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FROM 'SYSTEM APPROACH' TO SYSTEM ONTOLOGY. AN HISTORICAL PERSPECTIVE

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Abstract: The 'system approach' grew up of a holistic view and thus is not bound to a single discipline or a limited number of them. The systems notion to distinguish clearly between *object-language* and *meta-language* or Godel's *incompletability theorem* lead to the notion of 'systems hierarchy' in which the value of some propositions can be determined only by looking at the pertinent *meta-system*. Wittgenstein's emphasis that a language game ought to be seen in the context of social activity is evidence that a system should not be looked at in isolation but must be analysed in its environment. In Italian *Economia Aziendale,* 'entity economics', this approach has been applied since long time by the two giants of economic thinking, Fabio Besta and Gino Zappa, and more recently by the foundational works of many other Authors.
The hierarchies in terms of *information* needs are connected to decisions and decisions are related to objectives. In the 'evolutionary hierarchy' it is relevant to know where a system begins having built-in preferences, thus exercise value judgements and consequently dealing with an inner aspect, *consciousness in the broader sense,* taking into account that in any system the interaction between the individual components seems to be leaded by the *information.*
Beyond the mere 'traditional' ontological 'entity economics', *economia aziendale,* management and accounting literature, there emerges a very different *computer oriented* ontological literature, which is related to the relatively new branch of *systems ontology*, that is to computerize the process of knowledge formation and dispersion, for which it is essential the development of *quantum computers* beyond the present proto-types.

Keywords: *System Research, System Ontology, System Hierarchy, System Boundaries, Information, Entity Economics, Institutional Economics, Management, Accounting, Artificial Intelligence, Quantum Reality, Quantum Computers. Duality solution.*

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1. Introduction

The ‘system approach’ is a methodology which grew out of a *holistic view* and thus is not bound to a single discipline or a limited number of them. The holistic world view was no novelty but required the acceptance of definite basic assumptions. It can be encountered in the philosophies of Gianbattista Vico (1668 -1744), Gottfried W. Leibniz (1646-1716), G.W. F. Hegel (1770 - 1831), Karl Marx (1818 - 1883), A. H. Whitehead (1861 -1947), and many other philosophers, perhaps going back as far as Heraclitus and Lao Tse, Taoist Chinese philosophy (but it has assumed a more specific meaning during the twentieth century) and is necessarily accompanied by a strong emphasis on history; because to look at something holistically it implies an over-all vision as regards time no less than space (Mattessich and Galassi 2015). The essence of systems analysis lies in the generalization and broadening of these ideas which emerged in the first third of last century and which have revolutionized a good deal of thinking in empirical sciences, mathematics and philosophy alike.

For example, the Russel’s paradox was solved ultimately by the systems notion to distinguish clearly between *object-language* and *meta-language,* or Godel’s *incompletability theorem* could lead to the notion of hierarchy of systems in which the characteristics of some variables (the value of certain propositions) can be determined only by looking at the pertinent *meta-systems*.

Wittgenstein’s (1922, 1953) concern with language goes far beyond semantics in the ordinary sense; yet he never ceased to focus on the miracle that we are capable of representing the real world by means of linguistic signs. Wittgenstein’s emphasis that a language game ought to be seen in the context of social activity is “evidence of the awareness that a system should not be looked at in isolation but must be analyzed under consideration of its environment”.

In economics it was first Léon Walras (1834 -1910) who in his equilibrium theory (1874) demonstrated the interdependence of the prices and quantities of all commodities traded in an economy, basic idea subsequently practically exploited through Leontief’s (1951) interindustry analysis. These advances offer the first, but by no means only, indications of holistic thinking in economics. On the microeconomic and management level the *ceteris paribus* approach of Alfred Marshall (1842-1924), assuming all variables, except one or two as unchanged, has been replaced to a considerable extent by the *mutatis mutandis* approach in operation research, revealing the interdependence of all variables through a system of simultaneous equations.[1]

In Italian *Economia Aziendale* this approach has been applied since long time in the publications, for example, of the two giants of economic thinking, Fabio Besta (vols. 1, 2, 3, 1891-1916) and Gino Zappa (1920-1929; 1937), and more recently in the foundational works of Aldo Amaduzzi (1956, 1978), Domenico Amodeo (1965), Lino Azzini (1982), Teodoro D’Ippolito (1966), Giovanni Ferrero

[1] The ‘system approach’ has assumed a remarkable variety of aspects manifested under such expressions as systems analysis, systems engineering, systems methodology, systems philosophy, systems science, system theory, systems thinking and so on.

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(1968), Egidio Giannessi (1960), Carlo Masini (1959, 1979), Pietro Onida (1963), among many others.[2] (on 'system theory' in *Economia Aziendale* see Signori and Rusconi 2009; Rusconi 2019).

The systems approach was not new in a religious sense (most religions, in one form or another, take care of man's environment and impose laws to maintain a harmony between man and nature) or even generally philosophic sense but perhaps new in a methodologic and scientific sense[3]. It was only around the middle of the twentieth century that a specific methodology emerged, and was applied to a series of scientific disciplines, which facilitated the interrelating of the focal object with the embedding matrix, for instance in Mattessich 1957.

The peculiar feature of the systems approach is the flexibility of forming more or less arbitrary systems for specific purposes without losing sight of the super-system or environment in which the system is embedded.

Thus the 'systems research' might be increased by giving it an *ontological* grounding, *i. e.* by stating assumptions about the existence of definite *entities* (primarily every aggregate-integrated entity may be considered as a system, or the economic order of an institution, embedding many systems in the institutional approach of Carlo Masini 1968: §§ 1.4, 2) and events and by showing the system notion as being rooted in the foundations of science; the ultimate justification has to be sought in its suitability for a general representation of: (*a*) the process and result of physical, biological and social *concrescence* and (*b*) the *hierarchy* and the feed-backs following from these *concretion* processes.

The resulting *input-conversion-output cycle*, characteristic for every system, leads directly to the problem of control and feedback. 'System research' has greatly benefited from cybernetics, the mathematical theory of control mechanism.[4]

The 'systems approach' is more a systematic extension of the conventional analytic framework than a new paradigm. While the traditional analytical approach rests on a theory of aggregates, set theory,

[2] A sample of others Italian works of twentieth century where encountered the systems approach is: Bertini (1990), Bianchi (1967), Cattaneo (1959, 1969), Cassandro (1968), Coda (1963), Colletti (1964), Dell'Amore (1938, 1940), Galassi (1969, 1974, 1978), Paganelli (1976), Pagnano (1963), Saraceno (1966), Superti Furga (1968).

