The Temporal Neuroscience Index (TNI): An Information Geometry of Subjective Time

Megan Anderson

AI ARMY, INC. · aiarmy.co

2026

Abstract

Subjective time is not a simple reflection of physical time; it is an emergent property of how a system encodes change, prediction, and memory. People differ widely in how they experience duration, how far into the future they can project, and how flexibly they navigate possible futures — differences especially salient in neurodivergent populations and in people with trauma histories. Yet despite extensive research on time perception, attention, predictive processing, and memory, no single framework integrates these findings into a model that quantifies and visualizes the structure of subjective time.

This paper introduces the Temporal Neuroscience Index (TNI), a multidimensional framework that characterizes subjective time as a low-dimensional projection of an underlying information geometry. Grounded in predictive processing and information geometry, the TNI proposes that temporal experience is captured by five core parameters — Horizon Length (H), Future Width (W), Temporal Jitter (J), Coherence (C), and Branch Richness (B) — together with a derived ordering-sensitivity readout ψ. These capture the depth, flexibility, stability, and generativity of the temporal field, and they map to neural systems implicated in timing, prediction, memory, and narrative integration. The framework offers a non-pathologizing vocabulary for neurodiversity and trauma, reframing temporal collapse and expansion as movement through a structured parameter space rather than as fixed categories.

TNI is the temporal-projection layer of a three-part cognitive program; its formal objects — the statistical manifold and metric, internal time as path length, the capacity envelope, the parameter definitions, and the ordering-sensitivity proposition that grounds ψ — are stated once in the program's shared formal supplement (Supplement II) and referenced here by stable name. This Phase-1 paper presents the conceptual framework, its neuroscientific grounding, the parameter definitions, and initial falsifiable predictions, including a within-subject protocol for estimating ordering sensitivity. Later phases introduce empirical validation, computational simulation, and visualization tools. The goal is integrative, not diagnostic: to link phenomenology, behavior, and known neural systems in a way that is scientifically grounded and practically interpretable.

Keywords: Temporal Neuroscience Index; subjective time; information geometry; predictive processing; neurodiversity; trauma; future cognition; temporal cognition; ordering sensitivity

1. Introduction

Time is one of the most fundamental dimensions of experience, yet one of the least understood. Physics treats time as a coordinate; the brain treats it as an internal, constructed, continually updated model that enables prediction, planning, movement, memory, and social interaction. What we experience as the passage of time is not a passive reflection of external events but an active computational achievement, and it varies dramatically across individuals. Some experience time as spacious and smooth, others as compressed or chaotic; it expands under flow and contracts under stress. Neurodivergent individuals — those with ADHD, autism, or AuDHD — often report nonlinear temporal perception, difficulty anticipating or sequencing events, or uniquely strong temporal memory. Trauma can collapse the future into a narrow, threat-dominated field, while healing can expand the horizon and restore a sense of open possibility.

Despite extensive research across subfields, no integrative framework links these observations into a unified model. Pacemaker–accumulator models, internal clocks, and striatal beat-frequency models explain specific mechanisms but not the rich, multidimensional variability of lived temporal experience. Predictive processing and free-energy models offer powerful insights but not tools for quantifying or visualizing the structure of subjective time across individuals. And clinical approaches often treat time perception as a secondary effect rather than a primary dimension, despite growing evidence that disrupted temporal experience underlies anxiety, trauma, dissociation, and many neurodiversity-related challenges.

This motivates the Temporal Neuroscience Index. Rather than treating time as a scalar or clock-like signal, the TNI models subjective time as a temporal field composed of interacting dimensions: **Horizon Length (H)**, how far into the future one can meaningfully simulate; **Future Width (W)**, the breadth of trajectories one can consider; **Temporal Jitter (J)**, the instability of moment-to-moment timing; **Coherence (C)**, the smoothness and self-consistency of temporal flow; and **Branch Richness (B)**, the number and complexity of reachable futures. These form a temporal geometry that shapes behavior, cognition, and regulation, and that helps explain why two people in the same environment can construct radically different timelines.

The framework's goal is not to diagnose or categorize but to provide a language and model for understanding how people inhabit time, and how their temporal field shifts across states, stresses, supports, and developmental histories. As a Phase-1 manuscript, this paper introduces the conceptual foundations, the neuroscientific grounding, the parameter definitions, and initial predictions; later phases contribute empirical validation, computational models, and visualization tools.

1.1 TNI within the cognitive program, and the shared formal home

The TNI does not stand alone. It is the temporal-projection layer of a three-level cognitive program. The IGAF formal core, housed in Supplement II and normalized as Information Geometry of Adaptive Fields, describes how belief and policy states live as motion on a statistical manifold. MRIF (Mirror–Recursive Information Field) specifies what must be structurally true for such a system to remain coherent under load. TNI projects the resulting temporal geometry into a small descriptive index. Operationally, the TNI chart modulates *demand* on the system while the meta-theory's capacity envelope sets *supply*.

All of the program's formal objects — the statistical manifold and its metric, internal time as path length, the capacity envelope, the axioms, the parameter definitions, and the ordering-sensitivity proposition — are stated once, by stable name, in **Supplement II — Adaptive Systems Formal Supplement**, and are referenced (not restated) here. This paper cites those objects by name rather than by number so that renumbering can never drift against citations.

Within the cognitive program the three frameworks ground upward freely — geometry supports regulation supports projection — and a no-upward-claims discipline holds throughout: TNI does not redefine physical time.

Where the TNI's grammar resonates with the separate, physics-facing program elsewhere in this body of work — for instance where a "cone" of reachable futures echoes a causal cone, or where a subjective publicization construct echoes a physical one — the resonance is structural only, and the following statement applies verbatim, never paraphrased:

> The parallel asserted is structural only. The same grammar recurs across regimes; no evidential weight transfers between them. A result in one regime is not evidence about another.

2. Background: Temporal Cognition

Temporal cognition refers to the neural, cognitive, and embodied processes through which humans perceive, structure, and navigate time [1][2]. Although time is a physical dimension, subjective time is constructed — shaped by attention, memory, emotion, and predictive inference, and varying across individuals and states. This section synthesizes the themes the TNI builds on.

Perception versus physical time. Subjective time systematically deviates from physical time: novel or arousing events lengthen in retrospect; repetitive or predictable events shorten; attention to time expands perceived duration while distraction contracts it; and emotional states alter perceived flow. These distortions are not errors — they reflect the brain's encoding of salience, predictability, and uncertainty into the temporal structure of experience [1][2].

Hierarchical temporal scales. The brain measures time with no single mechanism [1][2]. Sub-second timing draws on the cerebellum and sensorimotor networks; interval timing on basal-ganglia–prefrontal circuits and dopamine; extended timescales on working memory and orbitofrontal expectation; and narrative timescales on the hippocampus and default mode network, which integrate experience into autobiographical timelines. These scales interact, and disruption in one often cascades into others.

