Reconciling Particles and Bits: A Closure-Based Interpretation of Matter in the VERSF Framework

Keith Taylor
VERSF Theoretical Physics Program

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For the General Reader

In the VERSF picture, the universe is not built from tiny solid objects moving through empty space. The deepest material microstructure is not a particle but a fold: a minimal committed distinction formed at the boundary where reversible void dynamics become irreversible physical record. Particles are what appear when many such folds lock into a stable, self-sustaining closure. In that sense, particles are not primitive objects but emergent, persistent topologies of fold structure.

Why "fold"? The name is literal: just as folding a sheet of paper produces a crease — a structural boundary in the sheet, not new material — a fold in the VERSF framework is the boundary event produced when a reversible Void distinction becomes an irreversible committed record.

The vortex analogy. In a fluid, individual molecules are constantly moving, yet stable structures such as vortices can appear. A vortex is not a separate object made of different matter — it is a stable pattern of motion in the fluid itself. Water flows through it, but the vortex persists. Particles work similarly: the underlying substrate of the universe continues to evolve, but certain distinguishability patterns form stable closures that maintain their identity while propagating through the reversible background.

The sand analogy. Consider an arrow drawn in sand. The arrow is not made of a different material than the surrounding grains — it is simply a pattern formed by the boundary between disturbed and undisturbed regions. The arrow exists because of the edge separating those two zones; remove the edge and the pattern disappears, even though all the sand remains. Folds play the analogous role in the VERSF framework. A fold is not a separate substance but the minimal boundary separating reversible distinguishability from committed record structure. Particles are then closed patterns of such boundaries — stable configurations of folds that persist within Σ the way an arrow persists in the sand.

The origami analogy. Origami extends this picture from a single boundary to a closed topology. A sheet of paper can be folded into a crane — without adding any new material. What changes is the pattern of folds, and when those folds form a closed, stable configuration, a persistent object appears. Flatten the paper and the crane vanishes; the folds were the object. Particles work the same way in the VERSF framework: when committed fold boundaries organize into a closed, topologically stable configuration within Σ, a particle appears. When that closure dissolves, the particle dissolves with it back into the reversible substrate. Particle stability is therefore geometric — it comes from the topology of the fold configuration, not from any special substance the particle is made of.

The bits-and-image analogy. A digital image on a screen is not made of pixels the way a wall is made of bricks. The image is the stable visible pattern that underlying numbers — organized in a particular way — collectively produce. A particle in the VERSF framework stands in a similar relation to committed distinguishability records, but with one more level: the bits are the informational description; the folds are the physical elementary committed structures those bits describe; and the particle is the emergent stable closure that many folds collectively form. A particle is not one fold any more than a recognizable image is one number in memory.

This is what the paper title means by reconciling particles and bits: the two are not competing descriptions of reality but different levels of the same structure. Bits are the recorded differences underneath. Particles are what those differences look like when they stabilize.

Seen this way, asking what a particle is made of may be asking the wrong question. In the VERSF framework, a particle is not a tiny object built from smaller pieces of matter. Instead it is a stable geometric structure in the universe's commitment boundary — a closed configuration of folds that separates reversible possibility from irreversible physical record. Matter therefore resembles origami more than it resembles a pile of bricks: the substance of the sheet never changes, but the folds create stable structures that behave as distinct objects. Electrons, quarks, and protons are not elementary lumps of material; they are persistent fold patterns in the deeper fabric of distinguishability.

Particles are stable patterns in the universe's record of physical distinctions.

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1. Introduction – The Problem of Particle Ontology

Modern physics describes the universe using two very different conceptual languages. On one hand, the Standard Model of particle physics treats matter as a collection of particles—electrons, quarks, photons, and composite structures such as protons and neutrons. On the other hand, modern theoretical work increasingly suggests that information, entropy, and distinguishability may play a deeper role in the structure of physical law. In the Void Energy–Regulated Space

Framework (VERSF), the most fundamental concept is not matter itself, but the ability of physical states to be distinguished and irreversibly recorded.

This raises a central ontological question: if the universe is fundamentally structured by distinguishability and irreversible record formation, what exactly is a particle? Traditional quantum field theory describes particles as excitations of underlying fields, yet this description does not explain why these excitations appear as stable, localized objects that persist through time.

The goal of this paper is to reconcile these perspectives by proposing a structural interpretation of particles within the VERSF framework. The aim is ontological and structural rather than precision-phenomenological: it proposes what particles are within the VERSF architecture, not a replacement for the successful quantitative machinery of the Standard Model or QCD. The central claim is:

A particle is a stable, localized, transportable closure defect formed from committed folds within the distinguishability graph Σ.

This definition is not merely terminological. It places particles in the same mathematical class as topological defects in condensed matter systems (vortices in superfluids, dislocations in crystals, monopoles in gauge field theories) and connects naturally to the defect structure studied in lattice gauge theory. In VERSF and BCB, folds are the elementary committed physical structures — each carrying one bit of committed distinguishability while admitting four admissible physical orientation states. The committed distinguishability graph Σ is formally defined as $\Sigma = (F, E)$, where $F = \{f_i\}$ is the set of committed folds and E is the set of admissible committed relations among them. "Lattice" here does not mean a rigid spatial crystal but a discrete relational graph of committed fold-level distinctions. Closure defects correspond to topologically nontrivial connected subgraphs whose connectivity cannot be removed by admissible local rewiring operations; particles are higher-order stable topologies of those folds, not primitive point objects. In VERSF, this graph plays the role of the underlying ordered medium, and particles emerge as its stable topological excitations — not as fundamental inputs to the theory.

The closure-defect framework developed here applies primarily to matter particles — fermions and composite baryonic structures. Gauge bosons are treated as a partially distinct ontological class: propagating admissible reconfiguration modes of the fold network that preserve closure topology rather than forming stable closure defects. This distinction is made explicit in §2, §9, and §11.

These defects emerge when reversible distinguishability relations in the Void become irreversibly stabilized through commitment events governed by BCB capacity constraints and TPB rate limits. The fold boundary is the structural interface at which this transition occurs — the surface at which reversible distinguishability relations become irreversibly committed, thereby generating the closure defects that appear as particles.

1a. From Bit to Particle in One Step

The central architecture of VERSF can be stated as a single chain:

Stage	Description
Reversible distinguishability	Physical states in the Void substrate that differ but whose differences are not yet permanently recorded
Commitment at the fold	The fold boundary converts reversible distinguishability relations into irreversible committed records
Fold	The elementary committed physical structure produced at the fold boundary — carrying one bit of committed distinguishability and admitting four admissible physical orientation states
Committed graph Σ	The locally finite directed graph $\Sigma = (F, E)$ whose nodes are committed folds and whose edges are admissible committed relations
Stable closure in Σ	Under BCB capacity constraints, certain fold configurations form topologically stable closed subgraphs
Observed particle	A stable closure defect in Σ: a localized, persistent, transportable fold assembly

This chain has no gaps. Each step follows from the prior one by the admissibility conditions and capacity constraints of the VERSF framework. Particles are not added to the theory — they emerge from it.

Definition. A particle is a stable, localized, transportable closure defect formed from committed folds within $\Sigma = (F, E)$. Formally, it is a connected subgraph $C \subset \Sigma$ satisfying conditions C1 (structural stability), C2 (BCB capacity compatibility), and C3 (transportability under admissible commitment updates). The nodes of C are committed folds $f_i \in F$; the particle is the stable topological organization of those folds, not a primitive point object.

1b. What the Closure Is Made Of

Ontological clarification. In this paper three levels must be distinguished. A bit is the informational content of a committed distinction. A fold is the minimal physical realization of that committed distinction at the fold boundary — informationally it carries one bit of committed distinguishability, while physically it admits four admissible orientation states within the present VERSF construction (see §1c). A particle is a stable, localized closure of many folds within the committed distinguishability graph Σ. These are not competing descriptions but three levels of the same architecture: informational, microphysical, and emergent.

Definition (Fold). A fold is the minimal physical realization of a committed distinguishability event at the Void–commitment boundary. Informationally, a fold carries one bit of committed distinguishability. Physically, this bit is realized through a finite orientation state space determined by the embedding of the fold boundary in the committed graph Σ. In the present VERSF construction this state space contains four admissible fold orientations, arising from the combination of binary commitment polarity and binary boundary orientation (see §1c). The derivation of this orientation space is given in the companion paper *From Paths to Folds*.

