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Give Me an Arrow and I Will Construct a World for You

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Abstract

To survive in a world of change (which is always changing), we must develop our intelligence, to quickly learn to construct models to understand processes and their effects, long or short term, close or distant to us in space, and if possible, to dominate them, that is, predict and control them. Accepting the hypothesis that intelligence is the capacity to construct, and rapidly modify, a *coherent system* of effective *models* which contain meaning for understanding the world's dynamics and developing effective behavior aimed at survival, this theoretical study will suggest the guidelines for learning and *quickly* constructing graphic models to understand, and to a certain sense dominate, the dynamics that characterize our existence. This paper will present the main ideas of Senge (2006) on Systems Thinking, which is considered not only as a technique but primarily as a discipline for efficient and effective thinking, learning, communicating and explaining with regard to the dynamics of our world. The title of the paper reveals that the proposed models derive from the logic and techniques of Systems Thinking, which provides Senge's personal interpretation—and one that, in many respects, is innovative—refining not only the concepts but also the techniques for constructing models of systems dynamics (that is, the Causal Loop Diagrams) utilizing the graphical tool of "arrows" to connect the variables to be represented and to identify their direction and sense of variation. There is no limit to the complexity that can be represented with the graphic models of Systems Thinking, which is why Senge was able to state that: "Give me an arrow (a causal relationship and a sufficient power of variation) and I will construct a 'world' for you; not a real world, of course, but a structural map of part of it" (Senge, 2006: 3).

Keywords

Systems Thinking, System Dynamics, Control Systems, Causal Loop Diagram, Stock & Flow Diagram, The Fifth Discipline, Archetypes

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1. Introduction

The title of this short conceptual paper is intended to make immediately clear that, in my opinion, Systems Thinking is one of the most powerful tools of knowledge and understanding because it teaches us to devise coherent and sense-making models of the world, which are among the most effective for improving our intelligence, modifying our world and constructing our existence.

> Intelligent persons are those who understand (and comprehend) quickly and effectively; who are not content to "look at the world with their eyes" (objects, facts, phenomena and processes) but who are able "to see the world with their minds" by constructing models to "understand" how the world is (description), how it functions (simulation), and how we can act as part of it (decision and planning), even without having the need, or possibility, of "looking at everything" (Mella, 2012: p. 3).

My opinion is based on three premises:

a) Intelligence is the ability to develop a system of coherent and meaningful models that allow us not only to survive in a world that is continually evolving but also to improve ourselves and make progress;

b) The most powerful and effective models are the systems ones that view reality as a set of connected and dynamic parts forming a whole. An understanding of the connection between the parts and the whole and their dynamics is the fundamental characteristic of operational and creative intelligence;

c) The most interesting and useful connections among the elements that make up reality are not the linear ones—characterized by chains of causes and effects—but the circular ones, the feedbacks and loops, which make the elements not only connected but also interconnected, not only dynamic but also interactive. The only efficient thinking is Systems Thinking.

These three points will be developed in the sections below. In order to enlarge intelligence and learn to construct powerful learning models regarding the world's dynamics, this paper aims to guide the reader in learning the logic and techniques of Systems Thinking, according to the powerful structure proposed by Peter Senge in his book *The Fifth Discipline*: *The Art and Practice of the Learning Organization* (Senge, 2006: 1st ed. 1990). Systems Thinking is one of the most powerful tools of knowledge and understanding, since it teaches us to devise coherent and sense-making models of our changing world that are among the most effective in permitting ourselves and our descendants and fellow beings to improve our intelligence and construct our existence.

> The great shock of twentieth-century science has been that systems cannot be understood by analysis. The properties of the parts are not intrinsic properties but can be understood only within the context of the larger whole. Thus the relationship between the parts and the whole has been reversed. In the systems approach the properties of the parts can be understood only from the organization of the whole. Accordingly, Systems Thinking concentrates not on basic building blocks, but on basic principles of organization. Systems Thinking is "contextual", which is the opposite of analytical thinking. Analysis means taking something apart in order to understand it; Systems Thinking means putting it into the context of a larger whole (Capra, 1996: pp. 29-30).

2. Looking without "Seeing" and Seeing without "Looking" the Role of Models

A wise ancient proverb says:

Some look and don't see.

Others see and don't look.

How can these words be interpreted, apart from in a mystical, naive sense? What significance can we derive from them? I suggest replacing "look" and "see" with "observe" and "understand", reformulating the saying as follows:

Some observe and don't understand.

Others understand and don't (have to) observe.

Expressed in this way it is easier to interpret. We know (Mella, 2014b) that "understanding the world" means in fact being able to construct coherent and meaningful models, which allow us to form and transmit new knowledge. These models are coherent in the sense they do not have to be in contrast with other models thought to be effective; they do not have to be incompatible with our knowledge but have to supplement our knowledge. The models are meaningful because they must directly or indirectly be linked to observed or theorized reality, after taking account of its nature. Models must allow us to reconstruct (descriptive models), simulate (operational models) or predict (theories and laws) what they represent, be this a concrete object (the structure of the Eiffel Tower, a probe placed on Mars, my cousin's wedding guests), a process (the behavior of a school of sardines, success in the fight against violence in football stadiums, the exploding of the pressure cooker), or even simply an object of pure imagination (what is the unicorn like, what is the structure of Dante's "Divine Comedy", how did the battle take place between earthlings and aliens in the film *The Invaders*).

Intelligent persons are those who understand (and comprehend) quickly and effectively; who are not content to "look at the world with their eyes" (objects, facts, phenomena and processes) but who are able "to see the world with their minds" by constructing models to "understand" how the world is (description), how it functions (simulation), and how we can act as part of it (decision and planning), even without having the need, or possibility, of "looking at everything".

How many times have we had to raise our voice when talking with friends at a restaurant, almost shouting in order to be heard because of the din, as if all the other diners were conspiring against us, speaking together to deny us a peaceful conversation. It is not enough "to look at" who is talking, count them, classify them by sex, age, dishes or wine ordered, in order "to see" what is happening. But a simple heuristic model (Mella, 2005, 2014a) immediately clarifies the situation: in order to communicate we must speak a few decibels higher than the background din; but the latter depends on the combination of the loudness of the individual speakers, so that if the noise increases the speakers will also raise their voices, thereby causing a further increase in noise, until this reaches a deafening level (as during a dinner with fellow workers to celebrate the approaching holidays). It is always like this; it is inevitable!

Thanks to models we not only can "understand the world" but above all "learn to live"—that is, to act, plan and foresee the future in order to improve our existence as well as that of our kin and descendants.

Thanks to models we can not only "understand the world" but above all "learn to live"—that is, to act, plan and foresee the future in order to improve our existence as well as that of our kin and descendants. In a changing world man, like organizations, must be able to adapt; he must acquire the capacity and desire to change himself based on his changing world. Survival learning" or what is more often termed "adaptive learning" is important —indeed it is necessary. But ... "adaptive learning" must be joined by "generative learning", learning that enhances our capacity to create (Senge, 2006: p. 14; see also Walker, 2001: p. 627).

> [In the international learning competition] ... those who are not willing and not prepared to live creatively and dynamically, to maintain their interest in broad-based learning during their entire lives, will lose this competition. Nations that are not able or willing to educate their children to aim for the highest possible objectives will be downgraded (Hampden-Turner, 1990: p. 4).

