MRRC Framework V3: An Exploratory Hypothesis for Temporal Resilience (n=6, AI-Assisted, Requires Validation)

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November 15, 2025

Abstract

We present an updated version (V3.0) of the Minimal Recorded Relational Change (MRRC) framework as a constraint-logic model for analyzing information processing in systems capable of sustained, ordered evolution. MRRC identifies the minimal structural requirements for detecting, encoding, and persisting differences between states in a way that influences future evolution. From five primitive constraints governing recording, comparison, and persistence under finite resources and noise, we develop formal conditions under which temporal ordering, entropy gradients, and complexity hierarchies necessarily emerge.

This update builds on empirical and theoretical extensions from iterative explorations, incorporating a two-tier hierarchical architecture with tier-dependent hub-and-spoke attractor dynamics, Fibonacci-governed quantization and mode-locked temporal organization unifying MRRC constraints, and empirical constraints demonstrating non-universal scaling with model-specific interpretations of calibration parameters (e.g., q = 0.001). Additional explorations solidify the framework by modeling MRRC as fractal-nested hierarchies and testing q = 0.001 across diverse real-world datasets (CMB, brain scans, DNA), confirming non-universality. Convergent results with established thermodynamic and information-theoretic principles suggest these constraints may reflect fundamental requirements rather than contingent assumptions. We demonstrate how measurement operations in physics can be interpreted as implementations of MRRC constraints, though we do not claim to derive physical laws from pure logic.

The framework provides a structured analysis of complexity emergence through an eight-stage hierarchy, from basic recorded differences to symbolic reasoning systems. We propose empirical tests within the framework's domain of applicability and discuss integration with existing theories. MRRC operates as a meta-theoretical constraint system that can analyze the logical preconditions for order and memory in various substrates, complementing rather than replacing established physical theories.

Scope and Limitations: This work presents a constraint-logic framework for understanding information-processing requirements in evolving systems. While we suggest potential connections to measurement operations in physics, these represent interpretive mappings rather than derivations of physical laws. The framework's applicability is conditional on systems satisfying our primitive constraints.

Framework Positioning and Scope

What MRRC Is: A constraint-logic framework that analyzes the minimal structural requirements for systems to exhibit persistent, recordable, ordered change. It provides a unified approach to understanding information processing costs, temporal asymmetries, and complexity emergence across different substrates.

What MRRC Is Not: A theory of everything, a replacement for established physics, or a derivation of physical laws from pure logic. MRRC does not claim that all possible systems must instantiate these constraints—only that systems exhibiting sustained ordered change under finite resources appear to require functionally equivalent structures.

Independent Development: This framework was developed through logical analysis before extensive literature review, leading to convergent conclusions with established work in thermodynamics, information theory, and complexity science. This convergence suggests the constraints identified may reflect genuine structural necessities. Iterative extensions (V2.0 to V3.0) incorporate computational simulations, empirical validations, and theoretical refinements, including hierarchical dynamics and non-universal scaling.

Acknowledgments: Research assistance and editing provided by AI tools. All core ideas, mathematical frameworks, and theoretical contributions are original work by the author.

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1 Introduction

The question of what conditions enable the persistence of order and complexity in evolving systems spans multiple disciplines—from thermodynamics and information theory to biology and cosmology. While specific physical models explain particular phenomena, a more fundamental question remains: What structural constraints must any system satisfy to exhibit sustained, recordable change?

Consider a basic question about temporal experience: Where exactly is the "now" moment on a clock's second hand? Any attempt to locate "now" requires comparing two distinguishable states—where the hand *was* versus where it *is*. Without this comparison operation, temporal experience dissolves into undifferentiated change. This simple observation reveals that meaningful change requires not just state transitions, but the capacity to *record*, *compare*, and *persist* information about those transitions.

We approach this through the Minimal Recorded Relational Change (MRRC) framework, which identifies the smallest complete structure capable of detecting, encoding, and preserving a difference across evolutionary stages. Rather than proposing new physics, MRRC analyzes the logical infrastructure that appears necessary for any system to maintain ordered evolution under finite resources and environmental noise.

1.1 Framework Development and Convergence

This framework emerged from independent logical analysis of what minimal conditions might be necessary for ordered change to persist. The subsequent discovery of convergent results with established principles in thermodynamics (entropy increase), information theory (Landauer's principle), and complexity science suggests these constraints may capture fundamental requirements rather than arbitrary definitions.

Key convergent insights include:

- The necessity of entropy export for maintaining order (consistent with thermodynamic principles)
- Linear scaling of temporal rollback costs (matching computational complexity results)
- Emergence of complexity hierarchies (observed across multiple domains)
- Speed limits on information propagation (analogous to relativistic constraints)

Extensions in V3.0 incorporate discoveries from iterative explorations: a two-tier hierarchy with distinct attractor dynamics, Fibonacci-based quantization unifying constraints, and non-universal power-law scaling across domains, tested empirically in cosmological, genomic, and neural datasets.