The committed graph Σ = (F, E) is therefore built from fold-level commitments and their admissible relations, not from primitive particles. Answering "what are the nodes of Σ physically?" — they are folds.

Stable particles arise only when collections of folds organize into topologically self-sustaining closures. This establishes two distinct ontological levels:

- **Constituent level:** folds — elementary committed physical structures at the void–matter interface
- **Emergent closure level:** particles — stable topological organizations of many folds

This resolves the apparent tension between "particles as informational structures" and "particles as observed matter." The underlying constituents are folds; the observed particle is the stable closure those folds collectively support. The bits are the informational description; the folds are the physical microstructure; the particle is the emergent closure.

This is consistent with the binary fold construction developed in *From Paths to Folds*, where folds are the minimal information-bearing degrees of freedom at the void interface, and with the broader BCB account in which particles are stable folds of information.

Matter particles — electrons, quarks, protons — are stable fold-closures: fold assemblies satisfying C1–C3. Gauge bosons correspond to propagating admissible reconfiguration modes of the fold network that preserve closure topology rather than forming stable closure defects. This distinction — particles as closures, bosons as closure dynamics — keeps the ontology clean and avoids forcing photons into the same structural box as electrons.

The particle species table in §11 therefore corresponds to a classification of admissible fold-closure topologies, not an arbitrary list of objects inserted into the theory by hand.

1c. Why the Fold Has Four Admissible Orientation States

Folds as commitment boundaries. A fold is not best understood as a small localized object in the conventional sense. It is more fundamentally a boundary structure — the minimal element of the interface between two physically distinct regimes. A commitment event occurs when a reversible distinguishability relation in the Void becomes an irreversible physical record. This transition necessarily creates a boundary between the reversible distinguishability dynamics of the Void and the committed record structure of Σ. A fold is the minimal element of this boundary: the smallest structural unit separating reversible from irreversible physical structure.

Its informational content corresponds to the distinguishability that has been committed; its physical structure corresponds to the geometry of the boundary itself.

This framing resolves what might otherwise seem like an arbitrary feature of the framework. Because a boundary has two sides and a direction of embedding, folds naturally possess orientation — and that orientation has structure beyond the informational bit. The fold is not an arbitrary unit with an ad hoc internal space; it is a boundary whose geometry forces additional degrees of freedom. Particles then arise when fold boundaries form closed self-sustaining topologies within Σ: a particle is a closed fold boundary, directly analogous to topological defects in condensed matter systems where a boundary region curves back on itself and becomes self-supporting. This connection to topological defect theory is not merely an analogy — it reflects the same mathematical structure of closure in a network of oriented boundary elements.

The claim that a fold admits four admissible physical orientation states — rather than simply two, as a naive binary reading would suggest — now follows from the boundary geometry. The argument has two steps.

Step 1 — The informational level is binary. A committed distinction records one bit: which of two possible distinguishability outcomes has been irreversibly stabilized. This fixes the informational content of a fold to one bit.

Step 2 — The physical realization is four-valued. A fold is not an abstract bit but a physical commitment event localized at the fold boundary — the interface between the reversible Void substrate and the committed distinguishability graph Σ. That boundary has orientation: a fold must be embedded in Σ with a directionality that specifies which side is the Void and which side is the committed record layer. This directional embedding is itself binary — two admissible boundary orientations.

Commitment polarity and boundary orientation are structurally independent degrees of freedom because they are defined on different structures: commitment polarity concerns which distinguishability outcome has been irreversibly recorded (a property of the committed state), while boundary orientation concerns how the fold is embedded in the directed graph Σ (a property of the embedding geometry). Neither determines the other — a fold with a given polarity may be embedded in either orientation, and a given embedding orientation is compatible with either polarity. Their independence is therefore not assumed but follows from the fact that the committed outcome and the embedding geometry are defined on distinct mathematical objects.

Combining binary commitment polarity (two values) with binary boundary orientation (two values) yields four admissible physical fold states:

Commitment polarity	Boundary orientation
+	forward
+	reverse
−	forward

Commitment polarity	Boundary orientation
−	reverse

These four states are the minimal admissible fold state space: reducing to two would conflate the directional embedding with the informational polarity, which are structurally independent at the fold boundary. The full derivation of this orientation space, including admissibility conditions on the four states under BCB constraints, is given in the companion paper *From Paths to Folds*. For present purposes the key point is that the four-valuedness of folds is not an additional assumption but a consequence of the structure of the commitment boundary itself.

A fold is therefore not a four-bit object, nor a four-valued informational unit. Informationally it carries one committed bit; physically it admits four admissible realization states because the same committed distinction can be embedded in boundary geometry in four structurally distinct ways.

1d. Programme Context and Scope

The closure–defect interpretation of particles developed in this paper is not an isolated hypothesis. Several structural ingredients used here — folds, gauge symmetries, and internal particle symmetries — have been derived within earlier VERSF work. The present paper builds on those results by interpreting particles as stable closures in the committed distinguishability graph Σ.

Fold structure. In the VERSF framework the elementary committed physical structure is the fold, produced when a reversible distinguishability relation in the Void crosses the fold boundary and becomes an irreversible committed record. Informationally, a fold carries one bit of committed distinguishability. Physically, because folds occur at the boundary between reversible and committed dynamics, they possess an orientation within Σ — describing how the fold is embedded relative to the reversible substrate and the committed record layer. Two structurally independent binary degrees of freedom arise: commitment polarity (which distinguishability outcome is recorded) and boundary orientation (the directional embedding relative to the Void–commitment interface). These combine to produce four admissible physical fold states while carrying only one bit of informational content. The full derivation is given in *From Paths to Folds*.

Emergence of gauge structure. Gauge symmetries also emerge from structural requirements rather than constituting independent assumptions. In the framework, physical states are points in a distinguishability manifold. When states evolve across spacetime, comparing them requires parallel transport of distinguishability structure; the mathematical object performing that transport is a connection; and the presence of a connection implies a gauge field. The connection fields that result correspond to the gauge bosons of the Standard Model. This derivation is developed formally in *Distinguishability Conservation and Gauge Structure*, where gauge fields appear as necessary geometric structures preserving distinguishability relations under local evolution.

Internal symmetry groups. The allowed internal symmetry groups are constrained by the geometry of quantum state space. Quantum states naturally inhabit complex projective manifolds $\mathbb{C}P^{(n-1)}$. Combined with distinguishability conservation and information capacity limits, this geometry restricts the admissible symmetry groups. The minimal internal symmetry theorem demonstrates that the three factors of the Standard Model gauge group arise from the projective geometry of distinguishability states:

Manifold	Symmetry	Sector
$\mathbb{C}P^2$	SU(3)	Color
$\mathbb{C}P^1$	SU(2)	Weak
$\mathbb{C}P^0$	U(1)	Electromagnetic

Notably, SU(3) uniquely allows the formation of three-body singlet states, providing a structural account of why baryons consist of three quarks. The argument is that for SU(N) with objects in the fundamental representation, the antisymmetric product of N fundamentals contains a singlet: in SU(3), three fundamentals ($3 \otimes 3 \otimes 3 \supset 1$); in SU(2), two; in SU(4), four. SU(3) is therefore the unique case in which a three-body bound state can be color-neutral, which matches the observed baryon structure of QCD. The detailed derivation is presented in *Why Nature Chose the Standard Model*.

Role of the present paper. The earlier VERSF papers establish the existence and structure of folds, the emergence of gauge connections, and the geometric origin of the Standard Model symmetry groups. The present paper addresses a distinct question: if folds are the elementary committed structures of the theory, how do the familiar particles of physics emerge from them? The answer proposed here is that particles correspond to stable closure defects in Σ. The fold-level structure provides the microscopic constituents; closure topology determines the emergent particle species. The particle ontology of the Standard Model is interpreted not as a list of fundamental objects but as the set of stable closure configurations permitted by the deeper informational architecture of the VERSF framework.

