QB2 – Emergence of Observable Structure from Transport Closure in Scalar–Conformal NUVO Systems

Preprint, Version 1.0[*]

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Notation and Conventions

- $\mathcal{M}$ denotes the spacetime manifold.
- η denotes the reference Lorentzian metric (typically Minkowski in a global chart).
- g denotes the physical metric.
- The scalar field $\Lambda : \mathcal{M} \to \mathbb{R}_{>0}$ is the NUVO modulation field.
- The physical metric is scalar–conformal:

$$g_{\mu\nu} = \Lambda^2 \, \eta_{\mu\nu}.$$

- $\Lambda_0 > 0$ denotes the baseline scalar availability level supported by the intrinsic delivery structure of the underlying field. In the absence of localized structural occupation the scalar field satisfies $\Lambda(x) = \Lambda_0$.
- The dimensionless scalar diagnostic is

$$\lambda(x) \coloneqq \frac{\Lambda(x)}{\Lambda_0}.$$

- The scalar field represents the *locally available structural capacity* of the underlying delivery field. Localized structures may reduce this availability through occupation or transport, but the intrinsic delivery baseline Λ_0 remains fixed.
- Greek indices $\mu, \nu, \ldots$ range over spacetime coordinates $0, 1, 2, 3$.
- We use the Einstein summation convention unless explicitly stated otherwise.

Remark 0.1. *Unless otherwise stated, the background signature is* $(-, +, +, +)$.

Abstract

[*]Bibliography is provisional. Cross-references to companion NUVO-series papers (M-, SR-, Q-, QB-, QM-series) will be updated with Zenodo DOIs in subsequent versions.

Building on the state representation established in QB1, we derive the observable structure of quantum mechanics from the transport closure system of scalar–conformal NUVO theory. We show that infinitesimal transport in spacetime induces a natural class of differential generators acting on the complex state representation, and that these generators give rise to the operator structure associated with momentum and energy.

The resulting operators are not postulated but emerge as representations of transport generators encoded through phase evolution. Their algebraic properties arise from the interplay between coordinate representation and differential action, rather than from an imposed operator framework.

No probabilistic interpretation, measurement postulate, or operator axioms are assumed. The present work establishes the operator-level bridge between transport closure and quantum-mechanical formalism, preparing the framework for the introduction of observable interpretation in subsequent papers.

This manuscript is mathematical in scope. It establishes definitions, structural identities, and variational consequences within a scalar–conformal setting. Sector reductions and correspondence limits are recorded only when explicitly stated as additional assumptions and are not used as premises in derivations.No claim of full dynamical equivalence to general relativity, quantum mechanics, or classical field theories is made at the level of the present foundational development. Where later papers compare limiting behavior, those comparisons are presented as correspondence targets rather than as identity statements.The NUVO program is organized as a sequence of internally consistent mathematical papers. Foundational papers (M-series) fix the scalar–conformal geometry, variational structure, and notation. Subsequent papers treat sectoral reductions (gravity, exchange, quantization, and bound-state structure) as controlled specializations of the foundational framework.Throughout the series we distinguish between (i) definitions and theorems proved in the present manuscript, and (ii) external results used only for context. References are cited for orientation and comparison and are not treated as axioms unless explicitly declared.All notation intended to be program-wide is centralized in the shared NUVO macro package and notation layer. This is done to maintain consistency across the series and to support future consolidation into a cohesive monograph-style presentation.**Scalar ontology.** The scalar field Λ represents the *locally available structural capacity* of an underlying delivery field permeating spacetime. The baseline level Λ_0 denotes the availability supported by this intrinsic delivery structure in the absence of structural occupation. Localized structures or transport processes may reduce the available capacity relative to this baseline, but the intrinsic delivery baseline itself is not altered. Consequently the scalar field measures the *available portion* of structural capacity rather than the intrinsic production of the underlying field.

1 Introduction

1.1 Position Within the QB-Series

The preceding paper (QB1) [1] established that the exchange-sector transport system admits a minimal local state description in terms of closure density and transport-derived phase, and that this state may be encoded losslessly as a complex-valued function Ψ.

The purpose of the QB-series is to bridge the transport closure framework of the Q-series to the formal structure of quantum mechanics in a sequence of controlled steps. Within this program:

- QB1 established the state representation,
- QB2 [2] derives the observable and operator structure,

- QB3 [3] will address measurement and probabilistic interpretation.