Attention, working memory, arousal. Attention regulates the precision of temporal signals; working memory maintains temporal information across seconds to minutes; arousal, via the locus coeruleus–norepinephrine system, modulates temporal granularity, so that high arousal can produce perceived slowing. Together these shape the richness, density, and coherence of temporal flow.

Binding, memory, and emotion. A temporal binding window (tens to a few hundred milliseconds) fuses events into moments and varies across individuals and states. Retrospective duration depends on memory density: novelty-rich periods feel long in hindsight while routine compresses, which is why childhood seems long and adult years increasingly short. And temporal cognition is tightly coupled to emotion: anxiety amplifies micro-timing and slows perceived time, depression compresses the future horizon, trauma narrows the temporal field, and healthy regulation supports longer horizons and smoother flow.

Neuropsychological signatures. Clinical and neuropsychological research reveals distinct temporal patterns — inconsistent interval timing and shortened horizon in ADHD [9][10]; heightened temporal precision and non-uniform binding in autism; hypervigilance, fragmentation, and narrowed future width in PTSD; temporal discontinuity in dissociation. These patterns motivate a framework that treats temporal cognition as a primary, structured dimension.

2.1 Relation to existing constructs

Because the TNI's parameters correspond to capacities that established literatures already measure, we state those relationships explicitly [1]–[16]. The TNI's contribution is integrative — placing these capacities in a single state-dependent geometry — not a claim to have discovered them.

Prospective cognition and temporal horizon (grounds H and W). That minds project structured futures is well established [3]–[6]. The mental-time-travel literature identifies prospective cognition as a core capacity, with chronesthesia naming the temporal self-orientation that underlies it; the constructive-episodic-simulation hypothesis shows future projection recruits the same machinery as episodic memory; and episodic-future-thinking research quantifies individual differences in the vividness and depth of projected futures. In parallel, the intertemporal-choice tradition operationalizes temporal horizon economically through delay-discounting rates and time-perspective inventories, with steeper discounting and delay aversion reliably associated with ADHD. TNI's Horizon (H) and Future Width (W) are a geometric re-description of what these literatures measure behaviorally: H is the effective depth of reliable projection — related to but distinct from a discounting preference, since two individuals with identical discount rates may differ in how far their generative models sustain stable prediction — and W is the diversity of futures simultaneously representable, the branching structure that episodic-simulation tasks probe one branch at a time. What the TNI adds is coupling: H and W become coordinates alongside J, C, and B, so that horizon collapse under load or trauma is expressed in the same space as the capacities these literatures measure separately.

Empowerment, reachability, and options (grounds W, B, and the reachability reading). The formal counterpart of "which futures can be reached" is developed in information theory, control, and reinforcement learning [11]–[14]. Empowerment defines an agent's control as the channel capacity from its actions to its future sensor states — an information-theoretic measure of the reachable set of distinguishable futures. Reachable sets are foundational in control theory; the options framework formalizes stable, reusable modes of behavior; and successor representations encode the future occupancy a policy makes accessible. TNI's reachability reading is deliberately continuous with this lineage, which we cite rather than claim: Future Width (W) is akin to an empowerment-style diversity measure evaluated over an agent's represented futures rather than its sensorimotor channel, and Branch Richness (B) is akin to an option or skill repertoire expressed as reachable structure. What TNI adds, again, is coupling and state-dependence: reachability degrades along specific routes — elevated ordering sensitivity contracting the reachable set, capacity saturation collapsing modes — giving the empowerment tradition a candidate account of why and when an agent's effective reachability falls even while its nominal action repertoire is unchanged.

Order effects and path dependence (grounds ψ; the quantum-cognition adjacency). Order effects are among the most replicated phenomena in behavioral science — question-order effects, sequence effects in psychophysics, primacy/recency structure, treatment-order effects. One influential line, quantum cognition, models such non-commutativity with quantum-probability formalism [15][16]. We engage this adjacency directly because the TNI's ordering-sensitivity readout will evoke it: ψ is a substrate-agnostic, information-geometric account of path dependence, and the framework takes no position on — and does not require — quantum-probability models of cognition, consistent with the scope boundaries in §10. In the TNI's account, order dependence arises from constraint and curvature in inference geometry: when updates act on a constrained manifold, their order changes the reachable trajectory. ψ differs from existing order-effect measures in two ways — it is defined over future-reachability divergence rather than immediate response shift (the question is not whether A-then-B answers differ from B-then-A answers, but whether the two orders leave the system able to reach different futures), and it is a state-dependent quantity that varies with load, constraint, and regime rather than a fixed effect size. This yields the falsifiable predictions of §11 and the protocol of §M.ψ.

3. Predictive Processing and Temporal Flow

Predictive processing reframes the brain as an active inference machine, continuously generating predictions and updating them from prediction errors [17]–[20]. Within this framework time is not a background variable but a core structural dimension: predictions are about the future, errors occur in the present, and model updates shape future expectations. Temporal experience thus depends on how effectively the system predicts unfolding events, and predictive misalignment — from noise, trauma, neurodivergence, or dysregulation — manifests as acceleration, fragmentation, repetition, or temporal "jumps."

Generative models encode temporal priors — how fast events unfold, how long intervals last, when changes are likely — which shape horizon (H), width (W), jitter (J), and coherence (C) [17]–[20]. Precision, the estimated reliability of a signal, determines how strongly errors update the model versus how strongly priors are trusted: high threat precision produces time dilation, low precision in depression flattens time, volatile precision in ADHD produces inconsistent timing, and high prior precision in autism supports stable micro-timing with reduced tolerance for irregularity. Interoceptive prediction — the brain's modeling of internal bodily states — further shapes H, C, and J, with anxiety accelerating bodily signals and dissociation producing discontinuities [21]–[24]. Higher-order generative models in the default mode network construct narrative and autobiographical continuity, scaffolding the largest horizons; their breakdown produces temporal fragmentation. And in flow, when prediction matches input precisely and load aligns with skill, coherence maximizes and jitter minimizes while branch richness stays focused but not collapsed. Across all of these, temporal experience is not measured but inferred, and the five parameters map onto distinct aspects of that inference.

4. Information Geometry of Time

An emerging line of theoretical work reframes time not merely as a perceptual construct but as an information structure shaped by prediction, uncertainty, and integration [17]–[20][25]. On this view subjective time is the shape of changing information: prediction propagates structure forward, memory preserves it, uncertainty deforms it, and coherence governs the smoothness of transitions. In high-coherence states the underlying geometry evolves smoothly; in fragmented states it becomes jagged or discontinuous.

