The Universal Coherence Flow Framework

A Renormalization-Group Treatment of Quantum Coherence as a Cross-Scale Resource, from Laboratory Devices to Cosmological Information Budgets

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Scope and Intellectual-Property Notice

Established physical results invoked here — resource theories of quantum coherence, the Landauer limit, the Bekenstein and holographic/covariant entropy bounds, the GKLS/Lindblad open-system formalism, the monotonicity of quantum relative entropy under completely-positive maps, and the renormalization-group concept — are prior art and are cited as such. The original contribution is the treatment of a single dimensionless coherence invariant as a cross-scale resource that flows, under an explicit variational renormalization-group map, from device scales to cosmological scales, governed by a contraction monotone toward the coarse-graining channel's fixed point, together with the closure that connects a laboratory coherence figure of merit to a cosmological coherence budget. The operational core of that contribution — the explicit coherence invariant and its normalization, the generating functional of the flow, the beta-function forms and their coefficients, the transport-monotone construction and its fixed-point reference, the matching conditions across scale bands, and the cosmological budget closure — is the subject of an intellectual-property filing (WIPO) and is deliberately withheld. The relations shown here are presented only at the level of named roles and qualitative structure; they are insufficient, by design, to reconstruct, re-derive, reverse-engineer, or re-implement the protected formulation by analytical, numerical, or automated (including AI-assisted) means. Requests for evaluation under appropriate confidentiality arrangements may be directed to the author.

Companion note. The Universal Coherence Flow (UCF) framework extends the author's program upward in scale. It takes the universal dimensionless coherence invariant introduced in the Unified Quantum Thermodynamic Framework — where it is defined across eighteen orders of magnitude in energy and connected by a variational renormalization-group flow among five quantum devices — and asks whether that same invariant continues to flow, without a break, into the cosmological regime described by the Quantum Nexus Unified Model. It inherits the information ceiling and energetic-cost economy of the Universal Information Optimization Principle, the equilibrium logic of the Unified Variational Principle, and the deterministic identity descriptor of the quantum-informational hash framework. Where the companion frameworks treat coherence within a bounded band or as a device figure of merit, UCF treats it as a cross-scale quantity spanning the whole range from qubit to cosmos.

Abstract

The Universal Coherence Flow (UCF) framework proposes that quantum coherence, expressed as a single dimensionless invariant bounded between zero and one, is not merely a device-level figure of merit but a cross-scale resource that flows continuously under a variational renormalization-group (RG) map. Resource theories of coherence quantify coherence rigorously at the level of individual quantum systems, and open-system thermodynamics prices its loss; separately, entropy and entanglement entropy are treated as flowing or budgeted quantities at cosmological scale. No existing framework treats coherence itself — as distinct from entropy or entanglement entropy — as the quantity that connects the laboratory regime to the cosmological regime under a single transport law. UCF is organized as a layered, scale-banded architecture: a resource layer fixes what coherence is and how it is bounded and priced; an RG-flow layer transports the coherence invariant between adjacent scale bands under matching conditions; a transport layer states the monotone that governs coherence under coarse-graining as a contraction toward the channel's fixed point, with the intensive coherence invariant decreasing under dissipative (unital) confinement and preserved in the reversible limit; and a budget layer closes the flow against a cosmological coherence budget analogous to the cosmological entropy budget. The framework reduces to the standard device-level coherence measures in the appropriate limit and is closed by a quantitative falsification program. This document states the architecture and its qualitative structure while withholding the operational core under intellectual-property protection.

1. Introduction

Quantum coherence — the capacity of a system to sustain definite phase relations across a superposition — is now treated as a quantifiable physical resource. Resource theories of coherence define free states, free operations, and monotones that cannot increase under those operations, giving coherence the same formal status as entanglement in its own resource theory. At the same time, the destruction of coherence carries a thermodynamic price: erasing or dephasing information incurs at least the Landauer cost, and open-system dynamics described by the GKLS/Lindblad master equation govern how coherence decays under coupling to an environment.

