About Systems Theory

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The origins of systems theory can be traced back many centuries when it was first used by scientists as a method of learning about complex systems. Scientists believed the best way to learn about a complex system were to break it up into its smaller components which in turn could be more readily identified and studied. This approach to studying systems became widely used and successful in the physical sciences such as biology, chemistry, and physics.

General systems theory evolved beginning in the 1920's as scientist's began to examine the characteristics of systems. Their observations concluded that no matter how different the components of different systems were, all systems shared a common set of rules of organization.

As a result of general systems theory, new methods of tackling complex real-world problems that spanned different disciplines were developed. In addition, general systems theory provided individuals with a macro view of how a complex system works.

Systems theory argues that however complex or diverse the world that we experience, we will always find different types of organization in it, and such organization can be described by concepts and principles which are independent from the specific domain at which we are looking. Hence, if we would uncover those general laws, we would be able to analyse and solve problems in any domain, pertaining to any type of system.

The systems approach distinguishes itself from the more traditional analytic approach by emphasizing the interactions and connectedness of the different components of a system. Although the systems approach in principle considers all types of systems, it in practices focuses on the more complex, adaptive, self-regulating systems which we might call "cybernetic".

System theory is basically concerned with problems of relationships, of structures, and of interdependence, rather than with the constant attributes of object.

What Is a System?

The term system has a number of special meanings that are often confusing. System may refer to a number system, school system, air-conditioning system, and so on. Webster defines a system as a "regularly interacting or interdependent group of items forming a unified whole," which "is in, or tends to be in, equilibrium".

Miller discusses a system as a set of units that have some definable relationships among them. He expands his definition by focusing on the term set. Hence set implies common properties among the units, and the state of each single unit influence the state of the other units within the system. Therefore may view a system may be viewed as a set of units with the capacity to interact within the scope of their environment to achieve certain goals.

A system is an entity which maintains its existence through the interaction of its parts. The key element of this definition is "interaction," rather than "parts." A system is composed of subsystems and at the same time a subsystem of one or more other systems. And, it is the interaction of the parts of a system which is responsible for its emergent characteristics.

This definition of a system implies something beyond cause and effect. Rather than simply A affects B, there is an implication that B also affects A. Examples of systems are particle, atom, molecule, cell, organ, person, community, state, nation, world, solar system, galaxy, and universe, in increasing levels of complexity.

Systems have four major characteristics that act together to maintain the system. **First**, all systems are **goal** oriented, that is, they have a specific function. **Secondly**, systems have **inputs** from their environment on which they act. **Next**, systems have **outputs**. An output is any information that the system sends out to its environment. **Lastly**, **feedback** from the environment gives the system information about its outputs. These characteristics will be further discussed in the next section of this lesson.

Systems Classification

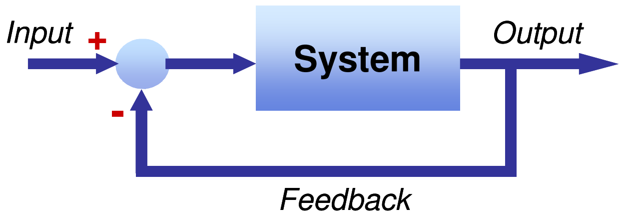
Systems are classified according to properties they are based on. Examples of classification include:

System attribute	*Contrasting attribute*	*Asserts whether or not ...*
Open loop	Closed loop	… there is a feedback loop
Single input single output	Multiple input multiple output	...the model equations have one input and one output only
Linear	Nonlinear	... the model equations are linear in the system variables
Time varying	Time invariant	...the model parameters are constant
Continuous	Discrete	...model equations describe the behaviour at every instant of time, or only in discrete *samples* of time

In many situations nonlinear models can be linearised around a user defined operating point.

All systems are either open or closed. An open system exchanges matter and energy with its environment, and a closed system has impervious boundaries through which no information, energy, or matter can transverse.

