Complete Information Retrieval:

A Fundamental Challenge

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Abstract

Impressive progress in physics has clearly established that the cosmic space is a vibrant field. It sustains everything as its energetic oscillations - all the observable EM waves, particles and other diverse fluctuations. Larger and larger assemblies of the stable particles give rise to the atoms, the molecules and eventually the larger bodies of planets, stars and the galaxies. Everything is embedded within this sea of fluctuations. No interactions, leading to newer measurable and observable outcomes, are free of influence from this stochastic background. So, our experience of the three **UN-**'s of this essay competition is natural. Yet, our knowledge of the working rules behind the evolving universe has been advancing remarkably well through several centuries. However, for last fifty years or so, the progress in physics appears to be slow. This essay presents an epistemology of successfully and synergistically using the set of tools available to us to keep getting closer and closer to the ontological reality, even though all the individual tools, separately, are quite limited. We can make the three UN-'s keep yielding to our progress without the need to be eliminated. Dissection of our scientific tool appears to be as follows. (i) The Mental Tool is dominantly used to generate the founding axioms/postulates to integrate a broad class of observed natural phenomena. (ii) The Measurement Tool is used to quantify our observations. (iii) The Math Tool, is used to construct mathematical theories utilizing the axioms as guidance. We are proposing an extension of the mental tools to incorporate our old tradition of visualizing the invisible interaction processes. Judicious and iterative use of all these four tools will assure our steady progress towards actual realities of the universe. Unlike Copenhagen Interpretation, we do not need to give up visualizing ontological reality.

1. Introduction

1.1. Our stochastic universe

We routinely encountering characteristics like, undecidability, uncomputability, and unpredictability at various situations of our theorization, measurement and computation. Isolated local phenomena (in time and space) are calculable, but with an analytically definable statistical

spread**.** The sustained successes behind Maxwell's classical EM wave equation, General Relativity, Schrodinger's wave equation, and more advanced theories to model particles, all imply that the cosmic space is some form of a field [1]. Cosmic Micro Wave Background (CMBR) clearly implies the cosmic space is alive with incessantly fluctuating microwave radiation everywhere in space. Particle theories also imply the presence of energetic "background fluctuations" across the universe. Predictions of Quantum Mechanics (QM) are also validated through statistical ensemble average. Therefore, we should not be hesitant to accept that the outcomes of all interactions in this universe should have a finite statistical spread. Fortunately, our theories and experiments do find that these statistically distributed outcomes are well-bounded and can be modeled analytically. Therefore, for us to experience the three **UN**'s are natural. What is not natural is the slow-down in the progress of physics [2, 3].

2. Incomplete Information, a Fundamental Challenge

We are built out of molecules, which are built out atoms, which are, in turn, built out of electrons, protons and neutrons, which are again diverse kinds of oscillations of the universal cosmic field [1, 4, 5]. We are then trying to fathom this field and its properties while being an assembly of oscillations of this very field. We are an integral part of the field, not standing outside to watch it! We have a long arduous journey to carry on our journey of scientific spiritualism!

Let us first briefly evaluate the strengths and weaknesses of the three common tools, Mind, Measurement and Math tools, which we are currently using. Then we will introduce a fourth tool, interaction process visualization, which we used to use before the Copenhagen Interpretation of QM came along.

2.1. Human Mental Tool

The human mind is a biological machine, dominantly run by quantum chemistry guided by DNA, which introduces a staggering variations in our mental logics. Decades of debate between Bohr and Einstein is an obvious example [1], which is still continuing today under a broader context [2, 3]. We have been using mental tools to observe, contemplate and create right set of axioms/ postulate for a well identified set of observations, which eventually guides us to develop mathematical theories.

2.2. Measurement tool

The "Measurement Problem", articulated by the founders of QM, needs to be re-visited and re-stated as a permanent "Information Retrieval Problem", which cannot be solved by elegant mathematical theorems [5, 6-Ch.12]. Let us enumerate the number of steps in a real measurement that are built into this last sentence.

(i) Data are some *physical transfo*rmation taking place inside the apparatus.

(ii) The *physical transformation* in a detectable material always require some *energy exchange* between the interactants, the "unknown" under study and the "known" as the reference interactant.

(iii) The interactants must have some intrinsic propensity to exchange energy to trigger mutual transformation. Therefore, the *energy exchange* must be guided by some *force of interacti*on operating between the chosen interactants.

