# What is Industrial Ecology about?

# Some musings from Complex Systems Theory

James Kay

# Definitions...

- **the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural and technological evolution. The concept requires that an industrial system be viewed not in isolation from its surrounding systems, but in concert with them."**
  Graedel, T. E. and Allenby, B. R. Industrial Ecology. New Jersey: Prentice-Hall; 1995.
- **"… the objective, multidisciplinary study of industrial and economic systems, and their linkages with fundamental natural systems."**
  IEEE electronics and the environment committee . White Paper On Sustainable Development and Industrial Ecology [Web Page]. 1995

# Definitions...

- **"..industrial ecology involves designing industrial infrastructures as if they were a series of interlocking manmade ecosystems interfacing with the natural global ecosystem"**
  Tibbs, B. C. Industrial Ecology: An Environmental Agenda for Industry. Whole Earth Review. 1992(Winter):4-19.

- **"..bringing systems thinking in ecology together with systems engineering (for design of products and processes) and economics"**
  O'Rourke, D.; Connelly, L., and Koshland, C. Industrial Ecology: a critical review. Int. J. Environment and Pollution. 1996; 6(2/3):89-112.

# Working definition

- **Industrial Ecology:**
  - **It is fundamentally about dealing with human transformations of mass and energy (i.e. industrial activities) from an ecosystem perspective.**

# Prospectus

- **Why industrial ecology?**
  - **Sustainable livelihoods and ecological integrity**
- **What do we understand about ecosystems?**
  - **Ecosystems are complex adaptive systems**
- **What is the relationship between "human" and "natural" ecosystems?**
  - **SOHO model**
- **Design Principles?**
- **Production Consumption Model**
- **Industrial Ecology redefined.**

# Raison d'être
# The Normative Basis

- **Sustainable livelihoods**
  - **the socio-economic impetus behind industrial ecology**

- **Ecological integrity**
  - **the bio-physical purpose of industrial ecology**

# Sustainable Livelihoods

- **Sustainable livelihoods is the capability of people to make a living, improve their quality of life, survive shocks and stress, and improve their material condition without jeopardizing the livelihood options of other peoples, either now or in the future. This requires reliance on both capabilities and assets (i.e., stores, resources, claims and accesses) for a means of living..**
  UNDP 1998
- **The UNDP programme on sustainable livelihoods provides a set of tools for evaluating, designing and implementing sustainable livelihoods.**

# Ecological Integrity

- the current organizational state of the system,
- the ability of the system to reorganize in the face of environmental change
- the system's capacity to continue to self-organize in its normal environment, that is to:
  - continue to develop, that is increase its organization relative to an attractor;
  - regenerate, to deal with birth-growth-death-renewal cycle, that is to deal with the multiple nested dual attractor problem; and to
  - continue to evolve, that is switch attractors spontaneously (emergent complexity).

# What do we understand about ecosystems?

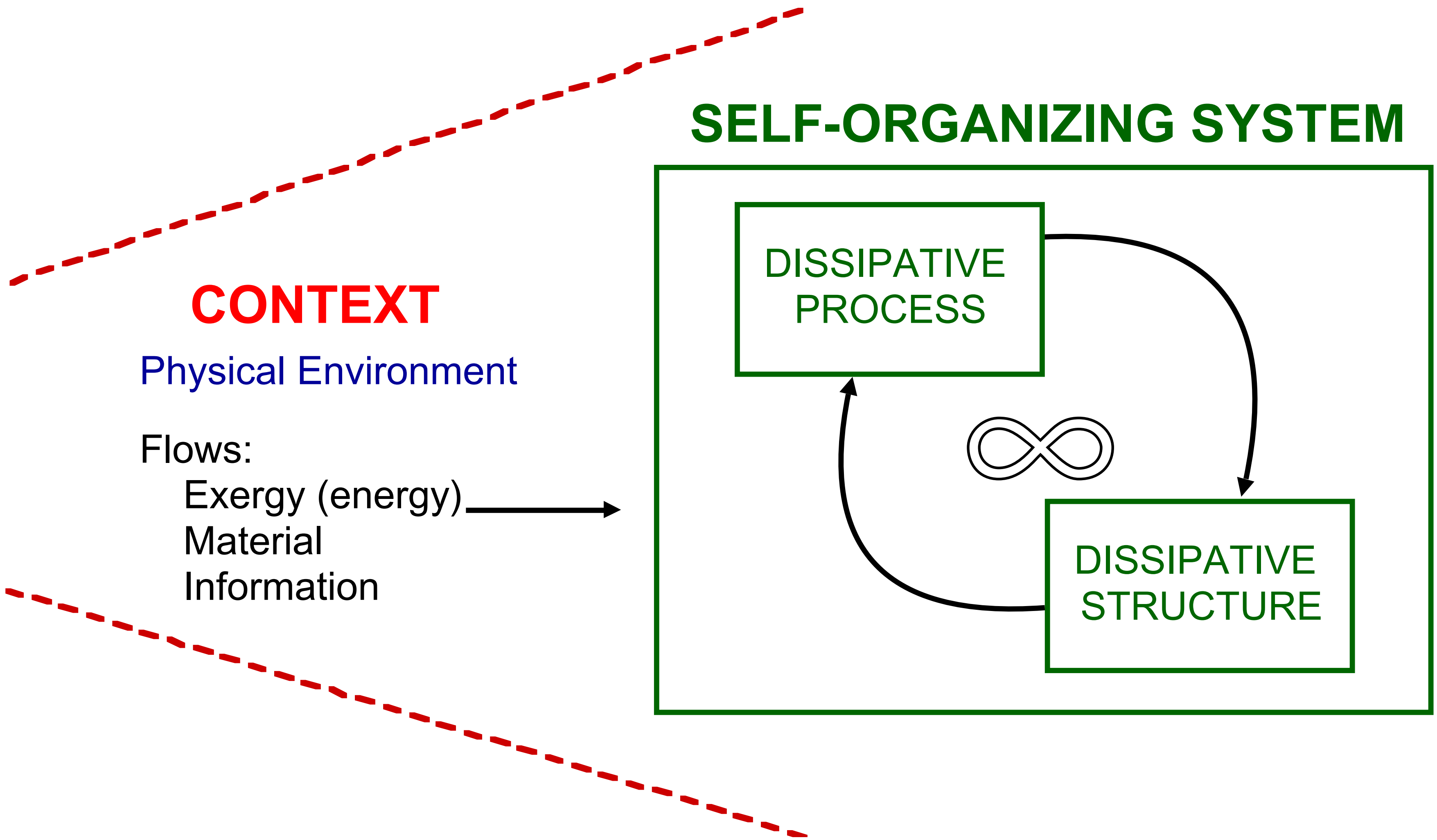
- **Ecosystems are complex adaptive systems**

- **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.

