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Systems Thinking

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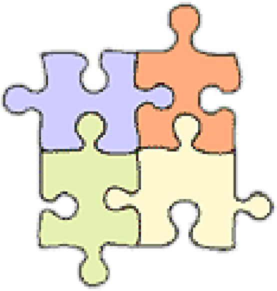
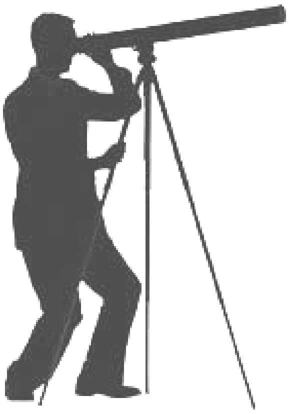


Systems Thinking, Systems Approach, System Dynamics, Systems Theory, and just "Systems" are but a few of the many common names most people have heard something about, many seem to feel a need for, and few really understand. I came across systems thinking when I was student in the Department of Futures Studies of University of Kerala. I found it worthwhile studying the present day complex problems in almost all disciplines, such as social, political and biological systems. This article is intended to provide a view on another way of thinking - systems thinking. This article is an attempt to explain what is Systems Thinking, and why we need it?

The history of elementary systems thinking can be traced back to the work of the Gestalt psychologists, a collection of psychologists who emphasized the study of the mind as a whole unit, rather than as a collection of psychological parts. This approach they described as holistic thinking. The idea of using a system to understand a phenomena is normally attributed to work conducted in the 1930s by Ludwig von Bertalanffy, a German Biologist. He gave the name general systems theory to a discipline devoted to formulating principles that apply to all systems.

Following Bertalanffy's pioneering work, systems thinking began to be applied to numerous fields. Prof. Jay W Forrester of MIT founded the field of system dynamics in 1956. Some take systems thinking to mean the same as system dynamics. Systems Thinking is not General Systems Theory, nor is it "Soft Systems" or Systems Analysis - though it shares elements in common with all of these. Systems thinking is different from the traditional form of analysis of separating the individual pieces of what is being studied. In contrast systems thinking studies how the individual components interact with each other.

Systems thinking has no clear definition or usage. I consider the definition by Barry Richmond, Managing Director of High Performance Systems Inc. (famous for it’s STELLA and iThink software) a good definition for systems thinking. He defined Systems Thinking “as the art and science of making reliable inferences about behaviour by developing an increasingly deep understanding of underlying structure”.



Systems thinking is a framework for seeing interrelationships rather than things separately, for seeing the forest *and* the trees. That is, people embracing Systems Thinking, position themselves such that they can see both the forest and the trees (one eye on each). One has to go beyond events to look for patterns of behaviour and interrelationship which are responsible for the behaviour and events.

In practice, Systems thinking is a continuum of activities ranging from the conceptual to the technical. At the conceptual end of the spectrum is the adoption of a systems perspective or viewpoint. You are adopting a systems viewpoint when you are looking from afar — both in space and time — enabling you to see the underlying web of ongoing, reciprocal relationships, with it's cycles that produces the patterns of behavior which the system exhibits.

There are a number of fundamental concepts that form the elements of systems thinking. Some of them are given below:

System: We are surrounded by systems. Our bodies are made up of various systems such as a digestive system and a central nervous system. We live on a planet that is part of the solar system. We engage with people in groups which form social, political and economic systems. We are educated in the use of number systems. Modern organisations would collapse without information systems.

At first sight these varied systems appear to have little in common. However, on closer scrutiny, we see that all these phenomena are collections of things that are inter-related through defined relationships. Systems thinking is the attempt to study such generic features of all systems.

Systems thinking employs the concept of a system: an organized whole in which parts are related, which generates emergent properties and has some purpose. A system is an assembly of parts where the parts or components are connected together in an organized way, the parts or components are affected by being in the system and are altered upon leaving it.

There are a number of ways in which we may define types of systems. Such types are normally expressed in terms of bi-polar properties which usually express the ends of some dimension. Some of the common types of systems are as follows:

Simple/Complex Systems: Simple systems include those such as a chair which integrate several non-moving parts together whereas Complex systems are those such as social systems that are made up of a multitude of parts and relationships.

Closed/Open system: A closed system is one in which there is no interaction between the system and its environment whereas an open system is one in which there are interactions between the system and its environment.

Steady-state/dynamic systems: The state of some systems demonstrate the property of equilibrium or a steady-state whereas the state of dynamic systems fluctuate rapidly.

Adaptive/ Non-adaptive: Some systems adapt to changes in their environments whilst non-adaptive systems fail to adapt to changes in their environment.

