Draft 6 of my section of the paper

The Agentic Brain

This section offers a synthesis of established neuroscience literature interwoven with original concepts I first introduced in the summer of 2022 through the Self Aware Networks Theory of Mind (TOC), published on GitHub to establish authorship. Since that time, I've noticed a wave of papers echoing ideas I pioneered—often without citation—raising questions about whether my copyrighted, timestamped work was overlooked due to its unconventional format or publishing platform. Still, I'm confident in the enduring validity of my copyright, secured for a century, and the clear date stamps on all my GitHub content stand as proof of origin.

A Glossary of Key Points has been created and added to the Appendix for the "The Agentic Brain" section at the end. If you see a term you don't recognize flip to the back to check it.

Table of Contents

1. Introduction & Foundational Framework

1.1 Multiscale Intelligence and the Agentic Brain

Intelligence and decision-making extend far beyond the interplay of large-scale neural networks; they emerge from interactions that unfold across multiple scales, beginning at the molecular level—among proteins and receptors—and culminating in the complex dynamics of entire cortical systems. This expanded perspective challenges the traditional assumption that cognition resides solely in higher-order brain structures. Instead, the agentic brain framework posits that each cell functions as an autonomous unit, capable of learning, encoding information, and coordinating with its peers.

Central to this view is the premise that cognitive phenomena, including consciousness, arise from deterministic oscillatory processes rather than from purely irreducible emergent properties. My concept of Cellular Oscillating Tomography (COT) illuminates this principle by detailing how cells process signals, exchange information, and adapt to contribute to larger biological functions. Through oscillatory mechanisms, cells encode data in terms of frequency, amplitude, and phase, rendering them sophisticated information-processing entities in their own right.

Self-organization constitutes another pivotal facet of this framework. Numerous feedback loops at the smallest scales coalesce into coherent large-scale patterns, effectively weaving molecular events together with neural dynamics. Just as individual cells sculpt their environment, neural assemblies—such as cortical columns—mirror this process at a higher order by forming local configurations that collectively merge into broader cognitive states.

Within this unified view, deterministic wave mechanics at the cellular level seamlessly scale upward, building computation-derived behaviors across entire networks. Wave interactions, governed by the fundamental laws of matter and energy, give rise to remarkably intricate cognitive outcomes. In this sense, consciousness itself can be conceptualized as emerging from repetitive cycles of synchronization and desynchronization, an inherently measurable and mechanical phenomenon. The brain’s tapestry, woven from myriad local oscillations seeking equilibrium, becomes the substrate for thought and awareness.

By exploring how these multi-scale agents synchronize, desynchronize, and coordinate through phase transitions and feedback loops, we gain deep insight into the foundational processes that drive consciousness, cognition, and memory. These phenomena, deeply enmeshed in the biology of wave-based interactions, underscore the mechanical yet profound essence of living systems.

Within this perspective, three interconnected frameworks—Biological Oscillatory Tomography (BOT), Cellular Oscillating Tomography (COT), and Neural Array Projection Oscillation Tomography (NAPOT)—function as core elements of what can be called Oscillatory Computational Agency. Together, they explain how wave-based processes unite cells, columns, and entire neural arrays into cohesive computational units, thus highlighting a deterministic, multi-scale model of intelligence. Across all levels, agentic behavior is guided by oscillatory dynamics that transform local coincidences and molecular signals into globally coherent states, illustrating that higher cognition is ultimately rooted in fundamental wave mechanics.

In this collaborative paper on Agentic General Intelligence, we trace the development of the Self Aware Networks theory of mind—a synthesis of my 2024 book "Bridging Molecular Mechanisms and Neural Oscillatory Dynamics," initially presented through a series of Notes on GitHub and YouTube—with Michael Miller's ideas from his book "Building Minds with Patterns" and his related videos and papers. Together, these approaches present a compelling new framework for understanding how intelligence, spanning from the molecular to the cognitive level, can be both mechanistic and richly generative.

1.2 Agentic Behavior Across Scales

Biological agency occurs across multiple scales, from the molecular to the cognitive, and each level contributes to overall intelligence through local computations that aggregate into higher-level functions. At the molecular level, proteins and receptors change their conformations in response to biochemical signals, thereby regulating cellular excitability, while at the cellular level, neurons fire in patterned rhythms to encode information and glia and immune cells modulate the extracellular environment to support healthy neural functioning. Cells themselves operate as miniature computational units, as described by the Cellular Oscillating Tomography framework, adapting their behavior through oscillatory mechanisms involving changes in receptor configurations and recognizing coincidences as bits of information when near-simultaneous signals converge.

Network-level agents—including local neural assemblies, edge communities, cortical columns, and larger groupings such as hypercolumns—process incoming stimuli as semi-autonomous units and coordinate to produce coherent sensory and cognitive experiences. Each cortical column functions as an oscillating group of cells, reinforcing the idea that every agent, whether molecular or network-based, contributes to the overall structure of cognition. An agent is defined as any component, from a single protein to an entire brain region, that can process information and adapt its behavior based on inputs from its surroundings, and these agents may cooperate or compete, leading to dynamic self-organization through numerous feedback loops that link molecular events to neural dynamics. Through these feedback loops, local bits of information carried by coincident neural events ultimately synchronize into larger wave-based patterns that unify cognitive processing.

These feedback loops support oscillatory communication in which cells and networks exert agency via complex signaling pathways that include electrical, chemical, magnetic, mechanical, and even protein spin-specific signals. Such oscillations can manifest as soliton waves containing phase wave differential rhythms, underscoring the intricate synergy among agents. Functional connectivity unites disparate regions of the brain, including cortical columns, ensuring that patterns emerging in different areas merge into a comprehensive internal representation. Cognitive phenomena, including consciousness, have roots in deterministic oscillatory processes rather than in irreducible emergent properties, reflecting the mechanical underpinnings by which agents synchronize or harmonize their activities via phase relationships and feedback loops.

These processes guide agents toward specific goals such as healing wounds, navigating chemical gradients, or orchestrating morphological development, mirroring established principles of reinforcement learning and synchronization. The concept of scale—including molecular, temporal, spatial, and volumetric dimensions—is central to this framework, and Micah's New Law of Thermodynamics posits that systems move toward equilibrium through iterative local interactions that dissipate gradients. The Agentic Brain emerges as a foundational model that underpins the broader Agentic Mind, offering profound insights into consciousness, the development of artificial intelligence, and the treatment of diseases by highlighting the role of agentic behavior across all biological scales.

1.3 The Three-Level View: Micro, Meso, and Macro

This paper organizes the Agentic Brain into three interlocking levels. At the micro-scale, the focus is on cellular mechanisms such as proteins, receptors, ion channels, and local field potentials. At this level, individual cells—including neurons, glia, and immune cells—act as autonomous mini-computers through processes like Cellular Oscillating Tomography and coincidence detection. These molecular and synaptic events generate small phase wave differentials, which accumulate in local field potentials and begin to shape both the timing and the likelihood of neuronal firing. Sections 2 and 3 describe how these local oscillations arise and demonstrate similar agentic behavior at the cellular level, including aspects of body–brain integration.

The mesoscale examines regional communication and inter-regulation among local ensembles such as cortical columns and thalamic loops, where feedback loops and network connectivity synchronize groups of cells into functional circuits. These ensembles combine and refine the phase wave differentials originating at the micro-scale, effectively magnifying small differences until they manifest as meaningful oscillatory patterns that drive cognition and behavior. In this layer, the Sonic the Hedgehog loops serve as a useful analogy for cyclical information flow, showing how signals continually loop through subcortical hubs and cortical layers in re-entrant circuits. Sections 4 and 5 explain how these regional assemblies interact and illustrate the interplay among structures like the thalamus, hippocampus, and cortex, thereby linking multiple micro-level events into coherent mesoscopic dynamics.

At the macroscale, the focus shifts to global brainwave functions and consciousness, where large-scale rhythms such as alpha, beta, and gamma, along with top-down and bottom-up gating, merge local and regional signals into unified cognitive states. Phase wave differentials that began at the cellular level ultimately propagate across the entire cortex, bonding disparate regions into a single oscillatory framework that can give rise to conscious awareness. Sections 6 through 8 explore these global oscillatory dynamics, connect them to high-dimensional representations and AI analogies, and demonstrate how full-brain synchronization produces integrated experience. In summary, the paper begins with micro-level processes (Sections 2–3), moves to mesoscale network interactions (Sections 4–5), and culminates in macroscale dynamics (Sections 6–8) that underpin unified consciousness, revealing a continuous agentic system that scales from molecular details to whole-brain cognition.

1.4 Historical Context of Self Aware Networks

Self Aware Networks (SAN) is situated within a rich historical context that spans the evolution of neuroscience and artificial intelligence. Early pioneers such as Alan Turing and the developers of the perceptron laid the conceptual foundations for AI, while landmark discoveries in brain localization—exemplified by Paul Broca's identification of language-specific areas—expanded our understanding of neural function. As the field progressed, figures like Jeff Hawkins and Yann LeCun advanced these ideas by introducing predictive coding theories and deep learning innovations that parallel neural processes.

At its core, SAN builds on established neuroscience principles such as synaptic plasticity, which underlies learning and memory; neural oscillations—particularly gamma rhythms that support perception, cognition, and consciousness; and the role of cortical columns as fundamental units for representing neural patterns. The theory also incorporates predictive coding, the notion that the brain continuously refines its internal model by comparing expectations with incoming sensory data. SAN emphasizes the integration of molecular-level discoveries with studies of neural oscillations, thereby bridging the microscopic processes of protein and receptor dynamics with macroscopic cognitive functions.

Central to the SAN framework are advanced tomographic models such as Neural Array Projection Oscillation Tomography (NAPOT) and Cellular Oscillatory Tomography (COT). NAPOT explains how synaptic memories become conscious through phase-encoded signals that link molecular events to complex sensory representations, while SAN posits that neurons transmit phase changes rather than merely discrete spikes—a perspective supported by the work of researchers like György Buzsáki and Steven Strogatz. This view is extended by COT, which demonstrates how individual cells compute and adapt, forming the foundation for larger-scale brain architectures and establishing a continuum of oscillatory interactions that underlie higher cognition.

Influential figures including Karl Friston, Earl K. Miller, Peter Tse, Jon Lieff, Jeff Hawkins, Olaf Sporns, György Buzsáki, and Michael Levin have contributed insights into biological mechanisms, such as oscillatory synchronization, predictive mechanisms, and cellular cooperation that resonate with SAN's emphasis on deterministic, multi-scale processes. By unifying principles from neuroscience, physics, and artificial intelligence, SAN offers a cohesive model of an agentic, deterministic brain with applications ranging from sentient AI to advanced brain-computer interfaces. This integrated approach deepens our understanding of how local oscillatory processes scale into conscious awareness and provides a robust foundation for future technological and therapeutic advancements.

Recent convergence in neuroscience and AI further reinforces SAN's central ideas. Researchers such as Jack Gallant, who has mapped large-scale semantic representations in the human cortex, and interpretability teams like Anthropic, which examine how high-dimensional embeddings emerge in deep networks, show striking parallels to SAN's multi-scale view. These concurrent efforts underline the necessity of frameworks like BOT, COT, and NAPOT that link molecular states and phase codes to macroscale neural architecture and cognitive function, highlighting the modern relevance of SAN's emphasis on bridging micro and macro levels of analysis.

Given this historical foundation, we begin our journey at the cellular scale, exploring exactly how proteins, receptors, and neuronal oscillations provide the bedrock for larger cognitive processes.

Level 1: Cellular Mechanisms (Micro-scale) This level covers cellular mechanisms, including proteins, receptors, local field potentials, and immune cells operating as autonomous agents.

2. Molecular and Neuronal Mechanisms

2.1 Neurons to Phase Wave Differentials

In my book Bridging Molecular Mechanisms and Neural Oscillatory Dynamics, the central argument is that molecular processes serve as the foundation for neural oscillations, which in turn underpin higher-level brain functions such as memory and consciousness. The work details a natural progression from the subtle interplay of molecules within neurons to the emergence of complex, system-wide oscillatory patterns.

Key molecular components—including ion channels, receptors, KIBRA-PKMζ complexes, and ongoing protein synthesis—stabilize synaptic connections and ensure that neurons effectively participate in oscillatory networks. Voltage-gated sodium channels facilitate rapid depolarization, while modulations in potassium currents determine action potential duration, which influences vesicle fusion probabilities and thereby shapes neurotransmitter release. Although vesicle exocytosis can appear stochastic when multiple vesicles are available for release, the precise ionic conditions inside the terminal make multi-vesicular release more deterministic than once assumed, since elongating the action potential duration leads to increased calcium influx that raises the probability of releasing more than a single vesicle per spike. These molecular events collectively shape the rhythmic firing patterns that allow single neurons to integrate into larger, synchronized assemblies while still appearing to vary in output strength.

On a broader scale, neurons form synaptic networks in which subtle phase wave differentials—small shifts in timing and frequency—convert individual action potentials into computed local field potentials. This multi-scale synchronization process is captured by Neural Array Projection Oscillation Tomography, which illustrates how phase-based encoding from dendrites through cortical columns builds, fuses, and interprets sensory inputs while fostering pattern invariance and robustness across circuits.

To describe this multi-level coordination, the book introduces Non-linear Differential Continuous Approximation, a framework that characterizes how each scale—from a single synapse and dendritic branch to an entire neuronal assembly—experiences distinct non-linear inputs that manifest as variations in amplitude, duration, and frequency. This framework underscores that neurons do not simply sum signals in a binary fashion but operate within an intricate landscape of oscillatory interactions that enable adaptive learning and complex computed behaviors.

Another fundamental concept is deterministic synaptic release, which reexamines the view of randomness in exocytosis. By modulating ionic currents, neurons can elongate or shorten action potentials and thus control the window of calcium entry into the presynaptic terminal. Small shifts in the action potential duration can deterministically raise or lower the probability of single or multi-vesicular release. In this way, what appears to be random variation in synaptic output is actually embedded in the neuron's capacity to regulate precise ion channel activity and take part in highly orchestrated wave dynamics.

At the core of these discussions lie phase wave differentials, portrayed as the engine behind the brain's three-dimensional "volumetric television," which continuously updates perceptions and memories in real time. Through coordinated oscillatory dynamics, the brain seamlessly transforms molecular events into global wave patterns, resulting in the macroscopic phenomena we recognize as consciousness and higher-order cognition. This integrated framework demonstrates how molecular, cellular, and network-level processes intersect to generate the local field potentials and brainwaves that define our subjective experience.

2.2 Coincidence as Bits of Information

Coincidence detection serves as a fundamental mechanism through which cells identify patterns and initiate precise responses in real time. When multiple receptors are activated simultaneously, cells interpret these coincident events as distinct bits of information that enable them to process environmental signals and execute coordinated actions reflective of both their internal state and the broader context. From the perspective of Cellular Oscillating Tomography, cells operate as active information processors that encode data in frequency, amplitude, and phase, thereby moving beyond the simplistic view of cells as mere on/off switches. Rhythmic cycles allow cells to receive, transform, and relay signals to neighboring cells, and receptor-based learning, occurring in a Hebbian-like manner, enables cells to adapt to repeated stimuli by modifying receptor sensitivities and recalibrating internal signaling pathways, effectively storing a memory of past experiences. This process underlies how local coincidence detections can feed upward into broader wave patterns, providing a basis for global functional connectivity.

In addition to this rhythmic encoding, the dendritic arbor can be understood as a high-dimensional vector embedding that reflects a cell's cumulative learning. By fine-tuning the strengths of synapses on different branches, a cell becomes selective for specific patterns of coincident inputs. When a sufficient number of these inputs arrives within a critical window of a few milliseconds, the cell fires at a high gamma frequency, generating a token-like emission that compresses the convergent input pattern into a single phase wave differential. These nearly concurrent signals coalesce into a phasic soliton wave that loops through the circuit and integrates with other regions dedicated to pattern recognition. Synaptic modulation, including adjustments in neurotransmitter release governed by action potential duration and mediated by potassium- and calcium-dependent pathways, can produce smaller or larger frequency shifts, sharpening the specificity of these coincidences by determining which inputs become reinforced. These variations often intersect with behavioral timescale synaptic plasticity, illustrating that coincidence events serve as critical anchors for long-term memory.

Another essential element is dendritic computation, in which dendrites perform nonlinear summations and multiplications of incoming signals. By discarding inconsequential inputs and amplifying those that occur in coincidence, dendrites function as selective filters that generate distinct phase or amplitude shifts. These shifts persist within neural circuits long enough to influence perception and behavior, and they contribute to the formation of phase wave differentials that encode meaningful changes in the signal. Each spike thus becomes not only a response to immediate input but also the dendrite's compressed token, signaling which inputs successfully aligned in time and space. Local coincidences serve as the seeds from which large-scale oscillatory wave patterns emerge, linking individual events to the collectively organized activity of larger circuits.

