WF-FI-BASTI1
Course Syllabus
«Towards a Contemporary Ontology: The New Dual Paradigm in Natural Sciences. Part I»

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Short Description:

This course constitutes the physical counterpart of the WI-FI-BASTI2 course, representing the formal logical-ontological part of the present one, being the coalgebraic formalism underlying both perspectives, the strong theoretical link connecting the two parts, into one coherent framework. The present course is concerned indeed with a descriptive ontology of the emerging new paradigm in fundamental physics, related with the so-called “information theoretic” interpretation of quantum field theory (QFT). The course aims essentially at deepening the notions of “information” and of “energy” in quantum physics, their differences and their relationships, as far as both are physical, measurable magnitudes. This study can help us for better understanding to what extent and in which sense these evidences support empirically and mathematically a “dual” ontology of the physical nature, having in the Aristotelian hylomorphic theory its pre-modern ancestor.

Full Description

Fundamental thesis of the course is that the quantum field theory (QFT) interpretation of quantum physics, as irreducible to the usual quantum mechanics (QM) interpretation, can offer, through the distinction and the indissoluble mutual dependence between gauge bosons and Nambu-Goldstone bosons in the constitution of every physical process/system, a suitable basis for supporting a dual ontology of nature. The course consists thus of four sections, each of two modules.

We give the first two sections in online modality, while we give the second ones by at-place classes.

The first two sections are devoted to a historical and epistemological reconstruction of the QFT background in modern physics.

In the FIRST SECTION we start from the atomistic ontology – of which Carnap’s logical atomism constitutes the formalized counterpart –and the representational epistemology underlying, not only the Newtonian mechanics, but also the statistical interpretation of quantum physics, typical of QM. What is to be stressed is that the inertia principle in mechanics is the necessary and sufficient condition for granting the applicability of the calculus to mechanics. Indeed, iff we are able to stop the derivation procedure to the second derivative (i.e., considering the system as closed or isolated) we can grant the integrability of the function.

In the SECOND SECTION we summarize the other two fundamental steps toward QFT. In the first module, we illustrate the main principles of QM, with a special attention to the difference between Wigner’s and Schrödinger interpretation of it, and with the birth of the “information theoretic” interpretation of QM, having in Feynman’s notion of “quantum computing”, and in Deutsch’s demonstration of the “Turing universality” of quantum computations, the two essential key-notions. In the second module, starting from the classical interpretation of QFT as a “second quantization”, w.r.t. QM, we illustrate the extraordinary successes of QFT in physics of the condensed matter, intimately related with the quantum vacuum (QV) notion, directly deriving from the third principle of thermodynamics, as a fundamental, ubiquitous, all including dynamic substratum of everything exists. What we will emphasize is the theoretical incompatibility of the “second quantization” interpretation of QFT – often disguised by the practical effectivity of calculations according to the QM paradigm – in physics of the condensed matter, given that it is here straightforwardly evident the necessity of interpreting QFT in the context of a quantized thermal field theory (TFT). In other terms, all the computational power of QM, both theoretical and practical, depends on the possibility of interpreting a quantum state as a “pure state” in the Hilbert formalism. This means that a quantum system in QM is interpreted as a “thermodynamically closed system”, according to the Newtonian paradigmatic notion of “isolated system”, core of any mechanistic ontology. This is however in marked contrast with the evidence that a quantum system is necessarily “open” to the ubiquitous QV fluctuations.

In the THIRD SECTION of the course, we illustrate, thus in the first module, the (co-)algebraic formalism of QFT as quantum TFT, based on the duality, in the category theory (CT) sense, between *q*-deformed Hopf algebras and coalgebras. In it, the deformation parameter, *q*, breaking the perfect symmetry of the classical Hopf bialgebra, and inducing a topology (set partial ordering) in it, is a thermal parameter. We illustrate the successful applications of thermal QFT both in the relativistic microscopic domain, and in its macroscopic many-bodies domain, emphasizing its relevance at the fundamental level for cosmology and for the standard model theory in quantum physics. This interpretation demonstrates indeed the inconsistency of the QFT interpretation as a “second quantization” w.r.t. QM, because the Stone-Von Neumann theorem (SVT) of the finitely many equivalent unitary representations of the canonical commutation representations (CCR), characterizing QM, does not hold in QFT. In other terms, the Hilbert formalism, strictly related to SVT, is recovered in QFT iff we include as an intrinsic component of any quantum system its thermal bath. Such an interpretation gives an ultimate coherence to the third principle of thermodynamics, as far as it necessarily supposes the presence of an “internal reservoir of energy” in whichever physical system. In this way, the “reverse of the arrows” (and of the compositions order), generally characterizing the homomorphism between an algebra and its coalgebra – in our case, between *q*-deformed Hopf algebras/coalgebras – finds as well a natural physical interpretation in the condition of energy balance, even in far from equilibrium conditions. Finally, for the very same reason, the non-commutative character of the morphisms in the *q*-deformed algebra-coalgebra relationship gives also an immediate physical and experimental sense to the non-commutative geometry interpretation of quantum physics developed by A. Connes and his colleagues, and by the Polish philosopher and mathematician M. Heller. QFT, indeed, is perfectly compatible with the algebraic interpretation of entropy allowed in the non-commutative geometry interpretation. Finally, QFT (co)algebraic duality finds its natural and experimentally controllable expression in the principle of the doubling of the degrees of freedom (DDF) between a system and its entangled thermal bath, which is a natural ingredient of any TFT theory in its C^*-algebraic interpretation.

