Uniwersytet
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Towards a Contemporary Ontology

The New Dual Paradigm in Natural Sciences: Part I

Module 3: The Information Theoretic Interpretation of QM

Course WI-FI-BASTI1

2014/15

Introduction

Module 3: The information theoretic interpretation of QM

Course modules

Modules	Topic	Suggested Readings
	SECTION ONE	
0.	*Introduction and Course Overview*	
1.	The Birth of Modern Science	Refs.: **1**, chs. 0, 1, 2.
2.	The Question of Truth in Modern Science	Refs.: **1,** chs. 3, 4.
	SECTION TWO	
3.	The Information Theoretic Interpretation of QM	Refs.: **4-10**.
4.	QFT interpretation as 'Second Quantization' and the Physics of the Condensed Matter	Refs.: **11**, pp. vi-xii, 1-35, 137-178; **12; 13**.
	SECTION THREE	
5.	The (Co)Algebraic Interpretation of QFT as q-deformed Hopf Algebra / Coalgebra	Refs.: **11,** pp. 131-185; **14**.
6.	The DDF Principle of QFT, its Cosmological Relevance and Its Ontological Interpretation	Refs.: **14-19**; **1**, ch. 5.
	SECTION FOUR	
7.	Universal Coalgebra and the Interpretation of QFT Systems as STS	Refs.: **16**; **20**
8.	*Conclusions*	

Bibliography

Bibliography of the Module 3

Bibliography I

- **Main Reference for the Module 3**:

1. Gianfranco Basti, "From formal logic to formal ontology. The new dual paradigm in natural sciences," in *Proceedings of 1st CLE Colloquium for Philosophy and History of Formal Sciences, Campinas, 21-23 March 2013*, F. M. Bertato (Ed.), Campinas, Brazil, 2014 (In Press). Particularly, Sects. 1-3 [attached].

- **Other references:**

2. Gianfranco Basti, *Philosophy of Nature and of Science. Volume I: The Foundations,* transl. by Philip Larrey, Rome 2012 (for student use only), ch. 2 [attached].
3. RICHARD FEYNMAN, «Simulating physics with computers», *Int. J. Theor. Phys.*, 21 (1982), 467–488.
4. D. DEUTSCH, «Quantum theory, the Church-Turing principle and the universal quantum computer», *Proc. R. Soc. Lond. A*, 400 (1985), 97–117 [attached].

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5. John Archibald Wheeler, «Recent thinking about the nature of the physical world: It from bit», *Ann. N. Y. Acad. of Sci.*, 655 (1992), 349-64.

6. *Information and the nature of reality. From physics to metaphysics*, Paul Davies & Niels Henrik Gregersen (eds.) , Cambridge UP , Cambridge, 2010.

7. Paul Davies, «Universe from bit», in *Information and the nature of reality. From physics to metaphysics.*, pp. 65-91.

8. Hans Dieter Zeh, «Wave function: 'it' or 'bit'?», in *Science and Ultimate Reality*, John D. Barrow, Paul C. W. Davies, Charles L. Harper Jr. (eds.), Cambridge UP , Cambridge, MA, 2004, pp. 103-120 [attached].

9. R. Penrose, «Foreward», in *A computable universe. Understanding and exploring nature as computation. Foreword by Sir Roger Penrose*, Hector Zenil (ed.), World Scientific Publishing , Singapore-Hackensack, NJ-London, 2013, pp. i-xxxvi.

Module 3 Class

The Information Theoretic Interpretation of QM

QM background I: Quantization principle

1. **Principle of quantization (1900):** In that year, more exactly on December the 14th, speaking at a meeting of the German Society of Physics, **Max Planck** (1858-1947) claimed that it was possible to free ourselves from the paradoxes of the classical theory of the emission-absorption of light by matter, if one accepted that *radiant energy could exist only under the form of discrete packets* that he defined as *quanta of light*.

