INTERNATIONAL JOURNAL OF
RECENT TRENDS IN MULTIDISCIPLINARY RESEARCH
https://www.doi.org/10.59256/ijrtmr.20260604033
July-August 2026, Vol 6 (04), 290-296.
ISSN No: 2583-0368

A Universal Grammar of Resilience from Cells to Cosmos

Rahul Rathod[1]*, Ramesh Bhatt[2]
[1, 2] *Research, PATHEY Research Initiative; Mumbai, Maharashtra, India.*

OPEN ACCESS
Article Citation:
Rahul Rathod[1]*, Ramesh Bhatt[2], "A Universal Grammar of Resilience from Cells to Cosmos", International Journal of Recent Trends in Multidisciplinary Research, July-August 2026, Vol 6(04), 290-296.

Abstract: Across the history of existence, science has been described using five physical dimensions: spatial extent (1D-3D: position, area, volume), time (4D) and mass/energy constraints (5D). This scaffold explains where systems are and how matter and energy evolve, from atoms to galaxies. Yet it does not specify how systems are resilient, remain coherent, govern themselves, recover after disturbance or transmit influence across systems and scales. We hypothesize that resilience continues dimensional description by extending the five physical lineage with four functional dimensions: Harmony (H_6), Autonomy (A_7), Response (R_8) and Impact (I_9). Their product defines a universal resilience index (R_{univ}) for any interacting system (S) with observable dynamics: $R_{univ}(S) = H_6(S)\, A_7(S)\, R_8(S)\, I_9(S)$. We connect these dimensions to measurement using three indices, Response Capacity (RC), Harmony Index (HI) and Adaptive Delay (AD), these formalize the framework through PATHEY's six Governing Laws, including the $\cup_2$ ("HARI$_2$ Mark") as a bounded continuity signature reported in units of Resilient Result (rr). In this form, PATHEY's HARI$_2$ advances a candidate functional grammar of resilience, enabling resilience to be treated as continuous, observable and comparable across systems and scales from cells to cosmos.

1. Introduction

Across the history of existence from atoms to galaxies, science has organized understanding of reality around five physical dimensions: Position, area and volume locate structure; time orders change; mass/energy constrains motion and transformation (1D-5D). **Newton**'s laws linked terrestrial motion with celestial order,[1] **Darwin** revealed continuity across living forms[2] and **Einstein** reframed space and time into a coherent geometry.[3] These frameworks did not replace earlier knowledge; they extended it and exposed profoundly unity across scales.

Across **Tangible** and **Intangible** realms, systems experience disturbance; some fragment, while others persist, reorganize and in some cases transform while retaining function across successive dynamical cycles.[4..7,10,27] However, from **Molecule** to **Matter**, across **Microcosm**, **Midcosm**, **Macrocosm**, **Macrocosmos** and **Megacosm**, a central open question remains: can **resilience** be defined and measured in a single, scale-portable way that allows comparison across fundamentally different systems and scales?[23,29,30]

- How do systems maintain coherence under disturbance?
- How do they govern themselves internally?
- How do they adapt and recover from disturbance?
- How does their influence persist across time and scale?[4..6,17,23,25]

We define resilience as the ability to withstand disturbance while maintaining, recovering or adaptively reorganizing its function.[6,10,27] Resilience is central to biological robustness[8,16], to ecological and social-ecological persistence and transformation,[6,7,10,27] engineered and urban infrastructure recovery,[12] and to networked systems where structure shapes robustness and cascading behaviour[17]. At the largest scales, stability and dynamics in physical and cosmological systems similarly motivates questions of persistence under disturbance.[1,3,5,19] Yet definitions and measurements of resilience remains fragmented, often represented by recovery rate metrics,[12] robustness mechanisms,[16] regime shift perspectives,[6,7] information transfer/causal influence measures[15,21,25] or network proxies such as connectivity and centrality.[17].

