TOWARD A SYSTEMS SCIENCE STRUCTURE

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ABSTRACT

We present a brief exploratory research work on the structure of Systems Science. To guide the exploration through the forest of domains, concepts, theories and methodologies, the Domain of Science Model developed by John Warfield was used as a compass.

Given that Systems Science is itself a system, it was researched as a conceptual/real system by considering the consensual points of view expressed by theoretical and practical systemists at conferences as well as in traditional and recent research reports.

This exploratory research helped to identify and elucidate the main components of the body of knowledge that composes Systems Science as a whole:

The domain of Systems Science
The conceptual space and language of Systems Science
The theoretical relations within Systems Science
The methods of Systems Science

At the end of the article we present some applications of the four main components of Systems Science.

Keywords: Science model, domain of Systems Sciences, concepts, theory, methodology, system

INTRODUCTION

Systems Science is considered a science in its first formative phases and there exists a great variety of points of view, approaches and concepts concerning its nature, scope, degree of formalisation and applicability. Table 1 lists a sampling of the great variety of approaches and tallies the quantity (257) of individual contributions to Systems Science according to the different disciplines (12) of the authors. This variety hinders the effectiveness/identification of applications but simultaneously stimulates the advance of progress in the processes of teaching-learning, communication, recognition of the theoretical research and professional practice.

Table 1. Some streams of systems thought

STREAMS	NUMBER OF AUTHORS
General Systems Theory	31
CyberneticS	14
Physical Sciences	21
Computer Sciences	18
Biology	23
Symbolic Systems	17
Social Systems	24
Mathematics	16
Ecology	12
Philosophy	73
Systems Analysis and Engineering	15
Encyclopaedias	3
Total	**257**

Adapted from Schwarz (2000)

After reviewing diverse definitions of science, e.g., Campbell (1952), Chalmers (2006) and Kerlinger (1973), we observed that there are some common concepts of what constitutes a science. For example, all authors agreed that a science should have: 1) a field, object or domain of study, 2) a set of concepts defined by special language, 3) a theory/philosophy and 4) a method for applications.

According to Warfield (1986, 2006), Systems Science should be able to cover four groups of activities, for which he proposes four basic components that integrate Systems Science and allow it to play the role of a transdisciplinary science. Briefly, the basic components are four sciences, as follows:

1 – The science of description: to describe problematic situations of any nature within the **domain** of Systems Science.

2 - The science of generic design: to design systems by means of applicable trans-disciplines through different disciplines, cultures and organisations that take into account the human being, the thought and the language of the systemic **concepts**.

3 – The science of complexity: to develop a metric and a modelling **theory** that facilitates the measurement and interpretation of the complexity of the problematic situations and the design of systems and methodologies.

4 – The science of action: to specify **methodologies** for solving problematic situations within the domain of Systems Science, including laboratories for practicing Integrative Management, Team Syntegrity, Agoras, etc.

The underlined terms denote the four basic components of Systems Science. The four integrated subsystems forms Systems Science for which the practical purpose is to contribute necessary and sufficient knowledge to solve problematic situations of any nature arising in any part of the domain of Systems Science. The four sciences hinge on the neutrality of the definition of a system:

System is any portion of the known universe (objective and subjective) that is selected mentally as separated from the rest of the universe, with the purpose of considering the different changes that can happen inside this portion of the universe under different conditions , organisations, structure, processes and environments (Warfield, 2003).
Considering the concepts expressed above, we propose the following general structure of Systems science. See Figure1.

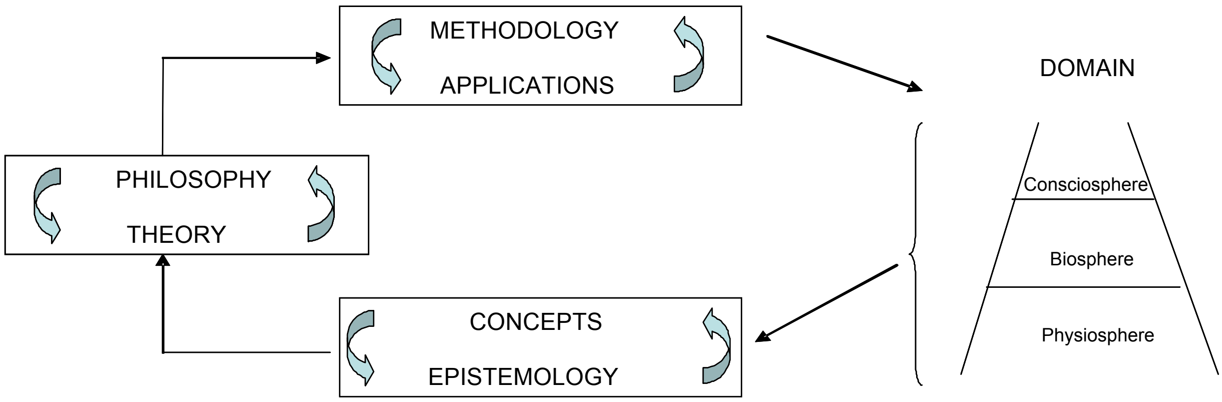


Figure 1. Main components of Systems Science.

THE DOMAIN OF SYSTEMS SCIENCE

Due to the general trans-disciplinary character of Systems Science, the domain of this science is constituted by the whole known universe in which many systems exist. To facilitate the study of these systems, several taxonomies have been developed by research areas, by evolutionary approaches, by objectivity-subjectivity approaches, and by complexity approaches.

The development of taxonomies of the universe of systems is not exclusive to a civilisation or time; in Western civilisation taxonomies have been developed and used in European and North American cultures.

For example, to cite a Mexican case, in her 1692 essay “First I Dream” Juana Inés de la Cruz wrote of apprehending the systemic cosmos by making abstractions from particular things to universal things highlighting the harmony of all with everything. In this process, she tried to embrace the entirety of the scientific knowledge of her time, including Plato, Aristotle, Nicolás of Cusa, and R. Descartes (Del Rio, 2006).

The outline of her essay; is similar to those formulated 300 years later by Teilhard (1959, 1967) and Laszlo (1996) (See Figure 2).

