Cortical Columns as Amplistwistor Cascades: A Multiscale Field-Theoretic Model of Neural Computation

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Abstract

This extended preview presents a unified mathematical and neurobiological framework in which cortical computation emerges from the interplay between local nonlinear transformations and global geometric dynamics. Cortical columns are modeled as *amplistwistors*—a family of nonlinear, multi-component operators acting on RSVP fields $(\Phi, \mathbf{v}, S)$ representing semantic density, inferential flow, and uncertainty, respectively. At the mesoscopic scale, these discrete operations compose into *amplistwistor cascades*, whose effects propagate through a continuous field substrate governed by semigroup evolution and spectral geometry. We argue that this hybrid discrete–continuous system forms a principled mathematical model of cortical computation capable of explaining multi-timescale neural integration, hierarchical processing, and wave-like phenomena observed in ECoG and ultrafast fMRI. The preview integrates field theory, operator algebra, spectral analysis, universal approximation theory, and empirical data into a single coherent narrative.

1 Introduction

Cortical computation takes place within a medium that is simultaneously symbolic, geometric, and dynamical. At local scales, cortical columns perform sharply nonlinear transformations on neural variables; at global scales, activity spreads across the cortical manifold through diffusion-like processes and resonant wave propagation. Traditional models tend to emphasize one of these domains at the expense of the others: symbolic architectures neglect field dynamics; neural field models underplay discrete nonlinearities; deep networks lack spatial geometry. The present framework integrates these perspectives by embedding columnar operations within a continuous field-theoretic substrate.

The mathematical foundation is the Relativistic Scalar Vector Plenum (RSVP), a nonlinear system of coupled PDEs describing the evolution of semantic fields across a spatial manifold. Cortical columns act as *amplistwistors*, nonlinear operators $\mathcal{A}_x$ that locally modify RSVP fields through gain modulation, orthogonal twisting, and normalization. Through temporal unfolding—interpreted biologically as microcircuit recurrence and mathematically as TARTAN recursion—these operators generate deep, compositional transformations analogous to layers in a language model. When combined with the global spectral structure of the cortical surface, amplistwistors give rise to cascades of activity with characteristic spatial and temporal scales.

This preview synthesizes the conceptual and mathematical components needed to understand amplitwistor cascades and outlines how they recover empirical phenomena observed in electrophysiology and neuroimaging.

2 Neuroscientific and Mathematical Background

Cortical columns operate as local computational modules embedded in a highly heterogeneous geometry. ECoG recordings reveal that sensory, associative, and prefrontal regions operate on different temporal windows, forming a hierarchy where deeper semantic computations unfold over progressively longer timescales. Ultrafast fMRI provides complementary evidence for stationary eigenmodes on the cortical manifold, suggesting that global activity patterns can be understood through Laplace–Beltrami eigenfunctions.

The mathematical tools needed to formalize these dynamics include compact manifolds, Sobolev spaces, nonlinear operators, and spectral theory. These frameworks allow RSVP fields to be treated as elements of $L^2(\mathcal{M})$ or $H^1(\mathcal{M})$, with well-posed dynamics governed by semigroup theory. Universal approximation results—generalizations of Stone–Weierstrass to manifolds and graphsprovide the theoretical guarantee that amplitwistors can approximate arbitrary smooth transformations needed for semantic computation.

3 RSVP Fields and Dynamics

The RSVP system describes the coupled evolution of a scalar field Φ, a vector flow $\mathbf{v}$, and an entropy-like field S:

$$\dot{\Phi} = c_1 \Delta \Phi + c_2 \Phi \times \mathbf{v} - c_3 S \Phi + \eta_\Phi,$$

$$\dot{\mathbf{v}} = c_4 \nabla \Phi + c_5 \nabla \times \mathbf{v} - c_6 S \mathbf{v} + \eta_v,$$

$$\dot{S} = c_7 |\nabla \cdot \mathbf{v}| + c_8 \Phi^2 - c_9 S + \eta_S.$$

These equations combine diffusion, nonlinear coupling, and entropy regulation, providing a biologically plausible model of cortical fields supporting inference, integration, and uncertainty reduction. Their abstract evolution form,

$$\dot{\Psi} = L\Psi + N(\Psi),$$

admits classical mild-solution formulations and semigroup analysis. The linear term L generates rapid smoothing; nonlinear terms modulate semantic content.

