The Universal Replication Principle as a Unifying Framework for the Expansion of Physical Vacuum and the Origin of Life

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Abstract

This work proposes the Universal Replication Principle (URP) as a unifying conceptual framework for interpreting the persistence, reproduction, and evolution of physical configurations in the universe. According to this principle, configurations that achieve a certain degree of stability and coherence tend to persist and, under favorable dynamical conditions, to generate new configurations with similar structural properties.

From this perspective, apparently diverse phenomena—such as the formation of gravitational structures, the accelerated expansion of the universe, and the emergence of living systems capable of replication—can be understood as manifestations of a common underlying dynamic of coherence replication.

In the cosmological domain, dark energy is interpreted as the observable manifestation of the expansion of the physical vacuum, understood as a dynamical state of space-time capable of extending its own structure. In the biological domain, the URP situates the origin of life within a natural continuity with processes of physical and chemical organization, as a transition toward advanced forms of structural and informational replication.

This approach does not introduce new physical interactions, but rather offers a unifying reinterpretation of known phenomena, connecting cosmology, fundamental physics, and biology under a common dynamical framework. Although further theoretical development and empirical validation are required, the proposed framework suggests that the evolution of the universe may be understood as a process in which coherence is not only preserved but, under certain conditions, replicated and transformed across different levels of organization.

1. Introduction

One of the most remarkable features of nature is the recurrent emergence of processes of persistence, replication, and self-organization across different levels of the universe. From the formation of large-scale cosmological structures to the emergence of living systems capable of self-replication, numerous phenomena exhibit a common tendency to generate configurations that preserve fundamental properties of prior states.

In cosmology, one of the most significant open problems is the nature of dark energy, which is responsible for the accelerated expansion of the universe. Despite the descriptive success of the

standard cosmological model, the physical interpretation of this phenomenon remains uncertain.

In parallel, another fundamental question persists in biology: the origin of life, understood as the emergence of systems capable of reproducing information and maintaining their organization against entropy. Although various physico-chemical scenarios have been proposed, there is still no clear consensus on the principles that made this transition possible.

Although these problems belong to different domains, both may be related to more general properties of the dynamics of the universe.

In this work, the Universal Replication Principle (URP) is proposed as a conceptual principle describing the tendency of certain stable physical configurations to persist and, under favorable dynamical conditions, to generate analogous configurations. From this perspective, phenomena such as the expansion of the physical vacuum associated with dark energy and the emergence of self-replicating living systems can be interpreted as manifestations of a common underlying dynamic.

2. The Universal Replication Principle (URP)

The Universal Replication Principle (URP) is proposed as a general conceptual principle describing a recurrent property in natural systems: the tendency of certain stable physical configurations to persist and, under favorable dynamical conditions, to generate new configurations with similar structural properties.

This principle does not introduce a new physical interaction nor does it replace established laws. Its function is descriptive: it identifies a regularity in the dynamics of nature that manifests across different levels of organization, from fundamental physical structures to complex systems.

In general terms, the URP can be formulated as follows:

Physical states that achieve a certain degree of stability tend to maintain their coherence and, under appropriate conditions, to generate analogous configurations.

The URP does not imply that every coherent configuration replicates; rather, this capacity depends on the dynamics of the system in which the configuration exists. Coherence is a necessary condition for persistence, but not sufficient for replication. Replication additionally requires the presence of a dynamical process capable of generating new configurations from prior states. In systems exhibiting such replicative capacity, coherence is not only preserved but may also propagate or reproduce under favorable conditions, whereas in systems lacking this dynamics, coherence remains local and does not give rise to replicative processes.

To describe this tendency conceptually, the notion of structural coherence C is introduced, understood as the ability of a system to maintain its organization in the presence of disordering processes.

In schematic form, this dynamics may be expressed as a proportional relationship between the temporal variation of coherence and the level of coherence present in the system:

$$dC/dt \propto C$$

This expression does not constitute a fundamental law, but rather a simplified representation of the tendency of certain systems to preserve and amplify their coherence under favorable conditions. These relations are illustrative in nature and are not intended to replace the established equations within existing theoretical frameworks. The formal solution of this relation corresponds to an exponential behavior:

$$C(t) = C_o\, e^{kt}$$

where C(t) represents the level of coherence of the system at time t, C_o the initial coherence, and k a parameter describing the efficiency with which coherence is preserved or amplified.

From this perspective, the URP may be interpreted as a general organizing principle that does not act as an additional force, but rather as an emergent property of certain physical systems that favors the persistence and generation of coherent configurations.