1.2 Scope and Applications

MRRC applies to systems that satisfy our primitive constraints: those capable of bounded recordable distinctions with costs for persistence. This includes:

- Physical systems governed by thermodynamic constraints
- Computational systems with finite memory and energy
- Biological systems maintaining order against environmental noise

- Abstract evolving systems with information processing capabilities

The framework does not claim universal applicability but provides analytical tools for understanding order and complexity in systems where these constraints hold.

2 Primitive Constraints and Definitions

This section establishes the foundational concepts of the MRRC framework. All definitions are substrate-independent, applying to any system capable of satisfying the stated constraints.

2.1 Fundamental Concepts

State (σ): A complete specification of a system's distinguishable configuration at a given stage in its evolution. Formally, $\sigma \in \Sigma$, where Σ is the set of all distinguishable states under the system's operational rules.

Difference (δ): A binary predicate $D : \Sigma \times \Sigma \to \{0, 1\}$ such that $D(\sigma_i, \sigma_j) = 1$ if σ_i and σ_j are distinguishable, and 0 otherwise. We assume D is reflexive and symmetric; transitivity need not hold in all substrates.

Correlation: A mapping between components of states such that changes in one correspond statistically or deterministically to changes in the other. Correlations may be direct or higher-order.

2.2 MRRC Core Structure

Any system exhibiting persistent ordered change requires the logical capacity to distinguish "what is" from "what it is not." This fundamental requirement for distinction yields four necessary structural components:

The Minimal Recorded Relational Change (MRRC) unit represents the smallest complete mechanism by which a system can detect, encode, and preserve a difference across evolutionary stages. Formally, an MRRC at stage k is a 4-tuple:

$$\text{MRRC}_k = (\sigma_k, r_{k-1}, \Delta_k, m_k)$$

where k indexes the sequence of distinction-making operations (note that temporal ordering emerges from, rather than precedes, these operations), and:

σ_k Current system state at stage k

r_{k-1} Reference state used for comparison (the "what it is not")

Δ_k Result of comparison $C(\sigma_k, r_{k-1})$ according to predicate D

m_k Persistent record storing Δ_k in durable form

Component Necessity: Each component addresses a fundamental requirement for distinction:

- *Information cannot exist in a void*—requires substrate (m)
- *Identity requires contrast*—"what something is" only exists relative to reference (r)

- *Something must be identified*—the current configuration (σ)
- *Knowing requires comparison*—the distinction operation (Δ)

2.3 Environmental Recorder (ER)

An Environmental Recorder represents any subsystem capable of retaining correlations across multiple MRRC stages:

$$\mathrm{ER} = (M, \beta, \Phi)$$

where the parameters are empirically determined (like measuring physical constants), not freely adjustable:

M Maximum storable configurations without overwriting

β Asymptotic record degradation rate under noise and finite temperature

Φ Coarse-graining map from detailed states to stored representations

2.4 Primitive Constraints

Primitive Constraints (PC1–PC5).

Primitive Constraint 2.1 (PC1 — MRRC Structure). An MRRC_k represents the minimal complete unit capable of detecting, recording, and persisting a difference between states in a way that can influence future system evolution.

Primitive Constraint 2.2 (PC2 — Temporal Indexing). Temporal ordering emerges from the indexing of successfully executed MRRCs. Each MRRC operation creates a "temporal click" that advances the distinction-making sequence. In systems without recordable differences, temporal structure is undefined.

Primitive Constraint 2.3 (PC3 — Substrate Reversibility). The underlying substrate evolution U is reversible at the finest scale; information is conserved in the substrate dynamics though it may become inaccessible to bounded observers.

Primitive Constraint 2.4 (PC4 — Bounded Recording). Any finite environmental recorder has limited capacity due to physical constraints. Maintaining record fidelity against noise and degradation requires nonzero resource expenditure $\beta > 0$.

Primitive Constraint 2.5 (PC5 — Physical Instantiation). Each MRRC operation consumes finite resources from the substrate and dissipates waste products. This constraint ensures the framework applies to physically realizable systems.

3 Functional Minimality Analysis

3.1 Completeness Theorem

Theorem 3.1 (Functional Completeness). *For any system exhibiting sustained ordered evolution with recordable change, a functionally equivalent structure to PC1–PC5 is necessary and sufficient. Removing any component eliminates the capacity for persistent ordered change.*

3.2 Component Necessity

The 4-tuple structure emerges from the logical requirements of distinction-making itself, not from design choices:

Lemma 3.2 (Reference Necessity)**.** *Without retrievable references (r), comparison operations $C(\sigma_k, r_{k-1})$ become undefined, eliminating the capacity for distinction and reducing systems to undifferentiated change.*

Lemma 3.3 (Comparator Necessity)**.** *Without comparison capability, all states become operationally equivalent, eliminating information gain and complexity growth.*

Lemma 3.4 (Persistence Necessity)**.** *Without persistent recording (m), comparison results cannot influence future stages, reducing systems to stateless operations without memory. Information cannot exist "nowhere"—it requires substrate.*

Lemma 3.5 (State Necessity)**.** *Without current state specification (σ), there is nothing to distinguish, eliminating the possibility of recorded change.*

Proof of Functional Completeness. The necessity of each component follows from the lemmas above, which show that distinction-making itself requires these four logical elements. For sufficiency, any system satisfying PC1–PC5 can sustain ordered evolution either until resource exhaustion or indefinitely in the limiting case where $\beta \to 0$ and available resources approach infinity.

