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Intelligence and reference.

Formal ontology of the natural computation

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Abstract. In a seminal work published in 1952, "The chemical basis of morphogenesis", A. M. Turing established the core of what today we call "natural computation" in biological systems, intended as self-organizing dissipative systems. In this contribution we show that a proper implementation of Turing's seminal idea cannot be based on diffusive processes, but on the coherence states of condensed matter according to the dissipative Quantum Field Theory (QFT) principles. This foundational theory is consistent with the intentional approach in cognitive neuroscience, as far as it is formalized in the appropriate ontological interpretation of the modal calculus (formal ontology). This interpretation is based on the principle of the "double saturation" between a singular argument and its predicate that has its dynamical foundation in the principle of the "doubling of the degrees of freedom" between a brain state and the environment, as an essential ingredient of the mathematical formalism of dissipative QFT.

Keywords: Morphogenesis, quantum field theory, self-organizing systems, dissipative structures, double saturation, degrees of freedom doubling, chaotic trajectory, cognitive neuroscience.

1 Introduction

1.1 Natural computation and algorithmic computation

Today the *Natural Computation* (NC) is considered as an alternative paradigm to the *Algorithmic Computation* (AC) paradigm in natural sciences and in computer sciences, being the paternity of only the latter one generally ascribed to Alan Mathison Turing (1912-1954) pioneering work. On the contrary, after the publication of his famous seminal paper on algorithmic computation in 1936 [1] based on the notions of Turing Machine (TM) and Universal Turing Machine (UTM), Turing worked for widening the notion of "computation" in the direction of what today we define as "natural computation".

Before all, he defined the notion of Oracle-machine(s)[1] and of their transfinite hierarchy, in his doctoral work at Princeton, under the Alonso Church supervision, published in 1939 [2].

[1] I.e., a TM enriched with the output of operations not computable by a TM, endowing the TM with the primitives of its computable functions.

Afterward, in 1947, in a lecture given at the *London Mathematical Society* [3], and hence in an unpublished communication for the *National Physical Laboratory* in 1948 [4], he sketched the idea of computational architectures made by undefined interacting elements, that can be suitably trained, so to anticipate the so-called Artificial Neural Networks (ANN) computational architectures.

Finally, in a much more known contribution on a new mathematical theory of morphogenesis, published in 1952 [5], Turing was the first who studied a model of pattern formation via non-linear equations, in the specific case of chemical reaction-diffusion equations simulated by a computer.

This pioneering work on non-linear systems, and their simulation via computers, is, indeed, among all the pioneering works of Turing, the most strictly related with the new paradigm of NC, because of its wide field of application in practically every realm of mathematical and natural sciences, from cosmology and fundamental physics, to thermodynamics, chemistry, genetics, epigenetics, biology, and neurosciences; but also in human sciences, from cognitive and social sciences, to ecology, to economical sciences, to linguistics, …, and wherever a mathematical modeling of empirical data makes sense.

In a recent paper devoted to illustrate the new paradigm of NC in relationship with the old paradigm of AC [6], G. Dodig-Crnkovic emphasizes the main differences between the two paradigms that can be synthesized according to the following, main dichotomies:

1. *Open*, interactive agent-based computational systems (NC)[2] vs. *closed*, stand-alone computational systems (AC);
2. Computation as *information processing and simulative modeling* (NC) vs. computation as *formal (mechanical) symbol manipulation* (AC);
3. *Adequacy* of the computational response via self-organization as the main issue (NC) vs. *halting problem* (and its many, equivalent problems) as the main issue in computability theory (AC).

Of course, such dichotomies must be intended, in perspective, as oppositions between complementary and not mutually exclusive characters of computation models. However, as Dodig-Crnkovic emphasizes, such a complementarity might emerge only when a foundational theory of NC will be sufficiently developed, overall as to the semantic and the logic of NC. The present contribution is devoted precisely to this aim, even though it is necessary to add to the previous list other two essential dichotomic characters of NC, emphasized by Dodig-Crnkovic in other papers, overall the more recent one published on the *Information* journal [7]:

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[2] So, she synthesizes this important fundamental character of NC approach: «Agent Based Models are the most important development in this direction, where a complex dynamical system is represented by interacting, in general adaptive, agents. Examples of such systems are in physics: turbulence, percolation, sand pile, weather; in biology: cells organs (including brain), organisms, populations, ecosystems; and in the social sphere: language, organizations, and markets».

