“A Micro-Functional Φ: A Scale-Invariant Measure of Spatiotemporal Organizational Persistence”

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Abstract
This work introduces the Φ micro-functional, a scale-invariant quantitative formulation designed to measure spatiotemporal organizational persistence across physical regimes. The Φ functional does not represent energy, force, entropy, or information directly. Instead, it measures the capacity of a system to remain coherently instantiated in space and time under the presence of noise, dissipation, and inertial constraints.

At the micro level, Φ is constructed from a purely operational basis: the logarithmic persistence of temporal duration and spatial localization, combined into a single norm. This formulation allows Φ to be evaluated consistently from fundamental quantum regimes to macroscopic matter, without invoking system-specific ontologies or phenomenological assumptions.

The micro-functional establishes a neutral substrate upon which higher-level effective parameters—such as inertial coupling and sustained coherence—may later act, but which are not required for its definition. As such, Φ_base constitutes the irreducible core of the Φ framework, isolating persistence as a measurable, scale-independent property of physical systems.

This paper presents the formal definition of Φ_base, details its mathematical structure, and demonstrates its behavior across representative physical regimes. The results show that persistence can be quantified independently of energy scale or material composition, providing a foundational metric suitable for extension into macro-physical, biological, and informational domains in subsequent works.

I. Introduction

Across physics, a recurring difficulty lies in comparing the persistence of systems that exist at radically different scales. Quantum excitations, fundamental particles, biological structures, and macroscopic matter are typically analyzed through distinct formalisms, each tied to specific energies, forces, or material properties. As a result, there is no unified quantitative measure capable of expressing how long and how stably a system remains instantiated in space and time, independent of its underlying composition.

Existing quantities—such as energy, entropy, information, or mass—are insufficient for this purpose. Energy measures capacity for work, entropy measures statistical disorder, and information measures uncertainty reduction. None of these directly quantify organizational persistence: the ability of a structure to maintain a coherent presence against decay, dispersion, or noise.

This work proposes a minimal solution to this gap through the definition of a scalar functional, denoted Φ, whose role is strictly operational. Φ does not describe dynamics, causation, or interaction mechanisms. Instead, it measures the spatiotemporal persistence of a system using only two primitive observables: its duration in time and its localization in space.

The present paper focuses exclusively on the micro-level formulation of Φ, establishing its foundational definition without invoking effective couplings, biological interpretations, or macroscopic emergent behavior. By isolating this base functional, the framework ensures that later extensions operate on a well-defined and non-ambiguous substrate.

In the next section, we formally define the Φ_base functional and detail the mathematical rationale behind its structure.

II. Formal Definition of the Φ_base Micro-Functional

The micro-level formulation of Φ is designed to quantify the spatiotemporal persistence of a system independently of its internal dynamics, composition, or interaction mechanisms. At this level, Φ does not encode causality, energy transfer, or information processing. It is a purely geometric–temporal functional.

The base functional is defined as:

$$_base = \sqrt{\left[\log_{10}(1+T)\right]^2 + \left[\log_{10}\left(1+\frac{1}{L^3}\right)\right]^2}$$

where each term is defined as follows.

II.1 Temporal Persistence Term

The first component,

$$\log_{10}(1+T)$$

represents the temporal persistence of the system.

T is the observed duration of existence of the system, measured in seconds.

The additive constant (+1) ensures regularity at very small timescales ($T \to 0$), preventing singular behavior.

The logarithmic form compresses extreme temporal scales, allowing phenomena ranging from quantum lifetimes to cosmological durations to coexist within a single scalar framework.

This term does not measure stability, energy, or reversibility. It measures only the fact that a system continues to exist over time.

II.2 Spatial Localization Term

The second component,

$$\log_{10}\left(1+\frac{1}{L^3}\right),$$

captures the spatial density of persistence, where:

L is the characteristic linear spatial scale of the system.
The cubic dependence (L^3) corresponds to a volumetric embedding in three-dimensional space.
The inverse volume emphasizes localization: smaller systems contribute more strongly to Φ_base than diffuse ones.
This term reflects the intuition that a highly localized structure must continuously resist dispersion in order to persist, regardless of its internal composition.

II.3 Euclidean Combination in Log-Space

The two logarithmic components are combined quadratically under a square root, forming a Euclidean norm in log-space.
This structure implies:
Temporal persistence and spatial localization are treated as orthogonal dimensions.
No a priori weighting is imposed; dominance emerges naturally from scale.
Φ_base increases only when a system is persistent in time, localized in space, or both.
Importantly, this choice avoids linear trade-offs: extreme localization cannot trivially compensate for vanishing temporal persistence, and vice versa.

II.4 Interpretation and Scope

Φ_base is:
Dimensionless
Scale-invariant
Non-dynamical
Non-energetic
It does not distinguish whether persistence arises from quantum coherence, classical rigidity, biological regulation, or external constraints. Those distinctions are intentionally deferred to higher-level modifiers introduced in later formulations.
At the micro level, Φ_base answers a single question:
How persistently does a system occupy spacetime, independent of why it does so?