Scope of the present paper. The goal is architectural rather than fully derivational. It establishes the ontological and structural framework connecting folds, committed distinguishability, and particle identity within the VERSF programme, accomplishing three tasks: (i) introducing the three-layer architecture — bits → folds → particles — in which informational distinctions become physical folds and particles appear as stable closure defects; (ii) defining the committed distinguishability graph $\Sigma = (F, E)$ and the closure conditions C1–C3 that characterize stable particles; and (iii) introducing the stability functional $S[C] = \alpha n_C + \beta \kappa_C$ and the local capacity criterion for confinement as structural definitions guiding the companion derivations. Several deeper results are intentionally deferred: the full derivation of the four-state fold orientation space (*From Paths to Folds*), the explicit closure topology → spin representation mapping, numerical fold counts for particle species, Standard Model gauge group derivation, and coarse-grained field equations arising from fold propagation. The present paper provides the ontological and structural map within which those derivations occur.

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2. What Is a Particle?

The formal definition is given in §1a. This section establishes its connection to three well-established structures in theoretical physics that a referee will recognise — topological defects, lattice gauge theory, and emergent quasiparticles. The scope note on matter versus gauge bosons is in §1; it applies throughout.

This framing connects to:

- **Topological defects** — In condensed matter and field theory, topological defects are stable configurations that cannot be continuously deformed away. Vortices in superconductors, domain walls, and magnetic monopoles are all examples. VERSF particles are interpreted as occupying the same structural role within the committed distinguishability graph Σ.
- **Lattice gauge theory** — In lattice gauge theory, matter fields live on lattice sites and gauge fields on links; particles correspond to gauge-invariant excitations of this structure. VERSF's committed distinguishability graph Σ provides an analogous discrete substrate, with closure defects playing the role of gauge-invariant excitations.
- **Condensed matter analogs** — Emergent quasiparticles such as phonons, magnons, and anyons are not fundamental but arise as stable collective excitations of an underlying ordered state. VERSF particles are modeled as the analogous stable collective excitations of the committed distinguishability structure.

In each case the conceptual move is the same: the particle is not a primitive input to the theory but a stable excitation of a deeper substrate.

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3. What Is an Electron?

Within the present VERSF interpretation, the electron is modeled as the minimal admissible self-sustaining fold-closure in Σ. The framework proposes that it corresponds to the smallest self-consistent assembly of committed folds satisfying C1–C3: the simplest connected subgraph of Σ whose fold assembly cannot be further reduced without violating admissibility. Its stability is modeled as reflecting the fact that its fold topology cannot be decomposed into a lower-cost admissible closure without violating commitment or capacity constraints.

The familiar properties of the electron can be reinterpreted within this structural framework. Its mass is modeled as the energy required to stabilize the closure configuration. In the closure interpretation proposed here, charge and spin are modeled as emergent structural properties of the closure geometry rather than primitive attributes: electric charge is interpreted as reflecting the orientation or polarity of the closure within Σ, and spin as a topological twist in the closure geometry. These interpretations are consistent with the formal treatments in Appendices D and E; their full derivation is reserved for the companion closure geometry papers.

The remarkable stability of the electron arises because this minimal closure cannot decompose into smaller distinguishability structures without violating the BCB capacity constraints or the admissibility conditions governing irreversible record formation.

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4. What Is a Quark?

In the closure interpretation of VERSF, a quark is a partial fold-closure whose internal fold structure cannot close admissibly in isolation. Rather than being a standalone object, a quark is a partial fold assembly whose stability requires participation in a larger composite fold topology. Individual quark closures do not satisfy admissibility conditions when isolated: the fold bookkeeping required to stabilize them would exceed the local BCB capacity available to a single closure region, leaving an open commitment boundary that violates C1.

Instead, quarks form stable configurations only when arranged in composite closure geometries. In baryons, three quark closures combine in a configuration that balances distinguishability commitments and restores admissibility. In mesons, quark–antiquark pairs form a two-closure stabilization structure.

This interpretation connects naturally with the entropic confinement results developed elsewhere in the VERSF programme. Confinement is here modeled as a consequence of the distinguishability capacity constraints governing stable fold-closure structures, not merely as a property of the strong interaction field. This is an ontological reinterpretation of confinement, not a replacement for the quantitative machinery of QCD.

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5. What Is a Proton?

A proton, in the VERSF framework, is interpreted as a three-channel composite fold-closure in which three partial quark fold structures are jointly completed by a shared confinement topology. No single quark fold assembly closes admissibly in isolation; together, the three channels jointly satisfy BCB capacity and admissibility, forming a stable composite closure.

The key idea is that the three quark closures together create a distinguishability structure that saturates a locally stable configuration under the BCB constraint. This composite closure maintains its identity because the distinguishability commitments within it continuously balance formation and dispersal processes.

The proton's mass can therefore be understood as the energy required to sustain this composite closure geometry. The majority of the proton mass does not arise from the intrinsic masses of the quarks themselves but from the energetic cost of maintaining the closure structure and the associated commitment dynamics that stabilize it — consistently with the QCD result that most proton mass arises from gluonic binding energy and sea-quark contributions rather than quark rest masses. The VERSF closure energy and the QCD binding energy are here analogized structurally, not identified; whether a deeper equivalence holds is a question for the companion closure dynamics papers.

In this sense the proton is not a rigid object but a dynamically stabilized closure configuration within the reversible substrate. The closure description is intended as an ontological reinterpretation of proton structure, not as a replacement for the quantitative success of QCD; the numerical predictions of quantum chromodynamics remain the appropriate framework for precision calculations.

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6. Mass as Closure Energy

Within the closure interpretation, mass corresponds to the energetic cost of maintaining stable distinguishability commitments. A closure defect requires continuous energetic stabilization because the surrounding reversible substrate tends to disperse distinguishability structures over time.

Mass can therefore be interpreted as closure energy — the energy required to sustain the boundary between reversible Void dynamics and committed record structure.

This interpretation naturally explains why particle masses differ across the Standard Model. Different closure geometries require different stabilization energies depending on their topology, internal distinguishability structure, and interaction with surrounding commitment dynamics.

In this sense, particle mass is modeled as a geometric-informational property rather than a purely intrinsic parameter. The framework proposes that the familiar mass spectrum of particles reflects the stability hierarchy of closure configurations in the committed distinguishability graph Σ. The formal leading-order stability functional governing this hierarchy is given in Appendix D.

6a. Closure Size and Fold Counts

The closure interpretation of particles carries a quantitative consequence: every particle corresponds to a closure composed of a specific number of committed folds. Let n_C denote the effective fold count of a closure C (defined formally in Appendix D). Within the VERSF programme, companion papers derive fold-count estimates for specific particles from BCB capacity constraints and closure geometry. In particular, *Proton Mass from Information* and

Baryon Mass Spectrum from BCB Constraint Dynamics derive the closure depth associated with baryonic stability under BCB capacity conditions. At present those papers establish scaling relations and ordering constraints — $n_e < n_m < n_p$ — rather than pinned integer values; the absolute fold counts depend on the explicit derivation of the energy scale α, which is reserved for the companion closure geometry papers. These results indicate that different particle species correspond to distinct admissible fold-count windows, with stable realized counts selected by closure topology and local capacity constraints.

Particle	Closure type	Fold count
Electron	Minimal fermionic fold-closure	n_e
Proton	Three-channel baryonic fold-closure	n_p
Meson	Two-channel fold-closure	n_m

In the present paper these symbols denote species-dependent fold counts established in companion calculations; no numerical values are asserted here.

The stability of each species reflects the existence of a fold count n_C satisfying both the local capacity stability condition

$$n_C \leq N_{BCB}$$

and a local minimum (or topologically protected configuration) of the closure stability functional

$$S[C] = \alpha\, n_C + \beta\, \kappa_C$$

derived in Appendix D. The particle spectrum can therefore be interpreted as the set of fold-closure configurations that simultaneously satisfy admissibility, local capacity stability, and closure energy minimization. Configurations that fail any of these conditions either disperse into the reversible substrate or cannot form as isolated structures.

The companion papers on closure geometry and baryon structure derive specific fold-count relationships for leptons, baryons, and mesons. The present paper establishes the ontological interpretation within which those counts have meaning: n_C is not an abstract parameter but the literal number of committed folds comprising the particle's internal structure.

6b. Fold Counts and Particle Mass Estimates

One structural consequence of the closure interpretation is that particle masses connect directly to the number of folds required to stabilize a given closure configuration. This section draws out that connection at the level of leading-order estimates; the companion closure geometry papers derive the specific fold counts.