In the second module of the third section, we discuss the consequence of the DDF principle of QFT both in fundamental physics and in physical ontology. We start from the formal evidence that such N “degrees” correspond to N collective oscillation modes of the fields/particles, and hence to N phase coherence domains allowed by the system topology. Because they are mediated by as many condensates of NG bosons, this opens the way to a quantum foundation of the notion of “dissipative structures”, of which relevance for the physics of chemical and biological systems as complex systems is well known. A quantum foundation that is lacking in Prigogine’s original theory. At the same time, it satisfies also a strong “dual” interpretation of the notion of information as “neghentropy” in quantum systems, certainly according to its original Schrödinger definition, interpreting it as “free energy”, but satisfying directly the intuition of the Nobel Prize A. Szent-Györgyi, during the 30’s of the last century. According to him, what makes “free” the energy supply to a system, making it able to perform a “work”, is an “organization” principle “channeling” the input energy “at the right place/time” to perform a work, without wasting it. This dynamic channeling function is in natural relationship with the notion of “phase coherence domain”, as also the everyday experience of “resonance” phenomena makes evident to everybody. All this finds its natural expression, at the fundamental level, by the rewriting of the wave-particle duality principle in QFT, w.r.t. to its original formulation in QM, with two emerging differences. The concerned “waves” are in QFT physical, force field oscillations, and not statistical representations of measurements, strictly depending on the experiment preparation, like in De Broglie-Schrödinger wave function interpretation of QM. Moreover, where a phase coherence appears as characterizing a collective behavior, it becomes physically meaningless to maintain the supposition of the existence of individual particles that become as many quanta of the relative force field, because the properties of the new matter phase are irreducible to the summation of those of the composing elements. We show that this “ontological” mutation finds its more natural interpretation in terms of Aquinas theory of “substantial unity” as an emerging new individual, and as depending on its substantial “form” organizing element dynamical interactions, within the wholeness of the new substance. On the other hand, at the cosmological level: 1) the algebraic interpretation of QV in the infinite volume limit, in terms of the infinitely many inequivalent unitary representations of CCR, and 2) the consequent principle of the infinitely many spontaneous symmetry breakings (SSB) of the QV at the ground level, each corresponding to the elicitation of a given phase coherence domain “inside it”, find their natural ontological interpretation in two other principles of hylomorpism. They correspond, respectively, 1) to the Aristotelian notion of the infinite potentiality of the “prime matter”, dynamically defined by him as “its being finite and ever always different”, and 2) to the principle of the “eduction” of forms from the matter, according to the very subtle analysis of this principle performed by Aquinas himself over the Aristotelian early intuitions.

