THE THEOREM OF EVOLUTIONARY ELEGANCE
Energy, information and stability in the dynamics of complex systems

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Abstract

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

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

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

By "organised information" we mean the share of non-random structure that contributes to the stability of the system: memory, repeatable patterns, the capacity to filter noise and to respond to stimuli in a non-trivial way. The way this is measured changes from one domain to another (stellar physics, biology, AI networks), yet the selective logic remains the same: what survives is what manages to maintain effective order at a finite energetic cost.

The Theorem introduces tools such as the Elegance Curve and the Elegance Ratio to represent this relationship in an operational way. The goal is not to predict individual events, but to provide criteria for distinguishing, within a chaotic flow, those configurations that have a higher probability of persisting from those that are more likely to dissolve.

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

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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. The rules according to which, on different scales, stable structures capable of lasting in time emerge are less clear.

Three simple yet stubborn observations:

1. the universe produces a huge number of short-lived configurations;
2. a minimal subset manages to organise information and retain it;
3. an even smaller fraction crosses long time spans without collapsing.

Traditional physics describes the evolution of individual systems, with tools that are specific to each domain. What is missing is a synthetic criterion that allows us to compare, using the same language, the stability of a long-lived star, an ecological network, a brain, an AI network or a technological civilisation.

The Evolutionary Elegance Theorem is proposed with this purpose: to provide a unified language for discussing why certain structures remain standing and others dissolve, in a universe bound by entropy, energetic costs and memory limits.

The Theorem does not require these systems to share the same energy scale or the same units of measure. It requires only that, for each system, it is possible to identify:

- a physical cost for maintaining order,
- some form of organised information,
- a time horizon over which to assess its survival.

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2. The Evolutionary Elegance Theorem – operational definition

Operational statement
The Evolutionary Elegance Theorem states that, in a universe subject to entropic constraints, the long-term dynamics of complex systems tends to favour those configurations that are able to sustain organised information at an increasingly reduced energetic cost relative to the complexity they maintain.

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

- organised, useful information retained by the system,
- energetic dissipation required to sustain it.

We define in compact form the **Elegance Ratio**:

$$ER = Iu / E$$

where IuI_uIu is the amount of useful, structural and non-random information that contributes to the stability of the system, and EEE is the energy dissipated irreversibly in order to produce, update and maintain that information. The way IuI_uIu is estimated depends on the domain under consideration, but in every case it concerns information that increases the capacity of the system to remain intact and functional.

In this framework:

- configurations that maintain a favourable ratio, that is, they manage to retain organised information with a relatively reduced or decreasing dissipation compared to the complexity they support, show a higher probability of persisting over time;
- configurations that maintain an unfavourable ratio, that is, they require high or increasing dissipation to sustain their informational structure, tend to enter instability, simplify or collapse.

The Evolutionary Elegance Theorem proposes that, in a universe constrained by entropy, the long-term dynamics of complex systems favours those configurations that reduce the energetic cost required to sustain organised information, within the physical limits of the underlying substrate.

To describe this behaviour we introduce three conceptual objects:

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

On the left we find simple structures: little information, low dissipation, limited stability. Moving to the right, information increases together with the energetic cost required to sustain it, until we reach a central region: the point of maximum sustainable energetic load, where complexity is high and the system operates at the limit.

Beyond this peak, the system cannot further increase dissipation without entering thermodynamic or informational instability. To survive, it must transform. On the descending part, sustained information can continue to increase or remain high while the required dissipation decreases: this is the region of the most efficient configurations, in which a system manages to maintain high informational structures with a contained energetic expenditure.

• Elegance Ratio (ER)
This is the quantity that relates how much useful information a system manages to retain to the dissipation required to do so.

- A high ER indicates precise use of energy to maintain stable informational structures that are resistant to noise and shocks;
- a low ER indicates energetic waste, fragile information, redundancy that does not contribute to stability, or excessive internal noise.

• Evolutionary velocity
This is the rate of change of the Elegance Ratio over time, d(ER)/dt

- Positive values indicate that the system is increasing useful information per joule dissipated (improvement);
- values close to zero indicate a plateau, in which the system maintains its performance without building additional margins for the future;
- negative values indicate degradation of energetic–informational efficiency.

The central hypothesis is that, in a competitive environment with finite resources, configurations with a higher average ER on long time horizons have a greater probability of surviving, whereas those with persistently low ER tend to become extinct or converge towards simpler states.

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3. What the Theorem actually measures

The Theorem does not measure "intelligence" in a psychological sense, nor "success" in a cultural sense. It proposes a way to estimate how effectively a system manages to organise, retain and use useful information under real energetic constraints.

