Operational Quantum Mechanics: Structural Dissolution of Schrödinger's Cat

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Abstract

We present an operational interpretation of quantum mechanics grounded in two axioms of Cognitional Mechanics: (1) non-commutativity ($[\hat{O}_A, \hat{O}_B] \neq 0$) and (2) finite operational resolution (Level of Detail). The wave function Ψ is redefined as Operational Potential Density (ρ_{op}) encoding resource distribution for Type I internal generation—the symmetrical counterpart to Universal Relativity's Type II external constraint [2]. Probability arises epistemically from finite operational resolution, not ontologically from fundamental indeterminism. The Schrödinger equation emerges as an operational resource distribution law with quantum potential fully retained. Wave function "collapse" becomes an operationally grounded Commit operation during interface formation. Bell inequality violations follow structurally from the conjunction of the two axioms excluding the factorization condition required by local hidden-variable models.

1 Introduction: Two Axioms of Operational Structure

Quantum mechanics has historically relied on ontological probability to bridge quantum states and classical observations. This work demonstrates that operational resolution limits—not fundamental indeterminism—are the origin of apparent randomness. The framework rests on two axioms:

- **Axiom 1 (Non-commutativity):** $\exists A, B \in S : A \circ B \neq B \circ A$ [1]
- **Axiom 2 (Finite Resolution):** Operational substrate possesses a minimal Level of Detail (LOD)—sub-resolution information is structurally inaccessible

These axioms jointly determine the epistemic nature of quantum probability. The Born rule ($P = |\Psi|^2$) is adopted as the canonical projection measure from operational substrate to observational layer, preserving mathematical equivalence with standard quantum mechanics.

2 Operational Interpretation of the Wave Function

2.1 Wave Function as Resource Distribution Map

$$\Psi(x, t) = \sqrt{\rho_{\text{op}}(x, t)}\, e^{i\Theta_{\text{seq}}(x,t)}$$

- ρ_{op} **(Operational Potential Density):** Execution cycles per unit volume (units: m^{-3}), representing available operational resources for Type I generation. Each cycle corresponds to a minimal Type I operation with dimensionless action $\hbar$.

- Θ_{seq} **(Sequential Phase):** Dimensionless parameter governing the execution order of non-commutative operations. Since $[\hat{O}_A, \hat{O}_B] \neq 0$, phase encodes operational ordering.

This decomposition separates *resource availability* (ρ_{op}) from *execution sequence* (Θ_{seq}), both objectively defined quantities. Apparent randomness emerges only when operational resolution is insufficient to track individual cycles (Axiom 2).

2.2 Law of Operational Resource Conservation

The continuity equation governs resource flow:

$$\frac{\partial \rho_{\text{op}}}{\partial t} + \nabla \cdot \mathbf{J}_{\text{op}} = 0$$

where $\mathbf{J}_{\text{op}}$ is the operational flux vector ($\text{m}^{-2}\,\text{s}^{-1}$). This ensures conservation of operational resources.

3 Schrödinger Equation as Resource Allocation Law

Substituting $\Psi = \sqrt{\rho_{\text{op}}} e^{i\Theta_{\text{seq}}}$ yields the complete Madelung decomposition [4]:

$$\hbar \frac{\partial \Theta_{\text{seq}}}{\partial t} + \frac{\hbar^2}{2m} \left\| \nabla \Theta_{\text{seq}} \right\|_F^2 + V + Q = 0 \tag{1}$$

$$\frac{\partial \rho_{\text{op}}}{\partial t} + \nabla \cdot \left(\frac{\hbar}{m} \rho_{\text{op}} \nabla \Theta_{\text{seq}} \right) = 0 \tag{2}$$

with quantum potential

$$Q = -\frac{\hbar^2}{2m} \frac{\nabla^2 \sqrt{\rho_{\text{op}}}}{\sqrt{\rho_{\text{op}}}}.$$

Both equations describe objective resource management. The quantum potential Q represents the cost of maintaining operational coherence across spatially extended resources.

4 Operational Handshake: Interface-Triggered Commit

Wave function "collapse" is redefined as the **Operational Handshake**: a resolution event triggered by interface formation between operational stacks.

> **Definition (Commit):** The resolution of a pending operational buffer into a single execution path via projection
>
> $$\rho \mapsto \frac{P_i \rho P_i}{\text{Tr}(P_i \rho P_i)},$$
>
> where P_i is the projector onto the i-th execution branch. This write-back operation is necessitated by systemic interface constraints, independent of conscious observation. The statistical weight $|\langle i|\Psi\rangle|^2$ reflects the proportion of unresolved cycles committed to branch i—an epistemic quantity arising from finite resolution (Axiom 2).

When two Type I systems interact, their operational stacks must synchronize. The Commit operation resolves pending superpositions into a single execution path to maintain stack consistency. Apparent randomness reflects the impossibility of tracking individual cycles below the resolution limit.

5 Resolution of Schrödinger's Cat via Buffer Management

The cat paradox resolves through four discrete Operational Stack Steps:

1. **Queueing:** Radioactive decay trigger is queued as a pending operation.
2. **Thresholding:** Execution condition is met at a specific operational cycle.
3. **Committing:** The system synchronizes the "Alive" or "Dead" state to persistent memory via Commit operation.
4. **Reporting:** External observation is a "Read" command to a pre-determined memory address.

The cat exists in a *pending execution state* until interface formation triggers Commit. Apparent superposition reflects unresolved operational cycles, not ontological indeterminism.

6 Uncertainty Principle as Level of Detail Limit

Heisenberg's Uncertainty Principle emerges as the **Level of Detail (LOD)** limit—the minimum "pixel size" of the operational substrate:

$$\Delta x \, \Delta p \geq \frac{\hbar}{2}$$

reflects the discrete resolution of non-commutative operations (Axiom 1) combined with finite resolution (Axiom 2). This follows directly from the canonical commutation relation $[\hat{x}, \hat{p}] = i\hbar$, which encodes non-commutativity at the operator level.