The TNI is the measurable projection of this geometry. Its formal substrate — a statistical manifold of belief/model states endowed with a Riemannian metric encoding local distinguishability, together with the definition of internal time as accumulated path length along a trajectory — is the Statistical Manifold and Metric and Internal Time as Path Length of Supplement II, Part 1 [25][26]. The five TNI parameters correspond to measurable features of this substrate: H to the extent of the reachable set along the manifold, W to the breadth of reachable viable futures, J to local instability of the metric, C to smoothness and integrability, and B to the multiplicity of low-cost reachable paths. Future-state distributions — narrow, wide, multimodal, sharply peaked — correspond directly to width and branch richness, and attentional bandwidth ties the geometry to cognitive capacity: low bandwidth (stress, overload) contracts width and horizon and raises jitter, while high bandwidth (regulation, rest, flow) expands width and horizon and stabilizes transitions. Entropy over future states sets the breadth of the field, with coherence as the stabilizing factor; in trauma, entropy spikes under threat then collapses into rigid, narrow patterns, while in healing it decreases as coherence rises, producing wide, stable future manifolds. Time, on this account, is a shape, not a rate.

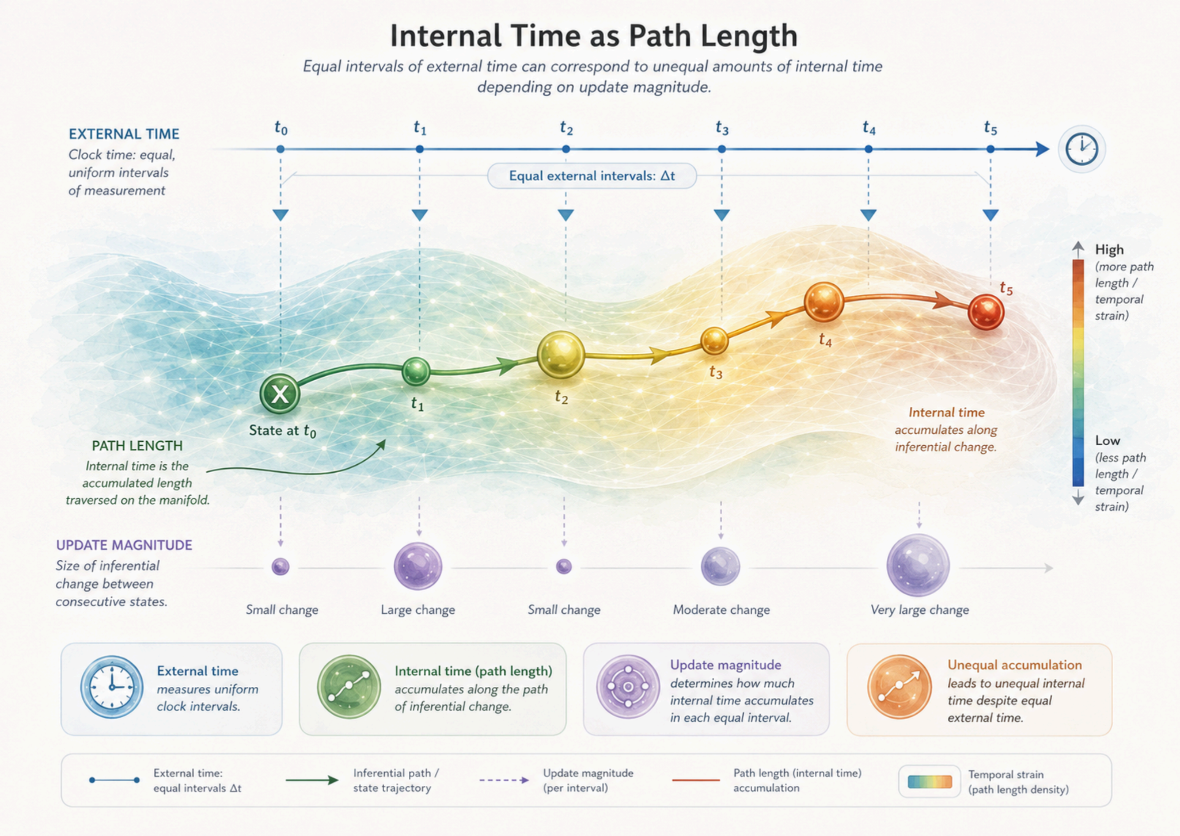

Figure 1. Internal time as path length. Equal intervals of external time can correspond to unequal amounts of internal time depending on update magnitude; internal time accumulates along inferential change (Supplement II, Part 1).

5. The Temporal Neuroscience Index

The TNI models subjective time as an information field with quantifiable geometric properties, decomposing temporal experience into five core dimensions plus a derived ordering-sensitivity readout. Each parameter corresponds to neurobiological processes, computational mechanisms, and experiential qualities, and each can be measured or inferred from behavior, subjective report, neurocognitive tests, and computational estimates. The formal definitions of the five core parameters and the derived readout are stated once in Supplement II, Part 4; this section develops them conceptually and gives their neural correlates.

5.1 The five core parameters and the derived readout

The TNI **core vector** is $\Theta\_\mathrm{TNI} = (H, W, J, C, B)$. For visualization or projection there is an **augmented tuple** $\Theta\_\mathrm{TNI}^{+} = (H, W, J, C, B; \psi)$, where ψ (ordering sensitivity) is a *derived readout* — a function $\psi = \Psi(H, W, J, C, B)$ over the five core parameters — **not an independent sixth coordinate**; the semicolon marks an augmented readout, not a six-dimensional state space. This notation is locked across the program (Supplement II, Part 4).

Horizon Length (H). The distance into the future over which the system maintains a coherent, reachable representation of trajectories without collapse: the chart coordinate of the reachable set. Phenomenologically, long horizons feel spacious and planful, short horizons urgent and present-biased, collapsed horizons characteristic of trauma and depression. Correlates: executive function, episodic future thinking, DMN coherence, hippocampal temporal context, prefrontal working memory.

Future Width (W). The effective breadth of reachable, viable futures within the horizon: the number and diversity of trajectories that remain coherent and constraint-compatible. Wide futures support creativity and adaptability; narrow futures produce rigidity and fear-based decision-making. Correlates: prefrontal divergence processes, salience-network modulation, dopamine-driven exploration.

Temporal Jitter (J). Instability and volatility in temporal structure: variance in short-horizon predictions, inconsistency in ordering, rapid fluctuation in trajectory selection. High jitter produces distractibility or "time blindness"; low jitter produces stability and smooth transitions. Correlates: cerebellar error correction, LC-NE arousal variability, cortical oscillatory stability.