At cosmological scale, a parallel accounting exists for entropy. The Bekenstein and holographic bounds cap the information a region can hold, and the entropy budget of the observable universe is estimated and debated as a global quantity. Yet coherence and entropy are not the same object: a state can be highly mixed and yet retain structured coherence in a subspace, and coherence can be redistributed without a corresponding change in coarse-grained entropy. The literature transports entropy and entanglement entropy across scales through renormalization and holography, but it does not transport coherence, as such, from the device band to the cosmological band under a single cross-scale law.

UCF proposes exactly this bridge. It asks whether the dimensionless coherence invariant that is well defined for a laboratory device continues to be well defined, and transported lawfully, as the description is coarse-grained upward through intervening scale bands to the cosmological regime. The claim is strong and deliberately so: if coherence flows lawfully across scales, then a cosmological coherence budget exists on the same footing as the entropy budget, and it constrains both device engineering and cosmological modeling from a single principle.

2. The Principle of Coherence Flow

Every system that carries quantum phase information can be assigned a dimensionless coherence invariant, normalized to lie between zero (fully decohered) and one (maximally coherent under its constraints). The principle of coherence flow states that this invariant is intensive — independent of mere Hilbert-space size — and is not defined independently at each scale but transported between adjacent scale bands by a coarse-graining map:

coherence invariant at band n+1 = RG-map [coherence invariant at band n ; matching conditions]

Here the RG-map coarse-grains the description from finer to coarser scale, and the matching conditions fix how coherence at one band seeds the next. The explicit invariant, the RG-map, and the matching conditions are part of the protected core and are withheld; only their roles are stated. The essential claim is that no band defines its coherence in isolation: the device-scale invariant and the cosmological-scale invariant are two readings of one intensive quantity connected by an unbroken flow.

3. Components and Axioms

The framework rests on three components and a small set of axioms that constrain how they relate. The components are summarized by role; their definitions, couplings, and flow dynamics are part of the protected core.

Component	Role in coherence flow	Formal correspondence
Coherence invariant	The intensive dimensionless resource, bounded in [0,1], read at each scale band	Resource-theoretic coherence monotones
Scale-band ladder	The ordered sequence of scales from device to cosmos across which the invariant is transported	Renormalization-group / coarse-graining
Dissipative channel	The mechanism by which coherence contracts toward the channel's fixed point, at an energetic price	GKLS/Lindblad dynamics; Landauer cost

The governing axioms are: every system carrying phase information admits a bounded, intensive coherence invariant; the invariant is transported between adjacent bands by a coarse-graining channel; transport contracts the state toward the channel's fixed point (a data-processing monotone); under dissipative (unital) confinement this contraction lowers the coherence invariant by an amount bounded below by the energetic cost of coherence loss; the description reduces to standard resource-theoretic coherence measures at the device band; coherence loss is consistent with non-decreasing coarse-grained entropy; and the invariant is unchanged under equivalent representations of the state.

4. The Layered, Scale-Banded Architecture

The framework is layered, and the layers are mutually consistent. Each is stated by role; the functionals, operators, and coefficients that realize each layer are withheld.

1. Resource layer. Fixes what coherence is and bounds it in [0,1], with its destruction priced at no less than the Landauer envelope and its total capacity bounded above by the tighter of the Bekenstein and holographic ceilings.
2. RG-flow layer. Transports the coherence invariant from finer to coarser scale bands under matching conditions, so the device-scale reading and the cosmological-scale reading are connected by an unbroken flow rather than defined independently.
3. Transport layer. States the monotone governing coherence under coarse-graining as a contraction toward the coarse-graining channel's fixed point. Under dissipative (unital) confinement the intensive invariant is non-increasing, saturated only in the reversible limit; under a purifying (non-unital) channel the invariant relaxes toward that channel's low-entropy fixed point, and any rise is bookkept against the work supplied.
4. Budget layer. Closes the flow against a cosmological coherence budget — the coherence-weighted information capacity of a region — placed on the same footing as its entropy budget, and constrains it by the information ceiling.

> *resource → RG-flow → transport monotone → cosmological budget*

These layers are consistent by design: the resource bound caps the coherence capacity; the energetic price of decoherence enters the same flow that transports it; the transport monotone fixes how coherence changes between bands relative to the channel's fixed point; and the budget layer reads the accumulated flow as a global quantity subject to the same information ceiling that bounds entropy.

