The implications of complexity

James J. Kay

- **Open** to material and energy flows.
- **Nonequilibrium**: Exist in quasi-steady states some distance from equilibrium.
- **Thermodynamics:** Maintained by energy **gradients** (exergy) across their boundaries. The gradients are **irreversibly** degraded (the exergy is used) in order to build and maintain organization. These systems maintain their organized state by exporting entropy to other hierarchical levels.
- **Propensities**: As **dissipative** systems are moved away from equilibrium they become organized:
  - they use more exergy
  - they build more structure
  - this happens in spurts as new attractors become accessible.
  - it becomes harder to move them further away from equilibrium
- **Feedback loops**: Exhibit material or energy **cycling**: Cycling and especially autocatalytic cycling is intrinsic to the nature of dissipative systems. The very process of cycling leads to organization. **Autocatalysis** (positive feedback) is a powerful organizational and selective process.
- **Hierarchical:** Are **holarchically nested**. The system is nested within a system and is made up of systems. Such nestings cannot be understood by focusing on one hierarchical level (holon) alone. Understanding comes from the multiple perspectives of different **types** and **scale**.
- **Multiple Steady States:** There is **not** necessarily a unique preferred system state in a given situation. **Multiple attractors** can be possible in a given situation and the current system state may be as much a function of historical accidents as anything else.
- Exhibit **chaotic** and **catastrophic** behavior. Will undergo dramatic and sudden changes in **discontinuous** and **unpredictable** ways.
  - **Catastrophic Behaviour:** The norm
    - Bifurcations: moments of unpredictable behaviour
    - Flips: sudden discontinuities, rapid change
    - Holling four box cycle Shifting steady state mosaic
  - **Chaotic Behaviour:** our ability to forecast and predict is always limited, for example to between five and ten days for weather forecasts, regardless of how sophisticated our computers are and how much information we have.
- **Dynamically Stable?:** There may not exist equilibrium points for the system.
- **Non-Linear:** Behave as a whole, a **system**. Cannot be understood by simply decomposing into pieces which are added or multiplied together.
- **Internal Causality:** non-Newtonian, not a mechanism, but rather is **self-organizing**. Characterized by: goals, positive and negative feedback, autocatalysis, emergent properties and surprise.
- **Window of Vitality:** Must have enough complexity but not too much. There is a range within which self-organization can occur. Complex systems strive for **optimum**, not minimum or maximum.

Problematique of Complexity

- Irreducible uncertainty
- Multiple attractors
- Hierarchical (scale and type)
  - Multi scale
  - Multiple perspectives
  - Nested

- Do not confuse complicated with complex

So what changes?

- Our understanding of how the world works
- Explanation
- How we frame a situation
- Raison d'être
- The role of the expert and science
- Who is involved in decision making
- Management, governance, monitoring
- Measures of quality

Our understanding of how the world works

- Clock work
  - mechanism
- Cause and effect can be separated
- Predictable in principle
- Science can tell us the correct answer

- Self-organizing
  - evolving and emergence, rapid change, flips, attractors, nested holarchies
- Effect is cause, feedback loops dominate
- Irreducible uncertainty
- Science may tell us a set of "correct" answers

