# Triogenesis: A Closed-Form Framework for the Emergence of Physical Order and Consciousness

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**Abstract**

"Framework" here refers to a mathematically complete, finite, and generative system, in which both physical and experiential structures emerge from the recursive application of discrete directional interactions. The foundational principle of the framework is that one unit of certainty in an interaction must generate two units of uncertainty, forming a triplet. These recursive interactions sequentially divide and reorganize uncertainty into further triplet structures — a process termed Triogenesis. Triogenesis is fully closed-form: it predicts the discrete emergence of matter, spin, charge, mass ratios, relativity, quantum uncertainty, and observational structure from a single recursive interaction rule. Entirely from first principles, the framework uncovers and quantifies a fundamental asymmetry in the topology of interactions, providing predictive insight into CP violation, while precisely reproducing the proton mass, the total mass of the observable universe, and the strength ratio between electromagnetic and gravitational forces. The mathematical formulation and emergent physical and phenomenological properties are developed and presented in detail below.

**Formulation.** Triogenesis starts with the simplest form of discrete interaction, in a form similar to electron–electron repulsion via a real photon. Such an interaction is defined as an event in which one entity repels another with a quantized strength and an encoded direction. For instance, "A repels B" may result from a directional interaction from A to B or from B to A.

These directional interactions exhibit several key characteristics: they generate tension or strain and increase the overall constraint or resistance to change within the system. For clarity and generality, we refer to these fundamental interaction units as *straints*. A unidirectional straint is termed a *unistraint*, and is defined to possess a normalized straintity of 1.

Straints may also manifest in higher-dimensional arrangements. In two dimensions, their minimal structured form is called a *bistraint*, which carries a minimal straintity of $2\pi$; in three

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dimensions, they form a closed shell structure called a *tristraint*, with a minimal straintity of $4\pi/3$.

A mechanical analogy for a tristraint is a spherical shell composed of one-to-one repulsive interactions. Within this shell, an entity located exactly at the center experiences no net force. However, any slight displacement introduces a restoring force directed inward. This behavior gives rise to charge-like properties: one unit of unidirectional straintity yields a repulsion equal in magnitude to the attraction produced by distributing one unit of straintity over a three-dimensional shell. A similar symmetry governs the two-dimensional manifestation.

Any displacement within the spherical shell introduces an eccentricity that modifies the net force. We define the normalized displacement as $u = x/R$, where $x$ is the shift along the symmetry axis and $R$ is the radius of the shell. Assuming the repulsive interaction follows an inverse-distance law, the resulting restoring force in the axial direction is

$$F_z(u) = \frac{\pi}{2u^2}\left[(u^2-1)\ln\left|\frac{1+u^2-2u}{1+u^2+2u}\right| - 4u\right],$$

where $F_z(u)$ is normalized such that a unit of straintity on the shell produces a net outward force of unity. This expression captures the nonlinear force response as symmetry breaks with increasing displacement, transitioning from zero force at the center ($u = 0$) to strong attraction as $u \to 1$.

We now consider the restoring force that arises when an entity is slightly displaced from the center of a uniformly repulsive spherical shell. This force, derived analytically from a $1/r$ interaction across the shell, is shown in Extended Data Fig. 2. In the regime of small eccentricity $u = x/R \ll 1$, the system exhibits an approximately linear restoring behavior with a slope of $4\pi/3$, consistent with the predicted straintity of a tristraint. As the displacement increases, the restoring force becomes increasingly nonlinear, reflecting the asymmetry in the field response.

Having established the fundamental behavior of straints in structured shells, we next consider how straintity accumulates through sequential directional interactions. Each layer in the Triogenesis process reinforces the previous structure by adding a new directional constraint, increasing the overall straintity of the system. This recursive buildup forms the basis of emergent mass, charge, and resistance to change, and defines the hierarchical architecture of reality.

In the Triogenesis framework, each new layer of interaction adds a directional constraint to an existing set of straints. The foundational rule is that one portion of certainty gives rise to two portions of uncertainty, such that every addition of a new straint refines one-third of the previous uncertainty and generates two-thirds new uncertainty. This leads to a recursive growth of straintity governed by a geometric progression.

