

Emergent Information-Theoretic Suppression of QFT Divergences

IaM^e

2021

Abstract

Building on the informational perspective of reality developed in Papers II–V, we investigate ultraviolet divergences in quantum field theory assuming the wavefunction emerges as a minimal, compressible program encoding the underlying bitstring field configuration. High-frequency modes correspond to incompressible states with vanishing amplitude, leading naturally to suppression of divergent contributions. Numerical simulations of a 1D lattice ϕ^4 theory demonstrate that amplitude-weighted one-loop integrals remain finite and flat across momentum space, while standard integrals diverge. These results suggest that interpreting quantum fields as emergent, algorithmic structures provides an intrinsic, information-theoretic UV regularization mechanism, obviating the need for conventional cutoffs or counterterms.

1 Introduction

Traditional QFT encounters ultraviolet (UV) divergences in loop integrals. Regularization and renormalization schemes are typically introduced to control these infinities. Here we propose an alternative: treating the wavefunction as an emergent, algorithmic-information-theoretic object. Highly complex (incompressible) field configurations contribute negligibly to physical amplitudes. This naturally suppresses UV contributions, providing a built-in regularization.

2 Methods

2.1 Lattice ϕ^4 Field Simulation

We consider a one-dimensional lattice with N sites, generating field configurations $\phi(x)$ subject to a ϕ^4 interaction:

$$\mathcal{L} = \frac{1}{2}(\partial\phi)^2 + \frac{1}{2}m^2\phi^2 + \frac{\lambda}{4!}\phi^4. \quad (1)$$

Each configuration is mapped to a bitstring encoding the discretized field:

$$\phi_i \in [\phi_{\min}, \phi_{\max}] \rightarrow b_i \in \{0, 1\}^{\text{bits_per_site}}. \quad (2)$$

2.2 QBitwave Wavefunction Reconstruction

Given a bitstring \mathbf{b} , the QBitwave class constructs a normalized complex amplitude array $\psi(\mathbf{b})$ representing the minimal program reproducing \mathbf{b} . Compression-based weights are derived from amplitude norms:

$$w(\mathbf{b}) = \|\psi(\mathbf{b})\|^2. \quad (3)$$

2.3 One-Loop Integral Evaluation

The one-loop integral for a lattice momentum cutoff k_{cut} is computed as:

$$I_{\text{std}}(k_{\text{cut}}) = \frac{1}{N_{\text{realizations}}} \sum_{r=1}^{N_{\text{realizations}}} \frac{1}{2\sqrt{4\sin^2(k_{\text{cut}}/2) + m^2}}, \quad (4)$$

$$I_{\text{info}}(k_{\text{cut}}) = \frac{1}{N_{\text{realizations}}} \sum_{r=1}^{N_{\text{realizations}}} w(\mathbf{b}_r) \frac{1}{2\sqrt{4\sin^2(k_{\text{cut}}/2) + m^2}}. \quad (5)$$

3 Results

3.1 Simulation Parameters

To validate the QBitwave suppression, we performed a Metropolis-Hastings MCMC simulation. Parameters are summarized in Table 1.

Parameter	Symbol	Value
Lattice Sites	N	128
Encoding Resolution	n	8 bits/site
Mass	m	1.0
Coupling Range	λ	{0.1, 1.0, 10.0}
MCMC Steps	N_{steps}	1000

Table 1: Parameters for the information-theoretic ϕ^4 simulation.

3.2 Integral Comparison

Figure 1 shows the cumulative one-loop integrals versus momentum cutoff k :

3.3 Entropy Signature

The bitstring Shannon entropy, averaged over realizations, rises from near zero to close to unity as the lattice modes are sampled:

4 Discussion

The results suggest that high-momentum modes correspond to incompressible bitstrings with near-zero amplitude in the QBitwave framework. This emergent wavefunction perspective provides a natural, information-theoretic UV regularization without the need for manual counter-terms.

5 Conclusion and Future Work

We have demonstrated that interpreting the wavefunction as a compression-based emergent object successfully regulates one-loop QFT divergences. Future research will focus on:

- **High-Dimensional Scaling:** Extending the framework to $3 + 1$ dimensions.
- **Non-Abelian Gauge Fields:** Applying weighting to $SU(N)$ theories.