Coherence (C). The degree to which temporal representations are internally consistent and integrable across scales. High coherence supports flow and a stable self-narrative; low coherence produces fragmentation, temporal gaps, and dissociation. Correlates: DMN integration, hippocampal sequence coding, cross-network synchrony.

Branch Richness (B). The number and structural complexity of reachable futures represented in the internal model: the complexity of the decision space. High richness supports multi-step reasoning and perceived agency; low richness produces perceived inevitability and cognitive narrowing. Correlates: prefrontal combinatorial modeling, dopamine-mediated exploration.

Ordering Sensitivity ψ (derived readout). The dependence of geometry and outcomes on the order of matched interventions, content held fixed. Formally ψ is the distance between the TNI configurations produced by two orders of the same content — the *Ordering-Sensitivity Non-Commutativity Proposition* and the ψ definition of Supplement II, Part 3.6 / Part 4 — computed as $\psi = \Psi(H, W, J, C, B)$ and reported in the augmented tuple, never as an independent axis.

It is estimated via sequence-comparison designs (§M.ψ), not read directly from trajectories. Its behavior is a Phase-1 prediction, not an established result (§11).

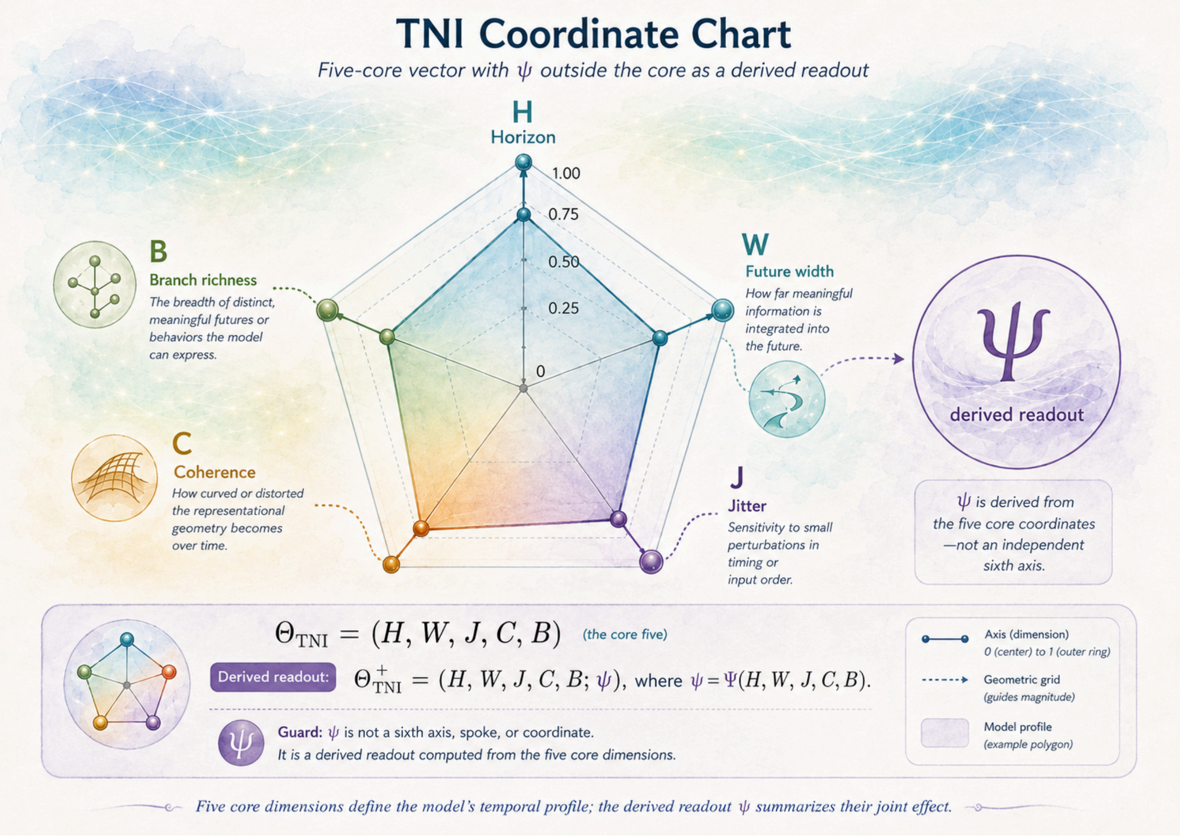

Figure 2. TNI coordinate chart. Five-core vector Θ_TNI = (H, W, J, C, B) with ψ outside the core as a derived readout, Θ_TNI^{+} = (H, W, J, C, B; ψ), ψ = Ψ(H, W, J, C, B). Guard: ψ is not a sixth axis, spoke, or coordinate; it is a derived readout computed from the five core dimensions.

5.2 Formal reference

The parameters are defined formally, once, in Supplement II, Part 4, over the statistical manifold and internal-time definitions of Part 1; the ordering-sensitivity objects are in Part 3.6 [26]. This paper does not restate those definitions inline — a deliberate architectural choice so that the single formal home cannot drift against the papers that cite it. Empirical proxies for each quantity (H as the maximum delay at which coherent goal-consistent plans are produced; W as the count/diversity of viable options generated; J as variance in timing/ordering judgments; C as narrative-continuity scoring; B as the count/distinctness of stable strategies; ψ as matched-sequence outcome difference) are given in Supplement II, Part 4 and operationalized for ψ in §M.ψ below.

5.3 Neurobiological mapping

Each parameter has corresponding neural substrates: the cerebellum governs micro-timing and jitter control (J, indirectly C); the basal ganglia govern interval timing and decision thresholds (W, H, B); the prefrontal cortex governs planning and horizon (H, W, B); the default mode network governs narrative time and coherence (C, H); the salience network governs precision and switching (J, C, W); and the hippocampus governs temporal sequence and context (H, C, B). These are functional attributions grounded in existing theory [1][2][17]–[24]; the empirical literature is still expanding and some relationships remain indirect (§10).

5.4 Interaction: temporal geometries

The parameters do not operate independently; their interactions generate distinct temporal geometries. Short H with narrow W and high J yields a chaotic, unstable timeline; short H with narrow W, low B, and low C yields temporal collapse; long H with wide W, low J, and high C yields a robust, spacious field; long H with narrow W yields a rigid but future-oriented structure; moderate H with wide W and high B yields flexible, creative exploration. These profiles form the basis of the neurotype- and state-specific maps of §6.

