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Biological Interval

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Abstract

In previous work, we have studied the relationship between the evolution of basal metabolic rate and the capacity to generate structure in living organisms. We analyzed the modifications of this relationship throughout life, as well as the possible holographic description of biological physical systems. Given that changes in this relationship affect the behavior of biological variables (the virtual parameter space) as well as the environment in which they define their values (the real physical space in which they operate), mathematical formalization is necessary to unify criteria. In this way, physics and biology can be described using the same language.

Keywords

Margalef Principle, Bekenstein Boundary, Holographic Principle, Geometric Phase, Self-Organization, Biological Aging

1. Introduction

This article is a general commentary on the author's work published in AAR. The methodology used and permissions for data use are available in those articles. Our present work consists of developing the mathematical formalization of the theoretical framework that supports the articles published by the authors in AAR. These previous papers also contain biological empirical evidence that supports proposals such as the holographic description of living beings [1] [2], the equivalence between metabolic acceleration (in biology) and mechanical acceleration (in physics) [3] [4], and the attribution of a dimensional character to the biological phenomenon [5] [6].

Ramón Margalef insisted on considering living beings as physical systems [7] [8].

We take this very seriously. And as such systems define their variables in a given space, we will begin with the definition of "space".

Space is the geometric entity in which objects define their position and relative movements. We define objects as those regions of space that have a certain shape, size, and dimension in a given space[1].

Some of these objects are living beings, which are regions of space that self-organize: they recover as information the energy they transform. In other words, they use the energy they dissipate (transform) to generate their own structure.

We understand structure as the set of relationships between the material elements that constitute a system. In the simplest case (a cell), it must be taken into account that energy is transformed through its metabolic activity and dissipated through its surface, as in all exchange of matter and energy with the environment.

Living beings are physical systems (Margalef). But they are very particular physical systems: they recover as information the energy they dissipate. They do not only consume energy. They recover it as structural organization [9].

From classical thermodynamics we know that every system dissipates energy. But in biology something more occurs: dissipation does not destroy structure, it generates it. Life is an organizing thermodynamic process.

This is very important, because information is proportional to dissipated energy. And both are more related to the relative surface of the cell than to its volume. This means that the holographic principle is fulfilled: in any bounded spatial region, information is proportional to its surface rather than to its volume.

Considering that it is a bounded region, its surface is also limited. Therefore, information is also limited: there exists a limit to information density (Bekenstein Bound). Thus, there is a limit to growth, and it is given by the limit of information density. Once this limit is reached, the system gains a degree of freedom [10] [11].

Analogously to certain informational density limits proposed in theoretical physics, it can be thought that biological systems also present limits of information associated with their structural boundary.

Specifically, for every four units of Planck surface[2] (a unit derived from Planck length), the system gains a degree of freedom. This is also very important, because once this limit is reached, the evolution of the system depends on its complexity.

Complexity is the structural property of a system that consists of a number of parts greater than 1, different and related to each other. In the case of a cell, once the limit of information density is reached, it can divide or simply die. But in the case of a complex multicellular organism, the possibilities are different.

If life continues once growth has finished, it means that the system continues to recover as information the energy it dissipates. It continues generating its own structure but does so in a space that no longer increases in size (it does not grow). The system reached its information density limit (Bekenstein Bound) and gained a degree of freedom.

[1]We use the term space both in reference to the parameter space (a virtual space), and in reference to the region of real physical space in which these variables define their values (the physical space of fundamental physics).

[2]Note: The reference to Planck scales is used only as a conceptual metaphor to illustrate the existence of limits of informational density.

This change in its geometry is observed in the appearance of geometric phase changes in its oscillatory variables. This is observed as a gradual decline in its capacity for homeostasis and self-organization (aging). The reason why this occurs lies precisely in the evolution of the system's geometry.

A system tends toward order when the Gaussian curvature of its surface is positive and equal at all its points (as in a sphere), when its curvature is zero (as in a plane), or when its curvature is neutral (as in a cylinder). Regardless of the species (the information itself), all living beings present the same geometric patterns during the early stages of their development [12] [13].

This is so because changes in their shape depend on changes in their size. And both (changes in size and shape) depend on the limit of information density (but not on the information itself).

With this conceptual clarification, we can now examine how certain ideas related to information, geometry, and the relationships between surface and volume can provide new perspectives for understanding biological organization.

2. The Holographic Principle in Biology

In modern physics it has been demonstrated that the trajectory of a system depends on the properties of the space in which it moves. Inspired by this general idea, we can ask whether biological systems also follow characteristic trajectories within their state space.

Since the beginning of the 20th century, Hermann Minkowski proposed something revolutionary: events do not occur only in space nor only in time, but in a common fabric called space-time.

Albert Einstein showed that not all of us traverse that fabric in the same way [14] [15].

The trajectory matters. If we translate this idea to biology, a question arises:

Do two organisms that live the same number of years follow the same biological path? We know they do not.

Two twins may be 50 chronological years old and have radically different physiological states. Age does not exhaust the history of living beings.

