Emergence of Fundamental Interactions from Time-Scalar Field Theory

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Abstract

We derive the emergence of fundamental interaction sectors from Time-Scalar Field Theory (TSFT), where time is promoted to a physical scalar field $\Theta(x,t)$. Beginning from coherence-stable particle eigenmodes previously derived within TSFT, we demonstrate that three distinct interaction regimes arise naturally from temporal-frame deformation dynamics.

These regimes correspond to (i) propagating curvature interactions, (ii) conversion interactions between eigenmodes, and (iii) composite coherence locking interactions. We show that these interaction classes emerge from the dynamical status of temporal deformation fields and admit a gauge-compatible formulation without externally imposed gauge postulates.

We further derive selection rules, conservation laws, and mediator structures governing these interaction sectors. From these results, we demonstrate the emergence of composite matter states, integer-charged bound structures, and residual composite interactions that naturally produce multi-core bound configurations.

This framework provides a unified derivation of interaction hierarchies, composite matter formation, and emergent nuclear-like structure directly from scalar-time dynamics.

1 Introduction

Time-Scalar Field Theory (TSFT) promotes time from a background parameter to a physical scalar field:

$$\Theta(x,t). \tag{1}$$

In this framework, physical dynamics arise from gradients and curvature of the scalar-time field. The fundamental dynamical quantity is therefore the temporal gradient:

$$\tau_\mu = \partial_\mu \Theta. \tag{2}$$

Spatial and temporal structure emerge from variations in $\Theta(x,t)$, and stable physical objects correspond to coherence-preserving eigenmodes of the scalar-time field.

Previously, stable particle eigenmodes were derived from the scalar-time coherence operator:

$$C_\Theta \psi_n = \lambda_n \psi_n, \tag{3}$$

where ψ_n denotes a persistent scalar-time eigenmode and λ_n is the corresponding coherence eigenvalue. These eigenmodes form the elementary particle spectrum within TSFT.

Each eigenmode is labeled by a discrete set of quantum indices:

$$\psi_{n,q,h,s}, \tag{4}$$

where:

$$n \quad \text{spectral level} \tag{5}$$
$$q \quad \text{family index} \tag{6}$$
$$h \quad \text{closure index} \tag{7}$$
$$s \quad \text{spin} \tag{8}$$

Admissible eigenmodes satisfy the closure condition:

$$3n + 2q + h \equiv 0 \pmod 6. \tag{9}$$

This closure condition defines the allowed particle spectrum within TSFT and determines the admissible eigenmode structure.

While particle eigenmodes arise from scalar-time coherence stability, interactions emerge from spatial variations of scalar-time coherence between eigenmodes. In particular, when multiple eigenmodes coexist, scalar-time gradients induce deformation of the temporal frame, producing interaction dynamics.

To describe this, we introduce the temporal-frame deformation field:

$$\tau_\mu = \partial_\mu \Theta + a_\mu, \tag{10}$$

where a_μ represents a local deformation of the scalar-time gradient.

The corresponding curvature tensor is defined as:

$$F_{\mu\nu} = \partial_\mu a_\nu - \partial_\nu a_\mu. \tag{11}$$

We will show that the dynamical behavior of a_μ determines three distinct interaction regimes:

1. Propagating curvature interactions
2. Eigenmode conversion interactions
3. Composite coherence locking interactions

These interaction classes arise directly from scalar-time dynamics and require no externally imposed gauge symmetries.

In the following sections, we derive these interaction sectors, establish their selection rules, and demonstrate the emergence of composite matter structures from scalar-time coherence dynamics.

2 Temporal-Frame Deformation Dynamics

Interactions in Time-Scalar Field Theory arise from spatial and temporal variations in scalar-time coherence. When multiple eigenmodes coexist, the scalar-time gradient becomes locally deformed, producing interaction dynamics.

We define the temporal-frame field:

$$\tau_\mu = \partial_\mu \Theta + a_\mu, \tag{12}$$

where $\Theta(x, t)$ is the scalar-time field and a_μ represents local temporal-frame deformation.

The curvature associated with this deformation is defined as:

$$F_{\mu\nu} = \partial_\mu a_\nu - \partial_\nu a_\mu. \tag{13}$$

This curvature describes rotational shear in the scalar-time field and serves as the fundamental interaction mediator.

We construct the dynamical action for the deformation field:

$$\mathcal{L}_a = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + \frac{1}{2} M_a^2 a_\mu a^\mu. \tag{14}$$

This represents a general quadratic Lorentz-invariant local action for the temporal deformation field. Higher-derivative or nonlocal terms may also be considered, but are not required for the leading-order scalar-time deformation dynamics.

Coupling between scalar-time eigenmodes and the deformation field is given by:

$$\mathcal{L}_{\text{int}} = g \bar{\psi} \gamma^\mu \tau_\mu \psi. \tag{15}$$

Substituting the temporal-frame definition:

$$\mathcal{L}_{\text{int}} = g \bar{\psi} \gamma^\mu (\partial_\mu \Theta + a_\mu) \psi. \tag{16}$$

Variation with respect to a_μ yields the field equation:

$$\partial_\nu F^{\nu\mu} + M_a^2 a^\mu = J^\mu, \tag{17}$$

where the current is defined as:

$$J^\mu = g \bar{\psi} \gamma^\mu \psi. \tag{18}$$

This equation determines the dynamical behavior of temporal-frame deformation and defines the interaction structure of TSFT.

The nature of the interaction depends on the dynamical status of the deformation field a_μ, which we classify in the following section.

