CICT: A Novel Framework for Biomedical and Bioengineering Applications

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Abstract— In 2013, Computational Information Conservation Theory (CICT) confirmed Newman, Lachmann and Moore's result (in 2004), generating analogous example for 2-D signal (image), to show that even the current, most sophisticated instrumentation system is completely unable to reliably discriminate so called "random noise" from any combinatorially optimized encoded message, which CICT called "deterministic noise". To grasp a more reliable representation of experimental reality and to get stronger physical and biological system correlates, researchers and scientists need two intelligently articulated hands: both stochastic and combinatorial approaches synergically articulated by natural coupling. CICT approach brings classical and quantum information theory together in a single framework, by considering information not only on the statistical manifold of model states but also on the combinatorial manifold of low-level discrete, phased generators and empirical measures of noise sources, related to experimental high-level overall perturbation. As an example of complex system (hirarchical heterogenous multi-scale system) with important implications, we consider classical relativistic electrodynamics, applied to biological system modeling (e.g. fullwave electromagnetic modeling of brain waves). CICT approach can offer an effective and convenient "Science 2.0" universal framework to develop innovative application and beyond, towards a more sustainable economy and wellbeing, in a global competition scenario.

1. INTRODUCTION

In 2004, Newman, Lachmann and Moore (NLM), have extended the pioneering 1940s research of Shannon to electromagnetic transmission. Specifically, they show that if electromagnetic radiation is used as a transmission medium, the most information-efficient format for a given message is indistinguishable from blackbody radiation [1]. Since many natural processes maximize the Gibbs-Boltzmann entropy, they should give rise to spectra indistinguishable from optimally efficient transmissions. Traditional scientific knowledge teaches that the only way to generate truly random numbers is through a random physical process, such as tossing dice or measuring intervals between radioactive decays. On the contrary, all computer programs can compute "random" numbers from defined calculations. Since the sequence of numbers is reproducible, mathematicians say that the numbers are "pseudo-random". Stochastic computer simulation uses extensively random number generation and the quality of these generators can play a crucial role on final simulation results. A full discussion of computer generate randomness quality is beyond the scope of this paper and for further reading, the interested reader is referred to [2]. In 2013, Computational Information Conservation Theory (CICT) confirmed Newman, Lachmann and Moore's result, generating analogous example for 2-D signal (image) [3]. So, paradoxically if you don't know the code used for the message you can't tell the difference between an information-rich message and a random jumble of letters. This is the information double-bind (IDB) problem in contemporary classic information theory. Scientific community laid itself in this double-bind situation. Even the most sophisticated instrumentation system is completely unable to reliably discriminate so called "random noise" (RN) from any combinatorially optimized encoded message, which CICT called "deterministic noise", DN for short [3]. It is a problem to solve clearly and reliably, before taking any quantum leap to more competitive and convenient, at first sight, post-human cybernetic approaches in science and technology. As a matter of fact, to grasp a more reliable representation of reality, researchers and scientists need two intelligently articulated hands: both stochastic and combinatorial approach synergically articulated by natural coupling [4]; lets say we need a fresh "Science 2.0" approach. To get stronger solution to advanced problems, like resonant nanoparticle, nanophotonic, optifluidics structure modeling, etc., we have to look for convenient arbitrary scaling BU (bottom-up) point-of-view (POV) (from discrete to continuum view $\equiv$ BU POV) to start from first, and NOT the other way around!

2. BRAIN WAVES MULTI-SCALE MODELING

As an example of complex system (hirarchical heterogenous multi-scale system) with important implications, let us consider classical relativistic electrodynamics, applied to biological system modeling (e.g. fullwave electromagnetic modeling of brain waves). It is well known that both the time domain and frequency domain based numerical computational electromagnetic methods (i.e. Method of Moments (MoM), the Finite Element Method (FEM), etc.) for solving the Maxwells equations suffer from the so-called "low-frequency-breakdown" problem [5]. They can only go down to a few hundred MHz in frequency, below which the result they yield becomes very inaccurate relatively quickly. It is not uncommon, therefore, to resort to quasi-static solvers once the frequency of interest falls below a certain frequency (say a few MHz), and to ignore the contribution of the displacement currents, and, hence, the coupling between the electric and magnetic fields. Unfortunately, however, this approximation is not valid for most of the materials inside the head, since the $\sigma/(\omega\epsilon)$ ratio ($\sigma \equiv$ medium conductivity, $\omega \equiv$ (angular) frequency, $\varepsilon \equiv$ medium permittivity ratio) of these materials is typically close to 1 [5, 6]. In fact, the quasi-static potential differs from the full-wave potential by nearly 30 % to 50 % [7], supporting the argument that a full-wave solution should be derived even at low frequencies for the head-modeling problem, since the quasi-static approach is not sufficiently accurate for the problem at hand. All the above, taking into account that neural activity inside the brain results in low frequency waves known as brain waves. These brain waves can be further classified into delta (0.1 to 3 Hz), theta (4 to 7 Hz), alpha (8 to 12 Hz), beta (12 to 30 Hz) and gamma (30 to 100 Hz) waves based on the rate of neural activity inside the brain. The success of neuroscience in the study of the structural and biochemical properties of neurons, glia cells, and all the biological units and cellular structures in the brain have not yet filled the gap between the behavior understood at cellular level (microscale) and the macroscopic dynamics involved in the traffic between the brain and the world which it is immersed within. There is an essential problem in the study of brain function (mesoscale dynamics) that even today, after so many years since Karl Lashley posed his dilemma, still waits for a solution. As recalled many times in the literature, in the mid 1940s he wrote [8]:

" .... Here is the dilemma. Nerve impulses are transmitted ...from cell to cell through definite intercellular connections. Yet, all behavior seems to be determined by masses of excitation...within general fields of activity, without regard to particular nerve cells... What sort of nervous organization might be capable of responding to a pattern of excitation without limited specialized path of conduction? The problem is almost universal in the activity of the nervous system."

In QT, the space-time distribution of matter and energy has a coarse-grained structure which allows its representation as an ensemble of quanta (particle representation). The local phase invariance is shown to hold if a field exists which is connected to the space-time derivatives of the phase. In a previous paper we show how Geometric Algebra (GA) can be used to relate spacetime invariant physical quantities to the variables employed by an inertial observer quite easily [9], if we take into consideration a generic electromagnetic field F, described by Riemann-Silberstein vector [10], and we follow the line of thought reported in spacetime algebra (STA) [11, 12, 13]. STA is built up from combinations of one time-like basis vector γ_0 and three orthogonal space-like vectors $\{\gamma_1, \gamma_2, \gamma_3\}$ [11]. F is defined as a complexified 3-dimensional vector field. The value of F at an event is a bivector according to GA [13]. The field bivector F is the same for all observers; there is no question about how it transforms under a change of reference system. However, it is easily related to a description of electric and magnetic fields in a given inertial system. For the purpose of mapping the brain, we are interested in estimating the fields at different points inside the head in the frequency range of 0.1–100 Hz when either one or many sources are located inside the head. In the case of a system made up of electrically charged components (nuclei and electrons of atoms), as a biological system, this is just the electromagnetic (e.m.) potential $\mathbf{A}_\mu$, where μ is the index denoting the usual four space-time coordinates $\gamma_0 = ct, \gamma_1, \gamma_2, \gamma_3$. The electric and magnetic fields are suitable combinations of the space-time derivatives of $\mathbf{A}_\mu$. In order to get the local phase invariance, we should assume that the system Lagrangian is invariant with respect to specific changes of the field $\mathbf{A}_\mu$. Thus a specific principle of invariance, named "gauge invariance," emerges; hence the name "gauge field" denotes $\mathbf{A}_\mu$. Actually it is well known that the Maxwell equations just obey the gauge invariance, which in quantum physics becomes the natural partner of the phase invariance to produce our world. Quantum fluctuations give rise to e.m. potentials which spread the phase fluctuations beyond the system at the phase velocity. This gives an intrinsic nonlocalizability to the system and prevents a direct observation of quantum fluctuations. Through the e.m. potential, the system gets a chance to communicate with other systems. Notice that all e.m. interactions occur in a two-level way; the potential keeps the interacting particles phase-correlated whereas the combination of its space-time derivatives, named e.m. field, accounts for the forces involved. The lower level, the potential, becomes physically observable only when the phase of the system assumes a precise value. The structure of electrodynamics makes possible the presence of a potential also when both electric and magnetic fields are absent, whereas on the contrary fields are always accompanied by potentials. The above solution, which stems from the mathematical formalism of QFT [14], opens the possibility of tuning the fluctuations of a plurality of systems, producing therefore their cooperative behavior. However, some conditions must be met in order to implement such a possibility. Let us, first of all, realize that in quantum physics the existence of gauge fields, such as the e.m. potential, dictated by the physical requirement that the quantum fluctuations of atoms should not be observable directly, prevents the possibility of having isolated bodies. For this reason, the description of a physical system is given in terms of a matter field, which is the space-time distribution of atoms/molecules, coupled to the gauge field with the possible supplement of other fields describing the nonelectromagnetic interactions, such as the chemical forces. According to the principle of complementarity, there is also another representation where the phase assumes a precise value; this representation which focuses on the wave-like features of the system cannot be assumed simultaneously with the particle representation. The relation between these two representations is expressed by the uncertainty relation, similar to the Heisenberg relation between position and momentum:

$$\Delta N \Delta \Phi \geq 1/2 \tag{1}$$

connecting the uncertainty of the number of quanta (particle structure of the system) ΔN and the uncertainty of the phase (which describes the rhythm of fluctuation of the system) $\Delta\Phi$. Consequently, the two representations we have introduced above correspond to the two extreme cases: (A) If $\Delta N = 0$, the number of quanta is well defined, so that we obtain an atomistic description of the system, but lose the information on its capability to fluctuate, since $\Delta\Phi$ becomes infinite. This choice corresponds to the usual, classic description of objects in terms of the component atoms/molecules. (B) If $\Delta\Phi = 0$, the phase is well defined, so that we obtain a description of the movement of the system, but lose the information on its particle-like features which become undefined since ΔN becomes infinite. Such a system having a well-defined phase is termed "coherent" in the physical jargon. In conclusion, a coherent system involves two kinds of interaction:

- (1) an interaction similar to that considered by Classical Physics, where objects interact by exchanging energy. These exchanges are connected with the appearance of forces. Since energy cannot travel faster than light, this interaction obeys the principle of causality;
- (2) an interaction where a common phase arises among different objects because of their coupling to the quantum fluctuations and hence to an e.m. potential. In this case there is no propagation of matter and/or energy taking place, and the components of the system "talk" to each other through the modulations of the phase field travelling at the phase velocity, which has no upper limit and can be larger than c, the speed of light.

3. CICT QFT RESULT

CICT is a natural framework for arbitrary multi-scale computer science and systems biology computational modeling in the current landscape of modern QFT [3, 4]. *CICT* new awareness of a discrete HG (hyperbolic geometry) subspace (reciprocal space) of coded heterogeneous hyperbolic structures [3], underlying the familiar $\mathbb{Q}$ Euclidean (direct space) surface representation can open the way to holographic information geometry (HIG) [15, 4]. *CICT* founding principles are the same on which Riemannian manifold theories are founded, principles of relativity and covariance, of optimization (least action and geodesic principles), applied to scale and accuracy relativity transformations of the reference system in HG. *CICT* interprets natural rational "OpeRational" (OR, [15] for definition) representation as a language of languages of phased directed number systems quite easily. In fact, we can take the concepts of modular magnitude and direction as basic, and introduce the concept of vector as the basic kind of directed number, with an associated phasing relation. Directed numbers are defined implicitly by specifying rules for adding and multiplying vectors. Furthermore, they can be related uniquely to their remainder sequences to identify "quantum support field" sequences, which subspace inner phased generators can be computed from. *CICT* result can be presented even in term of classic or formal power series to show the close relationships to classic and modern control theory approaches for causal continuous-time and discrete-time linear systems. Increasing the subspace representation accuracy, the total number of allowed convergent paths, as monotonic power series, for instance (as allowed subspace paths), increases accordingly till maximum machine word length and beyond; like discrete quantum paths denser and denser to one another, towards a never ending "blending quantum continuum," called "quantum mixture" by a Top-Down (TD) perspective for composite multi-scale system. The finer geometry of subspace itself becomes scale dependent. While differentiable trajectories found in standard mathematical physics are automatically scale invariant, it is the main insight of the $CICT$ theory that also certain non-differentiable paths (resultant paths, emerging from lower scales combined quantum trajectory interactions, which explicitly depend on the scale and accuracy of the observer) can be scale invariant. $\mathbb{Q}$ can be thought as a discrete continuum of connected rationals with two basic contiguity operators, LTR (downscale) and RTL (upscale). The first LTR $CICT$ fundamental relationship that ties together numeric body information of LTR convergent monotonic power series in any base (in this case decimal, with no loss of generality) with D right ending by digit 9 is given by the following equation:

$$\frac{1}{D} = \sum_{k=0}^{\infty} \frac{1}{10^W} \left(\frac{\overline{D}}{10^W} \right)^k, \tag{2}$$

where $\overline{D}$ is the additive 10^W complement of D, i.e. $\overline{D} = (10^W - D)$, W is the word representation precision length of the denominator D. When $\overline{D} > D$ the formal power series of (2) can be rescaled mod$D$, to give multiple convergence paths to $1/D$, but with different "convergence speeds." The second LTR $CICT$ fundamental relationship for LTR sequences relates power information to evolutive polynomially ordered representation structure counterpart exactly. For any base r and for any Natural number D it is given by the following equation [16]:

$$D_r^k + \overline{D_r} \cdot \left(\sum_{m=0}^{k-1} D_r^m \cdot r^{W \cdot (k-m-1)} \right)_k - r^{W \cdot k} = 0, \tag{3}$$

where $\overline{D}_r$ is the additive r^W complement of D_r, i.e. $\overline{D}_r = (r^W - D_r)$. In previous paper [3], we already saw that $CICT$ can supply us with co-domain OECSs perfectly tuned to their low-level multiplicative noise source generators, related to experimental high-level overall perturbation. Now, by (3), polynomial co-domain information functional closure can be used to evaluate any computed result at arbitrary scale, and to compensate conveniently, to achieve multi-scale computational information conservation by LTR sequences. Analogous relationships can be written for RTL power sequences [16]. Eventually, by comparing LTR and RTL sequences, we arrive to the general relationship that ties together numeric body information of divergent (RTL) and convergent (LTR) monotonic power series in any base (in this case decimal, with no loss of generality), with D ending by digit 9. It is given by the following $CICT$ fundamental LTR-RTL correspondence equation:

$$\frac{1}{D} = \sum_{k=0}^{\infty} \frac{1}{10^W} \left(\frac{\overline{D}}{10^W} \right)^k = \frac{1}{\sum_{k=0}^{\infty} (D+1)^k}, \tag{4}$$

with the usual meaning of symbols given for (2). Further generalizations of (4) related to D ending by digit 1 or 3 or 7 are straightforward [16]. Now, it is convenient to use a compact notation for LTR geometric series as follows:

$$\frac{1}{D} = \sum_{k=0}^{\infty} \frac{N}{10^W} \left(\frac{CR}{10^W} \right)^k \equiv N_W(CR_W), \tag{5}$$

where D is denominator, N numerator, CR power series constant ratio, and W the length of their digit strings. Then, it is immediate to verify that at $W = 1$ (precision $= 10^{-1}$), unity can emerge out of a foundamental symmetrical multiplicity of different countable paths:

$1(9) \equiv 1/1$, $2(8) \equiv 1/1$, $3(7) \equiv 1/1$, $4(6) \equiv 1/1$, $5(5) \equiv 1/1$, $6(4) \equiv 1/1$, $7(3) \equiv 1/1$, $8(2) \equiv 1/1$, $9(1) \equiv 1/1$.

At $W = 2$ (precision $= 10^{-2}$), we have: $01(99) \equiv 1/1$, $02(98) \equiv 1/1$, $03(97) \equiv 1/1$, $04(96) \equiv 1/1$, $05(95) \equiv 1/1$, ..., $96(04) \equiv 1/1$, $97(03) \equiv 1/1$, $98(02) \equiv 1/1$, $99(01) \equiv 1/1$.

At $W = 3$ (precision = 10^{-3}), we have: $001(999) \equiv 1/1$, $002(998) \equiv 1/1$, $003(997) \equiv 1/1$, $004(996) \equiv 1/1$, $005(995) \equiv 1/1$, ..., $996(004) \equiv 1/1$, $997(003) \equiv 1/1$, $998(002) \equiv 1/1$, $999(001) \equiv 1/1$. Ad so on for $W = 4, 5, \ldots, W \in \mathbb{N}$.

4. CONCLUSION

CICT approach can offer an effective and convenient "Science 2.0" universal framework, by considering information not only on the statistical manifold of model states but also on the combinatorial manifold of low-level discrete, phased generators and empirical measures of noise sources, related to experimental high-level overall perturbation. Traditional elementary arithmetic long division remainder sequences can be interpreted as OECS for hyperbolic structures, as points on a discrete Riemannian manifold, under HG metric, indistinguishable from traditional random noise sources by classical Shannon entropy, and current most advanced instrumentation approach. CICT defines an arbitrary-scaling discrete Riemannian manifold uniquely, under HG metric, that, for arbitrary finite point accuracy W going to infinity (exact solution theoretically), is isomorphic (even better homeomorphic) to traditional information geometry Riemannian manifold. In other words, HG can describe a projective relativistic geometry directly hardwired into elementary arithmetic long division remainder sequences, offering many competitive computational advantages over traditional Euclidean approach. Thanks to its intrinsic self-scaling properties, this system approach can be applied at any system scale: from single quantum system application development to full system governance strategic assessment policies and beyond.

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