There is no knowledge without models. According to Nonaka, the creation of knowledge is not simply a compilation of facts but a uniquely human process that cannot be reduced or easily replicated. It can involve feelings and belief systems that may not be conscious even for managers who create knowledge (Ichijo & Nonaka, 2007: p. 85). Models can be divided into *mental models* and *formal models*. The former are the models which any *intelligent* individual creates in his "private" mental sphere to represent the content of the meaning he wishes to transmit (if he is the sender) or that he must interpret (if he is the recipient). Such an individual uses mental models to evaluate "the world" and make instinctive decisions (Mella, 2014b). Peter Senge, in The Fifth Discipline, deals with mental models on more than one occasion, offering these definitions:

> Mental models" are deeply ingrained assumptions, generalizations, or even pictures or images that influence how we understand the world and how we take action. Very often, we are not consciously aware of our mental models or the effects they have on our behavior. For example, we may notice that a co-worker dresses elegantly, and say to ourselves, "She's a country club person". About someone who dresses shabbily, we may feel, "He doesn't care about what others think (Senge, 1990: p. 8).

Nevertheless, mental models, precisely because they are produced "in the private sphere", have a clear limit: not only can they be imprecise and vague but they are often *erroneous* and, if not corrected through subsequent verifications or educational processes, can produce seriously harmful results. There are an endless number of examples of this, some of which it is useful to present here. Before Isaac Newton, the prevailing mental model for gravity was, in simple words, that: "The apple breaking off from the branch falls toward the ground, attracted by the earth, following a trajectory directed toward the center of the globe". Newton changed the mental model of gravity as follows: "Apples are attracted to the earth as much as the earth is attracted to apples, following a trajectory determined by their mutual centers of gravity". Another prevailing mental model was: "All bodies in motion are destined to stop, unless a force intervenes to keep them in motion". Newton's First Law of Motion changed this mental model by introducing the principle of inertia: All bodies will continue moving in a uniform straight line (or remain still) unless some other force causes them to change this state".

Precisely to overcome these limits and risks due to reasoning and decisions based solely on *mental models*, man has always sought to accompany these, even at times replace them, with the more efficient *formal models* made up of systems of concrete signs, linguistic or symbolic, which formalize and transfer a meaning and are used to communicate and enable weighty decisions to be made. Formal models allow people to represent and share, through specific language, all thought content in a specific field, thereby allowing them to improve the *explanatory* processes and create science.

We must realize that most times "what we are interested in understanding" cannot be observed; instead, part of our "world" derives solely from models, which are often constructed without our being able to observe anything and, just as frequently, in contrast with what we observe: models represent reality, but reality derives from models. It should be remembered that Albert Einstein managed to "see" General Relativity before Arthur Eddington's observations in 1919 during a total solar eclipse confirmed the bending of light passing close to a large mass. And what about the brilliant development of the Theory of Evolution, which uncovered ("saw") the determinants of the evolutionary process without having ever before observed the evolution of a species.

We are forced to recognize that models are the instruments of our mind that allow us to "see" (to know) beyond "looking at" (beyond observations). Techniques are required to transform our knowledge into *explicit* or *declarative* (conscious) *knowledge*, transforming such knowledge into formal models that can be easily communicated from one person to another and thus verified and shared in their coherence and capacity to represent the world.

3. Systems Thinking the Theory in Brief

If the capacity "to see" and not simply "look at" depends on the ability to construct models to understand, explain and simulate the world, then Systems Thinking is one of the most powerful tools of knowledge and understanding, since it teaches us to devise coherent and sense-making models of the dynamics of the world even before we are able to perceive them. Due to its intrinsic logic, which observes a world of variables and of variations, interconnected by causal loops that form a system, Systems Thinking considers dynamic systems of any kind in any field, building models of a world of incessant movement in continual transformation and evolution, allowing us to describe and simulate the forces and interrelationships that shape the behaviour of the world (Mella, 2012).

This Section will present the main ideas of Systems Thinking, considered not only as a *technique* or a *language* but primarily as a *discipline* for efficient and effective thinking, knowledge creation, communication, prediction, and mastering of complexity.

> Systems Thinking is a discipline for seeing wholes, recognizing patterns and interrelationships, and learning how to structure those interrelationships in more effective, efficient ways (Senge & Lannon-Kim, 1991: p. 24).
>
> Systems Thinking [is] a way of thinking about, and a language for describing and understanding, the forces and interrelationships that shape the behavior of Systems. This discipline helps us see how to change systems more effectively, and to act more in tune with the larger processes of the natural and economic world (Senge et al., 1994: p. 6).
>
> Systems Thinking, a Systems Approach, Systems Dynamics, Systems Theory and just plain ol' "Systems" are but a few of the many names commonly attached to a field of endeavor that most people have heard something about, many seem to feel a need for, and few really understand. […] As I prefer the term "Systems Thinking", I'll use it throughout as the single descriptor for this field of endeavor (Richmond, 1991: p. 1).

In his excellent book, Peter Senge presents Systems Thinking in an intuitive way, but he does not provide the logical principles behind it. In my recent book, "Systems Thinking. Intelligence in Action" (Springer, 2012), I have tried to recognize the fundamental rules and principles as well as the cultural background of this discipline.

I believe that the logical structure of Systems Thinking can be summarized in *five* fundamental rules which the systems thinker must follow at all times.

1. Searching for Variables and Variations.
2. Searching for Causal Relationships.
3. Travelling Between Parts and Wholes. Searching for Causal Chains.
4. Building Closed Causal Chains. The relevance of Loops.
5. Defining Systems and their external and internal boundaries.

3.1. First Rule Searching for Variables and Variations

The FIRST RULE to follow in applying Systems Thinking can be simply expressed as follows:

We must not limit our observation to that which appears constant but "*search for what varies*"; *the variables are what interest the systems thinker.*

This rule requires intense discipline, since from the earliest age we become accustomed to observing *objects* and *structures*: grandmothers, apples, the sea, the bedroom, the Eiffel Tower, etc.; or *processes*: doing homework, dressing dolls, playing a video game, cooking, teaching, etc. With this first rule Systems Thinking tells us to shift from a "world of objects" to a "world of variables" that connote those objects. Time employed, errors committed, expected mark, required attention, fatigue and attention, stimulation from mother, stress, pleasure, etc.: these are some of the variables that connote doing tasks. Cost, taste, calories, the capacity to satiate us, etc.: these are some of the variables that characterize food. The objects must be "seen" as vectors of significant variables. Shifting over to the observation of *variables*, in a world of *objects*, seems easier than it really is. One needs sensitivity and experience to select the truly significant variables and restrict their number so as to consider only those most relevant for the construction of models.

By definition, a variable X may assume different values (measurements, states, quantity, etc.): let $x(t_0)$, $x(t_1)$, $x(t_2)$, $x(t_3)$, etc., represent the values of X measured at the end of regular intervals, $[t_1, t_2, t_3, t_4, \dots]$, all within a defined period of reference T. In this sense X is a (discrete) time variable and its measured values, arranged along a time axis, form the dynamics (motion, trajectory, evolution, trend, etc.) of X with respect to T. However, we must not limit ourselves to explicitly stating the variables we consider useful but must be able to measure the "variations" they undergo over time: $\Delta x(t_1) = x(t_1) - x(t_0)$; $\Delta x(t_2) = x(t_2) - x(t_1)$; $\Delta x(t_3) = x(t_3) - x(t_2)$; etc.

This, too, seems easier than it really is. Constructing a world of variables raises two types of complexity:

> Senge sorts two types of complexity from this—detail complexity and dynamic complexity. Detail complexity arises where there are many variables, which are difficult, if not impossible, to hold in the mind at once and appreciate as a whole. Dynamic complexity arises where effects over time of interrelatedness are subtle and the results of actions are not obvious; or where short term and long term effects are significantly different […] (Flood, 1999: p. 13).

3.2. Second Rule Searching for Causal Relationships

Systems Thinking is also based on a SECOND RULE, which completes the FIRST RULE by forming with it a highly powerful logical system for "seeing" well beyond what we "look at". The RULE can be expressed in a concise (even if not yet precise) manner:

If we truly wish to understand reality and change, we must make an effort «to understand the cause of the variations in the variables we observe" by forming chains of causal relationships among the connected variables.

