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Piero Mella

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Systems Thinking: The Art of Understanding the Dynamics of Systems

Piero Mella, University of Pavia, ITALY, ITALY

Abstract: Systems Thinking was introduced by Peter Senge in his book The Fifth Discipline (Doubleday, New York, 1990). It is a discipline for seeing wholes, recognizing patterns and interrelationships, and learning how to structure those interrelationships in more effective, efficient ways. Systems Thinking is a discipline in that it proposes: to train us to observe reality as composed of dynamic systems; to provide us powerful models of description and simulation; to improve our ability to gain knowledge, that is to learn; to develop our intelligence. Systems Thinking, in that it is a discipline, must be learned gradually, with practice, and continually perfected. In his book, Peter Senge presents Systems Thinking in an intuitive way, but he does not provide the logical principles behind it. I believe that the logical structure of this discipline can be summarized in five fundamental rules the systems thinker must follow at all times: if we wish to understand the world we must be able to see the "trees through the forest"; we must develop the capacity to "zoom" in and out from whole to parts, from systems to components; we must not limit our observation to what appears constant but "look for that which varies". Variables – and the "variations" that these undergo over time – are what interests the systems thinker; if we want to understand reality we must connect the variables which are of interest to us in a chain of causal relations among the connected variables; we must "link the variables" in order to specify the loops between all those variations, thereby transforming the linear variations into system interactions among the variables; when we observe the world we must always specify the boundaries of the system we are examining.

Keywords: Systems Thinking, System Dynamics, Leverage effect, Causal Loop Diagrams, Control Systems

Models for Intelligence

TO "UNDERSTAND THE world" means, in fact, to be able to construct *coherent and sense-making models* of it; such models – which may be explicit or implicit (Maturana&Varela, 1987) – should allow us to acquire, update and transmit our knowledge in order to forecast and programme the future, as well as to act and construct our existence and that of our descendants and fellow beings. «*"Survival learning" or what is more often termed "adaptive learning" is important – indeed it is necessary. But for a learning organization, "adaptive learning" must be joined by "generative learning", learning that enhances our capacity to create*» (Senge 1990:14).

Nonaka believes the generation of knowledge depends on our perspectives and on individual will and that the knowledge creation process is an art (mastery) and not a science. *The creation of knowledge is not simply a compilation of facts but a uniquely human process that cannot be reduced or easily replicated*. (Nonaka, 1994; Von Krogh-Ichijo&Nonaka, 2000).

Intelligent persons are those who learn quickly and effectively; they have the ability (innate or acquired) to construct, utilize and modify *models*; they can understand their interconnections and changes and always "know" what is happening and could happen in order to control events and successfully face the various situations of their existence, deciding in the most rational way how to solve problems.

Systems Thinking Produces Effective and Efficient Models

If intelligence depends on the ability to construct models (Gubbels, 1992), I believe that the most useful and effective models to strengthen our intelligence are system ones – developed following the logic of *Systems Thinking* – because such models can explore complexity, dynamics and change.

Two important definitions are worth mentioning.

> *«Systems thinking is a discipline for seeing wholes. It is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static "snapshots". It is a set of general principles ... It is also a set of specific tools and techniques, originating in two threads: in "feedback" concepts of cybernetics and in "servo-mechanism" engineering theory dating back to the nineteenth century»* (Senge, 1990: 68).
>
> *«Systems Thinking, Systems Approach, Systems Dynamics, Systems Theory, and simply Systems, are nothing other than some of the many terms commonly used for a field of activity many have*

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> *heard of, for which many feel the need, but which few actually understand.* [...] *Since I prefer the term Systems Thinking, I will use it everywhere to describe this field of activity»* (Richmond, 2000; see also, Bertalanffy, 1971).

Systems thinking has been proposed as the *The Fifth Discipline: The Art and Practice of the learning Organization*, precisely because, together with four other disciplines – Personal mastery, Mental models, Shared vision, Group learning – it is presented as a means for building *Learning Organizations*, which are organizations that develop a continual collective learning by putting all their members in a position to learn together while supplying them with the instruments for such collective learning; that is *«...organizations where people continually expand their capacity to create the results they truly desire, where new and expansive patterns of thinking are nurtured, where collective aspiration is set free, and where people are continually learning to see the whole together. »* (Senge, 1990: 3).

The cognitive effectiveness of Systems Thinking models derives from the facility in constructing them. They only require perspicaciousness and acumen, make use of elementary techniques, can be understood even by non-experts, and can be easily communicated, discussed and improved. They can, without too much difficulty, be translated into quantitative simulation models with the aid of System Dynamics tools (Forrester, 1961).