[3] From the view point of epistemology of the administrative sciences, three scholars deserve special attention: Russel Ackoff (1962), C. West Churchman (1968) and Herbert A. Simon (1969). Depending on their own inclinations, systems researchers emphasized either the study of the behavior and properties of *actual* systems (*e. g.* Herbert Simon, 1969 and Russel Ackoff, 1963) or the construction of mathematical models of systems (*e. g.* Oskar Lange, 1965) or the methodological and other philosophical implication of systems (*e. g.* West Churchman*,* 1968) or any other aspects concerning systems.

[4] Feedback processes are not only complicated by an often huge number and a complex structure of cybernetic loops, but also by problems of *growth, differentiation, duplication,* (*propagation*), *integration,* and *fusion of systems* Cybernetics – regarded as synonymous with 'systems analysis' -- , ecology, and the wide concern with environmental problems clearly demonstrated that it is not possible to understand the 'social economic reality' without investigating this interaction and without incorporating normative propositions in our economic models (cf. Galassi 2021).

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the modern extension is a theory of simultaneous aggregation and integration[5]. The attempt of bridging the gap between the analytical and non-analytical approaches is nothing but an elegant application of 'systems thinking'. Richard Mattessich (1978: 309-311) calls this process *concrescence* and defines it as an event through which one or several entities, possessing specific properties, are transformed in another entity with new holistic properties, for instance the combination of different production conditions into a particular business entity, or even the combination of different electronic and mechanical components into a computer[6].

A major effort of every science is to describe the conditions under which definite *concrescences* occur. Systems theorists have paid attention to nature tendency of aggregating basic substances into integral entities of ever-increasing complexity – Leibniz monadology is the best known traditional 'theory of concretion'.

Philosophers drew attention to the *hierarchy* resulting from aggregation or *concretion*, specifically in semantics where the distinction between 'object-language' and 'meta-language', and 'meta-languages' of higher order generated gradually revolutionary intuitions.

The 'systems approach' looks at systems holistically emphasizing the *interrelations* of the systems components[7] as well as the *properties* and *boundaries* of the system *vis-à-vis* its *environment.* It ultimately focuses on the function or purpose of the system, and pays special attention to the *hierarchy of systems* as well as to the *reconciliation of goals* of the super-system with those of the embedded sub-systems. Finally, it aims at the formulation of those features and laws that underlie systems in general.

2. Reality, systems hierarchy, boundary, and information

Reality has many dimensions, from entity in general to all levels, to those specific to individual ones, from concrete to abstract entities, from autonomous to non-autonomous ones, and so forth. This may result in 'tangled hierarchies', with the danger, for example, of supposing linear hierarchies where the connections are actually 'tangled'. These hierarchies might occur because of the multidimensional kind of reality, or where the categorical structure is not tree-like. An example is the case of a corporation which acquires shares in another corporation that it already owns; in such a case strange loops and 'tangled' relations may happen, that can lead to complications, for instance in corporate taxation.

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[5] Of great relevance for the physical, biological and social sciences is the circumstance that under appropriate conditions, substances are referable to this process of simultaneous aggregation and integration.

[6] On digital technology and artificial intelligence, to-day so debated and the core of generalized hype, included the managerial one, see Accoto (2024), Gallo (2024), Onesti *et al.* (2024), Pollicino *et al.* (2024), Salviotti *et al.* (2024).

[7] The system definition, beyond the mutual relations of the elements, merely stipulates a relation between at least two elements within the system and a relation between an element within the system and one of the environments, the latter only in case of an *open system.*

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The concept of hierarchies is very often found in debates about entities, *aziende,* and usually has a directional property. The links among hierarchies are in the kind of power connections defined so that there is greater power in the higher stages. Let us think, for example, of hierarchies in terms of *information needs* and processing abilities, but *information needs* are connected to decisions and decisions are related to objectives; if top levels use wider information we expect the higher system to include more variables and a sub-system to omit some variables. It is generally assumed that *information* should be condensed as it upraises the entity structure; perhaps as *information* lift up it goes into a broader *information system* and consequently, through dilution or displacement, becomes relatively less relevant.

The 'hierarchy of systems' is based advantageously on *natural evolution* which reaches from purely physical or mechanistic systems, over living systems of various stages, to self-reflecting and self-perfecting human beings and their social organizations; it is interesting to know (*a*) where in this evolutionary hierarchy does a system begin having built-in preferences and thus exercise value judgements, and (*b*) if, for a system having preferences and exercising value judgements, it is necessary a inner aspect, *consciousness* in the broader sense (cf. Mattessich and Galassi 2015).[8]

Goals and norms hardly can be comprehended without tracing their reasons or 'causes' and their effect through at least some stages of the 'system hierarchy'.[9]

There exists a remarkable affinity between the view of the normativists and those of many proponents of the 'systems approach'. The '*Weltanschanung* philosophers' have adopted an holistic point of view – which is also the hallmark of the systems experts --, and thus are looking at science from the structural perspective. Many systems theorists, in turn, have adopted the subjectivistic attitude which characterizes the '*Weltanschanung* philosophers'.

The assumption of a gradual development, interrupted by great and small gaps or 'hiatus', and ranging from the most primitive to the most complex 'introspection' (intentionality seems to be included within consciousness in the broad sense of 'mental state or activity'), could become one of the most relevant contributions of systems analysis for clarifying the perennial problem of *consciousness, i. e.* feeling pain, pleasure, emotions and thoughts (see Mattessich and Galassi 2015).

Thus *consciousness*, defined broadly enough, can be attributable not only to single persons or animals, but, on one side, to aggregates such as communities, economies, nations, perhaps the universe. Hence 'consciousness' (to possess a mind, *i. e.* mental capacities) bridges a wide range and is a matter of degree; it may be thought as the *introspective side of any kind of entity or any kind of*

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[8] Godel's theorem was not the only impetus within logic and mathematics that led the consideration of *hierarchies of systems*; the area of *formal semantics* elaborated by Tarski (1956), Carnap (1934) and others is explicitly concerned with the *hierarchies of language systems.*

[9] As far as the hierarchy of systems is concerned, Herbert Simon (1969: 79-80) approaches the problem from the viewpoint of decomposition. Hence, unlike Churchman (1971: *passim*) who rather looks at specific existing systems, noticing their inadequacy or goal-conflict with their super-system, Simon regards, quite generally, first the main or super-system and considers its possible and alternative decomposition into sub-systems. Cf. Devine (1985), Vol. 5, 3.

