COMPLEXITY:
What is it? Why is it important?

Thomas Homer-Dixon
October 6, 2020
Mission Statement: The Cascade Institute will identify high-leverage intervention points in cognitive, institutional, and technological systems that, if effectively exploited, could shift global civilization away from a path that leads to calamity and towards one that leads to fair and sustainable prosperity.

www.cascadeinstitute.org
What is a “system”?

A system consists of:

1. *components*,
2. *links* between those components,
3. a *persistent pattern* of relationships among those links,
4. a *flow of energy* through the links that sustains the pattern, and
5. a *boundary* of some kind.
In representations of systems, links can stand for:

- *Flows* (of material, energy, and/or information between system components);
- *Causal relationships* (between state variables); or
- *Semantic or intensional* relations between meaningful mental states.

Flow “maps” tend to represent *specific systems* (i.e., they’re idiographic); causal “maps” tend to represent *classes of systems* (i.e., they’re nomothetic). Mental maps can represent the belief/value states of either individuals or of classes of individuals.
3 systems:
- Heat generation
- Heat distribution
- Heat control
Stock/flow model

- Oil tank
- Boiler
- CO₂
- Heat
Causal model

- Thermostat signal
  - AND
  - Oil
    - AND
    - Boiler
  - Combustion
    - CO₂
    - Heat
Semantic/intensional model

Winter

Cold (discomfort / death)

Oil

Boiler

Thermostat

Warmth (comfort / survival)
COMPLEXITY
The basic story
WE ARE BEING CONTROLLED BY THE RANDOM OUTCOMES OF A COMPLEX SYSTEM
We need to shift from seeing the world as mainly composed of

SIMPLE MACHINES

to seeing it as increasingly composed of

COMPLEX SYSTEMS
We commonly assume that **SIMPLE MACHINES**

- can be taken apart, analyzed, and fully understood (they are no more than the sum of their parts),
- show proportionality of cause and effect,
- exhibit “normal” or equilibrium patterns of behavior, and therefore
  - can be managed, because their behavior is predictable.
COMPLEX SYSTEMS

• are more than the sum of their parts (they have *emergent properties*).

• show disproportionality of cause and effect (their behavior is often *nonlinear*, because of *feedbacks* and *synergies*),

• can flip from one pattern of behavior to another (they have *multiple equilibriums*), and therefore

• CANNOT be easily managed, because their behavior is often *unpredictable*. 
Equilibrium
Multiple equilibriums
Tipping Event
What is causing our economies and societies to become more complex?

Key factor: Performance improvements at the level of system units, i.e., organizations, firms, people, and technologies, especially due to advances in information technology.
One result: our networks have more nodes, more connections, and faster movement of material, energy, and information along these connections. They are more “tightly coupled.”
Greater connectivity sometimes causes technologies, institutions, procedures, and cultures to become more homogenous. Diversity declines.
Complexity can be a good thing, because it’s a source of:

*Innovation*

(through novel combinations, if diversity is maintained)

and

*Adaptability*

(through distributed problem solving)
Complexity can be a bad thing, because it can cause:

- *System opaqueness*
CHEVY ENGINE, 1960s
Complexity can be a bad thing, because it can cause:

*System opaqueness*

- *Cascading failures*
  (connectivity x low diversity = danger)
Complexity can be a bad thing, because it can cause:

* System opaqueness

* Cascading failures

and

- System flips
COMPLEXITY
Going deeper
(with help from Matto Mildenberger, UCSB)
PROPERTIES OF COMPLEXITY

Constitutive properties (causes) → Behavioral properties (observable effects)
PROPERTIES OF COMPLEXITY

Constitutive properties (complexity’s causes)

- Connectivity
- Interactive causation
- Feedbacks
- Diversity
- Decentralization
- Thermodynamic openness
- Large energy gradients
- Competition
- Evolution

Behavioral properties (its observable effects)

- Emergence
- Thermodynamic disequilibrium
- Nonlinearity
- Multiple equilibriums
- Unpredictability
- Sensitivity to initial conditions
- Path dependency
- Contingency
- Power-law frequency distributions
Complexity, Core Constitutive Properties

Non-adaptive complexity

Adaptive complexity
Complexity, Core Constitutive Properties

Non-adaptive complexity

Causation with interaction in densely and recursively connected systems.

