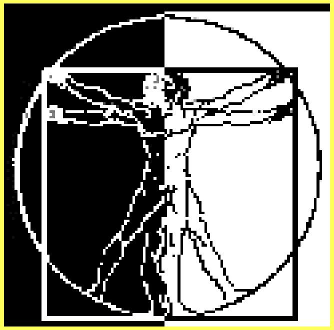


About Teaching Systems Thinking

James J. Kay

Jason Foster

Systems Thinking

- Systems thinking studies the way in which wholes and context give rise to emergent properties. It also examines how the whole is made up of the processes and structures which define it. Thus systems thinking is both reductionist and holistic, that is hierarchical.
- A number of common properties and behaviours of systems have been identified and it is these generalizations which give systems thinking its power.
- In short systems thinking is about synthesising together all the relevant information we have about an object so that we have a sense of it as a whole.

Pedagogical Approach

- Promote interest in the student by demonstrating the insights systems thinking offers;
- Explain the circumstances in which systems thinking applies;
- Provide individual systems thinking tools that can be applied to a wide variety of systems problems;
- Introduce the various perspectives and approaches that make up systems thinking;
- Integrate the tools and approaches into a comprehensive systems thinking perspective; and,
- Allow the student to practice systems thinking in the real-world context.

Major Elements of Systems Thinking

- System Studies
- General Systems Behaviour
- Complexity
- General Systems Tools
- Systems Approaches

System Studies

- Students must be given explicit opportunities to apply systems tools and approaches to real-world situations.
- Experience has shown that students can only really appreciate systems thinking and the issues related to it after they have undertaken a system study. Accordingly it must be the first element of a systems education.

System Studies

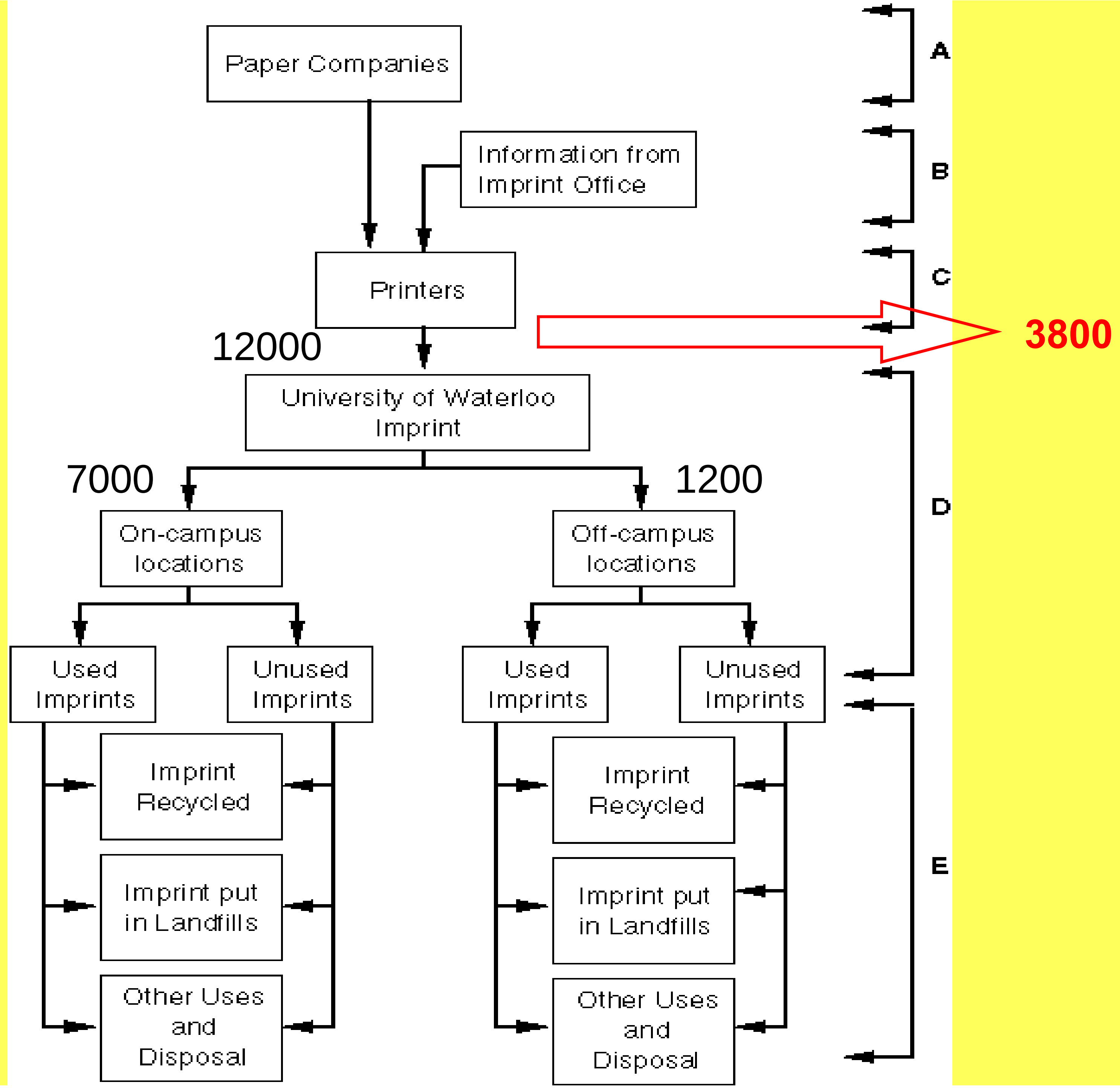
- A system study is a framing of the situation being examined, so that meaningful questions can be asked about it.
- The approach to introducing systems studies is two pronged, involving both **in class examples** and **system studies undertaken by students**.