1. *Intentional, object-directed, pre-symbolic* computation, based on *chaotic* dynamics in neural computation (NC) vs. *representational, solipsistic, symbolic computation,* based on *linear* dynamics, typical of the early AI approach to the cognitive neuroscience (AC).
2. *Dual ontology* of the energy-information distinction in natural (physical, biological and neural) systems (NC), based at the foundational level on Quantum Mechanics (QM), vs. *monistic ontology,* based on the energy-information equivalence in all natural systems (AC).

1.2 Relevance of the reference problem in NC

In this paper, we want to suggest how a foundational approach to NC, overall as to its logical and semantic components, cannot disregard the essential point of how to *integrate in one only formalism* the *physical* ("natural") realm, with the *logical-mathematical* ("computation") one, as well as their relationships. That is, the passage from the realm of the *causal* necessity ("natural") of the physical processes, to the realm of the *logical* necessity ("computational"), eventually representing them either in a sub-symbolic, or in a symbolic form. This foundational task can be performed, by the newborn discipline of *theoretical formal ontology* [8,9,10,11,12], as distinguished from *formal ontology engineering* – an applicative discipline, well established and diffused in the realm of computational linguistics and semantic databases.

Particularly, the distinction between the *formal logic* and the *formal ontology* is precious for defining and solving a foundational misunderstanding about the notion of *reference* that the NC approach had the merit of emphasizing, making aware of it the largest part of the computer science community – and also the rest, we hope, of the scientific community, as far as NC is spreading all over the entire realm of the natural sciences.

In fact, as A. Tarski rightly emphasized since his pioneering work on formal semantics [13], not only the *meaning* but also the *reference* in *logic* has nothing to do with the *real*, *physical world*. To use the classic Tarski's example, the semantic reference of the true statement "the snow is white" is not the whiteness of the crystalized water, but at last an empirical set of data, to which the statement is referring, eventually taken as a *primitive* in a given formal language. In other terms *logic* is always *representational,* it concerns relations among tokens, either at the *symbolic* or *sub-symbolic* level. It has always and only to do with representations, not with real things. This is well emphasized, also, by R. Carnap's principle of the *methodological solipsism* in formal semantics [14], that both (the early) H. Putnam [15] and J. Fodor [16] rightly extended also to the *representationalism* of cognitive science, as far as it is based in the so-called *functionalist* approach of the classic, symbolic AI, and hence of the classic AC paradigm. Finally, this is also the deep reason for what Quine defines as the "impenetrability of reference" beyond the network of equivalent statements, signifying the same referential object in different languages [17].

Now, in AC, any formal theory of reference and truth is faced with the Gödelian limits making impossible a recursive procedure of satisfaction in a semantically closed formal language. What we emphasized also elsewhere [18,19,20], as the core of the reference problem, is that such a recursive procedure, for being complete, would imply the solution of the *coding* problem through a diagonalization procedure; that is, the solution of the so–called "Gödel numbering" problem. In computational terms, the impossibility of solving the coding problem through a diagonalization procedure in AC means that no TM can constitute by itself the "basic symbols" of its own computations. For this reason Tarski rightly stated that, at the level of the propositional calculus, the semantic theory of truth has nothing to say about the conditions under which a given simple ("atomic" in L. Wittengstein's terms) proposition can be asserted. And for this very same reason, in his fundamental paper about *The meaning of "meaning"* [15], Putnam stated that no ultimate solution exists in logic both of the problem of *reference* and, at the level of linguistic analysis, of the problem of *naming.*

In this sense, Putnam stated, we would have to consider ultimately names as *rigid designators* in S. Kripke's sense [21], i.e. in a "one – to – one relationship" with their singular referential objects. However no room exists, also in Kripke's theory of the *partial reference* [22], for justifying formally (algorithmically) the condition of self-reference that the notion of rigid designation supposes. Kripke's modal theory, indeed, uses, in the context of a "three-valued logic", Kleene's genious solution of the partial recursive predicates, for dealing with the problem of the enumeration (*labeling*) of partial functions [23]. By defining the "label" outside the partial domain to be labeled, it avoids inconsistencies and hence undecidabilities, but at the cost of a *substantial arbitrariness* in defining the label. Hence a formal language has always to suppose the existence of names (or numbers) as rigid designators, and cannot give them a non-arbitrary foundation. However what the logic necessity cannot in principle give, the causal necessity could give, as R. Penrose suggested [24].