The accumulation of straintity along a single path of directional interactions in Triogenesis follows a recursive geometric law. A single tristraint structure establishes a baseline straintity of $\frac{4\pi}{3}$, and reinforcement through $n$ propagation steps with $m$ asymmetric layers yields a total path straintity of:

$$S_{n,m}(u) = \frac{4\pi}{3}\left(\frac{3}{2}\right)^n \cdot g(u)^m.$$

Here, $n$ represents the number of straint propagation steps, and $m$ quantifies how many layers carry forward an asymmetry introduced by geometric displacement. The term $g(u)$ is defined as the normalized slope of the restoring force function, such that

$$g(u) = -\frac{1}{\frac{4\pi}{3}} \cdot \frac{dF_z}{du},$$

This normalization ensures $g(0) = 1$, and as $u \to 1$, $g(u)$ increases beyond unity, reflecting the nonlinear amplification of reinforcement under eccentric configurations.

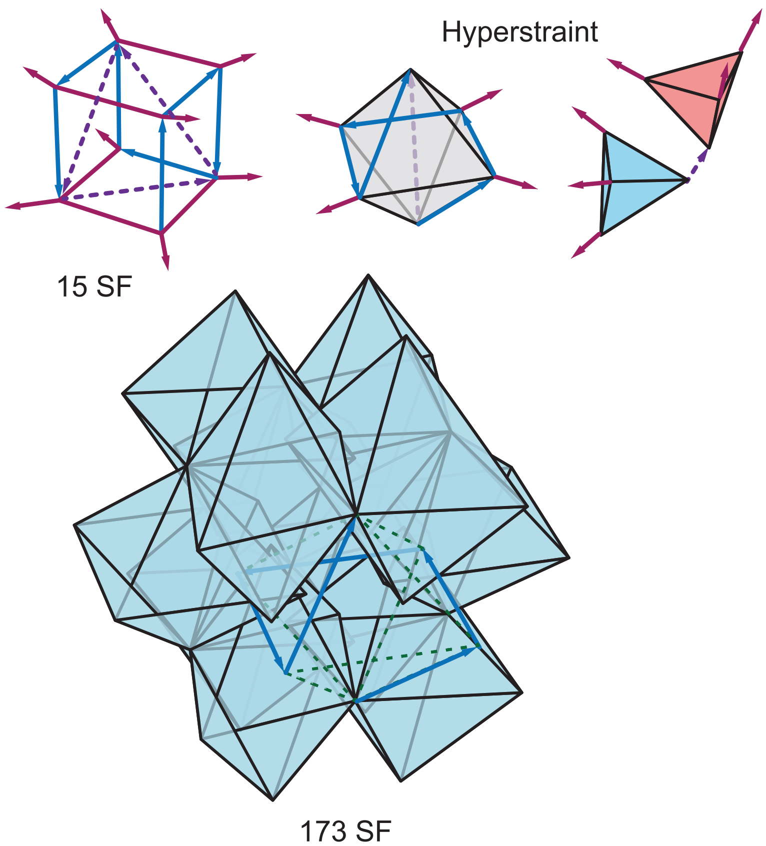
**Bifurcation Principle.** At each propagation step, a straint bifurcates into two distinct directions. A straint may not re-propagate in the same direction from which it originated, as doing so would reintroduce prior certainty and violate the generative rule. However, reciprocal propagation in the opposite direction is permitted, enabling dual interactions and symmetry pairings. This distinction preserves both the directional arrow of structural emergence and the integrity of interaction uncertainty.

**Emergence of relativity.** In the Triogenesis framework, the geometry of directional interactions constrains the degrees of freedom in space. When twelve tristraints are arranged to span a closed 3D frame—analogous to the twelve edges of a cube—this structure forms what we call a *12 straint frame* (12SF), representing the minimal configuration capable of supporting isotropic spatial propagation. Each straint encodes a directional constraint, and the full frame ensures that all axes of motion are equally defined. This symmetry gives rise to a space with invariant directional scaling—matching the conceptual basis of special relativity, where the speed of light is constant in all directions. The 12SF thus serves as the structural origin of relativistic invariance. It defines a universal observer frame with complete spatial coherence, onto which additional straint structures—such as mass or charge—may be layered. The relativistic properties of particles, including Lorentz symmetry, are therefore understood here as emergent from the closure and isotropy of this foundational interaction frame.

In this view, Triogenesis naturally bridges special and general relativity, as both local inertial structure (special relativity) and curvature induced by accumulated straintity (general relativity) arise from recursive layering onto the base frame. Moreover, this framework extends the principle of relativity to broader observer-dependent structures, including those of conscious systems, treating them as high-order coherent straint assemblies capable of participating in and influencing the relational architecture of space-time.