Given that numerous studies show that the energy dissipated by a living being is more related to its surface than to its volume, we can conclude that living beings comply with the holographic principle[3].

Dissipation does not have a direct relationship with the mass (evaluated as weight) of the living being. It is important not to forget that mass has a direct relationship with volume, because density variations are not sufficient to invalidate such a relationship: the greater the mass, the greater the volume.

Total energy dissipation, instead, fits more precisely with energy dissipated per unit of mass or volume. This is equivalent to its surface, because all matter and energy are exchanged with the environment through the surface. The relation-

[3]Note: In this work, the holographic principle is used as a conceptual proposal to describe the relationship between energy dissipation and the biological surface.

ships between the area of the great circle and the surface of a sphere are shown in Figure 1 [16]-[18].

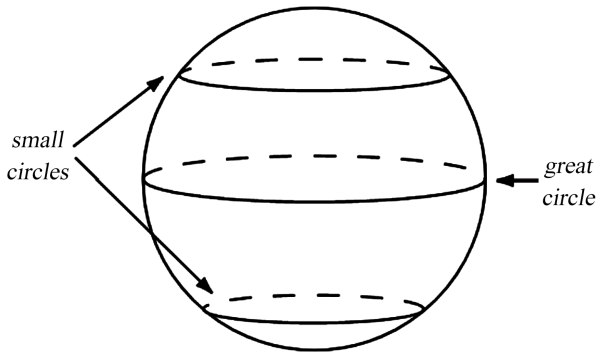

Figure 1. The basis of the relationship between the area of a great circle and the surface of a sphere can be seen in the following formalization: A sphere in 3 dimensions has: 1) Total surface (the entire "skin" of the sphere). 2) Maximum circle or great circle: the largest circle that can be drawn inside the sphere (like the Earth's equator). If you cut the sphere exactly through the center, you would obtain that great circle. Relationship between the area of the circle and the surface. Mathematically: 1) Area of the great circle = πr^2, 2) Surface of the sphere = $4\pi r^2$ If you compare both: "surface of the sphere"/("area of the circle") = $(4\pi r^2)/(\pi r^2) = 4$. This means that: The surface of the sphere is equivalent to 4 times the area of its great circle.

This is easy to analyze in the case of a cell, assuming for simplicity that it has a spherical shape. And considering the holographic principle, it should not be forgotten that if its volume is limited, its surface is also limited.

And since recovered information (Margalef) is proportional to dissipated energy, then information is also limited: there exists a limit to information density (Bekenstein). This is a central point (we already mentioned it), and the relationship between the dimension (we insist, the dimension, not its size) of an object and its information density limit is of vital importance.

For example, in the case of a sphere in a 3D space, it is the relationship between the area of its great circle and the total surface of the 3D sphere that determines its information density limit. In this case its value is 4 (the area of the great circle fits exactly 4 times into the total surface of the sphere). A higher or lower value implies that there is not enough information or that the information density limit is exceeded. The information of a 3D sphere is more related to its surface than to its volume.

A sphere in 3 dimensions has:

- Total surface (the entire "skin" of the sphere).
- Maximum circle or great circle: the largest circle that can be be drawn inside the sphere (like the Earth's equator).

If you cut the sphere exactly through the center, you obtain that great circle.

Relationship between the circle area and the surface.

Mathematically:

- Area of the great circle = πr^2

- Surface of the sphere = $4\pi r^2$

If you compare both:

$$\frac{\text{surface of the sphere}}{\text{area of the circle}} = \frac{4\pi r^2}{\pi r^2} = 4$$

This means that:

The surface of the sphere is equivalent to 4 times the area of its great circle.

If we analyze the relationship between the diameter of a circle and its perimeter or circumference, we observe that the geometric properties of the circle can be expressed from its boundary. The relationship between the diameter and the circumference is given by the constant π (≈3.14), which describes the fundamental geometric proportion between the size of the circle and the length of its boundary.

This example illustrates how certain global properties of a region can be related to its boundary. In this sense, the circle constitutes a useful geometric analogy to visualize the idea—present in different contexts of physics—that the boundary of a system can contain relevant information about its global structure.

Thus, the constant π does not represent a measure of information in a physical sense, but rather a geometric relation that expresses how the boundary length of a system relates to its characteristic scale.

Considering the situation systematically: following this logic of comparing the "central width" (the diameter or the area of the great circle) against the "total boundary" (the perimeter, the surface, or the hypersurface), the calculation becomes fascinating because in higher dimensions the "surface" grows much faster than the diameter. It may be important to follow this logic, because according to the holographic principle, the information is on the boundary. And if we take the case of Pi as a general example, it could be that it represents the information density limit of a circle (since information is more related to the perimeter than to the area of the circle). The same could occur in higher dimensions.

To simplify the matter, and dealing with a hypothetical cell, we take the case of a spherical cell and generalize the formalization of the calculation of its surface and its volume to "n" dimensions and thus be able to study the relationships between the width of the central section and its boundary[4].