   - This discovery confirmed by **Albert Einstein** (1879-1955) discovery of the **photo-electric effect (1905)** for which is was awarded by **Nobel Prize** in 1921. Such an effect consists in the emission of electrons by metallic surfaces that are bombarded with violet and ultraviolet light. The effect in question could be explained only by admitting the quantum nature of electromagnetic radiation, that is, the existence of **photons** or elementary quanta of electromagnetic energy. Existence of photons as direct consequence of the **finite velocity of electromagnetic light propagation → no all frequencies allowed for the electromagnetic wawe → existence of wave packets (photons) → special relativity theory (1905).**

- ***Principle of quantization.* Every physical magnitude, in particular every dynamical magnitude or intensity of an energy *E*, is an integer multiple *n* of *h*, according to the relation: $E = \hbar\nu \times n$, where ν is a wave frequency**

  - **→ Confutatione of Descartes' second idea:** physical matter is not like geometrical extension, i.e., 1) **Non infinitely divisible** (matter **quantization**); 2) **Non infinitely localizable** (quantum **non-locality**).

- **Planck *h*:** new constant of nature, effectively the most measured one**. All the fundamental magnitudes of matter at the microscopical level are multiples of Planck's *h***:

$$h = 6.626176 \times 10–34 \text{ J/sec (quantum of action, energy/time)}$$

QM background II: Bohr’s atom

- **Bohr’s semi-classical atom:** The picture of confirmations of Planck’s discoveries was completed when, in 1913, the Danish physicist Niels Bohr (1885-1962) applied this quantum hypothesis to the model of the atom endowed with an internal structure, discovered by the New Zealand physicist Ernest Rutherford (1871-1937) for explaining why in the Rutheford’s atom electrons “orbiting” around the nucleus – being endowed with opposite charges – **do not collapse over the nucleus** with orbits ever narrower. This paradox can be solved by adding the quantization principle: **not all the orbits are allowed but only those with an energy that is an integer multiple of *h***.
  - For the same reason an electron, when “bombed” by an energy input with an intensity **that is an integer multiple of *h*** will “jump” to the next allowed orbit without “passing through”, the intermediate ones.
  - → Explanation of the periodic distribution of element atoms in the **periodic table of elements** defined by Dmitrij Mendelejev (1834-1907).
  - → Explanation of the **discrete emission of light spectra**, different for each chemical element ,and depending **on the discrete distributions of the electron «orbitals»** (effectively: levels of energy) around the nucleus.

QM background III: uncertainty principle and wave mechanics

- **Werner Heisenberg's (1901-1976) uncertainty principle:** From the quantization principle the uncertainty principle follows immediately, ending another myth of classical mechanics: the possibility of an endless increasing in measurement precision (see the Laplace demon supposition).

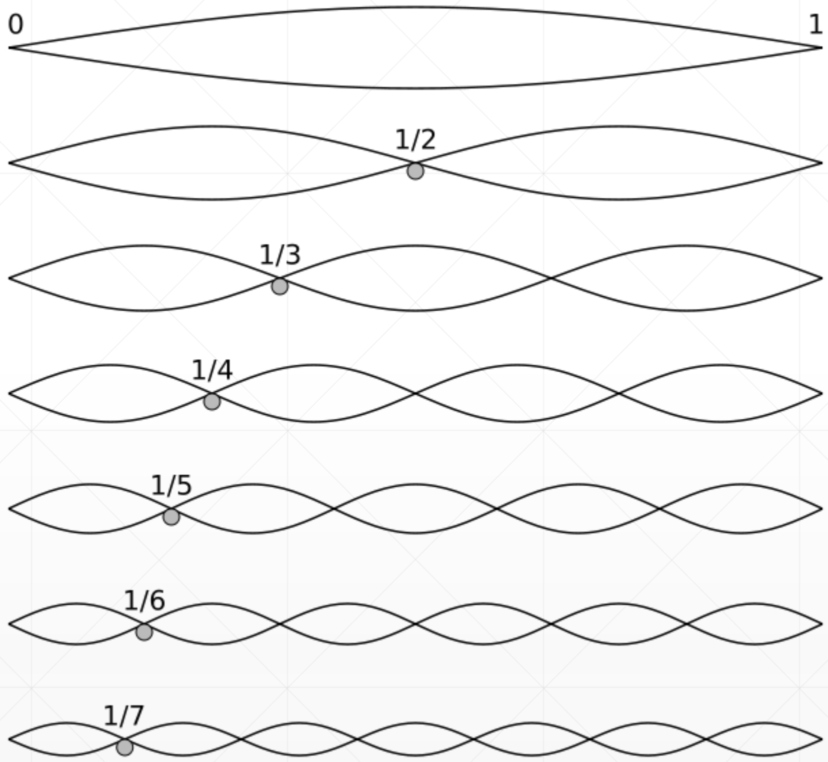
- ***Uncertainty principle.*** **The product of the uncertainties by which a magnitude and its conjugate are known (e.g., position and momentum) will never be inferior to** ***h*****:** $\Delta p\ \Delta q \geq h$.