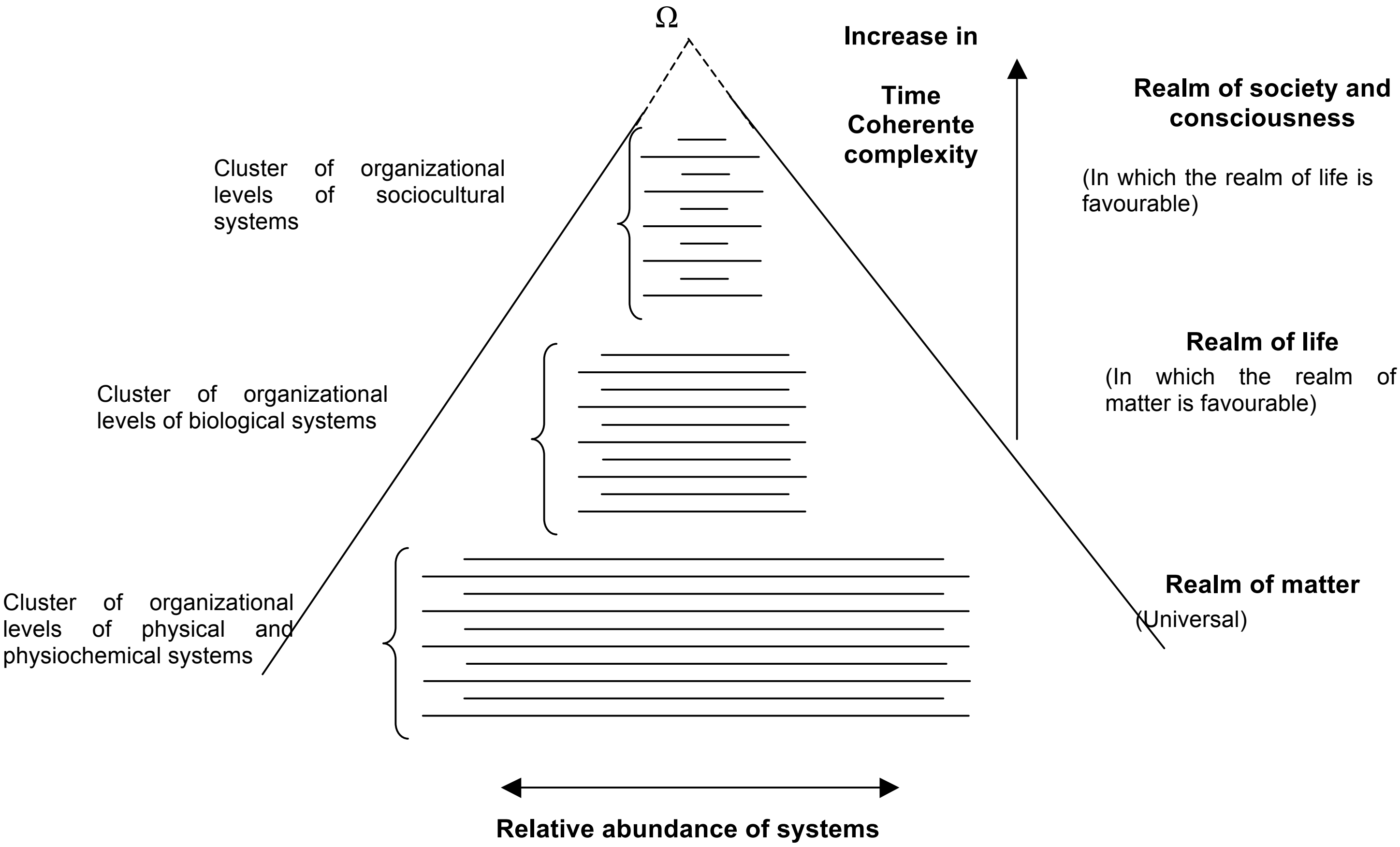


Figure 2. Domain of Systems Science.

Source: Adapted from Teilhard (1967), Laszlo (1996) and De la Cruz in Del Río (2006)

One of the most complete domains for Systems Science was presented by Wilber (2001) and Kira and Eijnatten (2008), based on the complementary principle, integrating the two main Occidental cosmovisions: Idealism and Materialism (Figure 3).

Wilber proposed four sub-domains:

- Interior Individual, mnemonic I – for Subjective Systems.
- Interior Collective, mnemonic WE – for Inter subjective Systems.
- Exterior Singular, mnemonic IT – for Natural and/or Designed Systems.
- Exterior Plural, mnemonic ITS – for Social/Ecological Systems.

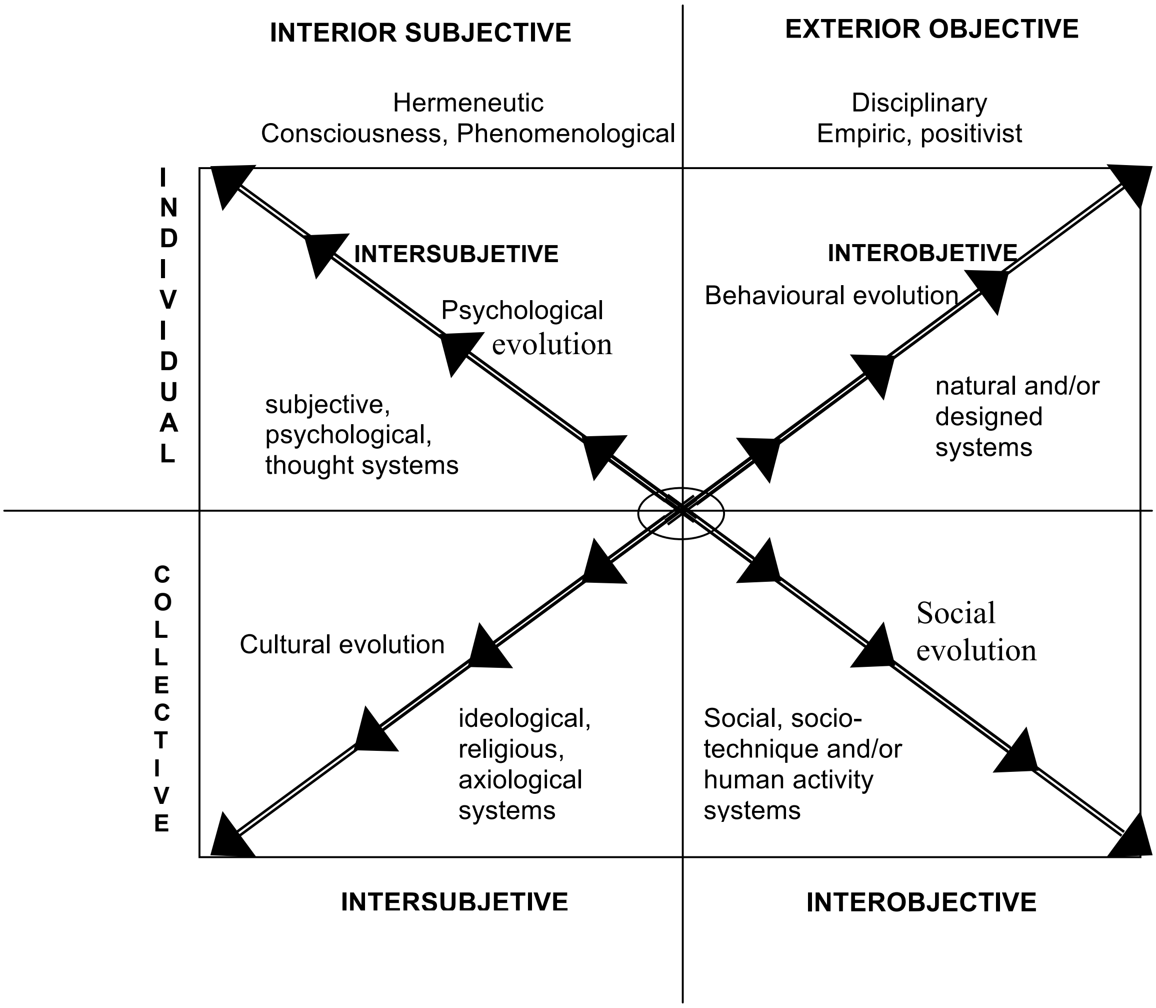


Figure 3. Domain Systems Science.
Source: Adapted from Wilber (2001) and Kira &Eijnatten (2008)

CONCEPTS OF THE SYSTEMS SCIENCE

Traditional sciences have operated along the continuum of the duality of form and matter, first postulated in the cradle of the Western civilisation more than 2,000 years ago. Form includes ideas, concepts, theories, assumptions and so on, while the matter includes observations, experiments, facts and data.