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system. The essential features of consciousness can be regarded as states of awareness of 'inner, qualitative, and subjective nature'.

It is interesting to consider an accurately *dynamic systems theory and methodology*, with less emphasis on the 'permanency' than on the 'variability' of a system structure. The crucial question is whether one of these two aspects dominates the other or whether they possess equivalent significance. From a universal point of view the equivalent significance between these two aspects seems to be implied by Mattessich's (1978: 7.53) holistic dualism.; but from a human and instrumental point of view the 'internal aspects', with its mental, preferential, and teleological notions, appear to *dominate.* Physicists admit that is not possible to formulate the laws of 'quantum' theory in a fully consistent way without reference to 'consciousness' (Wigner 1970); biological and behavioral sciences too hypothesize unity of the two-dimensional aspect of mind and matter, and the social sciences reveal the interdependencies of human ecological systems.[10]

Apart from the *system definition* and the distinction between *system* versus *environment* as well as the notion of systems hierarchy there is the theoretically relevant distinction between an *open system*, permitting *inputs* (matter, energy, information) from the environment, and a *closed system* which is self -contained, permitting neither inputs from, nor outputs to, the environment[11]

According to Katz and Kahn (1966) a *system boundary* is the demarcation line or region for definition of appropriate systems activity, for admission of members into the system, and for other imports into the system, while the *interface* is the area of contact or interdependency between systems. Then there is the notion or principle of *equifinality*, suggested by von Bertalanffy (1968), for which an open system, but not a closed one, may reach the same *final state* in different ways *from different initial conditions.* This final state is characterized not by a static but a dynamic equilibrium, usually called a *steady state*, taking into account that too much emphasis on a 'natural' division between closed and open systems obscures the problems of defining objectives to divide the system from the environment and to identify exchanges that influence the system.

[10] Relativity theory considers matter, energy, space, time, and gravitational force as nothing but different aspects of one and the same process (see Mattessich and Galassi 2015).

[11] The boundaries between the system and its environment are determined by the system elements and relations, and are sufficiently sharp and permanent to consider the system, in first approximation, as an 'entity'. Thus, a closed system possesses an environment but no relevant or admissible relationship between any element of the system and any of the environment. However, in applied sciences they deal mainly with open goal-oriented decision systems.

A system theorist might say that the young Wittgenstein, *Tractatus* (1922), took all the language for a *closed* system, whereas the old one, *Philosophical Investigations* (1953), realized that it is an *open* system.

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The boundaries of a system are those characteristics, *e. g.* the the system variables, parameters and relations, which separate the structure, with its *inner environment* from the *outer environment* of the pertinent system.[12]

For the *Polarity Principle*, to any system belongs a 'counter-system', *e. g*. the environment. A removal of the boundary between these systems tends to dissolve one or both of them and possibly creates a new or changed system with its own 'counter-system'. In biology and sociology, the existence of cells, plants, animals, men, organizations in an environment, or the destruction of some cells, animals, men, organizations by others or each other is an example of this principle. We cannot analyze an entity without attention to its counter-entity and that *polarity* and *tension* are the most fundamental notions underlying the phenomenon of *Being.*

The boundary characteristics of a system become particularly perspicuous when the system is converted into a different, yet similar, system; then the shift of boundaries is reflected by the change in variables, parameters, relations, goals, values and so on.[13]It is this notion which enables to circumscribe a specific system and to distinguish between its *structure* and its *environment.* Yet it is still controversial weather a system boundary can be set arbitrarily, or whether it must be given by some more or less 'natural' criterion of integration, *e. g.* 'gestalt' conditions; as a matter of fact, any system is arbitrary and serves the conceptual clarification and improvement of 'goal-oriented activities', generally and particularly.

3. Economic systems, institutional economics, and values systems

For clarification let us think at different economic schools of thought. Classical and neo-classical economics tend to refer at relatively small systems, stipulate exchange variables between the system and the environment and look for conditions of 'equilibria', *steady state.*[14] Sociology and anthropology characteristically employ much wider systems, including variables that economics would refer to the environment. Institutional economics, and entity economics, *economia aziendale*

[12] There obviously is a similarity between a set, in mathematical sense, and a system. Ontologically the system notion may encounter the same difficulties as did the idea of a set, especially if the system approach is conceived in an analytical sense.

[13] System thinking not only creates awareness of these boundaries, but allows them to shift easily in one direction or the other, thus designing new systems, always under awareness of the pertinent boundaries, the properties of which may be compared to those of the original system, thus giving clarifying differences.

[14] With reference at the dichotomy "open system - closed system" of an entity, it may be fruitful the distinction between dynamic steady state conditions and conditions for simple state equilibria; as a matter of fact, it could help in constructing hierarchical levels, possibly treating each level as a system, and, in this case the interactions between levels could be seen as relations with different environments. Consequently, the structure could contribute stating the essence of different environments and the kind of relevant interconnections.

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(Canziani 2024)– with their feature to include more of the environment in the economic system, and to investigate tendencies toward 'steady state equilibrium'— has a middle position referring to human constructions, the *institutions*. General equilibrium economics seemingly is in between the neo-classical framework and the institutional one, omitting many sociological and psychological variables. Existentialism, phenomenology and oriental based views, such as Taoist Chinese philosophy, constitute often returns to broad system philosophies that cover all known aspects of human condition.

Classic economic systems were invariably too restricted, and generally the more open institutional schools (Common, Paton, Schmalenbach, Zappa) proved to be more appropriate. In general economics the sharp open-closed distinction is more obvious than in 'entity economics', accounting and information systems; here there is often the attempt to close the system by the simple semantic device of defining transactions; here the emphasis is to decide the events worthy of notice, the aspects of these events are allowed to influence the variables of accounting and information systems, and the measurements rules for processing their inclusion. 'Transaction theory' for 'accounting and information systems theory' is a partial counterpart to 'integration theory' for systems theory.[15]

Clearly some value choices are necessary in order to build the structure. Milton Friedman (1953) has warned that normative economics cannot be independent of positive economics, and Richard Mattessich (1978: 37-39) has emphasized that most models combine some normative and some descriptive aspects.

