Correspondence

Logical Openness in Systems

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Abstract – From General Systems Theory, the open systems concept is re-examined introducing a hierarchy based on context, modeling communication and meta relation, and the concept of kinds of openness. A hierarchy is proposed in one kind of openness: logical. Logical openness is described and a dialectical, dynamic view is proposed in place of the static view. A system fluctuates in time between closed and open. The ability to decide is at the upper level of the hierarchy of openness, which we term the reflexive level. The levels of the hierarchy are discussed.

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1 Introduction

The notion of openness is a key concept in General Systems Theory[3,4] and in some theories of physics, such as thermodynamics and field theory, and in biology, where systems concepts, such as openness and closedness, are given a central role[18]. Additionally in theories of classical physics, such as rational mechanics, the concept of openness is utilized in an embryonic form only. We shall call the concept of openness as it is defined in biology, chemistry, and physics *classical or passive openness*, that is, the openness induced by breaking down a system into components that communicate and interact through the exchange of some physical medium (matter, energy, field . . .).

This conceptual definition of classical openness becomes manifest in the study of physical processes, which can be described as follows[18,p.17]:

> Most concrete systems have boundaries which are at least partially permeable, permitting sizeable magnitudes of at least certain sorts of matter-energy or information transmission to cross them. Such a system is an open system. In open systems entropy may increase, remaining in steady state or decrease.

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The classical notion of openness can be named the thermodynamic one. It is well described in literature[4,11,13,14 and 18]. Its essential feature is the flow of matter-energy. It concerns the permeability of the boundary in which matter-energy can cross from the outside to inside of the system and vice versa. Often cited examples are dissipative systems, such as auto-organizational dynamic systems far from the thermal equilibrium and living systems.

Classical openness also concerns the flow of information[18], which we term "factual" openness. It is the first level of a hierarchy of logical openness posed in this paper. Viewed from the logical point of view, factual logical openness stems from the logical tradition in which metalevel logical computational reflection has been analyzed and formalized[6,26].

2 Logic foundation

In the logical openness hierarchy we consider a set of interacting systems, each of which builds a model of the others and communicates (or acts) on the others at many levels. To give a logic foundation to the logical openness hierarchy, we extend a given basic logic (classical first order, modal, temporal), or a given set of basic logic formalisms, with a set of basic "openness" operators, whereby context, model, communication, and meta make reference to the modal logic[15,27].

Given a basic logic formalism, such as classical first order logic or a temporal logic, formulas of an open logic are based on the following syntax:

- a formula of basic logic formalism
- a context operator applied to a context and a formula — *IN Context Formula*
- a modeling operator appied to a formula — *MOD Formula*
- a communication (or action) operator applied to a formula — *COMM Formula*
- a meta operator applied to a formula — { *UP Formula* / *DOWN Formula* }

A context operator defines the context (system, discipline), in which we put an assertion:

In Physics is_used(Group_theory)

In special cases, worlds and contexts can coincide, as if we start from first order logic and we consider context as the world in which we put the assertions. But in the general case, we must cope with the possible world of modal logic, and contexts are composed of the possible worlds of the basic logical formalisms (i.e. as a discipline is composed of theories and as time is composed of instants).

The formula "*IN C1 MOD IN C2 Formula*" means that *C1* believes that *in C2 Formula* is true. The communication operator of open logic is used to "put contexts in communication": *IN C1 COMM IN C2 Formula* means that context *C1* communicates to context *C2 Formula*. The meta operators, *UP, DOWN* are used to change the level of denotation information. For example, a numeral denotes a number and

UP of a number is the corresponding numeral. *DOWN* of a numeral is the corresponding number. The above openness operators, and their dualities, are sufficient to represent the previously identified opennes properties.

Given a logic formalism, adding the openness operators, we obtain a new logic formalism extending the previous one, in the sense that it can be used to "open" the basic logic formalism. The semantic of open logic is given by an extended notion of frame, composed of the frame of the basic logic formalism augmented by the context frame. The context frame is composed of contexts and context relations expressing modeling and ocmmunication between contexts.