Open Loop System

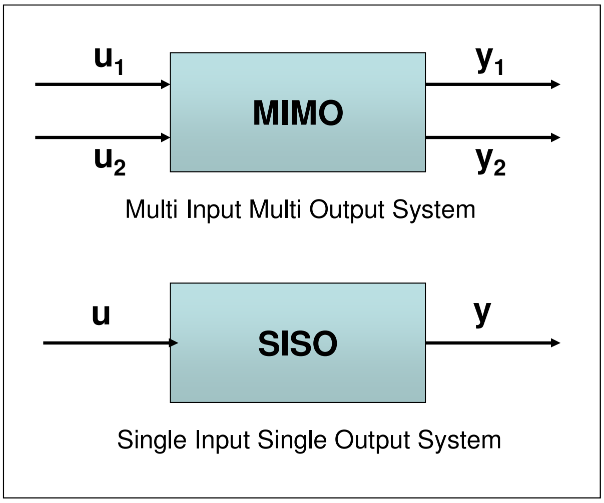


Closed Loop System

Living systems are open systems; their components need not be alive. Living systems may create artefacts that are objects made by man or animal and included in the system for some purpose.

Single-Input-Single-Output (SISO) and Multiple-Input-Multiple-Output (MIMO) Systems

When a system has only one input and one output, it is referred to as a single-input-single-output (SISO) system. When a system has more than one input or more than one output, it is termed as a multi-input multi-output (MIMO) system.



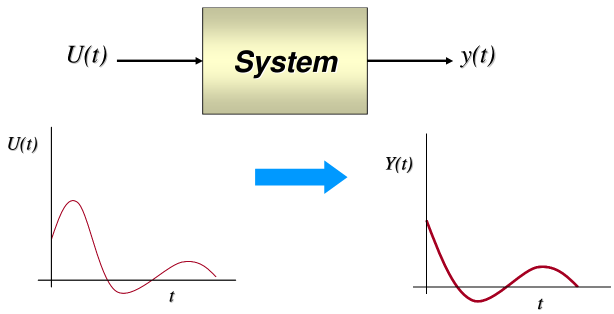
Decoupling

Decoupling is a requirement in MIMO control system design. If a system is dynamically decoupled then changes in the set-point of one process variable lead to a response in that process variable but all other process variables remain constant. The advantages of such a design are intuitively clear: e.g. a temperature may be required to be changed, but it may be undesirable for other variables (e.g. pressure) to suffer any associated transient. Full dynamic decoupling is a very stringent requirement. Thus in practice, it is more usual to seek dynamic decoupling over some desired bandwidth.

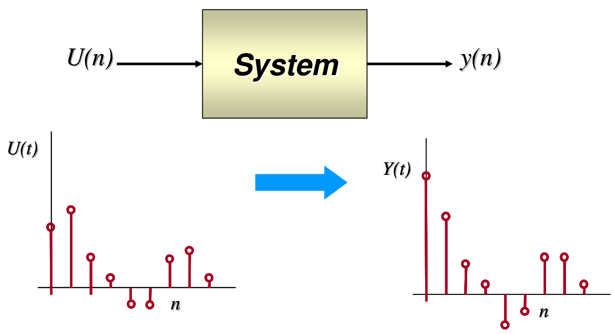
The purpose of decoupling is to isolate a system into several parts in such a way that individual parts can be controlled, changed, and replaced independently. The advantage of decoupling is local change, i.e., the system can be changed by modifying one or only a few parts, instead of changing everything.

Continuous and Discrete Systems

Continuous control applications involve process variables that can change at any instant--flow, temperature, and pressure, being prime examples. The process industries, particularly petrochemicals, were once heavily dependent on continuous control systems that could manipulate continuous process variables at all times.



Continuous System



Discrete System

In contrast, discrete variables that change only at specified intervals are subject to discrete control. An assembly line is a classic example. The countof-completed-assemblies is a discrete variable that changes only at the instant when the line moves forward and a finished product rolls off the line. A discrete control system can manipulate a discrete variable only when the schedule calls for the next operation.