In order to understand the world we of course must not be satisfied just with Systems Thinking models; but for those who have neither the time or resources to construct more sophisticated models the following proverb is always valid: *« Beati monocoli in terra coecorum »*: lucky are those who, knowing how to construct Systems Thinking models, have at least one eye in a complex world.

Being a discipline, Systems Thinking must be learned gradually, with practice, and continually perfected: *«To practice a discipline is to be a lifelong learner. You never arrive; you spend your life mastering disciplines .»* (Senge, 1990: 10)

But what does Systems Thinking consist in? What are its logical and theoretical bases?

Systems Thinking is based on *five* fundamental rules, which I shall present in this paper.

Seeing the Forest and the Trees. Travelling Between Parts and Wholes

The first rule behind systems thinking *obliges* us «to see the forest and the trees».

We can translate this rule – which requires constant practice to apply – as follows: if we want to broaden our intelligence *we must develop the ability to "zoom" between* parts *and* whole, *and between* units *and* components.

If we define a *dynamic system* as a *unit* of interrelated *variables,* then Systems Thinking views Reality as an intermixture *of interconnected systems*, of ever increasing range, that form a global structure that generates a global process that cannot be understood only by *placing ourselves outside it* (forest) or *inside it* (trees); we must always strive to "*see both the trees and the forest".*

Systems Thinking operationalizes the *holistic view* in that it not only specifies the range of our observation of the *whole/part* relation but, above all, tries to identify the links and constraints that make the *whole* and its *parts interdependent.*

Seeing the "Dance of the Starry Sky". The Importance of Variations

The second rule is perhaps more important than the first one, since it *obliges* us to change our normal way of *observing* the world.

From our earliest childhood we are taught to *describe* and *define* what we *"see"* by looking for the *fixed characteristics* that "make things what they are".

On the one hand, we *describe* the *objects* we observe in all their detail; on the other we use the innate process of *analogy* to *generalize* the various specific observations, seeking out the common traits of the different *objects* we have observed, or those traits which are "not too different", so as to define *concepts* and *ideas.*

There is nothing wrong with this way of "*looking at*" the world; what distinguishes the way Systems Thinking "sees"?

This discipline *obliges* us not to end our observation when we have found what appears constant but *to search for that which varies*; it obliges us *to shift our attention to* variables *that connote the objects*: «the objects must be observed as vectors of variables».

The second rule of Systems Thinking implies an equally important corollariy: we must not limit ourselves to the variables we hold to be significant: «we must be able to perceive the variations these undergo over time», measuring them with precision based on an appropriate temporal scale.

However, this way of observing the world is not at all automatic; even this second rule imposes a discipline on us. We must train ourselves to observe change and get used to this as soon as possible, even though this requires additional effort.

Unless you are astrophysicists studying the size of a galaxy with a *black hole* in its center, counting the stars on an August evening will not be very useful to you in constructing a model of the star-studded universe. This was well understood by the ancient astronomers. Yet motivated by the desire for knowledge, some of them decided to observe the positions of the planets and the *variations* in their trajectories, night after night, season after season, year after year, so that, by observing the dynamics of the stars, they managed to see the “marvellous dance of the starry sky”, which still today eludes most of us.

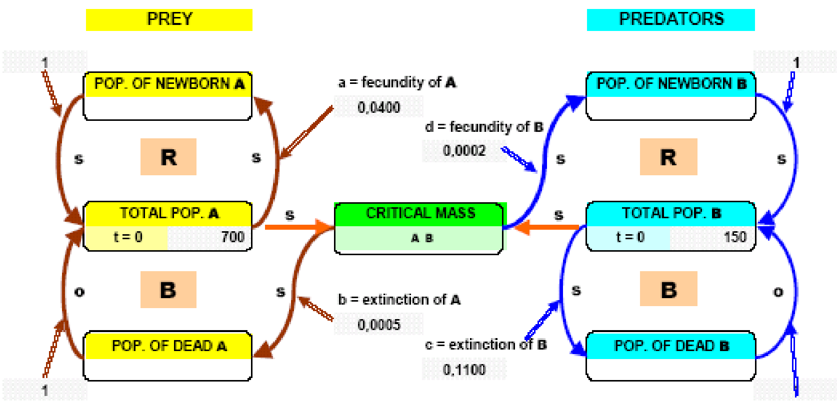
The “Why Game”. Searching for Causal Chains

Systems Thinking is also based on a third rule, which is the most important of all; this rule completes the two preceding rules and requires constant practice of them, forming together a very powerful logical system: «if you want to truly undestand the world do not be content with observing variables and their variations; you must search for the “cause” of the variations in the variables you observe».

