Metrological Governance Layer for Neural Signal Actionability

A safety-first framework for decision gating in BCI systems

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Executive Summary

This document presents a **metrological governance layer** for brain–computer interface (BCI) systems. The purpose is not to decode neural intent, but to **regulate when a neural signal should have operational consequences**.

The framework introduces necessary conditions for actionability based on coherence, entropy reduction, and causal stability. If these conditions are not met, the system **explicitly inhibits action**.

This approach reduces false positives, improves safety margins, and supports regulatory robustness in invasive and non-invasive BCI deployments.

Problem Statement

Current BCI pipelines excel at:

- high-resolution signal acquisition,
- pattern extraction,
- correlation-based decoding.

However, a critical gap remains unresolved:

> *How to determine when a neural signal is causally significant enough to justify action.*

In safety-critical contexts, correlational confidence is insufficient. What is required is a **governance criterion** that distinguishes:

- transient noise vs. genuine neural reorganization,
- high activity vs. actionable transition,
- apparent coherence vs. entropy-reducing structure.

Proposed Solution: Metrological Governance

We propose a **decision-gating layer** positioned between neural decoding and actuation.

This layer evaluates the signal under three necessary conditions:

1. **Coherence** (Σ): stable locking or synchronization over a defined temporal window.
2. **Causal consistency** (R): reproducibility between observation and governed reconstruction.
3. **Entropy reduction** ($\Delta H < 0$): evidence of internal reorganization rather than stochastic fluctuation.

Only when all conditions are satisfied does the system authorize downstream action.

Formal Criteria (Minimal)

Let $x(t)$ denote a neural signal or feature vector. Define:

$$LI \in [0, 1] \quad \text{(locking/coherence index)} \tag{1}$$

$$R \in [-1, 1] \quad \text{(consistency correlation)} \tag{2}$$

$$\Delta H = H_q - H_p \quad \text{(entropy change between windows)} \tag{3}$$

Actionability condition:

$$\text{Action Authorized} \iff \big(LI \geq 0{,}9\big) \wedge \big(R > 0{,}95\big) \wedge \big(\Delta H < -0{,}2\big) \tag{4}$$

If the condition fails, the system remains inert by design.

Time Model

The framework distinguishes between:

- **Metric time** (t_M): passive chronological indexing.
- **Causal time** (t_C): defined by the gradient of coherence.

$$t_C \propto \frac{d\Sigma}{dt_M} \tag{5}$$

Action windows are defined in t_C, not merely in clock time.

Safety and Regulatory Implications

This governance layer:

- suppresses false activations,
- reduces unintended actuation,
- enforces explicit non-action when evidence is insufficient,
- provides auditable decision criteria.

The design aligns with safety-first and regulatory expectations for clinical and assistive BCI systems.

Scope and Boundaries

The framework:

- does **not** interpret thoughts or intentions,
- does **not** decode semantic content,
- does **not** replace existing signal processing pipelines.

It exclusively governs **when outputs may exert causal influence**.

Implementation Status

The governance framework is operational in other complex domains under the **TCDS (Teoría Cromodinámica Sincrónica)** paradigm and is available for:

- conceptual integration,
- black-box evaluation,
- safety-focused pilot studies,

under appropriate confidentiality agreements.

Conclusion

As BCI systems scale in resolution and autonomy, the limiting factor is no longer sensing capability, but **decision legitimacy**.

Metrological governance introduces an explicit, auditable criterion for actionability, ensuring that neural signals govern reality **only when they demonstrate causal sufficiency**.

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