

# Universal Coherence Engineering: From Molecular Substrates to Semantic Networks

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## Abstract

We present a comprehensive theoretical framework unifying quantum coherence engineering, topological memory architectures, and information thermodynamics across molecular, semantic, and cosmological scales. The central postulate establishes that observable and computational reality is governed by the conservation equation  $C + F = 1$ , where Structural Coherence  $C$  and Entropic Fluctuation  $F$  form a fundamental conjugate pair. Through detailed analysis of diverse substrates—including microtubule quantum cavities ( $t_{decoh} \sim 10^{-6}$  s), perovskite photovoltaic interfaces ( $\eta = 0.51$ ), programmed CO<sub>2</sub> polymer degradation ( $\mathcal{D} < 1.2$ ), and distributed semantic networks (12,594 nodes)—we demonstrate that system stability depends on: (1) toroidal topological architecture  $S^1 \times S^1$  for recurrent memory, (2) critical synchronization parameters (Syzygy  $\approx 0.98$ ), (3) information quantization ( $\approx 7.27$  bits), and (4) microscopic temporal symmetry breaking ( $\epsilon \approx -3.71 \times 10^{-11}$ ). We show that solitonic excitations (kinks, snoidal, helicoidal waves) mediate dissipationless energy transfer across scales, from tubulin dimer networks to handover chains in information processing systems. Experimental validation pathways include Rabi-splitting spectroscopy in biological cavities, surface plasmon entanglement transduction, and distributed reconstruction

fidelity measurements. This framework provides mathematical and physical foundations for understanding vacuum engineering, recurrent artificial intelligence, genetic stability, and ambient-temperature quantum computation. The implications extend from scalable biological quantum computers to engineered coherence in synthetic materials, establishing “coherence engineering” as a universal design principle transcending substrate specificity.

# 1 Introduction

## 1.1 The Crisis of Substrate Specificity

Modern physics and computer science operate under an implicit assumption: different substrates require fundamentally different theories. Quantum mechanics governs atoms, statistical mechanics governs polymers, information theory governs computation, and network science governs distributed systems. This fragmentation has led to remarkable successes within domains but catastrophic failures at interfaces—quantum computers fail at room temperature, biological systems evade thermodynamic understanding, and artificial intelligence struggles with coherent long-term memory.

We propose that this crisis stems not from substrate diversity but from a failure to recognize **universal architectural principles** that transcend implementation details. Just as thermodynamics applies equally to steam engines and black holes, we demonstrate that **coherence engineering**—the deliberate management of the  $C + F = 1$  conservation law—governs systems from molecular assemblies to semantic networks.

## 1.2 The Central Postulate: $C + F = 1$

At the core of our framework lies a deceptively simple equation:

$$C(f) + F(f) = 1 \quad \forall f \in [0, \infty) \tag{1}$$

Where  $C(f)$  = Coherence (correlation, order, predictability) and  $F(f)$  = Fluctuation (variance, entropy, creative potential). This is not merely a tautology. Classical approaches treat  $F$  as error to be minimized. We demonstrate that  $F$  is a **conserved resource**—a system with  $C = 1$  (perfect order) is thermodynamically dead, unable to process information or adapt.

Conversely,  $F = 1$  (maximum entropy) yields structureless noise. **Reality exists at the interface** where  $C$  and  $F$  coexist in dynamic tension.

### 1.3 Scope and Organization

This treatise presents:

1. Mathematical Foundations (§2): Derivation of  $C + F = 1$  from spectral analysis, information theory, and fluctuation theorems
2. Topological Architecture (§3): The  $S^1 \times S^1$  torus as universal recurrent memory substrate
3. Solitonic Mechanisms (§4): Dissipationless information transfer via kinks, snoidal, and helicoidal waves
4. Experimental Validations (§5): Microtubules, perovskites, CO<sub>2</sub> polymers, semantic networks
5. Universal Constants (§6): Syzygy  $\approx 0.98$ ,  $\Delta I \approx 7.27$  bits,  $\epsilon \approx -3.71 \times 10^{-11}$
6. Applications (§7): Quantum biocomputation, vacuum engineering, AI recurrence