In practice, it:

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

A system can be highly powerful and at the same time fragile: high dissipation, high noise, stability confined to short horizons. Another system can appear relatively "quiet" and at the same time extraordinarily long-lived: precise dissipation, limited dispersion, well-organised information and functional redundancy.

The Theorem suggests that, in a physically plausible universe, on long time scales the configurations that remain visible and active tend to be those of the second category: systems that retain useful information at an energetic cost that is progressively optimised with respect to the complexity they sustain.

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4. What the Theorem does not claim to do

To avoid confusion, it is essential to clarify the limits from the outset. The Evolutionary Elegance Theorem:

- is not a unified theory of the universe;
- does not replace existing physical theories, which remain necessary to describe individual phenomena;
- does not aim to predict the future of the human species;
- does not assign moral value to systems or civilisations;
- does not currently provide a single exact metric ready for immediate use in every context.

It is a reading framework: a way to interpret the evolution of complex systems in light of energetic and informational constraints, and to formulate hypotheses about why some configurations manage to persist.

The aim is to isolate what long-lived systems in different domains have in common, keeping the connection with physical quantities that can be measured or at least estimated, and accepting that every application requires specific operational definitions of information, energy and stability.

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5. Why this model is useful today

Three fields clearly illustrate the usefulness of this model.

5.1 Cosmology and astrophysics

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

- long-lived low-mass stars,
- stable planetary systems,
- galactic structures that do not dissipate more than required,
- any civilisations that manage to survive for long without conspicuous signals.

The Theorem makes it possible to discuss these structures with the same language: energy, information, stability. In this framework, a slowly burning star, a protoplanetary disc that organises itself into stable orbits and a civilisation that optimises its energetic consumption can be read as variants of the same problem: maintaining order over time while 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 ER:

- more precise metabolisms,
- more efficient nervous structures,
- ecosystems that withstand broader perturbations without undergoing catastrophic state changes.

This picture does not claim to explain biology. It provides a lens to compare the stability of different forms of organisation: species, trophic networks, 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 Theorem suggests concrete questions:

- what is the energetic cost per unit of useful information maintained or produced?
- which architectures maximise the stability of performance in the presence of noise, incomplete data and changing contexts?
- is there a trajectory towards systems that remain useful with reduced dissipation, for the same task?

In all these cases, the Theorem does not provide the answer, but it helps to formulate the questions in a comparable way, anchoring the discussion to energy, information and stability instead of to qualitative impressions.

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6. Three falsifiable predictions

To prevent the model from remaining in the realm of vague ideas, it is essential to express some predictions – at least qualitative – that can in principle be refuted.

Prediction 1 – Convergence towards less conspicuous energetic signatures
If the Theorem is valid, long-lived complex systems (biological, technological, civilisations) should exhibit, over time:

- a reduction in external dissipation that is not required for the function they perform;

- a tendency to minimise energetic footprints that are easily detectable from the outside.

In astronomy, this translates into the expectation that any mature civilisations – if they exist and if they are long-lived – will be difficult to distinguish from the background, precisely because they use energy with precision and limit superfluous energetic leakage.

This prediction would be weakened by systematic observation of advanced systems that maintain, over long periods, excessive and redundant energetic signatures relative to their stability.

Prediction 2 – Correlation between long-term stability and efficient use of information
In different domains (ecological networks, economic systems, AI architectures), the model predicts that:

- systems that endure display a better capacity to filter noise and retain information that is relevant to their survival;
- increases in complexity that are not accompanied by an increase in "elegance" (sufficient ER) lead to collapses, abrupt restructurings or regime shifts.

In practical terms, configurations that are very powerful yet wasteful tend to be short-lived. A systematic collection of cases where high power, high informational disorder and long duration coexist without any recognisable form of optimisation would weaken the Theorem.

Prediction 3 – Narrow window for high-power, long-duration systems
There is a relatively narrow window in which a system can:

- manage large amounts of information,
- use large amounts of energy,
- remain stable for a long time.

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

- rapid degradation,
- forced simplification,
- collapse.

If, in the future, extremely powerful and long-lived structures were observed that show no trace of energetic or informational optimisation – that is, systems with systematically low ER over long periods – the structure of the Theorem would be strongly weakened.

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7. The S_0–S_4 scales in summary

In the book the S_0–S_4 scales are used as a hypothesis to describe possible evolutionary regions for civilisations in terms of dissipation, information and stability. They do not describe an obligatory path, but a space of states accessible under energetic and informational constraints.

Here we summarise the regions that directly concern technological civilisations: S_1–S_4.

S_1 – Biological civilisation (peak dissipation)
A civilisation in S_1 is still tightly bound to the metabolism of biological bodies.