# What is the relationship between "human" and "natural" ecosystems?

- **Self-organizing holarchic open (SOHO) conceptual model**

# Self-organizing holarchic open (SOHO) conceptual model



# Self-Organizing Holarchic Open Systems (SOHO)

- Self-organizing dissipative processes emerge whenever sufficient exergy is available to support them. The details of the processes depend on the raw materials available to operate them, the information present to catalyse the processes, and the physical environment. The interplay of these factors defines the context for (i.e. constrains) the set of processes which may emerge.

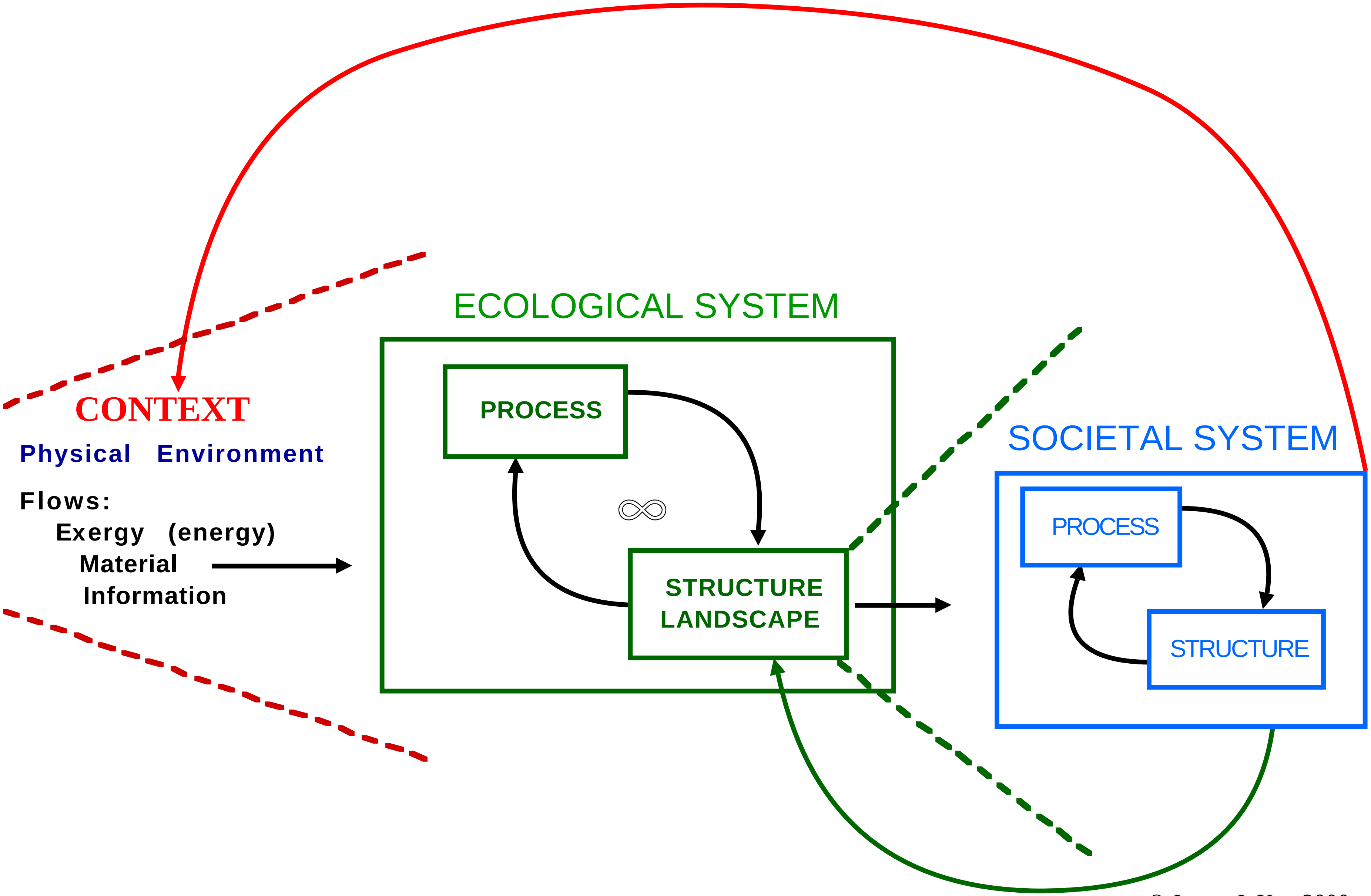
# Self-Organizing Holarchic Open Systems (SOHO)

- Once a dissipative process emerges and becomes established it manifests itself as a **structure**.
- These structures provide a new context, nested within which new processes can emerge, which in turn beget new structures, nested within which...
- Thus emerges a **SOHO system**, a nested constellation of self-organizing dissipative process/structures organized about a particular set of sources of exergy, materials, and information, embedded in a physical environment.

# Self-Organizing Holarchic Open Systems (SOHO)

- **The canon of the SOHO system is the complex nested interplay and relationships of the processes and structures, and their propensities, that give rise to coherent self-perpetuating behaviours, that define the attractor**

