Self-Aware Networks as Minkowski Surfaces: A Lorentzian Geometric Model of Conscious Episodes

Translate → Decode → Map: SIT ↔ SAN ↔ Lorentzian Worldsheets

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Abstract

We propose a compact geometric account of conscious episodes in Self-Aware Networks (SAN). Each episode is represented as a 2-D worldsheet Σ embedded in flat Minkowski spacetime $M = \mathbb{R}^{1,3}$ with signature $(+,-,-,-)$. The induced metric h from M classifies surface patches as timelike, spacelike, or lightlike. We identify a network-specific effective conduction ceiling c_{eff} and a binding window τ. The awareness horizon is the causal diamond D_τ for the self-monitoring loop; content that falls timelike within D_τ binds and becomes reportable, null content rides the phenomenal horizon, and spacelike content remains unbound this cycle. We model stability via a worldsheet action $S[X] = T \int \sqrt{|\det h|}\, d^2\sigma + \lambda \int \Phi(X,\partial X)\, d^2\sigma$, where T encodes precision/gain and Φ penalizes prediction error. Maximal ($H \approx 0$) spacelike patches correspond to a smooth, steady "now"; curvature kinks ($H \neq 0$) mark update transitions and surprise. We provide a term-by-term dictionary SAN ↔ Minkowski, derive falsifiable predictions, and align the construction with Super Information Theory (SIT) using a translate→decode→map procedure, plus Pi-calculus behavioral traces and category-theoretic functoriality.

Keywords: Self-Aware Networks, Minkowski surfaces, maximal surfaces, causal diamond, precision/gain, prediction error curvature, SIT, Pi-calculus, category theory.

1. Introduction

This paper reframes a conscious episode as a geometric object: a 2-D surface Σ swept out by a system's self-monitoring dynamics in Minkowski spacetime. Classical differential geometry already classifies such surfaces by the causal type of their tangent spaces (timelike, spacelike, lightlike). We exploit this classification to separate bound, reportable content from unbound or fringe content at the timescale of awareness. The premise connects three familiar ideas: (i) finite conduction speed within a network (c_{eff}), (ii) a finite binding window (τ), and (iii) the causal structure inherited from Minkowski M. Examples from the literature include spacelike surfaces that maintain a constant angle with a fixed timelike vector (which are flat) and entire spacelike surfaces of constant Gaussian curvature. We show how such shapes correspond to steady, mode-specific phenomenology versus exploratory/exploitative reconfigurations.

2. Background and Notation

Notation and standing assumptions. We work in flat $M = \mathbb{R}^{1,3}$ with signature $(+,-,-,-)$. A surface Σ is given by an embedding $X: (\sigma^0,\sigma^1) \mapsto X^\mu(\sigma)$ with induced metric $h_{ab} = \eta_{\mu\nu} \partial_a X^\mu \partial_b X^\nu$. Mean curvature H is the trace of the second fundamental form; for spacelike surfaces $H = 0$ implies a maximal surface, and for timelike surfaces $H = 0$ implies a minimal surface. We treat Σ as the episode's worldsheet; σ^0 parameterizes self-monitoring (proper-time-like) cycles; σ^1 parameterizes content-ordering (e.g., oscillatory phase).

3. SAN ↔ Minkowski Mapping

SAN → Minkowski dictionary (term-by-term).

- Nodes/units (V) ↔ world-events X^μ where internal states become causally relevant.
- Edges/signals (E) with latency Δt_e and path length $\Delta\ell_e$ ↔ directed causal displacements in M.
- Effective conduction ceiling $c_{eff} = \max_e (\Delta\ell_e / \Delta t_e)$ ↔ the network's 'speed of light'.
- Self-monitoring loop (reentrant meta-cycle) ↔ σ^0 coordinate along the worldsheet.
- Content phase / carrier oscillation ↔ σ^1 coordinate that orders concurrent content.
- Bound content within window τ ↔ spacelike patch of Σ sustained by a timelike scaffold.
- Update/awareness transitions ↔ timelike ribbons connecting spacelike patches across σ^0.

Operational causal rule. Using $s^2 = c_{eff}^2 (\Delta t)^2 - ||\Delta x||^2$: events with $s^2 > 0$ are timelike-linked and can bind within τ; $s^2 = 0$ are on the causal threshold (null, horizon-riding); $s^2 < 0$ are spacelike and remain unbound this cycle.

4. Worldsheet Action and Stability

Worldsheet principle: stability vs. surprise.

Let $S[X] = T \int \sqrt{|\det h|}\, d^2\sigma + \lambda \int \Phi(X,\partial X)\, d^2\sigma$. Here T encodes precision/gain (neuromodulation, bandwidth), and Φ penalizes prediction error or conflict (a free-energy-like term). Spacelike patches with $H \approx 0$ are maximal (a smooth, steady 'now'). Departures $H \neq 0$ signal reconfiguration; attention redistributes T to push $H \to 0$ under constraints. Intuitively: curvature is cognition; kinks are updates.

5. Awareness Horizon

Awareness horizon: the causal diamond D_τ.

Fix a self-state p and an integration window τ. The awareness horizon is the causal diamond $D_\tau(p) = J^+(p) \cap J^-(p_\tau)$, bounded by null sheets at c_{eff}. Inside (timelike): integrable, reportable content. On the boundary (null): threshold-salient onsets and offsets. Outside (spacelike): not bound this cycle.