Why does the number of sardines in the Adriatic Sea have a cyclical trend? The answer was supplied by the great Italian mathematician, Vito Volterra, with his famous dynamic equations of populations (Volterra, 1931) – also independently discovered by Alfred Lokta (1925) – which linked the number of sardines (prey) to the number of sharks (predators).

These equations provide a simple and *intuitive* explanation: if the number of sardines increases the sharks have more food, and thus their numbers also increase from feeding on a larger quantity of sardines. The voracity of sharks thus reduces the number of sardines, and those sharks who cannot find food are destined to disappear, thereby allowing the sardines to increase again, thus allowing the sharks to reproduce in greater quantity, etc., etc. The cycle constantly repeats itself and produces an oscillation in the number of sardines and sharks.

The model in Fig. 1 (the symbols will be explained in the following section), which was constructed based on Systems Thinking logic and simulated with EXCEL, shows the cyclical dynamics of two populations of preys and predators.



			PREY		CRITICAL MASS	PREDATORS	
YEARS	PREY A	PREDATORS B	born a A	died (-) b A B	A B	born d A B	died (-) c B
0	700,00	150,00			105.000,00		
1	675,50	153,45	28,00	52,50	103.655,40	19,9500	16,5000
2	650,69	156,27	27,02	51,83	101.688,45	19,6945	16,8795
3	625,88	158,40	26,03	50,84	99.136,33	19,3193	17,1892
4	601,35	159,81	25,04	49,57	96.088,70	18,8359	17,4235
5	577,35	160,49	24,05	48,05	92.657,71	18,2590	17,5788
6	554,12	160,44	23,09	46,33	88961,82	17,6050	17,6537
7	531,83	159,68	22,16	44,45	84923,67	16,8913	17,6483
8	510,64	158,25	21,27	42,46	80810,24	16,1355	17,5650
9	490,66	156,20	20,43	40,41	76640,70	15,3539	17,4078
10	471,97	153,58	19,63	38,32	72484,12	14,5617	17,1019

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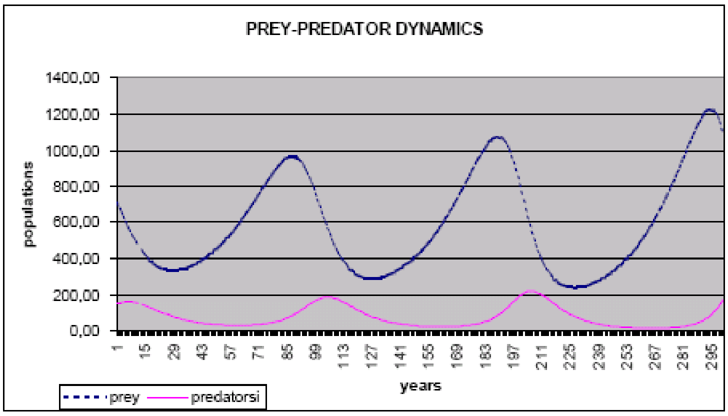

Fig.1: Prey-predator Simulation Model Based on the Equations of Volterra-Lotka

We can translate the third rule into an operational form: to understand the "cause" of the variations we observe in a given variable we must identify two closely connected elements:

1. the processes that produce the dynamics of the variables and the "machines" that carry out the processes:
2. the variables that "activate" those processes (causes or inputs) and those that "derive" from the processes (effects or outputs)

This almost seems obvious, but the fact that normally we forget that the *variables* change their values due to the work of some *process* carried out by some *machine* makes it extremely important to practice applying this rule.

What process increases my *weight*, given my physical structure (machine-body)?

Certainly the fact of eating more food; my colleague eats as much as me without gaining weight. Of course the quantity of food is important, but we must also take account of the amount of movement by which I burn calories. Why do I eat too much and move too little? Because I have little time! Why do I have little time? Because I work too much! Why do I work too much?

This is exactly like the "why game" we played as children. Each answer to a "why?" gives rise to a new question, to another "why?" The chain increases until there is no answer to the last "why?".

How do we bring the third rule into the "why" game?

Why does our car *speed* vary? This depends on the energy processes of the motor (the "machine"), the energy consumption processes owing to the grade of the road (environment), and the processes involving the operation of the accelerator and brake (control), as well as on the various sources of friction.