3 Classification of Interaction Regimes

3.1 Derivation of the Deformation Field Mass

The deformation field mass parameter M_a is not introduced arbitrarily. Rather, it emerges from the curvature of the scalar-time coherence potential.

Consider the effective scalar-time deformation energy:

$$\mathcal{E}_\Theta = \frac{1}{2} (\partial_\mu \Theta)^2 + V(\Theta) \tag{19}$$

Origin of the Scalar-Time Potential

The scalar-time potential $V(\Theta)$ is not introduced as an independent field-theoretic potential. Rather, it arises from scalar-time coherence stability.

In the TSFT framework, stable configurations correspond to extrema of the coherence functional

$$\mathcal{E}[\Theta] = \int \left[\frac{1}{2}(\partial_\mu \Theta)^2 + U(\rho_\Theta(\Theta))\right] d^4x, \tag{20}$$

where $\rho_\Theta(\Theta)$ denotes the scalar-time coherence density and $U(\rho_\Theta)$ represents the coherence viability functional derived in the particle-emergence framework.

Expanding about a coherence-stable background Θ_0, the effective potential is defined as

$$V(\Theta) = U(\rho_\Theta(\Theta)). \tag{21}$$

Thus the curvature of the scalar-time potential is determined by the second variation of the coherence functional:

$$M_a^2 = \left.\frac{\partial^2 V}{\partial \Theta^2}\right|_{\Theta_0} = \left.\frac{\partial^2 U}{\partial \Theta^2}\right|_{\Theta_0}. \tag{22}$$

Therefore, the deformation field mass arises directly from scalar-time coherence stability rather than from an independently introduced potential.

Expanding about a coherence-stable background Θ_0,

$$\Theta = \Theta_0 + \delta\Theta \tag{23}$$

we obtain

$$V(\Theta) = V(\Theta_0) + \frac{1}{2}\left.\frac{\partial^2 V}{\partial \Theta^2}\right|_{\Theta_0} (\delta\Theta)^2 + \cdots \tag{24}$$

The deformation field a_μ couples to gradients of Θ,

$$a_\mu \sim \partial_\mu \Theta \tag{25}$$

This proportionality follows from the definition of temporal-frame deformation as the deviation of the local scalar-time gradient from its coherence-stable background configuration. Thus a_μ represents fluctuations of the scalar-time gradient and therefore scales with $\partial_\mu \Theta$ to leading order.

This induces an effective mass term

$$M_a^2 = \left.\frac{\partial^2 V}{\partial \Theta^2}\right|_{\Theta_0}. \tag{26}$$

Thus the deformation field mass is determined by the curvature of the scalar-time coherence potential, and is therefore derived from TSFT dynamics rather than introduced by hand.

The interaction structure in Time-Scalar Field Theory is determined by the dynamical behavior of the temporal-frame deformation field a_μ. The governing equation derived previously is:

$$\partial_\nu F^{\nu\mu} + M_a^2 a^\mu = J^\mu. \tag{27}$$

The interaction regime depends on the effective mass parameter M_a. We now examine the three possible cases.

3.2 Massless Propagating Regime

When the deformation field is massless,

$$M_a = 0, \tag{28}$$

the field equation reduces to:

$$\partial_\nu F^{\nu\mu} = J^\mu. \tag{29}$$

In momentum space, this yields:

$$k_\nu F^{\nu\mu} = J^\mu. \tag{30}$$

The corresponding propagator takes the form:

$$D(k) \sim \frac{1}{k^2}. \tag{31}$$

This produces a long-range interaction. In coordinate space, the resulting potential behaves as:

$$V(r) \sim \frac{1}{r}. \tag{32}$$

This defines the first interaction regime:

$$\text{Class I: Massless Propagating Interaction.} \tag{33}$$

3.3 Massive Conversion Regime

When the deformation field acquires an effective mass,

$$M_a \neq 0, \tag{34}$$

the field equation becomes:

$$\partial_\nu F^{\nu\mu} + M_a^2 a^\mu = J^\mu. \tag{35}$$

The propagator then takes the form:

$$D(k) \sim \frac{1}{k^2 + M_a^2}. \tag{36}$$

In coordinate space, this yields the Yukawa-type potential:

$$V(r) \sim \frac{e^{-M_a r}}{r}. \tag{37}$$

This interaction is short-range and defines the second interaction regime:

$$\text{Class II: Massive Conversion Interaction.} \tag{38}$$

3.4 Auxiliary Confinement Regime

A third regime occurs when the deformation field is not an independent propagating degree of freedom, but instead is determined algebraically by composite coherence constraints:

$$\frac{\delta E}{\delta a_\mu} = 0. \tag{39}$$

In this regime, the deformation field becomes:

$$a_\mu = a_\mu[\rho_{\text{comp}}], \tag{40}$$

where ρ_{comp} represents composite coherence density.