Concepts represent abstractions formed by the generalisation of particular observed and experimental facts. For example, “complexity” is a concept that represents many observations of systems for which the attributes of systemhood are nonlinear, involving multiple feedback loops, while their structures, patterns and processes remain coherent.

Constructs are new concepts created for specific purposes within a research work. Definitions are delimited concepts with other conceptual expressions; Definitions may be descriptive or operational.

The four concepts frequently used in the applications of Systems Science located in the Collective External domain (systems of human activity) are: "emergency", "holarchy", "communication" and "control", which can all be defined operationally starting from observations via phenomenology/hermeneutics of real systems of human activity. In contrast the concepts of evolution, synergy, entropy and first and second level cybernetics can only be defined descriptively using the last concepts. See Figure 4.

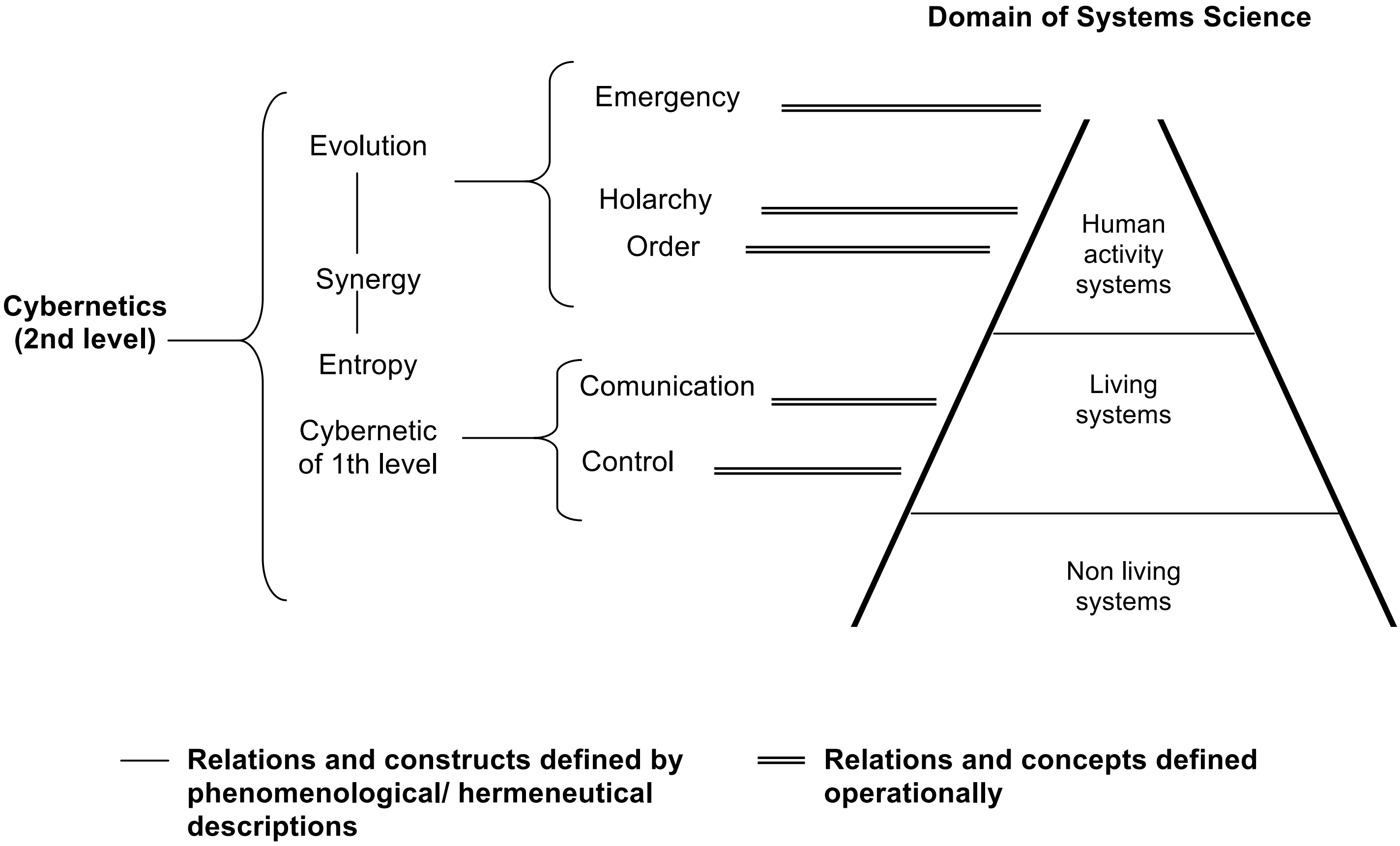


Figure 4. Constructs Concepts and definitions
Source: Adapted from Kerlinger (1973)

Troncale (2006) and his collaborators at the University of Sonoma have identified 102 concepts of Systems Science, many of them defined operationally are interrelated, forming one of the new theories of Systems Science. Troncale denoted these concepts as "system processes" (SP) or patterns, and the total network of interrelated systems processes is called "the system of systems processes" (SoPS).

Checkland (1991) recommended forming an epistemology of systems, gathering the different concepts of the Systems Science coherently in four levels. 1) Basic concepts, 2) Concepts of processes, 3) Concepts of behaviuor and 4) Perceived concepts, see Figure 5.

