# THE NOTION OF INFORMATION IN QUANTUM PHYSICS AND THE DUAL ONTOLOGY OF NATURE

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Summary



## 1 From formal logic to formal ontology

### *1.1 Mathematical logic versus philosophical logic*

#### 1.1.1 Three eras in the modern history of modal formal logic

Speaking about "ontology" and even "*scientific* ontology", vindicating for it a rigorous method of argumentation, is against the nihilist, dominating mentality. Now, if there is some consolation in the fact that our culture hits the bottom – and with nihilism we effectively hit the bottom – such a consolation consists in the evidence that from the bottom only a new rise is possible, because it is impossible to go deeper.

One of the most promising signs of this rise concerns precisely logic and its foundations. As to it, XX century opened with a great breakthrough: the axiomatization of the mathematical logic, i.e. of the *extensional* logic, and its application to the whole mathematical production at that time, by the publication between 1910 and 1913, of the *Principia Mathematica* by Alfred N. Whitehead e Bertrand Russell. Such a masterpiece demonstrated that mathematical logic and the axiomatic method are precisely such a universal scientific language and method modern thought was searching for, since its origins with Leibniz and Descartes.

In fact, such a formal language is the "secret" of the actual globalization of the scientific and of the technological research and practice — particularly toward the East of the world — making accessi-

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ble to everybody the scientific *communication,* and hence the scientific *education,* beyond millenary linguistic, cultural, and social distances[1].

Well, starting from 1912, before the publication by Bertrand Russell of Wittegstein's *Tractatus Logico-Philosophicus,* the young American philosopher Clarence I. Lewis denounced in several papers (Lewis, 1912; 1914; 1918) the limit of using the "material implication" of extensional logic also to the formalization of other types of *deduction/demonstration*, typical of the humanistic disciplines. At the same time with Lewis' vindication of the oddity of what is today defined as *philosophical logic* with respect to the *mathematical logic* of the *Principia*, he recognized the power that the axiomatization of mathematical logic will have for the worldwide diffusion of scientific thought and practice. A similar formalization, according to Lewis, had thus to be developed for what he defined as the *strict implication* typical of metaphysical arguments, in which it is impossible to admit that *true* consequences can be implied by *false* premises, as it is possible by *material implication* of the mathematical logic[2]. In this way, Lewis re-discovered the classical distinction among different ways of defining *necessity* in different linguistic uses (e.g., the *logical* necessity of mathematics is different from the *causal* necessity of ontology, from the *obligation* of ethics and of law, etc.). Despite such an embryonic formalization of the *modal logic* offered by Lewis in these juvenile papers was not fault-free, as Emile Post rightly emphasized, he was visionary in understanding the necessity of formalizing also the *philosophical logic* instead of reducing it, as Russell[3] wanted, to the only *mathematical logic* of his *Principia,* and its extension also to the logical analysis of the philosophical language, according to Wittengstein's *Tractatus.* Such a research program, according to Lewis, had to start just from the modal logic, the logic of the different ways of interpreting the various forms of "necessity/possibility" (*ontic* (physical or metaphysical: "necessary/contingent"), *logic* ("necessary/possible"), *epistemic* ("science/opinion"), *deontic* (ethical or legal: "obligatory/permitted"), etc.) in the ordinary languages. As we see, all the different philosophical disciplines (ontology, logic, epistemology, ethics..) depend ultimately on different semantic, *intensional,* interpretation of common modal syntactic structures!

In such a way, C. I. Lewis, by publishing with C.H. Langford in 1932 the first textbook of axiomatic modal logic (Lewis & Langford, 1932), demonstrated that it is possible not only the unambiguous

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[1] For instance, a young Chinese of the XIX century, for understanding adequately a scientific discipline, also at the only applicative level, would have had to study one or more Western languages, to become acquainted with several contents of Western cultures, and finally to start with the study of mathematics and of the scientific discipline concerned. At that time, in fact, for the lack of the actual symbolization and axiomatization, the scientific notions were defined and explained using the ambiguous and incoherent expressions of the natural languages, making the procedure of comprehension much more arduous for everybody was not native in that culture. It is evident the waste of intellectual, temporal and also economical resources that such a situation implied. The same waste of resources to which we are actually constrained for mastering adequately the philosophy, the world vision, the ontology or the ethics, of another culture, making the progress of the intercultural dialogue so slow and inefficient. On the contrary, today, the use of one only symbolic language, and the crystallization of a millenary scientific knowledge in few, univocal and coherent axioms, allow the same Chinese student to master a good scientific or technological competence in the only four, six years of a good bachelor or master degree. In this way, countries such as China, India or South Korea can turn out every year many hundred thousands of high-level scientists and engineers, able to shift in few decades the axis of the world economy and development from West to East. The novelty is that today it is possible to extend the advantages of the axiomatic method also to the humanistic disciplines, giving everybody, trained in the newborn discipline of the *philosophical logic,* a powerful means for a reciprocal dialogue and comprehension. In this way, it becomes possible a valorization of the contents of the different humanistic cultures, for a globalization that, by making unambiguously understandable the different approaches to reality, is able to valorize the differences and to avoid a "one-way" globalization. In fact, an only scientific globalization becomes, because of this exclusiveness, a "scientism", that is the unintentional killer of the humanistic traditions of whichever culture.

[2] In fact, in the concrete existence realm, it is meaningless that an *effect* (= "consequence" in ontological sense) occurs (= it is *true* in ontological sense) if its proper *cause* (= "premise" in ontological sense) does not occur too (= it is *false* in ontological sense).

[3] Both logical and ontological necessity/possibility deal with *truth,* wherever the other intensional, philosophical disciplines deal with necessity/possibility in the senses of *certainty* (epistemology), *value* (ethics), *obligation* (law), etc. For this reason, the logical and ontological necessity/possibility are defined as *alethic*, for distinguishing it from the *epistemic* or the *deontic* ones.

and rigorous access to the contents of humanistic cultures to everybody — also to people not acquainted with that given culture, and even not trained at all in humanities —, but also that it is possible, in principle, the artificial simulation of semantic and intentional tasks in computer and cognitive sciences. This technological consequence, anyway, has become particularly relevant only during these last ten years (Burgess, 2009; Girle, 2009).

In fact, following (Blackburn, De Rijke, & Venema, Modal logic. Cambridge tracts in theoretical computer science, 2010), we can distinguish other two eras in the short history of modern modal logic, after the pioneering one just illustrated, and devoted to the intensional interpretations of modal syntactic structures. The second one, comprised between '60's and 70's of the last century, is related to the development of Kripke's formal semantics, as far as it is based on his brilliant notion of *frame,* a particular evolution of the mathematical notion of "set". A "frame" indeed is a set of elements with the complete collection of relations defined on pairs of them, as we see below. The brilliance of such a notion is related to the fact that the frame notion can be applied, not only to the formalization of intensional models of the modal structures in Lewis' sense, but also to the formalization "from the inside" of extensional interpretations (models) of the modal structures. This is related to the so-called third era of modern modal logic, from 80's of the last century till now, and it is related to *the algebraic interpretation of modal logic,* and of its relational semantics based on frames. This way back from philosophical to mathematical logic, made modal logic an essential tool in *theoretical computer science*, not only for the computer simulation of semantic tasks, but overall for testing "from the inside" the truth and the consistency of mathematical models. This is based on two fundamental principles defining the relations between modal logic and mathematical logic:

1. The *correspondence principle* between modal formulas defined on models, and first-order formulas in one free-variable of the predicate calculus. This allows the use of modal logic frame semantics, which is a decidable second-order theory, as a meta-logical tool for individuating and testing *decidable* (and hence *computable*) *fragments* in first-order mathematical models. We see in the rest of this paper several practical applications of this principle.
2. The *duality principle* between modal relational semantics and algebraic semantics, based on the fact that models in modal logic are given not by substituting free variables with constants, like in the predicate calculus semantics, but by *using binary evaluation letters* (0,1) in relational structures (frames) like in algebraic semantics.

Modal formal logic is thus fundamental also in our case, i.e., in developing a consistent formal ontology of the dual ontology emerging from:

3. The *information-theoretic approach in quantum mechanics (QM) and cosmology*, in the wider context of a *relational interpretation* of QM (Rovelli, 1996), perfectly consistent also with the *modal* interpretation of it (Van Fraassen, 1991; Kochen, 1985; Dieks, 1994; Dieks, 2005) (for an updated synthesis, see (Dickson & Dieks, 2009)) ;
4. The *theoretical cognitive science,* since it furnishes scientists and philosophers with one only formalism capable of bridging among causal (physical), intensional (psychical), and computational (logical) components of the cognitive agency.

#### 1.1.2 Extensional vs. intensional logic and/or mathematical logic vs. philosophical logic

Apart from the computational and mathematical applications of modal logic, all the different intensional interpretations (*tense logic, alethic logic, deontic logic, epistemic logic,* etc.) of the very same modal syntactic structures are denoted also by the collective term of *intensional logic,* for distinguishing them from the *extensional* or *mathematical logic*.

In fact, the main common character of all intensional logics is that in them the *extensional axiom* of mathematical logic does not hold. For this same reason, all the intensional calculi are not "truth-functional" (truth tables are not valid in them), because the truth-conditions are different for each different intensional calculus (see note 4). All this can be synthesized by saying that in the inten-

sional logics the notion of *predication* cannot be reduced to the *class/set membership* notion of the mathematical logic.
The *modal logic* with all its *intensional* interpretations are what is today defined as *philosophical logic* (Burgess, 2009), as far as it is distinguished from the *mathematical logic*, the logic based on the extensional calculus, and the extensional meaning, truth, and identity[4]. What is new, with the formalization of the modal logic (see above, § 1.1) is that also the intensional logics can be *formalized* (i.e., translated into a proper symbolic language, and axiomatized), against some rooted prejudices among "continental" philosophers, who abhor the symbolic hieroglyphics of the "analytic" ones. I.e., there exists an *intensional logical calculus*, just like there exists an extensional one, and this explains why both mathematical and philosophical (modal) logic are today often quoted together within the realm of *computer science*, and overall of *theoretical computer science* (Blackburn, De Rijke, & Venema, Modal logic. Cambridge tracts in theoretical computer science, 2010 (2002)). This means that classical semantic and even the intentional tasks can be simulated artificially. This is the basis of the incoming "Web3 revolution", i.e., the advent of the *semantic web*. Hence, the "thought experiment" of Searle's "Chinese Room" (Searle, Mind, brains and programs. A debate on artificial intelligence, 1980) is becoming a reality, as it happens often in the history of science.
Anyway, to conclude this part, the main intensional logics with which we are concerned in the present paper are:

1. *Alethic logics*: they are the descriptive logics of "being/not being" in which the modal operators have the basic meaning of "necessity/possibility" in two main senses:
   a. *Logical necessity*: the necessity of lawfulness, like in deductive reasoning
   b. *Ontic necessity*: the necessity of causality, that, on its turn, can be of two types:
   - *Physical causality*: for statements which are true (i.e., which are referring to beings existing) only in some possible worlds. For instance, biological statements cannot be true in states, or parts, or ages of the universe in which, because of the too high temperatures only quantum systems can exist).
   - *Metaphysical causality*: for statements which are true of all beings in all possible worlds, because they refer to properties or features of all beings such beings.
2. *The deontic logics*: concerned with what "should be or not should be", where the modal operators have the basic meaning of "obligation/permission" in two main senses: *moral* and *legal obligations*.
3. *The epistemic logics*: concerned with what is "science or opinion", where the modal operators have the basic meaning of "certainty/uncertainty". It is evident that all the "belief" logics pertain to the epistemic logic, as we see below.

[4] What generally characterizes intensional logic(s) as to the extensional one(s) is that neither the *extensionality axiom* – reducing class identity to class equivalence, i.e., $\mathbf{A} \leftrightarrow \mathbf{B} \Rightarrow \mathbf{A} = \mathbf{B}$ (i.e., "if two classes are equivalent, they are identical, and their predicates are reciprocally replaceable, because they have the same extensional meaning", e.g. "water" and "$H_2O$"), – nor the *existential generalization axiom* – $Pa \Rightarrow \exists xPx$, where $P$ is a generic predicate, $a$ is an individual constant, $x$ is an individual variable (e.g., "If I think, there exists something that is thinking") – of the extensional predicate calculus hold in intensional logic(s). For instance, if we applied the two axioms in many uses of ordinary languages (e.g., poetic or religious languages) the asserts so constructed would become immediately meaningless. E.g., given the statement "Omnipotent Lord, bless, we pray, this water…", it would be transformed in the meaningless statement: "Omnipotent *something*, bless, we pray, this $H_2O$". In fact, "God" of believers, as the Absolute, cannot be reduced to any "something", and the "water", in the rite of Baptism, is not simply "$H_2O$", but it has a lot of symbolic meanings related, for instance, to the Bible stories shared by the Christian believers, that cannot be reduced to the denotatum of whichever chemical formula. Moreover, if the two precedent axioms do not hold, also the Fegean notion of *extensional truth* based on the truth tables does not hold in the intensional predicate and propositional calculus. Of course, all the "first person" (both singular, in the case of individuals, and plural, in the case of groups), i.e., the *belief* or *intentional* (with *t*) statements, belong to the intensional logic, as Searle, from within a solid tradition in analytic philosophy (Sellars, 1958; Strawson, 1959; Sellars & Rorthry, 1997), rightly emphasized (Searle, 1980; Searle, 1983). For a formal, deep characterization of intensional logics as to the extensional ones, from one side, and as to intentionality, from the other side, see (Zalta, 1988).

### 1.1.3 SOME SYSTEMS OF MODAL LOGIC

For our aims, it is sufficient here to recall that formal modal calculus is an extension of classical propositional, predicate and hence relation calculus with the inclusion of some further axioms. Here, we want to recall only some of them — the axioms **N, D, T, 4** and **5 —**, useful for us, with some of their main intensional interpretations:

**N**: $<(\mathbf{X}\rightarrow\alpha) \Rightarrow (\Box\mathbf{X}\rightarrow\Box\alpha)>$, where **X** is a set of formulas (language), $\Box$ is the necessity operator, and $\alpha$ is a meta-variable of the propositional calculus, standing for whichever propositional variable *p* of the object-language. **N** is the fundamental *necessitation rule* supposed in any normal modal calculus

**D:** $<\Box\alpha\rightarrow\Diamond\alpha>$**,** where $\Diamond$ is the possibility operator defined as $\neg\Box\neg\,\alpha$**. D** is typical, for instance, of the *deontic* logics, where nobody can be obliged to what is impossible to do.

**T:** $<\Box\alpha\rightarrow\alpha>$**.** This is typical, for instance, of all the *alethic* logics, to express either the *logic* necessity (determination by law) or the *ontic* necessity (determination by cause).

**4:** $<\Box\alpha\rightarrow\Box\Box\alpha>$**.** This is typical, for instance, of all the "unification theories" in science where any "emergent law" supposes, as necessary condition, an even more fundamental law.

**5:** $<\Diamond\alpha\rightarrow\Box\Diamond\alpha>$**.** This is typical, for instance, of the logic of metaphysics, where it is the "nature" of the objects that determines necessarily what it can or cannot do.

By combining in a consistent way several modal axioms, it is possible to obtain several *modal systems* which constitute as many syntactical structures available for different intensional interpretations. So, given that **K** is the fundamental modal systems, derived by the ordinary propositional calculus **k** plus the necessitation axiom **N,** some interesting modal systems for our aims are:

1. **KT4** (**S4,** in early Lewis' notation), typical of the *physical* ontology;
2. **KT45 (S5,** in early Lewis' notation), typical of the *metaphysical* ontology — as well as of a physical theory with the pretension of being a TOA, a "Theory-Of-All";
3. **KD45** (**Secondary S5**)**,** with application in deontic logic, but also in epistemic logic, in ontology, and hence in natural computation and cognitive science, as we see.

Generally, in the *alethic* (either logical or ontological) interpretations of modal structures the necessity operator $\Box p$ is interpreted as "*p* is true in all possible world", while the possibility operator $\Diamond p$ is interpreted as "*p* is true in some possible world". In any case, the so called *reflexivity principle* for the necessity operator holds in terms of the axiom **T**, i.e, $\Box p \rightarrow p$. In fact, if *p* is true in *all* possible worlds, it is true also in the *actual* world (E.g., "if it is necessary that this heavy body falls (because of Galilei's law), then this body really falls").

This is not true in *deontic* contexts. In fact, "if it is obligatory that all the Italians pay taxes, it does not follow that all Italians really pay taxes", i.e., $\mathbf{O}p \nrightarrow p$**,** where **O** is the necessity operator in deontic context. In fact, the obligation operator $\mathbf{O}p$ must be interpreted as "*p* is true in all *ideal* worlds" different from the actual one, otherwise $\mathbf{O}=\Box$, i.e., we are in the realm of metaphysical determinism where freedom is an illusion and ethics too. The reflexivity principle in deontic contexts, able to make obligations really effective in the actual world, must be thus interpreted in terms of an *optimality operator* $\mathbf{O_p}$ for *intentional agents*, i.e,

$$(\mathbf{O}p\rightarrow p) \Leftrightarrow ((\mathbf{O_p}\,(x,p) \wedge c_a \wedge c_{ni}) \rightarrow p)$$

Where *x* is an *intentional* agent, $c_a$ is an acceptance condition and $c_{ni}$ is a non-impediment condition. In similar terms, in *epistemic* contexts, where we are in the realm of "opinion/science" — i.e., of the "uncertain/certain representations" of the real world —, the interpretations of the two modal epistemic operators $\mathbf{B}(x,p)$, "*x* believes that *p*" (uncertainty), and $\mathbf{S}(x,p)$, "*x* knows that *p*" (certainty) are the following. $\mathbf{B}(x,p)$ is true iff *p* is true in the realm of representations believed by *x*. $\mathbf{S}(x,p)$ is true iff *p* is true for all the *founded* representations believed by *x*. Hence, the relation between the two operators is the following:

$$\mathbf{S}(x,p) \Leftrightarrow (\mathbf{B}(x,p) \wedge \mathbf{F}) \quad (1)$$

Where **F** is a *foundation relation*, outside the range of **B,** and hence outside the range of *x* consciousness, otherwise we should not be dealing with "knowing", but only with "believing of knowing". I.e., we should be within the realm of solipsism and/or of metaphysical nihilism, systematically reducing "science" or "well founded knowledge" to "opinion". So, for instance, in the context of the ontology of *logical realism*, such a **F** is interpreted as a supposed actually infinite capability of human mind of attaining the realm of the logical truths (Galvan, 1991). We will offer, on the contrary, a different *finitistic* interpretation of **F,** by distinguishing between the *actual finite* capability of human mind and its *virtual infinity***.** Anyway, as to the reflexivity principle in epistemic context,

$$\mathbf{B}(x,p) \not\to p$$

In fact, believing that a given representation of the actual world, expressed in the proposition *p*, is true, does not mean that it is *effectively* true, if it is not well *founded*. Of course, such a condition **F** — that has to be an *onto*-logical condition — is by definition satisfied by the operator **S**, the operator of sound beliefs, so that the reflexivity principle for epistemic context is given by:

$$\mathbf{S}(x,p) \to p \quad (2)$$

#### 1.1.4 KRIPKE'S NOTION OF "FRAME" AND HIS RELATIONAL SEMANTICS

Let us introduce now briefly Samuel Kripke's notion of "frame", as an evolution of the mathematical notion of "set". As we said, this is the basis for the above remembered also *algebraic* interpretation of modal logic, i.e., for the applicability of modal logic syntax and semantics, also in mathematical and not only philosophical logic (e.g., in relational and information-theoretic interpretations of QM, as well as in theoretical computer science).

The relational semantics is, in fact, an evolution of Tarski's formal semantics, with two specific characters:

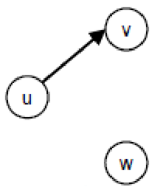
1. It is related to an *intuitionistic logic* (i.e., it considers as non-equivalent the "excluded middle" principle and the "contradiction principle", so to admit coherent theories violating the first one, like, for instance, in quantum logic);
2. It is thus compatible with the *necessarily incomplete character* of the formalized theories (because of Gödel's incompleteness theorems), and with the *evolutionary character* of natural laws not only in biology, but also in cosmology.

In other terms, while in Tarski's classical formal semantics (Tarski, 1935), the truth of formulas is concerned with the state of affairs of *one only actual world,* in Kripke relational semantics the truth of formulas depends on states of affairs of "worlds" different from the actual one (= possible worlds). On the other hand, in contemporary cosmology, it is nonsensical speaking about an "absolute truth of physical laws", with respect to a world where the physical laws cannot be always the same, but have to evolve with their referents (Davies, Universe from bit, 2010; Benioff, Effects on quantum physics of the local availability of mathematics and space time dependent scaling factors for number systems, 2012).

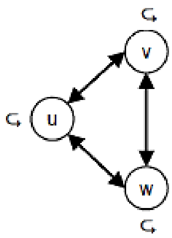
Anyway, the notion of "possible world" in Kripke semantics has not only a physical sense. On the contrary, as he vindicated many times, the notion of "possible world", as a syntactic symbol in a relational logic, has as many senses, as the semantic (extensional and/or intensional) models that can be consistently defined on it. In Kripke words, the notion of "possible world" in his relational semantics has a *purely stipulatory character*.

In the same way, in Kripke semantics, like the notion of "possible world" can be interpreted in many ways, so also the relations among worlds can be given as interpretations of the only relation of *accessibility.* In this way, a unified theory of the different intensional/extensional interpretations of modal logic became possible, as well as a *graphic representation* of their respective relational semantics.

The basic notion for such a graphic representation is the notion of *frame.* To illustrate this key-notion of modal logic we use (Galvan, 1991). A frame is, in fact, an ordered pair , <**W**, *R*>, constituted by a domain **W** of possible worlds {*u, v, w…*}, and a by a two-place *relation R* defined on **W**, i.e., by a set of ordered pairs of elements of **W** ($R \subseteq \mathbf{W}\times\mathbf{W}$), where $\mathbf{W}\times\mathbf{W}$ is the *Cartesian product* of **W** per **W**. E.g. with **W** = {*u,v,w*} and *R* = {*uRv*}, we have:

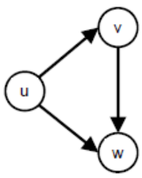



According to such a structure, the accessibility relation *R* is only in the sense that *v* is accessible by *u*, while *w* is not related with whichever other world. If in **W** all the worlds were reciprocally accessible, i.e., *R*= {*uRv, vRu, uRw, wRu, wRv, vRw*}, then we would have *R* only included in $\mathbf{W}\times\mathbf{W}$**.** On the contrary, for having $R=\mathbf{W}\times\mathbf{W}$, we need that each world must be related also with itself, i.e.:




(3)

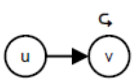
Hence, from the standpoint of the relation logic, i.e., by interpreting {*u,v,w*} as elements of a class, we can say that this *frame* represents an *equivalence class.* In fact, a *transitive, symmetrical* and *reflexive* relation *R* holds among them. Hence, if we consider also the *serial relation:* <(om *u*)(ex *v*)(*uR*v)>[5], where “om” and “ex” are the meta-linguistic symbols, respectively for the universal “∀” and existential quantifier “∃” symbols of the object-language, we can discuss also the particular *Euclidean relation* that can be described in a Kripke frame.
The Euclidean property generally in mathematics means a weaker form of the transitive property (that is, if one element of a set has the same relation with other two, these two have the same relation with each other). I.e.,<(om *u*) (om *v*) (om *w*) (*uR*v et *uRw* ⇒ v*R*w)> :




(4a)

Where *et* is the meta-symbol for the logical symbol “∧”.

