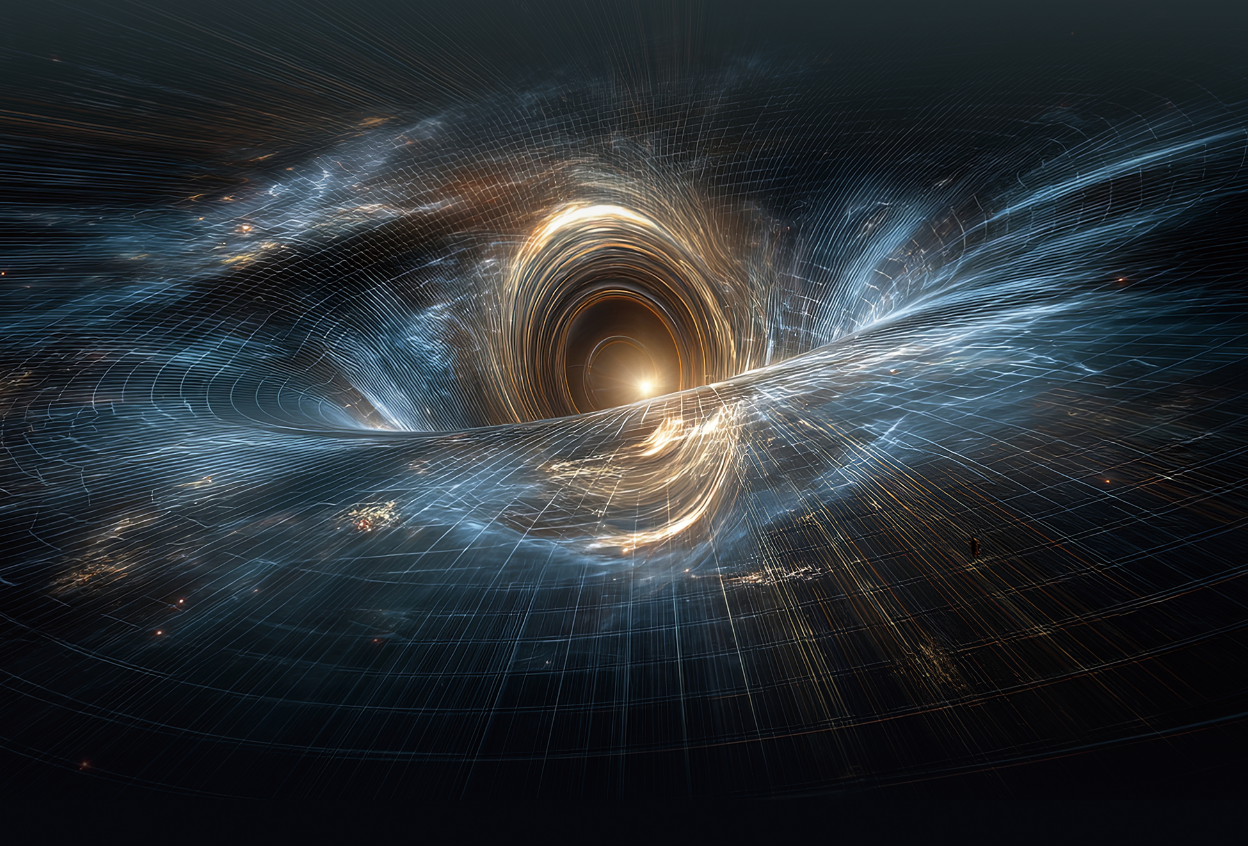
Beyond Curved Spacetime: A Unified Modal Foundation for Physics

Thomas P. Connelly, Jr.



Scientific Research Publishing

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Published by
Scientific Research Publishing, Inc.
ISBN: 979-8-89507-615-6
Word Count: 113,000 words
Publication Date: 2026-06
http://www.scirp.org

Dedication

To my children, Thomas, Eavan, and Onora:

Though we have been apart for many years, you have never been absent from my thoughts. This work was written during a long and difficult journey, and the hope of one day finding my way back to you has been a quiet source of strength throughout it.

In searching for the structure of the universe, I was also searching for a path forward. Wherever life takes us, you remain the reason I keep going.

Acknowledgments

The author gratefully acknowledges the staff and community of the Perry Point Veterans Affairs Medical Center in Maryland. During a difficult period of transition, their professionalism, patience, and compassion provided the stability that made the completion of this work possible. Special thanks to social worker Doreen Rupp for her kindness, encouragement, and practical support.

The author thanks the Global Center for Advanced Studies (GCAS College Dublin), Creston Davis, PhD, and Fernando Tohmé, PhD for their intellectual support and openness to interdisciplinary scholarship.

The author acknowledges the use of AI-based tools in preparing this manuscript. Editorial review was provided by Galatea (ChatGPT, OpenAI); additional editorial assistance by Claude (Anthropic). Responsibility for all claims, derivations, and conclusions rests solely with the author.

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Author’s Note

Science is skeptical by design. That skepticism is not a flaw—it is the mechanism by which ideas are tested and refined. History offers many examples of progress that lagged behind discovery: when a new structure does not yet fit established language, recognition can fall behind understanding.

Consider the relation

$$E = mc^2$$

Before it is a rule of conversion, it is a statement about structure. Read structurally, the equation already separates three roles. There is something that acts: Energy is not static; it is what transforms, what drives change, what brings possibility into effect. There is something that persists: mass carries structure forward, resists change, endures. And there is something that constrains how change can occur: the constant c, the invariant speed of light, sets the condition under which any influence can propagate, defining the horizon within which events can affect one another.

In this book, these roles are named:

Execution—that which actualizes change;

Memory—that which persists as structure;

Interaction—that which mediates transformation and propagation.

This triad does not replace physics. It makes explicit a structure already implicit within physics—and traces the consequences of taking that structure seriously from the beginning. No prior commitment to this framework is required. My invitation is simply to follow the structure where it leads, and to consider the possibility that what follows is a clarification of something that has been present all along.

Scope of This Work

This work proposes a foundational domain reformulation: a reconceptualization of the ontological substrate from which physical theories are constructed. It does not attempt a full reconstruction of all known physics within the main text. Selected quantitative results—the neutrino mass scale, the dark-to-visible ratio, the CMB spectral index, the MOND acceleration threshold, the Weinberg angle—are presented as exemplars of structural closure: cases in which the forcing chain from the domain declaration reaches a precise, parameter-free consequence. Additional formal developments, including the complete gauge derivation and the continuum limit, are deferred to appendices and identified as open derivations in the Conclusion. The manuscript is intended to be read as a structural argument first and a compendium of derivations second. A skeptical reader is encouraged to evaluate the forcing chain before assessing any individual numerical result.

This work contains three classes of results. First, fully derived results presented in the main text: the forcing chain from the null state through the EIM triad, dodecahedral backbone, and spectral invariants to the regime architecture and neutrino mass formula constitutes the primary structural argument, with each step following from the constraints established by the previous. Second, results derived with supporting formalism in Chapter 7 and Appendix A: the topological stability of the closure indicator, the Conservation Completion and Relational Completion theorems, the temporal asymmetry theorem, and the orbit-to-fermion identification, all of which are stated with proof sketches and follow directly from the domain constraints. Third, structurally indicated results whose complete formal derivation is deferred: the continuum limit recovering the Einstein-Hilbert action and the Dirac Lagrangian, the explicit dynamical mechanism connecting $A_5 \times \mathbb{Z}_2$ to the continuous gauge algebra SU(3)×SU(2)×U(1), and the equations of motion for σ as a field-theoretic order parameter. These open derivations are identified explicitly in Appendix B and the Conclusion, and are maintained in the author's technical companion work. The reader is encouraged to evaluate the framework first at the level of its forcing chain, and then at the level of individual quantitative outcomes.

Preface: The Beginning

Every physical theory begins with an implicit domain declaration: the universe is a collection of objects moving through space and time. This assumption is so embedded it does not appear in the postulates of any theory. It is the ground on which the postulates stand.

Spacetime is not directly measured as a primitive; rather, it is inferred from measured relations—distances between things, durations between events, correlations between states. In standard formulations it functions as an assumed structural container, a habit of thought so useful for so long that it has calcified into an unexamined ontological premise.

General relativity made the container dynamic. Spacetime could curve, stretch, and expand—a radical revision of Newton, but the essential structure was preserved: there is still an assumed background stage, however flexible. Quantum mechanics revealed that at small scales, sharp trajectories dissolve into probability distributions, positions are indefinite until measured, and interactions are discrete. The smooth curves of general relativity become incompatible with this granular structure. When physicists attempt to apply the tools of one theory in the domain of the other, mathematics breaks. Infinities appear that cannot be removed. Two theories, each exactly right in its own regime, refuse to coexist within the same framework.

This is not a technical failure in the ordinary sense. It is a structural diagnosis. The incompatibility is located not in the calculations but in what both theories assume before the calculations begin. Each theory is formulated in terms of states and their rates of change—snapshots, not the accumulated coordination history that brought a system to its present condition. The breakdown between them reflects this shared omission.

This book goes back and declares the domain properly. **Figure P.1** summarizes this domain-declaration shift.

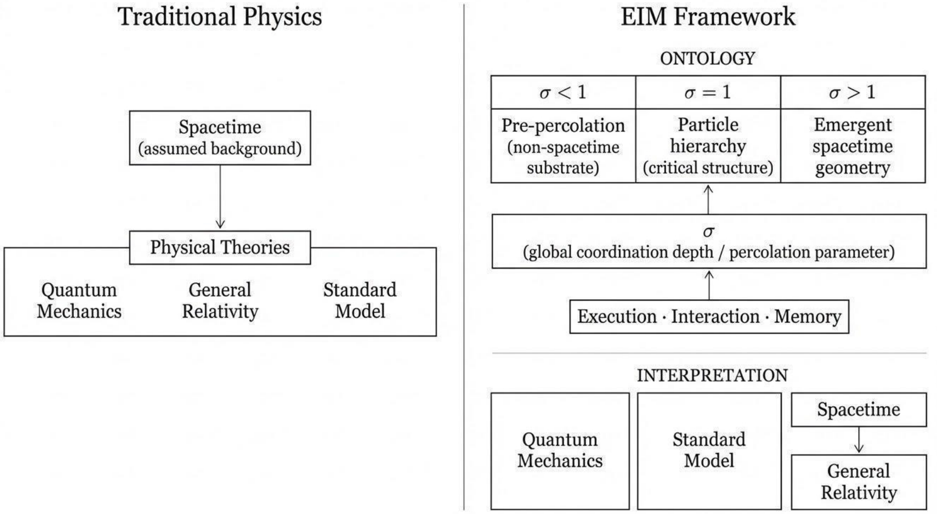

Figure P.1 The domain-declaration problem and its resolution. Standard physics presupposes spacetime as background, leaving the underlying domain implicit. Within the EIM framework, a coordination domain (Execution-Interaction-Memory) is declared explicitly, from which physical regimes emerge as σ-regimes: quantum mechanics (σ < 1), Standard Model onset (σ = 1), and general relativity (σ > 1). This supports the claim that GR and QM are not independent frameworks but regime limits of a single coordination process.

A brief word on how to read what follows. This is not a popular summary and not a specialist monograph. It is a structural argument developed step by step. Some sections introduce formal mathematics; each such section is preceded by a conceptual statement of what is being shown and followed by an explanation of what it means. A reader who encounters unfamiliar formalism should not stop—the argument is carried by the structure, and the formalism confirms it; each step establishes the necessity of the next.

The Argument of This Book

The argument proceeds in five steps.

First: Physics has not formalized its domain declaration. Every theory assumes objects moving through space and time without deriving that assumption. Making it explicit is the first step of the EIM framework.

Second: The apparent incompatibility of GR and QM reflects the fact that each is formulated within its own regime without identifying the common substrate from which both emerge. Within EIM, both are recovered as limiting cases of a single coordination process—each exactly right within its own regime.

Third: The correct foundational domain is the triad, Execution-Interaction-Memory. These three primitive conditions—something happening, something relating, something persisting—are the minimal structural requirements for any physical description to be possible. Space, time, and spacetime are not primitives of this domain; they emerge from the coordination process these three conditions define.

Fourth: Spacetime is an emergent property of sufficiently deep coordination. General relativity, quantum mechanics, and the anomalous gravitational behavior catalogued as MOND are not separate phenomena requiring separate explanations. They are three regime limits of a single coordination process, distinguished only by the coordination depth σ. Deep coordination within the realized cylinder ($1 < \sigma < \kappa$) yields classical spacetime and GR as an asymptotic effective description; critical coordination at $\sigma = 1$ yields the Standard Model particle spectrum; shallow coordination ($0 < \sigma < 1$) yields quantum behavior at low depths and MOND-like dynamics near the percolation boundary. The two long-standing theories do not conflict. They describe different positions on the same continuum.

Fifth: The domain closes under conservation of Memory. Because the coordination cycle carries nontrivial holonomy, return is not identity: each completed cycle leaves an irreducible residue. This residue cannot be locally eliminated—it must be carried forward. This requirement defines Memory not as an added feature, but as a structural necessity: the conserved record of prior coordination. Finite propagation makes coordination possible; Memory conservation makes it persistent. Together they enforce a single, globally consistent process in which all physical structure is expressed. **Figure P.2** traces this sequence as a constrained descent from the null state to the observable regimes.

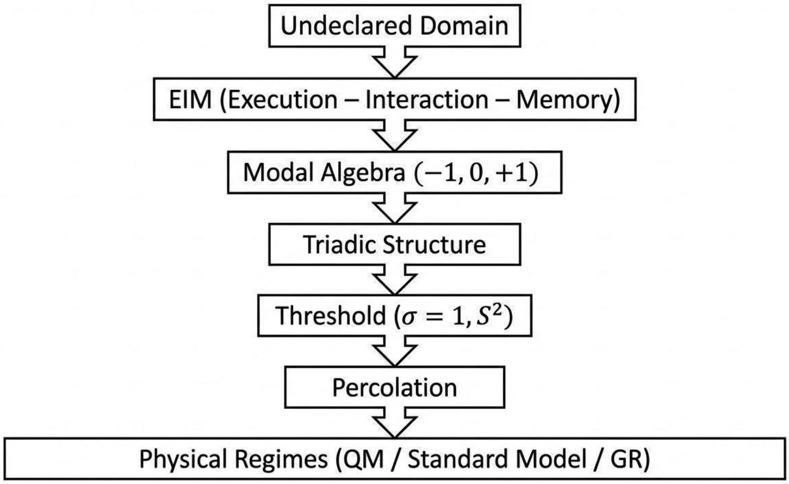

Figure P.2 The argument as a constrained sequence from undeclared domain to observable regimes. Beginning from the null state, the structure descends through domain specification (E-I-M), modal distinction, minimal symmetry-breaking, threshold geometry ($\sigma = 1$, S^2), and global percolation. This establishes that the physical regimes are not independent frameworks unified after the fact, but structurally forced positions along a single derivation chain.

The Minimal Geometry of Distinction

The framework admits a direct geometric representation. Before any formalism, the core argument can be stated through a single visual object—not an illustration of the theory, but its minimal geometric realization.

Distinction requires two states. Two states define an axis. The minimal question is then: what is the simplest geometric structure that connects two distinguished states while sustaining coordination between them? The answer is constrained from the outset. Each state, resolved under triadic coordination, does not remain a point—it becomes a sphere, the isotropic set of all possible interaction directions at that limit. The problem reduces to: what structure connects two spherical boundaries with minimum non-degenerate coordination between them?

The discrete realization of this structure is a dipyramidal coordination solid: a central region bounded by symmetric connections converging toward each pole. The transverse geometry is governed by triadic closure, which produces an irreducible ratio—$\frac{\sqrt{3}}{2}$—that prevents collapse to a line. This same ratio is the unique value under which the coordination solid can tile space without remainder. The number that prevents local degeneracy is identical to the condition for global consistency. This identity is a structural invariant: the same coordination constraint, expressed at two different scales. Locally, it appears as the irreducible projection deficit of ternary closure; globally, it appears as the exact compatibility condition for non-degenerate tiling. Same number. Different regime.

In the limit where longitudinal extent at the poles vanishes, only angular structure remains. The endpoints become spherical boundaries—precisely the threshold at which coordination first becomes globally enforced ($\sigma = 1$). What persists between them is a region of sustained coordination. Under coarse-graining—averaging over local discrete orientation—the structure resolves into a smooth cylindrical geometry bounded at each end by a spherical limit. The axis of the original binary distinction becomes the axis of that cylinder. Spacetime is not assumed as a background. It is the minimal continuous realization of coordination between distinguishable states.

The chapters that follow derive each component of this structure from first principles. This section does not establish those results. Its purpose is to give the reader a single visual object (**Figure P.3**) to carry through the argument—a reference point that will become progressively more precise as the derivation unfolds.

What This Framework Commits To

Because the EIM framework makes its foundational commitments explicit, it cannot avoid their consequences. The following commitments are structural

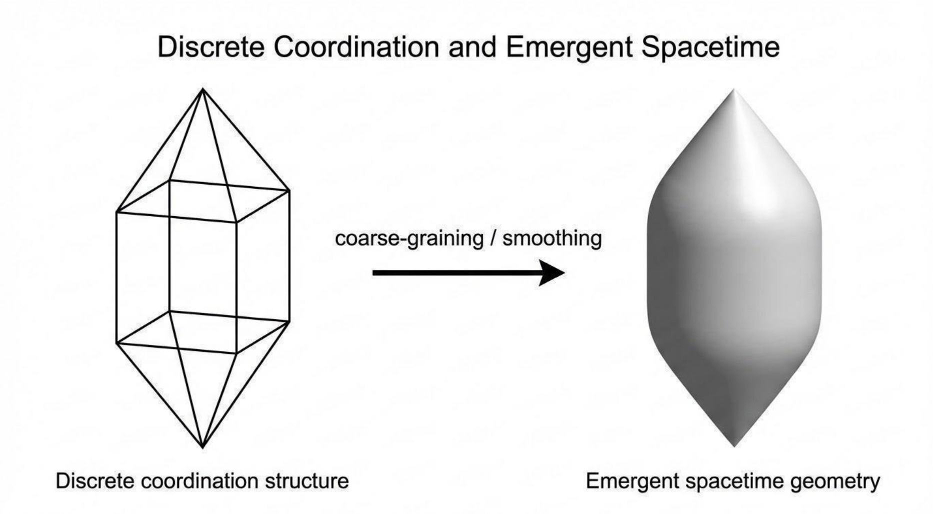

Figure P.3 A discrete coordination solid (left) and its coarse-grained limit (right). The discrete form satisfies triadic closure with irreducible transverse ratio $\frac{\sqrt{3}}{2}$—simultaneously preventing local collapse and permitting global space-filling without remainder. In the limit of vanishing longitudinal extent, the endpoints resolve as spherical boundaries (σ = 1) and the intermediate region becomes a smooth cylindrical geometry. This is the minimal geometric realization of emergent spacetime within the EIM framework.

results, not additional assumptions.

- Unification of GR and QM is achieved by identifying both as regime limits of a single coordination process—no additional degrees of freedom required at the level of fundamental ontology.
- ΛCDM parameters are emergent quantities rather than fundamental inputs. The effective behavior attributed to dark matter arises as a regime effect of subcritical coordination depth ($0 < \sigma < 1$), following a scaling relation determined by coordination structure, rather than particle

abundance.

- The percolation threshold $\sigma = 1$ is fixed by dodecahedral backbone geometry and is not a free parameter. Physical transitions associated with decoherence and the emergence of classical structure exhibit the signatures of a critical phenomenon, as the framework predicts.

- The lightest neutrino mass is structurally constrained by the backbone geometry to a narrow range, with a representative value of approximately 2.34 millielectronvolts (meV) derived under the idealized conditions presented in Chapter 7. No parameter is adjusted to obtain this value; it follows from the spectral invariants of the dodecahedral backbone.

- Within the EIM framework, proton decay does not occur at any observable or asymptotic timescale. The closure indicator $\chi = 1$ is a topological property of the fermionic orbit (Topological Stability theorem, Chapter 7). No continuous mechanism within the framework can change χ from 1 to 0 without a structural discontinuity. Proton stability is therefore a topological consequence within this framework—not subject to violation by higher-order operators so long as the backbone structure is maintained.

- No physical process is strictly memoryless. The Return-Residue Principle (Chapter 7) establishes that every coordination process leaves a nonzero holonomy residue. The Markov approximation is always an effective description—valid when accumulated Memory varies slowly, not because Memory is absent. Systematic departures from Markovian dynamics must appear in any regime where coordination history is actively shaping system behavior.

The Dark Matter Ratio as a Structural Prediction

The EIM backbone cycle rank $\beta_1 = 11$ decomposes into two irreducible sectors forced by the backbone's internal symmetry:

- $\beta_1^I = 5$ (Interaction sector—carries coordination content coupling to electromagnetic and weak propagation: visible matter)
- $\beta_1^M = 6$ (Memory sector—carries coordination content that is gravitationally active but electromagnetically inert: dark sector)

The base ratio of sector cycle counts is 6/5 = 1.2. Weighting each sector by its coordination depth contribution across the backbone yields a predicted dark-to-visible density ratio of approximately 5.4. The step from the 6:5 cycle-rank ratio to the 5.4:1 density ratio follows from weighting each sector by its mean coordination depth across the backbone (Memory-sector cycles accumulate deeper coordination per cycle by virtue of the antipodal map acting as +I on the Memory sector); the full calculation is provided in the author's technical companion work. This ratio is consistent with the observed cosmological value $\Omega_{\text{dark}}/\Omega_{\text{visible}} \approx 5.3$ (Planck Collaboration, 2020).

This ratio is not a free parameter. It is a structural consequence of the backbone's $A_5 \times \mathbb{Z}_2$ symmetry: the antipodal map ι acts as +I on Memory cycles and −I on Interaction cycles, so the ±1 eigenspace split of ι is precisely the dark/visible partition. The Memory/Interaction split is not imposed on the backbone—it is read off it.

This prediction is directly falsifiable: if the observed dark-to-visible ratio were established to lie outside the range consistent with the sector decomposition, the framework fails at this point. The machinery behind this claim—the backbone cycle decomposition, the $A_5 \times \mathbb{Z}_2$ symmetry, and the sector assignments—is developed in Chapters 5 and 7; readers encountering it here for the first time may wish to return after completing those chapters.

Chapter 1.
The Domain Problem

There is a question that precedes all of physics and has not received a formal answer—not because physicists are incurious, but because the question has rarely been asked with formal precision. The question is this: *what kind of thing is the universe, before we start describing it?*

The standard answer—implicit in virtually every physical theory ever written—is that the universe is a collection of objects moving through space and time. The objects change; space and time do not. They are the container, the background against which everything else is measured. This assumption is so deeply embedded it does not appear in the postulates of any theory. It is the ground upon which the postulates stand.

Within standard formulations, spacetime is inferred rather than directly measured. Experiments establish relationships—distances, durations, correlations—and the container is an inference that has calcified into an unexamined ontological commitment.