System Studies: Class Examples

- Examples which are done in a lecture setting should be directly related to the students' experiences.
- The example system study should be directly connected to asking a question about the world. It should demonstrate clearly how the system study provides new insights about the question.

System Studies: Class Examples

- Structure the examples so that each one introduces some new system concepts and builds on the concepts from the previous example.
  - Components and structure; flow
  - Suboptimization
  - Boundaries
  - Scale
  - Type
  - Nesting (hierarchy)



Paper Companies
Information from Imprint Office
Printers
12000
University of Waterloo Imprint
7000
1200
On-campus locations
Off-campus locations
Used Imprints
Unused Imprints
Used Imprints
Unused Imprints
Imprint Recycled
Imprint put in Landfills
Other Uses and Disposal
Imprint Recycled
Imprint put in Landfills
Other Uses and Disposal
A
B
C
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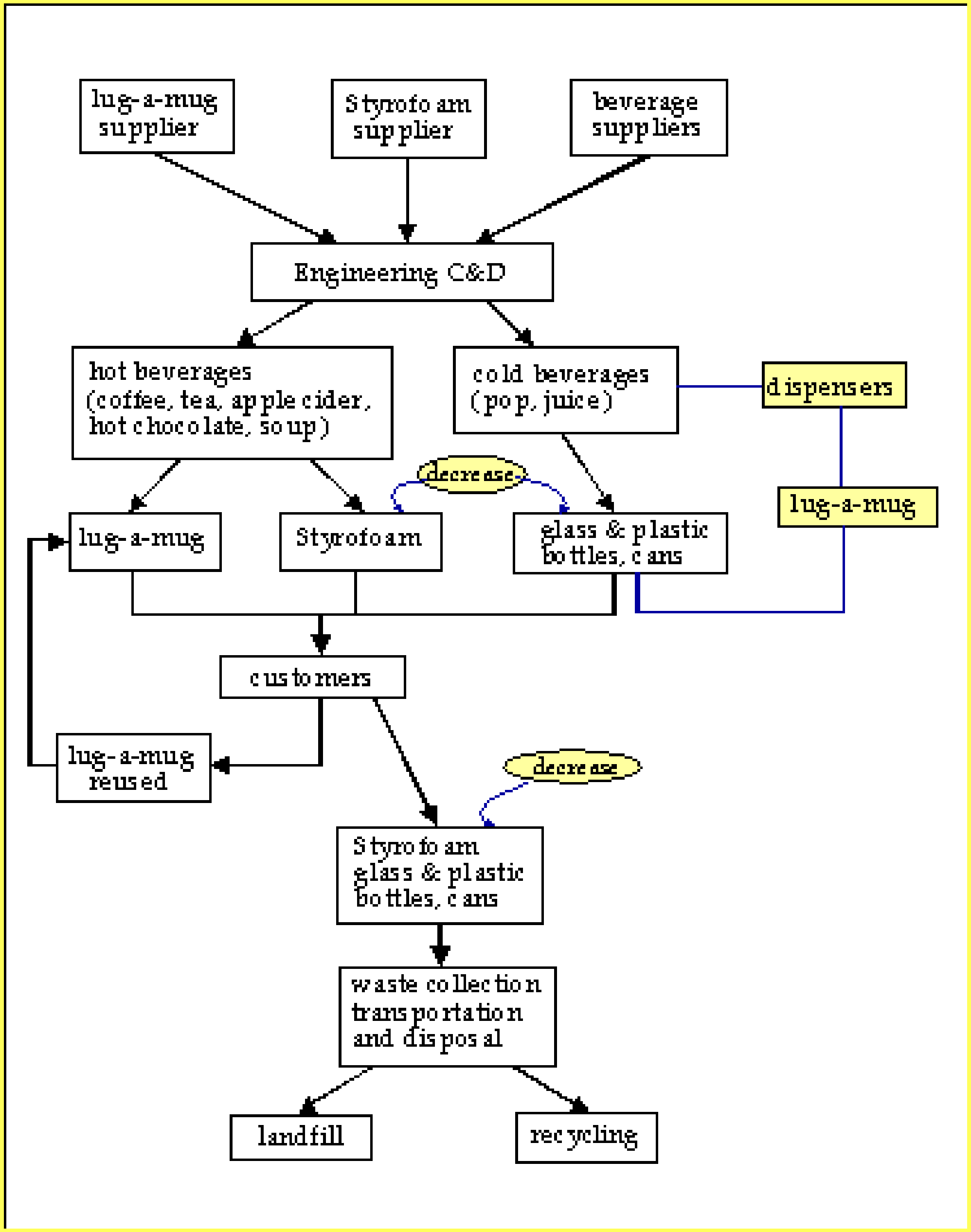
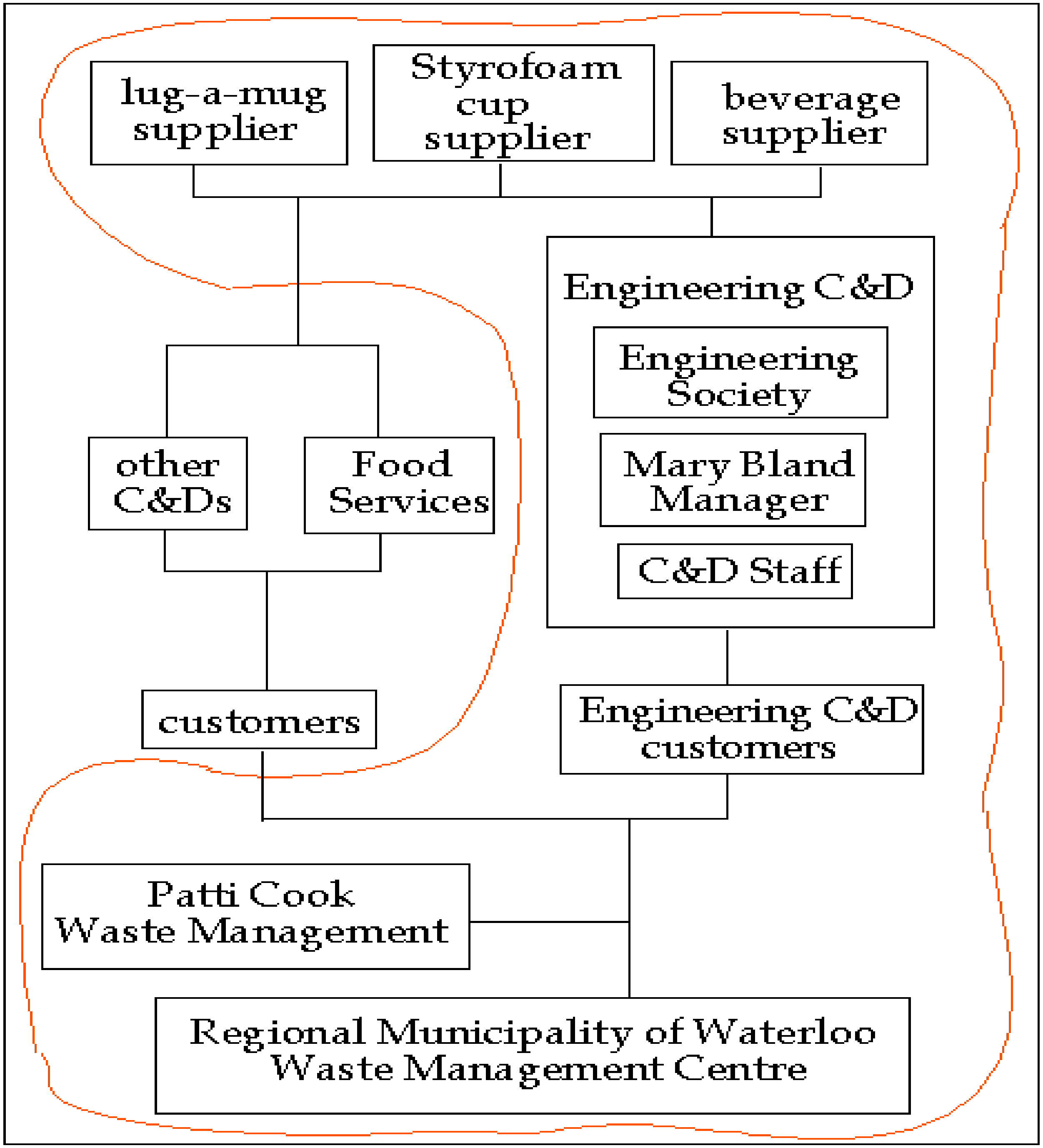
E
3800