- **Louis Victor Duke of De Broglie (1892-1975) idea of "wave mechanics (wave-particle duality)":** Bohr's disturbing idea of "jumping" between discrete orbitals can be avoid **by a suitable change of representation.** Instead of representing the evolution in time of the states of a quantum system by an **impossible one-dimensional trajectory** in the state space of the system supposing the perfect localizability of the particle in a point of the spece, if by the uncertainty principle, this localization corresponds to **a finite volume ("box"), with a side that is an integer multiple of** ***h*****,** within which the particle can be localized everywhere with the same probability, the **representation of the evolution in time** of such a volume will corresponds to a propagation of a **probability-wave with a given amplitude** depending on the "box" side.
  - Substitution of the Bohr's model of the atom as a planetary system with the wave-like model of the harmonic oscillator (e.g., in acoustics, a vibrating bell), that when hit with a hit that it is a multiple of *h* resonates by producing an acoustic wave), **provided that the De Broglie's (QM) waves are not oscillations of an energy field** like in the example of the bell**, but a geometrical representation of the evolution in time of our probability expectations on the particle positions.**
  - In this sense the «wave mechanics» is the quantum physics counterpart of the statistical mechanics, that is QM.

QM background IV: the Schrödinger equation

- **Erwin Schrödinger (1887-1961)** formulated a new and elegant mathematical theory of the hydrogen atom in terms of De Broglie's wave mechanics. For this, he received the Nobel Prize in 1933.
  - According to **Schrödinger's equation** Ψ, the different levels of energy into which a single electron of the hydrogen atom «jumps» when it is «excited» by the injection in the form of discrete energy from the outside, are calculated with incredible precision as **«vibrations» of a quantum harmonic oscillator**, **according to the «stationary waves» model**. This model describes the vibrations of an elastic string that is fixed at both extremes, as the strings of a violin or of a guitar, when it is played. By striking it, with an intensity that is two, three, or four times that of the original one, the string will vibrate proportionally with a frequency that is two, three, or four times the original. So, Ψ **is a linear equation**: with input-output proportionality.

An example of stationary wave



QM background V: the Schrödinger equation

- More exactly, **the wave function ψ(*x, y, z*)** that appears in the Schrödinger equation is a function of the spatial coordinates of the particle. If it is possible to find the solution to that equation for a given system (for example: an electron in an atom), then the solution, which depends on the boundary conditions (for example, the energy introduced into the system), **is a set of the allowed wave-functions (*eigen-functions*)** of the particle, each of them will correspond **to an allowed energetic level (*eigen-value*)**.

