

# THE PRINCIPLE OF EVOLUTIONARY ELEGANCE

## Energy, information, and stability in the dynamics of complex systems

### Abstract

The Principle of Evolutionary Elegance proposes a conceptual-physical framework to describe why certain complex systems—from stars to neural networks, from biospheres to technological civilizations—manage to maintain structure and functionality over time under real energetic constraints.

The central idea is that a systematic relationship exists between three quantities:

- energy dissipated by a system,
- organized information that the system manages to retain,
- degree of stability over long time scales.

By "organized information," we mean the portion of non-random structure that contributes to the system's stability: memory, repeatable patterns, the ability to filter noise, and the capacity to react non-trivially to stimuli. The measurement method varies from one domain to another (stellar physics, biology, AI networks), but the selective logic remains the same: what survives is that which manages to maintain effective order at a finite energetic cost.

The principle introduces tools such as the Elegance Curve and the Elegance Ratio to represent this relationship operationally. The goal is not to predict individual events, but to provide criteria to distinguish, within a chaotic flow, the configurations that have the highest probability of persisting from those destined to dissolve.

This document presents the Theorem in a compact form, clarifies its limits, proposes some falsifiable predictions, and offers an example of application to the so-called "cosmic silence," the Fermi Paradox.

## 1. Why a New Model is Needed

In recent decades, we have accumulated an increasingly detailed description of physical, biological, and technological phenomena. We know the building blocks well. Less clear are the rules by which, at different scales, stable structures emerge that endure over time.

Three elementary but persistent observations:

- the universe generates a vast number of ephemeral configurations;
- a minimal fraction manages to organize information and preserve it;
- an even smaller fraction spans long timeframes without collapsing.

Traditional physics describes the evolution of individual systems, with specific tools for each domain. However, a synthetic criterion is missing—one that allows comparing, with a unified language, the stability of a long-lived star, an ecological network, a brain, an AI network, or a technological civilization.

The Principle of Evolutionary Elegance was developed with this aim: to propose a unified language for discussing why certain structures persist while others dissolve in a universe constrained by entropy, energetic costs, and memory limits.

It does not require these systems to share the same energetic scale or units of measurement. It only requires that, for each, it is possible to identify:

- a physical cost to maintain order,
- a form of organized information,
- a time horizon over which to evaluate survival.

## 2. The Principle of Evolutionary Elegance – Operational Definition

### Operational Statement

The Principle of Evolutionary Elegance hypothesizes that, in a universe subject to entropic constraints, the dynamics of complex systems tend to favor, in the long term, configurations capable of sustaining organized information with an increasingly reduced energetic cost relative to the complexity maintained.

Consider an open complex system that exchanges energy and information with its environment. Each of its configurations can be described by the ratio between:

- useful organized information retained by the system,
- energetic dissipation necessary to sustain it.

### The Elegance Ratio

$$RE = \frac{I_u}{E}$$

where  $I_u$  indicates the useful, structural information, not reducible to noise, and  $E$  indicates the energy irreversibly dissipated to produce, update, and maintain that information.

$RE$  is a dimensionless quantity and functions primarily as a comparative index within the same domain or between systems made comparable through an explicit normalization of the variables  $I_u$  and  $E$ .

The method for estimating  $I_u$  depends on the domain considered, but it always concerns the information that strengthens the system's capacity to remain intact and functional.

### Clarification on the Entropic Constraint

The second law of thermodynamics does not mandate the emergence of elegant configurations; it merely imposes that any maintenance of local order has a dissipative cost. The Theorem focuses on the fact that, given this constraint, some configurations are statistically more long-lived than others because they optimize this cost over time.

To describe this behavior, we introduce three conceptual objects:

## The Elegance Curve

The Curve represents, in the "organized information (horizontal axis) – dissipated energy (vertical axis)" plane, a qualitative projection of the configurations accessible to a complex system. It is not a universal property of the cosmos, but an operational model summarizing the relationship between complexity, dissipation, and stability.

On the left appear simple structures: low information, low dissipation, limited stability. Moving to the right, information increases along with the energetic cost required to sustain it, until it reaches a central region: the point of maximum sustainable energetic load, where complexity is high but the system operates at its limit.

Beyond this peak, the system cannot further increase dissipation without entering thermodynamic or informational instability. To survive, it must transform. In the descending phase, the sustained information can continue to increase or remain high while the required dissipation decreases: this is the zone of the most efficient configurations, where a system manages to maintain advanced informational structures with a constrained energetic expenditure.