Here we hypothesize that **resilience is a continuation of dimensional description**, extending the established five physical dimensional lineage with **four functional dimensions** that capture how systems persist under disturbance:

- **Harmony (H_6)**, measurable coherence and synchrony among system or its sub-systems.[22,28,29] (without it, there is no togetherness; structure dissolves into noise).
- **Autonomy (A_7)**, cybernetic self-governance through self-regulation and operationalizable between internal and external informational influence. [15,21,23,25,26,29,30] (without it, there is no independence; the system cannot sustain itself).
- **Response (R_8)**, recovery effectiveness after disturbance [12,23,29,30] (without it, there is no adaptation; the system cannot regain function).
- **Impact (I_9)**, propagation and continuity of influence and legacy in coupled systems. [6,7,10,17,23,29,30] (without it, there is no continuity; recovery leaves no trace beyond itself).

Together, these four pillars unify the core concept of resilience theory, persistence, adaptation and transformation. [6,10,27] Each functional dimension is expressed as a normalized index, enabling resilience to be treated as continuous, observable and scale-invariant, across scales. Their product defines a universal resilience index for any system S with observable dynamics:

$$\mathbf{R_{univ}(S) = H_6(S)\ A_7(S)\ R_8(S)\ I_9(S).} \tag{1}$$

To link the framework to measurement, we introduce three measurable indices: **Response Capacity (RC)**, **Harmony Index (HI)** and **Adaptive Delay (AD)**, motivated by quantitative resilience in coupled systems,[11] recovery-stage measurement in engineered infrastructure,[12] information/causal influence tools separating internal vs external contributions,[15,25,28] and network structure effects on system-level recovery and propagation.[17] We further organize these quantities through **PATHEY's six governing laws**: the **Resilience Triad Law**, **Functional Dimension Law**, **Resilience Invariant Law**, **Composite HARI₂ Mark (U₂)**, **Generalized Systemic Lifecycle Law** and **Directionality Law**. These laws operate through the continuous **Generalized Systemic Lifecycle Law (GSLL)** loop: **Start → Exist → Run → Hold → Respond → Impact → Transform → Restart.**

Two-layer interpretation of "HARI₂" and the Mark "U₂": **HARI** denotes a **four-coordinate functional state space**: **Harmony (H_6)**, **Autonomy (A_7)**, **Response (R_8)** and **Impact (I_9)**. The subscript **"₂"** encodes a two-layer (dual-domain) view in which every system is simultaneously **(i) a whole governed by internal dynamics and (ii) a sub-system embedded in external coupling.** This notation keeps the avenue open for formal layer expansions, while future papers will detail domain-specific and dual-domain elaborations of each component. In this paper we implement a minimal dual-domain realization: internal resilience is primarily captured through endogenous coherence, governance and recovery via $\overleftrightarrow{\mathbf{H}}$**,** $\mathbf{A_7}$**,** $\overleftrightarrow{\mathbf{R}}$**, AD** (defined below), while external continuity is captured independently through I_9 (exogenous propagation to coupled systems). The composite mark **U_2** then summarizes both layers into a single bounded resilience signature in units of **rr** (Resilient Result).

We propose that, under PATHEY's HARI₂, resilience can be treated as a continuous, observable and comparable quantity across the full continuum of existence, covering molecular, biological, social, economic, cosmic and psychological domains. From the **Higgs-Boson**[4] to **organisms** to **ecosystems** to **cosmos** to **human thoughts**, from the **tiniest part of cells** to **gigantic galaxies**, the same functional law applies: **Harmony enables order; Autonomy sustains it; Response restores it; Impact extends it.** Systems, tangible or intangible; atoms, cells, infrastructures, ecosystems, cities organizations, stars or human thoughts, face disturbance (shocks, stress, failure, disease, conflict, noise or disruption). Some systems collapse; others recover or transform and continue.[6,7,10,27] Thus, **PATHEY's HARI₂ advances a candidate universal grammar of resilience**, **the ability to continue** (**resilience**), in a way that is measurable, comparable and scale-invariant, across the scales**, unifying physical and functional dimensions from cells to cosmos**.