(iv) Since we have *started with an unknown universe*, from the standpoint of building physics theories, the *"known" entities are known only partially*, never completely. This also creates information bottleneck for the "unknown" entity. Note that in spite of innumerable experiments, we still do not know what electrons and photons really are.

(v) All *forces of interactions* are distance dependent. Hence, the interactants must be placed within the range of each other's mutual influence (force-field). Force-field creates the necessary physical "entanglement" between interacting entities for the energy transfer to proceed. In other words, *interactants must be "locally regional*" within their physical sphere of influence. They must be "entangled" by a perceptible physical force. Our equations are built on such hard causality.

(vi) The final data in all instruments suffer from the lack of 100% fidelity. This is another permanent problem of imprecision. We can keep on reducing the error margin as our technology enhances; but we do not know how to completely eliminate this error.

Thus, the evidence creating data are always incomplete in information. Further, the measurement process can never give us the complete picture (mental video!) of the interaction processes that generated the data. The actual physical process of the emission of photoelectrons out of photodetectors have not been photographed yet. A semi-classical model is given in [7, 8].

2.3. The Math tool

Math is a strictly defined language of logic. Repeated observations and/or measurements of natural phenomena always appear to be reproducible to us since ancient times. Hence, the laws of nature must be logically expressible using the logics of math by constructing cause-effect relationship.

2.3.1 High value of math tool.

Mathematical intuitions to find symmetry by introducing "displacement current" helped Maxwell to unify the separate fields of electricity and magnetism and finding the expression for the velocity of light. So, math can guide us to extract deeper physical properties of nature that was not obvious from the existing separate mathematical formulation, validated by innumerable measurements.

Planck tried and eventually succeeded in giving an analytical expression for the measured Blackbody radiation curve. However, to succeed, one must choose the right parameter for the phenomenon. The parameter must be deeply connected in facilitating the ***physical transformation process*** under study. Many times we need to construct and use secondary math relations connecting ***primary and secondary parameters***, like $\nu = c/\lambda,\ c^2 = 1/\varepsilon_0\mu_0$. The velocity of light c is a derived parameter from the real physical properties of the cosmic space, which Maxwell did for us. But, what about λ vs. ν? Planck wrote in his book [9] that he had spent a lot of time to derive an analytical expression for the Blackbody radiation using λ without success. Finally, he realized that the wavelength of an EM radiation keep changing from medium to medium, while the frequency remains unchanged. Therefore, *the frequency must be the primary parameter in facilitating the radiation emission and absorption*. And he found the desired mathematical relation in terms of the frequency. The relation implied that the materials of the blackbody surface emit and absorb EM ***energy*** in discrete quanta of $h\nu$. (This is the key physics behind the eventual development of QM.). Planck explained that the emitted radiation ***amplitudes*** help maintain the avail equilibrium-energy-density within the cavity through diffractively spreading and multiple

scattering from the inner surface of the Blackbody. This realization by Planck was a crucially important break-through-thinking in *leveraging math to extract nature's physical behavior* (***process***). The then custom of presenting EM waves were dominated by "λ". Even the prevailing Ritz-Rydberg relation for the discrete spectral lines for hydrogen, etc., were expressed in terms of "λ", not "ν". In fact, Planck always was of the opinion that the frequency of radiation is determined by the inherent properties of the material dipole oscillators, while the emitted radiation always propagates out as waves, not discrete "bullets".

2.3.2.a. Math tool connected & disconnected from interaction process -- Fourier transform

Fourier Transform (FT) is a very powerful and useful tool for physics. Yet, it can lead us to interpret measured data erroneously when we confuse mathematical principle as nature's principle, albeit axiomatically constructed by some genius human mind. Let us compare two prevailing practices in physics, especially in optics. The far-field diffraction pattern due to a physical aperture, illuminated by phase-steady collimated beam of light, is the *Fourier transform of the aperture function*. This is mathematically derived, starting with Huygens' Principle of secondary wavelets, and by using HF diffraction integral. When physically acceptable far-field approximations are introduced, the HF integral naturally morphs into a *space-space Fourier Transform (SS-FT)* integral. Math being a self-consistent language, it is smart to use SS-FT in the world of application. In fact, optical signal processing is a major thriving field in optical engineering, because the origin of this SS-FT relies on *a principle that nature actually carries out* (the basic principle of wave propagation). Maxwell's EM waves are not bullets.