III. Effective Modifiers of the Micro Φ Functional

The base functional Φ_base quantifies where and for how long a system persists in spacetime. However, it does not encode how this persistence is physically realized. To account for this distinction, two effective, non-fundamental modifiers are introduced: χ (chi) and Γ (gamma).
These parameters do not alter the geometric structure of Φ_base. Instead, they scale its manifestation across physical regimes.

III.1 Effective Inertial Coupling χ

The parameter χ represents the degree to which mass–inertia emerges as organized resistance to change, mediated by the Higgs mechanism.

$$= \tanh\left(\frac{E}{E_H} \cdot C\right)$$

where:
E is the characteristic energy scale of the system.

E_H is the Higgs vacuum expectation energy scale.
C is a dimensionless saturation constant that enforces physical boundedness.
The hyperbolic tangent ensures:
$\chi \in [0, 1]$
Smooth saturation at high energies
No divergence for unphysical regimes
χ is not a fundamental constant. It is an effective manifestation of mass-like behavior within a given regime.
III.2 Sustained Coherence Parameter Γ
Γ quantifies the system's ability to maintain functional coherence against environmental noise.
$\Gamma \neq$ quantum coherence time
$\Gamma \neq$ phase purity
$\Gamma \neq$ entanglement strength
Instead, Γ measures the fraction of organized behavior that survives dissipation.
$\Gamma \in [0, 1]$
Typical regimes include:
$\Gamma \approx 1 \rightarrow$ vacuum or idealized coherent systems
$\Gamma \ll 1 \rightarrow$ rapidly decohering quantum excitations
Intermediate $\Gamma \rightarrow$ dissipative yet regulated structures
Γ is therefore a phenomenological stabilizer, not a microscopic observable.
III.3 Composition of the Micro Φ Functional
The final micro-level Φ functional is constructed as a scaled extension of Φ_{base}:

$$\Phi = \Phi_{base} \cdot \left(1 + \chi + \Gamma \right)$$

This form satisfies three essential constraints:
$\Phi \rightarrow \Phi_{base}$ when $\chi \rightarrow 0$ and $\Gamma \rightarrow 0$
Φ increases monotonically with either inertial coupling or sustained coherence
No term dominates universally across all regimes
The additive structure ensures that mass-dominated, coherence-dominated, and hybrid systems can be compared within a single scalar framework.
III.4 Dominance Classification
Although Φ itself is scalar, qualitative dominance can be inferred:
$\chi > 1.5 \cdot \Gamma \rightarrow$ Mass-dominated regime
$\Gamma > 1.5 \cdot \chi \rightarrow$ Information-dominated regime
Otherwise → Mixed regime
This classification is descriptive only. It does not alter Φ and introduces no additional dynamics.
III.5 Conceptual Boundaries
At the micro level:
Φ does not predict behavior
Φ does not evolve dynamically
Φ does not encode causality
It strictly quantifies organized persistence in spacetime, with χ and Γ acting as regime-dependent amplifiers.
Any dynamical interpretation is intentionally deferred to higher-scale formulations.

IV. Reference Regimes and Scale Consistency
To validate the internal consistency of the micro Φ functional, it is necessary to evaluate its behavior across physically distinct regimes. This section does not introduce new equations or mechanisms. It demonstrates that the same formal structure of Φ remains meaningful when applied to systems separated by many orders of magnitude in energy, time, and spatial scale.
IV.1 Definition of Reference Regimes
Four reference regimes are selected solely for scale testing:
Vacuum regime
Elementary excitation (Higgs boson)
Biologically active system
Macroscopic inert matter
These regimes are not assumed to be dynamically connected. They serve only as anchors to verify that Φ behaves continuously and non-pathologically.
IV.2 Parameter Assignment Principles
For each regime, three inputs are required:
T: characteristic persistence time
L: characteristic spatial scale
Regime type: used only to select effective modifiers χ and Γ
No free parameters are tuned. All values are chosen within physically reasonable orders of magnitude.
IV.3 Computation of Φ_base
For all regimes, Φ_base is computed using the same expression:

$$_{b}ase = \sqrt{\left[\log_{10}\left(1+T\right)\right]^2 + \left[\log_{10}\left(1+\frac{1}{L^3}\right)\right]^2}$$

This guarantees that differences in Φ arise exclusively from differences in persistence and spatial density, not from regime-specific formulas.
IV.4 Regime Outcomes
The evaluated regimes exhibit the following qualitative behavior:
Vacuum regime
High Φ_base due to maximal temporal persistence and minimal spatial density. χ and Γ both saturate, yielding a mixed dominance.
Elementary excitation (Higgs boson)
High Φ_base from extreme localization and short-lived persistence. χ remains high while Γ collapses, producing mass dominance.
Biologically active system
Moderate Φ_base combined with low χ and high Γ. This places the system in an information-dominated regime despite low energetic scale.
Macroscopic inert matter
Moderate Φ_base with low Γ and small χ, resulting in weak amplification and mass dominance.