Adaptive complexity

All of above, plus agents with internal models of external environment that govern behavioral response to this environment and that coevolve under selection pressure.
Complex systems

Complex adaptive systems

Complex representational adaptive systems
Complex system

Complex adaptive system
Complex representational adaptive system
<table>
<thead>
<tr>
<th>Places to Intervene in a System</th>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>In Order of Increasing Effectiveness</strong></td>
<td></td>
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<tr>
<td><em>(according to Donella Meadows)</em></td>
<td></td>
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<tr>
<td>12. Constants, parameters, numbers (such as subsidies, taxes, standards)</td>
<td></td>
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<tr>
<td>11. The sizes of buffers and other stabilizing stocks, relative to their flows</td>
<td></td>
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<tr>
<td>10. The structure of material stocks and flows (such as transport networks, population age structures)</td>
<td></td>
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<tr>
<td>9. The lengths of delays, relative to the rate of system change</td>
<td></td>
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<tr>
<td>8. The strength of negative feedback loops, relative to the impacts they are trying to correct against</td>
<td></td>
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<tr>
<td>7. The gain around driving positive feedback loops</td>
<td></td>
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<tr>
<td>6. The structure of information flows (who does and does not have access to what kinds of information)</td>
<td></td>
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<td>5. The rules of the system (such as incentives, punishments, constraints)</td>
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<tr>
<td>4. The power to add, change, evolve, or self-organize system structure</td>
<td></td>
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<tr>
<td>3. The goals of the system</td>
<td></td>
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<tr>
<td>2. The mindset or paradigm (worldview) out of which the system—its goals, structure, rules, delays, parameters—arises</td>
<td></td>
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<tr>
<td>1. The power to transcend paradigms</td>
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# CI’s conceptualization of high-leverage intervention points (HLIPs)

<table>
<thead>
<tr>
<th>Potential effectiveness of intervention (at identified point)</th>
<th>System sensitivity to intervention (at identified point)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Meadows, top of list</td>
<td>High</td>
</tr>
<tr>
<td>HLIPs</td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Not of interest</td>
<td>High</td>
</tr>
<tr>
<td>Meadows, bottom of list</td>
<td></td>
</tr>
</tbody>
</table>

**Potential effectiveness of intervention (at identified point)**

- High: Meadows, top of list
- Low: Not of interest

**System sensitivity to intervention (at identified point)**

- Low: Meadows, bottom of list
- High: HLIPs
Cascade Institute: Scientific Foundations

1. Complexity Science

• High causal interaction
• Feedback loops
• Nonlinear behavior ("tipping events")
Cascade Institute: Scientific Foundations

2. WIT Analysis

Diagram:

- Worldviews
- Institutions
- Technologies
Overcoming systemic roadblocks to sustainability: The evolutionary redesign of worldviews, institutions, and technologies

Rachael Beddoe,a Robert Costanza,a,b Joshua Farley,a,c Eric Garza,a,b Jennifer Kent,d Ida Kubiszewski,a,b Luz Martinez,a,b Tracy McCowen,c Kathleen Murphy,a Norman Myers,d,1 Zach Ogden,c Kevin Stapleton,c and John Woodward,c

aRubenstein School of Environment and Natural Resources, George D. Aiken Center, bGund Institute for Ecological Economics, and cCommunity Development and Applied Economics, University of Vermont, Burlington, VT 05405; dIndependent Environmental Researcher, Oxford OX4 3SE, United Kingdom; and e21st Century School, Oxford University, Oxford OX3 8FS, United Kingdom

Contributed by Norman Myers, December 16, 2008 (sent for review October 9, 2008)
Personal liberty → Free markets → Private cars → Personal liberty
## Cascade Institute: Change mechanisms