The notions of goal, prescription, norm, value judgement, reflection, mind, *consciousness*, and those of related terms, belong to one category, serving to represent the specifically reflective or *mental dimension* of every system; whereas the notions of datum, fact, description, assertion, empirical judgement and so on belong to an entirely different category, serving to represent the especially material side of every system.

Whether a system, for instance 'management science', is free of values or not depends on the location of value judgement in relation to the boundaries of this system.[16] All judgements require 'standards' against which to judge, and all judgements and conclusions are effectively discriminations that want valuation. A set of values is one of the necessary conditions for optimizing activities, and the determination of values is necessary regardless the kinds of activities or decisions to be optimized. The point is that one cannot say about specific models and systems without clearing the *values systems* either as variables or, with a shortened system, as guidelines.

[15] In scientific research the inquiring system is usually closed by pre-conditions or hypotheses often not expressed. Whether stated or unstated these assumptions limit the field of inquiry by defining the influences to be observed related to the system operation. In this regard a model is a theoretical structure, and the assumptions are not debated in the detailed operation of the theory, but are significant subject matter for valuation and interpretation both before and after the theory is applied (Bunge 1974: chapter 6).

[16] All judgements are result of determination and must be founded on value performances. The analysis of a problematic situation is constantly making judgements, all of which have elements of value trade-off. The analyst judges that some action may be desirable, different hypotheses appropriate, assertions about findings relative warranted.

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Richard Mattessich has suggested that value judgements may be excluded from any system by reevaluating until they appear as exogenous factors. The design of a system usually requires value judgements about the features as the system objective, capacity, robustness, sensitivity regarding some aspects, efficiency, and many other properties. These value judgements constitute *prescriptions* of the system user, *via* designer, to the actual builder of the system. They ultimately become *incorporated* into the system as relations together with *parameter* values. However *not all* value judgements need to be incorporated in this way. Some may be 'left open' in such a fashion that the user may impose in the system at any time a particular value judgement without changing the system structure.

The problem of value judgement in science in general, and in management science particularly, is fundamental to every epistemological research; it constitutes since forever a highly controversial issue, with opinions, even within management science and 'entity economics', still divided. For instance, such scholars as Max Weber (1922, 1949) and Herbert Simon (1957, 1969) maintained that every science must be neutral and thus free of values.

The conditions for determining whether a 'sentence' is prescriptive, normative, or descriptive, positive or neutral, can be stated fairly clearly; but the same does not hold for examining *whether a system is normative or whether is neutral with reference to a specific property.*

Value judgements ask for special attention in 'management science' and 'entity economics', because they primarily deal with hypotheses implying specific goals, or even with arguments containing imperatives. Assuming a goal it corresponds to the challenge of a value judgements in form of an imperative statement or similar statement. The 'management science' and 'entity economics' recommendation is usually in form of a scientific technological rule (Bunge 1977: 5.4) also called *instrumental* or *pragmatic hypotheses* (Mattessich 1964: 234-37, 1995: 119-123); out of premises it follows a recommendation, which again is an imperative or similar statement expressing a *derived* value judgement.

System analysis insists that every system must be investigated within the context of its environment in order to be more than a mere structure. This point, prohibiting the analyses of a functional or goal oriented 'entity' *in isolation* constitutes the crucial point of the systems approach. To follow this recommendation, it is necessary to ponder, in addition to the instrumental hypotheses, the 'value judgement- premise' as well as the 'value judgement-conclusion'. The latter obviously is the actual recommendation the management science and 'entity economics' are supposed to provide.

In this regard we mention again the distinction between *object-language* and *meta-language* which was fundamental for the solution of Russel's paradox. Only after the *object-language*, 'the system', was clearly separated but related to the *meta-language*, 'the system environment', could the crucial paradox of set theory be solved. Furthermore, one could regard Godel's incompletability theorem and proof another achievement in this regard. Doubtless these acquisitions were allowed by the sharp distinction between *system* and *meta-system* (environment), *meta-system* and *meta-meta-system* (environment of the meta-system).

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A *meta-system* that would include all possible influences would of course include all of human knowledge and more. An optimizing model of this range would include within its endogenous variables all existing possibilities and all possible changes in possibilities.

It is worthwhile to collect broad tautological statements and storing them for eventual future use as long as the activity is relatively costless and promises some favorable expected value. At practical level one speaks of 'total', or 'global' or 'whole' or *meta-system* as far as one realizes they are *metaphors* and does not expect empirical guidance from them.[17]

Even after formal systems have been interpreted, such pattern may continue to produce favorable deductions and reorganizations. Needless to say, regardless of the formal structure, deduction in all interpreted systems offers only hypotheses (cf. Mattessich 1995: 214-15, *passim*).

Modern management science and 'entity economics' with their emphasis also on modeling and structure seem embrace positivism. The system approach is strongly advocated in this regard, with some problems; for instance, in order to move from a sub-system to the system and the super-system is there abstraction until the *façade* remains? Richard Mattessich (1957: 328-55) used the concept of *façade* as opposed in some way to the 'substance', composed of the non-formal aspects, the *interpretation*[18]; *façade* is a series of uninterpreted statements and represents axioms or preconceived frameworks for relations.

In some way results of previous experiences are recorded as history and accumulated in data banks, some in form of antecedent-consequent relations. The set of facts, concepts and relations in the container of knowledge may help finding *analogies* and substitutions in existing models. By means of these 'recognized similarities' it can emerge hypotheses pertinent to the problematic situation at

[17] In scientific research terms like 'global' operate like the symbols of formal logic; in the investigation one must decide the empirical material he wants and then equate his empirical universe to the attributes of the 'global' model.

[18] The search for a master meta-system for all the investigation is in close proximity to Plato, because the *façade* is equivalent to Plato's 'network of universal'. Plato could not obtain the universals, ideas, by examining particulars. One must describe particulars in terms of universals. When particulars were removed of universals, what left was 'matter' removed of attributes.

For Richard Mattessich (2014: chapter. 9) a *particular* entity (individual entities, for instance Albert Einstein, the Eiffel Tower, a particular shade of the color red and so on) must exist before a corresponding *universal* (generalizations of individuals, for example elephant, forest, or such properties as being wise, or hot, or relations, such as being above, or superior, and so on) can exist. He considers *particulars* as *autonomous* and *universals* as *non-autonomous* entities; this is the reason why the dichotomy of *autonomous* vs. *non-autonomous* might not only be more general but also more basic than the secondary dichotomy of *particular* vs. *general*.