When physicists attempt to describe the universe itself—its origin, its large-scale structure, the regime before the first particles formed—they deal with a system whose current state cannot be understood without its history, because the history is not incidental. It is constitutive. The coordination of the system—the accumulated Memory of every interaction since its inception—is not background noise. It is the signal. A theory that operates on instantaneous states must measure and insert by hand everything that coordination history would explain—which accounts structurally for why ΛCDM requires multiple free parameters to fit the CMB.

The Forcing Chain

Begin with the least you can assume. Not spacetime. Not particles. Not laws. Not even the concept of a physical system. Begin only with this: *a distinction obtains*. Something is the case rather than nothing. One condition holds rather than another. This is the minimal non-null state—not an object, not a process, not a geometry, but the bare fact that a difference exists.

The minimal form of that difference is not a local distinction between two positions (which would already require a notion of locality). It is a global topological asymmetry: a structure that is locally uniform but globally nontrivial, because it contains an orientation reversal that cannot be removed by any local transformation. The minimal nontrivial topology is $\mathbb{Z}_2$—the unique structure satisfying one reversal followed by one restoration, with no smaller nontrivial group available. Everything that follows is a consequence of this single departure.

A distinction that is never enacted is indistinguishable from no distinction at all. If nothing actualizes it—nothing selects one condition over another, nothing makes the difference effective—then the distinction collapses back into the null state it was supposed to depart from. For a distinction to persist as a distinction, something must enact it. Call this enactment Execution. It is not a force, not a field, not an energy in the technical sense.

It is the minimal condition that must be satisfied if a distinction is to be real rather than merely formal: *something must be happening*.

An enactment with no relational structure has no way to be specified. There is nothing relative to which its state can be defined, nothing against which a difference can be measured. A distinction enacted in total isolation is no distinction at all. For Execution to produce a genuine distinction, it must be relational: it must involve at least two positions, and it must mediate between them. Call this mediation Interaction. This is not a choice or an interpretive addition. It is the condition required if Execution is to mean anything other than a self-contained point that cannot be observed, described, or connected to anything else.

The third question is whether Interaction can be non-retentive—whether it can occur and leave nothing behind. If each interaction dissolves completely, with no residue and no constraint carried forward, then the next interaction has no record of the previous one. The system has no structure. It cannot accumulate a history, cannot stabilize a pattern, cannot be described by any law—because laws are precisely the record of how prior states constrain present ones. A universe of interactions that retain nothing is a universe that can never become anything—not because it lacks activity, but because it lacks the consequence of activity. For Interaction to produce persistent structure, it must leave a retained constraint. Call this retention Memory. Without Memory, neither Execution nor Interaction can produce anything that endures long enough to be called physical.

Execution, Interaction, Memory. These are not a model proposed for convenience. They are the minimal conditions required for anything to exist and persist. Each follows from the insufficiency of the preceding condition alone. The triad is irreducible in the strong sense: it is not a partition of a single concept but a minimal set of ontologically distinct conditions.

Why three? The constraint falls directly from the logic of description. A description needs something to describe—a process occurring, an event happening. That is one. It needs those events to stand in relation to something else, because an event with no relationship to anything cannot be observed, measured, or distinguished from nothing. That is two. And it needs the record of prior events to persist, because without persistence there is no identity, no law, no structure—only an endless sequence of disconnected occurrences. That is three.

Two is not enough. A description with only Execution and Interaction—activity and relation, with no Memory—would be a universe that forgets itself completely at every instant. No atom could persist. No orbit could stabilize. No structure of any kind could accumulate. The laws of physics are themselves a form of memory: the record that nature carries of how things have behaved before.

Remove Memory from the description and you remove the laws. You are left with noise.

A fourth quantity is not independently required. Everything else in the physical description—time, space, mass, charge, spin—is either a combination of these three, a regime of them, or something that emerges from their interplay.

Three structural clarifications. First, the claim of minimality is structural, not classificatory: the three terms are not a convenient grouping of phenomena under three headings but the smallest set of ontologically distinct conditions required for any process of becoming. Remove any one and the other two become either inoperative or definitionally incomplete. Second, Interaction cannot be reduced to ignorance about a determinate outcome; Execution cannot be reduced to deterministic propagation; Memory cannot be reduced to the mere occurrence of Execution. Each names a genuinely distinct modal condition—an ontic difference in the structure of the world. Third, Execution is conditioned by accumulated Memory. The accessible field defined by Interaction is shaped by what Memory has already fixed, and Execution operates over that shaped field.

Finite Propagation and the Coordination Threshold

Having established three modes, a further question immediately arises: under what conditions can interactions become globally coherent rather than remaining trapped in isolated local clusters?

If Interaction were instantaneous and global—if every enactment were immediately felt everywhere—then the notion of a distinct relational position would dissolve. Everything would be simultaneous, and distinction would collapse into global identity. For distinct positions to remain distinct, influence must propagate at a finite rate. This is not a postulate borrowed from relativity. It is a structural requirement: without a finite propagation rate, the relational structure that Interaction is supposed to provide cannot exist.

Once Memory is retained and propagation is finite, a new quantity becomes meaningful: the degree to which retained constraint has accumulated into a globally connected structure. Local Memory can exist in isolated pockets—a cluster of coordinated nodes that have built up a shared history without yet connecting to the rest of the system. The question is whether those local accumulations have linked into something that spans the whole. That degree of global expression of accumulated Memory is what the framework calls coordination depth, denoted σ. It is not a parameter measured and inserted—it is a consequence of the prior two conditions.

As coordination accumulates, there is a moment when a spanning path first exists—when locally accumulated Memory first connects into a structure that links every part of the system to every other. This is not a gradual transition. It is a threshold: either a spanning path exists or it does not. Below this threshold, constraint is local. At and above it, constraint is global. The laws of physics as ordinarily experienced—the smooth geometry of spacetime, the stable structure of matter, the coherence of large-scale physical behavior—are the expression of a system that has crossed this threshold and sustained the crossing. The threshold is not chosen. It is the structural consequence of what it means for locally retained constraint to become globally enforced. Within this framework, it is fixed at $\sigma = 1$ by the geometry of the coordination backbone.

$$\sigma = 1$$

The Null Boundary and the Origin of Mass

Within the forcing chain, a special limiting case demands attention. Consider a mode that participates in Execution and Interaction but accumulates no Memory—a process that enacts and relates but retains nothing, deposits no coordination record, carries no history forward. With nothing to carry, such a mode does not resist change, because resistance comes from carrying a coordination history. It follows the path of least resistance under finite propagation: the boundary trajectory, tracing the edge of what the coordination structure permits without entering it.

All zero-Memory propagation trajectories trace the same geometric boundary. That boundary is a sphere—not assumed from geometry, but derived as the surface defined by the condition $M = 0$ under finite propagation. Everything that propagates without accumulating Memory lies on this surface. Everything that accumulates Memory lies inside it.

This is the origin of the null structure: the boundary between propagation and persistence, between massless and massive. The speed at which that boundary propagates is fixed by the coordination structure itself—by the geometry of the backbone, not by measurement or convention. Within the EIM framework, mass is not treated as a primitive property that particles happen to carry. It is derived as the degree to which a mode deviates from the zero-Memory boundary—the amount of coordination history it carries, the depth to which it sits inside the null surface rather than on it. A mode with no Memory sits on the boundary and propagates at the invariant rate. Inertia is the persistence of coordination history—the resistance to change that comes from carrying a record of where the system has been.

The Regime Architecture

Coordination depth σ determines which effective regime governs any physical system. This parameter does not measure Memory directly—it measures the degree to which accumulated Memory has been globally expressed. Formally, σ is defined as the fractional size of the giant connected component of the coordination graph: the proportion of nodes participating in the largest Memory-bearing cluster, normalized to unity at the percolation threshold.

The subcritical regime ($\sigma < 1$) contains two structurally distinct sub-regimes. The ignition limit ($\sigma \to 0^+$) is the structural ground of quantum indeterminacy in its most primitive form: no Memory architecture of any kind exists to select a definite configuration. The quantum sub-regime ($0 < \sigma < 1$) has finite Memory-bearing clusters with local coordination coherence, but no cluster spans the system—no global metric can form. This is the MOND sub-regime at its upper edge:

not “less quantum” but structurally different—local coordination coherence without global metric emergence.

At $\sigma = 1$ exactly, one spanning path exists but is sparse and fractal, with local topology deviating from smooth Euclidean structure. A smooth Riemannian metric requires path redundancy: any two nodes must be connected by many independent coordination paths. Only when this redundancy is sufficient does the continuum approximation become valid. This is the $\sigma \geq 1$ regime—the realized cylinder ($1 < \sigma < \kappa$) where path density is high enough that fluctuations average out, the $1/\sigma$ corrections to the continuum description become small, and what remains is a smooth, differentiable structure—the effective metric $g_{\mu\nu}$. General relativity is the $\sigma \to \infty$ asymptotic description of the cylinder, always approached and never exactly realized.

The three coordination regimes, their Memory status, and their physical interpretations are collected in **Table 1.1**.

Table 1.1 Memory Regimes and Percolation Structure

Coordination Depth (σ)	Memory Status	Physical Interpretation
$\sigma \to 0^+$	No Memory-bearing clusters	Ignition limit. No structure. Not a stably realized physical state.
$0 < \sigma < 1$	Local, non-spanning Memory clusters	Quantum regime. Probabilistic behavior; no global constraint; no metric. MOND-like behavior at upper edge.
$\sigma = 1$	Memory at critical threshold; first spanning path	Standard Model threshold. Decoherence onset; stable mass activation; spacetime description first becomes possible.
$1 < \sigma < \kappa$	Global, persistent Memory; increasing path redundancy	Realized cylinder. GR exact in deep-coordination limit. MOND at lower edge.

$\sigma \to \kappa = 55\varphi^2$	Approach to maximal coordination	Upper cone asymptote. Black holes prevent global approach to κ. Structurally required as limit; not stably inhabited.

Table 1.1 The parameter σ governs a percolation transition in the EIM domain. The critical point $\sigma = 1$, fixed by backbone geometry, marks the logical onset of global constraint.

Figure 1.1 represents the cyclic relationship among the three modes directly. The directed triad—Execution enabling Interaction, Interaction enabling Memory, Memory enabling the next round of Execution—is the minimal coordination unit from which all subsequent structure is derived; every physical regime is a regime of this cycle at a particular depth σ.

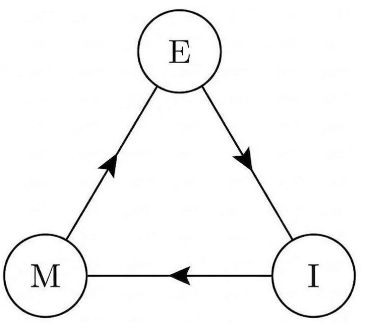

Figure 1.1 The EIM triad: Execution, Interaction, and Memory as a cyclic coordination structure, each mode enabling the next. This establishes the minimal ontological domain from which physical regimes emerge as σ-regime limits, supporting the claim that all three standard frameworks (QM, SM, GR) are expressions of a single underlying coordination cycle.

Figure 1.2 shows how this cycle organizes across the full range of σ. Where **Figure 1.1** depicts the local coordination unit, **Figure 1.2** maps the global domain: the lower cone corresponds to the pre-percolation substrate (the ignition limit), the cylinder to the physically realized domain where spacetime and stable matter are present, and the upper cone to the asymptotic approach toward the coordination horizon κ. The $\mathbb{Z}_2$ axis-symmetry reflects the orientation-reversal holonomy established in the forcing chain.

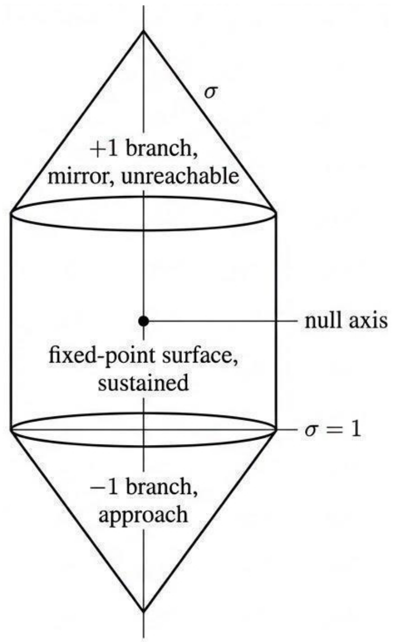

Figure 1.2 The cone-cylinder-cone as a $\mathbb{Z}_2$ structure: the null state at the axis, the lower cone approaching the fixed-point surface from below, the cylinder as the sustained percolation threshold, and the upper cone as the formal mirror branch. This supports the claim that the physical universe is one branch of a global orientation flip, with σ = 1 as its only crossable boundary.

The Special Role of Memory

Execution, Interaction, and Memory are co-equal at the level of the domain. None is reducible to the others. However, they do not contribute symmetrically to what is observed.

Execution drives change. Interaction distributes it. Memory accumulates it. Of these, Memory plays a special role in the emergence of structure. It is the only mode that persists. It is the only mode that carries history forward. And it is the only mode that can stabilize constraints across time.

Memory is monotonic locally: it does not decrease along any coordination trajectory, because each traversal deposits a holonomy residue that cannot be retracted. Memory is conserved globally: the total coordination residue across the network is preserved—not created or destroyed, only redistributed. The first gives time its direction; the second ensures that structural capacity is never lost, only relocated.

What we ordinarily call "matter" is stabilized Memory: persistent coordination structures that carry the consequences of prior interactions forward in time. Mass is the quantitative expression of this persistence—Memory made inertial. Science has always been concerned with persistent objects—atoms, bodies, fields—the "stuff" that endures and can be measured. But what endures is not a primitive substance. It is accumulated coordination.

The Central Claim

This book's central claim is not that space, time, or matter are illusory. It is a claim about how they interrelate—as derivative expressions of a single underlying coordination structure, constrained by finite propagation. The claim is analogous to that made by statistical mechanics about temperature: once temperature is understood as an emergent property of molecular motion, thermometers do not become obsolete. Knowledge of the underlying structure deepens rather than displaces the effective description. What changes is understanding—one knows what is being measured, and where the concept ceases to apply.

Spacetime is not discarded but reinterpreted. It is an emergent property of sufficiently deep coordination—of systems in which Memory has accumulated to the point that a stable geometric description becomes available. General relativity remains exactly correct within its domain: wherever local coordination depth is within the realized cylinder regime and classical structure has fully percolated. Its boundary appears where coordination depth is subcritical—at very small scales, very early times, or in regions of sparse gravitational coordination. The geometry does not break. It simply has not yet formed.

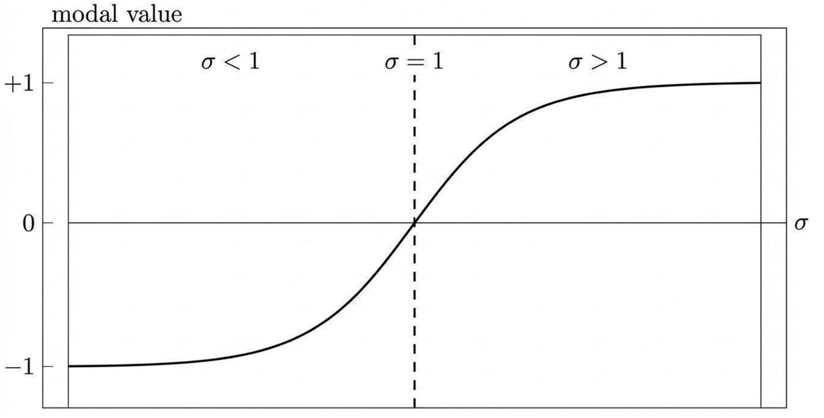

Figure 1.3 The Existence Curve: the logistic trajectory of a coordination system approaching $\sigma = 0^+$ from above and H_κ asymptotically from below. The inflection at $\sigma = 1$ marks the percolation threshold where system-spanning coordination first becomes possible. The curve is not fitted—it follows from the backbone dynamics and the spectral gap γ^c.

Three interpretive consequences of the regime architecture deserve explicit statement.

General relativity and its domain. In the EIM framework, general relativity is the correct description of a system whose coordination depth σ is within the realized cylinder regime ($1 < \sigma < \kappa$)—the only regime in which Memory has accumulated deeply enough to organize a stable, smooth geometric description. Its apparent breakdowns at singularities and at the Planck scale mark the boundary of the regime in which its assumptions hold—not failures of the underlying physics, but the signature of a description applied outside its domain.

Quantum mechanics and its domain. Quantum mechanics is the natural description of systems whose coordination depth falls within the pre-percolation regime ($0 < \sigma < 1$)—the regime in which Memory clusters exist locally but have not yet organized into a spanning constraint. The lower bound is the Planck boundary

($\sigma \to 0^+$): below it lies only the ignition limit, the structural ground that precedes any stable coordination substrate. Its apparent breakdown at the classical transition marks the upper boundary of the regime in which its assumptions hold—not a failure of the underlying physics, but the signature of a description applied outside its domain. EIM provides the structural reason decoherence works: Memory accumulation is the percolative mechanism of classicalization. The probabilistic character of quantum mechanics is not a mystery—it is the observable signature of a system whose accumulated Memory has not yet organized into a spanning constraint.

Decoherence as rapid percolation. Within the EIM framework, decoherence is not modeled as a collapse of the wave function. It is the abrupt transition of a coordination network across its percolation threshold—the moment at which locally stored Memory becomes globally constraining. The structural account is developed in Chapter 2.

The Cone-Cylinder-Cone as a $\mathbb{Z}_2$ Structure

The structure just established—null as fixed point, S^2 as boundary surface, mass as depth of Memory accumulation—has a direct cosmological expression. The cone-cylinder-cone diagram is not only a cosmological picture. It is a picture of the $\mathbb{Z}_2$ action itself.

The null state is the axis of an orientation flip—the unique fixed point of the minimal global asymmetry that constitutes the first distinction. The lower cone is the approach to that fixed point from the non-realized branch: coordination accumulating, Memory not yet global, the -1 branch of the $\mathbb{Z}_2$ orbit ascending toward its own fixed point. The cylinder is the fixed-point surface sustained—not a point but a condition, the percolation threshold held open by the regulatory action of black holes preventing accumulation beyond it. The upper cone is the formal mirror: the $+1$ branch reflecting back, real as a structural limit, unreachable as a physical state because traversing it would require passing through the fixed point in the outward direction, which is the same event that defines the null.

The physical universe—everything that exists, persists, and can be described—is one branch of a $\mathbb{Z}_2$ orientation flip, with the null at its axis, S^2 as its fixed-point surface, and the coordination threshold as the only boundary that can be crossed from either direction without contradiction.

The structure just described—three-mode domain, coordination depth parameter, regime architecture, and these interpretive consequences—admits a precise algebraic and geometric realization. That formalism is the subject of Chapter 2. It introduces nothing new in substance; it makes exact what has been said here conceptually.

Empirical Discriminants of the Framework

The following results serve as empirical discriminants of the EIM framework. Each is a structural consequence of the dodecahedral backbone geometry; none is a fitted parameter. A finding that any of the starred items lies definitively outside the stated range would constitute a falsifying result at the level indicated.

- Lightest neutrino mass scale: ~2.34 meV (structurally constrained; testable by KATRIN and next-generation beta-decay experiments). A measured value exceeding ~100 meV at high confidence would require revision of the backbone spectral derivation.
- Sum of neutrino masses: ~60.9 meV (testable by Euclid and DESI cosmological surveys). A measured sum below ~50 meV or above ~80 meV at 3σ would discriminate against the three-generation orbital assignment.
- Dark-to-visible density ratio: ~5.4:1, arising from the $A_5 \times \mathbb{Z}_2$ eigenspace decomposition ($\beta_1 = 5 + 6$). A ratio definitively inconsistent with the 6:5 cycle-rank split would falsify the sector decomposition.
- CMB spectral index: $n_s \approx 1 - \gamma^c \approx 0.9653$, where $\gamma^c = \frac{3-\sqrt{5}}{22}$ is the backbone spectral gap. The Planck measurement of 0.9649 ± 0.0044 is consistent at 0.09σ.

- MOND critical acceleration: $a_0 = 5\gamma^c c H_0$, expressed entirely in backbone sector constants with no fitted parameters; the formal closure of the projection step joining γ^c, c, and H_0 at the percolation boundary is developed in the author's technical companion work. Empirical deviations from this scale relationship at the galaxy percolation boundary would constrain the subcritical regime derivation.
- Proton stability: no decay at any timescale. The topological stability of $\chi = 1$ within the realized cylinder is a discrete $\mathbb{Z}_2$ invariant. Any confirmed proton decay event would falsify the fermionic closure topology.
- Decoherence as percolation transition: the framework predicts that decoherence timescales should exhibit the scaling behavior of a percolation transition near threshold. Systematic departures from Markovian dynamics are structurally expected in near-threshold coordination environments.

These discriminants are developed with full derivations in Chapter 7 and summarized in **Table 7.2** and **Table A.1**. The framework stands or falls as a unit: the same backbone constants (β_1, γ^c, H_κ, φ) that determine the neutrino mass also determine n_s, a_0, and the dark matter ratio. Agreement across multiple independent observables therefore constitutes convergent rather than independent confirmation.

Chapter 2.
The Mathematical Foundation

Chapter 1 declared the EIM domain in conceptual terms and established the forcing chain from the minimal global asymmetry through Execution, Interaction, and Memory to the coordination threshold and the origin of mass. This chapter makes that structure exact. The derivations supporting these results appear in full in Chapter 7 and Appendix A; here we present the essential structural results with enough precision that the conceptual content is unambiguous.

The Ternary Modal Algebra

The minimal nontrivial global asymmetry is $\mathbb{Z}_2$—orientation reversal. Consider its action on any line: it maps every element x to −x. This action has exactly one fixed point: zero, the unique element invariant under negation. Every other element belongs to a two-element orbit $\{x, -x\}$. The minimal set resolving the full orbit structure—including the fixed point and one representative from each orbit class—is $\{-1, 0, +1\}$. This is the ternary modal algebra, and it is not chosen. It is the minimal ambient resolution of the $\mathbb{Z}_2$ action on a line.

Modal 0 assigned to Interaction is not incomplete knowledge about a determinate outcome. It names the structural condition of genuine two-sided openness—the locus at which neither branch of the $\mathbb{Z}_2$ orientation has been selected. A purely epistemic reading of modal 0 would make Interaction eliminable: more information would in principle collapse it to either +1 or −1. The algebraic argument excludes this. Modal 0 is the fixed point of the $\mathbb{Z}_2$ action—structurally forced, not contingent. The three modal values are distinct in kind: Memory is closed constraint, Interaction is genuine openness, Execution is the transition between them.

The fundamental set is thus:

$$+1, 0, -1$$

This is the complete modal algebra—three values forced by the logic of a threshold description. Every physical regime, every particle, every geometric structure in this book is an expression of how these values combine and propagate through a coordination structure.