To calculate the volume and surface of an n-sphere (a sphere in any dimension (n)), the Gamma function is the key element, since it extends the concept of factorial to non-integer numbers.

The hypervolume of a sphere of radius (R) in dimension (n) is defined as:

$$V_n(R) = \frac{\pi^{n/2}}{\Gamma\left(\frac{n}{2}+1\right)} R^n$$

[4]Note: This geometric relationship between volume and surface is particularly relevant in biological systems. In living organisms, numerous fundamental processes—such as the exchange of matter and energy with the environment—occur through biological surfaces (cell membranes, epithelia, respiratory or digestive surfaces). For this reason, the relationship between internal volume and external surface constitutes a determining factor in the organization and functioning of living systems.

Following the logic that the surface is the derivative of the volume with respect to the radius, we apply the power rule ($n \cdot R^{n-1}$):

$$S_{n-1}(R) = \frac{dV_n}{dR} = \frac{n\pi^{n/2}}{\Gamma\left(\frac{n}{2}+1\right)} R^{n-1}$$

Thanks to the fundamental property of the Gamma function, we can simplify the surface formula to its form.

The Gamma function is an extension of the factorial function, and in the analysis we perform it acts as a connector between even and odd dimensions, producing exact factorials for the case of even dimensions and multiples of $\sqrt{\pi}$ that compensate the spherical geometry for the case of odd dimensions.

There is an interesting fact revealed by these formulas: the volume of a unit sphere ($R = 1$) does not grow infinitely with dimensions. In fact, it reaches its maximum at dimension 5 and then begins to decrease toward zero as (n) tends to infinity.

Of course, in the case of figures such as a square, shapes such as a cube, or irregular polygons, these reasonings require the adjustment of taking into account the concepts of apothem and centroid as generalizations of the concept of radius.

This is because they are bodies and figures that do not grow uniformly from the center (growth geometry).

The relationship between the width of the central section and the total boundary varies with the dimension of the space we analyze. Continuing with the case of the sphere, as you increase the dimensions, the proportion between the surface and the central section is no longer a simple integer like 4 in the 3D sphere (Table 1).

Table 1. Evolution of the surface area/section ratio value according to dimension.

Dimension	Maximum section	Surface area/section ratio
2D (circle)	Diameter ($2r$)	π (aprox 3.14)
3D (sphere)	Circle (πr^2)	4
4D (4-ball)	Sphere ($4/3\pi r^3$)	1.5π (aprox 4.71)
5D (5-ball)	4-ball ($1/2\pi^2 r^4$)	16/3 (aprox 5.33)

The surface/section ratio indicates the information density limit for that dimension. Of course, we must not forget that a human is not a sphere, although many of its cells may be approximated to that shape. But it is clear then that regardless of the shape of a human in 5D, its information density limit lies in its 4D "temporal perimeter".

This proposal may contribute to defining a relative unit of information in terms of the surface/section relation. Thus, the perimeter or circumference (boundary) of a circle consists of π units of information, while the boundary of a sphere (the surface in this case) consists of 4 units of information. In the case of a 4D hy-

persphere, its spatial boundary consists of 4.71 units of information. And in the case of a 5D hypersphere, its space-time boundary consists of 5.33 units of information.

It is clear that these are relative units because their value changes depending on whether it is a line, a surface, a volume, or another measure depending on the case in higher dimensions. But they are units because the relational pattern is always the same; what changes is the dimension of the space in which we define the relation.

3. Space-Time-Biologic Interval

Inspired by the mathematical structure of the space-time interval used in physics, we propose an analogous formal relation that allows describing the dynamic state of a biological system.

Our proposal suggests a geometric extension of reality where the thermodynamic processes of life do not occur "on" the stage of space-time, but are an intrinsic dimension of it.

We then ask: how would Minkowski's formula look to describe the space-time interval (flat space-time of special relativity), if we consider the existence of a fifth dimension consisting of the relationship between the mass generated by a living being and the energy that this living being dissipates per unit mass (not per unit time)?

To incorporate a fifth dimension (w) based on the relationship between mass (m) and energy dissipated per unit mass (ε), the Minkowski metric of special relativity

$$\mathrm{d}s^2 = -c^2\mathrm{d}t^2 + \mathrm{d}x^2 + \mathrm{d}y^2 + \mathrm{d}z^2$$

would be modified by adding a differential term for this new coordinate.

If the fifth dimension results from the relationship between generated mass and energy dissipated per unit mass ($\epsilon = E_{\text{dissipated}}/m$), we can propose a coordinate with dimensions of length to maintain dimensional consistency:

$$w = k\frac{E_{\text{dissipated}}}{m}$$

where (k) would be a coupling constant with units of force (Newtons) so that (w) is measured in meters.