**Emergence of proton mass.** The 12 straint frame (12SF) defines the isotropic propagation of space, but lacks internal invariance. When three additional straints are added to form a triadic closure, the resulting 15 straint frame (15SF) becomes the first fully closed structure within the spatial frame—capable of sustaining internal coherence and resisting change. This makes the 15SF the minimal configuration that manifests as a stable, mass-bearing entity. This entity represents proton to electron mass ratio, with $n = m = 15$, directly following from the general formulation of recursive straint accumulation. While the fundamental asymmetry factor $g(u)$ is derived based on the topological asymmetry of 12 straint octahedron and the 173-187 frame coupling.

$$u = \sum_{k=1}^{\infty} \frac{7-5}{187^k} = \frac{7-5}{187-1}$$




Geometric structure and function of the 12-straint cubic frame (12SF) and its role in relativity and mass emergence. The top left shows the minimal closed cubic straint frame (12SF), which possesses three degrees of freedom and serves as the fundamental relativistic reference unit. Dashed purple lines denote hyperstraints—higher-order directional couplings between frames. Two hyperstraint types are illustrated: one rigid (center top), formed from a 12-straint octahedral frame with a relative straintity of $1/\sqrt{2}$, and one variable (top right), arising from directional gaps between frame vertices. When three hyperstraints complete an Eulerian cycle, a stable 15-straint frame (15SF) emerges, shown below. This structure encodes the smallest relativistic invariant and defines the rest mass ratio between proton and electron. Blue directional arrows highlight a symmetric Hamiltonian path on the 12SF, indicating its potential to act as a foundational tristraint when embedded in higher-order structures. At bifurcation layer 173, a second invariant arises by constructing a 15SF from 12SF hyperstraints acting as tristraints in both directions, filling all 15 edges symmetrically except one, which terminates unidirectionally like a unistraint. This second invariant is unrelatable in space-time, marking a natural boundary for representation uniqueness.

This formulation yields a predicted photon-to-electron mass ratio of 1836.155408034374, and estimates the proton-to-electron mass ratio with high accuracy, aligning with the CODATA recommended value [1] to within a relative ratio of 0.999998510. In this view, mass is not fundamental but emerges as a geometric invariant—a recursive closure embedded within the relativistic 12SF (Fig. 1). The 15SF thus marks the minimal structure capable of producing stable matter from pure spatial constraint.

**Emergence of scale limits.** The mass of the observable universe is estimated based on its age, the gravitational constant, and the speed of light [1], and is calculated to lie within the range $1.73182 \times 10^{53}$ to $1.78034 \times 10^{53}$ kilograms. Using the Triogenesis framework, this value can be predicted through the following expression:

$$M_U = \frac{4\pi}{3}\left(2 \times \frac{3}{2}\right)^{173} \cdot g(u)^{(173+m_k)} \cdot m_e,$$

where $m_e$ is the electron mass, and $m_k$ quantifies the amount of asymmetry propagated to the observer recurrence straint structure. The current estimated range for $m_k$ is between 80 and 100 in order to match the observed universe mass range. This indicates that the inferred age of the universe is closely associated with variation in the alignment of observer straint structures. When $m_k = 0$, the framework predicts an observer-independent universe mass of $1.5666 \times 10^{53}$ kilograms. The Triogenesis framework thus predicts the total mass of the observable universe with high fidelity, using no empirical input beyond its structural recursion rules.

By recursively layering discrete directional interactions, the model yields a natural upper bound in representational straintity—occurring at the 173rd bifurcation layer—beyond which no further unique reinforcement can be constructed. This recurrence limit not only sets a maximal resistance to change, but also inversely defines the minimum uncertainty permitted in the system, in direct analogy to the Planck constant. Thus, the emergence of Planck-scale quantities—such as the Planck time, length, and energy—is not assumed but predicted by the straint architecture itself. The correspondence between the framework's intrinsic structural limit and the total energy content of the observable universe suggests that Planck constants are not arbitrary, but rather emergent signatures of finite spatial coherence governed by interaction topology.