The present work is positioned within general and interdisciplinary physics, nonlinear dynamics, and complex systems. It proposes a normalized, measurable framework for describing resilience in interacting systems under disturbance, using Harmony, Autonomy, Response & Impact as functional descriptors.

2. Functional Dimensions

PATHEY's HARI₂ states resilience is not a single magic number. It is built from **four functional dimensions**, a continuum of the physical dimensions:

2.1 Harmony (H_6): coherence of parts, it measures whether the parts of a system work together or behave like disconnected pieces. Mathematically, H_6 is computed from pairwise correlations between subsystems signals during the recovery window. If most pairs move in synchrony (positive correlation), coordinated system H_6 is high; if they fight or move randomly, noisy, fragmented system H_6 is low. The formula clips negative correlations so the value stays in **[0,1]**.

$$\mathbf{H_6 = \frac{2}{N\,(N-1)} \sum_{i<j} \max\left(0, \rho_{ij}\right)} \tag{2}$$

- $i,j \in [1, N]$. ((i,j) H is same as j,i)
- N: Number of subsystems (cells/sectors/sensors).
- ρ_{ij}: Correlation between component i & j on the recovery window $\in[-1, 1]$.
- $\max(0, \cdot)$: Clips negatives, so $H_6 \in[0, 1]$.

2.2 Autonomy (A_7): self-governed recovery, it measures how much recovery is driven by internal mechanisms versus external help. High A_7 = self-powered recovery; low A_7 = dependent recovery. It is defined as:

$$\mathbf{A_7} = \frac{\mathbf{R^2_{int}}}{\mathbf{R^2_{int}} + \mathbf{R^2_{ext}} + \boldsymbol{\varepsilon}} \tag{3}$$

- $\mathbf{R^2_{int}}$: Internal Predictive Variance (R^2 from internal variables).
- $\mathbf{R^2_{ext}}$: External Predictive Variance (R^2 from external variables) R^2_{ext}=max(0, R^2_{all}-R^2_{int}).
- $\mathbf{R^2_{all}}$: Internal + External Predictive Variance (R^2 from internal + external variables).
- We use $\varepsilon > 0$ as a numerical stabilizer; unless stated, $\varepsilon = 10^{-2}$.

2.3 Response (R_8): effectiveness of recovery, it measures how much of the loss a system can regain. It compares gain achieved (G) to severity of shock (S): High R_8 = strong bounce-back; low R_8 = weak bounce-back.

$$\mathbf{R_8} = \mathbf{min}\left(\mathbf{1}, \frac{\mathbf{G}}{\mathbf{S} + \boldsymbol{\varepsilon}}\right) \in [\mathbf{0}, \mathbf{1}] \tag{4}$$

$$\mathbf{S} = \min\left(1, \frac{|X_{base} - X_{min}|}{\max(|X_{base}|, \varepsilon)}\right)$$

$$\mathbf{G} = \min\left(1, \frac{|X_{ss} - X_{min}|}{\max(|X_{base}|, \varepsilon)}\right)$$

- $\mathbf{X_{base}}$: Pre-shock baseline performance.
- $\mathbf{X_{min}}$: Minimum performance during shock
- $\mathbf{X_{ss}}$: Steady-state post-recovery performance

2.4 Impact (I_9): outward propagation of resilience, it measures whether a system's recovery helps other connected systems stabilize too and $\Omega_{outflow}$ increases when more connected systems benefit, High I_9 = recovery spreads outward and low I_9 = recovery stays local, when the benefit is large compared to the system's own improvement. It is defined as:

$$\mathbf{I_9} = \frac{\mathbf{max}\,(\mathbf{0},\ \Omega_{outflow})}{\mathbf{1} + \mathbf{max}\,(\mathbf{0},\ \Omega_{outflow})} \in [0,1] \tag{5}$$

$$\boldsymbol{\Omega}_{\mathbf{outflow}} = \left(\frac{\mathbf{N_{benefited}}}{\mathbf{N_{connected}} + \boldsymbol{\varepsilon}}\right) \times \left(\frac{\boldsymbol{\Delta}_{\mathbf{benefit}}}{\boldsymbol{\Delta}_{\mathbf{self}} + \boldsymbol{\varepsilon}}\right)$$