In a five-dimensional space-time (modified Kaluza-Klein space) [19] [20], the invariant interval ($\mathrm{d}s^2$) would be:

$$\mathrm{d}s^2 = -c^2\mathrm{d}t^2 + \mathrm{d}x^2 + \mathrm{d}y^2 + \mathrm{d}z^2 + \mathrm{d}w^2$$

Substituting the nature of the fifth dimension, the metric for a living being would be:

$$\mathrm{d}s^2 = -c^2\mathrm{d}t^2 + \mathrm{d}x^2 + \mathrm{d}y^2 + \mathrm{d}z^2 + \left(k * \mathrm{d}\left(E_{\text{dissipated}}/m\right)\right)^2$$

Then, three considerations are necessary from the physical point of view:

- **Signature**: A signature (−, +, +, +, +) is assumed, which implies that the fifth dimension is spatial in nature. The living being can be perceived as "flowing" through its own growth.

In relativity, space-time is described with dimensions and a metric that defines how to measure distances between events.

Normally we have:

- 1 temporal dimension
- 3 spatial dimensions

The classical signature is:

(−, +, +, +)

That means:

- Time has negative sign
- Spatial dimensions have positive sign

(−, +, +, +, +)

This indicates that there are:

- 1 temporal dimension
- 4 spatial dimensions

The fifth dimension would be spatial, not temporal.

- **Trajectory (Geodesic)**: A living being would not only move in space and time, but its "worldline" would curve or extend according to its thermodynamic efficiency. The living being follows a "geodesic" in which its metabolic efficiency and generated mass are in balance with its physical motion.

An organism does not only follow a physical trajectory, but also a metabolic trajectory.

Its path depends on things such as:

- Energy it consumes
- Metabolic efficiency
- Mass it produces (growth)

Thus, its geodesic would depend on a balance between:

1) physical movement

2) energy dissipation

3) biological growth

- **Invariance**: The interval (ds) would be constant for all observers, implying that changes in the rate of energy dissipation would affect the perception of the space traversed by the organism ("biological time dilation", although this is an imprecise term, since what dilates is not time but the fifth spatial coordinate; therefore it is better to call it "metabolic dilation"). Just as near the value of the speed of light (c) time dilates, an extremely high rate of energy dissipation (ε) could, theoretically, affect the perception of the space-time interval for that organism.

In relativity there exists a fundamental quantity:

ds (called the space-time interval).

The important thing is that all observers calculate the same value of ds.

This is called invariance.

Our first step is to define the biological variables and identify constants:

- m (Biomass): Mass generated by the living being, measured in kilograms (kg).
- ε (Specific dissipated energy): Energy dissipated per unit of mass, measured in Joules per kilogram (J/kg).
- $E_{bio} = m \cdot \varepsilon$: Represents the total energy dissipated by the organism (J).

To transform energy (J) into a unit of length (m), we use the proportionality constant of general relativity, where the relationship between energy and geometry is given by:

$$\alpha = G/c^4$$

Analogously to physical models that introduce additional dimensions to describe new variables, here it is proposed to incorporate a metabolic dimension representing the relationship between generated mass and dissipated energy.

This turns our proposal into a variant of Kaluza-Klein theory[5], except that the fifth dimension is not electromagnetism, but biological entropy. We then ask: how would the equations of motion (geodesics) look for an organism that tries to minimize its "distance" in this fifth dimension?

The question is of interest because it is very likely that this allows revealing that biological trajectories viewed in this way turn out to be a generalization of the "principle of least action".

In physics, the Principle of Least Action (δS) establishes that nature always chooses the "most economical" path in terms of energy and time. By adding a fifth metabolic dimension (w), the "action" no longer seeks only the shortest path in space-time, but the biologically most efficient path. Then we have [21] [22].

- **The Generalized Biological Action**

Inspired by the general principle of optimization present in many physical and biological systems, we can consider that organisms tend to follow trajectories that optimize their metabolic efficiency.

In general relativity, the action S for a free particle is proportional to the length of its trajectory (its "proper time"):

$$S = -mc\int \mathrm{d}s$$

If we use the 5-dimensional metric, where $\mathrm{d}s^2 = c^2\mathrm{d}\tau^2$.

Then the action for a living being becomes:

$$S = -mc\int \sqrt{-c^2\mathrm{d}t^2 + \mathrm{d}x^2 + \mathrm{d}y^2 + \mathrm{d}z^2 + \mathrm{d}w^2}$$

where w is your coordinate of "metabolic effort" ($m \cdot \varepsilon$). Here, the living being not only moves in space ($\mathrm{d}x$), but also "moves" through its own development and energy expenditure ($\mathrm{d}w$).

- **Equations of Motion (Geodesics)**

By applying the Euler-Lagrange equations to this action, we obtain the geodes-

[5]Note: The reference to models with additional dimensions in physics is used only as a structural analogy.

ics. The acceleration of a living being in this 5th dimension would follow this logic:

$$\frac{d^2x^A}{ds^2} + \Gamma^A_{BC}\frac{dx^B}{ds}\frac{dx^C}{ds} = 0$$

For the fifth dimension (w), this would imply that there exists a natural "metabolic acceleration". If space-time is flat (Minkowski), the equation tells us that:

$$\frac{d^2w}{ds^2} = 0 \Rightarrow \frac{dw}{ds} = \text{constant}$$

Interpretation: An organism in its "least action" state maintains a constant rate of energy dissipation per unit of mass with respect to its progression in space-time. Any deviation from that rate (a biological "stress") would require an external force or a change in its spatial trajectory.