Substituting back into the energy functional yields an effective interaction:

$$E_{\text{conf}} = -\int \rho_{\text{comp}}(x)\rho_{\text{comp}}(x')K(|x-x'|)\,dx\,dx'. \tag{41}$$

Derivation of the Localization Kernel

In the auxiliary regime, the deformation field is determined by the stationary condition

$$\frac{\delta E}{\delta a_\mu} = 0. \tag{42}$$

Using the quadratic deformation energy,

$$E[a_\mu] = \int \left[\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \frac{1}{2}M_a^2 a_\mu a^\mu - J^\mu a_\mu\right] d^4x, \tag{43}$$

variation yields

$$\partial_\nu F^{\nu\mu} + M_a^2 a^\mu = J^\mu. \tag{44}$$

Formally, this equation may be inverted using the Green's function $G^\mu{}_\nu(x-x')$ of the auxiliary deformation operator, giving

$$a^\mu(x) = \int G^\mu{}_\nu(x-x')\,J^\nu(x')\,d^4x'. \tag{45}$$

Substituting this solution back into the quadratic energy functional yields the effective bilinear interaction

$$E_{\text{loc}} = -\frac{1}{2}\int J_\mu(x)\,G^{\mu\nu}(x-x')\,J_\nu(x')\,d^4x\,d^4x'. \tag{46}$$

For composite coherence states, the source current is induced by gradients of the composite coherence density, schematically

$$J^\mu \sim \partial^\mu \rho_{\text{comp}}. \tag{47}$$

Integrating by parts then gives an equivalent density-density form

$$E_{\text{loc}} = -\int \rho_{\text{comp}}(x)\,K(x-x')\,\rho_{\text{comp}}(x')\,d^4x\,d^4x', \tag{48}$$

where the kernel is determined by the Green's function of the auxiliary deformation field:

$$K(x - x') \sim \partial_\mu \partial'_\nu G^{\mu\nu}(x - x'). \tag{49}$$

Thus the effective localization kernel is not inserted phenomenologically; it is induced by eliminating the auxiliary deformation field in the non-propagating regime.

This interaction produces localized binding of coherence modes. While not necessarily generating linear confinement at large separation, the resulting kernel suppresses spatial separation and stabilizes composite coherence structures.

This defines the third interaction regime:

$$\text{Class III: Composite Confinement Interaction.} \tag{50}$$

Thus, three interaction classes emerge naturally from scalar-time dynamics:

$$\text{Class I} \quad \text{Massless Propagating Interaction} \tag{51}$$

$$\text{Class II} \quad \text{Massive Conversion Interaction} \tag{52}$$

$$\text{Class III} \quad \text{Composite Confinement Interaction} \tag{53}$$

These regimes arise directly from the dynamical status of the temporal-frame deformation field.

4 Interaction Sources and Conservation Laws

The three interaction regimes derived above are sourced by distinct coherence structures within the Time-Scalar Field Theory framework. These sources arise directly from the coupling term:

$$\mathcal{L}_{\text{int}} = g\bar{\psi}\gamma^\mu(\partial_\mu \Theta + a_\mu)\psi. \tag{54}$$

4.1 Diagonal Propagating Current

Variation with respect to the temporal-frame deformation field a_μ yields the source current:

$$J^\mu = g\bar{\psi}\gamma^\mu\psi. \tag{55}$$

This current sources the massless propagating interaction sector. Taking the divergence of the field equation in the massless case,

$$\partial_\nu F^{\nu\mu} = J^\mu, \tag{56}$$

and using the antisymmetry of $F^{\nu\mu}$ gives:

$$\partial_\mu \partial_\nu F^{\nu\mu} = 0, \tag{57}$$

hence

$$\partial_\mu J^\mu = 0. \tag{58}$$

Thus the diagonal current is conserved.

4.2 Off-Diagonal Transition Currents

Let ψ_m and ψ_n denote two distinct admissible eigenmodes. The off-diagonal interaction current is defined by:

$$J^{\mu}_{mn} = g\bar{\psi}_m \gamma^{\mu} \psi_n. \tag{59}$$

This current mediates transitions between distinct scalar-time eigenmodes. Its divergence is not generally zero, but instead defines a conversion density:

$$\partial_{\mu} J^{\mu}_{mn} = \mathcal{T}_{mn}, \tag{60}$$

where $\mathcal{T}_{mn}$ is the local mode-conversion rate.

The mode-conversion term $\mathcal{T}_{mn}$ arises from temporal coherence gradient coupling between eigenmodes. Explicitly, from the scalar-time coherence operator $\mathcal{C}_{\Theta}$.

$$\mathcal{T}_{mn} = \int_{\Omega} \bar{\psi}_m(x) \left(\partial_{\mu} \mathcal{C}_{\Theta}\right) \psi_n(x)\, d^3x \tag{61}$$

This expression shows that mode conversion occurs when spatial or temporal gradients of the scalar-time coherence field are present. In regions of uniform scalar-time coherence, $\mathcal{T}_{mn}$ vanishes and off-diagonal mode currents are conserved. Nonzero gradients therefore induce transitions between coherence eigenmodes, generating the Class II interaction dynamics.

Thus off-diagonal currents satisfy a balance law rather than a strict conservation law.

4.3 Composite Coherence Density

For multiple interacting eigenmodes, the relevant source for the confinement sector is the composite coherence density:

$$\rho_{\text{comp}} = \sum_{i,j} \bar{\psi}_i \psi_j. \tag{62}$$

This quantity measures the total locally locked coherence of a multi-mode composite state. Stability of a confined composite requires conservation of total composite coherence within the locking domain:

$$\frac{d}{dt} \int_{\Omega_{\text{lock}}} \rho_{\text{comp}}\, d^3x = 0. \tag{63}$$

4.4 Source Hierarchy

We therefore obtain three distinct source classes:

$$\text{Class I source:} \qquad J^{\mu} = g\bar{\psi}\gamma^{\mu}\psi, \tag{64}$$

$$\text{Class II source:} \qquad J^{\mu}_{mn} = g\bar{\psi}_m \gamma^{\mu} \psi_n, \tag{65}$$

$$\text{Class III source:} \qquad \rho_{\text{comp}} = \sum_{i,j} \bar{\psi}_i \psi_j. \tag{66}$$

These source structures define the full interaction hierarchy of TSFT:

- conserved diagonal current for massless propagating interactions,
- off-diagonal transition current for massive conversion interactions,
- composite coherence density for confined locking interactions.

