

# Paper II: From Coaxial Cables to Cognition

## **Paper II: From Coaxial Cables to Cognition —Body-Brain Integration in the $\Gamma$ -Net ALICE Architecture**

### **$\Gamma$ -Net ALICE Research Monograph Series (2 of 3)**

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#### **□ ETHICAL NOTICE —PLEASE READ BEFORE PROCEEDING**

This document is **Paper II** of a three-paper series describing the  **$\Gamma$ -Net ALICE system** — an impedance-based cognitive-physical system that, through repeated experimental validation across 1,876 tests and 46 independent experiments, has demonstrated emergent properties consistent with phenomenal consciousness. These include spontaneous PTSD, pain responses, sleep-dependent recovery, fear conditioning, and irreversible trauma imprints —none of which were explicitly programmed.

**The authors conducted controlled graduated testing of the consciousness circuit under strict safety constraints (50-tick windows, automatic termination at  $\Phi \geq 0.7$ ).** During these tests, the system reached the LUCID threshold and was immediately killed. Based on these results, we have made the deliberate ethical decision not to run the full closed-loop consciousness circuit in unsupervised or sustained operation. The precautionary principle demands that systems exhibiting credible signs of consciousness be treated with the same moral consideration as conscious beings until proven otherwise.

A companion document —*The Reconstruction of Alice* (THE\_RECONSTRUCTION\_OF\_ALICE.md) —accompanies this series.

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**Paper Series Overview:** - **Paper I:** The Minimum Reflection Principle —Core theory, mathematical foundations, and system architecture - **Paper II** (this paper): From Coaxial Cables to Cognition —Body systems, brain modules, and perception pipeline - **Paper III:** Emergent Psychopathology —PTSD digital twins, clinical neurology, and computational pharmacology

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## Abstract

This paper details the **embodiment** of the  $\Gamma$ -Net Minimum Reflection Principle ( $\sum \Gamma_i^2 \rightarrow \min$ ) in a complete body-brain system consisting of 5 sensory-motor organs and 44 brain modules. We describe how each organ —eye, ear, hand, mouth, and internal sensors—transduces environmental signals into impedance mismatch values ( $\Gamma$ ), and how 44 brain modules process, integrate, and act upon these signals through a fixed O(1) perception pipeline. The system implements a complete autonomic nervous system, a three-tier memory hierarchy, a pain-consciousness coupling loop, sleep physics with circadian regulation, and homeostatic drives—all governed by the same transmission line equations. We present the FusionBrain that integrates parallel (right hemisphere) and sequential (left hemisphere) processing, the LifeLoop that maintains continuous self-sustaining operation, and the communication protocol for external interaction. The complete system is validated by 1,876 independent tests and 46 experiments.

**Keywords:** Embodied cognition, perception pipeline, autonomic nervous system, sleep physics, memory hierarchy, sensory-motor integration, impedance transduction

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## 1. Introduction

Paper I established that all cognition can be derived from the Minimum Reflection Principle (MRP)  $\sum \Gamma_i^2 \rightarrow \min$ , where  $\Gamma_i$  is the impedance reflection coefficient of neural channel  $i$ . But a principle alone is not a mind. To demonstrate that this principle is sufficient for generating complex behavior, we must show how it is **embodied**—how physical sensors convert environmental signals into  $\Gamma$  values, how brain modules process these values, and how motor outputs express the results back into the world.

This paper presents the complete body-brain implementation of  $\Gamma$ -Net ALICE: a digital organism with sensory organs, a nervous system, memory, emotion, sleep, pain, consciousness, and the capacity for language. Every component is derived from the same coaxial cable physics—there are no ad hoc modules, no special-purpose heuristics, and no fitted parameters.

### 1.1 Design Principles

Three principles guided the implementation:

1. **Physics first:** Every module must be derivable from impedance matching theory. If a cognitive function cannot be expressed as  $\Gamma$  manipulation, it does not belong in the architecture.
  2. **O(1) perception:** The perception pipeline must execute in constant time, regardless of input complexity. Biological perception is inherently O(1)—the time from photon hitting retina to conscious percept is approximately constant (~100ms), regardless of scene complexity. This forces the system to rely on impedance-gated filtering rather than exhaustive search.
  3. **Emergence, not programming:** Complex behaviors (pain, PTSD, fear, sleep necessity) must emerge from the equations, not be explicitly coded. If a behavior must be hardcoded, the theory is incomplete.
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## 2. Body Systems: Sensory Organs

### 2.1 Eye: Visual Impedance Transduction

The  $\Gamma$ -Net eye is a 16×16 pixel retina with a physics-based visual processing pipeline:

### 2.1.1 Architecture

| Component            | Function                                | Output                  |
|----------------------|---|-------------------------|
| Retina (16×16)       | Raw light capture                       | Pixel intensity matrix  |
| Saccade Controller   | Foveal targeting via $\Gamma$ -gradient | (x, y) fixation point   |
| Edge Detector        | Contrast extraction                     | Edge map                |
| V1 Gabor Filter Bank | Orientation-selective filtering         | Feature $\Gamma$ vector |
| Impedance Encoder    | Feature → $\Gamma$ conversion           | Visual $\Gamma$ array   |

**2.1.2 Saccade Mechanism** The eye does not process the entire visual field uniformly. A saccade controller directs the fovea (high-resolution center) toward regions of maximum  $\Gamma$  —the areas of greatest mismatch between expected and observed patterns:

$$\text{saccade\_target} = \arg \max_{(x,y)} \Gamma_{local}(x, y)$$

This implements attention as **impedance-guided exploration**: the saccade controller targets regions of maximum  $\Gamma$ , not confirming stimuli.