I detect that the number of butterflies fluttering in the wind in the valley is increasing each summer; what is behind this increase? The number of butterflies will increase up to what limit? In other words: given that their reproductive capacity is constant, what conditions will favor the vital success of the butterflies in the valley? Does the question seem trivial? Perhaps, but it was precisely the need to answer a similar question—why does the number of sardines in the Adriatic have a cyclical trend—which provided the basis for the famous population dynamics equations of the celebrated mathematicians, Volterra (1926, 1931) and Lotka (1925). Volterra linked the number of sardines (prey) to the number of sharks (predators). Thanks to these equations (known as the Volterra-Lotka equations), the explanation was simple and intuitive: 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. The cycle constantly repeats itself and produces an oscillation in the number of sardines and sharks (Mella, 2014a: sect. 7.2).

Systems Thinking points out, above all, that any dynamics in a variable is caused by some process carried out by a "machine" (or systems structure). We must identify this process and, if possible, understand how the "machine" that produces it works (whether the machine is physical, biological, electronic, logical, organizational, social, etc.). This seems obvious, but the fact that we normally 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. 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. But how many of us are accustomed to thinking in this way? Isn't it simpler perhaps to think only 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? But how many of us are accustomed to thinking in this way? However, if we apply the SECOND RULE we are required to think 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. Using similar reasoning, it is natural to think that the speed (effect) derives from pressure on the gas and brake pedals (causes) and that these manoeuvres depend on the grade of the road and our speed objectives for arriving in a given place at a given time. I am sure that few would imagine that the speed depends on the revolutions per minute, tire consumption or engine capacity, even if it does so in reality.

Normally the processes that produce the variations in the variables we observe are unknown to us, or only approximately known. Precisely for this reason Systems Thinking admits that the *processes that produce variations* can be conceived of as a *black box* whose *internal* structure and functioning may not even be known. What is truly indispensable is to understand the rules (laws, functions, operations) by which the *variations* in the *input* variables cause variations in the *output* variables, as Norbert Wiener, the father of Cybernetics demonstrated (Wiener. 1961: xi, note 1).

Let us assume we have two variables, say X_t and Y_t, which are the inputs and outputs of a process (even a black box one), and that for simplicity's sake we could even call the input and output variables "causes" (causal variables) and "effects" (caused variables), respectively. In the formal language of Systems Thinking these cause and effect relations can be simply represented using arrows that *unequivocally* correlate their variations. The cause (input) variables are written in the tail of the arrow; the effect (output) variables at the head of the arrow, as shown in **Figure 1** (Sterman, 2000), which represents a basic or *standard module* (or even an *elementary system* without memory), directed from X to Y, since:

a) For each value, $x(t_0)$, of X there always corresponds one and only one value, $y(t_1)$, of Y, with the appropriate temporal shifts (normally, t_0 and t_1 depend on the operational cycle of the underlying "machine" and are not specified in the basic models);

b) *There is no memory* in the process (in the "machine) that produces the variations in Y given those in X.

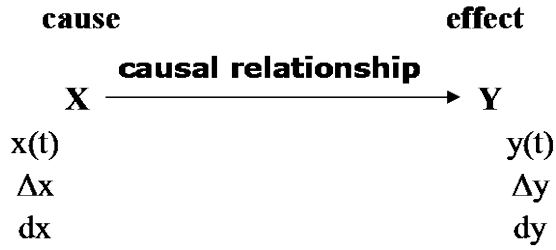

Figure 1. Standard module (different alternatives). Direction of connection.

Obviously, if we are drawing on a normal sheet of paper, the name of the variables, their respective positions, and the shape of the arrow can be freely chosen. The meaning of the *standard module* in **Figure 1** can be considerably enhanced by specifying not only the direction of the connection between the variables but the direction of variation as well. Two possibilities are shown in the graph in **Figure 2**. Two variables have the *same direction of variation* ("**s**") if increases or decreases in the former result in corresponding increases or decreases in the latter (left arrow). They have the opposite direction ("**o**") if increases or decreases in the former result in corresponding decreases or increases in the latter (right arrow).

We must also bear in mind that *two variables can be linked in two* opposite *directions*. The *quantity* produced of a certain good depends on its *price*, since the value of the latter influences the planning process regarding the quantity to produce. However, we can also note a relationship in the *opposite direction*: the price depends on the volume of production, since the producers will vary price in order to control their stock of goods when there is excess demand (rise in price) or unsold production (decrease in price). Thus it is important to choose the *direction* of the link between the variables precisely by taking into account the fact that the *causal link* underlies different processes in each of the two opposite directions and that by changing the direction the *direction of variation* can also change.

3.3. Third Rule Travelling Between Parts and Wholes Searching for Causal Chains

To understand a reality composed of a great number of interconnected variables we must not limit ourselves to observing only individual connections among variables and depicting these in standard modules; it is necessary to "see" even the larger groupings of variables, attributing to them an autonomous meaning. Systems Thinking proposes this THIRD RULE, which is at the basis of Systems Thinking modeling:

> *If we want to understand the world we must be able to "see the trees and the forest"; we must develop the capacity to "zoom" from the whole to the parts, from systems to components, and vice-versa.*

This RULE can be translated as follows: Reality is *permeated by systems*, increasingly vaster in scope, which form a global structure that creates a global process that cannot be *understood only* from the *outside* or *inside*. If we want to broaden our intelligence we *must develop the capacity to "zoom" from* parts *to* the whole, *and from* entities *to* components. In this sense we can say that this THIRD RULE of Systems Thinking "operationalizes" the *holonic view*, in that it not only specifies how far the observation of the whole/part connections between variables should extend but above all tries to identify the connections and constraints that make the whole system and its parts interdependent (Mella, 2009). The concept of holon was introduced in 1967 by Arthur Koestler in his book *The Ghost in the Machine*, using simple and clear intuition:

> Parts and wholes in an absolute sense do not exist in the domain of life [...] The organism is to be regarded as a multi-leveled hierarchy of semi-autonomous sub-wholes, branching into sub-wholes of a lower order, and so on. Sub-wholes on any level of the hierarchy are referred to as holons [...] The concept of holon is intended to reconcile the atomistic and holistic approaches (Koestler, 1967: Appendix I1).

This RULE enables the representation of the causal links among variables to be extended; it prescribes zooming in to identify other detail variables, for example, "W" and "Z", within a standard module between X and Y. At the same time, it imposes us to zoom out to identify other variables, for example, A and B, which extend the standard module and make it more general. Larger models are formed representing the causal relations among variables, which are called *open causal chains*.

Several simple examples of this are shown in **Figure 3**, in which the chain [4] is obtained by zooming in on chain [2]. The Systems Thinking technique allows us to easily identify the direction of variation of the entire *open causal chain*: if the first variable, at the left of the chain, varies positively (+), what sign will the variation in the last variable have? A simple method allows us to answer this: count the ("**o**") placed on the arrow of the chain. If there are no ("**o**"), or a positive number of them, then the entire chain has a direction of variation ("**s**"),

Figure 2. Directions of variations.

