An Inquiry into Atomic, Molecular, and Field Signatures of a Coherent Polar Cascade

Recursive Distinction, Semi-Bounded Fields, and the Progressive Accessibility of Ordered States

David E. Martin

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Abstract

This inquiry asks whether a recurring organizational pattern visible across atomic dynamics, molecular assembly, crystal growth, magnetic ordering, electrochemical interfaces, and fluid-bearing porous media may warrant examination as a shared physical hypothesis rather than as a collection of merely analogous phenomena. The proposed working term, *coherent polar cascade* (CPC), is not introduced as an established force, particle, or replacement for accepted theories. It is used provisionally to name a possible recursive process in which a locally realized distinction modifies the field, boundary conditions, or configuration space that governs the next admissible distinction. The inquiry is motivated by systems in which organization appears to recruit adjacent degrees of freedom, persist beyond the initiating perturbation, display strong history dependence, and produce morphology that cannot be adequately intuited from isolated point interactions alone.

The central question is whether the conventional description of motion as displacement of bounded objects through a pre-existing field obscures a complementary possibility: that observable trajectories, molecular orientations, crystal faces, domain structures, and pore-scale flow pathways may be successive local disclosures of a semi-bounded and continually reorganizing relational field. Within this formulation, the state at n does not simply cause a later state through linear propulsion. It reshapes an $n + 1$ event horizon—the set of dynamically, energetically, and geometrically admissible next states. Charge, polarity, phase, surface morphology, local stress, electrochemical double layers, and boundary-conditioned fields may jointly determine this horizon.

The paper develops no declaration that coherence is universally conserved. Instead, it asks whether certain systems exhibit a monotonic tendency toward the progressive reduction of inaccessible or mutually cancelling configurations, even while ordinary thermodynamic entropy may increase globally and local coherence may remain reversible. It distinguishes physical-space dimensionality from the higher-dimensional configuration spaces required to describe continuously changing local orientations and globally constrained field states. It then proposes falsifiable experimental questions spanning attosecond electron dynamics, electrically influenced crystal growth, magnetic and ferroelectric ordering, interfacial electrochemistry, and nanoporous hydrocarbon-bearing media. The purpose is to determine whether CPC is a useful cross-scale organizing hypothesis, a limited analogy, or an unnecessary relabeling of already sufficient mechanisms.

Keywords: coherent polar cascade; recursive distinction; configuration space; quantum trajectory; crystal growth; magnetization dynamics; electrochemical double layer; porous media; metastability; field morphology.

1 The Inquiry Rather Than the Declaration

The scientific value of an inquiry is not diminished by its refusal to declare prematurely. On the contrary, the disciplined question often begins where an apparently complete vocabulary has ceased to illuminate the

behavior it names. Electromagnetic theory describes local field values and their evolution with extraordinary success. Quantum mechanics describes amplitudes, phases, propagators, and measurement probabilities. Statistical mechanics and nonequilibrium thermodynamics describe ensembles, dissipation, fluctuation, and entropy production. Crystal-growth theory describes nucleation, attachment kinetics, surface free energy, step propagation, defects, and morphology. Micromagnetics describes exchange, anisotropy, demagnetizing fields, domain formation, precession, and damping. Electrochemistry describes interfacial potentials, adsorption, ionic screening, charge transfer, and double-layer structure. Porous-media physics describes capillarity, relative permeability, adsorption, wettability, pressure diffusion, and multiphase transport.

The question developed here does not arise from a claim that these descriptions are false. It arises from the possibility that their disciplinary completeness may conceal a shared organizational form. The same mathematical event can appear, depending upon scale and vocabulary, as a phase-conditioned electron transition, a surface-selected molecular attachment, a domain-wall displacement, a field-induced crystallographic preference, a wettability alteration, or a newly accessible flow pathway. The disciplines correctly preserve differences of mechanism. Yet scientific caution should not require the opposite error: assuming that recurrent structure across scales must be dismissed as superficial resemblance before it is investigated.

The working hypothesis of a coherent polar cascade therefore begins with a restrained question:

> Across atomic, molecular, electromagnetic, crystalline, and porous-media systems, do there exist recurring signatures of recursive field-conditioned organization that are not adequately understood when motion, ordering, or transport is reduced to the displacement of independently bounded entities through a passive background?

The term *cascade* is used because one locally realized state may change the accessibility of subsequent states. The term *polar* is used broadly but not carelessly: it refers to distinctions capable of producing directed relational asymmetry—charge separation, dipole orientation, phase relation, spin or magnetization orientation, interfacial potential, chemical affinity, stress polarity, wetting preference, or any corresponding conjugate distinction that generates directional response. The term *coherent* does not imply perfect phase coherence at every scale. It refers to a condition in which multiple degrees of freedom become relationally organized so that their combined evolution cannot be represented as an independent sum without loss of essential explanatory structure.

The provisional definition is therefore:

> A coherent polar cascade is a recursively conditioned process in which a realized local distinction modifies the relational field, configuration space, or boundary conditions governing the next admissible distinctions, thereby recruiting additional degrees of freedom into an organized trajectory, morphology, or transport state.

This definition is intentionally more general than any single constitutive law. It is not intended to replace those laws. It is intended to identify a possible architecture linking them.