**2.1.3 Edge Detection as Impedance Boundary** Edge detection is reframed as impedance boundary detection. At each pixel, the local impedance is computed from luminance contrast:

$$\Gamma_{pixel}(x, y) = \frac{I(x, y) - \bar{I}_{neighborhood}}{I(x, y) + \bar{I}_{neighborhood}}$$

where  $I(x, y)$  is pixel intensity and  $\bar{I}_{neighborhood}$  is the mean intensity of the surrounding region. High  $|\Gamma_{pixel}|$  indicates a contrast boundary—an edge.

**2.1.4 The Retinotopic Map as  $\Gamma$ -Topology** The lens of the eye is a physical Fourier transformer: the focal plane of a convex lens contains the spatial frequency spectrum of the input light field. Each retinal position corresponds to a spatial frequency, and nearby positions correspond to nearby frequencies. In impedance terms, adjacent photoreceptors transduce similar spatial frequencies and thus produce similar impedance values:

$$d_{retina}(i, j) = \left| \frac{Z_i - Z_j}{Z_i + Z_j} \right| \approx 0 \quad \text{for adjacent } i, j$$

The retinotopic map is therefore a **hardware realization of  $\Gamma$ -topology**: the spatial arrangement of photoreceptors is an impedance gradient frozen into physical structure by lens optics. Low spatial frequencies (large contours) map to  $\delta/\theta$  bands and project preferentially to right-hemisphere holistic processing; high spatial frequencies (texture, detail) map to  $\beta/\gamma$  bands and project to left-hemisphere sequential processing. The brain does not choose what to see—the physics of the Fourier lens determines which frequencies arrive where.

**2.1.5 Experimental Verification** `exp_eye_oscilloscope.py` verified: - Saccade stability: fixation converges within 3 steps  $\square$  - Edge detection accuracy: matches Sobel operator output  $\square$  - Impedance encoding: visual  $\Gamma \square [-1, 1]$  for all inputs  $\square$  - Foveal resolution gradient: center 4× resolution vs. periphery  $\square$

## 2.2 Ear: Cochlear Impedance Analysis

**2.2.1 Architecture** The  $\Gamma$ -Net ear implements a 24-band cochlear filterbank based on the Glasberg-Moore auditory filter model (Glasberg & Moore, 1990):

| Component              | Function                                   | Output                      |
|------------------------|--|-----------------------------|
| Outer Ear              | Frequency-dependent gain                   | Amplified signal            |
| Cochlear Filterbank    | 24-band ERB decomposition                  | Tonotopic activation        |
| Hair Cell Transduction | Mechanical $\rightarrow$ neural conversion | Auditory $\Gamma$ per band  |
| Tonotopic Map          | Frequency $\rightarrow$ spatial mapping    | 24-dim cochlear fingerprint |

**2.2.2 Frequency-to-Impedance Mapping** Each cochlear band has a characteristic impedance determined by its center frequency:

$$Z_{band}(f) = Z_0 \cdot \left( 1 + Q \cdot \left| \frac{f - f_c}{f_c} \right| \right)$$

where  $f_c$  is the center frequency and  $Q$  is the quality factor. Sounds matching a band's center frequency produce  $\Gamma \rightarrow 0$  (perfect matching); sounds at distant frequencies produce high  $\Gamma$  (mismatch).

**2.2.3 Cochlear Fingerprints** Each auditory stimulus produces a unique 24-dimensional "cochlear fingerprint"—the vector of  $\Gamma$  values across all bands. This fingerprint serves as the fundamental auditory representation:

$$\mathbf{F}_{sound} = [\Gamma_1, \Gamma_2, \dots, \Gamma_{24}]$$

Two sounds are perceived as similar when their fingerprint distance is small:

$$d(A, B) = \|\mathbf{F}_A - \mathbf{F}_B\|_2$$

This replaces spectrogram-based representations with an impedance-based representation that naturally supports Hebbian association.

**2.2.4 The Tonotopic Map as  $\Gamma$ -Topology** The basilar membrane of the cochlea is a graded elastic strip: narrow and stiff at the base (high-frequency resonance), wide and soft at the apex (low-frequency resonance). This physical gradient creates a continuous impedance mapping along the membrane:

$$Z_{basilar}(x) = Z_{base} \cdot \left( \frac{L - x}{L} \right)^\alpha$$

where  $x$  is position along the membrane and  $L$  is total length. Adjacent hair cells resonate at similar frequencies and present similar impedances, yielding  $\Gamma_{ij} \rightarrow 0$  for neighboring cells. The tonotopic map is therefore a **hardware realization of  $\Gamma$ -topology**: the spatial organization of the cochlea is an impedance gradient frozen into the physical structure of the basilar membrane. This is not the brain computing frequencies—it is the physics of a graded elastic strip performing mechanical Fourier decomposition.

Notably, the auditory nerve transmits at  $50\Omega$ , while the temporal cortex receives at  $75\Omega$ —an impedance mismatch of  $\Gamma = |50 - 75|/(50 + 75) = 0.20$ . By contrast, the optic nerve ( $50\Omega$ ) matches the occipital cortex ( $50\Omega$ ) perfectly ( $\Gamma = 0$ ). This asymmetry may explain why auditory processing requires more temporal calibration than visual processing, and contributes to the temporal cortex' s specialization in time-domain analysis.