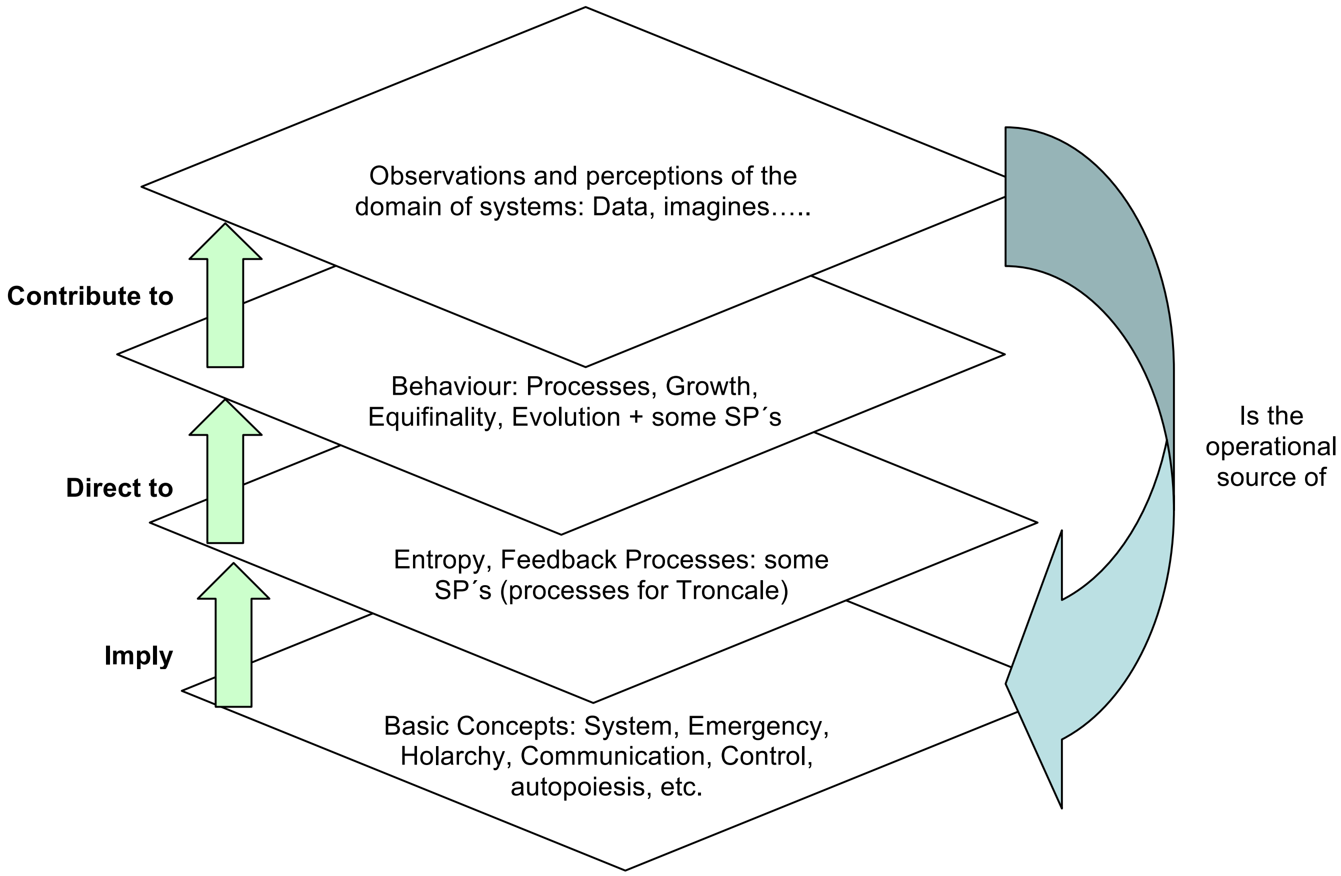


Figure 5. Coherent epistemology of Systems Science concepts
Source: Adapted from Checkkland (1991)

As in other sciences, Systems Science requires a certain language consisting of concepts and symbols that express the elements of the systemic speech and the relationships among concepts. This group of concepts and symbols constitutes a notation or a technical language. The effectiveness of a technical language or notation is decisive, as it represents an essential tool for the realisation of the logical or qualitative operations that are made with more facility and less ambiguity than with the symbols and concepts of ordinary language. One of the most frequent languages/notations used to represent complex systems, with qualitative and quantitative interrelations, is the System Dynamic (SD) set of archetypical patterns/models. For example, the causality relationships in the over exploitation of a resource, known as the "tragedy of the commons", is represented in Figure 6 using the standard SD symbols of arrows, arcs, delays and positive or negative feedbacks.

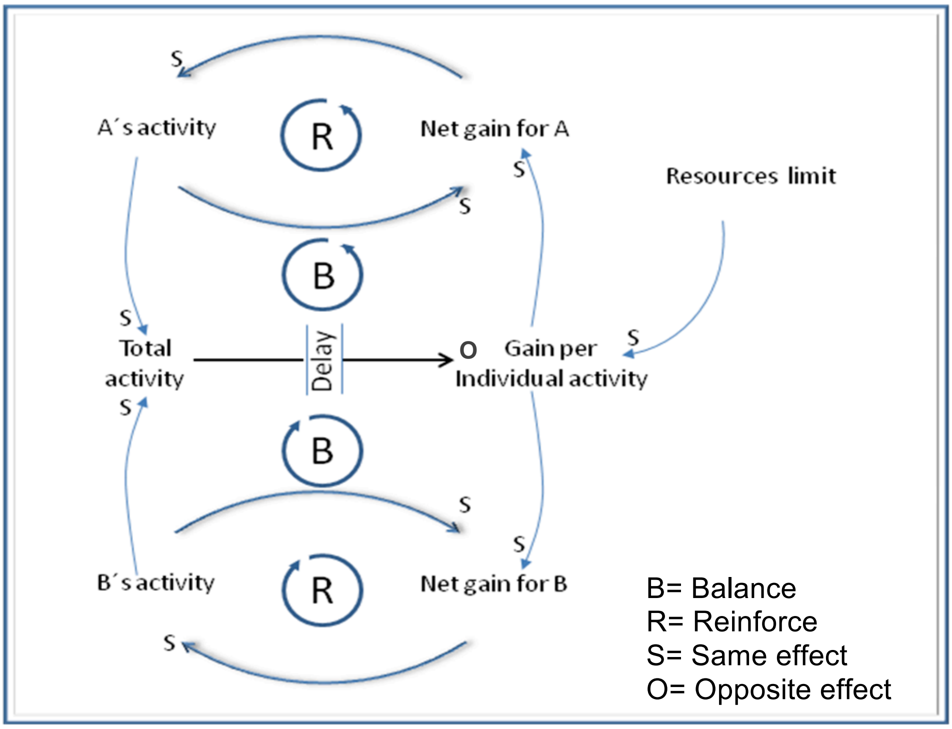


Figure 6. The "tragedy of the commons" archetype.
Source: Maani and Cavana (2007)

Maani and Cavana (2007:40) defined systems archetypes as "generic system models or templates that represent a wide range of situations. Systems archetypes provide a high-level map of dynamic processes. Using the analogy of language to illustrate system thinking, we can say that while *variables* are 'words' (building blocks) and pairs of variables (and the connecting arrows) are 'sentences', causal loops are stories and *systems archetypes* are common phrases".

One of the most important concepts, set forth in the objectives of the International Society for the Systems Sciences (ISSS) is the search for interdisciplinary isomorphisms. The word isomorphism was not invented by the scientific systemists. Initially mathematicians used it to describe formalisms and equations that maintain similar forms through many levels and in many disciplines.

THEORIES OF THE SYSTEMS SCIENCE

A theory is a system of concepts, definitions and propositions that presents a vision of a class of phenomena by means of specifying the relationships among the concepts, with the purpose of classifying, explaining and/or predicting these phenomena.