The present paper occupies the second stage of this development.

1.2 Objective of the Present Work

The central objective of this paper is to show that the operator structure of quantum mechanics arises naturally from the transport closure system when expressed in the complex state representation.

Specifically, we aim to:

1. define transport generators corresponding to infinitesimal spacetime evolution,
2. show that these generators act as differential operators on the complex state,
3. derive the spatial and temporal generators associated with phase evolution,
4. establish the algebraic relations between these generators,
5. interpret these generators as the precursor of observable structure.

No operator postulates are introduced. All structures arise from the representation of transport closure.

1.3 What is Not Assumed

The present work maintains the interpretive discipline established in QB1 and the Q-series.

- No probabilistic interpretation is assumed. The quantity $|\Psi|^2$ continues to represent closure density rather than probability density.
- No measurement postulate is introduced. The relation between the state and observed outcomes is deferred to subsequent work.
- No operator formalism is assumed a priori. Operators arise as representations of transport generators rather than as primitive objects.

1.4 Structure of the Paper

Section 2 introduces the notion of transport generators and establishes their differential representation. Sections 3 and 4 derive the spatial and temporal generators and identify their operator forms. Section 5 establishes the algebraic relations between these generators. Section 6 discusses the interpretation of these structures as precursors to observable quantities. The paper concludes with a summary and transition to the next stage of the QB-series.

2 Transport Generators

2.1 Transport as Infinitesimal Displacement

In the transport closure framework, the evolution of the system is described through the motion of closure structures across spacetime. At the level of the state representation $\Psi(x, t)$, this evolution corresponds to changes in the value of the state under infinitesimal displacements in space and time.

Consider a small spatial displacement

$$x \mapsto x + \epsilon a,$$

where a is a constant vector. The corresponding change in the state is given by

$$\Psi(x + \epsilon a, t) = \Psi(x, t) + \epsilon(a \cdot \nabla)\Psi(x, t) + O(\epsilon^2).$$

Similarly, for a small temporal displacement

$$t \mapsto t + \epsilon,$$

one has

$$\Psi(x, t + \epsilon) = \Psi(x, t) + \epsilon\partial_t\Psi(x, t) + O(\epsilon^2).$$

Thus the first-order response of the state to infinitesimal transport is governed by differential operators.

2.2 Definition of Transport Generator

Definition 2.1 (Transport generator)**.** *A transport generator is a linear differential operator acting on the state $\Psi(x, t)$ that represents the first-order change of the transport state under an infinitesimal displacement in a specified spacetime direction.*

This definition reflects the fact that transport is represented locally by the differential structure of the state.

2.3 Differential Representation of Generators

The preceding expansion shows that infinitesimal spatial and temporal displacements are represented by the differential operators ∇ and ∂_t, respectively.

Accordingly, any transport generator must be represented by a differential operator acting on the state. This is not an additional assumption, but a consequence of representing the transport state as a local function on spacetime.

2.4 Normalization from Phase Encoding

While ∇ and ∂_t represent infinitesimal displacement, they do not directly encode the transport structure associated with the phase.

From QB1, the state is given by

$$\Psi = \sqrt{\rho}\, e^{i\phi/\Phi_0}.$$

Differentiation of Ψ yields terms proportional to

$$\frac{i}{\Phi_0}\nabla\phi \quad \text{and} \quad \frac{i}{\Phi_0}\partial_t\phi,$$

which encode the transport direction and temporal evolution, respectively.

To extract the phase derivatives themselves as leading contributions, the differential operators must be normalized by factors of Φ_0 and i. This leads to the identification of the normalized generators

$$\mathcal{P} = -i\Phi_0\nabla, \qquad \mathcal{T} = i\Phi_0\partial_t.$$

These operators represent the fundamental transport generators associated with spatial and temporal evolution in the complex state representation.

2.5 Interpretation

The operators $\mathcal{P}$ and $\mathcal{T}$ arise directly from the structure of the transport closure system and the complex encoding of the state. They are not introduced as independent objects, but emerge as the natural representation of infinitesimal transport in spacetime.