2 From Position to the $n + 1$ Event Horizon

Classical kinematics privileges a bounded object whose changing position is represented by

$$\boldsymbol{x}_{n+1} = \boldsymbol{x}_n + \boldsymbol{v}_n \Delta t + O(\Delta t^2). \tag{1}$$

Within its domain this representation is indispensable. Yet it encourages an ontology in which position is primary, velocity is the carrier of continuity, and field is an external influence that bends or accelerates an otherwise self-identical object.

At atomic scale, this picture becomes incomplete. A reconstructed "electron path" in attosecond or strong-field experiments ordinarily refers to a phase-conditioned transition amplitude, a semiclassical saddle-point trajectory, a wavepacket evolution, or a momentum-space history inferred from interference and detection. Modern work can separate quantum trajectories, retrieve angular-momentum-channel phases, and measure attosecond delays with exquisite resolution, but the experimental object is not a continuously photographed corpuscle occupying a sequence of otherwise unambiguous positions [1–4].

A more general representation is

$$\Psi_{n+1} = U[\Phi_n, \boldsymbol{A}_n, \mathcal{B}_n, \mathcal{E}_n]\, \Psi_n, \tag{2}$$

where Ψ_n is the system state, Φ_n and $\boldsymbol{A}_n$ denote scalar and vector potentials, $\mathcal{B}_n$ denotes material and geometric boundaries, and $\mathcal{E}_n$ denotes coupled environmental degrees of freedom. The evolution operator U does not merely propel a point. It transforms the distribution of amplitudes, phases, momenta, and localization possibilities.

The CPC inquiry introduces the concept of an $n + 1$ event horizon:

$$\mathcal{H}_{n+1} = \mathfrak{A}(\mathcal{C}_n; \mathcal{F}_n, \mathcal{B}_n, \mathcal{M}_n)\,, \tag{3}$$

where $\mathcal{C}_n$ is the realized configuration at state n, $\mathcal{F}_n$ is the relevant field organization, $\mathcal{B}_n$ contains boundary conditions, and $\mathcal{M}_n$ represents material constitutive response. The operator $\mathfrak{A}$ returns neither a single future point nor an arbitrary universe of possibilities. It returns the dynamically accessible next-state set.

The event horizon is *semi-bounded*. It is bounded because conservation laws, causality, symmetry, constitutive relations, geometry, and prior interaction constrain what may follow. It is open because the next state is generally not determined by position and velocity alone, and because the field configuration itself may contain phase, polarization, topology, stochasticity, and nonlocal functional dependence. The realized next event,

$$\mathcal{C}_{n+1} \in \mathcal{H}_{n+1}, \tag{4}$$

then contributes to the construction of $\mathcal{H}_{n+2}$. The cascade is therefore recursive:

$$\mathcal{C}_n \longrightarrow \mathcal{H}_{n+1} \longrightarrow \mathcal{C}_{n+1} \longrightarrow \mathcal{H}_{n+2}. \tag{5}$$

The inquiry is not whether standard equations already contain every term needed to compute such evolution in principle. In many systems they may. The inquiry is whether naming the recursively reconstructed admissible-state horizon reveals a common structure that remains obscure when each discipline describes only its preferred projection.

3 Physical Space, Orientation Space, and the Metafield of Distinction

A magnetic field in three-dimensional physical space is represented as

$$\boldsymbol{B} : \mathbb{R}^3 \to \mathbb{R}^3. \tag{6}$$

At each point, $\boldsymbol{B}$ may assume continuously many orientations. Relative to a nonzero local field vector, an entire two-dimensional tangent plane is orthogonal to that direction. Thus infinitely many orthogonal orientations do not imply infinitely many independent Cartesian dimensions. They arise from continuous orientation within a three-dimensional vector space.

This familiar answer is mathematically correct but may be conceptually insufficient. It describes local directional possibility without fully foregrounding the simultaneous whole-field organization by which any local direction is distinguished. Maxwell's equations are local differential equations, but their admissible

solutions are globally constrained by sources, constitutive relations, continuity, gauge structure, and boundary conditions [**jackson1999**, 5]. A local field value is not an independent arrow attached to an otherwise indifferent point. It is one member of an entire solution.

The CPC inquiry uses the phrase *metafield of distinction* for the organization by which local field relations become meaningful as parts of a globally admissible configuration. This is not proposed as a new superluminal physical field. It is closer to a configuration-space structure. Let

$$\mathscr{K} = \{\mathcal{F}(\boldsymbol{r}) \mid \mathcal{F} \text{ satisfies relevant constraints and boundary conditions}\}\,. \tag{7}$$

A realized field configuration is one point in $\mathscr{K}$. An energy or action functional,

$$\mathcal{G}[\mathcal{F}], \tag{8}$$

distinguishes configurations through local and nonlocal terms. The "meta" level is the relational structure of $\mathscr{K}$ and the functional distinctions imposed upon it, not another geometric axis concealed beside x, y, and z.