This definition highlights three important aspects:

1. A theory is a group of propositions consistent in its interrelations of concepts (a conceptual system).

2. A theory establishes the interrelations among concepts forming a representation of the studied phenomenon.

3. A theory explains the studied phenomenon by means of the specifications by which concepts are related to each other and how these relationships operate, allowing the possible prediction of a phenomenon or certain new concepts derived from others.

Most of the theories of Systems Science are in the descriptive phase, with measurements at the nominal and sometimes ordinal level. Such are the cases of Ashby's law (1958), used to diagnose communication problems within organisations, and Beer's theory of viable systems (1979).

Living Systems Theory (LST)

The Living System Theory developed by Miller (1978) contains many concepts of Systems Sciences; two of them are the following:

1) A taxonomy of a system can be elaborated according to the common properties of a family of systems. Therefore, if a system belongs to a subdomain of the domain of Systems Science shown in fig 1, then it is possible to infer by abduction, several of the system's attributes. For example if the system under study is a hierarchical organisation that belongs to the consciosphere subdomain, it is possible to infer that it has the attribute of centrality of authority, without empirical verification.
2) Systems are holarchic, which means that the attributes of lower level systems are mixed or subyacent with the new emergent attributes of systems at upper levels.

The living theory identifies eight levels of organisation: 1) cells, 2)organs 3) organisms, 4)groups, 5) organisations, 6)communities, 7) societies and 8) supranational systems.

According to the LST, all living systems have 20 components, recursively situated in the 8 levels of organisation. Miller (1978) classified the 20 component subsystems into 3 classes according to their main functions, as follows:

A) Subsystems that process information only
   1-Input transducer
   2-Internal Transducer
   3-Chanel and net
   4-Timer
   5-Decoder
   6-Associator
   7-Memory
   8-Decider
   9-Encoder
   10- Output transducer.

B) Subsystems that process matter-energy only
   11- Reproducer
   12- Boundary

C) Subsystems that process information and matter-energy
   13- Ingestor
   14- Distributor
   15- Convertor
   16- Producer
   17- Storage
   18- Extruder
   19- Motor
   20- Supporter

Some of the most interesting aspects of the LST are the cross-level hypotheses that describes systems behaviour and hold at more than one level in the hierarchy of system levels. Ashmos and Huber (1987:614) state that "This feature offer the potential for organizational scientist to benefit more directly from the research finding of biologists, psychologists, physiologists who study lower order systems, as well as from the research findings of sociologists, economists, political scientists and historians who study higher order systems"
More recently, Nechansky (2010:111) concluded in a study of the relationships between Miller's LST and Beer's VSM, that"Miller's (1978) living system theory has a wider scope, and covers viability more completely than Beer's (1979) Viable System Theory……".
Nechansky's research is a good example of the work needed to bring coherence to the several isomorphic theories of Systems Science.

Recent theory of systems: the system of systems of processes (SoSP)

One of the recent theories of Systems Science is that developed by Troncale (2006) at the University of Sonoma in California. This theory is based on a fundamental conjecture called the **mutuality conjecture**, which posits that "All the 102 concepts of the Systems Science, interact mutually or they manifest influences one with another as a system of subsystems". Several ways exist of containing the 102 concepts. One way is by following the life cycle of systems in general; another way is a directed graph or web in which the names of the isomorphies (systems processes) act as the nodes. The SoSP forms a self-organising, self-generating, mutually reinforcing set, (see Figure 7).

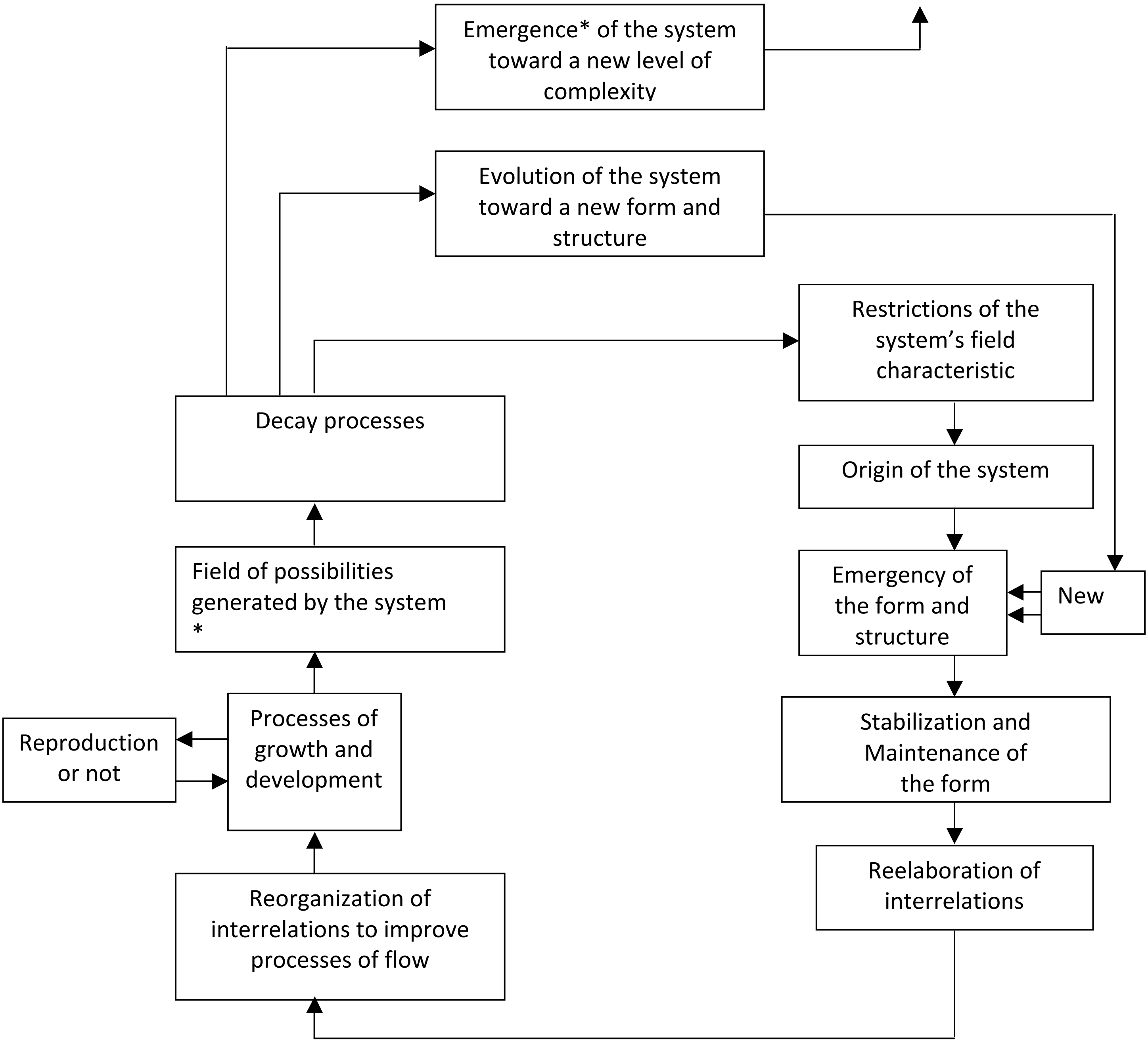


Figure 7. Twelve behaviour functions during the life cycle of a system. Source: course on SoSP Troncale (2008).