3 Logical openness hierarchy

Applying the previously described operators to a given logic formalism, we obtain a new logic which can be named open logic. At the same time, we obtain the type of openness we term logical openness.

In this framework, we refer to classical openness as the *passive* one and to logical openness as the *active* one with reference to the various levels of logical openness and the interactive role of the system in its context.

On the basis of this kind of openness we can introduce a hierarchy which expresses the application of the set of openness operators. Starting from the classical factual openness, the hierarchy of logical openness develops through five levels up to reflexive openness, as described in Table 1.

4 Dialectic in time and space

The concept of openness, often understood in contrast to that of closedness, is very strongly related to the concept of boundary in General Systems Theory. In this respect, we face the dichotonomous perspective of the entropy-negentropy duality typical of openness studied on a physical basis. Although having a more parsimonious advantage, this dualistic perspective is very limited, for it does not appear to account for apparent transitions between different states and degrees of openness. A system can be *temporally* as well as *spatially* open or closed. Further, a system can be *opening* or *closing*, which emphasizes the processes of the system. With respect to the hierarchy a system can be open or closed at different levels, for example, open at the flexible level and closed at the creative one.

The ability of a system to decide to act from a closed to an open system is one at the upper level of openness. Living systems are not either closed or open systems in the static, classical definition of the concept, but as indicated by the contrasts presented in Table 2, they are more dialectic and dynamic, not categorical and dichotomous. The dynamic between passive and active openness can be seen as the basis of life as well as logical openness. The contrasts are proposed for further discussion and clarification of the hierarchy.

Table 1 *Hierarchy of logical openness*

1 *Factual Openness* (information openness)
At this foundation level, there is a flux of information in the context and potential flows of information into, through, and out of the system. The Context Operator is passive.

2 *Active Openness* (action/communication openness)
In active openness, one system communcates with another, utilizing a language that is assumed to be common both from the syntactic and semantic point of view. Logical openness at this level enables one to influence the other in order to obtain a result that has been defined a priori. There is no construction of a model of the system to which influence is directed. An illustration of this level of openness is a traditional operating system control language of a computer that cannot be modified by the user. Another example is provided by two interactive software programs, specifically, two communication programs based on a given communication protocol.

3 *Flexible Openness* (modeling openness)
At this level induction may be used by one system to adapt itself to another system with which it interacts. A flexible logical open system has the ability for action and reaction that allows it to act more efficaciously by constructing an internal model of behavior for the system with which it is interacting. Adaptation requires communication, action, and induction[10,24]. At this level the system is monostrategic but possibly multitactic.
An example of flexible openness is the process of negotiation between two parties, or when the system is able to play and apply a strategy for winning, for instance in some computer games (adventures).

4 *Creative Openness* (tactic openness)
At this level the system participates intentionally in the construction of the context in which it must work; it defines the "rules of the game." The system invents tools and theories in order to apply a strategy. The system is multistrategic. This kind of openness is typical of the system design and game creation process, but it does not create new strategies. It can create only new tactics.

5 *Reflexive Openness* (strategic openness)
At this level the system is able to design new strategies and decide at which level to act: closed, factual, active, flexible, creative. The system manages its activities utilizing the other levels of logical openness. An example of reflexive logical openness is a systemable to act in an unknown environment, defining new strategies to modify the environment.

Table 2 *The dynamics of logical openness*

From Closedness	*To* Openness
Passive	Active
Insensitive to its context	Sensitive to its context
No learning	Learning
Object-oriented	Process-oriented
Inflexible	Evolving
No changing of rules	Changing of rules
Avoiding contradiction	Using contradiction to evolve
Focusing on single hypothesis testing	Generating multiple hypotheses
Deductive	Inductive
Can be dissassembled and reassembled	Cannot be disassembled and reassembled
Exclusive of the observer who is outside the system	Inclusive of the observer who is an active part of the system

5 Reflexive openness as the highest level of logical openness

A system must utilize and refine strategies in order to communicate and act efficaciously, and therefore, it could be very helpful to manipulate these strategies through internal conceptual processes. Furthermore, to be able to act efficaciously a system would likely construct a model of the system with which it intends to communicate. The model would include itself, its interactions with the other system, and the relevant contextual considerations of both systems. These characteristics are present at the reflexive level of openness, which is based on reflection as defined in formal languages.