This becomes especially clear in magnetized matter. The local magnetization $\boldsymbol{M}(\boldsymbol{r}, t)$ evolves under an effective field containing exchange, anisotropy, external, demagnetizing, and possibly magnetoelastic contributions. The precessional component of Landau–Lifshitz–Gilbert dynamics is

$$\frac{\partial \boldsymbol{M}}{\partial t} = -\gamma\, \boldsymbol{M} \times \boldsymbol{H}_{\text{eff}} + \frac{\alpha}{M_s} \boldsymbol{M} \times \frac{\partial \boldsymbol{M}}{\partial t}. \tag{9}$$

The cross product generates an instantaneous direction orthogonal to both the current magnetization and the effective field. As either changes, the locally orthogonal frame is regenerated. The demagnetizing contribution depends on the wider magnetization distribution; therefore the local orthogonal response is already conditioned by the global configuration [**landau1935gilbert2004**, **gilbert2004**, **brown1963**].

In CPC language, gyroscopic organization is not an extra spatial dimension. It is the recurrent generation of an orthogonal response direction by a globally conditioned local relation. The field configuration at n produces the effective distinction defining the local tangent direction; the resulting local motion modifies the global configuration from which the next tangent direction is generated. Infinite orthogonality becomes not an inventory of hidden axes but a persistent generative availability.

4 Atomic Inquiry: Is the Path the Residue of Recursive Field Reorganization?

The word "trajectory" spans several meanings. In classical mechanics it is a path in physical space. In semiclassical strong-field physics it may be a saddle-point solution with complex-valued times or coordinates. In path-integral formulations it refers to histories contributing amplitudes rather than one directly observed itinerary. In Bohmian mechanics it denotes an interpretation-specific guidance trajectory. In experimental attosecond science, trajectory language often identifies distinguishable classes of ionization and recollision histories whose amplitudes interfere [1, 6, 7].

This multiplicity invites a precise inquiry. Suppose the electron is treated not as a point plus an attached field, but as a distinguishable excitation inseparable from a semi-bounded electromagnetic and material relation. The state at n contains a distribution of localization and momentum possibilities. Interaction with a field does not merely modify velocity after a position has already been established. It changes phase, canonical momentum, kinetic momentum, angular composition, and interference structure. In minimal coupling,

$$\hat{H} = \frac{1}{2m}\,(\hat{\boldsymbol{p}} - q\boldsymbol{A})^2 + q\Phi + V, \tag{10}$$

the vector potential participates directly in the evolution of the state. The Aharonov–Bohm effect demonstrates that phase relations can depend on potential structure in circumstances where a classical local-force account is incomplete [8].

The conventional Lorentz magnetic force,

$$\boldsymbol{F}_B = q\,\boldsymbol{v} \times \boldsymbol{B}, \tag{11}$$

is orthogonal to instantaneous velocity and therefore changes momentum direction without directly changing kinetic energy. This already suggests that field organization need not be understood primarily as forward propulsion. The orthogonal relation structures the admissible curvature of motion. Quantum mechanically, the field participates in defining the evolving phase and localization geometry from which a path-like detection record emerges.

The CPC question is therefore not whether the electron secretly has a classical route determined by an unknown field. It is whether an observed sequence of localization events may be understood as the residue of recurrent field-conditioned redistribution:

$$(\Psi_n, \mathcal{F}_n, \mathcal{B}_n) \longrightarrow \mathcal{H}_{n+1} \longrightarrow (\Psi_{n+1}, \mathcal{F}_{n+1}, \mathcal{B}_{n+1})\,. \tag{12}$$

Here, "next position" is not merely where a point arrives. It is one disclosed localization within an admissible-state horizon whose shape was constructed by the preceding coupled configuration.

Three discriminations are essential.

First, unitary evolution alone does not imply monotonic narrowing. Wavepackets can spread, interfere, refocus, and revive. Therefore CPC cannot identify every infinitesimal time step with irreversible coherence gain.

Second, a measurement record or environmental interaction may redistribute coherence among system and environment rather than destroy it absolutely. What appears locally as decoherence may be entanglement-induced inaccessibility of phase relations.

Third, "field awareness" must not be confused with superluminal information transfer. A state may be globally represented on a spacelike hypersurface while changes in locally controllable observables remain causally constrained.

These limitations suggest a more careful atomic-scale candidate for the CPC event: not every interval of motion, but every interaction that measurably reconstructs the accessible phase-space or configuration-space relations governing subsequent localization.

5 Molecular Inquiry: Polarity as a Generator of Admissible Orientation

At molecular scale, polarity is conventionally represented through charge distribution, permanent or induced dipole moments, multipole interactions, polarizability, hydrogen bonding, solvent organization, and electrostatic potential surfaces. A dipole in an electric field experiences torque,

$$\boldsymbol{\tau} = \boldsymbol{p} \times \boldsymbol{E}, \tag{13}$$

and potential energy,

$$U = -\boldsymbol{p} \cdot \boldsymbol{E}. \tag{14}$$

These relations describe alignment tendency without implying that all molecules simply rotate into one static orientation. Thermal agitation, steric exclusion, solvent mediation, quantum effects, local dielectric response, and competing interactions produce ensembles of metastable configurations.

The CPC hypothesis asks whether molecular ordering becomes cascade-like when one realized orientation modifies the energetic landscape experienced by adjacent molecules. This is familiar in cooperative hydrogen-bond networks, self-assembly, membrane formation, ferroelectric ordering, and adsorption. The hypothesis adds no new interaction to these systems. It asks whether their common recursion may be represented explicitly.