- $\mathbf{\Omega_{outflow}}$: Normalized outward influence coefficient.
- $\mathbf{N_{benefited}}$: Number of connected systems that improved.
- $\mathbf{N_{connected}}$: Total connected systems.
- $\mathbf{\Delta_{benefit}}$: Average improvement in connected systems.
- $\mathbf{\Delta_{self}}$: System's own improvement.

3. Three Measurable Indices: These Indices Translate the Four Dimensions into Measurable Behaviors

3.1 Response Capacity (RC): recovery strength under internal support. RC combines recovery strength with internal structure (Harmony and Autonomy). So even if a system could recover in theory (Response), weak internal coherence or weak autonomy lowers practical capacity. High RC = strong recovery with strong internal support.

$$\mathbf{RC} = \mathbf{min}\left(\mathbf{1}, \mathbf{R_8} \cdot \frac{\mathbf{H_6} + \mathbf{A_7}}{\mathbf{2}}\right) \tag{6}$$

- **(H_6): Harmony** (0-1).
- **(A_7): Autonomy** (0-1).
- **(R_8): Response** (0-1).

3.2 Harmony Index (HI): timing alignment, HI measures whether components recover at similar times using dispersion of **$\tau 63, i$**, the time each component takes to reach 63% recovery. Lower dispersion means higher HI = synchronized recovery timing; low HI = scattered timing.

$$\mathbf{HI} = \mathbf{1} - \mathbf{min}\left(\mathbf{1}, \frac{\boldsymbol{\sigma}_{\tau}}{\bar{\boldsymbol{\tau}}_{63} + \boldsymbol{\varepsilon}}\right) \tag{7}$$

- $\sigma_\tau = \sqrt{\frac{1}{N}\sum_i(\tau_{63,i} - \bar{\tau}_{63})^2}$.
- $\bar{\tau}_{63} = \left(\frac{1}{N}\right)\sum_{i=1}^{N}\tau_{63,i}$, where $\tau_{63,i}$ is the time component i takes to reach 63% of its own recovery span (the standard 1 - e^{-1} point).

3.3 Adaptive Delay (AD): slowness adjusted by coherence, it measures lag in recovery per unit internal coherence. So coherence reduces effective delay. Low AD = fast, efficient adaptation; high AD = slow adaptation.

$$\mathbf{AD} = \frac{\bar{\boldsymbol{\tau}}_{63}}{\mathbf{T}^{*} + \boldsymbol{\varepsilon}} \cdot \frac{\mathbf{1}}{\mathbf{1} + \frac{\mathbf{H}_6 + \mathbf{A}_7}{\mathbf{2}}} \tag{8}$$

- Let $\bar{\tau}_{63} = \left(\frac{1}{N}\right)\sum_{i=1}^{N}\tau_{63,i}$ denoted system level 63% recovery time (standard 1 - e^{-1} point).
- T^* = baseline time for recovery.
- $(H_6+A_7)/2$: internal coherence/independence discount.

4. Universal Resilience Index:

PATHEY's $HARI_2$ defines a universal resilience index for any system (S): $R_{univ}(S) = H_6(S)\, A_7(S)\, R_8(S)\, I_9(S)$, This multiplicative structure ensures that resilience collapses if any single functional dimension approaches zero, reflecting a fundamental resilience principle: a system cannot be resilient without coherence, self-governance, effective recovery and continuity beyond itself.