# ECO-ECO Model



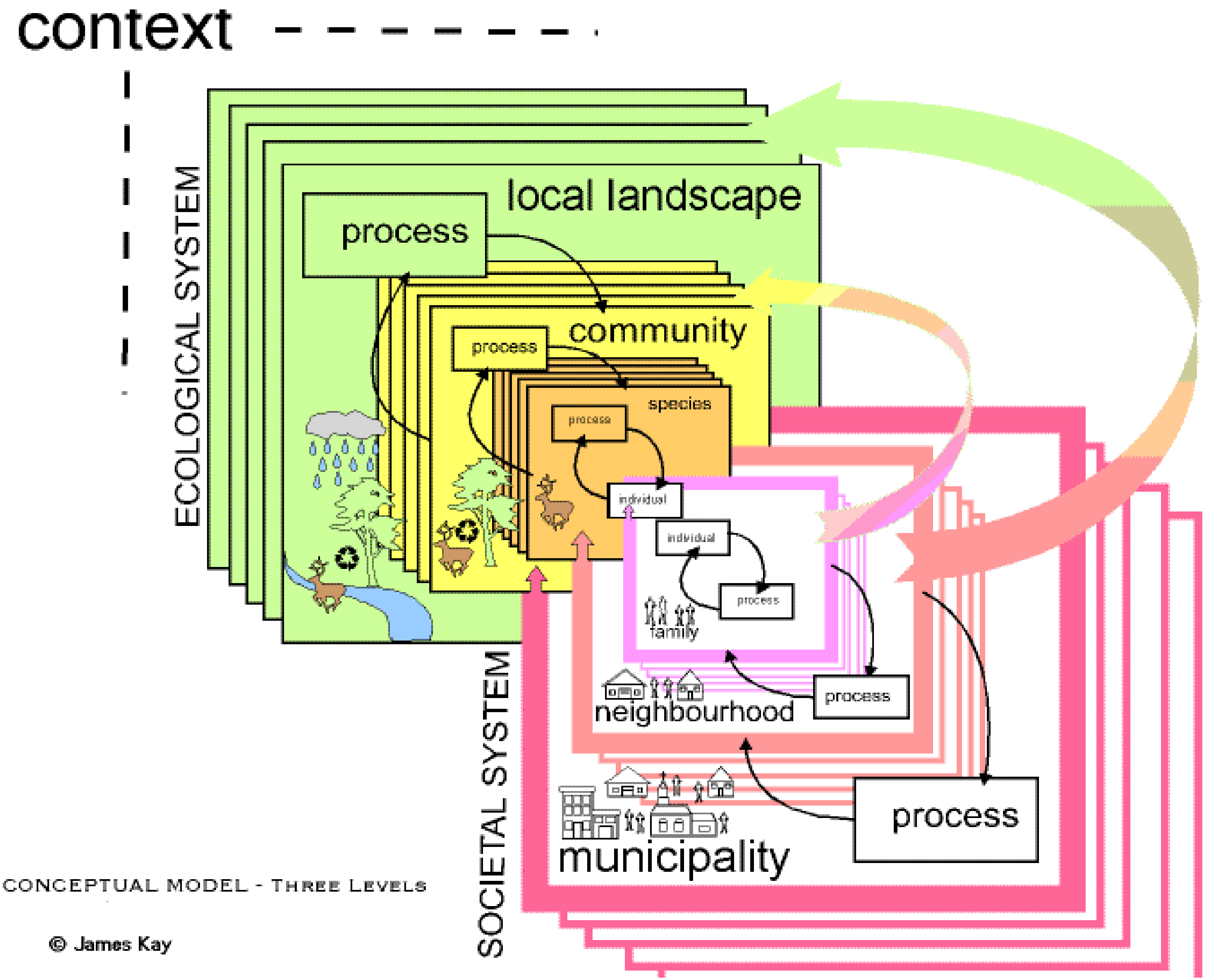
# Societal systems ⇔ Ecological systems

- **Ecological systems provide the context for societal systems.**
  - **That is, they provide the biophysical surroundings and flows of exergy, material and information that are required by the self-organizing processes of the societal systems.**
- **Societal systems can alter the structures in ecological systems.**
  - **For example, cutting down a woodlot, removing beaver from a watershed.**
  - **N.B. Changes in the ecological structure can then, of course, alter the context for the societal systems themselves.**

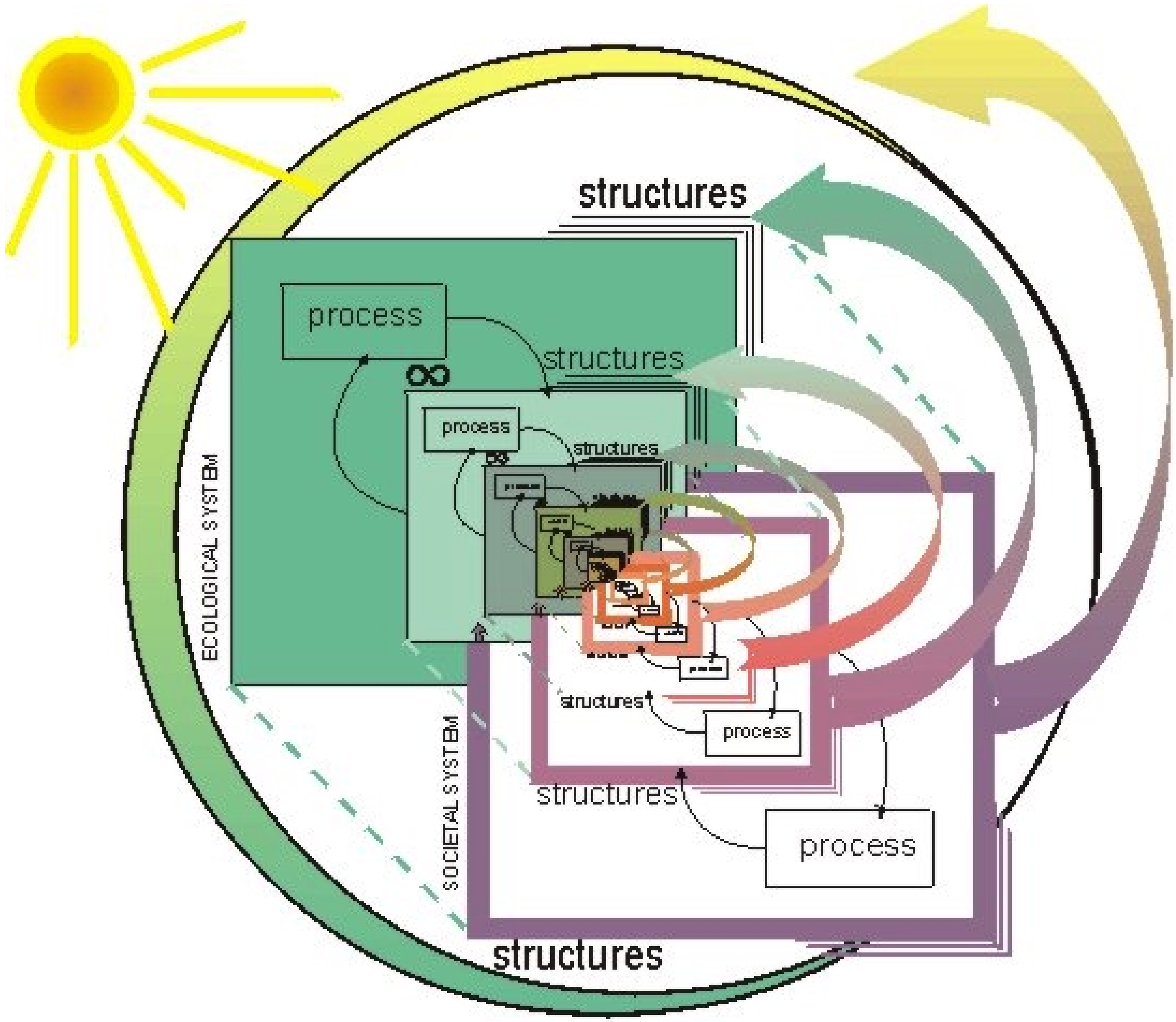
# Societal systems ⇔ Ecological systems

- **Societal systems can alter the context for the self-organizing processes of ecological systems.**
  - **For example, a change in the drainage patterns into a wetland, a change in the local micro-climate, such as a heat island effect, for a woodlot.**
  - **N.B. Changes in ecological process can alter ecological structure and consequently the context for societal systems.**

- **Each of these represents a qualitatively different aspect of the relationship between ecological and societal systems that should be considered.**




