BASIC CONCEPTS AND SYSTEMS PERSPECTIVES IN MODELING

1. WHAT IS A MODEL?

- An **abstraction** or **simplification** of reality
- A description of the essential elements of a problem and their relationships
- A **reconstruction of nature** for the purpose of study (Levins 1968)
- "A model is a caricature of nature ...... the simplest version of nature can be perturbed numerically with its responses being indications of the directions nature may take" (Scavia, Lang and Kitchell 1988).

> **Quotes of the Day**
>
> "Everything should be made as simple as possible, but not simpler."
> --- Albert Einstein
>
> "While intelligent people can often simplify the complex, a fool is more likely to complicate the simple." --- Swedish proverb

2. WHAT IS A SYSTEM?

- An organized collection of interrelated physical components characterized by a boundary and functional unity
- A collection of "communicating" materials and processes that together perform some set of functions
- An interlocking complex of processes characterized by many reciprocal cause-effect pathways
- Any collection of interacting objects or processes
- Any phenomenon, either structural or functional, having at least 2 separable components and some interaction between these components

3. TYPES OF MODELS

1) Physical vs. Symbolic (or abstract) Models
   - Physical: a scaled-down (or, less frequently, scaled-up) physical replicas of a real system
   - Symbolic: verbal, written language, or mathematical
2) Dynamic vs. Static Models
   - Dynamic: with time varying variables
   - Static: time invariant
3) Empirical (Correlative) vs. Mechanistic (Explanatory) Models
   - Empirical: without internal dynamics; descriptive; prediction
   - Mechanistic: with internal dynamics; explanatory; understanding/prediction
   - Whether a model is empirical or mechanistic is often relative, depending on the level of detail or the scale of observation.

4) Deterministic vs. Stochastic Models
    - Deterministic: with no random variables; point estimation of parameters
    - Stochastic: with one or more random variables; estimation of parameter variations (e.g., mean, variance, distribution)
5) Simulation vs. Analytical Models
    - Analytic models: pencil and paper; solvable in closed form analytically; relatively complicated mathematics; greater mathematical power and usually higher generality
    - Simulation models: use of computers; relatively simpler mathematics; usually less generality and more realism

4. ORGANIZED VS. UNORGANIZED COMPLEXITIES AND MODELING APPROACHES:

1) Small-number system:
    - Relatively few components, highly interrelated
    - Organized simplicity
    - Newtonian approach
2) Medium-number
    - Intermediate number of components, closely interrelated
    - Organized complexity
    - Systems approach
3) Large-number systems
    - Large number of components, loosely interrelated
    - Unorganized complexity
    - Statistical approach

❖ Rules of thumb for choosing methods of problem solving based on data availability and the level of understanding on the system:

Amount of Data	Level of Understanding	Appropriate Method
Many	Little	Statistics
Many	Good	Physics
Few	Little	System Analysis & Simulation
Few	Good	System Analysis & Simulation

5. WHY MODELS?

Models can be and have been used for several purposes other than prediction:

- Prediction
- Understanding
- Generate and test hypotheses
- Synthesis
- Identify areas of ignorance
- Serve as management tools

SYSTEMS PERSPECTIVES

(A) Systems Thinking

- Systems thinking is the art and science of making reliable inferences about system behavior by developing an increasingly deeper understanding of underlying structure and processes.
- Systems thinking is both a **paradigm** and a **learning method**.
- As a paradigm, system thinking consists of two aspects: vantage point and thinking skills.
    - Vantage Point: Determines where you position yourself to make observations of the system. The system thinking vantage point is characterized by the "bi-focal" perspective:
        - seeing both the forest and the trees (one eye on each)
        - structurally, both generic and specific
        - behaviorally, both the pattern and the process

    - Thinking Skills: Determine both how you perceive system components and their relationship to system behaviors. Three thinking skills are used in a progressive order: structure-as-cause-thinking, closed-loop thinking, and operational thinking:
        1) Structure-as-cause thinking (or the endogenous viewpoint):
            - Viewing the structure of a system as the cause of its behaviors, as opposed to seeing the behaviors as being imposed upon the system by outside agents.
        2) Closed-loop thinking:
            - Structural elements of the system are arranged in closed-loops (feedback loops).
            - Emphasizing reciprocal causal relationships
        3) Operational thinking:
            - What are closed-loops composed of? Primarily, stocks (state variables) and flows (rate variables).
            - System components form feedback loops which ultimately determine the behaviors of the system.

(B) Systems Analysis

1) What Is Systems Analysis?

