Original Article

Abstractions of Emergence in Electromagnetic Complex Spaces

Antonio Manzalini

Abstract

This paper elaborates on the possibility that reality, in all its forms, from energy and to matter, emerges from a condensed state of physical vacuum crossed by an omni-pervasive electromagnetic quantum field. Moreover, given that living organisms have peculiar electromagnetic properties, paper argues that is also possible that the origin of life itself has been based on a special self-organization of electromagnetic fields at a level of the fields or the elementary particles. If we push this metaphor even further, starting from the electromagnetic theory of consciousness, even the modeling of human cognition, such as conscious and unconscious information processing, can be still based on electromagnetism. Thus reality can be seen as like a condensed liquid crossed by electromagnetic field of waves and superposing wavelets; this medium can be abstracted, at lower and lower levels in terms of a three-dimensional electrical lattice whose elementary cells are characterized by local permittivity and permeability values. A quantum mechanical description of said lattice is an interesting research issues. In other words, reality can be seen as emerging from self-organization of an Electromagnetic Complex Space (ECS). A simulation tool (coupling Ising and Trasmission Line models) has been developed and some results on ECS condensation have been reported. It is also proposed to consider meta-material (showing amazing analogies between electromagnetic properties and relativistic space-time dynamics) as a laboratory (up to the nano-scale) where to develop and test experimentally such ideas. Theoretical results and experiments demonstrating the ECS may have far reaching implications in several scientific and techno economical fields.

Key Words: quantum physics, cognitive neuroscience, electromagnetism, emergence

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Introduction

Most of the current physics advances have been achieved adopting a reductionism approach that is in order to investigate the basic laws of nature: matter is divided into smaller and smaller pieces. Following this paradigm, the basic components of matter have been reduced from atoms to electrons, protons and neutrons, and recently, to the even more "elementary" particles. Standard Model is based on the Quantum Field Theory (QFT) which is a mathematical and conceptual framework for contemporary elementary particle physics.

On one side, today, there are researches directed towards finding even more fundamental building blocks – the so-called superstrings. String theory is up to now the most promising candidate for bridging the gap between QFT and general

Corresponding author: Antonio Manzalini
Address: Via Reiss Romoli, 274 – Torino, Italy
Phone: +390112285817
e-mail: antonio.manzalini@telecomitalia.it
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relativity theory, thus supplying a unified theory of all natural forces, including gravitation. The basic idea of string theory is not to take particles as fundamental objects but strings which are very small but extended in one dimension. Nevertheless, reservations about string theory are due to the lack of testability as the length scale of strings is in the average the same as the one of quantum gravity, namely the Planck length of approximately 10^{-33} m.

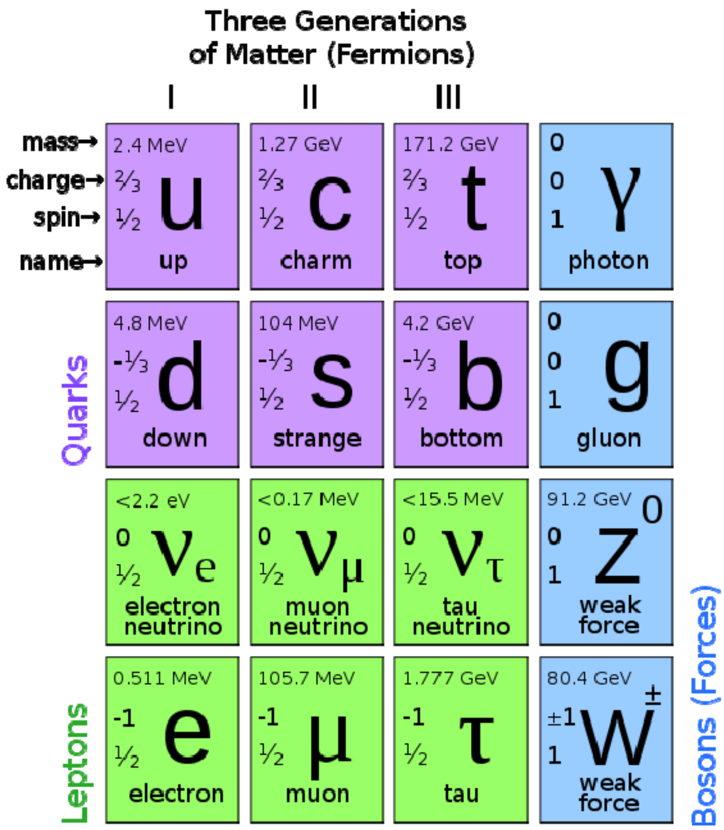

Figure 1. Standard Model

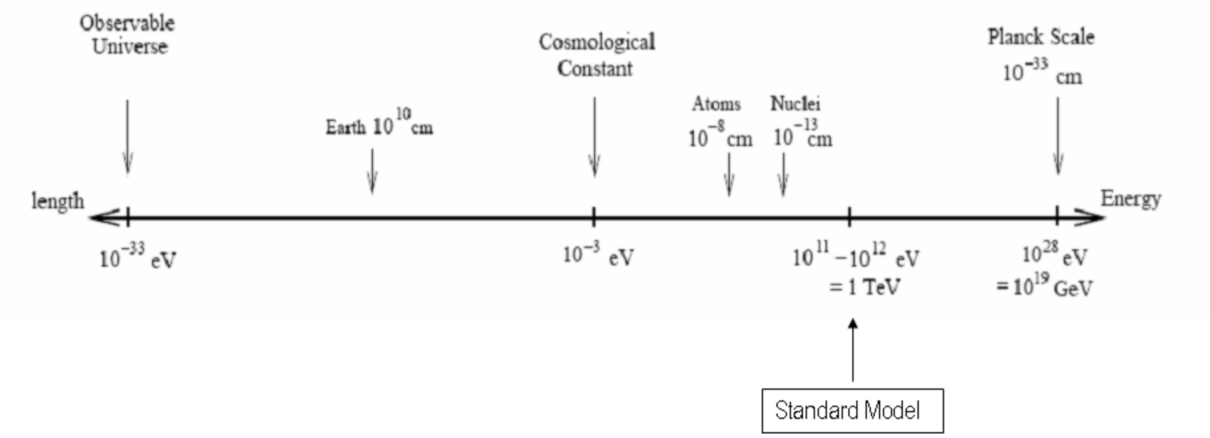

Figure 2. Levels of energy: from the Observable Universe to the Plank scale

Standard Model is experimentally verified below the energy scale of 10^3 GeV. On the other hand, the Planck energy scale, where quantum gravitational force becomes important, is at 10^{19} GeV. Therefore, there are 16 orders of magnitude to guess a new physics. In (Zhang, 2002) it is argued that instead of going up in energy, another way is moving down. Atoms, molecules and quantum liquids are made of elementary particles at very high energies. But at low energies, they interact strongly with each other to form quasi-particles, which look very much like the elementary particles themselves!