Let the configurational free energy be

$$\mathcal{G}[\rho, \boldsymbol{P}, c_i, \eta_j], \tag{15}$$

where ρ is mass or number density, $\boldsymbol{P}$ is polarization, c_i are species concentrations, and η_j are structural order parameters. The corresponding variational tendencies are

$$\mu_i = \frac{\delta \mathcal{G}}{\delta c_i}, \qquad \boldsymbol{E}_{\text{eff}} = -\frac{\delta \mathcal{G}}{\delta \boldsymbol{P}}, \qquad \Xi_j = -\frac{\delta \mathcal{G}}{\delta \eta_j}. \tag{16}$$

A local molecular rearrangement changes ρ, $\boldsymbol{P}$, c_i, or η_j, thereby changing the functional derivatives that define the next local tendencies. The state does not merely descend a fixed landscape. It may deform the landscape while descending it.

This distinction is central. A static optimization picture asks which configuration minimizes a given free energy. A recursive CPC picture asks how each realized configuration alters the effective free-energy landscape and accessible kinetic pathways for subsequent realizations. The latter is especially relevant when interfaces grow, surfaces acquire charge, solvent shells reorganize, ions adsorb, or strain accumulates.

6 Crystal Growth as the Canonical Morphological Inquiry

Crystal growth offers an unusually visible example of recursive organization. A nucleus establishes translational and orientational relations that did not exist in the disordered parent phase. A molecular or atomic species approaching a crystal surface encounters not an abstract bulk free energy but a structured interface containing terraces, ledges, kinks, defects, adsorbates, solvent layers, surface charge, and local strain. Attachment at one site changes the geometry and energetic character of neighboring sites. Growth therefore constructs the boundary conditions of its own continuation.

A simple phase-field description may use an order parameter η:

$$\frac{\partial \eta}{\partial t} = -L \frac{\delta \mathcal{G}}{\delta \eta}, \tag{17}$$

coupled to concentration, thermal, stress, or electrostatic fields. Although such equations can be written as relaxation toward lower free energy, the morphology that emerges is history-dependent because $\eta(\boldsymbol{r}, t)$ continually changes the interface upon which the next growth event occurs. Surface diffusion and anisotropic interface energy can generate facets, dendrites, needles, plates, branching forms, and defect-sensitive morphologies [9, 10].

The electric character of the interface is not incidental. Polar crystals may carry face-dependent surface charge. Charge compensation, ionic adsorption, solvent structure, and imposed electric fields can alter nucleation and growth kinetics [11, 12]. Electric fields have been used to influence colloidal crystallization and orientation, illustrating that morphology may be jointly generated by material attachment and field reorganization [13].

The CPC inquiry proposes a distinction between *material accumulation* and *morphological recruitment*. In accumulation, matter is added. In recruitment, each addition changes the local field of admissible subsequent additions. The crystal face becomes an energetic instruction without possessing a separate blueprint. Its order is propagated because existing relation alters the probability, kinetics, and geometry of next relation.

This permits a provisional order-accessibility functional. Let Ω_n denote the set of microscopically conceivable configurations compatible with coarse constraints, and let $\mathcal{H}_{n+1} \subseteq \Omega_n$ denote those dynamically accessible from state n. Define

$$\mathcal{A}_n = \mu(\mathcal{H}_{n+1}), \tag{18}$$

where μ is an appropriate measure on configuration space. CPC does not necessarily predict that $\mathscr{A}_n$ decreases. In some systems coherent growth may open new pathways and increase accessible organized states. A more relevant quantity may be the ratio

$$\chi_n = \frac{\mu(\mathcal{H}_{n+1} \cap \mathcal{O}_n)}{\mu(\mathcal{H}_{n+1})}, \tag{19}$$

where $\mathcal{O}_n$ is the subset of states compatible with the emerging relational organization. A cascade-like regime would exhibit an increasing conditional accessibility of organized continuation:

$$\chi_{n+1} > \chi_n \tag{20}$$

over a defined interval and scale.

This is not a proposed universal law. It is a measurement question. Does an established ordered interface make continued compatible ordering progressively more probable than would be predicted from independent local attachment rates alone? If so, can the excess be fully attributed to known surface-energy, electrostatic, elastic, and transport terms, or does a useful higher-level recursive descriptor remain?

7 The Problem of "Conserved Coherence"

The phrase "conservation of coherence" is provocative and potentially misleading. In quantum mechanics coherence has a specific basis-dependent meaning involving off-diagonal density-matrix terms. In optics it concerns phase correlations. In complex systems it may be used more loosely to describe collective order. A universal conservation law requires a precisely defined quantity, an associated symmetry or invariant, and a domain over which it remains constant. No such general law is asserted here.

The deeper intuition may be reformulated. Perhaps the candidate invariant is not coherence itself, but the persistence of a system's *capacity to generate distinction*. Observable ordering would then represent changing accessibility rather than creation of an ontologically new substance called coherence.

Let $\mathscr{I}_n$ denote a measure of dynamically relevant incoherence: configurations whose contributions are mutually cancelling, kinetically isolated, phase-inaccessible, or unable to participate in the emerging collective mode. Let $\mathscr{R}_n$ denote recruited degrees of freedom. The hypothesis to be tested is not necessarily

$$\mathscr{I}_{n+1} < \mathscr{I}_n \quad \text{universally.} \tag{21}$$

Rather, in a CPC regime one might observe

$$\frac{\mathrm{d}\mathscr{R}}{\mathrm{d}t} > 0 \qquad \text{and} \qquad \frac{\mathrm{d}}{\mathrm{d}t} \Pr(C_{n+1} \in \mathcal{O}_n \mid C_n) > 0 \tag{22}$$

for a finite scale and duration, even while total entropy production remains nonnegative.