Thus the interaction sectors of TSFT are not merely distinguished by mediator dynamics, but also by distinct source structures and conservation laws.

5 Interaction Selection Rules from Scalar-Time Closure

The particle states derived in the TSFT mass-emergence framework are labeled by:

$$(n, q, h, s) \tag{67}$$

subject to the closure condition:

$$3n + 2q + h \equiv 0 \pmod 6. \tag{68}$$

This constraint governs allowed particle transitions and therefore determines the selection rules of TSFT interactions.

5.1 Transition Closure Condition

Consider a transition between two states:

$$(n, q, h, s) \to (n', q', h', s'). \tag{69}$$

Both states must satisfy closure:

$$3n + 2q + h \equiv 0 \pmod 6 \tag{70}$$

$$3n' + 2q' + h' \equiv 0 \pmod 6 \tag{71}$$

Subtracting the two relations gives:

$$3(n' - n) + 2(q' - q) + (h' - h) \equiv 0 \pmod 6. \tag{72}$$

Define transition increments:

$$\Delta n = n' - n \tag{73}$$

$$\Delta q = q' - q \tag{74}$$

$$\Delta h = h' - h \tag{75}$$

The transition constraint becomes:

$$3\Delta n + 2\Delta q + \Delta h \equiv 0 \pmod 6. \tag{76}$$

This is the fundamental TSFT interaction selection rule.

5.2 Allowed Minimal Transitions

We now determine minimal allowed transitions.

5.2.1 Pure Level Transitions

If

$$\Delta q = 0, \quad \Delta h = 0 \tag{77}$$

then

$$3\Delta n \equiv 0 \pmod 6 \tag{78}$$

which implies:

$$\Delta n = 0, \pm 2, \pm 4, \dots \tag{79}$$

Thus level transitions occur in steps of two.

5.2.2 Family Transitions

If

$$\Delta n = 0, \quad \Delta h = 0 \tag{80}$$

then

$$2\Delta q \equiv 0 \pmod 6 \tag{81}$$

which implies:

$$\Delta q = 0, \pm 3, \pm 6, \dots \tag{82}$$

Thus family transitions occur in steps of three.

5.2.3 Charge Transitions

If

$$\Delta n = 0, \quad \Delta q = 0 \tag{83}$$

then

$$\Delta h \equiv 0 \pmod 6 \tag{84}$$

Thus:

$$\Delta h = 0, \pm 6, \pm 12, \dots \tag{85}$$

Charge transitions occur in multiples of six.

5.3 Mixed Transitions

General transitions involve combinations:

$$3\Delta n + 2\Delta q + \Delta h = 6k \tag{86}$$

for integer k. These define mixed transitions between particle families and charge states.

5.4 Interaction Interpretation

The three interaction classes derived earlier naturally correspond to these transition types:

$$\text{Class I:} \quad \Delta n = 0, \Delta q = 0, \Delta h = 0 \tag{87}$$

$$\text{Class II:} \quad \Delta n \neq 0 \quad \text{or} \quad \Delta q \neq 0 \tag{88}$$

$$\text{Class III:} \quad \text{Composite locking constraints} \tag{89}$$

Thus TSFT interaction structure emerges directly from scalar-time closure arithmetic.

5.5 Charge Constraints from Closure

Recall from Appendix H:

$$Q = \frac{h}{3}. \tag{90}$$

Therefore,

$$\Delta Q = \frac{\Delta h}{3}. \tag{91}$$

Since the transition constraint requires

$$\Delta h \equiv 0 \pmod 6, \tag{92}$$

we obtain

$$\Delta Q = 0, \pm 2, \pm 4, \ldots \tag{93}$$

Thus scalar-time closure constrains allowed charge transitions between particle states.

It is important to distinguish this result from absolute charge quantization. The allowed absolute charge values are determined by the admissible integer values of the closure index h, subject to the closure condition

$$3n + 2q + h \equiv 0 \pmod 6. \tag{94}$$

Thus:

- Closure constrains allowed charge transitions
- Closure also restricts admissible absolute charge values
- Together these produce a structured charge spectrum

Therefore, scalar-time closure produces a constrained charge structure, with both transition rules and admissible absolute charge values derived from coherence arithmetic.

5.6 Summary

Interaction selection rules in TSFT follow from closure arithmetic:

$$3\Delta n + 2\Delta q + \Delta h \equiv 0 \pmod 6 \tag{95}$$

This determines allowed transitions between particle states and defines the interaction algebra of TSFT.

6 Gauge-Theoretic Formulation Compatible with Scalar-Time Coherence

The interaction structure derived above admits a gauge-theoretic formulation compatible with scalar-time coherence. In this section, we do not claim to derive gauge symmetry directly from the scalar-time field $\Theta(x,t)$. Rather, we show that the temporal-frame deformation sector naturally supports a gauge-invariant formulation.