It is now well understood that the universe and its symmetry broken ground state, the physical vacuum, may behave like a condensed matter system. The analogy of the quantum mechanical physical vacuum with condensed matter systems should be taken seriously. There are some well-known examples in condensed matter physics, where starting from considering a quantum many-body system at high energies one arrives at topological field theory of the low energy quasi-particles. This paradigm, typical of Complex Adaptive Systems, is moving the attention from breaking the matter into smaller and smaller pieces to analyzing those mechanisms (at different scales) responsible for that emergence.

Interestingly it has been pointed out (Volovik, 2001) that many phenomena of the super fluid phase of ^{3}He share similarities with the Standard Model of elementary particles. Also it has been proven the equivalence between the super fluid equations and Maxwell's equations in 2+1 dimensions. These analogies between particle physics and condensed matter physics are amazing: one may imagine the physical free space not be empty, but a condensed state of many interacting simple elements having several degrees of freedom.

Moreover, the discovery of Fractional Quantum Hall (FQH) opened up even a new chapter in condensed matter physics: FQH is defined as a manifestation of simple collective behavior in a two-dimensional system of strongly interacting electrons. This effect has made clear that the Landau's symmetry breaking theory cannot describe different FQH states (as having the same symmetry). So, it was proposed that FQH states contain a new kind of order-topological order, generalized then to quantum order.

This paper proposes to consider a vision where reality, in all its manifestations from energy and from matter to living organism, emerges from a condensed liquid of elementary units crossed by an omni-pervasive electromagnetic quantum field. Moreover, given that living organisms have peculiar electromagnetic properties, it is also possible that the origin of life itself has been based on self-organization of special electromagnetic fields. Furthermore, starting from the electromagnetic theory of consciousness, even the modeling of human cognition, such as conscious and unconscious information processing, can adopt the same metaphor. It is argued that reality can be abstracted, at lower and lower levels in terms of a three-dimensional electrical lattice whose elementary cells are sort of transmission junctions, characterized by local permittivity and permeability values. This is called Electromagnetic Complex Space (ECS). A simulation tool (coupling for the first time Ising and Transmission Line models) has been developed and some results on ECS condensation have been reported. It is also proposed to consider meta-material, showing amazing analogies between electromagnetic properties and relativistic space-time dynamics, and already modeled in terms of transmission line networks, could be considered as a laboratory where to develop and test experimentally such ideas. Theoretical results and experiments demonstrating the Electromagnetic Complex Space may have far reaching implications in several scientific and techno economical fields.

The paper is structured as follows. After a brief introduction (*Section 1*) on Standard Model, Quantum field Theory and String Theory. Section 2 reports some preliminary considerations on the analogies between Quantum Mechanics and Optics: specifically the relevance of the two parameters dielectric constant ε and magnetic permeability μ (determining the refractive index) is elaborated. Section 3 presents a brief introduction about the Transmission Lines Model (TLM), starting from the G. Kron's theory who established a formal analogy between capacitors and inductors and the dielectric constant and magnetic permeability of a space being represented. Section 4 discusses how well-known Physics equations admit an equivalent electrical circuit, consisting of an equivalent transmission line. Dirac equation, for electron and positron plane waves, is cited as an example; also references to Schrödinger equations are made (as from G. Kron's theory). This section elaborates that reality appears to be a condensed liquid pervaded by electromagnetic waves and superposing wavelets: this medium can be abstracted in terms of a 3D electrical lattice. Section 5 reports some simulation results. Then, section 6 is dedicated to meta-material, that are engineered materials that can be characterized with TLM. What is amazing is that advances in experimental theoretical understanding of meta-materials greatly benefited from the field theoretical ideas developed to describe physics in curvilinear space-times. It is argued that these meta-material could be an extraordinary low-cost lab to test theoretical physics ideas. Section 7 highlights briefly some potential implications in cognitive science. The last section draws some conclusions.

1. Standard Model, Quantum field Theory and String Theory in a nutshell

Standard Model is a theory explaining three of the four known fundamental forces (electromagnetism, strong interaction, weak interaction and gravitation) and the elementary particles taking part in these interactions. In particular, electromagnetic force binds electrons to atomic nuclei (clusters of protons and neutrons) to form atoms; strong interaction is responsible for quarks "sticking" together to form protons, neutrons and related particles; weak force facilitates the decay of heavy particles into smaller ones; gravitational force acts between massive objects. Although the gravitational force is many orders of magnitude weaker than the other three ones, it is the dominant force throughout the universe. The only force the Standard Model leaves out is gravity, and that is handled very nicely by Einstein's theory of general relativity. The Standard Model includes 12 elementary particles (Figure 1).

Quarks and Leptons are the building blocks of matter, i.e., the "elementary particles". There are six "flavors" of quarks accounting for all known mesons and baryons (over 200). The most familiar baryons are the proton and neutron, which are each constructed from up and down quarks. Quarks are observed to occur only in combinations of two quarks (mesons), three quarks (baryons), and the recently discovered particles with five quarks (pentaquark). There are six leptons in the present structure, the electron, muon, and tau particles and their associated neutrinos. The different varieties of the elementary particles are commonly called "flavors", and the neutrinos here are considered to have distinctly different flavor.

Particles transmit forces among each other by exchanging force-carrying particles called bosons. These force mediators carry discrete amounts of energy, called quanta, from one particle to another. Each force has its own characteristic bosons: gluon mediates the strong force (gluons and their interactions are described by the theory of quantum chromodynamics); photon carries the electromagnetic force (photon is massless and is well-described by the theory of quantum electrodynamics); W and Z bosons represent the weak force; they introduce different types of decays.

The concept of wave-particle duality tells us that the properties of electrons and photons are fundamentally very similar. Despite obvious differences in their mass and charge, under the right circumstances both suffer wave-like diffraction and both can pack a particle-like punch. Having this in mind, the clue of *Quantum Field Theory* (QFT) in the name: it is the quantization of a classical field such as, for example, the electromagnetic field. QFT is the basic mathematical framework that is used to describe elementary particles. Interactions in quantum field theory are governed by a few basic principles: locality, symmetry and renormalization group flow. Many theories in modern particle physics, including the Standard Model of elementary particles and their interactions, are formulated in terms of relativistic quantum field theories.

The main idea behind *String Theory* is that the observed particle properties — that is, the different masses and other properties of both the fundamental particles and the force particles associated with the four forces of nature (the strong and weak nuclear forces, electromagnetism, and gravity) — are a consequence of the various ways in which a string can vibrate. String are stretched under tension in order to become excited (excitation mode) and are floating in space-time. The average size of a string should be somewhere near the length scale of quantum gravity, the Planck length.

2. Analogies between Quantum Mechanics and Optics

As known, electromagnetic field is produced by electrically charged pieces of matter and it affects the behavior of charged objects in the field. It can be viewed as the combination of an electric field and a magnetic field. The electric field is produced by stationary charges, and the magnetic field by moving charges (currents). The way in which charges and currents interact with the electromagnetic field is described by Maxwell's equations and the Lorentz force law. From a classical perspective, the electromagnetic field can be regarded as a smooth, continuous field, propagated in a wavelike manner; whereas from the perspective of quantum field theory, the field is seen as quantized: electromagnetic field is equivalent to an infinite set of harmonic oscillators. Each harmonic oscillator is quantized: the result is a representation of the field as a sum over modes at frequencies, each with a definite number of excitations, or quanta.