The flow of beverage containers in the C&D




lug-a-mug supplier
Styrofoam cup supplier
beverage supplier
Engineering C&D
Engineering Society
Mary Bland Manager
C&D Staff
other C&Ds
Food Services
customers
Engineering C&D customers
Patti Cook Waste Management
Regional Municipality of Waterloo Waste Management Centre

System Studies: Class Examples

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Student System Studies

- Assign students to small groups to undertake their own system study.
- The students will very quickly realize that even though they are looking at the same situation, they have quite different perspectives on it.
- The system study provides a systematic tool for identifying, integrating and resolving these different perspectives. In this way it acts as a boundary object.

Student System Studies

- The object of the system study should be related to a project that is being undertaken in another setting by the students.
  - The students already have background on the object of focus, saving them significant background research time.
  - They usually gain significant new insights about the project they are undertaking in another context, thus demonstrating to the students, in a very vivid manner, the relevance of systems thinking.

General Systems Behaviour

- von Bertalanffy identified the need for **general systems theories** that apply across disciplines and to a broad class of systems.
- Such theories are described as **transdisciplinary** or **isomorphic**.

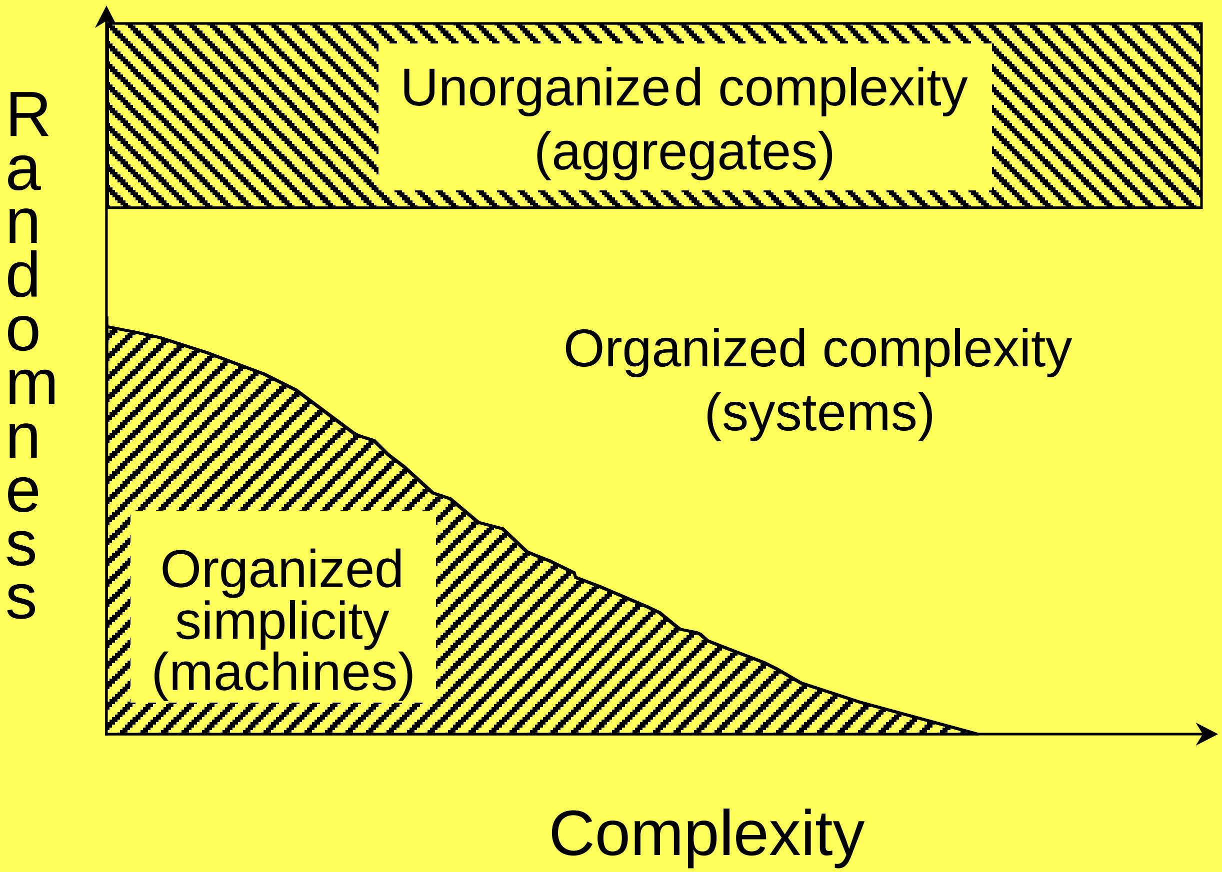
General Systems Behaviour

- Educating about general systems behaviours involves teaching about such phenomena as
  - non-linear behaviour,
  - attractors and flips between attractors,
  - feedbacks,
  - emergence,
  - self-organization
  - chaos.
- Generally these behaviours are not intuitive to students. They do not conform to the Newtonian linear causality mode of reasoning that is a cornerstone of our culture.

General Systems Behaviour

- Students must be given hands on experience with a variety of systems which exhibit such phenomena.
- This allows them to build up the gut intuitive feel that they need to understand these phenomena and a sense of the generality of the behaviours.
- Play should be encouraged both with physical systems and models.

Complexity


Randomness
Unorganized complexity
(aggregates)
Organized complexity
(systems)
Organized
simplicity
(machines)
Complexity

Complexity

- Systems thinking is most applicable to middle number situations.