4 Amplistwistors: Local Nonlinear Operators

An amplitwistor $\mathcal{A}_x$ located at cortical position x acts on local field values through three transformations: amplitude modulation α_x, twisting τ_x (an orthogonal map in the local tangent space), and projection π_x onto a biologically constrained subspace:

$$\Psi \mapsto \mathcal{A}_x(\Psi) = \pi_x\big(\alpha_x(\Psi)\,\tau_x(\Psi)\,\Psi\big).$$

These operators provide the elementary nonlinear events driving cortical computation. Under repeated applicationeither due to network recurrence or TARTAN temporal unfoldingamplistwistors generate deep transformations analogous to layers of a neural network, but grounded in geometric field theory rather than discrete vector spaces.

5 Cascades and Operadic Composition

The sequence of discrete amplitwistor events and continuous RSVP evolution defines an *amplistwistor cascade*. At times $t_0 < t_1 < \cdots < t_n$, the field satisfies

$$\Psi(t_{k+1}) = T(t_{k+1} - t_k)\,\mathcal{A}_{x_k}\big(\Psi(t_k)\big),$$

where $T(t)$ is the RSVP semigroup generated by L. Sequential composition reflects cortical causality, while parallel composition captures the superposition of simultaneous columnar activity. The algebra of these operators forms a subalgebra dense in $C(\mathcal{M})$, giving amplitwistor cascades the same approximation power as deep networks.

6 Spectral Geometry and Resonance

The global organization of cascades is governed by the spectral structure of the cortical manifold. Eigenmodes of the Laplace–Beltrami operator,

$$\Delta_{\mathcal{M}}\psi_n = -\lambda_n\psi_n,$$

form a natural wave basis for cortical activity. These modes decay at rates $e^{-\kappa\lambda_n t}$ and are selectively excited by Gaussian pop operators and amplitwistor actions. Low-frequency modes carry global, slowly varying information; high-frequency modes encode local detail. The spectral composition of a cascade thus determines its spatial reach and temporal integration depth.

This mirrors empirical findings: low-frequency modes dominate association cortex and support long-range semantic integration, whereas high-frequency modes dominate early sensory cortex.

7 TARTAN Recursion and Temporal Deepening

TARTAN provides the recursive temporal engine that unfolds amplitwistor action over time. Each recursion step applies localized transforms with trajectory-aware modulation and multiscale smoothing. Biologically, this corresponds to recurrent microcircuits that refine representations over tens to hundreds of milliseconds. Mathematically, TARTAN recursion implements a nonlinear operator sequence approximating deep semantic transformations while respecting geometric constraints of the cortical sheet.

8 Empirical Alignment

ECoG studies show a laminar and regional gradient in response latency proportional to semantic depth. This aligns with the cascade model: deeper amplitwistor compositions correspond to longer integration times. Ultrafast fMRI reveals standing-wave eigenmodes that provide the global carrier signals needed to coordinate cascades across cortical distances. Together, the data support the central idea that discrete nonlinear columnar events interact with continuous geometric propagation to produce hierarchical neural computation.

9 Conclusion

This extended preview synthesizes local nonlinear operations, global semigroup dynamics, spectral geometry, and recursive unfolding into a single theoretical account of cortical computation. Amplistwistor cascades offer a unifying mathematical structure capable of explaining empirical signatures of hierarchical processing, wave propagation, and semantic depth. The framework is simultaneously a theory of brain function, a platform for numerical simulation, and a blueprint for new AI architectures grounded in field-theoretic computation.