Bootstrapping the Quantum Field Theory QFT: A New Road to the Elementary Particles Spectrum

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Abstract: A new concept of bootstrap in particle physics is proposed, which is fully compatible with the formalism of quantum field theory (QFT). The emergence of spacetime and the spectrum of elementary particles is discussed in this context.

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1. Introduction

The study of elementary particles in theoretical physics experienced a split towards the end of the 1950s. On the one hand, quantum field theory (QFT) developed from quantum electrodynamics; it has gradually become the general reference for the study of particle interactions and the foundation of the Standard Model. In spite of several open problems inherent to the grandunification program, QFT is currently the most widely used approach.

On the other hand, the bootstrap model [1,2], developed by Chew and his followers with reference to the study of strong interaction, led to an alternative school of thought which, in spite of its crisis towards the end of the 1960s [3], survives in the form of the current theory of superstrings and branes.

In this article we present an approach inspired by Chew and his original idea of "bootstrap". However, a completely different interpretation of the bootstrap process is provided, that is consistent with QFT. By integrating bootstrap with QFT, some interesting results about the emergence of the spatial-temporal order of events and the structure

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of the spectrum of base states (elementary particles) are derived. QFT alone does not constrain these points significantly.

This paper is organized as follows. In section 2, the key concept is presented and differences with Chew's original program, which is now of merely historical interest, are evidenced. In section 3 we recall some notions of non-standard mathematical logic which will be later used to formalize the model. In section 4 we discuss the emergence of spatial and temporal order. In section 5 we discuss elementary fermions (quarks and leptons) and the emergence of physical particles (leptons and hadrons; we do not discuss gauge particles in this article). Section 6 tackles the difficult issue of mass and other unresolved problems.

2. QFT and Beyond

QFT is typically built upon the second quantization formalism, a language whose basic terms are represented by creation and annihilation operators of various "elementary particles" (photons, electrons, etc.). In the approach presented, these concepts and the relationships between them are adopted without alterations. The underlying assumption is that the QFT formalism is valid.

We propose a different interpretation of the basic terms instead, in the sense that we postulate a correspondence between each of the creation/annihilation operators a, a^+, b, b^+,... and a well-formed expression of a single logical calculus, the structure of which is described below. These expressions are not part of QFT formalism wherein this correspondence is therefore not visible.

We assume that elementary particles emerge from a fundamental substrate of physical reality that is not directly observable. QFT creation operators are associated with the emergence of a given type of elementary particle (electron, photon ...) from this unobservable substrate. Destruction operators are associated with the reabsorption of a given type of particle in this substrate. Logical expressions associated with these operators describe these processes of manifestation and reabsorption in a formal language distinct from QFT.

This substrate should not be confused with the ordinary "vacuum" of QFT, *i.e.* with the minimum energy state of a field represented for example by ket $| 0 >$ upon which QFT operators of that field act. This "vacuum" is in fact an eigenvector of the Hamiltonian of the corresponding free field, and as such it is a stationary state: it "lives" in time. We assume instead that the spacetime representation of events belonging to the history of a given particle emerges from this substrate; in other words, the substrate *logically precedes* spacetime representation. It is therefore a-spatial, a-temporal and essentially non-local.

We are therefore dealing with an Arché ($\alpha\rho\chi\eta$), and a poiesis ($\pi o\iota\eta\sigma\iota\varsigma$) process connecting the Arché to the manifestation/de-manifestation of elementary physical events, the a-temporal ($\alpha\iota\omega\nu$) to the becoming ($\chi\varrho o\nu o\varsigma$). Obviously, this process is synchronic rather than diachronic: it does not occur in time as the processes of particle propagation described by the dynamics of QFT. For this reason, the logical structure of this process, reflected in the logical expressions associated with QFT operators, is distinct from the formal structure of QFT which is purely dynamic.

In this approach, QFT creation/annihilation operators have a dual nature: dynamic (as expressed by their use in QFT formalism) on the one hand, and synchronic (which we propose to explore) on the other. They bridge the gap between two aspects of the physical world: one temporal, the other a-temporal. Where is the insertion point of this synchronic process in time domain? The idea that will be explored here refers to the phenomenon of zitterbewegung in relativistic quantum theory.