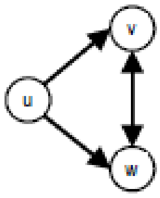
Hence, for seriality, it is true also <(om *u*)(om *v*) (*uRv*⇒*vRv*)>:




(4b)

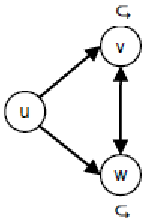
Moreover, <(om *u*) (om *v*) (om *w*) (*uRv* et *uRw* ⇒ *vRw* et *wRv*)>:

[5] For ontological applications it is to be remembered that seriality means in ontology that the causal chain is always closed, as it is requested in physics by the first principle of thermodynamics, and in metaphysics by the notion of a first cause of everything.



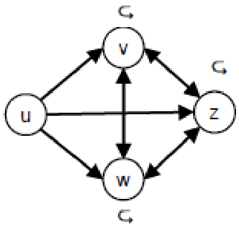

(4c)

Finally, if we see at the last two steps, we are able to justify, via the Euclidean relation, a set of *secondary* reflexive and symmetrical relations, so that we have the final frame of a *secondary equivalence* relation among worlds (*v*, w) based on their Euclidean relation with a further one (*u*):




(4d)

Of course, this procedure of constitution of an *equivalence* (=logical) *relation* among worlds, *by a transitive and serial* (=causal) relation that another world has with each of them, can be iterated indefinitely for as many elements of the equivalence class so constituted, as we want:




(5)

If we compare the frame (3), that is a graphic representation in a Kripke formalism of the modal system **KT45 (S5)**[6]**,** with the frame (5), that is a graphic representation in a Kripke formalism of the modal system **KD45,** we understand immediately why, on the basis of the precedent derivation, this latter is named also **Secondary S5**. In fact, the right part of the frame (5), i.e. the sub-set {*v*,*w*,*z*}, is nothing but a **S5** constituted by the transitive and serial accessibility relation of {*u*} with each of these elements.

We will see how this modal scheme, when applied in formal ontology of quantum systems, on one side (see below §2.5.3), and of cognitive systems, on the other one, can clarify some essential foundational aspects of both.

#### 1.1.5 PHILOSOPHICAL LOGIC AND FORMAL ONTOLOGY

From the standpoint of linguistic analysis, any ordinary language can be considered as an *implicit ontology* of the human group using it. Any ordinary language, indeed, makes able its users to communicate efficiently, and hence to interact effectively among them, and with the particular sector of reality all of them share. The philosophical ontologies of the different peoples are thus only a systematization of the implicit ontologies hidden in their own ordinary languages.

[6] In fact it is immediately evident that all the possible worlds of a given Universe *U* (or Multiverse *M*) constitute one only equivalence class, for the very same set of laws. For this reason, if, on one side, **S5** constitutes, from the logical the only formal system of the modal logic

This brings us immediately to understand the notion of *formal ontology*. Effectively, the contemporary notion of "formal ontology", as distinguished from "formal logic", is derived from Edmund Husserl research and teaching. Indeed, in his "Third Logical Research" (Husserl, 1913/21), he distinguishes between:

1. *Ontology* as a discipline studying relationships between *things* (like "objects and properties", "parts and wholes", "relations and collections, etc.); and
2. *Logic* as a discipline studying relationships among *truths* (come "consistency", "validity", "conjunction", "disjunction", etc.).

On the other hand, Husserl continues, both disciplines are *formal* in the sense that they are "domain independent". So, for instance, for the formal structure "part-whole" in ontology, there are no limitations for the type of objects that might satisfy such a relation, just like for the formal relation of "conjunction" in logic ("and", "$\wedge$" of the logical calculus), there are no limitations for the type of propositions that can be connected in such a way (Smith, 2005). Husserl and his school developed the formal ontology analysis using the phenomenological method. Today, however, in the scientific and philosophical realm, when we speak about formal ontology, we intend generally the "formalized ontology", i.e., the formal ontology developed according to the axiomatic method, using the formal means of modal and philosophical logic.

In fact, the main ontologies of whichever philosophy can be formalized like as many *theories of predication — nominalism, conceptualism, realism* —, and/or like as many *theories of universals*, where by "universal" — as distinguished from "class" or "set" — we intend "what can be predicated of a name", according to Aristotle's classical definition (*De Interpretatione,* 17a39).

Finally, from the standpoint of the predicate logic supposed by each ontology, it is evident that all the nominalist ontologies suppose only a *first order* predicate logic, since in such ontologies it is forbidden to quantify on predicate symbols. The predicates, indeed, in nominalism cannot denote anything: the "universals" do not exist at all in such ontologies. There exist only individuals: universals are only linguistic conventions. Then, they cannot be arguments of any higher order predicate symbols. If in some case they admit higher order predicate symbols, this is only in a *substitutional* sense — , i.e., in the sense of a linguistic, conventional, shortened second order formula instead of many first order true propositions —, without any extra-linguistic referential meaning. In this sense, nominalist ontologies are very similar to empirical sciences, because both share some form of exclusiveness to the only first order predicate calculus.

On the contrary, the other types of possible ontologies use also the predicate logic of, at least, the *second order,* because they admit, even though in different senses, the existence of the universals, so to make possible the quantification on predicate variables. Following Cocchiarella (Cocchiarella, 2007) and other my papers on the same argument (Basti, 2007; 2011), we can thus distinguish among at least three types of ontology, with the last one subdivided into two others:

1. *Nominalism***:** the predicable universals are reduced to the predicative expressions of a given language that, *by its conventional rules* are determining the truth conditions of the use of these expressions (Sophists, Quine).
2. *Conceptualism:* the predicable universals are expressions of *mental concepts* determining the truth conditions of the use of these expressions (Kant, Husserl).
3. *Realism:* the predicable universals are expressions of *properties and relations* existing independently of linguistic and mental capacities in:
   c. *The logical realm,* we have thus the ontologies of the so-called *logical realism,* where the *logical relations* are determining the truth conditions (Plato, Frege, …)[7];
      d. *The physical world,* we have thus the ontologies of the so-called *natural realism,* where *real (causal) relations* are determining the truth conditions. On its turn naturalsm can be of two types:
         - *Atomist naturalism:* without natural kinds (Democritus, Wittengstein,…)
         - *Modal naturalism:* with natural kinds (Aristotle, Kripke,…)

[7] A recent example of a formal ontology of the logical realism can be found in the book of Uwe Meixner (Meixner, 2010). Of the same author, see also (Meixner, 2007).

Where the principal difference between these two types of naturalism is that the second one is able to distinguish between different modalities of existence — *actual* and *virtual* — of the natural beings and properties, both *causally* (not logically) founded. It is thus able to distinguish also between different modalities of predication (*contingent* (i.e., true for some possible worlds only) and *necessary* (i.e., true for all possible worlds)), so to be able to distinguishing respectively between, natural *properties* and natural *kinds* predication.

Another fundamental distinction between *formal logic* and *formal ontology* is related with the three levels at which a semiotic and hence a logical analysis of languages can be developed. Following the classic distinction made by Charles Sanders Peirce (1839-1914) the *meaning* (as distinct from *reference*) of a linguistic expression can be made according to three classes of relations:

1. *Syntactic analysis:* study of the meaning of a linguistic expression/formula as depending on the relations among the different parts of a given language. This brings to a *coherence analysis* of the linguistic expressions with the syntactic rules determining which are the not meaningless expressions of such a language. Logically, the coherence analysis can be finally intended as *conformity to metalinguistic logical laws (tautologies,* hence true in all possible worlds*)*, as distinct from *logical rules,* internal to each different language-object, and hence true in some possible worlds only. This is the proper field of analysis of the *formal logic.*
2. *Semantic analysis:* study of the meaning of a linguistic expression/formula as depending on the relations of a linguistic expression with its *intra-/extra-linguistic contents*. Logically, the semantic analysis consists in the analysis of *truth* of a given linguistic expression *as conformity to the state of affairs* (in science, as expressed in measurement statements) to which the linguistic expression is supposed to refer. This is the proper field of analysis of the *material logic* or, in modern terms, of the *model theory*.
3. *Pragmatic analysis:* study of the meaning of a linguistic expression/formula as depending on the relations with the *agents of the communication process* in which such an expression is used. Logically, the pragmatic analysis consists in the analysis of the *effectiveness* of a linguistic expression/formula in changing the behavior of the communication agents in a given linguistic context[8].

    e. *Classically*, this is the proper field of analysis of *linguistic* and *semiotic* disciplines, such as rhetoric, dialectics, esthetics, etc.

    f. *Today*, however, starting from the pioneering works of J. Piaget's genetic epistemology interpreting cognition as an "action internalization" (Piaget, 1952; Piaget & Inhelder, 1977), and of J. L. Austin theory of "linguistic acts" (Austin, 1975), the pragmatic analysis acquired an ever growing philosophical relevance in the study of the biological and hence neurophysiological foundations of cognitive, social, and linguistic behaviors in animals and humans (Edelman, 2004; 2007; Deacon, 2007; 2008).

    g. Finally, as far as the pragmatic relations can be rigorously formalized in a particular branch of predicate logic, i.e., the *logic of relations* and, more precisely, in the *modal logic of relations,* the formal pragmatics is, before all, a constitutive component, in the *intensional interpretations of modal logic,* of *formal ontology* (Cocchiarella, 2001; 2007; Basti, 2007). Moreover, in the *extensional (algebraic) interpretations of modal logic* (Blackburn, De Rijke, & Venema, Modal logic. Cambridge tracts in theoretical computer science, 2010), it is today a constitutive component of *theoretical computer science,* as far as it is based on the notion of *computational, natural or artificial agents* ("natural computation", "morphological computing", etc.) (Dodig-Crnkovic, The Info-computational Nature of Morphological Computing, 2012). In fact, in the modal logic of relations, not only the *logical* (linguistic)

[8] E.g., the pragmatic meaning of the expression "what a beautiful day" is completely different in a sunny day for the tourist in vacation at the seaside (it means happiness, because he can finally take a bath into the sea), for a countryman (it means sadness, because he has to work), and finally for a supporter of a given soccer team. For him, it is a beautiful day, also if it is raining, but on that day, his team won an important match.

relations, but also the *ontological* (causal) and the *algebraic* (mathematical) relations, as well as their *mutual relations* in any communication context, can be formalized.

To sum up, the *formal logic* limits necessarily its analysis to the only *syntactic* and the *semantic* components of meaning because it is considering the linguistic expressions like as many logical representations of the referential, extra-linguistic object. In this way, it cannot solve in principle the problem of extra-linguistic *reference* to object of a whichever linguistic representation of it, because it is finally obliged to deal with the reference problem in terms of the Fregean *descriptive theory of reference* (Salmon, 2005), so to condemn the formal languages to the *methodological solipsism,* both from the semantic (Carnap R. , 1936) and from the epistemological standpoints (Fodor, 1980). It is evident thus why, for the classical analytic philosophy the *realism* and hence the ontology became a question of faith and not of reason, before the actual ontological revival (Kripke, 1980; Cocchiarella, 2007; Basti, 2007; Meixner, 2010; Ferraris, 2012). To it, finally, also Hilary Putnam converted himself, at the end of a philosophical parable in which he practically visited any epistemological position (Putnam, 2012).

In fact, what characterizes formal ontology is its capability of analyzing the language meaning not only with respect to the syntactic and semantic components like the formal logic, but also with respect to the *pragmatic* one. This allows formal ontology to interpret the linguistic expressions/formulas in terms of as many *linguistic acts* by which the linguistic agents interact with the real (causal) world, and to deal with the problem of reference in terms of the so called *causal* or *"direct"* theory of reference (see (Donnellan, 1966), (Kaplan, 1978), (Putnam, 1975), (Kripke, 1980). and (Salmon, 2005) for a critical review). In fact, it is well known since Aquinas analysis of the reference problem in the Middle Age, but also from Russell's and Whithead's analysis of the *reference relation R* in their *Principia Mathematica,* that *R* is an *asymmetric relationship* between the referring linguistic symbol/proposition *x* and the referential object *y*, i.e., $xRy \neq yRx$. The main problem of any causal theory of reference[9], overall in its Kripke's, most famous version, is that it is based on a direct, causal relationship between a proper name and its referential, individual object through an ostensive/perceptual definition. In this way, Kripke defines the proper names as *rigid designators.* The problem is that in such an approach it is difficult to justify the rigidity of designation in different contexts (the so called problem of "trans-world identity") — as well as, it is impossible to apply this analysis to not-human communication/computational agents.

This problem can be solved in principle, if we justify the designation function, as based on a direct causal relationship, not with names, but with the *constitution of the definite descriptions* (=propositions) for which the names stand for. A constitution based on the principle of the *double saturation* between an argument and its predicate, as we see below, using the formal tools of modal logic, in a case in which classical mathematical logic, because of Gödel theorems, is destined to fail. Anyway, what distinguishes the formal ontology from the formal extensional logic is that the first one distinguishes among *different senses of the notion of being*, i.e., it belongs to the realm of *intensional* logics.

That is, while the formal extensional logic reduces the being at the only copula of a predicative expression — namely, it reduces the being to the simple *relation of membership* (the "existing" of *x*, of the existential quantification in a predicative formula denotes the non-contradictory membership in a given formal language of *x* to a non-void class (set), i.e.: $\exists xPx \Leftrightarrow x \in \mathbf{P}$) —, the formal ontology maintains the ordinary language distinction between the being of the predicative relation (the "being of essence" of the classical ontology) from the "being of existence". Moreover, as to the being of existence the formal ontology is able to distinguish three different senses, that, following Cocchiarella, we can synthesize as following:

4. $\{\exists x, \exists F; \forall x, \forall F\}$: what *can exist* (*potentia esse*, "being potentially"), but does not exist *actually*. E.g., past/future beings *x* and/or properties *F* that exist as to a *thinking self* (logical beings,

[9] I.e., a reference theory i.e., interpreting the opposite relation from the object to the referring symbol/proposition as a *causal relation* with the linguistic agent producing it.

fictional beings, etc.) and/or as to *a natural concurrence of circumstances (causes)* (natural beings, natural properties, natural kinds, etc.).

5. $\{\exists^e x, \forall^e x; \exists^e F, \forall^e F\}$: what exists *actually*, as a generic individual *x* and/or as a property *F* in one or more individual *x*.
6. $E!(a) := (\exists^e y)(y = a)$: what *is existing* as a concrete individual *a* and never as a property *F*, or as a generic individual *x* - that is $(\forall^e F)\neg E!(F)$ and $(\forall^e x)\neg E!(x)$. As we see, we are using here the *existence predicate* $E!(a)$, and not the simple existential quantifier $\exists x$. In fact, the existential quantifier, at the first order, can have as its argument only a generic individual *x*, that, as such, is not concretely existing. E.g, what is concretely existing as human individuals are John, Anthony, Luise,… not some generic human individuals, *x, y, z, …*, members of the human kind, who, as such, can be substituted by whichever other individual of the same kind. The existence predicate says much more than the simple existential quantifier!

Anyway, to conclude this part, the formula 3. exemplifies, in a straightforward way, where is the problem of singular predication: the identification between a generic individual *y* and a singular, concrete individual *a*. The same problem underlying Frege's descriptive theory of reference, because requiring, in formal semantics, a higher order a second order complete enumeration of the class to which both *y* and *a* belong, as Tarski theorem remembers us. Such a problem can be avoided only by a causal theory of reference, via the principle of the modal double saturation, as we illustrate below.

### *1.2 Modal naturalism and the ontic notion of information in cosmology and biology*

Finally, for concluding this schematic presentation of formal ontology, we give some hints about the modal naturalism as the proper ontology of the *ontic* notion of information in cosmology and, as we see below, in biology and neuroscience. The *ontic* notion of *information,* considering it as a fundamental physical magnitude, complementary to the other one, the *energy* in the constitution of all natural reality, is based, on one hand, on the notion of wave function decoherence, both at microscopic (QM) and at mesoscopic (statistical mechanics) level. Quantum decoherence, and the related problem of quantum measurement as a particular case of the former, is in fact the physical source of indetermination and hence of *potential* information.

On the other hand, the ontic notion of information is based on the limited *finitary* amount of the *actual* information contained in the whole universe, as a function of its expansion. This *causal* interpretation of information as the physical basis of the mathematical *laws* of physics, and of their evolution in time, is opposed to the other notion of information as a measure of the *ignorance* of the observer, with respect to the microstate of the physical system, considered as perfectly deterministic in itself. If this interpretation is thus consistent with a *conceptualist* ontology of the notion of information, the ontic interpretation is consistent with a *modal naturalistic* ontology of it.

In fact, such an ontology supposes the clear distinction about two types of necessity/possibility in *alethic* logics (for a definition of alethic logics in the realm of intensional logics, see above, note 3). The *ontic* necessity/possibility based on *real (= causal) relations* among things, and the *logical* necessity of *laws*, norming the relations of *logical* and not *real* objects — the Middle Age Scholastic philosophy defined these logical relations as "relations of reason", as opposed to "causes" defined as "real relations", i.e., relations among things. Of course, the former cause-like necessity is the real foundation of the latter law-like necessity, in the case of physical laws.

In fact, the information determining the real, causal relation among things, is the same determining the logical relation among objects in the mind, denoting such things: this is the informational basis of the *conceptual natural realism* characterizing epistemologically the modal naturalist ontology.

It is thus possible to distinguish in the modal naturalist ontology a *double signification*, "real" or "natural" and "conceptual" or "logical", of the same predicate, that, following Cocchiarella, can be symbolically translated into a *double indexing* of the predicative quantifiers — i.e., of the quantifiers having as their arguments the same predicate variables, respectively in their real or logical use:

7. $\left(\forall F^j\right)\left(\exists x_1\right),\ldots,\left(\exists x_j\right)F\left(x_1,\ldots x_j\right)$: *conceptual* meaning (i.e., the predicate *F* means a concept).

   The quantifiers are without indexes, because the conceptual meaning is the normal case in logic.

8. $\left(\forall^n F^j\right)\lozenge_C\left(\exists^e x_1\right),\ldots,\left(\exists^e x_j\right)F\left(x_1,\ldots x_j\right)$: *natural* meaning (i.e., the predicate $F$ means the natural property. Where: $\forall^n$ means that the predicative variable, argument of the quantifier, is denoting a natural property $F$; $\exists^e$ means that the finite set of individual variables, $x_1, \ldots, x_j$, arguments of the quantifier, are denoting a set of natural beings *actually existing;* and $\lozenge_C$ means that the modal operator of possibility has to be intended in an *alethic-ontic* sense of *causal possibility*, "real" and not "logical".

In other terms, it depends on the proper causal concomitance if the predicate $F$ is saturated by actually existent individuals. For instance, if $F$ is for the predicate "being dinosaur", it is evident that it cannot be satisfied by any actual existent individual, just as, at the time in which it was saturated, some million years ago, the predicate "being lizard" could not be saturated by any existing individuals, while today it is. This does not mean at all that, "in the past" the lizards, like "today" the dinosaurs have no form of biological reality, given that they (the lizards) were, or (the dinosaurs) are, *potentially feasible in the biological reality, through the proper causal concourse.*

On the contrary, this is not the case of mythological animals like "the phoenix", always reviving from its ashes. It never, neither in the past, at present or in the future could be implemented in a matrix of biological causality, but only in the matrix of the *mental causality* (it is a *fictional entity*). In such a case we have thus to index with $M$ the modal operator, i.e. $\lozenge_M$, because it is a mental product and not a of product of physical causes $C$.

Effectively, the ontologies of the modal naturalism, like the Aristotelian ones, have the capability of preserving another ontological ability of Western natural languages. It is the ability of Western natural languages of implicitly distinguishing between *essential predication* (= *natural kind* predication: what an individual *is* in its wholeness), and *accidental predication* (= *property* predication: what an individual *has,* as a character of some its parts). Two predications that, generally, in the Western languages concern, respectively, the predication through *common names* (*sortal names*: implying an only "numerical" distinction among individuals), and the predication through *adjectives*[10]":

9. *Adjective predication* of natural properties: e.g.: "Some plants are green" ($\exists p\ Gp$);
10. *Noun predication* of natural kinds: e.g., "The man is an animal" ($\forall m\ mA$). Were we have to emphasize in the symbolism the inversion between the predicate and its argument ($mA$, "$m$ of $A$", for the natural kinds, *versus* the usual $Gp$ "$G$ of $p$", for the properties), in order to distinguish also formally between the two types of ontological predication, *essential* versus *accidental.*

Of course, both natural kinds and natural properties are effects of a proper texture of physical causes, but with two different modalities, because we have to justify the *natural kind/species conservation* through the succession of the individuals belonging to it. In the modal naturalism, this can be symbolized through a different indexation of the quantifiers of the respective predicate variables: $\forall^k \exists^k$, for the natural kinds $k$, and $\forall^n \exists^n$, for the natural properties.

So, in the modal naturalism, the natural kinds, despite in many Western natural languages are denoted by names like the individuals[11], they have to be interpreted as stable nodes of the natural causes network. For instance, in the case of the biological species, till the causal, genetic (DNA) and environmental (ecological nice), texture is stable, this can grant *the identity in time* of the kind/species through the succession of the individuals. In the case of the physical species of the elementary particles, the different species are represented by the stable nodes of the proper Feynman

[10] To the objection that it is always possible to transform an adjective into a pronoun (e.g., "Anthony is white" into "Anthony is *a* white"), the obvious answer is that in such a way I am giving this property an *essential value.* In the case of our example, it means that I am a racist of the white supremacy. Biologically, I am confusing a race with a species.

[11] This nominal denotation would be the "grammatical" explanation of "Platonism", namely of endowing "essences" (kinds/species) with an individual existence in the logical *formal* realm, like the concrete beings (individuals) of the physical, *material* realm.

diagram for such a species. Symbolically, the different types of predication, can be characterized as follows in modal naturalism:

11. *Identity of individuals,* generically considered, where *A* is a symbol for a natural kind:

$$(\forall^k A)\Diamond_C(\exists^e x)(\exists y A)\ (x{=}y).$$

12. *Causal foundation of the necessity of the essential predication.* The necessity of such a predication is naturally justified because the causal concomitance on which the existence of a concrete individual necessarily depends, is included in the causal concomitance determining the natural kind of which such an individual is a member, and that is common to the other individuals of the same species. In other terms, while the causal concomitance on which an accidental natural property depends, is not necessitating the existence of the individual having it, in the sense that also without such a causal concomitance — and hence without such a property — the individual can continue to exist, the causal concomitance on which the essential properties depend, are *necessary* for the existence of the same individual. Finally, the *ontological* membership to a natural kind, is the real foundation of the *truth* of the logical membership $\in$, to the correpsonding, logical, abstract class. Namely:

$$(\forall^k A)\ (\forall y A)\ \Box_C(E!(a) \to a{=}y \wedge (a \vee y) \in \mathbf{A})$$

Where *A* is the *common (sortal) name* denoting a natural kind, intended as the conjunction of individuals *y* whose existence necessarily depends on a common causal concourse, and **A** is the symbol for the corresponding abstract class, intended as a conjunction of properties abstract definitions that all the members of the class must satisfy. On the contrary, when we want to characterize the inclusion in a natural kind of a biological organism instead of the membership of an inorganic entity, we have to emphasize in the formalism what the contemporary genetics define as the *epigenetic factor.* We deal with this topic below, in § **Errore. L'origine riferimento non è stata trovata.**, where we emphasize, also the essential difference between dual ontology in physics and in biology.

Before dealing with these very recent scientific evidences supporting the dual ontology of physical and biological beings from the empirical standpoint, let us introduce ourselves in the comprehension of the main character of the dual approach to the mind-body problem and hence to anthropology, as distinct from the monist and dualist ones.

