SYSTEMS ECOLOGY AND ECOINFORMATICS LABORATORY
@ UNIVERSITY OF NORTH CAROLINA WILMINGTON

Essential System Concepts & Models

What is a system?
What is a model?

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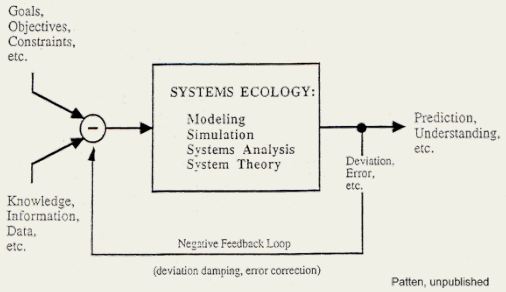
Recall: Elements of Systems Ecology



What is a system? What is a model?

What is a System?

Common System Characteristics

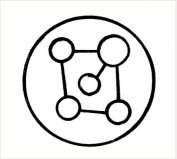
- All systems have some *structure* or *organization*;
- To some extent *generalizations*, abstractions, or idealizations of the real world;
- All *function* in some way;
- There are, therefore, *functional* as well as *structural relationships* between units;
- Function implies the *flow and transfer* of some thing (energy, matter, information);
- Function requires the presence of some *driving force* or source of energy; and
- All systems show some *degree of integration*.

White et al. 1992

Four Progressive Definitions

1. Reductionist
2. Holistic
3. Behavioral
4. Input-Output-State

Reductionist Definition of a System



A partially interconnected set of component parts.

Consider
1) What parts?
2) How many?
3) What relationships connect them?

System ≡ A {Definable, Observable, Measurable, …} Whole
Whole ≡ a set of {interconnecting, joined, coupled, …} Parts
Part ≡ A (sub)system

Hierarchical Organization of Systems

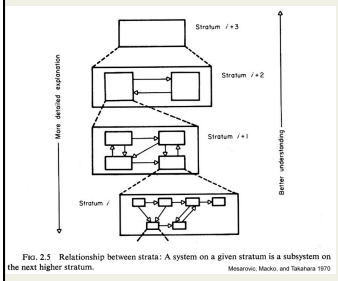


FIG. 2.5 Relationship between strata: A system on a given stratum is a subsystem on the next higher stratum. Mesarovic, Macko, and Takahara 1970

Levels of Analysis

1. Level of primary concern
2. Level above provides context
3. Level below reveals fine grained details

Nested Hierarchy
Scale Hierarchy

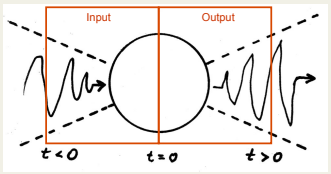
Importance of the Observer

Properties of Scale Hierarchies

- Distances (spatial scales) decrease
- Binding energies increase
  - (i.e., gravity, electromagnetic, weak and strong nuclear)
- Time scales decrease
- Behavioral frequencies increase

H.A. Simon 1973

Holistic Definition of a System



(1) The locus of a pair of environments.
(2) A set of non-intersecting component-level environs.

What is Environment?

Patten 1978

What is an Environment?

Dualistic Concept of Environment J. Von Uexkull (1926) and B.C. Patten

- Environment is a *dual concept* encompassing both causes (inputs) and effects (outputs).
- Environment is a *systems concept*, involving both proximate and ultimate relationships. (Sachs 1976)
- Environment is an *object* (e.g., organism) *centered and defined* concept.
- Environment is (in principle) *closed* by "*function circles*" connecting output to input environments.
- Environment and object are *mutually fitted*.
- The defining object and its two environments are *inseparable*; they form a nonautonomous unit which is *the ecological unit of nature*

Discerning Environment

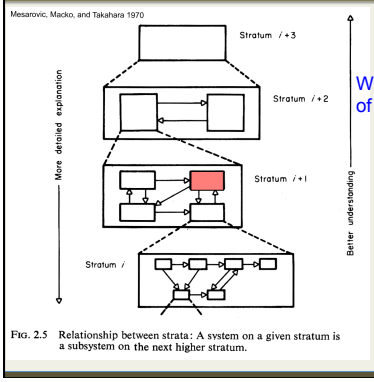


FIG. 2.5 Relationship between strata: A system on a given stratum is a subsystem on the next higher stratum.