These generators will be identified in subsequent sections with the operators corresponding to momentum and energy in the quantum-mechanical formalism.

3 Spatial Transport Generator

3.1 Phase Gradient and Transport Direction

Within the transport closure framework, the direction of local transport is encoded by the spatial variation of the transport-derived phase. In particular, the gradient $\nabla\phi(x,t)$ determines the local direction of admissible transport flow.

This identification follows from the role of phase as a transport consistency quantity: phase differences accumulated along admissible paths determine the coherence of transport, and their spatial variation specifies the direction in which transport is locally aligned.

Accordingly, any representation of spatial transport at the level of the state Ψ must recover the phase gradient as its leading structural component.

3.2 Derivation of the Spatial Generator

Let

$$\Psi(x,t) = \sqrt{\rho(x,t)}\, e^{i\phi(x,t)/\Phi_0}$$

be the complex state representation established in QB1.

We compute the spatial gradient of Ψ [4]:

$$\nabla\Psi = \nabla\left(\sqrt{\rho}\, e^{i\phi/\Phi_0}\right).$$

Applying the product rule,

$$\nabla\Psi = (\nabla\sqrt{\rho})e^{i\phi/\Phi_0} + \sqrt{\rho}\,\nabla\left(e^{i\phi/\Phi_0}\right).$$

The derivative of the exponential factor is

$$\nabla\left(e^{i\phi/\Phi_0}\right) = \frac{i}{\Phi_0}(\nabla\phi)\, e^{i\phi/\Phi_0}.$$

Thus,

$$\nabla\Psi = \left(\frac{\nabla\rho}{2\rho} + \frac{i}{\Phi_0}\nabla\phi\right)\Psi.$$

Multiplying by $-i\Phi_0$ yields

$$-i\Phi_0\nabla\Psi = \left(\nabla\phi - i\frac{\Phi_0}{2}\frac{\nabla\rho}{\rho}\right)\Psi.$$

The leading real contribution is the phase gradient $\nabla\phi$, which encodes the local transport direction, while the remaining term depends on spatial variation of the closure density.

This identifies the normalized differential operator $-i\Phi_0\nabla$ as the generator that recovers the transport-direction structure encoded in the phase.

3.3 Momentum Operator Theorem

Theorem 3.1 (Spatial transport generator)**.** *Let $\Psi(x,t)$ be the complex state representation of the transport state. Then the generator of infinitesimal spatial transport is represented by the differential operator*

$$\hat{p} = -i\Phi_0\nabla.$$

3.4 Proof

The definition of transport generator requires that the operator represent the first-order change of the state under infinitesimal spatial displacement.

From Section 2, infinitesimal spatial displacement is represented by the differential operator ∇. The preceding computation shows that, when acting on Ψ, the operator $-i\Phi_0\nabla$ produces a quantity whose leading contribution is the phase gradient $\nabla\phi$, which encodes the direction of transport.

Since the normalization factor $-i\Phi_0$ is uniquely determined by the exponential phase encoding, it follows that

$$\hat{p} = -i\Phi_0\nabla$$

is the normalized generator of spatial transport in the complex state representation.

□

3.5 Interpretation as Transport Generator

The operator $\hat{p}$ is not introduced as a primitive observable. Rather, it arises as the representation of infinitesimal spatial transport within the complex state formalism.

Its action on the state reflects two distinct contributions:

- a leading term determined by the phase gradient, encoding transport direction [5],
- a secondary term associated with spatial variation of closure density.

In regimes where the closure density varies slowly relative to the phase, the transport term dominates and one has the approximation

$$\hat{p}\Psi \approx (\nabla\phi)\,\Psi,$$

which corresponds to a well-defined local transport direction.

3.6 Role within the Emerging Operator Structure

The operator $\hat{p}$ will be identified in subsequent sections as the operator corresponding to momentum in the quantum-mechanical formalism [6]. At the present stage, however, it is understood solely as the generator of spatial transport derived from the transport closure system.

This distinction is essential: the operator structure is not assumed, but emerges from the representation of transport dynamics.

4 Temporal Transport Generator

4.1 Temporal Phase Evolution

Within the transport closure framework, temporal evolution is encoded through the time dependence of the transport-derived phase. The quantity $\partial_t \phi(x,t)$ determines the local rate of phase accumulation associated with transport and therefore governs the temporal evolution of the state.