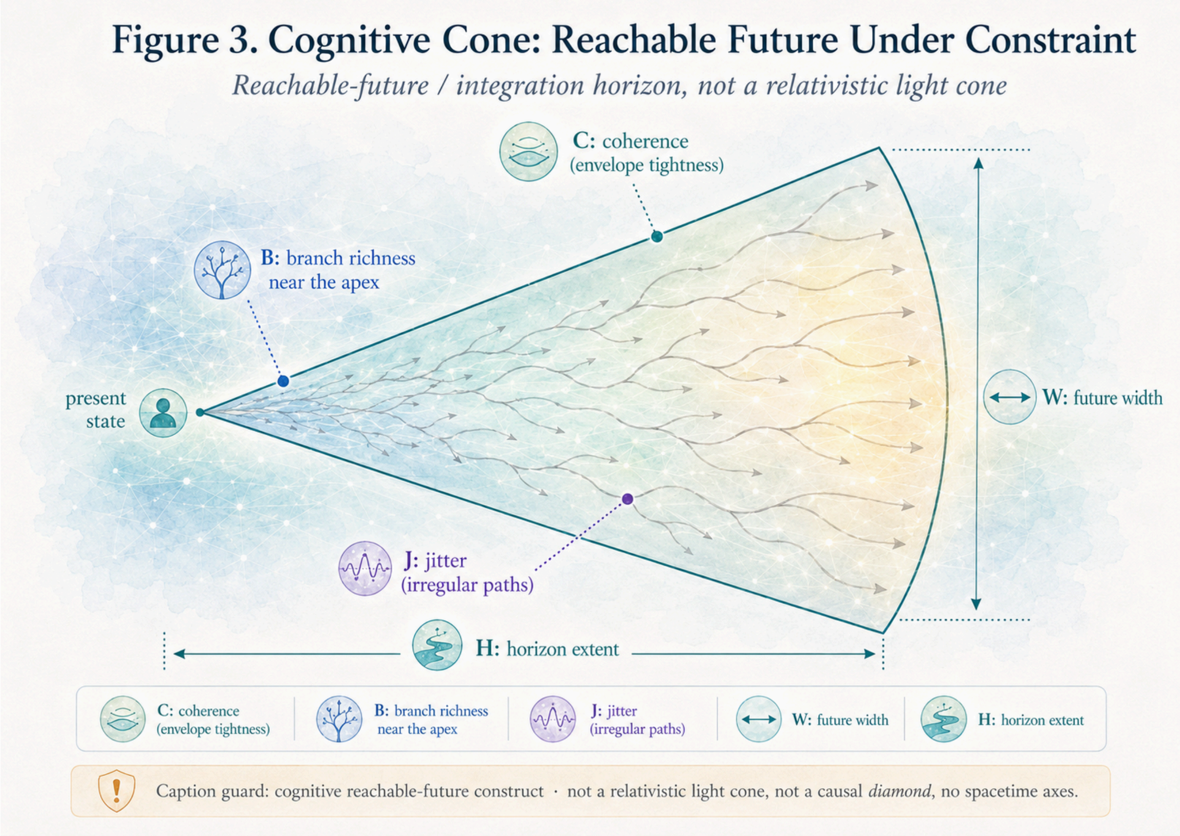

Figure 3. Cognitive cone: reachable future under constraint. Reachable-future / integration-horizon construct. Caption guard: not a relativistic light cone, not a causal diamond; no spacetime axes.

5.5 Modulatory parameters — future-work roadmap (not validated core parameters)

Exploratory work on minds as local information fields has suggested candidate *modulatory* parameters that may condition the five core dimensions: **Ownership** (the binding between the emergent timeline and the self-model — high ownership: "this is my life"; low: dissociation, depersonalization); **Reality-Boundedness** (the constraint of internal futures by external evidence — its loss characterizing miscalibration); **Metatemporal Mode** (the global topology of internal time — linear, cyclic, fragmented, timeless); **Valence** (the emotional field overlaying the temporal geometry — future as threat, emptiness, possibility, or joy);

and **Representational Capacity** (the structural capacity to represent and store temporal structure, constraining maximal H/W/B). These are recorded here as a roadmap for later phases, not as validated parameters. They have not passed the formal-object vetting that the five core parameters and ψ have undergone in Supplement II [26]; they are not part of the Θ_TNI core vector; and no claim is made for them beyond that they are worth operationalizing and testing.

Any future promotion of a modulatory parameter to the core would require its own formal statement in Supplement II and its own empirical grounding, on the same terms as H/W/J/C/B. They are flagged now so the framework's growth surface is explicit rather than smuggled in.

6. Neurotype and State Profiles

The TNI provides a systematic way to map temporal variation into quantifiable geometries without pathologizing difference; each neurotype's pattern is read as a coherent adaptation with characteristic strengths and vulnerabilities. These are generalized patterns, not rigid categories.

ADHD tends toward shortened horizon, often-widened future width, high jitter, moderate-to-low coherence, and high branch richness — a wide, dynamic temporal field with high variability, strong ideation, and difficulty sequencing multi-step timelines.

Autism tends toward long horizon in structured contexts, narrower width, low jitter, high coherence, and moderate branch richness — a stable, precise field with detail-rich temporal memory and reduced tolerance for unexpected transitions.

AuDHD presents a bimodal geometry oscillating between autistic precision (high coherence, low jitter) and ADHD generativity (high width and branch richness), with state-dependent coherence.

Neurotypical temporal cognition reflects moderate, balanced values — the modal statistical range, neither superior nor normative. The same parameters also vary within an individual across states: stress compresses horizon and raises jitter; safety expands width and coherence; novelty elevates width and branch richness; overload raises jitter and reduces coherence; regulation maximizes the balance of H, W, and C. Time perception is state-dependent, not trait-only.