- That is, in every point, **the square of the wave function is proportional to the probability that the particle will be found in an infinitesimal element of volume, d*x* d*y* dz, centered on that point**. The electron has only a certain probability of occupying a given position of space. Such probability is given by the solution of Schrödinger's equation, to obtain the wave function ψ: indeed the probability of finding the electron in a given position **is proportional to $|\psi|^2$.**

- An *atomic orbital* instead of being an orbit, a trajectory in the classical sense, corresponds to **a distribution of probabilities of a spatiotemporal localization around the nucleus** or, which is the same, to **a distribution of electric charges, in average as to time.**

- → **Problem: how to perform calculations in QM?** The non-commutative character of the canonic variables in QM does not allow to use the powerful device of **the mathematical analysis** of classical mechanics, despite the linearity of Ψ. Indeed, its geometrical background suppose **the necessity of commutative algebras/spaces,** as Hilbert demonstrated by its **axiomatization of geometry.** Hilbert himself, however, suggested the genial solution…

The basic Hilbert formalism of QM

- It is well-known that the main difference between classical mechanics and QM is that **the canonic variables** of a classic mechanical system, i.e., the position *x* and the momentum *p*, do not commute in QM, because are dependent on each other, according to the **uncertainty principle:**

$$\Delta x \Delta p \geq \frac{\hbar}{2}$$

- I.e., in QM the canonic variables are *conjugate* and not *separate* like in classical mechanics. This implies that in QM the commutability of the relationship can be recovered only as a function of the uncertainty quantum by the action of an "operator", a *commutator*. In other terms, in QM the Canonical Commutation Relation (CCR) is the fundamental relation between canonical conjugate quantities, which are related in such a way that the one is the Fourier transform of the other, according to the following:

$$[x, p_x] = i\hbar$$

- Where p_x is the momentum in the *x* direction in one dimension, $[x,p_x] = xp_x - p_x x$ is the commutator of *x* and p_x, and *i* is the imaginary unit. Of course, in the classical case all observables commute and hence the commutator is null.

Two standard representations of CCR in QM

- In the standard mathematical formulation of QM, the vectors of **observable values, x** and **p,** are represented as **self-adjoint operators** on some **Hilbert space**.
  - Generally, a self-adjoint operator on a complex vector space *V* with **inner product** $\langle \cdot,\cdot \rangle$ is an **operator** (a linear map *A* from *V* to itself) that is its own **adjoint:** $\langle Av,w \rangle = \langle v,Aw \rangle$.
- For allowing finite dimensional representations, the CCR are then rewritten in terms of **unitary operators** exp(*it***x**) and exp(*is***p**). The **uniqueness** of the CCR is finally guaranteed by the famous **"Stone-Von Neumann" theorem**.
- Effectively, indeed there are two standard representations of QM in the formalism of the **Hilbert space** – a third important one, the **Wigner representation** is on the phase space:

1. **The Schröndiger representation** in which the states of the Hilbert space are **time-dependent** and the commutator is **time-invariant.** This formalism, strictly dependent on **Schröndiger wave-function** Ψ is useful in the **non-relativistic** domain of quantum physics, both for single particles and many particles (**many-body QM).**
2. **The Heisenberg representation** in which the states of the Hilbert space are **time-invariant** and the commutator is **time-dependent.** This is a **matrix formalism** and is more useful in the **relativistic domain** of quantum physics, because the Lorenz constant can be naturally represented in the Heisenber matrix.

From the Stone-Von Neumann theorem to the standard formulation of QFT

- **The Stone-Von Neumann theorem** demonstrates that the CCR in these two representations are **unitarily equivalent** and that for each quantum system in QM there exist **finitely many** of them for representing it.
- By P. Dirac, and its **interaction representation (or interaction picture) of QM,** that is halfway between **Schröndiger and Heisenberg representations** because it considers, both operators and states of a Hilbert space as **time-dependent,** we can pass, via the **superposition principle** (the same quantum state can be occupied by more than one particle), from QM to the **many-body application** of **Ψ,** the so-called **standard formulation of the QFT.** That is, we are not considering single particles, but **interacting particles, i.e., fields,** in the framework of classical QM, without changing its formalism and overall the Stone-Von Neumann theorem**.**
- However, in 50's **P. Haag** demonstrated that the interaction picture and hence the Stone-Von Neumann theorem do not hold in QFT, where **there exist infinitely many representation of CCR's**.
- Nevertheless, because of the so many successes of QM and of the standard formulation of QFT, Haag theorem is not taken into account by the followers of the paradigmatic standard formulation of QFT. This discussion on QFT as to QM will be, however the main object of the next lecture.