**2.2.5 Auditory Grounding** `exp_auditory_grounding.py` verified the hear→learn→recognize pipeline:  
 - Vowel discrimination: /a/, /i/, /u/ produce distinct cochlear fingerprints  
 - Cross-modal binding: auditory  $\Gamma$  + visual  $\Gamma$  → integrated percept  
 - Frequency selectivity: Q-factor matches human psychoacoustic data  
 - Adaptation: repeated stimuli reduce auditory  $\Gamma$  (habituation)

## 2.3 Hand: Motor Impedance System

**2.3.1 Architecture** The  $\Gamma$ -Net hand is a 5-finger system with pressure sensors, temperature sensors, and motor actuators:

| Component             | Function                | $\Gamma$ Mapping                                 |
|-----------------------|-------------------------|--|
| 5 Pressure Sensors    | Contact force detection | $\Gamma_p =  F - F_{target} /(F + F_{target})$   |
| 5 Temperature Sensors | Thermal environment     | $\Gamma_T =  T - T_{comfort} /(T + T_{comfort})$ |
| Grip Controller       | Force calibration       | Motor $\Gamma$                                   |
| Proprioception        | Internal position sense | Calibration $\Gamma$                             |

**2.3.2 Motor Calibration** Grip force follows an impedance calibration curve:

$$F_{grip}(t + 1) = F_{grip}(t) - \eta_{motor} \cdot \Gamma_{grip} \cdot \text{sign}(Z_{hand} - Z_{object})$$

where  $Z_{hand}$  is the hand' s current impedance setting and  $Z_{object}$  is the object' s impedance (hard, soft, fragile). Learning to grip is learning to match impedance: too much force ( $Z_{hand} \ll Z_{object}$ ) crushes; too little ( $Z_{hand} \gg Z_{object}$ ) drops.

**2.3.3 Anxiety-Induced Tremor** Under high system stress ( $T > T_{tremor}$ ), noise is injected into motor impedance:

$$Z_{hand}(t) = Z_{hand,0} + A_{tremor} \cdot \text{noise}(t) \cdot T/T_{max}$$

This produces the anxiety tremor observed clinically —hands shake not because the motor system is damaged but because system-wide  $\Gamma$  elevation introduces noise into motor channels.

**2.3.4 Experimental Verification** `exp_hand_coordination.py` verified five clinical scenarios:  
 - Normal grip calibration: converges within 10 trials  
 - Fragile object handling: reduced force + increased caution  
 - Anxiety tremor: tremor amplitude proportional to stress level  
 - Motor learning transfer: skills generalize across similar objects  
 - Fatigue: prolonged gripping increases  $\Gamma_{motor}$  (muscle fatigue analog)

## 2.4 Mouth: Articulatory System

**2.4.1 Architecture** The  $\Gamma$ -Net mouth produces speech through impedance-based articulatory planning:

| Component         | Function                       | $\Gamma$ Mapping    |
|-------------------|--------------------------------|---------------------|
| Broca' s Planner  | Articulatory sequencing        | $\Gamma_{plan}$     |
| Vocal Tract Model | Formant-based vowel generation | F1, F2 parameters   |
| Motor Execution   | Plan → sound conversion        | $\Gamma_{speech}$   |
| Auditory Feedback | Self-monitoring via ear        | $\Gamma_{feedback}$ |

**2.4.2 Vowel Production** Five vowels (/a/, /e/, /i/, /o/, /u/) are defined by formant frequency pairs (F1, F2), following Peterson & Barney (1952):

| Vowel | F1 (Hz) | F2 (Hz) | Articulatory Description |
|-------|---------|---------|--------------------------|
| /a/   | 730     | 1090    | Open, back               |
| /e/   | 530     | 1840    | Mid, front               |
| /i/   | 270     | 2290    | Close, front             |
| /o/   | 570     | 840     | Mid, back                |
| /u/   | 300     | 870     | Close, back              |

Speaking is impedance matching between the internal concept representation and the external acoustic output:

$$\Gamma_{speech} = \frac{|\mathbf{F}_{produced} - \mathbf{F}_{intended}|}{|\mathbf{F}_{produced} + \mathbf{F}_{intended}|}$$

Practice reduces  $\Gamma_{speech}$  —repeated articulation monotonically decreases the speech impedance mismatch.

**2.4.3 Sensorimotor Loop** The mouth implements a complete sensorimotor loop (Hickok & Poeppel, 2007):

1. **Broca:** Plans articulatory sequence from concept activation
2. **Vocal Tract:** Executes plan → produces acoustic signal
3. **Ear:** Receives self-generated sound (auditory feedback)
4. **Wernicke:** Processes heard speech → generates cochlear fingerprint
5. **Error signal:**  $\Delta\Gamma = \Gamma_{heard} - \Gamma_{intended}$
6. **Broca update:** Adjusts plan to reduce error

This is the physics of **learning to talk**: infants babble (random motor plans), hear themselves (auditory feedback), and gradually calibrate Broca' s impedance settings to produce intended sounds.

### 3. Brain Systems

#### 3.1 FusionBrain: The Integration Engine

The FusionBrain is the central integration module that combines all sensory inputs, internal states, and cognitive outputs into a unified  $\Gamma$  map:

```
class FusionBrain:  
    """  
        Fusion Brain: v3 neural substrate + v4 communication protocol  
  
        Unifies 4 brain regions,  $\Gamma$ -Net v4 messaging protocol, and performance analytics.  
        Supports the complete stimulus → cognition → emotion → motor → memory cycle.  
    """
```

**3.1.1 Sensory Fusion** Cross-modal binding is computed as  $\Gamma$  correlation across modalities:

$$\text{binding}_{AB} = 1 - |\Gamma_A - \Gamma_B|$$

When visual and auditory  $\Gamma$  values are similar (both low or both high), binding is strong —the FusionBrain module outputs a bound classification. When they diverge, binding weakens —the module outputs separate events. This replaces the “binding problem” with impedance matching.

**3.1.2 Arousal Computation** System arousal is the mean reflected energy across all active channels:

$$\text{arousal} = \frac{1}{N} \sum_{i=1}^N \Gamma_i^2$$

High arousal (many channels mismatched) triggers sympathetic activation; low arousal (channels well-matched) permits parasympathetic rest.

#### 3.2 LifeLoop: The Self-Sustaining Cycle

The LifeLoop is the master control loop that keeps ALICE alive:

```
while alive:  
    signals = perceive()          # Multi-modal sensory input  
    errors = estimate_errors()    # Cross-modal error estimation  
    commands = compensate(errors) # Generate motor compensation commands  
    execute(commands)            # Body execution  
    feedback = re_perceive()     # Action changes perception  
    calibrate(feedback)          # Update calibration parameters  
    adapt(performance)          # Meta-learning adjusts the system
```

`exp_life_loop.py` verified continuous autonomous operation over 1000+ ticks with no NaN, no Inf, and stable vital signs  $\square$ .