A formal theory of systems

Klir (1991) proposed a formal theory for Systems Science, defining a system as S = {T,R,} where S,T and R denote, respectively, a system, a group of objects, and a group of relationships defined on T. This definition allows us to specify whether a system exists; an object is a system if and only if it can be described by this formula. Consequently, Systems Science is defined as the science that studies the objects (systems) defined by Klir's formula.

The formula contains two basic properties of systems: the concrete reality of the objects denoted **thinghood,** and the property denoted by their relationships, denoted **systemhood**. Systems Science is oriented basically towards the study of the systemhood properties, i.e. the relationships among the **attributes** of the objects constituting the system more than the objects themselves, whereas the traditional sciences are predominantly concerned with the study of the thinghood properties of the objects.

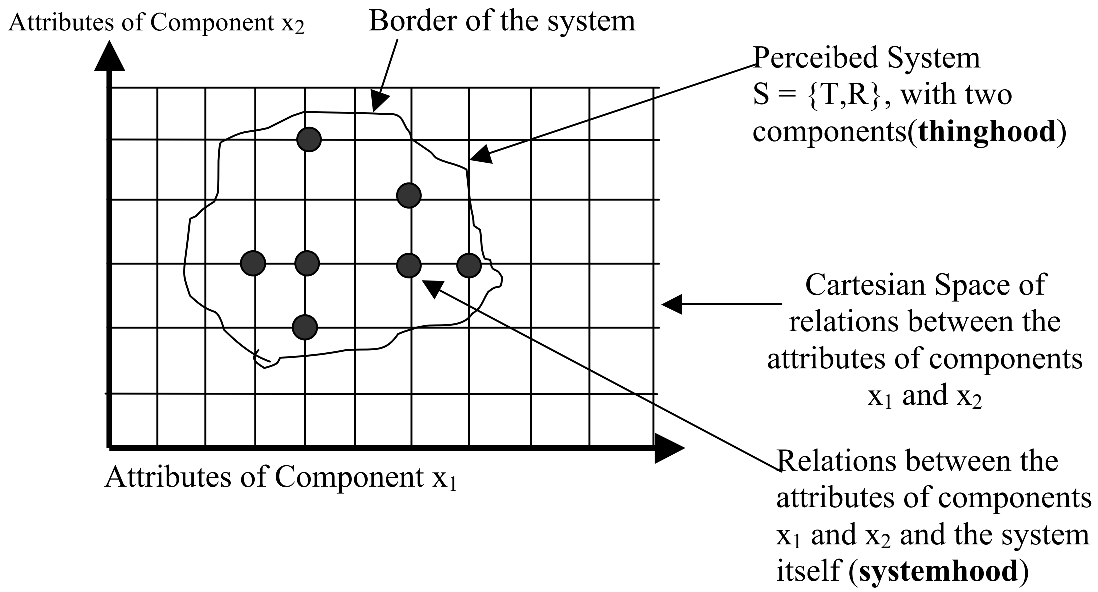


Figure 8. Graphical representation of a system with two components
Source: Adapted from Mesarovic (1963) and Klir (1991)

Bertalanffy (2004) suggested representing a system by means of a matrix of differential equations:

$$
\begin{aligned}
\frac{\delta Q_1}{\delta t} &= f_1 (Q_1, Q_2, \ldots\ldots\ldots Q_n) \\
\frac{\delta Q_2}{\delta t} &= f_2 (Q_1, Q_2, \ldots\ldots\ldots Q_n) \qquad (1) \\
&\vdots \\
\frac{\delta Q_n}{\delta t} &= f_n (Q_1, Q_2, \ldots\ldots\ldots Q_n)
\end{aligned}
$$

In which "Any change in some magnitude Q_i is a function of all the elements Q_1 to Q_n" (Bertalanffy, 2004:56).

The formalisation of Systems Science has been an oft-sought theoretical objective, since its origins in the 1950s, starting with the creator of the General Theory of Systems, Bertalanffy (1950,1986, 2004), and continued by Ashby (1958,1963), Mesarovic (1963), Miller (1972) and Rapoport (1963, 1986).

Barabasi (2003) attempted to use graph theory which has been applied to several networks composed of nodes and connections among nodes; for example, physical networks such as the internet, airports and airlines, highways and bus routes, friendships, epidemics, ideology, or political, criminal and sexual networks. The exponential laws that emerged in the representations of the growth of these networks. This growth begins with the formation of central axes of clusters. A long these axes, the new nodes. unite, giving probabilistic preference to the oldest nodes This means that there are attributes in the concentration axes that make them more attractive, such as seniority, wealth, talent and creativity.

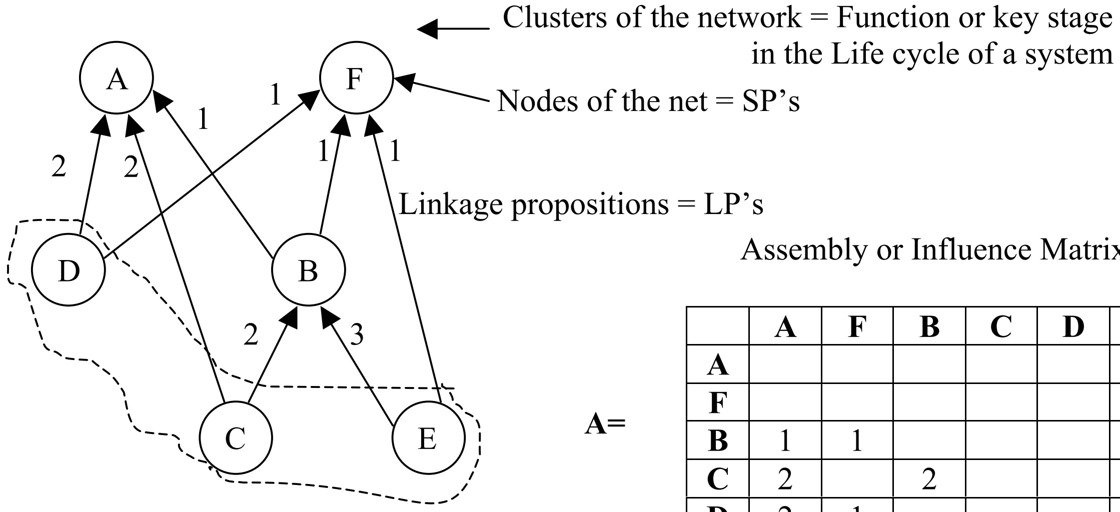
Practically graph theory could be used to represent the web of the System of System Processes (SoSP) or the net of interrelations that connect all the raw materials, assembly, and the finished products in the manufacturing industries. The equation is the following:

$$Y = (I - A)X \qquad (2)$$

Where:

Y = Vector of finished products
I = Identity matrix
A = Assembly matrix
X = Vector of raw materials, assembly, purchased parts and finished products

Figure 7. depicts a net of two finished products or two SP's A and F, and their components parts or neighbours SP's .