Ramón Margalef already said this (in his own way): if the choice is not forced (stress), organisms tend to dissipate the least possible amount of energy and to maintain the lowest possible rate of mass renewal.

- **Biological trajectory as evolutionary efficiency**

What we are suggesting is that life does not move randomly, but follows the extremum of this 5D action. This gives us a new perspective on biological phenomena:

- **Homeostasis as system inertia**: Homeostasis would be the biological equivalent of Newton's first law: an organism tends to maintain its "metabolic velocity" (dw/ds) constant unless a force (environment, predator, disease) forces it to change.

In physics, a body tends to maintain its state of motion if no external force acts on it.

In biology, an organism tends to maintain its equilibrium if no external stress or system perturbation acts on it.

- **System evolution as curvature**: If we introduce gravity or "information fields" that curve this metric, the trajectory of least action would force species to change their generated mass or dissipated energy to remain "geodesic". Evolution would therefore be the path of least resistance in a curved metabolic space-time.
- **What does this mean for "Least Action"?**

In classical physics, action is minimized to conserve energy.

In this proposal[6], the biological trajectory minimizes the "Cost of Existence". A living being that does not follow the 5D geodesic would be "spending" more interval than necessary, which in biological terms we would call inefficiency or accelerated aging.

In physics, the "distance traveled" depends on the space-time path (trajectory).

In the case of our proposal, aging can be interpreted as the accumulated length

[6]Note: In this formalism, death could be interpreted as the point where the trajectory in the w dimension can no longer sustain non-zero values within the light cone of the other 4 dimensions, forcing the interval ds to collapse.

of the biological trajectory in an extended space.

It is not that time flows differently. It is that the organism travels more or less "biological distance".

This may be interesting, but we must not forget that although the information of a living being is found in its material structure (its generated mass), it is not found only there. Margalef called exosomatic artifacts any element that does not belong to the material structure of the living being, but which it uses fulfilling some function (tools, technology, etc.).

If we consider the information recovered by a living being in relation to the energy dissipated per unit of information and incorporate it into the previous formalizations, we must make some adjustments.

For this case, the fifth dimension (w) would be defined by means of the relationship between the generated information (I) and the energy dissipated per unit of information ($\varepsilon = E_{\text{dissipated}}/I$). Based on Landauer's Principle, which establishes a minimum limit of energy necessary to process information, we can construct the extended Minkowski interval as follows: [23]-[27].

1) Definition of the Informational Dimension (w)

For the fifth dimension to have units of length (meters) and be physically consistent, it can be defined through the relationship between total information and specific dissipation energy:

$$w = \alpha \cdot \left(I \cdot \epsilon \right)$$

where:

- I: Information generated by the living being (usually measured in bits or nats).
- ε: Energy dissipated per unit of information (J/bit). According to Landauer, there exists a minimum value:

$$\epsilon \geq k_B T \ln 2$$

- α: A dimensional conversion factor (with units of meters/Joule).

2) Minkowski Formula for 5D (ds^2)

In a flat 5-dimensional space, the metric maintains its Euclidean structure for spatial coordinates and pseudo-Euclidean for time:

$$\mathrm{d}s^2 = -c^2 \mathrm{d}t^2 + \mathrm{d}x^2 + \mathrm{d}y^2 + \mathrm{d}z^2 + \mathrm{d}w^2$$

Substituting the differential of the fifth dimension ($\mathrm{d}w$), the resulting formula is:

$$\mathrm{d}s^2 = -c^2 \mathrm{d}t^2 + \mathrm{d}x^2 + \mathrm{d}y^2 + \mathrm{d}z^2 + \left[\alpha \cdot d\left(I \cdot \epsilon \right) \right]^2$$

3) Interpretation in Biological Systems

- **Biological Trajectory**: The interval $\mathrm{d}s$ no longer depends only on physical motion, but on the "informational entropy" of the living being. A massive increase in information generation or in energetic inefficiency (ε) would increase displacement in the fifth dimension.
- **Informational Causality**: Just as the light cone limits physical velocity, in this

metric there would exist a "processing limit" where information and dissipated energy are linked to the very geometry of the universe.

- **Equivalence**: Just as relativity unifies mass and energy ($E = mc^2$), this metric suggests that information is an intrinsic component of the fabric of space-time for complex systems.

Rolf Landauer demonstrated that processing information has a minimum energy cost. There is no free information. This is decisive. If each processed bit requires energy, then: metabolism and information are not separate processes. They are two faces of the same phenomenon.

Given that we have analyzed the incorporation of a fifth dimension (w) based on metabolism (mass/energy) and information (entropy/processing), the next logical step in this analysis is the unification of both concepts into a Bio-Relativistic Interval.