CONCEPTUAL MODEL - THREE LEVELS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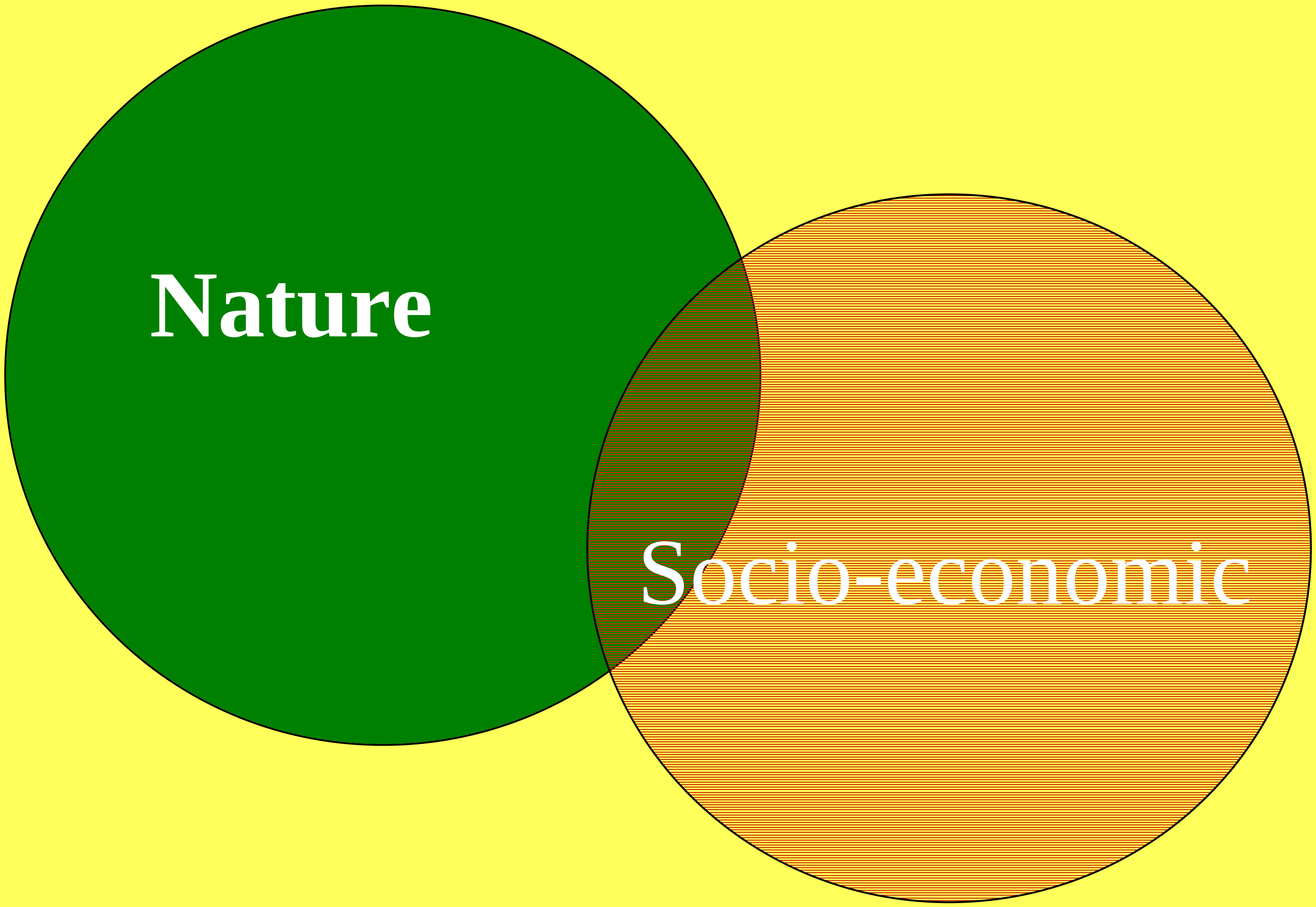