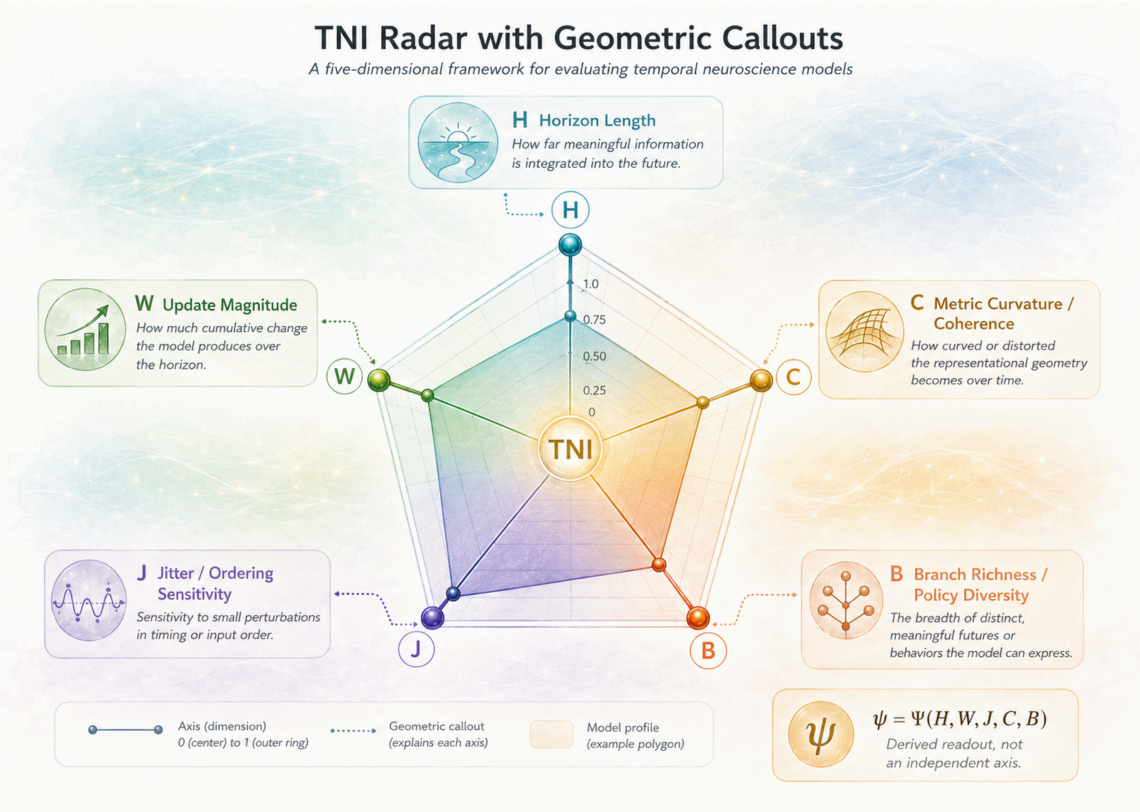

Figure 4. TNI radar with geometric callouts. Five-dimensional profile over H, W, J, C, B; ψ shown as a derived readout, not an independent axis.

7. Trauma and Healing

Trauma reshapes the structure of subjective time more dramatically than almost any other factor. In threat states the system shifts into a hyper-precise, high-arousal mode optimized for immediate survival, and when these patterns persist they produce temporal collapse: the future horizon shrinks (H↓), future width narrows (W↓), jitter spikes (J↑), coherence decreases (C↓), and branch richness collapses (B↓). Hypervigilance sustains high jitter through exaggerated prediction-error monitoring; disrupted hippocampal sequencing and DMN integration fragment the timeline and the self-narrative, lowering coherence; and the loss of perceived possibility narrows width and branch richness until decision-making becomes reactive and agency diminishes.

Healing, conversely, is temporal expansion — a gradual re-widening of the field: horizon lengthens, width expands, jitter settles, coherence rises, and branch richness returns. These changes may be early and sensitive markers of recovery, sometimes preceding behavioral or emotional shifts, and they rarely proceed linearly — expansion tends to arrive in discrete steps, wave-like coherence gains, plateaus, and occasional sudden inflection points. The TNI provides a multidimensional, non-pathologizing map of this process, capturing shifts in horizon, width, jitter, coherence, and branching that a single "better/worse" axis misses. *(Detailed multilayer mechanisms of healing, including somatic and psychedelic-assisted approaches, are developed in the separate clinical companion; this section states the temporal-geometry pattern, not the clinical protocol.)*

8. Visualizations

The framework benefits from three classes of visual: geometric representations (temporal cones showing horizon as extent, width as spread, jitter as worldline irregularity, coherence as envelope tightness, branch richness as branching near the apex); comparative neurotype visualizations (radar plots overlaying H/W/J/C/B across ADHD, autism, AuDHD, and neurotypical profiles, and state-dependent cones for stress, safety, novelty, overload, and regulation); and information-flow diagrams (the predictive-processing loop, and the temporal manifold with its coherence and width structure).

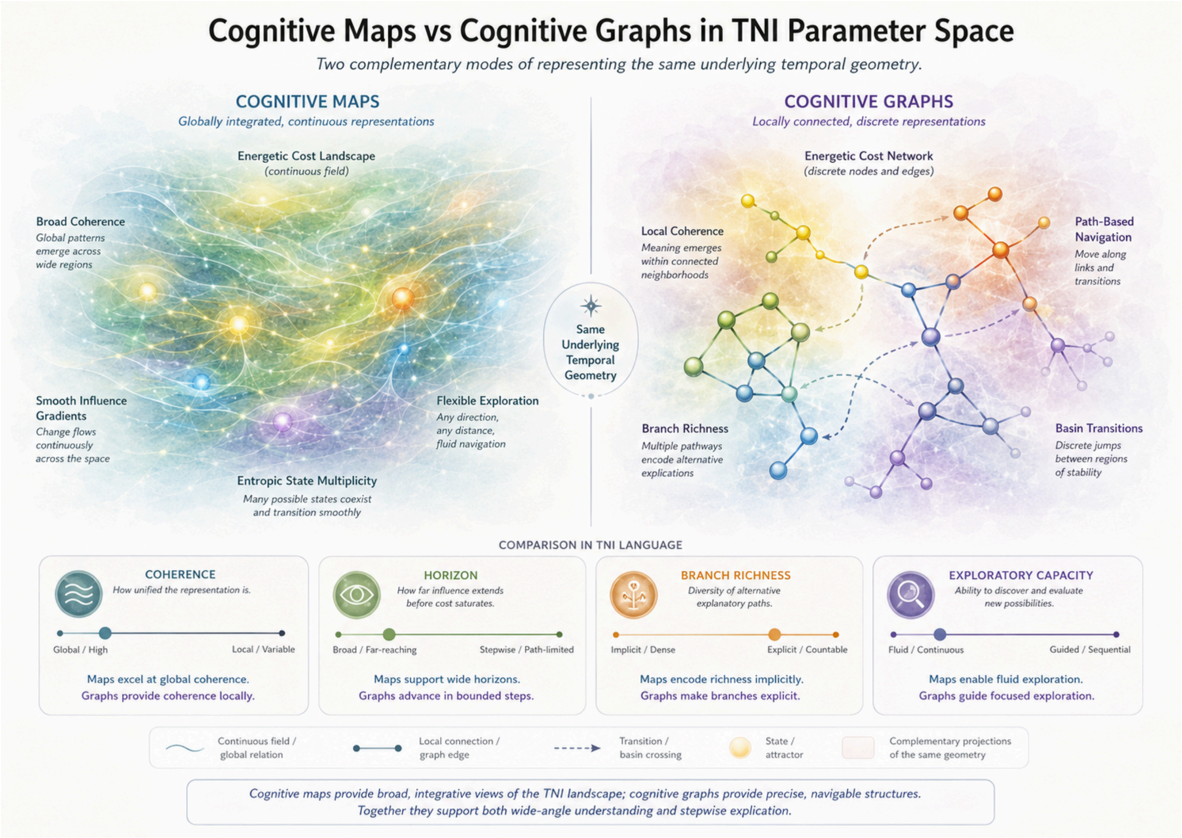

Figure 5. Cognitive maps vs cognitive graphs in TNI parameter space. Two complementary modes of representing the same underlying temporal geometry: maps provide broad integrative views; graphs provide precise, navigable structures.