This distinction avoids conflict with the second law. Local ordering can increase while entropy is exported or generated elsewhere. CPC would concern the morphology and recursion of accessibility, not a claim that the universe monotonically approaches lower thermodynamic entropy.

A stronger and more testable proposition is:

> In certain driven or metastable systems, each realized organized event modifies the coupled field and boundary conditions so that the conditional probability of compatible organized events in adjacent degrees of freedom increases.

The relevant conserved quantity, if one exists, might reside not in local order but in an action, topological constraint, generalized flux, information balance, or symmetry of the enlarged system-plus-environment description. Identifying such a quantity is an open mathematical task rather than a premise.

8 Field Organization, Simultaneity, and Causality

The phenomenology of magnets, crystals, and coherent media often gives an impression of simultaneous whole-field awareness. Ferromagnetic particles placed around a magnet align into a morphology that appears globally informed. Crystals preserve face relation across growing surfaces. Phase-coherent systems exhibit correlations that cannot be decomposed into independent local histories. Yet physical interpretation must distinguish three meanings of simultaneity.

The first is *solution simultaneity*: a static boundary-value problem is represented as one entire field configuration. The second is *constraint simultaneity*: local values are members of a globally admissible solution and cannot be specified independently. The third is *causal simultaneity*: an actual physical change at one location produces an immediately controllable change elsewhere. The first two are standard features of field descriptions; the third is prohibited by relativistic causality for ordinary signaling.

The metafield of distinction invoked here belongs primarily to the first two categories. It describes the whole configuration within which local distinctions are defined. Evolution from one configuration to another remains governed by hyperbolic field equations, retarded interactions, transport, or other causal dynamics. Where an effective theory contains instantaneous nonlocal terms—for example, magnetostatic demagnetizing fields—those terms generally represent an approximation or constrained solution within a wider causal theory.

CPC therefore does not require instantaneous causal transmission. It requires only that local evolution be conditioned by a state variable or functional whose definition includes wider configuration. In a quasi-static system this global dependence may appear instantaneous. In a fully dynamical system the recursive update is retarded.

9 Electrochemical Interfaces: Where Field, Molecule, and Morphology Become Inseparable

At a charged solid–liquid interface, surface chemistry, ionic adsorption, solvent orientation, diffuse charge, and electric potential form a coupled structure. The electric double layer is not a material sheet but an interfacial organization whose thickness and composition depend upon surface charge, electrolyte concentration, ion valence, adsorption, dielectric response, confinement, and surface heterogeneity. In nanopores, overlapping double layers and molecular-scale layering can make continuum approximations unreliable.

A generic free-energy functional may be written

$$\mathcal{G} = \int_V \left[f(c_i, \rho, \eta) + \frac{\varepsilon}{2}|\nabla\phi|^2 + \sum_i z_i e c_i \phi + \frac{\kappa}{2}|\nabla\eta|^2 \right] \mathrm{d}V + \int_S \gamma(\eta, c_i, \phi)\mathrm{d}S. \tag{23}$$

Variation yields coupled electrochemical potentials, field equations, and interfacial conditions. A change in adsorption alters surface charge; surface charge alters potential; potential alters ionic distribution; ionic distribution alters solvent and molecular orientation; these alter wettability, disjoining pressure, and adsorption energy; altered wetting and adsorption change fluid arrangement and accessible pore pathways. The recursion is not metaphorical. It is constitutive.

Existing literature on low-salinity recovery, shale interfaces, and electrokinetic transport shows that surface charge, double-layer structure, ionic exchange, wettability, and interfacial forces can influence hydrocarbon displacement, though the relative importance and even validity of specific mechanisms remain debated [14–17]. That debate is precisely why a nondeclarative inquiry is useful. CPC should not be presented as a substitute for double-layer expansion, ion exchange, interfacial-tension reduction, surfactant action, or pressure-driven flow. It should ask whether these processes can enter a mutually reinforcing recursive regime in which each local reorganization changes the likelihood and reach of subsequent reorganization.

10 Porous Media and the Reservoir-Scale Hypothesis

Hydrocarbon-bearing shale and tight formations contain a hierarchy of pore sizes, mineral surfaces, organic matter, adsorbed phases, confined fluids, capillary barriers, microfractures, stress-dependent apertures, and chemically heterogeneous interfaces. In such systems, "transport" is not a single phenomenon. Molecular diffusion, Knudsen transport, viscous flow, surface diffusion, desorption, capillary imbibition, electrokinetic coupling, pressure propagation, phase change, and geomechanical response may overlap [18].

The CPC reservoir hypothesis begins from field observations in which production response may persist or increase long after a simple reagent-consumption or near-wellbore displacement model would predict exhaustion. Such observations do not by themselves prove a new mechanism. They motivate a hierarchy of questions.