If this property constitutes a fundamental feature of the dynamics of the universe, its manifestation should be observable in the most basic physical states. In particular, it is natural to examine how this tendency is expressed in the two fundamental modes of physical existence: matter and the physical vacuum.

3. Replication of Fundamental Physical States

Within the framework of the Universal Replication Principle (URP), the fundamental physical states of the universe can be interpreted as different manifestations of a common tendency toward the preservation and replication of coherence. Among these states, matter and the physical vacuum stand out, not as completely independent entities, but as complementary modes through which this dynamic is expressed at different scales.

In the case of matter, gravitational interaction favors the concentration of mass. Under the action of gravity, regions of higher density tend to attract surrounding matter, leading to the formation of increasingly complex and organized structures such as stars, galaxies, and galaxy clusters. This process can be understood as a form of persistence and amplification of mass-dominated configurations.

In an analogous way, the physical vacuum exhibits its own characteristic dynamics. At cosmological scales, the physical vacuum shows a tendency to expand, generating new regions of space with similar properties. This expansion, observed in the evolution of the universe, can be interpreted as a form of vacuum replication, in which space itself extends by generating new regions with similar structural characteristics.

From the perspective of the URP, these two behaviors represent distinct manifestations of a single underlying dynamic: the tendency of the universe to preserve and replicate its own coherence.

Thus, while gravity favors the concentration of matter, cosmological expansion favors the extension of the vacuum. Both processes contribute to the structural evolution of the cosmos and can be understood as complementary expressions of the replicative dynamics described by the URP.

4. Vacuum Expansion and Dark Energy

The accelerated expansion of the universe constitutes one of the most significant phenomena in modern cosmology. Observations of distant supernovae and other cosmological data indicate that this expansion not only continues, but is also accelerating over time. Within the framework of the standard cosmological model, this behavior is attributed to so-called dark energy, a component estimated to account for approximately 70% of the total energy content of the observable universe.

However, the physical nature of dark energy remains largely unknown, opening the possibility of exploring alternative interpretations based on more fundamental properties of space-time.

Within the framework of the Universal Replication Principle, cosmological expansion may be interpreted from a different perspective. If the vacuum constitutes a physical state capable of preserving and replicating its coherence, then its expansion may be understood as a direct manifestation of this fundamental dynamic.

From this perspective, the vacuum is not regarded as a mere absence of matter, but as a physical state of space-time with its own dynamical properties. In particular, cosmological expansion may be interpreted as the tendency of the vacuum to extend itself, generating new regions of space with similar physical properties.

This dynamics may be represented in simplified form by a proportional relationship between the rate of expansion and the amount of existing vacuum:

$$dR/dt \propto R$$

where R represents a characteristic spatial scale (for example, the radius of an idealized vacuum region). This relation expresses that the expansion rate is proportional to the size of the system itself.

The solution to this relation leads to an exponential behavior of the spatial scale:

$$R(t) = R_o\ e^{Ht}$$

where R(t) represents a characteristic spatial scale (which may be interpreted, for example, as the radius of an idealized region of physical vacuum) at time t, R_o its initial value at a reference time, and H a constant describing the rate of expansion.

As in the previous case, this relation is schematic in nature and is not intended to replace the precise description of cosmological expansion provided by standard models.

Within this interpretative framework, vacuum expansion may be understood as a particular manifestation of space-time dynamics. While gravity produces attraction and concentration when acting on matter, its effect in vacuum-dominated regions may be interpreted as a tendency toward the expansion of space itself.

From this perspective, dark energy may be interpreted as the observable cosmological manifestation of this expansive vacuum dynamics. This interpretation is phenomenologically compatible with the standard ΛCDM cosmological model, in which accelerated expansion is described by a cosmological constant. In this sense, the acceleration of the expansion of the universe does not necessarily require the introduction of an independent entity, but may instead be understood as the expression of the tendency of the vacuum to extend its own structure, in accordance with the Universal Replication Principle.

The dynamics described here does not constitute an isolated phenomenon within the evolution of the universe. If the Universal Replication Principle acts as a fundamental property of reality, its manifestation is not limited to the cosmological domain, but extends across different levels of organization, contributing to the emergence of increasingly complex structures.

5. Structural Replication and Complexity

The Universal Replication Principle is not limited to describing cosmological processes, but manifests continuously in the progressive organization of matter across different scales.

