MASS HIERARCHY FROM PRIMORDIAL CORRELATION

A Derivation of Particle Mass Ratios from Initial State Information Structure

Abstract

The hierarchy problem, why fundamental particles exhibit the specific mass ratios observed, spanning five orders of magnitude, remains one of the outstanding puzzles in particle physics. The Standard Model provides no mechanism for deriving these ratios; the Higgs coupling constants are empirical inputs, not theoretical outputs. We propose that mass hierarchy is not arbitrary but emergent, arising from the correlation structure of the universe at the moment of electroweak symmetry breaking. Within the framework of Informational Relativity, where mass corresponds to computational density and spacetime emerges from information geometry, we argue that particles most strongly correlated with the initial quantum state acquired the highest computational load (mass), while particles that decoupled early remained light. The Higgs mechanism, in this interpretation, did not assign mass randomly but read the existing information topology and allocated computational cost accordingly. This proposal transforms the hierarchy problem from an unexplained coincidence into a fossil record of primordial quantum correlation, yielding testable predictions about relationships between particle masses and their information, theoretic properties.

1. Introduction: The Hierarchy Problem

The Standard Model of particle physics successfully describes the electromagnetic, weak, and strong interactions through gauge symmetries and the Higgs mechanism. The discovery of the Higgs boson in 2012 at approximately 125 GeV confirmed the final predicted particle of this framework. Yet the model contains a persistent anomaly: it cannot explain why particles have the masses they do.

The electron mass is 0.511 MeV. The top quark mass is 173,000 MeV, a ratio of approximately 340,000 to 1. The muon is 207 times heavier than the electron despite being otherwise identical in its interactions. The tau is 17 times heavier still. No principle within the Standard Model determines these values. The Yukawa coupling constants that govern particle, Higgs interactions are free parameters, measured experimentally and inserted by hand.

This is the hierarchy problem in its phenomenological form. Why these masses? Why these ratios? The Standard Model's silence on this question suggests that something fundamental is missing from our understanding.

We propose an answer: the mass hierarchy is a fossil record. The masses we measure today encode information about the correlation structure of the universe at electroweak symmetry breaking. Particles did not receive mass arbitrarily; they received mass commensurate with their informational relationship to the initial state.

2. Theoretical Framework

2.1 Informational Relativity: Brief Summary

This proposal builds upon the framework of Informational Relativity, which advances three foundational postulates:

Postulate 1 (Information): Physical reality consists fundamentally of information and relationships between informational entities. Particles are patterns; interactions are computations.

Postulate 2 (Space): Spatial distance is inversely proportional to mutual information density. High mutual information implies proximity; low mutual information implies distance.

Postulate 3 (Time): Temporal evolution is identical to entropy production. Time does not flow independently; it is the accumulation of irreversible state changes.

From these postulates, a key identification emerges: *mass is computational density*. The mass of a system corresponds to how much information must be resolved to determine its state, how much computational work the universe must perform to process that region of the information graph.

2.2 The Higgs Mechanism Reinterpreted

In the Standard Model, the Higgs field acquires a nonzero vacuum expectation value at approximately 10^{-12} seconds after the Big Bang, breaking electroweak symmetry. Particles that couple to this field acquire mass proportional to their coupling strength. But the coupling strengths themselves are unexplained.

We propose a reinterpretation: the Higgs mechanism is the process by which computational load is assigned to information patterns based on their correlation with the initial state.

Prior to symmetry breaking, all particles existed in a maximally correlated quantum state, the hot, dense initial condition of the universe. As the universe expanded and cooled, correlations diluted. Different particles decoupled from the initial state at different rates, depending on their interaction properties.