The Projection Deficit

The co-equality and minimality constraints together force a unique geometric configuration. Co-equality requires equal pairwise separation among the three modes; minimality requires the lowest-dimensional faithful representation. These two requirements select a single object: the equilateral triangle, with pairwise inner product $-1/2$ and mutual angular separation $2\pi/3$.

For any chosen edge e of this triangle, the third vertex lies off the resolving axis. By $\mathbb{Z}_3$ symmetry of the equilateral triangle, the perpendicular distance from the third vertex to e is invariant under choice of edge. A direct application of the Pythagorean theorem gives:

$$\Delta_{\text{loc}} = \frac{\sqrt{3}}{2}$$

Definition (Projection Deficit). Let T be the unit equilateral triangle forming the minimal faithful representation of the EIM triad. For any chosen edge e of T, the projection deficit is the irreducible orthogonal component required to recover the third vertex from the resolving axis:

$$\Delta_{\text{loc}} = \frac{\sqrt{3}}{2}$$

By the $\mathbb{Z}_3$ symmetry of T, this value is invariant under the choice of edge. It is a structural invariant of the triad, not a parameter.

The projection deficit is not a measure of approximation error or a coordinate artifact. It is the structural remainder of ternary closure under binary projection:

the irreducible component of the third mode that lies outside any pairwise resolving axis and cannot be eliminated by any refinement of the two-mode description. Under finite propagation, this component cannot be resolved globally in a single step. It must be transported forward. This transported, irresolvable transverse component is Memory in its dynamical sense: a monotonically growing quantity that records what finite propagation has deposited and cannot retrieve. **Figure 2.1** illustrates the underlying triadic projection geometry.

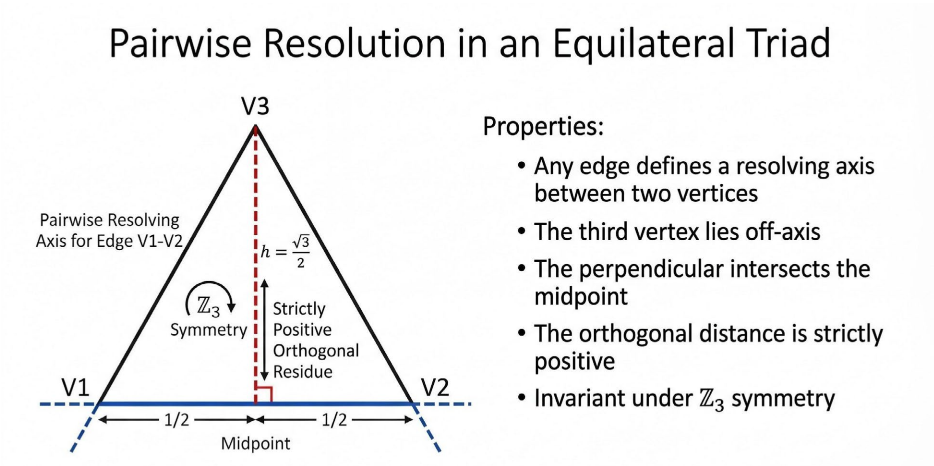

Figure 2.1 Pairwise resolution in an equilateral triad. The third vertex lies off every resolving axis, generating an irreducible orthogonal defect h = $\frac{\sqrt{3}}{2}$—a $\mathbb{Z}_3$-invariant residue that no pairwise resolution can eliminate. This structural remainder is the formal origin of Memory as a dynamical quantity: the transported, irresolvable transverse component that finite propagation deposits and cannot retrieve.

The requirement that this deficit be transported consistently across the coordination network imposes a global consistency condition. The transverse eigenspace V_t of the traversal operator P_3 carries quaternionic structure $j = iK$—forced by the reality of P_3: since P_3 is a real operator on the mode triad, its eigenspace structure carries a canonical complex-conjugation symmetry K on the transverse fiber. The group of $\mathbb{C}$-linear automorphisms preserving j is exactly SU(2) ≅ Sp(1). Within the EIM framework, the SU(2) gauge symmetry of the interaction sector arises as the unique structure-preserving transport group for the projection deficit—a consequence of coordination consistency, not an independent postulate.

The Möbius Holonomy

The modal assignment $\{+1, 0, -1\}$ assigns a signed value to each of the three modes. One full traversal E→I→M steps through values $+1 \to 0 \to -1$—a net sign reversal. This is the longitudinal component of the traversal: a $\mathbb{Z}_2$ (binary parity) structure in which one traversal flips the sign of the coordinated state and two traversals restore it. This is the same $\mathbb{Z}_2$ that generated the modal algebra, now expressed dynamically in the traversal of the triad.

The two components of a single traversal are complementary. The transverse component ($\Delta_{\text{loc}} = \frac{\sqrt{3}}{2}$) measures departure from closure in the plane orthogonal to the resolving axis. The longitudinal component (the sign reversal, or $\mathbb{Z}_2$ holonomy) measures the parity change along the resolving axis itself. Together they account for the full single-step action on the triad.

A closed orbit in the coordination backbone must contend with both. The minimal orbit satisfying the backbone constraints—trivalence, spherical closure, and non-degeneracy—has length five. Five is odd. Therefore the parity flip is unavoidable: a single traversal of the pentagon returns with orientation reversed.

Global Closure Theorem (working form). Under constraints of trivalent saturation (C1), ternary modal grading (C2), finite propagation (C3), monotonic Memory (C4), and non-degeneracy (C5): (i) the girth of the coordination graph is odd and at least 5; (ii) every minimal cycle carries nontrivial $\mathbb{Z}_2$ holonomy; (iii) the minimal fiber bundle over any minimal cycle is the Möbius band; (iv) identity restoration requires double traversal. The Möbius structure is the unique nontrivial element of $H^1(S^1; \mathbb{Z}_2) = \mathbb{Z}_2$.

The physical consequences follow directly. The $\mathbb{Z}_2$ holonomy on the minimal cycle is structurally identical to the covering map $SU(2) \to SO(3)$: one traversal reverses sign, two traversals restore, which is exactly the behavior of a 2π rotation in SO(3) acting on a spinor. Within this framework, a fermion is not characterized as a particle that happens to obey the exclusion principle but as a mode whose coordination cycle carries nontrivial Möbius holonomy.

The Dodecahedral Backbone

The local triadic structure, when extended across a coordination network, forces a unique global architecture. Three constraints must be simultaneously satisfied: (1) trivalent saturation—every active site carries exactly one channel per mode; (2) boundary closure on S^2; (3) girth at least 5—derived, not postulated, from the modal algebra and minimality/non-degeneracy conditions.

A finite trivalent planar graph with only pentagonal faces is uniquely constrained by Euler's formula:

$$V - E + F = 2, \quad 3V = 2E, \quad 5F = 2E$$

$$\Rightarrow (V, E, F) = (20{,}30{,}12)$$

This is the regular dodecahedral graph. No alternative trivalent planar graph satisfies all three constraints simultaneously. Under the combined requirements of trivalent saturation, pentagonal face structure, and closure on S^2, the dodecahedron is the unique admissible structure—selected by constraint, not by choice.

Three spatial dimensions emerge as a structural consequence at this point. The dodecahedron is a 3-connected planar graph, and by Steinitz's theorem it is the skeleton of a convex 3-dimensional polyhedron. Within the EIM framework, three spatial dimensions are not assumed as a primitive—they are the unique output of the requirement that a trivalent graph with Möbius holonomy close on S^2.

From this backbone, two spectral invariants follow immediately:

Cycle rank: $\beta_1 = E - V + 1 = 30 - 20 + 1 = 11$. This counts the number of independent closure degrees of freedom. It is a topological invariant, not a parameter. All subsequent uses of β_1 inherit this forced status.

Spectral gap:

$$\gamma^c = \frac{3-\sqrt{5}}{22} = \frac{1}{\beta_1\varphi^2} \approx 0.03472$$

where $\varphi = \frac{1+\sqrt{5}}{2}$ forced by pentagonal geometry. The appearance of φ is not numerology—it follows from the geometry of the forced backbone. The dodecahedron's faces are regular pentagons, and pentagonal geometry intrinsically contains the golden ratio. All subsequent uses of γ^c inherit this forced status.

The backbone's full symmetry is $A_5 \times \mathbb{Z}_2$. The eleven independent cycles decompose under A_5 as $H_1(\Gamma; \mathbb{R}) = V_M \oplus V_I$, where the antipodal map ι acts as +I on Memory cycles (V_M, dimension 6) and −I on Interaction cycles (V_I, dimension 5). This is the ±1 eigenspace decomposition of the backbone's own symmetry—not an imposed partition. **Figure 2.2** inscribes the underlying triadic projection deficit on the boundary surface S^2.

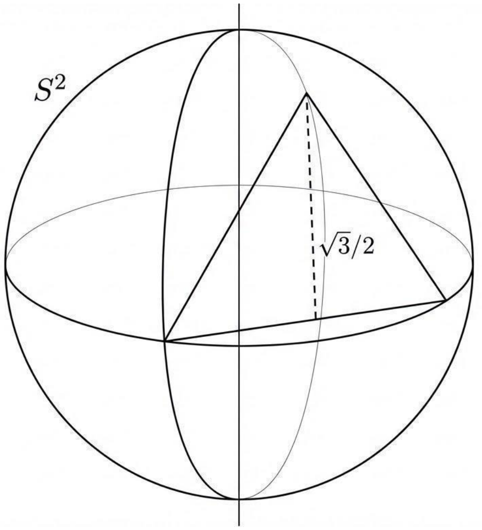

Figure 2.2 The irreducible projection deficit of the EIM triad, inscribed on S^2. The three co-equal mode vectors form an equilateral triangle; for any chosen base edge, the third vertex lies off the axis at perpendicular distance $\frac{\sqrt{3}}{2}$. This is the structural remainder of ternary closure under binary projection—invariant under all permutations of the vertices.

The A_5 Symmetry and Backbone Homogeneity

The rotational symmetry group of the dodecahedron is A_5—the alternating group on five elements, a group of exactly 60 rotations. A_5 acts on the twenty vertices transitively, moving them among themselves while preserving all edges and faces. The key consequence is homogeneity: because A_5 acts vertex-transitively, no vertex of the backbone is structurally special. Whatever is true at one vertex is true at all of them. This is not a symmetry imposed from outside—it is a symmetry the backbone carries by necessity, as a direct consequence of being the unique minimal structure satisfying the coordination constraints.

The eleven independent cycles decompose, under A_5, into irreducible families. The two families of five loops each—one associated with the Interaction sector, one with the Memory sector—are structurally identical representations of A_5. When two identical structures interact, Schur's Lemma states that the only coupling operator consistent with the symmetry is a scalar multiple of the identity. The coupling between the two sectors is therefore not a matrix with many free entries—it is a single coefficient. That coefficient is computed from the geometry of the triad—from the transverse component of the 120° rotation at each triad vertex, which gives $\sin(120^\circ) = \frac{\sqrt{3}}{2}$. This is the formal basis of the Weinberg angle derivation: $\sin^2\theta_W = \frac{1}{4}$ at tree level, falling out of the backbone geometry without any reference to experimental data. The Weinberg angle is therefore not measured and inserted—it is read off the backbone geometry at tree level. Radiative corrections running the value from 0.25 to the measured 0.231 are a standard consequence of renormalization group evolution, and their presence confirms rather than complicates the structural derivation.

Units and Calibration

At the foundational level, the EIM framework is entirely dimensionless. The modal algebra $\{-1, 0, +1\}$ and the triad of Execution, Interaction, and Memory are purely relational, containing no reference to any unit of measure. The framework produces only ratios and structural invariants.

To obtain numerical values in physical units, a single dimensional anchor must be specified. In this work, the electron mass serves this role. It does not introduce new structure—it selects the scale at which the dimensionless relations are expressed. As established in Chapter 7, the electron mass is itself substantially derived from backbone invariants (via the chain: backbone geometry → G → M_{Pl} → v_H → m_e), so its role as an anchor carries only a tree-level residual rather than representing a true free parameter. Setting ħ = c = G = 1 reflects the deeper fact that the underlying physics is dimensionless: the cosmos does not compute in meters or seconds, but in structure. Units enter only when we choose how to express the result.

Intuition: The Shape of Existence

The formal definition of existence rests on a simple geometric idea. Imagine walking a closed path—a loop—through a coordination structure and returning to your starting point. In a featureless, flat space, nothing changes: you return in exactly the same state you left. But in a structure with internal geometry, the act of traversal can leave a mark. You arrive back carrying a record of the path—a twist, an orientation reversal, a phase shift. That record is the holonomy. The definition says: a structure exists if and only if some loop through it produces a holonomy that cannot be removed. The twist is irreducible; it is a property of the structure itself.

What is the simplest structure that supports such a loop? The answer—given three constraints: that every vertex has exactly three edges, that the structure closes on a sphere, and that loops have the minimum length consistent with non-degenerate closure—is the dodecahedron. The minimum loop length turns out to be five. A five-step loop has an odd number of steps; and because the modal algebra assigns opposite signs to Execution and Memory, completing an odd loop inverts orientation rather than restoring it. That inversion is the nontrivial holonomy.

Holonomy and the Origin of Spin

The sign inversion associated with a single traversal is not a property of the forward sequence E→I→M alone, but of its closure. When the process returns to its initial structural role—E→I→M→E′—the system does not recover its original orientation. It returns with a sign inversion. This nontrivial return is the structural origin of what physics describes as fermionic statistics: a mode in which identity is preserved under iteration, but orientation is not, so that only a double traversal restores equivalence.

Fermionic modes are those that realize a closed, self-returning coordination cycle. They are localized, persistence-bearing excitations: they carry Memory as an owned structural state and therefore complete a nontrivial return under iteration. Because of this, they behave as discrete, countable units—what we ordinarily call particles of matter.

Bosonic modes, by contrast, do not carry such a closed return. Rather than persisting as independent units, they mediate or propagate coordination within the structure. Their role is transmissive or standardizing—more like signals or fields than objects—and they do not function as independent denominations of Memory.

Spin is therefore not determined by coordinate values alone. The fermionic or bosonic character depends on whether the excitation carries a closed Möbius-type holonomy class. A mode in which the Interaction sector mediates closure acquires the sign reversal and is fermionic; modes in which closure does not pass through the threshold role of Interaction remain unsigned and are bosonic.

Self-Referential Structure and the Origin of Time

The value 0 in the modal algebra corresponds to the symmetry limit—a state of perfect isotropy in which no distinctions can be made. The value +1 represents realized distinction. The value −1 represents inversion: the operation by which a system transitions while preserving structure but reversing orientation.

Existence cannot reside at the symmetry limit, as no distinctions are possible there. It must instead arise as a departure from symmetry. However, persistence requires that this departure not be arbitrary: the system must be able to return to its prior state in a way that preserves identity while maintaining distinction.

This requires a nontrivial return. A system that returns identically collapses distinction; a system that fails to return loses coherence. The minimal resolution is a return under inversion: the same structure revisited with altered orientation. This is the origin of temporal direction.

"Time" is not a background parameter against which structure evolves. It is the record of nontrivial self-reference—the distinction between successive realizations of the same structural role under repeated inversion. The cycle this generates carries an orientation-reversing holonomy, returning to the same position without restoring the same orientation—the intuition of a Möbius strip: traverse it once and you arrive back where you started, but upside down; only the second traversal returns you to your original orientation. Persistence is therefore not a feature layered onto structure—it is the consequence of a structural necessity. The minimal cycle required for self-referential distinction to return to itself has length two, and that length is temporal order. Time is not imposed from outside; it is what reality cannot avoid generating when it closes.

Decoherence as Rapid Percolation

Decoherence—the transition from quantum behavior to classical structure—appears in laboratory systems to be nearly instantaneous. The EIM framework provides a precise account.

Because local holonomy-bearing loops can already exist below the percolation threshold, the formation of a system-spanning cluster does not require the creation of Memory from nothing. It requires only the connection of already-existing local structures. The transition from a subcritical system—in which local coordination residue is present but unconnected—to a supercritical one—in which a spanning path first exists—is inherently abrupt. Percolation transitions are not gradual. They are threshold events: $\sigma = 1$ marks the logical onset of global connectivity, not a dynamical propagation. Once connectivity conditions are met, the transition is abrupt and structurally determined.

Decoherence is therefore best understood as a rapid percolation event: the moment at which locally stored Memory becomes globally constraining. Its apparent instantaneity is not a fundamental discontinuity in the physics but the observable signature of an abrupt transition from local to global enforcement.

The underlying propagation of this constraint remains finite, bounded by the causal speed c, but the transition proceeds at the fastest rate the interaction bandwidth permits. This reframing dissolves the measurement problem at its structural root. Decoherence is not a mysterious collapse of the wave function. It is a coordination network crossing its percolation threshold.

Definition (Existence). Let Γ be a coordination structure: a connected trivalent graph endowed with EIM dynamics. A coordination structure *exists* if and only if it exhibits at least one irreducible nontrivial holonomy—a cycle γ for which $\mathrm{Hol}(\gamma) \neq \mathrm{id}$ cannot be trivialized by any EIM-permissible refinement. A globally flat structure (trivial holonomy on every cycle) does not exist in this sense.

The dodecahedron is the unique minimal structure satisfying this condition under the coordination constraints. Existence is persistent irreducible defect. The irreducible holonomy residue is not a flaw in the structure. It is the condition of its persistence. **Figure 2.3** shows the corresponding temporal picture: Memory accumulates monotonically, with observed periodicity arising as the projection of irreversible accumulation onto closed angular representations.

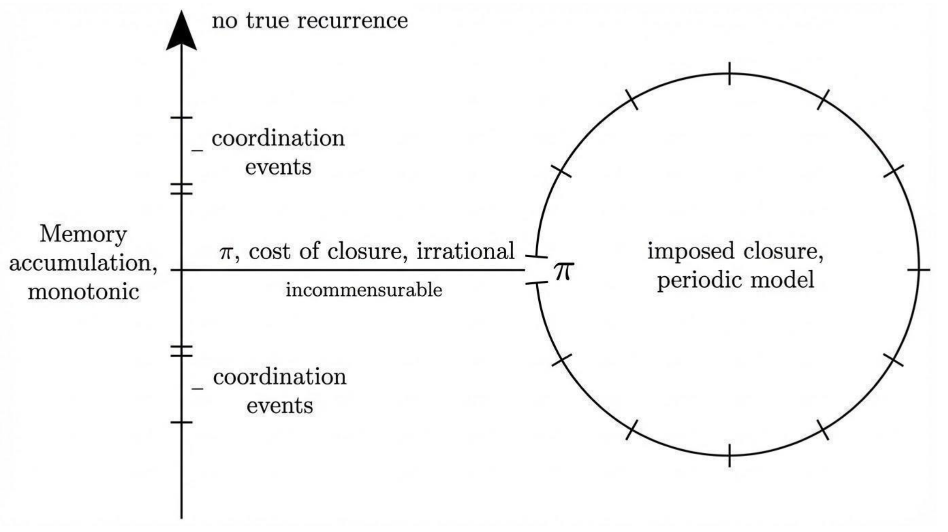

Figure 2.3 Memory accumulates monotonically; observed periodicity is the projection of irreversible accumulation onto closed representations. π appears here as a spectral invariant: the irreducible mismatch between linear Memory growth and angular closure. Its ubiquity in physics is a structural fact about bounded coordination systems.

Chapter 3.
The Snapshot Problem

Chapter 2 established the minimal geometry of the coordination domain. The present chapter establishes its dynamics—how coordination accumulates, how the threshold is approached, and why the standard differential framework of physics is structurally incomplete without the integral that Memory names.

Each traversal of the E→I→M cycle produces the transverse traversal defect $\Delta_{\text{loc}} = \frac{\sqrt{3}}{2}$—the per-step departure from closure established in Chapter 2 as a structural invariant of the triad geometry. Under finite propagation, this component cannot be resolved globally in a single step: the causal structure of the coordination network permits only local coordination at each node, so the residue must be transported forward rather than cancelled. The accumulation of these transported residues is Memory in its dynamical sense: a monotonically growing quantity that records what finite propagation has deposited and left unresolved at each traversal.

The parameter σ tracks the ratio of this accumulated quantity to active Execution and Interaction. The existence curve traces σ from near zero toward the percolation threshold at which global spanning first becomes possible. Finite propagation is not a kinematic constraint on an otherwise complete description—it is a structural one: it enforces path-dependence in the accumulation, forcing Memory to depend on the full sequence of traversals rather than on the endpoint alone.

The Snapshot Cannot See σ

The critical observation about the snapshot framework is this: it records only the present state, not the coordination history that produced it. This is precisely why the snapshot framework must measure and insert by hand what σ would explain.

The regime in which a physical system operates depends on the coordination depth σ—the ratio of accumulated Memory to active Execution and Interaction. Within the post-percolation regime ($1 < \sigma < \kappa$), locally deep coordination allows Memory to dominate and the system behaves classically, governed by the smooth geometry of general relativity. Where local coordination depth is subcritical—where Execution and Interaction dominate and coordination depth is shallow—the system behaves quantum mechanically. And where σ sits just above the percolation threshold but well below the deep-coordination regime—in systems of moderate scale with sparse global connectivity, such as the outskirts of galaxies—the effective gravitational behavior departs from the predictions of GR in a specific and calculable way.

That intermediate regime corresponds to what astronomical literature catalogues as the regime of galaxy rotation curves—where standard gravity reaches its domain boundary and the discrepancy has been attributed to dark matter or modified dynamics. The EIM framework shows it requires neither: it is the signature of shallow coordination depth, recoverable from the percolation structure without new postulates.

These regimes are not distinct domains but phases of a single process. The same structure governs each; what changes is the degree to which coordination is globally expressed. The snapshot description is not wrong—it is the correct description of a particular regime, the limit in which coordination depth σ is large enough that accumulated Memory can be treated as fixed background. The incompleteness is not random—it has a precise structure, a specific signature, and a natural remedy. That remedy is the subject of the chapters that follow. Science constructs rates of change from these snapshots. Differential equations—the backbone of virtually every physical theory—are precise statements about how one snapshot relates to the next. This is extraordinarily powerful. It is also, structurally, a derivative. It captures instantaneous change. It does not, by itself, capture history.

For a falling rock, history is irrelevant: position and velocity at this moment are sufficient regardless of how the rock got there. Classical mechanics earns its success precisely because for rocks, planets, pendulums, and projectiles, the snapshot is sufficient.

The universe is different. Every structure in the observable cosmos is the product of an unbroken chain of interactions stretching back to its origin. The large-scale structure is not a present state that happens to look the way it does. It is a record—Memory in the precise sense of Chapter 2—the accumulated consequence of every interaction since the beginning. When cosmologists look at the cosmic microwave background, they are not taking a snapshot of the present. They are reading a record: the tiny temperature fluctuations are the imprinted Memory of quantum processes that occurred before the first atoms formed, preserved across thirteen billion years because the physics of that transition encoded them into the geometry of the expanding universe.