Continuous and discrete control systems behave very differently and are generally designed according to different mathematical principles. However, the two come together in sampled control applications where the process variables change continuously, but can only be measured at discrete intervals.

Deterministic and Stochastic Systems

Uncertainty and disturbances are usual in real systems. In the deterministic case, the signals and the mathematical model of a system are known without uncertainty and the time behaviour can be reproduced by repeated experimentation. In the stochastic case this not possible due to uncertainty that exists either in its model parameters or in its signals or in both. The values of the signals or the variables occurring in the system can only be estimated with the help of the methods of probability and statistics.

Linear and Nonlinear Systems

Most natural systems are nonlinear. An important criterion that distinguished nonlinear systems from linear systems is the principle of superposition. If this principle holds good as it happens in linear systems, the sum of all the individual outputs due to several individual inputs, each considered to be acting alone on the system is equal to the output due to all the inputs acting simultaneously on a system.

Nonlinear systems do not obey the principle of superposition. The response of a linear system due to a sinusoidal input signal remains sinusoidal with an amplitude modification and phase shift, whereas a non-linear system produces distortion that gives rise to harmonic components of the input signal frequency in its output.

Stable and Unstable Systems

A system whose response either oscillates within certain finite bounds or grows without bounds is regarded as unstable. If for every bounded input the output is bounded, the system is said to be I/O stable. If this is not the case, the system is unstable. Stability in linear time invariant systems is easily ascertained by applying well-established criteria. Stability in a nonlinear system is quite complex; it depends on the inputs and the point at which the system is operated. Nonlinear systems can therefore be stabilised by manipulating the input signals acting on them, for example, sometimes by injecting additional high frequency signals. This is not possible in linear systems; its stability cannot be altered by external actions; they have to be stabilised by manipulating their inherent properties, that is, by altering the system parameters.

System Dynamics

System dynamics is a methodology for studying and managing complex feedback systems, such as one finds in business and other social systems. In fact it has been used to address practically every sort of feedback system. While the word system has been applied to all sorts of situations, feedback is the differentiating descriptor here. Feedback refers to the situation of X affecting Y and Y in turn affecting X perhaps through a chain of causes and effects. One cannot study the link between X and Y and, independently, the link between Y and X and predict how the system will behave. Only the study of the whole system as a feedback system will lead to correct results.

The methodology

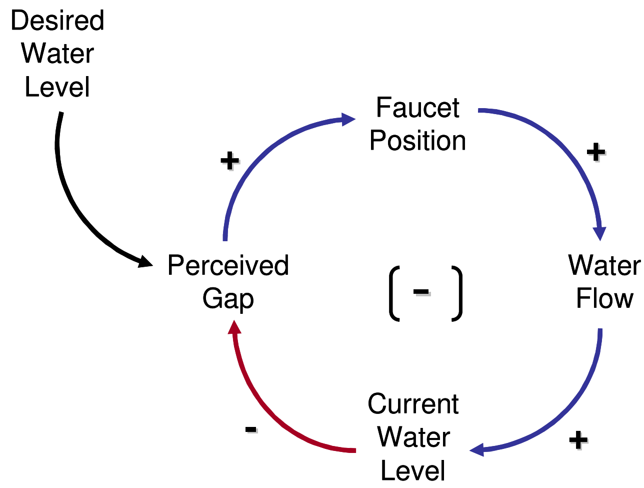
- identifies a problem,
- develops a dynamic hypothesis explaining the cause of the problem,
- builds a computer simulation model of the system at the root of the problem,
- tests the model to be certain that it reproduces the behaviour seen in the real world,
- devises and tests in the model alternative policies that alleviate the problem, and
- implements this solution.

Notations for Dynamics Systems

The dynamics diagrams are drawn in the style of the System Dynamics causal loops diagram. Causal loops diagrams emphasise the causal relationships among things. By better understanding these relationships, we can gain insights to the dynamics involved. It also allows us to develop possible policy or remedies.