We can thus write (Δ means "variation"):

Δ*velocity*=FUNCTION of [Δ*accelerator*, Δ*brake,* Δ*grade+wind*, *driver's objectives*]

always in reference to the car's mechanical *processes.*

But how many of us are accustomed to thinking in this way? Isn't it simpler perhaps to only think of the variables and consider that the variation in *velocity* is the effect of pressing down or letting up on the *gas* and *brake* pedals (automatic shift), as well as of the *grade* of the road and the *wind*?

However, if we apply the third rule we are required to think – as in the "why game" – that the speed depends also, and perhaps primarily, on the *mechanical processes* (piston displacement, revolutions per minute, tire consumption, load, etc.) and the *driving processes* (driving ability, haste, objectives) of the driver, and that the *pressure on the accelerator* and *brake* are the control variables (causes) of these processes.

But who among us can really say he knows how the mechanical processes taking place under the hood of our car operate?

It truly seems that the third rule – *you must understand what the variations in the variables of interest to us depend on* – is difficult to apply when we adhere to the requirement of identifying the *processes* that produce the *variations* and the *variables* that *cause* them.

Precisely for this reason Systems Thinking allows us to consider the *processes* as *black boxes* whose *internal* structure and functioning might also not be known.

What is truly indispensable is to note the *connection* between the *inputs* and *outputs* of the processes taking place in the *black box*.

It is for this reason that we can simplify the third rule as follows: «to understand the dynamics of an effect variable (output), search for the cause variables (inputs) and assume the process (even if unknown) that connects them is stable».

In this simpler form the third rule admits this important corollary, which is now easily recognizable: *the dynamics of a variable (output) always depends* *on the process that produces it through the action of its causes (input).*

We can now readily play the "why game" without any difficulty in order to identify the causes of the causes of the causes, etc., forming long causal chains of dependent *variables* that go on until our curiosity is satisfied.

But there are surprises in store for us.

The Serpent Swallows Its Tail. Closed Causal Chains. Loops

Let us try the "why game" with an example by Peter Senge.

We are back in the Cold War era. Why are American arms increasing? Because in the U.S. there is a rise in the fear over the increase in the Soviet Union's arms.

Why are Soviet arms increasing? Because there is a rise in the fear over the increase in U.S. arms.

There appears to be some error in this game. Each variable (U.S. and Soviet arms) increases because the other increases. It seems we are witnessing a *Uroboros*, a serpent that swallows its tail, or an Egptian *Mehen*, a coiled serpent.

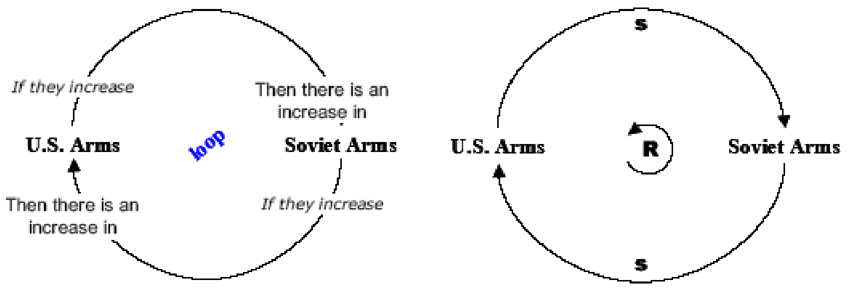

Fig. 2: Reinforcing Loop

But there is no error. It is precisely like this. The variations in the two variables are *reciprocally caused*. Between them there exists a *loop*, a technical term that gives the image of the serpent swallowing its tail, the symbol of continuity or, better yet, *interconnection*.

We can illustrate this with a simple diagram, the *Causal-Loop-Diagram* in Fig. 2, where the arrows indicate the directions in the variations: at the tail there is the cause (input), at the head the effect (output).

In this situation, for each *effect variable* (for example, U.S. Arms) there is a cause variable (Soviet arms); but this also holds for the other variable, so that between the two variables *considered together* there is no cause and effect but an interaction, an interconnection, a continual *feedback*, a *loop* in fact.

We can make it easier to write and read *Causal-Loop-Diagram 1* by recognizing that between U.S. and Soviet arms there is a relation in the same direction, ("s"), as well as between Soviet and U.S. arms. Both variables reinforce each other, and for this reason they form a *reinforcing loop*, [R], which is illustrated at the right of the diagram.

Does the example seem irrevelant after "detente"? Perhaps, but if we substitute the pair ["U.S. Arms" and "Soviet Arms"] with the pair ["U.S. Duties" and "EU Duties"], the pair ["Calculating power of the computer" and "Computational and graphical needs of software"], or the pair ["Offensive arms of predators" and "Defences of the prey"], don't we still encounter the same *Uroboros*?

Let's play again.

