Cortical Columns as Amplitwistor Cascades: A Preview of the Framework

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Abstract

This short preview introduces the central idea of the Amplitwistor Cascades framework: cortical columns behave as localized nonlinear transformations acting on continuous fields defined across the cortical manifold. Each column implements an *amplistwistor*—a structured combination of amplification, twisting, and projection—whose effects propagate through the surrounding neural tissue according to the dynamics of the RSVP semigroup. Discrete events (pops) and continuous field evolution jointly produce cascades of spatiotemporal waves that match empirical signatures of cortical computation. This document summarizes the conceptual structure, mathematical principles, and neural interpretation of this model.

1 Overview

Cortical computation can be interpreted as a hybrid dynamical system in which:

- **Local columns** apply nonlinear transformations to neural activity;
- **Global geometry** imposes spectral and spatial constraints;
- **Punctate events** inject structured perturbations;
- **Continuous evolution** diffuses and transports these perturbations.

Amplistwistor Cascades unify these components. Local transformations (*amplistwistors*) operate pointwise on RSVP fields, while their effects propagate through the cortex via semigroup evolution. Cascades of such events generate traveling waves, modal interactions, and hierarchical temporal processing.

2 Cortical Columns as Local Amplitwistors

Each cortical column is modeled as a local operator

$$\mathcal{A}_x = (\alpha_x, \tau_x, \pi_x),$$

where:

- α_x controls local gain or attenuation,
- τ_x encodes twisting or directional realignment in the tangent space,
- π_x regulates entropy, thresholding, or normalization.

Applied to RSVP fields $(\Phi, \mathbf{v}, S)$, an amplitwistor acts as

$$\mathcal{A}(\Phi, \mathbf{v}, S)(x) = (\alpha_x(\Phi(x)),\ \tau_x(\mathbf{v}(x)),\ \pi_x(S(x)))\,.$$

These operators generalize and formalize the intuitive picture of columns applying non-linear transformations to neural signals.

3 Pop Events and Localized Excitation

SpherePop supplies the discrete part of the architecture: a *pop* is a localized generative event characterized by a kernel $K_p(x)$ and a mode structure determining how it injects energy into RSVP fields.

A pop induces:

$$T_p(f) = f + \delta f_p, \qquad \delta f_p \propto K_p * \mathcal{A}_p.$$

Gaussian kernels approximate the Green's functions of the linearized RSVP operator, ensuring that pops excite the same modal structures observed in empirical cortical wave phenomena.

4 Continuous Evolution Between Events

Between pops, RSVP fields evolve according to a semigroup:

$$\frac{d}{dt}(\Phi, \mathbf{v}, S)(t) = F_{\mathrm{RSVP}}(\Phi, \mathbf{v}, S), \qquad (\Phi, \mathbf{v}, S)(t) = T(t)f_0.$$

This continuous flow integrates local perturbations and transmits them across the cortical manifold.

5 Cascades: Composition of Local and Global Dynamics

A sequence of pop events at times $t_1 < t_2 < \cdots < t_n$ produces:

$$(\Phi, \mathbf{v}, S)(t_n) = T(t_n - t_{n-1}) \circ T_{p_{n-1}} \circ \cdots \circ T(t_1) \circ T_{p_0}(f_0).$$

This defines an *Amplitwistor Cascade*. Its structure mirrors the compositional behavior of neural computation:

- early pops excite high-frequency, rapidly decaying modes,
- later pops recruit wider, slower global modes,
- long cascades build hierarchical processing analogous to deep network layers.

6 Spectral Interpretation

Eigenfunctions of the Laplace–Beltrami operator or the connectome Laplacian provide a natural basis for analyzing cascades. A pop excites coefficients

$$\alpha_n = \langle K_p, \psi_n \rangle,$$

while evolution damps them exponentially:

$$T(t)\psi_n = e^{-\kappa \lambda_n t} \psi_n.$$

This reproduces:

- fast, localized sensory responses (high λ_n),
- slow, distributed association dynamics (low λ_n),
- coherent traveling waves across the cortical surface.

7 Interpretation in Neuroscience

Amplitwistor Cascades provide a principled mechanistic account of:

- traveling cortical waves,
- multiscale temporal processing,

- long-range coherence,
- modal structure in fMRI and MEG signals,
- hierarchical response latencies observed in ECoG studies.

The model captures how discrete local transformations interact with global field geometry to produce the layered, compositional behavior characteristic of biological computation.

8 Conclusion

This preview outlines a unified mathematical framework for understanding cortical computation as a cascade of amplitwistor events propagating on a dynamic field substrate. Full development includes a rigorous operadic semantics, numerical implementation in Lean, and integration with the RSVP formalism. The result is a coherent theory that connects local microcircuit transformations to large-scale wave dynamics and hierarchical cognitive processing.