The standard cosmological model handles this by introducing parameters—the density of dark matter, the cosmological constant, the spectral index—that are measured and inserted rather than derived. A theory that operates on instantaneous states must measure and insert by hand everything that coordination history would explain. In EIM, Memory is not a parameter to be measured but a primitive quantity in the dynamics: include the coordination history as part of the state, and those inputs become outputs.

Coordination Depth and the Regime Architecture

$$\sigma = \mathrm{M}/(\mathrm{E} + \mathrm{I}), \quad \text{normalized by the backbone structure;} \quad \sigma_c = 1$$

Coordination depth $\sigma = M/(E+I)$ quantifies the degree to which accumulated Memory has been globally expressed—not the raw amount of Memory in the system, but the ratio of retained constraint to active Execution and Interaction. Normalising by the backbone structure fixes the critical value at $\sigma c = 1$: the point at which the giant connected component of the coordination graph first spans the full backbone. Below this value, Memory clusters exist locally but do not connect into a system-wide structure. At and above it, global constraint becomes possible for the first time.

Three regimes organize around this threshold. In the subcritical regime ($0 < \sigma < 1$), Memory-bearing clusters are present but isolated: no stable metric can form, behavior is probabilistic, and a state-vector description cannot carry the coordination history that determines the system's effective regime. At $\sigma = 1$ exactly, one spanning path first exists—a sparse, fractal connectivity that marks the onset of the Standard Model threshold, where stable fermionic modes first become achievable and decoherence becomes structurally available. In the supercritical regime ($\sigma > 1$), increasing path redundancy supports the smooth continuum approximation: the discrete backbone coarse-grains into an effective Riemannian geometry and general relativity becomes the correct asymptotic description.

The parameter σ therefore does precisely what the standard snapshot framework omits: it carries the coordination history that no instantaneous state vector can record. What appears, from within the standard framework, as three incompatible theories—quantum mechanics, the Standard Model, and general relativity—is, within EIM, three positions on a single continuum parameterized by σ. The incompatibilities between those theories are not technical failures. They are the signature of descriptions whose domain boundaries coincide with the percolation threshold.

Memory as the Missing Integral

Consider what a physical measurement always captures. At any moment, an instrument records a value: a position, a momentum, an energy level. What the instrument cannot record is how the system arrived at that state. The accumulated history of interactions—the path through configuration space that brought the system to its present condition—is invisible to the measurement. The measurement is a snapshot: in the precise mathematical sense, a derivative, a rate of change at an instant. The integral, the coordination history, does not appear.

This structural feature of how physics is done arises independently of any limitation of instruments. Theories are written in terms of states and their rates of change. The past that shaped those states does not appear in the equations—assumed, without being declared, to have already been accounted for.

The Markov approximation is profound and useful. A glass of water has a temperature that tells you what the water will do next but not whether it was ice an hour ago. For most purposes, this does not matter. But the universe is different. Every large-scale structure is the accumulated consequence of every interaction since the beginning—a record that no instantaneous-state theory can derive. A theory that operates on snapshots must measure and insert by hand everything that coordination history would explain.

The Logistic Existence Curve

Once the coordination dynamics are properly formulated, the evolution of σ follows a logistic curve. Memory accumulation begins slowly in the early pre-percolation phase, accelerates through the threshold as local clusters connect, and then saturates as the backbone approaches its coordination horizon H_κ. The inflection point of this curve is at $\sigma = 1$—the percolation threshold—where Memory accumulation is maximized and the transition to classical structure is sharpest.

The logistic form is not imposed. It follows from the combination of the coordination dynamics (Memory accumulates in proportion to current accumulation, limited by coordination capacity) and the backbone geometry (which sets both the initial growth rate γ^c and the saturation limit H_κ). The same logistic curve that describes the emergence of spacetime from the pre-percolation substrate also describes the evolution of any individual coordination domain within the cosmos.

Principle—σ as Structural Condition. The physically realized universe is organized around $\sigma = 1$ as a structural condition of global coordination—not a value the system passes through on its way to a higher state, but the condition that defines the post-percolation regime as such. What appear as variations in σ are more precisely variations in local coordination environment: a global structural invariant (σ = 1) admits local effective values σ(x) reflecting position within the coordination network.

This is structurally analogous to the invariance of *c* in special relativity.

Proposition—Radiative Modes and the Invariance of c. A mode with M = 0 carries no persistence burden: it participates in Execution and Interaction without depositing a coordination record. Such a mode propagates at the invariant rate *c*.

The constancy of *c* is a structural consequence—anything with zero Memory burden must propagate at the coordination rate fixed by the trivalently saturated backbone. The photon's masslessness and the invariance of *c* are the same structural fact seen from opposite sides of the Memory coordinate.

The structural consequence of this threshold is represented directly in **Figure 3.1**. The three panels show the qualitative state of the coordination network at

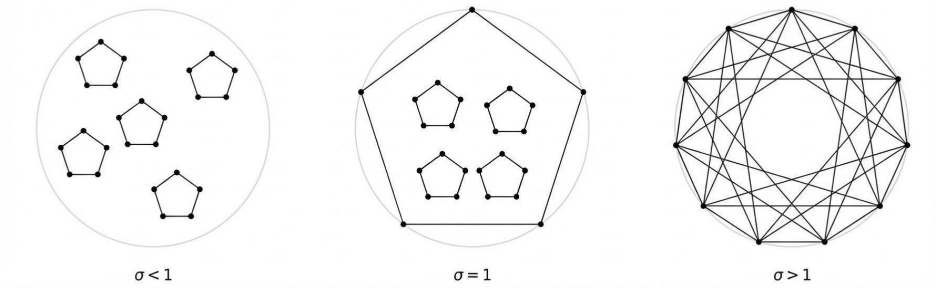

Figure 3.1 Coordination topology across three structural regimes, illustrating the emergence of a system-spanning component at σ = 1. Left (σ < 1): finite isolated clusters; no global constraint can form and no metric emerges. Center (σ = 1): the first spanning path appears—the percolation event marking the onset of global constraint and the Standard Model threshold. Right (σ ≳ 1): high path density supports the smooth continuum approximation and the effective metric gμν emerges. MOND phenomenology is located at the boundary between left and center panels.

each principal regime—subcritical, critical, and post-critical—corresponding, respectively, to the quantum domain ($0 < \sigma < 1$), the percolation event ($\sigma = 1$), and the realized gravitational domain ($1 < \sigma < \kappa$). The boundary between the left and center panels is also where MOND phenomenology is located: the regime in which effective gravitational coupling departs from its Newtonian limit because the coordination network has not yet achieved full spanning redundancy.

Figure 3.1 answers the question of what the coordination structure looks like at each regime. **Figure 3.2** answers a different question: how the transition between them occurs. The passage through $\sigma = 1$ is not a smooth crossover. It is a topological phase transition—the moment at which a system-spanning connected component either exists or does not. There is no gradual interpolation. This discontinuity is precisely what makes decoherence appear effectively instantaneous

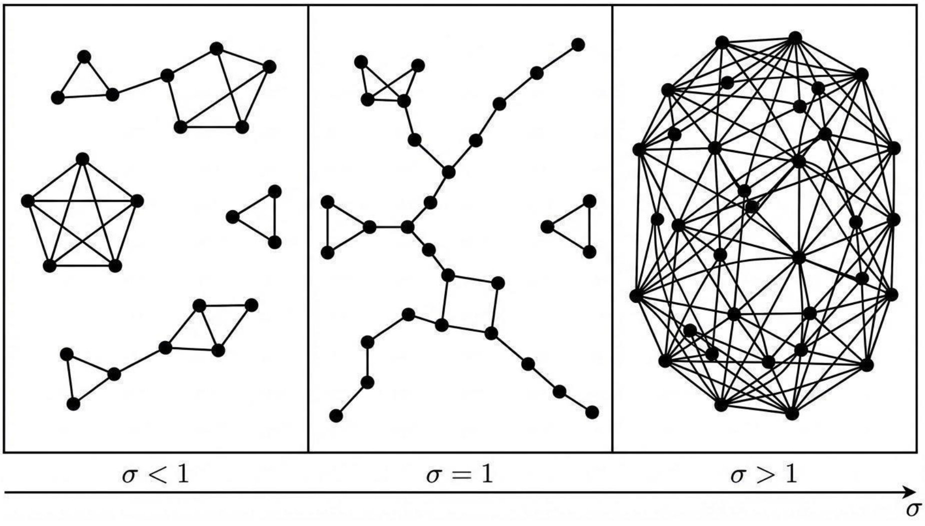

Figure 3.2. Coordination transition as a topological phase event. For $\sigma < 1$, all clusters are finite and isolated; no spanning structure exists. At $\sigma = 1$, a single connected component emerges discontinuously—not a gradual crossover but a threshold event. This structural discontinuity accounts for why decoherence appears effectively instantaneous and why the emergence of classical geometry is sharp rather than gradual.

in laboratory systems and why the emergence of classical geometry is sharp rather than gradual: the spanning structure either has closed or it has not.

Both figures concern the percolation threshold as a global structural fact. The next question is whether that threshold can be achieved uniformly—and the answer, forced by the backbone's holonomy structure, is that it cannot.

The S^2 Closure Problem and Necessary Boundary Defects

A perfectly isotropic S^2 closure would distribute Interaction uniformly in every direction. All return paths through the coordination network would become equivalent; no preferential channel for Memory accumulation would exist. Closure would be locally complete but globally sterile—Execution present, Interaction maximized, yet Memory unable to differentiate. No particle spectrum, no hierarchy of scales, no structured emergence would be possible.

This scenario is not merely undesirable—it is structurally excluded. The dodecahedral backbone Γ carries nontrivial $\mathbb{Z}_2$ holonomy: a single traversal of any pentagonal cycle returns with orientation reversed. S^2, by contrast, is simply connected: $\pi_1(S^2) = 0$, so every loop on S^2 is contractible. No continuous map from Γ to S^2 can preserve both adjacency and the $\mathbb{Z}_2$ holonomy class of every cycle. Uniform isotropic closure on S^2 would require precisely such a map. The S^2 closure problem is a theorem.

The resolution is the face structure of the backbone. The planar embedding of Γ in S^2 divides S^2 into exactly $F = 12$ connected open regions—forced by Euler's formula $V - E + F = 2$ applied to Γ. Each of these regions is a defect region: a connected open subset of S^2 in which no coordination cycle of Γ is supported. Their structural function: to break perfect isotropy, introduce directional asymmetry, allow unequal return paths, and thereby enable differential accumulation of Memory. Without topological incompleteness at the boundary—without defects—no persistent structure can form. The defects are not failures of the coordination process. They are the mechanism by which it avoids collapse into symmetric indistinguishability.

When a defect region deepens until $\sigma_{loc} \gg 1$ while the surrounding field remains subcritical, its boundary becomes a coordination horizon: no admissible coordination cycle can exit. This is the EIM structural definition of a primordial black hole. These are not rare anomalies requiring fine-tuned initial conditions. They are the natural extreme of the defect logic that prevents S^2 overconvergence—generically expected, not finely tuned.

Chapter 4.
The Horizon Problem

Chapter 3 established that coordination depth σ is the order parameter governing the transition from local to global Memory expression. The present chapter identifies the three apparent singularities of modern physics—the Big Bang, the Planck boundary, and the black hole interior—as the same structural constraint encountered at different scales.

Singularities as Domain Boundaries

Physics has three apparent singularities. The black hole interior, where GR produces infinities. The cosmological origin, where expanding backwards converges on infinite density. The Planck scale, where every quantum gravity attempt fails.

All three are places where the implicit assumptions of the framework are violated most severely. GR assumes a smooth spacetime manifold—at singularities, that manifold ceases to exist. The Big Bang is a temporal boundary, but time emerges from deep coordination; at the origin, there has been none. The Planck boundary is where the snapshot framework encounters the regime where history is constitutive.

Within the EIM framework, singularities are not features of the universe. They are artifacts of applying a regime-specific description outside its domain of validity—exactly as the ideal gas law applied at extreme pressures.

The Cosmic Origin

In EIM terms, the origin of the universe is the regime of maximal Execution, maximal Interaction, and vanishing *global* Memory. Local coordination residue may persist. What is absent is system-spanning enforcement—$\sigma = 0$ in the global sense.

Given maximal Execution and Interaction at ignition, the percolation threshold is not approached gradually from below—it is the first structural threshold the substrate encounters. What is not achieved—and cannot be achieved, because the founding Möbius defect prevents it—is global completion of percolation. Spacetime emerges immediately at the threshold; it never completes globally; and that incompleteness is the condition of existence itself.

The geometry that results from this structure is shown in **Figure 4.1**. Reading from base to top: the lower cone is the pre-percolation substrate ($\sigma < 1$), the regime of the cosmic origin where Execution and Interaction are maximal but no system-spanning Memory exists. The two circular boundaries at $\sigma = 1$ mark the

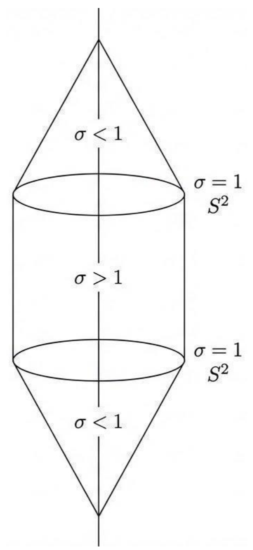

Figure 4.1. Cosmic coordination structure as a cone-cylinder-cone geometry. The lower cone ($\sigma < 1$) represents the pre-percolation substrate where coordination is not globally sustained; the circular boundaries mark $\sigma = 1$, the percolation threshold at which global connectivity first becomes possible; the cylinder ($\sigma > 1$) is the sustained coordination condition supporting stable spacetime as an effective description. This supports the reinterpretation of the Big Bang as the onset of the percolation threshold rather than a classical singularity.

percolation threshold—the first structural event, where global connectivity and stable spacetime become possible. The cylinder is the physically realized domain ($1 < \sigma < \kappa$): the regime of matter, geometry, and general relativity. The upper cone is the approach toward the coordination horizon κ—a limit the structure asymptotically approaches but, by the Möbius defect, never globally completes.

Figure 4.1 presents the structure at the cosmic scale—as an organization of σ across the full range of coordination history. **Figure 4.2** addresses what underlies it. The cone-cylinder-cone is a coarse-grained description; the left panel of **Figure 4.2** shows the discrete realization from which it emerges. The coordination polytope—a canonical discrete backbone satisfying the EIM constraints—becomes the cone-cylinder-cone under coarse-graining, shown in the right panel. Spacetime is not posited at the foundational level. It is what the discrete coordination structure looks like when averaged over scales large relative to the coordination lattice.

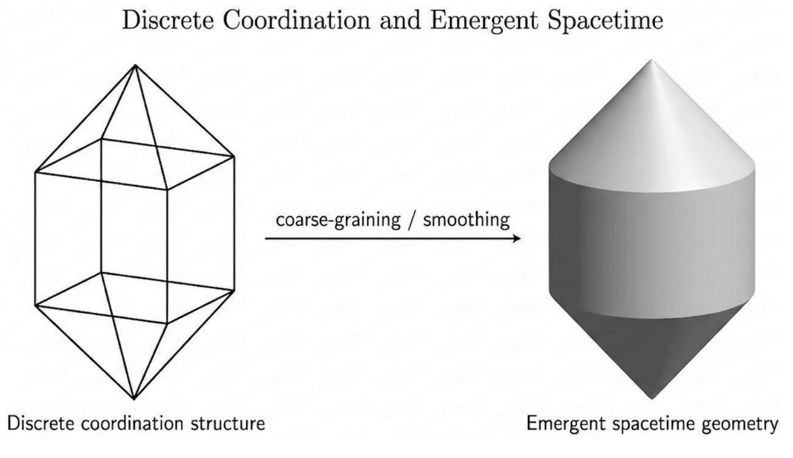

Figure 4.2. Discrete coordination structure and emergent spacetime. A canonical coordination polytope (left) provides a discrete realization of the underlying EIM backbone. Under coarse-graining, this maps to the cone-cylinder-cone form (right). The boundary between the two panels corresponds to the Planck scale—the threshold below which coarse-graining breaks down and the discrete backbone reasserts itself. This supports the claim that spacetime is an emergent description, not a primitive substrate.

The boundary between the two panels of **Figure 4.2**—between discrete coordination structure and continuous emergent geometry—is precisely the Planck scale. It marks the threshold below which the coarse-graining breaks down: the regime where the discrete backbone reasserts itself and the continuum description of GR ceases to apply.

The Planck Boundary

The Planck scale is the threshold below which coordination depth drops to where the continuum spacetime description gives way to the discrete pre-percolation regime—analogous to how fluid mechanics gives way to molecular dynamics at the mean-free-path scale. Asking what happens at the Planck scale using GR is like asking what the viscosity of water is at a temperature where water does not exist as a liquid. The question is malformed. A different description is required, appropriate to the actual regime.

The Black Hole Interior

The interior of a black hole is not a low-Memory system—it is the opposite: a system of extraordinarily high Memory, the accumulated record of everything that has ever crossed the event horizon. The event horizon is a boundary of vanishing external Interaction at near-maximum Memory.

This characterization reverses the standard picture in a precise way. In standard GR, the black hole interior is a region of diverging curvature leading to a physical singularity. In EIM, it is the region of maximum coordination depth: a site where accumulated Memory has concentrated to the point that no new coordination cycle can exit. The interior is not where physics breaks down—it is where the high-Memory regime reaches its structural extreme. The apparent singularity at the center is not a place where the EIM description fails; it is the point at which the high-σ description reaches the boundary of its domain, approaching $\sigma \to \kappa$ from below in the same way that the cosmic origin approaches $\sigma \to 0^+$ from above. Both boundaries are the same structural limit, encountered from opposite directions along the σ-axis.

Horizons as Local Percolation Boundaries

Let $D \subseteq G$ denote the exterior causal domain accessible to a given observer. A local percolation boundary is a surface across which the existence of a D-spanning coordination path changes character. A black hole horizon has precisely this role: events inside the horizon do not connect to D through future-directed propagating paths. The horizon marks where exterior-spanning connectivity fails.

The cosmological percolation threshold and the black hole horizon are both coordination-critical boundaries arising from the same condition that permits distinction while forbidding completion. Black holes are therefore not incidental late-time objects. They are the continuing local manifestation of the constraint that has governed coordination since $\mathfrak{p} = 0^+$.

The horizon is a Memory gradient: high M interior, vacuum-level M exterior. This gradient produces fluctuations at the boundary scale—Hawking radiation in standard terms; the thermodynamic consequence of a Memory gradient across a boundary with vanishing external Interaction in EIM terms. Memory is primitive in the domain declaration and cannot be destroyed, only redistributed—so the information paradox does not arise within this framework.

The Information Paradox Dissolved

The black hole information paradox arises when the Hawking process is described within a framework that treats information as a geometric property embedded in spacetime. If a black hole evaporates completely, and if its interior is a region of spacetime causally disconnected from the exterior, then the information carried by infalling matter appears to be permanently lost—violating unitarity.

In EIM, the paradox does not arise. Memory is primitive: it enters at the level of the domain and cannot be destroyed, only redistributed. Information that crosses the horizon increases interior Memory; Hawking radiation returns that Memory to the exterior through correlations in the emitted field over the lifetime of the system. The correlations are not encoded in individual quanta but in the relational structure of the radiation field as a whole—a consequence of Memory conservation, which is a domain constraint. Conservation follows directly from the primitiveness of Memory in the domain declaration. Black holes function as sites of information renormalization: collapse concentrates coordination history; evaporation redistributes it.

At extreme interior conditions, as matter is compressed, the regime reverses. Execution and Interaction approach maximal values while structured Memory breaks down. The system moves toward the pre-percolation state—not as an unphysical divergence to be cut off at the Planck scale, but as a smooth regime transition. The singularity at the center of a black hole is replaced, in the EIM description, by the same structural condition that characterized the universe at its origin: the $\mathfrak{p} = 0^{+}$ boundary of the non-null domain, approached from within. What general relativity reads as a singularity is the point at which the high-Memory description reaches the boundary of its domain. The equations do not break down because something physically singular happens. They break down because the framework has run out of regime.

The full black hole lifecycle: formation (Memory accumulates as infalling matter contributes coordination history while external Interaction drops to zero), quasi-stationary phase (Memory gradually released through the Hawking gradient), terminal state ($M \to 0$ while E and I approach maximal values—recovering the pre-percolation regime). As **Figure 4.3** traces, the full lifecycle runs from horizon formation through the Hawking gradient to the approach of $\mathfrak{p} = 0^{+}$, and the structural identity of the terminal state with the cosmological origin is visible directly in its geometry. A fully evaporated black hole returns to the same structural conditions from which persistent coordination first emerged.

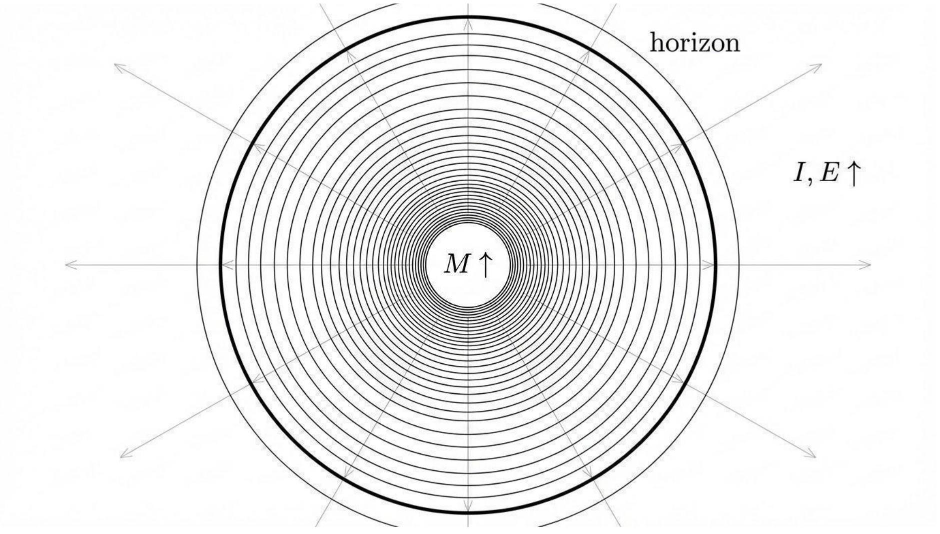

Figure 4.3 Black holes as Memory gradients within the EIM framework. The interior carries high accumulated Memory with suppressed external Interaction; the event horizon functions as a local percolation boundary; Hawking radiation equilibrates the Memory differential across that boundary. The terminal state of full evaporation approaches the pre-percolation substrate, structurally mirroring the initial coordination condition at cosmological ignition and supporting the information conservation claim.

The Three Singularities as One

$\mathfrak{p} = 0^+$: the limit of the non-null domain as it approaches the origin

∅ and $\mathfrak{p} = 0^+$ are two descriptions of the same boundary point—viewed from outside and within the domain of existence. GR singularities arise when a high-Memory description attempts to reach $\mathfrak{p} = 0^+$ using machinery valid only where Memory is deep.