Finally, IN THE FOURTH SECTION, at the end of such a fascinating itinerary, we come back to the informational/computational interpretation of quantum physics from the standpoint of QFT. We start from the demonstration of the formal utility of the interpretation of QFT formalism in terms of the notion of "Universal Coalgebra" (UC), as dual of the "Universal Algebra" (UA) one. J. Rutten introduced UC notion only fourteen years ago, as a general theory of dynamic systems and of computing systems, interpreted as state transition systems (STS), producing an impressive quantity of publications in the field of theoretical computer science (TCS), but also in the field of theoretical physics . A deeper analysis of UC notion is object of the complementary course. Nevertheless, two notions are important for us. In UC it is possible to define formally the notion of "observational (behavioral) equivalence" corresponding to the common sense evidence that two systems/machines are equivalent, if their behaviors are observationally indistinguishable. This notion is different from the other coalgebraic one of "equivalence by bisimulation (bisimilarity)", involving instead the equivalence of states, and not only of the observable behaviors of the dynamic/computational systems studied. Both notions, however, are "dual" in UC as to the notion of algebraic "congruence" and "substitution by congruence" in UA. The notion of "observational equivalence" is particularly useful, of course, in quantum computing, given that in quantum physics, both in QM and QFT, we work exclusively on the physical observables and not on the physical states. The other notion is the possibility of formalizing in UC the semantics of an infinite data type (stream), in terms of satisfiability of each algebraic formula in some of the infinitely many states of the system, so to give a computational equivalent of the notion of QV as the "final" UC of all QFT systems. In it, each QFT system behavior is representable in terms of a final sub-coalgebra (topology) of its dual sub-algebra. All this opens the way to the possibility of interpreting the (co)algebraic formalism of QFT as describing a particular class of STM, so to define a new class of quantum computers based on QFT. The universality in their computations can be justified in terms of a "(co-)algebraic universality", given that the "Turing universality" of QM does not hold in QFT computing systems. However, while is well-known that every Turing machine (TM) is representable as a STS, the opposite it is not true. The Coalgebraic Universality Criterion in computability is wider than the Turing Universality Criterion, indeed. On this basis, we can offer a systematic comparison between some essential QM and QFT notions of computing systems, starting from the two most intriguing ones.

Whereas in QM computations a Hamiltonian operator controls the two-level state, i.e., the q-bit state, in QFT the double q-bit state is controlled by a free-energy like (covariant derivative) operator, with the (electromagnetic) gauge field acting as entropy, and where a geometric phase, indicating a singularity, appears. Now, in QFT computations, according to the DDF principle, the "free-energy" is a dynamic, intrinsic, measure of the distance between the two algebraic (topological) structures (an initial algebra with its dual final coalgebra) involved. Respectively – in the doubled representation space characterizing a QFT computing system – of the input (algebraic) space and of the output (coalgebraic) space, so that only when this distance becomes null, the quantum gate switches to "1". This means that such a QFT version of a q-bit implements effectively the CNOT (controlled NOT) logical gate, essential for granting universality in computation, which flips the state of the q-bit, conditional on a control of effective input matching, according to some constraints (matching criteria), which, in our case, are purely dynamic and hence *automatic*.

Finally, and this is the second most intriguing property, in QFT computations no read-out problem from the micro- to the observable macro-state exists, like in QM, because no quantum decoherence phenomenon appears in QFT during such a passage. In QFT, whichever phase-coherence domain implies intrinsically a robust change of scale from the micro- to the macro-state, as an infinity of condensed matter phenomena demonstrate, so that no decoherence exists. Such properties can be of an extreme interest in TCS, given that a phase coherence domain in dynamics corresponds to a given correlation order in geometry and/or a given "clustering of the variables" in statistics and functional analysis. In this way, a computing device based on such QFT principles is able to define automatically by DDF on its output space (= Coalgebra) a "filter" (topology) fitting with the hidden correlations of its input data set (= Algebra). Such a property is always extremely interesting in TCS, but overall it is interesting when we are faced with the computational management of the so-called "big-data" problems, where to find the significant inner correlations among the data – and not according some our arbitrary "embedding" of them in some space of reduced dimensionality – is often a "mission impossible"…

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Course Schedule (every module corresponds to 4 classes, except those in italic font (1 class):

Modules	Topic	Suggested Reading
	SECTION ONE	
0.	*Introduction and Course Overview*	
1.	The Birth of Modern Science	References: 1, chs. 0, 1, 2.
2.	The Question of Truth in Modern Science	References: 1, chs. 3, 4.
	SECTION TWO	
3.	The Information Theoretic Interpretation of QM	References: 4-10.
4.	QFT interpretation as 'Second Quantization' and the Physics of the Condensed Matter	References: 11, vi-xii, 1-35, 137-178; 12; 13.

Modules	Topic	Suggested Reading
	SECTION THREE	
5.	The (Co)Algebraic Interpretation of QFT as *q*-deformed Hopf Algebra / Coalgebra	References: 11, 131-185; 14.
6.	The DDF Principle of QFT, its Cosmological Relevance and Its Ontological Interpretation	References: 14; 15-19; 1, ch. 5; .
	SECTION FOUR	
7.	Universal Coallgebra and the Interpretation of QFT Systems as STS	References: 16.; 20
8.	*Conclusions*	

Examinations:

Evaluation of an examination paper prepared by the student about some topics developed in the course.