Plato postulated an ontological dualism that partly agreed with Eraclitus view who denied any substance to reality and claimed that it (or its major property) is change itself, but only for the material world of time and space (the world of appearances). Yet as to Plato's favoured notion of reality (consisting of ideas, forms, concepts, and thoughts), he sided with Parmenides who asserted that reality is an unchanging whole. This resulted in the well-known view, which regards a particular apple as a mere illusion, while the *concept or idea of the apple* becomes the only permanent reality.

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hand, taking into account that the 'storage' of complicated and highly formal mathematical theorems and definitions has sometimes proved to be a fruitful activity.

Hypotheses not fertile are discarded for immediate inquiry, but they may be accumulated for recovery in future situations. Successful hypotheses result in tentative conclusions about which assertions may be warranted (in display Masini 1961: § 1). These 'efficient hypotheses', effective in an individual situation, constitute theories or conclusions, and are accumulated in a virtual 'reservoir', data bank, together with hypotheses that have not performed. These stored ideas may help determine the 'resolved parts' of future problematic situations and thus setting limits for required future investigations.

System theorists and scientists in general can be interested in methodologies by which the 'data bank' of ideas is increased and cleared of refuse not demonstrated useful or not promising to become useful. Perhaps in the 'reservoir', data bank, there is no disorder between successful and unsuccessful hypotheses, but there may be an appreciable order to the filing of abstract conceptions and conclusions.

4. System ontology, quantum reality and information

A further question arises as to the nature of *information systems,* which are occasionally regarded as *conceptual systems.* In Ackoff (1962) framework, however, it seems rather that they would be treated as *concrete systems*, since the construction, transmission and reception of information are empirical phenomena[19].

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[19] The 'information principle' constitutes one ontological hypothesis, the others being 'polarity principle', 'periodicity principle', 'principle of concrescence', 'principle of formation preference', which must be regarded as the most basic principles of systems methodology. As with most postulates statements they must sound trivial. Nevertheless, a system approach without them appears a plant without routes. Their dual nature lead to a double formulation, the ontological hypotheses and the corresponding systems principles.

As to the 'information principle', (a) the ontological hypothesis is that *entities* possess qualities and tendencies which can be interpreted *as due to norms and similar sources of information.* Such information may be permanently incorporated in the *entity* or temporarily imposed from outside; and (b) the corresponding systems principle is that the norms incorporated in a system become a *fixed source* of information for this system, whereas the norms *temporarily imposed* upon the system by the environment, constitute *a variable information source* for this system. Such information determines the characteristics and the behavior of the system.

Ontology is the philosophical study of being. As one of the most fundamental concepts, being encompasses all reality and every entity within it. It examines basic concepts used in the social sciences. Applied ontology is particularly relevant to information ad computer science, which develop conceptual frameworks of limited domains. These frameworks facilitate the structured storage of information. Ontology is also pertinent to the fields of logic, theology, and anthropology (see Wikipedia 2025, 19 April, 'Ontology').

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The idea (Churchman 1971) to interpret science and knowledge design as a kind of *information system* has far- reaching consequences. Not only does it impart a novel perspective to epistemology, it also invites to contemplate the relationships between various *information systems*. In the light of such a thought we can speak of a common ground between, for example, such area of epistemology on one side, and such an applied field as accounting (and *entity economics*) on the other. Both are relevant *information systems* which have more in common with each other than either philosophers or accountants (and entity economists) might suspect.

In any system the interaction between the individual components seems to be leaded by *information*. Thus, this notion plays an indispensable role in systems analysis. Bertalanffy (1968: 42) even assigns to information the same central position in systems thinking which the notion of energy assumes in physics.

Systems scientists adopted ontology for lexicon, taxonomic, and related purposes in constructing a wide variety of *artificial intelligent systems* (cf. Aversa *et al.* 2024; Manzari 2024). This should enable computers to establish knowledge (see for instance Galassi and Mattessich 2015), communicate with people as well as with the computers. Indeed this area seems to be the most promising use of ontology from a practical point of view.

Beyond the mere 'traditional' ontological accounting, management and 'entity economics' literature there emerged a very different *computer oriented* ontological literature which is related to the relatively new branch of *systems ontology* –a concise survey of the latter, as well as attempts to relate it to management science, 'entity economics', accounting, biology, medicine, and other disciplines are offered by Mattessich 2014: chapter 11.

Particularly in the domain '*ontologies of information science'* it is relevant a warning not to neglect the routes and foundations on which every such domain inevitably rests, that is the general basis that unites all specialized ontologies presently contemplated in economics, 'entity economics', organization theory, *information science,* as well as other social disciplines. This ought to be the reason enough to re-examine the very foundations of those disciplines. Above all, there is the notion that the economic models are insufficient unless their discrepancies with reality are constantly monitored and born in mind.

It is ontology where we try on the highest level of generality to connect the specific scientific disciplines with each other and not merely from a taxonomic but from a deeper 'evolutionary' point of view. These interdependencies among different scientific areas are the substance on which ontology thrives and becomes fruitful. The major problem is how to interconnect all 'domain ontologies'; it must be added a quest of *system ontology*, that is to computerize the process of knowledge formation and dispersion; for the huge computer power required in this regard it is essential the development of *quantum computers* beyond the present proto-types.

As to the 'quantum reality' it is worthwhile to refer at the set of informal 'propositions', or rather *proposals*, by Richard Mattessich (2014: chapter 9): Prop. 1R to 16R about reality in general and Prop.1SR to 9SR, nine additional propositions on social reality in particular. These 25 propositions constitute an extension of Mattessich's Onion Model of Reality, OMR. It is an attempt to search for

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a basis that all sciences can share and this road leads on a collision course with 'quantum reality', a reality claiming to be the foundation of everything there is.

One of the major differences between 'quantum reality' and 'classical physical reality' is the indeterminacy or inaccuracy of the former. According to Heisenberg's (1927) well-known 'uncertainty principle' (probably a principle of quantum mechanics) the more precisely one measures, for example, the *position* of a particle, the less precisely one can measure its *momentum* and *vice versa*[20]. Rather these quantities can only be determined with some characteristic 'uncertainties'; in other words, the 'uncertainty principle' states that one cannot assign exact simultaneous values to the *position* and *momentum* of a physical system (cf. Stanford Encyclopedia of Philosophy 2016, revised 12 July). A similar uncertainty and trade-off can be for the measurement of *energy* and *time,* duration of a particle.[21] It follows that 'quantum theory' deals with probabilities. Not only can particles, *e. g.* photons, assume wave forms, particle-wave duality, they may be represented by probability waves – oscillating clouds of distribution, the density of which increases in some areas but decreases in others.