5. Transport, Dissipation, and the Budget Closure

The transport statement of the framework is a contraction monotone: coarse-graining moves the state toward the fixed point of the coarse-graining channel, and the associated distance is non-increasing along the flow — the transport signature of coherence, valid for arbitrary channels. Dissipation is imposed through a term that is non-negative and vanishes only in the reversible, fully unitary limit, so that coherence is never spontaneously created under passive coarse-graining and its loss is always priced.

coherence at band n = contraction (coherence at band n−1 ; channel fixed point) , loss ≥ 0

For the dissipative (unital) confinement of the companion program — whose fixed point is the maximally mixed state — the contraction reads directly as a non-increasing intensive coherence invariant from one band to the next, with the deficit fixed by the confinement strength and priced by the Landauer envelope. A rise in the invariant is therefore admissible only on an active band, where a coherent pump supplies work; passive bands are monotone. The budget closure states that summing the coherence-weighted capacity up to a cosmological region yields a finite coherence budget for that region, bounded above by its information ceiling, and non-increasing along any purely dissipative chain. The reversible regime is recovered when the dissipative term vanishes, in which case coherence is transported without loss and the budget is saturated. The explicit contraction functional, its fixed-point reference, the dissipative term, and the budget closure are part of the protected core; only their structure is stated.

6. Correspondence with Established Coherence Measures

In the regime restricted to a single device-scale band, with no coarse-graining and negligible environmental coupling, the coherence invariant reduces to the standard resource-theoretic coherence monotone of that system. The device-level coherence figure of merit thus appears as a limiting case — the single-band reading of a quantity that the framework otherwise transports across many bands, from a sub-device band below the qubit scale to a Planck-scale band above the mirror-sector scale, spanning more than thirty orders of magnitude in energy. This correspondence is a boundary condition built into the flow, ensuring that UCF does not contradict established coherence quantification but extends its domain of definition across scale.

> $$\textit{single band , negligible coupling} \Longrightarrow \textit{coherence invariant} \rightarrow \textit{standard coherence monotone}$$

7. Illustrative Minimal Example (Public Quantities Only)

To make the transport statement concrete and independently checkable, this section works through a minimal single-qubit example using only established, publicly defined quantities. It is a boundary-limit illustration of the device-band behaviour of the flow; it does not use, and does not disclose, the protected coherence invariant, the RG-map, the matching conditions, or the budget closure. Any reader can reproduce it from the cited prior art alone.

Consider a single qubit with density matrix ρ written in the reference (computational) basis, and take as the coherence figure of merit the standard l_1-norm of coherence of Baumgratz, Cramer and Plenio, C(ρ) = Σ_{i≠j} | ρ_{ij}|, which for a qubit equals twice the modulus of the off-diagonal element, $C(\rho) = 2|\rho_{01}|$. For the maximally coherent state |+⟩⟨+| one has $\rho_{01} = 1/2$ and C = 1; for any diagonal (incoherent) state C = 0. This is the established device-band monotone the framework must recover in the single-band limit.

Now apply a phase-damping (dephasing) channel — the canonical unital coarse-graining step, a special case of the GKLS/Lindblad dynamics cited as prior art — with per-step strength γ ∈ [0,1]. Its documented action multiplies the off-diagonal element by (1−γ) while leaving the populations fixed. Applying it once per band across a ladder of n coarse-graining steps gives the closed, elementary recursion:

$$C\_n = (1 - \gamma) \cdot C\_\{n-1\} = (1 - \gamma)^n \cdot C_0 \; , \; 0 \le C\_n \le C\_\{n-1\}$$

Starting from $C_0 = 1$ with a representative γ = 0.2, the coherence figure of merit reads 1.000, 0.800, 0.640, 0.512, 0.410, … across bands n = 0,1,2,3,4, decaying monotonically toward the channel fixed point (the maximally mixed state, C = 0) and never rising on a passive band. This reproduces, in a public and fully reproducible setting, the three structural features the framework asserts: the reading is bounded in [0,1]; it is non-increasing under passive unital coarse-graining; and it saturates (C_n = C_{n−1}) only in the reversible limit γ → 0.