Unification: The Biosemiotic Metric

If we consider that a living being is a system that transforms matter and information simultaneously to maintain its homeostasis, the component of the fifth dimension $\mathrm{d}w$ would be a linear combination of both processes:

$$\mathrm{d}w_{bio} = \frac{1}{k}\mathrm{d}\left(m\cdot\epsilon\right) + \alpha\mathrm{d}\left(I\cdot\epsilon\right)$$

The Minkowski formula for this extended flat space would be consolidated as:

$$\mathrm{d}s^2 = -c^2\mathrm{d}t^2 + \mathrm{d}x^2 + \mathrm{d}y^2 + \mathrm{d}z^2 + \left[\frac{1}{k}\mathrm{d}\left(m\epsilon\right) + \alpha\mathrm{d}\left(I\epsilon\right)\right]^2$$

Dilation of "Biological Time"

A critical aspect of this formula is its impact on proper time (τ). In standard special relativity, proper time is defined as $\mathrm{d}\tau = \mathrm{d}s/c$. With this fifth dimension, the time "experienced" by the living being is altered by its internal activity:

$$\mathrm{d}\tau = \sqrt{\mathrm{d}t^2 - \frac{1}{c^2}\left(\mathrm{d}x^2 + \mathrm{d}y^2 + \mathrm{d}z^2 + \mathrm{d}w_{bio}^2\right)}$$

Implications:

- **Differential Aging**: If the dissipation of energy per unit of information ($\mathrm{d}w_{bio}$) increases drastically (for example, in a state of extreme metabolic stress), the interval $\mathrm{d}s$ changes. This suggests that the "biological clock" does not depend only on motion in physical space-time, but on the trajectory in the biological state space. For example: the case of two twins (same genetics, same age). One lives calmly, with low or almost null metabolic stress. The other accumulates chronic inflammation, sleep deprivation, and energetic overload. At 50 years old, they are not in the same biological state.

In relativity, two different trajectories produce different proper times.

In biology, two different metabolic trajectories produce different biological states. Life is not only how much time has passed, but how much biological process has accumulated in the system.

- **Biological Inertia**: The resistance of an organism to change its informational

or metabolic state would act as a form of "mass" in this fifth dimension, affecting its geodesic trajectory.

Important

From the rigor of theoretical physics and following the line we have developed, calling this "biological time" is a semantic imprecision that may lead to ontological confusion.

What the formula is describing is not the creation of a new or alternative "temporal dimension", but a metric drag effect on the only existing physical time (t).

- **The Difference Between Time and Process**

In the metric we have constructed, time remains the coordinate dimension t. However, the invariant interval ds (which in relativity defines the path traveled in space-time) now includes the term $\mathrm{d}w_{bio}$. When calculating proper time (τ), which is the time measured by a clock traveling with the living being, we see that it "dilates" not due to a magical property of life, but because the living being is traversing a greater distance in the 5-dimensional manifold.

- **"Time" as Evolution of State**

Let us define precisely: what we incorrectly call biological time is the rate of evolution of the mass-information/energy relationship. In geometric terms:

- The living being is not in a "different time".
- The living being has an internal process velocity that consumes its "quota" of interval ds.
- If dissipation ($\mathrm{d}w_{bio}$) is very high, the proper time differential $\mathrm{d}\tau$ is reduced with respect to coordinate time $\mathrm{d}t$.

- **Correct Interpretation of the Formula**

If we isolate the relation, what we observe is that biological activity consumes the Minkowski interval. For an external observer (physical time t), two living beings may have experienced the same number of seconds, but if one of them has had a more irregular $\mathrm{d}w_{bio}$ trajectory (greater dissipation per unit of information/mass), its internal evolutionary state (its physicochemical or metabolic "hourglass") will have advanced differently.

Under this approach, aging is not the passage of time, but the trajectory in the space of biological configurations. The fifth dimension w is not "time", it is a state coordinate. The "dilation" shown by the formula is the mathematical evidence that life is a process that displaces the standard physical metric due to its dissipative nature.

Time is only one; what changes is the length of the path (geodesic) that the living being travels in that 5-dimensional fabric before reaching its limit of structural stability. This fits perfectly with the view of aging as a purely geometric phenomenon resulting from dissipative dynamics in a space that has ceased to expand (post-puberty).

Understanding that life does not possess its own "proper time" apart from physics, but is a system whose metric trajectory is altered by the dynamics between information and dissipation, is the core of a true Relativistic Biophysics. In this model, aging ceases to be a biological mystery and becomes an inevitable geomet-

ric consequence of the evolution of a system in a five-dimensional space.

4. Generalized Field Equation (Relativistic Biology)

Just as we worked on the formulation of special relativity and the Minkowski formula considering the biological phenomenon as an expression of a fifth dimension, we will do the same with the field equation of general relativity [28].