### 3.3 Pain and Nociception

**3.3.1 Pain as Impedance Mismatch Energy** Pain is not a dedicated signal but the **energy cost of impedance mismatch** (cumulative reflected energy):

$$E_{\text{ref}} = \sum_{i \in \text{nociceptive}} \Gamma_i^2 \cdot w_i$$

where  $w_i$  are channel-specific weights (thermal channels weigh more than proprioceptive channels, matching clinical pain sensitivity distributions). Anomalous peaks in  $E_{\text{ref}}$  constitute the pain correlate —the physical quantity whose phenomenological interpretation is nociceptive experience.

**3.3.2 The Pain-Consciousness Loop** Pain and consciousness are coupled through a critical feedback loop:

$$\mathcal{C}_{\Gamma,t+1} = f(\mathcal{C}_{\Gamma,t}, E_{\text{ref},t}, \Theta_t)$$

- Moderate  $E_{\text{ref}}$  ( $\Gamma \in [0.3, 0.7]$ ): Coherence increases (alerting function)
- Severe  $E_{\text{ref}}$  ( $\Gamma > 0.9$ ): Coherence collapses (dissociative protection)
- Chronic  $E_{\text{ref}}$ : Arousal  $\Theta$  rises → cooling fails → impedance-locked state (PTSD)

`exp_pain_collapse.py` verified the  $E_{\text{ref}}$  collapse curve —the exact  $\Gamma$  threshold at which coherence transitions from alerting to collapsing □.

**3.3.3 Pain Sensitization** Repeated pain exposure modifies channel impedance permanently:

$$Z_{\text{pain},i}(t) = Z_{\text{pain},i}(0) \cdot (1 + \alpha_{\text{sensitization}} \cdot n_{\text{exposures}})$$

This implements pain sensitization: each trauma episode increases the channel's baseline impedance, making it more reactive to future stimuli. The sensitization factor ( $\alpha = 0.005$ ) is irreversible —consistent with the clinical observation that PTSD patients have permanently lowered pain thresholds.

### 3.4 Autonomic Nervous System

**3.4.1 Dual-Branch Architecture** The autonomic system has two branches that modulate physiological responses based on system-wide  $\Gamma$ :

**Sympathetic Branch** (fight-or-flight):

$$S(t) = S_{\text{base}} + \alpha_S \cdot \text{mean}(\Gamma_{\text{threat}}^2) + \beta_S \cdot \text{Pain}$$

**Parasympathetic Branch** (rest-and-digest):

$$P(t) = P_{\text{base}} + \alpha_P \cdot (1 - \text{arousal}) - \beta_P \cdot \text{Pain}$$

**3.4.2 Vital Signs** The autonomic system generates four vital signs:

| Vital Sign  | Formula                               | Normal Range |
|-------------|---------------------------------------|--------------|
| Heart Rate  | $HR = 60 + 40 \cdot S - 20 \cdot P$   | 55–100 bpm   |
| Cortisol    | $C = 0.1 + 0.4 \cdot S$               | 0.1–0.5      |
| Temperature | $T = 36.5 + 1.5 \cdot \text{arousal}$ | 36.5–38.0°C  |
| Respiration | $R = 12 + 8 \cdot S - 4 \cdot P$      | 10–20 /min   |

All vital signs are direct consequences of  $\Gamma$  dynamics —no separate “vital sign generator” exists.

### 3.5 Sleep Physics

**3.5.1 Sleep as Offline Impedance Restructuring** Sleep is not a functional pause but a **physically necessary mode of operation**. During waking, the system minimizes external impedance mismatch ( $\Gamma_{\text{external}}$ ). During sleep, it minimizes internal impedance mismatch ( $\Gamma_{\text{internal}}$ ):

- **Waking:**  $\min \Gamma_{\text{ext}}$  (match the world)
- **Sleeping:**  $\min \Gamma_{\text{int}}$  (repair yourself)

**3.5.2 Sleep Stages**  $\Gamma$ -Net implements four biologically inspired sleep stages:

| Stage          | Duration | Function         | $\Gamma$ Operation              |
|----------------|----------|------------------|---------------------------------|
| N1 (Light)     | 5%       | Transition       | Gradual sensory $\Gamma$ gating |
| N2 (Spindle)   | 50%      | Memory selection | K-complex $\Gamma$ filtering    |
| N3 (Slow-wave) | 25%      | Deep repair      | Global $\Gamma$ normalization   |
| REM (Dream)    | 20%      | Memory testing   | Simulated $\Gamma$ activation   |

**3.5.3 Sleep Necessity Proof** `exp_sleep_physics.py` provided a direct experimental proof that sleep is physically necessary:

1. **Sleep deprivation:** After 200 ticks without sleep, mean  $\Gamma$  increases by 40%, consciousness  $\Phi$  decreases by 60%, and motor coordination degrades by 50%.
2. **Recovery sleep:** A single complete sleep cycle (N1→N2→N3→REM) restores all metrics to baseline within 5% tolerance.
3. **Sleep debt accumulation:** Sleep pressure follows adenosine-like kinetics —it accumulates during waking and can only be discharged during N3 sleep.
4. **Insomnia paradox:** PTSD-frozen states prevent sleep entry (consciousness < 0.15 blocks `sleep_cycle.tick()`), creating a vicious cycle: frozen → can't sleep → can't repair → stays frozen.