Could a finite initiating treatment cause a prolonged redistribution of surface charge and electrochemical potential? Could that redistribution alter adsorption energies and wettability beyond the initially contacted volume? Could desorption and mobilization change local composition, ionic strength, dielectric response, capillary pressure, and stress, thereby conditioning adjacent pore domains? Could pressure and compositional changes expose new reactive or polar surfaces, extending the cascade without requiring the original agent to be materially transported to every subsequently responding site? Could the formation be progressively recruited into a different accessibility state?

A minimal coupled representation might contain

$$\frac{\partial c_i}{\partial t} = -\nabla \cdot \boldsymbol{J}_i + R_i, \tag{24}$$

$$\boldsymbol{J}_i = -D_i \nabla c_i - \frac{D_i z_i e}{k_B T} c_i \nabla \phi + c_i \boldsymbol{u} + \boldsymbol{J}_{i,\mathrm{surf}}, \tag{25}$$

$$\nabla \cdot (\varepsilon \nabla \phi) = -\rho_f - \sum_i z_i e c_i, \tag{26}$$

$$\frac{\partial \theta_a}{\partial t} = \mathcal{K}_{\mathrm{ads/des}}(c_i, \phi, p, T, \theta_a)\,, \tag{27}$$

$$\frac{\partial \eta_w}{\partial t} = \mathcal{W}(\phi, \theta_a, c_i, \sigma, C)\,, \tag{28}$$

where c_i are species concentrations, ϕ is electric potential, $\boldsymbol{u}$ is fluid velocity, θ_a is an adsorbed fraction, η_w is a wetting-state variable, σ is stress, and C represents composition. The novelty is not in any individual equation. It is in asking whether the feedback architecture generates a self-extending regime.

The CPC state variable could be represented schematically as

$$C_n = \{c_i, \phi, \boldsymbol{P}, \theta_a, \eta_w, p, S_\alpha, \boldsymbol{\sigma}, k_{\mathrm{eff}}, \mathcal{G}_{\mathrm{conn}}\}_n\,, \tag{29}$$

where S_α are phase saturations, k_{eff} is effective permeability, and $\mathcal{G}_{\mathrm{conn}}$ is a pore-connectivity graph. The next-event horizon then includes possible desorption, wetting transition, pore-throat opening, phase redistribution, and connectivity recruitment events:

$$\mathcal{H}_{n+1} = \mathfrak{A}(C_n). \tag{30}$$

A conventional transport model may predict response according to how rapidly material or pressure reaches a location. A CPC model would additionally predict response according to whether intervening events progressively alter the accessibility of adjacent configurations. Spatial distance remains relevant, but distance in configuration space may become equally important. Two physically adjacent pores may be dynamically remote if separated by a capillary, adsorption, or electrostatic barrier; two physically distant regions connected through a fracture, conductive mineral surface, pressure network, or compositional pathway may be dynamically near.

The phrase *coherent emancipation* may be useful here. It does not imply release of hidden energy without accounting. It denotes the progressive removal or reduction of constraints that prevented stored mass, pressure, surface-bound molecules, or connected pore volume from participating in flow. The formation would not be supplied with new hydrocarbons by the cascade. Rather, previously inaccessible hydrocarbons could enter the effective transport network as the configuration changes.

11 A Cross-Scale Comparison

Domain	**Local distinction**	**Field or configuration modified**	**Candidate cascade signature**
Atomic	Phase, momentum channel, localization, spin	Wavefunction, electromagnetic potential, environmental entanglement	Successive localization or emission probabilities conditioned by prior phase-resolving interaction
Molecular	Dipole orientation, adsorption, bonding, conformation	Electrostatic landscape, solvent structure, local free-energy surface	Cooperative recruitment exceeding independent-pair prediction
Crystal	Nucleation, step attachment, defect formation	Surface morphology, charge, strain, diffusion field	Existing order progressively increases accessibility of compatible growth
Magnetic	Moment or domain orientation	Exchange, anisotropy, demagnetizing and external effective field	Locally orthogonal precession reconstructs the global field defining subsequent precession
Electrochemical	Ion adsorption, charge transfer, surface protonation	Double layer, potential, ionic composition, wetting state	Interfacial change propagates through coupled charge–chemistry–morphology feedback
Porous reservoir	Desorption, wetting shift, phase movement, pore recruitment	Pressure, composition, surface charge, capillary barriers, connectivity	Delayed and persistent production response disproportionate to reagent transport alone

Table 1: Cross-scale organization considered in the CPC inquiry. The table identifies analogical structure without asserting identity of mechanism.

12 What Would Distinguish CPC from a New Name for Known Feedback?

A hypothesis becomes scientifically useful only if it can fail. CPC would add little if every purported signature were merely a poetic restatement of coupled differential equations. The following criteria could distinguish a meaningful CPC regime from ordinary linear response.

12.1 History-dependent recruitment

Two systems brought to the same apparent macroscopic state by different sequences should exhibit measurably different subsequent accessibility if the hidden configuration retains recursively generated organization. This is stronger than ordinary hysteresis only if the difference can be tied to a structured recruitment variable rather than an unspecified memory term.

12.2 Superadditive organization

If two initiating perturbations applied independently generate responses R_A and R_B, a coupled CPC regime may generate

$$R_{A+B} > R_A + R_B \tag{31}$$

over a defined interval because the first perturbation changes the event horizon through which the second acts. Superadditivity alone is not proof; nonlinear chemistry and transport can produce it. The test is whether a measured state variable predicts the effect across conditions.