In QFT, the equation of the free evolution of a field is derived from the second quantization of the relativistic quantum wave equation associated with the particle which is the quantum of that particular field. On the other hand, different wave equations admit representations (such as the hydrodynamic representation) that make the phenomenon of zitterbewegung explicit: the particle "runs along" a multitude of virtual paths on each of which the instantaneous speed in a given direction is $\pm\, c$, the speed of light in a vacuum. In any case, for particles with defined mass M the modulus of average velocity is $\leq c$ and the amplitude ρ of delocalization due to zitterbewegung satisfies the uncertainty principle $\rho \approx \hbar/Mc$.

In terms of the method of path integration, the particle is defined as a set of "internal quantum numbers" transported along various zitterbewegung paths, each of which represents a "virtual copy" of the particle. This picture is often used to describe the unitary evolution of the particle wave function; in this paper we will not consider wave function collapse phenomena (actual quantum leaps). Elementary motion is therefore an infinitesimal jump to the speed of light taken by the particle at a generic event-point on one of its virtual paths: the "internal" quantum numbers are "transported" along the jump. The Breit equation provides a relativistically covariant description of the jump:

$$\frac{dx_\mu}{d\tau} = \gamma_\mu \; ; \qquad \mu = 0,\, 1,\, 2,\, 3; \tag{1}$$

where the eigenvalues of gamma operators are $\pm c$, and the symbols maintain their conventional meaning.

Poiesis must carry in existence this elementary motion, including the "transported" internal quantum numbers. The correspondence of logical expressions describing the poiesis with the creation/annihilation QFT operators of that given type of particle is thus defined. Since we are talking about the free propagation of a particle, poiesis must be a free and spontaneous process. Causality represented by the preservation of internal quantum numbers along the generic virtual path has to be an emerging property of this spontaneous process.

"Spontaneity" is modelled as the condition that the elements that emerge from poiesis coincide with the factors that determine the occurrence of these same elements: what is created (destroyed) is what creates (destroys). This is a typical bootstrap condition. Formally, it means that logical expressions associated with QFT creation/destruction operators should be self-dual, *i.e.* their form should remain unchanged when operators and operands are exchanged therein. This requirement recalls the old style hadronic bootstrap "duality" condition; however, while this referred to Feynman graphs related through crossing operations [1,2], the condition proposed here defines the correspondence between QFT creation/destruction operators and specific self-dual graphs.

3. Calculus of Distinctions

Poiesis cannot be represented by expressions of a standard logical calculus. In a formal system, we infer propositions from other propositions, whereas with poiesis a proposition or expression is created from nothing (the primordial Arché). Thus, the required calculus must be sufficiently general to include the genesis of any formal system, including its gödelisation as well. At this level of generalization, the requested calculus must coincide with the most extensive manipulation of signs possible; within this "maximal" sign system, formal deductive systems are defined by clumps of sign system defined by special manipulation rules. These standard sub-calculi are modelled by appropriate restrictions; conversely, the required calculus must be highly polysemic and allow the contradiction "$A =$ not A".

Thanks to the work of L.H. Kauffman [4-6], and much to his surprise, the author of these notes learnt of the existence of a calculus that has all the required characteristics. This is C.S. Peirce's system of "existential graphs", which, as Kauffman skillfully proved, is superposable to other proposal in the literature: Spencer Brown's calculus of indications (the so-called "laws of form" [7]), a model proposed by Nicod and Sheffer, Frege's two-dimensional graphic calculus. It will be taken here in the form of a "calculus of distinctions" or "indications". Our description is limited to that strictly necessary for our purposes; further details can be found in the references by Kauffman.

In this calculus, the originary "oneness" or Arché is simply denoted by a white space; this extremely primeval symbol (a simple white sheet) indicates the logical value "True". The act to perform a distinction in this "oneness" is identified with the connective "negation", which for typographic reasons is here indicated by a set of round brackets (). The symbol () also represents the logical value "False". The negation of A will be written as (A), the "outside" of A. The logical conjunction of two propositions A and B (their logical "and") is written as $AB = BA$.