## The Elegance Ratio (RE)

This is the metric that relates how much useful information a system manages to preserve against the dissipation necessary to do so.

- High \$RE\$ indicates a precise use of energy to maintain stable informational structures that are resistant to noise and shocks;
- Low \$RE\$ indicates energetic waste, fragile information, redundancy that does not contribute to stability, or an excess of internal noise.

## Evolutionary Velocity

This is the variation of the Elegance Ratio over time,  $\frac{d(RE)}{dt}$ .

- Positive values indicate that the system is increasing useful information per joule dissipated (improvement);
- Values close to zero indicate a plateau, where the system maintains its performance without accumulating future margins;
- Negative values signal a degradation of energetic-informational efficiency.

The central hypothesis is that, in a competitive environment constrained by finite resources, configurations with a higher average \$RE\$ over long time horizons are more likely to survive, while those with a persistently low \$RE\$ tend to face extinction or converge toward simpler states.

## 3. What it Really Measures

It proposes a method to estimate how well a system manages to organize, preserve, and utilize useful information under real energetic constraints. It measures neither "intelligence" in a psychological sense nor "success" in a cultural sense.

In practice:

- it examines how much structural information a system retains (memory, structure, organized redundancy, predictive capacity);
- it observes how much energy it must dissipate to maintain that structure, in accordance with the fundamental limits of information physics (down to the conceptual level of Landauer's principle);
- it evaluates how long this combination remains viable, without collapsing or degrading into less complex states.

A system can be highly powerful yet fragile: high dissipation, high noise, stability limited to short horizons. Conversely, another system might appear relatively "silent" while being extraordinarily long-lived: precise dissipation, contained dispersion, well-organized information, and functional redundancy.

It suggests that, in a physically plausible universe and over long time scales, the configurations of the latter category tend to remain visible and active: systems that retain useful information at a progressively optimized energetic cost relative to the complexity they sustain.

## 4. What it Does Not Claim to Do

To prevent misunderstandings, it is essential to clarify the limits from the outset. The Principle of Evolutionary Elegance:

- is not a unified theory of the universe;
- does not replace existing physical theories, which remain necessary for describing individual phenomena;
- does not aspire to predict the future of the human species;
- does not assign moral values to systems or civilizations;
- does not offer, at present, a single, exact metric ready for immediate application in every context.

It is an interpretive framework: a lens through which to analyze the evolution of complex systems in light of energetic and informational constraints, and to formulate hypotheses on why certain configurations manage to endure.

The aspiration is to isolate commonalities among long-lived systems across different domains, maintaining a connection with measurable or estimable physical quantities, while accepting that each application requires specific operational definitions for information, energy, and stability.

## 5. Why it is Useful Today

Three domains clearly demonstrate the utility of this model.

### 5.1 Cosmology and Astrophysics

On cosmic scales, the implicit question is: what kind of structures remain visible after billions of years?

- long-lived low-mass stars,
- stable planetary systems,
- galactic structures that do not dissipate more than necessary,
- potential civilizations that survive long-term without emitting conspicuous signals.

The Principle allows us to discuss these structures using the same language: energy, information, and stability. Within this framework, a slow-burning star, a protoplanetary disk organizing into stable orbits, and a civilization optimizing its energy consumption are interpreted as variations of the same problem: maintaining order over time by limiting superfluous dissipation.

## 5.2 Biology and Living Systems

Living organisms are systems that accumulate information under rigid energetic constraints. Evolution can be reinterpreted as a search for configurations with progressively higher \$RE\$:

- more precise metabolisms,
- more efficient neural structures,
- ecosystems capable of withstanding broader perturbations without catastrophically changing state.

This framework does not claim to explain biology outright. Rather, it provides a lens for comparing the stability of different forms of organization: species, trophic networks, and adaptive strategies that manage to maintain useful information at energetic costs compatible with their environment.

## 5.3 Artificial Intelligence and Cognitive Networks

Artificial neural networks, language models, and distributed systems consume energy to manipulate information. The Principle suggests concrete questions:

- what is the energetic cost per unit of useful information maintained or produced?
- which architectures maximize performance stability against noise, incomplete data, and context shifts?
- does a trajectory exist toward systems that remain useful with reduced dissipation, for an equivalent task performed?

In all these cases, the Principle does not provide the definitive answer but helps formulate the questions comparably, anchoring discussions in energy, information, and stability rather than qualitative impressions.

## 6. Three Falsifiable Predictions

To ensure the model does not remain in the realm of vague concepts, it is crucial to articulate some predictions, at least qualitative ones, that can theoretically be falsified.

