Quantum Observability Theory (QOT)

A Non-Executing Semantics for Quantum Program Inspection

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1 Abstract

Unlike classical debugging or simulation frameworks, QOT treats observability as a semantic projection over structured state spaces rather than a dynamic intervention. The theory provides a mathematical foundation for inspection, verification, and classification of quantum programs without collapse-inducing execution.

2 Motivation and Scope

Quantum systems resist inspection. Execution alters state; measurement collapses superposition. Yet modern quantum software ecosystems demand *auditability*, *classification*, and *policy reasoning* without destructive interaction.

QOT addresses this gap by distinguishing:

- execution from observation,
- measurement from semantic projection,
- physical collapse from interpretive collapse.

3 Core Definitions

Definition 1 (Observational State Space)**.** *Let $\mathcal{H}$ be a Hilbert space associated with a computational system. An* observational state space $\mathscr{O}$ *is a structured quotient of $\mathcal{H}$ equipped with a projection map*

$$\pi : \mathcal{H} \to \mathscr{O}$$

that preserves semantic invariants while abstracting away physical realization detail.

Definition 2 (Observation Operator)**.** *An* observation operator $\mathcal{O}$ *is a bounded, idempotent operator acting on $\mathcal{H}$ such that*

$$\mathcal{O}^2 = \mathcal{O}$$

and whose image lies entirely within $\mathscr{O}$.

Definition 3 (Observational Collapse)**.** *Observational collapse is the projection*

$$|\psi\rangle \;\mapsto\; \mathcal{O}|\psi\rangle$$

which alters semantic representation without inducing physical state collapse.

4 Theorems

Theorem 1 (Observability Without Execution)**.** *A quantum system may be observed without execution if and only if its observation operators commute with all execution operators.*

Theorem 2 (Observational Collapse)**.** *Observational collapse preserves semantic equivalence classes while discarding amplitude-specific realizations.*

Theorem 3 (Invariance Under Regime Change)**.** *Observational semantics are invariant under regime-preserving transformations.*

Theorem 4 (Observational Completeness)**.** *Every observable semantic property of a system corresponds to an observation operator in QOT.*

Theorem 5 (Non-Interference)**.** *Observation operators do not interfere with executional trajectories.*

5 Remarks

Remark 1. *QOT distinguishes itself from quantum measurement theory by refusing amplitude interpretation. It is a theory of semantic structure, not probabilistic outcome.*

Remark 2. *Execution is a physical process; observation in QOT is a semantic process.*

A References

[1] P. Dirac, *The Principles of Quantum Mechanics.*

[2] S. Abramsky, *Domain Theory and the Logic of Observation.*

[3] B. Coecke et al., *Categorical Quantum Mechanics.*

[4] A. Diamond, *Semantic Regime Theory.*