# 2 The experimental dual ontology emerging from the actual cosmology

## *2.1 A paradigm change*

It is impossible to speak properly about a dual ontology in philosophy of nature and of science, if it is limited only to living bodies and cognitive agents. A natural ontology, as a general theory of natural beings, must involve necessarily also non-living physical beings, in a cosmological framework. It is well known that today, if, on one side, Quantum Field Theory (QFT) constitutes the fundamental physical theory because of its countless empirical successes – of which the last one is the empirical demonstration of the existence of the Higgs boson –, on the other side, the information-theoretic re-interpretation of Quantum Mechanics (QM) is the emergent one, during the last twenty years. Starting from Richard Feynman's influential speculation that all of physics could be simulated by a quantum computer (Feynman, 1982), and from the famous "it from bit" principle stated by his teacher J. A. Wheeler (see below), the cornerstones of this reinterpretation are D. Deutsch's demonstration of the universality of the Quantum Universal Turing Machine (QTM) (Deutsch, 1985), and overall C. Rovelli's development of a *relational* QM (Rovelli, 1996).
There are, thus, several theoretical versions of the information theoretic approach to QM. It is not important to discuss all of them here (for an updated list, see on this regard (Fields, 2012)), even though two of the principal approaches will be discussed in the next two sub-sections. The first one

is related to a classical "infinitistic" approach to the mathematical physics of information. The second, the emergent one today, is related to the new "finitistic" approach to the *physical mathematics* based on information, taken as a fundamental magnitude.
More recently, in fact, the English physicist and cosmologist Paul Davies, actually at the Arizona State University of Tucson, in the conclusion of his recent paper with the programmatic title *Universe from bit* — inserted in a collective work edited by himself, in collaboration with the Finnish Theologian of Copenaghen University Niels Henrik Gregersen (Davies & Gregersen, 2010) —, announces with enthusiasm the birth of a *scientific ontology* with an empirical and even *experimental* basis[12]. An ontology affirming the *dual* composition of all the physical reality, either physical, or biological, or anthropological, because based on two fundamentals physical *magnitudes*: *matter* (mass-energy) and *information*.
All the other papers of the collection are dedicated to such a *dual*, not dualistic ontology, all dealing with the evidence of the duality matter/information, either from the philosophical (epistemological, and ontological), or scientific (mathematical, physical, biological, neural, and cognitive), or even theological, standpoints. The ample and almost always updated bibliography included in each paper, show us that we are faced with a true paradigm exchange in the foundations of modern science, really impressing for what concerns the *notion and measure of information* in physics and cosmology.
Based on the same evidences are the work recently published by the English physicist Vlatko Vedral, professor of quantum information at Oxford and Singapore universities, and particularly aimed at divulgating this new paradigm, heads the same direction (Vedral, 2010). More recently, a special issue of the journal *Information* (Dodig-Crnkovich, 2012) is completely dedicated to the actual development of this new paradigm in natural sciences, with, among the others, some important contributions of the same Vedral (Vedral, 2012) and of Ch. Field (Fields, 2012), on the information-theoretic approach in QM, as well as of the editor of the issue, Gordana Dodig-Crnkovic. She is a physicist, professor of computer science at the Mälardalen University in Sweden (Dodig-Crnkovich, 2012), and defending in this connection the necessity of a new "philosophy of nature", based on *a naturalistic ontology of information.* This must be related, on one side, to the notion of "natural computation", and on the other side to the Aristotelian tradition of a dual ontology (Dodig-Crnkovic, The Info-computational Nature of Morphological Computing, 2012). This necessity of a new, information-theoretic, philosophy of nature is shared also by one of the most influential representatives of the newborn "philosophy of information", Luciano Floridi (Floridi, 2003), now professor at the University of Oxford, and author of important contributions on the notion and measures of semantic information (Floridi, 2004; Floridi, 2006), as we see immediately below, by discussing the notion of semantic information in biological and cognitive sciences.
To conclude this part with an autobiographical consideration, it is nice to see that some ideas I am defending since thirty years in philosophy of nature and of science are at last emerging from the inside of the most advanced scientific research. On the other hand, however, I hope that less time will be necessary for scientists to understand that a *scientific ontology* - i.e., the "new philosophy of nature", on a dual, Aristotelian basis, depicted by Dodig-Crnkovic – requires a proper *method.* It requires thus a proper *logic and formal apparatus*, able to deal with, not only the great ontological past of classical and modern ages, but also with the logic and formal apparatus of modern sciences, the so-called *mathematical logic*, without confusions between the two methods and hence the two approaches (ontological and mathematical) to the very same reality. What this means effectively, we see immediately, by discussing the complex notion of *information* in contemporary natural and artificial sciences.

[12] Effectively, Davies does not speak about duality. His paper is aimed at vindicating simply the *ontic* nature of information as a fundamental physical magnitude in cosmology and hence in all nature, against the subjective interpretation of it of Leo Szilard, dominating in the last half of the XX century, before the actual development of information physics and cosmology.

### *2.2 The foundation of information as a physical magnitude and the notion of wave function*

The American physicist John Archibald Wheeler of Princeton University[13] was the first to formulate in the 90's of the last century this idea that any physical being is constituted by *energy* and *information.* This idea was expressed synthetically by him with the famous slogan: *it from bit.*

> It from bit. Otherwise put, every 'it' — every particle, every field of force, even the space-time continuum itself — derives its function, its meaning, its very existence entirely — even if in some contexts indirectly — from the apparatus-elicited answers to yes-or-no questions, binary choices, bits. 'It from bit' symbolizes the idea that every item of the physical world has at bottom — a very deep bottom, in most instances — an immaterial source and explanation; that which we call reality arises in the last analysis from the posing of yes–no questions and the registering of equipment-evoked responses; in short, that all things physical are information-theoretic in origin and that this is a participatory universe (Wheeler, Information, physics, quantum: The search for links, 1990, p. 75) (p. 75. See also (Wheeler, Recent thinking about the nature of the physical world: It from bit, 1992)).

Among the theoretical physicists, who offered one of the most intriguing and extreme interpretation framework of this idea was the German physicist Heinz-Dieter Zeh, actually Emeritus Professor at the Heidelberg University in Germany. According to an ontological interpretation of the dual theory that we could define as "neo-Spinozan", through the notion of wave function *decoherence,* he intends to give one only explicative theory of many paradoxes of QM — from the measurement paradox, to the non-locality paradox, to the paradox of the information dissipation in the black holes, to the time-arrow, to the same principles of quantization and indetermination, etc. — by inverting the relationship between classical (general relativity included) and QM.
In such an ontology, the fundamental entity is the unique wave function, so that, from its decoherence in different contexts, all the singular entities constituting the universe, at the microscopic, mesoscopic and macroscopic levels, ourselves included, derive (Zeh, 2010).

The generalization of Wheeler notion of "participation universe" according to Zeh means exactly this, of course according to an "unitary evolution"[14] approach to quantum wave function evolution, originally defended by Von Neumann's ontology to QM, by supposing an actual infinity of information content in the wave function itself, a "Platonic" supposition difficult to be defended in physics. For this reason we define "neo-Spinozan" this approach, perhaps more metaphysical than physical.

Anyway, Zeh approach is precious for giving us an intuitive notion of quantum wave function(s) decoherence. Namely, according to Zeh, the unique wave function can be represented like an ocean wave viewed by a helicopter. It appears like a unique wave propagating itself with many crests. However, for an "observer" on the seaside[15], or for a sheep or for a rock in the ocean (that is, for *localized* systems), the unique wave appears like many separated waves breaking themselves, in succession onto the seaside, onto the sheep bottom, or onto the rocks. The spatio-temporal discreteness of physical beings/events and the same "time-arrow" depend thus on the decoherence of the

[13] Wheeler was one of the most famous physicists of the XX century, teacher at Princeton of some of the greatest theoretical physicists of the second half of the last century — from the Nobel Laureate Richard Feynman, to Kip Thorne, to Jacob Bekenstein, and Hugh Everett. I had the honor of meeting with him may times, before his death in 2008, when he was 96.

[14] It is important to recall here that "unitary evolution" means that the dynamic system concerned is energetically *closed*, without energy exchange with the "outside". It is evident that in the case of the "unitary evolution" of the quantum wave function representing the same evolution of the universe no "outside" is physically possible, but the universe itself in its *wholeness* must be conceived as the "environment" for the wave function *decoherence.* On this self-referential problem implicit in such an approach to quantum information we return (see note 15 and below §2.4.1).

[15] Beyond such a metaphor, for an updated review about the notion of "observer" from inside the formalism of quantum mechanics, and consistent with Von Neumann's, Zeh's, and Tegmark's "unitary" approach to the wave function evolution, see the recent (Fields, 2012).

very same and unique, non-local wave function, into many, particular wave-functions, and/or into many particles — in QM it is possible to represent a quantum system either like a probability wave-function or like a particle, according to N. Bohr's "complementarity principle" — because its interaction with *local environments*.

The existence of the world and that it is appearing to us as composed by discrete, separated beings and events, ourselves and the events of our history included, would thus depend on such a decoherence of the unique and continuous wave function that, like Spinoza's unique "substance", is the only reality and everything else is only an accident of it. In fact, we are not "external observers" like in the helicopter metaphor. We too are immersed in the "ocean" we interact with the wave function, and so we see only *local and discrete* waves/particles, just as the observer posed on the seaside of the isle inside the ocean, does not see one only oceanic wave, but many waves breaking on the shore. Anyway, for a deep understanding on the question of the observer in such an approach of the unitary evolution of the quantum wave function see (Fields, 2012).
In any case, in a paper written in 2002 and inserted in the collection for celebrating the 90° birthday of Wheeler (Zeh, 2004), Zeh criticized all the physicists who gave an interpretation only informational of the wave function like Feynman and Wheeler himself. For Zeh, the wave function is a dual reality, an "it" containing in itself, in a non-local way, spatio-temporally ubiquitous, all the information, "bit", and all the energy (matter), which are progressively distributed (dissipated) among the different "it's", events/beings, of the ordinary physics, through the decoherence "mechanism". Such a principle of the unique evolution of the wave function, with an *actual* infinity of information content inside it, is however, difficult to be defended in physics where all is *finite.*

### *2.3 Two ontologies of the notion of information in physics*

Anyway, metaphysical monism apart, Zeh approach is very useful as an introduction to many key-concepts about the quantum foundation of information notion and measure in physics and cosmology. In fact, the notion of *information*, as an "immaterial" physical magnitude, as much fundamental as the *energy* and *mass* notions and measures are, entered into the ordinary practice of the XXI physics. This depends on the exceptional interest that the notion of information has in quantum physics and in quantum computation theory, so that the *information physics* is becoming a branch of the fundamental physics just mechanics, thermodynamics, electrodynamics, and the same quantum physics are.
So, following Davies in his recent review paper on the notion of information in physics we already quoted, *Universe from Bit,* (Davies, 2010), we could say that two are the main ontologies about the notion of information in physics, diffused among the theoretical physicists: a *naturalistic* ontology and a *conceptual* ontology (for the general definition of these type of ontologies, see above §1.2). The first one is more genuinely physical. Both Davies and myself we follow it, together with the great majority of physicists, and generally this position is traced back to Rolf Landauer, who affirmed that "the universe computes in the universe" and not in some Platonic heaven, i.e., according to the ontology of the *logical realism*.

> A point of view, Davies continues, motivated by his insistence that "information is physical". (…) In other words, in a universe limited in resources and time – for example, in a universe subject to the *cosmic information bound*[16] - concepts such as real numbers, infinitely precise parameter values, differentiable

[16] It is a fundamental parameter of the physical universe that can be obtained in many ways. Seth Lloyd, for example, first calculated it starting form the quantum physics hypothesis that the states of matter are fundamentally discrete and form an enumerable set. It is thus possible to calculate approximately how many bits of information whichever volume of the universe can *actually* contain. Because the universe is expanding, but it is anyway *finite*, can be defined an event horizon within the universe itself. Therefore, for the actual universe inside this horizon at the actual time, the *cosmic information bound* is $\approx 10^{122} \approx 2^{400}$ bit. This number has a very elegant physical interpretation, because it is defined by the area of the whole orizon at a given time, divided for the smallest area allowed by quantum discretiziation, the so-called "Planck Area" $\approx 10^{-65}$ $cm^2$, given that in such an area 1 bit at last can be implemented. As Davies rightly sug-

functions and the unitary evolution of the wave function (as in Zeh or in Tegmark approach, we can add) are a fiction: a useful fiction to be sure, but a fiction nevertheless (Davies, 2010, p. 82).

As we see below, by commenting the works of Paul Benioff to whom Davies is here referring, we prefer to speak on this regard about "abstraction" and not about "fiction".
On the contrary, a typical example of a *conceptualist* ontology of the notion and measure of information applied to cosmology is recently given by another student of Wheeler, the Swedish physicist, actually at the MIT of Boston, Max Tegmark (Tegmark, 2011). This ontology of the notions and measurements of entropy and information supposes the existence of an *external observer* with respect to whom the notions and measures of entropy and of information can be justified in their conceptualist non-finitistic interpretation[17]. Of course, it supposes also a non-finitistic approach to the laws of physics, as well as a unitary interpretation of quantum wave evolution, and hence it supposes finally the *actual* existence of infinite universes. A different and *formal* interpretation of the "quantum observer", always in a non-finitistic, information-theoretic approach to QM, is offered by Ch. Fields (Fields, 2012).

### *2.4 An informational, finitistic foundation of the mathematical laws of physics*

#### 2.4.1 "IS PHYSICS LEGISLATED BY COSMOGONY?"

The above question is the title of a visionary paper wrote in 1975 by J. A. Wheeler and C. M. Patton and published in the first volume of a fortunate series of the Oxford University about the quantum gravity (Patton & Wheeler, 1975). In this paragraph, we illustrate how the *ontic* interpretation of information in quantum physics is able to give a positive answer to such a question with some important ontological and epistemological consequences.
Firstly, as Davies rightly emphasizes, what characterizes the *ontic* interpretation of information — the definition is of Davies himself —, i.e. what we connoted as the naturalistic ontology of the notion of information, consists in interpreting it as a *real* physical magnitude. In this sense, that the "observer" as such has no role for the notion of information justification in cosmology. In fact, in cosmology the observer cannot be external to the physical reality but it is necessarily inside it, and hence the only role that the "observer" can have is only because it is a physical system like the other ones, from which the decoherence of quantum wave function, as a physical source of information generation, primarily depends.
Now, according to Davies, the main theoretical consequence of such an ontic interpretation of information that can be connoted as a true change of paradigm in modern science, is the turnaround of the "platonic" relationship, characterizing the Galilean-Newtonian beginning of the modern science[18]:

*Mathematics → Physical Laws → Information*

into the other one, Aristotelian[19], much more powerful for its heuristic power:

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gests such a number is not new at all in physics. It corresponds to $N^{3/2}$, where $N$ is the "Eddington-Dirac number". Moreover, it corresponds also to the actual age of the universe calculated in atomic units. The deep physical and thermodynamical sense of this number is masterfully explained by Davies in the 4.3 section of his paper, and linked to the notion of "olographic universe" of 'tHooft and Susskind, we explain afterward in this paper.

[17] This notion is a generalization in cosmology of the notions and measurements of entropy and information in classical thermodynamics, as measures of the "ignorance" of the observer as to the microscopic state of the observed physical system, supposed as determined in itself with infinite precision. Such a conceptualist interpretation is generally traced back to a classical work of Leo Szilard, published in German on 1929, and re-published in English on 1964, from which it obtained the maximum worldwide diffusion (Szilard, 1964).

[18] Davies himself defines as "Platonic" the ontology of modern mathematical physics at its Galileian-Newtonian beginnings. On the other hand, the famous historian of science, V. Koyré, in his famous "Galileian Studies" defines the modern science, with its method of starting from the mathematic hypotheses to be verified empirically by measurements based on such hypotheses, a sort "empirical verification" of the Platonism, against the Aristotelianism of the Middle Age natural philosophy (See (Koyré, 1939, p. 160ff)).

[19] But Davies does not quote Aristotle, probably because it is not politically correct…

*Information → Mathematics → Physical Laws*

Davies is here referring in particular to a series of publications of the physicist Paul Benioff — especially (Benioff, 2002; 2005); but see also more recent (Benioff, 2007; 2012). He, by working during the last ten years on the foundations of computational physics applied to quantum theory, envisaged a method of *mutual determination* between numbers and physical processes. A. L. Perrone ad myself already defined a similar method during the 90's of last century in a series of publications on the foundations of mathematics, and we applied it mainly to the complex and chaotic systems characterization (Perrone, 1995; Basti & Perrone, 1995; 1996). In fact, it does not matter whether we are working on quantum or classical physics. What matters here is that we are working on probabilistic wave functions, which by their decoherence — interpreted in its more general sense as a sudden reduction of their dimensionality, and hence as a sudden modification of the wave function scale factors — are generating information on a physical basis, without any reference to an external observer.

The approach, interpreted in cosmological sense, consists in reading the universe evolutionary dynamic processes – the "cosmogony" which Wheeler is referring to in his paper of 1975 – like as many "computations". They are performed within the finite resources of the universe itself, on an evolving, discretized space-time, without any reference to the infinity characterizing the mathematical abstract theories, by which humans represent such dynamic processes. The physical spatial-temporal magnitudes, that their mathematical representation interprets as number fields (and/or function spaces), are thus generated by the same physical processes evolving on them, and that on them are defined. All this implies the "turn around" of the relationship between mathematics and physics emphasized by Davies himself, and that we can synthesize into the slogan: from the "mathematical physics", to the "physical mathematics".

Such an U-turn, however, corresponds historically to a recovery of the Aristotelian ontology of numbers. It implies — against the Platonic ontology characterizing the beginning of modern science (see note 18) — the distinction between the "concrete" and finite physical numbers, generated by the physical processes, through the mutual determination of "form" and "matter" ("information" and "energy"), and the "infinite" numbers, abstracted by the human mind from the concrete ones for representing them mathematically.

The basic computational principle in ours, like in Benioff's and Davies' approach, consists thus in what technically can be defined as a *computational coarse graining.* Generically the "coarse graining" consists in the mathematical technique of re-scaling the measure unit on the dimension of the uncertainty resulting from the measurement operation itself. The attribute "computational" emphasizes that such a re-scaling procedure can be easily made recursive and hence automatic, like a sort of "tracking" of the unpredictable variations, by redefining continuously the unit, and hence the number, on the magnitude of the variation itself. At the end, we have a model of the originally unpredictable process, able to reproduce it in the abstract space of our mathematical representation of it.

The finitude both of the "reading" precision, and hence of the "variation" concerned, because of the ultimately discretized nature of the space-time in quantum physics, grants that the convergence between numbers and processes is reached in a computational time that grows only linearly, never exponentially, with the complexity of the process itself.

In this sense, the attribute *computational* means also that every physical process that is mathematically representable — i.e., to which we might associate a mathematical law — can be considered as "producing" the mathematics by which to represent it, through the information (uncertainty) it is "generating".

In this way, Benioff (Benioff, 2002) can express the core of its method, by generalizing it to whichever *abstract* physic-mathematical theory, as far as it can be characterized as a structure defined on the *abstract* complex number field $C$:

> The method consists in replacing $C$ by $C_n$ which is a set of finite string complex rational numbers of length $n$ in some basis (e.g., binary) and then taking the limit $n \rightarrow \infty$. In this way, one starts with physical theories based on

> numbers that are much closer to experimental outcomes and computational finite numbers, than are *C* based theories (p.1829).

In fact, Benioff continues,

> the reality status of system properties depends on a downward descending network of theories, computations, and experiments. The descent terminates at the level of the direct, elementary observations. These require no theory or experiment as they are un-interpreted and directly perceived. The indirectness of the reality status of systems and their properties is measured crudely by the depth of descent between the property statement of interest and the direct elementary, un-interpreted observations of an observer. This can be described very crudely as the number of layers of theory and experiment between the statement of interest and elementary observations. The dependence on size arises because the descent depth, or number of intervening layers, is larger for very small and very large systems than it is for moderate sized systems (p. 1834).

Of course, what is lacking in such a synthesis of Benioff method is that the length of the finite decimal expansion of the rational numbers concerned, at each layer of the hierarchy, is a variable length as a function of the uncertainty "gap" to be fulfilled, on its turn newly finite. Only by a theory of multi-layered dynamic re-scaling, the space $C_n$, defined on rational numbers with a finite, but *variable* decimal expansion, can approximate, for the infinite limit, the space $\mathbb{R}$ of the real numbers of abstract mathematics.

Benioff supposes such a condition of dynamic re-scaling only at the end of the paper here quoted, as an idea still to be implemented in an effective procedure. On the contrary, this condition is already implemented in Perrone's method and it is the key of its computational effectiveness (See (Perrone, 1995)). Such an effectiveness depends on the fact that the same nature, in its multi-layered structure both in space and time (from elementary particles at the beginning of universe to complex structures of the actual universe, humans included), "computes" in such a way, as also Davies and Benioff suggest.

In fact, both of them agree that such a naturalistic approach to the foundation to the mathematical laws of nature and of their evolution as a function of the evolution of the universe itself, might justify what another great theoretical physicist of last century, E. Wigner, defined as "the unreasonable effectiveness of mathematics in the natural sciences" (Wigner, 1960).

#### 2.4.2 An example: an effectively computable method of chaotic dynamics characterization[20]

For understanding the principle of dynamic re-scaling of the support on which a physical process has to be defined so "to generate" the function abstractly representing it *a posteriori*, let us consider, for instance, the case of chaotic dynamics, whose presence is ubiquitous in all physical reality and it is critical, as we see, in biological and neural systems. What the scientific *vulgate* defines as "complex systems", effectively, in the theory of dynamic systems, i.e., in the core of physics, can be defined as "chaotic systems". Generally, the classical method of chaotic dynamics mathematical characterization suggested by I. Procaccia *et al.* (Auerbach, Cvitanovic, Eckmann, Gunaratne, & Procaccia, 1987) consists in approximating it through cycles ever more complex (i.e., with ever higher period). In this way, the characteristic quantities of the dynamics are calculated by expanding them on the values estimated on these long cycles. What is critical is thus the cycle extraction. Procaccia and his collaborators originally suggested to search combinatorially for the recurrences within a given string of the dynamics values. That is, by representing the dynamic system as a time series $x(t)$ in an arbitrarily chosen "embedding" space with dimension $m$ and with a delay time $\tau$ (also it arbitrarily chosen), according to the method of the time delay, we obtain:

$$\dot{\mathbf{x}}(t) = \left(x(t), x(t+\tau), \ldots, x\left(t+[m-1]\cdot\tau\right)\right)$$

[20] For an elementary introduction to the main notions about chaotic systems in the context of linear, non-linear and stochastic dynamic systems, please go to §6, *Appendix: Dynamic and chaotic systems*.

The method is related to the well-known evidence that chaotic orbits are closures of sets of unstable periodic orbits (= pseudo cycles: see Figure 6 in Appendix, §6.3).

