A Minimal Collapse-Selection Model for Two-Path Interference

Stephen Garner

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Abstract

Collapse-based approaches to quantum foundations require application to standard physical scenarios in order to assess their viability. In this note, we construct a minimal two-path interference model based on a collapse-selection operator acting on relational phase configurations. The model reproduces the transition between coherent interference and incoherent outcomes without taking linear superposition as a primitive assumption. Instead, interference emerges as a property of configurations that remain stable under collapse. This provides a concrete example of how collapse-driven selection can reproduce a canonical quantum phenomenon in a minimal setting.

1 Introduction

Collapse-based frameworks must demonstrate applicability to standard quantum systems in order to be physically meaningful. Two-path interference provides a canonical benchmark, capturing the essential distinction between coherent superposition and incoherent mixtures.

The aim of this note is to construct the simplest possible collapse-based model that reproduces:

- interference patterns in a coherent regime,
- suppression of interference in an incoherent regime.

The approach taken here treats collapse as a selection process acting on relational phase configurations prior to coarse-graining. Observable structure is then interpreted as arising from configurations that remain stable under this selection.

2 Standard Benchmark: Two-Path Interference

In the standard formulation, the intensity at a point x is given by:

$$I(x) \propto |\psi_1(x) + \psi_2(x)|^2 \tag{1}$$

Expanding:

$$I(x) \propto |\psi_1(x)|^2 + |\psi_2(x)|^2 + 2\,\mathrm{Re}\left[\psi_1^*(x)\psi_2(x)\right] \tag{2}$$

The interference pattern arises from the cross term. Suppression of interference corresponds to the disappearance of this term, yielding:

$$I(x) \propto |\psi_1(x)|^2 + |\psi_2(x)|^2 \tag{3}$$

3 Minimal Collapse-Selection Construction

3.1 State Space

We define a minimal relational phase system:

$$\Sigma = \{(\theta_1, \theta_2)\}, \quad \theta_i \in S^1 \tag{4}$$

This represents two coupled phase degrees of freedom corresponding to two paths. Phase relations are treated as primary.

3.2 Collapse Operator

We define a collapse-selection operator $\Phi : \Sigma \to \Sigma$:

$$\Phi(\theta)_i = \arg\left(\sum_{j\sim i} e^{i\theta_j}\right) \tag{5}$$

For the two-path system:

$$\Phi(\theta_1, \theta_2) = (\bar{\theta}, \bar{\theta}), \quad \bar{\theta} = \arg(e^{i\theta_1} + e^{i\theta_2}) \tag{6}$$

This operator maps configurations toward phase-aligned fixed points, projecting onto coherence-stable sectors. Repeated application of Φ converges to a fixed point configuration. In this sense, the collapse operator maps configurations to a phase-aligned fixed point, making it effectively a projection onto a collapse-stable sector.

3.3 Observable Projection

We define the observable intensity as a function of relative phase:

$$I(x) \propto 1 + \cos(\Delta\theta(x)) \tag{7}$$

where:

$$\Delta\theta = \theta_1 - \theta_2 \tag{8}$$

4 Behavior Under Collapse

4.1 Coherent Regime

If:

$$\theta_1 \approx \theta_2 \tag{9}$$

then:

$$\Phi(\theta_1, \theta_2) \approx (\theta_1, \theta_2) \tag{10}$$

The relative phase is preserved, and the interference pattern remains stable.

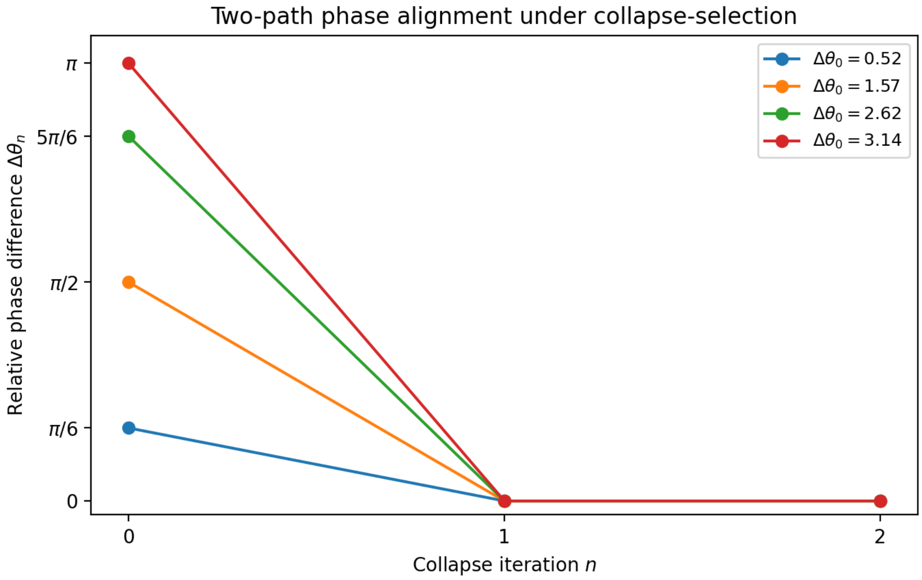

Figure 1: Relative phase difference under the minimal two-node collapse-selection map. For a range of initial phase separations $\Delta\theta_0$, one application of the collapse operator maps each configuration to a phase-aligned fixed point, sending $\Delta\theta_n \to 0$. In this minimal model, interference-preserving and interference-suppressing behavior are recovered as different initial relational configurations subjected to the same collapse rule.

4.2 Incoherent Regime

If:

$$|\theta_1 - \theta_2| \sim \pi \tag{11}$$

then:

$$(\theta_1, \theta_2) \xrightarrow{\Phi} (\bar{\theta}, \bar{\theta}) \tag{12}$$

The relative phase collapses:

$$\Delta\theta \to 0 \tag{13}$$

yielding:

$$I(x) \to \text{constant} \tag{14}$$

That is, the collapse operator maps the configuration to a phase-aligned fixed point. corresponding to loss of interference.

5 Interpretation

In this construction, interference is not treated as a primitive consequence of linear superposition. In the present construction, the observable intensity reproduces the standard interference form, but is interpreted as arising from collapse-stable phase configurations rather than linear superposition alone. Instead:

- Interference corresponds to configurations that remain stable under collapse.
- Suppression arises from collapse-driven reconfiguration of phase relations.

Collapse acts as a selection operator on relational configurations, with observable structure emerging from the configurations that survive this process.

6 Relation to Prior Results

This model is consistent with previously studied collapse dynamics in lattice systems, where:

- local phase variance decreases under iteration,
- global invariant structures are preserved.

The present construction represents a minimal two-node realization of these dynamics.

7 Limitations and Next Steps

This model is intentionally minimal. It does not yet provide:

- a full derivation of quantum mechanics,
- a treatment of scattering processes,
- a complete measurement theory.

Future work will extend this framework to:

- multi-path interference,
- repeated measurement scenarios,
- simple scattering analogues.

8 Conclusion

We have presented a minimal collapse-selection model that reproduces the transition between coherent interference and incoherent outcomes in a two-path system. This demonstrates that collapse-based dynamics can account for a canonical quantum phenomenon in a simple setting, providing a concrete step toward grounding collapse-based frameworks in standard physical scenarios.

References

[1] D. J. Griffiths, *Introduction to Quantum Mechanics.*