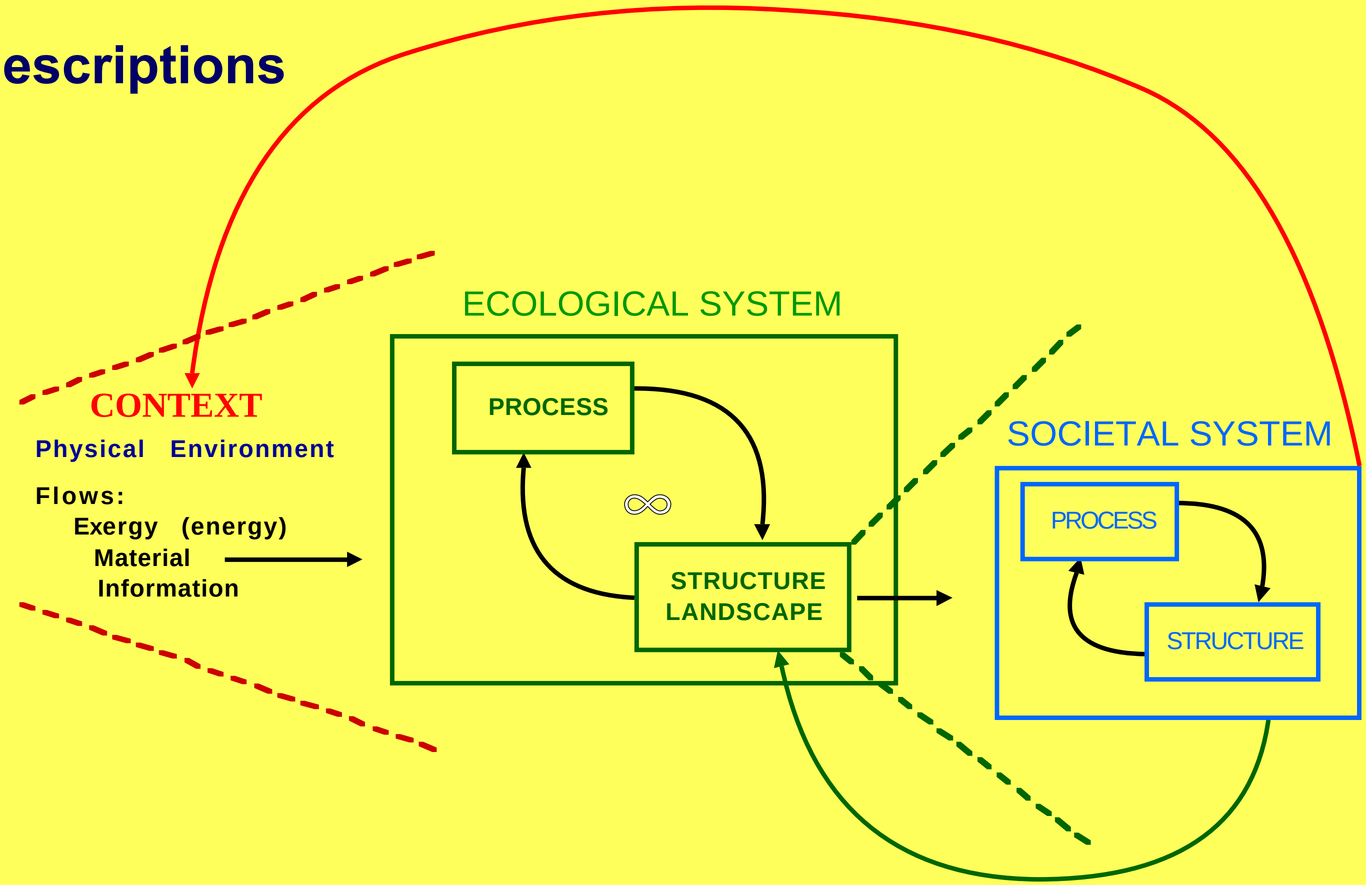
Remember Lake Erie and nutrient loading;

Global climate change issues

How we frame a situation

- Single perspective
- Multiple perspectives and scales

SOHO descriptions



Explanation

- Linear cause and effect
- Predictive quantitative models
- Extremum principles
  - Maximize, minimize

- Effect is cause, feedback loops
- Narratives: self-organization about attractors, canon, propensities
- Optimums, strike a balance, tendencies

Can lead to simple elegant interventions

Raison d'être

- Prediction
- Control
- Find the right answer
  - Solve the problem
- Efficiency

- Understanding
- Adaptive approach
- Charting a course
  - Resolving tradeoffs
- Adaptability, resiliency

Collaborative Learning Systems

Ecosystem Approaches

Integrative Science

The role of the expert and science

- Prediction
- Solve the problem

- Possibilities
- Inform about options, tradeoffs and uncertainties

Post Normal Science
Futures 26, 6 94
Futures 31, 7 99

Who is involved in decision making

- Experts
- Community

Participatory Approaches

(How do you get the public to be bothered?)