5. Pathey's Six Governing Laws

5.1 Law 1: Resilience Triad Law (RT^L) This law says resilience rises when systems are capable, aligned and quick:

$$\mathbf{RT^L} \propto \frac{\mathbf{RC \cdot HI}}{\mathbf{AD}} \tag{9}$$

5.2 Law 2: Functional Dimension Law (FD^L) **Resilience emerges from the combined function of the four functional dimensions:**

$$\mathbf{FD^L} = \mathbf{f}(\mathbf{H}_6, \mathbf{A}_7, \mathbf{R}_8, \mathbf{I}_9) \tag{10}$$

5.3 Law 3: Resilience Invariant (R^*) **This captures a trade-off: core resilience diluted by impact burden, If impact rises faster than internal strength, the invariant drops:**

$$\mathbf{R^{*L}} = \frac{\mathbf{H}_6 \cdot \mathbf{A}_7 \cdot \mathbf{R}_8}{\mathbf{1} + \mathbf{I}_9} \tag{11}$$

5.4 Law 4: Composite $HARI_2$ Mark (U_2) This is the system's bounded "resilience fingerprint," combining structure, timing, recovery and delay into one signature, measured in rr (Resilient Result). U_2 summarizes "how resilient this system is overall," accounting for quality and speed of recovery. Internal quality (H, A, R), External continuity (I) and Speed penalty (AD).

$$U_2 = \frac{\left(\overleftrightarrow{\mathbf{H}}^{\omega_H} \cdot \mathbf{A}_7^{\omega_A} \cdot \overleftrightarrow{\mathbf{R}}^{\omega_R} \cdot \mathbf{I}_9^{\omega_I}\right)^{\frac{1}{\omega_H + \omega_A + \omega_R + \omega_I}}}{(\mathbf{1+AD})^{\delta}}, \tag{12}$$

(measured in rr)

$$\overleftrightarrow{\mathbf{H}} = \mathbf{H}_6^{\alpha}\mathbf{HI}^{1-\alpha}, \qquad \overleftrightarrow{\mathbf{R}} = \mathbf{R}_8^{\beta}\mathbf{RC}^{1-\beta}$$

- $\alpha, \beta \in [0,1]$ are mixing weights (often 0.5), $\omega_H, \omega_A, \omega_R, \omega_I > 0$ are pillar weights (default 1), $\delta \geq 0$ is the delay penalty exponent (default 1), $AD \geq 0$.
- rr: is represented as a fundamental unit of the $\cup_2$. rr is a dimensionless score label, reported on [0,1] unless re-scaled for domain-specific certification.

5.5 Law 5: Generalized Systemic Lifecycle Law (GSLL) **All systems operate in cycles:** Start → Exist → Run → Hold → Respond → Impact → Transform → Restart **and the four functional dimensions modulate how systems traverses this stages.**

$$\mathcal{G} = \int f\,(E_{init}, X_{1..3}, t, M, H_6, A_7, R_8, I_9)\,dt \qquad (13)$$

- **(E_{init}):** initial/boundary conditions defining system emergence (starting state).
- **($X_{1..3}$):** core spatial state variables (1D-3D state coordinates).
- **(t, M):** temporal progression and mass/energy throughput.
- **(H_6, A_7, R_8, I_9):** functional dimensions shaping system coherence, governance, recovery and continuity along the lifecycle trajectory.

5.6 Law 6: Directionality Function (D(θ)) Resilience is generally anisotropic: in spatial and networked systems, the capacity to withstand and recover from disturbance can differ by direction or pathway. A system may exhibit strong resilience along certain orientations while remaining vulnerable along others. Directional resilience is defined as:

$$\mathbf{RD(\theta)} = \frac{\mathbf{RC(\theta)} \cdot \mathbf{H_6(\theta)}}{\mathbf{1 + AD(\theta)}} \qquad (14)$$

- θ denotes orientation, pathway or directional axis within the system.
- RC(θ): is the response capacity measured along direction θ.
- $H_6(\theta)$: represents directional Harmony, capturing structural coherence and coordinated behaviour along that pathway.
- AD(θ): is the adaptive delay along direction θ.

This law formalizes the principle that resilience depends not only on system-level capacity but also on direction-dependent coherence and recovery speed, allowing asymmetric vulnerabilities and preferential resilience pathways to be explicitly quantified.