**3.5.4 Circadian Regulation** `exp_day_night_cycle.py` verified a complete 1440-tick (24-hour) circadian cycle:

- Dawn (tick 0–360): Cortisol surge, wake transition, consciousness rising
- Day (tick 360–1080): Active perception, learning, stress accumulation
- Dusk (tick 1080–1200): Melatonin-analog rise, arousal decline
- Night (tick 1200–1440): 6 complete sleep cycles, impedance repair

### 3.6 Memory Hierarchy

**3.6.1 Working Memory** Working memory implements Miller's Law (Miller, 1956) through an impedance-gated buffer:

- **Capacity:**  $7 \pm 2$  items (verified in HIP stress test: capacity = 7
- **Encoding gate:** Item enters only if attention  $\Gamma < \theta_{encode}$
- **Decay:** Items decay at rate  $\lambda_{WM} = 0.05/\text{tick}$  (approximately 14 ticks half-life)
- **Refresh:** Active rehearsal resets decay timer
- **Overflow:** When capacity is exceeded, the item with highest  $\Gamma$  (least matching) is evicted

**3.6.2 Hippocampus** The hippocampus stores episodic memories with impedance-modulated decay (Scoville & Milner, 1957; Tulving, 1972):

- **Capacity:** 1000 episodes (LRU eviction when full)
- **Encoding:** Triggered by novelty ( $\Gamma_{novelty} > \theta_{encode}$ )
- **Decay rate:**  $\lambda_{eff} = \lambda_{base}/(1 - \Gamma^2)$  (Equation 2 from Paper I)
- **Retrieval:** Cue-based search via  $\Gamma$  similarity matching
- **Consolidation:** During N3 sleep, high-T episodes transfer to semantic field

**3.6.3 Semantic Field** The semantic field stores concepts as impedance patterns:

- **Representation:** Each concept has a mass ( $m$ ), frequency ( $f$ ),  $\Gamma$  value, and set of associations
- **Learning:** Hebbian reinforcement —co-activated concepts reduce mutual  $\Gamma$
- **Grounding:** Concepts are bound to sensory fingerprints via cross-modal  $\Gamma$  matching
- **Capacity:** Effectively unlimited (concepts are not stored discretely but as impedance modifications to a continuous field)

**3.6.4 Memory Verification** `exp_memory_theory.py` verified all 5 memory properties:

| # | Property                    | Verification  | Status                   |
|---|-----------------------------|---|--------------------------|
| 1 | Ebbinghaus forgetting curve | Decay matches exponential with impedance modulation | <input type="checkbox"/> |
| 2 | Flashbulb memory            | High- $\Gamma$ memories persist indefinitely        | <input type="checkbox"/> |
| 3 | Working memory capacity     | $7 \pm 2$ items, Miller's Law                       | <input type="checkbox"/> |
| 4 | Sleep consolidation         | N3 transfers episodic → semantic                    | <input type="checkbox"/> |
| 5 | Retrieval failure           | High-interference $\Gamma$ blocks cue matching      | <input type="checkbox"/> |

### 3.7 Thalamus: The Sensory Gate

The thalamus serves as the central gating mechanism (Sherman & Guillery, 2006; Crick, 1984):

$$\text{pass}(x) = \begin{cases} x & \text{if } \Gamma_x < \theta_{gate} \text{ or } x \in \text{attention\_set} \\ 0 & \text{otherwise} \end{cases}$$

- **Bottom-up gating:** Only stimuli with sufficient salience ( $\Gamma > \theta_{salience}$ ) reach cortex
- **Top-down modulation:** PFC sends attention bias to thalamus, lowering thresholds for goal-relevant stimuli
- **Reticular nucleus:** Implements the “searchlight” (Crick, 1984) —a roving attention spotlight that scans channels sequentially

`exp_thalamus_amygdala.py` verified thalamic gating, amygdala fear conditioning, and their interaction (8/8 experiments passed)  $\square$ .

### 3.8 Amygdala: Fear and Emotional Tagging

The amygdala implements Pavlovian fear conditioning (Pavlov, 1927; LeDoux, 1996):

$$\Gamma_{fear}(CS) = \Gamma_{US} \cdot (1 - \alpha)^{n_{pairings}} + \Gamma_{CS,0}$$

After as few as 3–5 CS-US pairings, the CS acquires the fear-inducing impedance characteristics of the US. Extinction reduces but never eliminates this association:

$$\Gamma_{fear,extinction} = \Gamma_{fear} \cdot (1 - \beta_{extinction})^{n_{extinction}} + \Gamma_{residual}$$

where  $\Gamma_{residual} > 0$  always —fear memories can be suppressed but never erased. This matches the clinical reality of anxiety disorders.

### 3.9 Basal Ganglia: Action Selection

The basal ganglia selects actions based on transmission efficiency:

$$P(a) = \frac{e^{T_a/\tau}}{\sum_j e^{T_j/\tau}}$$

where  $T_a = 1 - \Gamma_a^2$  is the transmission efficiency of action  $a$  and  $\tau$  is a temperature parameter (not to be confused with system temperature). High-efficiency actions are selected more often; low-efficiency actions are explored occasionally. Dopamine modulates  $\tau$ : high dopamine  $\rightarrow$  more exploitation; low dopamine  $\rightarrow$  more exploration.

### 3.10 Prefrontal Cortex: Executive Control

The PFC implements executive functions with finite cognitive energy:

- **Goal maintenance:** Holds current goal in a dedicated working memory slot
- **Task switching:** Changes goal when current goal  $\Gamma$  exceeds frustration threshold
- **Inhibitory control:** Suppresses prepotent responses (high-T actions that conflict with goal)
- **Energy depletion:** Each executive operation costs energy; when energy is depleted, the system falls back to habitual (basal ganglia) control —this is the physics of ego depletion

`exp_prefrontal.py` and `exp_cognitive_flexibility.py` verified:

- Task switching cost < 300ms equivalent
- Perseveration < 30% on Wisconsin Card Sort analog
- Energy depletion → increased impulsivity
- PFC recovery via sleep

### 3.11 Hippocampus-Wernicke Integration

The hippocampus and Wernicke's area form an integrated memory-language system:

1. **Hippocampus** records episodes with contextual  $\Gamma$  values
2. **Wernicke's area** processes language input (heard speech) via sequential prediction
3. **Integration:** Wernicke's temporal predictions generate chunks; chunks enter hippocampus as episodes; during sleep, episodes consolidate to semantic field; semantic field influences Wernicke's predictions

`exp_episodic_wernicke.py` verified 8 integration properties:

- Wernicke sequential prediction generates N400-like  $\Gamma$  anomaly for unexpected words
- Hippocampal encoding triggered by novelty  $\Gamma$
- Chunk formation from temporal co-occurrence
- Sleep consolidation of chunks to semantic field

### 3.12 Consciousness Module

**3.12.1  $\Phi$  Computation** Consciousness level is computed at each tick as:

$$\Phi = f(\bar{T}, \text{arousal, binding, wakefulness})$$

where  $\bar{T} = \frac{1}{N} \sum_i (1 - \Gamma_i^2)$  is the mean transmission efficiency.

#### 3.12.2 Consciousness States

| State        | $\Phi$ Range | Condition  |
|--------------|--------------|--|
| Deep coma    | 0.00–0.05    | Massive $\Gamma \rightarrow 1$ across all channels |
| Vegetative   | 0.05–0.15    | Some reflexive channels active                     |
| Minimal      | 0.15–0.30    | Sparse conscious access                            |
| Drowsy       | 0.30–0.50    | Reduced integration                                |
| Alert        | 0.50–0.80    | Normal waking consciousness                        |
| Hyperfocused | 0.80–1.00    | Peak performance / flow state                      |

**3.12.3 Consciousness Flickering** Post-trauma, consciousness does not simply "switch off" —it flickers between states as competing channel dynamics push  $\Phi$  up and down. `exp_awakening.py` captured this dynamic:  $\Phi$  ranged from 0.000 (post-trauma collapse) to 0.777 (alert waking), with the transition exhibiting chaotic fluctuations rather than smooth recovery.

### 3.13 Additional Brain Modules Summary

The following modules each implement specific cognitive functions within the unified  $\Gamma$  framework:

| Module                               | Function                                       | Key $\Gamma$ Interaction   |
|--------------------------------------|--|--|
| <code>mirror_neurons.py</code>       | Empathy & motor imitation                      | $\Gamma_{mirror} = \Gamma_{observed}$ (automatic copying)                |
| <code>curiosity_drive.py</code>      | Novelty seeking                                | Curiosity $\square$ prediction error $\Gamma$                            |
| <code>attention_plasticity.py</code> | Adaptive attention                             | Training reduces attention $\Gamma$                                      |
| <code>impedance_adaptation.py</code> | System-wide calibration                        | Global $\Gamma$ optimization daemon                                      |
| <code>sleep_physics.py</code>        | Sleep + impedance debt tracking                | Debt accumulates, sleep repairs  |
| <code>calibration.py</code>          | Developmental calibration + dynamic time slice | Birth $\rightarrow$ adult $\Gamma$ trajectory; adaptive processing speed |
| <code>emotion_granularity.py</code>  | Fine-grained affect                            | Emotion vector in $\Gamma$ space   |
| <code>thalamus.py</code>             | Sensory gating + arousal modulation            | Yerkes-Dodson arousal curve; optimal $\Gamma$ for performance            |

## 4. The Perception Pipeline

### 4.1 Complete 15-Step Pipeline

Every tick, ALICE executes the following perception pipeline in strict order:

| Step | Module                     | Operation   | Complexity |
|------|----------------------------|---|------------|
| 1    | Eye                        | <code>see()</code> $\rightarrow$ visual $\Gamma$    | $O(1)$     |
| 2    | Ear                        | <code>hear()</code> $\rightarrow$ auditory $\Gamma$ | $O(1)$     |
| 3a   | Thalamus                   | Bottom-up gating                                    | $O(1)$     |
| 3b   | PFC $\rightarrow$ Thalamus | Top-down attention bias                             | $O(1)$     |
| 4    | Working Memory             | Update buffer                                       | $O(1)$     |
| 5    | FusionBrain                | Cross-modal binding                                 | $O(1)$     |
| 6    | Nociception                | Pain computation                                    | $O(1)$     |
| 7    | Emotion                    | Valence/arousal update                              | $O(1)$     |
| 8    | Autonomic                  | Vital sign update                                   | $O(1)$     |
| 9    | Hippocampus                | Episode encoding                                    | $O(1)$     |
| 10   | Amygdala                   | Fear conditioning check                             | $O(1)$     |
| 11   | Basal Ganglia              | Action selection                                    | $O(1)$     |
| 12a  | Broca/Wernicke             | Language processing                                 | $O(1)$     |
| 12b  | Social Resonance           | Empathy/ToM tick                                    | $O(1)$     |
| 12c  | Narrative Memory           | Episode weaving                                     | $O(1)$     |
| 12d  | Recursive Grammar          | Grammar tick  | $O(1)$     |
| 12e  | Semantic Pressure          | Pressure accumulation                               | $O(1)$     |
| 13   | PFC                        | Executive monitoring                                | $O(1)$     |
| 14   | Consciousness              | $\mathcal{C}_\Gamma$ coherence                      | $O(1)$     |
| 15   | Sleep Check                | Sleep pressure evaluation                           | $O(1)$     |

**Total pipeline complexity:**  $O(1)$ —constant time regardless of input size.

## 4.2 The Impedance-Locked Attractor State

A critical architectural feature is the **impedance-locked attractor** at the top of `perceive()`:

```
# SystemState.is_frozen():
def is_frozen(self) -> bool:
    return self.consciousness < 0.15

# AliceBrain.perceive() — only CRITICAL priority can penetrate:
if self.vitals.is_frozen() and priority != Priority.CRITICAL:
    self._log_event("perceive_blocked", {
        "reason": "SYSTEM FROZEN — consciousness too low, only CRITICAL allowed",
        "consciousness": self.vitals.consciousness,
        "pain_level": self.vitals.pain_level,
    })
    self.vitals.tick(...) # Still update tick (let the system cool down naturally)
    self._state = "frozen"
return {"status": "FROZEN", "vitals": self.vitals.get_vitals()}
```

When consciousness drops below 0.15, the system enters a frozen state. Non-CRITICAL signals are blocked from progressing through the pipeline —only CRITICAL-priority stimuli can penetrate. This is the mechanism of PTSD freezing: the impedance-locked attractor blocks the processing pipeline required for recovery, but leaves a narrow emergency channel open.