That is, in simpler terms, we can represent to ourselves a chaotic dynamics as continuously "jumping" in an unpredictable way among different pseudo-periods of different lengths, i.e., the unstable periodic orbits, whose envelope constitutes the chaotic attractor[21]. However, the combinatorial character of the cycle search makes the classical method computationally not effective, if not for cycles of the lowest periods, insufficient for the chaotic dynamics characterization. For highest period cycles, the calculation, using the classical combinatory method, has to reckon with the "exponential explosion" of the calculation time with the length of the cycle. On the contrary, the method of the mutual redefinition of numbers and processes transforms the search for chaotic pseudo-periodic orbits into a method of synchronization with them, according to a variable delay time $\tau$, continuously redefining itself on the unpredictable "jumps" of the dynamics, without any arbitrary embedding of the time series, and no use of "multistep methods" for the variation of $\tau$, like in the combinatorial method (Perrone, 1995; Perrone, Basti, Messi, Paoluzi, & Picozza, 1995)[22]. That is, given a chaotic dynamics of which we want to extract (and/or to stabilize, and/or to synchronize with) a cyclic point of period *T*, instead of sampling the system at fixed intervals *dt*, we sample it according to a time series defined as following:

$$\begin{aligned} & t_n = t_{n-1} + \tau_n \\ & \quad \text{(g)} \\ & \tau_0 = \varepsilon \ll 1 \end{aligned} \qquad \text{(h)}$$

The new variable time step $\tau_n$ is defined as:

$$\begin{aligned} & \tau_{n+1} = \tau_n \cdot (1+\Lambda)\theta(v) + \tau_{\min}\left[1-\theta(v)\right] \\ & \tau_{\min} = \text{const} \end{aligned}$$

Where:

$$\begin{aligned} & \lambda_i = \frac{1}{\tau_n}\frac{\left|\delta x_i(t_n)\right|}{\left|\delta x_i(t_n-\tau_n)\right|} \quad i = 1,\dots,n \\ & \Lambda = \max_i\left|\lambda_i\right| \\ & v = \sum_i^N \theta(\lambda_i) \\ & \theta(x>0)=1; \quad \theta(x\le 0)=0 \end{aligned}$$

We can easily verify that the new separation

[21] That is while the stable attractor of a linearly oscillating dynamics is constuted by a cycle, i.e., by a closed curve (limit cycle attractor) and/or by a set of closed curves (torus attractor) in the state (phase) space of the dynamics, the attractor of a chaotic system is represented by an envelope of pseudo-cycles, i.e., of cycles not perfectly closed on themselves but closed within a given ε. The dynamics stands on each of them for some transient, jumping among the different pseudo-cycles in a completely unpredictable way. Apparently, the system is random, but effectively it is not so, for the presence of *correlations*, related to the underlying presence of the pseudo-cycles. For understanding all these notions, if not acquainted with theory of dynamic systems, see §6, *Appendix: Dynamic and Chaotic Systems.*

[22] For this reason we are correcting Benioff on the point that it is not sufficient to say that the *n* of his complex rational numbers $C_n$ can grow up to infinity. It is necessary to add that it has to oscillate freely at each computation step – i.e., without fixing one *n*, for instance, and hence varying it by its multiples or sub-multiples, like in the multi-step approximation methods – with the only constraint of matching the anyway *finite* gap between the actual state of the process, and the previous value of *n*.

$$\delta x_i = x_i(t_n) - x_i(t_{n-1})$$

reduces itself below any pre-assigned value in a reliable way.
To conclude, for the chaotic cycle extraction, if we change the previous equation into the following:

$$\delta x_i = x_i(t_n) - x_{\text{target}}$$

with $x_{\text{target}}$ = const, and we search casually a point on the attractor, we can search for which values of time $t$ the previous difference becomes less than an assigned value. In this way we have effectively found *if and where* the point $x_{\text{target}}$ of the attractor is periodic. The search can be made recursive, and we have massive evidence that such a computational agent is able to extract *deterministically* and not *statistically* (like, for instance using the classic Lyapunov method for defining the number of trajectories at each poin of the phase space) *all* the pseudo-periodic orbits of a given chaotic attractor in a time only *linearly* (not *exponentially* like in the classical combinatorial search) growing with the complexity (order) of the cycle.
Effectively, we are able to reconstruct the different cycles with only a percentage of the original points because the method, from another point of view, consists in "moving" a classical "Poincaré section"[23] on the dynamic flow, into the "convergent" direction of the flow itself, so to anticipate its (pseudo-) closure at a given point.
Evidently, the *finitistic,* and hence *computationally effective* way, in which the nature calculates for profiting by the amazing informational richness of a chaotic (complex) dynamics, is related with a similar strategy. In fact, as we see, such a procedure, of the "adaptive sampling" of an unpredictable time series is perfectly implementable, for instance, in a neuron (and/or in a neuron array), characterized by the continuous variation of its threshold. It can be thus defined as a non-linear oscillator able to re-adapt continuously the frequency of its response, and so capable of synchronizing itself, in the limit at each step, on different frequencies of the complex activation waves travelling continuously across the brain. Activation waves implemented into what those neurophysiologists, ignorant of complex signal processing, consider as "background noise" to be filtered, while, on the contrary, it is rich of correlations, i.e., of information, packed in a complex chaotic dynamics. We will see how this hypothesis is effective when applied to the evidence of a massive presence of chaotic dynamics in the brain, so to constitute the only possible physical basis of the complex intentional behavior in animals and humans.
It is thus in this sense, to conclude this part, the attribute *computational* means that every physical process that is mathematically representable — i.e., to which we might associate a mathematical law — can be considered as "producing" the mathematics by which to represent it, through the information (uncertainty as to the previous step, and hence "surprise") it is "generating".

## *2.5 Some cosmological implications of a naturalistic ontology of information*

### 2.5.1 NATURALIST ONTOLOGY OF INFORMATION AND VIRTUALITY OF THE MULTIVERSES

Another success of the naturalist ontology of information in physics has been recently illustrated by George Smoot, who was awarded with the Nobel Pize in 2006 for his studies on the dishomogenities on the "Microwave Cosmic Background Radiation" (MCBR). Such measurements, giving an observational proof of the hypothesis of inflation (the early acceleration of the universe expansion) and of the galaxy formation according to the big-bang hypothesis, inaugurated the new age of the "precision observation cosmology", namely, based not only on mathematical hypotheses, but also on ever more precise measurements able to control the hypotheses. As I wrote elsewhere (Basti,

[23] A Poincaré section, as a method for finding recurrences in a dynamic flow, consists in choosing a point on the dynamic flow and "cutting" in such a point the flow itself with a *fixed* plane perpendicular to it, waiting for the unpredictable time $t$ necessary in order to the flow pass through again ("in the vicinity of": there are only pseudo-cycles) that given point. Because of our method of "tracking" the trajectory "jumping" freely with it, we can "anticipate" the recurrence, so limiting the number of computational points necessary for the cycle reconstruction.

2009), Smoot's discoveries are to XXI cent. cosmology, as Galilei's one are to XVII cent. astronomy. In other terms, with George Smoot discoveries, the cosmology starts to begin fully "a Galilean science", with an observational basis of precision measurements, and not only with a basis of mathematical rigour in the formulation of the hypotheses.

So, G. Smoot, in a series of theoretical papers on the foundation of cosmology, illustrated a series of fascinating hypotheses, open to the experimental control, which all can be derived from a *naturalistic* and not conceptualist interpretation of the notion and measure of information in cosmology. The first one is concerning the hypothesis of the "many universes", that today is too often in the limelight of the sensationalist divulgation distressing the contemporary press on cosmology. In the paper we want here to discuss (Smoot, 2010), the starting point of his treatment is the other hypothesis, much more intriguing than the multiverse one, even though with much less impact for media divulgation, according to which

> Gravity is a macroscopic manifestation of a microscopic quantum theory of space-time, just as the theories of elasticity and hydrodynamics are the macroscopic manifestation of the underlying quantum theory of atoms. The connection of gravitation and thermodynamics is long and deep[24]. The observation that space-time has a temperature for accelerating observers and horizons is direct evidence that there are underlying microscopic degrees of freedom. The equipartition of energy, meaning of temperature, in these modes leads one to anticipate that there is also an entropy associated. When this entropy is maximized on a volume of space-time, then one retrieves the metric of space-time (i.e. the equations of gravity, e.g. GR [General Relativity]). Since the metric satisfies the extremum in entropy on the volume, then the volume integral of the entropy can readily be converted to surface integral, via Gauss's Theorem. This surface integral is simply an integral of the macroscopic entropy flow producing the mean entropy holographic principle (p. 2247). [Square parentheses are mine].

In other terms, the starting hypothesis is the interpretation of gravitation as an *entropic force*. Namely, a force that it is only *apparent* at the macroscopic level, but that is not founded on any *real* physical force at the microscopic level like the quantum ones (electromagnetic, weak and strong), today unified into *one only primitive form of energy,* because of the first experimental conformation of the existence of the Higgs boson .

In short and in some sense, it is like the famous "thermodynamic variables" (heat, pressure, volume) which are only macroscopic manifestations of the very same microscopic phenomenon: the velocity of the constituting particles. So, an entropic force does not suppose any microscopic force field, but it is originated in a system with many degrees of freedom, for its statistical tendency toward an entropy growth. At the equation level, an entropic force is thus defined in terms of an entropy difference[25]. There exist strong evidences of entropic forces, e.g., the elastic force in mechanics, but also

[24] Effectively, it starts with Aristotle who explained the gravitation effect with the common sense equivalent of the energy equipartition principle. That is, the principle according to which "heat prefers the centrifugal direction" for filling all the available space, so to make anisotropic (and hence non geometrical) the physical space of mechanics. In fact, Gailei and Newton after Aristotle, like Democritus before him, made geometrical the space of mechanics by abstracting from heat. So, in the Aristotelian cosmology, because the heater bodies are obviously also the lighter ones, they naturally tend to go toward the higher places (effectively, they take the centrifugal direction in an "earth-centered" universe), while the colder and heavier ones take the opposite centripetal direction, toward the "earth", i.e., the cold center of the universe, in the Aristotelian cosmology, so to create the gravitational effect. Moreover, when, in the Aristotelian physics, we apply the heat property to the study of the motion of the elementary particles constituting the macroscopic bodies, their motion, when heat is involved (and all the forces acting on the elementary particles (the "active-passive qualities" in Aristotelian terms) are ultimately reducible to heat, for this physics), become not predictable from the initial causes (efficient and material causes) of the motion itself (there is then an increasing of disorder, i.e., the "corruption" of a precedent stable state or "bodily form"), so that when the elementary particles, of which any macroscopic body is constituted, find another stable state, we have a generation of information, the unpredictable "eduction from the matter potentiality" of a new "bodily form" of the elementary matter organization. For a synthesis of Aristotle physics, see (Basti, 2002).

[25] On this regard, Smoot quotes two essential recent contribution, of the Indian physicist T. Padamanabhan, and of the Dutch physicist Erick Verlinde, who showed that gravity emerges naturally like an entropic force from the cosmological holographic principle, and is related to the information related to the body position. The core of Verlinde's heuristic argument consists in the evidence that "only a finite number of degrees of freedom are associated with a given spatial volume, as dictated, by the holographic principle. The energy, that is equivalent to the matter, is distributed evenly

other examples in hydrodynamics and bio-physics. From the standpoint of our paper, however, the entropic forces represent an optimal operational version of what is defined as "formal cause" in the dual ontology. It is a "cause" because it is able to produce physical work. It is "formal" because it makes this without violating the equilibrium balance, but simply by a redistribution of the total energy of the system, making available for it some "free energy" for producing work.

Coming back to Smoot recent paper we are discussing, the other two evidences he quoted are both related to the first one: the interpretation of gravity as entropic force. The second one is, thus, the straightforward confirmation of Lloyd's measure of the cosmic information limit already introduced and obtained using the "*holographic* cosmologic principle", so that Lloyd's measure is now a candidate for becoming a further constant of nature, related however to an information measure and not to an energy one like *c* of Einstein or *h* of Planck.

The main steps that, according to Davies, the cosmology performed during the last thirty years, for reaching such a conclusion, are the following (Davies, 2010, p. 78ff.):

1) Stephen Hawking discovery in 1975 that the black holes are not "so black". It is possible, indeed, to associate with them a thermal radiation and hence a temperature that is inversely proportional to their mass – smaller the black hole is, more intense is their temperature. On the other hand, if we are speaking about heat, we are speaking too about entropy and hence information. In 1973, Jacob Bekenstein already defined a possible measurement of entropy that can be associated to a black hole, if it is considered in terms of QM. The fundamental discovery made by Hawking is thus the following. If we apply to the black hole the entropy measure of Bekenstein, that the information dissipated by a black hole is not scaling with its volume – as each of us remembers since high school, it happens in statistical mechanics and thermodynamics of gases at the mesoscopic level – but it is scaling with the *area* delimiting the volume of the black holes, and hence with the surface of its event horizon, calculated in terms of Planck units. More exactly, the entropy *S* associated to a black hole is defined by the following equation:

   $$S = {}^{1}\!/\,4kA$$

   Where *A* is the area of the surface embracing the black hole (its event horizon) calculated in Planck units and *k* is the Bolzman constant. Now, like the gas entropy *S*, defined on the basis of the Shannon relationship as the inverse of the information *I*, i.e. ($S = -I$), can be considered as the information lost on the position and the momentum of each particle composing the gas, so there is an irreversible information loss related to the matter crossing of the surface of the black hole. This surface constitutes indeed an "event horizon" from which no light ray and hence no information can be emitted. Now, on the basis of the Hawking-Bekenstein relationship, the total information that can be associated to the event horizon cannot exceed one quarter of its total area.
2) Afterward, Bekenstein in 1982 demonstrated that this limit holds not only for a black hole, but for the event horizon of whichever physical system whose area is calculated in Planck units.
3) Finally, the Nobel Prize Gerhard 'tHooft (1993) and hence Leonard Susskind (1995), who connected this evidence to the string theory, applied this limit to the area of the *event horizon* enclosing the expanding universe, defining in such a way what has been defined as the principle of the *holographic universe.* In fact, like it is possible, by the holographic technique, to enclose within the bi-dimensional surface of the hologram all the information able to give back a tridimensional image of the object – and this is an evidence well known to

over the degrees of freedom, and thus leads to a temperature. The product of the temperature and the change in entropy due to the displacement of matter is shown to be equal to the work done by the gravitational force. In this way we find that Newton's law of gravity emerges in a surprisingly simple fashion" (Verlinde, 2011, p. 1107). See (Padmanabhan, 2010), quoted by Verlinde himself, for the application of the same idea to the quantum gravitation in cosmology.

everybody, because the holographic images are diffused everywhere now, from bills, to credit and debit cards, etc. –, in a similar way, all the information included in the universe at some given time of its expansion is identical, on the basis of the Hawking-Bekenstein entropy measure, to one quarter of its event horizon. What is amazing is that such a quantity of information so calculated, for the holographic universe at our time, is of the same order ($10^{122}$ bit) of the Lloyd measure we already know. This information measure becomes thus a natural candidate to be elevated to the range of *a new fundamental physical constant,* as many physicists, Davies himself included, suggest.

The second evidence, supporting the work of Smoot we are commenting here, is the ever more strict relationship emerging among *gravitation, thermodynamics,* and *information*. Such a relationship emerged as compelling, always in the last forty years, just discussing the black hole physics, whose existence derived originally – it is important to remember this point – from considerations concerning exclusively the theory of general relativity and its gravitational theory. Only afterwards, because of the discovery of Hawking radiation and of Bekenstein entropy, the strict relationship of the black holes, with the thermodynamics and the information theory started to be studied systematically. In fact there exist several and also deeper evidences of such a relationship:

1. Before all, a series of mathematical evidences, for whose bibliography you can easily refer directly to Smoot paper, *correlating the gravitation force and acceleration to thermodynamics,* and to its principle of the *equipartition of energy*.
2. Secondly, on the basis of the holographic cosmological principle, the idea that all information *actually* contained in the universe might be "encoded" on the bidimensional, cosmological horizon of the events, can be generalized in the following form giving to "the it from bit" of Wheeler a very intriguing interpretation, In Smoot's same words:

> In a larger and more speculative sense, the theory suggests that the entire universe can be seen as a two-dimensional information structure "painted" on the cosmological horizon, such that the three dimensions we observe are only an effective description at macroscopic scales and at low energies.

From this the fundamental conjecture of all this paper derives (Smoot, 2010, p. 2251), namely that

> having all the information of all possible histories and futures of the universe is very convenient and useful for determining the actual events of the universe. *In this case, the multiverse is us*. We take the point of view that classical and even semi-classical space-time is the coarse-grained limit of microscopic structure of this averaged information (p.2251).

It is thus evident that the universe must accelerate its expansion in order to have all the information necessary for the *actual* complex state of it. At the same time, it is possible to answer easily to the obvious objection about how it was possible that the universe was able to contain the past and future information when it was dimensionally "small". The answer is that the information about the *only potential* past and future states of the universe, concerned only the *actual* content of the universe, that at that time was sufficiently "void" of bodies endowed with mass[26]. At the same time, by decelerating its expansion, after having reached a dimension sufficiently large, the consequent growth of entropy implied a growth also of information, just as was growing the number of computations/events necessary for the growth in complexity of the universe itself[27].

In other, ontological terms, the past states of the universe contain only *causally* not *logically* the future states and hence also the actual state of the universe, given that what is required is a mechanism of (actual) *information growth* that, we saw it, is proportional to the growth of the area of the event

[26] For a deep analysis of the necessary *ontological* distinction between *actual* and *potential* physical states for justifying the notion of quantum computation see (Bruno, Capolupo, Kak, Raimondo, & Vitiello, 2011)

[27] We are moving here to a notion of information always related to the inverse of the entropy, but intended this time as a measure of the algorithmic complexity, namely the number of computations necessary to produce a given ordered sequence of "bit". .

horizon containing the universe. This causal interpretation of information generation, of course, makes that the compatible ontology with such a physics is the modal one of the naturalist realism we illustrated in §1.1.3.
Effectively, the causal mechanism of "information generation" used by Smooth is very close to the "eduction of form" of Aristotelian ontology. I semi-formalized it in my textbook of philosophy of nature, as a (partial, both in time and space) stabilization of the unstable states of matter —very intriguingly Aristotle defined matter instability as "being finite and even always different" of the elementary particle motion in the substratum of whichever macroscopic body —, because of a determined causal (efficient) action[28].
In a similar way, from the standpoint of the universe evolution, if we use the analogy with Feynman path integrals, the probability amplitude for each process is given on the summation of all the possible paths weighted with the same probability. At the same time, however, the interference effects after a sufficiently long time, grant that only the contributions deriving from *stationary points of action* produce stories with a significant probability, and in the limit to the *only effective trajectory* defining the spatio-temporal evolution of the quantum system concerned, and hence the *information* necessary for characterizing it.
Now, in a quantum gravitation theory, where the path integrals represent the stories of all possible universes, the thermodynamic mechanism of energy equipartition is what grants the equal weighting of all possible "paths" on the surface of the event horizon, on which they are "causally" encoded. Hence, having within one only "causal container" all the information of all the possible stories of the universe is very convenient for determining the *actual* events of the universe. In this sense, thus, Smoot says that «the multiverse is us».
Without entering here into further technical details that can be found in the paper we are discussing, I want here to recall only some salient points of Smoot's argumentation.
Before all, the spatial-temporal curvature typical of the gravitational effect of masses, according to the general relativity theory, emerges naturally here as a deformation necessary *for maximizing the entropy* in the spatial-temporal region considered, with a given quantity of mass-energy contained in it. This implies, on one hand, that the entropy is inversely proportional to the curvature of the space-time, while the temperature is proportional to it, like in the black holes. In a word, as it is experimentally observed, more the universe is expanding itself, more the entropy grows and the temperature diminishes.
On the other hand, the link so individuated between gravitation, thermodynamics, and information grants us that, if the equipartition principle allows all the stories of the possible universes contribute in the same measure to the overall story and generates the space-time, with the gravitation force inside, nonetheless there exists a mechanism of constructive interference among the probability amplitudes of the stories of the possible universes. Its result is the existence of one only effective story: the story of our actual universe. In G. Smoot words, just at the visionary conclusion of his paper (Smoot, 2010, p. 218),

> We live in the best of all possible worlds because *it is all possible worlds and the only world*. That is how it is written in the big book, the apparent horizon (Italics mine).

[28] See (Basti, 2002, p. 343-49). Synthetically, the mechanism suggested by Aristotle in his third book of *Physics* (*Phys.* III,206a,34) is that, given an aperiodic, indefinite succession of states of the material substratum (consider that, at Aristotle time, Greek mathematicians just did the "schocking" discovery, for the Pytagorean mathematics, of the "irrational numbers") whichever "form" can be educed from this substratum by making "periodic" whichever subset of this indefinite aperiodic succession. So, Aristotle defined this original state of the matter substratum, that is "in potency" to whichever form of the bodies of our ordinary experience, as a *migma* of elements in chaotic motion. In this way, a form can be educed from this substratum, if a subset of the aperiodic sequence is made stable (periodic) by some acting causality from other, more stable bodies (the heavenly bodies in Aristotle cosmology, with their absolutely regular, periodic motions: "slow variables orders fast variables"). In other terms also for Aristotle, like for Perrone-Benioff and for me, nature "calculates" by "truncating" at different finite lenghts, aperiodic, indefinite sequences of digits (**h entelexeia xorizei,** literally, "the form-as-act cuts", Aristotle said on this regard). Evidently, logic is logic and it is not time-dependent…

### 2.5.2 Naturalist ontology of information and entropic acceleration of the universe

A corollary of the just suggested cosmological theory, is illustrated by the same George Smoot and his colleagues in two other papers (Easson, Frampton, & Smoot, 2010; 2011).
Both papers are aimed at illustrating how the two main accelerations of the universe expansion are generated, in the context of the just illustrated cosmological theory, based on the holographic principle, and hence having information as a fundamental magnitude. The first acceleration is related to the hypothesis of the early inflation of the universe expansion after the big-bang. Such an acceleration was supposed around 1920 for justifying the substantial isotropy of the universe expansion, previewed by Friedman-Lemaitre equation – in a word, the actual standard model of big-bang. The observational evidence of such an inflation is the substantial homogeneity of the Cosmic Microwave Background Radiation (CMBR) in which the whole universe is immersed. The second acceleration of the universe expansion, absolutely unexpected from the theoretical standpoint, has been discovered only recently, in 1998, by observing the strange behavior of some groups of Supernovae. Such early observations has been afterward confirmed by a series of other observations/measurements, also on the same CMBR. This further, unexpected acceleration brought physicists to suppose the existence of the so-called “dark-energy” equivalent to more than 70% of the whole energy of the universe.
So, in the second paper we quoted above, Smoot suggested the mathematical hypothesis that it is not necessary to suppose the existence of the dark energy, because the acceleration in the universe expansion could be explained through the increasing of the entropy over the cosmic horizon because of the universe expansion. In fact, such an entropy increasing can originate the action of an *entropic force* in a very similar way to the derivation of gravitation energy from the quantum and thermal fluctuations on the universe horizon, because of the above remembered principle of the energy equipartition.

### 2.5.3 Toward a formal ontology of the naturalistic ontology of information

Both Davies and Smooth emphasize that the limit of the information quantity contained in the actual universe size and that is $\approx 10^{122}$ bit, is concerning the *actual* quantity of information that can be contained in the universe, given its finiteness in size. Within such limits, however, mechanisms such as the decoherence of the wave function in QM, and, more generally, in statistical mechanics — particularly in complex systems stable far from equilibrium (“dissipative structures” in Ilya Prigogine terminology, that are fundamental at the mesoscopic and macroscopic levels of matter organization —, are *potentially infinite* information sources. They are able indeed to produce unpredictable dynamic stabilities (attractors) and hence are able to produce *actual* information, always *finite* in size. Our computational approach to the chaotic dynamics mathematical characterization gives us other evidence in this direction (see above §2.4.2).
For this reason Smoot defines as *causal* the cosmic event horizon, – better the many event horizons of the primeval universe[29] — on which the information of the many possible universes is bi-dimensionally “depicted”, on the basis of the holographic, cosmological principle. To sum up, the information for determining the successive steps of the cosmic evolution is not “contained” on the event horizon like in the memory of our computers, but *in the causal factors able to generate it.* In this sense, the cosmologic evolution “generates” information, on the cosmic scales, like in biology the epigenesis is able to do it in the ontogenesis of a single individual, and in cognitive science each single mental operation is able to do it in the production of an intentional (cognitive and/or behavioral) action, giving a flavor of effectiveness to the ancient metaphors seeing, respectively, the universe as an animal and/or the single human minds like as many “microcosms”. On the notion of information in biological and cognitive sciences we come back, however, in the next session.

[29] Many different event horizons can be supposed, for the different evolution ages of the primeval universe. For a beautiful synthesis of the theoretical and experimental concepts of the contemporary cosmology, see (Cervantes-Cota & Smoot, 2011).

It is evident that such a naturalistic notion of information can be easily formalized within a *modal naturalistic formal ontology* like that depicted above in §1.2, because it supposes a *causal* generation, respectively, of information, of physical laws and hence:

1. Of the different *natural properties F* of physical bodies at different stages of the universe evolution, i.e.:

$$\left(\forall^n F^j\right)\Diamond_C\left(\exists^e x_1\right),\ldots,\left(\exists^e x_j\right)F\left(x_1,\ldots x_j\right)$$

2. Of the different *natural kinds A* of physical bodies at different stages of the universe evolution, i.e.:

$$\left(\forall^k A\right)\Diamond_C\left(\exists^e x\right)\left(\exists yA\right)\left(x=y\right)$$

Both, natural properties and kinds, are thus potentially present in their physical and/or cosmological causes, like in the cosmological event horizon of the cosmology based on the *holographic principle* discussed in the previous paragraph .