In contrast, the time-frequency Fourier Transform (TF-FT), extensively used in physics and engineering do not have supporting principle of nature. Linear optical spectrometers, like passive gratings or a passive Fabry-Perot's, can never execute the mathematical Fourier algorithm over a light pulse propagating through it at the speed of light. However, we continue to believe and keep teaching that an optical pulse of width δt contains a *physical* spectrum broadened to $\delta\nu$. Surprisingly, during actual experiments, we do find that the output fringe width generated by a pulse is broadened by an amount given by the convolution of the TF-FT response function. However, even this is true in measurements only when we record the fringe over a period of time that is longer than the replicated and stretched array of pulses generated by the spectrometer. However, if one uses, say a nano second input pulse and a modern pico second streak camera to record the output fringe, one would find that fringe width is varying with time over multiple nano seconds! This has been analyzed by the author [6, see Ch.5]. The temporal response of a spectrometer to a short pulse does create a broader output fringe. This is a spread out of energy due to the same incident frequency (-ies) originally contained in the input pulse. No new physical frequencies are created by the *linear* spectrometer. The point is that the mathematically derived indeterminacy relation $\delta\nu\delta t \geq 1$ is basically correct. However, an ad hoc contrived product of two different half-widths belonging to *two different mathematical spaces* is not a correct approach to modeling nature's actual (ontological) behavior. Unlike SS-FT of diffraction physics, TF-FT is certainly not based upon any physical principle of nature. It is important, in this context, to note that we have a highly matured separate field of optical science and engineering of nonlinear optics on how to convert one physical source-determined frequency to another one. Output fringes generated by spectrometers like Gratings and Fabry-Perot's are due to their linear responses.

Fourier algorithm can be executed by human and computer calculators, not by linear and passive optical components.

2.3.2.b. Math tool connected & disconnected from interaction process-Photoelectric equation

Einstein's photoelectric equation is a correct data validating mathematical construct. This relation was formulated eight years before the publication of quantized Bohr-atom model and twenty years before the publication of the formalism of quantum mechanics. It did not address the interaction process that triggers the release of a quantum mechanically bound electron. The frequency of oscillation of the electric vector of the incident EM wave must first trigger the resonant excitation of the bound electron before it can absorb a quantum cupful of energy, and then get released out of the binding force. Einstein correctly recognized the existence of inherent "quantum-ness" behind the photometric effect from the cut-off frequency published in the data. Unfortunately, he assigned the quantum-ness to EM wave instead of to the quantum "dipole-like" binding energy of the electrons in materials. Even after some 115 years after Einstein's publication, we are still reluctant to admit that EM waves are not bullet-like, rather all electrons are bound quantum mechanically in materials. This fact is understood by all physicists working in any branch of solid state physics.

2.3.2.c. Math tool disconnected from principles of nature - Space-time four dimension

In the above section, we have underscored the prevailing mistaken belief that the time-frequency FT is not supported by any principle of nature. Here we will explore the nature of the parameter "t", the running time. Recall from section 2.3.1 how Planck had to change his approach to using frequency of light instead of its wavelength to derive the correct analytical relation for the measured Blackbody radiation. The emission and absorption of light by atoms and molecules are determined by their dipolar frequencies. In constructing a theory and drawing conclusions out of it, the supremacy must be given to the parameter that is an intrinsic characteristic of a physical entity, a physical parameter. ***The running time is not a physical parameter of any natural object.*** Creating the concept of the running time is a remarkable invention by human species. Our modern society will come *almost* to a halt, not completely though. The Covid-19 pandemic has demonstrated that! Our universe is full of harmonic oscillations and motions, from atoms to our planetary system. We invert the frequency of well-designed oscillator to define a period. Then we keep counting many many periods to create longer and longer periods, which give us a sense of running time. We also know the physical techniques on how to "dilate" or "contract" the frequencies of well-designed oscillators. That is what happens in any real physical clock. The "running time", not being an engineer-able real physical parameter of any physical object, it cannot be physically dilated or contracted, except indirectly in our book-keeping math. The ***frequency*** of emission in human-made Atomic "clocks" will, of course, be sensitive to velocity through Doppler Effect, which is not relativistic [6, see ch.11]. We have been wasting very valuable and brilliant brain-times for over a century debating twin-paradox, etc.!