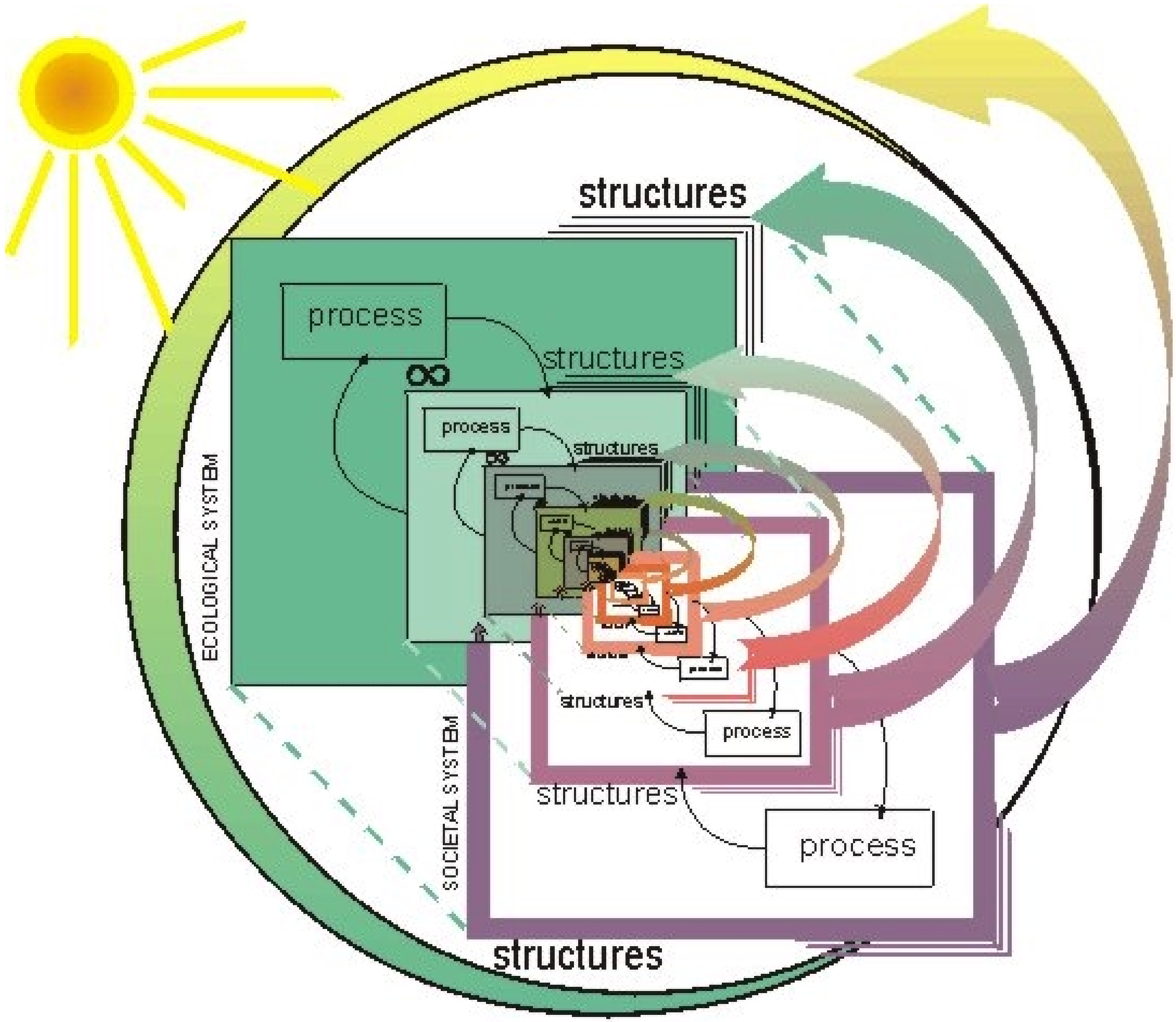
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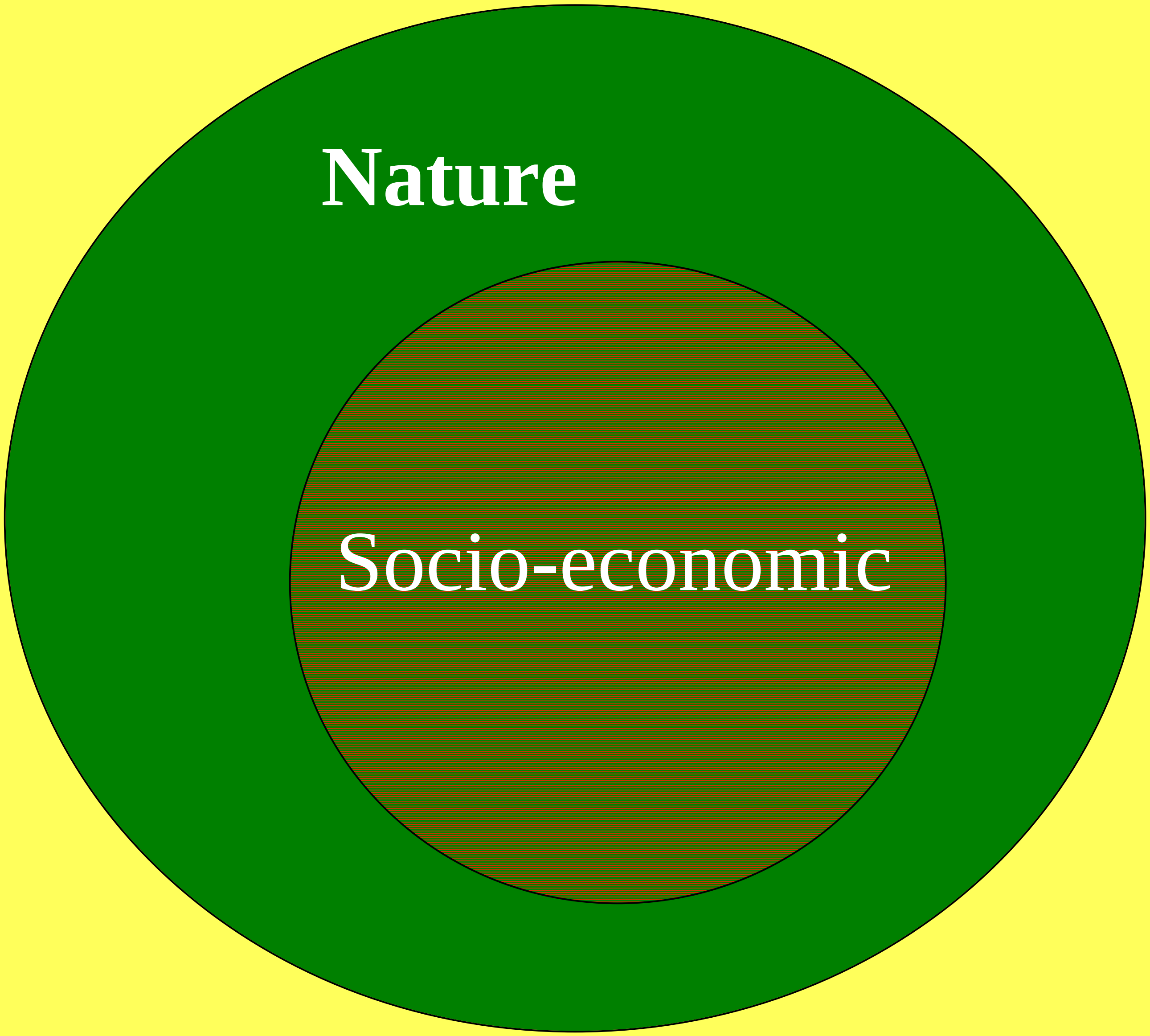