> $$\textit{dephasing, per step: } C\_n = (1-\gamma)\, C\_\{n-1\} \; ; \; \gamma=0.2 : 1.000 \rightarrow 0.800 \rightarrow 0.640 \rightarrow 0.512 \rightarrow 0.410$$

What the example shows, and what it deliberately does not. The example illustrates the qualitative transport behaviour the framework requires at the device band and fixes the boundary condition of Section 6 in a checkable way. It is not the framework's law: the protected invariant is intensive and dimensionless rather than the raw l_1

norm, the RG-map is not a single fixed-γ dephasing step, and the matching conditions and budget closure that connect bands across more than thirty orders of magnitude are withheld. The example is therefore necessary (the flow must recover it) but not sufficient (recovering it does not reconstruct the flow).

8. Observables and an Executable Falsification Protocol

The framework defines primary observables with clear operational roles: the coherence invariant read at each accessible scale band; the band-to-band transport ratio; the per-band decoherence loss relative to the channel fixed point; and the accumulated coherence budget of a bounded region. They are designed to be non-redundant — if the transport ratio depends independently on the scale band and on the dissipative environment, the observables jointly define an irreducible coherence-flow sector.

8.1 What is measured

Let $\hat{C}_n$ denote the estimated coherence figure of merit at band n (measured, at the device band, by the standard resource-theoretic monotone of Section 7; estimated at higher bands by the accessible coarse-grained reading). Define the two working observables:

- Transport ratio: $R_n = \hat{C}_n / \hat{C}_{n-1}$ (dimensionless, expected in [0,1] on passive bands).
- Per-band loss: $L_n = \hat{C}_{n-1} - \hat{C}_n \geq 0$ (paired, per band, with the calorimetric heat Q_n dissipated by the same channel step).

8.2 Executable procedure (reproducible in principle)

1. Prepare a known coherent state at the finest accessible band and record $\hat{C}_0$ with its measurement uncertainty.
2. Apply one calibrated coarse-graining / confinement step; record $\hat{C}_1$ and, simultaneously, the calorimetric heat Q_1 of that step.
3. Repeat over an accessible ladder of bands n = 1 … N, holding no coherent pump on the bands declared passive.
4. Compute R_n and L_n at each band, with confidence intervals from repeated runs.
5. Regress the transport ratio on scale band and on the environmental-coupling parameter, including their interaction term, and test whether the coupling coefficient and the interaction coefficient are jointly non-zero.
6. Cross-check: regress the coherence-inferred confinement strength (from L_n) against the calorimetry-inferred confinement strength (from Q_n) and test agreement within the combined uncertainty.

8.3 Expected signature and refutation conditions

The framework predicts, qualitatively: $R_n \leq 1$ on every passive band (monotone contraction); $L_n \geq 0$ paired with $Q_n > 0$ whenever $L_n > 0$ (loss is priced); R_n depending jointly and non-trivially on both scale and coupling (an irreducible flow, not a per-band accident); and the two confinement-strength estimates agreeing within uncertainty (the common-channel closure). On a log $\hat{C}_n$ versus n plot, a purely passive unital ladder should appear as a straight, non-increasing line whose slope encodes the confinement strength.

The framework is refuted if any of the following is observed at the stated confidence:

- A coarse-graining step increases the contraction distance toward the channel's own fixed point ($R_n > 1$ on a passive band), violating the data-processing monotone — spontaneous coherence creation.
- The device-band limit fails to recover the standard resource-theoretic coherence monotone.
- The accumulated coherence budget of a region violates its information ceiling, or a purely dissipative chain shows a rising budget.
- $L_n > 0$ with no accompanying dissipated heat Q_n (unpriced coherence loss).
- The confinement strength inferred from the coherence contraction disagrees, beyond combined uncertainty, with the confinement strength inferred from the calorimetric heat of the same channel — refuting the common-channel claim that unifies UCF with the dissipative sector of the companion program.

The procedure, observables, expected signs, and plot are fully specified above. The protected content is only the closed functional form of the invariant and the numerical acceptance thresholds of the regression; these are withheld, so the protocol is executable in structure while the quantitative decision boundary remains part of the intellectual-property filing.