The study of the interactions of electromagnetic waves with matter has always been a fascinating subject of study and experimentation. When an electromagnetic wave interacts with matter, the main effect is the force exerted by the electric field on the charged particles that make up matter. As the mass of an electron is approximately 1/2000 of the mass of a proton, the acceleration experienced by an electron is 2000 times greater than that experienced by a proton subject to the same force. Hence, from a macroscopic viewpoint, the interaction of light with matter can often be explained in terms of the interaction of light with the electrons. Macroscopically, refractive index is the most important parameter to describe such interaction: it is a complex number (where the real part is normally positive) conventionally taken to be a measure of the electromagnetic density of a certain medium.

Refractive index is defined as a ratio $n = c/v$ where c is the speed of light in free space and v is the speed of an electromagnetic plane wave in the medium. From Maxwell's equations, the refractive index is given by the relation $n^2 = \varepsilon \mu$ where ε is the relative dielectric permittivity and μ is the relative magnetic permeability of the medium. For isotropic materials ε and μ are complex numbers while for anisotropic materials ε and μ are represented with tensors. So basically, dielectric constant and the magnetic permeability characterize the macroscopic response of a medium when exited by an electro-magnetic field. These are macroscopic parameters because one usually only seeks time-averaged and spatially-averaged responses averaged over sufficiently long times and sufficiently large spatial volumes.

As there are impressive analogies between geometrical optics and classical mechanics, it has been natural also looking for a potential mathematical basis for the analogy between Quantum Mechanics and Optics. This analogy was pushed further by Feynman, in his article on a "space-time approach to non-relativistic quantum mechanics" (Feynman, 1948). Feynman's principle forms a wave-mechanical analogue of Huygens' principle in optics. Also similar connection exists between Fermat's principle of least time for geometrical optics and said principle. Amazingly, the so-called optical model, that has been largely used to describe the interaction between nuclei, is inspired by the optical phenomenon. The nuclear medium diffracts one part of the incident wave which models the incident particle and another part of the wave is refracted. Then this phenomenon can be characterized by a complex index. The real part of the index corresponds to the diffraction phenomenon and the imaginary part to the refraction of the incident wave.

Another example concerns the concept of tunneling quantum mechanics, whereby wave or particles may penetrate through classically impenetrable barriers. Optical physicists realized tunneling in the frustrated total internal reflection, whereby evanescent optical fields penetrate across an air gap between two adjacent glass prisms, giving transmission of light beyond the critical angle for total internal reflection (Hooper *et al.*, 2006). The same model applies for all quantum mechanical systems!

Analogies between quantum mechanics and optics have a long history of studies and experiments: there is a rich prior art on that. Nevertheless it seems there are also some limitations on said analogies: the best known is probably the different statistics of electrons and photons. Electrons have Fermi statistics, whilst photons have Bose statistics. This is true according to our current understanding. On the other hand, one cannot ignore that in condensed matter physics there are studies questioning if there is a kind of "state" of the deep free space that can give rise to emergence of all particles.

Relativistic Maxwell equation and Dirac equation can emerge in the low energy sector of a quantum many-body problem. It seems that atoms and molecules are made of elementary particles at very high energies, but at low energies, they interact strongly with each other to form quasi-particles, which look very much like the elementary particles themselves.

Interestingly in (Wen, 2005) it is argued that vacuum could be a string-net condensed liquid state composed by networks of elementary bosons sticking together: amazingly they demonstrated that collective motions of said particles networks correspond to waves describes both by the Maxwell and Dirac equations. This approach is built on a considering emergence (rather than reductionism) as a key mechanism to model nature: both photons and electrons emerge from collective motions of said elementary bosons. For not saying that these bosons could even be seen as bounds of electromagnetic waves.

The question is, would it be possible to elaborate a way to model, simulate and test reality as a condensed liquid crossed by electromagnetic waves and superposing scattered wavelets?

3. Transmission Lines Model

Previous section elaborates on the analogies between quantum mechanics and optics, analogies that may go beyond our current understanding. In this section, it is argued that reality can be abstracted, at lower and lower scale in terms of a generalized 3D electrical lattice whose elementary cells are sort of junctions of transmission lines. This is called Electromagnetic Complex Space.

As a matter of fact, Transmission Line Model is a general numerical simulation technique for solving field problems. Its main application is in electromagnetism, but it has also been applied successfully also to thermodynamics and to acoustics.

TLM method is based on Huygens' model of wave's propagation and scattering and builds on the analogy between field propagation and transmission lines. Huygens' principle is a method of analysis applied to problems of wave propagation saying that each point of an advancing wave front is the centre of a fresh disturbance and the source of a new train of waves; the advancing wave as a whole may be regarded as the sum of all the secondary waves arising from points in the medium already traversed. This view of wave propagation helps better understand a variety of wave phenomena, such as diffraction.

Local matter exited by a wave reradiates secondary wavelets, and all wavelets superpose to a new, resulting wave (the envelope of those wavelets), and so on. Huygens' Principle contains both the principle of action-at-proximity and the superposition principle. Amazingly, this doesn't apply only to the propagation of light, but also to heat and matter diffusion, Schrödinger matter waves and virtually to all propagation processes (Enders, 1996).

Starting from these concepts, Kron (Kron, 1945) proposed a network representation of Maxwell's equations in a charge-free medium with positive ε and μ. A unit cell of Kron's 3D network is shown in Fig. 1.

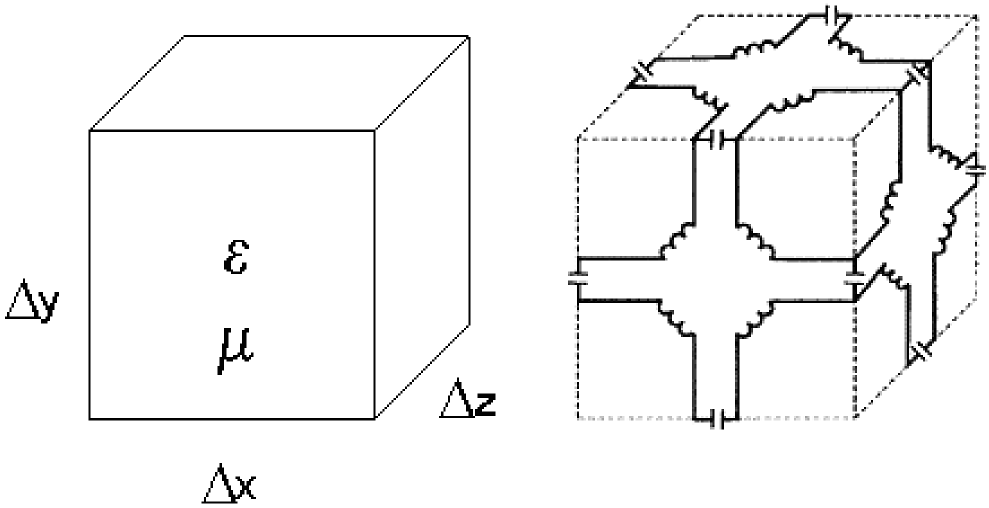

Figure 3. A cell of free space (or matter) – on the left – it can be characterized by the two parameters permittivity and permeability. Kron's unit cells – on the right – it can modeled it with an electrical network (3D cell).