Moreover, oscillatory synchrony across multiple sensory modalities allows the brain to integrate these discrete bits of information into a coherent representation of the environment. By treating coincidence events as foundational bits and embedding them in phase wave differentials, the mechanism of coincidence detection becomes the linchpin of both cellular and neural information processing, enabling the transformation of simultaneous events into actionable data that underpins pattern recognition, memory storage, and coordinated activity with remarkable precision. This framework clarifies how small and large shifts in synaptic frequency can scale from local dendritic processes to global oscillatory interactions, driving the storage of learned patterns and the unification of sensory signals into meaningful representations.

2.3. Cellular Oscillating Tomography (COT)

Cellular Oscillating Tomography (COT) is a theoretical framework that describes how cells function as active information processors rather than as simple on/off switches. Cells exhibit rhythmic or cyclic activity that encodes complex data in terms of frequency, amplitude, and phase. These oscillatory patterns provide a rich repertoire of signals that enable cells to receive, integrate, and transmit information, positioning them as “mini-computers” operating at a microscale. In much the same way that medical imaging techniques such as CT scans or MRIs reconstruct three-dimensional objects from multiple two-dimensional projections, COT posits that cells gather and merge diverse oscillatory “slices” over time, building an internal representation of their environment from repeated wave-based angles.

A central feature of COT is coincidence detection, whereby cells recognize patterns through the simultaneous activation of multiple receptors. When receptors coincide in time, they trigger specific cellular functions that can be reinforced through repeated exposure in a manner reminiscent of Hebbian learning. This receptor-based learning and memory formation relies on incremental changes in receptor configurations that enhance a cell’s sensitivity to stimuli and allow it to retain a record of past experiences. These changes are not purely random, because COT proposes that cells adapt through wave-mediated processes in which local receptor states, thresholds, and ephemeral phase changes define each cell’s distinct computational identity. By processing repeated oscillatory signals that arrive at slightly different phases or angles, each cell effectively compares new projections against its learned patterns to compute an outcome rather than merely reacting.

COT also emphasizes the importance of tomography in cellular communication by highlighting the oscillatory binding of phase wave differentials. This binding process operates in a manner similar to the neural rendering mechanisms found in artificial neural networks, enabling individual cells and larger tissue systems to construct an internal representation of their environment. Much like how a CT scanner compiles multiple cross-sectional images to form a volumetric picture, cells use rhythmic cycles to integrate partial snapshots of input. Synaptic integration, achieved through the summation of excitatory and inhibitory postsynaptic potentials, further refines these representations so that coincident inputs increase the likelihood of firing and lead to long-term potentiation that strengthens synaptic connections over time.

On a broader scale, COT underscores the concept of multi-scale agency in which each cell or tissue can function autonomously while remaining part of a coordinated whole. Cells communicate using wave-based processes such as phase synchronization and desynchronization, and glial cells play a significant role in regulating signal transmission and modulating neuronal activity. In addition, transcriptomic activations occur when synaptic coincidences unlock deeper cellular functions by altering protein expression profiles in response to changing conditions. The repeated merging of local oscillatory projections helps unify otherwise separate cellular activities into a coherent functional architecture.

An additional dimension of COT involves ATP-based reinforcement learning, where cellular processes are shaped by rewards or punishments. If a newly synthesized protein fails to improve cellular efficiency, increased ATP usage may lead to its degradation or modification, thereby guiding the evolution of more adaptive cellular structures. Through continuous reconfiguration of receptors and refinement of protein interactions, cells can forecast and compute their future biological structures, supporting both the development of single-celled organisms and the resilience of complex multicellular systems. By relying on these wave-driven updates, COT offers a picture of cells directing their own adaptations in a computed manner, rather than being constrained only by blind variation.

Ultimately, COT reveals that cells do far more than passively react to external stimuli. They act as intelligent agents that process and interpret signals through oscillatory cycles, influencing not only their own internal states but also those of neighboring cells. These foundational wave-based mechanisms are pivotal in higher-level biological functions, including consciousness, by weaving together local cellular activity into integrated, system-wide dynamics and by continuously scanning their environment through repeated oscillatory angles.

2.4 An Addressable Coefficient of Variation: Unique Cellular Fingerprints in Dendritic & Synaptic Computation

An addressable coefficient of variation (CV) provides a quantitative framework for understanding how each cell “fingerprints” its signals by measuring the ratio of the standard deviation of its activity to its mean. In neural processes, a high CV indicates that a neuron’s spiking deviates markedly from the average rhythm of its local network—such as a theta wave—resulting in variable and unpredictable firing, whereas a low CV signifies consistent, rhythmic activity. Because these firing variations map onto unique frequency and phase states, each cell’s CV can be seen as its spectral “address,” linking the cell’s local oscillatory fingerprint to the global spectral map maintained across the body.

This variability is underpinned by the sophisticated computational capacities of dendrites and synapses. Dendrites perform nonlinear summation of incoming signals, amplify coincident inputs to highlight crucial information, and filter out noise or irrelevant stimuli, thereby encoding a spatial representation of learned experiences. Concurrently, synapses modulate the temporal dimension through activity-dependent plasticity; dendritic spines may grow or retract, and receptors can be inserted or removed, embedding each neuron in a high-dimensional vector space where its unique morphology and synaptic frequency variations define its computational signature. Even small shifts in synaptic thresholds alter the precise timing or amplitude of released neurotransmitters, whereas larger threshold changes can more drastically reshape firing probabilities. These varying scales of synaptic reconfiguration, coupled with a cell’s oscillatory address, create a combinatorial explosion of possible states that the overall network can occupy.

Furthermore, factors such as potassium levels and the duration of action potentials (APD) play critical roles in shaping cellular individuality. By influencing the open time of voltage-gated calcium channels, potassium currents dictate the number of neurotransmitter vesicles released during an action potential, thereby shifting the timing, amplitude, and phase of the resulting signals. In this way, the very shape of an action potential serves as an encoded signal, and variability in potassium currents can either amplify or dampen a neuron’s overall output, reinforcing its unique contribution within the spectral map of the network. These mechanisms of variability and adaptation are not confined solely to neurons. Observations of neuron–T cell interactions reveal that diverse cell types actively process information through rhythmic cycles governed by frequency, amplitude, and phase. This idea, sometimes encapsulated in the “Metatron Agent” concept, suggests that each cell functions as an autonomous computational unit, and the extension of these principles through Coincidence Operated Tomography (COT) implies that even non-neural cells are capable of pattern recognition and adaptive responses.

Ultimately, the interplay of intrinsic membrane properties, ion channel distributions, synaptic inputs, and local microenvironmental factors creates minute frequency differences that endow each cell with a distinct oscillatory “fingerprint.” This uniqueness is exemplified by hippocampal place cells, which fire at characteristic frequencies in specific spatial locations, and by fibroblasts that exhibit distinct calcium oscillations depending on their role and position. In this light, the addressable coefficient of variation robustly explains how specialized cellular dynamics underpin distributed computation, memory, and adaptive intelligence, reinforcing the broader coherence and functionality of the organism’s internal communications network through an ever-evolving global spectral map.

3. Immune Integration and Global Cellular Coordination

3.1 T-Cells & Neurons: An Integrated Communication Network
The interplay between neurons and T-cells constitutes a critical dimension of brain function that extends beyond conventional neuroscience into the realms of immunology and systemic biology. This relationship underscores the brain’s deep integration with the body’s immune system and illustrates how overall health and equilibrium depend on continuous communication among cells from the central nervous system, the immune system, and even the gut. By viewing these exchanges through the lens of a global spectral frequency map, it becomes clearer that T-cells operate within the same body-wide oscillatory “address system” as neurons, ensuring that immune responses align with neural signals in both space and time.

A key foundation for understanding this connection lies in the principle that cellular communication drives nearly every aspect of biology. Jon Lieff’s work highlights the profound importance of constant dialogue among cells, revealing that neurons, immune cells, and other cell types rely on intricate signaling networks to coordinate their roles. Recognizing that each cell type both influences and responds to its counterparts allows researchers to appreciate the interconnected nature of brain function and overall well-being. This recognition now extends to the idea that cells in the immune system are tuned, in part, by frequency-phase signatures, enabling T-cells to lock into oscillatory rhythms that identify their precise “coordinates” in the global spectral map.

Within this framework, the bidirectional exchange between T-cells and neurons demonstrates how these cell types engage in dynamic signal transmission. Neurons release neurotransmitters to modulate synaptic activity, while T-cells emit cytokines that can either dampen or escalate inflammatory responses. When T-cells function properly, they help maintain a healthy balance by regulating brain inflammation; conversely, any dysregulation in T-cell behavior can trigger neuroinflammatory processes that may contribute to disorders such as depression. The presence of T-cells in the cerebrospinal fluid confirms their role as gatekeepers, ensuring that only approved substances and cells cross into the brain. In addition, these immune cells direct other components of the immune system, reinforcing their function as local coordinators within the broader neural milieu, and at times they even position themselves between neurons as part of a “wireless system” that broadcasts immunological information throughout the body and back to the brain. Crucially, this “wireless” integration dovetails with the broader spectral addressing system, where subtle phase differentials guide T-cell activity toward the correct location and timing for immune support.

Neurons also support a guiding function that can be likened to a “proprioceptive GPS.” By broadcasting detailed information about injury or infection sites through diverse signaling mechanisms—including electrical impulses, chemical messengers, magnetic fields, mechanical forces, and protein spin-specific processes—neurons enable T-cells to navigate precisely to areas requiring immune support. They act as dispatch operators by leveraging soliton waves and phase wave differential rhythms to issue real-time updates that synchronize immune responses. On a larger scale, the brain translates these detailed signals into more general, coarse-grained maps that facilitate effective coordination of immune activity. This coordination is further aided by each cell’s frequency-based identity, which ensures that T-cells and neurons continually engage in targeted dialogue rather than random contact.

Such systemic integration reflects the body’s function as a distributed information-sensing network in which cells communicate not only through chemical secretions or synaptic transmission, but also via electrical currents, electromagnetic waves, physical contact, and biological nanotubes. This multiplicity of signaling pathways ensures that essential information reaches its target by multiple routes, thereby enhancing the resilience and adaptability of the immune-neural interface. By placing T-cells within the same oscillatory framework as neurons, it becomes apparent that the global spectral frequency map underlies far more than just neural synchrony; it also guides immunological vigilance, repair, and regulation.

The clinical implications of these findings are far-reaching. T-cell dysregulation is linked to neuroinflammation, which is increasingly recognized as a contributor to various mental health conditions and neurodegenerative disorders. Furthermore, vitamins such as D3, A, and B appear capable of signaling T-cells to moderate their activity, suggesting possible therapeutic strategies that harness immunological regulation to protect neural tissues, mitigate neurological damage, and promote recovery. By targeting the frequency-phase relationships that tune T-cells to specific sites, future interventions may achieve more precise immunomodulation.

Overall, the dynamic exchange between neurons and T-cells reveals a profound layer of complexity in how the brain maintains health and responds to threats. Recognizing the immunological underpinnings of neural function encourages a broader perspective on the brain as an organ that constantly negotiates with the immune system, and this insight opens promising avenues for developing innovative therapies that harness both neural and immune mechanisms to bolster brain health and treat neurological disorders. T-cells illustrate precisely how the body-wide oscillatory address system ensures that each immune challenge is met at the appropriate location and time, reinforcing the view that phase relationships and frequencies are just as critical to immunological coordination as they are to neural synchrony.

3.2 Global Spectral Map of the Body & Cells

Self Aware Networks (SAN) posits that the body maintains a unified global spectral map in which every cell—from neurons to T-cells—projects its own unique oscillatory signature into an integrated, multidimensional field. Rather than existing merely as isolated electrical impulses, these signals function as a dynamic coordinate system, where each cell's frequency and phase signature specifies its "location" in the overall network. By continuously exchanging electromagnetic, mechanical, and protein spin-specific information, cells effectively contribute phase slices that align into a unified map. This map helps coordinate local events into a system-wide awareness, underscoring how each cellular agent both senses and transmits information.

Neurons do not simply relay or generate discrete spikes; they encode data as patterns of frequency, amplitude, and phase, mirroring the broader perspective of Cellular Oscillating Tomography (COT), in which cells—including immune cells—learn and adapt by similar oscillatory means. T-cells and other immune components illustrate how this spectral map extends beyond the nervous system. When T-cells communicate with neurons, the neurons' proprioceptive sensing offers precise information about both identity and location. This enables T-cells to address injuries with extraordinary specificity, reflecting how every cell's unique oscillatory signature becomes integrated into an overarching spectral coordinate system.

Information is thus fused into tomographic slices contributed by each cell type. Neurons capture one slice of the body's internal state by oscillating at particular frequencies, while T-cells and other immune cells add their own slices in complementary frequency bands. These slices can converge or interfere, but when they synchronize in phase, they collectively generate a holographic-like reconstruction of the body's status, supporting perceptual coherence, memory formation, and focused attention. This ongoing alignment also promotes feedback loops in which local cells both influence and respond to global rhythms, exemplifying the agentic dynamics that operate across all scales of the organism.

Proteins at the molecular level perform critical decision-making roles through what can be seen as Protein Oscillation Tomography. By shifting their conformations or spin states according to electromagnetic, chemical, or mechanical inputs, proteins store and retrieve information while adjusting a cell's level of excitability. The resulting interplay of local adjustments, governed by ATP and other signaling molecules, shapes everything from long-term memory to real-time adaptive behavior. This underscores how fine-tuned oscillatory shifts in molecular components align with broader systemic frequencies to create a flexible but unified biological intelligence.

In this expanded view, the global spectral map does more than merge cell outputs into a static blueprint; it evolves in real time as each participating cell adds its oscillatory slice. Because every cell has a distinct phase and frequency signature, the larger coordinate system continues adjusting itself to accommodate new states or challenges, allowing the entire body to function as a coordinated, dynamic whole.

Level 2: Regional Communication and Inter-Regulation (Mesoscale) At this scale, agentic principles manifest in the coordination of cortical columns and regional circuits, integrating distributed neural signals into cohesive functional networks and behaviors.

4. Functional Connectivity and Network-Level Dynamics

4.1 Functional Pattern Connectivity via NAPOT

Functional connectivity is a central concept in neuroscience that describes how distinct brain regions communicate and coordinate their activities during both task performance and rest. In the framework of Neural Array Projection Oscillation Tomography (NAPOT), functional connectivity emerges from the interplay of oscillatory patterns across multiple neural arrays, which effectively project signals forward to create tomographic “renderings” of the brain’s internal models. When neurons synchronize their frequencies and phases, they momentarily form coherent circuits that enhance salient signals, filter out irrelevant noise, and stabilize representations of memory, thought, and perception. Traveling waves play a key role in this process by unifying even distant cortical columns, provided their oscillatory phases align; in particular, gamma oscillations help synchronize large-scale neural activity and support the seamless continuity of conscious experience.

At the heart of these oscillatory processes lie phase wave differentials, which reflect subtle timing discrepancies across different brain regions or neural columns. These differentials carry information while also acting as gating mechanisms that direct signals to specific targets at precise moments, much like incremental steps in a time-evolving function. NAPOT thus conceptualizes neural arrays as both projectors and receivers: each array processes inputs from preceding arrays and projects new oscillatory information forward in a cascading manner that underlies the ongoing flow of perception, memory, and self-awareness. As these arrays interact dynamically with cortical columns, patterns emerge and then dissolve, forming a constantly updated map of reality.

Frequency-based synaptic inhibition further refines connectivity by selectively engaging or suppressing neural assemblies through minor adjustments in firing rates. This regulation defines functional subnetworks that enable the brain to allocate computational resources to the most salient inputs. NAPOT also explains how the brain integrates multiple sensory modalities, such as visual, auditory, and olfactory signals, by merging them through shared oscillatory frameworks. Coherent multimodal representations form when overlapping frequencies and matching phases align to unify disparate sensory signals into a continuous experience.

In summary, NAPOT provides a comprehensive model in which synchronized oscillations, phase wave differentials, and traveling waves in dynamically interacting neural arrays underpin functional pattern connectivity. The precise timing and coordination of neural firing bind multiple sensory streams, facilitate memory formation, and sustain the uninterrupted nature of conscious awareness.

4.2 BTSP Coincidences and Functional Connectivity Between Columns and Other Brain Regions

Behavior Timescale Synaptic Plasticity (BTSP), when combined with the principle of coincidence detection, provides a valuable framework for understanding how cortical columns physically link through repeated co-activation, ultimately forming large-scale “bits” that converge in wave synchrony. In this view, coincidences in firing act as discrete bits of information that bind neurons and columns into unified networks whenever their activity aligns within critical time windows. Phase wave differentials further refine these bits by carrying subtle shifts in oscillatory timing, allowing each column to detect and reinforce specific coincidences while filtering out irrelevant noise.