The inference $A \to B$ is written as $(A)B$, the conjunction of B with (A), the negation of A; indeed, the negation of this expression $[((A)B) = A(B)]$ is always false if $A \to B$. If the causal physical connection is modelled by a relation of implication by canonical reasoning, we derive two important results. Firstly, the negation (destruction) of property A and the assertion (creation) of B are implicit in writing $(A)B$. Every elementary causal connection is therefore a primary transformation that destroys the old (A) and creates the new (B). Since the order of destruction-creation is linear, this transformation is parametrized by a one-dimensional variable. To change the new property B, it must in turn be destroyed and replaced by another property C, and so on. This yields an alternating succession of creations and destructions and if we define this sequence as a model of physical time, there

exists a local arrow of time that goes from destruction to creation even if global temporal orientation remains undefined. Secondly, if $B = A$ the self-implication relationship in the form $(A)A$ is the simultaneous affirmation of A and its negation (A). An unexpected connection with the logical equivalence $A = (A)$ emerges, which, as a "static" expression, is a contradiction. This contradiction is easily overcome by interpreting the sign "=" as an operative instruction, for example, "the negation of A is A"; the implementation of this instruction yields the recursive chain ... $(A)A(A)A$... unlimited in both directions. A classic example is the iterative action of the thermostat in a home heating system, where proposition A means "current temperature is higher than programmed temperature." The input (A) to the thermostat activates the system until it produces the new output A. This becomes the new thermostat input which deactivates the system producing the new output (A), and so on.
These concepts will be used in the next section to model the zitterbewegung of an elementary particle.

4. Emergence of Spacetime

We ignore the internal quantum numbers of a generic elementary particle for now, and we consider the spatial-temporal order of events related to its history. Elementary motion along a zitterbewegung virtual path (*i.e.* the speed of light jump described above) is interpreted as a particular logical implication $(A)A$. Thus, that implication yields a motion of infinitesimally small duration at the speed of light in three-dimensional space. Due to the self-duality condition which expresses the bootstrap principle, the light jumps from a given event-point which are mutually linear independent form a self-dual set: they coincide with their reciprocal transformations (think of M. Escher's famous masterpiece "drawing hands"). This condition fixes the dimensionality of space. Thus, if N is the cardinality of the set of jumps, the cardinality of the set of their reciprocal transformations (assuming total connection) is $N(N\text{-}1)/2$ omitting identical and inverse transformations. Two cardinalities of the same set must be the equal; thus, $N = N(N\text{-}1)/2$; the only solution is $N = 3$. Let $A,\ B,\ C$ define the spatial projections of these three light jumps. We have:

$$\hat{A} \ = \ B(C); \qquad \hat{B} \ = \ C(A); \qquad \hat{C} \ = \ A(B); \tag{2}$$

as expressions of the transformations (spatial rotations of $\pi/2$) that convert these projections between them. The set of these transformations, modelled as unit vectors, is merely a different representation of the projections:

$$\left\{\hat{A},\ \hat{B},\ \hat{C}\right\} \ = \ \{A,\ B,\ C\}\,.$$

This is represented by the graph represented in Figure 1. Clearly:

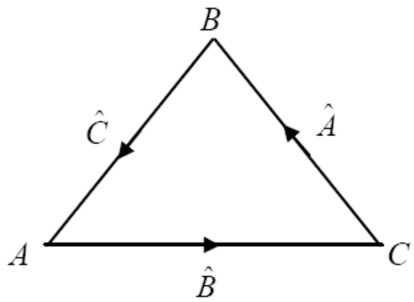

Fig. 1 Self-duality

$$\hat{A}^{-1} = \hat{C}\hat{B}; \qquad \hat{B}^{-1} = \hat{A}\hat{C}; \qquad \hat{C}^{-1} = \hat{B}\hat{A}; \tag{3}$$

$$\hat{A}\hat{A}^{-1} = \hat{A}^{-1}\hat{A} = \hat{I}, \text{ etc.}$$

Thus, by letting $\hat{A}^{-1} = i$, $\hat{B} = j$, $\hat{C} = k$, $\hat{I} = 1$, we obtain the usual relations occurring between quaternionic unities:

$$\hat{A}\hat{A}^{-1} = \hat{I} \quad \Rightarrow \quad (i)(-i) = 1 \quad \Rightarrow \quad ii = -1$$

$$\hat{A} = \hat{B}^{-1}\hat{C}^{-1} \quad \Rightarrow \quad i = (-j)(-k) \quad \Rightarrow \quad i = jk \text{ etc.}$$