Can we do any experiment on any real physical Inertial Frame (table)? All the galaxies are moving relative to each other. Are all these velocities fixed and steady? Or, are variable and suffers from acceleration? All the stars within every galaxies are also moving. Are their velocities

absolutely fixed, or varying slowly? The Sun is one such star in our Milky Way galaxy. Does the Sun really has a fixed velocity? Even if anyone of theses stellar objects has well-defined fixed velocity to theoretically provide us with a fixed velocity inertial platform, we do not have access to set up any lab experiment on any of these "inertial tables". We have been carrying out plenty of experiments in our laboratory tables which are stationary on the earth. However, the earth is tugged by the Sun. The earth spins on its axis and rotates around the Sun in an elliptical orbit. Therefore, we really do not have inertial-tables on earth for our experiments. Should not we re-evaluate our thinking? Could it be that the Inertial Frame of reference is the stationary cosmic field [4, see Ch.11 in 6)? Is that the reason why the laws of physics are same in the entire universe? Should we not try to reconstruct a new, but a single set of coherent postulates, which could liberate us out of the bondage of many separate sets of postulates? We might then be able to create a new set of theories, but emerging out of the same set fundamental postulates that directly connects with the physical interaction processes in nature. The re-shuffled and re-constructed axioms must help us visualize the physical interaction processes going on in nature.

2.3.3. Math tool – its symmetry and some disconnectedness from reality

Math does deserve the accolade for its inherent logical symmetry, and hence its beauty and elegance. However, if we carefully look at nature, beauty and elegance are "in the eyes of the beholder". Nature is driven by incessant cycle of creation-destruction-recreation for continuing evolution. In the biological world, continuity of the modern mammal species depends upon the successful birth of the next generation of new babies. However cute the babies look like after being cleaned up, the very birthing process certainly does not look very beautiful! But it is a very complex and absolutely essential natural process.

Symmetry usually brings some stability to a system. But the dynamic evolution in nature, from our biosphere to diverse galaxies, experience routine built-in instability as they keep evolving, eventually new structure or new species come into being. Therefore, asymmetry must be built into nature's pattern of evolution. Should we not look into how asymmetry evolves within symmetric and stable systems?

The Gaussian, Lorentzian and exponential curves extends to infinity. However, no real physical parameter can keep on varying to infinity. It must terminate after some finite value. Energy conservation demands that. We accept these finiteness as approximations in the real world, but we never explore whether the termination to zero at a finite boundary has some deeper physical meaning for the phenomenon under consideration. The amplitude envelope of a stable laser mode is represented by a Gaussian envelope. But it is generated out of a physically finite and bounded cavity. Given that the laser gain medium terminates to zero after some distance within the cavity, the Gaussian tails of the laser mode must also terminate to zero. Could we learn anything more about wave propagation and energy extraction by stimulated emission by developing more detailed and microscopic model for laser mode evolution beyond current laser theories?

The use of complex representation in advanced physics is ubiquitous. In classical physics, it is used only for computational convenience. However, in quantum physics, it plays a critical role, as if nature itself is mindful of the necessity of complex representation. We derive measurable real number $\psi * \psi$ from the complex quantity ψ, which is defined as the "mathematical probability amplitude". We believe that it should be re-defined as the real physical state of stimulation of the particle, only expressed in the form of complex expression $\exp[iEt/\hbar]$, instead of as a real function

$\cos(Et/\hbar)$. Squaring and time averaging this real cos function over a couple of cycles will yield the same result as the square modulus of the complex function, except with an extra factor of (1/2). Could this mean that a finite time averaging is built into $\psi * \psi$ [6], which we are not recognizing? In other words, it could be that there is no sudden "collapse" of wave function. Rather, there is a finite quantum-resonance-compatibility-sensing dancing before the quantum transition.

2.4. Interaction process mapping tool

We believe that the re-introduction of the ancient mental skill of trying to visualize the invisible interaction processes that goes on in nature, will add more strength in bringing out ontological reality in modeling nature. One can also think that the Interaction Process Mapping Epistemology (IPM-E) is an extension of axiom making, with the addition of visualization. IPM-E will help us focus on identifying measurable parameters belonging to a phenomenon under development. We would be saved from making theories that do not yield any measurable parameters, like the theory of "Many Universes", etc.

Let us consider some historical case examples to underscore the importance of bringing back IPM-E.