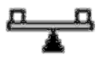
Consider a simple system – filling a glass of water (adopted from Senge's Fifth Discipline). As we fill the glass, we are watching the water level rise. We monitor the "gap" between the level and our goal, the desired water level. As the water approaches the desired level, we adjust the faucet position to slow the flow of water, until it is turned off when the glass is full. We have five variables in this system: our desired water level, the glass's current water level, the gap between the two, the faucet position, and the water flow. These variables are organised in a circle or loop of cause-effect relationships which is called "feedback process"

The sample diagram below illustrates the notations of causal loops diagrams:



1. Words denote *variables*, values that can go up or down.
2. Arrows denote causal relationships between variables.
3. Arrows with "+" sign indicate positive correlation.
4. Arrows with "-" sign indicate negative correlation.
5. A closed loop of arrows form one causal loop.
6. A loop with "-" sign indicates a balancing loop which stabilises.
7. A loop with "+" sign indicates a reinforcing loop which magnifies the values.

Symbols used in causal loops diagrams.

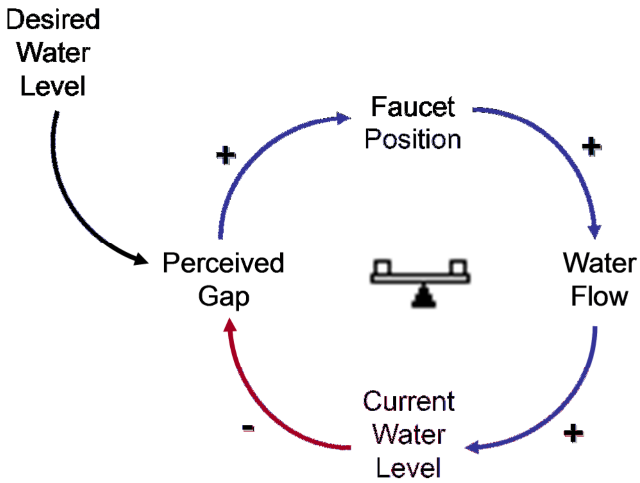
System	Sign	Symbol	Feedback
Reinforcing loop	+		Positive Feedback
Balancing loop	-		Negative Feedback
Delay			

The two main building blocks of all system representations are reinforcing and balancing feedback loops.

A reinforcing loop is one in which an action produces a result which influences more of the same action thus resulting in growth or decline. The reinforcing loop is one of the two foundational structures of systems thinking, the other being the Balancing Loop.

Reinforcing loops generate exponential growth (positive reinforcement) and collapse (negative reinforcement) and, as a result, are often represented in systems diagrams by the ‘snowball’ effect. A reinforcing loop will always, sooner or later, come up against a limiting or *balancing* effect.

Balancing feedback operates whenever there is a goal-oriented behaviour. If the goal is to be not moving, then balancing feedback will act the way the brakes in a car do. If the goal is to be moving at hundred kilometres per hour, then balancing feedback will cause you to accelerate to hundred but no faster. The “goal” can be an explicit target, as when a firm seeks a desired market share, or it can be implicit, such as bad habit, which despite disavowing, we stick to nevertheless. Balancing processes generate resistance, maintain stability and help achieve equilibrium.



In a balancing system, there is a self-correction that attempts to maintain some goal or target. Filling a glass of water is a balancing process with the goal of a full glass. Balancing feedback processes underlie all goal-oriented behaviour.

Delay. Many feedback processes contain “*delays*”, interruptions in the flow of influence which make the consequences of actions occur gradually. Delays are interruptions between actions and their consequences.

Delays exist everywhere in systems. Adjusting the shower temperature, for instance, is far more difficult when there is a ten-second delay before the water temperature adjusts, than when the delay takes only a second or two. During the ten seconds after you turn up the heat, the water remains cold. You receive no response to your action; so you perceive that your act has had no effect. You respond by continuing to turn up the heat. When the hot water finally arrives, it is too hot and you turn back; and after another delay, it’s frigid again. Each cycle of adjustments in the balancing loop compensates somewhat for the cycle before.