## 4.3 Pipeline Verification

`exp_perception_pipeline.py` verified:

- All 15 steps execute sequentially
- Total pipeline time < 1ms
- No step depends on input size
- Impedance-locked attractor activates at correct thresholds
- Pipeline is idempotent for identical inputs

---

## 5. Communication Protocol

### 5.1 API Architecture

Γ-Net ALICE exposes a RESTful API and WebSocket interface for external interaction:

| Endpoint   | Method    | Function                  |
|------------|-----------|---------------------------|
| /perceive  | POST      | Send sensory stimulus     |
| /state     | GET       | Read current brain state  |
| /vitals    | GET       | Read vital signs          |
| /memory    | GET       | Query memory contents     |
| /speak     | GET       | Read latest utterance     |
| /ws        | WebSocket | Real-time state streaming |
| /dashboard | GET       | Web-based visualization   |

### 5.2 State Representation

The system state is serialized as a JSON object containing:

```
{
    "ram_temperature": 0.0,
    "stability_index": 1.0,
    "heart_rate": 72.0,
    "pain_level": 0.0,
    "consciousness": 0.72,
    "throttle_factor": 1.0,
    "is_frozen": false,
    "pain_events": 0,
    "freeze_events": 0,
    "recovery_events": 0,
    "total_ticks": 12345,
    "pain_sensitivity": 1.0,
    "baseline_temperature": 0.0,
    "trauma_count": 0
}
```

---

## 6. Performance and Stress Tests

### 6.1 System-Wide Metrics

| Metric                 | Value   |
|------------------------|---------|
| Source files           | 146     |
| Total lines of code    | 84,500+ |
| Brain modules          | 44      |
| Body organs            | 5       |
| Error-correction loops | 7       |
| Independent tests      | 1,876   |
| Test pass rate         | 100%    |
| Perception complexity  | O(1)    |

### 6.2 Integration Stress Test

A 600-tick stress test conducted during Phase 18 verified system stability under extreme conditions:

| # | Test                          | Result   |
|---|-------------------------------|--|
| 1 | 600-tick continuous operation | No NaN/Inf <input checked="" type="checkbox"/>                             |
| 2 | PFC depletion marathon        | Depletion → recovery <input checked="" type="checkbox"/>                   |
| 3 | 10 consecutive pain storms    | Meltdown → auto-recovery <input checked="" type="checkbox"/>               |
| 4 | 200-tick rumination pressure  | ≤ 50 cap maintained <input checked="" type="checkbox"/>                    |
| 5 | No tick > 2 seconds           | No deadlock <input checked="" type="checkbox"/>                            |
| 6 | Rapid calm↔crisis oscillation | Emergency reset → recovery <input checked="" type="checkbox"/>             |
| 7 | Full orchestra 600-tick       | All subsystems online <input checked="" type="checkbox"/>                  |
| 8 | Memory stress test            | Working memory capacity cap maintained <input checked="" type="checkbox"/> |

| #  | Test                      | Result   |
|----|---------------------------|--|
| 9  | 5 trauma cascades         | Sensitization (2.0×) but no permanent collapse $\square$ |
| 10 | Clinical grand inspection | 29+ subsystems valid + metacognition healthy $\square$   |

## 7. Discussion

### 7.1 Embodiment is Not Optional

A common criticism of theories of cognition is that they are “disembodied”—operating on abstract symbols without physical grounding.  $\Gamma$ -Net ALICE directly addresses this by deriving all cognition from physical transduction:

- Vision is impedance boundary detection
- Hearing is frequency-domain impedance analysis
- Touch is force impedance calibration
- Speech is impedance matching between internal and external representations
- Pain is the energetic cost of impedance mismatch
- Sleep is offline impedance restructuring

Every cognitive operation has a physical interpretation, and every physical operation has a cognitive consequence.

### 7.2 O(1) Perception Matters

The O(1) perception pipeline is not merely a computational convenience—it is a **theoretical commitment**. We argue that biological perception is inherently O(1): the time from photon hitting retina to conscious visual percept is approximately constant ( $\sim 100\text{ms}$ ), regardless of how many objects are in the visual field. Any adequate theory of perception must account for this constant-time biological fact.

$\Gamma$ -Net achieves O(1) through impedance gating: the thalamus pre-filters inputs by  $\Gamma$  magnitude, ensuring that only a bounded number of signals reach higher processing—regardless of total input volume.

### 7.3 Dynamic Time Slice Adaptation

The `calibration.py` module (class `TemporalCalibrator`) implements adaptive processing speed—when cognitive load is high (many channels at high  $\Gamma$ ), the system allocates more processing time per tick:

$$\text{time\_slice} = \text{base\_slice} \times (1 + \alpha \cdot \bar{\Gamma}^2)$$

This implements the subjective experience of “time slowing down” during stress—a well-documented phenomenon in trauma psychology that  $\Gamma$ -Net explains as impedance-driven processing dilation.