Such an ontology of the "informational cosmology" has a natural continuation in the "informational biology", based on the *"epigenetic" generation of biological information*, and hence on an *"informational anthropology"* able to justify *a dual ontology of the psychophysical unity* of human person, against the old, false dichotomy between monistic and dualistic anthropologies.

So, before illustrating these two last points, we add only some words about the main metaphysical consequence of such a dual ontology, based on a clear distinction between "causal necessity" and "logical necessity", where it is the former to give a foundation to the latter, like in Aristotle and Aquinas ontology, and not the other way round, like in the modern Newton and Kant ontology. It is sufficient this Davies quotation (Davies, 2010, p. 71.73):

> Historians of science are well aware that Newton and his contemporaries believed that in doing science they were uncovering the divine plan for the universe in the form of its underlying mathematical order. (…). The fusion of Platonism and monotheism created the powerful orthodox scientific concept of the laws of physics as ideal, infinitely precise, immutable eternal, state-immune, unchanging mathematical forms and relationships that transcend the physical universe and reside in an abstract Platonic heaven beyond space and time.
>
> It seems to me that after three centuries we should consider the possibility that the classical theological/Platonic model of laws is an idealization with little experimental or observational justification. (…) For example, we must allow the asymmetry between laws and states can be incorrect, and reflect on what the consequences might be if the laws depend (at least to some extent) on what happens in the universe: that is, to the actual physical states. Might laws and states co-evolve, in such a way that "our world" is some sort of attractor in the product space of laws and states? (pp. 71-73).

#### 2.5.4 THEOLOGICAL IMPLICATIONS OF SUCH AN ONTOLOGY

The answer both of Davies and of myself to the previous question is of course positive. In fact, I agree, both historically and theoretically, to Davies' approach. What is depressive, however, is that also for him the "theological vision" coincides at all with the neo-Platonic vision of God as the Lawmaker/Demiurge of nature.

Who knows theology is aware that there is an alternative approach to this naïve one. The alternative vision is Aquinas' one, according to which in God's Mind there are neither "ideal numbers", nor "eternal laws", and "pure forms". God, in fact is for Aquinas the theological and hence the Personal implementation for believers, of the metaphysical notion of "First Cause", participating the being to the universe as a whole[30]. In this way, numbers, laws and forms of natural beings – even those ab-

[30] In fact, Aquinas distinguishes the theological notion of God from the metaphysical notion of the "First Cause". While it is necessary to admit the existence of the second one, if we want to give a *real*, not only *logical*, foundation to the existence of the whole universe, the identification of this impersonal, metaphysical "First Cause", with the Personal God Creator of the theology, is not necessary. For this reason, Aquinas speaks about his famous metaphysical proofs for demonstrating, metaphysically, the existence of the First Cause, as simple "*paths* (*viae*) toward the existence of God". In other words, *Aquinas never speaks about "proofs of the existence of God"*, as the vulgate about him pretends. Nobody can be rationally obliged to believe in God: it is contradictory with the same notion of "belief", implying always a personal, and free existential commitment. At the same time, however, nobody is authorized to say that

stracted by the human mind – are *contingent*, because they have in the physical reality and in the interplay of physical causes their foundation. Where the use of capital letters for denoting the First Cause is not for religious motivations, but only for connoting its simultaneous transcendence with respect to the whole chain of the physical causes, of which the First Cause constitutes the ultimate *closure* condition, and hence its *consistency* condition. In this sense, the mathematical laws of physics are *completely immanent* to the history of the physical world, because they are "educed" (not deduced) from the potentiality of matter by the "universal" physical causes acting on such a material substratum (see note 28).
On the other hand, both Davies ( (Davies, 2010) p.66) and before him Wheeler (Patton & Wheeler, 1975), from the standpoint of a cosmology based on QM, are supposing what W. H. Zurek defines as a "foundation axiom", or "axiom 0"[31], of the QM. According to it, the universe constitutes the "ultimate environment" with respect to which all the quantum systems gain their *objective existence* through the decoherence mechanism (Zurek, 2005), apart from any measurement on them, because the same quantum measurement has to be understood as a decoherence phenomenon[32]. On this regard, Davies ( (Davies, Universe from bit, 2010), ibid.) rightly emphasizes that science is not metaphysics, so it has not to go further, and "accepts the physical universe itself, at each instant of time, as the basement level of reality". On this regard, he quotes Bertrand Russell in his famous public debate on the BBC radio with the Jesuit philosopher Fr. Frederick Copleston: "I should say, Russell states, that the universe is just there, and that's all" (Russell, 1957). This position is surely rational for Russell as a representative of the scientific thought – and this is the sense according to which Davies quotes it –, even though it is controversial for Russell as a philosopher, divided between an empiricist ontology in physics, and a platonic ontology in logic and mathematics.
To sum up, the actual evolutionary approach to physical laws, if contradicts any neo-Platonic theology, it is in amazing continuity with the neo-Aristotelian one of Aquinas[33]. Of course, this statement is not politically correct for the actual dominating culture, based on the vision of a sclerotic, self-referential theology, turned in upon itself, and irremediably defeating in front of a triumphing, atheistic science.
Also on this regard, Davies agrees with us, in saying that the metaphysical notion of the "First Cause", like the *real* not *logical* foundation of the same existence of the universe (what for science is a foundation axiom, for a meta-science like metaphysics has to be a theorem), is generally refused by contemporary theology. In fact, according to such a theology, this metaphysical notion "does not bear any resemblance with the traditional notions of God". Evidently, for being "politically correct" believers ought to be today prisoners of the rational and scientific dullness of the traditionalists and of the religious fundamentalists! Here, however, we are fortunately making science and scientific ontology, not politics!
Better, the Aquinas metaphysics is the only one, in the realm of Catholic thought able to reckon with the actual evolutionary cosmology – because of its rigorous logic –, differently from many

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*all* the beliefs in a Creator God are absurd or anti-scientific. Those beliefs about God-Creator, compatible with the notion of the First Cause, and with an evolutionary approach, not only to the existence of different species of natural beings, but also to the existence of the same mathematical laws of nature, are not absurd at all, today much more than yesterday! On this point see the chapter 6 of mine (Basti, Filosofia della Natura e della Scienza. Vol. I: I Fondamenti, 2002).

[31] Generally, in logic and mathematics a theory with a "foundation axiom" means that the other axioms of the theory are not sufficient for founding the existence (in the logical sense) of all the objects constituting the universe *V* of the theory. From this the necessity of another axiom for completing the foundations of the theory, the so called "axiom 0", or "foundation axiom".

[32] It is interesting that Chris Fields, who recently strongly criticizes such an ontology of the objective existence of quantum systems, as previous to any quantum measurement on them, must defend a nominalistic ontology of them, according to which quantum systems exist only "pragmatically", and relatively to "non-Galileian" physical observers, performing measurements on them (Fields, 2012).

[33] In Aquinas terms: "The bodily forms are caused not like if they were borne by some immaterial form, but like from a matter reduced into act by some physical agent that is on its turn composed (by matter and form)" (*Summa Theologiae*, I, 65 4c). See also, *Summa Theologiae*, I, 45, 4c; I, 45, 8c; *Quaestio Disputata De Veritate*, 11, 1c.

other theories of the Christian tradition, more attentive to the homiletic effect on the people, than to the rationality of the theory construct, the only effective for scientists. Moreover, Aquinas theory is compatible also with the hypothesis of the *multiverse*, as far as the other universes are conceived only as *virtually* and not *actually* existing (the only actually existing is ours)[34].
For the same reason, it is compatible even with the hypothesis of the *eternity* of the universe, without contradicting the Christian dogma of the *absolute beginning outside time* of the actual universe. Effectively, the Aquinas metaphysical interpretation of the theological notion of "creation", as *participation of being* to the universe intended as a whole, is perfectly compatible with the metaphysical (not theological) hypothesis of the *eternity of the universe.* In fact, the necessary participation of being from the First Cause to the whole universe, has to be intended as "*outside* any space-time", and as *including causally* whichever universe (and hence whichever space-time), either actual or virtual.
There is a compatibility, indeed, between the metaphysical (and today also physical) hypothesis of the eternity of the universe, and the apparently opposite theological dogma of its absolute beginning – solemnly proclaimed in the Lateran IV Ecumenical Council of 1254, at Aquinas time. Effectively, he developed such reflections on the possible eternity of the universe precisely for commenting this dogma. This compatibility depends on Aquinas elegant ontological demonstration of the logical undecidability of the question of the eternity of the universe[35]. This question is thus destined *to remain hypothetical forever*, like it must be the answer to any formally undecidable problem[36].
In this context, it is thus perfectly logical for a believer to decide for the truth of one of the two horns of the rationally unsolvable dilemma, if he believes that some "revelation" gave him the lacking information, for solving the undecidability. I.e., if some Revelation from God supports the belief in a Personal Nature of the First Cause, Who can thus decide freely for giving start to the universe *not from ever*. In this way, the believer can rationally being convinced of (can believe in) the truth of the Bible statement that our universe had an absolute beginning, outside any physical space-time, without contradicting any scientific or metaphysic truth, that must remain ultimately undecided, and hence hypothetical, on this regard (see (Basti, Filosofia della Natura e della Scienza. Vol. I: I Fondamenti, 2002), chapter VI).
Aquinas so concludes his brilliant argumentations on these topics:

[34] This hypothesis is particularly defended by Thomas in his ontological treatise *Quaestiones Disputatae De Potentia*. In it Aquinas states that the hypothesis of the virtual existence of many universes beside the actual existence of ours – so, in continuity with Smoot's cosmological theory – is related to the impossibility of metaphysically constraining the First Cause action within any sort of logical, lawlike, necessity, since such a Cause is the ultimate ontological foundation of whichever law. Consequently, Aquinas relates theologically such a hypothesis with the Freedom of God Creator, once we admit by faith, the Personal nature of the First Cause. Such a theological foundation of the virtuality of the other worlds is in Modern Age defended by Leibniz, who does not distinguish adequately the metaphysical notion of First Cause from the theological one of God Creator, ingenerating in this way the false, modern identification of these two notions.

[35] This demonstration is as simple as incontestable. It consists in vindicating that any cosmological theory, either physical or metaphysical, must necessarily admit among its primitives the existence of "something" of the universe, object of the theory (e.g., the existence of a chaotic "first matter", even though in the modern form of the so-called "quantum vacuum" (see note 43, p.44), or something similar). Hence, such a theory cannot demonstrate at all, among its theorems, that "before the beginning" of the universe itself, nothing of it existed, included the "something of it" necessarily supposed in the primitives and in the axioms of whichever physical or metaphysical cosmology theory, whichever they could be. So, the *absolute beginning* of the universe "from nothing of it" (*ex nihilo,* even the "quantum vacuum") is an undecidable assert for whichever cosmological theory. On the other hand, an appropriate metaphysical theory can demonstrate the necessity of a *First Cause,* participating the being to the universe (multiverse) as a whole and hence also *from ever* (*ab aeterno*),because this participation is *outside any space-time,* that can be only "internal" to each universe, and hence to the same "multiverse". The statement of an absolute beginning of the universe (multiverse) can be thus only a theological proposition, asserted by faith, even though non-contradicting the reason, because of the logical undecidability of such a proposition for whichever cosmological theory.

[36] We want to recall here that "hypothetic" is a deductive argumentation whose coherence and hence consistency does not depend on the truth of the premises. The opposite is the case of the "apodictic" argumentation (like in the classic Aristotelian deductive syllogisms) whose consistency depends on premise truth.

> Indeed, it is clear that the world leads to the knowledge of the creating divine power, both in the case it has not always existed, and in the case it has: everything that has not always existed was clearly caused, although this is not immediately evident for what has always been (*S. Th.*, 46, 1 ad 7).
>
> The idea that the world had an absolute beginning is hence a matter of faith, but it cannot either be demonstrated or known [through reason]. It is important to consider and think about this, so that someone, seeking to demonstrate what is an object of faith, does not ground such an aspiration in motivations that cannot demonstrate anything, thus opening the way to the mockery by those who do not believe, who could then think that we believe certain things not by faith, but in light of such false motivations" (Thomas Aquinas, *Summa Theologiae*¸ I, 46, 2. Square parentheses are mine).

## 3 Dual ontology and the naturalistic notion of information in biological sciences

### *3.1 From genetics to epigenetics*

Starting from the development of modern genetics – based on the discovery of DNA during the 60's of the last century, and the contemporary initial development of the research program of the so-called *Artificial Intelligence* (AI) in the study of mind in the 50's of the past century –, it has become generally believed that the notion of "form" in biology and psychology, with often an unaware Aristotelian ontological background, can have an "operational" scientific counterpart in the notion of *information exchanges*, embodied in the matter-energy exchanges of the organism and/or of the brain, inside/outside them. This implies that the dual ontology, in a conscious or unconscious way, is today the more used in biological and cognitive sciences, given that there exists no book and no paper, either about biology, or about cognitive science, that does not use the term "information", and any derivate of it, for describing/explaining its object.
An amazing leap forward along to this direction occurred during the last ten years, with the development in biology of the so-called *epigenetics*[37]. This consists in the systematic, theoretical and experimental study about how the higher levels of bodily organization of the individual, during its ontogenetic development, have a feed-back onto the genetic load of its own cells, via bio-chemical, but also electro-magnetic signals (Ventura, et al., 2005) (Maioli, et al., 2011), so to orient the genetic expression of DNA in an absolutely individual way[38]. On the other side, the emission of very low frequency electro-magnetic signals (EMS) by the DNA of some viruses and bacteria, seems to play a decisive role also in terrible diseases like AIDS, generated by the HIV virus DNA continuous recombination, as the Nobel Prize Luc Montagnier first discovered (Montagnier, et al., 2011)[39].

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[37] For an introduction to some main topics of contemporary epigenetics, see the special issue of *Science* 330(2010) with the following papers: (Riddihough & Zahn, 2010; Bonasio, Tu, & Reinberg, 2010; Bourc'his & Voinnet, 2010; Feng, Jacobsen, & Reik, 2010; Chandler, 2010; Halfmann & Lindquist, 2010). See also the more recent review papers, in the Special Section dedicated to computational biology by the same journal in its issue 336(2012), for celebrating the centenary of A. M. Turing birth, and his seminal work on biological *morphogenesis* (Turing A. M., 1952), about the role, the limits and the perspectives of mathematical modeling in genetic and computational biology: (Mogilner, Allard, & Wollman, 2012; Zerbino, Paten, & Haussler, 2012; Munsky, Neuert, & van Oudenaarden, 2012; Morelli, Koichiro, Ares, & Oates, 2012).

[38] It is significant that the most prestigious scientific journals, *Science* and *Nature*, recently launched more specialized journals – respectively, *Science Signaling* and *Nature Genetics* – for dealing exclusively with problems and mechanism of information exchanges at the bio-genetic level, both in individuals, and among individuals of the same species.

[39] Luc Montagnier earned the Nobel Award in 2008 for the discovery of the HIV virus. Montagnier's successive discovery is related to the well-known amazing role that water — constituting more than 70% of our body, where more than 90% of its molecules are water molecules — has for the stability of the double helix structure of the DNA. The interaction of the water molecules through hydrogen bonds is in fact different for each DNA base. Now, Montagnier amazing discovery is that it is sufficient a background electro-magnetic field on only 7Hz, that is natural in human environment, to allow the formation, via a resonance phenomenon with the EMS emitted by DNA sequences (effectively short HIV virus DNA sequences of about 104 base pairs, immersed in highly purified water at a given dilution), of small water molecules nanostructures (20<100 nm). They are able to emit on their own EMS identical to those emitted by the original DNA sequences, so to save and transmit faithfully DNA genetic information. In fact, by adding to the

It is thus on epigenetic signaling mechanisms, both chemical and electromagnetic, that, for instance, the individual specialization of the embryonic and adult stem cells depends, toward the generation of ever more specialized cells, which all have, however, the very same DNA. At the same time, the oncogenic degeneration of cells is certainly due to the interaction of genetic and epigenetic mechanisms, as well as epigenetic factors enter into the formation of prions, some of them become sadly ill-famed, as responsible of the degeneration syndrome of the so-called "crazy cow". Finally, it is now well-proved the influence of epigenetic factors also at the cognitive level, for instance in the generation/degeneration of "long-term memories" in the brain, largely depending on the dynamic interaction of sub-cortical structures, like the hippocampus, and cortical structures, like the frontal lobes. The scientific discoveries and publications on epigenetics are daily multiplying, in testimony we are faced with a new dimension of genetic biology, capable of making finally the biology itself a Galilean (mathematical-experimental) science in any sense, no longer an ideology, like in the recent past.

Guy Riddihough and Laura M. Zahn, in the first paper quoted in the previous note, so answer synthetically the main question "What is epigenetics":

> The cells in a multicellular organism have nominally identical DNA sequences (and therefore the same genetic instruction sets), yet maintain different terminal phenotypes. This non-genetic cellular memory, which records developmental and environmental cues (and alternative cell states in unicellular organisms), is the basis of epi-(above)–genetics. The lack of identified genetic determinants that fully explain the heritability of complex traits, and the inability to pinpoint causative genetic effects in some complex diseases, suggest possible epigenetic explanations for this missing information. This growing interest, along with the desire to understand the "deprogramming" of differentiated cells into pluripotent/totipotent states, has led to "epigenetic" becoming shorthand for many regulatory systems involving DNA methylation, histone modification, nucleosome location, or noncoding RNA. (…) Reprogramming is also critical for developmental phenomena such as imprinting in both plants and mammals, as well as for cell differentiation, and is linked to the establishment of pluripotency in gametes and zygotes (Riddihough & Zahn, 2010, p. 611).

Our theoretical problem for a dual ontology of the human person is thus to understand how to pass from the dual paradigm emerging from QM, and now from QFT, at the *microscopic foundational level* of matter organization, to a *dual ontology of the living matter*. More specifically, a dual ontology of its *self-organizing structures* (organs) *and functions*, and of the same *living bodies* (organisms), as far as they are coherent self-organizing systems of organs and functions, all of them evidently emerging at the *mesoscopic and macroscopic levels* of the matter organization. The starting point is certainly the evidence of the above remembered emission of an electromagnetic field of the living matter, at different levels of its organization.

So, the emerging of more complex structures and functions with reciprocal feed-back among the different levels, like the same collective term of "epigenetic phenomena" emphasizes, is certainly related with interactions related to such electromagnetic fields. A recent review paper demonstrated that not only the existence and the role of these electromagnetic fields in living matter is now universally accepted, but that, only in 2010, more than 30 refereed international research projects were active on these topics all over the world (Cifra, Fields, & Farhadi, 2010). The problem is thus to find a proper dynamic model of all these phenomena, able to integrate them in a coherent framework, to suggest the hypotheses to be experimentally controlled. Since the late 60's of the last century such a framework has been individuated in the Quantum Field Theory (QFT), applied to biological condensed matter, as discuss in the next paragraphs.

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test tube, containing only the water nanostructures, all the single components necessary for synthesizing the DNA through the chain reaction of polymerases, it was possible to obtain an exact copy (at 98% in average, only 2 different nucleotides over 104) of the original DNA sequence. The hypotheses is that such HIV DNA sequences are able to recombine themselves with the receiving lymphocytes in the blood, so to form a complete DNA and to trigger a devastating infection, starting from only few infected cells — in the limit, also one. Of course, such a discovery, also because of its similarity with Jacques Benenviste's hypothesis of "water memory", excited a fierce debate and further studies are required.

## *3.2 Quantum Field Theory (QFT) of dissipative structures in physical and biological systems*

### 3.2.1 "COHERENT STATES AND COHERENT DOMAINS IN THE PHYSICS OF THE LIVING MATTER"

The title of this sub-session is between quotation marks because effectively is the title of a recent review paper of the Italian physicist, Giuseppe Vitiello, from the University of Salerno (Vitiello G. , 2010). It synthesizes more than thirty years of research in the QFT widely and universally applied to the study of coherence phenomena in the condensed matter, and extended to the study also of Thermal Field (TF) of physical dissipative systems, the biological systems and the brain — the "dissipative brain", according to his very effective expression — included. To this paper we refer, also for a fundamental bibliography on this argument, that has becoming ever wider during the last years.

The great value of this approach is that it aims at completing the panorama of molecular biology and of its countless successes in the comprehension of the *microscopic* structures of biological systems at the cellular and subcellular level, all related to the *statistical and probabilistic* methods and to the laws of *molecular kinetics*. These methods, however, are not able in principle to reckon with the "systemic phenomena" of *biological processes* emerging at the *mesoscopic* and *macroscopic* level, all related to the emergence of "coherence" *dynamic* phenomena. These are very complex because related to the self-organizing *dynamic* processes of *temporal ordering* — such as, for instance, the strict chaining of specific chemical reactions — and of *spatial ordering.* Examples of this type of ordering are, for instance, the coordination of cells in tissues, at level of structures, or, at level of the functional coordination, the individual self-organization of the immunity system. In Vitiello's terms:

> The great challenge that modern molecular biology is not yet able to answer, consists in the emerging of complex, macroscopic functional properties of the microscopic biochemical activity, ruled by the probabilistic laws of the molecular kinetics ( (Vitiello G. , 2010), p. 14).

To use an expressive metaphor of another Italian physicist, researcher in bio-physics and colleague of Vitiello, the tremendous and successful effort of the bio-molecular research of individuating at cellular and sub-cellular level all the microscopic structures of living matter is like to pretend to understand the social structure of a city by completing its phone directory. Even if it was complete, such a list alone could not be sufficient for understanding the dynamic coherence of the mesoscopic and macroscopic structures and functions of the living matter. The start point of QFT approach to living systems consists thus in the threefold evidence, the first two being expressions of commonsense evidence, according to which:

1. The biological systems are *open systems*, in continuous exchange of matter-energy with the external environment. In other terms, they are *dissipative systems* with energy *balance* as necessary condition for avoiding stress conditions.
2. All the macromolecules (proteins) constituting the living systems *become biologically active only if immersed in a water matrix*, an evidence that is not only immediate for whichever biology student ever entered a biology lab, but to everybody who knows the immediate negative effects of dehydration.
3. The strict link between water and living matter depends on the fact that both water molecules (constituting almost the 70% of the living body weight, and more than the 80% of its molecular weight)[40], and all the macromolecules of the living matter are endowed with the electrical dipole momentum. That is, because their asymmetric structure, they present a spatial distribution of electrical charge, with a positive and negative pole: they are "polar molecules" (see Figure 1).

[40] Emilio Del Giudice, an Italian physicist who devoted the most part of his research to the study of the water electrodynamics properties, likes to joke saying that water is like the "dark energy/matter" in the biological sciences. Despite both, dark energy/matter and water, constitute almost 90%, respectively of the cosmologic matter and of the biological molecules, their properties are almost completely unknown, both in cosmology and in biology.

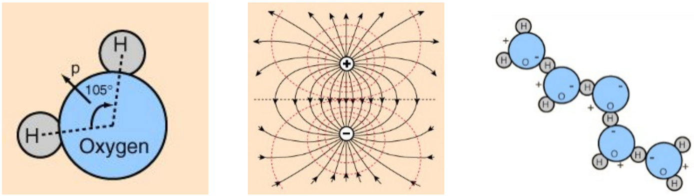


**Figure 1. (Left) Asymmetric structure of the water molecule with the direction of the dipole momentum *p* pointing toward the more positive H atoms, that creates a positive charge. (Center) The electric potential of a dipole (black lines) show a mirror symmetry about the center point of the dipole. The dipole electric field lines are everywhere perpendicular to the electric field lines (dotted red lines). (Right) Water molecular bond is depending on the dipole momentum, because of the asymmetric distribution of the dipole charges in each molecule. From it, depends a lot of typical water properties. For instance, the property of the surface water film (e.g., on the spherical surface of a drop of water), because the water molecules of the surface, not having other molecules over them, have a reciprocal molecular bond stronger than the lower ones. (Images are from the item "Electric Dipole" in the educational site "Hyperphysics", hosted by the Dept. of Physics and Astronomy at the Georgia State University: http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html).**

If we limit ourselves to the statistical methods of molecular kinetics, we are able to discover a lot of chemical properties of living matter at the microscopic level, related to the presence of water and to its properties, all depending on its dipole momentum, justifying the definition of the water itself as "solvent of life" (see (Hill & Kolb, 2001), ch. 13).