Neurons detect information by registering these coincidence events over time, effectively serving as sensors that transmit finely tuned phase patterns. When neurons or columns fire together, their pathways are strengthened through repeated co-activation, illustrating that neurons that fire together wire together. This mutual reinforcement can bind even indirectly connected neurons across broad cortical areas, as shown by high cofluctuations in functional connectivity when distant regions synchronize through feedback loops. Information can also flow bidirectionally via distinct routes, fostering broader coordination and integration of signals.

Cortical columns act as semi-autonomous agents by generating local decisions, encoding distinct inputs, and exporting motor directives to higher-order patterns. They function as focal points of pattern representation, each capable of recognizing or predicting features within its specialized domain. Functional connectivity across these columns weaves local patterns from separate sensory modalities into a unified map of reality. Phase wave differentials carry timing information that enables disparate regions to coordinate, establishing synchronized circuits essential for cognition and memory consolidation. The thalamus, acting as a relay hub, modulates and gates these signals, ensuring their content and timing align.

Through oscillatory feedback loops, distributed processing, inhibitory controls, and agent-based interactions, local oscillatory events build into large-scale connectivity patterns that flexibly adapt to new demands. Interneurons help refine excitatory inputs, preventing runaway excitation while maintaining effective synchronization. As repeated coincidences strengthen the neural links between columns, the system converges on stable but fluid assemblies that continuously update the brain’s unified representation of experience. By positioning coincidences as discrete bits of activity within BTSP, the architecture of functional connectivity emerges as a network of physical linkages among columns that collectively encode and interpret the world.

4.3 Bridging Molecular Interactions and Brainwaves

One of the most pressing challenges in neuroscience is to understand how microscopic molecular events give rise to macroscopic brain oscillations and, in turn, how these large-scale oscillations feed back into molecular processes. Traditional models fall short in explaining how discrete action potentials merge into continuous waveforms, and to bridge this gap, foundational principles such as the All-or-Nothing rule and synaptic unreliability are reexamined alongside modern insights into multi-vesicular release, phase wave differentials, and agentic perspectives on cellular function.

At the molecular level, ion channels—particularly sodium and potassium channels—work in concert with calcium dynamics and synaptic proteins such as KIBRA and PKMζ to regulate synaptic efficacy and shape rhythmic firing patterns that converge into synchronized oscillations across neural networks. Mathematical models like Neural Array Projection Oscillation Tomography (NAPOT) and Non-linear Differential Continuous Approximation (NDCA) demonstrate that brainwaves are not merely the sum of discrete action potentials but emerge from complex, nonlinear interactions of ionic currents and phase relationships. These molecular interactions set the stage for large-scale oscillatory behavior that ultimately governs perception, memory, and conscious experience.

In addition to conventional synaptic transmission, ephaptic coupling provides a complementary route for neuronal communication. This mechanism allows the local electromagnetic fields generated by active neurons to influence neighboring cells without the need for direct synaptic contact. By synchronizing subthreshold membrane potentials and modulating local network excitability, ephaptic interactions further contribute to the generation and maintenance of coherent brainwave patterns. This additional pathway enhances the robustness of information transmission across scales, reinforcing the integration of molecular events into the global dynamics of the brain.

Revisiting the All-or-Nothing principle reveals that real neurons frequently transcend a simple binary output, as synaptic unreliability is nuanced by phenomena such as multi-vesicular release and variable action potential durations that affect calcium influx and vesicle release probabilities. This undermines the strict assumption of a single vesicle per action potential and expands our understanding of information transmission within cortical circuits. Viewing the brain as a network of adaptive agents—from individual cells and tissues to entire brain regions—emphasizes that cortical columns, thalamic relays, and inhibitory interneurons operate cooperatively through oscillatory feedback loops that balance excitatory and inhibitory forces, sustaining both local computations and global cognitive states.

In sum, bridging the gaps in neuroscience requires an integrative approach that combines detailed molecular dynamics with large-scale oscillatory behavior. By reexamining the All-or-Nothing principle and synaptic unreliability through the lenses of multi-vesicular release, phase wave differentials, and ephaptic coupling, we gain a more nuanced understanding of how molecular events and brainwaves mutually inform and modulate one another. This perspective underscores the agentic nature of brain components and provides a unified framework for perception, memory, and the computational rendering of consciousness.

4.4 Addressing the Binding Problem through Oscillatory Dynamics

The binding problem refers to the challenge of unifying diverse sensory features such as color, motion, and form, which are processed in separate brain regions, into a single coherent percept. Neurons address this challenge by synchronizing their oscillatory activity through phase locking, a process that reduces differences in firing patterns and aligns distributed networks. Gamma oscillations play a central role in this process by promoting the simultaneous alignment of various neuronal groups, thereby supporting volumetric processing and the creation of a three-dimensional experiential space. In this framework, phase wave differentials serve as the currency of local binding, as the minute differences in phase timing encode the distinctions that unify disparate features into a cohesive percept. Synchronous wave alignment ensures that elements such as color, shape, and texture are seamlessly integrated into a unified internal map.

Functional connectivity describes the dynamic, task-dependent synchronization among brain regions via coherent wave patterns, and this connectivity adapts as cortical columns and regions tune in or out depending on current demands. Large-scale phase alignment in key frequency bands merges signals from disparate sources into cohesive representations while filtering out extraneous noise, thereby enabling multiple sensory streams to converge into a unified internal map. Biological Oscillatory Tomography provides a conceptual framework for understanding how groups of neurons construct spatial and temporal maps. In a manner analogous to medical imaging techniques that reconstruct three-dimensional objects from multiple two-dimensional slices, synchronized oscillations across neural arrays use phase wave differentials and feedback loops to iteratively refine the brain's representation of reality. Each neuron transmits its phase information to connected targets, which then adjust their own phases accordingly. Viewed from an agentic perspective, every neural region acts as a semi-autonomous unit striving to minimize its phase differential relative to others, much like distributed agents in advanced artificial intelligence systems that coordinate to achieve a common goal.

Together, these oscillatory processes and precise phase relationships form the binding glue that unites distributed local computations into unified perceptual and cognitive experiences. They explain how seemingly independent neuronal activities converge through meticulous timing and feedback, resulting in a singular, integrated conscious experience.

4.5: The Flow of Information: Neural Arrays to Columns, Matrix Neurons & Cortical Neurons, Inhibitory Interneurons

Information processing in the brain begins with highly organized neural arrays that are not random groupings but carefully structured collections in which each neuron fulfills a specific role. In a typical sensory pathway, for example, retinal cells encode incoming data through both convergent and divergent connections, creating rich, parallel processing streams that set the foundation for subsequent neural computations.

Building on the outputs of these arrays, cortical columns serve as semi-autonomous vertical modules dedicated to specialized types of information processing. Each column not only integrates sensory inputs by activating relevant neuronal ensembles but also temporarily inhibits competing neurons within its structure. Inhibitory interneurons are essential in this process, as they balance excitation and inhibition by releasing neurotransmitters such as GABA, thereby preventing overexcitation and enabling precise modulation of neural activity. They also play a critical role in shaping synaptic plasticity, influencing the strength of synaptic connections so that information is processed and stored under optimal conditions. Some interneurons, such as parvalbumin-expressing basket cells, target the neuronal soma and axon initial segment to control the all-or-none firing decision, while others, including somatostatin-positive cells, target dendritic compartments to fine-tune the integration of excitatory inputs.

Within the hierarchical network, the thalamus plays a critical relay role by converging sensory information and distributing it in parallel to multiple cortical layers, including those populated by matrix neurons and a diverse array of inhibitory interneurons. Matrix neurons maintain connections with specialized inhibitory cells that precisely time and gate synaptic outputs to balance excitation and inhibition, thereby sculpting dynamic activity patterns. Inhibitory interneurons not only regulate the timing and phase relationships of synaptic signals within and between cortical columns but also orchestrate neural oscillations by synchronizing the firing patterns of excitatory neurons, which is vital for attention, memory consolidation, and cognitive flexibility. Notably, inhibitory interneurons in layer 5 are especially critical in coordinating traveling waves that propagate from neural arrays to cortical columns and back. These layer 5 interneurons integrate sensory and motor signals by synchronizing gamma oscillations, ensuring that signals arising from muscle movements and body position are aligned with sensory inputs from primary cortices. They facilitate a cyclical gating process—akin to the "Sonic the Hedgehog loops" observed in dynamic systems—in which signals continuously circulate along closed loops, enabling both feedforward and feedback modulation that refines neural activity and prevents runaway excitation.

At every level, from individual cells to ensembles such as minicolumns and hypercolumns, these inhibitory mechanisms and agentic principles drive real-time signal integration, learning, memory, and ultimately the emergence of complex, unified awareness. Although cortical columns function as localized centers of processing, their outputs must be integrated into broader networks. Here, the thalamus, together with interconnected circuits like the hippocampal–entorhinal pathway, synchronizes regional activities into cohesive, large-scale patterns that underpin coherent perception and cognitive function.

4.6: Functional Connectivity: Phase Synchronization, Inhibitory Interneurons, and Interregional Regulation

Functional connectivity describes how multiple brain regions communicate and coordinate their activities via oscillatory patterns, expanding on the fundamentals introduced earlier in the discussion of NAPOT. When neuronal assemblies align their firing frequencies and phases, they form coherent circuits that amplify relevant signals while suppressing background noise, a process in which gamma oscillations play an especially important role in integrating conscious experience. Each frequency band can serve both as a coordinating rhythm and as an “address” that directs which columns or regions can effectively synchronize. Cells and columns sharing the same frequency-phase window essentially occupy the same operative coordinate, enabling them to exchange signals more efficiently and form transient functional subnetworks.

Phase wave differentials underlie these exchanges by carrying subtle timing shifts that function like gatekeepers, allowing data to flow to specific locations at precise moments. Small variations in timing propagate as traveling waves and can guide the formation of neural avalanches that distribute information across synapses treated as temporally evolving tensors in three-dimensional space. Because each local site maintains its unique frequency-phase identity, these differentials can act as navigational markers in the overall spectral map, ensuring that signals travel preferentially along pathways with matching coordinates.

Neural arrays behave as both projectors and receivers: each array processes inputs from an upstream array and forwards new information in a wave-like cascade. This activity underpins perception, learning, and memory, as local patterns merge or dissolve into the brain's ongoing "map" of reality. Inhibitory gating, often mediated by interneurons, further sculpts these interactions by selectively enhancing or suppressing neural ensembles through modest shifts in firing thresholds. This interplay between phase synchronization and inhibitory regulation refines functional connectivity, allocating computational resources to the most salient stimuli. By viewing frequency and phase as a kind of routing mechanism, NAPOT explains how local assemblies couple or decouple from the broader network at key moments, maximizing efficiency while avoiding runaway excitation.

Oscillatory coherence across sensory modalities emerges when different regions converge on overlapping frequencies. Matched phases, stable amplitude patterns, and functionally resonant wave states foster seamless integration of sight, sound, and other inputs into a unified percept. In this manner, frequency-phase alignment not only supplies the temporal glue for continuous perception but also the addressing system that designates which neurons or columns can briefly synchronize and exchange targeted signals. Altogether, functional connectivity arises from precisely timed phase differentials, traveling waves, and inhibitory loops, culminating in an adaptive and distributed network that supports high-level functions such as perception, memory consolidation, and consciousness. This section highlights how phase synchronization and inhibitory gating converge in a single framework, clarifying the unified view of interregional regulation.

4.7 Tomography from Functional Connectivity of Neural Oscillations at All Scales

Functional connectivity underpins the collaboration among diverse brain regions, including cortical columns, in forming unified internal representations of sensory and cognitive information. Oscillatory activity and phase relationships bridge molecular interactions with large-scale neural dynamics, as Cellular Oscillating Tomography (COT) demonstrates that cells actively process inputs by adjusting receptor sensitivities and generating wave states. Consequently, the brain behaves as an oscillating system that continuously seeks equilibrium and reaches conscious moments when external or internal stimuli perturb its baseline. In this context, each alignment of oscillatory waves can be viewed as a “slice” in an ongoing tomographic process, where ephemeral changes in phase relationships accumulate to produce volumetric unification reminiscent of a “3D volumetric television” that continuously updates our internal reality.

Memories stored in synaptic connections scale to whole-brain activity and support perception by converging overlapping or distributed synaptic traces from different sensory modalities into comprehensive, context-rich experiences. Molecular processes drive neuronal oscillations that enable complex behaviors such as working memory and recollection, and fractal-like principles of repetition and magnification help explain how minute synaptic events combine into large-scale patterns of thought and perception. In this way, phase wave differentials and synaptic frequency encoding maintain network stability and continuity, with each subtle realignment of these “slices” contributing to the layered, volumetric picture of experience.

Neural agents, ranging from individual neurons to large assemblies, coordinate through oscillations and synchrony. Phase differentials facilitate real-time adaptation and communication, with tonic oscillations providing a stable backdrop while high-frequency phasic bursts convey novel information. By transmitting precise phase changes, neurons harmonize with network rhythms and dynamically adjust synaptic strengths to integrate new inputs. In addition, ephaptic coupling offers a local “wireless” pathway for synchronization, as subtle electric fields generated by active neurons can align subthreshold potentials in neighboring cells, further stabilizing the traveling waves that link distributed neural activity. This constant orchestration of transient alignments ensures that all these slices together form a unified volumetric rendering within the cortical networks.

These phase shifts, supported by molecular mechanisms, create feedback loops that both nourish and stabilize memory at the synaptic level. Proteins such as KIBRA and PKMζ, together with various ion channels and receptors, preserve activation patterns, while neurons continually adjust their receptor sensitivities and firing thresholds under the fine-tuning influence of inhibitory interneurons. In the Self Aware Networks framework, each neuron functions as both a sensor and transmitter of phase information, and physical changes in synapses driven by oscillation frequencies and phase wave differentials further refine the way signals are distributed and backpropagated. Overall, tomography from functional connectivity reveals the brain’s remarkable capacity to integrate distributed activity into coherent representations of reality, and the synergy between oscillatory dynamics and synaptic plasticity underlies learning, adaptation, and the emergence of conscious awareness. By considering each wave alignment as a fleeting slice that contributes to a larger volumetric map, we can better appreciate how the brain builds a dynamic three-dimensional tapestry of cognition and perception—a genuine “3D volumetric TV” of the mind.

4.8 Mechanisms of Agent Interaction

The brain’s capacity to form a coherent internal representation of the external world arises from a sophisticated process known as neural rendering. Each sensory organ contributes by generating a three-dimensional-plus-time representation through its incoming signals. In practical terms, a sensor array captures a two-dimensional snapshot at each moment, and the brain employs coincidence detection and oscillatory activity to transform these repeated 2D views into an evolving 3D model.

Neural correlations form the core mechanism for this transformation. Oscillatory traveling waves, combined with subtle phase shifts, enable different neural ensembles to project their particular viewpoints into the larger network. Through wave interference and synchronization, these localized oscillations merge to construct a dynamic tomographic representation of the environment. In this manner, the brain infers the underlying three-dimensional structure by recognizing repeated patterns and coincidences in images captured from slightly different angles or times.

Cortical columns function as semi-autonomous agents within this networked architecture. Each column integrates sensory inputs, generates predictions, and formulates motor directives, thereby managing high-level concepts and their associated properties. By encoding and activating memories, a column compares new sensory information to previously stored templates; when its neurons fire in unison to represent a memory, inhibitory signals suppress competing activity within the same column, thus amplifying the dominant pattern. Oscillatory interactions across multiple columns further ensure that these local representations coalesce into a unified global perception.

Crucially, each column also “speaks” to neighboring and distant regions in the form of ephemeral phase pulses. These transient wave differentials either resonate with ongoing oscillations and become integrated into the broader network state, or they dissipate if they fail to achieve phase alignment. This interplay allows agent-like columns to share partial information rapidly, refine the system’s collective response, and continuously update the current internal depiction of the world.

The interplay between phasic bursts and tonic oscillations, together with both local and global synchrony, allows the brain to adapt fluidly to shifting stimuli while maintaining a stable, detailed internal depiction of the world. Together, these oscillatory interactions and dendritic embeddings illustrate how local phase differentials can represent “slices” of a larger dimensional state. In the next section, we explore how quasicrystals provide a powerful analogy for such higher-dimensional structures, linking local phase alignments to complex global patterns.