From the Stone-Von Neumann theorem to the information theoretic interpretation of QM

- What we have to emphasize here is that the standard formulation of QFT emphasized ever more than QM **the role of observer.** Indeed already in QM Ψ wave function has as referent not some physical reality but **probability distributions about observables.**

- In the QFT extension of QM according to its standard formulation the observer role is enhanced becuse it depends on him **the choice of which are the finite number of equivalent CCR's** for characterizing the quantum system among the infinitely many, inequivalent ones. This is generally expressed in literature by the key role of the **experiment preparation in QM.** The experiment outcome is not the causal modification of some physical magnitudes of the systems, but the modification of the **expectation values of the observer statistical representation** of the system state.

- This led, starting form 80's of the last century, to the so-called **information theoretic interpretation (ITI)** of quantum mechanics (QM), as the emergent one during the last twenty years ← prepared by fundamental works of Feynman (1982), Deutsch (1985), Rovelli (1996) and interpreting quantum systems as **quantum computing systems.**

- The core of the QM version of ITI of quantum physics is related with the so-called **decoherence of the quantum wave function (QWF),** where the decoherence is interpreted as a «source of surprise», i.e. **of information in Shannon's syntactic sense, for the observer**.

The notion of qubit in QM computations

- In quantum computing QC, a **qubit** (/ˈkjuːbɪt/) or **quantum bit** (q-bit) is a unit of quantum information —the quantum analogue of the classical bit. A q-bit is a **two-state bit** of a QM system, (e.g., photon polarization).
- In a classical system, a bit would have to be in one state or the other. However quantum mechanics allows the q-bit to be in **a superposition of both states at the same time** = fundamental property of QC.
  - One classical bit can be fully encoded in a q-bit, but q-bit can encode much more information **up to 2 bits.**
  - The two superpossed states in QC based on QM are two **basis (vector) states** of the Hilbert space of the system, generally denoted using the bra-ket notation, $|0\rangle$, $|1\rangle$ (ket-0, ket-1).
  - A **pure q-bit state** $|\psi\rangle$ is constituted by the linear superposition of the two states $|0\rangle$, $|1\rangle$, respectively with probability amplitude α, β that are **complex numbers,** i.e.:

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

  - When we measure the q-bit in the standard basis, the probability of the $|0\rangle$ outcome is $|\alpha|^2$, while of $|1\rangle$ is $|\beta|^2$, so to satisfy the condition:

$$|\alpha|^2 + |\beta|^2 = 1$$

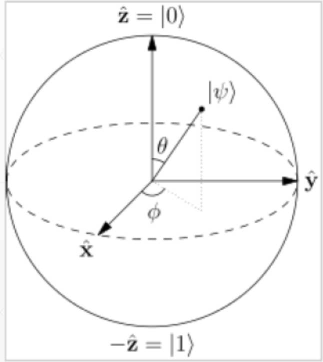
  - This means that by the measurement of the observer (corresponding in the Schrödinger representation of QM to the collapse of the wave function Ψ), the q-bit will switch in one of its two possible states so to satisfy the above condition.
  - The computation using q-bits is perforemd when we pass from a **pure q-bit state** to a **mixed q-bit state** by using the **quantum entanglement** for a quantum implementation of **logical gates**. Mixed states play the function of **registers** in quantum computing.

Quantum entanglement and quantum computation in QM

- We recall here that logical gate is a physical device implementing a Boolean function; that is, it performs a logical operation on one or more logical inputs, and produces a single logical output. E.g., an ideal logical gate composed by three interconnected lamps (two inputs, one output), each with two states on-off, can give as output all the possible outcomes of the true tables of the logical connectives (1000; 1110; 1011, etc.).