Why is there a decline in sardines? Because there is an increase in sharks.

Why do sharks increase? Because sardines increase.

Why do sardines increase? Because sharks decline in numbers.

Why do sharks decline in number? Because sardines decline in number.

Now the game becomes more complicated because there is an *intersecting series* of increases and declines which are less simple to identify.

We can help ourselves with the *Causal-Loop-Diagram* in Fig. 3, which is similar to the preceding one. «Why is there a decline in sardines [effect]?»; the answer: «Because the sharks increase [cause]». Why do the sharks increase (arrow at top right)? Because the sardines decline (arrow at top left).

To make the *Causal-Loop-Diagram* easier we observe that there is a relation in the same direction, ("s"), between the number of *sardines* and *sharks* (more sardines, thus more sharks; fewer sardines, thus fewer sharks); but between *sharks* and *sardines* there is a relation in the opposite direction, ("o"), (more sharks, thus fewer sardines; fewer sharks, thus more sardines). The variables take turns *balancing* each other, and thus form a *balancing loop,* [B], which is illustrated on the right in Fig. 3.

Does it seem like a trivial game? Then let's change it by substituting "Sardines" with the "Demand" for a certain good and "Sharks" with the market "Price" of that good.

Why does Demand fall? Because Price increases.
Why does Price increase? Because Demand increases.
Why does Demand Increase? Because price Falls.
Why does Price fall? Because demand Falls.
Why does supply increase? Because price increases.
Why does price increase? Because supply falls.
There seems to be some problems with these causal chains.

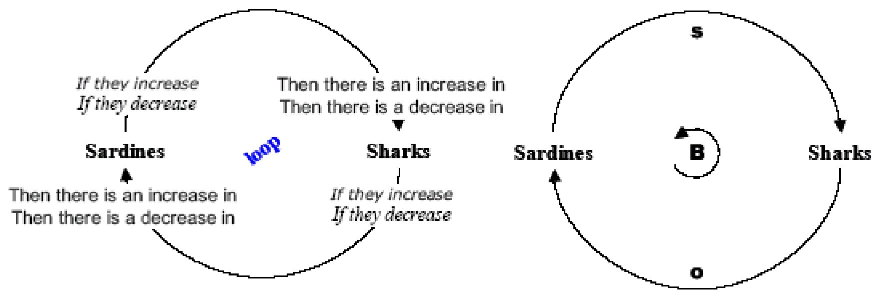

Fig. 3: Balancing Loop

Yet, there is no problem. In the *Causal-Loop-Diagram* in Fig. 4 we find two "serpents that are swallowing their tails" at the same time. Systems Thinking has simply rewritten in a simplified and clear manner the law of demand and supply (in simplified form).

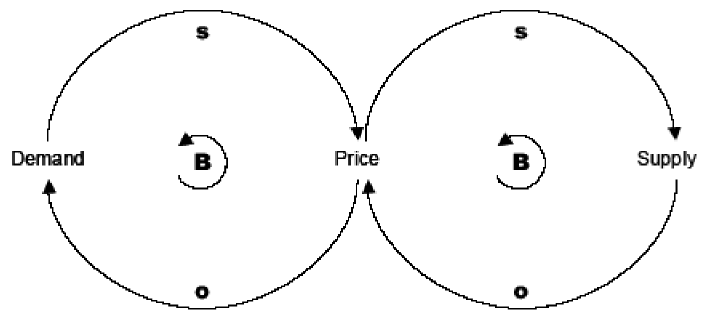

Fig. 4: Balancing Loop: Demand and Supply

The *reinforcing,* **[R]** *,* and *balancing,* **[B]** *,* Causal-Loop-Diagrams represent *basic modules* (Anderson&Johnson;1997).

Systems Thinking states that a dynamic world, no matter how complex, can be thoroughly described and modelled by means of various combinations of these two modules, by inserting into the loops a greater number of variables connected in a causal relationship, or by connecting two or more loops to form more complex structures, keeping in mind that we must zoom in to analyze the processes in more detail in order to identify and connect other important variables (Kim&Senge, 1994).

Figure 5, for example, offers a first indication of the system that leads to conflicts.

If we consider conflicts as the variable we start from to interpret this phenomenon, then we can consider competition as the cause that triggers the process of the struggle for life. Competition is the effect of the scarcity of resources. The process of destruction connected to conflicts reduces resources, thereby producing a loop [R] (there are two "o" s in the loop).

The external connections that form a loop [B] (there are three "o"s) show that conflicts re-equilibrate the population, and this reduces the need for resources and probably competition as well.

