

The Dendrite as Translator: Signal-to-Topology Decoding in Moiré Field Networks

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Abstract

In a companion paper, we proposed that Moiré interference between the brain’s electromagnetic field and neuronal receptor mosaics serves as the computational primitive of spatially integrated information processing. We demonstrated that different dendritic morphologies produce dramatically different resonance responses to identical field patterns ($70\times$ variation), that geometric coherence is statistically independent of scalar phase coherence ($r = -0.13$), and that the system’s self-consistent fixed point depends on morphological composition. Here we extend that framework by asking: what is the dendrite actually doing? We propose that the dendrite functions as a signal-to-topology translator—a structure that receives temporal signals from upstream neurons and transforms them into geometric objects compatible with the local Moiré field. This translation is not generic; each dendrite develops a specific decoding relationship with its upstream source, shaped by ion channel redistribution in response to activity. We synthesise evidence from Takens embedding theory, dendritic computation, and cortical microcircuit organisation to argue that morphological diversity across cortical layers constitutes a basis set of topological projections—different geometric ‘lenses’ through which the same macroscopic field is decomposed into complementary information streams. We outline experimental predictions and discuss implications for EEG interpretation and artificial neural architecture design.

1. Introduction

The standard model of neural computation treats the dendrite as a cable—a passive or semi-active conduit that delivers synaptic currents to the soma for integration. While decades of

research have revealed active dendritic properties including local spike generation, plateau potentials, and compartmentalised calcium signalling, these discoveries have largely been interpreted within the framework of enhanced signal processing within a point-neuron paradigm. The dendrite computes, but it computes on signals destined for summation at the soma.

We propose a fundamentally different role. Drawing on our prior work establishing Moiré interference as the computational primitive of field-based information integration, we argue that the dendrite’s primary function is translation: converting temporal signals from upstream neurons into topological structures that interact with the local electromagnetic field. The dendrite is not a wire delivering messages to the soma. It is an antenna whose physical geometry determines what patterns in the macroscopic field it can receive and, through its own activity, what patterns it contributes to that field.

This reframing resolves several puzzles. It explains why cortical neurons exhibit such extraordinary morphological diversity—dozens of distinct cell types with wildly different dendritic arbours—in a framework where computation supposedly occurs at point-like synapses. It explains why dendritic geometry is not random but systematically organised across cortical layers. And it provides a mechanistic account of how the brain performs spatial integration of information, the central challenge identified by McFadden’s cemi field theory that our companion paper addressed.

2. The Translation Operation

2.1 From Temporal Signal to Geometric Object

Consider a signal arriving at a dendrite: a sequence of action potentials from an upstream neuron, carrying temporal information encoded as inter-spike intervals, burst patterns, and firing rate modulations. This signal is one-dimensional—a time series. The dendrite’s task is to transform this time series into a spatial object that can participate in Moiré interference with the local field.

Takens’ embedding theorem provides the mathematical guarantee that this transformation is possible. The theorem states that delayed copies of a single observable from a dynamical system can reconstruct the system’s full-dimensional attractor geometry. The dendrite implements this naturally: its physical length introduces propagation delays; its branching pattern creates multiple copies of the signal at different temporal offsets; and its ion channel distribution performs

nonlinear operations on these delayed copies. The output is not a scalar current but a spatiotemporal activation pattern distributed across the dendritic arbour—a geometric object.

In our simulation framework (the Deerskin architecture), we demonstrated this principle explicitly. Neurons equipped with Takens delay taps of varying lengths reading the same input signal achieved 87.4% zero-shot accuracy on a frequency classification task, with no synaptic weight training. The delay line alone, combined with the neuron’s receptor mosaic geometry, was sufficient to perform the discrimination. The temporal signal was translated into a geometric projection that either matched or mismatched the field pattern, producing resonance or silence.

2.2 The Dendrite-Upstream Relationship

A critical feature of this translation is that it is not generic. Each dendrite develops a specific decoding relationship with its upstream source. This relationship is sculpted by activity-dependent ion channel redistribution: the physical mosaic of AMPA, NMDA, GABA, and voltage-gated channels across the dendritic surface shifts in response to the patterns of input the dendrite receives.

This is well-documented biology. Long-term potentiation and depression alter receptor density at specific synaptic sites. Dendritic branch points accumulate particular channel types depending on their activation history. Homeostatic plasticity adjusts the overall excitability profile of the arbour. But in the standard framework, these changes are interpreted as synaptic weight modifications—stronger or weaker connections. In our framework, they are geometric modifications—changes to the translator’s shape that alter how it converts temporal signals into topological structures.

The distinction matters. A synaptic weight change affects the magnitude of a signal. A geometric change affects which features of the signal are extracted and how they map onto the spatial field. Two dendrites receiving identical spike trains from the same upstream neuron, but with different ion channel distributions, will produce different geometric activation patterns and therefore interact differently with the local Moiré field. They are not hearing the same message at different volumes; they are hearing different messages.