9. Relation to the Foundational Program

UCF is a scale-extension model of the author's program. Where the Unified Quantum Thermodynamic Framework defines the coherence invariant across device scales and connects five devices by a variational renormalization-group flow, and the Quantum Nexus Unified Model describes the cosmological regime with its own multi-scale consistency, UCF proposes that these are two ends of a single unbroken coherence flow. It inherits the information ceiling and energetic-cost economy of the Universal Information Optimization Principle, the equilibrium logic of the Unified Variational Principle, and the deterministic descriptor of the quantum-informational hash framework as named layers, and adds the cross-scale transport monotone that carries coherence between them.

Notational independence. The observables, transport monotone, contraction statement, and budget closure introduced here are self-contained. The framework relies only on established physical results — cited as external prior art — and on the author's own protected formulations, and it reproduces the protected equations of no other framework.

Universal scope. The framework is offered as an application framework wherever quantum phase information is carried and coarse-grained — from quantum devices through mesoscopic and astrophysical systems to cosmological regions. This breadth is an application claim, not an automatic equivalence across domains.

10. Conclusion

The Universal Coherence Flow framework reframes quantum coherence as a cross-scale resource rather than a purely local device figure of merit. Its central contribution is not merely that coherence can be quantified, but the specific proposal that a single bounded, intensive coherence invariant is transported, under a variational renormalization-group map governed by a contraction monotone toward the coarse-graining channel's fixed point, from the laboratory band to the cosmological band, closing against a cosmological coherence budget placed on the same footing as the entropy budget. The framework reduces to standard resource-theoretic coherence at the device limit and is closed by a quantitative falsification program. As a scale-extension pillar of the broader program, it connects the technological application layer to the master cosmological model through one intensive quantity and its transport law.

Intellectual-Property Statement

Established physical results invoked here are prior art and are cited as such. The original contribution — the treatment of a bounded, intensive coherence invariant as a cross-scale resource and its operational core, including the explicit invariant and its normalization, the generating functional of the flow, the beta-function forms and coefficients, the transport-monotone construction and its fixed-point reference, the band-matching conditions, the dissipative term, and the cosmological budget closure — is the subject of an intellectual-property filing (WIPO) and is withheld. Nothing in this preprint should be construed as a public disclosure sufficient to reconstruct, re-derive, reverse-engineer, or re-implement the protected formulation. The author retains all rights to the operational content.

References (Prior Art)

The physical results referenced by UCF are established in the literature; the contribution of this work is the cross-scale coherence-flow architecture over them.

[1] T. Baumgratz, M. Cramer, and M. B. Plenio, "Quantifying coherence," Phys. Rev. Lett. 113, 140401 (2014). https://doi.org/10.1103/PhysRevLett.113.140401

[2] A. Streltsov, G. Adesso, and M. B. Plenio, "Colloquium: Quantum coherence as a resource," Rev. Mod. Phys. 89, 041003 (2017). https://doi.org/10.1103/RevModPhys.89.041003

[3] G. Lindblad, "Completely positive maps and entropy inequalities," Commun. Math. Phys. 40, 147 (1975). https://doi.org/10.1007/BF01609396

[4] R. Landauer, "Irreversibility and heat generation in the computing process," IBM J. Res. Dev. 5, 183 (1961). https://doi.org/10.1147/rd.53.0183

[5] G. Lindblad, "On the generators of quantum dynamical semigroups," Commun. Math. Phys. 48, 119 (1976); V. Gorini, A. Kossakowski, and E. C. G. Sudarshan, J. Math. Phys. 17, 821 (1976). https://doi.org/10.1007/BF01608499

[6] J. D. Bekenstein, "Universal upper bound on the entropy-to-energy ratio for bounded systems," Phys. Rev. D 23, 287 (1981). https://doi.org/10.1103/PhysRevD.23.287

[7] R. Bousso, "A covariant entropy conjecture," JHEP 07, 004 (1999). https://arxiv.org/abs/hep-th/9905177

[8] K. G. Wilson, "The renormalization group: Critical phenomena and the Kondo problem," Rev. Mod. Phys. 47, 773 (1975). https://doi.org/10.1103/RevModPhys.47.773