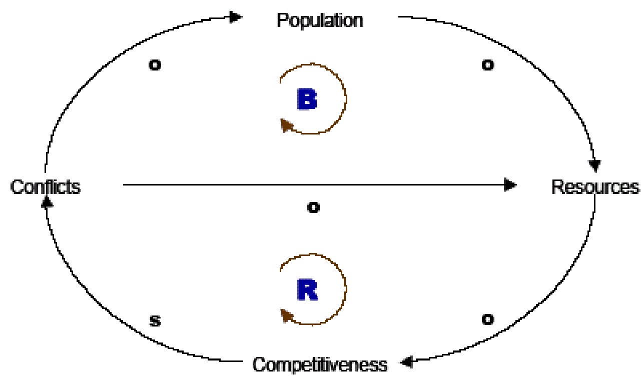

Fig. 5: An Easily Interpretable Causal-Loop-Diagram

He who Plants Date Palms does not Eat Dates. The Importance of Delays

What is missing in the preceding models? It is clear that the Causal-Loop-Diagrams in the previous figures only illustrate the *logical structure* among the variables. Why have we not explicitly shown the processes that produce variations?

For Systems Thinking *the dynamics of the variables depend on the logical structure* of the *loops* that connect them; the operational "machine" can be ignored, as long as its physical structure remains constant over time.

This is enough to understand how a system functions.

In effect, who can specify what the psychological processes were, linked to the fear of the potential enemy, that moved the U.S. and the U.S.S.R. to undertake the technical, innovative, economic and financial processes to continually expand their war arsenals? And who can specify the processes that move consumers and producers to change their decisions as a function of the price level?

Nevertheless, we cannot totally ignore the processes. We must at least consider the *delays* between their inputs and outputs.

We can understand the effect of *delays* by considering how many times we have turned the mixer in the shower without the expected variations in temperature, so that we have to turn the mixer more and suffer the devastating effect of the water becoming scalding and then ice cold due to an unpredictable delay.

Delays make the dynamics of a system quite complex, but they do not depend on functioning defects; instead they are connected to the functioning of the "machines" that activate the processes. Thus they cannot be eliminated, arbitrarily reduced or even ignored.

An Arab proverb more or less says: *«He who plants date palms does not eat dates»*, to indicate the long delay before a date palm produces its first fruit. It is useless to insist; there are no date palms that bear fruit after only one season.

Taking into account *delays* and the impossibility of eliminating them, only one strategy remains: learning to *identify them* and, through experience, to *reduce their numbers* and *duration*.

Everything Comes Around Again. Systems and their External and Internal Boundaries

Though simple, the examples presented so far are sufficient to understand the sense of the fourth rule of Systems Thinking: «if you really want to understand the world and its changes you must *make an effort* to link the variables you observe and to specify the loops among their variations» (Richardson, 1991).

The consequences of this rule are of the utmost importance: the "why game" must continue until we realize that the *answer* to the last "why?" lies precisely in the *question* we posed at the beginning, as *Leonardo da Vinci* had already clearly understood: *«Everything comes from everything, and from everything we produce everything, and everything comes around again... ».*

The concept of *cause* and *effect* that pertains to two (or more) *linked* variables loses its significance when we consider those variables connected by one or more loops; these become *" Uroboros* that swallow their tails" and constitute a unit that takes on an *independent meaning*.

These variables represent a *dynamic system*.

This definition, though apparently different, is entirely in conformity with those proposed by the other traditional systems disciplines, which consider systems as units of interrelated elements that produce emergent processes, thanks to the micro processes carried out by the component parts (von Bertalanffy, 1968; Sandquist, 1985).

The following point needs stating: Systems Thinking holds that in order to "understand" the world it is enough to understand the *logical structure* of the *dynamic systems* it is composed of, leaving to engineers, biologists, doctors, economists, sociologists, psychologists and other specialized scientists the task of examining or building the *operational structure* of those systems (Weinberg, 2001).

We can now derive the first general law of Systems Thinking: «to explain the dynamics of a variable do not seek out a cause but define the logical structure of the dynamic system the variable belongs to».

But how large is the dynamic system? How many variables do we need to connect?

Let us not forget that the first rule of systems thinking obliges us to *zoom* inside a system – thereby identifying increasingly smaller subsystems – as well as outside a system to identify ever larger supersystems.

Are we thus destined (we could say "condemned") to having a holistic view without limits?

Certainly not! Systems Thinking is the *art* of "seeing" the world, and in order for what we see to have a true meaning it must depend on our *cognitive interests*. We cannot have a forest without limits.