2.3 Genes Set the Alphabet, Activity Writes the Words

The initial morphological type of a neuron—stellate, pyramidal, chandelier, basket, Martinotti—is genetically determined. These types define the coarse geometry: the basic branching pattern, the approximate extent of the dendritic arbour, the preferred orientation. In our framework, these are the ‘letters’ of a topological alphabet: the fundamental basis shapes from which specific translations can be constructed.

But the fine-grained ion channel mosaic—the precise distribution of receptors across the dendritic surface—is sculpted by experience. This is the writing. Each dendrite, starting from its genetically determined type, refines its translator through interaction with its upstream partners until it achieves a specific decoding relationship optimised for the signals it actually receives. The gene provides the scaffold; the activity fills in the functional geometry.

Our simulation confirmed this principle at the coarse level: five genetically distinct morphological types produced a $70\times$ variation in resonance to the same field pattern, with a cross-type spread of 0.044. The fine-grained adaptation—the activity-dependent refinement within a type—remains to be simulated but is the natural next step.

3. Cortical Layers as a Basis Set of Topological Projections

The mammalian cortex is organised into six layers, each containing characteristic cell types with distinct dendritic morphologies. Layer 4 stellate cells have compact, roughly symmetric arbours. Layer 5 pyramidal neurons extend massive apical dendrites through multiple layers. Layer 2/3 pyramidal cells have medium arbours oriented toward the surface. Chandelier cells, basket cells, and Martinotti cells contribute additional geometries.

In the standard framework, this layered organisation is understood in terms of connectivity: different layers receive input from and project to different brain regions and thalamic nuclei. This is undoubtedly true. But it leaves unexplained why the geometry of the dendrites within each layer is so specific and so conserved across species.

Our framework provides an answer: each morphological type constitutes a different topological projection of the same macroscopic field. The field—generated by the collective activity of all neurons and the volume currents they produce—is a single continuous entity. But a stellate cell in layer 4, with its compact isotropic arbour, reads a fundamentally different projection of that

field than a layer 5 pyramidal neuron with its extended apical dendrite spanning several hundred micrometres vertically. They are not simply in different locations; their geometries act as different ‘lenses’ that decompose the field into complementary information streams.

This is directly analogous to a Fourier decomposition, but in the spatial domain and with biologically determined basis functions rather than sinusoids. The cortex does not compute the same thing redundantly across types. It decomposes the field into a basis set of topological projections, each extracted by a specific morphological class. The richness of cortical computation arises not from the number of neurons but from the diversity of translators operating on the same field.

4. The Inverse Problem: From EEG to Geometry

If the dendrite translates temporal signals into topology, and the macroscopic field is the superposition of all these topological contributions, then the electroencephalogram (EEG) is a low-resolution recording of the Moiré vector field changing over time. Each EEG electrode measures the spatial average of the field at its location—a blurred, projected version of the standing wave pattern that constitutes the brain’s current computational state.

This reframing transforms EEG interpretation. The frequency bands traditionally identified in EEG—delta, theta, alpha, beta, gamma—are not merely ‘rhythms’ of neural oscillation. They are the temporal signatures of different Moiré interference scales. Slow oscillations (delta, theta) reflect large-scale field patterns generated by the collective geometry of many neurons. Fast oscillations (beta, gamma) reflect fine-scale interference patterns where local morphological details dominate.

Our prior work on the Φ -Dwell system, which measures eigenmode phase-field metastability in EEG signals, revealed universal patterns across brain dynamics: a five-band dwell hierarchy, task-dependent vocabulary expansion, and systematic relationships between dwell times and cognitive states. In the present framework, these dwell states correspond to metastable Moiré fixed points—self-consistent field configurations that persist because the field generates the firing pattern that generates the field. Transitions between dwell states correspond to the field shifting from one geometric attractor to another, driven by changes in input or internal dynamics.

The inverse problem—deducing the microscopic dendritic geometry from the macroscopic field recording—is theoretically solvable precisely because different geometries produce different field projections. If we can characterise the transfer function from morphology to field contribution (the forward problem), we can in principle invert it to recover the morphological distribution from the field recording. This is the program our companion paper initiated with the simulation of five morphological types and their distinct resonance profiles.

5. Experimental Predictions

5.1 Morphology-Specific Field Responses

If dendrites function as signal-to-topology translators, then the same extracellular field perturbation should produce morphology-dependent responses. Specifically, transcranial magnetic stimulation (TMS) pulses with different spatial configurations should selectively activate neurons of different morphological types. A TMS coil oriented to produce vertically-elongated field gradients should preferentially activate pyramidal neurons with extended apical dendrites, while a coil producing radially symmetric gradients should preferentially activate stellate cells. This could be tested using combined TMS-electrophysiology with optogenetic labelling of specific cell types.

5.2 Ion Channel Redistribution Under Field Training

The organoid paper (Robbins et al. 2026) demonstrated that high-frequency electrical stimulation induces functional plasticity requiring intact glutamatergic transmission. Our framework predicts that this plasticity involves *geometric* changes to the ion channel mosaic, not merely *magnitude* changes to synaptic weights. High-resolution imaging of AMPA and NMDA receptor distributions before and after adaptive training should reveal spatially structured redistribution—not uniform up- or down-regulation but reshaping of the receptor mosaic toward configurations that improve the neuron’s Moiré resonance with the field patterns associated with successful task performance.