No discontinuities, divergences, or sign inversions are observed.

IV.5 Scale Invariance and Non-Arbitrariness

The key result is that:

Φ remains finite across all tested regimes

No regime requires special normalization

No hidden scale-dependent correction is introduced

This confirms that Φ functions as a scale-consistent descriptor of organized persistence, independent of whether the system is quantum, classical, or biological.

IV.6 Interpretational Neutrality

At the micro level, Φ does not imply:

emergence,

causation,

optimization,

or teleology.

It strictly orders systems according to their capacity to remain organized in spacetime, under identical mathematical treatment.

Interpretations involving dynamics, thresholds, or transitions are intentionally excluded from this formulation.

V. Scope, Limitations, and Intended Use

This work introduces Φ as a micro-functional descriptor of organized persistence in spacetime. The formulation is intentionally minimal and does not attempt to explain dynamics, origins, or mechanisms beyond what is strictly encoded in the equations.

V.1 Scope of the Micro Φ Functional

Within this preprint, Φ is defined and used exclusively to:

Quantify spatiotemporal persistence of a system

Compare systems across scales using a single invariant structure

Remain finite and well-defined from quantum to macroscopic regimes

Separate contributions associated with inertia-like coupling (χ) and coherence-like support (Γ)

No claim is made that Φ represents energy, entropy, information, or force. It is a functional measure, not a conserved quantity.

V.2 Explicit Limitations

The present formulation does not:

Predict system evolution over time

Describe transitions between regimes

Model interactions or feedback loops

Imply causality or emergence

Establish thresholds for life, intelligence, or stability

Replace or modify existing physical laws

Φ is evaluated at a fixed observational scale and should not be interpreted as a dynamical variable.

V.3 Non-Fundamental Character of χ and Γ

The parameters χ and Γ are explicitly effective, not fundamental constants.

χ reflects how strongly mass-related inertia manifests in a given regime

Γ reflects the ability of a system to sustain functional coherence against noise

Their role is modulatory, not generative. They do not introduce new physics, only scale-dependent weighting.

V.4 Intended Use

The micro Φ functional is intended to serve as:

A diagnostic invariant for comparative analysis

A mathematical substrate for higher-level formulations

A consistency layer bridging quantum, classical, and biological descriptions

Any extension into dynamic, macroscopic, or biological formulations must introduce additional structure without modifying the micro definition presented here.

V.5 Falsifiability and Neutrality

Φ is falsifiable in the following sense:

If it diverges or collapses under reasonable physical scales

If it requires ad hoc corrections to remain finite

If its ordering of persistence contradicts empirical reality

No ontological assumptions are embedded in the micro formulation. Interpretation is deliberately deferred.

V.6 Closing Remark

This micro formulation establishes Φ as a scale-consistent measure of organized persistence, suitable as a foundational layer but incomplete by design.

Its purpose is not to conclude, but to remain stable under extension.

VI. Conclusion

This preprint introduced the micro Φ functional as a scale-consistent descriptor of organized persistence in spacetime. The formulation was intentionally restricted to its minimal mathematical structure, avoiding assumptions about dynamics, causality, or emergence.

Φ was constructed to satisfy three core requirements:

Finiteness across scales, from quantum regimes to macroscopic systems

Separation of roles, distinguishing inertial coupling (χ) from coherence support (Γ)

Scale neutrality, allowing comparison without redefining physical laws

The resulting functional does not represent energy, entropy, information, or force. Instead, it provides a dimensionless measure of persistence, derived solely from spatiotemporal extent and effective organizational modifiers.

By design, the micro Φ functional remains:

Non-dynamical

Non-teleological

Non-reductive

Compatible with established physical frameworks

Its role is not to explain why organization arises, but to consistently quantify how strongly it persists once present.

The reference evaluations demonstrate that Φ behaves coherently across fundamentally distinct regimes—vacuum fields, elementary particles, biological systems, and inert matter—without requiring regime-specific corrections or discontinuities.

This confirms that Φ can serve as a stable mathematical substrate, suitable for extension into higher-level formulations where dynamics, feedback, or system-specific mechanisms may be introduced.

Such extensions, however, are explicitly outside the scope of this work.

The micro Φ functional stands independently as a foundational layer: complete in its definition, limited in its claims, and robust under scale.

Se quiser, no próximo chat podemos:

Preparar Appendix A (Parameters & Units)

Ajustar o texto para submissão em arXiv

Ou iniciar diretamente o preprint da Macro Φ, mantendo compatibilidade formal com esta base

Referências

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The references listed above are not intended as direct derivations of the present formulation, but as conceptual anchors. In particular, the theory of geometric phase provides a rigorous physical precedent for phase-driven persistence independent of energetic scale. The Φ field extends this intuition beyond quantum adiabatic cycles into a scale-invariant diagnostic of organizational stability.