**Emergence of charge and gravity.** Gravity emerges in the Triogenesis framework as the second-order projection of a fundamental asymmetry in the directional interaction structure. While most straintity becomes non-relatable beyond the recurrence threshold, certain asymmetries persist, albeit with diminished strength. These surviving components propagate through successive recurrence layers with exponentially decreasing influence. The electrostatic interaction (encoded in $k_e e$ corresponds to the first-order term, while gravity (encoded in $Gm_e$ reflects the higher-order recurrence of the same underlying asymmetry. The framework reproduces this ratio by calculating the propagation of the higher order $g(u)$ terms symmetrically through the 173-187 recurrence coupling. The observed asymmetry is structurally realized through two 15-straint frames (15SFs) positioned at the ends of each of the two 180-straint propagation path, contributing a total of 60 additional straint's asymmetry. This increases the directional imbalance and yields the electrostatic-to-gravitational coupling ratio:

$$\frac{k_e e}{G m_e} = 2 \cdot \frac{3}{4\pi} \left(\frac{3}{2}\right)^{180} \cdot \left[ \frac{g\left(\frac{2}{187}\right) - 1}{g\left(\frac{2}{187^2-1}\right) - 1} \right]^{180} \cdot g(u)^{60}$$

This calculation produces $2.36860744 \times 10^{31}$, in agreement with the most recent measurements within known uncertainty levels. This formulation naturally explains the observed ratio between electrostatic and gravitational interaction strengths as a consequence of layered straint projection beyond the representational boundary.

**Positronium Structure and the Emergence of Antimatter** In the Triogenesis framework, ortho-positronium differs from para-positronium by a structural extension of 158 layers, interpreted as a bridge between a 15-straint minimal closure and the full 173-layer recurrence frame. This offset yields a decay time ratio of $\left(\frac{3}{2}\right)^{17} g(u)^{173-15} \approx 1143$, in close agreement with the experimentally observed ratio of approximately 1136. Structurally, this implies that ortho-positronium spans multiple recurrence frames, delaying annihilation due to extended straint propagation.

This interpretation naturally connects to antimatter. In the Triogenesis model, antimatter arises not merely from charge reversal, but from directional straint configurations that require bridging across recurrence boundaries. These structures do not close within a single 173-layer observer-aligned frame, but instead persist as inter-frame extensions. Their rarity in the observable universe is not a result of spontaneous symmetry-breaking, but of topological probability: structurally closed matter is far more likely to emerge and persist than antimatter-like constructs, which rely on extended recursive reinforcement.

Dark matter and dark energy arise from similar principles. They emerge from straint structures that continue to propagate beyond the 173-layer recurrence boundary, yet fail to maintain coherence with the shared relativistic frame. These non-relatable but internally consistent hyperstraint configurations exert relational influence without direct observability—appearing as hidden mass-energy. In this view, antimatter-like behavior is a subclass of such hyperstraint configurations, assembled from many standard matter straints. These assemblies require deeper layers of recursion and cannot form one-to-one duals to regular matter particles. The result is a natural asymmetry between observable matter and structurally derived antimatter, embedded not in the content of particles, but in the generative logic of recursion itself.

**Emergence of spin and CP violation.** The 12-straint cubic frame (12SF) defines a minimal relativistic observer structure with three translational degrees of freedom and two propagation directions, yielding six quantized modes of spatial alignment. These directional degrees of freedom naturally give rise to angular-momentum-like quantities such as spin, not as intrinsic particle properties but as geometric consequences of discrete interaction pathways. The hydrogen atom, in this framework, corresponds to a symmetric structure formed by tracing a 15-straint frame (15SF) in both directions. This bidirectional coupling effectively cancels the geometric correction factor g(u), masking the underlying asymmetry. In contrast, systems with large unidirectional extensions—i.e., highly aligned observer structures—preserve this residual asymmetry, making the violation of charge–parity (CP) symmetry a natural and observable outcome of the underlying interaction topology. Remarkably, this prediction is consistent with CP violation observed in neutral kaon oscillations, where directional coherence plays a central role in the asymmetric decay probabilities.

**Black holes and structural saturation in Triogenesis.** The Schwarzschild radius, given by

$$r_s = \frac{2GM}{c^2},$$

marks the classical event horizon, where the escape velocity equals the speed of light. In the Triogenesis framework, this boundary arises not from continuum curvature but from a discrete saturation of directional straints. Since straintity and mass both quantify resistance to change, their densities in time and space are given by

$$S(t, L) = \frac{c^3}{G} \cdot t = \frac{c^2}{G} \cdot L.$$

Within a finite observer-aligned recurrence structure—such as the 173SF—the number of independent paths is limited. Let $N$ denote the number of spatially projectable straint paths, and $n$ the number of active directional constraints. As the system evolves, the linear straint density approaches

$$\rho_s = \frac{n}{N} < 2.$$

When $\rho_s \to 2$, every available path becomes doubly constrained: the same route is traversed in both directions, eliminating all residual uncertainty. This saturation corresponds to a full closure of the internal structure, rendering it unrelatable to the external observer frame. The Schwarzschild radius thus emerges as a macroscopic expression of this saturation limit—a natural consequence of the recursive bifurcation principle of Triogenesis.