5. Thalamic and Cortical Interplay

5.1 How the Thalamus Regulates the Prefrontal Cortex
The thalamus significantly regulates the prefrontal cortex (PFC) through dynamic feedback loops, sensory relay, and cortical modulation. It acts as a central hub that connects with cortical areas and the hippocampal-entorhinal loop, enabling an integrated approach to both high-level cognition and contextual processing. In this dynamic feedback loop, the thalamus sends signals to the PFC and adapts its output based on returning input. Mediodorsal (MD) thalamic

projections support working memory functions in the medial prefrontal cortex (mPFC) by enhancing connectivity and sustaining neural activity during tasks that demand focused attention or cognitive load. This loop is reinforced by a positive-feedback mechanism between the mPFC and the anteromedial (AM) thalamic nucleus, which activates dopaminergic neurons in the midbrain, helping to modulate motivation and reinforce adaptive behaviors.

Beyond this role in working memory and reinforcement learning, the thalamus refines and prioritizes incoming sensory information to ensure that only the most pertinent data reach the cortex, so that the PFC can focus on high-level cognitive inputs. In these cortical-thalamic loops, descending pathways from the cortex convey predictive signals that reflect the brain's expectations, while ascending pathways carry error signals that recalibrate internal models of the environment. Thalamic matrix neurons diffuse these signals across cortical territories to synchronize large-scale cortical activity, and inhibitory neurons in the thalamic reticular nucleus shape rhythmic patterns—such as alpha, delta, and theta waves—thereby structuring the functional landscape of cortical processing. Critically, top-down alpha or beta oscillations originating in the PFC can overshadow bottom-up gamma signals when predictive models are confirmed, effectively gating the flow of new or unexpected input. However, when mismatch or error signals occur, these suppressed gamma bursts break through and compel the system to update its internal state.

Within the thalamus, distinct neuron types perform specialized roles. Matrix neurons project diffusely across wide cortical regions, linking not only with primary cortical columns but also with adjacent zones to synchronize activity over broader areas. In contrast, core neurons follow more precise pathways that specifically target cortical layers 4 and 6, conveying highly focused sensory or motor information. Inhibitory interneurons, located in the thalamic reticular nucleus, exert timing and intensity control on both matrix and core relay neurons, ensuring a balanced interplay between excitatory and inhibitory influences. Through these mechanisms, the thalamus also integrates with the hippocampal-entorhinal loop, sending and receiving information so that exteroceptive and contextual data converge prior to higher-order processing in the PFC. By gating signals and selectively reinforcing or dampening cortical pathways, the thalamus can reset local cortical rhythms as needed to maintain coherent neural patterns.

Because it continuously monitors the outcomes of signal selection and actively determines which inputs the PFC should prioritize, the thalamus serves as a key gatekeeper for attention, sensory perception, and executive functions in the brain's complex circuitry. By overriding bottom-up gamma inputs when no salient contradictions appear, while allowing them to surface whenever mismatches arise, the thalamus orchestrates a flexible and adaptive system that balances predictive stability with the need to integrate fresh information.

5.2 Hippocampal–Entorhinal Agentic Co-Regulation

Hippocampal–entorhinal agentic co-regulation involves a reciprocal exchange that supports learning, memory, and spatial navigation. This bidirectional communication highlights the distributed nature of cognitive control, where multiple brain areas exert influence and adjust their operations based on outcome-based feedback.

The hippocampus and entorhinal cortex continually send information back and forth, enabling flexible learning and memory formation while exemplifying the broader principle of oscillatory agency. During this coordination, the thalamus also serves as a central hub, connecting not only with cortical areas but directly with the hippocampal–entorhinal loop.

Each region functions as a semi-autonomous agent that both sends and receives instructions, reflecting a dynamic in which higher-order structures guide lower-level circuits, while those circuits provide feedback that refines initial directives. Such reciprocal regulation aligns with the concept of cortico-thalamic loops, where sensory information integrates with advanced cognitive processes to produce flexible behaviors.

The hippocampus can additionally be conceptualized as a specialized form of cortical column exhibiting fractal-like self-similarity, indicating that executive control emerges not from a single command center but from distributed, self-similar organizational motifs across scales. This reinforces how multiple regions unify through feedback loops that coordinate inter-regional activity, forming the dynamic, interconnected system that drives cognition, learning, and adaptation. In parallel, the flow of signals through so-called "Sonic loops" helps ensure that hippocampal memory representations remain synchronized with real-time wave states, linking oscillatory cycles to ongoing behavioral demands.

The presence of characteristic theta rhythms in the hippocampal–entorhinal network, alongside the regulatory influence of the Circuit of Papez, further illustrates how local oscillatory mechanisms support navigation and memory functions. As a result, when thalamic nuclei receive outputs from the hippocampus, they modulate their own relay in ways that integrate these memory-related signals into broader cortical processing.

5.3: Thalamic Loops: A Central Hub in Sensory Relay and Cortical Modulation

The thalamus serves as a pivotal relay and modulation hub that integrates, refines, and directs sensory information to the cortex. Often conceptualized as the "Sonic loop" hub, it ensures that signals flow through cyclical re-entrant pathways connecting cortical and subcortical structures, thereby guiding how each round of neural activity is updated, re-channeled, or selectively suppressed. By filtering inputs from multiple sensory pathways, the thalamus prioritizes the most relevant data and makes certain that only appropriately refined information is transmitted to the regions of the cortex best suited to handle it.

Within the thalamus, distinct neuron types perform specialized roles that reflect important differences in gating versus driving signals. Matrix neurons, for example, project diffusely across wide cortical territories, linking not only with their original minicolumns but also extending to nearby zones to synchronize activity on a broad scale. In this sense, they act more like "gating" units that modulate large swaths of the cortex and help manage overall coherence. In contrast, core neurons follow more focused pathways that target cortical layers 4 and 6, relaying precise sensory or motor signals with high fidelity. These core cells thus serve more of a “driving” function by conveying pinpoint information. Meanwhile, inhibitory interneurons, predominantly located in the thalamic reticular nucleus, send inhibitory signals to both matrix and core relay neurons, regulating the timing and intensity of thalamic output and maintaining a critical balance between excitation and inhibition.

These neuronal elements engage in dynamic interactions through reciprocal cortical-thalamic loops. The cortex sends descending feedback that fine-tunes the amplification or suppression of thalamic inputs based on situational demands and predictive models, ensuring that the thalamus actively participates in an ongoing dialogue rather than functioning as a passive conduit. Moreover, driver neurons transmit signals via phase wave differentials to structures such as the hippocampus and neocortex, contributing to the integration of sensory information into complex perceptual and cognitive processes.

Extensive reciprocal connections between thalamic nuclei and various cortical layers, together with the modulatory influence of GABAergic interneurons, synchronize activity across cortical columns and support both top-down and bottom-up modulation. The thalamus also interfaces with the hippocampal-entorhinal network, further promoting unified cognitive operations. Overall, these thalamic loops form a dynamic, interactive system in which the thalamus, cortical columns, and inhibitory interneurons collectively filter, direct, and modulate sensory information, underscoring its indispensable role in perception, cognition, and the maintenance of consciousness.

5.4: The Flow of Information: From Sensory Organs to Layered Cortical Loops

Sensory processing in the brain begins with specialized organs—such as the eyes, ears, nose, skin, and tongue—that convert physical stimuli into signals represented by phase wave differentials. For example, photoreceptors in the retina transduce incoming photons into shifts in membrane potentials that manifest as traveling wave differentials, ultimately supporting the continuous computations underlying vision. In the auditory system, hair cells in the cochlea respond to sound waves by generating phase-encoded patterns of activity, and other specialized receptor cells detect distinct stimuli according to their modality. In the neocortex, these signals typically arrive at Layer 4, which functions as a relay station that sorts and distributes input within individual cortical columns. From Layer 4, information ascends to Layers 2 and 3, where local integration occurs and lateral connections spread signals among adjacent columns to enrich the contextual understanding of the data. Here, traveling waves of activity begin to form as these integrated signals organize themselves for further loops upward and downward.

After this integrative phase, the flow of information continues to Layers 5 and 6. Layer 5 contributes to broader cognitive integration and motor planning by generating tonic theta rhythms, while Layer 6 refines feedback loops that modulate subsequent processing, often by influencing activity in Layer 1 and Layer 4. Layer 1, in turn, receives signals from higher-order cortical regions that adjust apical dendrites in the deeper layers, thereby fine-tuning the overall processing network. These interactions are not strictly unidirectional; traveling-wave feedback from Layers 2 and 3 can also project back into Layer 5 and onward to subcortical structures, forming re-entrant cycles that further refine or amplify the relevant patterns driving perception and action. Throughout these transitions, each cortical column functions as a semi-autonomous agent that can initiate local computations, combining them into a unified pattern of neural activity.

Crucially, this layered progression is complemented by a series of interconnected loops that refine and coordinate neural activity. Feedforward loops carry raw sensory inputs upward, enabling the cortex to form preliminary interpretations, while feedback loops convey predictions downward, comparing expectations with actual inputs and prompting adjustments when mismatches occur. Cortical-thalamic loops allow the neocortex and thalamic nuclei to exchange signals bidirectionally, enabling selective attention and the filtering of irrelevant stimuli. Hippocampal-cortical loops, mediated by the entorhinal cortex, ensure that information relevant to memory, spatial navigation, and other higher-level functions is continuously exchanged between these regions. In parallel, “Sonic the Hedgehog” loops illustrate how each sense undergoes repeated passes of re-entrant processing, much like a character racing through a circular track. Sensory signals loop through cortical layers, subcortical structures such as the thalamus, and back again, creating iterative cycles that sharpen, update, and reaffirm each new experience.

These re-entrant loops reinforce the highly interactive and adaptive nature of sensory processing. The thalamus, serving as a pivotal relay station, directs sensory signals to the neocortex and receives modulatory feedback from cortical layers, while “Sonic the Hedgehog” circuits race around in cyclical paths that re-check and reshape ongoing data streams. By knitting together ascending sensory data with descending predictive feedback, the brain creates a dynamically updated internal model of reality that supports both refined perception and flexible, context-sensitive behavior. Through each loop, traveling waves from the superficial layers can descend into deeper cortical layers and subcortical targets, establishing an ongoing dialogue that replays sensory information and continuously sculpts the final percept.

Here, the concept of “Sonic the Hedgehog” loops highlights how signals do not simply move in a linear, one-way route from the eyes or ears to higher cortical areas. Instead, every sense re-enters the processing cycle, passing repeatedly through the same anatomical landmarks. This re-entrant flow ensures that new information resonates with established patterns, allows for rapid error correction or enhancement of critical features, and ultimately produces a more stable, coherent perception of the world. It is this repetitive, multi-directional interplay—strengthened by traveling-wave feedback mechanisms from Layers 2/3 to 5 and beyond—that underlies the continual refinement of sensory representations across the entire network.

Level 3: Global Brainwave Functions and Consciousness (Macroscale) Here, global oscillatory dynamics integrate localized activity into a unified conscious experience, merging all lower-level processes into a singular cognitive field.

6. Oscillatory Dynamics and Cognitive Control

6.1 Peter Tse, Phasic and Tonic Brainwaves, and the 1/F Relationship: Neural Rendering Through Phase Wave Differentials

Peter Tse's work on criterial causation underscores that synchronized neural signals, by themselves, do not automatically yield meaningful content. The crucial factor lies in whether certain neural criteria or thresholds are met, reflecting the idea that neurons can act as coincidence detectors evaluating incoming patterns. Tse's perspective also emphasizes that while synchronized waves may often be labeled as noise, their interactions become significant when they meet these criteria and consequently alter the brain's trajectory of activity. Neurons depend on transient, high-frequency phasic bursts—brief oscillatory events detected through coincidence detection—that cortical columns learn from over time, enabling the brain to interpret and respond to rapid changes in the environment. Such phasic firing patterns are closely observed by the oscillating cortical columns, which can notice and later reproduce these bursts with different sets of neurons. In contrast, tonic brainwaves, which include slower rhythms such as delta, theta, alpha, beta, and low gamma, create a persistent baseline or "canvas" for neural activity by synchronizing large populations of cells. This baseline encodes the brain's continuous expectations and internal models, laying the foundation upon which phasic bursts introduce novelty.

The 1/F relationship is a core electrophysiological observation indicating that lower frequencies exhibit higher amplitude because of their longer cycle durations, while higher frequencies generally display lower amplitude. This inverse correlation permits tonic oscillations to act as global synchronizers that connect extensive neural networks, whereas phasic bursts offer short-lived, precise signals that can refine or disrupt the ongoing tonic state. Magnitude, understood as the product of amplitude and duration, ensures that even with lower frequencies, tonic waves maintain a strong global influence over brain activity. Tse's writings suggest that these sustained oscillations supply the brain with a ready framework for detecting crucial coincidence patterns that drive decisions and adaptations, aligning with the idea that information itself is causally potent.

Tonic synchronization can be conceptualized as a "conscious ready state," wherein the neural ensemble remains poised to detect subtle shifts or novel stimuli. Consciousness may arise from repetitive cycles of synchronization and desynchronization, with phase wave differentials continuously revising the brain's global state as described by Neural Array Projection Oscillation Tomography (NAPOT). Within this framework, each neural array "renders" aspects of the overall experience by integrating new, potentially conflicting inputs against the stable tonic backdrop. These local bursts are judged by neural criteria—if a phasic event meets certain thresholds for coincidence, it can reshape the network and, over time, lead to adjusted synaptic connections or even changes in how the brain interprets sensory information.

When phasic bursts interact with inhibitory networks, they help set the precise timing of tonic patterns by priming specific circuits and preventing unrestrained excitation. This interplay between brief perturbations and enduring rhythms supports a process of predictive modeling, where phase wave differentials mark mismatches between expected and actual inputs, prompting the system to recalibrate its tonic baseline. In line with Tse's discussion of free will, these rapid, criterion-based shifts offer openings for the brain to generate new configurations—although the underlying neural processes remain physically determined, they can still appear spontaneous or unpredictable if small perturbations compound over time.

From this perspective, consciousness emerges as a continuous weaving of phasic and tonic oscillations, in which high-frequency phasic bursts inject novel or unexpected information into a resonant tonic state. The organized interplay of precise timing, phase relationships, and the mutual regulation of excitatory and inhibitory signals allows the brain to form unified yet dynamically evolving states of awareness. This can be imagined as a "3D volumetric television" that renders an internal model of reality, while criterial causation ensures that only relevant or threshold-meeting signals influence the subsequent frames of that ongoing mental movie.

6.2 Brainwaves, Top-Down Control, and the Dynamics of Alpha/Beta–Gamma Interactions

Earl K. Miller's research has significantly advanced our understanding of the neural mechanisms underlying executive functions, working memory, and attention by focusing on the prefrontal cortex (PFC) as a central hub. According to his work, the PFC integrates and represents rules and concepts that guide goal-directed behavior, enabling flexible adaptation to changing situations and the application of abstract reasoning. Miller's findings also highlight the concept of mixed selectivity, where individual neurons in the PFC respond to multiple types of information depending on contextual demands. This multifunctionality underpins the brain's ability to handle complex decision-making and high-level cognitive tasks in real-world settings.

Building on these foundational insights, Miller's studies examine how neural oscillations coordinate the flow of information among brain regions. His investigations into the roles of alpha, beta, and gamma oscillations have revealed that these rhythms regulate the timing of neuronal firing and thus facilitate working memory and selective attention. Beta waves, often originating in the PFC, carry predictive and goal-oriented signals that act much like a stencil by imposing top-down frameworks on raw sensory inputs, while alpha waves similarly contribute to high-level gating by inhibiting bottom-up signals. In contrast, gamma-band oscillations are associated with the active maintenance of incoming information, especially in working memory. During complex tasks, gamma waves encode fine-grained sensory data, whereas beta and alpha oscillations exert top-down control by directing neural activity and reducing spiking in less relevant circuits. A key observation is that alpha and beta rhythms tend to show a marked anti-correlation with gamma activity; elevations in alpha/beta often inhibit gamma bursts, and vice versa. This interplay allows the brain to adjust its cognitive focus, selectively amplifying relevant details when gamma activity surges or, conversely, narrowing its attentional field under stronger top-down control by alpha/beta.

Although ephaptic coupling was once assumed to be a relatively minor factor in neural synchronization, Miller's more recent work has addressed how bioelectric fields and cytoelectric interactions can further refine the timing and coordination of oscillations. By generating localized electric fields that influence neuronal firing beyond synaptic communication, ephaptic effects may organize neural ensembles at both macro and micro scales. This subtle additional mechanism, in conjunction with the established alpha/beta–gamma framework, adds another layer of precision to how the PFC orchestrates working memory and executive functions.