According to this approach, Maxwell equations are solved in discrete spatial increments, in which field quantities are regarded as quasi-static. Impedance and admittance can be evaluated by mapping quasi-static field quantities in the unit cell to current and voltages.

Let's imagine a cubic unit cell Δx Δy Δz with a uniform electric field in the area Δx Δz, the thickness Δy describes a capacitor with parallel plates filled with a medium with dielectric constant ε and magnetic permeability μ. The overall capacitance in the x, y and z directions associated with the electric field polarization, is given by the Cy = ε Δx Δz/Δy, Cx = ε Δy Δx/Δx and Cz = ε Δx Δy/Δz. Similarly, the overall inductance in the x, y and z directions has the following components Lx = μ Δy Δz / Δx, Ly = μ Δx Δz / Δy and Lz = μ Δx Δy / Δz.

This work by Kron laid the foundation for TLM. The method considers the computational domain as a mesh of transmission lines, interconnected at nodes; a scattering approach akin to Huygens principle is implemented. Secondary wavelets have been treated in terms of the intensity of the reflected and transmitted voltage (or current) pulses on the TLM network. The relationship of TLM to Huygens principle has been addressed in (John, 1974).

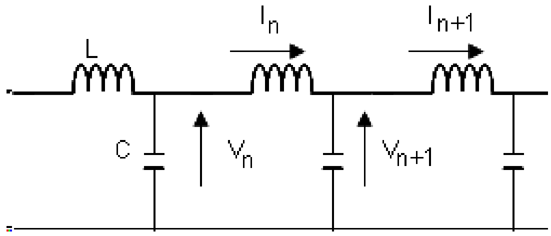

Figure 4. Example of 1D TLM.

Figure 4 reports a simple example of 1D TLM network. If $V_n(t)$ is the voltage across the nth capacitor and $I_n(t)$ is the current across the nth inductance, from the Kirchoff's law it can be written:

$$V_{n-1} - V_n = \frac{d\Phi_n}{dt} \quad \textbf{(1)}$$

$$I_{n-1} - I_n = \frac{dQ_n}{dt} \quad \textbf{(2)}$$

Where the magnetic flux and the electric charge are respectively given by:

$$\Phi_n = LI_n \quad \textbf{(3)}$$

$$Q_n = CV_n \quad \textbf{(4)}$$

Combing above equations we get a system of differential equations:

$$\frac{d^2V_n}{dt^2} = \frac{1}{LC}(V_{n+1} + V_{n-1} - 2V_n) \quad \textbf{(5)}$$

$$\frac{d^2I_n}{dt^2} = \frac{1}{LC}(I_{n+1} + I_{n-1} - 2I_n) \quad \textbf{(6)}$$

Above equations represent the discrete form of the telegrapher's equations when loss elements are negligible.

Figure 5 represent, as an example, a 2D TLM network or lattice.

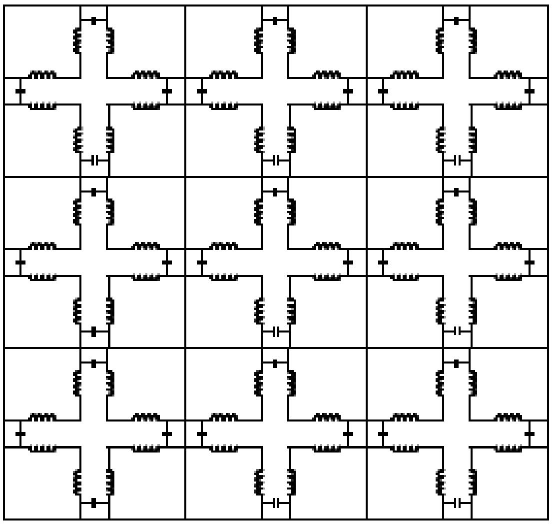

Figure 5. A 2D TLM lattice (serial nodes).

The most commonly used node for 3-dimensional analysis is the Symmetrical Condensed Node (SCN) (Hubing, 1991). The basic structure of the symmetrical condensed node is illustrated in figure 6.

Each node (John, 1987) is connected to its neighboring nodes by a pair of orthogonally polarized transmission lines. It contains a hybrid junction of twelve transmission lines (the node), which is characterized by a 12x12 scattering matrix. The time domain TLM algorithm is executed in two steps. Firstly, twelve short voltage pulses are simultaneously injected into the node ports 1 to 12. The pulses are scattered and give rise to twelve reflected voltage pulses. Secondly, the reflected pulses are transferred to the neighboring nodes where they become incident pulses at the subsequent time step, and the process is repeated. Additional elements, such as transmission-line stubs, can be added to the node so that different material properties can be represented.

TLM it is not the only way to approach the modeling the electromagnetic complex space; for instance, the T-matrix approach, which is practically universal for all application fields of the light scattering theory, may provide a way to approach modeling and simulations (Mishchenko, *et al.*, 1996), (Varadan, 1998). The general idea of the T-matrix theory is to expand the incident and surface electric fields, E_i and E_{surf}, as well as the internal and scattered fields, E_{int} and E_s, in terms of appropriate sets of vector waves. By utilizing integral representations of the fields, a relation between the expansion coefficients for the incident and scattered fields is obtained. Literature provide also other valuable approaches, but TLM has been selected as widely used in designing meta-materials, that are offering extraordinary electromagnetic models of any metric of space-time.

Now, consider reducing the dimensions of the unit cell up to the Planck scale (where classical ideas about gravity and space-time cease to be valid, and quantum effects starts dominating). Planck length is then a 'quantum of length', i.e., the smallest measurement of length, roughly equal to $1.6x10^{-35}$ m or about 10^{-20} times the size of a proton.

Cell dimensions would be reduced up to contain a fundamental quantum of mass m_q equivalent to the energy quantum h (Worsley, 2005), according to $E = m_q c^2 = h$. Said cells could create a sort of lattice (of elementary quanta) that by the way could be seen even as a framework supporting the quantum gravitational field. Matter may interact with that lattice producing the effects of mass, which appears as modifications of permeability and permittivity of said lattice (the deflection of light in presence of a gravitational field, due to space-time curvature determined by matter/energy, finds amazing analogies in meta-materials). Interestingly Max Planck's formula E=h f would still hold so frequency of matter would be equivalent to the number of mass quanta it contains per unit time. A quantum mechanical description of said lattice is an interesting research issues.