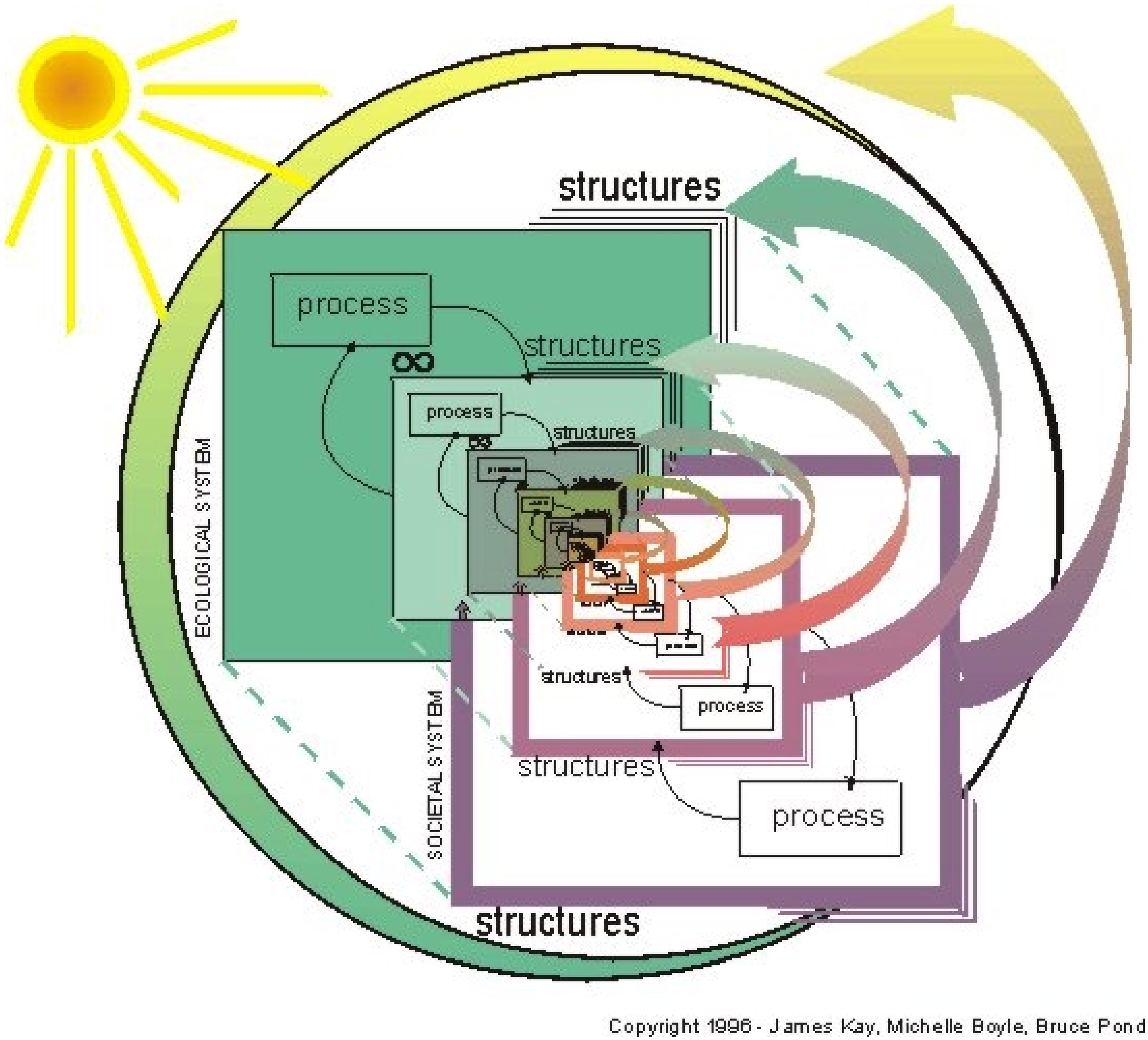
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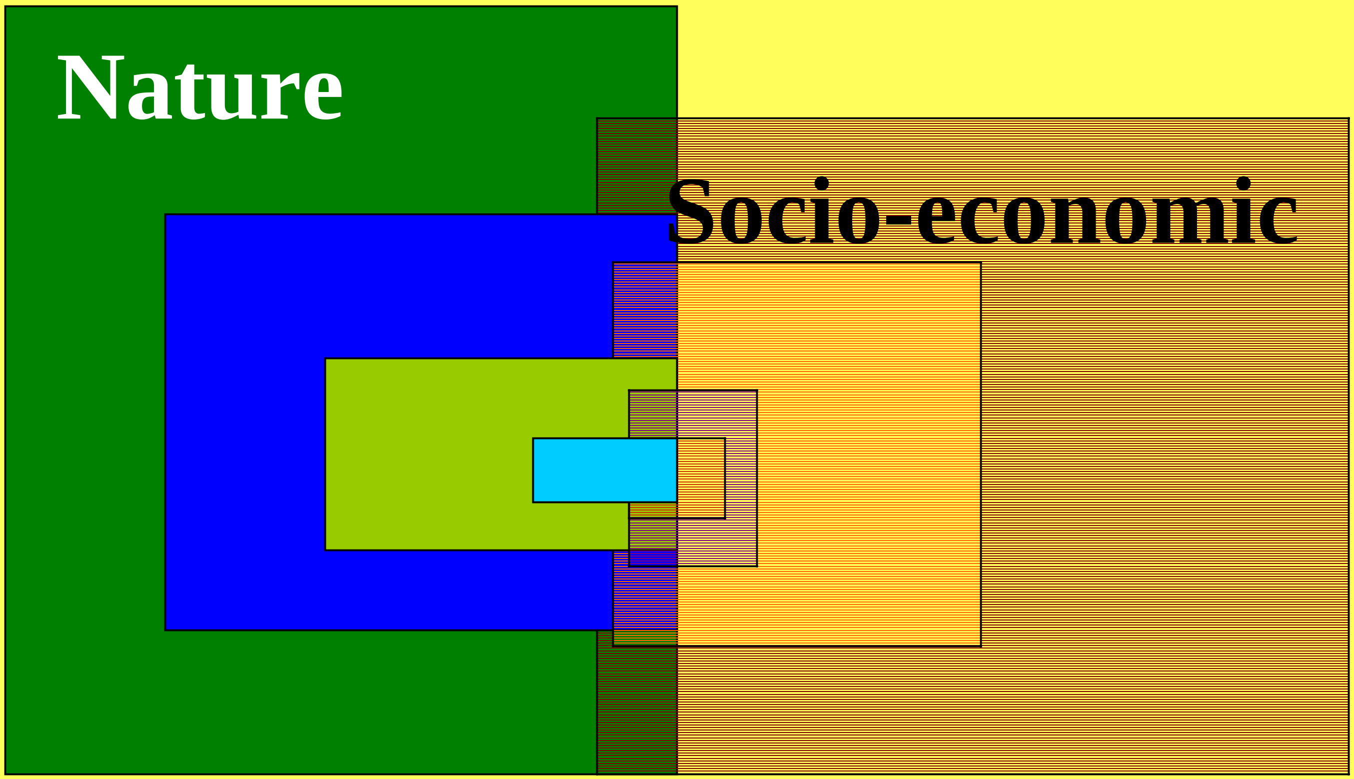
# From the side



# Prospectus

- Why industrial ecology?
  - Sustainable livelihoods and ecological integrity
- What do we understand about ecosystems?
  - Ecosystems are complex adaptive systems
- What is the relationship between "human" and "natural" ecosystems?
  - SOHO model
- Design Principles?
- Production Consumption Model
- Industrial Ecology redefined.

# Design Principles: I

- the interface between societal systems and natural ecosystems reflects the limited ability of natural ecosystems to provide energy and absorb waste before their integrity is significantly altered, and that the integrity of natural ecosystems must be maintained. This is referred to as the problem of interfacing.

# Interfacing

- In an ideal situation, efforts to address the interfacing problem, would be based on an analysis of the situation using the SOHO system description discussed above.
- a non-linear hierarchical mindset, which takes into account thresholds, cumulative effects, buffering, flips between attractors and cross-scale dynamics, must be used.
- Unfortunately our current state of knowledge is not up to the task. We know the questions to ask, but not how to answer them. This is a fundamental challenge for the practice of industrial ecology. How do we proceed in the face of such profound uncertainty? These are two strategies: adaptive design and the precautionary principle.

# Interfacing: Adaptive Design

- Adaptive design involves assuming that one's design is at best a temporary transient solution to a situation. Then one must build into one's design the ability to change and adapt to changing circumstances. This requires that a design be inherently flexible. It also requires that comprehensive monitoring be carried out so that change in the environment can be detected sufficiently early to allow for appropriate change in the design. In effect, our design process must change so that the resulting systems have the capacity to re-organize. They should be constructed as self-organizing systems. This involves a profound shift in paradigm. We can no longer treat our designs as mechanical clock work edifices designed to withstand the test of time.