Assembly or Influence Matrix

A=

	A	**F**	**B**	**C**	**D**	**E**
A						
F						
B	1	1				
C	2		2			
D	2	1				
E		1	3			

.

Figure 9. A directed net and its matrix

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The same net can represent a simplified System of Systems Processes (SoSP) integrated by six isomorphies or System Processes (SP's), A, B, C, D, E and F connected by 8 Linkage Propositions (LP) where each LP is a working hypothesis or a specific influence of one isomorphy on another, expressed in a language and logic and formulated from empirical natural science research.

METHODOLOGIES OF SYSTEMS SCIENCE

In Systems Science, a methodology does not mean the treatment of a method or the correct method that it is followed to obtain a result. Rather, it means a creative approach to understanding the phenomena or situations of the reality.

Diverse systemic methodologies have been developed, most of a qualitative type, in which it is fundamental to consider the interpretation of the data. Two of the authors that have deepened the concept of the interpretation of reality are Husserl (2005), by means of phenomenology and Heidegger in Gaos (1996) by means of the Hermeneutic methodology.

These authors apply the qualitative process of interpretation to the forms of knowledge and the ontological and epistemological interpretations of reality. Such interpretations consider the cultural context and space of the studied phenomenon and the consensual interpretation of diverse actors with theoretical and practical knowledge.

The phenomenology process is the basis for the construction of Phase 3 of the Soft System Methodology by Checkland (1981, 1993).

Total Systems Intervention (TSI) Metamethodology

According to Jackson (2003:285) "TSI should strictly be described as a metamethodology" consisting of three phases labelled: creativity, choice and implementation, as follows:

Creativity	
Task	To highlight significant concerns, issues and problems
Tools	Creativity-Enhancing devices including systems metaphors
Outcome	Dominant and dependent concerns issues and problems identified
Choice	
Task	To choose an appropriate systems intervention methodology or methodologies
Tools	Methods for revealing strengths and weaknesses of deferments methodologies (e.g the SoSM)
Outcome	Dominant and dependent methodologies chosen for use
Implementation	
Task	To arrive at and implement specific positive change proposals
Tools	Systems methodologies employed according to the logic of TSI
Outcome	Highly relevant and co-ordinated change that secures significant improvement in the problem situation

TSI was developed from the Systems of Systems Methodologies (SoSM) which is taxonomy of systems approach related to problem situation, see Figure 8 and 9.

		PARTICIPANTS		
		UNITARY	PLURALIST	COERCIVE
SYSTEMS	SIMPLE	Simple-Unitary	Simple-Pluralist	Simple-Coercive
	COMPLEX	Complex-Unitary	Complex-Pluralist	Complex-Coercive

Figure 10. Taxonomy of problem contexts

		PARTICIPANTS		
		UNITARY	PLURALIST	COERCIVE
SYSTEMS	SIMPLE	HARD SYSTEMS THINKING	SOFT SYSTEMS APPROACHES	EMANCIPATORY SYSTEMS THINKING
	COMPLEX	SYSTEMS DYNAMIC ORGANISATIONAL CIBERNETICS COMPLEXITY THEORY		POST MODERN SYTEMS THINKING

Figure 11. Systems approach related to problem contexts

APPLICATIONS

Let us see how well the four components of Systems Science are applicable to a didactic description of the domain, concepts, theory and methodology for a new branch of complexity theory: Fractal Geometry, (see Figure 8).

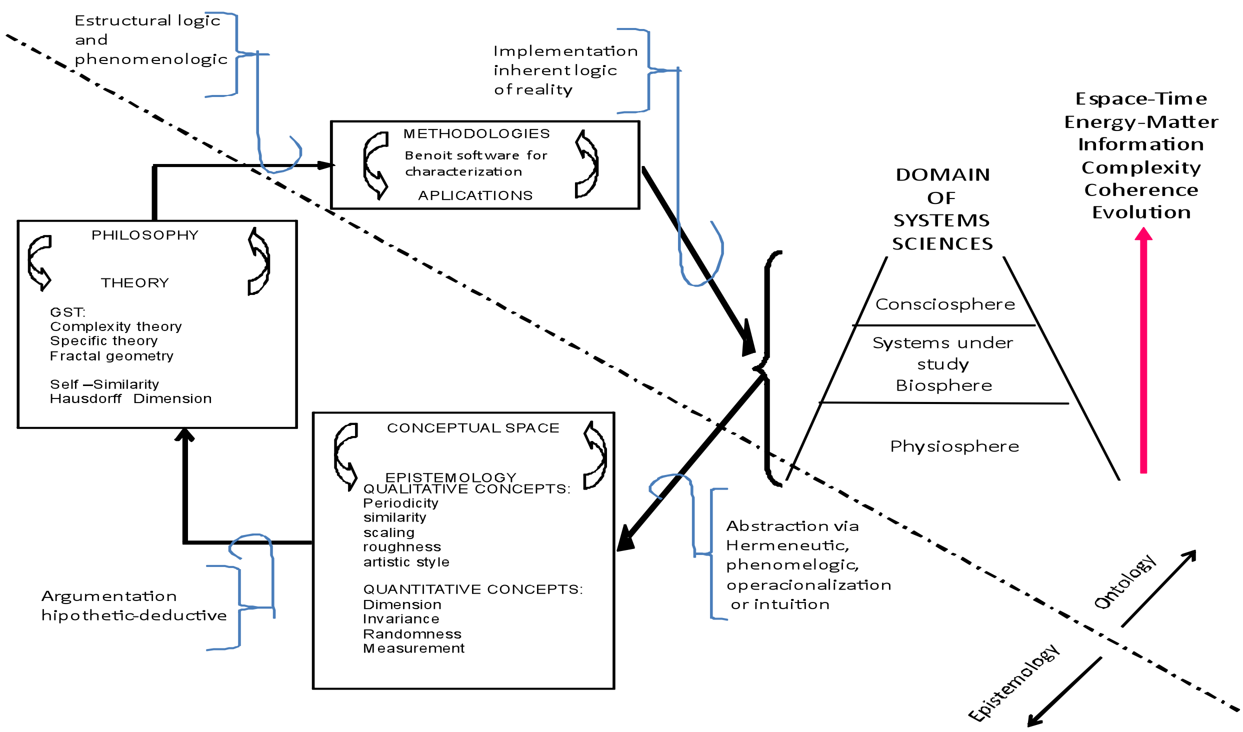

Figure12. Example of the four component structure of Systems Sciences applied to a branch of Complex Theory of Systems: Fractal Geometry.

Domain

There are systems behaviour that generate random data series i.e. prices of goods, demand of stocks, internal surface of lungs etc.

Conceptual Space

The dimension of a fractal Koch's curve object is a real number (D_H) that characterizes the way in which the measured attribute of the object increase as scale decrease.

Theory

The dimension of a fractal course is a real number defined by

$D_H = \text{Lim}(\log N/\log 1/r)$

N= Number of segments necessary to cover the points of the curve.
r= length of the segment.