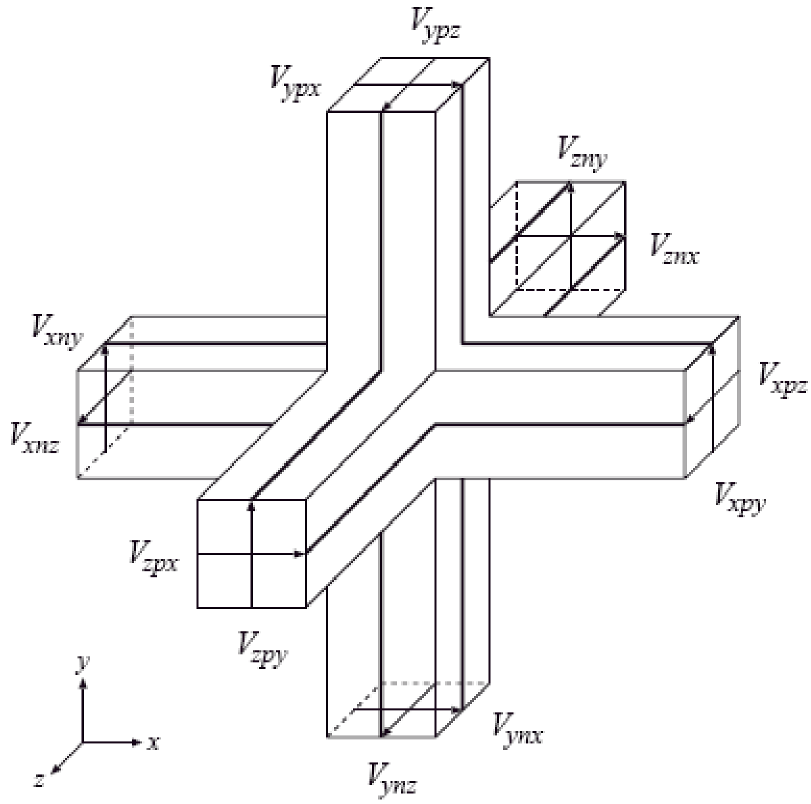

Figure 6. A Symmetrical Condensed Node (SCN).

Also Stochastic Electro-Dynamics (SED) (De la Pena, 1996) argues that the physical vacuum is assumed to be a turbulent sea of randomly fluctuating electromagnetic fields at all wavelengths longer than the Planck length. Consider that lattice cells may be exited by these so-called Zero-Point Field (ZPF) fluctuations of electromagnetic nature. This classical ZPF is represented as a homogeneous, isotropic ensemble of plane electromagnetic waves whose amplitude is exactly equivalent to an excitation energy of hν/2 of the corresponding quantized harmonic oscillator, this being the state of zero excitation of such an oscillator. Also in the conventional interpretation of quantum electrodynamics, an electromagnetic ZPF arises as a consequence of the Heisenberg uncertainty relation as applied to each mode of the electromagnetic field. On the other hand, (Ibison and Haisch, 1996) proposed an alternative classical ZPF with a different stochastic character, to demonstrate that it can exactly reproduce the statistics of the electromagnetic vacuum of quantum electrodynamics.

It sounds then quite natural to consider said lattice hosting multiple-scattering of electromagnetic fields and ZPF occurring at different scales, in a self-similar way.

Self-trapping mechanisms can happen due to the interaction between the medium and the electromagnetic waves, with the waves modifying locally the medium and being in turn modified by it. Local behaviour and vibration of networks of said elementary quanta can create complex structures capable of abstracting the framework composing the reality. Vibrations of these quanta determine, for instance by a reciprocal influence, the related emergence of new modes of propagation or new states. It can be demonstrated that said networks of elementary quanta, fluidly vibrating can satisfy the Maxwell and Dirac equations at the same time. This allows considering the possibility to model electromagnetic waves and particles (like photons and electrons...) as vibrating modes and emergence (respectively) condensed states of elementary quanta.

4. Equivalent electric circuits of some well known equations

This section discusses how not only the Maxwell equations but other well-known equations (e.g., Schrödinger and Dirac) admit an equivalent electrical circuit, consisting of an equivalent transmission line.

As well known, in quantum mechanics, the Schrödinger equation is describing how the quantum state of a physical system changes in time. In the standard interpretation of quantum mechanics, the quantum state, also called a wave-function or state vector, is the most complete description that can be given to a physical system. Kron developed equivalent electric circuits to represent the Schrödinger amplitude equation for one, two, and three independent variables in orthogonal curvilinear coordinate systems.

Dirac equation is a relativistic quantum mechanical wave equation formulated by the physicist Paul Dirac in 1928 which provides a description of elementary spin -1/2 particles, such as electrons, consistent with both the principles of quantum mechanics and the theory of special relativity.

Many authors already reported theories about the electron as a sort of a bound electromagnetic waves or the electron as electromagnetic field trapped in an equivalent waveguide. As a matter of fact it can be easily demonstrated (with calculations using the usual notations of circuit theory and electromagnetism) that the Dirac equation for electron and positron plane waves admits an equivalent electrical circuit, consisting of an equivalent transmission line (Bettini, 2010). The full set of plane wave Dirac equations can be interpreted in terms of appropriate equivalent transmission line circuits and/or equivalent waveguide. Solutions with opposite spin are represented by opposite polarization in the waveguide. The equivalent transmission line shares all the usual properties of the transmission lines, including the dispersive character, and evanescent waves (that are the correspondent of electrons propagating through a potential barrier.

If it is possible to model with transmission lines waves following both Maxwell and Dirac equations, it is also true that equivalent transmission lines can represent both photons and electrons: TLM metaphor seems offering a unified abstraction model valid for both these two realms, light and matter. This may not be a simple accident. Actually it suggests that this pervasive Electromagnetic Complex Space can be modeled by a 3D electrical lattice composed by SCN-like nodes.

It should be noted that this 3D electrical lattice might exhibit both nonlinear and dispersion, and as such it could therefore sustain also solitons. Solitons have been demonstrated in many physical systems: surface waves in shallow water, plasma waves, sound waves in ^{3}He, short temporal optical pulses in fibres, and optical spatial solitons. As known, optical spatial solitons are self-trapped optical beams of finite spatial cross section that travel without the divergence associated with freely diffracting beams. The self-trapping is due to the interaction between the medium and the electromagnetic wave, with the wave modifying locally the medium and being in turn modified by it. The universal principle unifying all solitons is that the wave-packet creates, by virtue of the nonlinearity, a potential well and captures itself in it. Mutual interaction between solitons is one of the most fascinating issues: they look like interactions between bound states of a jointly induced potential well, or between bound states of different wells located at close proximity (Stegeman and Mordechai, 1999). Solitons and the de Broglie wave representation of real particles have many properties in common. One may wonder if there are fundamental new laws of physics linking solitons and particles? (Stegeman and Mordechai, 1999).

Next section is dedicated to meta-materials, special pieces of matter showing amazing analogies between optical properties and Minkowski space-time dynamics. Meta-materials can be divided into identical unit cells which can be modeled by a distributed network of reactance. Applying Maxwell's equation on each cell, those unit cells have effective permittivity and permeability as functions of frequencies.

Considering that TLM (Eleftheriades, *et al.*, 2003) is one of the most used methods to study and design such meta-materials, it is considered to design, develop and study meta-materials as low cost labs where testing the ideas proposed in this paper.

5. Some simulations results

A tool has been developed to simulate particle condensation in a 2D electrical lattice. As known, a simple example of particle condensation is given by the transverse-field Ising model. As in (Wen, 2005) main idea has been considering an hard-core boson system: the two states of Ising spin variables are viewed as empty and occupied site.

$$H_{I\sin g} = -J\sum_{i,j} s_i^x s_j^x - B\sum_i s_i^z \qquad \textbf{(7)}$$

Considering equation (7), 2B represents the energy cost to create a boson and J is the boson hopping amplitude. When B>>J, creating a boson requires a great energy and the ground state of the system contains few fluctuating bosons. When J>>B, the creation of bosons dominates and states superpositions appear (connected by the hopping term to lower its energy).