Governance & Decision Making

- Find the right answer to solve the problem; move on to the next problem

- Ongoing collaborative learning and resolution of tradeoffs as the situation unfolds.

Requires very different institutional arrangements

The biggest challenge?

Management

- Top down
- Command and Control
- Manage nature
- Anticipatory

- Collaborative learning
- Promote or discourage self-organization about specific attrators
- Managing humans, controlling the context
- Adaptive

See the work of Dean Bavington

Canadian Policy Research Awards, Graduate Prize, 2000

Martin Bunch and Derek Armitage

Monitoring

- Have we done anything wrong?
- What are the problems?
- Error Correction

- Telling the story as it unfolds
- What decisions need to be made?
- Learning

Boyle, M., Kay. J., and Pond, B., 2001. Monitoring in Support of Policy: an Adaptive Ecosystem Approach, in Munn, T., (eds), *Encylopedia of Global Environmental Change*, Volume 5, John Wiley and Son.

Measures of quality

- Prediction
- Facts
- Ability to control
- No surprises
- Solve the problem

- Understanding
  - Possibilities
- Perspectives
- Ability to adapt
- Resiliency, cope with surprise
- Move forward toward sustainability

Rigour?

Advance the transition toward sustainability

(Ecological Integrity & Sustainable Livelihoods)

- Enable collaborative learning systems through infrastructure and policy
- Build the capacity (theory, practice and experience) to operate collaborative learning systems
- Develop an understanding of the co-evolution of biophysical (ecological) and societal systems
  - Further develop complex systems theory

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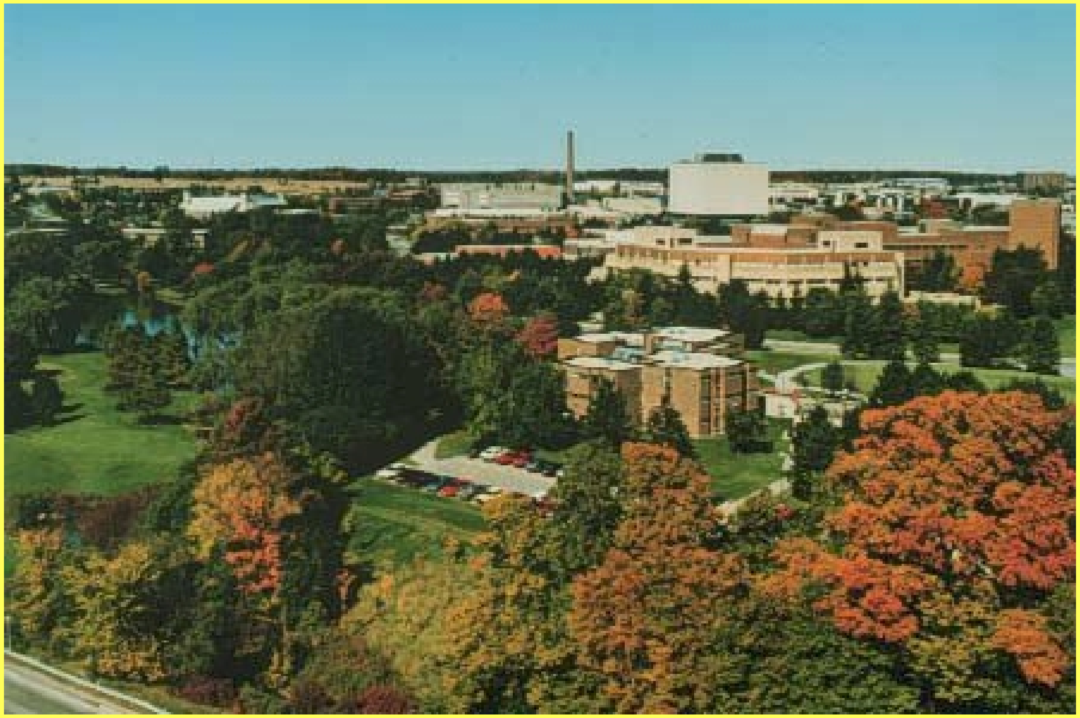

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