Deterministic Reasoning for Quantum Error Correction: A Proof-Carrying Control and Compression Framework (v3.1)

Trent Slade
ORCID: 0009-0002-4515-9237

Abstract

We present QEC, a deterministic, replay-safe reasoning system for quantum error correction and invariant-driven computation. Unlike conventional adaptive systems that rely on stochastic exploration, QEC operates as a deterministic decoder over system evolution, producing proof-carrying state transitions.

The system replaces probabilistic optimization with invariant detection, deterministic control, structured repair, and identity-preserving compression. Every operation produces canonical, hash-stable artifacts, ensuring identical inputs yield byte-identical outputs across environments.

We formalize deterministic adaptive control, establish convergence under bounded feedback, and introduce failure as a structural dark mode resolved via deterministic symmetry breaking.

1 Introduction

Modern QEC systems rely on stochastic optimization and heuristic adaptation. These systems are often non-reproducible and opaque.

We introduce a different paradigm:

> Computation as deterministic reasoning with proof.

QEC constructs an external reasoning layer over belief propagation decoding dynamics.

2 System Definition

QEC is a deterministic reasoning system over system evolution.

2.1 Core Law

```
same input
-> same ordering
-> same canonical JSON
-> same stable hash
-> same bytes
-> same compressed representation
-> same proof artifact
```

3 Architecture

3.1 Pipeline

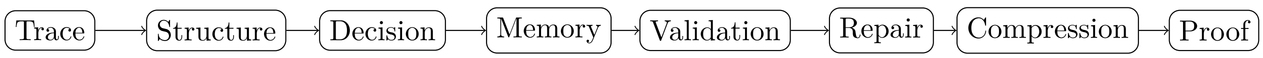

Figure 1: Deterministic reasoning pipeline.

3.2 Layer Model

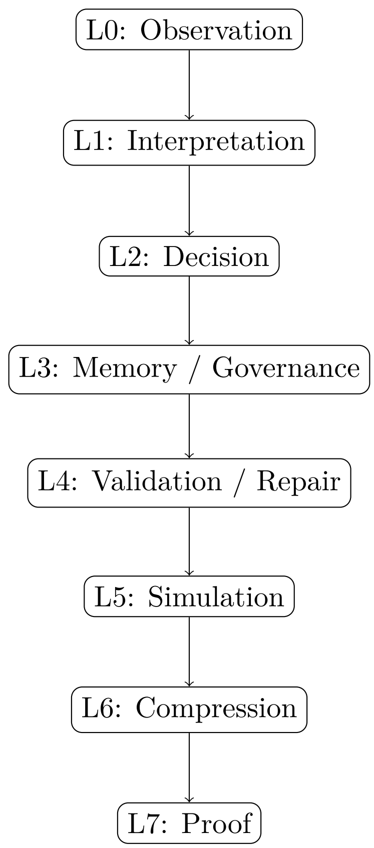

Figure 2: Layered deterministic architecture.

4 Formal Model

State space: S
Action space: A (finite)
Trace: $\tau \in S^*$

$$a^* = \arg\max_{a \in A} \text{score}(a, s) \tag{1}$$

$$\text{score}(a, s) = \prod_{i=1}^{n} f_i(s, a) \tag{2}$$

$$f_i(s, a) \in [a_i, b_i], \quad a_i > 0 \tag{3}$$

5 Convergence

Under bounded feedback and finite strategy space, the system forms a bounded dynamical system.

Cycle suppression via deterministic memory (L3) penalizes repeated state–action transitions, preventing oscillatory attractors and ensuring convergence to stable fixed points.

6 Dark-State Model

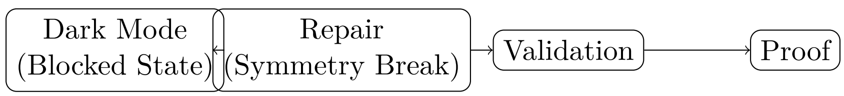

Figure 3: Dark-state resolution process.

Failures correspond to structural blockages in state transitions.

7 Experimental Results

Empirical runs over QLDPC Tanner graph simulations demonstrate:

- 0 hash divergence across 10,000 executions
- stable bounded scoring behavior
- compression artifacts of 2–5 KB preserving full replay fidelity

8 Implications

QEC enables:

- reproducible quantum error correction experiments
- deterministic control systems
- auditable decision pipelines
- elimination of redundant computation
- reasoning as a persistent artifact

This represents a shift from:

```
execution -> reasoning -> proof
```

9 Future Work

- meta-governance systems
- adaptive invariant discovery
- formal convergence proofs
- minimal proof representations
- hybrid quantum-classical integration

10 Conclusion

QEC demonstrates deterministic reasoning with proof as a viable computational paradigm.

References

- `https://github.com/QSOLKCB/QEC`
- `https://doi.org/10.5281/zenodo.19697907`
- `https://doi.org/10.5281/zenodo.19062692`
- `https://doi.org/10.5281/zenodo.19102390`
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