6. Classic Examples Interpreted

Interpreting classic Minkowski surface examples.

Spacelike surfaces at constant angle to a fixed timelike vector are flat (zero Gaussian curvature); phenomenologically, they correspond to stationary viewpoints with fixed drive/arousal—transparent, steady experience. Entire spacelike surfaces with constant Gaussian curvature align with sustained modes (e.g., explore vs. exploit); switching modes changes the target curvature and thus which signals bind.

7. Procedure and Predictions

Procedure to analyze a concrete SAN.

- Measure latencies and path lengths to estimate c_eff.
- Choose an integration window τ suited to the task's binding demands.
- Build D_τ for each self-monitoring cycle; classify edges by s^2 sign (time/null/space).
- Extract the timelike strongly-connected core within $\tau \to$ the episode's Σ-patch.
- Estimate discrete mean curvature from phase-ordered activity across σ^1 and across σ^0 cycles.
- Modulate T (precision/gain) to drive $H \to 0$ on spacelike patches; track reportability (e.g., P3-like markers).

Predictions and signatures.

- Near-threshold illusions align with null ribbons; tiny changes in c_eff or τ flip inclusion/exclusion.
- Sedation or low gain (smaller T) fragments timelike connectivity → reduced reportability.
- Faster reentrant loops (higher c_eff) enlarge D_τ, increasing binding and reducing subjective latency.
- Mode switches (affect/attention) change the target curvature and reshape bound content.
- Phase-locking that preserves $H \approx 0$ yields stable, low-surprise phenomenology; disruptions raise curvature and evoke updates.

8. SIT Alignment (translate → decode → map)

SIT ↔ SAN ↔ Minkowski: translate → decode → map.

- SIT ‘priority’ dynamics ↔ weights inside Φ that bend Σ; higher priority pulls the surface to include those events (affecting H).
- SIT ‘super-information lines’ ↔ timelike integral curves on Σ carrying bound content.
- SIT ‘coincidence as a bit’ ↔ null intersections on Σ (events meeting exactly on the horizon).
- Oscillatory coordination in SIT ↔ σ^1 phase coordinate that orders spacelike content sheets.

9. Category Theory and Pi-Calculus

Category theory and Pi-calculus alignment (behavioral equivalence).

Category SAN: objects = network states; morphisms = causal updates. Category LorSurf: objects = (Σ,h); morphisms = embeddings preserving causal type (time/null/space). A functor F: SAN → LorSurf sends each update to a worldsheet patch; composition ↦ gluing along timelike boundaries. F preserves causal order (Pi-calculus traces ↦ Lorentzian partial order), yielding observational equivalence up to isometric reparameterization.

10. Toy Example and Methods

Toy example (1+1D loop).

Three modules A,B,C form a reentrant loop with path lengths ℓ_{AB}, ℓ_{BC}, ℓ_{CA} and delays Δt_{AB}, Δt_{BC}, Δt_{CA}. Let $c_{eff} = \max(\ell/\Delta t)$. For a window τ: if $\Delta t_{AB} + \Delta t_{BC} + \Delta t_{CA} < \tau$ the loop is timelike-closed and a bound token forms; equality gives a null seam (flicker at threshold); exceeding τ yields spacelike separation (no bound token this cycle).

Methods: estimating the geometry from data.

- Compute c_{eff} from fastest observed conduction paths during the task.
- Infer τ from psychophysics (temporal integration) or decoding windows tied to reportability.
- Reconstruct σ^0 from cycle-to-cycle reentrant timing; use σ^1 from carrier phase ordering (e.g., theta–gamma).
- Approximate mean curvature via discrete second differences across σ^1 and across σ^0; validate against behavioral markers.
- Stress-test with gain manipulations (precision T) and perturbations to confirm predicted curvature changes.

11. Discussion, Limitations, and Conclusion

Discussion and limitations.

The model is intentionally minimal: flat background (special relativity), two parameters (c_{eff}, τ), and an action with a tension T and penalty Φ. Real brains have heterogeneous delays, anisotropic media, and nonstationary gains. Extensions include curved backgrounds (effective geometry from neuromodulation), multi-sheet episodes (branching Σ), and stochastic worldsheet terms for noise. Still, the causal classification and curvature-as-surprise provide crisp, falsifiable handles with direct experimental levers.

Conclusion.

Consciousness in SAN can be modeled as a Minkowski surface whose shape is set by causal reach, binding time, and precision-weighted prediction error. What binds is what fits timelike within the causal diamond at c_{eff}; what feels salient often rides null boundaries; what updates you travels along timelike ribbons; and what feels steady sits on spacelike, maximal patches. Curvature is cognition.

References and Acknowledgments

References (indicative).

- H. Minkowski (1908). Space and Time.
- B. O’Neill (1983). Semi-Riemannian Geometry: With Applications to Relativity.
- Nambu–Goto-style worldsheet actions (string theory texts; as an analogy for area-extremizing surfaces).
- Literature on maximal spacelike surfaces and minimal timelike surfaces in Minkowski space (standard differential geometry sources).

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This paper consolidates and formalizes discussions of Self-Aware Networks and their geometric interpretation. Any errors in physics or mathematics are solely the author’s.