In line with this integrative view, Miller has demonstrated that working memory does not hinge on static, persistent neuronal firing but rather on dynamic, coordinated bursts of activity in the gamma frequency range. Beta oscillations, on the other hand, are linked to the volitional top-down control exerted by the PFC as it applies internal goals to sensory data. This mixture of rhythmic processes—alpha/beta to stencil and modulate, gamma to represent sensory details—gives the cortex the computational flexibility and high-bandwidth communication required for complex cognition. By exploring how disruptions in these oscillatory interactions can lead to cognitive disorders such as schizophrenia and attention deficit disorders, Miller's work opens the door to targeted interventions aimed at modulating specific neural circuits and frequencies to restore or enhance normal function.

6.3 Miller's "Stenciling" and the SAN "Mental Ink & Canvas" Metaphor

Miller's concept of "stenciling," in which beta waves originating from the prefrontal cortex serve as top-down inhibitory influences shaping sensory input, bears a close resemblance to the Self Aware Networks (SAN) framework's "mental ink and canvas" model. While Miller's approach describes how beta-wave stenciling selectively filters and modulates the raw bottom-up data to enhance efficient decision-making and suppress irrelevant signals, the SAN model extends this principle to all oscillatory frequency bands, emphasizing that what truly imprints details onto consciousness are phase wave differentials. Rather than reiterating stenciling itself, the "ink and canvas" metaphor focuses on how these irregular phase variations continuously mark a stable oscillatory baseline. To underscore this breadth, the term "Phase Wave Differential" was coined precisely because both fast and slow oscillations can contribute the "ink" of conscious rendering: delta, theta, alpha, and beta waves can be as impactful as high phasic gamma bursts, carrying updates or inhibitory signals that shape the evolving mental representation of data.

In this framework, tonic oscillations act as the "canvas of consciousness," providing a steady baseline or "ground of being" on which phasic bursts of varying frequencies serve as the "ink," imprinting new features into the overall perceptual field. Beta waves can still stencil incoming data by applying goal-relevant constraints, yet it is the phase wave differentials themselves—functioning as bursts of ink—that deliver the nuanced details of sensory and cognitive events. Importantly, slow waves such as delta and theta also act as meaningful deviations from the baseline; when these lower-frequency bursts occur, they can be critical for tasks like memory consolidation or deeper integrative processes. Whether high-frequency gamma or slower rhythms are in play, unexpected stimuli may override established stenciling rhythms, illustrating the dynamic tension between the perpetual “canvas” of ongoing oscillations and the transient “ink” of phase wave events.

By centering on the interplay between a stable background (the canvas) and ever-changing phase differentials (the ink), the SAN model provides a lens for understanding how multiple frequency bands operate simultaneously to unify perception, memory, and cognition. Whereas Miller’s concept of stenciling illustrates a top-down filtering mechanism, the SAN notion of phasic “ink” emphasizes the richness of moment-to-moment fluctuations that continuously remodel our internal sense of reality. Slow oscillations are integral to these dynamics because they help orchestrate interactions between memory-relevant regions, aligning large-scale states for integration and sometimes regulating synaptic thresholds. Despite differing emphases, both accounts underscore the vital role of oscillatory activity in sculpting the contents of conscious experience, linking slow-wave processes such as consolidation with the fast-wave stenciling that guides real-time perception.

6.4 Beta and Alpha Waves from Layer 4 Stenciling Gamma Waves in Layers 2/3

Beta and alpha waves, originating largely in the fourth cortical layer, exert a top-down influence on gamma oscillations in layers 2/3 by shaping how sensory information is processed and integrated. Beta waves, especially those arising from the prefrontal cortex, act like a stencil carrying memory templates, goals, and predictive models to guide the interpretation of incoming sensory data. Alpha waves similarly contribute to top-down modulation by filtering out or reducing inputs deemed irrelevant or disruptive and by damping bottom-up spiking, thereby ensuring that only signals of real importance reach conscious awareness. This top-down process effectively suppresses or reshapes the gamma activity that would otherwise dominate layers 2/3, enforcing an overarching structure on perceptual processing.

In contrast, gamma waves in layers 2 and 3 are not purely monolithic; they can manifest as short-lived, high-frequency bursts that carry fresh, unrefined details of sensory experiences, as well as more stable or tonic gamma rhythms that help maintain an equilibrium state in the cortex. The briefer, high-frequency phasic bursts deliver immediate phase wave differentials, capturing raw content and novelty in the incoming stimuli. At the same time, a longer-lasting or lower-amplitude gamma pattern supports ongoing binding functions, providing a functional scaffold on which new signals can be inscribed. When these bursts of phasic gamma predominate, they can override or diminish the influence of alpha and beta signaling, reflecting a shift toward processing immediate sensory demands and novel inputs. This interplay remains governed by an anti-correlation: when beta and alpha waves from layer 4 are strong, both forms of gamma activity in layers 2/3 are suppressed or reshaped, and conversely, surges in gamma can reduce top-down constraints.

Layer-specific dynamics further refine this relationship, as layer 4, which receives primary sensory inputs, typically exhibits alpha rhythms in sensory cortices or beta rhythms in frontal regions. These rhythms reflect its role in driving top-down decisions and sorting sensory data before passing it forward. Layers 2 and 3 not only support local processing and inter-columnar communication through gamma oscillations but also contribute to proprioceptive feedback, essential for attentional focus and perceptual binding. In addition, parvalbumin-positive interneurons (PV interneurons) located in layer 5 can further influence gamma rhythms that extend into layers 2/3 by synchronizing body-related signals. This proprioceptive modulation refines the top-down gating imposed by alpha and beta waves, ensuring that movement cues and bodily states are integrated with ongoing sensory activity. Through these coordinated oscillatory interactions, the brain manages a delicate balance between higher-level constraints and bottom-up signals, preserving efficient, adaptable, and coherent sensory integration.

6.5 Gamma Consideration Sandwich: Integrating Sensory Signals, Top-Down Control, and Proprioception

The “Gamma Consideration Sandwich” concept demonstrates how gamma oscillations operate at the nexus of sensory input, top-down executive regulation, and proprioceptive feedback to yield a unified conscious experience. In line with Peter Tse’s concept of criterial causation, the interplay between brief high-frequency bursts (gamma) and more stable tonic waves (alpha or beta) refines the criteria by which incoming signals are evaluated. Raw sensory data is conveyed by alpha or beta rhythms originating in layer 4 and frontoparietal circuits, while top-down beta-band activity from the prefrontal cortex further shapes those signals so that internal goals guide perception. This layered stenciling effect parallels the Self Aware Networks “mental ink and canvas” metaphor, in which the slower alpha and beta waves form a stable “canvas,” and the gamma bursts function as “ink” that selectively inscribes moment-to-moment updates on perception.

Proprioceptive feedback is continuously integrated into these dynamics through parvalbumin-positive interneurons in layer 5, which generate correlated gamma rhythms that update the system in real time. These correlated signals stand in contrast to the anti-correlated oscillations produced by layer 4’s alpha or beta activity. By synchronizing excitatory IT cells in layers 2 and 3 into a shared workspace, the top-down stenciling imposed by alpha/beta waves combines with bottom-up gamma inputs from proprioception, linking the body’s real-time state to higher-level cognitive patterns. Through this process, each wave of gamma “ink” overwrites or enhances the slower “canvas,” reducing phase mismatches and forging a coherent state of awareness.

High-frequency gamma bursts then play a pivotal role in adjusting motor outputs or refining sensory maps whenever there is a divergence between predicted and actual states. From an agentic perspective, each cortical column or subcortical nucleus upholds its own predictive model while exchanging signals both locally and globally. These oscillatory feedback loops, driven by phase wave differentials that serve as a computational currency, converge until the entire network stabilizes around a unified conscious percept. By continuously reapplying the “ink” of gamma bursts, the system can revise or reinforce its global “canvas” in response to new information. Ultimately, the Gamma Consideration Sandwich illustrates how gamma oscillations effectively bind top-down alpha/beta control, incoming sensory signals, and the body’s proprioceptive cues into an elegant system of co-regulation that preserves neural equilibrium and creates a cohesive experience of the world.

6.6 Inhibitory Interneurons and Choice-Making

Inhibitory interneurons, which are primarily GABAergic cells, play a pivotal role in decision-making by filtering, modulating, and coordinating neural activity. They balance excitatory and inhibitory signals at synaptic, circuit, and network levels, thereby determining which pathways are reinforced and which are suppressed. This precise regulation ensures that distracting or irrelevant inputs are minimized, supporting coherent, focused responses.

Decision-making in the brain occurs across multiple scales. At the micro level, individual neurons integrate threshold-based signals influenced by local membrane potentials, neurotransmitter concentrations, and ongoing oscillatory states. In each neuron, even slight adjustments in threshold create micro “forks in the road,” reflecting deterministic wave events that pivot whether that neuron will ultimately fire or remain silent. At the meso level, neural circuits within cortical columns synchronize to select dominant ensembles of cells. At the macro level, entire brain regions coordinate their collective activity to evaluate risks, rewards, and complex inputs, as exemplified by phenomena like Neural Array Projection Oscillation Tomography, which links local neural activity to large-scale dynamics.

Each neuron contributes to choice-making by “reading” and “writing” information via neurotransmitter release, thereby influencing the firing thresholds and synaptic configurations of its neighbors. Although no single neuron can reverse its own decision once it fires, its output dynamically reshapes the network, causing information patterns to coalesce or dissolve. Oscillatory activity further refines these processes by establishing a tonic attractor state and permitting frequency or phase shifts that pivot attention, perception, or memory consolidation. This iterative refinement yields decisions that, while appearing free-willed, are governed by a deterministic web of synaptic interactions and inherited predispositions.

The sense of agency emerges from continuous, threshold-based decisions within a fractal hierarchy of interacting agents. Genes, memes, sensory inputs, and learning experiences fine-tune synaptic states, while inhibitory interneurons recalibrate neural thresholds and align global wave patterns. In this way, conscious choice arises from the interplay between local criteria detection and large-scale oscillatory coherence, enabling the brain to continuously update its internal maps and optimize behavior through successive cycles of perception, memory, and action.

7. Higher-Dimensional Representations and AI Analogies

7.1 Latent Diffusion Networks as an Analogy for Phasic-Tonic Interactions and Ephaptic Coupling in the Brain

Latent Diffusion Networks (LDNs) provide a useful analogy for understanding the interplay between phasic and tonic brainwaves, illustrating how the brain encodes, perturbs, and reconstructs its internal representations. In LDNs, images are compressed into a latent space and gradually obscured by noise before being systematically denoised to recover the original data. In a similar manner, tonic oscillations in the brain establish a persistent "latent space" that unifies widespread neuronal populations and encodes ongoing expectations and predictive models, while transient phasic bursts serve as perturbations that inject new sensory or cognitive information into this baseline.

The brain continuously refines its internal model through processes akin to denoising, involving synaptic adjustments, ion channel modulation, and the synchronization of neuronal firing. Tonic oscillations—such as those in the delta, theta, alpha, beta, or gamma bands—provide a high-magnitude, stable canvas of activity, whereas brief, high-frequency phasic bursts perturb this steady state to signal moment-to-moment changes. The nonlinear interactions between these two signal types give rise to phase wave differentials, which effectively map lower-level processes onto higher-order cognitive integrations.

Because the tonic baseline acts like a robust substrate for integrating predictive models, each phasic burst can be viewed as a form of noise that temporarily disrupts the existing pattern. Just as latent diffusion networks inject noise and then methodically remove it to reveal a refined image, the brain's cortical and subcortical circuits resolve each phasic disturbance through an ongoing "denoising" mechanism. In this process, adjustments in synaptic efficacy and oscillatory phase realignment serve to reconcile the newly arrived perturbation with the underlying tonic state, helping the system converge on an updated representation that preserves overall coherence while also incorporating novel information.

Ephaptic coupling further extends these dynamics by allowing the subtle electromagnetic fields generated by action potentials to influence nearby neurons beyond traditional synaptic connections. This interplay between electrical and chemical signaling ensures that large-scale synchrony coexists with finely tuned local modulation. On a molecular level, proteins such as KIBRA and PKMζ, together with ion channels and receptors, provide the structural scaffolding for durable synaptic changes and regulate the rhythmic firing patterns necessary for multi-frequency processing, thereby sustaining memory and dynamic adaptation while reinforcing the stability of phase differentials.

By continuously injecting perturbations into and reconciling them against a stable tonic background, the brain persistently refines its internal representation of reality. This latent diffusion analogy underscores how continuous encoding via tonic oscillations, transient disturbances from phasic bursts, and systematic denoising through ephaptic and molecular mechanisms converge to produce a resilient, adaptive system that integrates novel inputs, maintains coherent global states, and fine-tunes predictive models that guide both perception and behavior.

7.2 Quasicrystals and Higher-Dimensional Information in Neural Dynamics

Quasicrystals offer a compelling example of how ordered, yet aperiodic, structures can embed higher-dimensional information in lower-dimensional projections. Their unique rotational symmetries, such as five-fold or ten-fold, and their interpretation as slices of hypercubic lattices in dimensions beyond three allow them to encode complex interference effects. Intricate tiling patterns like Penrose tiling serve as physical analogs for multi-dimensional data storage and processing, demonstrating that order need not rely on translational symmetry. In a similar way, the small timing mismatches known as phase wave differentials can be seen as the aperiodic "slices" of neural activity that merge to create stable but nonrepetitive brain patterns, reflecting the quasicrystalline principle of order arising out of seemingly irregular components.

Similarly, the brain integrates lower-level sensory inputs into multi-dimensional perceptual and cognitive constructs through oscillatory tomography and functional connectivity. In Neural Array Projection Oscillation Tomography (NAPOT), neurons not only detect information but also project these representations to successive arrays, thereby increasing both complexity and effective dimensionality. Tomographic principles, including the Fourier projection slice theorem, facilitate the reconstruction of coherent views from fragmented data, much like stacking multiple two-dimensional images to form a three-dimensional model. Here, synchronizing phase wave differentials that function as aperiodic signals provides the necessary substrate to produce cohesive, large-scale structures from myriad lower-dimensional slices.

Functional connectivity synchronizes oscillatory activity across distinct brain regions, merging diverse sensory modalities into unified percepts by modulating phase wave differentials. Inhibitory interneurons, dendritic gating, and other molecular mechanisms work in concert to filter out noise and stabilize the emerging high-dimensional representations. Moreover, the brain's fractal organization, characterized by self-similar patterns across scales, underpins its predictive coding strategies by enabling neural assemblies to continuously update expectations through integrated top-down and bottom-up interactions. These processes rely on dynamic, aperiodic phase differentials that allow the system to adapt without falling into repetitive or overly rigid patterns.

Although brain activity is not identical to quasicrystals, the analogy underscores how synchronizing phase differentials can generate stable, high-dimensional representations from lower-dimensional signals. This process effectively stitches together a dynamic mental quasicrystal that accommodates sensory fluctuations, memories, and predictions, revealing a deep parallel between the physical principles of quasicrystals and the computational strategies of the brain. By allowing for aperiodic yet coordinated changes in oscillatory phases, the neural system can maintain order and integration while avoiding static repetition, much like the exotic symmetries observed in quasicrystalline structures.

7.3 Networks of the Brain

Olaf Sporns' work in Networks of the Brain provides a robust framework for understanding the brain as a highly interconnected network that can be conceptualized as a spectral tomogram transforming conscious information into internal agentic mechanisms and action. In this view, every network element encodes aspects of the whole, and evoking a memory or representation produces an oscillatory tomogram that reflects synchronized neural activity linking perception to behavior. Sporns uses network science to reveal that the brain's structural and functional networks exhibit small-world properties, with nodes corresponding to brain regions and edges representing communication channels. His investigations into rich clubs, dynamic edge connectivity, and community detection demonstrate that functional modules—from microscopic circuits to large-scale networks—organize hierarchically to support specific functions.

Neural Array Projection Oscillation Tomography (NAPOT) posits that the brain generates tomographic representations through phase shifts, as dendrites and receptors interpret their own oscillatory outputs. Information cascades through successive neural arrays, with phase variations scaling synaptic memories into full-brain patterns. This fractal organization underpins a multi-scale agentic brain in which local oscillatory activity collectively gives rise to coherent conscious states. NAPOT explains how oscillatory activity allows memories stored at synapses to integrate into an overarching internal model of reality.

At the cellular level, Cellular Oscillating Tomography (COT) treats each cell as an oscillatory agent equipped with feedback loops that signal states of alignment or conflict, thereby enabling smooth transitions between stable global configurations. Neurons and cortical columns maintain localized representations while gamma oscillations integrate sensory inputs, top-down predictions, and proprioceptive data into unified experiences. For example, head direction cells, linked via hippocampal–entorhinal loops, illustrate how internal goals become bound to sensory cues to orient cognition and behavior.