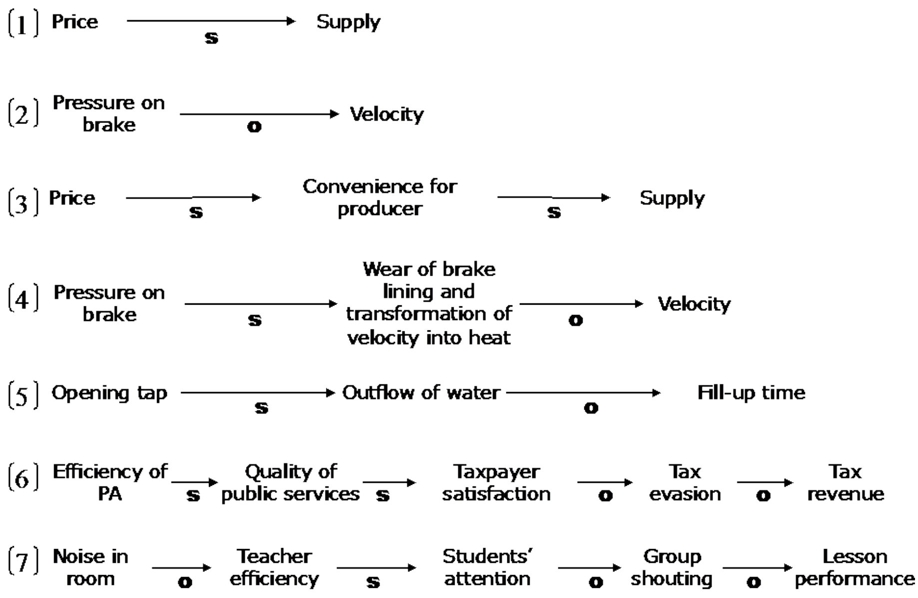

Figure 3. Examples of open causal chains (Source: Mella, 2012: p. 61).

and the last variable has a variation with the same sign as the first (+). If there is an odd number of ("**o**"), then the entire chain has a direction of variation ("**o**"), as seen by examining the chains [4], [5] and [7] in **Figure 3**.

According to the SECOND and THIRD RULE, the world appears mainly composed of causal loops and *open causal chains* of variables.

3.4. Fourth Rule Building Closed Causal Chains the Relevance of Loops

When two variables, X and Y, can have two opposite directions of connection, thus forming two distinct causal chains, it is possible to join the latter to form a *closed causal chain*, that is a *loop*, a circular link between two (or more) variables. Loops can be *basic*, when there are only two variables, or compound, when more than two variables are joined in a circular link, as a consequence of the THIRD RULE. There are only two basic types of loop (**Figure 4**):

1) *Reinforcing* loops **[R]**, which produce a *reciprocal increase or reduction*—in successive repetitions of the system's cycle—in the values of the two variables having *identical* direction of variation: "**s** and **s**" or "**o** and **o**" (**Figure 4**, left).

2) *Balancing* loops **[B]**, which *maintain relatively stable the values* of the connected variables, which are connected by a *different* direction of variation: "s and o" or "o and s" (**Figure 4**, right).

There is no limit to the number of interconnected variables. A system of variables linked by arrows forming a loop, without there being an initial and final variable, is defined as a *Causal Loop Diagram*, as shown in the examples in **Figure 5**, in which all the variables are connected by causal links. The most immediate way of identifying the *causal loop* is by trying to "close" the *open chains* by connecting the first and last variables, or even other variables in between, when this appears sensible (**Figure 5**).

Each CLD can be read starting from any of the interconnected variables, but the cognitive objectives and practice allow the systems thinker to easily identify the variables from which to begin and the direction to proceed in. In the CLD at the right in **Figure 5**, we could be interested in evaluating how Tax Evasion depends on the Efficiency of PA. If we proceed from Efficiency of PA, then the direction and interpretation of the graph is defined by the causal relations indicated by the arrows. For example, if Efficiency of PA is reduced, so too is the Quality of Public Services (**s**), which causes a reduction in Taxpayer Satisfaction (**s**), which produces a rise in Tax Evasion (**o**). The increase in Tax Evasion in turn reduces Tax revenue (**o**), and as a result resources for Investment in Modernization (**s**) as well, which inevitably causes a reduction in the Efficiency of PA (**s**). The reinforcing loop [**R**] can be repeated several times, resulting in the continued reduction in the Efficiency of PA, on the one hand, and the continued increase in Tax Evasion on the other.

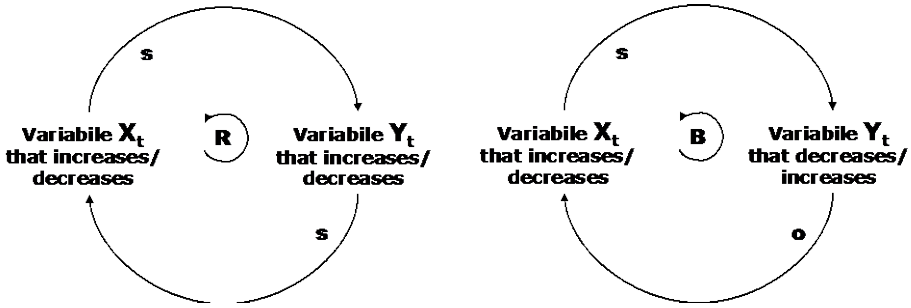

Figure 4. Reinforcing and balancing loops.

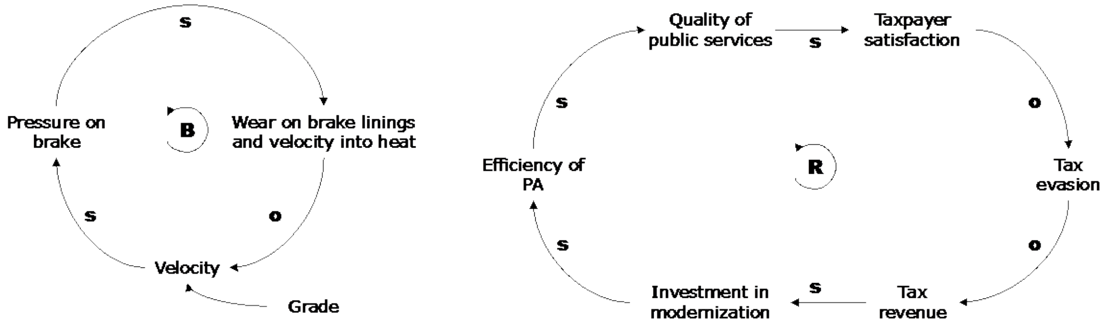

Figure 5. Closing the causal chains (chain [4], left, and [6], right, in **Figure 3**).

Generalizing, Systems Thinking recognizes that if we really want to "understand" the world and its changes, it is not enough to reason in terms of chains of causes and effects between variables; we must recognize that the effects can, in turn, become the causes of their causes, thereby creating a *loop*, a circular connection, between two variables connected from opposite directions. We thus have the following fourth rule:

We must make an effort to link together the variables until we obtain a loop among their variations. In other words, we must move from the causal chains to the systemic interconnections and from the linear variations to the systemic interactions among the variables of interest.

In brief, we must see the world in terms of circular processes, or feedback loops, abandoning the "linear thinking" ("laundry list thinking") that only considers chains of causes and effects and becoming accustomed to "circular thinking" (loops and Causal Loop Diagrams) in order to identify the loops that interconnect the variables.

> [...] If you took the time to record your thoughts, I'll bet they took the form of a […] "laundry list". I like to refer to the mental modeling process that produces such lists as laundry list thinking. I believe it to be the dominant thinking paradigm in most of the Western world today. [...] The Systems Thinking paradigm offers alternatives to each of these assumptions. First, according to this paradigm, each of the causes is linked in a circular process to both the effect and to each of the other causes. Systems thinkers refer to such circular processes as feedback loops (Richmond, 1993: 117).

We can connect any number of reinforcing and/or balancing loops to form a single system of variables which are not only *interconnected* but *interacting*. Some examples of these are constructed in Section 4. Note that chain [7] in **Figure 3** cannot be transformed into a causal loop, since the last variable cannot be, in a significant sense, connected to the first in a cause and effect relationship. *An error to avoid at all costs*, even if it is very frequent, is to confuse the *causal maps* with the *cognitive* ones (the term has been coined by Tolman, 1948) or semantic maps, concept maps, and so on.