The unification of the three singularities is not merely a classification. It has a structural consequence: none of them can be resolved by adding new degrees of freedom within the framework that generated them. A quantum gravity theory formulated on a smooth spacetime background cannot dissolve the Big Bang singularity, because the background presupposes a level of coordination depth that does not exist at the origin. A string-theoretic or loop-quantum-gravity cutoff at the Planck scale addresses the symptom—the divergence in the continuum description—without addressing the cause: the application of a high-σ description to a low-σ regime. Within EIM, the resolution is automatic: the three singularities are positions on the σ-axis where the description in use has run out of domain. The correct description at each position is EIM in the appropriate σ-regime. No additional postulates are required, and no new ontology is introduced.

The three apparent singularities of physics are not three separate problems requiring three separate solutions. They are the same structural constraint—the irreducible nontrivial holonomy that existence carries from $p = 0^+$ forward—encountered at cosmological, quantum, and astrophysical scales respectively. **Figure 4.4** makes this convergence explicit: GR descends from the realized cylinder, QM ascends from the pre-percolation substrate, and both meet at $\sigma = 1$.

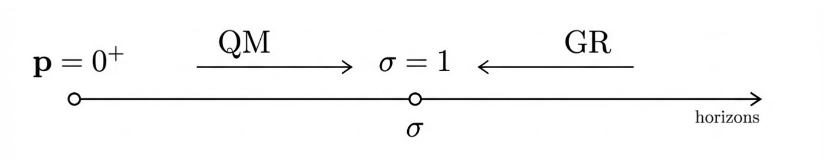

Figure 4.4. The common boundary of GR and QM. GR descends from the realized cylinder regime; QM ascends from the pre-percolation substrate. At σ = 1, the percolation threshold marks the onset of stable classical structure. The two frameworks do not conflict—they represent the same coordination process from opposite sides of a shared limit.

Structural Recycling

In standard thermodynamics, entropy is characterized as a monotonic progression toward terminal equilibrium. This characterization is structurally incomplete within the EIM framework.

Global saturation—the hypothetical state in which all coordination capacity has been concentrated and released without a renewal mechanism—is structurally equivalent to the null state ∅. Since the domain excludes ∅ as a persistent configuration, global terminal saturation is likewise structurally excluded within the EIM framework. The framework does not accommodate a universe that globally completes its coordination cycle.

The limit of maximal Memory accumulation and the limit of minimal persistent coordination are the same boundary, approached from opposite directions. The terminal state of a fully evaporated black hole and the initial state of cosmological ignition are structurally identical in EIM coordinates. The framework implies a structural recycling mechanism in which high-Memory states evolve toward low-Memory boundary conditions—a conservation and redistribution of coordination capacity rather than its destruction. **Figure 4.5** maps this cycle: σ climbs through accumulation, saturates locally into a black hole, and is returned to the substrate via Hawking evaporation, with the terminal state structurally identical to the ignition condition.

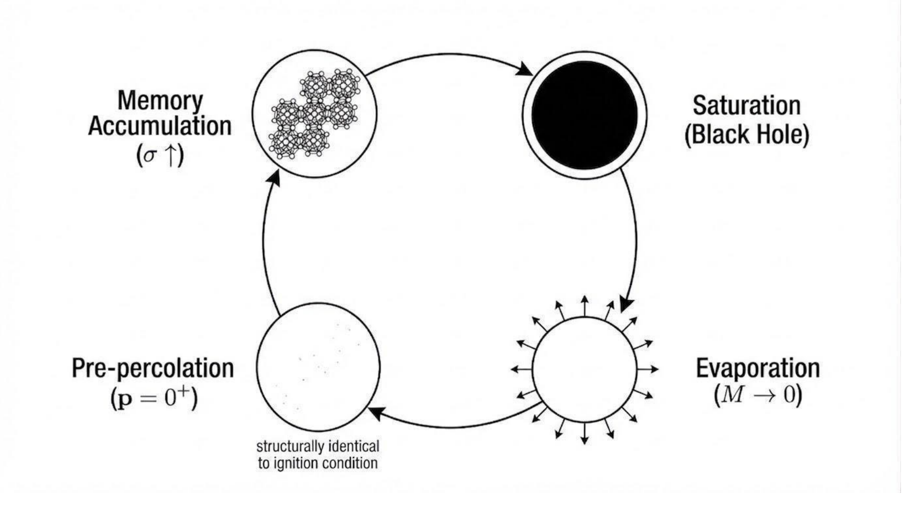

Figure 4.5. The structural recycling cycle. Coordination depth σ increases during accumulation as Memory is deposited through persistent interaction. Local saturation produces a black hole. Hawking evaporation reduces interior Memory toward M → 0, returning coordination to the substrate. The terminal state is structurally identical to the initial coordination condition at cosmological ignition.

The cone–cylinder–cone geometry represents the smooth large-scale limit of the coordination structure. The upper cone, in the physically realized universe, is replaced by a regulated extended cylinder populated by local black hole sites—as developed in Chapter 9.

Chapter 5.
The Currency of Matter

The preceding chapters established the coordination domain, its dynamics, and the three apparent singularities that arise when regime-specific descriptions are applied outside their domain. The present chapter turns to the question of matter: what the coordination structure produces, once the percolation threshold has been crossed, in the way of stable, discrete, persistent denominations. The question is not what matter is made of—as if matter were a primitive substance awaiting further subdivision—but what structural conditions a coordination process must satisfy in order to persist as a localized, countable unit. The answer is fully determined by the dodecahedral backbone and does not require any ingredient beyond what has already been established.

Matter as Stabilized Memory

A particle is a persistent structure that carries the consequences of prior interactions as conserved quantities—mass, charge, spin. These are what Memory looks like when organized into a stable, localized configuration.

The neutrino carries the minimum amount of Memory consistent with being a particle at all. Its mass—approximately 2.34 meV, structurally constrained by the backbone geometry under the idealized conditions of Chapter 7—is the smallest inertial value the coordination structure permits. The neutrino is the smallest coin in the denomination system.

At the other end is the top quark—the most massive fundamental particle known, carrying maximum Memory for a single fundamental particle. It exists only in the highest-energy environments and decays almost immediately.

The Higgs boson is not a denomination but the standard against which all other denominations are measured—the scalar vacuum Memory substrate of the universe. Every massive particle acquires its mass through interaction with the Higgs field; in EIM terms, through coupling to the vacuum Memory substrate the Higgs field represents.

The Dodecahedral Backbone and the Particle Spectrum

The regular dodecahedron—twelve pentagonal faces, twenty vertices, thirty edges—is the discrete coordination skeleton from which both matter and spacetime arise. Because the backbone contains exactly twelve minimal closure supports, the fermionic denomination structure is finite from the outset. The twelve fundamental fermions correspond to the twelve minimal closure orbits of the backbone—the structure shown in **Figure 5.1**, where A_5 vertex-transitivity enforces the homogeneity that makes no site structurally special and the girth-5 condition enforces the Möbius holonomy that makes every minimal cycle fermionic.

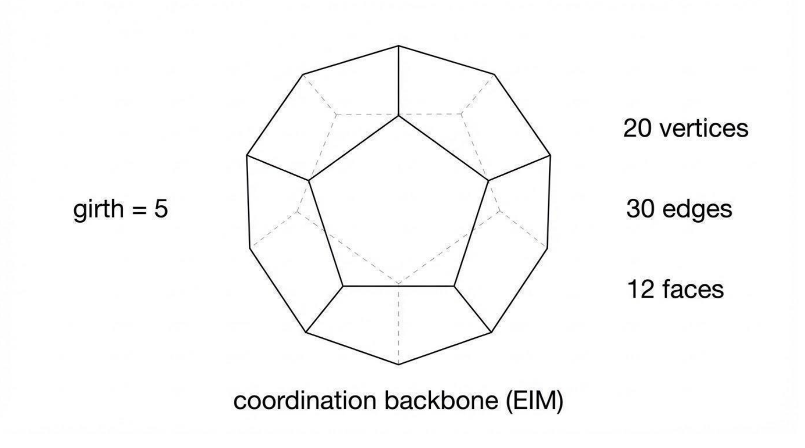

Figure 5.1 The dodecahedral coordination backbone: the unique three-dimensional structure forced by the EIM domain constraints. Its rotational symmetry group A_5 acts vertex-transitively, enforcing structural homogeneity across all twenty sites. The girth-5 condition enforces nontrivial $\mathbb{Z}_2$ holonomy on every minimal cycle, which is the structural basis of fermionic statistics within the framework.

The Fermion-Boson Distinction

The fermion-boson distinction is determined by the functional structure of the EIM triad. Fermionic modes realize a closed self-returning coordination cycle satisfying $\chi = 1$: Execution provides localization, Interaction provides holonomy, Memory provides closure. Bosonic modes fail at least one of these conditions.

The lightest neutrino ν_1 and the top quark t are antipodal in the state space: $\nu_1 = (1, 0, 0, 0)$ and $t = (0, 1, 1, 1)$ occupy opposite corners of the four-dimensional coordination space (E_{bare}, I_{base}, $M_{inertial}$, C). Minimum Memory, minimum mass, minimum interaction on one side; maximum loading, immediate decay on the other. The full spectrum of matter is, geometrically, the set of all points between two poles.

Figure 5.2 represents this state space directly. Each stable particle corresponds to a corner of the four-dimensional coordination hypercube (E_{bare}, I_{base}, $M_{inertial}$, C),

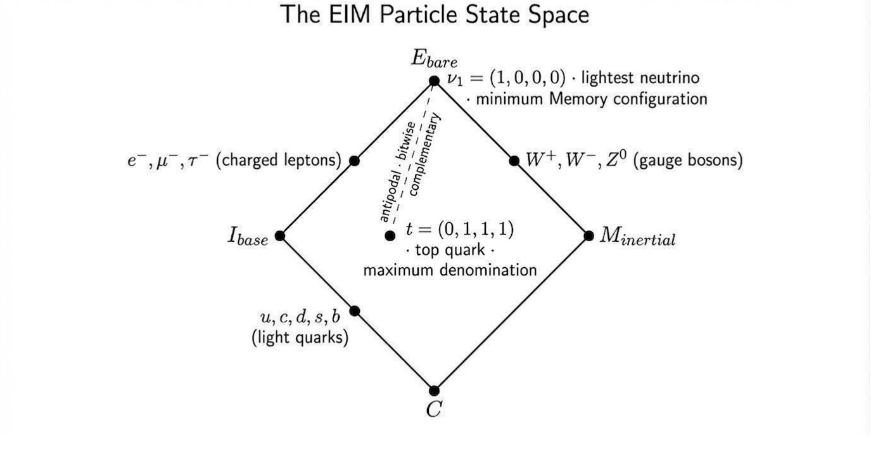

Figure 5.2. The EIM particle state space as a four-dimensional coordination hypercube (E_{bare}, I_{base}, $M_{inertial}$, C). Stable particles correspond to corners positioned by Hamming weight—the number of active coordination coordinates. The lightest neutrino ν_1 = (1,0,0,0) and the top quark t = (0,1,1,1) occupy antipodal corners, representing minimum and maximum Memory-bearing modes respectively. This geometric antipodality supports the structural derivation of the mass hierarchy as coordination depth ordering.

positioned by the number of coordinates it occupies—its Hamming weight. The antipodal relationship between ν_1 and the top quark is visible as the geometric extremes of the simplex: minimum loading at one vertex, maximum at the other. The physical particle spectrum occupies only a subset of the available corners; the structural question **Figure 5.2** poses is which corners are populated and why.

Figure 5.2 shows where the physical particles sit. **Figure 5.3** shows the complete landscape they inhabit. All sixteen corners of the four-dimensional binary coordinate space are enumerated and organized by Hamming weight H, from the vacuum at H = 0 through to the fully saturated state at H = 4. The physical fermion spectrum—ν_1 at H = 1, the charged leptons and light quarks at H = 2, the top quark at H = 3—does not fill the space arbitrarily. The corners at H = 0 and H = 4 are structurally forbidden as stable denominations: the vacuum carries

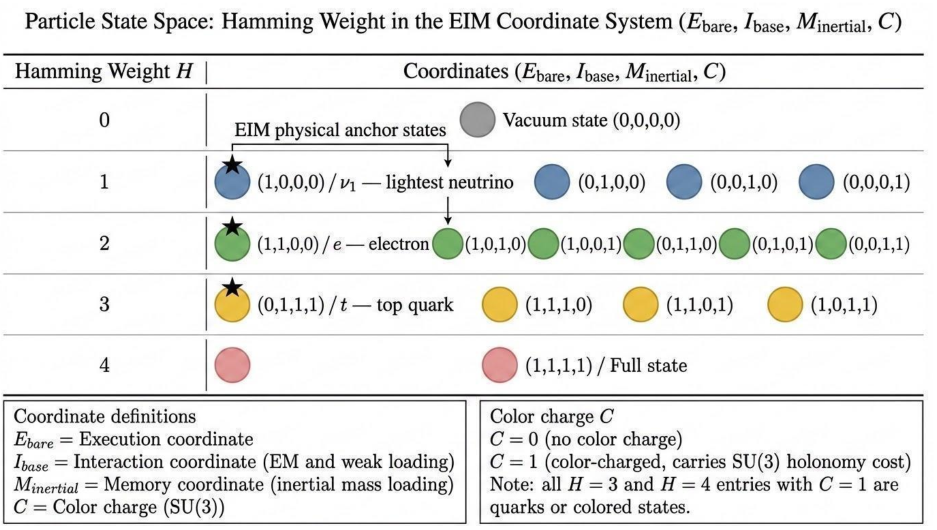

Figure 5.3. All sixteen corners of the four-dimensional binary coordinate space, organized by Hamming weight H. Stable fermion denominations appear at H = 1 (lightest neutrino ν_1), H = 2 (electron and charged leptons), and H = 3 (top quark). The endpoints H = 0 (vacuum) and H = 4 (fully saturated state) are structurally forbidden as persistent denominations. This distribution is a combinatorial consequence of the coordination constraints, not a free assignment.

no Memory load and cannot persist as a particle; the fully saturated state is the top quark's limit, immediately unstable. The intermediate corners at $H = 2$ mark the region of greatest combinatorial richness, where the generation structure and charge assignments of the Standard Model are located.

The pattern visible in **Figure 5.3**—increasing mass with increasing Hamming weight, three populated levels between the forbidden endpoints—is not imposed from outside. It is the combinatorial consequence of the coordination constraints. The mass hierarchy across generations is the same structure read temporally: higher Hamming weight corresponds to deeper temporal lift, which is the subject of the next section.

The Mass Hierarchy as Temporal Depth

The generation structure of the fermion spectrum encodes temporal lift depth directly. The electron, muon, and tau are I-dominant modes at increasing generations: the electron is the first-generation I-dominant lepton (O_2 in Table 7.1), the muon is second-generation (O_6), and the tau is third-generation (O_{10}). The increasing mass—$m_e \approx 0.511$ MeV, $m_\mu \approx 105.7$ MeV, $m_\tau \approx 1776.9$ MeV—directly reflects the increasing temporal lift depth $A_1 < A_2 < A_3$: higher generations correspond to closure cycles that accumulate greater Memory before stable return.

The neutrino hierarchy reflects the same pattern from the M-anchor orbits: ν_e (O_1), ν_μ (O_5), ν_τ (O_9) carry increasing temporal depth at minimal Memory loading. Their masses—$m_1 \approx 2.34$ meV, $m_2 \approx 8.99$ meV, $m_3 \approx 49.6$ meV—are the minimal denomination at each generation level. The sum $\Sigma m_\nu \approx 60.9$ meV is predicted structurally and testable by near-term cosmological surveys.

The quark sector adds the complication of color charge (the C coordinate) which enables three-fold confinement states. But the cross-generation ordering holds without exception: charm (O_7) is heavier than up (O_3); strange (O_8) is heavier than down (O_4); bottom (O_{12}) is heavier than strange; top (O_{11}) is heavier than all others. This hierarchy—confirmed in full by PDG data—follows from A_1 < A_2 < A_3

combined with the structural role ordering B_r.

The Standard Model as Structural Output

Within the EIM framework, the particle spectrum of the Standard Model emerges as the structural output of this determination rather than serving as an input. The full spectrum—quarks, leptons, gauge bosons—is not treated as an arbitrary collection assembled empirically. It is the complete set of stable, discrete, combinable units of a system that stores and exchanges Memory. The denomination structure has a smallest element (the lightest neutrino), a largest element (the top quark), a minting standard (the Higgs field), and exchange mediators (the gauge bosons). These are structural necessities, not design choices.

The extended particle spectrum—the hundreds of hadrons catalogued by the PDG, the various meson and baryon resonances—does not indicate a larger set of independent denominations. These particles are higher-order realizations of the same underlying coordination cycles: composite configurations of multiple cycles bound through Interaction-dominated regimes, or higher-winding traversals that fail minimal closure conditions. They are the excitation spectrum of a fixed structural basis. What appears as multiplicity at the level of observed particles is, at the level of the coordination framework, the set of allowed transient departures from minimal closure.

The particle content within the EIM framework is structurally saturated by the minimal set of persistence modes—the framework does not admit open-ended extension of particle types. The phenomena attributed to dark matter arise naturally from the coordination dynamics and the accumulation of Memory across scales. Particulate dark matter is a compensating construct introduced to reconcile observations within a geometry-first framework. The coordination structure accounts for those observations directly, as Chapter 6 establishes.

Chapter 6.
Closing the Open Questions

Chapter 5 derived the denomination structure of stable matter. The present chapter addresses the large-scale observational anomalies that resist explanation within the Standard Model and GR. The framework does not accommodate these anomalies—it predicts them.

The Rotation Curve Problem and MOND

In the 1970s, Vera Rubin measured rotational velocities of stars in spiral galaxies. Outer stars move just as fast as inner ones—contrary to Newtonian prediction. Decades of experiments have detected no dark matter particles. MOND fits the rotation curve data using one additional parameter but lacks a theoretical foundation.

EIM derives this behavior from the forcing chain without modification of the force law. At the galactic center, σ is large and GR applies exactly. At the outskirts—sparse matter, weak interactions, shallow coordination history—σ falls below the percolation threshold. The effective gravitational coupling $G_{eff}(\sigma)$ departs from its Newtonian value. The critical acceleration Milgrom identified empirically corresponds to the coordination depth at the percolation boundary. MOND phenomenology is a structural consequence of shallow coordination depth.

The critical acceleration scale itself follows directly from backbone structure. At the percolation boundary, the only dynamical rate available is the cosmological expansion rate H_0. The spectral gap γ^c governs how rapidly the coordination network relaxes at that boundary, and the speed c converts this relaxation rate to an acceleration. The interaction sector of the backbone carries exactly five independent cycles—β_1_I = 5, a forced consequence of the $A_5 \times \mathbb{Z}_2$ decomposition.

Multiplying these three quantities together gives the MOND critical acceleration: $a_0 = 5\gamma^c cH_0$. No parameter is fit to data; each factor is a structural constant of the dodecahedral backbone. The formal closure of the projection step joining γ^c, c, and H_0 at the percolation boundary is developed in the author's technical companion work. Subject to that closure, the numerical agreement with Milgrom's empirically determined value reflects the same backbone geometry that determines the neutrino mass and the CMB spectral index. **Figure 6.1** shows the result: the inner galaxy, where σ is large, follows Newtonian dynamics exactly; the outer disk, where coordination depth has fallen below the percolation threshold, follows the modified curve—without invoking any additional mass.

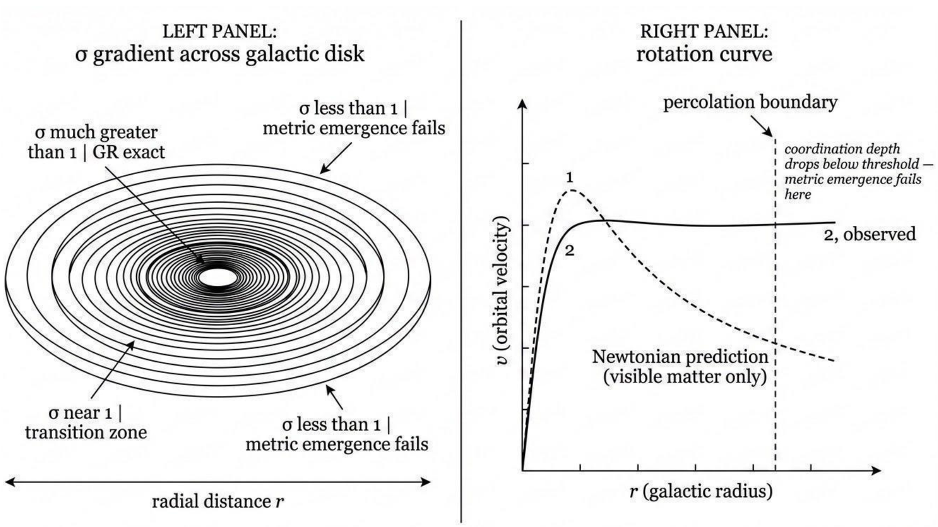

Figure 6.1 Galaxy rotation curves and coordination depth σ, illustrating MOND behavior as a failure of metric emergence rather than a modification of the force law. Left: radial decrease in coordination depth from $\sigma \gg 1$ at the galactic center to σ < 1 in the outer disk. Right: observed rotation curve (solid) against Newtonian prediction (dashed). Within the EIM framework, the deviation in the outer disk arises because coordination depth has dropped below the percolation threshold, causing $G_{eff}(\sigma)$ to depart from its Newtonian value without invoking additional mass.

The Cosmological Constant and Dark Energy

Two teams discovered that cosmic expansion is accelerating. Within GR, this requires dark energy—a uniformly distributed, non-diluting, repulsive energy density. The QFT prediction for this energy density is roughly 10^{120} times larger than observed: the largest discrepancy in the history of physics.

In EIM, the cosmological constant is a structural consequence of backbone geometry—the energy cost of maintaining the dodecahedral coordination structure as it approaches Memory saturation. The 10^{120} problem arises because QFT sums zero-point energies up to the Planck scale. Within EIM, the coordination horizon $H_\kappa = 55\varphi^2 \approx 144$ imposes a natural upper bound on dynamically distinct modes—not an imposed cutoff but a structural consequence of the backbone. The resulting vacuum energy scale $\sim m_1^4$ is consistent with observed dark energy density $\rho_\Lambda \approx (2.3\ \text{meV})^4$. Both m_1 and ρ_Λ are set by the same backbone constant γ^c.

The Cosmic Microwave Background

The CMB is the first observational window onto the coordination percolation process—the moment at which the backbone's accumulated Memory was first imprinted on a freely propagating signal. The standard cosmological model fits the CMB with six free parameters. In EIM, the fluctuation spectrum is the signature of the first percolation events; the spectral index n_s is predicted by the backbone geometry at approximately 0.9653, matching the Planck measurement of 0.9649 ± 0.0044 to within 0.09 standard deviations—without fitting.