Methodology

For certain data series, the fractal dimension is estimated from the power spectrum or the variogram.

It is important to realize that true fractals are ideal objects. No curve, surface or data series is a true fractal (Green, 1995)

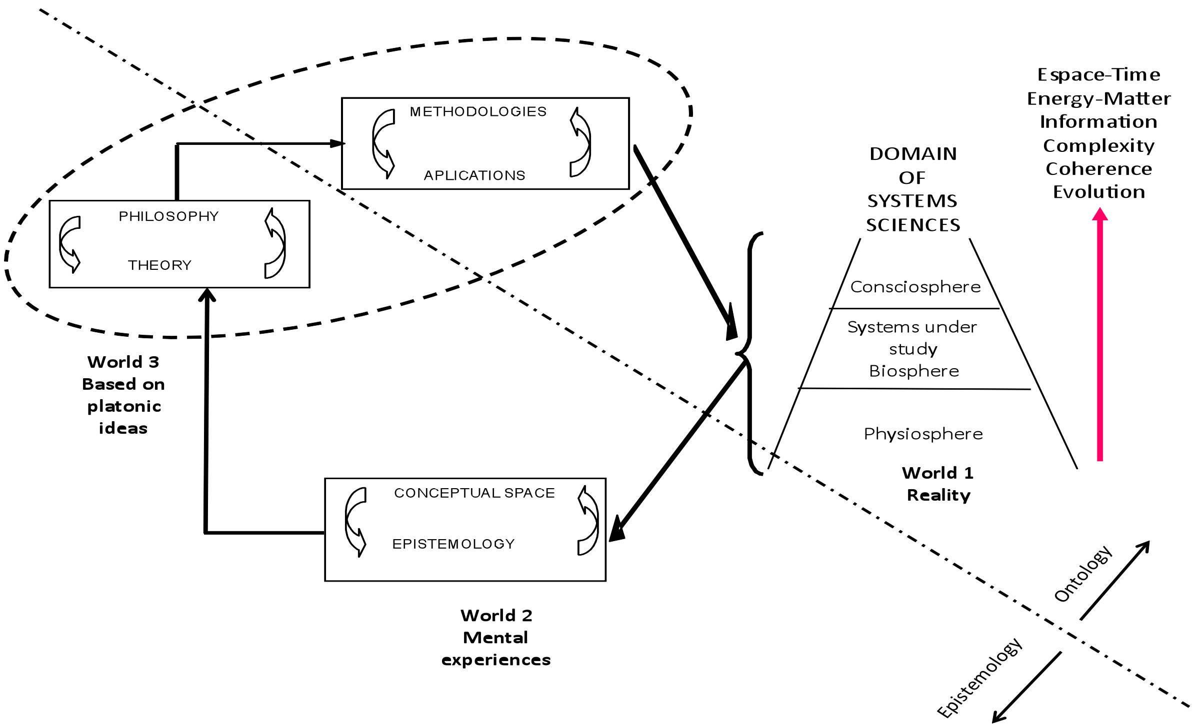

Figure 13. Popper's epistemological model

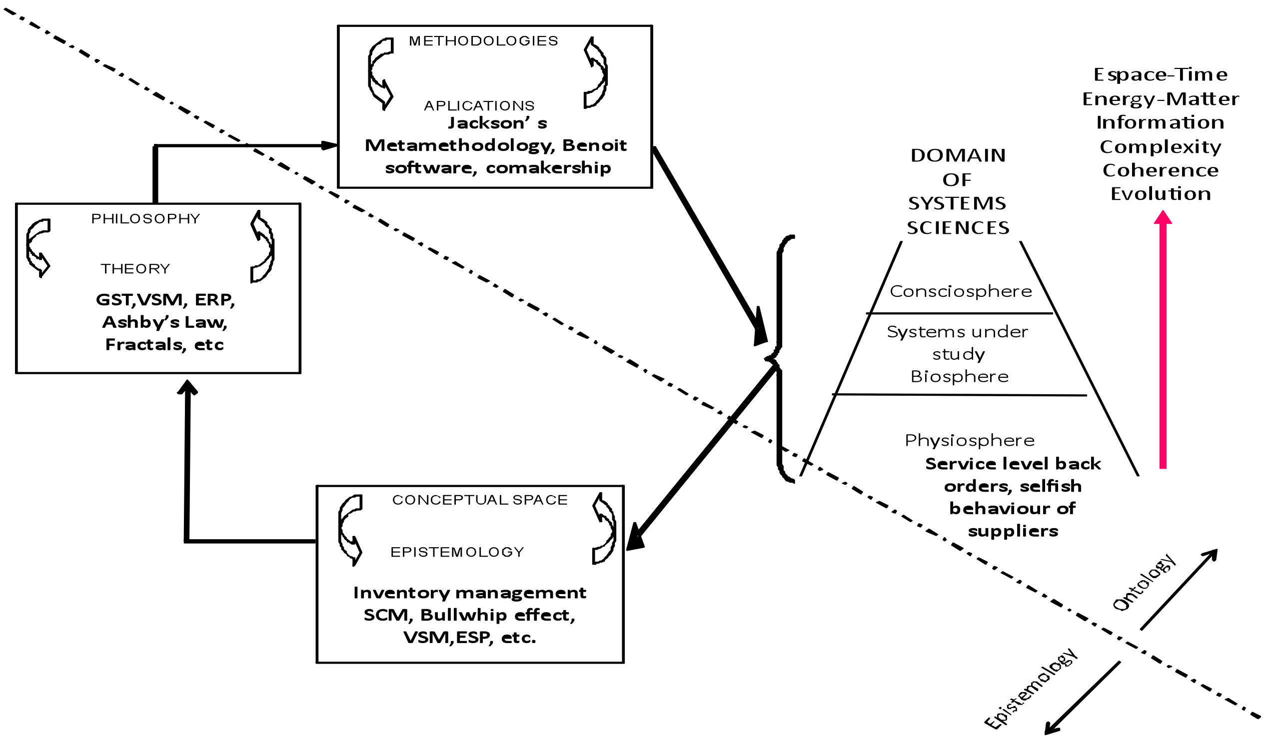

Figure 14. SCM as a Systems Science structure

CONCLUSIONS

A global or total knowledge (of a Renaissance type) at the individual level is impossible today. What is possible is to build, collectively, cohesively and as globally as possible, a unifed system of knowledge, concepts, theories and methodologies by means of systemic tools, in syntegrity teams, agora, and nominal groups.

It is inconvenient for specialists to become general systemists because they have a thorough knowledge of their domain of the particular investigative or professional discipline; instead, it is more convenient for Systems Science to provide them with a systemic, transdisciplinary metalanguage with which they can intercommunicate to solve complex situations. The International Encyclopaedia of Systems and Cybernetics is oriented towards addressing this issue.

The proposed structure of the four components of Systems Science forms a convenient frame of reference to bring order to the study of its concepts, theories and methodologies.

The language of Systems Dynamics is a good candidate for representing quantitative and qualitative variables, processes or components and the relationships among them.

Note: An earlier version of this paper was submitted to SRBS and is now under reviewing process

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