-Rass			446
9	16.8	Pipeline Construction	Tabuk - Dumat Al-Jandal			421
10	15.9	Power Plant Construction	Ras Al-Khair	Gas	793 MW	

# Strategic Project: Medina-Ar-Rass Water Pipeline



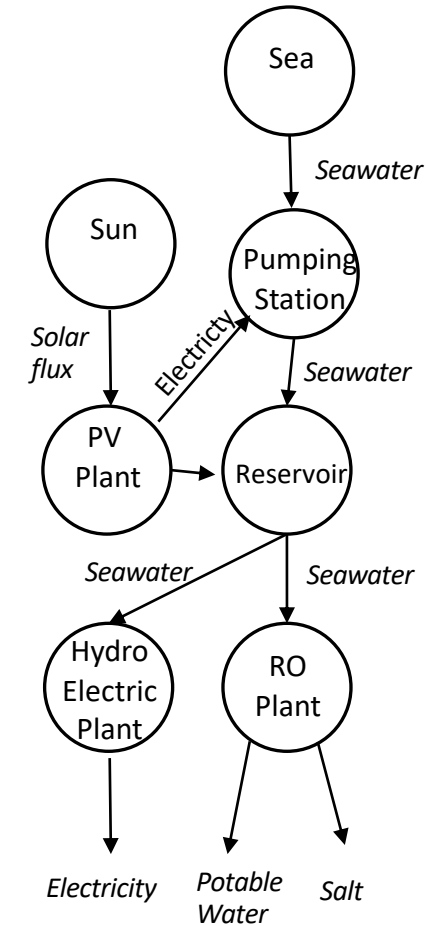


# Potential Seawater-Pumped Storage

沖縄やんばる海水揚水発電所



[https://en.wikipedia.org/wiki/Okinawa\\_Yanbaru\\_Seawater\\_Pumped\\_Storage\\_Power\\_Station](https://en.wikipedia.org/wiki/Okinawa_Yanbaru_Seawater_Pumped_Storage_Power_Station)



First Seawater-pumped Hydro-power station in the world (1999) is in Japan !

# GMCNF Applications

	Equilibrium $A^{a\pm}$	Transformation $B^a$	Concurrency $C^{a\pm}$	Loop	Multigraph
Space Logistics	✓	✓	✓	✓	✓
Water/Energy Infrastructure	✓	✓		✓	
Intermodal Transportation		✓	✓		✓
EV Itinerary Planning		✓	✓	✓	
TSP		✓		✓	

# Typical Problem Sizes in GMCNF

	Space Logistics Network	Saudi Arabia Water Planning	Multi-Modal Transportation
# of Nodes	18	208	1,251
# of Arcs	601 (incl. loops)	812 (incl. loops)	4,380 (incl. virtual arcs)
# of Commodities	20	6	29
A Matrix for equality constraints	12,020 x 24,040	4,872 x 21,112	0 (reduced GMCNF)
A Matrix for inequality constraints	5,591 x 24,040	20,736 x 21,112	300,483 x 127,020





**33<sup>rd</sup>** Annual **INCOSE**  
international symposium

hybrid event

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July 15 - 20, 2023

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