It is thus evident the necessity of *formal ontology* for formalizing a non-arbitrary approach to the meaning/reference problem in the NC paradigm. That is, it is evident the necessity of *a formal calculus of relations* able to include in the same, coherent, formal framework both "causal" and "logical" relations, as well as the "pragmatic" (real, causal relations with the cognition/communication/computation agents), and not only "syntactic" (logical relations among terms) and/or "semantic" (logical relations among symbols) components of meaningful actions/computations/cognitions.

2 From formal logic to formal ontology

2.1 Three eras in the interpretation of modal logic syntactic structures

Following [25], we can distinguish three eras in the short history of the modern modal logic.

1. The *first era* is related with the origins of modern modal logic. 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 [26,27,28] the limit of using the "material implication" of extensional logic also for the formalization of other types of *deduction/demonstration,* typical of the humanistic disciplines. At the same time, Lewis' vindication of the oddity of what is today defined as *philosophical logic,* with respect to the *mathematical logic* of the *Principia*, recognized also the power that the axiomatization of mathematical logic will have for the worldwide diffusion of the 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[3]. 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.).

2. After Lewis' pioneering work devoted to the intensional interpretations of modal syntactic structures, the *second era* of modal logic development, 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,* as 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, mathematical and algebraic interpretations (models) of the modal structures.
3. All this is related to the so-called *third era* of modern modal logic, from 80's of the last century till now, that is, to *the algebraic interpretation of modal logic,* and of Kripke's relational semantics based on frames. This way back from the philosophical to the 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. Of course, this holds also for the models of *computational physics* and *biology*. This algebraic interpretation is based on two fundamental principles defining the relations between modal logic and mathematical logic:
   (a) 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, and hence of computer programs too.
   (b) 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 (energy-information) ontology* emerging from:

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[3] 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 (did) not occur too (= it is *false* in ontological sense).

1. The *information-theoretic approach in quantum physics and cosmology* ("It from bit"), in the wider context of a *relational interpretation* of QM [29], perfectly consistent also with its *modal* interpretation [30,31,32,33]. We cannot develop here this point (for an updated synthesis, see [34]).
2. The *information-theoretic approach* of dissipative QFT and its *algebraic* formalism, as a foundational theory of the dissipative structures, applied to the study of the chemical and the biological systems, neural systems included.
3. The *theoretical cognitive science,* since the modal logic furnishes scientists and philosophers with *one only syntactic formalism,* capable of bridging among causal (physical), intensional (psychical), and computational (logical) components of the cognitive agency. This is fundamental for an effective solution *of the reference problem.*

2.2 Intensional interpretations of modal logic

The *modal logic* with all its *intensional* interpretations constitutes the "first era" of its development, i.e., what is today defined as *philosophical logic* [35], 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].

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:

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 α 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] 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., $\mathbf{A}\leftrightarrow\mathbf{B}\Rightarrow\mathbf{A}=\mathbf{B}$ - 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 – of the extensional predicate calculus hold in intensional logic(s). Consequently, also the Fegean notion of *extensional truth* based on the truth tables does not hold in the intensional, predicate and propositional calculi. 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 J. Searle, from within a solid tradition in analytic philosophy, rightly emphasized [75]. 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 [76].

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, given by the ordinary propositional calculus **k** plus the necessitation axiom **N,** some interesting modal systems are for our aims are: **KT4** (**S4,** in early Lewis' notation), typical of the physical ontology; **KT45 (S5,** in early Lewis' notation), typical of the metaphysical ontology; **KD45** (**Secondary S5),** with application in deontic logic, but also in epistemic logic, in ontology, and hence in NC as we see.

As we said (see note 4), the extensional notion of truth does not hold in intensional logics, but each of them has its own *truth condition* characterizing it. Generally, the truth condition of a given intensional logic is expressed in *terms of a reflexivity principle,* i.e., a formal scheme that, by applying the proper modal operator of this logic on its argument, is able to give back it as *true*. So, 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 worlds", while the possibility operator $\Diamond p$ is interpreted as "p is true in some possible worlds". So, the *reflexivity principle* for the necessity operator in its alethic interpretations 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., $\mathbf{O}p \not\rightarrow p$**,** where **O** is the necessity operator in deontic context. In fact, the obligation operator **O**p must be interpreted as "p is true in all *ideal* worlds" different from the actual one, otherwise **O**=$\Box$, i.e., we are in the realm of (meta)physical 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,

$$(\mathbf{O}p\rightarrow p) \Leftrightarrow ((\mathbf{O_p}\,(x,p) \wedge c_a \wedge c_{ni}\,) \rightarrow p) \qquad (1)$$