- The idea of partitioning problem situations based on complexity and organization is key to understanding the domain of applicability of systems thinking.

Complexity

- Over the past two decades, a number of new insights, that go well beyond those of general systems theory, have emerged from the study of adaptive, self-organizing complex systems and the field of chaos theory.
- Together these insights are referred to as **complex systems theory**

Complexity

Self-organizing holarchic open (SOHO) systems:

The emergence of non-equilibrium, open hierarchical systems which are dominated by feedback loops. They self-organize, adapt and are capable of persisting for extended time periods.

Complexity

- **Non-Linear**: Behave as a whole, a system. Cannot be understood by decomposing into pieces which are simply added together.
- **Hierarchical**: Cannot be understood by focusing on one hierarchical level (holon) alone. Understanding comes from the perspective of different **types** and **scale**.
- **Multiple steady states**: There is not necessarily a unique preferred system state in a given situation.

Complexity

- **Window of Vitality**: Must have enough complexity but not too much. Complex systems strive for optimum, not minimum or maximum.
- **Catastrophic Behaviour**: The norm
  - **Bifurcations**: moments of unpredictable behaviour
  - **Flips:** sudden discontinuities, rapid change
  - **Holling four box ∞:** Shifting steady state mosaic
- **Chaos Theory**: our ability to forecast and predict is always limited regardless of how sophisticated our computers are and how much information we have.

Complexity

- We must deal with irreducible uncertainty, emergence and surprise, the lack of a preferential perspective, and the reality that life is a tradeoff.
- We no longer have the luxury of dealing with problems for which reductionist "scientific method" approaches are sufficient and predictability and the ability to anticipate are the hallmark of success.
- The epistemological stance, demanded by the realities of "middle number" systems, is what differentiates systems approaches from approaches which are merely systematic or holistic

General Systems Tools

- Examples of these tools include:
  - **network thermodynamics (e.g. graph theoretic descriptions of physical flow systems),**
  - **information theory,**
  - **pattern recognition,**
  - **group theory,**
  - **statistics,**
  - **stability (catastrophe) theory,**
  - **cybernetics,**
  - **causal loop analysis,**
  - **self-organization theory**.