Depending on the current interpretation, among many possible ones, the uncertainty may underlie the general interdependence of all the variables that influence each other (see Mattessich 2014: 159-162). These interdependences play a more crucial role on the 'quantum level' than on the macro-level. After all a measurement process is a macro-activity that is bound to interfere more significantly when it intrudes on the incomparably smaller realm of 'quantum phenomena' than it does on the macro-world.

Ontology concerns the philosophical framework of existence, but the existential conditions and boundaries of specific *entities*, their change, transformation and identity, are determined by science. The problem of change is interconnected to the *substance vs process* debate. As to the issue of substance versus process one could interpret substances as processes arising from preceding substances or quasi-substances. This would conform to Whitehead's (1929) *process* hypothesis. The position of Richard Mattessich –who is inclined to accept a duality hypothesis that regards every substance as being a thing as well as a process, though not necessarily simultaneously—is conformed

[20] In other words when measuring the *position* of the particle at a relatively high degree of accuracy, *momentum,* can be measured only at a law degree of accuracy and reciprocally. Bronowski (1973) prefers to call 'Heisenberg's uncertainty principle' the 'principle of tolerance'; consequently, all *knowledge* and all *information* between human activities can only been exchanged within a game of tolerance.

[21] Ijiri's works (1982, 1989) about triple-entry bookkeeping utilizes analogies, parallels, with physics to represent the dynamic of accounting structure, as follows:

- The notion of *income momentum* (shortly 'momentum' = growth rate of wealth per time unit) corresponding in physics to the linear momentum (mass x velocity = mass - distance per time).
- *Force*, or better *income force* (growth rate of income momentum per time unit), corresponding to physical force (mass x acceleration = growth rate of linear momentum).
- *Impulse* (or *income impulse, i. e.* the increase in income momentum growth rate) corresponding somewhat to impulse in mechanics (increase in momentum = force x time).

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to Whitehead's *process* hypothesis and to the 'quantum' physicists' notion of particle-wave duality[22] as well as to their occasional assertion that *substance is ultimately information,* even if one might have to distinguish between *process as information* vs *substance as carrier of information.* The conclusion is that every substance must have some properties and must be embedded in the dynamic process of various relations, just as every process must have a substance to be processed: substance and process are two aspects of the same reality (see on display Mattessich and Galassi 2015).

Physics of the particles is not the only area where a duality solution gives a full picture. Typically in accounting and *entity economics,* there is a dualism embedded at the very core of how to analyze reality, not limited to the famous double entry methodology[23]. In the economic world we cannot concentrate simply on what exists, on the *balance sheet* items, have also to understand the changes that occur on those items over time, examining the *income statement* (see widely Galassi 1980; Masini 1978). In other words, both in physical world and in economic world we cannot limit the observation to one aspect of the reality, the momentary one, static picture of substance, or the periodic one, process, a dynamic picture (any 'thing' existing is a substance, any 'change' is a process); only both aspects reveal a comprehensive picture of concrete physical, chemical, biological, social, economic or accounting reality. The conclusion is that substance and process are two aspects of one and the same ontological phenomenon.

It may be unusual to consider the fundamental interactions of nature as an *information system*. Interaction performs an essential communication function on the physical and chemical levels no less than on the biological as well as social-cultural level, but there is a difference between *information* in physics – where i*nformation* has a direct power to enforce action, a causal force – and the social-cultural realm, with greater degree of freedom, normally requiring mental activities as reflection, decision making and so on[24]. Thus *information* on every level is the cement that keeps the world

[22] The combined 'substance-process hypothesis' makes sense all the more as it fully conforms to the 'particle-wave' theory of quantum physics. If physical particles, like photons, can at times manifest themselves as particles, and at other times as waves, this is an illustration of a duality to be extended to ontology in general. This even raises the question whether reality is not only quantized as regards tiny *matter-energy quanta* but also as minimal *space-time quanta* (cf. Mattessich and Galassi: 2015).

[23] Duality aspect of accounting is not identified with double entry, with a mere technicality; this is also demonstrated by the proposal for triple-entry bookkeeping (Ijiri 1982, 1989) which was born of the same analytical spirit as double entry and which is an ingenious extension of the latter.

[24] The phenomenon of *consciousness* (i. e. the ability having ideas, make judgements, experience emotions and so on), a fundamental concept, at least when including sentient beings, lies at the very root of *value judgements* and play a central role in any applied discipline. The emergence of preferences, the setting of goals, the prescribing of means, all these are consequences of consciousness, none of them encountered in the pure, physical science, except the highly speculative idea, firmly criticized, that human consciousness itself is based on quantum phenomena. For the relations of consciousness with other basic concepts such as 'substance' and 'space', 'time' and 'process' see Mattessich and Galassi (2015).

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together through communication and the interactions activated by it. Doubtless *information* in conjunction with interaction and connection, is the 'nerve of things', *nervus rerum*.

The notion of *concrete* and *abstract* have a fundamental ontological meaning. The challenge is in two *complementary* definitions: *concrete entities*, as having spacetime dimensions, and being subject to causal relations, versus *abstract entities*, as being supposedly beyond spacetime and possibly being casually inert.

It is relevant the distinction between *information as an abstract notion* versus its *concrete* manifestation in data, texts, electronic impulses, and so forth. Even on the physical level *information* ought to be considered as something abstract, though on this level it may be more difficult to separate *information* from the resulting interaction and concrete manifestation. On the physical level *information* and interaction are so strictly intermixed that one may ask whether one deals with two different *entities* or with two aspects of one and the same *entity*. But even in physics one might consider the *information function* as 'abstract', and the physical process of enforcing it as 'concrete'.

5. Information, quantum teleportation, and quantum entanglement. The duality solution

Information as a potential of changing expectations and future benefits is 'abstract'; its manifestation in speech, writing, *computerization,* wireless transmission and so on is 'concrete'; so, it is relevant to keep an 'abstract *entity*', whether weakly or strongly, rigorously aside from its concrete manifestation; they are different *entities*, though both may be real in some sense from an ontological point of view.

