GENERAL SYSTEMS CONCEPTS

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Abstract.

1. General Systems Thinking

General systems thinking arises from the observation that all observations are related to *systems*. Modern science and engineering also hold that systems are *dynamical*. The idea is to formalize these concepts.

General systems arises from success of dynamical systems methods when applied to non-natural science systems like biology and logic economics.

2. How do I Know It's Right?

The purpose of this chapter is to provide concepts that are used to develop and evaluate models and simulations. The ideas presented here appear in almost every discipline. We are interested in may different disciplines, so the terminology is broadly translatable to a specific discipline. Eventually, we shall see that there are five ways to define a system.

	Definition
S1	External quantities and their resolution level
S2	A given activity
S3	Permanent behavior
S4	Real CC
S5	Real ST

3. Systems, Environments, and Behavior

The organizational structure of any STEM discipline centers on systems*.* A *system* is an object with *behavior*, and systems interact with their *environment*. What do we mean by behavior? Behavior is defined by the investigator:

- In physics, we generally mean "some function of time."
- In economics, we may mean "consumer reaction to inflation."
- In biology, we may mean "the reaction of a cell to stress."

Notice that the last two do not mention *time*. Generally, the term *behavior* means *observations of inputs and outputs quantities*. But generally, the term *behavior* has a more restricted meaning: behavior generally means *fundamental quantities* that describe the essence of the system.

We take as a fundamental tenet that systems and their environments are defined by their behavior.

3.1. **Attributes, Quantities, and Values.** *One of the hallmarks of science is development of a system of definitions.* It is impossible to define *everything*, so inevitably some items must be understood on their own terms. Generally in science, we make *nominal definitions*: definitions that define a new word in terms of words we already have defined.

Attributes, quantities, and values are inter-related. We must start *somewhere*. An *attribute* is the name of some characteristic property of a system. Generally, we *attribute* means something essential and permanent. Attributes can be observed and measured and that measurement requires *values* and *quantities* (or *units*). For example, we can measure the heat of an object and we record that heat as a temperature measured on some temperature scale.

Attribute: heat.

Quantity: temperature scale.

Value: observed temperature.

3.2. **Resolution Level.** *We cannot measure values infinitely precisely.* This is true whether using a meter stick or a chromatograph. Therefore, we must take care to describe the exact set of possible values that a measurement can take on.

A simple example of a resolution level *that is not a physical measurement is the storage of numbers in a computer.* Most personal computers can store integers ranging from -2^{31} to

$2^{31} - 1$; in decimal terms, -2,147,483,648 to 2,147,483,647. Or approximate 4 billion values. That's not very many in the scheme of things: Avagadro's Number requires 23 digits.

This is a good place to introduce two important concepts: accuracy and precision. In numerical work, *precision* is the "fineness" with which we can record values; the discussion above on computer numbers is about precision. *Accuracy*, on the other hand, describes how close we are to the true value.

3.3. **Activity.** The set of external quantities and the resolution level describes how the values can be recorded. Activity *is recording of values over time at resolution.* The concept here is that activities are not necessarily understood in the total theory of the system; they are observations. Activities are recorded and analyzed within the confines of the behavior: the total theory.

3.4. **Behavior.** We can now understand the term *behavior*. *If we understand the behavior of a system, then we would be able to generate all possible observations (activities) at any resolution level.* The most common way behavior is presented is as a function with time as an independent variable.

However, there are two other common ways to depict behavior that are commonly used in STEM disciplines: (1) state-transition (ST) systems and (2) component-coupling (CC) systems.

4. Component-Coupling Definitions of Systems

The central concept of component-coupling (CC) definitions of systems is what engineers call "block diagrams". [Show several]. In our terminology, each component is a system; i. e., it is an object with a behavior. Components are coupled and this could be in many forms.

- A car's engine (component) and its transmission (component) are literally coupled together.

- In economics, the manufacturing sector (component) and the consumer sector (component) are linked by goods flowing from the manufacturers to the consumers and money flowing from the consumers to the manufacturers.
- Some couplings are not well understood. Even though Newton's Universal Law of Gravitation seems to hold, we don't understand how gravity works.

Several of the tools we will use in this course are CC-based. For example, VenSim uses boxes to represent components and arrows to represent couplings. The assumption is that there is a functional relation between coupled components and that the behavior is the time-evolution of CC system.

5. State-Transition Definitions of Systems

The component-coupling definition assumes that we have a set of components and we know which components interact — and how they interact — to produce behavior. There are many systems for which we do not have a clear picture of the physical structure but we have a large number of observations. *In the* state-transistion *definition we have a observations related by time. We call each time instant a* state of the system *and changes of state are called* transitions.

State-Transition (ST) definitions of systems are the fundamental method of exploring scientific and engineering systems. The mathematical study of *mathematical analysis*, of which undergraduate calculus is a small part, studies such systems. *More broadly, we call systems amenable to ST definitions* dynamical systems.

6. The Triad Theorem

Systems can be defined in any definition and often different sub-systems are defined using a different approach. *The important part here is the following idea: The three are interconvertable.*

[Proof]

7. Fundamental Logical Requirements of System Definitions

Based on [2], we can list the requirements for a rational definition of a system. Before we begin, let's agree that the word *trait* means a distinguishing attribute; the *sine qua non* — that without which an object would not be the same. A *secondary trait* is an attribute that is functionally determined by *independent traits* (some times called *primary traits*).

A definition of a system must be

- T1 Based on constant traits.
- T2 Based on primary traits supposedly completely known.
- T3 Based on traits that make it possible to determine uniquely for each secondary trait whether or not it is consistent with the given traits. (Not underdetermined).
- T4 Has no redundant traits (Not Overdetermined).

T3 and *T4* are important considerations mathematically. *Underdetermined systems* have fewer conditions than it has traits to be defined; this means that not every trait is uniquely determined. Likewise, *Overdetermined systems* have more conditions than traits and therefore some traits may be counterdicted. Overdetermined systems, then, may not exist!

8. Problems, Problems, Problems

Systems can have problems: in fact, we study systems because there are problems we wish to solve and the key to the solution is system understanding. There are four standard problems that we see.

- **Analysis:** Analysis problems start with a system and behavior and the solution to an analysis problem is the ST structure.
- **Synthesis:** Synthesis problems start with an ST structure and seek to develop a system consisting of components from a given set and with specified couplings.
- **Clear (White) box:** we have a complete description of the system and all its subsystems. the term *clear* comes from our ability to "see inside" the system.
- **Black box:** Black box system definitions are comprised of just input-output values at resolution.

References

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[2] George J. Klir. *An Approach to General Systems Theory*. Van Nostrand Reinhold, 1969.

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