3.5. Fifth Rule Defining Systems and Their External and Internal Boundaries

The THIRD RULE obliges us to zoom inside a system—thereby identifying increasingly smaller subsystems—as well as outside a system, to identify ever larger super systems. Are we thus destined (or "condemned") to having a holistic view without limits? Certainly not! Systems Thinking is the art of "seeing" the world and its dynamics, and in order for what we see to have true meaning it must depend on our cognitive interests. We cannot have a forest without limits. This is why Systems Thinking requires a FIFTH and final RULE:

When we observe the world we must always specify the boundaries of the system we wish to *investigate.*

More precisely, this means that whoever practices Systems Thinking must always identify, define or decide on the variables that form the system (within the boundary) and, by exclusion, those whose interconnections are too weak to be held capable of significantly influencing the others (beyond the boundary). 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, almost more spontaneous, the solution to this problem becomes.

3.6. Variables for All Needs

I will conclude this long section with several brief operational details to allow us to more effectively construct Causal-Loop-Diagrams. The first point is: which variables can we represent? The answer is:

-flow variables (flow of water from tap, national income, arrivals, departures, births, deaths, etc.),
-stock variables (water level, national wealth, waiting lines, warehouse stocks),
-intensity variables (opening of a tap, daily production, delivery schedules, pressure on car pedals),
-real variables (employees, hirings, complaints, financing),
-mental or psychological variables (fear, stress, satisfaction, fatigue).

The second point is: how do we assign names to the variables? It is absolutely "prohibited" to use names for the variables which do not denote true variables but instead denote objects, processes, people, etc. We must use names that best indicate the type of variable indicated in the previous list. If possible, avoid names that denote actions (eat, work, etc.) or those that already indicate a variable with its variation (a lot of sun, little fatigue, increase in quantity, etc.). It is not possible to use proper names (Peter, Lawrence, Charles) or non-variable attributes. Lastly, what characteristics must the variables have? The variables used to construct the Causal Loop Diagrams must have two characteristics: they must be *pertinent* and, if possible, *measurable*; pertinence concerns the existence of a relationship with other variables; the inclusion of non-pertinent variables results in a useless expansion of the CLD while hiding the importance of the pertinent variables. Measurability refers only to the quantitative variables, which can be expressed on a cardinal scale (height, weight, cost, profit, etc.); in a more general way we can extend the concept to qualitative variables, whose values must in any case be gradable according to appropriate scales (colors, flavors, noise, etc.).

4. Systems Thinking Free Your Mind

4.1. Simple Models for Learning the Language of Systems Thinking

Now that we have summarized the five rules of Systems Thinking and represented the structure of some simple systems, we can understand the approach of the Fifth Discipline, which presents additional simple models of dynamic systems.

The left of **Figure 6** shows that the price of a good has a direction of variation contrary to that of the volumes of supply (downward arrow, "**o**"); however, the price variations produce a same direction variation in the production volumes (upward arrow, "**s**"). In successive *cycles of the system* an equilibrium [**B**] is produced among the variables; if the price falls too much then supply falls; if supply declines then the price increases again.

The two variables, Price and Supply, mutually balance one another. It is easy to make a parallel observation for the CLD at the center, which indicates the equilibrium between price and demand. The CLD at the left shows that it is useful to join the two balancing loops to form a more complete system that describes the well-known "law of the market under perfect competition".

Price represents the key variable that produces an equilibrium between supply and demand; if the price falls too much then supply will also fall and demand rise, so that even the price will again increase, thus inverting the direction of variation in demand and supply.

The CLDs in **Figure 7** instead represent two very interesting general loops. The CLD at the left describes a

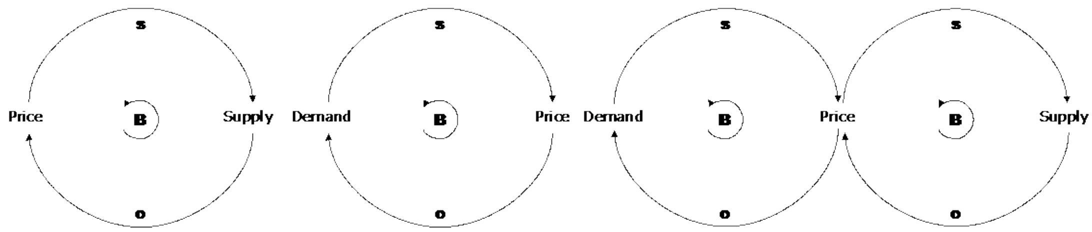

Figure 6. Basic *Ring* connecting price, supply and demand.

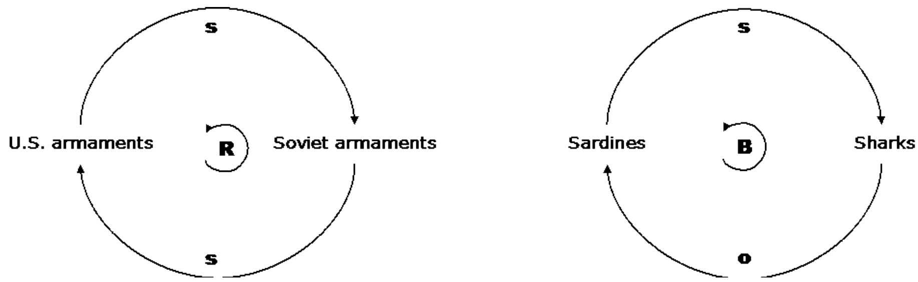

Figure 7. Escalation and prey/predator populations models.

very common *process of escalation* in which both variables reciprocally increase their values; the CLD at the right represents a very general *dynamic of prey/predator populations*.

The Model in **Figure 8** represents a composite, though simplified, model of the system that regulates the struggle for life among populations, groups and individuals of any kind. By reading the model starting from any variable, the structure will immediately be clear. For example, an increase in Population reduces available Resources (**o**), which increases Competition for those resources (**o**) and Conflicts aimed at possessing them (**s**). Many Conflicts produce a reduction in Population (**o**), which permits all the Resources to reproduce themselves (**o**). The loop [**B**] thus forms, which, however, intersects with loop [**R**], which shows the destructive link between Conflicts and Resources (**o**). The two loops are inseparably interacting to form a powerful explanatory model for many situations we can observe in history and daily life.

The phenomenon studied obviously depends on a number of other variables: capacity to produce new resources, pollution level, and so on. The model can be easily enriched with these variables as well as many others, *thereby extending the system's boundaries*.

Figure 9 shows the structure that regulates our job intensity and wealth aspirations.

The CLD in **Figure 10** shows the very general structure that produces and accentuates the process of "burnout from stress"; the search for short-term symptomatic solutions for stress (loop **B1**) can aggravate the problem in the long run rather than solve it (loop **B2**), thus producing collateral effects: for example, an Addiction to Sleeping Pills or the adoption of destructive personality traits (two delays have been introduced).

The Systems Thinking models are certainly not the only ones capable of increasing our knowledge of the world, but in my view their cognitive effectiveness owes to their ease of construction and communication. They allow us to learn together to collectively improve our understanding of the world and can be easily translated into quantitative simulation models.

4.2. A General Law: The System's Structure Produces the Behavior of the Variables

After learning the basic elements of Systems Thinking *language*, several important lessons can be derived for use in "seeing" even without "looking at", and in particular in avoiding serious errors in judgment. The first lesson to be taken from the logic of Systems Thinking is that the latter observes only dynamic systems composed of variables interconnected by causal relations and by loops; thus the systems are composed of interacting variables. This leads to the *first fundamental law of Systems Thinking*:

a) on the one hand, the behavior of a *single variable* depends on the system (structure of loops) in which it is included;
b) on the other hand, the behavior of the *entire system* depends on its structure; that is, on the *causal interconnections* among its component variables.