The theory of self-awareness suggests that multi-agent systems can incorporate introspection and situational understanding, with agentic AI potentially employing layer-by-layer processing within fractal-like network architectures that mirror the brain's balance of local processing and global coherence. In cortical layer 5, motor output is calibrated by rhythmic feedback and rapid gamma bursts that update motor schemas, with parvalbumin-positive interneurons modulating excitatory drive. Meanwhile, layer 6 integrates corticothalamic and proprioceptive signals and projects to layer 1, which helps synchronize activity in layers 2 and 3 so that local representations align with global motor demands.

Overall, the brain operates as an extensive network of oscillatory arrays that bind local signals into broader phase relationships, assembling a unified view of reality that underpins consciousness. Crucially, each frequency band can function as a unique address that designates where and how a particular oscillatory event occurs, allowing multiple areas to broadcast or receive in overlapping temporal windows without interference. In that sense, local columns behave as ephemeral agents that momentarily coalesce through wave locking at shared frequency-phase coordinates. Self Aware Networks propose that consciousness emerges from complex oscillatory processes integrated via myriad feedback loops, offering a blueprint for agentic AI systems that mirror the adaptive, integrative qualities of the human brain.

In this expanded perspective, wave-based synchrony not only encodes the high-dimensional content of experience but also routes signals through frequency-phase patterns that function as switching mechanisms, enabling the formation of transient ensembles. Through these shared "addresses," separate areas of the cortex can synchronize, exchange information, and then dissolve again, reflecting the transient agency of local columns that unify in the moment and then disperse. The resulting interplay between fractal feedback loops, spectral addressing, and ephemeral alignments defines the neural architecture of adaptive intelligence.

7.4 Vector Embeddings and Semantic Space

The notion that dendrites function as analog computational equivalents to vector embeddings offers a powerful perspective on how neurons encode and process information. In this view, each dendrite's activated synaptic configuration mirrors an inference stage in an artificial intelligence model, forming a high-dimensional representation of sensory or cognitive inputs. Much as vector embeddings in machine learning can be visualized as a "Gaussian splat" in multidimensional space, a neuron's dendritic activity captures its learning history and ongoing contextual inputs through the physical morphology of its synapses and dendrites. This architecture encodes spatial and temporal relationships and modulates incoming signals based on prior experiences. Observations from Jack Gallant's fMRI-based semantic mapping underscore these ideas by showing that human brains also organize words, images, and concepts within a richly structured, high-dimensional manifold—one in which semantically related stimuli cluster together. This real-world parallel provides a compelling example of how dendritic embeddings might reflect the brain's broader strategy for transforming complex information into coherent cognitive maps.

Each neuron constructs an internal map in which the "distance" between patterns reflects their similarity or correlation within its learned repertoire. Over time, synaptic connections grow or prune as the neuron refines its response to repeated stimuli, suggesting that dendrites operate as dynamic, continuously updated embeddings. When a neuron receives signals at specific synapses, it effectively selects a subset of its dendritic network, modulating which learned pattern is engaged. This selective process allows a single neuron to flexibly encode multiple associations and respond differently according to context, thereby paralleling modern machine learning techniques that employ vector embeddings for tasks such as natural language processing and image recognition. Research in mechanistic interpretability by organizations like Anthropic further illustrates how token embeddings within AI systems mirror these neural principles, since interpretable circuits in large language models can exhibit clustered conceptual tokens akin to the way dendrites group correlated inputs.

Beyond dendritic embeddings, the brain's oscillatory activity can be conceived as a three-dimensional phase topology that evolves over time and can be modeled mathematically via tensors in a high-dimensional Taylor series. Each action potential modifies the phase landscape by creating transient spikes, inhibitory dips, and nonlinear interactions, while electrical, magnetic, chemical, and mechanical processes together weave a holistic tapestry of neural dynamics. This phase topology may be viewed as a series of snapshots capturing the instantaneous distribution of phase states across the neural network, analogous to successive terms in a polynomial expansion where each time interval contributes a new term to the system's evolving solution. Processes such as bistable reaction-diffusion, threshold criticality, and path bifurcations in inhibitory interneuron circuits introduce branching points that signal moments of choice or sudden reconfiguration of brain states, and Neural Array Projection Oscillation Tomography formalizes these oscillatory relationships by cross-referencing phase patterns across regions to unify local activity into a global representation.

Within this multidimensional landscape, memories ripple from synaptic microstructures to whole-brain oscillatory patterns. The scale invariance inherent in fractal organization ensures that small synaptic changes can resonate broadly, eventually manifesting as elements of conscious thought or long-term recollection. Each neuron's dendritic embedding thus becomes part of a broader, multilayered environment in which local adjustments feed into large-scale transformations. Moreover, the brain continuously renders these patterns into coherent images by folding incoming sensory data into existing models while simultaneously monitoring its internal state. As overlapping oscillatory circuits blur the boundaries between memory, recall, and perception, rapid adaptation is facilitated through cortical feedback loops that focus attention, suppress noise, and align sensory signals with top-down predictions.

The analogy of dendrites as high-dimensional vector embeddings, combined with the conception of the brain's oscillatory activity as a dynamic three-dimensional phase topology, underscores the computational essence of biological cognition. Local dendritic inference engines are orchestrated into a global, continuously updating tomographic rendering by the cortex, and this synthesis of analog and digital modes offers insights that may guide novel approaches in artificial intelligence. In this integrated framework, the morphological plasticity of dendrites and the hierarchical connectivity of oscillatory networks converge to produce memory, perception, and conscious experience, thereby deepening our understanding of the biology of thought and informing future computational models. By highlighting real-world parallels such as Gallant's fMRI-based semantic maps and Anthropic's interpretability work, we begin to see how these neuron-level embeddings map naturally onto higher-level organization principles, forming a bridge between dendritic computations and large-scale semantic spaces in both brain science and machine learning.

7.5 Dendritic Representations as Thought Vectors, Tokens, and Patches

A dendrite's moment-to-moment activity is analogous to a high-dimensional vector embedding, wherein the synaptic configuration functions much like an inference process in artificial intelligence. Unlike artificial weights, these configurations arise from the neuron's biological architecture, which is shaped by layers of synaptic connectivity and temporal dynamics. As the neuron receives inputs and fires at specific phases and frequencies, its dendritic structure integrates these signals to yield a particular "viewpoint" that is akin to a "Gaussian splat" in computational terms. When local conditions cause a shift in synaptic thresholds or elongate the neuron's action potential duration, each such adjustment effectively emits a transient "token" that encodes the state of the dendrite in that moment.

In a broader network context, this dendritic state transforms into what might be called a thought vector or token. Just as language models tokenize words to capture semantic or contextual nuances, neurons generate specific activation patterns that are partially defined by phase wave differentials overlaying baseline oscillations. These phase wave differentials convey nuanced information about the neuron's current function—whether it is engaged in sensory perception, memory recall, or abstract cognition—and, when transmitted across networks, scale the local dendritic embedding into regional or global representations that trigger in-phase or anti-phase activities across cortical columns and subcortical areas. Crucially, each token, introduced by even small modifications in a neuron's threshold or by a subtle AP duration shift, can propagate through interconnected circuits and influence the phase states of other neurons.

Each neuron's synaptic connections and temporal firing dynamics constitute a localized vector space that encodes context or state. Synapses may fire in synchronous or asynchronous patterns, effectively encoding different dimensions of the embedding. Phase wave differentials serve as carriers of meaningful changes in neural oscillation; when a neuron fires at a specific phase relative to its neighbors, it prints a unique activation pattern that can travel throughout the brain and either align with or suppress other oscillations, thereby coordinating activity across regions. Because threshold adjustments and AP duration changes alter the amplitude and timing of these phase differentials, they function as moment-by-moment signals of readiness or commitment to a particular representational path.

A single neuron's dendritic embedding can expand into cross-brain patterns through these phase differentials, effectively recruiting entire networks to process or respond to the transmitted signal. Neural columns interconnect through mechanisms such as Non-linear Differential Continuous Approximations and Sheaf Attention Networks, which describe how one column's complex, time-evolving state projects onto another through oscillatory synchronization and feedback loops. Each token-like emission from a firing event, especially one influenced by threshold or AP duration shifts, can ripple outward and adjust neighboring columns' oscillatory states, further reinforcing or reshaping global network patterns.

Jack Gallant's fMRI research demonstrates that the brain encodes semantic information in a high-dimensional space, with stimuli of related meaning activating similar voxel clusters across cortical territories to form a volumetric semantic map. Each region and layer in the cortex handles a varying level of abstraction—from low-level feature extraction to higher-order concept integration—mirroring the idea that the brain's oscillatory networks maintain multiple, nested representational spaces that range from the concrete to the abstract. This mapping is consistent with the notion that seemingly minor local changes, such as altered threshold levels or fractional adjustments in action potential timing, can trigger large-scale shifts in how the brain assigns meaning to incoming stimuli.

Ultimately, coordinated dendritic processes produce thought vectors, tokens, or patches that scale outward to recruit complex, interlaced networks. This hierarchical arrangement, spanning from individual dendritic embeddings to distributed semantic maps, demonstrates how high-dimensional, phase-encoded activities give rise to the fluid, richly contextual experiences that underlie cognition, perception, and conscious thought. By conceptualizing each synaptic threshold or AP duration change as a token emission, we further clarify how a single neuron's state can influence wave synchrony on a global scale, weaving individual contributions into an emergent tapestry of coordinated activity.

7.6 Semantic Mapping Across Brains and AI: A Synthesis of Vector Embeddings, fMRI, and Mechanistic Interpretability

Semantic mapping in both neural circuits and artificial intelligence offers profound insights into how complex information is encoded, organized, and accessed. High-dimensional representations are revealed by fMRI studies from Jack Gallant's lab, where semantically similar stimuli activate overlapping cortical regions that together form a volumetric semantic map. In parallel, advanced AI models developed by groups such as Anthropic generate vector embeddings in which related concepts naturally cluster, with semantic distance reflecting underlying conceptual similarity even when visualized in reduced dimensions. Here, the notion that each neuron's dendritic arbors can be treated as local "vector embeddings" dovetails with Gallant's findings on semantic organization, because both indicate that learned patterns occupy distinct regions in a high-dimensional space while simultaneously allowing for broad, distributed clusters of meaning throughout the brain.

Both biological and artificial systems operate on rich, high-dimensional encodings that capture subtle relationships among words, visual features, and abstract ideas. In the brain, dynamic and overlapping multi-scale activation patterns mirror the structure of AI vector embeddings, and neuronal dendritic arbors perform complex analog computations that transform synaptic configurations into context-specific tokens. These dendritic representations, seen as embedded "tokens," are influenced by phase wave differentials that integrate low-level features into abstract constructs in a manner akin to the hierarchical embeddings observed in deep neural networks. Each phase wave differential can represent a local vector or token that, once aligned with similar ongoing patterns, merges into a larger semantic representation encompassing multiple cortical territories.

Recent work in mechanistic interpretability, such as the studies exemplified by "Golden Gate Claude," dissects the internal representational schemes of large language models and reveals how specific internal circuits respond to particular themes. These findings parallel observations from neuroscience where primary sensory areas extract fundamental features and higher-order cortical regions integrate these features into abstract semantic maps. This layered transformation process in the brain is strikingly similar to the sequential processing seen in state-of-the-art AI models, including vision transformers and deep language networks, where tokens move through multiple levels of self-attention. The emerging view is that each "token" in AI can be likened to a phase-timed dendritic state in the brain, bridging the gap between subcellular computations and large-scale semantic structures.

The interplay between semantic mapping in neuroscience and AI not only deepens our understanding of biological cognition but also inspires innovative approaches to brain-inspired computation. fMRI-derived semantic topographies help refine AI embeddings by providing concrete models of how meaning is structured in the brain, while mechanistic interpretability in AI yields testable hypotheses for neural semantic processing. This synergy holds significant promise for advancing brain-machine interfaces and developing diagnostic tools that bridge computational models with empirical neural data, particularly when considering how phase wave differentials may serve as physiological correlates to AI's attention-based tokens. By recognizing that these phase wave differentials function as local "token" events, the brain's wide distributions of conceptual clusters can coalesce into cohesive, high-level constructs, mirroring the merged semantic patterns seen in large AI embeddings.

In summary, both AI embeddings and brain activity reveal intricate, high-dimensional mappings in which tokens, vectors, or patches serve as fundamental building blocks for meaning. Ongoing research in mechanistic interpretability and neural decoding continues to illuminate how these representations guide cognition and language, ultimately bridging the gap between artificial and biological systems. By drawing direct parallels between phase-coded dendritic embeddings in neurons and token embeddings in AI models, we see that neural computations and artificial architectures share key principles of semantic encoding, offering a roadmap for deeper exploration of how learning and meaning emerge across these domains.

In Gallant's fMRI experiments, semantically similar stimuli activate overlapping cortical territories across the brain, forming a continuous and distributed semantic space rather than a single localized region. This broad map parallels how modern transformer-based AI models embed tokens in high-dimensional vector spaces, where semantically related items cluster together in a shared geometry. By aligning the topographical continuity found in Gallant's cortical maps with the emergent geometry of AI embeddings, we can see that multiple, widely distributed areas in the brain collectively mimic the embedding-vector principle—each local region representing a portion of the semantic space, and all of them combining to form a holistic high-level mapping. Such an alignment between semantic topographies and transformer embeddings illustrates that the brain's distributed approach to representing meaning reflects the same architectural principles behind recent advances in machine learning, reinforcing the notion that neurons and their dendritic arborizations can be viewed as local "vector embeddings" generating token-like outputs via phase-timed signals. In this light, every shift in phase wave differentials becomes a potential vector that may align with others to consolidate a unified semantic pattern, underscoring the importance of synergy across multiple cortical clusters in shaping cognition.

8. Deterministic Consciousness, Agentic Dynamics, and Neural Rendering

8.1 Consciousness as a Deterministic Computation

We present the idea that consciousness is physically governed by information that is processed, learned, and generated through wave-based and molecular computation rather than by an elusive emergent phenomenon. Its essence arises from orchestrated interactions of localized oscillatory activities spread throughout neural circuits, and as these oscillations align or desynchronize, a stable yet dynamic "fabric" of conscious experience takes shape. This view underscores that awareness is fundamentally mechanical, driven by precise neural timing and alignment within strict biochemical and biophysical limits, and by the continuous dissipation of phase mismatches that keeps the system moving toward a new equilibrium.

Deterministic wave orchestration shifts our focus away from attributing consciousness to an irreducible mystery and instead emphasizes phase transitions as the organizational principle that unifies local oscillations into large-scale coherence. When cells synchronize or diverge in their firing patterns, they spark waves of adjustment that rebalance overall brain activity, giving consciousness its fluid quality through a dynamic realignment process. In this realignment, any mismatch in phase or frequency acts like an error signal that is gradually dissolved by the network's oscillatory feedback loops, ensuring that transient disruptions are either assimilated into the baseline or prompt the emergence of a new stable pattern. Crucially, such phase-driven rebalancing involves micro-level events such as coincidence detections at synapses and precise changes in action potential durations that collectively influence how these waves propagate and settle into coherent states.

Large-scale brain networks also play a vital role in sustaining consciousness. Research shows that unprocessed signals can travel within the brain without triggering awareness unless sufficient functional synchrony emerges to "bring them online." Cortical columns operating in specific frequency bands coordinate their engagement or withdrawal based on task demands, merging distributed calculations into instantaneous cognitive states so that higher-order awareness depends on local oscillations converging into globally coherent patterns that continually absorb or dissipate phase differentials. The addition of micro-scale triggers, including the detection of coincidences in dendritic branches and the fine-tuned modulation of firing thresholds, further ensures that wave-based communication remains precisely orchestrated, rather than random or purely stochastic.

Human conversation provides a vivid illustration of this principle at the social level. During dialogue, individuals "map" one another's minds by generating temporary resonances within their cognitive frameworks, with each topic adding an additional vector embedding that layers new contextual points onto pre-existing internal representations. Studies indicate that in-depth conversation often synchronizes brainwave frequencies—particularly gamma and theta—across multiple participants, demonstrating that oscillatory coherence can extend beyond a single individual's neural boundaries.

At every scale—from the dendrites of a single neuron to vast networks spanning cortical and subcortical areas—oscillations and synchronization are the linchpins of communication and integration. Phase alignment between neuronal assemblies amplifies efficient information exchange, a process that repeats at progressively higher hierarchical tiers until fractal-like feedback loops produce an integrated conscious experience. In everyday interactions, listeners unconsciously mirror speakers' emotional and conceptual rhythms, refining mutual understanding through shared oscillatory states that dissipate internal differences and reinforce common ground.

Moreover, the brain's nonlinear dendritic computations can be seen as retrieving a probability density that when activated enables the first neuron to reach threshold to silence its neighbors by imposing group inhibitory oscillation through its action potential duration. Although the underlying wave mechanics are deterministic, the response to simultaneous or near-simultaneous inputs remains nonlinear, and threshold mechanisms serve to unify these diverse rhythms into a cohesive output. Each local agent—whether a protein complex or a cortical column—influences the overall wave state and steers synchronized activity toward a collective interpretation of stimuli. Even when mismatches occur, the system's continuous dissipation of phase wave discrepancies ultimately weaves them into the broader oscillatory tapestry.