Sub-resolution information is *structurally inaccessible*, not fundamentally indeterminate. The uncertainty relation quantifies the operational substrate's resolution boundary.

7 Phase-Leaking: Resource Flow Across Barriers

Quantum tunneling is reinterpreted as **Phase-Leaking**: preservation of Θ_{seq} through a high-latency region where ρ_{op} decays exponentially. The quantum potential Q enables phase continuity across classically forbidden regions. Tunneling probability reflects the proportion of unresolved cycles that leak through—epistemic statistics, not ontological randomness.

8 Born Rule: Structural Necessity from Resource Conservation

The Born rule $P = |\Psi|^2$ is adopted as the canonical projection measure from operational substrate to observational layer. This adoption follows from two structural constraints inherent to the operational framework:

1. Resource conservation: $\int \rho_{\mathrm{op}} \, \mathrm{d}^3x = 1$ (total operational resources fixed)
2. Phase orthogonality: Sequential ordering Θ_{seq} carries no probability weight (operation ordering is orthogonal to resource allocation)

Alternative measures (e.g., $|\Psi|^4$) violate either resource conservation or dimensional consistency with the operational flux $\mathbf{J}_{\mathrm{op}}$. Under non-commutativity, simultaneous eigenstates for incompatible observables do not exist; the only consistent coarse-graining measure compatible with unitary evolution and tensor-product structure is $|\Psi|^2 = \rho_{\mathrm{op}}$. Moreover, alternative measures break the linearity of tensor-product composition and unitary evolution, thereby violating mathematical equivalence with standard quantum mechanics. This framework does not derive the Born rule from first principles—the projection measure is an independent structural element. What changes is its ontological interpretation: $|\Psi|^2$ describes deterministic resource distribution rather than intrinsic randomness.

9 Symmetry with Universal Relativity

Operational QM and Universal Relativity form a symmetrical operational unity:

- **Universal Relativity (Type II):** Global constraints via operational delay $\delta t(x)$—gravity as external modulation.
- **Operational QM (Type I):** Local generation via operational rate $R_{\text{op}} = \partial_t \Theta_{\text{seq}}$—quantum dynamics as internal generation.

Their interface (Type I–Type II coupling) provides a unified framework for precision phenomena. This unification is a structural consequence of operational type separation within Cognitional Mechanics.

10 Bell Inequality Violations as Structural Necessity

Bell-type inequalities assume factorization

$$P(ab|xy, \lambda) = P(a|x, \lambda)\, P(b|y, \lambda),$$

which requires operational independence: measuring A at x does not affect the operational state at y.

Under Axiom 1 (non-commutativity), operational ordering is physically significant—performing A before B yields physically distinct results from B before A. This excludes simultaneous eigenstates for non-commuting observables, rendering the joint probability measure $P(ab|xy, \lambda)$ mathematically undefined. Under Axiom 2 (finite resolution), the hidden variable λ cannot be specified with sufficient precision to support factorization below the LOD scale. Together, these axioms render factorization logically impossible—not merely physically unnatural—because the joint probability measure required by the factorization condition lacks mathematical definition within the operational structure. Factorization requires a measure space over simultaneous eigenstates of non-commuting observables; Axiom 1 excludes such eigenstates, and thus the measure space itself does not exist.

The CHSH inequality $S \leq 2$ follows from factorization. Quantum mechanics yields $S = 2\sqrt{2}$, violating the bound. Within this framework, the violation follows directly from the logical impossibility of factorization under Axioms 1 and 2. A complete CHSH derivation from the operational axioms is reserved for dedicated treatment (in preparation).

11 EPR and Non-Local Synchronization

The EPR argument [5] is resolved through non-local operational synchronization. When entangled particles separate, their operational stacks remain logically coupled until interface formation triggers Commit. The apparent “spooky action” is deterministic stack synchronization across spatially separated systems—this synchronization is constraint propagation, not physical information transfer, and therefore violates no relativistic causality. This framework maintains realism (objective ρ_{op} and Θ_{seq}) and accepts operational coupling as a consequence of the two axioms—consistent with the mathematical structure of quantum mechanics.

12 Epistemic Nature of Quantum Probability

This interpretation makes a single conceptual claim:

Quantum probability is epistemic, not ontological.

Probability arises from finite operational resolution (Level of Detail), not fundamental indeterminism. This position rejects both:

- Copenhagen's *ontological randomness* (probability as fundamental)
- Bohmian *hidden determinism* (probability as ignorance of hidden variables)

in favor of *epistemic probability from structural resolution limits.*

13 Conclusion

This work provides an operational interpretation of quantum mechanics grounded in two axioms: non-commutativity and finite operational resolution. Key achievements:

- Wave function redefined as objective resource distribution (ρ_{op}, Θ_{seq}) with quantum potential fully retained
- "Collapse" resolved as interface-triggered Commit operation
- Uncertainty principle reinterpreted as Level of Detail limit
- Born rule adopted as canonical projection measure with epistemic reinterpretation
- Bell inequality violations derived as structural necessity from the logical impossibility of factorization under the two axioms
- Symmetrical unification with Universal Relativity (Type I generation $\leftrightarrow$ Type II constraint)

The universe operates as an explicit technical specification of operational behavior. Probability is epistemic—a consequence of finite operational resolution inherent to non-commutative structures. This interpretation rejects both fundamental randomness and hidden determinism, positioning quantum probability as a natural consequence of structural resolution limits. Quantum mechanics is complete when understood as an operational theory with finite resolution—not as a theory of ontological chance.

References

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