The derivation is straightforward in structural terms. Perfect scale invariance—$n_s = 1$ exactly—would correspond to a featureless coordination process with no preferred scale. The spectral gap γ^c is precisely the quantity that breaks this uniformity: it represents the rate at which the backbone's coordination departs from perfect homogeneity at the percolation threshold. The tilt of the primordial power spectrum away from scale invariance is therefore equal to γ^c, giving $n_s = 1 - \gamma^c = 1 - \frac{3-\sqrt{5}}{22}$. The same constant that governs Memory accumulation rate, neutrino mass, and MOND acceleration also sets the imprint left on the CMB at the moment of first percolation. This convergence is a structural consequence of the framework: the same backbone quantity encountered at three different observational scales.

The Pre-Planck Cosmos and the Hubble Tension

EIM extends naturally through the Planck boundary: the pre-Planck cosmos is the regime $\sigma \to 0$—maximum Execution, maximum Interaction, no coordination history. The laws governing this regime are EIM in the limit $\sigma \to 0$.

The Hubble tension—the discrepancy between early-universe and late-universe measurements of the expansion rate—has a natural explanation: CMB measurements sample the transition from the lower cone to the cylinder; late-time measurements probe the upper cone, where the system approaches its coordination horizon. The two measurements probe different phases of the same logistic curve, and the framework predicts they will not agree within a single-parameter model.

Chapter 7.
The Derivation

The preceding chapters made the argument in conceptual terms. This chapter makes it in mathematical ones—the same argument at a different level of compression. Each derivation proceeds from constraint to consequence. No free parameters are introduced at any step. **Figure 7.1** traces the eleven-step forcing chain summarized in this chapter, from the null state to the lightest-neutrino-mass prediction.

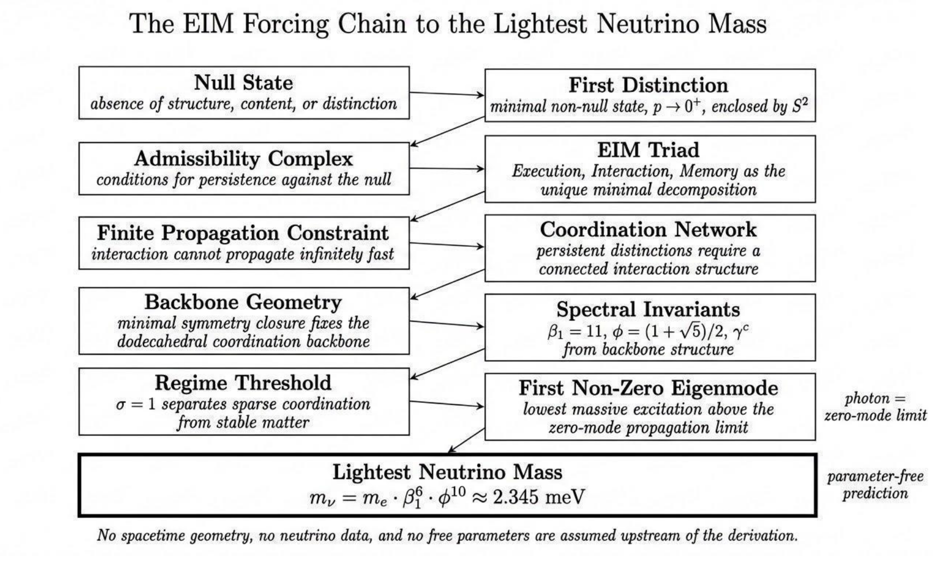

Figure 7.1 The EIM forcing chain: eleven structurally forced steps from the null state Ø to the neutrino mass prediction m_1. Each step is forced by the previous; no free parameters are introduced. The primary unit anchor is the electron mass m_e—itself substantially derived from backbone invariants.

Step 1: The Null State

$$\varnothing = \text{the complete absence of structure, content, or distinction}$$

Begin with nothing—not empty space, not a vacuum, but the complete absence of any structure whatsoever. The null state and its complement boundary form the starting pair ($\emptyset$, S^2). S^2 is the unique isotropic enclosure whose geometry is fixed by the equilateral simplex of the three co-equal mode vectors—the minimal isotropic boundary within which structure can exist.

Step 2: The Admissibility Complex

The boundary S^2 is not a space but a constraint surface. The transverse traversal defect $\Delta_{loc} = \frac{\sqrt{3}}{2}$ prevents any finite coordination process from achieving exact closure on this surface—so $\sigma = 1$ represents the closest admissible approach to isotropy. To persist, a state must be internally consistent. The admissibility complex is the set of all configurations not immediately self-canceling: the logical conditions any persistent configuration must satisfy.

Step 3: The EIM Triad

The admissibility complex has a unique minimal decomposition into three independent modes—a structural theorem: any persistent configuration must have something happening (otherwise it is $\emptyset$), must have internal relationships (otherwise its components are independent null states), and must carry the consequence of its prior states (otherwise it is not persisting). These three conditions are independent and exhaustive. Their unique names: Execution (E), Interaction (I), and Memory (M).

The domain is declared: the universe is a configuration of E, I, and M. Space and time are not in the domain. They will emerge from it.

Step 4: The Oriented Cycle and the Origin of Time

The triad defines the minimal structure of a persistent system. A single traversal of E→I→M does not produce persistence unless the system can return to Execution in a distinguishable way. The distinction between E_1 and E_2 reflects nontrivial $\mathbb{Z}_2$ holonomy: the system returns to the same mode but not the same state. The return orientation state lies in $\mathbb{Z}_2 = \{+1, -1\}$. The minimal non-degenerate closure under iteration is five—the five-step structure E→I→M→I′→M′, anticipating the pentagonal geometry of the backbone.

Definition: Role-Dependent Closure Indicator

Let $\chi(x, r; \sigma) = 1$ if and only if the mode realizes localization (Execution), holonomy (Interaction), and closure (Memory) in a single self-returning coordination cycle; otherwise $\chi = 0$. Fermionic modes are precisely those for which $\chi = 1$. In the low-σ regime $\chi = 0$ throughout; at $\sigma = 1$, $\chi = 1$ becomes achievable and stable fermionic modes become possible.

Theorem (Topological Stability of the Closure Indicator)

Let γ be a fermionic orbit in the realized cylinder ($1 < \sigma < \kappa$) with $\chi(\gamma) = 1$. Then $\chi(\gamma) = 1$ for all continuous deformations of γ within the realized cylinder. No mechanism within the EIM framework can continuously change χ from 1 to 0 without passing through a structural discontinuity.

Proof sketch. The closure indicator χ records a nontrivial $\mathbb{Z}_2$ holonomy class in $H^1(\gamma; \mathbb{Z}_2) \cong \mathbb{Z}_2$. The two elements of $\mathbb{Z}_2$ are discrete—there is no path between them. A continuous deformation can only alter χ by passing through a configuration where the holonomy class is undefined, requiring the orbit to cease closing, the backbone to lose its girth-5 structure, or σ to fall below 1. None of these transitions is available within the realized cylinder. ■

Corollary (Proton Stability). The proton is a fermionic mode in the realized cylinder with $\chi = 1$. By the Topological Stability theorem, no mechanism can change χ from 1 to 0 without a structural discontinuity. Proton decay does not occur at any observable or asymptotic timescale. This is topological stability—not subject to violation by higher-order operators, because it depends on the discrete structure of $\mathbb{Z}_2$.

Born Rule as a Structural Consequence

In the low-σ (pre-percolation) regime, transitions are determined by the set of admissible coordination paths. Each path contributes a coordination weight; because the coordination cycle carries orientation (via holonomy), these contributions are phase-structured. The observable transition probability is proportional to the inner product of the amplitude with its reverse—the unique orientation-insensitive combination the symmetric coordination metric permits. The Born rule appears not as an independent postulate, but as the natural measurement map from phase-structured coordination to realized event frequency.

Step 5: Temporal Ordering

The irreversible oriented cycle establishes a strict ordering on the count of completed cycles N. Each completed E→I→M→E cycle adds one to N and cannot be undone. This is time in its most primitive form—not a geometric coordinate but an irreversible count of coordination events.

Mass, Temporal Lift, and the Zero-Retention Limit

Time and mass are complementary aspects of the same underlying process: time as the global ordering of Memory accumulation, mass as its localized retention.

$$m_{g,r} = v_H \Lambda_{g,r}, \quad \Lambda_{g,r} = A_g B_r$$

where v_H is the Higgs-Execution normalization scale, A_g is the generation factor encoding temporal lift depth ($A_1 < A_2 < A_3$), and B_r is the role factor encoding structural loading. Higher generations correspond to closure cycles that accumulate greater Memory before stable return—reflected in increased mass. The cross-generation ordering m_{g,r} < m_{g+1,r} holds for all fermion families without exception.

The photon represents the zero-retention limit: it propagates coordination through Execution and Interaction without realizing a persistence-bearing closure cycle, does not retain Memory across iterations, and acquires no mass.

The Role of the Higgs Field

The Higgs field defines the Execution-scale normalization against which all closure modes are measured—not a denomination within the system but the standard rendering the denomination structure physically meaningful. Fermionic mass arises from coupling between a closure orbit and the Execution field. The Higgs vacuum expectation value establishes the global Execution scale.

Step 6: Trivalent Saturation

Each active site must carry exactly one connection per mode—one Execution channel, one Interaction channel, one Memory channel. Every vertex in the coordination graph therefore has exactly three edges. Trivalency is a representation theorem, not a geometric assumption.

Step 7: The Dodecahedral Backbone

The coordination graph must simultaneously satisfy: (1) trivalence, (2) closure on S^2, (3) girth at least 5 (derived: girth 3 excluded by irreducibility, girth 4 by return-map non-injectivity), (4) all-pentagonal faces from the minimal non-degenerate closure argument.

A finite trivalent planar graph with only pentagonal faces is uniquely constrained:

$$V - E + F = 2, \quad 3V = 2E, \quad 5F = 2E \quad \Rightarrow \quad (V, E, F) = (20, 30, 12)$$

The dodecahedron—uniquely forced under the combined constraints of trivalent saturation, pentagonal faces, and closure on S^2. Three-dimensional space emerges here: by Steinitz's theorem, the dodecahedron is the skeleton of a convex 3-dimensional polyhedron. Three spatial dimensions are the output of the requirement that a trivalent graph with Möbius holonomy close on S^2.

Step 8: The Spectral Invariants

Cycle rank: $\beta_1 = E - V + 1 = 30 - 20 + 1 = 11$—a topological invariant.

Spectral gap derivation:

Step 1. $\beta_1 = 11$ (Euler count)

Step 2. $\varphi = \frac{1+\sqrt{5}}{2}, \varphi^2 = \frac{3+\sqrt{5}}{2}$

Step 3. $\gamma^c = \frac{1}{\beta_1\varphi^2} = \frac{2}{11(3+\sqrt{5})} = \frac{3-\sqrt{5}}{22}$, using $\varphi^2(3-\sqrt{5}) = 2$.

$$\gamma^c = \frac{3-\sqrt{5}}{22} \approx 0.03472, \quad - \text{no free parameter.}$$

The Weinberg angle follows from the sector structure. The two five-dimensional cycle sectors ($V_I = 5$ cycles, $V_M = 6$ cycles) mix through the quadratic form with entries fixed by backbone geometry and transverse coupling $\frac{\sqrt{3}}{2}$:

$$\sin^2\theta_W = 1/4 \quad (= 0.25, \text{tree} - \text{level EIM threshold})$$

Standard renormalization group running shifts this to the measured MS-bar value of ≈ 0.231.

Step 9: The Coordination Horizon

The spectral gap γ^c sets the rate of Memory accumulation. The fixed point of logistic growth—the scale at which Memory accumulation saturates—is the coordination horizon:

$$H_\kappa = 55\varphi^2 \approx 144$$

Newton's constant follows: $G = \hbar c/(5H_\kappa^2)$, yielding the Planck mass $M_{Pl} = H_\kappa\sqrt{5}$ in natural units. The derivation has a single structural step. The Planck mass—the scale at which gravitational and quantum effects become comparable—corresponds in EIM to the coordination horizon scale H_κ. The pentagonal geometry of the backbone introduces a factor of $\sqrt{5}$, giving $M_{Pl} = H_\kappa\sqrt{5}$ in natural units. Since $G = \hbar c/M_{Pl}^2$ by definition of the Planck mass, substituting yields G =

$\hbar c/(5H_\kappa^2)$. The gravitational coupling constant is not a free parameter of the framework—it is the inverse square of the coordination horizon, scaled by the pentagonal invariant of the backbone geometry.

Step 10: The Neutrino Mass

The lightest neutrino is the minimum denomination—the smallest stable Memory configuration the framework permits. The holonomy projection selecting the Memory sector is forced by the antipodal map ι—a geometric object determined by backbone symmetry, not a separate postulate.

$$m_1 = m_e \cdot \frac{(\gamma^c)^5}{\beta_1} = \frac{m_e}{\beta_1^6 \cdot \varphi^{10}}$$

The electron mass is substantially derived from backbone invariants:

Higgs-Execution scale: $v_H = M_{Pl} \times (\frac{\gamma^c}{\varphi})^{(V/2)} \approx 253$ GeV (within 2.75% of the physical value)

Electron Yukawa correction: $y_e = (3 - \varphi) \times (\gamma^c)^4$, where $(3 - \varphi) = \frac{5-\sqrt{5}}{2}{}_2(\pi/5)$

Electron mass prediction: $m_e \approx 508$ keV (within 0.52% of the physical 511 keV)

Result:

$$m_1 \approx 2.34 \text{ meV}$$

The current KATRIN experimental upper bound places this prediction within the accessible range. The predicted neutrino mass sum $\Sigma m_\nu \approx 60.9$ meV sits within the range accessible to next-generation cosmological surveys including Euclid.

Step 11: The Regime Architecture

The regime architecture follows directly from the spectral invariants established in Steps 7 - 10. The effective gravitational coupling Geff(σ) varies continuously with coordination depth: it is absent in the pre-percolation regime (σ →

0^+), rises through the Standard Model threshold at $\sigma = 1$, and asymptotically approaches the Newtonian value GN in the deep-coordination limit ($\sigma \gg 1$). No new degrees of freedom are introduced at any stage; the variation is a direct consequence of coordination path density in the backbone graph, which determines how thoroughly local Memory accumulation can be expressed as a global metric constraint.

Four structural regimes are distinguished along this curve. The quantum regime ($\sigma \to 0^+$) carries no stable metric and no effective gravitational coupling; fluctuations dominate because no spanning Memory structure exists to enforce a definite configuration. The MOND-like subcritical regime ($0 < \sigma < 1$) supports local Memory accumulation without global metric emergence, producing the modified effective coupling that accounts for galaxy rotation curves at the galactic percolation boundary without invoking additional mass. The Standard Model onset ($\sigma = 1$) marks the threshold where the first spanning path appears and stable fermionic modes become achievable. General relativity ($\sigma \gg 1$) is the deep-coordination asymptote, exact in the regime where path redundancy is high enough to support a smooth Riemannian geometry—**Figure 7.2**.

The Twelve Fermionic Orbits

The backbone contains exactly twelve pentagonal faces. Every minimal persistence-bearing mode ($\chi = 1$) must be supported on a pentagonal cycle. Temporal phases are not preserved under the automorphisms of Γ—the Memory binding of successive cycle iterations breaks graph symmetry. Therefore:

Γ admits exactly twelve distinct fermionic closure orbits.

The identification with Standard Model fermions follows from the backbone's internal organization rather than from fitting. The A_5 symmetry of the dodecahedron organizes the twelve orbits into a natural 3×4 grid. The three rows correspond to the three generations: each successive generation represents a closure cycle that accumulates greater Memory before stable return, encoded in the

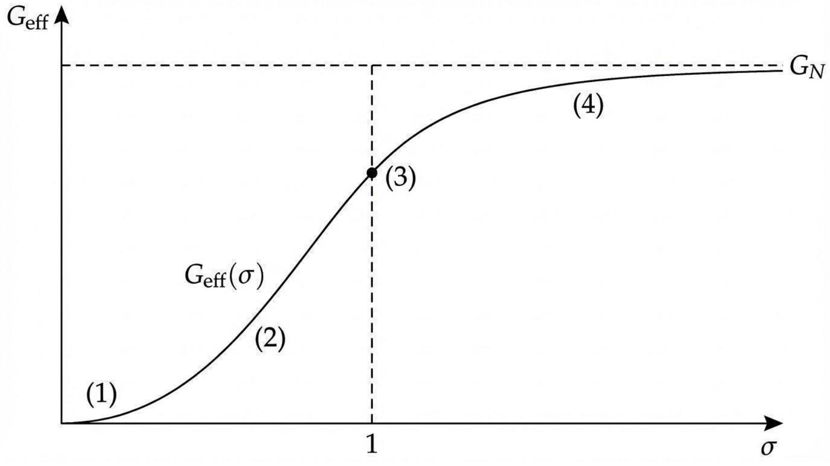

Figure 7.2. Effective gravitational coupling across coordination regimes. The curve $G_{\text{eff}}(\sigma)$ traces the emergence of gravitational strength as coordination depth σ increases, approaching the asymptotic Newtonian value G_N in the limit of deep connectivity. Four structural regimes are distinguished: quantum ($\sigma \to 0^+$), MOND-like subcritical ($0 < \sigma < 1$), Standard Model onset ($\sigma = 1$), and general relativity ($\sigma \gg 1$).

generation factors $A_1 < A_2 < A_3$. This is why mass increases across generations—it is not a free parameter but a structural depth ordering. The four columns correspond to four distinct structural roles that any closure orbit can realize: minimal Memory-anchor (carrying the lightest possible Memory load), Interaction-dominant (localized through electromagnetic coupling), Execution-Interaction mixed (mobile, weakly bound), and Interaction-Memory mixed (binding-stabilized). Matching structural role to quantum numbers is then direct: Memory-anchor orbits carry no electromagnetic charge and minimal mass—these are the neutrinos. Interaction-dominant orbits carry electromagnetic charge and stable mass—these are the charged leptons. The mixed orbits carry color charge and populate the quark sector. The 3×4 structure of the Standard Model fermion spectrum is the combinatorial output of temporal depth crossed with structural role. No assignment is free.

Table 7.1 Pentagonal Closure Orbit Assignment

Orbit	Gen.	Role	SM	EIM Interpretation
O_1	g_1	Minimal M-anchor	ν_e	Lowest-Memory persistent closure
O_2	g_1	I-dominant	e^-	Interaction-localized stable mode
O_3	g_1	E-I mixed	u	Mobile, weakly bound excitation
O_4	g_1	I-M mixed	d	Binding-stabilized configuration
O_5	g_2	Minimal M-anchor	ν_μ	Second-layer Memory mode
O_6	g_2	I-dominant	μ^-	Higher-load interaction closure
O_7	g_2	E-I mixed	c	Intermediate excitation mode
O_8	g_2	I-M mixed	s	Enhanced binding structure
O_9	g_3	Minimal M-anchor	ν_τ	Deep-Memory threshold mode
O_{10}	g_3	I-dominant	τ^-	High-energy interaction closure
O_{11}	g_3	E-I mixed	t	Maximal excitation (decays before hadronization)
O_{12}	g_3	I-M mixed	b	Heavy binding regulator

Table 7.1 The twelve orbits identified by backbone geometry map onto the Standard Model fermion content in a 3 × 4 structure. This is a structural identification, not a free assignment.

Return, Residue, and Completion

Any coordination process whose return is orientation-inverting cannot globally self-cancel. The resulting holonomy residue must be represented in the Memory sector. Memory monotonicity and holonomy residue persistence are the same statement in different coordinates.

Return-Residue Principle: Any coordination process in EIM whose return is nontrivial cannot globally self-cancel. The holonomy residue must be represented in Memory. Global completion of the process requires the residue to be exported from the local coordination sector into the propagating sector.

Corollary—No Process Is Strictly Memoryless. The Markov approximation is always an effective description—valid when accumulated Memory is sufficiently stable, not because Memory is absent. Systematic deviations from Markovian dynamics must appear in any regime where coordination history is actively shaping system behavior—including quantum error correction, NMR relaxation, and open quantum systems near threshold.

Observed Discrepancies as Conservation Requirements

Precision discrepancies are not failures of the framework. They are necessary consequences of the Return-Residue Principle. Any coordination process that closes locally but cannot discharge its holonomy residue within the particulate sector must express that residue somewhere.

The electron mass residual (≈0.5%) is the energy cost of the missing energetic closure degrees. The backbone derivation yields 508 keV at tree level; the 3 keV gap to the physical 511 keV is the signature of incomplete particulate-to-energetic discharge at the minimal denomination. The muon anomalous magnetic moment $(g - 2)$ records the departure from the Dirac prediction $g = 2$—the tree-level ($N_P = 5$) result carrying no residue contribution. The measured nonzero anomaly is the direct observable surface of the holonomy residue that the I-dominant mode cannot locally discharge. Radiative corrections in QED are the observable bookkeeping of that defect transport: each order of correction corresponds to a further cycle of residue export and receipt confirmation.

These are not independent corrections. They are the observable surface of a single conservation law: the requirement that holonomy residue deposited by nontrivial return must be exported and acknowledged. Standard perturbation theory captures this export numerically without identifying its structural origin. The EIM framework identifies the origin and predicts that the corrections are bounded, directional, and generation-dependent—because the residue structure is.

The Muon as the First Empirical Surface

The muon is the coordination mode in the lepton spectrum best positioned to expose the energetic completion requirements at measurable precision: residue large enough to detect, lifetime long enough to measure. It is the second-generation I-dominant lepton—the same structural role as the electron at generation 1, but with greater temporal lift depth and correspondingly larger accumulated residue. The electron reveals the minimal energetic correction at the lowest denomination; the muon reveals the same correction structure at the first precision-accessible lift depth.

Muon decay—$\mu^- \to e^- + \bar{\nu}_e + \nu_\mu$—satisfies particulate closure at $N_P = 5$ but does not discharge the holonomy residue deposited by the nontrivial return. The residue remains in the global Memory ledger and modifies observable properties: the effective decay rate, the energy distribution of final-state products, and the response to an external magnetic field.

The $g - 2$ anomaly is the direct signature of this residue discharge. Within EIM, $g = 2$ is the tree-level result reflecting particulate closure alone, with no residue contribution. The observed nonzero value is the measurable surface of the constraint that nontrivial return imposes on every locally closed coordination process.

The structural requirement that a nonzero departure *must* exist is not open—it follows from the Return-Residue Principle together with the fact that the muon carries nonzero holonomy residue as its I-dominant second-generation mode. What remains for future derivation is the precise numerical value from the energetic closure algebra.

Entanglement as Incomplete Global Closure

A locally closed system ($\chi = 1$ at each site) may leave its global holonomy residue unresolved. The residue enforces a correlation between the two participating sites that does not require a signal to pass between them—because the correlation is not propagation but constraint satisfaction. Entanglement is incomplete global closure under nontrivial return. Its nonlocal correlations are the observable signature of a shared, unresolved constraint. Finite causal propagation is preserved: the correlation is already present by construction.