6.1 Local Phase Redundancy of the Interaction Sector

Consider the fermionic field ψ under a local phase transformation:

$$\psi(x) \to e^{i\alpha(x)}\psi(x). \tag{96}$$

Under this transformation, the ordinary derivative becomes

$$\partial_\mu \psi \to e^{i\alpha(x)} \left(\partial_\mu + i\partial_\mu \alpha\right) \psi. \tag{97}$$

To preserve covariance of the interaction sector, we define the coherence-covariant derivative

$$D_\mu = \partial_\mu + ig(\partial_\mu \Theta + a_\mu). \tag{98}$$

Requiring

$$D_\mu \psi \to e^{i\alpha(x)} D_\mu \psi \tag{99}$$

implies the transformation law

$$a_\mu \to a_\mu - \frac{1}{g}\partial_\mu \alpha. \tag{100}$$

Thus the interaction sector admits a local $U(1)$-type redundancy.

6.2 Gauge-Invariant Field Strength

The associated field strength tensor is

$$F_{\mu\nu} = \partial_\mu a_\nu - \partial_\nu a_\mu. \tag{101}$$

Under the transformation above,

$$a_\mu \to a_\mu - \frac{1}{g}\partial_\mu \alpha, \tag{102}$$

the field strength remains invariant:

$$F_{\mu\nu} \to F_{\mu\nu}. \tag{103}$$

Thus the curvature of the temporal-frame deformation field is gauge-invariant.

6.3 Compatible Gauge-Invariant Interaction Lagrangian

The interaction sector may therefore be written in the gauge-compatible form

$$\mathcal{L} = \bar{\psi}\, i\gamma^\mu D_\mu \psi - \frac{1}{4} F_{\mu\nu} F^{\mu\nu}. \tag{104}$$

This is not presented as an independent postulate replacing scalar-time dynamics. Rather, it is a compatible reformulation of the temporal-frame deformation sector already derived in Sections 2–4.

6.4 Extension to Multiple Coherence Sectors

If multiple coherence eigenmodes are collected into a multiplet ψ_i, then the same logic permits a non-Abelian generalization:

$$\psi_i \to U_{ij}(x)\psi_j, \tag{105}$$

with

$$U(x) \in U(N) \tag{106}$$

or a subgroup thereof, depending on the structure of the coherence sector under consideration. The corresponding covariant derivative takes the form

$$D_\mu = \partial_\mu + igA^a_\mu T^a. \tag{107}$$

We do not claim here that TSFT uniquely derives a specific non-Abelian group such as $SU(N)$. Rather, we note that multi-sector coherence structure naturally admits such gauge-theoretic extensions.

6.5 Interpretive Status

The result of this section is therefore modest but important:

- scalar-time coherence dynamics produce a temporal-frame deformation sector,
- that sector admits a gauge-invariant formulation,
- and the associated curvature tensor provides the natural mediator structure for the propagating interaction regime.

Accordingly, the present paper establishes gauge compatibility, not a full first-principles derivation of gauge symmetry from $\Theta(x, t)$ alone.

7 Physical Interpretation of Interaction Classes

We now interpret the three interaction regimes derived from scalar-time coherence. This interpretation is structural rather than phenomenological; no identification with known forces is assumed a priori.

7.1 Massless Propagating Interaction

The Class I interaction is defined by a massless gauge field:

$$\partial_\nu F^{\nu\mu} = J^\mu. \tag{108}$$

This interaction is long-range, with propagator:

$$D(k) \sim \frac{1}{k^2}. \tag{109}$$

and potential:

$$V(r) \sim \frac{1}{r}. \tag{110}$$

Such interactions transmit coherence shear across large distances and preserve diagonal eigenmode structure:

$$\Delta n = 0, \quad \Delta q = 0, \quad \Delta h = 0. \tag{111}$$

Thus Class I interactions preserve particle identity while transmitting coherence distortions.

7.2 Massive Conversion Interaction

The Class II interaction is defined by:

$$\partial_\nu F^{\nu\mu} + M_a^2 a^\mu = J^\mu. \tag{112}$$

This produces Yukawa-type interactions:

$$V(r) \sim \frac{e^{-M_a r}}{r}. \tag{113}$$

These interactions allow transitions between eigenmodes:

$$\Delta n \neq 0 \quad \text{or} \quad \Delta q \neq 0. \tag{114}$$

Thus Class II interactions mediate particle conversion processes.

7.3 Composite Confinement Interaction

Class III interactions arise when the deformation field is algebraically constrained:

$$\frac{\delta E}{\delta a_\mu} = 0. \tag{115}$$

This produces composite locking of multiple eigenmodes:

$$\rho_{\text{comp}} = \sum_{i,j} \bar{\psi}_i \psi_j. \tag{116}$$

The resulting interaction is localized and produces confinement behavior.

Composite states therefore arise from coherence locking.

7.4 Structural Correspondence

Without assuming identification, the three interaction regimes structurally resemble:

$$\text{Class I} \quad \text{Long-range identity-preserving interaction} \tag{117}$$

$$\text{Class II} \quad \text{Short-range conversion interaction} \tag{118}$$

$$\text{Class III} \quad \text{Composite confinement interaction} \tag{119}$$

These three regimes emerge directly from scalar-time coherence dynamics.

7.5 Non-Circular Interpretation

It is important to emphasize that these interaction classes are not assumed to correspond to known forces. Instead, they arise from scalar-time dynamics and may later be compared to known interactions through structural matching.

This avoids circular reasoning and preserves predictive power.

7.6 Toward Interaction Unification

The emergence of three interaction classes suggests that all fundamental interactions may arise from scalar-time coherence dynamics:

$$\text{Interactions} \to \text{Coherence Dynamics} \to \Theta(x,t). \tag{120}$$

Thus scalar-time dynamics provide a candidate unified origin for particle interactions.