Systems Approaches

- Historically “system approaches”, referred to methodologies for problem solving and design. **Hard-systems** problems, such as the space programme, have been solved with success using problem solving techniques such as Systems Engineering and Operations Research.
- However, as we have begun to deal with complex issues such as the environment, ecological economics, and information technology, weaknesses in the hard systems methodologies have become evident.

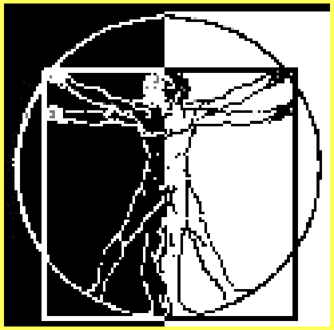
Systems Approaches

- In **soft-systems** situations the risks, uncertainties, and potential benefits inherent in the situation are all high. The situations are complex.
- Characterizing the undertaking of dealing with such situations as “problem solving” is too limited a description. Rather it is about methods for framing situations and identifying and resolving tradeoffs related to technology, societies, economics, people and the environment, under conditions of irreducible uncertainty.

Systems Approaches

Whether dealing with soft or hard systems situations, instruction about systems approaches is best done in the form of case studies, both presented in class and undertaken as student projects. In this regard, we can not overstate the importance of students participating in project work. One cannot learn to drive a car or to ride a bicycle by attending lectures or watching others doing it. One must do it oneself under the guidance of an experienced practitioner. Learning about systems approaches is learning a craft and as such the apprenticeship model is the appropriate mode of instruction.

The challenge of a systems education is to teach students not just how to analyse a situation from a disciplinary perspective, but how to synthesize the insights gained from several disciplinary analyses into an overall understanding that leads to action.



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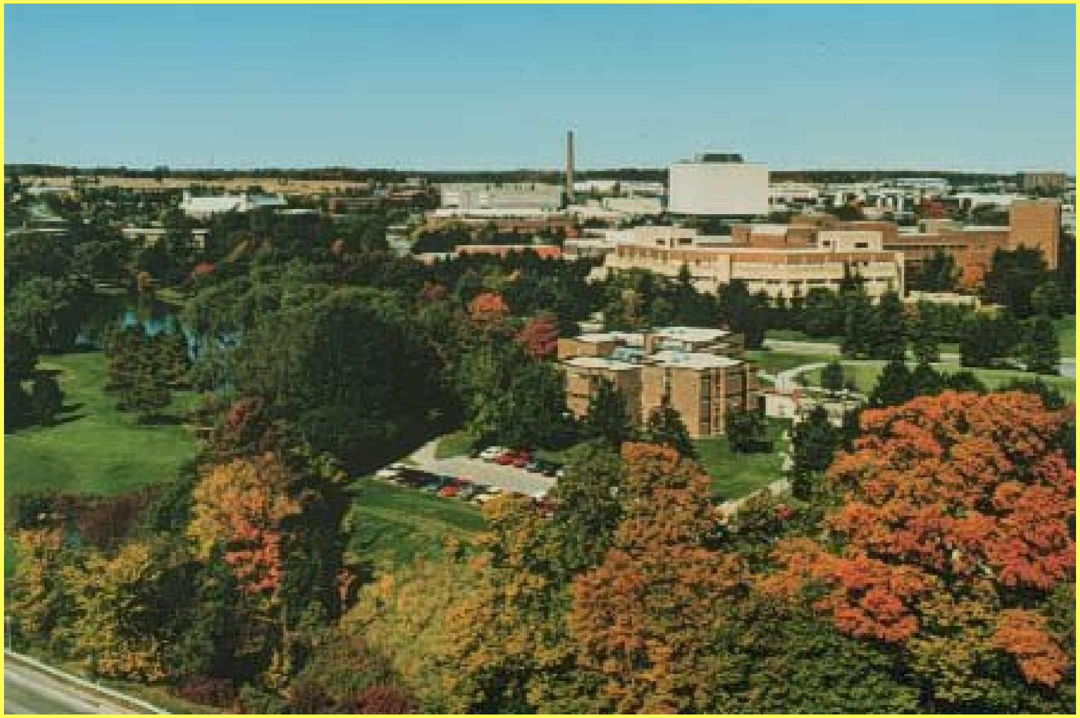

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