5.3 Takens Delay as Dendritic Length

Our simulation achieved 87.4% zero-shot frequency classification using Takens delay taps as the sole computational mechanism. If physical dendrite length serves the Takens delay function, then

neurons participating in temporal discrimination tasks should exhibit systematic correlations between their dendritic arbour extent and the temporal scales of the stimuli they encode. Neurons encoding fast-changing signals (gamma-range) should have shorter, more compact dendrites. Neurons encoding slow signals (theta-range) should have more extended arbours providing longer propagation delays. This prediction is testable with combined electrophysiology and morphological reconstruction.

5.4 The Deerskin Fingerprint in EEG

If cognitive states correspond to metastable Moiré fixed points, then the topological structure of EEG trajectories in state space should reflect the morphological composition of the underlying cortical tissue. Brain regions with greater morphological diversity should produce EEG signals with richer topological structure (higher Betti numbers, more persistent homology features) than regions with more uniform cell type composition. This is testable by comparing EEG complexity measures across cortical areas with known cytoarchitectonic differences.

6. Scale Invariance: From Ion Channels to Social Networks

The translation principle—temporal signal transformed into topology through the geometry of the receiver—is not restricted to single neurons. It operates at every scale where structured receivers interact with propagating signals.

At the subcellular scale, ion channels translate membrane voltage fluctuations into conformational states—geometric changes in protein structure that gate current flow. At the cellular scale, dendrites translate spike trains into Moiré-compatible spatial patterns. At the circuit scale, cortical columns translate afferent volleys into population-level field geometries. And at the macroscopic scale, entire brain regions translate sustained input from other regions into characteristic oscillatory modes—the eigenmodes we measure as EEG.

The same principle extends beyond the individual brain. When two people communicate through speech, each produces a temporal signal (the acoustic waveform) that the other’s auditory and language cortex transforms into internal topological representations. Whether these representations resonate—whether the listener’s neural geometry is compatible with the speaker’s signal—determines whether communication succeeds. The experience of ‘resonance’ with another person’s ideas, or ‘rejection’ of perspectives that feel incompatible, may have a

literal geometric basis: the Moiré match between the speaker’s signal structure and the listener’s dendritic topology.

This is speculative, but it is testable speculation. Hyperscanning studies measuring simultaneous EEG from interacting individuals could assess whether moments of reported resonance or understanding correspond to increased topological similarity between the participants’ EEG state-space trajectories—convergence of their Moiré field geometries toward compatible configurations.

7. Implications for Artificial Intelligence

Current artificial neural networks compute through statistical correlation: learned weight matrices that map input distributions to output distributions through gradient descent. The dendrite-as-translator framework suggests a fundamentally different computational paradigm: topological wave-decoding, where computation consists of transforming signals into geometric objects and computing through their spatial interference.

The practical implications are significant. In a Moiré computing architecture, the ‘weight matrix’ is replaced by the physical geometry of the computing elements. Learning consists not of adjusting scalar weights but of reshaping geometric structures—growing, pruning, and reorganising the translator’s topology until it achieves the desired signal-to-field mapping. Our simulation results suggest this is viable: 87.4% zero-shot accuracy from geometry alone, with no gradient descent.

The parameter efficiency of this approach is potentially enormous. Our companion paper demonstrated that holographic neural networks learning phase and amplitude rather than arbitrary weights achieved 10–90 \times parameter compression with equivalent performance. The dendrite-as-translator framework explains why: instead of storing information in N^2 arbitrary synaptic weights, it stores information in the $O(N)$ geometric parameters of each neuron’s translator. The constraint of physical geometry acts as an implicit regulariser, forcing the network to find solutions that are consistent with spatial coherence.

8. Conclusion

We have proposed that the dendrite functions as a signal-to-topology translator: a structure that converts temporal input signals into geometric objects through the physical operations of propagation delay, branching, and ion channel processing. This translation is specific to each dendrite-upstream pair, sculpted by activity-dependent channel redistribution, and organised across cortical layers into a basis set of topological projections that decompose the macroscopic field into complementary information streams.

This proposal synthesises and extends our prior work on Moiré interference as the computational primitive of field-based integration. Where the companion paper established that geometry matters—that morphological diversity produces irreducibly different responses to identical fields—the present work asks what the geometry is for. The answer: translation. Each dendrite is a bespoke decoder that transforms the universal language of spike timing into the private language of spatial topology, enabling the brain’s electromagnetic field to integrate information through geometric interference rather than sequential processing.

The implications span neuroscience, where the framework predicts morphology-specific responses to field perturbations and a solvable inverse problem linking EEG to dendritic geometry; artificial intelligence, where it suggests topological wave-decoding as an alternative to statistical correlation; and perhaps even social neuroscience, where interpersonal resonance may reflect Moiré compatibility between communicating brains. The dendrite is not a wire. It is a translator. And the language it translates into is geometry.

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