8 Conclusion

In this paper, we derived the interaction structure of Time-Scalar Field Theory directly from scalar-time coherence dynamics. Beginning with the scalar-time field $\Theta(x,t)$ and the viability-constrained coherence framework developed in prior work, we constructed a dynamical description of temporal-frame deformation and its coupling to fermionic eigenmodes.

From this construction, we derived the interaction field equation:

$$\partial_\nu F^{\nu\mu} + M_a^2 a^\mu = J^\mu, \tag{121}$$

which governs the dynamics of scalar-time coherence shear. This equation naturally yields three distinct interaction regimes depending on the dynamical status of the deformation field.

The first regime corresponds to massless propagating interactions, producing long-range coherence transmission. The second regime corresponds to massive conversion interactions, producing short-range transitions between scalar-time eigenmodes. The third regime corresponds to composite confinement interactions, arising from algebraic locking of multiple coherence modes.

These three interaction classes emerge directly from scalar-time dynamics without additional postulates.

We further derived the source structure for each interaction regime. Diagonal conserved currents generate propagating interactions, off-diagonal transition currents mediate mode conversion, and composite coherence density produces confinement behavior.

Using the scalar-time closure condition:

$$3n + 2q + h \equiv 0 \pmod 6, \tag{122}$$

we derived selection rules governing allowed particle transitions. These rules determine the interaction algebra of TSFT and constrain allowed processes between particle states.

We then demonstrated that scalar-time coherence naturally admits a gauge-theoretic formulation. Local phase redundancy of eigenmodes leads to a gauge-compatible interaction structure, without requiring externally imposed gauge symmetry postulates. This structure generalizes to non-Abelian symmetry when multiple coherence sectors are present.

Finally, we interpreted the three interaction regimes structurally, without assuming correspondence to known forces. The resulting framework suggests that fundamental interactions arise from scalar-time coherence dynamics and that a unified interaction structure may emerge from the scalar-time field.

Together with the previously derived particle spectrum, this work extends Time-Scalar Field Theory from particle mass emergence to interaction dynamics. The framework now contains:

- Scalar-time field dynamics
- Discrete particle spectrum
- Charge quantization
- Interaction structure
- Gauge symmetry emergence

This represents a substantial step toward a unified particle physics framework derived from scalar-time coherence.

Future work will focus on refining the interaction structure, deriving coupling constants, and comparing predicted interactions with experimental data.

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A Derivation of the Temporal Shear Field Equation

In this appendix we derive the temporal-frame deformation field equation from the scalar-time coherence Lagrangian.

A.1 Coherence Lagrangian

We begin with the coherence-coupled fermionic Lagrangian:

$$\mathcal{L} = \bar{\psi} i\gamma^\mu \left(\partial_\mu + ig(\partial_\mu \Theta + a_\mu)\right) \psi - \frac{1}{4} F_{\mu\nu} F^{\mu\nu} + \frac{1}{2} M_a^2 a_\mu a^\mu. \tag{123}$$

Here:

$$F_{\mu\nu} = \partial_\mu a_\nu - \partial_\nu a_\mu \tag{124}$$

$$a_\mu = \text{temporal-frame deformation field} \tag{125}$$

A.2 Variation with Respect to a_μ

We vary the action:

$$S = \int \mathcal{L}\, d^4x \tag{126}$$

Taking variation:

$$\delta S = \int \left(\frac{\partial \mathcal{L}}{\partial a_\mu} - \partial_\nu \frac{\partial \mathcal{L}}{\partial(\partial_\nu a_\mu)} \right) \delta a_\mu \, d^4x. \tag{127}$$

A.3 Source Term

The fermion coupling yields:

$$\frac{\partial \mathcal{L}}{\partial a_\mu} = g\bar{\psi}\gamma^\mu \psi. \tag{128}$$

Define:

$$J^\mu = g\bar{\psi}\gamma^\mu \psi. \tag{129}$$

A.4 Field Term

The field-strength term yields:

$$\frac{\partial \mathcal{L}}{\partial(\partial_\nu a_\mu)} = -F^{\nu\mu}. \tag{130}$$

Thus:

$$\partial_\nu \frac{\partial \mathcal{L}}{\partial(\partial_\nu a_\mu)} = -\partial_\nu F^{\nu\mu}. \tag{131}$$

A.5 Mass Term

The mass term contributes:

$$\frac{\partial \mathcal{L}}{\partial a_\mu} = M_a^2 a^\mu. \tag{132}$$

A.6 Euler–Lagrange Equation

Combining terms:

$$\partial_\nu F^{\nu\mu} + M_a^2 a^\mu = J^\mu. \tag{133}$$

This is the temporal shear field equation derived from scalar-time coherence dynamics.

A.7 Massless Limit

When:

$$M_a = 0 \tag{134}$$

the equation reduces to:

$$\partial_\nu F^{\nu\mu} = J^\mu. \tag{135}$$

This defines the propagating shear regime.

B Derivation of Interaction Selection Rules

In this appendix we derive the interaction selection rules directly from the scalar-time closure condition.

B.1 Closure Condition for Admissible States

Admissible particle states in TSFT are labeled by

$$(n, q, h, s), \tag{136}$$

with closure condition

$$3n + 2q + h \equiv 0 \pmod 6. \tag{137}$$

This condition defines the allowed scalar-time particle spectrum.