Therefore a correspondence exists between spatial projections of light jumps and i, j, k, -i, -j, -k. Using standard algebra we then build the correspondence between these projections and Pauli operators σ_1, σ_2, σ_3.
Light jumps can be taken towards the future or the past of an event-point which represents their initial position. The choice is linked to the sign of the eigenvalue of the Dirac operator γ_0 and the complete light jump is represented by the Clifford operator $\gamma_0\sigma_i = \gamma_i$, ($i$ = 1, 2, 3). The condition that the jump is a light jump is then precisely expressed by Eq. (1). The fact that this condition not depends on the choice of the base implies that the base is defined unless of transformations that convert the future (past) local lightcone into itself. These transformations form the proper Lorentz group, yielding a justification of Lorentz covariance of physical laws, including Eq. (1).
It should be noted that in Eq. (1) the evolution parameter τ is not time t as measured in a laboratory, thus the zitterbewegung may occur both forwards and backwards in t. The operation $\tau \to$ -τ presumably converts a particle into its antiparticle. As one can see, Eq. (1) remains unchanged under this operation if the transformation $x_\mu \to$ -x_μ is applied at the same time, *i.e.* if spacetime coordinates are inverted. In other words, the simultaneous application of charge conjugation, space inversion and time inversion leaves the zitterbewegung unchanged.
Kozyrev [8] had already understood the relationship between spatial rotations and time described in this section; appropriately written, his Eq. (1) is our Eq. (1). However

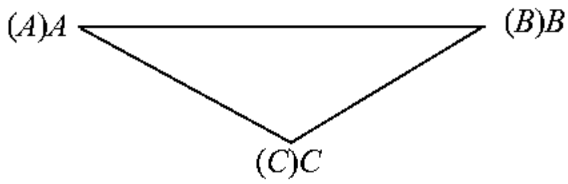

Fig. 2 First family

Kozyrev expresses this relationship by applying it to classical macroscopic bodies rather than elementary processes; he thus obtains inexistent "torsional" effects.

5. Forms of matter

We now consider the set of quantum numbers "transported" along the light jump, which define the "type" of particle. If we assume that, in addition to have a common origin in Arché, space, time and matter are identical in substance, then fundamental entities of matter must be the same as fundamental entities of space, namely A, B, C, (A), (B), (C).

We can imagine a set consisting of one, two or three copies of the triad A, B, C to be transported along the generic virtual path which the particle takes through spacetime. As a result we have one, two or three copies of the unit vector A (the same applies to B and C). We assume that in a light jump each unit vector belonging to a copy should be converted into another unit vector of the same copy, provided that the final number of copies of that unit vector remains equal to the initial number.

If only one copy of the triple A, B, C is transported, we assume three operations satisfying this condition: the creation of A (B, C) concomitant with the destruction of A (B, C). This can be expressed as:

$(A)A\ (B)B\ (C)C$

Denoting the logical conjunction "and" by a line, this expression can be graphically represented as illustrated in Figure 2.

A creation/destruction pair appears to each vertex of this graph. In principle each vertex can be in one of two states denoted by -1 and 1. If, at that vertex, creation precedes destruction, the state is -1; otherwise the state is 1. In state -1 creation closes the previous jump and destruction opens the next jump, and vice versa in state 1.

We now consider the case where two copies of the triad A, B, C are propagated. In this case the bootstrap condition on each copy will be satisfied by the triple transformation:

$(A)B\ (B)C\ (C)A$

or by the inverse $(B)A\ (C)B\ (A)C$. These transformations are none other than the same unit vectors subject to transformation and thus their appearance is spontaneous [Note

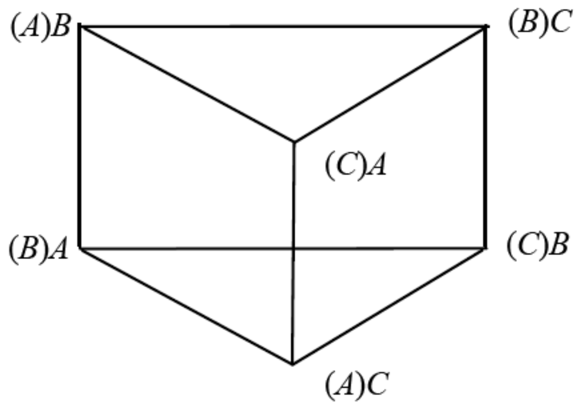

Fig. 3 Second family

that the transformation of a single copy seen above is just another way of writing this, and coincides with a triple self-implication which regenerates A, B, C].
We assume that by inserting of a creation/destruction pair, each vertex of the graph in Figure 2 is split into two vertices. These then become:

$$(A)A \to (A)B\ (B)A$$

$$(B)B \to (B)C\ (C)B$$

$$(C)C \to (C)A\ (A)C$$

The first group of 3 vertices forms the graph of transformations acting upon the first copy of the triad, *i.e.* $(A)B\ (B)C\ (A)C$; the second group of three vertices defines the graph of transformations acting upon the second copy of the triad, *i.e.* $(B)A\ (C)B\ (A)C$. The vertices from the split of a given vertex in Figure 2 inherit the state of that vertex (-1 or 1); they are graphically represented as "opposed" (Figure 3).
At this point we assume that the process is repeated on the vertices of one of the two opposing triangles in the graph in Figure 3. Let us assume for example that the vertices of the lower triangle are splitted:

$$(B)A \to (B)C\ (C)A$$

$$(C)B \to (C)A\ (A)B$$

$$(A)C \to (A)B\ (B)C$$

and that the newly formed vertices inherit the parent state -1 or 1. The lower triangle in Figure 3 is replaced by two new triangles associated with the transformations acting on the second and third copies of the triad A, B, C respectively. At the vertices of the two triangles we have the transformations $(B)C\ (C)A\ (A)B$ and $(C)A\ (A)B\ (B)C$

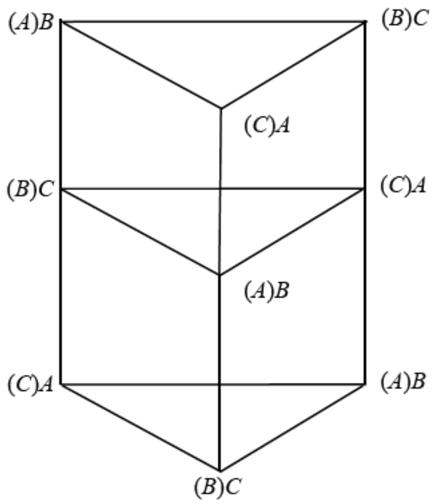

Fig. 4 Third family

respectively. These vertices will be laid out as shown in Figure 4.
Figures 2, 3 and 4 show that the resulting graphs consist of superposed triangles, each corresponding to the transformations performed on a given copy of the triad of fundamental operators. Each of these triangles (horizontal planes of the graph) is supported by a bootstrap process and is self-dual. The vertical lines joining the vertices on different planes obtained by splitting the same originary vertex (which we call "towers") are also derived from the bootstrap. Starting from the vertex $(A)A$ in Figure 2 and then inserting the pairs $(B)B$ and $(C)C$ the corresponding towers in Figures 3 and 4 are obtained. Thus, we obtain the logical product $(A)A\ (B)B\ (C)C$ which is equivalent to the self-dual form $(A)B\ (B)C\ (C)A$. Iterating the vertex splitting mechanism by inserting opposing pairs, leads to the appearance of redundant creations or destructions; for example:

$$(C)A \to (C)B\ (B)A$$

that should split into $(C)B$ and $(B)A$ on two new different triangles. But the operators B and (B) already appeared in the first step of the genetic splitting process. Thus, the bootstrap process implements a different separation: on the one hand $(C)A$ as before, and $(B)B$ on the other. Thus a separated triangular graph, identical to that in Figure 2, is obtained; and the process is re-initialized. Assuming that the structure of creations and annihilations involved in one infinitesimal light jump holds *for every choice* in the spatial base A, B, C, this structure defines the particle's "inner" state J. The systematic of possible values of J is then clear. Firstly, we have I^{st}, II^{nd} and III^{rd} family elementary fermions depending on whether the graph associated with J has 1, 2 or 3 horizontal planes, respectively. Moreover, the state of each tower (*i.e.* the state common to all vertices of that tower) has to be taken into account for a given family; this determines the fermion's flavor/color state within that particular family. Table I illustrates the scheme of the I^{st} family, which is identical for subsequent families.