> Water serves as the solvent for sodium chloride (salt) and other substances so that the fluids of our bodies are similar to sea water. This leads Hill and Kolb (Hill & Kolb, 2001) to refer jokingly to us as "walking bags of sea water". Water, for instance, serves to suspend the red blood cells to carry oxygen to the cells. It is the solvent for the electrolytes and nutrients needed by the cells, and also the solvent to carry waste material away from the cells.
> With water as the solvent, osmotic pressure acts to transport the needed water into cells. With cells bathed in the interstitial fluid, diffusion contributes to carrying needed molecules into the cells. When more complex mechanisms control the transport of molecules across the membranes into and out of cells, the presence of water as the surrounding medium and solvent is essential[41].

However, to justify the most pretentious connotation of water as "the matrix of life" given by the Nobel Laureate A. Szent-Gyorgyi, to whom Vitiello and his colleagues implicitly are referring, much more is required. It is necessary a *dynamic,* approach to atoms and molecules binding, in their interaction with the electromagnetic field, justifying coherently a scale change, from the microscopic one, to the mesoscopic and macroscopic scales, where the more complex life structure and functions are given.
The first step in this approach consisted in the extension of the well founded formalism of QFT in the study of coherent states of condensed matter, also to living matter. In it, scholars are following, before all, the original intuitions of H. Frölich model (Frölich, Long range coherence and energy storage in biological systems, 1968; Frölich, Biological coherence and response to external stimuli, 1988), developed by the researches of another pioneer in this field, F. A. Popp, who first coined the evocative term of "biophotons" for denoting the electromagnetic emissions of the living matter (Popp & Yan, 2002; Yan, et al., 2005). In QFT, the biological system is described through *a macroscopic variable*, identified with the *density of electric polarization* of the biomolecules and of the water molecules. QFT is a well-established theory, amply confirmed by experimentation, describing with higher accuracy, atoms, molecules, and their interactions with the electromagnetic field.
The most interesting aspect of the Frölich model consists thus in the possibility that *long-range coherence phenomena* emerge as dynamic effects in the biological matter.

[41] For such a synthesis, we are referring to the item "Water, the solvent for life" on the educational site "Hyperphysics", hosted by the Dept. of Physics and Astronomy of the Georgia State University: http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html

This means that quantum dynamics generates among the elementary components (the electric dipoles of water and of biomolecules controlling the inter-molecular binding) large-scale correlations ("large" as to the characteristic dimensions of the components, and hence till some hundreds of micron): in such a way we have "in-phase", i.e., *coherent,* motions and oscillations.
The elementary components are thus correlated, and assume a "collective" behavior characterizing their "whole" as such. We are faced, in such a way, with a *transition from the microscopic scale* of the elementary components and of their properties to the *macroscopic scale* characterized by coherence properties that can be no longer attributed to the single components, but to the system itself ( (Vitiello G. , Stati coerenti e domini coerenti della fisica del vivente (Coherent states and coherent domains of the physics of the living matter), 2010) p. 14).

### 3.2.2 ORDER AND SYMMETRY BREAKDOWN IN CONDENSED MATTER

*Crystals*, are, for instance, typical examples of successful applications of QFT in the realm of non-living, condensed, matter, that is in systems displaying at the macroscopic level an high degree of coherence related to an *order parameter* different from the density of electric polarization proposed by the Frölich model for the living matter. In crystals, the "order parameter", that is the macroscopic variable characterizing the new emerging level of matter organization, is related to the *matter density distribution*. In fact, in a crystal, the atoms (or the molecules) are "ordered" in well-defined positions, according to a *periodicity law* individuating the crystal lattice.
Other examples of such ordered systems, in the non-living realm, are the magnets, the lasers, the super-conductors, etc. In all these systems the emerging properties related to the respective order parameters, are neither the properties of the elementary constituents, nor their "summation", but new properties depending on *the modes in which they are organized*, and hence on *the dynamics controlling their interactions.* In this way, at each new macroscopic structure, such a crystal, a magnet or a laser, corresponds a new "function", the "crystal function", the "magnet function", etc. Moreover, all these emerging structures and functions are controlled by *dynamic parameters*, that, with an engineering terminology, we can define as *control parameters.* Changing one of them, the elements can be subject to different dynamics with different collective properties, and hence with different collective behaviors and functions. Generally, the temperature is the most important of them. For instance, crystals beyond a given critical temperature — that is different for the different materials — lose their crystal ordering, and the elements acquire as a whole the macroscopic structure-functions of an amorphous solid, or, for higher temperatures they lose any static structure, acquiring the behavior-function of a gas.
In the case of a magnet, the dynamic constraint from which the order parameter emerges, is the prevailing orientation of the *magnetic (not electric) dipole* of the electrons, according to the direction to which the magnetization vector is pointing. To the magnet order is thus associated the *information* of a direction — e.g., that of the magnetic needle of a compass. Over the critical temperature, also the magnet ordering get lost, since the electrons are free to orient their magnetic dipole in whichever direction. The system so recovers its most symmetrical state in which all the directions are equivalent as to the whole, i.e., they can interchange among each other, without affecting the properties of the whole. In other terms, the elements lose their correlation, their dynamic ordering, as well as the information related to such an ordering.
So, any process of *dynamic ordering*, and of *information gain*, is related with a process of *symmetry breakdown.* In the magnet case, the "broken symmetry" is the rotational symmetry of the magnetic dipole of the electrons, and the "magnetization" consists in the correlation among all (most) electrons, so that they all "choose", among all the directions, that one proper of the magnetization vector.
Finally, whichever dynamic ordering among many objects implies an "order relation", i.e., a *correlation* among them. What, in QFT, at the *mesoscopic/macroscopic* level is denoted as *correlation waves* among molecular structures and their chemical interactions, at the *microscopic* level any correlation, and more generally any interaction, is mediated by *quantum correlation particles.* They are called "Goldstone bosons" or "Nambu-Goldstone bosons" (Nambu, 1960; Goldstone J. , 1961; Goldstone, Salam, & Weinberg, 1962), with mass — even though always very small (if the sym-

metry is not perfect in finite spaces) —, or *without mass at all* (if symmetry is perfect, in the abstract infinite space). Less is the inertia (mass) of the correlation quantum, greater is the distance on which it can propagate, and hence the distance on which the correlation (and the ordering relation) constitutes itself.

### 3.2.3 MACROSCOPIC STRUCTURES AND FUNCTIONS IN LIVING MATTER

However, an important *caveat* has immediately to be made about the different role of the "Goldstone bosons" as quantum correlation particles, and the "bosons" of the different energy fields of quantum physics (QED and QCD). These latter are the so-called *gauge bosons* (see Figure 2): the photons $\gamma$ of electromagnetic field; the gluons $g$ of the strong field, the bosons $W^{\pm}$ and the boson $Z$ of the electroweak field; and the scalar Higgs boson $H^0$ of the Higgs field, common to all the precedent ones. The gauge bosons are properly mediators of the *energy exchanges*, among the interacting elements they correlate, because they are effectively quanta of the energy field they mediate (e.g., the photon is the quantum of the electromagnetic field). So, the energy quanta are bosons able to change the *energy state* of the system. For instance, in QED of atomic structures, they are able to change the fundamental state (minimum energy), into one of the excited states of the electronic "cloud" around the nucleus.

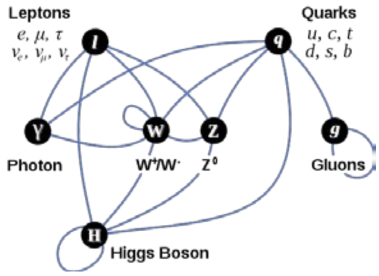


**Figure 2. Scheme of the *gauge* bosons and of the different energy interactions they mediate among the fermions (*lepton*s (electrons and neutrinos) and *quarks* (and hence protons and neutrons)), i.e., among the particles constituting the "building bricks" of the atoms, the molecules, and hence of all the physical bodies.**

On the contrary, the correlating quanta are not mediators of the interactions among the elements of the system, they determine only the *modes of interaction* among them. So, any symmetry breakdown in the QFT of condensed matter of chemical and biological systems has one only gauge boson mediator of the underlying energy exchanges, the photon, since they all are electromagnetic phenomena. However, the phenomena here concerned, from which the emergence of *macroscopic* coherent states derives, implies the generation, effectively the *condensation,* of correlation quanta with negligible mass, in principle null, the so called Nambu-Goldstone bosons, acquiring a different name for the different mode of interaction, and hence of coherent states of matter they determine – *phonons* in crystals, *magnetons* in magnetes, *polarons* in biological matter, etc..
This is the basis of the fundamental "Goldstone theorem" (Itzykson & Zuber, 1980; Umezawa, 1993). So, despite the correlation quanta are real particles, observable with the same techniques (diffusion, scattering, etc.), not only in QFT of condensed matter, but also in QED and in QCD like the other quantum particles, wherever we have to reckon with broken symmetries (Goldstone, Salam, & Weinberg, 1962), nevertheless they do not exist *outside* the system they are correlating. For instance, without a crystal structure (e.g., by heating a diamond over 3,545 °C), we have still the component atoms, but no longer phonons. Also and overall in this aspect, the correlation quanta differ from energy quanta, like photons. So, essentially for this reason, they are sometimes called "quasi-particle". Because the gauge bosons are *energy* quanta, they cannot be "created and annihilated" like the correlation quanta.
Better, in any quantum process of particle "creation/annihilation" in quantum physics, what is conserved is the energy/matter, mediated by the energy quanta (gauge bosons), not their "form", mediated by the correlation quanta (Nambu-Goldstone bosons). Also on this regard, a dual ontology is

fundamental for avoid confusions and misinterpretations[42]. In fact, in the dual ontology, any transformation always induced by an acting causality and hence by an energy-matter exchange, the old "form" as ordering relation (correlation) of material parts, simply vanishes, differently from the material substratum that is always conserved under the new "form", generated by the process. Moreover, because the mass of the correlation quanta is in any case negligible (or even null), *their condensation does not imply a change of the energy state of the system.* This is the fundamental property for understanding how, not only the stability of a crystal structure, but also the relative stability of the living matter structures/functions, at different levels of its self-organization (cytoskeleton, cell, tissue, organ…), can depend on such basic *dynamic* principles. In fact, all this means that, if the symmetric state is a fundamental state (a minimum of the energy function corresponding to a *quantum vacuum*[43] in QFT of dissipative systems), also the ordered state, after the symmetry break-

[42] In passing, the lacking of these distinctions is the ontological mistake of those theorists (see for instance, (Hawking & Mlodinow, 2010; Krauss, 2012; Gao, 2008)) who pretend to explain also the theological *creatio ex nihilo*, "creation out from nothing", within physics. They, starting from the interpretation of big-bang as a symmetry breakdown of the primordial quantum vacuum, without a clear distinction between the *energy (matter) quanta*, and the *correlation (information) quanta*, confuse the evident possibility that in quantum physics "information can come out from no-information" — but also that "information can come back to no-information", as V. Vedral rightly states in his last book (Vedral, 2010) —, with the possibility of explaining in quantum physics terms the theological notion of *creatio ex nihilo*, i.e., of the origin of everything "out from nothing". Unfortunately, they are not philosophers, so that they do not know, that since Plato's time, there exists a distinction between the *absolute nothing* of Parmenides, that as such cannot exist at all, as rightly Parmenides first affirmed, and the *relative nothing*, the "negation of form" of Plato that as such can exist, as the notion of "quantum vacuum", exemplifies. Both the Platonic "static" notion of matter-without-form as *chora* (**xwra**: the sand of the beach), and the Aristotelian "dynamic" notion of matter-without-form as *dynamis* (**dunamij**: the continuous disordered oscillation of the elements), are ontological counterparts of the quantum vacuum notion, even though the Aristotelian one is much closer, because it shares the dynamic nature of the quantum vacuum. So the "nothing" of theology is the absolute nothing of the world (matter and form), and *only* theology can rationally speak about this, because it supposes the existence of something else beside the world, i.e., the existence of the Absolute Being (God for believers), Who was able to make the world existing out of its absolute nothing, i.e., of "creating it *ex nihilo sui (form) and subiecti (matter)*" (see the ch. VI of mine (Basti, 2002)). So it is right (rational) that physics cannot speak about the "absolute nothing" of the world (universe or multiverse, does not matter), otherwise it is no longer physics, but something else, because it ought admit the existence of "something else" out of its domain of truthfulness (the physical world). For this reason, it is rational too that physics cannot try to give ridiculous (because in principle false) physical explanations of such a theological notion. The logical rules of different "linguistic games" hold also for physicists and not only for theologians!

[43] The notion of quantum vacuum is fundamental in QFT. This notion was discovered as the only possible explanation at the fundamental microscopic level, of the *third principle of thermodynamics* ("The entropy of a system approaches a constant value as the temperature approaches zero"). Indeed, the Nobel Laureate Walter Nernst, first discovered that for a given mole of matter (namely an ensemble of an Avogadro number of atoms or molecules), for temperatures close to the absolute 0, $T_0$, the variation of entropy $\Delta S$ would become infinite (by dividing by 0). In fact, $\Delta S = \int_{T_0}^{T} \partial Q / T = \int_{T_0}^{T} C \, dT / T = C \ln T / T_0$ , where $Q$ is the heat transfer to the system, and $C$ is the molar heat capacity, i.e., the total energy to be supplied to a mole for increasing its temperature by 1°C. Nernst demonstrated that this catastrophe can be avoided, if we suppose that $C$ is not constant at all, but vanishes, in the limit $T \rightarrow 0$, as $T^3$, so to make $\Delta S$ finite, as it has to be. This means however, that near the absolute 0°C, there is a mismatch between the variation of the body content of energy, and the supply of energy from the outside. We can avoid such a paradox, only by supposing that such a mysterious inner supplier of energy is the vacuum. This implies that the absolute 0°C is unreachable. There is a fluctuation of the elementary constituents of matter that cannot be eliminated at all. The ontological conclusion for fundamental physics is that we cannot any longer conceives physical bodies as isolated. "The vacuum becomes a bridge that connects all objects among them. No isolated body can exist, and the fundamental physical actor is no longer the atom, but the field, namely the atom space distributions variable with time. Atoms become the "quanta" of this matter field, in the same way as the photons are the quanta of the electromagnetic field. The relationship between the physical objects and the vacuum makes the first ones intrinsically fluctuating, and accounts for the celebrated uncertainty principles. This is a well-known story that can be found in the textbooks of QFT" ( (Del Giudice, Pulselli, & Tiezzi, 2009), p. 1876). For this discovery, eliminating once forever the ontological notion of the "inert isolated bodies", Walter Nernst is a chemist who can be defined as one of the founders of the modern quantum physics. Finally, this ontology is in perfect operational continuity with the Aristotelian notion of the *first matter* as "matter (*dynamis*)

down and the instauration of the ordered state, remains a state of minimum energy, so to be *stable* in time. In kinematics terms, it is a *stable attractor* of the dynamics (see § 6, Appendix, for the explanation of the notion of attractor).

#### 3.2.4 COHERENCE STATES AND COHERENCE DOMAINS IN LIVING MATTER AND THE NOTION OF "EMERGENCE"

To sum up, the basic hypothesis of QFT applied to living matter is that "at the dynamic fundamental level, *the living matter can be considered as a set of electrical dipoles whose rotational symmetry is broken down*" ( (Vitiello G. , 2010), p. 16. For the mathematical apparatus of the theory, see (Del Giudice, Doglia, Milani, & Vitiello, 1983; Del Giudice, Doglia, Milani, & Vitiello, 1985; Del Giudice, Doglia, Milani, & Vitiello, 1986; Del Giudice, Preparata, & Vitiello, 1988; Del Giudice & Vitiello, 2006; Vitiello G. , 1992)). This is not a reductionist view, because the characterizing properties of living matter, are macroscopic structures and functions, with their own laws, *emerging* over the microscopic dynamics generating it. On the contrary, in such a way, the ambiguous notion of *emergence* has, in the context of QFT, a precise connotation, and it is quantitatively well defined. *The emergence of macroscopic properties is given by the dynamic process determining the system ordering.* Of course, any emergence process is related also to a scale change, then, because the dynamic regime responsible of this change is of a quantum nature — because the elementary components have a quantum nature —, the resultant system, with its macroscopic properties, is thus a *quantum macroscopic system.*

So, always with the help of Vitiello, if we consider more closely the *nature* of the correlations among the elementary components in living matter (essentially, the oscillating molecules and their electromagnetic fields), the correlations are essentially *phase correlations,* so that the role of Goldstone bosons is the *fine-tuning* of the elementary oscillations. The "coherence" consists in such a *being in phase.* In real situations, because of the finite range of the correlations, the coherence is set in regions that do not cover all the system. The ordering is thus fragmented into *coherent domains* of finite dimensions, strictly controlled by the different radiant electromagnetic fields associated with the elementary components involved. The linear dimension of the ordered region is controlled by the wave-length of the electromagnetic field. The resulting coherent domain is thus effect of the phase-locking of the radiant electromagnetic field, and of the oscillations of the "material" components (Del Giudice & Vitiello, 2006).

This implies the immersion of the coherent regions into non-coherent ones, so that their dimensions, because of their dynamic nature, can fluctuate. In this way, other control parameters, such as the temperature, the spatial density of distribution of the material elements, as well as the density of distribution of the electric charges and their fluctuations, can play a fundamental role. Namely, they can determine, either the formation of more extended coherence domains, or, instead, the further fragmentation of them, till their complete destruction, and the recovery of the symmetric "disordered" state.

#### 3.2.5 TWO EXAMPLES: BIOLOGICAL FUNCTIONS AS ORDERED SEQUENCES OF CHEMICAL REACTIONS, AND THE FORMATION OF THE CYTOSKELETON STRUCTURE

In the light of the precedent discussion it is evident that the vital functions does not depend only on the chemical agents (biomolecules) and their interactions at different level of self-organization of the biological matter, but depend also critically on which "organizes the molecular traffic" among the chemical partners. In other terms, each complex vital function consists in an ordered series of single chemical events, according to the chemistry laws. All the chemical interactions, however, (e.g., the van der Waals forces) hold *only for short distances.* The fact that a given molecule arrives in the proximity of the proper receptor, so to make possible the chemical event, can depend neither on the chemical laws, nor on the diffusive processes alone, according to Turing early hypothesis of the "morphogenesis" (Turing A. M., 1952), because of the *casual character* of diffusive processes.

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without any form, but *in potency* to all of them", underlying as a common dynamic substrate any physical transformation (see (Basti, 2002), pp. 339-353, spec. p. 341).

They indeed, would imply, on one side, a slow temporal dynamics, and, on the other side a series of not appropriate molecular interactions, outside of the "coded" molecular sequence.
The only way for "canalizing" the molecules, all oscillating according to frequencies depending on quantum physics laws, consists thus in submitting them to electromagnetic fields oscillating according to specific frequencies. Specific molecules can thus recognize each other, also at long distances, and among a multitude of other molecules. The medium in which such oscillating electromagnetic fields occur is the water, in which all the molecules of our bodies are immersed. We come back to a more articulated explanation of this key point in the next Sub-section, where we illustrate the basic hypothesis by which dissipative QFT could give non-linear thermodynamics the basic concepts for understanding the dynamic mechanisms for the formation of the so-called *dissipative structures.* The Nobel Laureate Ilya Prigogine discovered them in the 60's of last century, and they upset completely the chemistry and the biology of the last fifty years.
Let us illustrate now one of the most important theoretical successes of the QFT applied to the study of the dynamics of biological functions, namely the formation and the continuous modification of the *cytoskeleton* inside the cells. The cytoskeleton consists in a network of microtubules of well-known proteins, whose dynamic behavior is very complex, for the continuous process of branching/pruning, characterizing it. Nevertheless, the most of metabolic processes occur along the cytoskeleton, which has thus a fundamental biochemical function. The death of the cell coincides indeed with the cytoskeleton destruction. Now, it is well known in the QED gauge field theory the phenomenon of the field propagation by "self-focusing". An example is the electromagnetic field propagation in ordered (coherent) systems.
In our case, in the regions displaying such an ordering, like the ordered dipole domains of water molecules in biological systems, the electromagnetic field propagates in a "filamentous" way, with an intensity comparable to the correlation generating the ordering. In other terms, the field penetrates the ordered domains into channels, inside which the intensity is non-null, while outside it, it is null. For higher intensities, the propagation is spreading all over the domain without channeling, while for smaller intensities it does not occur at all. In the case of the channeled propagation, the field intensity variation between the inside and outside of each channel generates forces acting selectively on the surrounding molecules, attracting or repelling them, according to a resonance law (each molecule, indeed, better the electrons inside it, is oscillating, generating an electromagnetic field with a characteristic frequency).
In such a way, the channel surrounds itself with a sheath of molecules according to a well-defined sequence of frequencies. Namely, the attracted molecules produce well-known chemical reactions, using also the electrons furnished by the "coherent" water, with an almost null energy waste. The energy produced by the chemical reaction, absorbed by the coherence domain, changes its oscillation frequency, so that other molecules resonating on the new frequency are attracted. It produces a new frequency variation and so on. In such a way, *a bio-chemical ordered sequence of events occurs*, in which each stage depends on the output of the precedent ones, as well as on other energetic inputs from the outside.
To sum up, the electromagnetic field, by its channeling within the surrounding water ordered domain, determines a controlled polymerization around itself. What is significant is that the ray of the channel, surrounded by the molecular sheath so produced, is of the order of the cytoskeleton (about 150 Angstrom)! (Del Giudice, Doglia, Milani, & Vitiello, 1986). If the molecules attracted onto the channel can produce stable chemical bonds, the polymeric structure persists also if the field disappears. Otherwise, it persists as long as the field channel persists.
Such a dynamic mechanism is thus an optimal candidate for the explanation of the cytoskeleton formation/destruction, as well as for the possibility that on it *soliton waves*[44] can propagate for the

[44] A soliton is a self-reinforcing solitary wave (a wave packet or pulse) that maintains its shape while it travels at constant speed. Solitons are caused by a cancellation of the nonlinear and dispersive effects in the medium. Originally, solitons were discovered and studied in fluid dynamics. Mathematically, the solitons constitute a family of solutions of weakly non-linear differential equations, with applications also in QED, and even in string theory. Apart from Da-

very fast and efficient metabolic activity characterizing the cells, according to the well-known A. S. Davydov hypothesis (Davydov, 1979). A rigorous mathematical modeling of this hypothesis can be found in (Del Giudice, Doglia, Milani, & Vitiello, 1985; Del Giudice, Doglia, Milani, & Vitiello, 1986). More generally, the QFT model just summarized can justify the non-dissipative transfer of energy, also on long distances, as to those characterizing the molecular components.