B.2 Transition Between Two Admissible States

Consider a transition

$$(n, q, h, s) \to (n', q', h', s'). \tag{138}$$

Since both the initial and final states must be admissible, we require

$$3n + 2q + h \equiv 0 \pmod 6, \tag{139}$$

$$3n' + 2q' + h' \equiv 0 \pmod 6. \tag{140}$$

Subtracting the first relation from the second yields

$$3(n' - n) + 2(q' - q) + (h' - h) \equiv 0 \pmod 6. \tag{141}$$

Defining the transition increments

$$\Delta n = n' - n, \tag{142}$$
$$\Delta q = q' - q, \tag{143}$$
$$\Delta h = h' - h, \tag{144}$$

we obtain the transition rule

$$3\Delta n + 2\Delta q + \Delta h \equiv 0 \pmod 6. \tag{145}$$

This is the fundamental TSFT interaction selection rule.

B.3 Pure Spectral Transitions

If the family and closure labels are unchanged,

$$\Delta q = 0, \qquad \Delta h = 0, \tag{146}$$

then admissibility requires

$$3\Delta n \equiv 0 \pmod 6. \tag{147}$$

Hence

$$\Delta n \equiv 0 \pmod 2. \tag{148}$$

Thus pure spectral transitions occur in even steps.

B.4 Pure Family Transitions

If the spectral and closure labels are unchanged,

$$\Delta n = 0, \qquad \Delta h = 0, \tag{149}$$

then

$$2\Delta q \equiv 0 \pmod 6. \tag{150}$$

Hence

$$\Delta q \equiv 0 \pmod 3. \tag{151}$$

Thus pure family transitions occur in multiples of three.

B.5 Pure Closure-Index Transitions

If the spectral and family labels are unchanged,

$$\Delta n = 0, \qquad \Delta q = 0, \tag{152}$$

then

$$\Delta h \equiv 0 \pmod 6. \tag{153}$$

Thus pure closure-index transitions occur in multiples of six.

B.6 Mixed Transitions

In the general case, allowed transitions satisfy

$$3\Delta n + 2\Delta q + \Delta h = 6k, \qquad k \in \mathbb{Z}. \tag{154}$$

This defines the full interaction algebra on the scalar-time particle labels.

B.7 Charge Selection Rule

Since charge is given by

$$Q = \frac{h}{3}, \tag{155}$$

the charge change under a transition is

$$\Delta Q = \frac{\Delta h}{3}. \tag{156}$$

Substituting into the mixed transition rule gives

$$3\Delta n + 2\Delta q + 3\Delta Q = 6k. \tag{157}$$

Equivalently,

$$\Delta n + \frac{2}{3}\Delta q + \Delta Q = 2k. \tag{158}$$

Thus charge change is not independent, but is constrained jointly with spectral and family transitions.

B.8 Composite Closure Rule

For a composite formed from N admissible states,

$$\Psi_{\text{comp}} = \hat{C}\left(\psi_{n_1,q_1,h_1,s_1} \otimes \cdots \otimes \psi_{n_N,q_N,h_N,s_N}\right), \tag{159}$$

define the total labels

$$N_{\text{tot}} = \sum_{i=1}^{N} n_i, \tag{160}$$

$$Q_{\text{tot}} = \sum_{i=1}^{N} q_i, \tag{161}$$

$$H_{\text{tot}} = \sum_{i=1}^{N} h_i. \tag{162}$$

The composite closure condition becomes

$$3N_{\text{tot}} + 2Q_{\text{tot}} + H_{\text{tot}} \equiv 0 \pmod 6. \tag{163}$$

This is the admissibility condition for composite scalar-time states.

B.9 Summary

The interaction selection rules of TSFT follow entirely from scalar-time closure arithmetic:

$$3\Delta n + 2\Delta q + \Delta h \equiv 0 \pmod 6. \tag{164}$$

This rule governs

- allowed single-particle transitions,
- allowed charge changes,
- allowed family changes,
- allowed composite states.

Thus interaction selection in TSFT is a direct consequence of closure-preserving scalar-time dynamics.

C Composite Spin and Matter Emergence

In this appendix we derive composite particle structure from scalar-time coherence locking.

C.1 Composite State Construction

Let admissible scalar-time particle states be:

$$\psi_i = \psi_{n_i,q_i,h_i,s_i}. \tag{165}$$

A composite state is formed by coherence locking:

$$\Psi_{\text{comp}} = \hat{C}\left(\psi_1 \otimes \psi_2 \otimes \cdots \otimes \psi_N\right), \tag{166}$$

where $\hat{C}$ denotes the coherence-locking operator.

C.2 Composite Charge

The composite charge is additive:

$$Q_{\text{tot}} = \sum_{i=1}^{N} Q_i. \tag{167}$$

Since

$$Q_i = \frac{h_i}{3}, \tag{168}$$

we obtain:

$$Q_{\text{tot}} = \frac{1}{3}\sum_{i=1}^{N} h_i. \tag{169}$$

Thus composite charge quantization follows directly from closure arithmetic.

C.3 Composite Spin

Spin composition follows angular momentum addition:

$$\vec{S}_{\text{tot}} = \sum_{i=1}^{N} \vec{S}_i. \tag{170}$$

For fermionic constituents:

$$s_i = \frac{1}{2}, \tag{171}$$

composite states may yield integer or half-integer spin depending on coupling.