Table I - The first family

Tower 1	Tower 2	Tower 3	Particle name
1	1	1	*electron, positron*
1	1	-1	*quark up red, anti-up anti-red*
1	-1	1	*quark up blue, anti-up anti-blue*
-1	1	1	*quark up green, anti-up anti-green*
-1	-1	1	*quark down red, anti-down anti-red*
-1	1	-1	*quark down blue, anti-down anti-blue*
1	-1	-1	*quark down green, anti-down anti-green*
-1	-1	-1	*electronic neutrino, anti-electronic neutrino*

QFT creation/annihilation operators of a given fermion, for example the quark down blue, correspond to its graph which in turn represents a well formed formula of the logical system that describes the bootstrap. Note that for what concerns leptons, the generic permutation of towers numbering transforms the lepton into itself, while in the case of quarks, it changes the color. If we assume this numbering is arbitrary, it follows that quarks cannot be created/destroyed in isolation, but only in globally colorless aggregates (hadrons). To illustrate the concept, we introduce the notion of "logical and" between two elementary fermions as follows:

$$Q_1 \text{ and } Q_2 = [T^1{}_1\ T^1{}_2,\ T^2{}_1\ T^2{}_2,\ T^3{}_1\ T^3{}_2]$$

where $T^i{}_j$ represents the state -1 or +1 of the i-th tower of fermion Q_j. Thus, we assume that this state is not only an index of precedence of creation over destruction or vice versa, but also an operator of preservation (+1) or inversion (-1) of the order of precedence. Thus a law of composition conforming to the rule of signs applies to this index.

By inspection of Table I, it is clear that the "logical and" of the three color states of a given quark is always (1, 1, 1) or (-1, -1, -1). The "logical and" of the color state of a u-type quark and of the two color states of a d-type quark that are complementary to it have the same property. We can thus define, consistently with Table I, the anticolor of a given color as that color whose logical "and" with the given color is (1, 1, 1) or (-1,

-1, -1). If we denote the color states by R, G, B, $\bar{R}$, $\bar{G}$, $\bar{B}$ [red, green, blue and their complementary], let the "logical and" be their product, and let the state [(1, 1, 1) or (-1, -1, -1)] be the unit of the product operation, then:

$$R\bar{R} = G\bar{G} = B\bar{B} = 1$$

$$\bar{R} = GB; \quad \bar{G} = BR; \quad \bar{B} = RG. \tag{4}$$

Eqs. (4) assume that the product of two quarks (antiquarks) is always an antiquark (quark), for similarity to the graph in Figure 1. Clearly, the relations in (4) are very similar to (3) and define a self-duality pattern as well. This suggests that QFT creation/destruction operators of physically possible aggregates of sub-particles (we call these aggregates *physical particles*) are associated with well formed formulas of a logical calculus induced, this time, by Eqs. (4). These formulas and their corresponding graphs are generated by mechanisms that are identical to those presented for the sub-particles as they are consistent with the same bootstrap process. We start from a leptonic (antileptonic) state characterized by three different virtual copies of the same lepton (antilepton). The three identical operations RGB, GBR, BRG ($\bar{R}\bar{G}\bar{B}$, $\bar{G}\bar{B}\bar{R}$, $\bar{B}\bar{R}\bar{G}$), equivalent to identity, act on these three copies. Each copy will thus be colorless; this is represented in Figures 5 and 6.

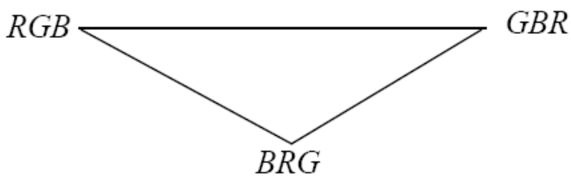

Fig. 5 Lepton

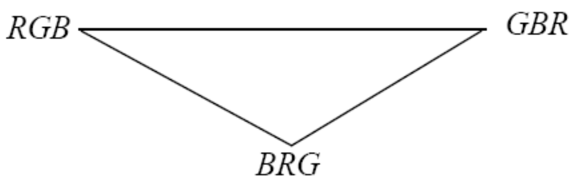

Fig. 6 Anti-lepton

These graphs respectively correspond to the QFT creation/annihilation operators of a *lepton* and an *antilepton.* Assume that that each "virtual" copy of the lepton splits into a pair consisting of a quark and an antiquark of complementary color, through the separations:

$$RGB \rightarrow R \;\; GB = R \;\; \bar{R}$$

$$GBR \rightarrow G \;\; BR = G \;\; \bar{G}$$

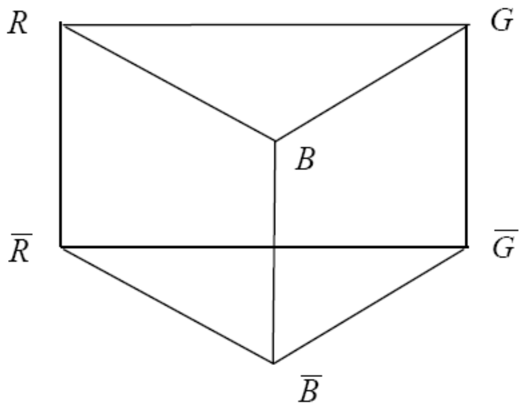

Fig. 7 Meson

$$BRG \;\rightarrow\; B \;\; RG \;=\; B \quad \bar{B}$$

The graph in Figure 5 converts into Figure 7. It is easy to verify that the same result is attained starting from Figure 6, if we imagine that every copy of the antilepton is split according to the conjugate relations of those reported above.

Each tower in Figure 7 corresponds to a different virtual copy of the same aggregate consisting of a quark and an antiquark.This aggregate is a *meson.* In QFT, the resulting graph corresponds to the creation/annihilation operator of a meson.

If each copy of the antiquark in this meson forks into two quarks the logical product of which is identical to the original antiquark (unless of a negation) according to relations:

$$\bar{R} \;\rightarrow\; G \quad B; \qquad \bar{G} \;\rightarrow\; B \quad R; \qquad \bar{B} \;\rightarrow\; R \quad G$$

we get an aggregate of three quarks whose "logical and" is still (1, 1, 1) or (-1, -1, -1). This aggregate is a *baryon.* This is shown in Figure 8.

Otherwise, if for the same meson, the quark forks into two antiquarks the logical product of which is identical to the original quark (unless of a negation) according to relations:

$$R \;\rightarrow\; \bar{G} \quad \bar{B}; \qquad G \;\rightarrow\; \bar{B} \quad \bar{R}; \qquad B \;\rightarrow\; \bar{R} \quad \bar{G}$$

we obtain an aggregate of three antiquarks with "logical and" still given by (1, 1, 1) or (-1, -1, -1). This aggregate is an *antibaryon.* This is shown in Figure 9.

The QFT operators associated with these graphs implement the creation or annihilation of a baryon and an antibaryon respectively.

Clearly, the structure of the creation/annihilation operator derived for a mesons, baryon or antibaryon is always (1, 1, 1) or (-1, -1, -1). The arbitrary permutation of the numbering of towers has no effect on that operator; therefore, these aggregates are possible. Naturally, the creation/annihilation operator is no longer that of a single quark, but that

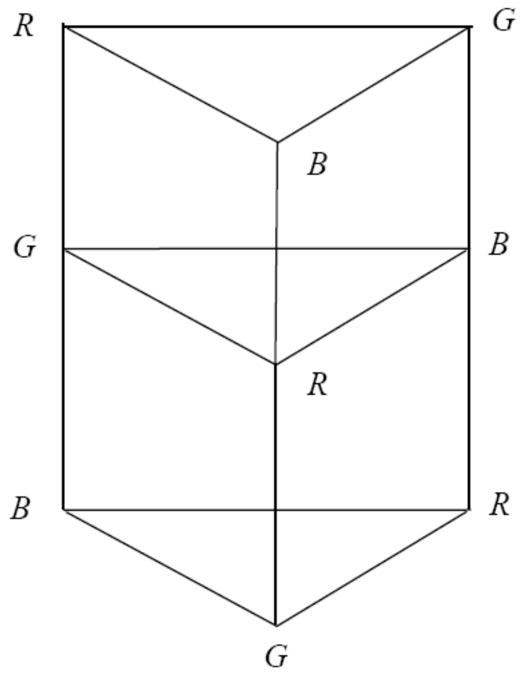

Fig. 8 Baryon

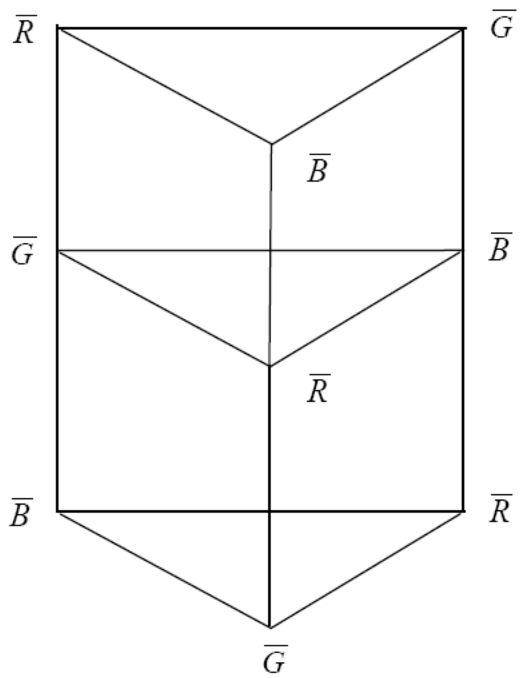

Fig. 9 Anti-baryon

of the aggregate.