# Interfacing: Precautionary Principle

- **Given our ignorance about how our interactions with natural systems will affect them, it behooves us to minimize these interactions. This is the precautionary principle. Whenever possible we should limit the effluent from societal systems (waste materials, information and energy) flowing across the interface into natural systems. We should minimize the displacement on the landscape of natural systems by societal systems. Given that human society is appropriating more than half the photosynthetic capacity of the biosphere, human systems must decrease their use of energy. In short, adoption of the precautionary principle mandates that our designs minimize their ecological footprint.**

# Design Principles II

- **the behavior and structure of large scale societal systems should be as similar as possible to those exhibited by natural ecosystems. This is referred to, after Papanek, as the principle of bionics. (In the IE literature it is often referred to as mimicry)**

# Bio Mimicry

- **ecosystems are complex, adaptive, self-organizing hierarchical systems. There are two broad themes to self-organizations of ecosystems:**
  - Coping with a changing environment
  - Making good use of available resources.
- **At any time the state of development of an ecosystem reflects a historical balancing act between these sometimes contradictory themes. An ecosystem which is superefficient, and has a highly articulated mass-energy flow network is usually quite brittle, that is unable to cope with change. So to successfully apply this principle we need to significantly alter our notion of how ecosystems develop. Ecosystems are not necessarily about "closing the loop" but rather about making effective (in a second law sense) use of the resources available while maintaining adaptability. Striking this balance is what maintaining ecological integrity is about.**

# Bio Mimicry

- ecosystems are complex, adaptive, self-organizing hierarchical systems. There are two broad themes to self-organizations of ecosystems:
  - Coping with a changing environment
  - Making good use of available resources.
- Mimicry of natural ecosystems must be tempered by an appreciation that humans have a set of priorities which will cause them to find a different balance, between the need to make good use of resources while coping with a changing environment.

# Design Principles III

- **whenever feasible the function of a component of a societal system should be carried out by a subsystem of the natural biosphere. This is referred to as using appropriate biotechnology.**
  - **Use of natural landscapes for storm water management, in place of concrete channels.**
    - (e.g. holding ponds, creeks with natural vegetation on the slopes). Capital and operating costs are about 10%. Furthermore, these waterways double as aesthetically attractive recreational amenities in the community.
  - **Replacement of turfgrass with natural communities that are self-maintaining. This significantly reduces the cost (both dollars and environmental damage due to chemicals etc.) of maintaining landscapes.**

# Design Principles III

- whenever feasible the function of a component of a societal system should be carried out by a subsystem of the natural biosphere. This is referred to as using appropriate biotechnology.
  - Composting: diverting solid waste from local landfills.
  - Luvall's work on greening U.S. cities has demonstrated how judicious use of trees and other flora can significantly reduce the heat load on a city.
- The experience with appropriate biotechnology has been that it saves much money, both in capital and operating costs.

# Design Principles IV

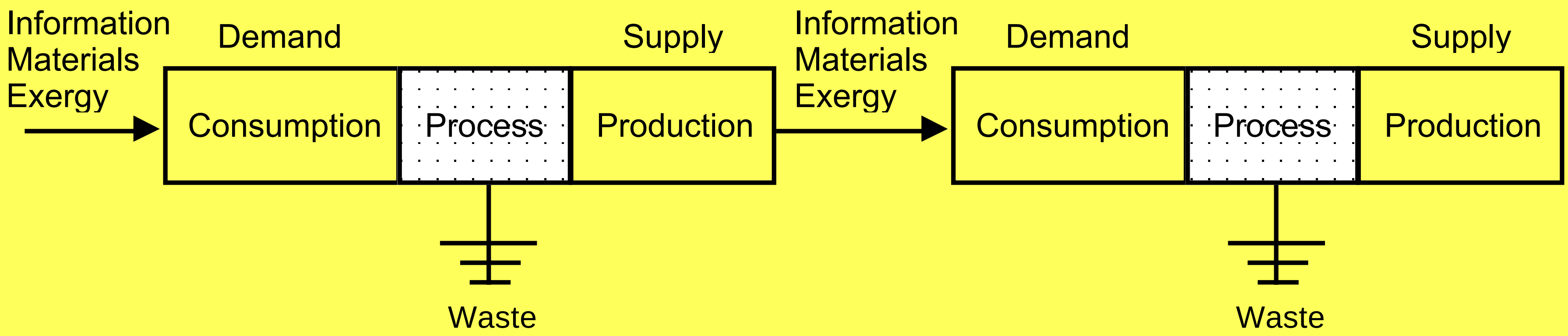
- **non-renewable resources are used only as capital expenditures to bring renewable resources on line.**
  - **(When a resource is used at a rate which is less than the rate at which the resource can be replenished by natural systems, then the use of the resource is renewable. Replenished means the natural system is producing stock of the resource at a rate such that the stock of the resource in the natural system does not decrease. )**

- **(These principles are from:**
  **Kay, James. An Investigation into Engineering Design Principles for a Conserver Society [Master's Thesis]. Waterloo, Ontario, Canada: Systems Design Engineering, University of Waterloo; 1977)**

# Design Principles

- **Interfacing (SOHO Approach)**
  - **Adaptive design**
    - our design process must change so that the resulting systems have the capacity to re-organize.
  - **Precautionary Principle**
    - minimize their ecological footprint.
- **Biomimicry**
- **Using appropriate biotechnology**
- **Operating using only renewable resources.**

# Production-Consumption Model




**Each component of a SOHO system consumes exergy, materials and information. The dissipative process transforms these inputs into new forms of exergy, materials and information. These products or outputs of the dissipative process serve as inputs for another component in the SOHO system. Each element not only consumes exergy, materials and information but also produces exergy, materials and information for the next element in the concatenation. Each element provides the context for another element. So horizontally each element in the SOHO system model has a Janus two face, its consumption face and its production face. Therefore each component of a SOHO system must be thought through both as a producer and as a consumer.**