As in the spatial case, the phase serves as the fundamental quantity encoding transport consistency. Its temporal variation specifies how the transport structure evolves with time.

4.2 Derivation of the Temporal Generator

Let

$$\Psi(x,t) = \sqrt{\rho(x,t)}\, e^{i\phi(x,t)/\Phi_0}$$

be the complex state representation.

We compute the time derivative:

$$\partial_t \Psi = \partial_t \left(\sqrt{\rho}\, e^{i\phi/\Phi_0} \right).$$

Applying the product rule,

$$\partial_t \Psi = (\partial_t \sqrt{\rho}) e^{i\phi/\Phi_0} + \sqrt{\rho}\, \partial_t \left(e^{i\phi/\Phi_0} \right).$$

The derivative of the exponential factor is

$$\partial_t \left(e^{i\phi/\Phi_0} \right) = \frac{i}{\Phi_0} (\partial_t \phi)\, e^{i\phi/\Phi_0}.$$

Thus,

$$\partial_t \Psi = \left(\frac{\partial_t \rho}{2\rho} + \frac{i}{\Phi_0} \partial_t \phi \right) \Psi.$$

Multiplying by $i\Phi_0$ yields

$$i\Phi_0 \partial_t \Psi = \left(-\partial_t \phi + i \frac{\Phi_0}{2} \frac{\partial_t \rho}{\rho} \right) \Psi.$$

The leading real contribution is $-\partial_t \phi$, which encodes the temporal evolution of the transport phase, while the remaining term reflects temporal variation of the closure density.

This identifies the normalized differential operator $i\Phi_0 \partial_t$ as the generator that recovers the temporal transport structure encoded in the phase.

4.3 Energy Operator Theorem

Theorem 4.1 (Temporal transport generator)**.** *Let $\Psi(x,t)$ be the complex state representation of the transport state. Then the generator of infinitesimal temporal evolution is represented by the differential operator*

$$\hat{E} = i\Phi_0 \partial_t.$$

4.4 Proof

From Section 2, infinitesimal temporal displacement is represented by the operator ∂_t. The preceding computation shows that, when acting on Ψ, the operator $i\Phi_0\partial_t$ produces a quantity whose leading contribution is the temporal phase derivative $-\partial_t\phi$.

The normalization factor $i\Phi_0$ is determined by the exponential phase encoding and ensures that the operator extracts the transport-phase evolution.

Therefore,

$$\hat{E} = i\Phi_0\partial_t$$

is the normalized generator of temporal transport in the complex state representation.

□

4.5 Interpretation as Temporal Generator

The operator $\hat{E}$ arises as the representation of infinitesimal temporal transport within the complex state formalism.

Its action reflects:

- a leading term determined by the temporal phase evolution,
- a secondary term associated with temporal variation of closure density.

In regimes where the closure density varies slowly in time relative to the phase, one obtains the approximation

$$\hat{E}\Psi \approx -(\partial_t\phi)\,\Psi,$$

which corresponds to a well-defined temporal transport rate.

4.6 Parallel Structure with Spatial Generator

The spatial and temporal generators derived in Sections 3 and 4 exhibit a direct structural parallel:

$$\hat{p} = -i\Phi_0\nabla, \qquad \hat{E} = i\Phi_0\partial_t.$$

Both operators arise from the same mechanism:

- infinitesimal displacement in spacetime,
- differential representation of the state,
- normalization determined by phase encoding.

This parallelism demonstrates that the operator structure is not imposed, but is inherited directly from the representation of transport closure.

4.7 Transition to Generator Algebra

Having identified the spatial and temporal transport generators, the next step is to determine their algebraic relations and the structure they induce on the state representation. This is addressed in the following section.

5 Algebra of Transport Generators

5.1 Position Representation

In the complex state representation, the state $\Psi(x,t)$ is defined as a function on spacetime. Accordingly, spatial position is represented by multiplication by the coordinate functions.

For each spatial coordinate x^j, define the operator X^j acting on Ψ by

$$(X^j\Psi)(x,t) \coloneqq x^j\Psi(x,t).$$

This definition follows directly from the representation of the state as a function over space and does not introduce additional structure.