It should be noted that in the hadronic case, each quark follows its own zitterbewegung virtual universe line, but the reciprocal distance of quarks cannot exceed the Compton wavelength of the aggregate.

6. The problem of mass

The transport of the complex of properties J, associated with a graph or a formula defined by procedures described in the previous section, along a virtual path consisting of a sequence of light jumps represents the recursion obtained by interpreting the assertion $J = (J)$ as "the act of negation of J is J". This version of the liar's paradox avoids the contradiction derived from a "static" interpretation of the assertion. Each graph J is thus destroyed at the beginning of a light jump and newly created at the end of the jump.
There is an essential distinction between the graphs of sub-particles and those of physical particles; for the first group, the light jump that joins the events of creation and destruction has infinitesimally small duration, as made explicit in Eq. (1). However, this is impossible for the graphs the second group associated with hadrons, as hadrons have a finite spatial extension of the order of 10^{-13} cm or less; a light jump involving the whole structure should have a minimum duration no less than the time required for light to travel along this extension ($= 10^{-23}$ s). We assume that this applies to all graphs of the second group, even those associated with leptons, and that the upper bound of the duration of the jump is $\tau_0 = d_0/c \approx 10^{-23}$ s, where d_0 is the classical radius of an electron (which is also the range of the strong force!). If this is true, then τ_0 is a fundamental constant of Nature, which is equally relevant for leptons and hadrons. The special mass m such that $mc^2 = \hbar/\tau_0 = 70$ MeV is thus immediately defined.
There are indications that as a first approximation, the masses of leptons and hadrons are quantized and multiples of 70 MeV [9]. We assume that the proportionality factor is defined by topological aspects of the graphs associated with a physical particle and its constituent sub-particles; reference [10] in the bibliography provides a first step on this direction.
Once the mass M of the lepton or hadron has been defined, the zitterbewegung oscillation radius is determined by $\rho \approx \hbar/Mc$. If this is correct, the bootstrap, which produces the elementary particles, defines their mass at the same time. The duration τ_0 defines the time (and length $d_0 = c\tau_0$) scale typical of "elementary particles". It is conceivable that in a suitable reference system, the "light jump" associated with a graph of the second type is actually a purely temporal jump (γ_0) with extension ρ/c. Thus, on proper time intervals smaller than $\rho/c \approx h/Mc^2$, the particle is not distinct from its antiparticle because this distinction relates to a type 2 graph. In any case, the flavor of elementary fermions, which is a property of type 1 graphs, is also defined at these smaller scales. This conforms to the proven fact that at these scales the physical particle "dissolves" into particle/antiparticle pairs of its constituent sub-particles. The rest frame of reference of a physical particle is thus defined only on intervals of proper time greater than ρ/c. In other words, the inertia of the particle exists only on temporal scales greater than this. If the principle of equivalence between inertia and gravitation is assumed to hold on all temporal scales, it seems plausible that there is no gravitational interaction on scales smaller than ρ/c, a result that could place significant constraints on the current debate about the quantization of gravity.

Concluding Remarks

The original idea of the bootstrap, limited to the analysis only of strong interaction, was proposed by Chew as a radical alternative to QFT: there was an ideological contrast between "bootstrappers" and "fundamentalists" [11]. In this paper we reformulated this concept in such a way as to avoid the conflict with QFT, and to make it a useful complement to this theory. This reformulation is made possible by the availability of formal logical tools that are not widely used in the physics community, such as Spencer Brown's calculus of indications. Bootstrap thus becomes a *non dynamic* process that defines at least some of the characteristics of base states in QFT, for example their systematics. Thus, "fundamental entities" of QFT regain their fundamental nature, denied by the "bootstrappers" in the sixties, precisely thanks to the bootstrap process! The issue of whether the peaceful coexistence of QFT and the bootstrap presented here can evolve into a more organic connection in future remains to be seen.

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