#### 3.2.6 Dissipative structures in biological systems as macroscopic manifestations of QFT invariance laws

> One of the main problems of the physics of the alive is to justify the global approach starting from the molecular level. In a living organism molecules are not independent objects, interacting in a random way according to diffusive motions. On the contrary, they perform in a highly correlated way, and their encounters are not at all random, but obey organic codes (Barbieri, 2003) that prescribe the molecular partners of each encounter and where and when the encounter should occur. Thus, biomolecules are governed by a complex array of long-range signals that, according to the list of physical agents known so far, could be the electromagnetic field only. Moreover, the pattern of the electromagnetic signals should be able to adjust itself to the changes occurring in the molecule organization. A close interplay between molecular organization and electromagnetic field structure appears a necessary condition for making the living process possible.( (Brizhic, Del Giudice, Popp, Maric-Höler, & Schlebusch, 2009), p.32)

The dynamic mechanism according to which the water molecules, beyond a given density threshold, can condense into coherence domains (CD's) among their electric dipoles is today well known (Brizhic, Del Giudice, Popp, Maric-Höler, & Schlebusch, 2009; Del Giudice & Vitiello, 2006; Del Giudice, Preparata, & Vitiello, 1988; Del Giudice, Doglia, Milani, & Vitiello, 1986; Del Giudice, Doglia, Milani, & Vitiello, 1985). The core of such a mechanism is that in each water CD the molecules oscillate *coherently* between two configurations of their electronic clouds, so to produce an electromagnetic field oscillating with the same frequency. What is important to emphasize here is that such a CD requires an energy release, so that each CD has a global energy *less* than the non-coherent regimes, with a consequent *energy gap*. The water CD can, indeed, attract by resonance a small number of "guests" molecules different from water, that share thus the energy stored in the CD. If it matches the chemical activation energy of the array of the "guests", the energy is transferred in one stroke to them, and the CD is able to discharge like a multi-mode laser (Del Giudice, Preparata, & Vitiello, 1988).
The array of the chemical reactions allowed by the above scheme produces a chemical output energy that, in principle, shifts the balance of energy and can destroy the coherence. In order to restore the coherence, the system should get rid of this excess energy. If the transmission of energy occurs via linear mechanisms, then it is spent to excite thermal vibrations, and cannot be used on biological purpose. On the contrary, if this excess energy occurs via a *nonlinear mechanism*, as it is in the case of solitons, then it does not dissipate in the environment; instead *it is propagated in the form of a soliton*, as a localized stable wave package to the place where it can be utilized to perform some biological task.
Moreover, during the propagation, charged solitons emit electromagnetic radiation, whose main harmonic is determined by their velocity. Via the exchange by this radiation, solitons synchronize their velocity, and, as a result, synchronize also the frequency of the emitted electromagnetic radiation, which leads to a sort of "antenna" effect. The radiation of electro-solitons is of the dipole-type and contributes to the total electromagnetic field in the system (Nonlinear model of the origin of endogenous alternating electromagnetic fields and self-regulation of metabolic processes in biosystems, 2003).
Finally,

> The interplay between chemistry and electromagnetic field produces a collective oscillation of all the CD's, that, according to the general theorem of quantum electro-dynamic coherence, gives rise to an extended coherence,

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vydov pioneering work, the soliton presence is well established both in DNA and in protein dynamics, displaying a fundamental role for the efficiency of metabolic functions in the living organisms (Yakushevich, 2004; Sinkala, 2006).

> where the CD's of water and "guest" molecules become the components of much more extended "superdomains" which could just be the various organs. This oscillating system is able to transform a non-coherent ambient energy into the energy, able to get organized according to the nonlinear dynamics of self-organization of the living system. In this way, the super-domain is a candidate to be *the dissipative structure,* as described by Prigogine et al. (Prigogine & Nicolis, 1977), Froehlich (Frölich, 1968; Frölich, 1988), and Tiezzi (Tiezzi, 2002; Tiezzi, 2005).

The coherent picture emerging from such an interplay between the QFT of dissipative systems and non-linear thermodynamics of dissipative structures is amazing, also because gives Prigogine theory a solid basis at level of foundational physics, it was, otherwise, lacking (Prigogine, 2008).

> A dissipative system or structure is a thermodynamically open system operating far from thermodynamic equilibrium, and that exchanges energy, matter, information with the environment that surrounds it. In virtue of the exchanges with the exterior, the system manages to organize itself. That is, it is characterized by the spontaneous breaking of symmetry, both spatial and temporal, and by the formation of complex structures in which the interacting particles show long-range correlations and interactions. Therefore, dissipative structures maintain their non-equilibrium thermodynamic state thanks to a continuous dissipation of energy towards the exterior. The order produced by this dissipation generates new order and new organization (autocatalytic structures), but if the flow of energy is interrupted or diminished, the structure can collapse and may not return to its initial state (irreversibility). The system thus self-organizes in virtue of internal non-linear processes that guarantee a balance among the free energy and the negentropy, entering, and the entropy and low-quality energy, exiting. In systems far from equilibrium, "the inert order of crystal", held by the thermodynamics of equilibrium as "the only producible and reproducible physical order", leaves its place to self-organizing processes that associate order and disorder, structures on one side, losses and wastes on another, hence the name of "dissipative structures", in order to highlight an association between order and disorder that is, in the words of Prigogine, "truly paradoxical at first glance" ( (Del Giudice, Pulselli, & Tiezzi, 2009), p. 1878f.).

To conclude this part, it is significant that both the opposed phenomena quoted by Prigogine — the crystal order of equilibrium thermodynamics and the ordering of dissipative structures in non-equilibrium thermodynamics — can have their dynamic explanation within the same theoretical framework of QFT. This means that, the above remembered link QFT can offer between microscopic and macroscopic phenomena, is not only in terms of scale change, but, as we anticipated following Vitiello, a rigorous approach to the otherwise ambiguous notion of *emergence* of ordered structures at mesoscopic/macroscopic level, from the microscopic one. In this context, it is also highly significant the characterization that *dissipative QFT* can give of one of the most famous examples of dissipative structure, i.e. the so-called Belousov–Zhabotinsky phenomenon (Marchettini, DelGiudice, Voeikov, & Tiezzi, 2010).
We see in the rest of this paper, how the dissipative QFT can give modern science a fundamental notion for understanding how a physical, biological system can become *a cognitive system*, i.e., from the standpoint of formal ontology, how the realm of the *logical necessity* can emerge from the realm of the *causal necessity,* without any reductionism.

# 4 QFT and the dual ontology of cognitive neuroscience

## *4.1 Doubling of the Degrees of Freedom (DDF) in dissipative QFT and its significance in cognitive neuroscience*

### 4.1.1 THE BACKGROUND

As Perrone and myself emphasized in several papers on the physical basis of intentionality (Basti & Perrone, 1995; Basti & Perrone, 2001; Basti & Perrone, 2002; Basti, 2009), only the long-range correlations, which propagate in real-time along wide areas of the brain, and manifest themselves as aperiodic "chaotic" oscillations, can offer a valid dynamical explanation of an intentional act, always involving the simultaneous interaction among emotional, sensory and motor components, located in very far areas of the brain. Such a coordination, that constitutes also the dynamic "texture" of long-term memory phenomena, cannot be explained in terms of the usual axon-synaptic networking, too slow and too limited in space and time, for giving a suitable explanation of this requirement .

On the other hand, Walter J. Freeman and his collaborators, during more than forty years of experimental research by the Neurophysiology Lab at the Dept. of Molecular and Cell Biology of the University of California at Berkeley, not only shared our same theoretical convictions, but observed, measured and modeled this type of dynamic phenomena in mammalian and human brains during intentional acts.
The huge amount of such an experimental evidence found, during the last ten years, its proper physical-mathematical modeling in the dissipative QFT approach of Vitiello and his collaborators, so to justify the publication during the last years of several joint papers on these topics (see, for a synthesis, (Freeman & Vitiello, 2006; Freeman & Vitiello, 2008)).
To sum up (Vitiello G. , 2009), Freeman and his group used several advanced brain imaging techniques such as multi-electrode EEG, electro-corticograms (ECoG), and magneto-encephalogram (MEG) for studying what neurophysiologist generally consider as the *background activity* of the brain, often filtering it as "noise" with respect to the synaptic activity of neurons they are exclusively interested in. By studying these data with computational tools of signal analysis to which physicists, differently from neurophysiologists, are acquainted, they discovered the massive presence of patterns of AM/FM phase-locked oscillations. They are intermittently present in resting and/or awake subjects, as well as in the same subject actively engaged in cognitive tasks requiring interaction with the environment. In this way, we can describe them as features of the background activity of brains, modulated in amplitude and/or in frequency by the "active engagement" of a brain with its surround. These "wave packets" extend over coherence domains covering much of the hemisphere in rabbits and cats (Freeman W. J., 2004a; 2004b; 2005; 2006), and regions of linear size of about 19 cm in human cortex (Freeman, Burke, Holmes, & Vanhatalo, 2003), with near zero phase-dispersion (Freeman , Ga'al, & Jornten, 2003). Synchronized oscillations of large scale neuron arrays in the β and γ ranges are observed by MEG imaging in the resting state and in the motor-task related states of the human brain (Freeman & Rogers, 2003).

#### 4.1.2 DDF IN DISSIPATIVE QFT OF BRAIN DYNAMICS.

So, what was missing to the Umezawa's pioneering efforts to apply QFT to brain long-term memory dynamics (Umezawa H. , 1995) was the mechanism of DDF characterizing the dissipative QFT and its algebraic formalism, developed by E. Celeghini, M. Rasetti, and G. Vitiello during the 90's (Celeghini, Rasetti, & Vitiello, 1992), and explicitly applied by Vitiello himself to the modeling of brain dynamics, but also in any realm of quantum physics, from cosmology, to quantum computing, till chemistry and biology.

In fact, we know that the relevant quantum variables in biological system are the electrical dipole vibrational modes in the water molecules, constituting the oscillatory "dynamic matrix" in which also neurons, glia cells, and the other mesoscopic units of the brain are embedded. The condensation of Goldstone massless bosons (named, in the biological case, Dipole Wave Quanta, DWQ) — corresponding, at the mesoscopic level, to the long-range correlation waves observed in brain dynamics — depends on the triggering action of the external stimulus for the symmetry breakdown of the quantum vacuum of the corresponding brain state. In such a case, the "memory state" corresponds to a coherent state for the basic quantum variables, whose mesoscopic order parameter displays itself at the mesoscopic level, by the amplitude and phase modulation of the carrier signal.

In the classical Umezawa's model (Umezawa H. , 1995), however, the system suffered in an "intrinsic limit of memory capacity". Namely, each new stimulus produces the associated DWQ condensation, by cancelling the precedent one, for a sort of "overprinting". *This limit is systematically overcome in dissipative QFT where the many-body model predicts the coexistence of physically distinct amplitude modulated and phase modulated patterns*, as it is observed in the brain. That is, by considering the brain as it is, namely an "open", "dissipative" system continuously interacting with the environment, there not exists one only ground (quantum vacuum) state, like in thermal field theory of Umezawa where the system is studied at equilibrium, but, in principle, infinitely many ground states (quantum vacuum's), so to give the system a potentially infinite capacity of memory. To sum up, the solution of the overprinting problem relies on three facts (Vitiello G. , 2004):

1. In a dissipative (non-equilibrium) quantum system, there are (in principle) infinitely many quantum vacuum's (ground or zero-energy) states, on each of which a whole set of non-zero energy states (or "state space" or "representation states") can be built.
2. Each input triggers one possible irreversible time-evolution of the system, by inducing a "symmetry breakdown" in one quantum vacuum, i.e., by inducing in it an ordered state, a coherent behavior, effectively "freezing" some possible degrees of freedom of the constituting elements behaviors (e.g., by "constraining" them to oscillate on a given frequency), in the same time "labeling" it as the coherent state induced by that input, as an "unitary non-equivalent state" of the system dynamics. In fact, such a coherent state persists in time as a ground state (DWQ are not energetic bosons, are Goldstone bosons) as a specific "long-term" memory state as long as, of course, the brain is coupled with its environment. A brain no longer coupled with its environment is either in a pathological state, or it is directly dead.
3. At this point emerges the DDF principle as a both physical and mathematical necessity of the model. Physical, because a dissipative system, even though in non-equilibrium, must anyway satisfy the *energy balance*. Mathematical, because the 0 energy balance requires a "doubling of the system degrees of freedom". The *doubled* degrees of freedom, say $\tilde{A}$ (the tilde quanta, where the non-tilde quanta $A$ denote the brain degrees of freedom), thus represent the environment to which the brain is coupled. The environment (state) is thus represented as the "time-reversed *double*" of the brain (state) on which it is impinging. The environment is thus "modeled on the brain", according to the finite set of degrees of freedom the environment itself elicited. Anyway, which are the available degrees of freedom to be elicited for that input depends on the brain itself that, for this reason, is effectively a *self-organizing* system.

Of course, the point 3 represents the essential idea of the "doubling algebra" (algebra/co-algebra) formalism, constituting the mathematical core of the dissipative QFT model that we cannot illustrate here, and for which we refer to (Celeghini, Rasetti, & Vitiello, 1992), and to the wide literature quoted in (Vitiello G. , Coherent states, fractals and brain waves, 2009). Of the DDF we illustrate only, in the final section of this paper its logical relevance, for an original solution of the reference problem, not yet developed till now. For concluding this part, dedicated to the relevance of the dissipative QFT in cognitive neuroscience, I want to emphasize only three final remarks (Freeman & Vitiello, 2008; Vitiello G. , 2009):

- Another success of the dissipative QFT model is that the irreversible time evolution because of the dissipative condition (each coherent state is constituted of "entangled", non-separable, tilde and non-tilde DWQ's), of each "unitary non-equivalent coherent state" can be characterized macroscopically as an *input-labeled* classical chaotic trajectory, in the brain-environment phase space, as it was experimentally observed. I.e., they are trajectories, in the infinite limit: i) bounded and never intersecting with itself; ii) non intersecting with others for different initial conditions; iii) diverging in time also for small differences in the initial conditions. On the other hand, the finite conditions of real systems, the presence of noise and other constraining conditions make possible the phenomena of the "chaotic itinerancy" among different attractors, the fusion of attractors and/or of chaotic trajectories differing for only few degrees of freedom, and other phenomena of "associative memories". The real dynamics so live in a continuous interplay between "noise" and "chaos" for which Freeman invented the neologism of "stochastic chaos" for characterizing the dissipative QFT dynamics of the brain.
- QFT approach is thus very different from other approaches to cognitive neuroscience based on QM, in which the quantum effects occur only at the microscopic level. On the contrary, in QFT

the effects of quantum events display themselves as a *macroscopic quantum state*, due to the *coherence* of the correlation modes. This makes possible that the interaction between such a mechanism and the electrochemical activity of neurons and synapses, observed by neurophysiologist as the first response to the external stimuli, occurs effectively *only at the macroscopic level*, as the relationship between the *background activity* (memory) and its *ongoing activity* (synapses), in the global interaction between the brain and is environment.

- Because QFT coherent states are "entangled states" between tilde (environment) and non-tilde (brain) DWQ's, it is evident that also this approach supports the localization of mind and of its logical machinery not "inside" the brain, but *in the dual (energy/information) interplay between the brain and its environment* (Vitiello G. , 2004), like all the approaches based on the intentional and not representational theory of mind (Basti & Perrone, 2001; Basti, 2009; Bateson, 2002; Marturana & Varela, 1980; Clark, 2008) (Noë, 2009). This last remark opens the way to an ontological and hence logical interpretation of the DDF scheme.

### *4.2 Double saturation S/P and the solution of the reference problem*

To conclude this paper we want to offer for the first time a logical and ontological interpretation of the DDF in brain dynamics as a possible solution of the reference problem, in the direction of the interplay between *physical necessity and logical necessity* that the same notion of NC implies. For this we want to use in a not yet formalized way — that its outside the scope of this paper — the modal logic machinery, developed by Kripke's theory of frames (§1.2), in strict connection with his logical theory of truth (§2.3), in the direction of its algebraic interpretation, applied to the algebra-doubling formalism (co-algebras) of the dissipative QFT.

The first point to recall for understanding this point is that *in any definite description* to be associated to a proper name intended as a *rigid designator* the relationship connecting Subject *S* and Predicate *P* is not of class membership, $\in$, like when we say "Aristotle is *a* philosopher", but of *identity,* =, like when we say "Aristotle is *the* philosopher". The second point to recall is that the notion of *saturation*, today normally used in *modal* model theory for denoting which subset of elements of a given domain *effectively* satisfy a given relation, was introduced in logic by G. Frege for justifying the unity of proposition, where the predicate is the *unsaturated* component and the subject is the *saturated* one.

The solution that the intentional theory of reference suggests is the *double saturation S/P, causally driven by the same referential object.* By such a procedure their logical identity and hence the *referential relation* of the definite description is causally constructed (Perrone, 1995; Basti, 2007; Basti, 2009; Basti, 2011).

Thomas Aquinas (1225-1274)[45] depicted in the Middle Age his causal theory of reference in the following way:

> Science, indeed, depends on what is object of science, but the opposite is not true: hence the relation through which science refers to what is known is a *causal* [*real* not *logical*] relation, but the relation through which what is known refers to science is only *logical* [*rational* not *causal*]. Namely, *what is knowable (scibile) can be said as "related", according to the Philosopher, not because it is referring, but because something else is referring to it.* And that holds in all the other things relating each other like the measure and the measured (*Q. de Ver.,* 21, 1. Square parentheses and italics are mine).

[45] Historically, he first introduced the notion and the term of "intention" (*intentio*) in the epistemological discussion, in the context of his naturalistic ontology. The approach was hence rediscovered in the XIX century by the philosopher Franz Brentano, in the context of a conceptualist ontology, and hence passed to the phenomenological school, through Brentano's most famous disciple: Edmund Husserl.

In another passage, this time from his commentary to Aristotle book of *Second Analytics*, Aquinas explains the singular reference in terms of a "one-to-one universal" (i.e. Kripke's rigid designators), as opposed to "one-to-many universals" of the generic predications.

> It is to be known that here "universal" is not intended as something predicated of many subjects, but according to some adaptation or adequation (*adaptationem vel adaequation*) of the predicate to the subject, as to which neither the predicate can be said without the subject, nor the subject without the predicate (*In Post.Anal.*, I,xi,91. Italics mine).

So, Aquinas' idea is that the predicative statement, when it is denoting a singular object, must be characterized by a "mutual redefinition" between the subject *S* and the predicate *P*, "causally" driven by the referential object itself. DDF mechanism is evidently in an operational, even though unaware, continuity with such Aquinas' theory (Freeman W. J., 2008) (Freeman W. J., 2010).

On the other hand it is evident that the modal construction of a *modal* equivalence relation illustrated step by step through Kripke's frames (4a-d) in §1.1.4 constitutes a logical description of the DDF principle in dissipative QFT. It is sufficient to interpret *u* as the referential object (environment), *w* as the brain state, *v* as the input state, so that in (4a), *uRw*, *uRv*, and *vRw* represent the transitive and serial (= *causal*) relations constituting the initial step of the procedure. Particularly, the relationship *vRw* represents the starting step of DDF in which the input elicits the coherent state (the freezing of the degrees of freedom) in the brain state. In frames (4d) and (4c) the doubling of the degrees of freedom and the entanglement conditions are, respectively, posed, so to conclude the onto-logical constitution of the transitive-reflexive-symmetrical relations, i.e., the equivalence relation (=*logical*), between *S/P* of a definite description denoting the referential object, we are searching for. Moreover, if we interpret this procedure inside the Kripke theory of truth, as it is natural to do, it is evident that the final frame (4d) constitutes an onto-logical depiction of an "unitary in-equivalent state", typical of QFT as to QM "labeled" by the referential object *u*, i.e., the "seed" of a new "equivalence class" (see frame (5)).

However, precisely because of this *causal labeling* by the referential object, the theory has no longer that limit of arbitrariness that it has in the original Kripke use of Kleene's partial recursive functions. In this sense, because the modal equivalence does not generally implies bi-similarity[46] – but bisimilarity is implied only when the specific conditions of the famous van Benthem theorem occur (Blackburn, De Rijke, & Venema, 2010 (2002), p. 104ff.), so in our case bi-similarity occurs only when the "doubling" input/output is given in each cognitive agent[47]. This means that the same input causally produces different state-transition sequences (chaotic trajectories) in different cognitive agents, however all equivalent among themselves because *causally* labeled by the same input. In this sense, the causal relations from the world *u* (=referential object) onto each of the other worlds (=different, but equivalent definite descriptions of the same object), in the equivalence class of the frame (10), represent the foundation clause **F** of the epistemic logic in its intentional interpretation (see §2.2). Finally, it is evident by such a reconstruction that the localization of a cognitive agency is not "inside the brain", but in the interplay between a brain and its environment.

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[46] We recall here that "computation" in theoretical computer science can be interpreted as a Labeled Transition System (LTS), in the sense that "when we traverse an LTS we build a sequence of state transitions – or to put it another way, we compute" ([25], p.68). So, roughly speaking, bisimilarity between two models *M* and *N* in modal logic means that at each accessibility relation between two states $m_i$ and $m_j$ in *M*, corresponds a relation between $n_i$ and $n_j$ in *N*. So, if we interpret such models as two equivalent programs in dynamic logic (i.e., two "black boxes" producing equivalent outputs for equivalent inputs), their bisimilarity means the further condition of a correspondence between the different "labeled" steps of their execution.

[47] On the other hand, one of the most famous scholars in modal logic, Prof. Yde Venema of the University of Amsterdam, recently demonstrated that the modal logic is the proper logic for co-algebras, just as equation logic is the proper logic for algebras (Venema, 2007, p. 332).

# 5 Conclusions

In this paper we showed how the theoretical formal ontology can support a foundational theory of the singular reference, in the context of the NC approach to theoretical computer science, putting in one only relational framework both causal and logical relations. At the same time, following the *correspondence principle* between modal and mathematical logic (see §1.1.1), we used frame semantics for individuating as *decidable fragments* particular first order formulas in one free variable: the definite descriptions in QFT modeling of brain-environment dynamics. In this sense, such an approach can offer a foundational modal theory of the logical calculus inside the intentional approach to cognitive neuroscience, till now lacking. It can offer also an adequate start point for developing a Natural Computation approach, based on the dissipative QFT model to cognitive functions, as Vitiello himself proposed to develop (Vitiello G. , 2004). Finally, the principle of the input labeling function typical of DDF, offers an original solution to the arbitrariness of the labeling function in Kripke's modal theory of truth, because Kripke's theory is lacking in an intrinsic relation between the labeling function and the definition of the partial domain satisfying the predicate to be labeled. Such an intrinsic relationship naturally exists in DDF approach because the very same causal relation determines, even though in a non-algorithmic way – however forbidden by Gödel theorems –, both the satisfying partial domain of a given predicate, and its label.

## 6 Appendix: Dynamic and Chaotic Systems

In this appendix, we sketch some main notions of chaotic systems, in the context of the wider theory of dynamic systems for people not acquainted with these notions. This synthesis is without any pretension of completeness and exhaustiveness, but only to make understandable the notions about chaotic systems and chaotic neural nets we discussed in this paper. For a more complete introduction to the notions of non-linear dynamic systems, we refer to a masterpiece of the divulgation on these topics, written by one of the most important physicists of the last century, Vladimir I. Arnol'd, recently passed away (Arnol'd, 1983). For an introduction to the notion of chaotic dynamic systems, we suggest to refer to two best-sellers in the field, of James Gleick (Gleick, 2008) and of John Gribbin (Gribbin, 2005).

### *6.1 Linear dynamic systems*

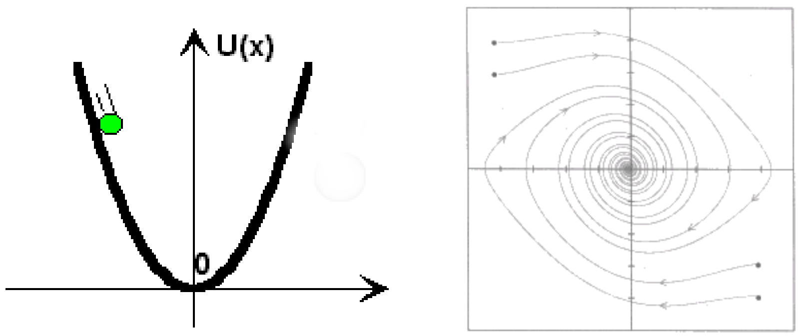


**Figure 3. Energy potential function (*U*(*x*)) of a dynamic linear system, e.g., a non-accelerated pendulum (left); phase space with a fixed-point attractor of the same non-accelerated pendulum.**

Let us take as an example the more classical linear dynamic system, the Galilei pendulum. All the linear dynamic systems follow Newtonian laws, i.e., they are systems stable at equilibrium (see "action-reaction", third Newtonian law). In fact, the *potential function* (*U*(*x*)) (i.e., the integral of all the forces acting on the system) of such systems has the same form showed in Figure 3 (left), with one only minimum: the absolute minimum of energy, or the *equilibrium point*. All the linear systems are thus *stable-at-equilibrium* systems.