In many open physical systems, certain configurations reach relatively stable states that allow them to persist over time and, in some cases, to generate new similar structures. This behavior can be observed in a wide range of phenomena, from the formation of gravitational structures to the organization of complex chemical systems.

The evolution of the universe shows a recurrent tendency toward the emergence of increasingly organized structures. From the earliest particles and fundamental fields, atoms are formed, followed by molecules, and later by chemical structures of growing complexity. Each of these levels introduces new forms of stability and organization.

From the perspective of the URP, this progression can be interpreted as a manifestation of the tendency of coherent configurations to persist and reproduce under favorable dynamical conditions. Structures that are able to maintain their coherence in the presence of disordering processes tend to endure and to generate related configurations.

In this way, the evolution toward increasing complexity does not depend solely on random processes, but can also be understood as a consequence of the dynamics through which the universe preserves and replicates structurally stable configurations.

This process of structural replication establishes the physical and chemical context in which systems capable of explicit replication—one of the defining features of living organisms—can emerge.

As structural complexity increases, the replication of coherence acquires progressively more elaborate forms. In this process, certain configurations not only succeed in persisting over time, but also actively participate in the generation of new similar structures. This development sets the stage for a transition in which replication is no longer purely structural or dynamical, but comes to incorporate the transmission of information, a defining characteristic of living systems.

6. The Origin of Life as a Replicative Process

In this context, the emergence of life may be interpreted as a natural consequence of the progressive development of coherence replication in increasingly complex physical systems. In living organisms, matter acquires the ability to maintain organized structures, exchange energy with the environment, and reproduce information through replication mechanisms.

In current scientific approaches, the origin of life is typically understood as the result of a series of gradual transitions in increasingly complex chemical systems. Starting from simple molecules, certain systems may develop reaction cycles that favor the formation of structures capable of reproduction or participation in autocatalytic processes.

In this context, the emergence of replicative systems does not necessarily represent a rupture with previous physical dynamics, but rather an intensification of organizational processes already present at more basic levels of matter.

From the perspective of the Universal Replication Principle, life may be interpreted as a particularly complex manifestation of the tendency of coherent configurations to persist and reproduce. Unlike simple physical or chemical systems, living organisms introduce a new level of organization: the replication of structured information.

The emergence of molecules capable of storing and transmitting information—such as primitive molecular replicators analogous to RNA or DNA—allows certain configurations not only to persist, but also to reproduce with heritable variations. This process opens the possibility of biological evolution through natural selection.

From this perspective, life does not constitute an exception within the laws of the universe, but rather a continuation of the general dynamics through which stable configurations are preserved and reproduced over time.

Thus, biological replication may be understood as an advanced form of the replicative tendency that manifests across different levels of organization in nature, from fundamental physical structures to living systems capable of evolution.

7. Cosmological and Biological Implications

The hypothesis presented in this work suggests that different phenomena observed in the universe may be interpreted as manifestations of a common underlying dynamic associated with the persistence and replication of coherent configurations.

In the cosmological domain, the Universal Replication Principle provides a conceptual framework for interpreting the accelerated expansion of the universe from the perspective of vacuum dynamics. Rather than considering dark energy as an independent entity, it may be understood as the observable manifestation of the tendency of the vacuum to extend itself and generate new spatial regions under specific cosmological conditions.

This interpretation remains consistent with the standard cosmological model at the level of observational description, while proposing an alternative reading of its physical meaning. Within this framework, gravity may manifest differently depending on the medium in which it operates. When acting on matter, it favors mass concentration and the formation of gravitational structures. When acting in vacuum-dominated regions, its effect may be interpreted as a tendency toward the expansion of space itself. From this perspective, vacuum expansion and gravitational attraction may be understood as complementary manifestations within the global dynamics of space-time.

In the biological domain, the URP suggests a possible continuity between processes of physical organization and the emergence of living systems. Life may be interpreted as a particularly complex form of structural replication, in which matter acquires the ability to preserve and reproduce information in a stable manner.

Under this interpretation, the origin of life does not appear as a completely isolated phenomenon within the evolution of the universe, but rather as an advanced manifestation of the same general tendency toward the persistence and reproduction of coherent configurations.

Although this hypothesis requires further theoretical development and empirical validation, it provides a conceptual framework in which apparently separate phenomena—such as vacuum expansion, the formation of cosmological structures, and the emergence of life—can be understood within a single general dynamic of structural replication.