Discrete/Continuous: In some systems the changes between system states are discrete, i.e., at defined intervals. In continuous systems, change is continuous throughout some period.

Deterministic/Stochastic: In a deterministic system the behaviour of the system is predictable in every detail. In a stochastic system behaviour is affected by random inputs.

Sub-systems: Systems generally can be seen as being composed of sub-systems. Hierarchy seems to be an inherent property of most systems. An automobile can be viewed as being composed of sub-systems such as the electrical sub-system, transmission sub-system etc. Alternatively, the human body may be viewed as being made up of sub-systems such as the nervous system, the circulatory system, the digestive system etc.

State: The behaviour of a system can be defined in terms of the notion of it’s state. The state of a system is defined by the values appropriate to the systems' attributes of it’s state variables. At any point in time, a value can be assigned to each of a systems' state variables. The set of all values assumed by the state variable defines the systems' state.

Holistic thinking: Systems thinking maintains Aristotle’s dictum that the whole is more than the sum of its parts. Systems thinking proposes that it is important to investigate and understand complex phenomena holistically. The early ideas in systems thinking can be seen as a reaction against the reductionism inherent in the scientific method.

Emergent Properties: Systems have emergent properties. A system is a complex entity that has properties which do not belong to any of it’s constituent parts, but emerge from the relationships or interaction of its constituent parts. For example, in a traffic network, a traffic jam experienced at some intersection is the result of the interactions of a large body of components (vehicles) interacting in particular ways. A bottleneck is not a property of any one component (vehicles), it is only a property of the traffic system as a whole.

Environment : In thinking about a system, we necessarily define a boundary that separates those things which are part of the system from those things outside of the system. Those things outside of a system constitute the system’s environment.

Inputs and Outputs: A system communicates with its environment in terms of inputs to and outputs from the system. A system transforms inputs into outputs. For example, a manufacturing firm considered as a system transforms raw materials (inputs) into finished products (outputs) for its customers. Accumulations into the system are called Levels/Stock while the flow into or out of the system is called Rate/Flow.

Feedback: Outputs from the process of a system are fed back into the system. The system then adjusts the control signals to the process on the basis of the data it receives. Feedback has two major forms: positive and negative feedback.

Negative Feedback: The monitoring subsystem monitors the outputs from the system and detects variations from defined levels of performance. If the outputs vary from established levels then the monitoring subsystem initiates some actions that reduce the variation. For example, in a thermostat, if the temperature falls below some specified level then the thermostat initiates an action such as opening some hot water valve.

Positive Feedback: Positive feedback is a deviant version of control evident in many systems. Commonly known as a 'vicious circle', it involves the monitoring sub-system increasing the discrepancy between desired and actual levels of performance.

Feedforward: Feedback is a reactive form of control. Feedforward is a proactive form of control. Feedforward controls and predicts how changes in inputs are likely to affect system behaviour and sends control signals to the system that will maintain such behaviour as close as possible to the desired course. Most organisational planning is a form of feedforward control. For instance, managers attempt to predict the likely short-term future for areas such as orders for their products and on this basis may decide to increase or decrease stock levels of their products.

System Lags: In most systems there is a time lag in the exercise of control. Lag is a delay between the issuing of a control signal and the adjustment of the system process to the signals. Take the case of a shower in which a human controls the temperature of the water by turning a tap. Usually there is a perceivable lag between turning the tap and experiencing the required water temperature.

Now let us see how to get along with it. The first step is to grasp the system structure and the associated dynamic relations. Then we develop causal loop diagrams (an influence diagram) — a simple map of the reciprocal relationships which you believe to be principally responsible for producing the behavior patterns that a system exhibits. These diagrams will give you an idea about how the structure creates behaviour. Next step is to construct a more disciplined diagram to show what really makes the system tick. And finally translate the structural diagram into a set of equations. These equations show the nature of the relationships that are laid out in the structural diagram. Now you are ready to simulate the system's behavior on a computer. This activity also includes assigning numerical values to define the direction and strength of these relationships. Now you may be able to generate to a certain degree, the behaviour patterns that are being produced by the actual system. This will produce a major insight - and perhaps more importantly, produce a quantum increase in the clarity of the understanding. It also doesn't necessarily involve computer-based simulation - though this often is useful.