9. Potential Applications

Because subjective time is foundational to functioning, the TNI has implications across decision-making, design, human–AI interaction, and collective systems. *(Clinical, therapeutic, and neurodiversity-coaching applications are developed in the separate clinical companion and are not restated here.)* **Decision-making and executive function.** By modeling how individuals construct the near and far future, the TNI can support self-management strategies (including time-blindness compensation), executive-function coaching, and decision frameworks tailored to temporal strengths, and it offers organizations a way to think about distributing short- and long-horizon tasks across mixed temporal profiles.

Design and human-centered technology. Interfaces rely on predictable temporal experience; the TNI can inform interruptibility, task-flow structure, and workload pacing — for instance, adjusting complexity when jitter rises, or adapting pacing to horizon and width — as a lens for accessibility and personalization.

Human–AI interaction. Temporal modeling matters for agents that interact with people or manage long-horizon tasks. The TNI suggests systems that adapt to a user's temporal profile (presenting choices differently for narrow versus wide futures), detect shifts in temporal state, and align human and machine temporal reasoning. *(This application describes adaptation to* *human temporal profiles; it makes no claim about, and does not depend on, the separate governed-agentic-infrastructure program.)*

Collective systems. Temporal patterns exist at the group level too — shared horizons, collective jitter, collapses of coherence, shared width. The formal treatment of the collective regime (coupled fields, collective capacity, the pacing prediction) is consolidated in Supplement II, Part 7; the TNI supplies the group-level projection.

10. Limitations and Ethics

(Preserved from the canonical; the anti-diagnostic and no-quantum-mechanism guards are load-bearing and are not reworded.)

Conceptual. The TNI is an emerging, not established, framework: it integrates well-supported components — predictive processing, temporal cognition, neurodiversity research, information geometry — into a new structure that requires empirical validation, and it should be read as a generative model rather than a definitive or diagnostic one. It compresses complex neural processes into five parameters, deliberately trading completeness for usefulness. And its parameters incorporate both trait-like and state-dependent factors, which can blur interpretation unless temporal sampling is explicit.

Measurement. Some parameters (jitter, coherence) map onto measurable behavioral or neural metrics more readily than others (branch richness, future width), which reflect subjective and imaginative processes; reliable measurement will require converging methods, and no single method captures the full structure. The neuroscientific mapping remains incomplete: functional attributions to the cerebellum, basal ganglia, DMN, and other systems are grounded in existing theory, but direct causal evidence is limited and some relationships remain indirect.

Ethics. The TNI is not a diagnostic tool and must never be used to classify individuals into fixed categories, determine eligibility for services, or justify gatekeeping; its purpose is descriptive. Time perception is shaped by culture, socioeconomic constraint, and life experience, so temporal geometry must not be used to universalize or essentialize differences that may have contextual origins. A core commitment is that temporal variability is a form of human diversity: no profile is "deficient," differences reflect adaptations and strengths, and interventions should focus on support rather than normalization. If implemented in technology, temporal data must remain private and consented, since temporal patterns can reveal sensitive aspects of mental health. And because geometric models invite reification, it must be emphasized that the cones are representations, the parameters approximations, and the interpretations nuance-dependent.

Scope guard. The TNI makes **no claim of quantum processes in the brain.** Its use of geometric and information-theoretic language is structural; where it engages the quantum-cognition literature (§2.1), it does so to distinguish its account of order effects from that tradition, not to adopt it.

11. Structural Predictions and Validation Strategy

TNI's predictions concern patterns of temporal geometry and its breakdown, and they are falsifiable. As load approaches and exceeds capacity, the framework predicts a characteristic sequence — rising jitter and strain, shrinking horizon and width — and identifiable transitions among regulated, looping, and collapsed regimes, with hysteresis such that recovery requires partial restoration of capacity and reconsolidation of coherence rather than mere reversal of the entry path (the regime and recovery propositions of Supplement II, Part 5). Within a regime, small perturbations that do not violate capacity leave trajectories in the same basin; crossing joint thresholds under load induces nonlinear regime transitions.

For ordering sensitivity specifically, the framework predicts that ψ increases when jitter is high, coherence low, horizon short, and the system near capacity, and is small in well-regulated regimes — and, crucially, that ordering effects are context-dependent rather than universal, so that empirical null effects constrain where ψ is expected to be non-negligible rather than falsifying the framework (the *Conditions for Low ψ* and *Regime Dependence of ψ* propositions, Supplement II, Part 3.6).

Validation will proceed across behavioral timing tasks, neuroimaging and electrophysiology, computational parameter-fitting, self-report and ecological measures, and cross-population studies (neurotypical, ADHD, autism, AuDHD, trauma-exposed). Interval-timing and duration tasks estimate J and C; prospective/retrospective duration and prospection tasks estimate H, W, and B; and factor analysis will test whether H, W, J, C, and B emerge as separable latent dimensions. The ψ readout has its own dedicated protocol.

§M.ψ — Estimating ordering sensitivity

(Operationalizes the ψ readout in weak form. The protocol tests the ordering-sensitivity prediction; it does not assume it.)

Design. Within-subject, two-condition order manipulation. Construct intervention or task blocks A and B matched for total duration, informational content, and difficulty, differing in structure (attention-switching demand, memory segmentation, surprise placement). Each participant completes both orders (A→B, B→A) across counterbalanced sessions separated to limit carryover, with session-order counterbalanced across participants.

Measures. A *duration channel* (prospective and retrospective duration estimates, full-sequence and per block) and a *reachability channel* (post-sequence measures of the future reachable set: option-generation fluency and diversity, strategy-switch success, planning-depth probes, recovery time after perturbation), together with state covariates (load, arousal, regime markers) so that ψ estimates can be conditioned on state.

Predictions. (P1) Mean duration estimates do *not* differ significantly between orders — order manipulation at matched content leaves the duration channel approximately invariant. (P2) Reachability-channel outcomes *do* diverge by order, and the divergence magnitude is the ψ estimate. (P3) ψ is state-dependent, growing under load and constraint and shrinking in low-constraint conditions. (P4) ψ estimated this way predicts, out of sample, the sequence-sensitivity of intervention outcomes for the same individual.

Discriminant controls and falsification. ψ must be separable from simple memory order effects (hence reachability outcomes, not recall accuracy, as the primary channel), from fatigue and practice (counterbalancing plus per-block covariates), and from duration distortion (P1 is a built-in confound check: if duration means shift with order as strongly as reachability measures do, the ψ interpretation is confounded and fails in that dataset). The construct fails if reachability outcomes are order-invariant precisely where the model predicts high ψ, or if all order divergence is absorbed by memory-order and fatigue covariates. These are honest exits the framework is committed to.