What is the environment of the marked object?

Behavioral Definition of a System

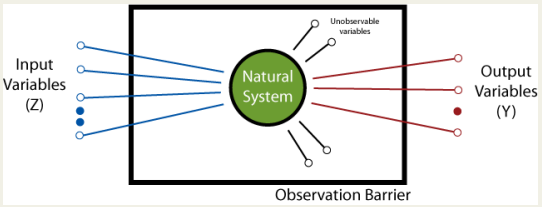
Behavioral

A set of behaviors
(time functions of behavioral attributes)

Entities have properties or states, some of which can be measured using discrete or continuous variables.

Behavioral descriptions
- initial state
- steady–state
- equilibrium
- chaotic
- stable

System Variables



Variables show behavior.

What variables are key to understanding system behavior?

What variables are observable? Measurable?

Redrawn after Zeigler 1976

System Behavior

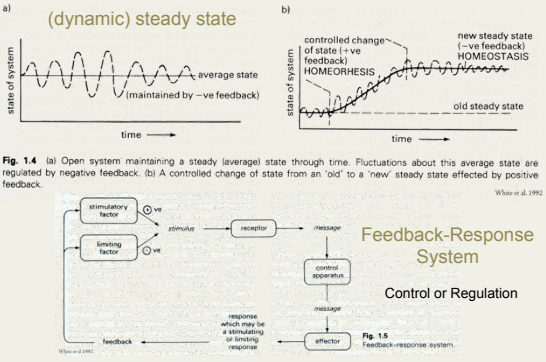


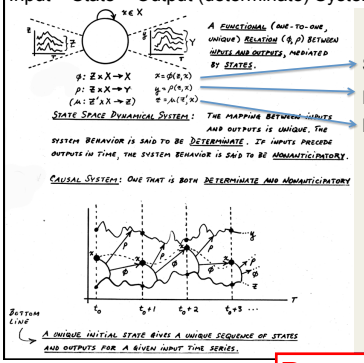
Fig. 1.4 (a) Open system maintaining a steady (average) state through time. Fluctuations about this average state are regulated by negative feedback. (b) A controlled change of state from an 'old' to a 'new' steady state effected by positive feedback.

White et al. 1992

Fig. 1.5 Feedback-response system.

Putting the System Definitions Together

Input – State – Output (determinate) System



State transition function

Response function

Modeling function

Patten, pers. com.

System Types w.r.t. Boundary Exchange

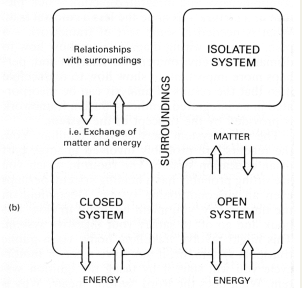


Fig. 1.2 (a) Approaches to the definition of energy systems; (b) Classification of energy systems on the basis of their interactions with their surroundings into isolated, closed and open systems.

White et al. 1992

Thermodynamic Classification

What is a Model?

Definition: What is a Model?

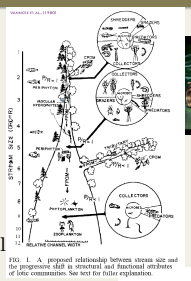
Model

A **model** is an abstract (perhaps idealized), non-unique, description of a natural system that captures its features essential for addressing the modeling objectives.

Patten, Per. Com.

Forms of Models

- Conceptual or Verbal
- Diagrammatic
  - Forrester Diagrams
  - Flow Diagrams
  - Process Diagrams
  - Concept Maps
  - Time Lines
- Physical
  - Objects in wind tunnel
- Formal
  - Represented using formal techniques such as mathematics.



$$\frac{dX}{dt} = rX$$

Model Types

- Qualitative vs. Quantitative
- Empirical vs. Mechanistic
  - Does the mathematics have an explicit representation of mechanistic processes?
- Static vs. Dynamic
  - Is there an explicit representation of future states?
- Temporally Discrete vs. Continuous
  - Difference equations, differential equations, algorithms
- Spatially Homogenous vs. Heterogeneous
  - Is space represented explicitly?
- Deterministic vs. Stochastic
  - Random variables? Environmental and Process error