6. Results and Discussion

This work advances the hypothesis that resilience is a measurable, scale-invariant construct that extends the established physical description of reality. The five physical dimensions, position, area, volume, time and mass/energy, have long provided the foundational grammar for matter and motion, yet they do not explain how systems preserve coherence, govern themselves, adapt to disturbance or sustain continuity across scales. PATHEY's $HARI_2$ Framework addresses this gap by complementing the physical scaffold with a functional one by introducing **four functional dimensions: Harmony, Autonomy, Response and Impact**. These dimensions do not replace existing theories; rather, they organize and connect long-standing insights from cybernetics, thermodynamics, ecology and network science into a single dimensional formulation. The multiplicative form of the universal resilience index formalizes a fundamental principle: resilience collapses when any essential functional dimension is missing. By treating resilience as a continuous quantity rather than a categorical label, **PATHEY's $HARI_2$** enables direct comparison across systems traditionally studied in isolation, from molecular assemblies and cells to societies, infrastructures and cosmic structures. Importantly, Resilience is framed not only self-recovery; but also the capacity to sustain continuity and influence across interconnected systems.

The framework has immediate implications across disciplines. In biology and medicine, PATHEY's $HARI_2$ offers a way to compare robustness and recovery across molecular, cellular and organismal levels. In ecology and climate science, it provides a unified language for assessing cross-scale stability and transformation. In socio-economic and engineered systems, it enables quantitative comparison of recovery capacity, governance structure and long-term impact using a common index. More broadly, PATHEY's $HARI_2$ opens the possibility of certifying resilience in complex systems using standardized, dimensionless measures.

7. Conclusion

We hypothesize that resilience constitutes a **fundamental principle of continuity**, complementing the five physical dimensions of existence with four functional ones. PATHEY's $HARI_2$ Framework introduces, a unified dimensional grammar through which resilience becomes **Visible, Measurable and Comparable** from **Molecule to Matter**, across **Microcosm, Midcosm, Macrocosm, Macrocosmos** and **Megacosm**. By expressing resilience quantifiable along a single continuum, this work lays the foundation for a universal science of recovery, adaptation and persistence, one that connects cells, societies, stars and human thoughts through a shared functional architecture. **PATHEY's** $HARI_2$ Universal Continuum concludes that, the same functional laws of resilience apply from cell to cosmos structures when PATHEY's $HARI_2$ is non-zero.

This study is grounded in observable system dynamics, their empirical calibration across scales and domain-specific, dual-domain elaborations of each component (endogenous, exogenous) requires further work. Future studies should focus on large-scale validation using real-world datasets, refinement of measurement protocols and exploration of how PATHEY's $HARI_2$ behaves near critical transitions. Extensions to probabilistic, stochastic and quantum regimes also remain open avenues of investigation.

8. Acknowledgments

To the eternal inspiration of Shri B. S. S. SWAMINARAYAN, Shri G. GUNATIT, Shri SHASHTRIJI M, Shri YOGIJI. M., Shri G. H. P. P. SWAMIJI, P. PATHEYBHAI. To Dr. Rawal for guidance, insightful discussions and valuable suggestions. The authors also acknowledge the role of open scientific data repositories, including ISRO, NIST, NASA ADS, ESA Gaia Archive, SDSS, Planck Legacy Archive, Human Cell Atlas, CODATA, MESAHub, Harvard Dataverse, Network Repository, World Bank Open Data, whose publicly accessible datasets and standards support for enabling reproducibility across scales.

9. Funding

The authors and this research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

10. Competing Interests

The authors declare that there are no conflicts of interest regarding this work.

11. Ethics Approval

Not applicable. This study did not involve human participants, human data, human tissue or animals.

12. Consent to Participate

Not applicable.

13. Consent for Publication

Not applicable.

14. Data Availability

No datasets were generated or analyzed during the current study.

15. Code Availability

Not applicable.

16. Authors' Contributions:

All authors have equal contribution and all authors have read and approved the final manuscript.

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