At the moment of electroweak symmetry breaking, the Higgs mechanism 'read' the existing correlation structure and assigned computational load accordingly:

• Particles retaining strong correlation with the initial state → high computational load → high mass

• Particles with weak residual correlation → low computational load → low mass

• Particles fully decoupled (photons, gluons) → zero load → massless

3. Formal Development

3.1 Correlation Depth

Let $|\Psi_0\rangle$ represent the initial quantum state of the universe. At time t, a particle species i exists in state $|\psi_i(t)\rangle$. We define the *correlation depth* of particle species i as:

$$C_i(t) = |\langle\Psi_0|\psi_i(t)\rangle|^2$$

This quantity measures how much of the initial state's information structure is preserved in the particle's current state. High C_i indicates the particle 'remembers' the initial conditions; low C_i indicates the particle has decoupled.

3.2 The Mass Assignment Principle

We propose that the mass m_i acquired by particle species i at electroweak symmetry breaking (t = t_EW) is proportional to its correlation depth at that moment:

$$m_i = \kappa \cdot C_i(t\_EW)$$

where κ is a universal constant with dimensions of mass, potentially related to the Higgs vacuum expectation value v ≈ 246 GeV.

This principle asserts that the Higgs mechanism did not assign mass arbitrarily. Rather, it measured each particle's correlation with the initial state and assigned computational load proportionally.

3.3 Correlation Decay Dynamics

The correlation depth evolves according to the particle's interactions. Particles that interact strongly with the primordial plasma maintain correlation; particles that interact weakly lose it. We model this as:

$$dC_i/dt = ,\ \gamma_i C_i + \Sigma_j\ \Gamma_{ij}\ C_j$$

where γ_i is the intrinsic decoherence rate of species i, and Γ_{ij} represents correlation transfer between species through interactions.

Particles with strong self, interactions (like the top quark, with its large QCD and Yukawa couplings) maintain correlation. Particles with weak interactions (like neutrinos) decouple rapidly and arrive at t_EW with minimal residual correlation, hence minimal mass.

4. Explaining the Observed Hierarchy

4.1 The Top Quark

The top quark is the heaviest known fundamental particle at 173 GeV. In our framework, this indicates it retained the deepest correlation with the initial state.

This is physically plausible: the top quark has the strongest Yukawa coupling (≈1, near the unitarity limit), the largest QCD color charge interactions, and decays so rapidly ($\tau \sim 10^{-25}$ s) that it never hadronizes. It remains, in a sense, closest to the primordial quark, gluon plasma. It remembers the beginning.

4.2 The Electron and Light Leptons

The electron has no color charge and weak Yukawa coupling. It interacted minimally with the dense initial state and decoupled early. By t_EW, its correlation depth was low, hence its low mass (0.511 MeV).

The muon and tau are heavier than the electron despite identical gauge quantum numbers. In our framework, this implies they retained higher correlation through mechanisms not captured by gauge interactions alone, potentially through generation, mixing effects or different initial, state populations.

4.3 Massless Particles

Photons and gluons are massless. In the Standard Model, this follows from gauge invariance. In our framework, we add an informational interpretation: these particles carry information but do not hold it. They are maximally decoupled from the initial correlation structure. They propagate at maximum bandwidth precisely because they carry no computational load, no memory of the beginning.

4.4 Neutrinos

Neutrinos have tiny but nonzero masses (< 1 eV). They interact only via the weak force, decoupling from the primordial plasma extremely early. Their near, zero correlation depth at t_EW translates to near, zero mass. The fact that they have any mass at all suggests some residual correlation survived, perhaps through their mixing with heavier states.

5. Testable Predictions

Prediction 1: Correlation, Mass Correspondence

Particles with similar masses should exhibit similar quantum coherence properties when probed at high energies. Specifically, the decoherence rates of different particle species should correlate with their mass ratios. The top quark's extreme instability makes direct tests difficult, but bottom and charm quarks should show measurable differences in quantum coherence properties proportional to their mass ratios.

Prediction 2: Generation Structure

The three, generation structure of the Standard Model (electron/muon/tau, up/charm/top, down/strange/bottom) may correspond to three correlation epochs. If masses encode decoupling history, the generations might represent particles that decoupled at distinct phase transitions. Mass ratios between generations should relate to the timing of these transitions.