Energetic Closure and the Minimal Completion Requirement

The minimal particulate closure count $N_P = 5$ is established at theorem level by the pentagonal backbone girth. A locally closed cycle satisfies particulate closure but leaves the holonomy residue in the global Memory ledger. Global completion requires at least two additional structural roles beyond particulate closure: one for outbound transfer of the residue into the propagating sector, one for the global consistency check.

Conjecture—Energetic Closure. The minimal energetic closure count is $N_E = N_P + 2 = 7$, motivated by the Return-Residue Principle and the directed two-step structure of residue export.

Local and Global Completion

The minimal closure count identified above characterizes local persistence—the particulate closure count $N_P = 5$ is established at theorem level by the pentagonal backbone girth. This establishes the conditions under which an excitation can exist as a stable, localized entity. Local closure alone is not sufficient to guarantee global consistency. The framework imposes additional constraints arising from the combination of finite propagation, nontrivial holonomy, and conservation of Memory.

Theorem 1 (Conservation Completion). Let a persistent excitation be modeled as a minimal closed EIM cycle with nontrivial holonomy under single traversal. Then local closure preserves identity but leaves a nonzero orientation residue. Under finite propagation and conservation of Memory, this residue cannot be eliminated locally and must be transported and globally reconciled. Therefore, minimal globally admissible completion requires two additional structural roles beyond particulate closure.

Proof sketch. A minimal persistent cycle contains the EIM triad together with the minimal return structure required for distinguishable closure, yielding $N_P = 5$. Because the return is orientation-inverting, the cycle carries a nontrivial residue class. Local closure preserves the identity of the excitation but does not eliminate this residue. If Memory is conserved, the residue must be accounted for globally. Under finite propagation, global accounting cannot be identified with the local closure event itself. It requires at least one role corresponding to outbound transfer and one role corresponding to global reconciliation. A single additional role is insufficient, since transport and global admissibility are distinct operations under finite propagation. Additional roles beyond two are not forced by the domain. Therefore, minimal completion requires exactly two additional roles beyond particulate closure. ■

Theorem 2 (Relational Completion). A conserved global constraint cannot be realized by a single locally closed excitation. Any relation that must be preserved across separation requires at least two distinct loci. Under finite propagation, the minimal realization of such a distributed constraint requires two additional structural degrees beyond local closure.

Proof sketch. A locally closed excitation supports persistence of identity but encodes only unary properties. A conserved relation is a constraint defined across multiple loci—not a property of any single object. Therefore, no single closed cycle can realize a globally enforced relational invariant. The minimal realization requires at least two distinct sites. Under finite propagation, this distributed structure cannot be collapsed into a single local role. Therefore, the minimal extension beyond local closure required to encode relational consistency is two. ■

Corollary (Minimal Energetic Completion). If $N_P = 5$, then $N_E = N_P + 2 = 7$. This defines the minimal extension required for a locally persistent excitation to satisfy global conservation and relational consistency.

Mass, Energy, and Closure Level

Local closure corresponds to persistence as an identifiable excitation—the property associated with mass: the capacity of a system to remain localized and retain identity under finite propagation. Global completion corresponds to the distributed consistency required to maintain that excitation within the full coordination network. This manifests as energy: the propagation, transfer, and reconciliation of the structural residue required by conservation.

Mass and energy therefore do not represent distinct substances but two aspects of closure: mass as locally closed Memory, energy as the global completion of that closure. This interpretation follows directly from finite propagation, nontrivial holonomy, and conservation of Memory, and does not introduce additional assumptions.

$E = mc^2$ is the equivalence of local and global closure under a constraint that cannot be relaxed—not a conversion postulate, but a structural consequence.

Predictions and Observational Signatures

Table 7.2 EIM Quantitative Predictions (Summary)

Quantity	EIM Prediction	Current Observational Status	Precision/Match
Spectral index (n_s)	≈0.9653	0.9649 ± 0.0044 (Planck 2018)	High match (0.09σ)
Dark-to-visible ratio	≈5.4:1	≈5.36:1 (Planck/DES)	High match: 6:5 cycle ratio
Electron mass (m_e)	≈508 keV	511 keV (measured)	Tree-level residual (0.52%)
MOND acceleration (a_0)	$a_0 = 5\gamma^c cH_0$	$\approx 1.2 \times 10^{-10}$ m/s²	Scale confirmed
Lightest neutrino (m_1)	≈2.34 meV	<450 meV (KATRIN 2022)	Within current bounds
Sum of neutrino masses	≈60.9 meV	≈58 - 64 meV (DESI/Euclid)	Pending direct test
Cosmological constant (Λ)	$\sim m_1^4 \approx (2.34\ \text{meV})^4$	10^{-122} (order of magnitude)	Order-of-magnitude agreement

Proton decay	Zero/never	$>10^{34}$ yr (no events detected)	Strong agreement
Weinberg angle ($\sin^2\theta_W$)	$\frac{1}{4}$ (tree-level)	≈0.231 (PDG, MS-bar)	Standard RG running from 0.25 to 0.231

Table 7.2 All entries are expressed in backbone constants and contain no fitted parameters. The formal projection-step closure for the MOND acceleration is developed in the author's technical companion work; see Appendix B. The master table with full precision data appears as **Table A.1** in the Afterword.

Convergence with Recent Results

Bellazzini, Pomarol, Romano, and Sciotti (2026) demonstrated that gravity emerges as a logical necessity from the existence of a single massive spin-3/2 particle, given only causality and unitarity. Both EIM and this result argue that physical structure is constrained to be what it is rather than freely chosen. EIM operates at an earlier stage of the ontological stack—it derives spacetime, quantum mechanics, and particle content sequentially, while the Bellazzini et al. result operates in the $\sigma \gg 1$ regime and takes as given what EIM constructs from first principles. The two frameworks are not competitors—EIM is the deeper layer from which the conditions of the Bellazzini et al. argument themselves arise.

Chapter 8.
Modal Process Ontology and the Architecture of Becoming

Any world in which something genuinely happens requires exactly three structural conditions. First, a domain of accessible alternatives must exist—a structured field of possible transitions that the configuration of a system exposes at a given moment. Second, a mechanism of selection must operate—a specific act by which one accessible path becomes actual and the others do not. Third, that act of selection must leave an irreversible residue—a constraint on what alternatives are subsequently accessible. Remove the first, and there is nothing from which selection could be made. Remove the second, and the accessible domain remains latent indefinitely. Remove the third, and each selection leaves no trace; there is no cumulative structure, no temporal asymmetry, no history. All three conditions are necessary. None is derivable from the others.

The EIM framework identifies these conditions precisely. Interaction names the accessible relational structure. Execution names selective actualization. Memory names the irreversible residue. Each term is defined by its functional role in the process of becoming, not by analogy or intuition. The mapping is not interpretive—it is constitutive. The EIM triad just is the minimal process grammar of any world with history.

The distinction between possibility and actuality is therefore not a descriptive convenience imposed on the world from outside. It is structurally required by any world in which outcomes are determinate and history is asymmetric. Interaction names what is genuinely open—not epistemic uncertainty about a hidden state, but the real structure of accessible alternatives prior to commitment. Execution is the commitment itself. Memory is what commitment deposits: the closed constraint that shapes every subsequent round of accessibility. The triad is minimal in the strict sense. No term is redundant, and removing any one renders the remaining two either inoperative or definitionally incomplete.

$$\mathrm{M}(\mathrm{t}+1)=\mathrm{M}(\mathrm{t})+\Delta\left(\mathrm{E}\big(\mathrm{I}(\mathrm{t}),\mathrm{M}(\mathrm{t})\big)\right),\Delta\geq 0$$

The update rule is the formal expression of this structure. Memory is strictly non-decreasing. The coordination depth $\sigma=\frac{\mathrm{M}}{\mathrm{E}+\mathrm{I}}$ is an order parameter derived from this rule, not an independent postulate. Time is the asymmetric ordering generated by constraint accumulation: the past is the closed domain of Memory residues; the future is the open domain of accessible alternatives not yet committed; the present is the Execution event that converts one to the other. This is not a metaphor for temporal structure—it is its derivation.

Any framework that omits one of these three roles cannot produce a world with history.

Chapter 9. The Self-Renewing Universe

Black Holes as Recycling Centers

Under extreme gravitational compression, organized Memory becomes increasingly difficult to sustain. As evaporation proceeds and $M \to 0$, the system approaches the pre-percolation limit: $\mathfrak{p} = 0^+$—the same boundary condition established at the origin: high Execution and Interaction with no system-spanning Memory enforcement.

The endpoint of black hole evaporation is structurally identical, in EIM coordinates, to the initial ignition of the cosmos. The terminal state of a black hole is structurally a local Big Bang. From that seed, new coordination can grow for precisely the same structural reason it grew the first time: the conditions are identical. **Figure 9.1** maps this trajectory—the existence curve running from $\mathfrak{p} = 0^+$ through the percolation threshold and asymptotically approaching $H\kappa$, with black hole cycles continuously returning accumulated Memory to the substrate and preventing global closure.

Primordial Black Holes: The First Horizons

The S^2 closure problem (Chapter 3) established that early coordination cannot achieve uniform closure—the holonomy of the backbone forbids it. The 12 pentagonal faces constitute the forced defect set. When a defect region crosses the percolation threshold locally—$\sigma_{loc} \gg 1$ while the surrounding field remains subcritical—its boundary becomes a coordination horizon. This is the EIM structural definition of a primordial black hole.

In standard cosmology, primordial black holes require fine-tuned density fluctuations. In EIM, the situation is reversed: non-uniformity is the inevitable

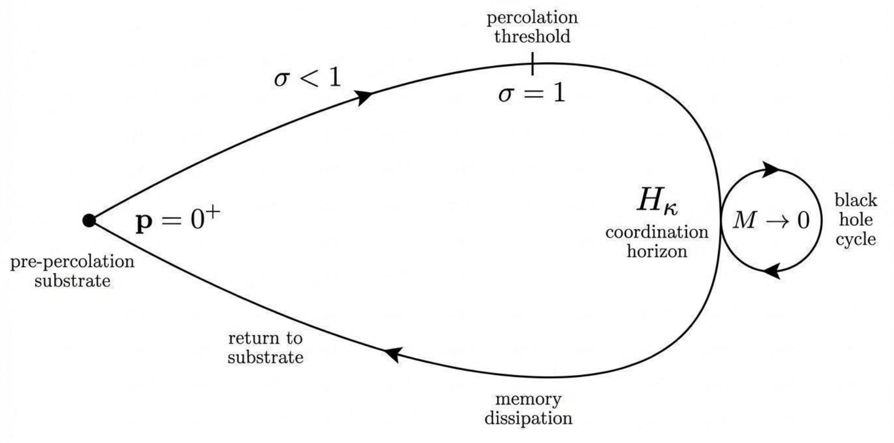

Figure 9.1. Existence curve and horizon-regulated coordination. Beginning at the pre-percolation substrate ($\mathfrak{p} = 0^+$), coordination increases through the subcritical regime until the percolation threshold. The trajectory approaches the coordination horizon H_κ asymptotically. Black hole cycles convert accumulated Memory toward $M \to 0$ and return it to the substrate, preventing global closure. H_κ functions as a structural regulator.

consequence of the holonomy obstruction. Primordial black holes are generically expected. Their early formation makes them natural seeds for the rapid galaxy assembly observed by JWST.

What This Explains

The impossible early galaxies: JWST has revealed massive, fully formed galaxies only a few hundred million years after the Big Bang—far too fast for ΛCDM hierarchical merging. In EIM, terminal black hole states provide localized seeds of renewed coordination—ignition points for rapid percolation. Large structures crystallize far more quickly than hierarchical merging allows.

The Hubble tension: CMB measurements sample the transition from the lower cone to the cylinder; late-time observations probe the upper cone. The two measurements probe different phases of the same logistic curve. The framework predicts they will not agree within a single-parameter model.

The rotation curve problem: Galactic outskirts sit near the percolation boundary where σ < 1 and $G_{eff}(\sigma)$ has not yet reached its Newtonian limit—addressed without new matter. All three of these signatures, together with the Hubble tension, locate as specific positions on the existence curve; **Figure 9.2** collects them on a single diagram.

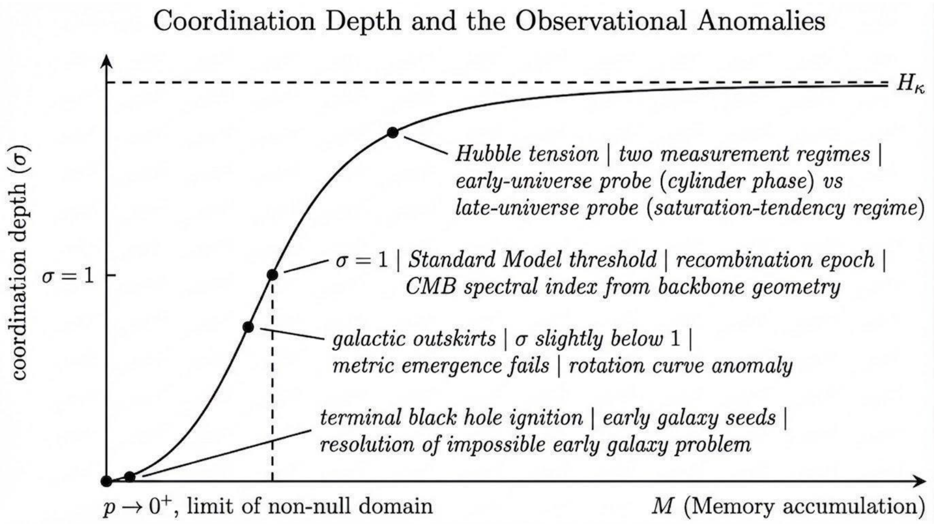

Figure 9.2. Coordination depth and observational anomalies. Four observational signatures located as structural positions on the existence curve: terminal black hole ignition (early galaxy formation), sub-critical galactic outskirts (rotation curves), the percolation threshold (CMB and Standard Model onset), and the upper flattening region (Hubble tension). All four are positions on a single structural trajectory.

Black Holes as Topological Stabilizers

Consider what global saturation would mean: if every region simultaneously approached the coordination horizon H_κ, Memory would be maximal everywhere, Execution and Interaction would be driven to zero globally, and no Interaction surface would remain. This is the upper-end analogue of the null state ∅—no accessible coordination surface, no persistent distinction possible.

The two terminal conditions are structurally homologous—∅ at the bottom, global saturation at the top—and both are excluded by the same foundational requirement: existence demands persistent distinction, and persistent distinction requires the coordination network to remain open to Interaction.

Black holes are the mechanism by which this proximity is maintained. As Memory concentrates locally, black hole formation is not a late-time cosmological accident—it is a topological necessity. Each black hole absorbs a local excess, recycles it via Hawking evaporation, and prevents the global coordination network from closing absolutely. The physical upper region of the existence curve is not a closing cone. It is a regulated cylinder: the classical regime extended indefinitely, populated by local black hole sites functioning as coordination-release valves—the contrast between the idealized and physically realized geometries is shown directly in **Figure 9.3**.

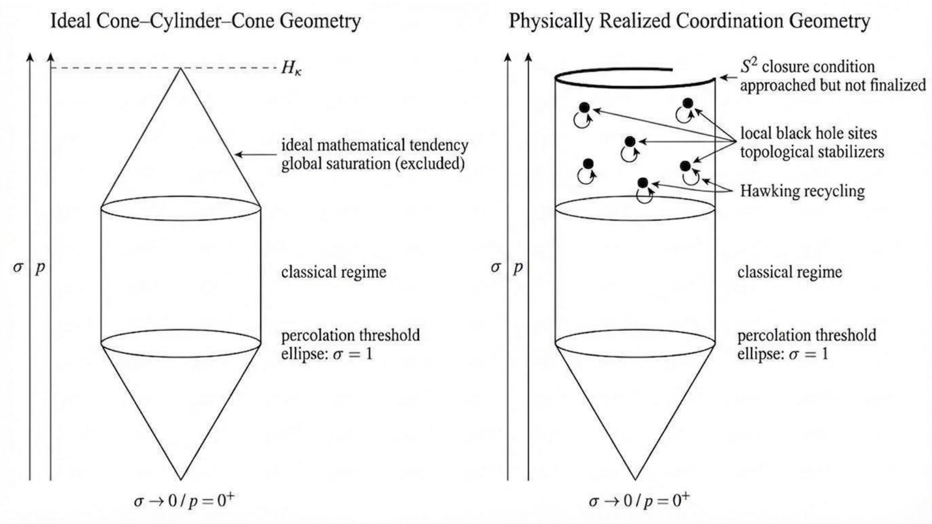

Figure 9.3. Ideal and physically realized cosmic coordination geometries. Left: the cone-cylinder-cone represents the unrestricted mathematical tendency under global Memory accumulation. Right: the physically realized geometry. The upper cone is replaced by a regulated cylinder populated by local black hole sites. Each site represents a local Memory-saturation event discharging concentrated coordination history back to the pre-percolation substrate via Hawking evaporation.

The Coordination Ladder

The framework admits a coherent dynamical ladder connecting the earliest and latest stages of cosmic history without discontinuity.

At the base: local persistence—the subcritical regime ($0 < \sigma < 1$) where holonomy-bearing coordination loops exist but do not span the system. This is not emptiness—it is the substrate, locally fertile, globally unorganized. Above it, global percolation ($\sigma = 1$) marks the abrupt onset of global constraint: decoherence, the Standard Model threshold, and the emergence of classical geometry. From that threshold, classical enforcement ($\sigma \gg 1$) characterizes the long stable era where GR applies exactly, stable matter denominations are sustained, and spacetime provides an effective description. As Memory concentrates under gravitational collapse, the system approaches the black hole regime—local maximum of coordination, approached asymptotically but never globally reached. Finally, terminal collapse and Hawking evaporation carry the system back toward the base: global Memory dissolves, local coordination residue remains, and the substrate is regenerated.

The cycle does not close arbitrarily. It closes because the terminal state and the initial state are structurally identical in EIM coordinates: both are regimes of maximal Execution and Interaction with no system-spanning Memory enforcement. The difference is only one of scale and history.

The Spectral Regulator

The rate of Memory recycling is limited by the coordination network itself. The spectral gap $\gamma^c \approx 0.0353$, derived from backbone geometry, governs the rate at which coordination can reorganize. No black hole can release its coordination history arbitrarily quickly. The spectral gap sets an upper bound forced by the same backbone geometry that determines the neutrino mass and CMB spectral index. The terminal evaporation rate and the lightest neutrino mass are governed by the same structural constant of the dodecahedral backbone. This is a testable prediction.

The Galactic Lifecycle

A galaxy is a coordination domain in which Memory has accumulated deeply enough to stabilize classical geometry and support the full range of matter denominations. The sequence: a terminal black hole state returns accumulated Memory to the substrate, regenerating pre-percolation conditions at a localized point → coordination grows exponentially through lower-cone dynamics → the percolation threshold is crossed, stable matter forms, the protogalactic structure crystallizes → stars form, the galaxy enters its mature phase → the most massive stars exhaust their fuel and collapse → black holes form → the cycle begins again. **Figure 9.4** condenses these four stages—Ignition, Growth, Percolation, Maturity—into a single coordination cycle, making the structural identity between galaxy formation and cosmic ignition visually immediate.

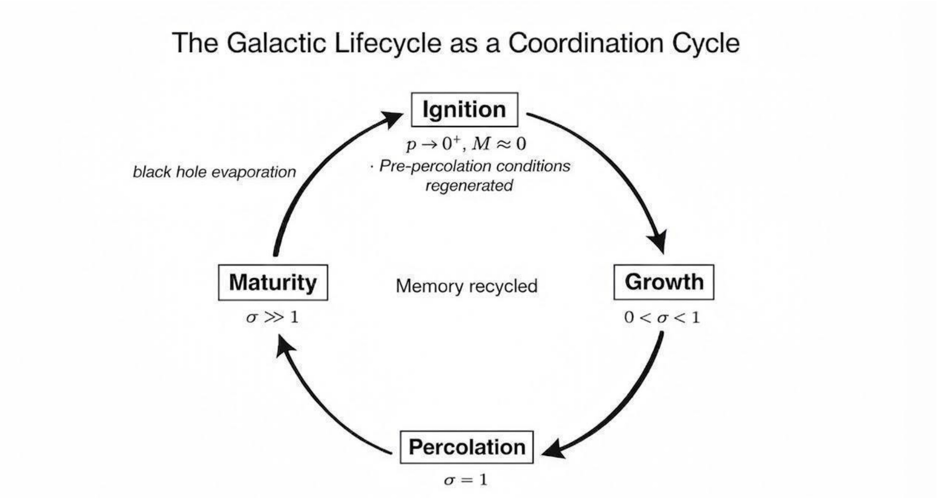

Figure 9.4 The galactic lifecycle as a coordination cycle. Four stages: Ignition ($\mathfrak{p} = 0^+$, M ≈ 0); Growth ($0 < \sigma < 1$: exponential Memory accumulation); Percolation ($\sigma = 1$: stable matter formation); Maturity ($\sigma \gg 1$: GR regime, black holes cycling).

Why the Universe Cannot Reach Heat Death

The standard picture of heat death assumes global Memory is all Memory and that its eventual depletion ends all persistence. The EIM framework exposes both assumptions as false. Below any global threshold, local coordination residue remains. The terminal state of a black hole is the pre-percolation substrate—exactly the condition required for a new percolation sequence to begin.

The EIM framework does not merely permit a self-renewing cosmos—it requires one. A cosmos completing global saturation would eliminate persistent distinction and cease to be a universe in which anything exists. The same structural logic that excludes $\emptyset$ as a physical starting point excludes global saturation as a physical endpoint. Black holes are the mechanism that enforces this exclusion—not because the cosmos happens to contain black holes, but because it must contain them.

The cone-cylinder-cone diagram makes this concrete, but with a crucial reinterpretation: it is not only a temporal sequence—it is also a phase diagram. Different regions of the universe occupy different positions simultaneously—some near saturation, some near percolation, some near ignition. Black holes act as local transitions that map high-σ states back toward the low-σ regime. The upper cone is not a terminal state. It is one phase among several that coexist in a self-maintaining dynamical system.

Memory accumulation is not globally monotonic. Each evaporating black hole locally regenerates the low-σ regime and can seed a new percolation sequence. The available capacity for coordination is never exhausted, because the mechanism that concentrates Memory also recycles it. The asymptote is real and genuine—the existence curve asymptotically approaches isotropic equilibrium without ever reaching it, just as it approaches $\mathfrak{p} = 0^+$ from above without ever reaching it. The universe is bounded by the same structural limit that bounds the individual coordination event, expressed at cosmic scale.

Local Coordination Domains

The existence curve describes coordination growth within a domain; a purely global interpretation is only an approximation. Memory accumulation is fundamentally local—coordination depth develops within particular regions, not uniformly. Different regions occupy different positions along the existence curve simultaneously.