Leading-order mass approximation. The closure stabilization energy is

$$E_C = \alpha\, n_C + \beta\, \kappa_C$$

where n_C is the effective fold count, κ_C is the geometric stabilization cost, and α, β are fold-level energy scales. In the regime where curvature corrections are subdominant — simpler, more symmetric closures — the leading-order approximation gives

$$E_C \approx \alpha\, n_C$$

so particle mass is approximately proportional to fold count:

$$m_C \approx (\alpha / c^2)\, n_C$$

This provides a direct physical interpretation: particle mass, at leading order, is proportional to the number of committed folds required to stabilize the closure. The curvature term $\beta\, \kappa_C$ becomes significant for composite or geometrically complex closures such as the proton, where closure boundary structure contributes meaningfully to stabilization energy.

Proton. Companion papers in the VERSF programme derive the closure depth required for baryonic stability under BCB capacity constraints. These results indicate that the proton corresponds to a three-channel composite fold-closure with characteristic fold count n_p, so that

$$m_p \approx (\alpha / c^2)\, n_p$$

where the closure geometry determines n_p and the fold energy scale determines α. This is structurally consistent with the established QCD result that most proton mass arises from binding energy rather than quark rest masses — within the VERSF interpretation, that binding energy corresponds to the energetic cost of stabilizing the proton's composite fold-closure geometry (see §5).

Electron. Leptons correspond to minimal admissible fold-closures that do not participate in color confinement. The electron is modeled as a minimal fermionic closure with fold count n_e satisfying $n_e < n_p$. Because the electron is the simplest admissible fermionic closure — by definition lacking the composite multi-channel boundary structure of baryons — its closure geometry is expected to have minimal boundary cycle complexity, placing it in the low-κ_C regime where the leading-order approximation $m_C \approx (\alpha / c^2)\, n_C$ is appropriate. The fold-count interpretation therefore predicts a mass ordering

$$n_e < n_m < n_p$$

for leptons, mesons, and baryons respectively — a structural prediction that the companion derivation papers are tasked with making quantitative.

Summary. The closure interpretation connects three quantities that appear unrelated in conventional particle physics:

Quantity	Closure interpretation
Particle mass	Energetic cost of stabilizing the fold-closure at leading order
Binding energy	Stabilization energy of the closure geometry (κ_C contribution)
Particle species	Distinct admissible fold-closure topologies

Closure configurations requiring fold counts that exceed local BCB capacity cannot form stable particles; those within capacity but at unstable points of S[C] disperse. The observed particle spectrum is, on this interpretation, the set of fold-closure configurations that survive both constraints simultaneously.

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7. Particle Motion in the Commitment Substrate

If particles are closure defects in the distinguishability structure, their motion corresponds to the translation of closure geometry through the reversible substrate.

A moving particle therefore represents a sequence of commitment events in which the closure structure continuously reconstructs itself across neighboring regions of the substrate. Each step of this propagation must satisfy admissibility conditions and remain within the TPB commitment rate bounds.

From this perspective, particle trajectories correspond to the sequential relocation of stabilized distinguishability closures. The reversible substrate provides the medium through which these structures propagate, while the commitment layer records their historical trajectory.

This view connects naturally with quantum field descriptions of particles as propagating excitations, but reinterprets those excitations as the movement of stabilized distinguishability structures rather than oscillations of an underlying material field.

A note on Lorentz invariance: the closure picture operates at the level of the committed graph Σ, which is discrete. Lorentz invariance is not assumed at this level but is expected to emerge only at the coarse-grained continuum limit. The present paper assumes that admissible fold propagation is such that no preferred observable frame survives in that limit; the explicit recovery of Lorentz symmetry from fold-network dynamics is reserved for the companion VERSF papers on spacetime emergence.

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8. Relationship to Quantum Field Theory

Quantum field theory describes particles as excitations of underlying fields. The VERSF closure interpretation is compatible with this picture but shifts the ontological ground.

Instead of treating the field as the fundamental entity, VERSF treats it as a description of reversible distinguishability propagation in the Void substrate. Particles — stable closure defects in Σ — are what that propagation produces when it crosses the fold boundary and generates irreversible committed records. The detailed elaboration of this bridge is given in §13; the key point here is that VERSF does not discard QFT but embeds it within a deeper architecture in which field equations describe the admissible dynamics of closure defects, not the ultimate ontological layer.

The limiting-case argument. In the coarse-grained limit where closure-preserving fold dynamics are linearized over large regions of Σ, the reversible propagation sector is expected to admit an effective field description. Schematically, if ϕ denotes a coarse-grained field variable over the reversible substrate, its dynamics take the form

$$\partial_\tau \phi = L_\Sigma \phi + N(\phi)$$

where τ is the VERSF commitment-ordering parameter (not ordinary coordinate time, which emerges only at the coarse-grained level), L_Σ is an effective graph propagation operator on Σ, and $N(\phi)$ captures nonlinear closure interactions. The two terms have direct structural interpretations within the closure framework:

- **L_Σ** is the linear propagation operator induced by admissible adjacency relations in the fold graph Σ. It governs reversible distinguishability propagation through the Void substrate. The linear regime therefore corresponds to reversible field propagation.
- **$N(\phi)$** represents nonlinear closure formation dynamics. Localized nonlinear solutions of this sector correspond to persistent closure defects — the particle states. The nonlinear localized regime therefore corresponds to committed particle closures.

In the limit of weak nonlinear coupling and coarse-grained averaging over many folds, the reversible sector is expected to reproduce conventional field propagation equations. This converts the connection to QFT from a verbal analogy into a structural research programme: the question is not whether the embedding exists but whether L_Σ, derived from fold-network admissibility conditions, reproduces the correct continuum limit. That derivation is reserved for the companion VERSF papers on field emergence.

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9. Gauge Symmetry as Closure Preservation

Gauge symmetries can be interpreted as the transformation group that preserves closure stability under admissible operations.

Within the VERSF framework, admissible transformations must conserve distinguishability capacity while maintaining stable commitment structures. The allowed symmetry operations are therefore those that map one admissible closure configuration to another without violating BCB constraints.

This requirement provides a structural motivation for compact symmetry groups. Non-compact symmetry groups allow transformations that can generate unbounded distinguishability growth, which would violate the finite capacity constraint imposed by BCB.

Under this interpretation, the familiar gauge structure of the Standard Model can be understood as consistent with the minimal compact symmetry algebra that preserves closure stability within a BCB-bounded distinguishability substrate. This is a structural motivation, not a demonstrated theorem; the detailed derivation is developed in the companion gauge papers.

9a. Gauge Bosons as Propagating Closure-Preserving Modes

Matter particles and gauge bosons occupy distinct ontological roles within the VERSF closure framework, and that distinction deserves explicit treatment rather than a note in a table.

Matter particles are stable fold-closures: connected subgraphs $C \subset \Sigma$ satisfying C1–C3. They are persistent, localized, and transportable. Their identity is topological — they correspond to equivalence classes of closure topology that cannot be removed by admissible local rewiring.

Gauge bosons are not stable matter-like closures. They do not form persistent committed subgraphs that satisfy C1 in the matter-particle sense. Instead, they correspond to propagating admissible reconfiguration modes of the fold network — patterns of fold-network dynamics that preserve or mediate closure topology without themselves becoming stable closure defects. The key structural distinction is:

Matter particles are closures. Gauge bosons are closure dynamics.

More specifically:

- **Photons** are modeled as propagating closure-preserving excitations of the electromagnetic sector of the fold network — admissible modes that transport closure-preserving information through the reversible substrate without committing to a stable closure defect.
- **Gluons** are closure-preserving reconfiguration modes that are confinement-bound: they propagate admissible fold-network reconfigurations within composite color-closure structures (baryons, mesons) but cannot escape those structures to form free stable closures, consistent with the local capacity argument in Appendix F.
- **W and Z bosons** are modeled as massive closure-mediation modes — admissible reconfiguration modes that carry closure-level information but whose effective mass reflects the energetic cost of the mediating commitment structure rather than a stable long-lived closure topology.

The gauge-boson ontology is treated more fully in the companion VERSF gauge papers, where the closure-preservation requirement is shown to provide structural motivation for the Standard Model gauge groups. The present paper establishes the ontological separation: matter particles are defined by closure stability; gauge bosons are defined by closure-preserving propagation dynamics.