A delay is an interruption between an action and its consequences. Delays occur frequently in dynamic systems. This often results in *overshooting* a desired outcome.

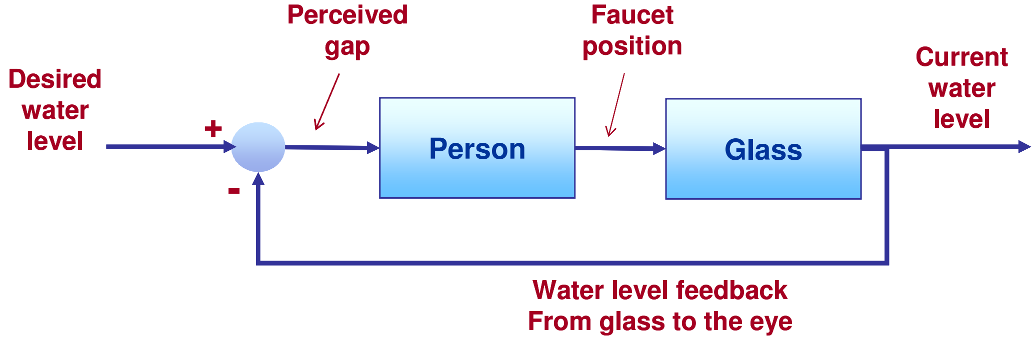
According to system dynamics a complete dynamic system can be modelled by combining these different elements, like reinforcing feedbacks, balancing feedbacks, and delays.

Leverage. Sometimes small, well focused actions can produce significant, enduring improvements - if they are carried out in the right place. This is referred to as *leverage*. The problem with leverage is that it is often difficult to find. This is because it is usually not close in space and time to the symptoms of the problem. As a result, in order to find high-leverage changes it is necessary to identify underlying structures in the system. A number of such structures are common to a very large variety of situations. These structures are called systems *archetypes*.

Block Diagram Representation

A block diagram is a graphic representation of a system showing the individual elements/subsystems and their interconnections. Based on certain conventions, block diagrams can be manipulated and simplified for ease of analysis. Systems are denoted as transfer elements or blocks. Transfer elements possess a unique direction of action indicated by arrows; their action is not reversible. Every controllable and observable transfer element has at least one input and at least one output. The output of a transfer element depends only on its own input but not on the loading effect of the following connections. Transfer processes are described by block diagrams with appropriate connections among the blocks.

The following diagram represents the system “Filling a glass of water” mentioned earlier.



Systems Thinking

System thinking has its foundation in the field of system dynamics, founded in 1956 by MIT professor Jay Forrester. Professor Forrester recognized the need for a better way of testing new ideas about social systems the way we can test ideas in engineering. Systems thinking allows people to make their understanding of social systems explicit and improve them in the same way that people can use engineering principles to make explicit and improve their understanding of mechanical systems.

The approach of systems thinking is fundamentally different from that of traditional forms of analysis: instead of focusing on the individual pieces of what is being studied, systems thinking focuses on how the thing being studied interacts with the other constituents of the system - defined as a set of elements that interact to produce behaviour - of which it is a part. This means that instead of isolating smaller and smaller parts of the system being studied, systems thinking expand its view to larger and larger numbers of interactions as it continues to study an issue.

The field of system dynamics gave rise to and serves as the bedrock for the field of systems thinking. With its emphasis on simulation modelling, system dynamics is generally seen as the more rigorous, academic field—though many management consultants use computer models in their work with clients. Systems thinking take the principles of systemic behaviour that system dynamics discovered—and applies them in practical ways to common problems in organizational life.

Systems thinking look at exactly the same kind of systems from the same perspective. It constructs the same causal loop diagrams. But it rarely takes the additional steps of constructing and testing a computer simulation model, and testing alternative policies in the model.