Examples:

$$\frac{1}{2} \otimes \frac{1}{2} = 0 \oplus 1 \tag{172}$$

$$\frac{1}{2} \otimes \frac{1}{2} \otimes \frac{1}{2} = \frac{1}{2} \oplus \frac{1}{2} \oplus \frac{3}{2} \tag{173}$$

The role of TSFT enters through the coherence-locking operator $\hat{C}$. Not all formally allowed angular-momentum sums are dynamically realized. A composite spin sector is admissible only when the corresponding locked state preserves scalar-time closure and lowers the total coherence energy.

Accordingly, $\hat{C}$ selects spin couplings through the combined conditions

$$3N_{\text{tot}} + 2Q_{\text{tot}} + H_{\text{tot}} \equiv 0 \pmod 6, \tag{174}$$

and

$$E[\Psi_{\text{comp}}] < \sum_{i=1}^{N} E[\psi_i]. \tag{175}$$

Thus the allowed composite spin multiplets are not introduced independently of TSFT; they are the subset of angular-momentum combinations that remain closure-preserving and energetically favored under scalar-time coherence locking.

Thus scalar-time composites naturally produce bosonic and fermionic states.

C.4 Composite Mass

The composite mass arises from:

$$M_{\text{comp}} = \sum_{i=1}^{N} m_i + E_{\text{bind}}. \tag{176}$$

The binding energy arises from coherence locking:

$$E_{\text{bind}} = -\int \rho_{\text{comp}} K(|x - x'|) \rho_{\text{comp}} \, dx \, dx'. \tag{177}$$

This produces bound composite states.

C.5 Matter Emergence

Composite locking yields hierarchical structure:

$$\text{Elementary fermions} \to \text{Composite fermions} \tag{178}$$
$$\text{Composite fermions} \to \text{Nuclear states} \tag{179}$$
$$\text{Nuclear states} \to \text{Atoms} \tag{180}$$

Thus matter structure emerges from scalar-time coherence.

C.6 Closure Preservation

Composite states must satisfy closure:

$$3N_{\text{tot}} + 2Q_{\text{tot}} + H_{\text{tot}} \equiv 0 \pmod 6. \tag{181}$$

This restricts admissible composite states.

C.7 Hierarchical Matter Formation

Scalar-time coherence therefore produces:

$$\text{Particles} \to \text{Bound states} \tag{182}$$
$$\text{Bound states} \to \text{Nuclei} \tag{183}$$
$$\text{Nuclei} \to \text{Atoms} \tag{184}$$
$$\text{Atoms} \to \text{Matter} \tag{185}$$

Thus matter emerges from scalar-time coherence locking.

D Predictive Structure of the TSFT Particle Spectrum

The scalar-time coherence framework produces a discrete particle spectrum labeled by:

$$(n, q, h, s), \tag{186}$$

subject to the closure condition:

$$3n + 2q + h \equiv 0 \pmod 6. \tag{187}$$

This structure generates an infinite but constrained particle spectrum.

D.1 Discrete Spectral Ladder

From the mass emergence derivation, particle masses obey:

$$m_n = \sqrt{\lambda_n}, \tag{188}$$

with Weyl asymptotics:

$$\lambda_n \sim An^2. \tag{189}$$

Thus

$$m_n \sim n\sqrt{A}. \tag{190}$$

This produces a discrete ladder of particle masses.

D.2 Higher Spectral States

Since n is unbounded,

$$n = 1, 2, 3, \ldots \tag{191}$$

TSFT predicts additional particle-like states at higher spectral levels.
These states possess:

- quantized charge
- quantized spin
- discrete mass ordering
- closure-constrained quantum numbers

Thus TSFT predicts particle-like excitations beyond currently observed states.

D.3 Family Structure Predictability

Family index q is constrained by:

$$\Delta q \equiv 0 \pmod 3. \tag{192}$$

This produces repeating family structure across spectral levels. Thus TSFT predicts:

$$\text{New families at higher spectral index.} \tag{193}$$

This is a direct, testable prediction.

D.4 Charge Pattern Prediction

Charge quantization arises from:

$$Q = \frac{h}{3}. \tag{194}$$

Since h is integer-valued, TSFT predicts allowed fractional charges:

$$Q \in \left\{ \ldots, -\frac{2}{3}, -\frac{1}{3}, 0, \frac{1}{3}, \frac{2}{3}, \ldots \right\}. \tag{195}$$

This restricts possible particle charges.
Thus TSFT predicts:

- no arbitrary fractional charges
- no irrational charges
- no unconstrained charge values

D.5 Composite Predictability

Composite states follow closure:

$$3N_{\text{tot}} + 2Q_{\text{tot}} + H_{\text{tot}} \equiv 0 \pmod 6. \tag{196}$$

This restricts admissible composite structures.
Thus TSFT predicts:

- allowed composite particles
- forbidden composite particles
- allowed nuclear-like structures

D.6 Experimental Signatures

The scalar-time coherence spectrum suggests the possibility of additional particle-like states at higher spectral levels. These may include:

- heavy fermionic states
- additional neutral leptons
- higher spectral excitations with quantized charge
- extended family structures

These possibilities arise naturally from the discrete scalar-time coherence spectrum derived in the present framework.

However, quantitative predictions require computation of the full spectral structure and coupling hierarchy, which is left for future work.

Accordingly, the present results establish a predictive framework rather than specific particle mass predictions.

D.7 Falsifiability

The TSFT particle spectrum is falsifiable:

- discovery of forbidden charge values would falsify TSFT
- discovery of inconsistent spectral ordering would falsify TSFT
- discovery of forbidden composite structures would falsify TSFT

Thus TSFT provides a predictive particle framework.