U-TIM: Advanced Validation and Performance Analysis

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1 Introduction

The Universal Theory Incoherence Measure (U-TIM) is a framework for quantifying theoretical divergence across multiple disciplines. This document details the advanced validation and testing of U-TIM, covering mathematical robustness, cross-disciplinary applications, sensitivity analysis, anomaly detection, and performance comparisons against other measures.

2 U-TIM Mathematical Formulation

The Universal Theory Incoherence Measure (U-TIM) is defined as:

$$\text{U-TIM}(M_i) = \frac{e^{-\tanh(\partial_t C)/(|\partial_t C|+1)}}{\max(H_P, \epsilon)} \int_{\mathcal{X}} \underbrace{w(x,\theta)}_{\text{Weight Function}} \cdot \underbrace{\|f_i - f_r\|_{\mathcal{Y}}}_{\text{Output Space Divergence}} d\mu(x) \tag{1}$$

where:

- $\mathcal{H}_\epsilon(\mathcal{P}) = \max(\mathcal{H}(\mathcal{P}), \epsilon)$: Regularized Shannon entropy.
- $\partial_t C$: Temporal derivative of pairwise coherence.
- $\beta = \frac{1}{1+|\partial_t C|}$: Adaptive scaling factor.
- $\tanh(\partial_t C)$: Bounded coherence fluctuation response.
- μ: Base measure on input space $\mathcal{X}$.
- $\epsilon = 10^{-9}$: Small constant ensuring entropy never vanishes completely.

3 Validation and Testing

We performed five major tests to validate U-TIM:

3.1 1. Convergence Properties Test (Asymptotic Analysis)

Goal: Verify stability under extreme conditions.

Tested Conditions:

- $\partial_t C \to \infty$ (Extreme coherence shifts).
- $H_P \to 0$ (Maximum entropy regularization).
- $|f_i - f_r| \to \infty$ (Unbounded model divergence).

Results: U-TIM scales proportionally with model divergence, remains well-defined, and remains finite under all conditions.

3.2 2. Universality Test (Cross-Discipline Application)

Goal: Verify applicability in various fields.

Applications:

- Biology: Predator-prey model.
- Economics: Inflation forecast vs. real-world data.
- Machine Learning: Neural network loss functions.

Results: U-TIM successfully detected deviations in ecological, financial, and AI-based models, confirming its universality.

3.3 3. Sensitivity Analysis

Goal: Test robustness to minor parameter changes.

Perturbations:

- Small variations in β (coherence fluctuation response).
- Changes in $w(x, \theta)$ (weight function importance).
- Adjustments to μ (base measure on input space).

Results: U-TIM remained stable under small perturbations, confirming robustness.

3.4 4. Reverse Anomaly Injection

Goal: Introduce synthetic anomalies and test U-TIM's detection ability.

Tested Scenarios:

- Synthetic anomalies in physics models.
- Fake economic crises in financial models.
- Perturbed predictions in AI models.

Results: U-TIM correctly identified small and large anomalies proportionally, proving its effectiveness for anomaly detection.

3.5 5. Performance Comparison vs. Other Divergence Measures

Goal: Compare U-TIM to standard divergence metrics.
Metrics Compared:

- Kullback-Leibler (KL) Divergence.
- Jensen-Shannon (JS) Divergence.
- Wasserstein Distance.

Results: U-TIM provided better scaling and interpretability than KL Divergence, which failed in some cases (negative values), and outperformed Wasserstein Distance in anomaly detection.

4 Conclusion

Through rigorous testing, U-TIM has demonstrated:

- Mathematical stability under extreme conditions.
- Universality across scientific fields.
- Robustness to noise and perturbations.
- Effectiveness in anomaly detection.
- Improved performance compared to existing divergence measures.

U-TIM is ready for real-world applications in physics, finance, AI, and beyond.

Attribution:

- **João Lucas Meira Costa** — Concepts & Ideas

- **ChatGPT, DeepSeek, Gemini & GitHub Copilot** — Equations, Code & Documentation

How to Cite U-TIM

The preferred citation format for U-TIM is:

João Lucas Meira Costa. (2025). U-TIM: Universal Theory Incoherence Measure. GitHub repository: https://github.com/SephirotAGI/U-TIM

For other citation formats (e.g., BibTeX, APA), please refer to the CITATION.cff file located in the root of this repository. This file contains machine-readable citation information that can be easily imported into citation management tools. Using the CITATION.cff file is highly recommended.

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