2.4.1. Wave-particle duality

Recall that the debate of wave-particle duality started during the second half of 1600 between Newton ("Corpuscular") and Huygens ("Secondary Wavelets"). Newton was visualizing the *physical process of light emission* from individual Na atoms fed into the flame of a Bunsen burner. From the standpoint of conservation of energy, the individual Na-atoms can emit only one pulse of light at a time, hence "corpuscular"!

Huygens was visualizing in his mind the *physical process of wave propagation*, and not the physical process behind the generation of light. To him light was a wave as it could propagate through the cosmic ether from distant stars to earth. So he proposed "secondary wavelets" emanating out of every point on the wave front. Surprisingly, both models are still alive today. During the last century, Newton's model has taken the form of "indivisible light quanta", as proposed by Einstein. Einstein model is still under serious debate because Huygens' model, through Huygens-Fresnel diffraction integral, has been serving the entire community of optical science and engineering very well. In fact, there is no equivalent "bullet photon" model that can successfully replace classical optical science, including the recent developments in Nanophotonics and Plasmonic Photonics.

Just as Newton and Huygens believed that their wave-particle debate reflected their ignorance about the deeper nature of light, so do the author believe that we are still suffering from the ignorance about the real physical origin of particle-particle superposition effect. See a proposal by the author [6-see Ch.11.5.2].

2.4.2. Non-Interaction of waves and space as a Complex tension Field, or CTF (old ether)

Huygens also wrote in his 1690 book [10] that his postulated secondary wavelets evolve through each other spreading out in space without interacting with each other, meaning, without perturbing individual wave front properties. This is Non-Interaction of Waves (NIW) [6]. That SP is not an observable is supported by the NIW-property. Eq.1 is not observable. So, the "+" sign in Eq.1 does not represent any physical operation between the two amplitudes [6, 7]. It only implies that

the two signals are simultaneously propagating through the same physical space. Note that the meaning of the operator "+" will changes for Eq.2.

$$\Psi(t,\tau) = \psi_1(t) + \psi_2(t+\tau) = a_1 e^{i2\pi\nu(t-\tau/2)} + a_2 e^{i2\pi\nu(t+\tau/2)} \tag{1}$$

The observable, Eq.2, is the non-linear square modulus of the linear Eq.1. It must incorporate a detector's interaction parameter χ. The Superposition Effect, or the energy absorbed by the detector, $D(t,\tau)$, depends upon the amplitudes and phases of both the fields. The causal mathematical relation tells us that the measured signal energy is drawn out of two fields, not one photon [7, 8]. The visualization of the interaction process is very valuable.

$$D(t,\tau) \equiv \left|\Psi(t,\tau)\right|^2 \left|\chi a_1 e^{i2\pi\nu(t-\tau/2)} + a_2 e^{i2\pi\nu(t+\tau/2)}\right|^2 = \chi^2[a_1^2 + a_2^2 + 2a_1 a_2 \cos 2\pi\nu\tau] \tag{2}$$

3. Summary and Conclusions

Our universe is a stochastic system. This has given rise to the three **UN**'s of this essay competition. Modern quantum physics has clearly established that all outcomes of interactions have finite statistical spread, which is analytically accountable when we use well defined forces of interaction between different entities. This essay, instead of debating the three UN's, we have underscored how to keep advancing physics by managing them through the recognition of the over-arching real issue: "Complete Information Retrieval: A Fundamental Challenge". The essay explains the origin behind our limitations in extracting complete information out of any natural phenomenon. First, we have identified the three tools (Mental Tool, Measurement Tool and Math Tool), we have dominantly been using for our scientific explorations during the last couple of centuries. All these tools, individually, are limited in extracting complete information about any natural phenomenon. However, using them in combination, helps us extract more information. Even then we are limited. Therefore, I have proposed to extend our Mental Tool to re-incorporate our practice of visualizing the invisible interaction processes. The Mental Tool should not be confined just to create axioms to help build theories. Its visualizing capacity should be extended to "see" the physical interaction processes. This will help us identify the primary measurable parameters that drive the interaction process. This system engineering thinking will re-connect us with nature. Our math logics do not possess perfect one-to-one mapping capability with the laws of nature, which are quite complex. A small set of our math logics, even when succeed in mapping one small segment of the reality of the very large and complex natural system, it may not even map the real ontological small set of the complex system. Complexity theory tells us that. We should not try to tell nature how she ought to behave simply based upon our powerful and sophisticated mathematical logics. More we study nature more the cosmic evolution appears to be a magnificent creative system engineer [11].

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