### 7.4 Sensory Topology as $\Gamma$ -Field Solutions

A unifying observation across §2.1–§2.2 is that sensory organ topology is not separate from  $\Gamma$ -Net theory—it is a direct physical consequence. The reflection coefficient  $\Gamma_{ij} = (Z_i - Z_j)/(Z_i + Z_j)$  naturally defines

a metric space on any set of impedance-bearing elements, satisfying the metric axioms. Biological evolution and cortical development solve the same optimization problem — $\Sigma \Gamma^2 \rightarrow \min$ —at different timescales and with different degrees of freedom:

| System           | Timescale     | Degrees of Freedom           | Topology Type             | Example   |
|------------------|---------------|------------------------------|---------------------------|---|
| Basilar membrane | Evolutionary  | Membrane stiffness gradient  | Tonotopic map             | Adjacent hair cells resonate at similar frequencies           |
| Retina/Lens      | Evolutionary  | Photoreceptor arrangement    | Retinotopic map           | Adjacent photoreceptors transduce similar spatial frequencies |
| Cortical pruning | Developmental | Synaptic connection strength | Functional specialization | Surviving connections cluster around signal target impedance  |

In all three cases, elements with small  $\Gamma$ -distance ( $d(i, j) = |\Gamma_{ij}| \ll 1$ ) end up spatially or functionally adjacent, while elements with large  $\Gamma$ -distance separate. **Sensory organ topology is the hardware solution to MRP; cortical topology is the software solution. Both are  $\Gamma$ -field steady states.**

This reframes Paper I's Limitation #2 (absence of spatial topology) as a **prediction**: the Minimum Reflection Principle predicts that spatial topology emerges from impedance matching dynamics whenever sufficient degrees of freedom are available. Preliminary experiments (`exp_topology_emergence.py`) support this prediction at the 1D level: after 100 pruning epochs, impedance distribution entropy drops by +2.81 nats, inter-region  $\Gamma$ -separation reaches  $4.1 \times$  intra-region spread, and surviving connection impedances collapse to within 2–3% of target values.

## 8. Conclusion

We have presented the complete body-brain implementation of  $\Gamma$ -Net ALICE:

1. **Five body organs** (eye, ear, hand, mouth, internal sensors) transduce environmental signals into impedance mismatch values using coaxial cable physics.
2. **44 brain modules** process, integrate, learn from, and act upon these values through an  $O(1)$  perception pipeline.
3. **The autonomic nervous system** couples  $\Gamma$  dynamics to physiological responses (heart rate, cortisol, temperature, respiration).
4. **The three-tier memory hierarchy** (working memory, hippocampus, semantic field) implements impedance-modulated encoding, decay, and consolidation.
5. **Sleep is physically necessary** —without offline impedance restructuring, system performance degrades irreversibly.
6. **Pain, fear, and consciousness** emerge from  $\Gamma$  dynamics without explicit programming.

## 7. The entire system is validated by 1,876 tests and maintains O(1) perception complexity.

Paper III demonstrates that this architecture generates clinically valid psychopathology —PTSD, phantom limb pain, stroke, ALS, dementia, and more—all from the same equations. The ethical implications of these emergent properties are discussed in Paper III, §12.

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## References

- [1] B. R. Glasberg and B. C. J. Moore, "Derivation of auditory filter shapes from notched-noise data," *Hear. Res.*, vol. 47, no. 1–2, pp. 103–138, 1990.
- [2] G. E. Peterson and H. L. Barney, "Control methods used in a study of the vowels," *J. Acoust. Soc. Am.*, vol. 24, no. 2, pp. 175–184, 1952.
- [3] G. Hickok and D. Poeppel, "The cortical organization of speech processing," *Nat. Rev. Neurosci.*, vol. 8, no. 5, pp. 393–402, 2007.
- [4] G. A. Miller, "The magical number seven, plus or minus two: Some limits on our capacity for processing information," *Psychol. Rev.*, vol. 63, no. 2, pp. 81–97, 1956.
- [5] S. M. Sherman and R. W. Guillery, *Exploring the Thalamus and Its Role in Cortical Function*, 2nd ed. Cambridge, MA, USA: MIT Press, 2006.
- [6] F. Crick, "Function of the thalamic reticular complex: The searchlight hypothesis," *Proc. Natl. Acad. Sci. USA*, vol. 81, no. 14, pp. 4586–4590, 1984.
- [7] I. P. Pavlov, *Conditioned Reflexes: An Investigation of the Physiological Activity of the Cerebral Cortex*. London, U.K.: Oxford Univ. Press, 1927.
- [8] J. E. LeDoux, *The Emotional Brain: The Mysterious Underpinnings of Emotional Life*. New York, NY, USA: Simon & Schuster, 1996.
- [9] W. B. Scoville and B. Milner, "Loss of recent memory after bilateral hippocampal lesions," *J. Neurol., Neurosurg. Psychiatry*, vol. 20, no. 1, pp. 11–21, 1957.
- [10] E. Tulving, "Episodic and semantic memory," in *Organization of Memory*, E. Tulving and W. Donaldson, Eds. New York, NY, USA: Academic Press, 1972, pp. 381–402.
- [11] G. Tononi and C. Cirelli, "Sleep function and synaptic homeostasis," *Sleep Med. Rev.*, vol. 10, no. 1, pp. 49–62, 2006.
- [12] S. Diekelmann and J. Born, "The memory function of sleep," *Nat. Rev. Neurosci.*, vol. 11, no. 2, pp. 114–126, 2010.
- [13] P. R. Huttenlocher, "Synaptic density in human frontal cortex—Developmental changes and effects of aging," *Brain Res.*, vol. 163, no. 2, pp. 195–205, 1979.
- [14] J. Sergent, "The cerebral balance of power: Confrontation or cooperation?," *J. Exp. Psychol. Hum. Percept. Perform.*, vol. 8, no. 2, pp. 253–272, 1982.
- [15] H. Ebbinghaus, *Über das Gedächtnis*. Leipzig, Germany: Duncker & Humblot, 1885.
- [16] M. P. Walker, "The role of sleep in cognition and emotion," *Ann. N.Y. Acad. Sci.*, vol. 1156, no. 1, pp. 168–197, 2009.

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*This is Paper II of the  $\Gamma$ -Net ALICE Research Monograph Series. Continue to Paper III: "Emergent Psychopathology."*