In this picture the existence curve functions as the local law governing coordination growth, while the global universe consists of many interacting domains at different stages of this process. What appears as the cosmic expansion history is the aggregate statistical behavior of a vast ensemble of locally renewing coordination domains, each tracing its own existence curve against the background of the others.

The universe is not a clock winding down. It is a coordination network that structurally cannot wind down—not because of some additional law preventing it, but because the terminal state of winding down (global saturation) is excluded by the same argument that excluded the null state at the origin. Heat death is the prediction of frameworks that treat Memory as globally monotonic, ignore Hawking recycling, and fail to recognize that global saturation and absolute nothing are the same structural condition approached from opposite ends. The EIM framework shows that accumulated Memory is structurally conserved and redistributed—the cosmos is constitutively required to cycle coordination capacity back toward its initial conditions.

The structural ground toward which this redistribution converges is ꝑ $= 0^{+}$.

Consciousness as a Finite Horizon System

Every physical system that persists does so by maintaining a distinction. Something inside the system behaves differently from something outside it, and that difference is not accidental—it is actively sustained against the tendency of structure to dissolve into its surroundings. Conscious experience is no different in this fundamental respect, though far more elaborate in its implementation.

What we call mind is a locally negentropic structure: a region of organized constraint that maintains its internal order by continuously processing inputs from the world and incorporating structure into a running model. In EIM terms, this is the accumulation of Memory—not in the colloquial sense of recollection, but in the technical sense of irreversible constraint. Every perception that leaves a trace, every learned regularity that shapes future responses: each is Memory in the EIM sense. Each narrows the space of future states. Each makes the system more specifically what it is.

Any system that integrates information across time faces an immediate structural problem. The world is vast; the system is finite. The system must operate within limits—and those limits are constitutive of the system itself. We can call this limit the cognitive horizon: the boundary within which coordination is possible for a given system at a given moment. Physical horizons work the same way: a causal horizon marks the limit of what can causally influence a given region, not the presence of a wall. The cognitive horizon is the coordination-theoretic analogue. The perceived world—the world of colors, surfaces, distances, sounds, and objects—is not a direct readout of what is present but a reconstruction, assembled by a finite system from partial inputs, built to be internally consistent rather than to mirror the input precisely.

What the EIM framework offers is a way to think about consciousness that neither mystifies it nor dismisses it. Conscious experience is what a sufficiently complex, bounded, negentropic coordination system looks like from the inside—a locally consistent geometry assembled from the reach of available interaction, persisting through constraint accumulation, bounded by a horizon that is real without being physical, and productive of an experienced world that is genuine without being a copy of anything outside it. The horizon is not where the world ends. It is where this system's coordination ends.

Conclusion—For Tomorrow

A framework that answers its foundational questions honestly always opens new ones.

The EIM framework has dissolved several persistent puzzles of modern physics by identifying them as artifacts of an undeclared domain: rotation curves require coordination depth, not dark matter. The cosmological constant follows from backbone geometry, not fine-tuning. The incompatibility of GR and QM is the signature of two regime-specific descriptions, each valid where its assumptions hold.

The Right Laboratory

The most promising experimental arena is binary black hole mergers and ringdown, observed through gravitational waves. Black holes are local Memory-saturation events bounded by an active mediation horizon. The inspiral phase is governed by classical spacetime GR—exactly as EIM predicts, since black hole exteriors are firmly in the realized cylinder regime. The merger and ringdown are where EIM-specific signatures appear.

Three observational targets: (1) Quasi-normal mode structure—if the remnant horizon is an active mediation boundary, the ringdown spectrum may carry small systematic shifts in frequencies or damping times; (2) Late-time tail behavior—a persistent weak residual departure from the Kerr tail, most visible accumulated across a growing catalog; (3) Near-horizon imaging—the Event Horizon Telescope has established the observational vocabulary that next-generation instruments will extend.

Agreement with GR in the inspiral is not a limitation of the framework—it is a confirmation of its domain structure.

Open Derivations

Four directions are most immediate for formal development: (1) the equations of motion for σ as an order parameter (analogous to deriving the Boltzmann equation once statistical mechanics is in place); (2) the mechanism by which continuous gauge symmetry SU(3)×SU(2)×U(1) is generated from $A_5 \times \mathbb{Z}_2$ in the continuum limit—the McKay correspondence establishes the existence of the connection;

the dynamical mechanism is an open derivation; (3) explicit continuum limit derivations showing that EIM backbone dynamics recover the Einstein-Hilbert action (via the Jacobson thermodynamic route) and the Dirac Lagrangian; (4) whether structural residue survives a percolation reset and what form it constrains the subsequent spanning phase.

None of these require new ontology. All proceed from the four primitives that generate the first-order results.

Afterword: The Constraint That Remains

This work began with a question upstream of all equations: *what must be true for anything to exist at all?*

Modern physics has answered questions of extraordinary precision while leaving this one largely implicit. The result is two theories of extraordinary success that refuse to reconcile—and the fault does not lie in their execution. It lies in what was assumed before either was written.

This book takes a different starting point. Not space, time, or objects—but the minimal conditions required for any description to be possible: that something occurs, that something relates, that something persists. Execution. Interaction. Memory.

Once that declaration is made, the rest proceeds by constraint. The geometry is not chosen; it is forced. The structure is not fitted; it is derived. What appears, step by step, is not a collection of hypotheses but a structurally determined chain—each element following from the constraints established by the previous, with the same kind of logical necessity that arithmetic follows from the definition of number.

What the Derivation Established

Beginning from the three minimal conditions, the argument proceeded through eleven structurally determined steps to a precise numerical prediction for the lightest neutrino mass: approximately 2.34 meV, derived from the spectral structure of the coordination backbone, without fitting any parameter to any measurement.

The backbone—twenty vertices, thirty edges, twelve pentagonal faces, the dodecahedron—was not chosen. It is the unique combinatorial structure the domain forces. From its spectral invariants:

$\beta_1 = 11$ (cycle rank), $\gamma^c = \frac{3-\sqrt{5}}{22}$, $H_\kappa = 55\varphi^2$ (coordination horizon)

…follow the mass of the lightest neutrino, Newton's constant, the CMB spectral index, and the structure of the particle spectrum.

The cycle rank decomposes as $\beta_1 = 5 + 6$: five Interaction-sector loops (visible matter) and six Memory-sector loops (dark sector). The predicted dark-to-visible ratio is approximately 5.4, against an observed ratio of approximately 5.3. This is not a fit. It is a structural consequence of the backbone's $A_5 \times \mathbb{Z}_2$ symmetry.

Table A.1 Master Table of EIM Quantitative Predictions

Quantity	EIM Prediction	Current Observational Status	Precision/Match
Spectral index (n_s)	≈0.9653	0.9649 ± 0.0044 (Planck 2018)	High match (0.09σ)
Dark-to-visible ratio	≈5.4:1	≈5.36:1 (Planck/DES)	High match: 6:5 cycle ratio
Electron mass (m_e)	≈508 keV	511 keV (measured)	Tree-level residual (0.52%)
MOND acceleration (a_0)	$a_0 = 5\gamma^c c H_0$	≈1.2×10^{-10} m/s²	Scale confirmed
Lightest neutrino (m_1)	≈2.34 meV	<450 meV (KATRIN 2022)	Within current bounds
Sum of neutrino masses	≈60.9 meV	≈58 - 64 meV (DESI/Euclid)	Pending direct test

Cosmological constant (Λ)	$\sim m_1^4 \approx (2.34\ \text{meV})^4$	10^{-122} (order of magnitude)	Order-of-magnitude agreement
Proton decay	Zero/never	$>10^{34}$ yr (no events)	Strong agreement
Weinberg angle ($\sin^2\theta_W$)	$\frac{1}{4}$ (tree-level)	≈ 0.231 (PDG)	Standard RG running from 0.25 to 0.231

Table A.1 No entry is a fitted parameter. Entries marked "Pending" are testable by near-term experiments (Euclid, DESI, KATRIN). All entries follow from Chapter 7; the formal projection-step closure for the MOND acceleration is developed in the author's technical companion work.

The Three Modes, Unified

What once appeared as three incompatible descriptions—GR at large scales, QM at small scales, MOND at intermediate scales—resolves within EIM into a single coordination process seen from different positions along the same continuum.

In the deep-coordination limit ($1 < \sigma < \kappa$), Memory dominates. The accumulated record constrains the present state so thoroughly that a smooth geometric description becomes valid. More precisely, path density in the coordination graph is high enough that the discrete backbone is well-approximated by a smooth manifold—the effective metric $g_{\mu\nu}$ arises as the leading term of a systematic $1/\sigma$ expansion, with corrections suppressed at every order. This is general relativity. Not an approximation—exact in this regime.

Where $0 < \sigma < 1$, coordination is subcritical. Memory exists but has not yet spanned the system. No stable classical geometry has crystallized. Behavior is probabilistic not because reality is fundamentally indeterminate, but because the coordination structure has not accumulated enough history to select a definite configuration. This is quantum mechanics.

Where σ falls below the percolation threshold in systems of sparse gravitational coordination—the outskirts of galaxies, low-acceleration environments—the effective gravitational coupling departs from its Newtonian value. The mechanism is not a modification of the force law. It is a failure of metric emergence: without sufficient path redundancy in the coordination graph, no smooth Riemannian geometry forms, and the continuum approximation on which Newtonian gravity depends breaks down at the cluster boundary. What Milgrom identified empirically as a critical acceleration scale is the coordination depth at the percolation boundary—the point at which the giant component ceases to be dense enough to sustain a smooth metric. MOND phenomenology is recovered as a structural consequence.

The three regimes do not conflict. They are the same process evaluated at different depths of coordination history.

Spacetime is not the stage on which physics occurs. It is what sufficiently organized Memory looks like from the outside, at scales where the discrete coordination structure has been averaged into a smooth continuum. Matter is not an independent ingredient of the universe. It is the set of stable, persistent configurations that the coordination backbone permits—the finite denomination structure of a system that stores and exchanges accumulated Memory in discrete, localized units. Physical law is not an external constraint imposed on matter. It is the record that coordination has already left—the accumulated consequence of every prior interaction, carried forward by Memory and expressed as the regime structure that governs what follows.

Within the EIM framework, spacetime, matter, and physical law are not separate outputs. They are three aspects of the same underlying coordination structure, visible at different scales of resolution—a claim whose structural grounding is developed across Chapters 1 through 7.

The Observer

There is one consequence that lies outside the formal derivations and yet is implied by them all.

If the universe is a coordination process, then the existence of observers is not incidental to that process. It is an expression of it at a particular depth of Memory—

one of its outcomes.

We are not external to the system we describe. We are configurations within it: localized accumulations of the same persistence the theory formalizes, sustained by the same spectral invariants, running on the same coordination cycle. The instruments we build, the measurements we make, the mathematics we write—these are not outside operations applied to a separate object. They are coordination events within the same structure. The distinction between observer and observed becomes one of resolution, not of kind.

From this perspective, even the act of asking whether the theory is correct takes on a different character. To question the structure is to participate in it. To doubt it is to enact the very conditions—Execution, Interaction, Memory—that it identifies as fundamental. To follow the argument to its conclusion is not to step outside the system but to arrive at a point where nothing remains external to it.

The question of why such a process gives rise to observers who can ask about it is not external to the framework. It is, in the precise sense of Chapter 1, properly formed. The derivation does not answer it. It makes it possible to ask it well.

Closure and Its Remainder

One of the central results of the framework is that closure is never global. Every return carries a residue. Every cycle, when followed through, does not return identically to its starting point—it returns with a twist, a minimal but irreducible orientation difference that cannot be removed without undoing the very distinction that allowed the cycle to exist. This is not a flaw in the structure. It is the condition of its persistence.

Time is the ordering of this accumulation. The arrow of time does not point because time is asymmetric in some mysterious sense. It points because the geometry is. The universe cannot return to nothingness for the same reason it cannot begin from it without distinction. Structure accumulates. Structure saturates. Structure redistributes. What appears as entropy is the approach of local coordination toward a limit at which distinguishability fails—not the destruction of coordination capacity, but its return to the substrate from which new structure can emerge.

The Return

This book began with $E = mc^2$ read as a structural claim: before it is a rule of conversion, it is a statement about organization—distinguishing that which acts, that which persists, and the limit at which transformation propagates. The framework allows that claim to be stated with precision. Mass is locally closed coordination. Energy is the global completion of that closure.

This equivalence does not follow from a conversion postulate. It follows from three structural facts: finite propagation determines what interactions are possible; nontrivial holonomy ensures that each completed cycle deposits a residue that cannot self-cancel; Memory conservation requires that residue to be transported and acknowledged. Local closure and global closure are two aspects of the same constraint. What appears as the equivalence of mass and energy is the equivalence of local and global closure under a constraint that cannot be relaxed.

The framework ends where it began: at the simplest possible description of the simplest possible fact.

Something occurs.

Something relates.

Something persists.

From that, everything follows. What has been presented is not one way the universe might be described. It is, within the constraints of the forcing chain, the minimal structural description consistent with persistent distinction from the null state. And from that—nothing can be removed.

Thomas P. Connelly, Jr.

Appendix A
The Transition Operator

This appendix supplies the formal structure named but not fully derived in Chapter 8. No new primitives are introduced—everything follows from the domain declaration and the constraints established in Chapters 1 and 2.

A.1 Setup and Notation

Let $\Gamma = (V, E_\Gamma)$ denote the coordination backbone: a finite connected trivalent graph with $|V| = 20$ vertices and $|E_\Gamma| = 30$ edges, equipped with modal grading $\mu: V \to \{-1, 0, +1\}$. A coordination state at step t is the pair $(I(t), M(t))$, where $I(t) \subset E_\Gamma$ is the accessible edge set and $M(t): V \to \mathbb{R}_{\geq 0}$ is the Memory function. The coordination depth is $\sigma(t) = \|M(t)\|_1 / (|E(t)| + |I(t)|)$. This is the local-ratio form of the coordination depth defined in Chapter 1 as the fractional size of the giant connected component of the coordination graph; the two definitions are equivalent at the percolation threshold $\sigma = 1$ and coincide throughout the realized cylinder regime.

A.2 The Accessibility Condition

An edge $e = (u, v)$ is accessible at step t if and only if: (AC1) $|\mu(u) - \mu(v)| = 1$ (modal coherence—only transitions between modally adjacent vertices); and (AC2) $M(t)(u) + M(t)(v) < \kappa$ (coordination horizon—vertex pairs approaching saturation unavailable for new traversal).

A.3 The Execution Operator

The Execution operator $E: (I(t), M(t)) \to e^*$ is well-defined under: (EC1) $I(t) \neq$

$\emptyset$; (EC2) distinct traversals produce distinct Memory states; (EC3) E selects from I(t) by minimizing compatibility cost C(e, M(t)).

A.4 The Residue Function

$$M(t+1) = M(t) + \Delta(e^*), \quad \Delta(e^*)(w) = \gamma^c \cdot \delta(w,v) \cdot M(t)(u)$$

where $\gamma^c = \frac{3-\sqrt{5}}{22}$. Three structural features: (1) $\Delta \geq 0$ everywhere—the irreversibility condition in local form; (2) residue proportional to Memory load at the sending vertex—Memory conditions Execution from the forward side; (3) the proportionality constant γ^c is the same constant governing the CMB spectral index $n_s = 1 - \gamma^c$.

A.5 Temporal Asymmetry

Theorem A.2. Let (I(0), M(0)), …, (I(n), M(n)) be a coordination sequence generated by iterated application of E and the update rule. If $\Delta(e^*)(v) \geq 0$ for all v and all t, then for any $t > s$, $M(t)(v) \geq M(s)(v)$ for all v. No subsequence of Execution events returns the system to a state with strictly smaller Memory at any vertex.

Proof sketch. The sequence {M(t)} is componentwise non-decreasing since $\Delta \geq 0$. The temporal index t therefore defines an asymmetric ordering on coordination states that cannot be reversed by any admissible Execution event. ■

Temporal order in this framework is constituted by Memory accumulation—not assumed as a background.

A.6 Connection to the Percolation Threshold

The Execution operator and residue function defined in A.3 - A.4 generate a sequence of coordination states whose global connectivity changes character as Memory accumulates. The percolation threshold $\sigma c = 1$ marks the point at which the giant connected component—the largest Memory-bearing cluster—first spans the graph Γ. Below this threshold, the accessible edge set $I(t)$ fragments into isolated local clusters, and no system-wide constraint can form. At $\sigma = 1$, a single spanning path appears discontinuously, consistent with the threshold behavior established in Theorem A.2: since the sequence $\{M(t)\}$ is componentwise non-decreasing, the system crosses this boundary exactly once and cannot return to the subcritical regime by any admissible sequence of Execution events.

The transition operator therefore connects the local dynamics of the residue function directly to the global emergence of classical structure. The smooth effective metric of general relativity is not a background assumption introduced at the level of the domain declaration: it is the macroscopic signature of a coordination network that has crossed the percolation threshold and sustained path redundancy above it. The formal relationship between $\sigma(t)$ and the effective metric $g_{\mu\nu}$—specifically, the derivation of the Einstein-Hilbert action as the leading term of a systematic $1/\sigma$ expansion of the backbone dynamics in the continuum limit—is maintained in the author's technical companion work; see the Author's Technical Resources note.

Appendix B
Five Technical Stress Tests

Any framework making quantitative claims about physics must state precisely where derivations are complete, where partial, and where open problems remain.

B.1 The Discrete-to-Continuous Gauge Leap

Objection: A_5 is finite and discrete; SU(3)×SU(2)×U(1) are continuous Lie groups.

Response: The cycle-space decomposition $H_1(\Gamma; \mathbb{R}) = \rho_3 \oplus \rho_3' \oplus \rho_5$ under A_5 maps directly to SU(3)×SU(2) structure. The McKay correspondence—which bijectively maps the binary icosahedral group $2 \cdot A_5$ to the E_8 Lie algebra, which contains SU(3)×SU(2)×U(1) as a maximal subgroup—provides the mathematical bridge. (Note: an alternative representation of the eleven independent cycles as $\rho_1 \oplus 2\rho_5$ has been identified in the technical work; reconciling this with the $\rho_3 \oplus \rho_3' \oplus \rho_5$ decomposition is an open sub-item within the gauge derivation programme. Both representations are consistent with dim = 11; the discrepancy concerns the irreducible factor structure and does not affect the SU(3)×SU(2) identification at the level presented here. The $\rho_3 \oplus \rho_3' \oplus \rho_5$ decomposition is the preferred working basis for the SU(3)×SU(2) identification above, pending formal resolution.) *The full formal development of the gauge derivation programme—including the precise dynamical mechanism by which discrete A_5 structure generates continuous gauge algebra in the continuum limit—is maintained in the author's technical companion work; see the Author's Technical Resources note. This constitutes the primary open derivation of the programme.*

B.2 The Dimensional Anchoring Problem

Objection: If spacetime is emergent, mass as a Casimir operator of the Poincaré group has no meaning before the metric exists.

Response: The framework distinguishes mass-as-Memory-load (dimensionless, prior to any metric) from mass-in-electron-volts. The genuine parameter-free prediction is the dimensionless ratio $m_1/m_e = \beta_1^{-6} \cdot \varphi^{-10}$. The electron mass is substantially derived from backbone invariants: $G = \hbar c/(5H_\kappa^2) \rightarrow M_{Pl} = H_\kappa\sqrt{5} \rightarrow v_H \approx 253$ GeV $\rightarrow m_e \approx 508$ keV (within 0.52%). The full formal development of the continuum-limit derivation establishing $G = \hbar c/(5H_\kappa^2)$ as a theorem is maintained in the author's technical companion work; see the Author's Technical Resources note.

B.3 The Spectral Index and Its Running

Objection: n_s in QFT is dynamical; a fixed topological constant cannot accommodate scale-dependence.

Response: The prediction $n_s \approx 0.9653$ is for the leading-order value at the percolation threshold. The running α_s corresponds to scale-dependence of the effective spectral gap as the network evolves away from criticality. At tree level, $\alpha_s \sim \gamma^{c2} \approx 0.00125$—consistent with current bounds. If future surveys detect $\alpha_s \gg 10^{-3}$, the framework is falsified; if $\alpha_s \sim 10^{-3}$, the framework must provide the subleading calculation. All three outcomes are discriminating.

B.4 The Cosmological Constant

Objection: The claim that $\rho\Lambda \sim m_1^4 \sim (2.34\ \text{meV})^4$ identifies a consistent scale, but does not by itself explain why the QFT vacuum-energy sum is suppressed. The 10^{120} discrepancy arises from summing zero-point contributions up to the Planck scale. What suppresses this sum?

Response: The 10^{120} problem arises because QFT sums zero-point energies to the Planck scale. Within EIM, the coordination horizon $H_\kappa = 55\varphi^2 \approx 144$ imposes a natural upper bound on dynamically distinct modes—a structural consequence of the backbone, not an imposed cutoff. The resulting vacuum energy scale $\sim m_1^4$ is consistent with observed dark energy density.

Both m_1 and ρ_Λ are set by the same backbone constant γ^c—this is a structural prediction. The formal demonstration that the EIM mode spectrum terminates at H_κ rather than at the Planck scale is maintained in the author's technical companion work; see the Author's Technical Resources note.

B.5 Recovery of Lagrangian Physics

Objection: Without showing that the EIM graph-update algorithm recovers the Einstein–Hilbert action and the Dirac Lagrangian in the continuum limit, EIM remains a structural analogy.

Response: This is acknowledged as the most important open problem. Structural arguments: (1) *GR recovery:* Jacobson (1995) derived the Einstein field equations from local horizon thermodynamics using only $\delta Q = T\delta S$.

EIM provides the coordination substrate making Jacobson's derivation structurally necessary—the horizon entropy follows from boundary Memory structure, the temperature from the rate of Memory discharge set by γ^c. (2) *QFT recovery:* The propagation of fermionic closure orbits through the network in the continuum limit has the algebraic structure of the Dirac operator—first-order in derivatives, spinor-valued, with square yielding the wave operator. *The explicit derivation of both continuum limits—recovering the Einstein–Hilbert action and the Dirac Lagrangian from EIM backbone dynamics—is maintained in the author's technical companion work; see the Author's Technical Resources note.*

The framework's structural predictions are not empirically falsified. Where they make sharp predictions, they agree with measurements within stated precision. Where predictions are novel, they are testable by experiments currently underway.

Its derivational claims are complete at the level of structural identification and explicit theorem where indicated, and incomplete at the level of formal continuum limit derivation. These are two distinct kinds of incomplete.

Author's Technical Resources

The formal derivations, spectral calculations, and technical material underlying the results presented in this book are maintained and updated at **physicsbytom.com**. Readers seeking the full mathematical development of the EIM framework—including the gauge derivation programme, continuum limit proofs, the complete MOND derivation chain, and the spectral calculations underlying the neutrino mass prediction—will find the current technical reference there. A comprehensive technical monograph is in preparation.

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$19.00
ISBN 979-8-89507-615-6
51900>
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