12.3 Propagation without stoichiometric transport of the initiator

A cascade hypothesis becomes relevant where organized response extends beyond the measured reach or lifetime of the initiating species, provided pressure, heat, ordinary diffusion, fracture communication, and measurement artifacts are quantitatively excluded. The mechanism may still involve propagated fields, secondary species, or endogenous reactions. "Without initiator transport" must never be confused with "without causal transport of any kind."

12.4 Scale-dependent monotonicity

A CPC system may display increasing recruitment at one observational scale while remaining fluctuating or reversible at another. The prediction should therefore specify a coarse-graining scale over which a quantity analogous to χ_n in Equation (19) increases.

12.5 Morphological anticipation without teleology

The system may appear to "know" its future form because existing organization constrains the next admissible states. CPC must express this through local and nonlocal field dependence, not purpose or backward causation.

13 Proposed Experimental Program

13.1 Attosecond electron dynamics

Use phase-resolved pump–probe measurements to compare reconstructed trajectory classes under deliberately altered boundary and potential configurations. The specific test is whether the probability distribution of later emission or localization events is better predicted by instantaneous local field and canonical momentum alone, or by a state functional containing prior coherence-changing interactions. Candidate observables include channel-resolved phase, Wigner time delay, momentum-angle correlations, recollision yield, and decoherence under controlled environmental coupling.

13.2 Electrically conditioned crystal growth

Grow polar and nonpolar crystals under matched supersaturation while independently controlling external field, surface charge compensation, ionic strength, and seed orientation. Image step propagation and morphology in real time. Determine whether local attachment events produce a measurable increase in adjacent compatible attachment probability after accounting for concentration and field gradients. A spatial point-process or transfer-entropy analysis could test directional recruitment.

13.3 Magnetic and ferroelectric domain evolution

Prepare nominally equivalent samples with different field histories. Measure domain evolution after the same final applied field. Compare a local effective-field model with a configuration-history model incorporating domain topology and demagnetizing-field reconstruction. Search for a state-dependent orthogonal response whose predictive power resides in the prior global configuration rather than merely the current local vector.

13.4 Electrochemical nanopores

Use model slit pores or mineral nanopores with controlled surface charge and hydrocarbon/brine composition. Simultaneously measure zeta potential or surface potential, ion distribution, wetting, adsorption/desorption, and flow. Apply a finite initiating perturbation, then remove it. Test whether interfacial reorganization persists and recruits adjacent pore regions through secondary changes in charge, composition, and wetting.

13.5 Reservoir cores and field data

Design core-scale experiments with spatially resolved sampling rather than only inlet–outlet production. Label the initiating treatment where possible. Measure its physical reach, while independently monitoring pressure, ionic composition, produced hydrocarbon distribution, zeta potential, contact angle, NMR response, micro-CT connectivity, and acoustic or electrical properties. Compare four model classes:

(i) advection–diffusion with reaction;

(ii) pressure and capillary redistribution;

(iii) coupled electrochemical–wettability transport;

(iv) the same coupled model augmented by an explicit recursive recruitment state variable.

Field-scale evaluation should use blind forecasting. A CPC model should predict the timing, magnitude, and spatial sequence of production response better than conventional alternatives without merely adding unconstrained parameters.

14 A Minimal Mathematical Scaffold

The paper does not yet justify a unique CPC equation. A useful scaffold should nevertheless make the hypothesis explicit enough to test.

Let $\boldsymbol{y}(\boldsymbol{r}, t)$ collect physical state variables and let $\kappa(\boldsymbol{r}, t) \in [0, 1]$ denote a provisional recruitment field: the local fraction of relevant degrees of freedom participating in the organized response. Then

$$\frac{\partial \boldsymbol{y}}{\partial t} = \mathcal{L}[\boldsymbol{y}] + \mathcal{N}[\boldsymbol{y}, \kappa] + \boldsymbol{\xi}, \tag{32}$$

$$\frac{\partial \kappa}{\partial t} = D_\kappa \nabla^2 \kappa + \mathcal{R}(\boldsymbol{y}, \nabla \boldsymbol{y}, \kappa) - \mathcal{D}(\boldsymbol{y}, \kappa). \tag{33}$$

Here $\mathcal{L}$ contains accepted linear transport or field terms, $\mathcal{N}$ contains established nonlinear couplings, $\boldsymbol{\xi}$ represents fluctuations, $\mathcal{R}$ is a recruitment term, and $\mathcal{D}$ is de-recruitment or decoherence.

The CPC-specific claim would not be the existence of a new scalar κ by definition. It would be that a low-dimensional recruitment field can predict cross-scale persistence and propagation that otherwise require many unrelated empirical memory terms. A candidate recursive term might be

$$\mathcal{R} = \beta\, \kappa(1 - \kappa)\, Q[\boldsymbol{y}] + \lambda(1 - \kappa) \int_V K(\boldsymbol{r}, \boldsymbol{r}')\, Q[\boldsymbol{y}(\boldsymbol{r}', t - \tau)]\, \mathrm{d}\boldsymbol{r}', \tag{34}$$

where Q measures local compatibility with organized continuation, K is a causal coupling kernel, and τ allows finite propagation delay. The logistic factor prevents unbounded growth. This equation is illustrative, not canonical.