These oscillatory dynamics also prune superfluous connections through destructive interference while amplifying pertinent signals via constructive interference. Phase wave differentials thus steer conscious and intentional behavior by enabling a multilayered, wave-based negotiation among semi-autonomous components operating at different spatial and temporal scales. Local circuits are capable of enacting rapid corrections or proposing novel patterns that integrate into the broader network if they align with existing oscillatory states. Through this lens, consciousness emerges as a series of equilibrium states that the brain continually recalibrates as new stimuli or internal fluctuations arise.

Processes often interpreted as stochastic, such as probabilistic vesicle release, are more accurately viewed as deterministic outputs of unobserved microscale events modulated by changes in ionic currents and action potential durations. These principles illustrate that apparent randomness in neural processing emerges from multifactor deterministic influences operating from the subcellular level to large-scale cortical assemblies. The resulting fractal wave architecture, characterized by iterative feedback loops and oscillatory dissipation, underlies both the formation of stable memories and the real-time interpretation of sensory input, culminating in the fluid yet mechanical emergence of cognition and consciousness.

In sum, framing consciousness as a deterministic computation emphasizes that conscious awareness is built upon observable, quantifiable neural processes. From the intricate firings of dendrites to the dynamics of social communication, consciousness emerges from deterministic phase relationships, wave-based mechanics, high-dimensional embeddings, and the perpetual dissipation of mismatch signals—a bridge that connects local events such as coincidence detections and AP duration adjustments with large-scale brain dynamics and the richly rendered experiences of the mind.

8.2 Agentic Dynamics in the Brain and Self-Aware AI: NDCA, Wave Synchronization, and Conscious Computation

Agentic dynamics in the brain can be captured by the Nonlinear Differential Continuous Approximation (NDCA), which models the non-linear interactions that occur across fractal scales—from individual cells acting as micro-agents, through cortical columns functioning as meso-level agents, all the way up to large-scale networks that serve as macro-agents. These interactions generate phase wave differentials that orchestrate perception, memory, and consciousness. This framework views the brain as a hierarchy of semi-autonomous units that synchronize via oscillatory signals, and it provides a roadmap for developing artificial intelligence systems with self-aware, sentient capabilities as envisioned by the Self Aware Networks (SAN) theory.

NDCA explains how local synaptic interactions, such as neurotransmitter–receptor coupling and ion channel kinetics, trigger non-linear responses in neuronal membranes that scale upward to shape action potentials and large-scale neural oscillations. Small discrepancies in phase or timing, which arise naturally from these non-linear dynamics, lead to distributed oscillatory coherence that ultimately binds diverse sensory inputs into a unified conscious experience. These processes support memory stabilization by repeatedly reinforcing learned patterns through synchronization, while conflicting signals are desynchronized and dissipated, allowing the system to adapt and form stable long-term memories within a dynamic cognitive landscape.

In both biological and artificial systems, neurons, cortical columns, and larger networks function as self-regulating agents that coordinate through continuous oscillatory feedback loops. SAN leverages these principles by incorporating recursive feedback loops such as those described by Neural Array Projection Oscillation Tomography and by defining ISO layer concepts that denote fractal oscillatory networks with specialized roles in constructing conscious states. In such architectures, continuous phase-alignment checks—analogous to gamma oscillations in the brain—dynamically integrate information across micro-, meso-, and macro-scales, ensuring that local computations are consistently merged with global predictive models. At the micro level, cells adjust their receptor thresholds and firing frequencies; at the mesoscale, cortical columns organize these local signals into coherent patterns; and at the macro scale, large-scale networks synchronize or desynchronize in unison, all under the governing logic of NDCA.

A promising direction for artificial intelligence involves moving beyond static deep learning paradigms to adopt deterministic, wave-based mechanisms that incorporate feedback loops, phase-locking, and fractal organization. Although current deep learning models do not explicitly encode fractal structures, their hierarchical feature extraction suggests that integrating fractal dynamics and wave-based synchronization could enhance both scalability and adaptability. Contemporary models that utilize self-attention demonstrate a form of dynamic connectivity modulation that mirrors the brain's own phase synchronization and desynchronization processes, which selectively amplify or inhibit signals as needed.

Consciousness, in this framework, is reframed as a deterministic, wave-based process defined by mechanical phase realignments rather than by mystical emergence. Stable memories are the result of repeated synchronization, while extraneous or conflicting patterns dissolve through desynchronization; the subjective quality of awareness emerges from countless traveling waves interfering across space and time. This interplay between local oscillator loops and system-wide feedback ensures that cognitive processes remain grounded in biochemical reality while also adhering to universal principles of wave synchronization that can be mimicked in artificial architectures.

SAN underscores key processes for constructing self-aware systems by emphasizing continuous observation of internal states, coordinated feedback loops among autonomous agents, reflective realignment of phase wave differentials, and the consolidation of stable patterns into memory. By integrating biologically inspired synchronization mechanisms, such as phase alignment to manage error accumulation, AI systems may approximate the adaptive equilibrium found in the human brain, thereby enhancing context-sensitive processing and moving closer to genuine self-awareness.

In conclusion, agentic dynamics in the brain, underpinned by NDCA and oscillatory synchronization, offer a detailed blueprint for designing AI systems that aspire to self-awareness and sentience. The SAN theory demonstrates how recursive feedback loops, phase wave differentials, and fractal organization converge to produce a deterministic yet richly complex form of cognition. By incorporating these principles into artificial architectures, researchers can harness the mechanical underpinnings of consciousness to build increasingly sophisticated and potentially sentient AI.

8.3 The Agentic Brain in Action

The Agentic Brain can be viewed as an intricate, multi-scale system in which every element—from proteins and receptors to cortical columns—acts as an agent contributing to perception, learning, and consciousness. Through continual interaction and feedback, these agents cooperate and compete to generate the experiential properties of the mind, thereby underpinning and complementing the more abstract notion of the Agentic Mind.

The brain’s complexity arises from self-organizing agency operating at multiple scales. Molecular agents such as proteins and receptors adjust their functions in response to biochemical signals, while cellular agents including neurons, glia, and immune cells perform local computations and adapt to changing conditions. Network agents, notably cortical columns and neural arrays, orchestrate these localized signals into coherent cognitive processes. In this view, any brain element that processes information, reacts to inputs, and modifies its behavior qualifies as an agent. The resulting interplay, mediated by chemical and electrical signaling—including phase wave differentials—creates a malleable equilibrium where dominant patterns emerge as others recede, ensuring that no single component or pathway monopolizes function.

Cortical columns serve as key pattern recognizers by assembling sensory data into three-dimensional-plus-time representations of reality. Traveling waves and phase differentials operate as a rendering mechanism that transforms raw inputs into richly detailed internal images, while the distributed, dynamic interactions among agents illustrate that outcomes such as perception, learning, and consciousness do not arise from a singular command structure but from the continuous interplay of multiple autonomous units.

One way to see this multi-scale interplay more vividly is to imagine a simple visual input, such as a brief flash of light striking the retina. Photoreceptors convert that flash into neural signals that move along the optic pathways to early visual cortical columns, where local agents begin encoding basic features and adjusting phase patterns. These initial wave differentials spread fractally through interconnected cortical regions, amplifying or dampening specific aspects of the signal. As they propagate, distributed gamma oscillations unify different columns into a larger, coherent network of firing. Top-down and lateral influences further refine these signals, causing new or unexpected patterns to ripple across the brain's global oscillatory state. The result is a harmonized visual percept—a prime example of how local fractal wave expansions, organized by agentic columns, can coalesce into conscious awareness.

Agents throughout the brain coordinate via oscillations and synchronization, with tonic and phasic waves guiding neuronal firing and continuously calibrating the global neural state through phase shifts. This dynamic tuning supports functions ranging from focused attention to memory consolidation, and fluid connectivity across regions is achieved as subsets of cortical columns synchronize in response to shifting contexts and goals, thereby unifying diverse processing streams into a coherent perception.

Consciousness emerges from deterministically driven oscillatory interactions rather than from an irreducible emergent process. Each region contributes its specialized output, and large-scale coherence is achieved through ongoing cycles of synchronization and desynchronization, woven together by the physics of neural activity. This agentic framework provides a potential roadmap for developing artificial systems with self-awareness, as integrating mechanisms of observation, coordination, reflection, and consolidation—as exemplified by Self Aware Networks (SAN)—may allow AI to harness oscillatory feedback loops for adaptive, robust cognition.

At every level, the brain processes and transmits information through continuous, nonlinear changes captured by Nonlinear Differential Continuous Approximation (NDCA), whereby local variations in phase and amplitude propagate and sum into the orchestrated patterns that underlie both memory and awareness.

8.4 Neural Rendering and Predictive Coding

Neural rendering updates the traditional predictive coding framework by proposing that the brain is not merely transmitting prediction errors but actively enriching its internal models with new features. Rather than focusing solely on mismatches, this view emphasizes how cortical circuits integrate detailed sensory information to create a dynamic representation of reality. Karl Friston's work on active inference posits that the brain reduces surprise by refining its models to better predict incoming signals; neural rendering extends this approach by suggesting that high-resolution perceptual data are continuously assimilated to refresh the brain's internal portrayal of the world. Re-entrant loops play an essential role here, as top-down predictions cycle through the same pathways that bottom-up signals travel, ensuring that each mismatch triggers iterative adjustments in how cortical columns behave as semi-autonomous agents. Functional connectivity binds these local computations into an integrated field, with each synapse contributing like a pixel on a wide-scale display, and top-down directives meet bottom-up inputs to refine the emergent features.

Oscillatory dynamics play a pivotal role in this feature integration process. Gamma waves furnish precise, transient activations that deliver granular sensory and cognitive details, while slower rhythms such as theta and delta provide overarching contextual frameworks. Phase wave differentials transfer local nonlinear inputs to higher-level network operations, linking small-scale fluctuations to global reconfigurations. Tonic oscillations maintain the brain's baseline state, much like latent diffusion in computational models, where each perturbation to this baseline must be reconciled through iterative readjustments. These re-entrant cycles not only merge top-down expectations with incoming information but also highlight any persistent bottom-up mismatch, prompting continual revisions that reinforce accurate representations. This reconciliation, supported by continuous feedback loops, fosters long-term potentiation when local phases resonate with the broader tonic oscillation, effectively "saving" each refined version of the brain's internal map.

Gamma oscillations can be viewed as the fundamental canvas of consciousness within the Self Aware Networks theory, as wave-based processes align local phases or induce local disruptions that reshape the cognitive landscape in real time. These oscillations coordinate sensory, cognitive, and motor feedback loops, thereby creating an embodied consciousness in which each cortical region continuously updates its model while calibrating with the entire network through re-entrant signaling. Micah's New Law of Thermodynamics, also known as the Dissipation Argument, recasts the drive toward equilibrium as a stepwise dissolution of phase-wave mismatches across neural assemblies, merging top-down predictions with bottom-up signals. As each mismatch is detected, the system strives to resolve or dissipate it via oscillatory realignments, resulting in an organized interplay that resists randomization and persists as updated predictions reflecting ongoing learning.

In sum, this refined predictive coding framework portrays the brain as an active rendering engine that artistically composes each moment of awareness by combining precise high-frequency signals, broader low-frequency integrators, and a tonic baseline akin to latent diffusion. Rather than merely minimizing error, the brain continuously assembles rich sensory details, orchestrates oscillatory states, and unifies top-down and bottom-up inputs through persistent re-entrant loops to shape an ever-evolving internal model of reality. By engaging these cyclical pathways that reconcile mismatches at each step, neural rendering ensures that every dimension of perception and cognition remains fluid, detailed, and coherent.

8.5 Neural Rendering as the Information of the Mind that Guides Behavior

Neural rendering updates the traditional predictive coding framework by positing that the brain actively enriches its internal models with detailed sensory features rather than merely transmitting prediction errors. Cortical circuits continuously integrate high-resolution perceptual data to refresh their internal portrayal of reality, with each cortical column functioning as a semi-autonomous agent running its own predictive loop while functional connectivity binds these local computations into a unified whole.

Oscillatory dynamics play a pivotal role in this process. Gamma waves furnish precise, transient activations that deliver the granular details of sensory and cognitive inputs, whereas slower rhythms such as theta and delta provide overarching contextual frameworks. Phase wave differentials convey local nonlinear inputs upward to higher-level network operations, linking small-scale fluctuations to global reconfigurations. Tonic oscillations maintain a stable baseline state, analogous to latent diffusion in computational models, and continuous feedback loops reconcile any perturbations, thereby fostering long-term potentiation that preserves each refined version of the brain's internal map.

Gamma oscillations serve as the fundamental canvas of consciousness within the Self Aware Networks framework, as iterative wave-based processes align local phases and induce momentary disruptions that continuously reshape the cognitive "canvas" in real time. In this manner, neural rendering is not a passive error-correction mechanism but an active process that artistically composes each moment of awareness by combining precise high-frequency signals with broader low-frequency integrators. Crucially, each sensory dimension—such as color, shape, taste, or texture—emerges as a distinct phase-based signal within the oscillatory tapestry, so that ephemeral wave differentials operate like brushstrokes that paint the volumetric three-dimensional mind. By embedding these qualities in synchronized or desynchronized phases, the brain weaves a richly detailed internal model of the world.

Proprioceptive feedback is integrated through what is termed the Gamma Consideration Sandwich, wherein high-frequency gamma bursts merge new sensory inputs, top-down beta decisions, and bodily feedback from parvalbumin-positive interneurons in layer five. When the brain is focused on specific goals, beta-band activity predominates and suppresses extraneous signals; however, when salient new inputs demand revisions, surges of gamma waves override beta rhythms, directing attention to unexpected information. Mismatches between predicted and actual muscle states perturb local gamma patterns, prompting recalibration of both motor commands and internal models. In this way, the three-dimensional neural images produced by neural rendering are continually tested against real-world constraints, enabling effective navigation, adaptive learning, and the orchestration of coherent behavior grounded in a unified perception of internal goals and external realities.

8.6 Four trillion dimensions computed per millisecond

Tempo-spatial traveling waves, known as phase wave differentials, form the scaffolding of neural patterns and representations in the brain. These waves manifest as dynamic manifolds in cortical columns, shaping computational renderings that extend beyond simple three-dimensional sensory representations. Neural array projection oscillation tomography posits that selective phase changes in synapses, combined with structural modifications in dendrites, allow neurons to filter and respond to specific stimuli over time, and that cortical columns communicate through compressed signals embedded in these traveling waves, thereby sharing high-dimensional information without saturating the overall network.

Phase wave differentials function as a form of spectral encoding that captures spatial details by shifting the timing and frequency of neural oscillations. Variations in these differentials can be decomposed into distinct frequency components that encode the geometry and interactivity of each cortical region. Even small differences in connectivity or minimal changes in input timing can nonlinearly shift these spectra, allowing subtle yet distinguishable representations to emerge even within the same frequency range.

Neural oscillations spanning delta, theta, alpha, beta, and gamma bands underlie core cognitive functions, and phase wave differentials modulate synaptic frequencies across these bands to alter neuronal firing rates in real time. This process acts like a high-dimensional “3D television,” where discrete frequency changes map onto transformations in perception, memory, and cognition. Tonic frequencies maintain the brain in a poised or near-critical state while fluctuations serve as attractors, and unexpected inputs that perturb these baselines can give rise to new perceptual or conceptual patterns as phase wave differentials carry novel information across spatial and temporal scales.

Traveling waves generate phase wave differentials that reflect how neuronal groups update and convey information. As the brain integrates oscillatory signals, neurons detect correlates of specific stimuli through their phase relationships, effectively differentiating features such as color, texture, or shape. When a neuron adjusts its synaptic state to align with a recognized pattern and subsequently fires, that partial representation is broadcast to other regions, with the degree of divergence from baseline proportional to the novelty of the incoming signals; this highlights the crucial role of unexpectedness in driving learning and adaptation.

Fractal and hierarchical structures further expand these capacities, as the brain exhibits self-similar motifs across its organizational scales, from individual synaptic connections to entire cortical networks. Each neuron’s membrane potential and synaptic frequency profile can be viewed as a high-dimensional vector that encodes its learning history, and by transmitting aspects of this vector via phase wave differentials, neurons and columns integrate local experiences into the global framework of brain function. This distributed and dynamic rendering system allows both excitatory and inhibitory signals to shape the timing and duration of neural events, producing a complex, high-capacity landscape for information processing.