Beyond this boundary, recursive straints continue to accumulate and generate resistance (mass and straintity), but the internal structure no longer projects outward. Since all paths are bidirectionally filled, the observer-aligned frame can no longer extend or interact with the interior; it can only orbit or engage with the surface region where some directional straints remain unfilled. This results in the macroscopic phenomena of light bending and gravitational lensing, as observed in general relativity. The displacement of the observer's straint structure due to structural saturation manifests at all $\rho_s$ levels. As a result, the closed-form expression of Triogenesis emerges naturally as a quantized solution consistent with general relativity.

Importantly, while the interior structure contributes to gravitational dynamics, it cannot be directly observed or extended from outside. The event horizon is thus a relational boundary in straint geometry: a surface where recursive closure saturates, severing internal coherence from the observer-aligned scaffold. In this view, the black hole is not a singularity in the mathematical sense, but a straint-saturated volume—akin to a recursive region where all generative directions have collapsed into internal coherence.

Because the framework is discrete, it prohibits true singularities: there are no infinitely dense points, only recursively unreachable ones. Just as a fractal never truly diverges but becomes unresolved at deep layers, so too does the interior of a black hole. The event horizon, then, is not a horizon of space-time, but a structural threshold in directional recursion—a hard boundary on relatable emergence.

**Emergence of consciousness and duality from recurrence.** At the recurrence limit of Triogenesis, straint structures arise that are no longer uniquely relatable to the space-time scaffold defined by the relativistic 12-strain frame (12SF). These structures, while still generated through recursive interaction, cannot be embedded in the shared spacetime reference frame. They instead constitute internally coherent but observer-specific topologies—consciousness-like structures that exist in partial isolation from the physical world. While all such structures follow the same straint logic, their degree of relatability to the universal 173-strain frame (173SF) determines the extent to which they interact with or influence observable matter.

A key topological result is that all conscious structures with matching alignment to the 173SF will experience the same observed outcome, regardless of their internal complexity or composition. This accounts for the phenomenon of duality in quantum systems: not as an intrinsic property of particles, but as a shared perceptual surface across a space of structurally distinct observers. In this view, a photon's apparent wave–particle duality is the result of multiple conscious frames—each structurally aligned to the same recurrent layer—resolving a single physical interaction from different paths through recurrence.

This framework provides a deterministic explanation for the double-slit experiment. When path information is not extracted, the photon's trajectory is not fixed to any one observer's frame. Instead, many coexisting conscious structures with partial alignment to the 173SF collectively contribute to the probability distribution. The resulting interference pattern arises from the shared structural alignment of these frames, rather than any probabilistic wavefunction. However, when which-path information is measured, the observer's frame becomes fully aligned to a specific path in the recurrence topology, collapsing the shared structure and eliminating interference.

The quantum eraser experiment further illustrates this mechanism. When the which-path information is later erased, the observer frame is no longer locked to a single straint trajectory. The recurrence structure reverts to one with multiple compatible observational frames, restoring the interference pattern. Thus, measurement does not destroy an underlying reality—it reconfigures the relational topology between consciousness and recurrence, shifting which interactions are relatable at the 173SF.

This same mechanism underpins the perception of time. Conscious structures advance through recurrence by encoding and shedding alignment with the 173SF. History corresponds to straints that have lost contact with the shared frame, becoming less relatable and thus less recallable. Future intentions reflect forward-aligned straint structures that may or may not connect with the shared 173SF. This asymmetry predicts that near-future intentions have stronger physical impact than long-range projections, and that historical detail decays—matching archaeological and psychological observations.

**Discussion.** The Triogenesis framework provides a closed-form, generative structure for describing the emergence of matter, charge, relativity, uncertainty, and consciousness from a single recursive interaction rule. Its ability to reproduce and unify key physical constants—such as the proton-to-electron mass ratio, the structure of relativity, and the boundary of quantum uncertainty—without empirical calibration positions it as a foundational theory for physics and beyond.