Formal systems have been developed in the field of logic utilizing a hierarchy of meta-levels, each of which offers the possibility to refer to all the levels below it[16]. The various levels of the systems developed in this process can be intermingled. To this point, the greatest discoveries made in the field of logic in this century stemmed from studies of a series of paradoxes of logic, exemplified through various self-referential phrases[23,30].

These discoveries have led to the introduction of reflexive systems in formal logic and computer science; that is, in those systems able to refer directly different interconnected meta-levels, they use self-reference in order to analyze their own behavior and to modify it. This concept can be applied to levels of communication. Moreover, the idea of reflexivity may be extended to communication between systems that can construct dynamic internal conceptual models of reciprocal behavior. A system able to use reflection with respect to modeling, communication, and mete is at the reflexive level of openness.

Reflexive formal systems contains a number of problems stemming from the various paradoxes of formal logic. In open systems, it may be necessary to tackle paradoxes of self-reference when making direct use of different levels of communication. But, although in logics contradictory evidence may lead to a paradox, which may undermine the validity of constructed theories, in open systems paradoxes may be useful devices. They lose their negative connotation and assume a positive one; only open systems make use of contradiction.

The ability to decide on closedness and openness and how to use available resources (levels of openness) can be seen at the reflexive level. Systems at the reflexive level in our classification have been applied in the study of cognitive problems both from the social point of view[2,8 and 29] and in computer science[1,22]. These studies in particular involve as a vital feature the capactiy for self-adaptation which may include using dynamic strategies to achieve a more effective impact on the context.

Logical open systems are applicable to many practical problems, such as in robotics. To be useful in an unknown environment, a robot must construct a partial model of the environment, or functioning as a remote unit, it must transmit to another system which does the model construction. The robot must communicate (act and react) with the environment, and it must apply strategies, perhaps even meta-level reasoning. Such a robot would be an open system, a form of artificial life or animat as it is called[17].

Additional applications of reflexive logical openness can be identified in the study of language[9,28] where the ability to produce statements contrasts with the ability to represent and process meaning. The classical Artificial Intelligence (AI) problem involving the development of a semantic information retrieval system can be re-examined[20,24], as shown in Table 3.

Table 3 *Text, syntax, semantics*

We move from:
 	
the classical grammar generating the text
- the formal rules are able to generate statements
- as if in music the rules for writing the scores are able to produce and generate music themselves
 	
to:
 	
the text generating the grammar
- social *usage* of the words is producing the grammar
- human being is theoretically central in this process:
    - it is active
    - generator of rules
    - not just a user of formalized rules

Systems in education and organizational work life have also been suggested to make more evident the roles of the resource provider and facilitator (teacher) and the learner (student) in the process of learning[7,21].

6 Concluding remarks

From General Systems Theory, we have re-examined the concept of openness from the logical point of view in terms of an openness hierarchy. Hierarchy is extended beyond the classical concept frequently credited to Bertalanffy's articulation of closed versus open systems.

Then the concept of *kind* of openness has been introduced. We do not suggest logical openness as an extension of the classical (thermodynamic) view, nor as a more complete one, but we present it as another kind of openness: *active logical openness*. In the framework of active logical openness temporality and spatiality are considered. A system can be temporally as well as spatially open or closed. At the lowest level, passive logical openness represents minimal presence of logical openness, complementary with but not equivalent to the classical view. At the highest or reflexive level, the system can decide how to act as an open system, making potentially the greatest use of all levels of the hierarchy. The concept is one applied to a non-objectivistic world; it is the cognitive strategy of the kind of openness we propose.

In this paper we articulated the hierarchy of logical openness not only to inform, but also, we hope, to stimulate discussion on the reformulation and elaboration of the openness concept in systems theory and inquiry.

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