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 representations of the real world we have a different intensional interpretation of modal operators. The interpretations of the two modal epistemic operators **B**(x,p), "x believes that p", and **S**(x,p), "x knows that p" are the following: **B**(x,p) is true iff p is true in the realm of representations believed by x. **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:

$$\mathbf{S}(x,p) \Leftrightarrow (\mathbf{B}(x,p) \wedge \mathbf{F}) \tag{2}$$

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 a "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 "believing". So, for instance, in the context of a *logicist* ontology, such a **F** is interpreted as a supposed actually infinite capability of human mind of attaining the logical truth [36]. We will offer, on the contrary, a different *finitistic* interpretation of **F** within NC **.** Anyway, as to the reflexivity principle in epistemic context,

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

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 hence 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:

$$\mathbf{S}(x,p) \rightarrow p \tag{3}$$

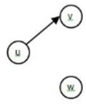
2.3 Kripke's relational semantics

The "second era" of modern modal logic is related with Kripke's relational semantic that is an evolution of Tarski formal semantics, with two specific characters: 1) it is related to an *intuitionistic logic* (i.e., it considers as non-equivalent excluded middle and contradiction principle, so to admit coherent theories violating the first one), and hence 2) it is compatible with the *necessarily incomplete character* of the formalized theories (i.e., with the Gödel theorems outcome), and with the *evolutionary character* of natural laws, not only in biology but also in cosmology. In other terms, while in Tarski classical formal semantics, 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 of 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 [37,38].

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 syntactic structure in a relational logic, has as many senses as the semantic models that can be consistently defined on it. In Kripke words, the notion of "possible world" in his 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 interpretations (alethic – ontology included –, deontic, epistemic, etc.) of modal logic became possible, as well as a graphic representation of their relational semantics.

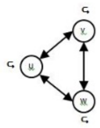
The basic notion for such a graphic representation is the notion of *frame.* This is an ordered pair , <**W**, *R*>, constituted by a domain **W** of possible worlds {*u, v, w*…}, and a by a two-place *relation R* defined on **W**, i.e., by a set of ordered pairs of elements of **W** ($R \subseteq \mathbf{W}\times\mathbf{W}$), where **W**×**W** is the *Cartesian product* of **W** per **W**.

E.g. with $\mathbf{W} = \{u,v,w\}$ and $R = \{uRv\}$, we have:



(4)

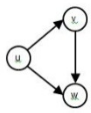
According to such a model, the accessibility relation *R* is only in the sense that *v* is accessible by *u*, while *w* is not related with whichever world. If in **W** all the worlds were reciprocally accessible, i.e., R = $\{uRv, vRu, uRw, wRu, wRv, vRw\}$, then we would have *R* only included in **W**×**W**.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



(5)

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 *R, transitive, symmetrical* and *reflexive* relation 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 of the universal and existential quantifier, we can discuss also the particular *Euclidean relation* that can be described in a Kripke frame.

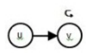
The Euclidean property generally in mathematics means a weaker form of the transitive property (that is, if one element of a set has the same relation with other two, these two have the same relation with each other).
I.e.,<(om *u*) (om *v*) (om *w*) (*uR*v et *uRw* ⇒ v*R*w)> :



(6)

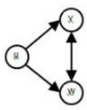
Where *et* is the meta-symbol for the logical product.

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



(7)

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



(8)

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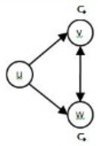
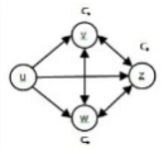
5 For ontological applications it is to be remembered that seriality means in ontology that the causal chain is always closed, as it is requested in physics by the first principle of thermodynamics, and in metaphysics by the notion of a first cause of everything.

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 based on an Euclidean relation with a third one:



(9)

Of course, this procedure of *equivalence constitution by a transitive and serial* (=causal) relation can be iterated indefinitely:



(10)

Let us consider now the algebraic interpretation of modal logic applied to the QFT approach to biological and neural systems for an original solution of the reference problem in formal ontology.

3 Dissipative QFT in biological and neural systems and the formal ontology of the reference problem

3.1 "Coherent states and coherent domains in the physics of the living matter"

The title of this sub-section is between quotation marks because effectively it is the title of a recent review paper of the Italian physicist, Giuseppe Vitiello, from the University of Salerno [39]. 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 dissipative systems, the biological systems and the brain — the "dissipative brain", according to his very effective expression — included.