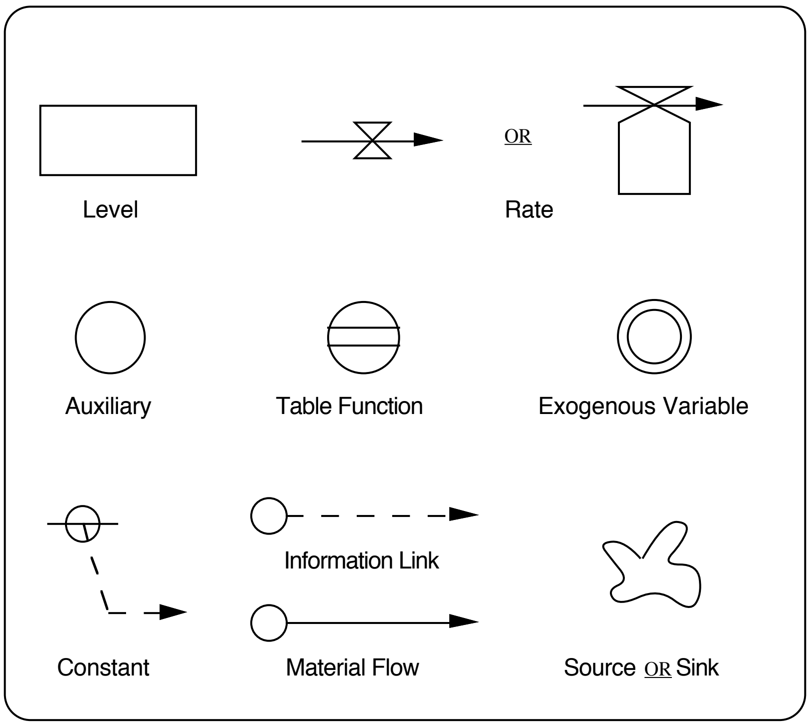
- A methodology originally developed by the military to deal with the complex logistical problems during World War II.
- Systems analysis consists of the determination of important system components, systems simulation, systems optimization, and systems measurement (Watt 1968).
- Conscious application of scientific method to complex organizations in order that no important factor be overlooked (Morton 1964).
- The application of scientific method to complex problems, which is distinguished by the use of advanced mathematical and statistical techniques and by the use of computers (Dale 1970)

- A philosophical approach and a collection of techniques, including statistical analysis and simulation, for dealing with complex systems.

2) Systems Models and Systems Diagrams

- Stocks (or state variables or accumulations) are the major concerns which change through time (e.g., population size, biomass, etc.).
- Flows (or rate variables) represent flows of material or energy between state variables and characterize the rate of change of these state variables as a result of specific processes.
- Information links between variables are established by auxiliary variables (converters).

❖ **Symbols used for systems modeling (Forrester diagram)**



(C) Four Basic Phases in Systems Analysis (or Systems Modeling)

Phase 1: Conceptual model formulation

- Define the problem
- Specify model objectives
- Delineate system boundaries
- Construct causal diagrams
- Understand feedback loop structure

Phase 2: Quantitative model specification

- Select general quantitative structure for the model

- Choose basic time step for simulations
- Identify functional forms of model equations
- Estimate parameters of model equations
- Code model equations for the computer
- Execute baseline simulation
- Present model equations

Phase 3: Model evaluation
- Components of model evaluation
- Model verification
- Model validation

Phase 4: Model application
- Develop and execute experimental design for simulations
- Analyze and interpret simulation results
- Examine additional types of management policies or environmental situations
- Communicate simulation results

* NOTE: The four phases are interactive, meaning that one often has to go back and forth among the four phases during model development.

(D) Systems Ecology

1) What Is Systems Ecology?
- The application of systems analysis procedures to ecology
- The approach to the study of the ecology using the techniques and philosophy of systems analysis for studying, characterizing and making predictions about complex ecological systems (Kitching 1983)

2) Some significant events in the development of systems ecology before 1980
- In the 1960s, digital computers became available to many ecologists.
- Founders: George Van Dyne, Jerry Olson, Bernard Patten, Ken Watt and C.S. Holling
- Watt's (1966) book, "Systems Analysis in Ecology", may be considered the first book in introduction to the systems approach in ecology or systems ecology.
- Watt's (1968) book, "Ecology and Resource Management", was the first work to cover the techniques, philosophy and applications of ecological modeling.
- Systems ecology was greatly boosted by the International Biological Program (IBP) in the 1960s and 1970s.
- 1970s - a period of great excitement: many people with adequate backgrounds in biology, mathematics and computing carrying out research on a wide range of topics using the systems approach.
- As a result, the 4 monumental volumes edited by B. C. Patten marked the firm establishment of the new field of Systems Ecology:

- 1975 - Ecological Modeling (an international journal of ecological modeling and systems ecology) was created, and ISEM (International Society of Ecological Modeling) founded.
- 1979 - A benchmark book on systems ecology edited by Shugart and O'Neill was published.
- …

(E) System Dynamics and STELLA

1) System Dynamics (SD)

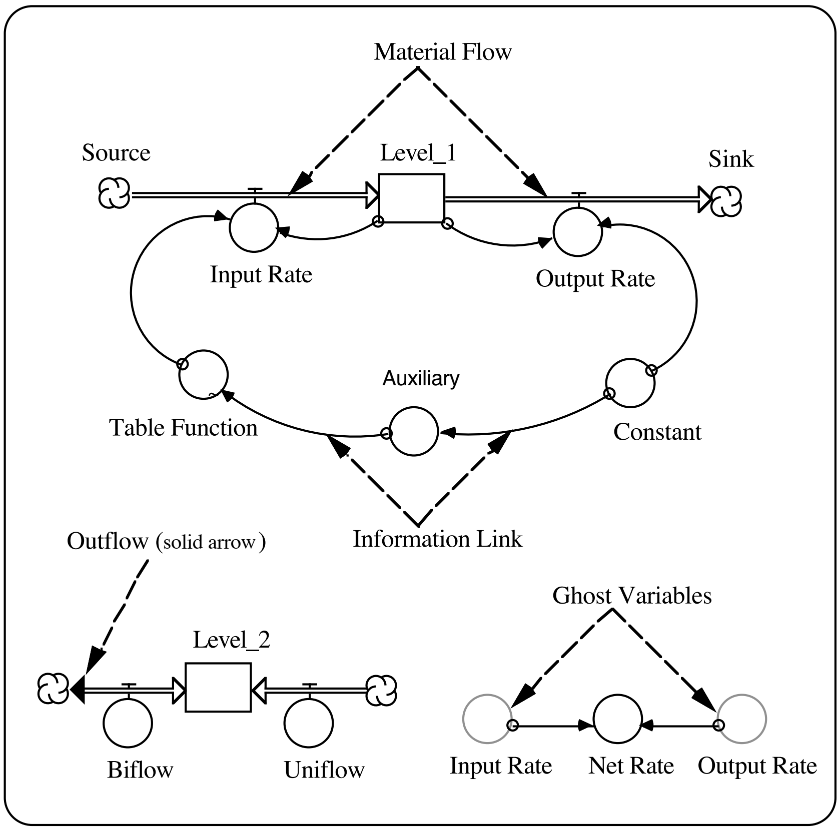
- Founded by Forrester and his associates at MIT in 1950s (Forrester, 1961, 1968)
- Holds that the macro behavior of a system is primarily determined by its internal micro structure
- Emphasizes the connections among the various parts that constitute a system and applies feedback principles to model and analyze dynamic problems
- Holds that the core of system structure is composed of feedback loops (positive and negative) that integrate the three fundamental constituents: state, rate, and information.
- DYNAMO – the computer language born with System Dynamics.
- Based on general systems theory, incorporates cybernetics and information theory, and has become a unique, powerful simulation modeling methodology
  - General Systems Theory
    - Put forward by Ludwig von Bertalanffy in 1920s, but the term "general systems theory" was introduced by von Bertalanffy in 1947
    - Whole is more than the sum of parts - known as "The law of von Bertalanffy"
    - Systems of different types and at any scale or level of detail can be studied using a common set of principles and techniques
    - von Bertalanffy (1968): General System Theory: Foundations, Development, Applications. George Braziller, New York.

  - Cybernetics (Control Theory)
    - Cybernetics - from the Greek *kybernete* = hlmsman
    - The study of regulating and self-regulating mechanisms in nature and technology
    - Developed by a group of American scholars led by the mathematician and physicist, Norbert Wiener

  - Information Theory (Theory of Communication)
    - Developed by C. E. Shannon and others in the late 1940s, originated in the field of communication
    - [Shannon, C. E. and W. Weaver. 1949. The mathematical Theory of Communication. Univ. of Chicago Press, Urbana.]
    - Study of information processing and transfer using applied probability theory and statistical methods
    - Information theory forms a basis for cybernetics: things can only be controlled with information flowing!

2) STELLA

- STELLA (acronym for Structural Thinking Experiential Learning Laboratory with Animation)
- Icon-oriented and self-debugging systems simulation package
- First released in August 1985 by High Performance Systems, Hanover, New Hampshire
- Designed to facilitate System Dynamics modeling and make it available for even those lacking computer experience and mathematical expertise
- Awarded as "the best published piece of work in the [SD] field between 1984 and 1989" (Forrester Award Committee)



Symbols used for structural diagrams in STELLA