Kinds of Models

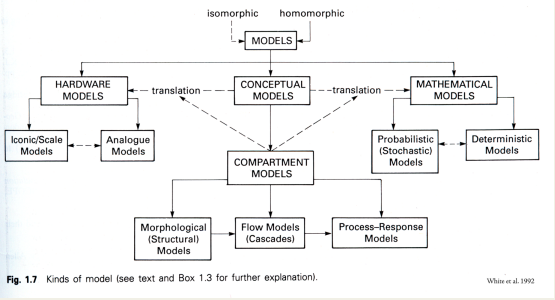
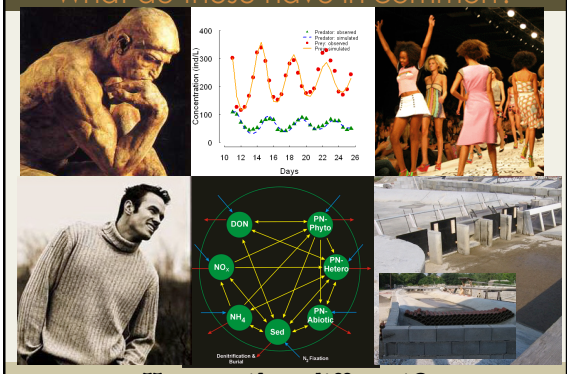


Fig. 1.7 Kinds of model (see text and Box 1.3 for further explanation). White et al. 1992

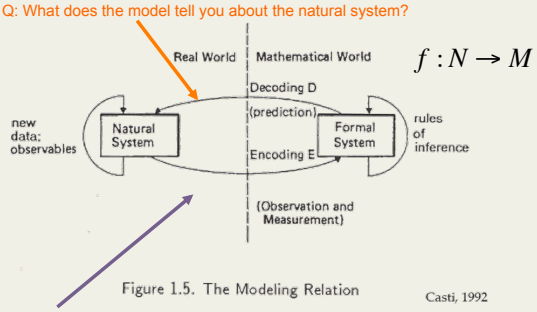
What do these have in common?



How are they different?

The Formal Modeling Relation

Q: What does the model tell you about the natural system?



$f : N \rightarrow M$

Figure 1.5. The Modeling Relation Casti, 1992

This abstraction process is key to model making.

Q: What do you include in the model and how do you formally represent it?

Constraints on Models

Three properties of models (Levins 1966)

Realism
degree with which the model mimics the real world

Precision
accuracy of model predictions

Generality
the number of systems or situations to which the model correctly applies

All three cannot be maximized simultaneously: Tradeoffs exist

All Models are Wrong, Some are Useful

G.E.O. Box

Uses of Models

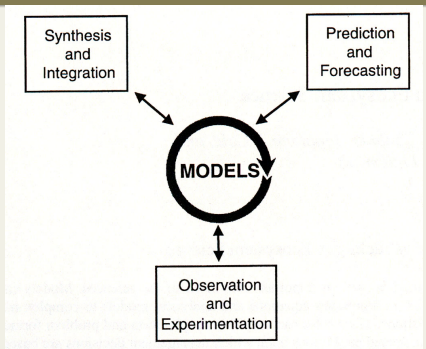


Figure 1.1

Canham et al. 2003. Models in Ecosystem Science

Summary

- 4 Definitions of a system
  - Reductionist
  - Holistic
  - Behavioral
  - Input-Output-State
- Environment is a type of system
- A model is an abstract, non-unique, description of a natural system that captures features essential for a purpose
- There are a wide variety of models types
- Models serve different purposes in science

Working Syllabus

Sunday - Foundations
- Introduction to Systems Ecology
- Introduction to Thermodynamics for Ecology, Part 1
- Systems Concepts

Monday - Networks & Energy
- Thermodynamics for Ecology, Part 2
- Network Models
- Energy & Information with Examples
- Ecological Network Analysis
  - Big Picture
  - ENA Software – enaR, EcoNet

Tuesday
- Ecosystem Growth and Development
- Water Resource Applications of ENA
- Introduce Class Project & Homework

Wednesday
- Working with enaR
- Work on Project

Thursday
- Project Summaries & Synthesis
- Additional Examples of Systems Ecology
  - Throughflow Centrality
  - Agricultural Energy Flows
  - Indirect Effects