# Prospectus

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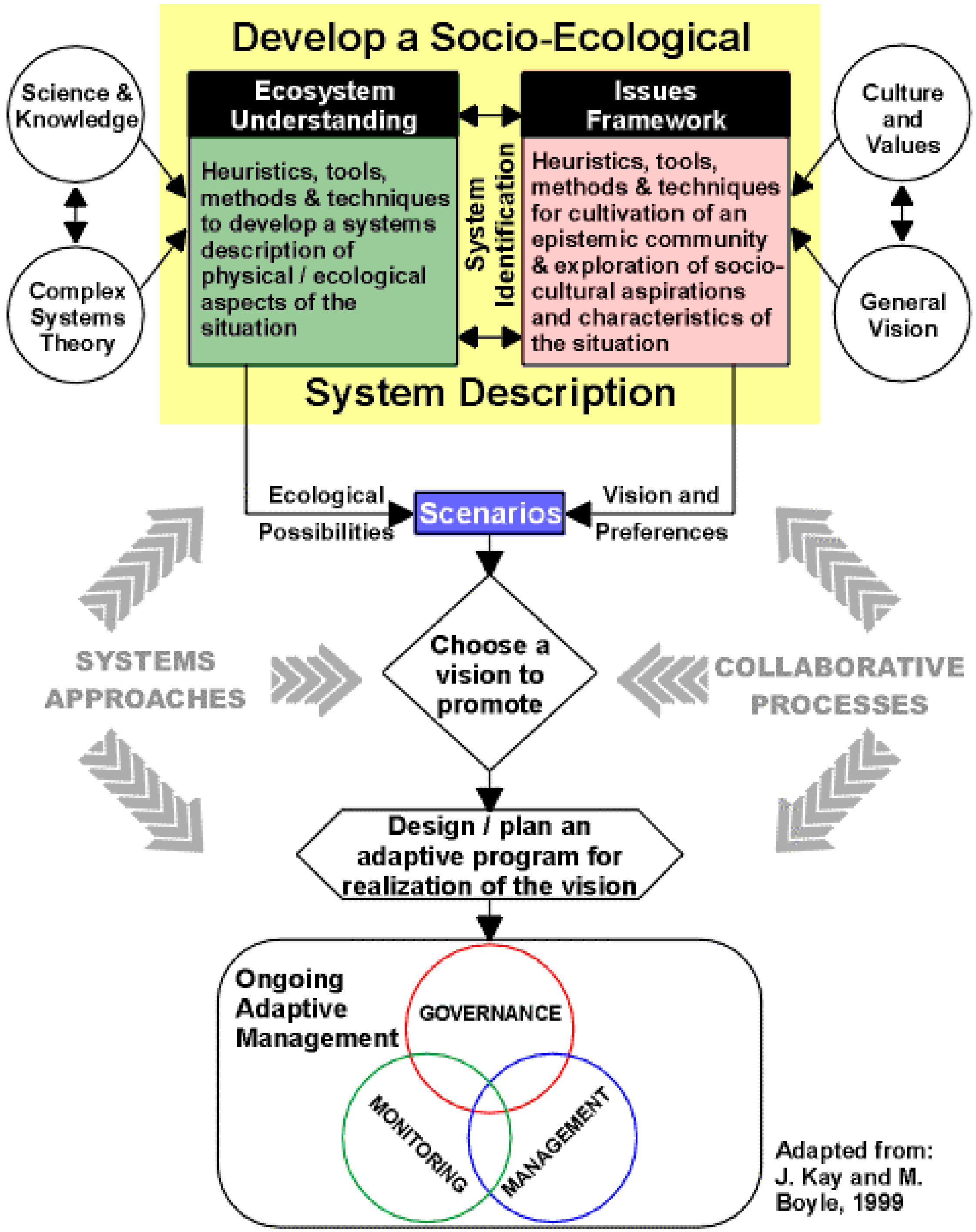
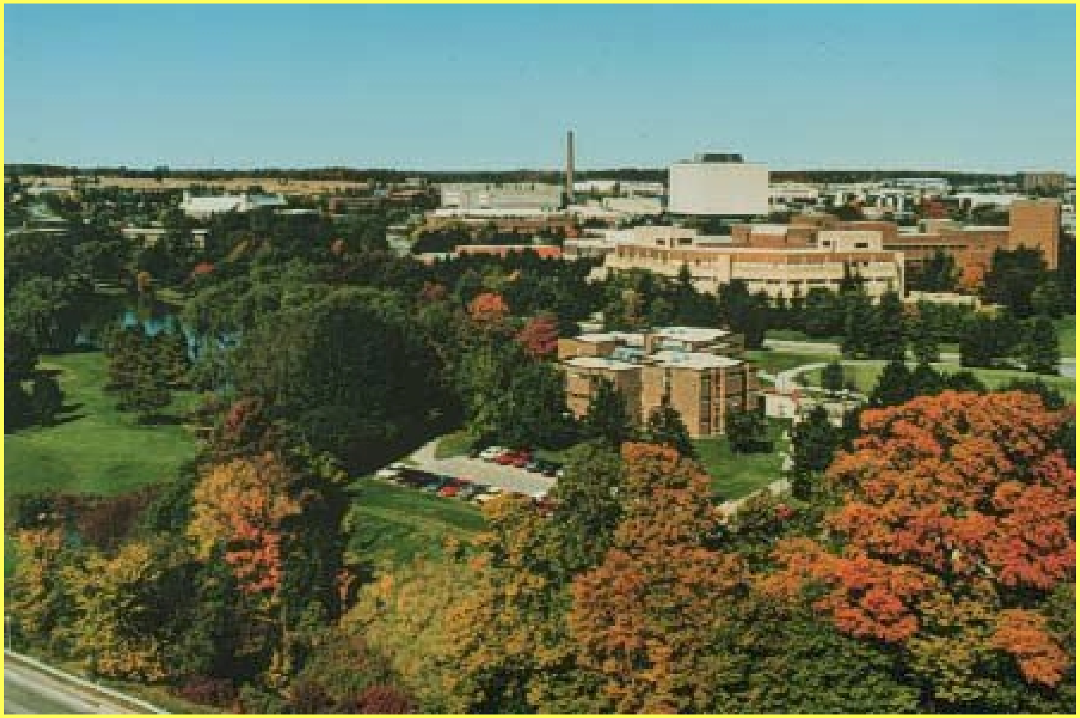
# Industrial Ecology

- Industrial ecology is the activity of designing and managing human production-consumption systems, so that they interact with natural systems, to form an integrated (eco)system (complex adaptive system) which has ecological integrity and provides humans with a sustainable livelihood
- In essence industrial ecology is about designing human ecological-economic systems which fit in with natural ecological systems.


Develop a Socio-Ecological
System Description
Science & Knowledge
Complex Systems Theory
Ecosystem Understanding
Heuristics, tools, methods & techniques to develop a systems description of physical / ecological aspects of the situation
System Identification
Issues Framework
Heuristics, tools, methods & techniques for cultivation of an epistemic community & exploration of socio-cultural aspirations and characteristics of the situation
Culture and Values
General Vision
Ecological Possibilities
Scenarios
Vision and Preferences
SYSTEMS APPROACHES
Choose a vision to promote
COLLABORATIVE PROCESSES
Design / plan an adaptive program for realization of the vision
Ongoing Adaptive Management
GOVERNANCE
MONITORING
MANAGEMENT
Adapted from: J. Kay and M. Boyle, 1999

**James J. Kay**
**Department of Environment and Resource Studies**
**Faculty of Environmental Studies**
**University of Waterloo**


**www.fes.uwaterloo.ca/u/jjkay/pubs/ie/**




**jjkay@uwaterloo.ca**