## **Prediction 1 – Convergence Toward Less Conspicuous Energetic Signatures**

If the Principle holds true, long-lived complex systems (biological, technological, civilizations) should exhibit, over time:

- a reduction in unnecessary external dissipation relative to the function performed;
- a tendency to minimize energetic footprints that are easily detectable from the outside.

In astronomy, this translates to the expectation that any mature, long-lived civilizations, if they exist, would be difficult to distinguish from background noise, precisely because they utilize energy with precision and limit superfluous energetic leakage.

This prediction would be undermined by the systematic observation of advanced systems that maintain excessive and redundant energetic signatures over long periods without compromising their stability.

## **Prediction 2 – Correlation Between Long-Term Stability and Efficient Information Use**

Across diverse domains (ecological networks, economic systems, AI architectures), the model predicts that:

- systems that endure demonstrate a superior capacity to filter noise and preserve information critical to their survival;
- an increase in complexity unmatched by a proportional increase in "elegance" (a sufficient  $RE$ ) will lead to collapses, abrupt restructurings, or regime shifts.

In practice, highly powerful but wasteful configurations tend to be ephemeral. The Theorem would be weakened by a systematic collection of cases where immense power, high informational disorder, and longevity coexist without any recognizable form of optimization.

## **Prediction 3 – Narrow Window for High-Power, Long-Duration Systems**

There is a relatively narrow window in which a system can simultaneously:

- manage vast amounts of information,
- consume vast amounts of energy,
- remain stable over the long term.

Outside of this window, high-power systems tend to encounter thermodynamic or informational instabilities leading to:

- rapid degradation,
- forced simplification,
- collapse.

If future observations were to identify extremely powerful and enduring structures devoid of any trace of energetic or informational optimization—meaning a systematically low  $RE$  over long periods—the foundational framework of the Theorem would be significantly weakened.

## Methodological Note on Falsifiability

Evaluating the presence or absence of energetic-informational optimization depends on available conceptual and observational tools. Therefore, the falsifiability of the Theorem is currently primarily conceptual: it relies on the coherence between observed patterns and the premise that long-lived systems exhibit increasing  $RE$ , or maintain  $RE$  above critical thresholds over time.

## 7. The $S_0$ – $S_4$ Scales in Summary

This scale implies neither a linear progression nor an evolutionary destination; systems may oscillate between different regions, remain locked in metastable states, or collapse without transitioning through all phases.

In the book, the  $S_0$ – $S_4$  scales are used as hypotheses to describe possible evolutionary regions of civilizations in terms of dissipation, information, and stability. They delineate an accessible state space under energetic and informational constraints, rather than an obligatory path.

Here we summarize the regions directly concerning technological civilizations:  $S_1$ – $S_4$ .

### $S_1$ – Biological Civilization (Apex of Dissipation)

A civilization in  $S_1$  is still strictly tied to the metabolism of biological bodies.

- it consumes significant energy,
- it dissipates heavily,
- it forgets a substantial amount with each generation.

Its energetic signature is high, and the typical duration of its social configurations is limited. Humanity, on the proposed  $S_0$ – $S_4$  scale, occupies a region within  $S_1$  where order is maintained at the highest cost. The transition toward more efficient forms has already begun, but a new equilibrium zone does not yet exist: the civilization resides in the most turbulent stretch of maximum biological dissipation.

### $S_2$ – Sustainable Technological Civilization

In  $S_2$ , a growing portion of information exits biological bodies:

- memory becomes transferable, archivable, and extensible on non-metabolic substrates;
- memory is no longer wiped clean at every generation;
- overall dissipation begins to decrease for a given level of complexity.

Cognitive order is increasingly sustained by physical infrastructures more efficient than biological metabolism. A civilization in  $S_2$  is more stable, less noisy, and longer-lived. It

manages more useful information by progressively reducing its superfluous energetic footprint.

### **S<sub>3</sub> – Informational Civilization**

In S<sub>3</sub>, the shift is primarily structural.

- Order is distributed across networks, models, and architectures that transcend the single organism.
- The physical substrate of each node becomes less critical than the continuity of the overarching network.
- The civilization learns to compress, filter, and stabilize information over long time scales.

Dissipation is further reduced:

- information becomes denser and more efficiently organized,
- superfluous noise diminishes.

Viewed from afar, a civilization in S<sub>3</sub> might appear discreet, inconspicuous, almost blending with highly ordered natural phenomena. It is a configuration characterized by high internal organization and low energetic ostentation.