8. Implications and Possible Avenues for Verification

The framework proposed in this work does not introduce new physical interactions, but rather offers a unifying reinterpretation of already observed phenomena. In this context, its scientific value depends in part on its ability to generate testable implications or, at least, to guide the interpretation of existing data within a coherent perspective.

In the cosmological domain, interpreting dark energy as a manifestation of vacuum expansion suggests that cosmic acceleration may not necessarily require the introduction of an independent component, but could instead be understood as an intrinsic property of space-time. This perspective is compatible with current observations, while opening the possibility of exploring whether certain features of the expansion—such as its stability, homogeneity, or possible large-scale deviations—can be more naturally described within this framework.

Furthermore, the proposal suggests that the distinction between gravitational attraction and vacuum expansion may be interpreted as different regimes of a single underlying dynamic. This idea opens the possibility of investigating the existence of intermediate behaviors or transitional regimes in the evolution of cosmological structures, particularly in contexts where matter-dominated and vacuum-dominated regions coexist.

In this regard, high-precision observations of the large-scale structure of the universe, as well as of the cosmic expansion rate across different regimes, may provide relevant information for assessing the consistency of this interpretation.

In the domain of the origin of life, the Universal Replication Principle suggests that the emergence of replicative systems may be a natural consequence of increasing structural coherence in complex chemical environments. From this perspective, research in prebiotic chemistry may be oriented toward identifying conditions under which structural replication intensifies to the point of giving rise to systems capable of storing and transmitting information.

More generally, the proposed framework suggests that replicative-type dynamics may be present in different physical systems in which coherence is not only preserved, but also propagated or amplified under appropriate conditions. This opens the possibility of analyzing phenomena in which the persistence and generation of coherent structures manifest recurrently across different scales.

Although these lines of inquiry remain exploratory, the proposed approach makes it possible to articulate potential connections between observation, modeling, and experimentation, positioning the Universal Replication Principle as an interpretative framework open to further development and progressive empirical assessment.

9. Distinction from Existing Principles

The Universal Replication Principle (URP) is not intended to replace established principles in physics or biology, but rather to provide a unifying conceptual perspective on phenomena that are typically studied separately.

In thermodynamics, entropy describes the tendency of systems toward disorder, although local decreases in entropy are possible in open systems. The URP does not contradict this framework, but instead focuses on the persistence and propagation of coherent configurations under conditions in which organization can be locally maintained or amplified.

In the context of self-organization, many physical and chemical systems exhibit the spontaneous formation of structures. However, such processes are usually treated as domain-specific phenomena. The URP extends this perspective by suggesting that these behaviors may reflect a more general tendency of coherent configurations to persist and, under certain conditions, to generate analogous structures across different scales.

In biology, natural selection explains the evolution of replicative systems once they already exist. The URP, by contrast, addresses a more general question: the conditions under which replicative dynamics may emerge from non-living physical systems.

In cosmology, the standard ΛCDM model successfully describes the expansion of the universe through a cosmological constant. The URP does not challenge this descriptive framework, but proposes an interpretation in which vacuum expansion may be understood as a manifestation of a more general tendency toward the replication of coherent physical states.

In this sense, the URP acts as a conceptual bridge connecting thermodynamics, self-organization, cosmology, and biology within a common interpretative framework, without introducing new fundamental interactions.

10. Conclusion

In this work, the Universal Replication Principle (URP) has been proposed as a conceptual framework for describing a general property of the universe: the tendency of stable physical configurations to persist and to generate analogous structures over time. From this perspective, apparently diverse processes—such as the formation of gravitational structures, the expansion of the vacuum associated with dark energy, and the emergence of living systems capable of replication—can be interpreted as manifestations of a common underlying dynamic.

In the cosmological domain, this approach allows the accelerated expansion of the universe to be reinterpreted as an expression of the dynamics of the physical vacuum, understood as a state with active properties capable of extending its own structure. Within this framework, dark energy may be interpreted as the observable manifestation of this process.

In the biological domain, the URP suggests a continuity between physical organization, chemical complexity, and the emergence of systems capable of informational replication. Life may thus be understood as an advanced expression of the same dynamic of preservation and reproduction of coherent structures.

Although this framework requires further theoretical development and empirical validation, it provides a unified reading of processes that have traditionally been studied independently. From

this perspective, the evolution of the universe may be understood as a process in which structures not only persist, but also give rise to new forms of organization over time.

Within this framework, the replication of coherence does not constitute a local or emergent phenomenon, but rather a structural feature of the dynamics of the universe, present across different levels of physical organization.