Prediction 3: Beyond, Standard, Model Particles

If supersymmetric or other BSM particles exist, their masses should correlate with their coupling structure to Standard Model particles in predictable ways. Particles strongly coupled to the top quark should be heavier than those coupled to light quarks, following the correlation inheritance principle.

Prediction 4: Cosmological Signatures

The correlation structure at t_{EW} should leave imprints in cosmological observables. The specific values of particle masses affected Big Bang nucleosynthesis rates; if those masses encode primordial correlation, subtle correlations should exist between particle physics observables and CMB patterns.

Prediction 5: Mass Running

In the Standard Model, running masses (variation with energy scale) are computed from renormalization group equations. Our framework predicts an additional effect: at energies approaching the electroweak scale, masses should show deviations from standard running as the correlation, assignment mechanism itself is probed.

6. Relation to Existing Approaches

Technicolor and Composite Higgs: These approaches attempt to generate mass dynamically through new strong interactions. Our framework is agnostic about whether the Higgs is fundamental or composite; it addresses why the correlation, reading mechanism yields the values it does, regardless of the mechanism's microscopic origin.

Supersymmetry: SUSY relates masses of bosons and fermions through symmetry. Our framework is complementary: supersymmetric partners, if they exist, would have their masses set by the same correlation principle, providing predictions for the SUSY mass spectrum.

String Theory Landscape: The string landscape approach accepts mass values as environmental selection from a vast ensemble. Our framework offers a dynamical alternative: masses are determined, not selected. The specific correlation structure of our universe's initial state fixed the masses uniquely.

Anthropic Arguments: Some argue that mass values are constrained by requiring a universe compatible with observers. Our framework is orthogonal: it explains why masses have the values they do, regardless of whether those values happen to permit observers.

7. Discussion

The proposal advanced here transforms the hierarchy problem from a mystery into a historical question. The mass values are not arbitrary; they are data about the early universe encoded in every particle. When we measure the top quark mass, we are measuring how strongly that particle species remained correlated with the initial quantum state through the first 10^{-12} seconds of cosmic evolution.

This perspective has a precedent: the cosmic microwave background encodes information about conditions at recombination ($t \sim 380{,}000$ years). We propose that particle masses encode information about conditions at electroweak symmetry breaking ($t \sim 10^{-12}$ seconds). Just as CMB analysis reveals early, universe physics, precision mass measurements may reveal the correlation topology of the primordial quantum state.

The framework's most significant implication is ontological: mass is not a property assigned arbitrarily to particles. It is a measure of how much each particle remembers the beginning. Heavy particles are those most entangled with the origin. Light particles are those that forgot.

8. Conclusion

We have proposed that the hierarchy problem admits an informational solution. The mass spectrum of fundamental particles is not a set of arbitrary parameters but a fossil record of primordial quantum correlation. The Higgs mechanism, rather than assigning mass randomly, read the correlation structure of the universe at electroweak symmetry breaking and assigned computational load accordingly.

This proposal emerges naturally from the framework of Informational Relativity, where mass corresponds to computational density and physical properties encode information, theoretic relationships. Within this framework, the hierarchy is not puzzling, it is precisely what one would expect. Particles that interacted strongly with the initial state remained correlated; particles that decoupled became light; particles that never coupled remained massless.

The predictions outlined in Section 5 provide paths toward empirical discrimination. If mass truly encodes correlation depth, this should manifest in measurable relationships between particle masses and their quantum information properties. The masses cease to be inputs and become outputs, derived from the correlation topology of the initial state rather than inserted by hand.

The hierarchy problem has persisted for decades because it was framed as a question about mechanism: what process generates these masses? We suggest the question should be historical: what does the pattern of masses tell us about the initial conditions? Viewed this way, the hierarchy is not a problem but a message, data from the first moments of the universe, encoded in every particle, waiting to be read.

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Mass is memory. The heavier the particle, the more it remembers the beginning.