For this reason Systems Thinking contains a fifth rule, which can be summed up as follows: «When we observe the world always specify the boundaries of the system we wish to study».

In reality there are two *boundaries*: an *external* boundary that delimits the system when we zoom from the parts to the whole, and an *internal* one when we zoom from the whole to the parts.

It is not easy to identify or set these *boundaries*; fortunately, the more we apply ourselves to the discipline of Systems Thinking the easier and more spontaneous it becomes to find the solution to this problem.

A Snowball's Memory. The Systems of Systems Thinking

It is important to clarify which systems Systems Thinking examines and what types of models can thereby be obtained.

Due to its intrinsic logic, which observes a world of variables and of variations, Systems Thinking mainly considers *dynamic systems*, building models of a world of incessant movement in continual transformation and evolution. Such systems are not only dynamic but must also be *repetitive* systems, able to repeat their processes over time, as well as *recursive* systems, capable of interacting with themselves in the sense that their output, entirely or in part, becomes their own inputs, so that in a certain sense the system appears closed within itself in order to repeat its processes over a temporal sequence.

Even if we are not used to observing them, *recursive* systems are all around us. They are the typical essence of nature; life itself is recursive in its typical process of birth, reproduction and death, which is destined to repeat itself again and again.

Sharks feed on sardines, reproduce, and their offspring will eat other sardines born from subsequent reproductive acts. Car manufacturers as well as producers of computers, bread, fruit, clothing, and any other type of consumer good (which does not last forever) well know that they could not survive for long if the consumers, at more or less regular and lengthy intervals, did not repeat their purchases.

Only the pyramids – like the mountains – are (almost) eternal; no one would destroy them to build new ones!

Man is also a recursive system for almost all the processes of his existence. Wakefulness is followed by sleep to allow us to face a new period of wakefulness, which requires sleep again; work is followed by rest, the office by a vacation, a discovery by new research. There would be no arms race if today the production of arms were not followed tomorrow by an increase in enemy arsenals. And languages would not survive over time if their teaching was not repeatedly passed on from parents to children, generation after generation; we wouldn't pay taxes each year if each year we didn't produce new income; feuds wouldn't continue over time if each offence weren't followed by a vendetta; and there wouldn't even be an increase in the average temperature if day after day, year after year, there wasn't a repeat of heat emissions.

Now that we have underscored that Systems Thinking makes it possible (though this is not easy, since it is a discipline) "to see" an *interconnected*, *dynamic, repetitive* and *recursive* world, we must also realize that the systems observed by Systems Thinking are systems (*processes* and *machines*) that normally have a memory.

The system can no longer be observed simply through the input and output variables; the *internal state* variables have to also be considered at the same time.

Memory is present in almost all dynamic systems, producing physical, biological, psychic and social processes.

Unlike a rock that is rolling, there is *memory* in a snowball which, when thrown in a gully, rolls over itself and accumulates more snow, rotation after rotation, generation after generation. There is memory in the populations that pass on their language, generation after generation; or in the consumers that prefer the newest products; or in firms, which learn from their successes and try to avoid past failures; or even in my bank account, which accumulates interest year after year, thereby producing higher interest; just as there is memory in my mind that grows tired and needs restorative sleep, day after day; and we know how memory is the engine behind eternal feuds between individuals and peoples, behind scientific progress and the search for new records.

We must realize this for Systems Thinking, which isn't easy.

The General Law of Systems Thinking

Having clarified that Systems Thinking considers systems to be repetitive and recursive, we can state the second general law, which we shall call the Law of dynamic instability. Paraphrasing Newton's first law of mechanics: *«Every object remains in its state of rest or uniform motion in a straight line unless a force intervenes to modify this state .»* Systems Thinking states: «Every repetitive system does not endlessly produce its own reinforcing or balancing processes because other processes intervene to reverse its dynamics», as shown in the general model in Fig. 6.

In other words, every expansion is attenuated and reversed by *brake* variables and connected *balancing* processes which, in turn, can be upset by external *disturbances* or even by associated *reinforcing* processes.

In the world of dynamic systems it seems impossible to respect the wise motto: *« Quieta non movere , mota quietare !»* .

Everything moves, but fortunately *nothing varies endlessly*. And who knows: when the thermal death of the universe arrives, perhaps another universe will spontaneously appear!