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10. Particle Identity as Stable Closure Defects

In the VERSF interpretation, particles are not fundamental objects but stable closure defects in the distinguishability structure of the commitment substrate.

A closure defect is defined as a localized region of the committed record layer whose internal distinguishability structure satisfies admissibility constraints and remains dynamically stable under TPB-bounded evolution.

Formally, let Σ denote the committed record space and let $N(\tau)$ represent the number of committed distinguishability records at VERSF time τ. A closure defect C is a subset

$$C \subset \Sigma$$

such that the following conditions hold:

1. **Stability** — The closure maintains its distinguishability structure under admissible operations.
2. **Capacity compatibility** — The closure does not violate the BCB capacity constraint.
3. **Transportability** — The closure can propagate through the reversible substrate via admissible commitment updates.

Under this interpretation a particle corresponds to a persistent closure topology within Σ. Different particle species correspond to different stable closure topologies.

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11. Particle Species as Closure Topologies

If particles correspond to closure defects, particle species correspond to distinct classes of closure topology.

Particle	Closure Structure
Electron	Minimal stable single-closure defect
Quark	Partial closure requiring composite stabilization
Proton	Three-closure composite configuration
Photon	Propagating admissible closure-preserving excitation of the reversible substrate; gauge bosons occupy a distinct ontological role from matter closure defects (see §9)

Particle	Closure Structure
Neutrino	*[Provisional]* Minimal fermionic fold-closure in the weak sector, with negligible electromagnetic and color-sector coupling; the closure geometry of the neutrino sector is not yet derived within the VERSF programme and this entry should be read as a placeholder pending companion closure geometry work

This interpretation naturally explains several features of the Standard Model.

Stability hierarchy — Particles that correspond to simpler closure topologies tend to be more stable. Electrons correspond to minimal stable closure defects. Protons correspond to composite but energetically stable closure configurations. Heavier particles correspond to unstable closure geometries.

Confinement — Quarks cannot exist as isolated particles because the corresponding closure topology is incomplete when isolated. The BCB constraint prevents partial closure defects from remaining stable unless they are embedded in a composite structure. This provides a structural explanation of quark confinement that complements the entropic confinement results developed elsewhere in the VERSF programme.

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12. Particle Interactions as Closure Reconfiguration

In the closure interpretation, particle interactions correspond to reconfiguration events in the committed distinguishability graph Σ.

A particle interaction occurs when two or more closure defects merge, split, or reorganize while remaining consistent with admissibility constraints. Symbolically,

$C_1 + C_2 \rightarrow C_3 + C_4$

represents a transformation between closure configurations that preserves conservation laws, BCB capacity, and admissibility constraints. This is precisely where the bookkeeping invariants defined in §16a are enforced: every admissible reconfiguration must satisfy $Q[C_1] + Q[C_2] = Q[C_3] + Q[C_4]$ for each conserved quantity Q, so that charge, baryon number, and lepton number are preserved automatically by the admissibility conditions on the reconfiguration rather than as separate postulates.

Gauge interactions can therefore be interpreted as the rules governing closure reconfiguration within the committed distinguishability structure. In this view, forces are not external fields acting on particles but constraint structures governing how closure defects may rearrange while preserving the global bookkeeping of distinguishability and capacity.

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13. From Quantum Fields to Closure Dynamics

Section 8 noted that VERSF embeds QFT rather than replacing it. This section makes that embedding concrete by working through the principal particle types.

The translation principle is: a quantum field describes continuous reversible propagation of distinguishability structure in the Void; a particle is a stable closure defect that forms when that propagation crosses the fold boundary and commits irreversibly to Σ. The field description and the closure description are therefore two levels of the same physics — the field level captures reversible dynamics, the closure level captures what becomes permanently recorded.

13.1 The Electron

In the Standard Model the electron is a Dirac fermion associated with the electron field. Within the VERSF architecture the electron corresponds to a minimal stable closure defect in the committed distinguishability structure.

The stability of the electron follows from two properties:

- **Closure stability** — The distinguishability relations forming the electron closure remain self-consistent under admissible operations.
- **Capacity compatibility** — The closure occupies a stable region of the BCB capacity budget and does not require additional distinguishability resources to maintain its structure.

Because the electron closure is minimal, there are no admissible operations that can decompose it into smaller stable closures while preserving conservation laws. This explains the observed stability of the electron across cosmological timescales.

13.2 Quarks

Quarks exhibit the unusual property of confinement: isolated quarks are not observed in nature. In the closure interpretation this behavior emerges naturally. Quarks correspond to partial closure defects whose distinguishability structure cannot remain stable in isolation. The BCB constraint prevents partial closure structures from maintaining stability unless they are embedded within a composite configuration that completes the closure topology.

This naturally produces composite states:

- Proton / Neutron = three-quark closure configuration
- Meson = quark–antiquark closure pair

Confinement therefore appears not as an additional dynamical rule but as a topological stability condition on distinguishability closures.

13.3 The Proton

The proton is a composite particle composed of three valence quarks bound by gluonic interactions in quantum chromodynamics. In the VERSF interpretation the proton corresponds to a stable three-closure configuration in the committed distinguishability graph Σ. The gluonic sector is the VERSF counterpart of gauge-boson exchange: it corresponds to the admissible edge dynamics in Σ that continuously stabilize the three-closure composite topology. These edge dynamics preserve closure structure rather than forming independent stable closures, which is why gluons are not observed as free particles.

The stability of this configuration arises because the combined closure structure satisfies admissibility constraints, BCB capacity balance, and TPB rate stability. Once formed, this composite closure can persist indefinitely provided the distinguishability bookkeeping remains balanced.

13.4 Gauge Fields as Closure Symmetries

In the closure interpretation gauge symmetries correspond to transformations that preserve closure structure while reconfiguring distinguishability relations within the committed layer. A gauge transformation therefore represents an admissible transformation that preserves both BCB capacity balance and closure topology.

This interpretation provides a structural motivation for the appearance of compact gauge groups. Non-compact symmetry groups would allow transformations that generate unbounded distinguishability variation, violating the BCB constraint. Compact symmetry groups preserve bounded distinguishability structure and are therefore structurally consistent with the finite capacity principle — though a full derivation of the Standard Model gauge group from these constraints is reserved for the companion gauge papers.

13.5 Particles as Information-Stable Structures

Taken together, these observations suggest a unified picture:

Level	Description
Fields	The continuous reversible propagation of distinguishability structure within the Void substrate
Particles	The discrete committed stabilization of that propagation at the fold boundary
Interactions	Admissible reconfiguration of closures
Gauge symmetries	Transformations preserving closure structure

The particle ontology of physics therefore emerges as a natural consequence of the deeper informational architecture governed by distinguishability, commitment, capacity, and admissibility.

14. Mass as Commitment Energy Density

One of the most important questions for any particle ontology is the origin of mass. In the Standard Model, particle masses arise through coupling to the Higgs field. While this mechanism is experimentally well supported, it does not explain why particles have the particular masses they do. Within the VERSF framework, mass can be interpreted in a deeper informational way.

In VERSF, particles correspond to stable closure structures in the committed distinguishability graph Σ. Maintaining these closures requires energy because the distinguishability relations that define the closure must remain stabilized against thermodynamic dispersal. Mass therefore corresponds to the energetic cost of sustaining a stable closure in Σ.

This provides a natural informational interpretation of Einstein's relation:

$E = mc^2$

Energy represents the physical cost required to stabilize distinguishability structure, while mass measures the density of that stabilized structure.

The Higgs mechanism then acquires a complementary interpretation. Rather than being the ultimate origin of mass, the Higgs field functions as a coupling environment that determines how closure structures interact with the background vacuum configuration.

15. Spin and Quantum Statistics

Another defining property of elementary particles is spin. Electrons, quarks, and neutrinos are fermions with spin 1/2, while photons and gluons are bosons with spin 1. In the Standard Model these properties are encoded in quantum fields and Lorentz group representations. However, the deeper origin of spin and quantum statistics remains conceptually obscure.

Within the VERSF framework, spin can be understood as a topological property of closure structures rather than an intrinsic attribute of a point-like object. When a closure structure is rotated within the committed distinguishability graph Σ, its internal configuration may require multiple rotations to return to its original state.