- The computation of a q-bit can be represented as **unitary trasformation** among states formally representable as rotations on the so-called **Block spehere** in which not only the two states |1〉/|0〉 of the **pure state** at the N and S pole of the sphere can be represented but in principle infinitely many for each point of the sphere, representing a q-bit in a **mixed (entangled) states.**

- However the **only measurable (observable) outcome** of all this computing power is a given value after the **decoherence** of the mixed state, because of the measurement process. Effectively, it is an unpredictable modification of the expectation values of a given probability distribution for the observer. In this sense it is «syntactic information in Shannon's sense».



The ITI of QM: «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, 1990, p. 75) (See also (Wheeler, 1992)).

Infinitistic *vs* . Finitistic version of the ITI of QM and the new scientific ontology

- Several versions of the ITI in QM (Fields 2012) → two main ones:
  1. **Infinitistic,** as the classical mathematical-physical one
  2. **Finitistic,** related to the interpretation of the emergemce of the matemathical laws of physics from the evolution of the universe.
- It is based on the interpretation of information as a **fundamental physical** magnitude: physical-mathematics of information
- P. Davies (2010): birth of the **scientific ontology** with an empirical and even **experimental** basis → *dual* composition of all the physical reality by two fundamentals physical *magnitudes*: *matter* (mass-energy) and *information*.
- Two problems:
  1. Justifying in fundamental physics the ontic *vs.* subjective interpretation of information notion and measure → **dynamic** (QFT) *vs.* **statistical** (QM) foundation of information.
  2. Defining the logical and epistemological statute of the **natural ontology** as to the **natural science(s).** Both from the theoretical and historical perspectives.

Natural *vs.* algorithmic computation and the philosophy of information

- ITI interpretation of QM → notion of **natural computation,** both in microphysisics and macrophysics, as opposed to **algorithmic computation** in artificial devices.
- → 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, 2012).
- → Newborn discipline of **philosophy of information** related with the definition of a notion and measure of **semantic information** (Floridi 2012).
- The **coalgebraic interpretation** of computation, both in artificial (algorithmic) and dynamic (natural), systems gives a more comprehensive theoretical framework in which interpreting all these notions (semantic (dynamic) and syntactic (statistical) notion and measure of information included) → QFT (*vs.* QM) interpretation of quantum systems as computing systems.

The ITI of QM: the unitary evolution of QWF. I

- **The fundamental entity** is the unique (non-local) wave function,→ from its **decoherence** in different environments, all the singular (local) entities constituting the universe, derive (Zeh, 2010).
- This interpretation of Wheeler notion of "participation universe" based on the notion of **unitary evolution of quantum wave function** (QWF) in QM → **infinity of information content** in the wave function itself → "neo-Spinozian" character of this approach.
- "Unitary evolution" of the QWF means that the dynamic system concerned is **energetically closed.** → In the case of the "unitary evolution" of the QWF 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** generating the local objects populating progressively the universe.
- **QWF decoherence** in QM *versus* **Quantum Vacuum (QV) spontaneous symmetry breaking** in QFT: a **conceptualist** *versus* a **naturalistic** ontology of the universe.

The ITI of QM: the unitary evolution of QWF. II

- The decoherence of the QWF and **the metaphor of the sea-wave** (Zeh).
- Unique wave function can be imagined 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, 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, or 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 very same and unique, non-local wave function, into many, particular wave-functions, and/or into many particles.
- In QM it is possible, indeed to represent a quantum system either like **a statistical wave-function**, or like a particle, according to N. Bohr’s “complementarity principle”. In fact, it is the interaction of the observer measurements that elicits the decoherence of QWF.

The ITI of QM: the unitary evolution of QWF. III

- Two main criticisms as to such an ontological interpretation of the ITI of QM:

1. The QWF of QM and its decoherence do not exist in the physical reality but only **in the QM laboratories**, as to observers, respectively non interacting or interacing with the observbles. I.e.:
   - The QWF in QM is **a statistical not dynamical entity,** like on the contrary are the «waves» of a force field **in QFT.** QWF is a necessary statistical representation of a QM system, because of the **conjugate and hence non-commutative** character of the canonical variables, *p* and *q* of classical mechanics in quantum systems (see below).
2. **The infinity of information content** of QWF unitary evolution, necessary for justifiying Zeh cosmological interpretation of it, is **in contradiction**:
   - With the **finite character** of the quantity of information in the universe, clculated on such a QM basis.