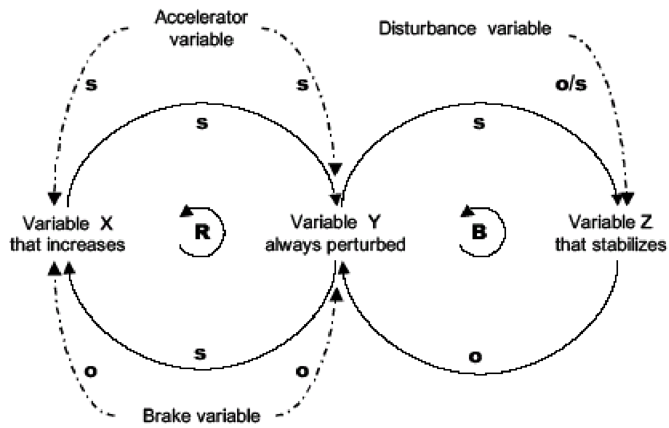

Fig. 6: The Causal-Loop-Diagram of the General Law of Dynamic Instability

Conclusion. Systems Thinking and Intelligent Decisions. The Leverage Effect

Systems Thinking is particularly useful in the field of decision-making processes. It offers many useful indications and rules, two of which are fundamental:

Above all, Systems Thinking warns us that a problem must not be identified with the evident symptoms that require urgent measures: *the symptom is not "the" problem because "the" problem is in the structure of the system and its dynamics*.

In order to solve "the" problem it is not enough to remove the *symptom* – settling for short-term symptomatic solutions with equally short-term effects – but to intervene on the structure producing that symptom.

Senge defines a definitive solution that exploits the potential of the system's structure and its loops – not limiting itself to symptomatic interventions on individual variables – as the *leverage effect*.

> *«The advantage of systems thinking derives from the leverage effect – seeing in what way the actions and changes in the structures can lead to long-lasting, meaningful improvements. Often the leverage effect follows the principle of the economy of means, according to which the best results do not come from large-scale efforts but from well-concentrated small actions. Our non-system way of thinking causes significant specific damage because it continually leads us to concentrate on low leverage effect changes*: *we concentrate on symptoms of higher stress. We correct and improve the symptoms*: *but such efforts are limited, when things go well, to improving short-term factors, while worsening the situation in the long run .»* (Senge, 1990: 131).

Obviously, as this quote clearly demonstrates, exploiting the *leverage effect* means identifying the *loops* in the structure – that is, the subsystems – which allow for *greater beneficial effects* on the symptoms with a *minimum use of resources*, taking into account the time needed for the *leverage effect* to take effect.

Senge describes the concept of leverage presernting an example of a firm, WonderTech, which had recurring problems with sales. While the sales went down, the marketing and sales vice president, took a course of action:

«He held high-powered sales meetings with a single message: "Sell! Sell! Sell!" He fired the low performers. He increased sales incentives, added special discounts and ran new advertising promotions describing the machine in an exciting new way. And indeed, sales rose again. [but] After a year, delivery times began to rise again – first to ten weeks, then to twelve, and eventually to sixteen. The debate over adding capacity started anew. But this time, having been stung on the last occasion, the top management was still more cautious. Eventually, approval of a new facility was granted, but no sooner had the papers been signed than a new sales crisis started. The slump was so bad that the sales and marketing vice president lost his job.».

The pattern is clear: increased sales meant more orders for the production department. Production had limited capacity, which, once exceeded, showed in increased delivery times. These in turn reduced customer satisfaction and lead to sales difficulties. Increasing production capacity took a long time, and if the managers reacted only after the capacity was exceeded, it was already too late. When a new factory was ready there was already a sales crisis

Managers did not see the relationship of these phenomena, because they were so dispersed in time and space.

This example clearly emphasises the importance of understanding the system as a whole. Only then we may focus our actions so that they have the greatest leverage.

In fact, the causal diagrams do not automatically highlight any solution; instead they must be carefully studied in order to identify one or more linked loops – which are called system, or structural levers – which, by being acted upon, can cause the *leverage effect*.

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About the Author

Prof. Piero Mella

Born in Pavia, graduated in March 1969 with a first class degree in Industrial administration, in 1985 I won a chair as a full professor and lectured in Business Economics and Administration at the Faculty of Economics of Pavia. In 1986 I was elected Head of the Department of Business Research at the University of Pavia. From 1987-88 to 1992-93 I was Dean of the Economics Faculty at the University of Pavia. Since it was founded in 1990 I have been the scientific Director of the Masters in Accounting, Budget and Financial Control in profit organizations, set up by the University of Pavia. In 1997 I became Co-ordinator of the Doctorate in Business Research at the University of Pavia. In 2000 I created the scientific web site www.ea2000.it. My interests also deal in the fields of Complex and Holonic Systems and of Networks. In 1997 I have proposed the Combinatory System Theory, described at the web site: www.ea2000.it/cst.

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