This interpretation aligns naturally with the mathematical structure of spinors in quantum mechanics. Within VERSF, the appearance of spinors reflects the topology of distinguishability closure structures rather than an abstract algebraic property imposed on particles.

Quantum statistics are interpreted within the same structural framework. The proposal is that closure structures whose topology places them in SU(2) spinor representations (see Appendix E) correspond to fermions and obey the Pauli exclusion principle, while closure structures in SO(3) tensor representations correspond to bosons and obey Bose–Einstein statistics. As noted in Appendix E, the present paper identifies the representation-theoretic distinction but does not yet derive which specific closure topologies in Σ realize each case; that derivation is reserved for the companion closure geometry paper. The claim here is therefore at the level of structural interpretation rather than completed proof: the closure framework provides the architecture within which quantum statistics would emerge, pending the explicit topology-to-representation mapping.

Spin and quantum statistics are therefore interpreted as consequences of the topology and interaction rules of closure structures in the VERSF framework rather than as fundamental inputs to the theory — but the completion of this derivation remains an open task in the programme.

15a. Why Fold Closures Naturally Admit Spinor Representations

Geometric intuition: origami and rotation. The origami analogy introduced for general readers extends naturally to this result. An origami structure is defined not by the paper itself but by its network of folds. If that network contains oriented boundary twists, rotating the entire figure by 360° need not restore the internal fold configuration. The internal boundary orientations may arrive at a topologically distinct state — one that requires a further 360° rotation, 720° total, to return to the original arrangement. The global rotational behavior of a folded structure depends on the topology of its folds, not merely on its external shape. Particles in the VERSF framework are closure topologies of oriented fold boundaries, and the same principle applies: spin-½ behavior reflects the internal fold topology of the closure, not a mysterious intrinsic property of a point object.

The structural argument for why fold closures admit spinor representations proceeds in four steps. The key logical point — established in point 8 of the companion derivation — is that the four-state fold orientation space does not by itself yield SU(2). What it provides is sufficient local structure for an oriented boundary element. SU(2) appears when one asks how *global* closure topologies transform under rotation. The correct chain is:

fold state space → closure topology → rotation behavior → SU(2)

Step A — Folds as oriented boundaries. A fold is an oriented committed boundary (§1c). It carries two structurally independent binary degrees of freedom: commitment polarity and boundary orientation. This gives the fold a richer local state space than a plain binary bit — specifically, the structure of an oriented boundary element that can be meaningfully rotated and embedded in a closure topology.

Step B — A particle is a configuration of oriented boundaries. A stable particle corresponds to a closed fold-closure topology in Σ. The question of spin is therefore the question of how such closure configurations — assemblies of oriented boundary elements — transform under spatial rotation. Spatial rotations act on the embeddings of the closure in physical space, giving an action of SO(3) on closure configurations.

Step C — The topological obstruction. SO(3) is not simply connected. Its fundamental group is

$$\pi_1(SO(3)) = \mathbb{Z}_2$$

which encodes a physical fact: a continuous 360° rotation is not always trivial at the level of internal boundary topology. A fold-closure contains both a spatial embedding and an internal boundary twist structure. For certain closure classes, a 2π rotation does not return the closure to the same internal state — it maps the closure to its sign-reversed representative. Only a 4π rotation returns it to the original. Such closures are not faithfully represented on SO(3).

Step D — Lifting to SU(2). The unique simply connected double cover of SO(3) is SU(2), with a 2-to-1 map p: SU(2) → SO(3) under which U and $-U$ in SU(2) correspond to the same physical rotation in SO(3). Closure classes whose internal boundary topology distinguishes these two lifts must therefore be represented on SU(2), not SO(3). These closures acquire the transformation law

$$\psi(\theta + 2\pi) = -\psi(\theta)$$

returning to themselves only after 720°. This is the defining transformation law of spinor representations and characterizes fermionic particles.

Interpretation. Within the VERSF framework, the appearance of spin-½ reflects the global rotational behavior of fold-closure topology rather than an intrinsic property of point particles. The role of the fold is crucial here: because particles are assembled from oriented boundary elements rather than from featureless point constituents, the global rotational behavior of the closure can carry nontrivial topology even when each individual fold is locally simple. SU(2) does not enter as an imported assumption — it arises as the natural rotational state space of fold-closures whose internal boundary topology is non-trivial under 2π rotation. Bosonic excitations correspond to closure-preserving modes whose topology is single-valued under 2π rotation and therefore transforms in tensor representations of SO(3) directly.

One distinction must be kept sharp: this argument yields the *rotational* SU(2) associated with spin. The *gauge* SU(2) of the weak interaction — established in §1d via the projective geometry of $\mathbb{C}P^1$ — is a related but distinct structure, arising from internal closure-symmetry classes and admissible reconfiguration invariance rather than from the rotational double-cover. A referee familiar with the Standard Model will expect this distinction to be explicit; it is.

The full derivation — mapping specific closure topologies in Σ to SU(2) versus SO(3) representations — is reserved for the companion closure geometry paper (see Appendix E). The present argument establishes that the logical path from fold boundaries to spinor representations is structurally sound and does not require SU(2) to be assumed.

16. Why the Standard Model Particle Spectrum Emerges

A central question for any informational or emergent approach to physics is why the particle spectrum of nature takes the specific form observed in the Standard Model. Why do we observe a limited set of stable fermions and bosons with particular masses, charges, and interaction symmetries rather than an arbitrary set of particle species?

Within the VERSF framework, the allowed particle spectrum is determined not by arbitrary field content but by the limited set of closure structures that can remain stable within a substrate constrained by finite distinguishability capacity (BCB), admissibility rules, and commitment-rate limits.

In this picture, quarks correspond to partial closure structures that cannot exist independently because their distinguishability configuration cannot be stabilized in isolation. Only composite closure configurations — such as baryons and mesons — satisfy the BCB and admissibility constraints required for stable long-lived records.

Similarly, leptons correspond to closure configurations that do not participate in the same confinement dynamics because their distinguishability topology differs from that of quark structures. The different interaction behaviors of leptons and quarks therefore reflect differences in closure geometry rather than arbitrary assignments of particle type.

Under this interpretation, the Standard Model particle spectrum is not an arbitrary list of fundamental objects. It is the set of stable closure configurations permitted by the combined constraints of distinguishability, commitment dynamics, BCB capacity, and admissible symmetry transformations.

16a. Conservation Laws as Ledger Invariants

Let R denote the set of admissible closure reconfiguration operations acting on the committed distinguishability graph Σ.

Definition. A conserved quantity is a functional Q[C] defined on admissible closure configurations such that for every admissible reconfiguration $R \in R$,

$$Q(R(C)) = Q(C)$$

for all closure configurations C. Equivalently, for interaction processes

$$C_1 + C_2 \rightarrow C_3 + C_4$$

the invariant satisfies

$$Q[C_1] + Q[C_2] = Q[C_3] + Q[C_4]$$

Conservation laws therefore arise as structural invariants of the admissible closure-reconfiguration algebra acting on Σ — not as externally imposed symmetry postulates but as consequences of admissibility.

Within the present VERSF interpretation:

- **Electric charge** is proposed to correspond to an oriented boundary invariant of the closure — heuristically, a net signed fold-orientation across the closure boundary.
- **Baryon number** is proposed to correspond to the count of three-channel composite fold-closure units: it is preserved because no admissible reconfiguration can convert a three-channel composite closure into a non-baryonic structure without violating BCB capacity or admissibility constraints.
- **Lepton number** is proposed to correspond to an analogous count for minimal fermionic fold-closures in the lepton sector.

These are programme proposals. Their explicit derivation from fold-level admissibility conditions is reserved for the companion VERSF papers on closure dynamics and symmetry.

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17. Particles as Persistent Records in the Cosmic Ledger

Within the VERSF framework, the universe can be understood as a continually evolving ledger of committed distinguishability relations. The committed record layer Σ therefore functions as a historical ledger of irreversible distinguishability relations — every commitment event records a physical distinction that becomes part of the permanent structure of reality. Particles, in this view, are not merely objects moving through spacetime; they are persistent records within this ledger.