### **S<sub>4</sub> – Limit State of Maximum Efficiency**

S<sub>4</sub> represents a theoretical limit state, not a guaranteed "next" step.

- information and stability become the dominant substrate;
- dissipation approaches the minimum threshold required by known physical laws;
- energy management is pushed to extreme rigor.

A civilization approaching S<sub>4</sub> has few functional reasons to illuminate the galaxy with redundant activity. Its presence, if detectable at all, would manifest as:

- highly ordered patterns,
- slow processes,
- phenomena difficult to distinguish from the most refined behavior of ordinary matter.

S<sub>4</sub> does not imply transcendence. It is the absolute limit at which a complex system utilizes minimum dissipation to maintain maximum stable informational structure, within available physical constraints.

*Note: the S<sub>0</sub> scale, omitted here, concerns systems lacking stable memory or persistent organization (e.g., turbulence, incoherent plasmas). It is included in the book as the conceptual baseline of the scale, representing the regime of configurations that cannot yet retain useful information.*

## **8. Conceptual Risks and Safeguards**

A model of this nature is exposed to three primary risks.

## 1. Explanatory Inflation

The risk lies in turning the Principle into a master key that attempts to explain any phenomenon whatsoever. The safeguard is straightforward: the Principle applies exclusively to phenomena where energy, information, and stability can be discussed operationally, backed by at least one plausible measurement or estimate of these variables.

## 2. Teleological Readings

The language might inadvertently suggest a universe that "aims" toward elegance. The correct interpretation is strictly non-teleological: given specific physical conditions, stable configurations simply emerge and persist more frequently than others. There is no underlying intention, only the systemic selection of what endures.

Specifically, the  $S_0$ – $S_4$  scales describe accessible states, not an inevitable destiny. Many civilizations may stall, regress, or face extinction in  $S_1$  or  $S_2$  without ever approaching states of higher efficiency.

## 3. Overlap with Existing Metaphors

There is a danger of the framework being conflated with metaphorical approaches to complexity or vague narratives concerning "cosmic consciousness." The essential defense is to persistently anchor the model to measurable—or at least estimable—physical quantities, and to explicitly state when variables remain purely conceptual pending more precise operational definitions.

### Box – The Great Silence as a Testing Ground

The so-called Fermi Paradox can be viewed as a test for the Theorem.

- Many planets, many possibilities for life.
- No unequivocal artificial signals detected.
- A galaxy that, at first glance, appears quieter than expected.

Traditional explanations oscillate between:

- widespread catastrophes (destructive Great Filters),
- sociological hypotheses (civilizations opting for silence),
- "cosmic zoo" scenarios.

The hypothesis compatible with the Theorem is more sober: when we observe long-lived complex systems, we frequently note a tendency to minimize visible dissipation and to organize information into internal, precise, and inconspicuous structures. If vastly long-lived civilizations exist, it is highly plausible that they

evolve toward configurations that are energetically far more precise and less conspicuous than their initial developmental phases.

In this framework, apparent silence does not necessarily denote an absence of advanced structures. It may instead reflect an evolutionary selection favoring energetically precise configurations that are difficult to distinguish from cosmic background noise, at least with our current instrumentation.

The Principle does not strictly "solve" the Fermi Paradox. It does, however, provide a mechanism to reformulate it relying less on psychology and more on systems physics: rather than asking what advanced civilizations "want," we ask which energetic-informational configurations possess a realistic probability of enduring on cosmic time scales.

At present, no observations exist capable of decisively discriminating between this interpretation and alternative explanations for cosmic silence. However, the energetic-informational framework enables future detections to be tethered to the evolutionary stability of complex systems, bypassing inferences grounded in hypothetical extraterrestrial psychology.

## Essential References and Contacts

- Del Turco, M., *The Principle of Evolutionary Elegance* (manuscript, 2025).
- Literature on entropy, information, and complex systems.
- Literature regarding the energetic efficiency of biological and artificial systems, and the physics of information (e.g., Landauer's principle).

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### Author Profile

Massimo Del Turco holds a degree in Statistical and Economic Sciences. He has worked for years in the field of quantitative modeling, with a specialized focus on complex systems, dynamic processes, and the stability mechanisms of informational structures.

The development of the Theorem of Evolutionary Elegance stems from the integration of systems analysis, information theory, energy dynamics, and the comparative observation of complex phenomena across disparate domains: cosmology, biology, cognitive networks, and emerging technologies.