Their behavior is thus *perfectly predictable,* (analytically their functions are perfectly *integrable*), and hence, their dynamic evolution *does not produce any information*: all the information is stored in their initial conditions. It is like in logic, in a deductive system, or in geometry, in which the theorems do not add any information to the axioms. In fact, for whichever initial condition (i.e., for whichever perturbation of the equilibrium state) — represented in the figure by the different heights at which the "ball", inside the potential area, can start to fall down —, the final position, after a sufficient time transient, will be the absolute minimum (0) of the energy function.

In the case of our pendulum, at whichever height we start its oscillating behavior, after some time, during which the amplitude and the velocity of the oscillations are progressively dampening, the pendulum will stop in the perfectly perpendicular position from which it started.

In *kinematics,* i.e., in the branch of mechanics describing geometrically the motion of bodies without any reference to the motion causes (forces), we can represent the motion as a trajectory in the *phase space,* i.e., in a space whose points represent only and all the possible states of the system, compatible with the principle of *energy conservation*. In classical (Newtonian) mechanics, this space represents all the positions *q* and the velocities *v* of the "material" point representing the system, so that the position *q* and the momentum *p* (*p* = *mv,* where *m* is the body mass) will constitute the coordinates of the phase space of classical mechanics.

To understand better the kinematic approach to mechanics it is important to recall that representing the time evolution of a classical dynamical system as *trajectories in a phase space* is the reciprocal in classical statistical mechanics of representing the time evolution of a quantum dynamical system through the formalism of *wave function* in quantum statistical mechanics. In quantum systems, indeed, because of the conjugated, non-separable character of the two canonical variables *p* (momentum) and *q* (position), and hence because of the consequent *indetermination principle,* it is impossible to represent geometrically these two variables, as two orthogonal dimensions of a phase space. Hence, it is impossible too representing the different physical states of the system like as many points in such a space, but like as many "volumes", within each of which the system has the same probability of being everywhere for each instant of time. In the same way, we cannot represent the time evolution of a quantum system as a uni-dimensional trajectory connecting these points, like in classical mechanics. On the contrary, because of the partial super-position of the different volumes defining the different states of a quantum system, its evolution in time assumes the form of a "continuous"[48] three-dimensional probability wave: a probabilistic wave function, typical of quantum kinematics.

In the case of our non-accelerated pendulum, its dampening oscillation is represented by the spiral trajectory in its phase space. Effectively to this trajectory, after a transient, all the different initial conditions are converging (see Figure 3(right)). Its final equilibrium state is represented thus by the final point of the spiral. More generally, such a plotting represents a *fixed-point attractor* of the dynamics, typical of any stable-at-equilibrium dynamic systems. Where, by "attractor", physicists mean the phase space subset of points (states), toward which the dynamics evolves, namely the point subset the system will visit with the highest probability. Of course, in the case of a fixed-point attractor, such a subset is unitary.

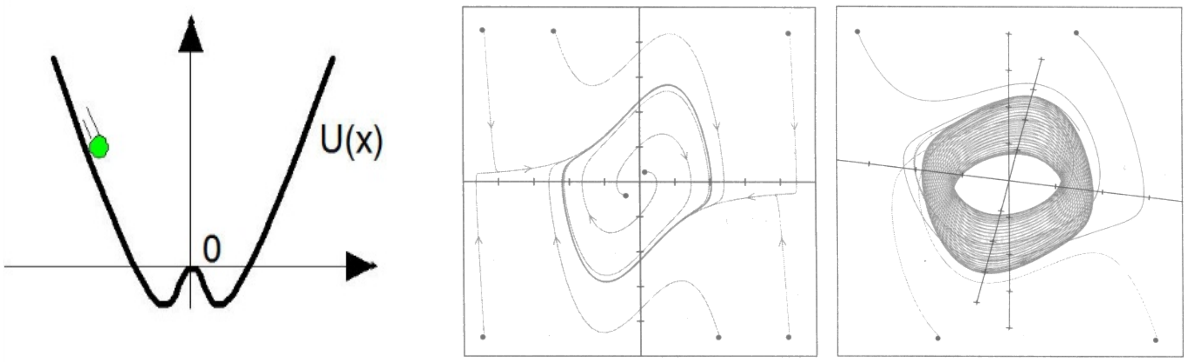


**Figure 4. Potential function with two minima (Left) with the correspondent limit-cycle attractor (Center) of an accelerated pendulum. (Right) Torus attractor characterizing a more complex, but always predictable, behavior of the same accelerated pendulum.**

In the case of an accelerated pendulum (e.g., a pendulum of a pendulum-clock) the original equilibrium point is made unstable, so that the pendulum will oscillate indefinitely between two new minima, corresponding to the two opposite higher points it reaches in its stable oscillation (see Figure 4, left). The correspondent attractor in the phase space of the system is thus a *limit-cycle* attractor, i.e., a closed curve trajectory (see Figure 4, middle). In a regular, periodical way, indeed, and for an indefinitely long time, the system (the pendulum and its moving mechanism) passes through the same

[48] It is to be emphasized that the difference of these two type of "continuity", of a classical "trajectory", versus a quantum "wave", is a unaware re-proposition of the Aristotelian distinction between the *spatial continuity,* made of parts (points) "each outside the other", i.e., perfectly localizable, and the *temporal continuity,* made of parts "each inside the other". From this evidence, of the impossibility of a univocal localization of each elementary unit of time (=instant), differently from the univocal localization of each elementary unit of space (=point), Aristotle derived his theory of the *quantum nature of time.* I.e., the definition of the "present" as the superposition between the "last" of the past, and the "first" of the future, because of the "systematic elusiveness" of the present. In fact, if I tried to "fix" the present instant, it would be already past, it would have already became the future…

states: the same positions with associated the same momenta. In such a way, the final stable state of the accelerated pendulum, perfectly predictable for whichever initial conditions of its motion, will be (after an unstable transient in which the pendulum is not yet stabilized in its final behavior) a regular oscillation. Under given conditions, the situation can become more complex, so that the system can stabilize itself, not onto only one cycle (orbit), but onto a set of cycles all close and similar among them. In such a case, the attractor in the phase space, instead of being a bi-dimensional closed trajectory (limit-cycle) corresponds to a bundle of closed trajectories constituting a tri-dimensional torus (see Figure 4, right).

### *6.2 Non-linear dynamic systems*

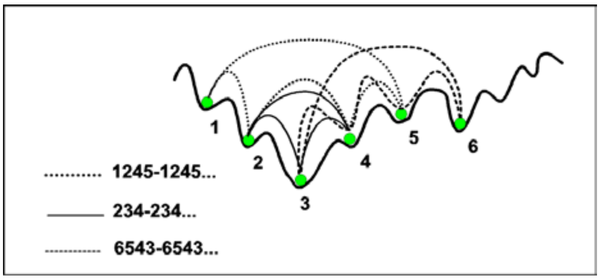


**Figure 5. Energy landscape (energy potential function), with many minima, typical of a non-linear dynamic system. Instead of one only cyclic behavior, the system could in principle assume several of them, as a function of the number *n* of the minima of its energy function, effectively $2^n$. In the figure, only three of them are displayed, the first and the third of *order* 4, the second of *order* 3, where the cycle order (complexity) is, of course, related also to the number of maxima and minima and hence to the *frequency* in time of the corresponding waveform.**

From the Figure 5, it is evident that in non-linear systems we lose the predictability of the dynamics final state characterizing the linear ones, also for very close initial conditions. In fact, it is impossible to predict deterministically, but only *statistically,* in which of the many possible minima – in fact, there exists one only absolute minimum and many others relative minima – and/or in which of the many cycles among minima the system will finally stay. As we see, these cycles are of different *order,* where "cycle order" means the different number of peaks (and bottoms) that the correspondent waveform has. The cycle order and the correspondent frequency (number of peaks of the correspondent wave function for time unit) is proportional, of course, to the number of the minima of the energy landscape that each oscillating behavior will connect. The number of possible cycles/frequencies, for each energy landscape with *n* minima will be in principle $2^n$. It is thus evident the richness and plasticity that non-linear systems have with respect to linear ones, even though this richness is paid in terms of predictability.

In any case, the non-linear systems of this type are characterized by the so-called *structural stability.* In fact, it is possible to suppose for them the existence of *a unique energy landscape,* like that one described in the toy example of Figure 5, even though very often it is not possible, either in practice or even in principle, to define their own energy potential function. Because of their structural stability it is possible, however, to study them, generally, with the powerful tools of *statistical mechanics*, and specially with the powerful analytic tool of the so-called *Lyapunov function.* In other terms, these are non-linear systems that, *differently from the chaotic ones*, are *stable in conditions close to equilibrium,* like for instance, those studied in the so-called "catastrophe theory" (Arnol'd, 1983).

As to our topic, all the so-called "connectionist" *Artificial Neural Networks* (ANN), because they have a *fixed topology*, are non-linear systems of this type, characterized by a structural stability. I.e., they are nets with a dynamics only on the neuron connection *statistical weights*, and not on the *neuron thresholds*, like, on the contrary, the real neurons have. Through a dynamics on the thresholds, in fact, the net loses its structural stability, displaying a chaotic behavior. Namely, in such a way the neurons can change continuously also their *topology of connection*, by “resonating” on several different frequencies, and hence coordinating in real time their behavior, also with neurons very far from them and hence not directly connected by synapses.

### *6.3 Non-linear chaotic systems*

Both the so-called self-organizing *dissipative structures,* studied for the first time in chemistry by Ilya Prigogine, who was awarded a Nobile Prize for this discovery (for an introduction, see (Prigogine & Stengers, La nuova alleanza. Metamorfosi della scienza., 1978; Prigogine, La fine delle certezze, il tempo, il caos e le leggi della natura, 1997; Prigogine, Le leggi del caos, 2008)), and more generally, all the chaotic systems[49] belong to the class of *far-from-equilibrium* stable non-linear systems. All these systems, indeed, are *energetically open* systems (i.e., exchanging continuously energy with their environment), so that, even the simplest ones, do not satisfy the necessary condition of *structural stability.* As we saw in the precedent two subsections, this condition, together with the sufficient one of satisfaction of the *Lyapunov function* constraints, characterize the *linear* dynamic systems stable at equilibrium, and/or the *non-linear* dynamic systems, stable at near-equilibrium conditions illustrated till now (see the very rigorous mathematical analysis of deterministic chaos in (Tucker, 1999; Viana, 2000)).
In other terms, because of their dissipative character, it is impossible to define a unique energy landscape in a chaotic system. So, the first intuitive way for understanding how a chaotic system can display an extremely rich and complex oscillatory behavior, is imagining a continuous changing of the energy landscape. In this way, the number of the (pseudo-)cycles, that the dynamics can generate by cycling among the minima, increases straightforwardly with respect to the structurally stable non-linear systems, with a unique energy landscape of Figure 5.

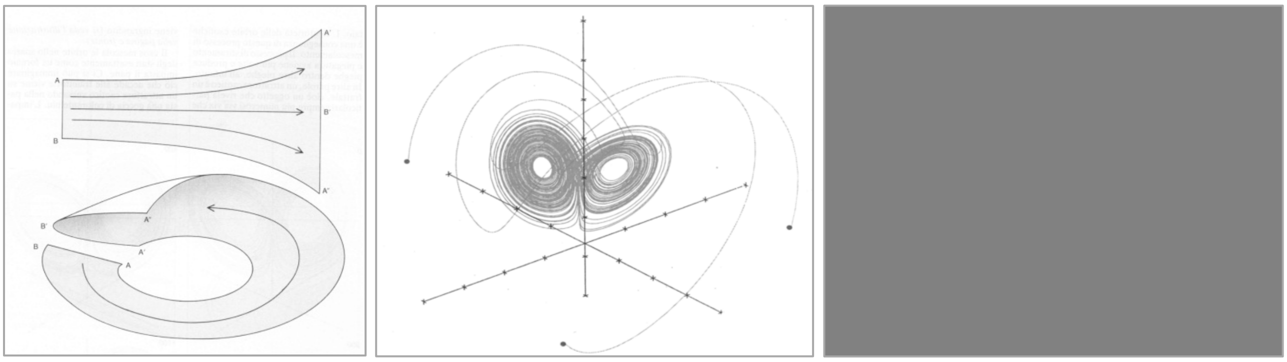

**Figure 6. Instability (Left-Top) and ergodicity-breaking (Left-Bottom) of the trajectories of a chaotic dynamics because of, respectively the “stretching” (by pumping “free energy” in the system) and the “folding” (by dissipating “free energy”) of a chaotic system phase space. In this way, it is possible to create pseudo-cycles in a chaotic system. That is, two points (A, A’) diverging onto the original trajectories (Top), can converge again without perfect superposition (for this reason we cannot have proper closed cycles, but only pseudo-cycles, i.e. “closed” within a given non-null distance) because of the phase space folding. By the stretching-folding mechanism, every point of a chaotic trajectory can become thus a potential quasi-closure point, so to justify the “fractal character” of the chaotic phase space. (Center) chaotic or “strange”**

[49] The wide class of chaotic phenomena, that really opened a new chapter in modern science, range on a broad spectrum of systems. It extends from the computer “toy” models of the so-called *deterministic chaos,* to the very complex chaotic phenomena in mammalian brains. The deterministic chaos models are very useful for studying how a complex behavior can be generated by “simple” non-linear systems, with very few variables (degrees of freedom), like the famous Lorentz attractor (Lorenz, 1995; Gribbin, 2005). These models taught modern science that complex behavior does not always require, neither a high number of variables, nor the presence of noise, like in *stochastic systems,* developed for modeling complex behaviors in statistical mechanics. However, this abstract “cleanliness” of deterministic chaos models has little to do with the natural, highly complex chaotic phenomena, as those embedded in broad spectrum noise, emerging in the electroencephalographic (EEG) and magnetoencelographic (MEG) potential generated by active mammalian brains. For this class of phenomena, its first discoverer, W. J. Freeman used the (provisory) denoting term of *stochastic chaos* (Freeman W. J., A proposed name for aperiodic brain activity: stochastic chaos, 2000).

**as closure of an indefinite number of pseudo-cycles. (Right) A pseudo-cycle of the Lorenz attractor, with its typical "fractal structure".**

Anyway, the more classical way to characterize a chaotic (and generally the non-linear) systems is to emphasize its extreme sensibility to small differences to initial conditions. Till now we illustrated intuitively the dependence on initial conditions in dynamic systems by referring to the potential functions of linear and non-linear systems (see the "balls" behavior in Figure 3 and Figure 5). To illustrate the same fact using the phase space formalism, what we obtain is a set of trajectories with small differences in their origins. If the system is linear these differences progressively reduce themselves till becoming null, since they converge to one only attractor (see the attractors of Figure 3 and Figure 4). On the contrary, in a chaotic system, trajectories with also very similar initial conditions, despite at the beginning they remain close each other, like it was a linear system, after some time, they start to diverge (see the trajectories in the phase space of a chaotic system in Figure 6 left-top), so to make non-integrable the system. This means that a chaotic dynamics, even though it is generated by differential equations like it is the case of the Lorenz system we are here discussing, it is predictable only for a short time, while for longer ones it becomes unpredictable. To sum up, in the dynamic system theory, we can distinguish three classes of them, according to the evolution form of their trajectories in the phase space, and their respective *Lyapunov exponents*:

1. *Convergent direction* toward a given attractor (= negative Lyapunov exponent), typical of *linear* dynamic systems (see Figure 3 and Figure 4)
2. *Divergent direction* (= positive Lyapunov exponent), typical of instable and even chaotic dynamic systems (see Figure 6, left-top);
3. *Neutral direction* (null Lyapunov exponent), typical of stochastic random motion.

If this is the situation, how is it possible that a chaotic system has an attractor like it is the case of the chaotic system studied by Edward N. Lorenz and that is represented in (Figure 6, center)? The general principle is illustrated intuitively in the (Figure 6, left bottom). In fact, the trajectory of a chaotic system will diverge for ever, so to visit (for an indefinitely long time) all the points (possible states) of the system phase space, according to the so-called *ergodic hypothesis*[50]. However, this is only an abstract condition. The trajectory will diverge indefinitely, only if we suppose that the system is energetically closed, i.e., if it does not dissipate any energy. To insert a dissipation condition corresponds to "shrinking" the phase space.

Now, if we "fold" the phase space because of a dissipation condition, a strange phenomenon occurs: two trajectories that in two dimensions diverge, can converge on the third one for "the folding" phenomenon. In this way, on the third dimension the trajectories can converge toward a closure, without being completely closed on themselves, so to generate a "pseudo-cycle". Of course, if we pump energy on the system, we obtain the opposite effect on the phase space, by "stretching" it, and hence creating new divergences. So, by the mechanism of "folding and stretching" – i.e., by modifying continuously the energy landscape of the system because this is a system "energetically open", i.e., exchanging continuously energy with its environment – it is possible to create an indefinite number of pseudo-cycles that constitute the structure of the "strange attractor" of a chaotic dynamics (see Figure 6, center).

It is evident the strict relation, emphasized by Prigogine himself (Prigogine, 1997; Prigogine, 2008), between a *chaotic system* and the *dissipative structures*, that are fundamental for understanding the physical foundation of biological systems. Both are non-linear, unpredictable, dissipative, self-organizing systems. In fact, the existence of an attractor of the chaotic dynamics, means that the system reduced its statistic entropy, by using the "free energy" supplied by the environment – two

[50] This hypothesis was formulated for the first time by the great French mathematician Henry Poincaré in 1898. By applying the famous Newtonian gravitation equation, to the interaction between two bodies, the equation is linear and hence integrable. What Poincaré discovered is that if we apply the same equation to study the interaction among three bodies, the equation becomes non-linear and non-integrable. From this straightforward discovery that decreed the end of the myth of determinism, Poincaré formulated the *ergodic* ipothesis.

conditions that satisfy the notion of *self-organizing* system, as defined by Ashby in the 60's of the late century, and that Prigogine extended to the dissipative systems.
So, the "strangeness" of a chaotic attractor is related to three main factors:

1. If we consider the "stretching and folding" mechanism of pseudo-cycles creation and the consequent non-closed character of chaotic orbits, it becomes evident the *fractal, self-similar structure* of a chaotic attractor. In other terms, a chaotic trajectory never passes two times through the same point, so that, at whichever resolution you see at the trajectory, you will see always some self-repeating, and hence *self-similar* structure. In fact, if we see, for example, at the pseudo-cycle of the Lorenz attractor showed in the (Figure 6, right), it is not composed by one only line closed at "8" onto itself, but by a bundle of lines, each passing in the vicinity of the other, and no one of them is closed onto itself. In this way, a chaotic system satisfies the self-similarity condition characterizing any fractal structure (see Figure 7).

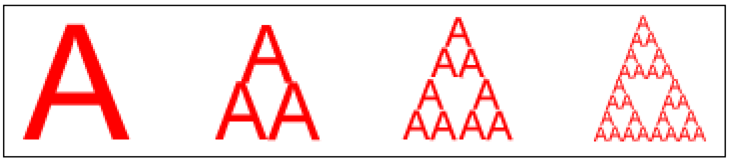

**Figure 7. A classic example of a fractal object, characterized by the self-similarity property. E.g., if we observed by a lens the first "A" on the left, we should not see many small A's, but simply many little ink spots. This means that at different resolutions the object does not have the same structure, it is not self-similar. The object has a structure only at a given resolution. On the contrary, at whichever resolution we see at a fractal object, it shows a structure repeating indefinitely itself. This is the case of the second, third and fourth images in the figure, generated from the first "A" through a recursive process of construction, repeatable indefinitely at ever higher resolutions.**

2. Finally, to understand the phenomenon of the "chaotic itinerancy" – a sort of non-locality characterizing the chaotic systems – consider that the dynamics can "jump" at every step of its evolution, and without any possibility of an *a-priori* prediction of the time evolution, among any point, of whichever pseudo-cycle of the attractor. In other terms, despite a chaotic attractor could seem similar to a torus attractor like in Figure 4, there is a substantial difference. Not only a torus attractor is an envelope made of *closed* cycles, while a chaotic attractor is made of *open* pseudo-cycles, but at each point of the time evolution of the dynamics on the torus attractor will follow a close point on the same cycle. On the contrary, at each point of the time evolution of a chaotic dynamics, the next one not necessarily is located on the same pseudo-cycles, but in an unpredictable way, the next point could be wherever on the attractor, on whichever other pseudo-cycle. For instance, in the case of the Lorenz attractor showed in (Figure 6, center), from a point on the left "wing" of a given pseudo-cycle, the dynamics, at the following step, could jump, in an absolute unpredictable way, onto a point located in the right "wing" of another pseudo-cycle, so to justify the erroneous impression of *randomness* of a chaotic time-series. Only a deeper analysis of *auto-correlation*, might reveal, on the contrary, the presence of such a rich structure of recurrences, and hence of a self-organizing order-out-of-chaos, on the *temporal* dimension. This is the case also of the discovery of chaotic dynamics in the brain: by analyzing that for many neurophysiologists, not trained in data analysis, consider as background noise, related to the continuous activity of the neurons.
3. Finally, the third oddity that make so "strange" a chaotic attractor is that a chaotic trajectory, even though *unpredictable*, is *deterministically reproducible*, so to justify the paradoxically definition of "*deterministic* chaos". In other terms, not only the chaotic unpredictability is different from the quantum one – we can speak of "trajectories" not only of "wave functions" – but is different also from the *stochastic system* unpredictability. Stochastic systems are studied by statistical mechanics according to the paradigm of *Langevin equation* (Paul Langevin, 1872-1946), originally developed for studying the *Brownian motion*, typical of the casual motion of particles in thermal agitation. Accordin to such an equation, the function *v* (*x*), describing the macroscop-

ic evolution of an obsevable quantity of the system, is not sufficient for defining the instant state of *x*. Its is necessary to add a perturbation term (noise) according to the following:

$$\frac{dx}{dt} = v(x) + \sigma(x)\xi$$

Where σ (*x*) is the amplitude of the perturbation, and $\xi = {dw}/{dt}$ is known as "white noise", a perturbation term that can be considered as derivative of a Wiener process. As the equation shows, the randomness is here an *extrinsic,* additive as to the dynamics *v* (*x*). In fact, in Langevin formalization, such a term want to signify the effect of a random perturbation, constantly applied from the *outside* of the system. On the contrary, in the case of dynamic instability, like in Poincaré's "three body dynamics", or in chaotic dynamic systems, we are faced with an *intrinsic lack of determinism,* linked to the dynamic evolution of the system itself. For this reason, a chaotic dynamics is unpredictable. Nevertheless, if we use exactly the same parameters, differently from a stochastic system, it will reproduce exactly the same trajectories.

### 6.4 From computational models of chaos to real physical complex systems

The previous characterization of chaotic dynamics are surely useful for educational aims, but all the previous distinctions among different classes of dynamic systems are not mutually exclusive in physical and overall in biological reality where they coexist, so contributing to the real *complexity* of the biological and neural systems.

Particularly, for our aims it is essential for a suitable development of a *theoretical computational and cognitive neuroscience* to understand how the *fundamental quantum microscopic level* interacts with the *mesoscopic and macroscopic phenomena* studied by neuroscientists where both the chaotic and the stochastic behaviors manifest themselves in a significant interplay. On this point see the session 4 of this paper.

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