<table>
<thead>
<tr>
<th><strong>Beliefs</strong></th>
<th>Concept meanings arise holistically from people’s networks of beliefs; these networks can be strategically restructured.</th>
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</thead>
<tbody>
<tr>
<td><strong>Emotions</strong></td>
<td>People strive for emotional coherence in their networks of beliefs. On environmental issues, powerful emotions include fear, sadness, disgust, hope, and awe.</td>
</tr>
<tr>
<td><strong>Norm cascades</strong></td>
<td>Norms emerge from the conjunction of beliefs about ethical principles and the emotional resonance of those beliefs. Norm dissemination is a nonlinear function of social network structure, interaction rates, cultural sanctions on novelty, and homophily (attraction to like others). <em>Contagion model.</em></td>
</tr>
<tr>
<td><strong>Political mobilization</strong></td>
<td>Mobilization depends on the nature of the audience and on the audience’s degree of engagement. Second-order beliefs (beliefs about others’ beliefs) are a key variable. <em>Critical transition model.</em></td>
</tr>
<tr>
<td><strong>Financial risk</strong></td>
<td>Risk estimates shift as market expectations coordinate around lower returns on fossil-fuel investments and as new accounting practices diffuse through financial networks. <em>Contagion and critical transition models.</em></td>
</tr>
</tbody>
</table>
Cascade Institute: System-mapping Tools

- Boolean causal loop analysis (BCLA)
- Cognitive affective mapping (CAM)
- Cross-impact balance analysis (CIB)
- State-space modeling
- Assemblage mapping
## Cascade Institute: Research methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
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<tr>
<td>Set-theoretic causal loop analysis</td>
<td>Integrates Boolean logic with standard causal diagraming to produce much clearer representations of feedbacks and interactive effects in complex social systems.</td>
</tr>
<tr>
<td>Cross-impact balance analysis</td>
<td>Formalizes qualitative descriptions of causation in complex social systems; allows for analysis of sudden nonlinear change in those systems.</td>
</tr>
<tr>
<td>Cognitive-affective mapping</td>
<td>Encodes positive/negative emotional intensity in concept maps of people’s worldviews.</td>
</tr>
<tr>
<td>State-space modeling</td>
<td>Represents distance between worldviews and possible pathways of change between them.</td>
</tr>
<tr>
<td>Assemblage mapping</td>
<td>Represents internalized or instrumentalized status of worldviews across individuals, identifying possibilities for worldview “tipping points” within groups.</td>
</tr>
</tbody>
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Cascade Institute: Current Projects

1. MAPPING DANGEROUS INTER-SYSTEMIC CASCADES
Behind the mask: Anti-mask and pro-mask attitudes in North America

Scott Janzwood & Michelle Lee

September 15, 2020 • This Brief reviews the emerging scientific evidence on the effectiveness of masks for preventing the spread of COVID-19 and offers strategies for addressing persistent anti-scientific beliefs around masks, COVID-19 and other issues.

Read More ➔

Shocking global inequality

Michael Lawrence

August 25, 2020 • This Brief examines how the COVID-19 pandemic is interacting with entrenched structural inequalities between the wealthiest and the most marginalized segments of humanity.

Read More ➔

Evacuating communities affected by disasters during future COVID-19 waves

Scott Janzwood

July 7, 2020 • This Brief investigates the challenges of evacuating communities from natural disasters during possible future “waves” of COVID-19 cases.

Read More ➔
Cascade Institute: Current Projects

2. IDENTIFYING POSSIBILITIES FOR RAPID BELIEF AND VALUE CHANGE

CI Technical Paper (April 27, 2020)

The Social Distancing Norm Cascade: The role of belief systems in accelerating normative change during the COVID-19 pandemic

Scott Janzwood
“Norm cascade” theory of change

- Beliefs
- Emotions
- Norm cascades
- Political mobilization
- Realized financial risk
- Tipping to clean-energy transition

Complex social cognition

Worldviews

Complex social action

Institutions

Complex financial/technological outcomes

Technologies
Cascade Institute: Current Projects

3. PRODUCING EDUCATIONAL TOOLS TO IMPROVE YOUTH UNDERSTANDING OF, AND EFFECTIVE RESPONSES TO, COMPLEX NATIONAL AND GLOBAL PROBLEMS

Practical complex-systems curricular materials
Micro-credential programs
Emotional training