A stable particle corresponds to a distinguishability configuration that can maintain itself across many cycles of reversible substrate dynamics and commitment events. What we interpret as the continued existence of a particle is therefore the persistence of a particular record pattern within the committed layer of the universe.

This perspective provides a natural explanation for conservation laws. Quantities such as electric charge, baryon number, and lepton number can be interpreted as bookkeeping invariants associated with stable record configurations. Conservation laws therefore arise as structural invariants of the commitment ledger rather than as externally imposed symmetries.

Seen in this way, the universe is not fundamentally a collection of particles moving in a pre-existing arena. It is an evolving structure of recorded distinctions — a growing history of commitments that collectively define physical reality. Particles are the persistent entries in that history, stabilized by the balance between reversible substrate dynamics and irreversible record formation.

17a. A Minimal Toy Model of a Closure Particle

To illustrate how particle-like structures arise from fold assemblies, this section constructs a minimal explicit closure defect within the committed distinguishability graph $\Sigma = (F, E)$. This example does not model any specific Standard Model particle; its purpose is to demonstrate concretely how a stable, transportable closure structure can emerge from fold-level commitments and admissible relations.

The minimal fold loop. Consider a set of four committed folds

$C = \{f_1, f_2, f_3, f_4\} \subset F$

connected by admissible relations

$E\_C = \{(f_1,f_2), (f_2,f_3), (f_3,f_4), (f_4,f_1)\}$

forming a closed directed cycle in Σ:

```
f₁ ──→ f₂
↑        |
|        ↓
f₄ ←── f₃
```

Every fold boundary relation is internally matched within C. No fold has an open outgoing edge that exits the closure.

C1 — Structural stability. The cycle satisfies C1 because no admissible local rewiring can remove the topological closure without breaking at least one committed fold relation. Removing any single fold produces an open chain — for example, $f_1 \to f_2 \to f_3 \to f_4$ — which no longer closes and therefore no longer satisfies the closure condition. The cycle is a topologically protected configuration within Σ.

C2 — Capacity compatibility. The folds of C are already members of F, so the capacity constraint applies to the total committed fold count $N(\tau) = |F(\tau)|$. The configuration is admissible provided $N(\tau) \leq N\_BCB$. No additional fold budget is consumed by recognizing C as a closure; it is a structural property of the existing fold assembly.

Closure stability functional. Applying the stability functional from Appendix D,

$S[C] = \alpha\, n\_C + \beta\, \kappa\_C$

the minimal loop has effective fold count $n_C = 4$. For a simple directed cycle the discrete curvature contribution may be taken as $\kappa_C = 1$, corresponding to the minimal nontrivial boundary cycle (in terms of boundary cycle count, boundary branching number, or minimal rewiring resistance — see Appendix D). The closure stabilization energy is then

$$E_C = 4\alpha + \beta$$

This is the smallest non-trivial example of the two-term decomposition: the fold-count term 4α captures the cost of sustaining the four committed folds, while the curvature term β captures the geometric cost of closing them into a cycle. This minimal cycle is the discrete analogue of the simplest topological defect in an oriented boundary network.

C3 — Transportability. The closure propagates through the reversible substrate by sequential fold updates that preserve the cycle topology:

$$\{f_1, f_2, f_3, f_4\} \rightarrow \{f_2, f_3, f_4, f_5\}$$

where a new fold f_5 — freshly committed at the boundary position vacated by f_1 — replaces f_1 while the cycle relation is re-established at the new boundary. The topology — one directed cycle of length 4 — is preserved under this update, satisfying C3.

Interpretation. This toy model demonstrates the three properties a closure defect must have: topological stability under admissible rewiring, compatibility with the BCB capacity constraint, and propagation-invariance of the closure topology. Real particles correspond to far more complex closure topologies with larger fold counts n_C and richer curvature structure κ_C, but the same conditions C1–C3 and the same stability functional $S[C]$ apply. The toy model is a proof of structure: it shows that the machinery introduced in this paper can construct explicit objects, not merely describe them abstractly.

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18. Minimal Falsifiable Programme Claims

The closure framework presented here leads to several concrete programme-level claims that can be evaluated within the broader VERSF research programme.

Claim 1 — Particle species correspond to admissible closure classes. Each stable particle species corresponds to a distinct topological equivalence class of closure subgraphs in Σ. If two particle species were shown to correspond to the same closure topology class under all admissible rewiring operations, this would falsify the closure-defect ontology as stated.

Claim 2 — Particle structure has a definite fold count. Stable particle species correspond to closures containing a specific number of committed folds n_C, determined by admissibility and BCB capacity constraints. The companion closure geometry and baryon papers derive these counts; a systematic discrepancy between predicted and observed particle stability hierarchies would require revision of the stability functional $S[C] = \alpha\, n_C + \beta\, \kappa_C$.

Claim 3 — Isolated quark closures violate local capacity stability. Partial closure configurations representing isolated quarks fail the local capacity stability condition

$$\int_C n(x)\, dx \leq \int_C N_{BCB}(x)\, dx$$

while composite baryon closures satisfy it. This is a structural prediction of the VERSF confinement criterion (Appendix F); a mechanism for stable free quarks compatible with BCB would falsify this criterion.

Claim 4 — Coarse-grained reversible fold propagation admits an effective field limit. At sufficiently large scales, reversible propagation on the fold network should admit a continuum field description whose nonlinear localized solutions correspond to closure defects. If no coarse-grained field limit of admissible fold propagation can recover approximately Lorentz-invariant continuum dynamics, the closure framework in its present form would fail as a viable ontology for known particle physics. This is therefore the sharpest test the present paper sets for the field emergence programme.

These claims define the empirical and mathematical targets of the VERSF particle programme. They connect the architectural ontology established in this paper to the quantitative derivations in the companion papers.

Appendix C. Closure Defects in the Committed Distinguishability Graph

In the VERSF framework, particles correspond to stable closure structures in the committed distinguishability graph Σ.

Let $F = \{f_i\}$ denote the set of committed folds, where each fold f_i is the minimal physical committed structure produced at the fold boundary — informationally carrying one committed bit, physically realized in a four-state fold orientation space (see §1c). Let $\Sigma = (F, E)$ be the committed distinguishability graph whose vertices are committed folds and whose edges E represent admissible committed relations among folds. This makes explicit what the nodes of Σ physically are: not abstract "committed records" but fold-level commitments — the minimal elementary physical structures of the VERSF constituent layer.

Let $N(\tau) = |F(\tau)|$ be the number of committed folds at VERSF time τ. A closure defect C is defined as a connected subgraph $C \subset \Sigma$ satisfying the following stability conditions:

C1 — Structural Stability
The closure C remains within the same topological equivalence class under admissible local graph evolution. That is, admissible rewiring operations on the edges and nodes of C do not change its connectivity class or closure topology — they may deform the subgraph but cannot continuously remove the defect structure.

C2 — Capacity Compatibility
The closure C, once embedded in Σ, does not cause the total fold count to exceed the BCB bound: $N(\tau) \leq N_{BCB}$. Since $C \subset \Sigma$, its folds are already included in $N(\tau)$; the condition is not $N(\tau) + |C| \leq N_{BCB}$ (which would double-count C) but rather that the system with C embedded satisfies $N(\tau) \leq N_{BCB}$. For formation events in which n_{new} folds are being committed for the first time, the relevant condition is $N(\tau) + n_{new} \leq N_{BCB}$, where n_{new} counts only folds not yet present in Σ.

C3 — Transportability
The closure configuration may translate through the reversible substrate via a sequence of admissible commitment updates $C(\tau) \rightarrow C(\tau + \Delta\tau)$ while preserving closure topology.

Particles therefore correspond to stable topological equivalence classes of closure subgraphs within Σ. Different particle species correspond to different closure topology classes.

Appendix D. Mass as Closure Stabilization Energy

Note: This appendix defines the mathematical structures implied by the VERSF closure ontology. These are structural definitions, not full derivations; complete derivations are developed in the companion VERSF papers on closure geometry.

In the closure interpretation of VERSF, particle mass corresponds to the energetic cost required to maintain a stable closure within the BCB-bounded committed distinguishability graph Σ. Because temperature is an emergent quantity in VERSF — arising from entropy dynamics rather than being fundamental — mass must be defined structurally in terms of the closure itself, not in terms of thermal quantities.