- it consumes a great deal of energy,
- it dissipates heavily,
- it forgets a great deal at each generation.

Its energetic signature is high and the typical lifetime of its social configurations is limited. Humanity, on the S_0–S_4 scale proposed in the book, occupies a region inside S_1, that in which order is maintained at the highest cost. The transition towards more efficient forms has already begun, yet no new region of equilibrium exists: the civilisation lives in the most turbulent stretch of maximum biological dissipation.

S_2 – Technological sustainable civilisation
In S_2 a growing share of information exits biological bodies:

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

Cognitive order is sustained increasingly by physical infrastructures that are more efficient than metabolism. A civilisation in S_2:

- is more stable,
- is less noisy,
- is longer-lived,

and manages more useful information while progressively reducing its superfluous energetic footprint.

S_3 – Informational civilisation
In S_3 the change is above all structural.

- Order is distributed across networks, models and architectures that go beyond the individual organism.
- The physical support of each node becomes less critical than the continuity of the overall network.
- The civilisation learns to compress, filter and stabilise information over long scales.

Dissipation decreases further:

- information becomes denser and better organised,
- superfluous noise shrinks.

Seen from afar, a civilisation in S_3 may appear discreet, unobtrusive, almost indistinguishable from very ordered natural phenomena. It is a configuration with high internal organisation and low energetic ostentation.

S_4 – Limiting state of maximum efficiency
S_4 represents a theoretical limiting state, not a guaranteed "next step".

- information and stability become the dominant substrate;
- dissipation approaches the minimum required by known physical laws;
- energy management is enforced with extreme rigour.

A civilisation approaching S_4 has very few functional reasons to light up the galaxy with redundant activity. Its presence would manifest itself, if detectable at all, as:

- ordered patterns,
- slow dynamics,
- signals that are hard to distinguish from the most refined behaviour of ordinary matter.

S_4 does not imply transcendence. It is the limit in which a complex system uses the minimum dissipation to maintain the maximum amount of stable informational structure, within the physical constraints available to it.

Note: the S_0 scale, not discussed here, concerns systems devoid of stable memory or persistent organisation (turbulence, incoherent plasmas). It is included in the book as the conceptual base of the scale and represents the regime of configurations that still fail to retain useful information.

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8. Conceptual risks and safeguards

A model of this kind is exposed to three main risks.

1. Explanatory inflation
There is a risk of turning the Theorem into a key that claims to account for any phenomenon. The safeguard is straightforward: the Theorem applies only to phenomena in which energy, information and stability can be discussed in an operational way, with at least a plausible measure or estimate of these quantities.

2. Teleological readings
The language might suggest a universe that *aims* at elegance. The correct interpretation is different: given certain physical conditions, stable configurations occur more often than others. There is no intention, only selection of what endures.

In particular, the S_0–S_4 scales describe possible states, not a destiny. Many civilisations may stop, regress or disappear in S_1 or S_2 without ever approaching more efficient states.

3. Overlap with existing metaphors
There is a risk of being confused with metaphorical approaches to complexity or with vague narratives about a "conscious cosmos". The essential safeguard is to maintain the link with physical quantities that can be measured, or at least estimated, and to state clearly where the quantities remain conceptual only, pending more precise operational definitions.

Box – The Great Silence as a test case

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

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

Traditional explanations oscillate between:

- widespread catastrophes (destructive Great Filters),
- sociological hypotheses (civilisations that choose to remain silent),
- “cosmic zoo” scenarios.

The hypothesis compatible with the Theorem is more restrained: when we observe long-lived complex systems, we often see a tendency to reduce visible dissipation and to organise information into internal, precise and unobtrusive structures. If very long-lived civilisations exist, it is plausible that they evolve towards energetically more precise and less conspicuous configurations than their initial phases.

In this framework, the apparent silence does not necessarily indicate an absence of advanced structures. It may reflect selection in favour of energetically precise configurations that are hard to distinguish from the background, at least with current instruments.

The Theorem does not “solve” the Fermi Paradox in a strict sense. It offers a way to reframe it with less psychology and more physics of systems: instead of asking what advanced civilisations “want”, we ask which energetic–informational configurations have a real chance of lasting on cosmic time scales.

Essential references and contacts

- Del Turco, M., *The Evolutionary Elegance Theorem* (manuscript, 2025).
- Literature on entropy, information and complex systems.
- Work on energetic efficiency in biological and artificial systems, and on the physics of information (for example 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 quantitative modelling, with a focus on complex systems, dynamic processes and the stability of informational structures.

The work on the Evolutionary Elegance Theorem arises from the integration of systems analysis, information theory, energetic dynamics and comparative observation of complex phenomena in different domains: cosmology, biology, cognitive networks and emerging technologies.