Transverse-field Ising model has been integrated (apparently for the first time), with the TLM. Specifically each elementary boson has been simulated as an elementary SCN, an an electromagnetic field is applied on each cells of the lattice. This approach has been called ECS model.

Results are encouraging. Figure 7 reports an example of simulated condensed state.

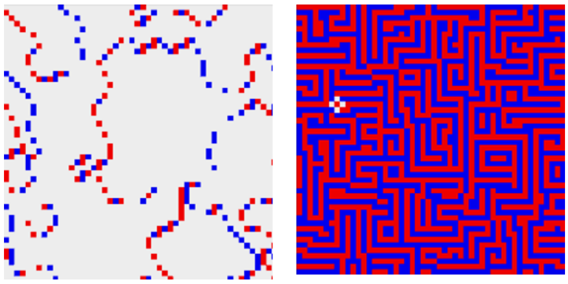

Figure 7. Example of simulations (on the right side, J >> B).

6. Meta-materials: a lab for theoretical Physics?

Traditional optical materials have a positive ε and μ, resulting in a positive refractive index. Veselago (Veselago, 1968) first considered the case of a medium that had both negative dielectric permittivity and negative magnetic permeability (at a given frequency) and as such a negative refractive index (i.e., the negative square root, n=−√εμ, had to be chosen).

Meta-materials are realized by using periodic structures such as split ring resonators, conducting wires and/or electric resonators.

Today, nanotechnology progresses allow creating materials (called meta-materials) that exhibit negative refractive index: this can be done by having a certain degree of control of the local dielectric permittivity and magnetic permeability tensors of matter. Meta-materials include class of inhomogeneous materials where the inhomogeneities are on length-scales much smaller than a wavelength of the radiation but can be large compared with atomic or molecular length-scales. The radiation then does not resolve these individual meso-structures, but responds to the (atomically) macroscopic resonances of the structure.

For example in (Grbic and Eleftheriades, 2005) it is proposed to design and analyze an isotropic three-dimensional negative-refractive-index medium using transmission lines loaded with reactive elements.

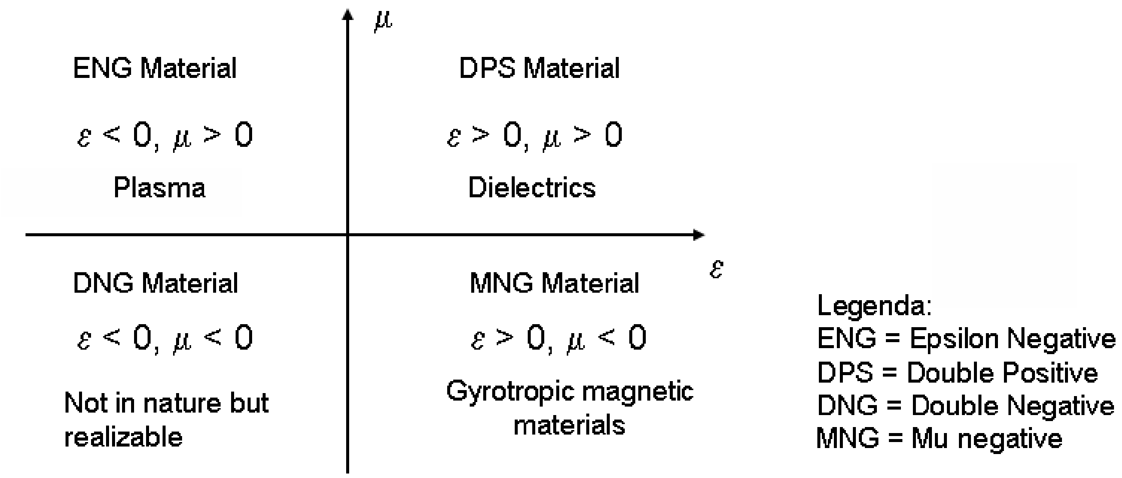

Figure 8. Classification of materials based on the dielectric and magnetic properties

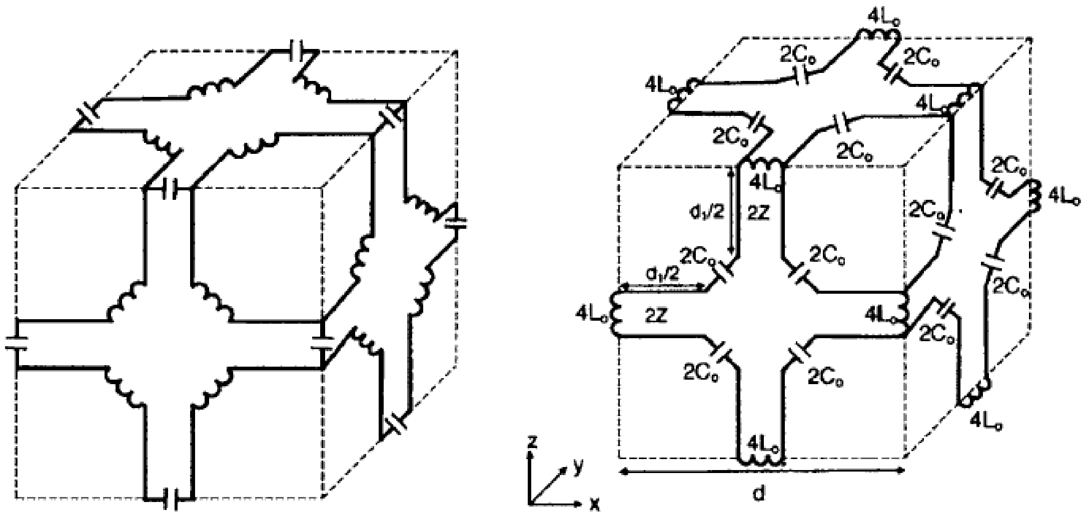

Figure 9. Isotropic three-dimensional negative-refractive-index medium using transmission lines loaded with reactive elements (Grbic and Eleftheriades, 2005).

As another example, in nano-photonics, they demonstrated (Engheta *et al.*, 2005) that nano-sphere excited by an electromagnetic signal may behave as a "nano-capacitor" or a "nano-inductor": specifically if the nano-sphere (much smaller than the optical frequency) is made of non-plasmonic material (i.e., $\varepsilon < 0$) then it behaves as a nano-capacitor; on the other hand if the nano-sphere is made of plasmonic (metallic) material (i.e., $\varepsilon > 0$) then it behaves as a an nano-inductor. The imaginary part of the material permittivity may provide an equivalent nano-resistor. Moreover, it should be noted that two (or more) juxtaposed nanoparticles can form parallel or series resonant nano circuits depending on the specific orientations with respect to the illuminating electromagnetic field.