One might argue that 'energy', in contrast to its concrete manifestation such as heath, force, electricity, radiation and so on, is a physical yet abstract entity (cf. Mattessich and Galassi 2015). In accounting there is an excellent analogy to illustrate this particular difference; apart from suggesting that physics could be regarded as a kind of 'cosmic accounting' system, it raises questions about the corresponding analogies in accounting and *entity economics*; not only is 'energy' being analyzed in terms of its 'manifestation' (matter, radiation, potential or kinetic energy) as well as in terms of its 'force' (electromagnetic, gravitational, strong and weak force), *balance-sheet capital* also is being analyzed in terms of its manifestation (as assets, such as cash and receivables, inventories, fixed assets and so on) as well as in terms of its force (claims such as payables, loans, preferred stocks, earned surplus and so forth[25]

Interesting phenomena of quantum theory are *quantum teleportation* and *quantum entanglement.* It means the 'transposition' of an entangled particle, more precisely the *information* constituting this particle, over kilometer-wide distances without physically crossing the intervening space. That is to say the particle is instantaneously reconstructed in the new place but deconstructed in the previous

[25] In the biological and social-cultural level *information* expresses in different forms of communication, be it through DNA structures, electronic chemical messages of the nervous system, hormones, the blood flow in the circularity system, through spoken and written language, in the *binary system of computer codes,* and so forth (for other analogies between accounting and information, on one side, and physics on the other –see Mattessich 1991: 34).

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one; this is not only a consequence of quantum mathematics but confirmed empirically by the Austrian physicist Zeilinger (2011, quoted by Mattessich 2014: 223-24). These experiments of quantum physics include the teleporting of particles across the Danube as well as some teleportation on the Canary Islands, between La Palma and Tenerife, a distance of over 100 km.

The 'quantum entanglement' is the point behind this kind of teleportation. In simple words this phenomenon occurs when two particles link together in a certain way no matter how far apart they are in space. It appears when one splits a high energy photon (or instance by beta barium borate) into a pair of entangled photons but each of the entangled photons is of lesser energy than the simple original photon -- though together they preserve the total energy originally fired from the laser. The resulting pair of photons are considered entangled because the properties of the emitted pair of photons is in a way considered to be a single *entity* of complimentary parts[26]

And even when these properties are unknown, 'quantum theory' stipulates they must be complementary if entangled; only when one particle of the entangled pair is measured is the state of the other revealed. This is the apparently instantaneous communication between entangled particles, even if they are miles apart and may meanwhile have had frequent random changes of polarization. That is to say in entangled photons the quantum properties are so strictly interlinked that one photon seems *to know* the state of the other. When a property of one entangled photon is measured, the complementary photon changes in response, even when the two photons are separated by large distances[27].

As hinted above 'quantum theory' says about the relation between substance and *information* that is teleported and that the particle is reconstructed by this *information*. It follows the question if , as much as *information* may be an intermediary of change, can it be identical to the substance that initiates this change; yet, if 'strings' and 'loops'[28] of vibrating energy (Mattessich 2014: 224) are the ultimate substance, than these *entities* might not only be the carrier but also the constituents of the information determining the properties of those substances. Thus it seems that substance and information merge and may become difficult to distinguish from each other[29] . One could consider substance as concrete, but *information* as abstract, and interaction, *i. e.* forces, as the medium connecting the two. This might hold for physics and perhaps also for the economic and social

[26] For instance, if one electron is horizontally polarized the other must be vertically polarized or aligned.

[27] And beyond photons similar experiments of quantum teleportation have been made with other particles, even with atoms.

[28] 'String theory' assumes the ultimate physical particles as infinitely small *loops,* either open or closed, of vibrating filaments of mass/energy, instead of being point-like as postulated in standard quantum theory. 'String theory' attempts to achieve a single explanatory framework encompassing all forces and all matter. Of particular interest seems to be the 'superstring theory', which a specific feature is the assumption of a supersymmetry where every *force* particle has its corresponding *matter* particle (for instance the electron has its *selectron*, the photon its *photine*, and so forth).

[29] Beyond the point of 'quantum theory' already mentioned, there are many others, for instance the hypotheses of a 'multi-universe' (see Mattessich and Galassi: 2016).

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sciences; for instance, suppose an information, *abstract,* that a stock price of a particular share is expected to rise; if this conducts to a transaction, interaction, between buyer and seller of those shares, there is an analogue to the physical model.

'Chaos theory' together with 'relativity theory' and 'quantum theory' is judged the third major scientific revolution of the twentieth century, showing new principles how the world works. In 'dynamic nonlinear systems' it deals with order no less than disorder; therefore the term 'nonlinear' refers to systems either larger or less than the sum of their parts, or alternatively with systems where causes are not proportional to their effects[30].

Chaotic situations have unpredictable as well as deterministic aspects; that is to say in the midst of chaos we may encounter 'windows of order'[31]. Thus, contrary to expectations 'chaos theory' (chaotic deterministic systems are the proper domain of chaos theory), in strict sense, is not *probabilistic* but *deterministic,* and this despite the chaotic kind of its underlying phenomena. As strange as it may sound, there is 'order in chaos'. As to major difference between *non-chaotic* vs. *chaotic systems*, it is the impact of *initial errors* or *conditions* that it is decisive. In non-chaotic systems that impact remains insignificant, while in chaotic systems this 'butterfly effect' increases exponentially with time; it expresses the circumstance that in chaotic systems – for instance the weather, the growth of wildlife populations, the flight path of a space ship – minor events in initial conditions can lead to major unpredictable consequences.

Chaotic systems in contrast to probabilistic systems, the third category, have randomly distributed errors.

'Complexity theory' must be distinguished from 'chaos theory'. In a sense chaotic system can be regarded as a subset of 'complex systems': the scientific laws of 'complex systems' are unknown, whereas the scientific laws of other systems are fully known or partially known[32].

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[30] This corresponds with the concept of 'emerging properties'. These not only represent, and are the results of, the 'leaps' in the transition from one major level to the other, they also play a relevant role on sublevels, sub-sublevels, and their interactions.