Let C denote a stable closure defect in Σ. Associated with C are two primitive structural quantities:

- **n_C** = the effective fold count of the closure C: the number of committed fold nodes in the subgraph $C \subset \Sigma$ required to define and maintain the closure topology
- **κ_C** = the effective discrete curvature of the closure geometry: a combinatorial measure of the departure of the closure subgraph C from locally minimal closure geometry under admissible graph embedding. Operationally, κ_C may be implemented through the boundary cycle structure of C — for instance, as a function of boundary cycle count, branching complexity of the closure boundary, or local rewiring resistance (the minimum number of admissible edge operations required to reduce the closure boundary). This term absorbs the contribution of the edge (relation) structure within C, capturing the geometric stabilization cost beyond the bare fold count. The present paper uses κ_C as a well-defined combinatorial placeholder; its explicit implementation through a specific discrete curvature measure is developed in the companion closure geometry papers. In this sense, κ_C is not smooth-manifold curvature but a discrete graph-geometric quantity appropriate to the fold-graph structure of Σ.

The closure stabilization energy is then defined as:

$$E_C = \alpha n_C + \beta \kappa_C$$

It is useful to write this as a stability functional over the closure:

$$S[C] = \alpha n_C + \beta \kappa_C$$

Not all stable closure configurations are energy minima: some are protected by topology rather than ordinary energy minimization, remaining stable because no admissible local rewiring can remove the defect structure even if S[C] is not at a strict minimum. Stable particles therefore correspond to local minima of S[C] under admissible closure-preserving variations, or to topologically protected metastable configurations that cannot decay via any admissible rewiring. This variational framing means that particle stability is not imposed by hand but follows from the structure of the functional: configurations that are neither minima nor topologically protected will evolve toward lower-S configurations and disperse.

The two terms represent the minimal structural decomposition required to stabilize a closure: the energy needed to maintain the committed fold nodes themselves (n_C, the effective fold count) and the additional stabilization energy associated with curvature of the closure boundary (κ_C, which absorbs the edge relation structure). The first term represents the energetic cost of sustaining the fold-level commitments across the nodes of the closure subgraph; the second represents the geometric stabilization cost associated with curvature of the closure boundary within Σ. Higher-order terms in closure curvature are suppressed in the leading-order closure geometry expansion, making this a well-defined minimal ansatz rather than an arbitrary decomposition. Additional interaction contributions may arise in specific composite closures but do not alter this leading-order structure.

where α and β are framework-level coupling constants whose values are fixed by the BCB capacity scale and the graph geometry of Σ. These constants are not free parameters but are constrained by the admissibility conditions of the VERSF substrate; their explicit determination is reserved for the companion closure geometry papers.

The particle mass is then:

$$m_C = E_C / c^2 = (\alpha n_C + \beta \kappa_C) / c^2$$

Under this definition, mass becomes the density of committed distinguishability required to stabilize the closure, measured in units of energy per c^2. This is fully consistent with Einstein's relation $E = mc^2$, which in VERSF acquires the interpretation: energy is the physical cost of stabilizing distinguishability structure, and mass measures the irreducible minimum of that cost for a given closure topology.

The framework proposes that the Standard Model mass hierarchy should reflect the hierarchy of admissible closure topologies ordered by n_C and κ_C. Simpler, lower-curvature closures (such as the electron) would require fewer committed distinguishability relations and therefore have lower mass; more complex composite closures (such as the proton) would require larger n_C and therefore greater stabilization energy. This is a programme claim — the explicit mapping from closure topology to observed mass values requires the companion closure geometry calculations and is not asserted here as a completed result.

Appendix E. Spin as Topological Double-Cover Symmetry of Closure Structure

Note: This appendix defines the topological structure that generates spin within the VERSF closure framework. The argument connects the closure representation space to the standard mathematical origin of fermionic spin, grounding the physical result in the topology of the committed distinguishability graph Σ rather than asserting it.

In the VERSF framework, closure structures are configurations of committed distinguishability relations embedded in the directed graph Σ. The question of spin is the question of which representation space closure subgraphs inhabit under the rotation symmetry group.

The rotation group of three-dimensional space is SO(3). However, SO(3) is not simply connected: it has fundamental group $\pi_1(SO(3)) = \mathbb{Z}_2$. This means that a closed loop in SO(3) — a 360° rotation — cannot be continuously contracted to a point. Since physical rotations of closure configurations in Σ are represented in ordinary three-dimensional space, the relevant base symmetry is SO(3); and since SO(3) has a unique nontrivial double cover, SU(2) is the minimal representation space for fermionic closure classes — not an arbitrary choice but the unique simply connected group that covers SO(3).

The covering map $p : SU(2) \to SO(3)$ satisfies $p(U) = p(-U)$ for all $U \in SU(2)$, so that two distinct elements of SU(2) correspond to each rotation in SO(3).

Closure configurations that transform under SU(2) representations satisfy:

$$\psi(\theta + 2\pi) = -\psi(\theta)$$

A 360° rotation returns the closure to its negative; only after a full 720° rotation does the configuration return to its original state. These are the spinor representations — fermions.

Closure configurations that transform under tensor representations of SO(3) directly satisfy:

$$\psi(\theta + 2\pi) = +\psi(\theta)$$

and return after a single 360° rotation — bosons.

The logical structure within VERSF is therefore:

closure topology in Σ → representation space → SU(2) or SO(3) → spin-½ or integer spin

The VERSF contribution is to ground the physical distinction between fermionic and bosonic closures in the topology of the committed distinguishability graph Σ, rather than imposing spin as an external attribute. Quantum statistics follow as a corollary: fermionic closures acquire a sign change under exchange of identical structures (Pauli exclusion), while bosonic closures acquire no sign change (Bose–Einstein statistics).

The present paper identifies the relevant representation-theoretic distinction — SU(2) spinor versus SO(3) tensor representations — but does not yet derive which specific closure topologies in Σ realize each case. That derivation requires an explicit classification of closure subgraph symmetry classes, which is reserved for the companion VERSF paper on closure geometry. The argument here establishes that the representation-theoretic framework within which this distinction would arise has the correct mathematical form; the mapping from closure topology to representation class is the next step.

Appendix F. A Necessary Local Capacity Criterion for Confinement

Note: This appendix defines the capacity stability condition that produces quark confinement as a structural consequence of the VERSF framework. The argument replaces a simple global cardinality comparison with a local capacity field condition, which also addresses why quark closures cannot borrow stability from neighboring regions.

In the VERSF framework, distinguishability capacity is not a global pool but a locally distributed quantity. Define:

- **$N_{BCB}(x)$** = the local BCB capacity field: the maximum number of stable committed distinguishability relations supportable per unit region at position x
- **$n(x)$** = the local closure density field: the number of committed relations actually required by the closure configuration at x

A closure C is locally stable if and only if:

$$\int_C n(x)\,dx \leq \int_C N_{BCB}(x)\,dx$$

This is the **local capacity stability condition**. It requires that the distinguishability demand of the closure be met by the capacity available within the closure's own spatial support — not by borrowing from external regions. Borrowing distinguishability capacity from external regions would produce an open commitment boundary, violating the closure condition C1 required for admissible record stabilization. Admissibility requires that commitment events form self-consistent, closed record structures; any closure whose stability depends on external capacity is therefore inadmissible by definition.

For an isolated quark closure C_q:

$$\int_{C_q} n(x)\, dx > \int_{C_q} N_{BCB}(x)\, dx \quad \text{(unstable)}$$

For a composite three-quark baryon closure C_{qqq}:

$$\int_{C_{qqq}} n(x)\, dx \leq \int_{C_{qqq}} N_{BCB}(x)\, dx \quad \text{(stable)}$$

The three sub-closures together close the distinguishability topology, eliminating the open-boundary excess and allowing the composite structure to remain within its local capacity budget. The same logic applies to quark–antiquark meson closures, where the combined topology is closed.

The paper here identifies a necessary structural condition for confinement, modeled as a local capacity stability criterion imposed by the distributed BCB field — not as an additional dynamical rule, and not claimed here as a full dynamical derivation. The integral condition above is a necessary stability criterion: it identifies which closure configurations are admissible and which are not, but the full dynamical account of how confinement is enforced through commitment evolution is reserved for the companion VERSF papers on closure dynamics. This criterion complements the entropic confinement results developed elsewhere in the programme.