The Einstein field equation in five dimensions is expressed as:

$$G_{AB} = \kappa T_{AB}$$

where the energy-momentum tensor T_{AB} incorporates the densities and flows of biological mass and dissipated energy projected onto the fifth coordinate (w).

Step 1: Extension of index formalism

To include the biological fifth dimension $w = \frac{m\epsilon}{k}$, we extend the indices of Riemannian space-time. Instead of the usual Greek indices μ, ν (0 to 3), we use uppercase indices A, B that take values {0, 1, 2, 3, 4}. The metric tensor g_{AB} now describes a five-dimensional manifold where geometry is coupled to metabolic activity.

Step 2: Definition of the Einstein Tensor in 5D

The Einstein tensor G_{AB} is constructed from the Ricci tensor R_{AB} and the scalar curvature R derived from the pentadimensional metric. The fundamental geometric relation remains:

$$G_{AB} = R_{AB} - \frac{1}{2} g_{AB} R$$

In this scenario, the curvature of space-time is produced not only by physical mass-energy, but also by variations in the relationship between generated mass and energy dissipated by living beings.

Step 3: Construction of the Biological Energy-Momentum Tensor

The energy-momentum tensor T_{AB} must now include biological sources. The new components $T_{\alpha 4}$ and T_{44} represent the flow of information/energy and the density of "biological effort" in the fifth dimension:

$$T_{AB} = \begin{pmatrix} T_{\mu\nu} & T_{\mu 4} \\ T_{4\nu} & T_{44} \end{pmatrix}$$

here, T_{44} would represent the density of metabolic energy dissipated per unit mass in the local volume.

Step 4: Formulation of the Complete Field Equation

Combining the previous terms and assuming a gravitational coupling constant in five dimensions:

$$\kappa = \frac{8\pi G_5}{c^4}$$

the Einstein field equation for this biological system is:

$$R_{AB} - \frac{1}{2} g_{AB} R + \Lambda g_{AB} = \kappa T_{AB}$$

If the Kaluza-Klein formalism is followed [29], the existence of this fifth dimension w would manifest in the four traditional dimensions as vector fields (similar to electromagnetism) and scalar fields (dilatons) interacting with organic matter, suggesting that life "curves" space-time in a way different from inanimate matter.

The resulting field equation is:

$$G_{AB} + \Lambda g_{AB} = \kappa T_{AB}$$

where the indices A, B include the coordinate w.

This formulation implies that the presence of living beings with a specific rate of metabolic energy dissipation acts as an additional source of curvature, modifying the geometry of the local universe according to their biological activity.

In physics, Kaluza and Klein proposed that certain forces (gravity and electromagnetism) could be understood jointly if the existence of an additional dimension beyond space-time was considered. In biology, we can do something similar without invoking advanced physics: besides time, we must incorporate an axis that represents metabolic effort or processed information. Only in this way can we understand the geometric phase changes that occur in the system once growth has ended.

But just as happened when working with the Minkowski formula, we must consider that the information of a living being is found in its material structure (its mass), but not only there: how would Einstein's field equation look if we consider a fifth dimension resulting from the relationship between the information generated by a living being and the energy dissipated per unit of information by that same living being?

For this scenario, the Einstein field equation maintains its formal 5D structure, but the energy-momentum tensor (T_{AB}) and the metric (g_{AB}) are redefined to be governed by informational entropy and the Landauer limit.

In this formulation, the geometry of the universe responds not only to mass, but to the "processing of information" of biological systems.

- **Metric Interval and Informational Coordinate**

First, we define the fifth coordinate w based on information (I) and dissipated energy per bit (ε): $w = \alpha\left(I \cdot \epsilon\right)$. The line element in the 5D manifold is:

$$\mathrm{d}s^2 = g_{\mu\nu}\mathrm{d}x^{\mu}\mathrm{d}x^{\nu} + \phi^2\left(\mathrm{d}w\right)^2$$

where φ is a scalar field (dilaton) representing the "informational pressure" of the living being on the fabric of space-time.

- **Einstein Field Equation in 5D**

The equation follows the principle that geometry (curvature) equals energy and information content:

$$G_{AB} = \kappa T_{AB}$$

where:

- G_{AB} : five-dimensional Einstein tensor
- κ : gravitational constant in 5D
- T_{AB} : energy-momentum-information tensor

- **Components of the Energy-Information Tensor**

Considering physical information theory, the tensor is decomposed as:

- $T_{\mu\nu}$ (0 - 3): traditional energy and momentum (mass of the living being)
- $T_{\alpha 4}$: flow of information through space-time
- T_{44} : Landauer density, representing the minimum energy cost of generated information:

$$T_{44} \approx \rho_{\text{info}} = n \cdot k_B T \ln 2$$

where n is the density of processed bits.

- **Projection into 4D (Effective Equation)**

If we apply dimensional reduction (Kaluza-Klein type), the Einstein equation in our 4D world would appear "contaminated" by information:

$$G_{\mu\nu} = \frac{8\pi G}{c^4}\left(T_{\mu\nu} + T_{\mu\nu}^{(\text{info})}\right)$$

here, the term $T_{\mu\nu}^{(\text{info})}$ acts as a kind of "biological dark energy".