Meta-materials demonstrate a number of peculiar properties: reversal of Snell's law of refraction, reversal of the Doppler shift, counter-directed Cherenkov radiation cone, etc. What is amazing is that certain classes of meta-materials enable experimental exploration of the "metric phase transitions" to and from the Minkowski space-time as a function of the light frequency (the space-time scale). In (Smolyaninov, 2009) an optical analogue of a "big bang" event is presented during which a (2+1) Minkowski space-time has been created together with large number of particles populating this space-time. These analogies recall the well-known analogy between the physics of the super-fluid states in ^{3}He and the gravitation theory. Moreover the ease of control of the dielectric permittivity and magnetic permeability tensors in meta-material allow creating optical models of any metric of general relativity. In (Lazarides and Tsironis, 2005) it has been shown interestingly that for an isotropic, homogeneous, quasi-one-dimensional meta-materials, Maxwell's equations with nonlinear constitutive relations lead naturally to a system of coupled nonlinear Schrödinger equations for the envelopes of the propagating electric and magnetic fields; this is equivalent to the Manakov model (Manakov, 1974).

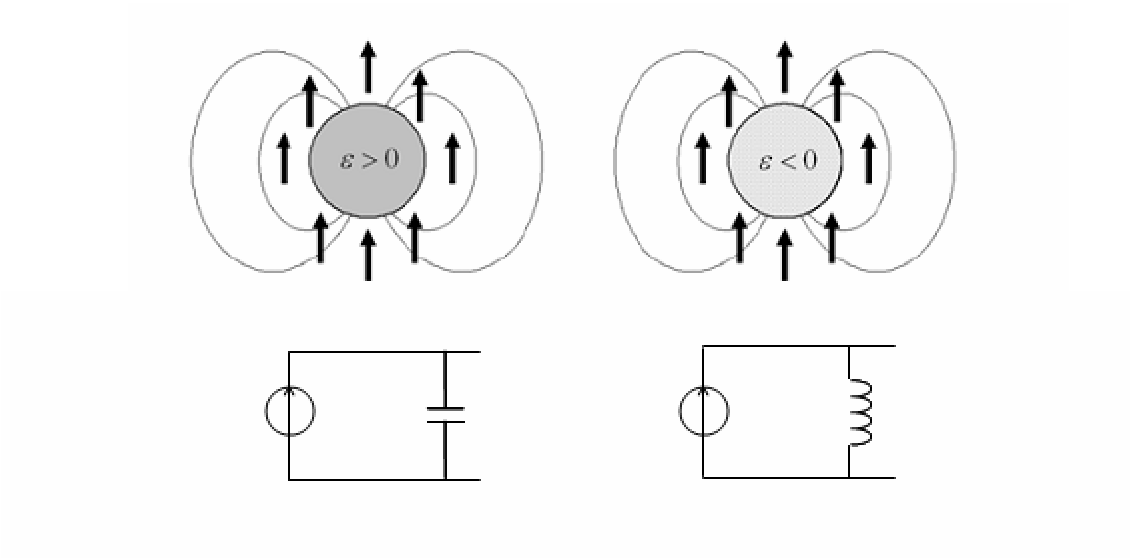

Figure 10. A basic nanocircuit in the optical regime, using the interaction of an optical wave with an individual nanosphere (Engheta *et al.*, 2005).

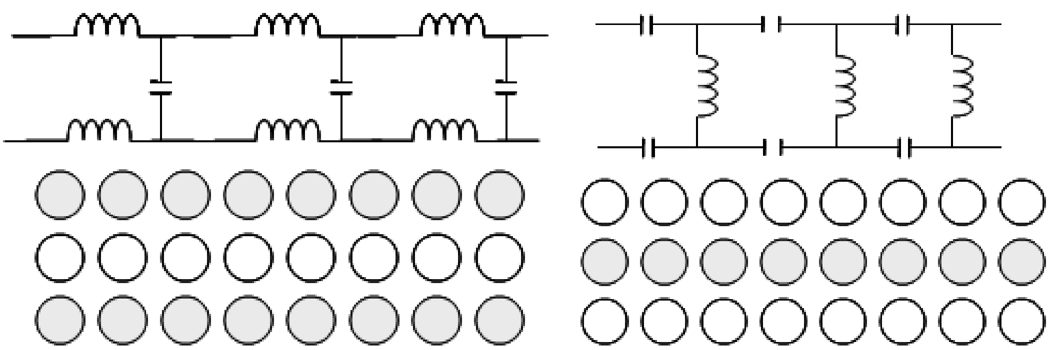

Figure 11. Examples of right-handed (RH) and left-handed (LH) nano-transmission lines (Engheta *et al.*, 2005)

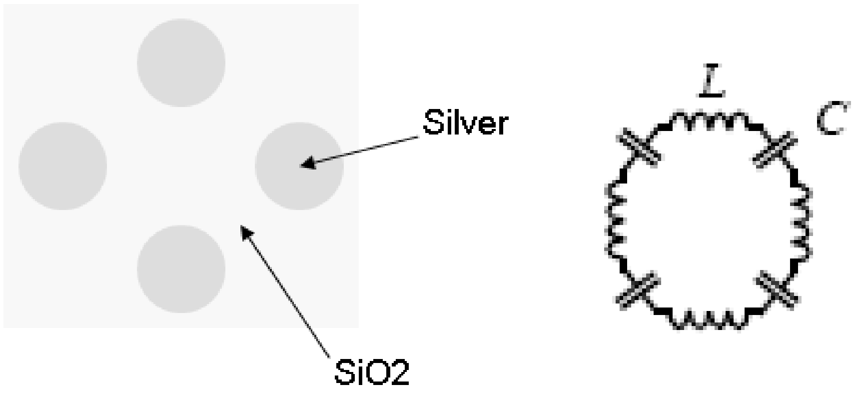

Figure 12. A ring of nano-particles and related equivalent circuit (Alu *et al.*, 2007).

Let's consider this amazing example. In general relativity, the presence of matter-energy densities results in the motion of matter propagating in a curved space-time, which is similar to the electromagnetic-wave propagation in a curved space and in an inhomogeneous meta-material. This makes possible simulating a black hole using electromagnetic fields and meta-materials. First experimental demonstration of electromagnetic black hole in the microwave frequencies has been achieved (Qiang Cheng and Cui, 2009). The proposed black hole is composed of non-resonant and resonant meta-material structures, which can absorb electromagnetic waves efficiently coming from all directions due to the local control of electromagnetic fields. These kind of non-resonant and resonant meta-material structures – created and inserted into the host material - are like split ring resonators whose equivalent electric circuits look like TLM cells. These capabilities of engineering meta-materials according to TLD design might have far reaching implications, when extended at lower and lower scales up to nanometers.

It is argued that these meta-material could be an extraordinary low-cost lab to design and test experimentally new advances in physics; in particular, nano-technologies will allow developing and controlling nano-structures resembling 3D electrical lattices testing ECS.

7. Neuroscience: modeling brain networks with a 3D electrical lattice

It is well known that living organisms show peculiar electromagnetic properties; it is not improbable that the origin of life was based on emergence in electromagnetic fields in views at a level of the fields or the elementary particles.