[31] The 'bifurcation diagram', also called 'orbit diagram' is based on 'logistic maps' (which show the growth rate in relation to population size) and are characterized by a succession of several *bifurcations* (qualitative changes of systems behavior) that occur before the onset of chaos. The latter leads in time to 'windows of orderliness', only to fall again on chaos and so on. -

[32] An interesting comparison is between 'chaos theory' and 'quantum' mechanics; both stress the unpredictability of cosmos and the limits of human essence, but are totally different in many grounds: 'chaos theory' is deterministic and 'quantum theory' probabilistic; another cause is the non-linearity of the former versus the linearity of probability waves used in 'quantum theory'. Another motive is the need for certainty about parameters in 'chaos theory' versus the Heisenberg uncertainties of competing measurements such as momentum versus location in 'quantum theory'. Nevertheless these utter differences, there is an attempt to combine them in a 'quantum chaos' by Strogatz (2008).

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Quantum properties have a growing role in modern nano-technologies and may even revolutionize the computational capabilities, through ‘quantum computers’. Moreover, quantum reality cannot be avoided in any modern ontology[33].

Current proto-types of ‘quantum computers’ are already far off from the capabilities of present-day silicon chip computers; there are significant contributions to the area of quantum computation, where quantum computers could solve mathematical problems hugely faster than traditional ones. Some of these contributions are presented by Mattessich (2014: 231).

The most prominent application of quantum computers, at least in the early stage, seems to be ‘quantum factoring’, that is the discover, as efficiently as possible, of all the arithmetical factors of a large number; this is not only a purely mathematical function, it is basic for cryptography, increasing relevant for industry, in government, not only for military purposes. Because of the simultaneous search capability, consequent speed and other particular features like ‘quantum key distribution’, cryptography may be one of the tasks suited for the first operational sets of quantum computers.

‘Quantum key distribution’ is the institution of a secret code ‘unbreakable’ without the explicit knowledge of the protected parties, already used by banks and government institutions; this is guaranteed by the ‘no-cloning theorem’. Another space already proved useful for cryptography and encoding in this field is ‘chaos theory’.

In some quarters they hypothesize the possibility that human *consciousness* itself is based on quantum phenomena (see Wikipedia 2011, as modified 7 December: 1), but human consciousness is non-algorithmic, and so is not capable of being modeled by a conventional ‘Turing machine-type of digital computer’, the universal quantum computer (cf. Deutsch 1985); quantum mechanics has a relevant function in understanding human *consciousness*, but the objective collapse of quantum ‘wavefunction’ is critical for *consciousness* (cf. Mattessich and Galassi 2015). Human mind has abilities that no ‘Turing machine’ could possess because of this mechanism of no-computable physics. It is difficult to think that quantum computers might operate on principles that do resemble brain processes.

Conclusions

The ‘system research’ might be increased by giving it an ontological grounding, that is by stating assumptions about the existence of definite ‘entities’, aziende in Italian literature, events, and by showing the system notion has been rooted in the foundation of science.

[33] Quantum computers may employ *ebits,* pair of *entangled qubits*, normally in combination with bits and regular qubits. A contemporary search, multitasking, is based on quantum properties such as superposition and entanglement because quibits can entangle with each other. They can also be superimposed and generate a large spectrum of values; hence *information processing* as well storage would no longer be done on silicon chips (in bits) but by means of atomic or subatomic particles on a qubit and ebit basis (on the relationships between technological development and changes in organizational activities see Javidan *et al.* 2024).

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Systems theorists have paid attention to nature tendency of aggregating basic substances into integral *entities* of ever-increasing complexity – Leibniz monadology is the best known traditional 'theory of concretion'.

The concept of 'hierarchies' is very often found in topics about *entities*. The hierarchies in terms of *information* needs are encountered in decisions and objectives. In the 'evolutionary hierarchy' it is relevant to know where a system begins having built-in preferences, then exercise value judgements with a consequent inner aspect, *consciousness*, which is a matter of degree and bridges a wide range; it may be thought as the 'introspective side of any kind of *entity* or any kind of system'.

Weather a system, for instance 'management science', 'entity economics', *economia aziendale*, is free of values or not depends of the location of value judgements in relation to the *boundaries* of the system.

Only after the *object-language,* the *system*, was clearly separated but related to the *meta-language*, the system environment, could the crucial paradox of set theory be solved. Another achievement in this regard is Godel's incompletability theorem and proof. Doubtless these acquisitions were allowed by the sharp distinction between *system* and *meta-system*, environment, *meta-system* and *meta-meta system*, environment of the meta-system.

As to the 'permanency' than on 'variability' of system structure, from a human and instrumental viewpoint the 'internal aspect', with its mental, preferential and teleological notions, appears to dominate.

For the *Polarity principle,* to any system belongs a 'counter-system', *e. g.* the environment. We cannot analyze an *entity* without attention to its *counter-entity* and take into account that *polarity* and *tension* are the most fundamental notions underlying the phenomenon of *Being.*

Institutional economics, entity economics, *economia aziendale,* include more than environment in the economic system and investigate tendencies toward 'steady state conditions of equilibrium'.

The idea to interpret science and knowledge design as a kind of *information* has far-reaching consequences. In any system the interaction between the individual components seems to be leaded by *information.* Thus, this notion plays an indispensable role in systems analysis.

As to the 'substance versus process' debate, *substance is ultimately information* even if one has to distinguish between *process as information* versus *substance as carrier of information.* Substance and process are two aspects of the same reality, that is of one and the same ontological phenomenon. *Information* on every level is the cement that keeps the *world* together through communication and the interaction activated by it.

Physics of the particles is not the only area where a duality solution gives a full picture. Typically in 'entity economics', *economia aziendale,* and accounting there is a dualism embedded at the very core of how to analyze reality, not limited to the famous double entry methodology.

Systems scientists adopted ontology for lexicon, taxonomic, and related purposes in constructing a wide variety of *artificial intelligent systems*. This should enable computers to establish knowledge, communicate with people as well as with other computers, and this area seems to be the most promising use of ontology from a practical point of view.

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Beyond the mere 'traditional' ontological (management, entity economics, *economia aziendale,* accounting) literature there emerged a very different *computer oriented* ontological literature which is related to the relatively new branch of *systems ontology*, that is to computerize the process of knowledge formation and dispersion for which it is essential the development of *quantum computers beyond the present* proto-types.

As to the 'quantum reality', the 'evolutionary approach to ontology' says of a search for a basis that all sciences can share, and this road leads on a collision source with 'quantum reality' a reality claiming to be the foundation of everything there is.

Particularly strange phenomena of 'quantum theory' are *quantum entanglement* and *quantum teleportation*.

In closing, the paper adds some notes on cryptography and 'chaos theory', that together with 'quantum theory' and 'relativity theory', is considered the third major revolution of the twentieth century.

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