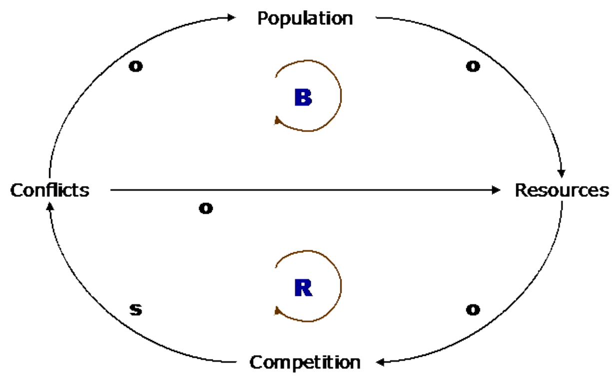

Figure 8. Struggle for life.

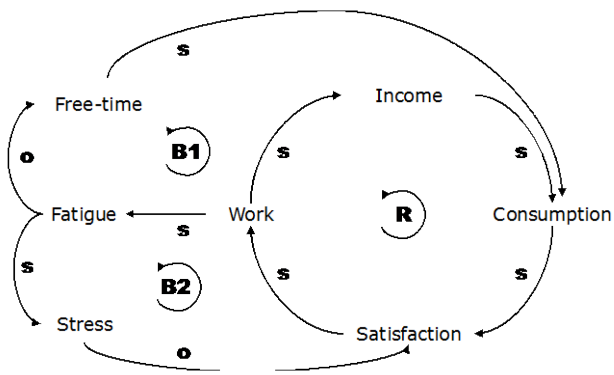

Figure 9. Job satisfaction.

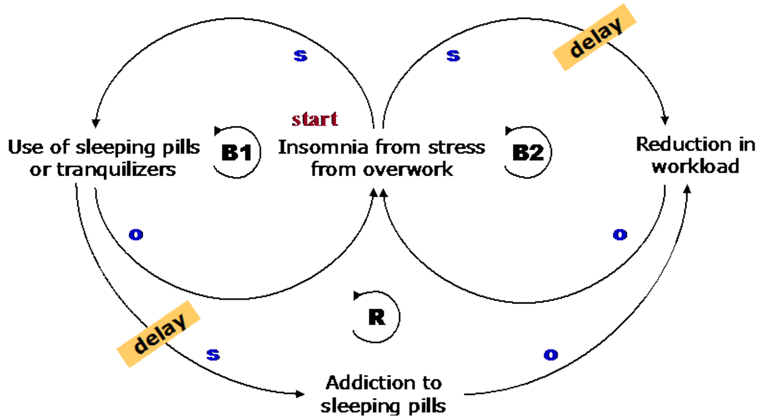

Figure 10. Burnout from stress.

This law has two *corollaries*:

1. it is useless to try to modify the values of a variable if first we do not understand the systemic structure of which it is a part, since the balancing loops will restore its value and the reinforcing loops will increase it;
2. in observing a dynamic world, the "ceteris paribus" assumption is never valid.

Connected to the preceding law is a *second fundamental law of Systems Thinking*, which shall be called:

THE LAW OF DYNAMIC INSTABILITY: *expansion and equilibrium are processes that do not last forever; they are not propagated ad infinitum. Sooner or later stability is disturbed. Sooner or later the dynamics are stabilized.*

Operationally speaking, the law of dynamic instability affirms in a simple way that, though we are unaware or unable to observe this, every expansion loop is always associated with a balancing loop that dampens the expansion dynamics; and *vice-versa*, every balancing loop is associated with some type of expansion loop that counters the balancing effect. Moreover, external disturbances can come from the environment in the form of braking variables that counter the expansion, or acceleration variables that eliminate the balancing effect, as shown in the model in **Figure 11**.

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 could instead state that: "Every repetitive system does not endlessly produce its own reinforcing or balancing processes, since other processes intervene to reverse the dynamics". It seems impossible to respect Plato's wise motto: "Mota quietare, quieta non movere!" ("Do not move settled things, settle moving things!") (Mella, 2012: p. 73).

In fact, the model encompasses all the basic possibilities:

- loop **[R]** would lead to infinite growth (positive or negative) if it were not activated by loop **[B]** and if the brakes (o) were not present; loop **[R]** sees its growth attenuated by the balancing effect of loop **[B]**, which is instrumental to the former;
- loop **[B]** would lead to infinite stability if loop **[R]** were not activated and the disturbances (**o/s**) were not present; loop **[B]** sees its balancing effect disturbed by the reinforcement of loop **[R]**, which is instrumental to the former.

4.3. Some Evidence

In order to allow the reader to learn the language for constructing formal model based on the Systems Thinking approach, several simple CLDs will be suggested, without any precise order, representing some interesting phenomena. The reader is encouraged to use paper and pencil in order to reconstruct and eventually expand the models.

Figure 12 concisely illustrates how the model to halt the arms race between the two superpowers might look. It represents an application of the Law of Dynamic Instability (**Figure 11**). Loop **[R]** depicts the escalation in arms due to mutual fear on the part of the two Super Powers. Loops **[B1]** and **[B2]** describe the limits to growth from the gradual depletion of economic resources needed for further weapons expansion, as described by Richardson (1949), considered to be the founder of the scientific analysis of conflicts. The external arrows with broken lines indicate the braking action (**o**) when international public opinion causes some supranational authority to intervene to "stop" new arsenals from being produced. Note that such variables do not form a loop but depend on factors *external* to the system's boundaries, as shown by the segmented line. By replacing "arms A" and "arms B" with "product of firm A" and "product of firm B", where A and B are competitors in the same market, we obtain the same logical system.

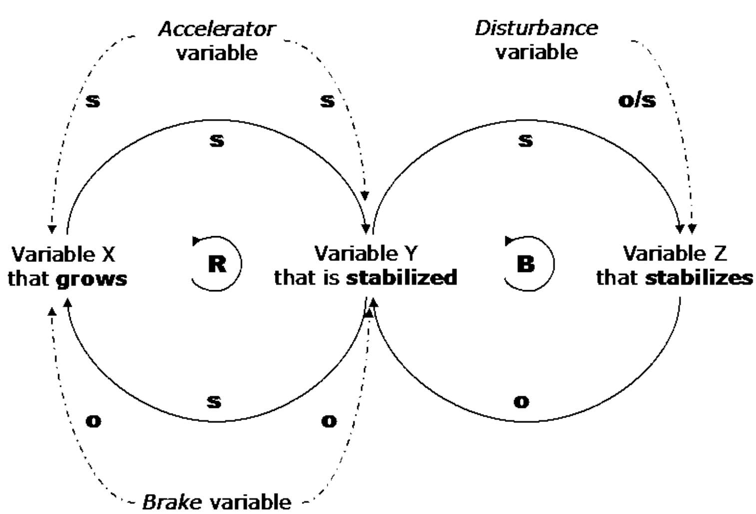

Figure 11. The general law of dynamic instability.

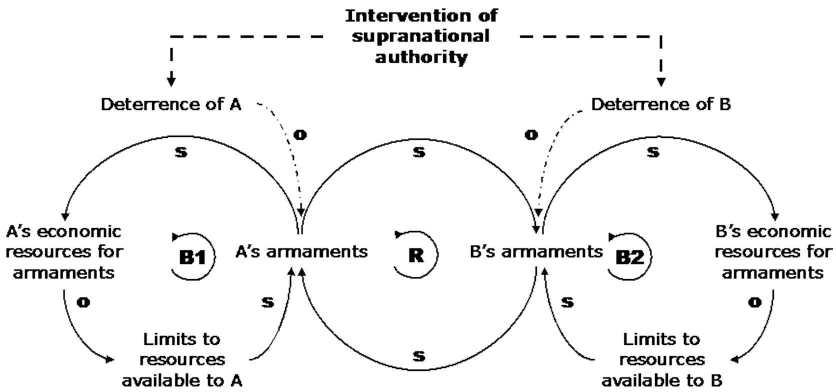

Figure 12. Limits to armaments growth.

The CLD in **Figure 13** connects the main variables that drive marketing strategy, representing a second example of the action of the Law of Dynamic Instability (**Figure 11**).