In fact, it is evident that the vital functions do 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 "morphogenesis" [5], because of the *casual character* of diffusive processes. 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 efficiently "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 [40] [41]. The medium in which such oscillating electromagnetic fields occur is the *water*, constituting more than 70% of our bodies, over the 80% of our molecules, in which all the proteins of our bodies are immersed, and in which only the biomolecules are *active*. Now, what characterizes both water molecules and organic molecules is a strong *electrical dipole field.* So, 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*" ([39], p. 16. For the mathematical apparatus of the theory, see [42,43,44,45,46,47]). 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, 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 correlation waves is the *fine-tuning* of the elementary oscillations. The "coherence" consists in such a *being in phase.* 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 Dual nature of the dissipative QFT approach to biological systems

Crystals, are, for instance, typical examples of early successful applications of QFT in the realm of non-living, condensed, 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.*

So, any process of *dynamic ordering,* and of *information gain,* is related with a process of *symmetry breakdown,* the symmetry of the disorder of the "quantum vacuum"[6], related to the "third principle of thermodynamics", i.e., with the irreducible motion of particles at the fundamental level and the associated quantum field. 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" [48,49,50], with mass — even though always very small (if the symmetry is not perfect in finite spaces) —, or *without mass at all* (if symmetry is perfect, in the abstract infinite space). Hence, differently from the *gauge bosons* (the photons γ of electromagnetic field; the gluons g of the strong field, the bosons $W^{\pm}$ and the boson Z of the weak field; and the scalar Higgs boson H^0 of the Higgs field, common to all the precedent ones), which are energy exchange mediators the Goldstone bosons simply vanish when the ordered *modality* of interaction they mediate disappear (e.g., by heating a diamond over 3,545 °C). This is the basis of the fundamental "Goldstone theorem" [51,52]. So, despite the correlation quanta are real particles, observable with the same techniques (diffusion, scattering, etc.) of other particles, not only in QFT of condensed matter, but also in QED and in QCD, wherever we have to reckon with broken symmetries [50], nevertheless they do not exist *outside* the system they are correlating. Also on this regard, a dual ontology is fundamental for avoid confusions and misinterpretations.

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

The background

As Perrone and myself emphasized in several papers on the physical basis of intentionality [20,18,53,54], 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

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[6] In a disordered macrostate, any microstate is equivalent and hence symmetric as to the whole conservation. This is no longer the case, when an ordered macrostate emerges: not all the microstates are equivalent as to the ordered macrostate conservation. Dynamic ordering is thus always related with a symmetry breakdown of the microstate equivalence.

"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, [55,56]).

To sum up [57], 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 neuro-physiologists, 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 [58,59,60,61], and regions of linear size of about 19 cm in human cortex [62], with near zero phase-dispersion [63]. 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 [64].

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 [65] 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 [66], 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 [65], 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 [67]:

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 [66], and to the wide literature quoted in [57]. 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 [56,57]:

1. 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.
2. QFT approach is 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 electro-chemical 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.
3. 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* [67], like all the approaches based on the intentional and not representational theory of mind [18,54,68,69,70,71]. This last remark opens the way to an ontological and hence logical interpretation of the DDF scheme.

3.4 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, ∈, 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 [72,10,54,11].

Thomas Aquinas (1225-1274)[7] 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).

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

[7] 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.

predicate *P,* "causally" driven by the referential object itself. DDF mechanism is evidently in an operational, even though unaware, continuity with such Aquinas' theory [73] [74].

On the other hand it is evident that the modal construction of an equivalence relation illustrated step by step in the frames (6)-(9) in §2.3 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 (6), *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 (8) and (7) 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 (9) constitutes an onto-logical depiction of an "unitary in-equivalent state", "labeled" by the referential object *u,* i.e., the "seed" of a new "equivalence class" (see frame (10)).

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 (see above §1.2). In this sense, because the modal equivalence does not generally implies bisimilarity[8] – but bisimilarity is implied only when the specific conditions of the famous van Benthem theorem occur ([25] pp.104ff.), so in our case bisimilarity occurs only when the "doubling" input/output is given in each cognitive agent[9]. 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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[8] 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.

[9] 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 ([77], p. 332).

4 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. Effectively, this approach satisfies all the NC features listed in §1.1. At the same time, following the *correspondence principle* between modal and mathematical logic (see §2.1), 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 NC approach, based on the dissipative QFT model to cognitive functions, as Vitiello himself proposed to develop [67]. 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 (see §1.2). 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.

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