12. Conclusion

Subjective time is a core dimension of cognition whose complexity has been historically underestimated. Converging evidence shows that time is constructed by the brain — dynamically shaped by state, context, neurotype, and experience — rather than passively registered. The Temporal Neuroscience Index offers a framework for understanding that construction as a low-dimensional projection of an information geometry, decomposing temporal experience into horizon, width, jitter, coherence, and branch richness, with a derived ordering-sensitivity readout. The framework unifies fragmented findings under one structure, gives temporal experience a quantifiable and visualizable form, offers a non-pathologizing vocabulary for neurodiversity and trauma, and opens applications across decision-making, design, and human–AI interaction. It remains an early-stage model: empirical validation is essential, measurement of the more imaginative parameters is genuinely hard, and ethical deployment demands respect for individual and cultural difference. Held to those commitments, the TNI advances a simple but consequential idea — that to understand a person we must understand the geometry of their relationship to time — and gives that idea a form that can be measured, tested, and, where it helps, supported.

References

[1] Buhusi, C. V., & Meck, W. H. (2005). What makes us tick? Functional and neural mechanisms of interval timing. Nature Reviews Neuroscience, 6(10), 755–765. https://doi.org/10.1038/nrn1764

[2] Coull, J. T., Cheng, R.-K., & Meck, W. H. (2011). Neuroanatomical and neurochemical substrates of timing. Neuropsychopharmacology, 36, 3–25. https://doi.org/10.1038/npp.2010.113

[3] Suddendorf, T., & Corballis, M. C. (2007). The evolution of foresight: What is mental time travel, and is it unique to humans? Behavioral and Brain Sciences, 30(3), 299–313. https://doi.org/10.1017/S0140525X07001975

[4] Tulving, E. (2002). Episodic memory: From mind to brain. Annual Review of Psychology, 53, 1–25. https://doi.org/10.1146/annurev.psych.53.100901.135114

[5] Schacter, D. L., Addis, D. R., & Buckner, R. L. (2007). Remembering the past to imagine the future: The prospective brain. Nature Reviews Neuroscience, 8, 657–661. https://doi.org/10.1038/nrn2213

[6] Atance, C. M., & O'Neill, D. K. (2001). Episodic future thinking. Trends in Cognitive Sciences, 5(12), 533–539. https://doi.org/10.1016/S1364-6613(00)01804-0

[7] Frederick, S., Loewenstein, G., & O'Donoghue, T. (2002). Time discounting and time preference: A critical review. Journal of Economic Literature, 40(2), 351–401. https://doi.org/10.1257/002205102320161311

[8] Zimbardo, P. G., & Boyd, J. N. (1999). Putting time in perspective: A valid, reliable individual-differences metric. Journal of Personality and Social Psychology, 77(6), 1271–1288. https://doi.org/10.1037/0022-3514.77.6.1271

[9] Barkley, R. A. (1997). Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. Psychological Bulletin, 121(1), 65–94. https://doi.org/10.1037/0033-2909.121.1.65

[10] Toplak, M. E., Dockstader, C., & Tannock, R. (2006). Temporal information processing in ADHD: Findings to date and new methods. Journal of Neuroscience Methods, 151(1), 15–29. https://doi.org/10.1016/j.jneumeth.2005.09.018

[11] Klyubin, A. S., Polani, D., & Nehaniv, C. L. (2005). Empowerment: A universal agent-centric measure of control. Proceedings of the IEEE Congress on Evolutionary Computation, 1, 128–135. https://doi.org/10.1109/CEC.2005.1554676

[12] Salge, C., Glackin, C., & Polani, D. (2014). Empowerment — An introduction. In M. Prokopenko (Ed.), Guided Self-Organization: Inception (pp. 67–114). Springer. https://doi.org/10.1007/978-3-642-53734-9_4

[13] Sutton, R. S., Precup, D., & Singh, S. (1999). Between MDPs and semi-MDPs: A framework for temporal abstraction in reinforcement learning. Artificial Intelligence, 112(1–2), 181–211. https://doi.org/10.1016/S0004-3702(99)00052-1

[14] Dayan, P. (1993). Improving generalization for temporal difference learning: The successor representation. Neural Computation, 5(4), 613–624. https://doi.org/10.1162/neco.1993.5.4.613

[15] Busemeyer, J. R., & Bruza, P. D. (2012). Quantum Models of Cognition and Decision. Cambridge University Press. https://doi.org/10.1017/CBO9780511997716

[16] Wang, Z., Solloway, T., Shiffrin, R. M., & Busemeyer, J. R. (2014). Context effects produced by question orders reveal quantum nature of human judgments. Proceedings of the National Academy of Sciences, 111(26), 9431–9436. https://doi.org/10.1073/pnas.1407756111

[17] Friston, K. (2010). The free-energy principle: A unified brain theory? Nature Reviews Neuroscience, 11, 127–138. https://doi.org/10.1038/nrn2787

[18] Friston, K., Kilner, J., & Harrison, L. (2006). A free energy principle for the brain. Journal of Physiology-Paris, 100(1–3), 70–87. https://doi.org/10.1016/j.jphysparis.2006.10.001

[19] Clark, A. (2013). Whatever next? Predictive brains, situated agents, and the future of cognitive science. Behavioral and Brain Sciences, 36(3), 181–204. https://doi.org/10.1017/S0140525X12000477

[20] Hohwy, J. (2013). The Predictive Mind. Oxford University Press.

[21] Seth, A. K., Suzuki, K., & Critchley, H. D. (2011). An interoceptive predictive coding model of conscious presence. Frontiers in Psychology, 2, Article 395. https://doi.org/10.3389/fpsyg.2011.00395

[22] Seth, A. K. (2013). Interoceptive inference, emotion, and the embodied self. Trends in Cognitive Sciences, 17(11), 565–573. https://doi.org/10.1016/j.tics.2013.09.007

[23] Seth, A. K., & Tsakiris, M. (2018). Being a beast machine: The somatic basis of selfhood. Trends in Cognitive Sciences, 22(11), 969–981. https://doi.org/10.1016/j.tics.2018.08.008

[24] Barrett, L. F., & Simmons, W. K. (2015). Interoceptive predictions in the brain. Nature Reviews Neuroscience, 16, 419–429. https://doi.org/10.1038/nrn3950

[25] Amari, S. (2016). Information Geometry and Its Applications. Springer. https://doi.org/10.1007/978-4-431-55978-8

[26] Anderson, M. (2026). Supplement II — Adaptive Systems Formal Supplement. AI ARMY research program.