- In any case it is evident, because of (1), that the ontology of the natural reality based on QM can be only a **conceptualist, ontology.**

The ITI of QM: the finitistic interpretation. I

- The finitistic interpretation traces 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** we have to suppose, if we refute the **conceptualist** ontology of QM.
  - “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* - concepts such as real numbers, infinitely precise parameter values, differentiable 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).

The ITI of QM: the finitistic interpretation. II

- The **cosmic information bound** results from two different and independent interpretations of ITI of QM applied in cosmology → Davies: is it a new constant of nature like Newton's *G*, Einstein's *c* or Plank *q*?

1. **S. Lloyd's calculation:** He first calculated it starting from 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 horizon at a given time, divided for the smallest area allowed by quantum discretization, 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 suggests such a number is not new at all in physics. It corresponds to $N^{3/2}$, where the large number *N* ($\approx 10^{40}$) is the "Eddington-Dirac number", emerging many times when we consider the relation between microscopic and cosmic magnitudes, as to cosmological constants.

The ITI of QM: the finitistic interpretation. III

2. **The calculation by the «cosmic holographicprinciple».** Three steps:

   - **Hawking-Bekenstein (1975)** calculation of the entropy associated with a black-hole where information is scaling with the **bidimensional area** of the event-horizon, and not with the three-dimansional volume like in classical thermodynamics. The Hawking-Bekenstein relationship demonstrates that the total information that can be associated to the event horizon cannot exceed one quarter of its total area

   - **Bekenstein extension (1982)** of the black-hole limit can be extended for the event-horizon of whichever quantum system whose area is calculated in terms of Planck unitis.

   - **'tHooft (1993) and Susskind (1995) «holographic universe» hypothesis.** Like an hologram is a bidimensional object containing all the information necessary for reproducing a bidiemensional object, so the event-horizon of the expanding universe at each given time of its expansion. → 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 !**

The ITI from QM to QFT: «Is physics legislated by cosmogony?» I

- Of course, such a «thermodynamic evolution» of the ITI of quantum physics has its most natural interpretation in QFT as a quantum thermal field theory, before all for the natural derivation of the same quantization principle as **information dissipation,** related to t'Hooft cosmological holographic principle, as we see.
- «Is physics legislated by cosmogony?» 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).
- On this regard, Davies' position – on the boundary between the QM and the QFT version of the ITI – emphasizes that what he defines as **the ontic interpretation** of information as a **real, dynamical magnitude** in quantum physics, implies a change of paradigm in modern science, from its early Platonic-Newtonian interpretation.

The ITI from QM to QFT: «Is physics legislated by cosmogony?» II

- Such a **change of paradigm** in modern science, is **the turnaround of the "Platonic" relationship**, characterizing the Galilean-Newtonian beginning of the modern science:
  - ***Mathematics → Physical Laws → Information***
- Into the other one, Aristotelian, much more powerful for its heuristic power:
  - ***Information → Mathematics → Physical Laws***
- This paradigm change, however, is **not yet formally defined**, if not for its dynamic part considering each physical system at the fundamental level, as **an open system**, and no longer as an isolated system like in Newtonian and Quantum mechanics.
- The next step consists in the interpretation of a QFT open system as a computation system by using the Universal Algebra/Coalgebra notion of computing system as **a state transition dynamic system**.
  - Such a notion of computing system includes the Turing Machine one, just as the Hilbert representational formalism of QM – at the basis of ITI of QM – can be recovered in QFT iff we include the thermal bath of a QFT system. I.e., we interpret it in terms of the ***q*-deformed Hopf algbra/coalgebra** formalism.