Collective phenomena are the essence of life at any level, both for human beings and animals, who operate as part of populations, societies (cities, nations, tribes, associations, teams, social units) and groupings of various kinds (crowds, hordes, flocks, flights, herds, schools, and so on). I define a population as a collectivity of similar individuals (normally of the same species) that live in a given geographical area and can reproduce by crossbreeding with other individuals in the collectivity. **Figure 14** shows how populations are normally self-balanced by the variables that form the balancing loops. With the aid of this figure we can try to reflect on the fact that the oceans are not only populated by sharks and the savannas by lions, even if these species are among the most efficient hunting machines in their environments; the seas abound in sardines and the savannas are populated by antelopes, even if both of these species are prey for large populations of predators.

There is no limit to the number of phenomena that can be usefully explored using the language of Systems Thinking. **Figure 15** shows the interconnected variables of the guidance system that allows an airplane pilot to reach his destination.

The manager of this system—the pilot together with the ground staff—must simultaneously control at least three main operational variables—direction, speed, and altitude—by using a certain number of "levers", as shown in the model in **Figure 15**. The pilot can achieve the final objective, represented by the flight destination, only by maintaining control of these variables for the entire length of the flight. I shall leave it to the reader's intuition to interpret the CLD in **Figure 15**, though it is quite clear that what makes the control complicated is the fact the three variables indicated are interconnected, since many "control levers" are common to at least two of them, so that it is not possible to regulate one variable without also regulating the others (see Mella, 2012: Sect. 3.7, for a more detailed description).

If we observe the world around us we can easily identify a large number of situations that exploit scarce common resources—or commons—that risk becoming depleted: too many fishermen fishing in waters with limited populations of fish; the search for oil, minerals and precious stones in the same area and, in general, the exploitation of limited natural resources by many users. It is no wonder the tropical forests are reduced when their inhabitants try to transform them into arable land; the aquifer levels in the desert fall when in many areas irrigation systems are built that take water from them; and rivers run dry because alongside them ever larger areas are transformed into rice fields. It appears that even Easter Island was abandoned after its inhabitants destroyed all the island's wood resources in order to build their Moai. In order to understand these phenomena simple CLDs can be constructed that interconnect the variables that generate the consumption of the commons and create the risk of their being depleted, resulting in the Tragedy of the Commons, as Garrett Hardin has emphasized: populations that share a common vital resource almost always head toward tragedy.

> Adding together the component partial Utilities, the rational herdsman concludes that the only sensible course for him to pursue is to add another animal to his herd. And another; and another. But this is the conclusion reached by each and every rational herdsman sharing a commons. Therein is the tragedy. Each man is locked into a system that compels him to increase his herd without limit—in a world that is limited. Ruin is the destination toward which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons. Freedom in a commons brings ruin to all (Hardin, 1968: p. 1244).

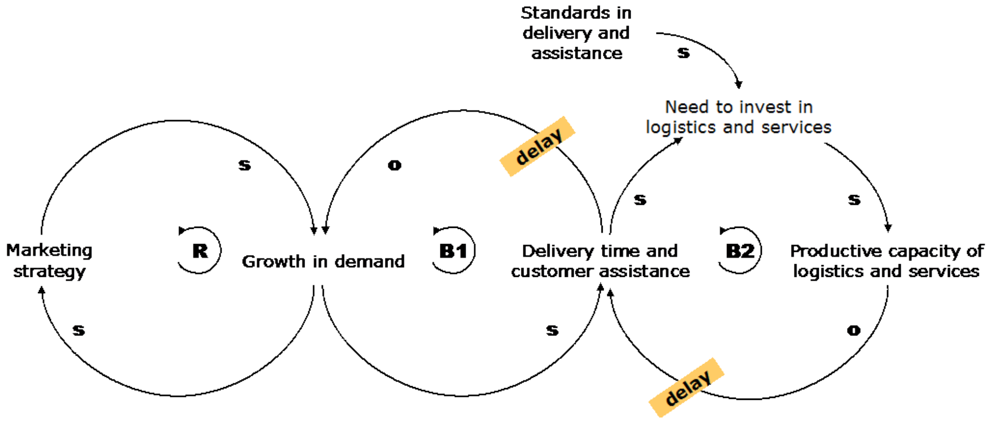

Figure 13. Marketing strategy with constraints.

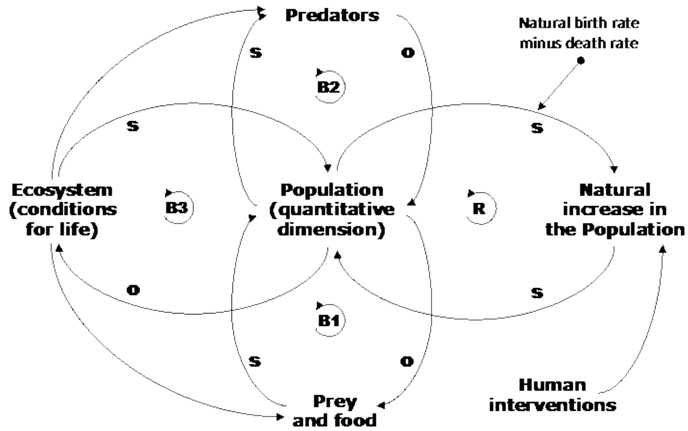

Figure 14. The system that regulates population dynamics.

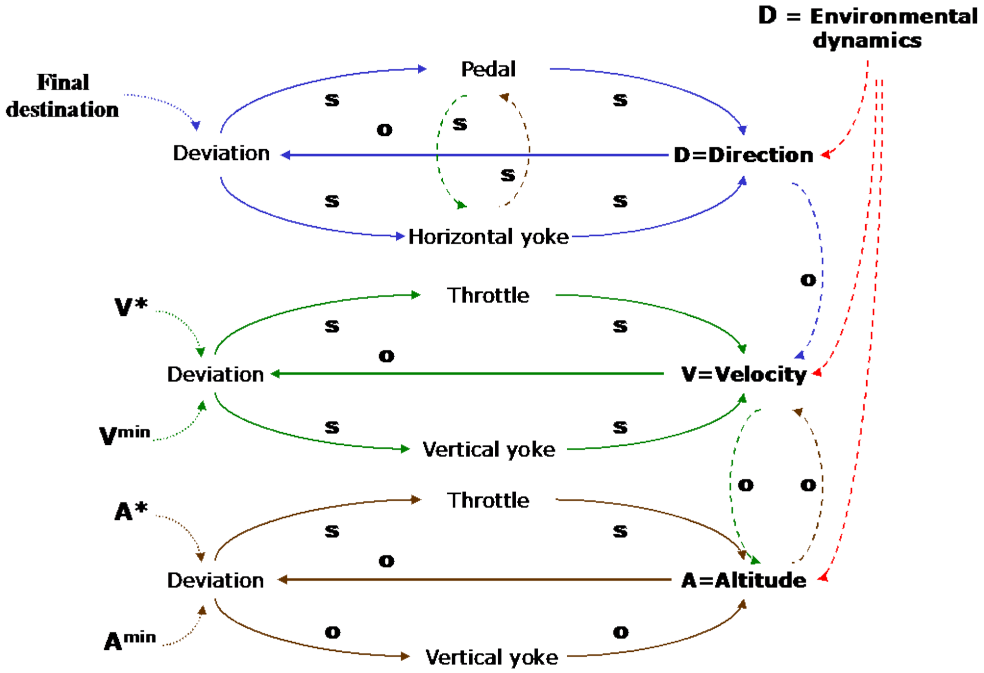

Figure 15. Understanding the basic rules for controlling an airplane.

The presence of limited common resources can cause conflicts that represent a second tragedy included in the tragedy of the commons. The clearest evidence of this are the numerous wars fought over water and oil, which are among the most limited and scarce vital goods on earth. **Figure 16** shows how whale hunting can lead to the animal's extinction.