5.2 Commutation Structure

Having identified the spatial transport generator

$$\hat{p}_k = -i\Phi_0\partial_k,$$

we examine its algebraic relation with the position operator X^j.

The commutator is defined by

$$[X^j, \hat{p}_k]\Psi = X^j(\hat{p}_k\Psi) - \hat{p}_k(X^j\Psi).$$

5.3 Commutation Theorem

Theorem 5.1 (Position–transport commutator). *Let X^j be the position operator defined by multiplication and let*

$$\hat{p}_k = -i\Phi_0\partial_k$$

be the spatial transport generator. Then [7]

$$[X^j, \hat{p}_k] = i\Phi_0\delta^j{}_k.$$

5.4 Proof

Let Ψ be a sufficiently smooth state.

First compute

$$X^j(\hat{p}_k\Psi) = x^j(-i\Phi_0\partial_k\Psi).$$

Next compute

$$\hat{p}_k(X^j\Psi) = -i\Phi_0\partial_k(x^j\Psi).$$

Applying the product rule,

$$\partial_k(x^j\Psi) = (\partial_k x^j)\Psi + x^j\partial_k\Psi = \delta^j{}_k\Psi + x^j\partial_k\Psi.$$

Thus

$$\hat{p}_k(X^j\Psi) = -i\Phi_0\delta^j{}_k\Psi - i\Phi_0 x^j\partial_k\Psi.$$

Subtracting,

$$[X^j, \hat{p}_k]\Psi = (-i\Phi_0 x^j\partial_k\Psi) - (-i\Phi_0\delta^j{}_k\Psi - i\Phi_0 x^j\partial_k\Psi).$$

The derivative terms cancel, yielding

$$[X^j, \hat{p}_k]\Psi = i\Phi_0 \delta^j{}_k \Psi.$$

Since this holds for all Ψ, the operator identity follows:

$$[X^j, \hat{p}_k] = i\Phi_0 \delta^j{}_k.$$

□

5.5 Origin of Non-Commutation

The non-vanishing commutator arises from the fundamental difference between multiplication and differentiation operations.

- The position operator X^j multiplies the state by the coordinate function.
- The transport generator $\hat{p}_k$ differentiates the state with respect to the coordinate.

These operations do not commute, and the resulting commutator is therefore a structural consequence of the representation of the state as a spacetime function together with the differential nature of infinitesimal transport.

No additional algebraic assumptions are required.

5.6 Interpretation

The commutation relation obtained above is not postulated but arises as a representation identity of the transport closure system.

In particular:

- The operator $\hat{p}_k$ is derived as the generator of spatial transport.
- The operator X^j arises from coordinate representation of the state.
- The commutator reflects the incompatibility of multiplication and differentiation.

Thus the algebraic structure commonly associated with quantum mechanics emerges directly from the representation of transport generators, without the introduction of operator axioms.

5.7 Transition to Observable Structure

The emergence of a nontrivial commutation structure indicates that the transport generators possess an algebraic organization compatible with the operator formalism of quantum mechanics.

The next step is to clarify how these generators relate to observable quantities within the present framework. This is addressed in the following section.

6 Representation of Observables

6.1 Generators as Observable Structure

The preceding sections established that the operators

$$\hat{p} = -i\Phi_0\nabla, \qquad \hat{E} = i\Phi_0\partial_t,$$

arise as representations of spatial and temporal transport generators acting on the state $\Psi(x, t)$.

These operators encode fundamental aspects of the transport closure system:

- $\hat{p}$ encodes the spatial transport direction through the phase gradient,
- $\hat{E}$ encodes temporal evolution through the time derivative of the phase.

Accordingly, these generators provide a natural representation of physical quantities associated with transport structure.

6.2 Observables as Generator Actions

Within the present framework, an observable quantity is identified with the action of a transport generator on the state.

This identification is motivated by the following considerations:

- The state Ψ encodes all local transport information through closure density and phase.
- Transport generators extract specific structural features of this information.
- These extracted features correspond to physically meaningful quantities associated with transport.

Thus, rather than introducing observables as independent objects, they arise as derived quantities associated with generator actions on the state.

6.3 Local Character of Observable Structure

The action of a transport generator on Ψ produces a local quantity defined at each spacetime point. For example,

$$\hat{p}\Psi \quad \text{and} \quad \hat{E}\Psi$$

encode local transport information through their dependence on phase derivatives and closure density.