An equivalent configuration-space formulation may be more fundamental. Let $P_n(C)$ be the distribution over configurations after event n. Then

$$P_{n+1}(C') = \int_{\mathscr{K}} T(C' \mid C; \mathcal{F}[C])\, P_n(C)\, \mathrm{d}C, \tag{35}$$

where the transition kernel depends on the field functional generated by the current configuration. Ordinary state-dependent dynamics already possess this form. CPC becomes distinctive only if the realized transition modifies the kernel in a manner that systematically increases compatible recruitment:

$$T_{n+1} \neq T_n, \qquad \Delta\chi_n > 0 \tag{36}$$

over the relevant regime. The system is therefore not merely moving through a landscape; its realized events are sculpting the transition landscape.

15 Relation to Nonequilibrium Thermodynamics and Self-Organization

CPC belongs near, but should not be conflated with, established ideas including dissipative structures, synergetics, self-organized criticality, reaction–diffusion systems, phase-field dynamics, active matter, autopoiesis, and free-energy-principle formulations. Many of these already describe spontaneous order, collective variables, bifurcation, slaving of microscopic degrees of freedom, and pattern persistence.

The distinctive emphasis proposed here is narrower: *recursive distinction*. Each event not only changes the state variables; it changes the admissible organization of next events through a field or boundary reconstruction. This may ultimately prove equivalent to a familiar nonlinear state-dependent dynamical system. If so, CPC should be abandoned as unnecessary. It becomes useful only if it provides one or more of the following:

(a) a cross-scale state variable with measurable predictive value;

(b) a rigorous criterion distinguishing transport from recruitment;

(c) a way to relate field morphology to delayed material response;

(d) a parsimonious explanation of persistent organization after a finite perturbation;

(e) a falsifiable prediction not naturally generated by existing models.

16 Critical Questions and Failure Conditions

Several questions must remain open.

Is polarity essential? Some self-organizing systems possess no obvious electric or magnetic polarity. If CPC requires only generic asymmetry, the word "polar" may become too broad to be useful. The hypothesis should specify which conjugate distinction carries the recursion in each domain.

What is coherent across scales? Quantum phase coherence, orientational order, morphological continuity, and correlated reservoir response are not identical quantities. A valid framework must not convert semantic similarity into physical equivalence.

What is the event? At atomic scale it may be a coherence-changing interaction or detected transition. At crystal scale it may be attachment, nucleation, or step propagation. At reservoir scale it may be desorption, wetting transition, pore recruitment, or phase reconnection. Without an operational event definition, $n + 1$ remains rhetorical.

What is conserved? No conservation claim should be retained unless a measurable invariant is identified. Progressive reduction of incoherence may be a finite-regime tendency, not a conserved quantity.

Does the hypothesis survive model comparison? If conventional coupled multiphysics models predict the same observations with equal or superior parsimony, CPC adds no scientific value.

Can recruitment be reversed? Crystals dissolve, domains randomize, electrons decohere, and reservoirs re-trap fluids. A complete model requires de-recruitment, hysteresis, and scale-dependent reversibility.

17 Provisional Synthesis

The inquiry began with the visual fact that field-organized matter appears to manifest more than a collection of independent local vectors. Ferromagnetic particles do not expose a hidden fourth spatial axis, but they reveal how local orientation is already situated within a whole-field solution. Gyroscopic response does not require an additional dimension, but it does reveal a continuously regenerated orthogonal tangent direction defined by the relation between a present orientation and a globally conditioned effective field. Modern electron-trajectory experiments do not photograph a point traversing a determinate route, but they increasingly reveal phase-conditioned wavepacket and quantum-path structure in which potentials, fields, and boundaries participate in defining what may be observed next. Crystal growth does not simply accumulate atoms; an existing interface constructs the energetic and morphological conditions of its own continuation. Charged interfaces do not merely host ions; they recursively couple surface chemistry, potential, solvent orientation, adsorption, wetting, and transport. Porous formations do not merely contain fluids; their accessible flow network may change as local interfacial and mechanical events recruit previously isolated states.

These observations permit a common question:

> Does a class of physical systems evolve through recursively reconstructed event horizons in which each realized distinction modifies the field of admissible next distinctions, producing a cascade of progressively recruited organization?

If the answer is no, the inquiry may still clarify why superficially similar systems require distinct mechanisms. If the answer is yes only in narrow domains, CPC may become a useful mesoscale descriptor. If a cross-scale invariant, state variable, or predictive law can be identified, the inquiry may point toward a more general theory of recursively field-conditioned organization.

The present paper therefore closes without declaration. It proposes that "motion," "growth," "alignment," and "flow" may sometimes be observable projections of a deeper relational process: not an object simply passing through an unchanged field, but a coupled system continuously remaking the distinction by which its next state becomes possible.

Data, Conflicts, and Status of the Hypothesis

This manuscript is a conceptual inquiry and does not report a new controlled experiment. Any proprietary reservoir observations motivating the inquiry should be introduced in a later empirical section only with

complete metadata, controls, uncertainty estimates, and comparison against conventional mechanisms. The term *coherent polar cascade* remains a working hypothesis and should not be represented as an experimentally established law.

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