When the returns from hunting start to diminish, the whale hunters, in order to fill their oil and meat holds (the objective of every whale hunter), are pushed to intensify the hunt (remaining longer at sea), as shown in loops **[B1]** and **[B2]**, until the whales reach the minimum admissible population, as shown in loops **[R1]** and **[R2]**. The two control systems, **[B1]** and **[B2]**, can have different modes of action, all inevitably destined to result in the extinction of the whale population.

5. From Systems Thinking to System Dynamics

The construction of the Causal Loop Diagram is a crucial step for "seeing" and understanding the systems that operate around us and interact with our behavior. Since Systems Thinking by nature considers systems to be *dynamic*, it is natural to develop simulation techniques to try to numerically and graphically represent the succession of values generated by the system under examination, as in the attempts made in the preceding section. Systems Thinking, when *quantitatively expressed* in simulations, is commonly known as the study of the dynamics of dynamic systems, or (Dynamic) *System Dynamics*, a discipline that all agree goes back to Jay Forrester and his fundamental book *Industrial Dynamics* (Forrester, 1961).

In a recent article, the founder of this discipline defines it in this way:

> By "Systems Thinking" I mean the very popular process of talking about systems, agreeing that systems are important, and believing that intuition will lead to effective decisions. … "System dynamics" is a professional field that deals with the complexity of systems. System dynamics is the necessary foundation underlying effective thinking about systems. System dynamics deals with how things change through time, which covers most of what most people find important. System dynamics involves interpreting real life systems into computer simulation models that allow one to see how the structure and decision-making policies in a system create its behavior (Forrester, 1999: p. 1).

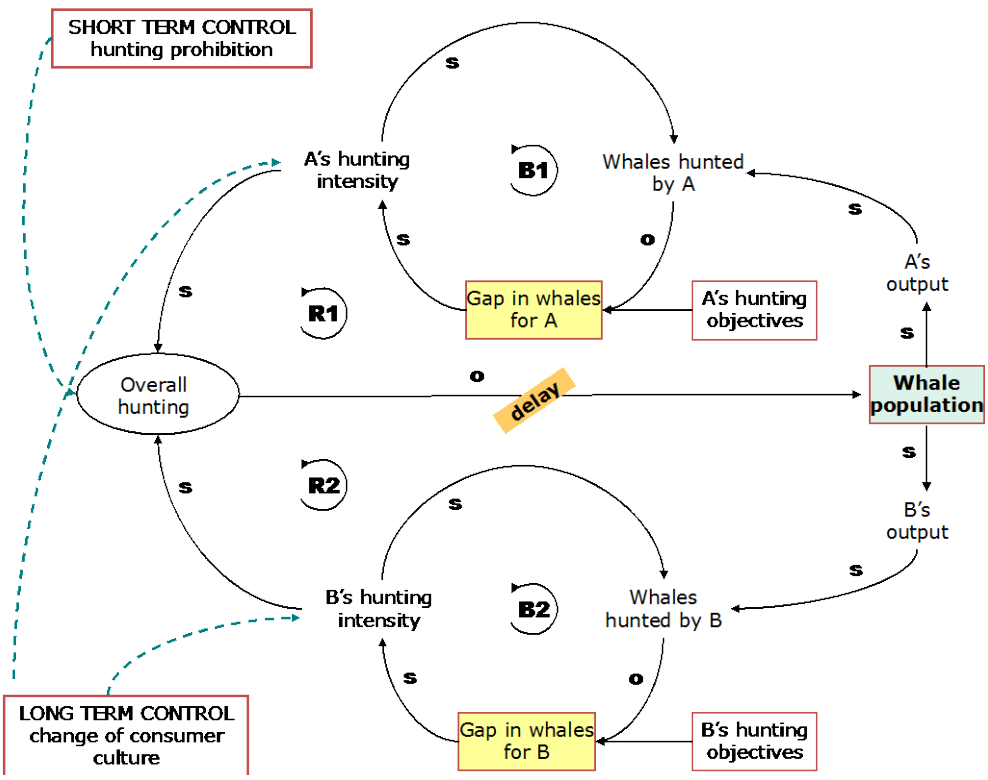

Figure 16. Whale hunting. An example of the tragedy of the commons (Source: Mella, 2012: p. 253).

6. Conclusions: Systems Thinking Is a Discipline

Due to the possibility of representing a dynamic world of interconnected variables, building CLDs makes clear that *Systems Thinking* represents a very powerful and efficient way of thinking that enhances our intelligence. Systems Thinking must be considered, however, not only as a technique but primarily as a discipline for efficient and effective thinking, in that it proposes:

- to train us to observe reality as composed of dynamic systems,
- to provide us powerful models of description and simulation,
- improvements in our ability to gain knowledge, that is, to learn,
- to develop our intelligence.

Systems Thinking, precisely because it is a tool for developing our intelligence, must be learned gradually through practice and continual improvement. It is a discipline that requires the systems thinker to have a deep knowledge and to constantly apply its rules, as well as to have the willingness to continually improve:

> By "discipline", I do not mean an "enforced order" or "means of punishment", but a body of theory and technique that must be studied and mastered to be put into practice. A discipline (from the Latin disciplina, to learn) is a developmental path for acquiring certain skills or competencies. […] To practice a discipline is to be a lifelonger learner. You never arrive; you spend your life mastering disciplines (Senge, 2006: p. 10)

This objective can be achieved by developing the necessary competencies in order to:

- perceive and recognize the circularity of phenomena,
- see how systems really function,
- intuit the effects of actions over time,
- feel responsible for the system's performance,
- predict the future,
- control dynamic processes.

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 *defines* "system" *as a* unitary set *of interconnected variables possessing its own autonomy*, *whose* logical structure *is examined and represented by Systems Thinking and* considers *dynamic* and *repetitive* systems of any kind in any field, building models of a world of incessant movement in continual transformation and evolution. A particularly useful class of systems that Systems Thinking deals with are control systems (Mella, 2014a), particular structures which, in successive cycles of the system, allow us to try to achieve (objective) or maintain (constraint) a given value.

In any type of organization, public as well as private companies, we can identify standard structures known as systemic archetypes: general models of relations that frequently recur in various situations and in different environments and whose aim is to rapidly increase the capacity of the decision-maker/manager to see the systemic problems and to recognize the structures that determine these problems.

> One of the most important, and potentially more empowering, insights to come from the young field of Systems Thinking is that certain patterns of structure recur again and again. These "systems archetypes" or "generic structures" embody the key to learning to see structures in our personal and organizational lives. […] Because they are subtle, when the archetypes arise in a family, an ecosystem, a new story, or a corporation, you often don't see them as so much as feel them. Sometimes they produce a sense of deja vu, a hunch that you've seen this pattern of forces before. "There it is again" you say to yourself (Senge, 2006: p. 93).

I believe that the above discussion has demonstrated the simplicity of the language of Systems Thinking and the explanatory power of the models this approach allows us to construct (Anderson & Johnson, 1997). As with any other language and technique for the construction of models of knowledge, Systems Thinking is not the panacea for solving all of man's problems involving knowledge, judgment and behavior; nevertheless, it is an instrument that broadens our way of thinking. Of course we should not be content only with Systems Thinking models, but for those with little time or resources to construct more sophisticated (though less immediate) models the following proverb always applies: "*Beati monoculi in terra coecorum*", that is, in a dynamic and complex world blessed are those who, knowing how to construct Systems Thinking models, have at least one eye in a land of blind people. In this regard, we can paraphrase Lucius Annaeus Seneca ("*Ignoranti quem portum petat*, *nullus suus ventus est*", VIII, Ep. 71) and conclude that: "*No wind is favorable for those who know not what port they are making for*". However, for the man who knows where he is headed in the sea of knowledge, even the breeze of Systems Thinking is sufficient to navigate.

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