Let us now take an example. The predator/prey models are classic examples. In this type of system the elements are essentially dependent on each other from the perspective that the quantity of one element determines the quantity of the other element. The Foxes/Rabbits example is a predator/prey system. The Foxes eat the Rabbits and its' population increases. Increased numbers of Foxes eat most of the Rabbits; deplete their food supply, and subsequently their numbers. Fewer Foxes allow the Rabbits to flourish and increase; whereupon, there would be more to eat for the remaining Foxes and their ascendancy would begin again (see figure 1). In other words we can describe the system like this: “I will feed upon you even though my existence is dependent upon your existence”. No natural system is this simple; the food supply of the Rabbit varies, Foxes eat more than one kind of Rabbit, humans may intervene, and so on. Nevertheless, here we consider only the basic dynamic relations only to make it simple.

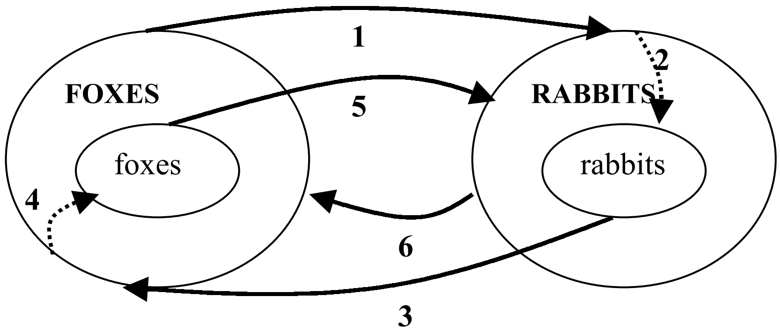


Figure 1 Predator/Pray System

Now we will draw the model diagram using standard symbols. And your model diagram should look like as in figure 2 if we implement it in STELLA software.

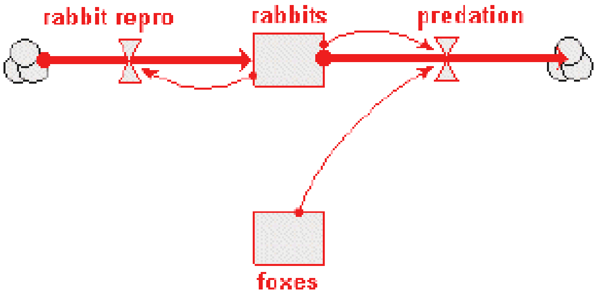


Figure 2 Predator/Prey System

Mathematically, the model is conventionally expressed as:

$$dX/dt = aX - bXY$$

$$dY/dt = cbXY - dY$$

where:

X = size of the prey population (you can set an initial value, say, 5000 to perform the simulation exercise)
Y = size of the predator population (45)

a = number of offspring per prey per year (set to 0.5)
b = proportion of the prey population consumed by one predator per year (0.01)
c = conversion of one prey consumed into new predators (0.01, i.e. 100 rabbits eaten gives rise to one new fox)
d = proportion of predator population dying per year (0.2).

Now you can run the model using software such as STELLA and you can analyse the behaviour of the system. In the above model if you add predator dynamics, your model diagram should look like as shown in figure 3

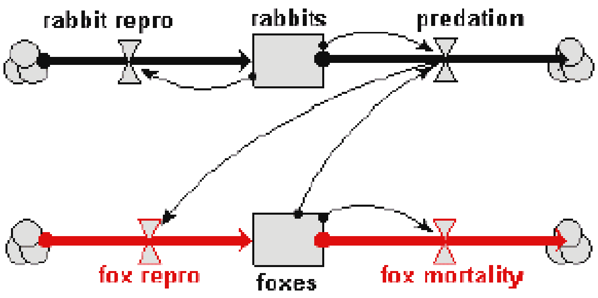


Figure 3 Revised Predator/Prey System adding predator dynamics

Even now the model is based on a number of assumptions that are biologically unsound. For example, it assumes that the number of rabbits eaten per fox is directly proportional to the number of rabbits, so doubling the number of rabbits doubles the number eaten per fox — even if there are millions of rabbits around! You can tackle this by adding in a couple of variables and changing the influence arrows, but retaining the same mathematical structure to make it biologically more realistic. Nevertheless, when we study interactions, it is essential to determine where to draw the boundaries to limit consideration. In doing this, there is always a trade-off. If we limit the domain of interactions consideration too much, what remains may be so narrow as to omit some of the relevant interactions essential to understanding the system. If we make the domain of interactions too broad the system under consideration is quite apt to be so complex as to limit our ability to understand the interactions in the midst of the complexity.

Scope of this article is limited to introduce systems thinking to you. There are numerous studies and several books published on this subject. If you want to learn more about systems thinking, you can download free self learning materials on system dynamics called ‘Road Maps- A Guide to Learning System Dynamics’ from Massachusetts Institute of Technology (MIT) system dynamic group web site (http://sysdyn.clexchange.org/road-maps/home.html).