This local character reflects the underlying transport framework, in which all structure is defined through local interactions and phase accumulation along admissible paths.

6.4 Integral Structures

While the present work does not introduce a probabilistic interpretation, it is natural to consider integral expressions constructed from the state and generator actions.

For a spatial region Ω, one may consider quantities of the form

$$\int_\Omega \Psi^*(\hat{p}\Psi)\, d^3x, \qquad \int_\Omega \Psi^*(\hat{E}\Psi)\, d^3x,$$

which combine the state and generator action into global quantities associated with the region.

At this stage, such expressions are interpreted as structural integrals of the transport system, rather than as expectation values.

6.5 Relation to Schrödinger Representation

In QB1 [1], it was established that the transport closure system admits a Schrödinger-type representation in terms of the state Ψ.

The operators derived in the present paper are precisely those required to express that representation in differential form. In particular, the temporal generator $\hat{E}$ and spatial generator $\hat{p}$ provide the building blocks for the evolution equation satisfied by Ψ [4, 8].

Thus the observable structure identified here is consistent with, and required by, the dynamical representation obtained previously.

6.6 Interpretive Discipline

The identification of observables with generator actions is subject to the following constraints:

- No probabilistic interpretation is assigned to the state or to the integral expressions introduced above.
- No measurement postulate is assumed.
- The operators are not introduced as primitive observables, but arise from transport structure.

These constraints ensure that the present development remains within the deterministic transport framework established in the Q-series and QB1.

6.7 Transition to Interpretation

The generator-based representation of observables provides the structural foundation for a more complete interpretation of physical quantities.

The relation between these structures and measurement, statistical interpretation, and observable outcomes will be addressed in the subsequent paper (QB3).

7 Interpretive Clarifications and Exclusions

7.1 No Operator Postulates

The operators introduced in this paper are not postulated as fundamental objects. They arise as representations of infinitesimal transport generators acting on the complex state.

Accordingly, the operator structure is derived from the transport closure system and is not assumed independently.

7.2 No Measurement Interpretation

The present work does not assign measurement meaning to the operators or to their action on the state. The relation between the state representation and observed outcomes is not addressed here and is deferred to subsequent work.

7.3 No Probabilistic Interpretation

The quantity $|\Psi|^2$ continues to represent closure density and is not interpreted as a probability density. Integral expressions involving the state and generator actions are treated as structural quantities of the transport system, not as expectation values.

7.4 Scope of the Present Results

The results of this paper establish the emergence of operator structure from the transport closure framework. They do not constitute a complete formulation of quantum mechanics, but provide the operator-level bridge required for such a formulation.

7.5 Role within the QB-Series

Within the QB-series, the present paper completes the derivation of the state and operator structure. The remaining step is to relate these structures to observable outcomes and statistical interpretation, which will be addressed in QB3.

8 Conclusion

8.1 Summary of Results

We have shown that the operator structure associated with quantum mechanics arises naturally from the transport closure system when expressed in the complex state representation.

Specifically:

- Transport generators were defined as infinitesimal spacetime displacements acting on the state.
- These generators were shown to admit differential representations determined by the local structure of the state.
- The spatial and temporal generators were identified as

$$\hat{p} = -i\Phi_0\nabla, \qquad \hat{E} = i\Phi_0\partial_t.$$

- The algebraic relation between position and spatial transport was derived as a representation identity, yielding

$$[X^j, \hat{p}_k] = i\Phi_0\delta^j{}_k.$$

- Observable structure was identified with the action of transport generators on the state.

These results were obtained without introducing operator postulates, probabilistic interpretation, or measurement assumptions.

8.2 Programmatic Significance

The emergence of operator structure from transport closure provides a direct bridge between the geometric framework of the Q-series and the formal structure of quantum mechanics.

The operators are understood as representations of transport generators rather than as primitive objects, and their algebra arises from the representation of the state as a spacetime function.

8.3 Next Steps

The present work establishes the structural foundation for observable quantities but does not address their interpretation in terms of measurement or probability.

The next paper in the QB-series (QB3) will develop the relation between the state representation, operator structure, and observable outcomes, including the emergence of statistical interpretation from the underlying transport framework.

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