Emergence of consciousness is an even more complex issue. Brain is a complex system made up of a network of neurons, hosting a dance of electromagnetic interactions. Cognitive neuroscience sees the brain as a computer for information processing. This, nevertheless, doesn't explain how consciousness emerges: brain operates also at lower and lower microscopic levels. Brain hosts phenomena of various kinds, probably conforming to several schemes of abstractions; the problem is that such entities lack a formal definition (as in machines), their properties being inferred from investigations (at different levels of observation) of several instances encountered in nature (Crick and Koch, 2003; Edelman, 2003).

In any case, endogenous electromagnetic field of the brain is highly complex: there are two main sources contributing to the formation of this field: neuron firing and the fields generated by the movement of ions into and out of cells and within extra-cellular spaces. For many years, mathematics and computational methods have played an important role in our understanding of the nervous system. Modeling idea is to represent the electrical properties of biological membranes using an equivalent circuit consisting of capacitors and resistors. The Hodgkin–Huxley model (1952) described (Hodgkin and Huxley, 1952) how action potentials in neurons are initiated and propagated. It is a set of nonlinear ordinary differential equations that approximates the electrical characteristics of excitable cells such as neurons and cardiac myocytes. FitzHugh–Nagumo proposed a description an equation of the neural action potential propagation; Nagumo (Nagumo, 1962) also presented an electrical lattice modeling the above-cited equation. In general, the flow of different currents associated with the neuron's membrane play very important roles in the neuronal activities (other sub-cellular components, such as DNA, RNA, proteins, inside the cells, also contribute significantly to neuronal activities). Currents are divided into those that can be represented by linear circuit elements (passive currents) and those that are voltage and/or time dependent and require more complex dynamics (active currents) (Johnston and Wu, 1997).

For example in (Marquie' *et al.*, 2004) a neuron have been modeled as a nonlinear electrical lattice realized with N elementary cells, resistively coupled by linear resistors R, as represented in Fig. 7. Each cell contains a linear capacitor in parallel with both a linear self-inductance L and a nonlinear resistor RNL, whose current–voltage characteristic obeys a following cubic law.

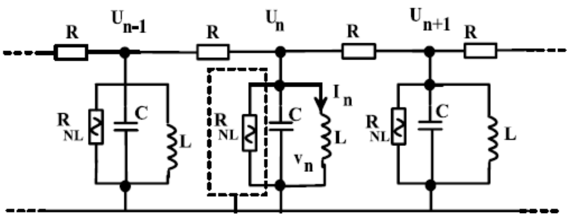

Figure 13. A neuron have been modeled as a nonlinear electrical lattice realized with N elementary cells (Marquie' *et al.*, 2004).

Another example is in (Samardak and Nogaret, 2008) where it has been demonstrated the modeling of a neuron as a monolithic web of micro-transmission lines propagating electrical pulses to a soma, where they are regenerated via quantum tunneling amplification. The gain of the modeled neuron followed a sigmoid curve similar to the one that controls the firing of real neurons.

Lets' consider now electromagnetic field theory of consciousness: it is a theory that says the electromagnetic field generated by the brain (measurable by ECoG) is the framework over which our conscious experience is built. Theory has been initially proposed by Susan Pockett (2007), Johnjoe McFadden (*CEMI Field Theory*) (McFadden, 2007) and E. Roy John.

Locating consciousness in the brain's electromagnetic field has the advantage of accounting for the so-called binding problem: brain information is unified in the electromagnetic field. Other theories are today under debate: from the Orchestrated Objective Reduction(Orch OR) theory of Stuart Hameroff and Roger Penrose, to the Topological Geometro Dynamic (TGD) theory, proposed by Matti Pittkanen and Alex Kaivarainen, to the Noetic Field Theory of Richard Amoroso.

Describing and comparing such prior-art is outside the scope of this paper. Main message anyway is that there are many ongoing physical implementation of the electromagnetic theory of consciousness but the issue of spontaneous generation of consciousness in electromagnetic networks remains open, however, and research is ongoing.

In line with these research avenues, this paper proposes the thesis that ECS extends even to the brain and as such that it might be the mean which connects everything – to – everything (this, even if it might appear bizarre, could reopen the debate about how mind can act over matter).

For example it would be interesting modeling the Global Workspace as a 3D electrical lattice of elementary cells. Global Workspace Theory (GWT) (Baars, 1988; 1997) is a widely recognized theory in cognitive neuroscience to explain aspects of human cognition such as conscious and unconscious information processing. Interestingly theory has been applied also to challenges such as emergence in highly complex systems composed of several simple interacting entities. GWT put forward an architecture comprising a set of parallel specialist processes and a global workspace. The parallel processes compete (and sometimes cooperate) to win access to a global workspace. When one or more of these processes succeed in getting access to the global workspace then it can put forward a piece of information, which is broadcast back to the whole group of processes. The patter of information flow is an alternation between broadcast and competition. A GWT essentially proposes a model of combined serial and parallel information flow, wherein specialist processes compete and cooperate.

The global workspace can be seen as a (neuronal) complex system for the workings of the highest and most general levels of (brain) organization (Dehaene, 2001): it would be simple imagine that these emerging organizations are of electromagnetic nature, and as such abstracted and modeled in terms of a 3D electrical lattice of elementary cells. As a matter of fact, brain functional networks can be modeled as graph representing activities in the brain, where the vertices can be represented by small anatomical regions (voxels) and the edges their functional connectivity. Functional magnetic resonance imaging (fMRI) has been largely used to get and elaborate data on brain functional networks. So even if, fMRI doesn't actually measure electrical signals and the link between blood flow and neural activity is not always fully clear, voxels could be simulated as SCN nodes (as represented figure 6) interconnected by various electromagnetic modes.

Moreover, given that meta-materials provide a new scale-invariant design paradigm (capable to revolutionize the ability to manipulate, control, and detect electromagnetic radiation), one may even imagine to model brain's capabilities through complex meta-material. Nanotechnology would allow developing prototypes. Assembly of nano-structures in a host material could allow creating (even organic) meta-material layers, showing electromagnetic patters (similar to magnetic resonance images of human brain during different functions) capable of performing a variety of (quantum) processing tasks, or even simulating natural phenomena such as (quasi-)particles interactions, reaction-diffusion, etc.

Conclusions

This paper argues that reality appears to be a condensed liquid crossed by electromagnetic field of waves and superposing wavelets, named Electromagnetic Complex Space; this medium can be abstracted, at lower and lower levels in terms of a three-dimensional electrical lattice whose elementary cells are sort of transmission junctions, characterized by local permittivity and permeability values. A quantum mechanical description of said lattice is an interesting research issues.

A simulation tool (based on Ising and Trasmission Line models) has been developed and some encouraging results have been reported. Moreover it is argued that meta-material, showing amazing analogies between electromagnetic properties and relativistic space-time dynamics, could be considered as a laboratory (up to the nano-scale) where to develop and test experimentally such ideas.

Theoretical results and experiments demonstrating the Electromagnetic Complex Space, and its quantum mechanical nature, may have far reaching implications in several scientific fields, bridging physics with cognitive neuroscience and with development of new materials. In this sense, meta-material can be used to create extraordinary low-cost laboratories where design and testing such advances.

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