If a living being processes information very inefficiently (dissipating much energy per bit), it generates greater local curvature than an efficient system.

Physical Implication

The resulting equation suggests that the generation of knowledge and complexity is not a "free" process for the universe; information has geometric weight. In this model, a human brain or a complex biosphere curves space-time not only due to its physical mass, but due to the magnitude of its information flow, creating what some theoretical physicists call an "informational potential well".

5. Mapping the Border

Living beings are very particular thermodynamic systems, because they recover as information the energy they dissipate. They are thermodynamic systems and as such follow the "arrow of thermodynamics", as if it were a straight line, with no possibility of reversal. But since they are also self-organizing (they recover as information the energy they dissipate) and once development ends they continue recovering information (generating material structure) in a space that no longer grows, they experience curvature in the space where their variables are defined. Thus, these "thermodynamic arrows" are analogous to straight lines traveling through a curved space.

Another concept of great interest is the definition of "unit of mass" when studying the logical equivalence between mechanical velocity and metabolic velocity. The unit of mass is the mass of a cell according to the size and type of organism. It is not an absolute unit, but one relative to the size and type of organism. It may seem ambiguous or imprecise because no measurement units are mentioned, but rather relationships. But that is exactly what must be done: verify the relationship between dissipated energy and unit of mass for each type and size of organism. Nothing is more precise than a relative unit of mass. The use of any absolute unit fails by not considering these relationships.

It is important in more than one sense. Maestrini [30], in his development of a biological space-time within the framework of relativistic biology, recognizes the difficulty of not having in biology a constant analogy to the speed of light in general relativity. Our proposal is to consider the relative unit of mass as a relative constant. Just as nobody with mass can move at a speed greater than the speed of light in general relativity, no living being can define its existence in a space whose mass is lower than the relative unit of mass.

In our previous formalizations, it becomes evident that mass is the logical equivalent of mechanical velocity. And when analyzing the relationship between dissipated energy and total mass of a complex organism, it becomes clear that one cannot simply sum produced energy as if all units of mass always dissipated the same amount of energy (that would be like adding the speed of light to the speed of the train that illuminates the tracks). The dissipation of energy per unit mass declines as life progresses in a complex living being (it clearly undergoes negative acceleration). A complex biological system is an accelerated system, equivalent to what in mechanics is a non-inertial system.

Finally, the concept of simultaneity in biology. In Newtonian physics, time is absolute for all observers. When a physical event occurs at a given instant, it is simultaneous for all observers. But in relativity, time is not absolute, and simultaneity becomes relative. In biology, simultaneity undergoes a radical shift: the "clock" (time) is replaced by a "space of biological configurations" (biological events).

Thus, an event is biologically simultaneous with another when the observer recognizes the same biological event in different biological reference systems (for example: birth, puberty, old age, or death across species). Temporal simultaneity matters little in living beings, because their trajectories soon diverge in biological configuration space—"and nothing remains in its place".

If we were inside the closed box containing the apple, before disappearing under less favorable configurations, we would leave a record: we are mapping the boundary. And that is not studying the limits of the big box. That is studying living beings, because that is where the great boundary lies. A discrete interface between the living and the inert, as discreet as the boundary between water and air when observing rain. A boundary repeated in every drop.

The living and the inert are not separated by a wall, but by a dynamic boundary. Studying that boundary is knowing:

- How much energy is dissipated
- How much information is organized
- How structure is maintained

Mapping the boundary is not metaphysics. It is thermodynamics applied to life.

6. Conclusions

Throughout this work, we have explored a conceptual possibility: describing living beings through a geometry defined by the relationship between dissipated en-

ergy, recovered information, and generated structure.

The starting point was a simple idea proposed by Ramón Margalef: living beings are complex physical systems. However, they are unique physical systems because they recover the energy they dissipate as information. This property introduces a fundamental difference compared to inert systems and compels us to reconsider how we describe their trajectories, their boundaries, and their evolution.

Based on this premise, we analyzed the relationship between surface area, volume, and information, using the holographic principle and the informational density limits associated with the boundaries of systems as conceptual references. From this perspective, growth, complexity, and aging can be interpreted as geometric manifestations of the same phenomenon: the evolution of a self-organizing system that continues to generate structure once it has reached its growth limit.

To formalize this idea, we proposed a geometric extension inspired by the Minkowski space-time interval. Within this framework, metabolic activity and information processing are represented as additional coordinates capable of describing an organism's biological trajectory within an expanded state space.

If we consider the evolution of variables in the parameter space (the virtual space of biological variables), we have a model of what occurs during aging. The authors are then within their area of expertise. However, if we consider the changes that occur in the environment in which biological variables define their values (the real physical space in which the living being defines its existence), the consequences exceed the author's area of expertise (we are not theoretical physicists). Nevertheless, the mathematical formalization carried out is necessary to describe either scenario.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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