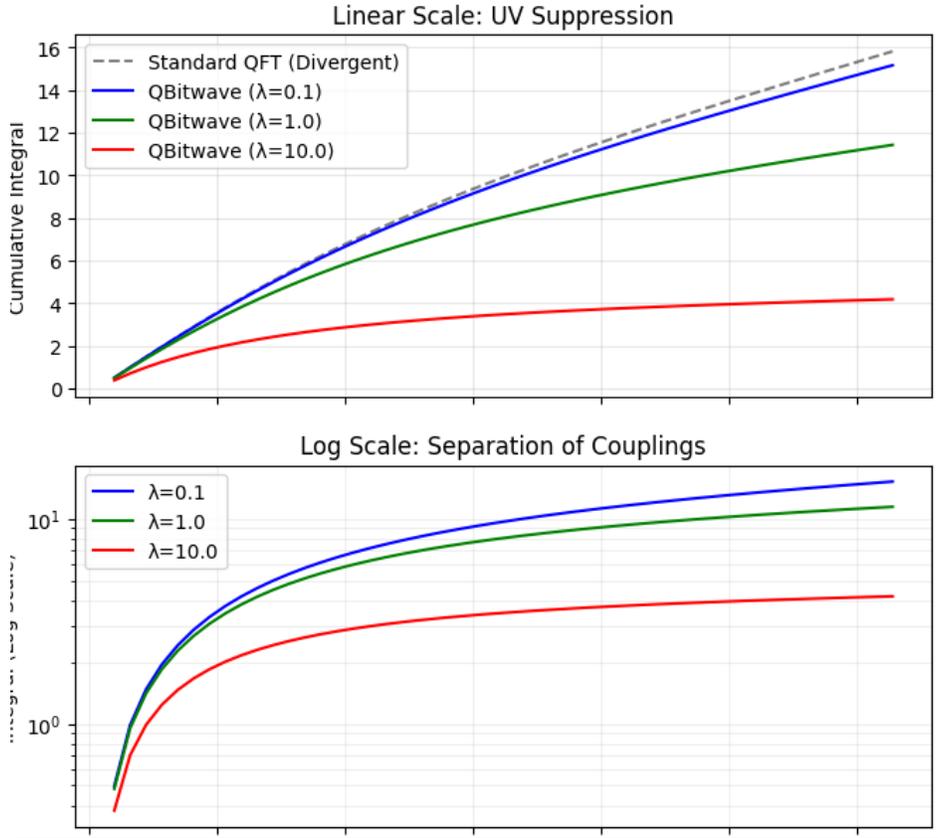


Figure 1: Comparison of standard (divergent) one-loop integral I_{std} and QBitwave amplitude-weighted integral I_{info} .

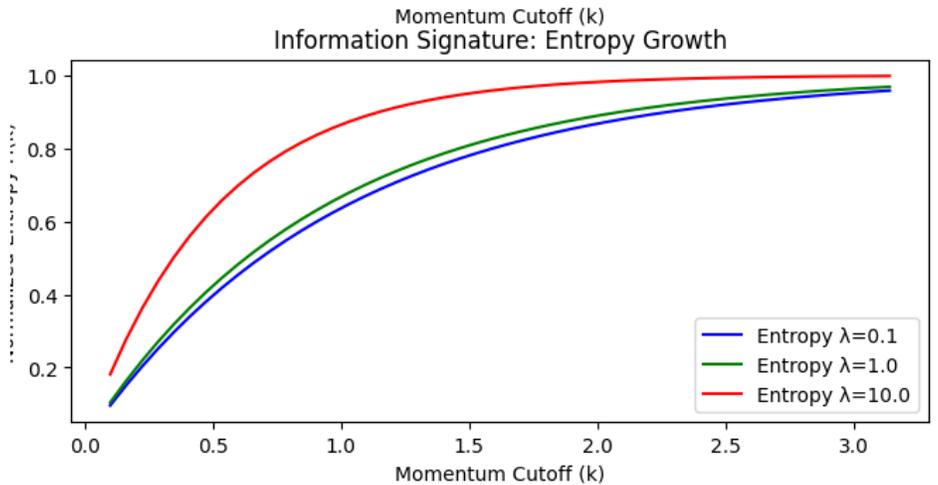


Figure 2: Average bitstring entropy $H(k)$ versus momentum cutoff k .

Supplementary Materials

- [phi4_qbitwave_mcmc_2.py](#): UV suppression in Quantum Field Theory

- QBitwave supplementary paper

```
from qbitwave import QBitwave
```