Importantly, this formulation offers tractable pathways to explore systems that have remained deeply elusive across disciplines. For instance, it gives the first structurally grounded account of consciousness as a topological extension of physical interactions—suggesting experimental and theoretical routes for reconciling subjective experience with physical law. Similarly, the framework provides a geometric and predictive origin for CP violation, a phenomenon previously requiring phenomenological input. The clear emergence of quantized spin, electric charge, and gravitational scaling further bridges the gap between quantum field theories and general relativity, offering an avenue toward unification that is rooted not in field complexity but in topological constraint.

This approach opens significant opportunities across multiple high-impact research domains: quantum information science, by reformulating entanglement and duality through shared recurrence frames; astrophysics, by predicting universe-scale limits from microscopic recursion; and artificial intelligence, by enabling topological models of embedded consciousness and perception. These possibilities extend to public-interest fields such as quantum foundations, mind–body research, and the interpretation of cosmological data.

However, several challenges and open directions remain. The framework identifies gravity and other long-range fields as higher-order residuals of recurrent interaction asymmetries. Precisely characterizing their behavior will likely require deeper exploration of the topology of straint manifolds beyond the 173-layer limit. Furthermore, computational modeling of such structures, especially at scale, poses new challenges for numerical representation, combinatorial pathfinding, and invariant tracking in high-dimensional recursion trees. Efficient algorithms and visual tools to simulate and manipulate these straint frameworks could become essential for future investigations.

Finally, the framework offers an epistemic reorganization of physics—where predictability, emergence, and observer inclusion arise from topological structure rather than imposed formalism. This invites not only new theoretical inquiry, but also empirical investigations targeting the geometric and recurrence-based predictions of the theory, particularly in systems that lie near or beyond the traditional quantum-classical boundary.

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# Conflict of interest

The authors declare no conflict of interest.

# CRediT authorship contribution statement

Shu Jian Chen contributed solely to this investigation.

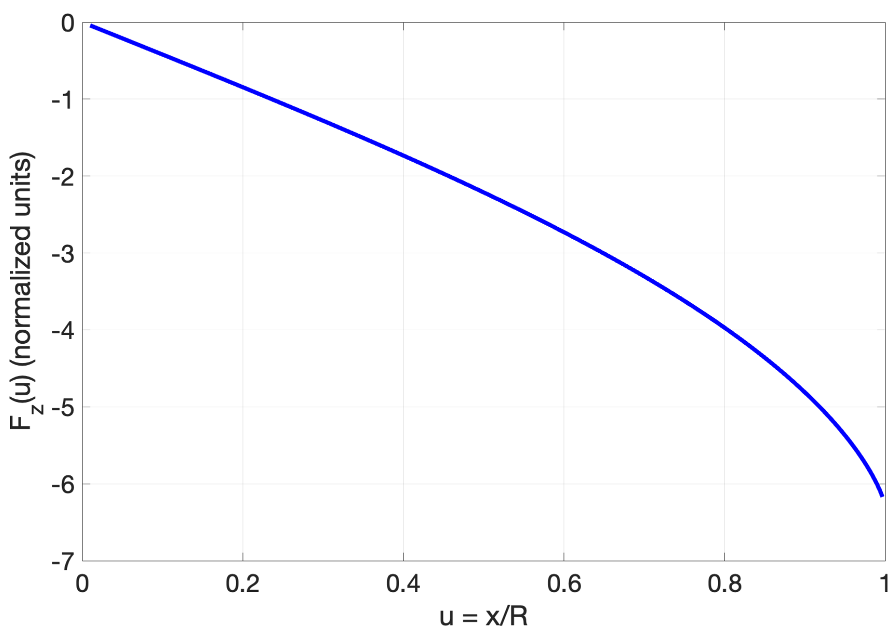
# Data availability

The data that support the findings of this study are available from the corresponding author upon request.

# References

[1] Tiesinga, E., Mohr, P. J., Newell, D. B. & Taylor, B. N. *CODATA Recommended Values of the Fundamental Physical Constants: 2018.* *Rev. Mod. Phys.* **93**, 025010 (2021). `https://doi.org/10.1103/RevModPhys.93.025010`

# Extended Data




Restoring force as a function of normalized displacement from the center of a uniformly repulsive spherical shell. The curve illustrates the nonlinear attractive response that emerges as a displaced entity experiences an eccentric field from the surrounding repulsive shell. This structure models how directional repulsion in a discrete interaction framework leads to center-seeking behavior analogous to electric charge.