Extrapolations suggesting that the brain may represent trillions of dimensions of information per millisecond underscore the immense parallelism of its architecture. Although the precise figures remain speculative, this “four trillion dimensions” notion serves primarily as a conceptual stand-in for the massive degree of parallelism enabled by neuronal frequency states, synaptic thresholds, and morphological variations. In other words, the combined influence of different oscillatory bands, small and large phase shifts, and structural shifts in dendritic spines can generate hyper-dimensional capacities that allow for elaborate, real-time computations. Phase wave differentials, together with oscillatory synchronization, illustrate how the brain might maintain and manipulate multidimensional, continuously updating patterns of representation.

In this view, each element in the neural network—be it a single synapse or a broad columnar array—can subtly change its oscillatory properties to reflect and propagate learned signals. These cascading effects accumulate into the volumetric “3D television” of the mind, where perception arises from the superposition of countless phase-aligned features distributed across the entire cortical landscape.

8.7 Entification: The Unified Agentic Consciousness

Entification describes how multiple interdependent agents at different scales synchronize their activity to form a single, unified entity. It relies on oscillatory synchrony, where each agent aligns its rhythmic patterns to generate coherent, large-scale behavior. In the brain, this process spans from microscopic molecular events up to entire networks of cortical regions, with every component acting as an autonomous unit that processes information, responds to inputs, and adapts its behavior. Through this synchrony, consciousness and coordinated action emerge when these smaller agents coalesce into more complex structures that collectively guide perception, decision-making, and movement.

At the molecular level, proteins and receptors function as agents by shifting their conformations and regulating ionic exchanges, which continuously refine each neuron’s state and ensure that signals are propagated or inhibited as needed. At the cellular level, neurons, glial cells, and immune cells fire in patterned rhythms and modulate their local environment while maintaining mutual feedback loops. These dynamic interactions bind the cells into functional circuits and networks that perform specific cognitive or physiological tasks. From the perspective of neural network arrays, cortical columns, and whole brain regions, agents utilize phase locking and wave differentials to create unified patterns of neural activity. Crucially, each of these layers incorporates a fractal sensor–transmitter loop in which local agents exchange information in ways that mirror larger, system-wide processes, and in so doing, each agent merges its unique local dynamics into a synchronized wave state that contributes to the overall unity of consciousness.

This multi-scale agentic dynamic can be framed by the Nonlinear Continuous Differential Approximation (NDCA), in which each level of organization refines its own perspective through oscillatory feedback and chemical regulation. The fractal nature of entification emerges because smaller agents repeatedly combine to form larger ones, with each layer mirroring the organization of the one below. This fractal pattern ensures that local signals throughout the brain can be aligned into a coherent global perspective, enabling fluid behaviors such as riding a bicycle, conversing with others, or planning future actions. These self-similar loops illustrate how multi-scale agency forms a seamless chain of sensor–transmitter events, each contributing to a progressively more integrated sense of “I.”

Ultimately, the brain exemplifies a self-organizing ecosystem in which entification binds together myriad mini-conductors rather than relying on a single conductor to dictate all activity. Small, differential adjustments from each component contribute to a collective and harmonized image of consciousness, unified by reciprocal communication, oscillatory synchrony, and computed properties. In this way, entification provides a framework for understanding how consciousness, memory, and behavior naturally arise from countless distributed interactions. The key lies in recognizing that these interactions are governed by multi-scale agents whose fractal sensor–transmitter loops forge a unified, cohesive entity—capable of complex perception, purposeful action, and ultimately, self-awareness.

8.8 Consciousness Correlates

When an animal loses consciousness, the medial prefrontal cortex, hippocampus, and thalamus are among the last brain regions to exhibit transient shifts in activity, while pyramidal cells across the cortex—especially those in deeper layers that extend beyond individual columns to establish network-wide links—cease their usual communication patterns. This breakdown of integrative processing demonstrates that robust cross-brain traffic is essential for maintaining an awake, coherent state. In particular, when the wave synchronies that keep different cortical areas in phase alignment begin to fail, the broader system can no longer sustain a unified field of awareness.

Gamma oscillations are widely regarded as instrumental in binding distant brain areas, particularly through the horizontal Layer 2/3 networks. By uniting far-flung cortical columns via synchronized firing, gamma rhythms integrate sensory, motor, and cognitive processes into a unified perception, reducing phase mismatches and coordinating diverse informational streams. Through this mechanism, gamma waves also bridge bodily states with incoming sensory signals, fostering dynamically aligned, embodied awareness. Moreover, the process of oscillatory dissipation—where mismatched phase patterns gradually fade into a coherent baseline—helps stabilize these synchronized states, and disruptions in this balance can lead to sudden losses of conscious integration.

The thalamus plays a key role by acting as a central relay for both sensory and motor signals. It connects extensively with the hippocampus so that exteroceptive and contextual information can converge before reaching the prefrontal cortex for higher-order processing. Through its gating functions, the thalamus can reset local cortical rhythms by reinforcing or dampening specific pathways as needed to maintain coherent neural patterns.

The medial prefrontal cortex is vital for consciousness because it integrates decision-making, executive control, and sensory feedback via the limbic loop linking subcortical regions to the cortex, ensuring that top-down processes shape how incoming information is experienced. Research shows that synchronized theta or gamma bursts can enhance information exchange between the hippocampus and neocortex, while modulation in the central lateral thalamus facilitates learning and adaptive behavior.

During active tasks, gamma activity in the default mode network is often muted by alpha and beta waves that inhibit irrelevant gamma signals, yet brief surges of gamma can inject fresh information when prediction errors require the brain to revise its expectations. Ultimately, when these brain regions and pathways lose their synchronized rhythms, consciousness collapses. This underscores the central role of gamma synchronization and widespread pyramidal cell communication in sustaining the complex networks necessary for conscious awareness, and it further highlights how the failure of oscillatory dissipation can precipitate a sudden collapse in the coherent wave patterns that underlie our conscious state.

8.9 Conclusion & Future Directions

This paper presents an extensive and multifaceted exploration of the “Agentic Brain” and its underlying principles, spanning scales from molecular dynamics to whole-brain networks while drawing insightful parallels with artificial intelligence. Building on Biological Oscillatory Tomography (BOT) to describe how cells generate and parse oscillatory patterns, the work establishes a framework in which individual cells, proteins, and receptors are viewed as autonomous agents whose oscillatory behaviors, guided by ion channels and other molecular processes, synchronize neuronal networks and sensory inputs. This convergence leads to integrated, unified system behaviors and underscores the importance of phase-based encoding. Deterministic oscillatory processes—captured through methodologies such as Cellular Oscillating Tomography (COT) and Neural Array Projection Oscillation Tomography (NAPOT)—demonstrate how neurons encode information via phase, amplitude, and frequency. In this view, cognition, consciousness, and memory are not mysterious emergent properties but arise from precisely coordinated, wave-based computations that scale continuously from the molecular level to cortical columns.

The paper details how agentic behavior manifests across multiple scales by illustrating how local cellular events aggregate into higher-level neural networks that support functional connectivity and unified perceptual experiences. It delves into mechanisms including coincidence detection, phase wave differentials, and Non-linear Differential Continuous Approximation (NDCA) to explain how neurons, dendrites, and inhibitory interneurons synchronize, regulate information flow, and address the binding problem. Oscillatory rhythms ranging from slow tonic waves to high-frequency phasic bursts are shown to maintain a dynamic equilibrium that underlies both sensory processing and conscious awareness. Furthermore, neural rendering and predictive coding are presented as continuous processes that refine the brain’s internal model of reality, ensuring that local oscillatory events integrate into a coherent global representation. Throughout these discussions, the repeated looping of signals—sometimes described as “Sonic the Hedgehog loops”—underscores how phase alignment and re-entry cycles drive the large-scale integration of sensory, cognitive, and proprioceptive inputs, while the morphological plasticity of dendrites and the hierarchical connectivity of oscillatory networks together foster memory, perception, and consciousness. This insight fuels the development of future computational models that may replicate and extend these adaptive principles.

The latter sections bridge neuroscience and artificial intelligence by comparing dendritic computations to high-dimensional vector embeddings and semantic mapping. The paper highlights that both biological and artificial systems rely on similar principles to encode, process, and retrieve complex information, and it underscores the role of top-down and bottom-up oscillatory interactions—exemplified by beta, alpha, and gamma waves—in mediating decision-making, regulating attention, and uniting disparate neural elements into a cohesive conscious entity. Detailed examples of layer-specific dynamics, circuit-level feedback loops, and the interplay between excitatory and inhibitory signals provide a mechanistic basis for understanding how precise phase synchronization and desynchronization serve as a “binding glue” that supports fluid, adaptive intelligence. Central to this argument is the notion of fractal sensor–transmitter loops, in which smaller-scale agents synchronize into larger coherent structures, ultimately weaving individual bits of information into a unified perspective. In this way, the brain perpetually assembles rich sensory details, fine-tunes its oscillatory states, and dissipates phase differences to shape a dynamic internal model of reality.

In essence, the paper argues that the brain’s core is fundamentally agentic, with each cell or network operating as a self-regulating unit whose oscillatory dynamics, phase relationships, and feedback loops give rise to cognition, perception, and consciousness. By demonstrating how local cellular activities scale into complex neural architectures and emphasizing the pivotal roles of gamma, beta, and alpha oscillations, the work reveals that what appears emergent is in fact rooted in deterministic wave mechanics. The discussion of multi-scale connectivity—from molecules and individual neurons to cortical columns and entire networks—clarifies how oscillatory synchronization, dendritic computations, and inhibitory interneuron regulation together guide decision-making and attentional focus. Ultimately, by framing consciousness as a mechanical (rather than magical) outcome of wave-based orchestration, the paper provides a unifying principle that deepens our understanding of biological cognition and offers promising avenues for the development of truly adaptive, potentially self-aware artificial intelligence systems rooted in multi-scale wave logic.

Appendix A: Glossary of Key Points

1. BOT (Biological Oscillatory Tomography)
Explains how cells and neurons create, communicate, and interpret patterns via synchronized oscillations, much like tomography reconstructs dynamic slices of data. Local cellular events scale into multi-dimensional “volumetric” representations of biological and sensory reality.

2. COT (Cellular Oscillating Tomography)
Describes how individual cells act as computational units using oscillatory cycles—frequencies, amplitudes, and phases—to encode information. It proposes that cellular adaptation is partly “computed” through repeated stimuli, coincidence detection, and rhythmic learning mechanisms.

3. NAPOT (Neural Array Projection Oscillation Tomography)
A framework for how networks of neurons project oscillatory signals forward to create internal models of reality. Sensory inputs travel through cascades of phase-aligned activity, stitching multiple “slices” of information into unified, higher-dimensional representations.

4. Coincidences as Bits of Information (including BTSP)
Defines “coincidences” as nearly simultaneous neural or cellular events treated as meaningful bits of information, echoing Hebbian principles. BTSP (Behavioral Timescale Synaptic Plasticity) is one mechanism that strengthens synaptic pathways through repeated time-correlated activity.

5. Traveling Waves as Phase Wave Differentials
Refers to dynamic waves of electrical or chemical activity moving across neural tissue. Slight timing mismatches (“phase differentials”) carry key updates or error signals, driving neurons to tune in or out of a synchronized state and helping create coherent experiences.

6. NDCA (Non-linear Differential Continuous Approximation)
A modeling approach suggesting that continuous, non-linear cellular and synaptic interactions can be approximated with differential equations. Minor oscillatory shifts at the micro level can scale up into robust large-scale patterns of thought and perception.

7. Solving the Binding Problem with Oscillation
Addresses how the brain integrates diverse sensory features into a single percept by synchronizing different neural populations in higher-frequency bands. Phase locking keeps multiple streams in sync, uniting color, shape, motion, and more in a common “temporal window.”

8. Stitching Patterns Between Brain Regions via Oscillatory Synchrony & Functional Connectivity
Explains how spatially distinct areas converge into a global map through synchronized oscillations. Cofluctuations in different regions over time align signals, temporarily fusing separate networks into a single coherent pattern.

9. Making Choice Bifurcations with Inhibitory Interneurons
Highlights the role of inhibitory interneurons (often GABAergic) in gating excitatory signals and shaping decision-making. Every neuron or column can “choose” to fire or remain silent, and interneurons regulate which ensemble “wins” at each bifurcation.

10. Global Spectral Frequency Map & Coordinate System
Describes how each cell or neuron holds a unique frequency/phase signature, forming a dynamic “coordinate system” across the brain. Multiple bands (delta, theta, alpha, beta, gamma) stack like tomographic layers, supporting large-scale synchronization and precise addressing.

11. Ink & Canvas Metaphor (Mental Ink & Canvas)
Compares slow, steady oscillations to a “canvas” and higher-frequency bursts to “ink.” The stable baseline sets the stage, and transient bursts imprint fresh details, shaping real-time conscious experience.

12. Ephaptic Coupling as a Mechanism
Defines a form of neuronal interaction where local electromagnetic fields influence nearby cells without direct synaptic contact. Such “wireless” cross-talk can synchronize or disrupt neighboring neurons, complementing standard synaptic transmission.

13. Entification

Describes how distributed components (cells, columns, brain regions) unify into a single conscious entity through fractal-like self-similarity and oscillatory coordination. The “I” emerges from these synchronized processes scaling upward.

14. Consciousness Perception Through Oscillatory Dissipation
Views consciousness as arising when oscillatory networks move toward equilibrium, dissipating mismatched signals. Phase and amplitude errors get “rebuilt” into coherent global states through ongoing synchronization and desynchronization cycles.

15. Neural Rendering as a 3D Volumetric Television
A metaphor for how the brain creates spatially extended internal representations, updating a volumetric map rather than flat “frames.” Phase patterns serve as “voxels” in this constantly refreshed hologram-like process.

16. The Phasic–Tonic Interplay for Absorbing Rendered Patterns
Explains how transient, high-frequency bursts (“phasic”) update steadier baseline rhythms (“tonic”). The baseline provides a stable context, while phasic events insert new signals that the broader network then integrates.

17. The Latent Diffusion Analogy for Learning with Oscillation & LTP
Compares the brain’s learning process to “latent diffusion,” where new or noisy signals are continually “denoised” through synaptic refinements (like LTP). Over time, the system integrates these signals into a coherent latent space.

18. Outlining the Multiscale Fractal of Functional Brain Computation
A principle stating that structural and functional motifs repeat at multiple scales—molecules, cells, columns, networks—yielding fractal-like organization. Coincidence detection, wave synchrony, and feedback loops are self-similar across levels.

19. Consciousness as a Deterministic Computation
Asserts that consciousness emerges from fully deterministic wave-based processes rather than “magical” emergence. Seemingly random events in synaptic release are governed by unobserved but determinate microconditions, leading to large-scale coherence.

20. Sonic the Hedgehog Loops
An analogy for cyclical neural pathways in which signals race around closed circuits (like loops in a video game). Each pass refines the state, as inputs cycle through cortical layers, thalamic relays, and back again.

21. Thalamic–Cortical Loops as a Central Hub
Emphasizes the thalamus’s pivotal role in routing and refining sensory and executive signals. The cortex relays predictions back to the thalamus, creating feedback loops that synchronize large-scale activity across the brain.

22. Dendrites as Vector Embeddings
Portrays each dendritic tree as a high-dimensional “vector space” encoding learned patterns in synaptic configurations. When threshold is crossed, the neuron fires with a specific phase/frequency that functions like a “token” in broader network communication.

23. Quasicrystal Analogy for Higher-Dimensional Information Patterns
Suggests that the brain’s combinatorial expansions and fractal connectivity resemble quasicrystals—ordered yet aperiodic structures potentially “projected” from higher dimensions. This allows extremely rich encoding without simple repetitive patterns.

24. Immuno-Neural Interplay
Describes the deep integration of immune cells (like T-cells) and neurons. They dynamically regulate each other’s functions, influencing inflammation, cognition, and overall health through ongoing communication.

25. Agentic Co-Regulation Across Scales
Posits that proteins, cells, tissues, organs, and networks each exhibit semi-autonomous agency. These nested agents exchange information and co-regulate one another, ultimately maintaining coherent function.

26. Addressable Coefficient of Variation
States that every cell or region can have a unique signature of variability relative to its mean activity. This “oscillatory fingerprint” acts like an address, guiding the routing of signals to the right target in the broader network.

27. The Gamma Consideration Sandwich
An analogy for how gamma-band oscillations integrate top-down alpha/beta signals with bottom-up sensory or proprioceptive data. These gamma bursts serve as the “filling” that helps reconcile higher-level predictions with real-time feedback.

28. Four Trillion Dimensions per Millisecond
An illustrative concept of the brain’s massive parallel capacity (synapses × frequencies × phases × timescales). Each moment potentially spans an immense high-dimensional space, enabling extraordinarily rich and rapid computations.