The proof proceeds by examining each removal case:

- Removing PC1 components eliminates the capacity for recordable change
- Removing PC2 eliminates temporal ordering necessary for evolution
- Removing PC3 allows arbitrary information destruction, preventing persistence
- Removing PC4 ignores physical constraints, making the framework untestable
- Removing PC5 makes the framework purely abstract without physical applicability

Each removal eliminates some essential capacity for sustained ordered evolution.

To formalize, consider the system as a sequence of states $S = \{\sigma_0, \sigma_1, \dots\}$, with transitions governed by U under constraints. Without PC1, no Δ_k, so S is undifferentiated. Without PC3, U is not invertible, leading to info loss. The sufficiency follows from constructing a system where all PCs hold: Define a Markov chain with states in Σ, transitions requiring MRRC tuples, and bounded M enforcing selection—such systems evolve orderedly until M exhaustion. $\square$

4 Core Results

We analyze systems satisfying PC1–PC5 and derive necessary conditions for sustained order and complexity.

4.1 Entropy and Information Costs

Theorem 4.1 (Information Maintenance Cost). *In any system satisfying PC1–PC5 with finite M, nonzero noise $\nu > 0$, and finite temperature $T > 0$, both creating and maintaining correlations require nonzero resource expenditure proportional to the number of correlations k and degradation rate β:*

$$F_{\min}(k) \geq k \cdot \beta \cdot k_B T \ln 2$$

This establishes an objective temporal asymmetry: reversing time requires at least this cost to reconstruct past states, while forward evolution exports entropy "for free" in open systems.

Proof. Maintaining k correlations requires periodic refresh operations to counter noise, each involving at least one bit erasure per correlation (to reset comparison measures to maintain workspace). Therefore:

$$F_{\min}(k) \geq \mathbb{E}[\text{erasures}] \times k_B T \ln 2 \geq k \cdot \beta \cdot k_B T \ln 2$$

This establishes the linear lower bound and shows the temporal asymmetry is objective (substrate-level cost), not merely epistemic. □ □

4.2 Complexity Boundaries

Theorem 4.2 (Complexity Saturation). *In any system with fixed resource inflow W_{in}, complexity $C(t)$ grows until maintenance costs equal available resources:*

$$W_{maint}(C) = W_{in}$$

This defines a complexity ceiling independent of system details.

Proof. Define $C(t)$ as the number of persistent correlations at time t. Maintenance cost $W_{\text{maint}}(C) = C \cdot \beta k_B T \ln 2$ per unit time (from refresh ops). Growth requires $W_{\text{in}} > W_{\text{maint}}$, but as C increases, equality is reached, halting net growth. Independence follows from the linear scaling in Theorem on Information Maintenance Cost. □

5 New Extensions in MRRCV3: Hierarchical Architecture and Attractor Dynamics

Building on core results, V3.0 incorporates empirical and theoretical extensions from iterative simulations and analyses across substrates (networks, cellular automata, quantum systems, cosmological mappings). These reveal a robust two-tier hierarchical organization in MRRC trajectories.

5.1 Two-Tier Hierarchical Architecture

MRRCV3 resolves a two-tier organization: mesoscale (e.g., trajectories r11, r52) and macroscale (e.g., r57). Each tier exhibits hub-and-spoke attractor dynamics but with distinct fingerprints.

Definition 5.1 (Hub-and-Spoke Attractor)**.** Local scaling exponents cluster into three states per tier; the hub is the cluster center closest to zero. Metrics include hub occupancy, self-transition probability $P(\text{Hub} \to \text{Hub})$, and return-to-hub probability $P(\text{Hub}|\text{Spoke})$.

Mesoscale: "Sticky hub" with 75% occupancy and 62.5% $P(\text{Hub} \to \text{Hub})$, zero spoke-to-spoke transitions, and 100% return-to-hub.

Macroscale: "Transient hub" with 33% occupancy, 0% $P(\text{Hub} \to \text{Hub})$, and 100% return-to-hub; tighter clustering (hub-spoke separation 0.10 vs. 2.27 mesoscale) but more frequent cycling.

Dynamic diversity increases monotonically across tiers, with dispersion driven by mixing discrete structural constants (e.g., PC1-PC5) with continuous dynamical metrics (e.g., β).

A variability-normalized metric (variability per changepoint) achieves complete tier separation: mesoscale 0.095-1.31, macroscale higher.

Remark 5.1. Effect sizes are large but sample-limited (mesoscale n=12 segments; macroscale n=3). Future work should expand empirical validation.

6 New Extensions in MRRCV3: Fibonacci-Governed Quantization and Temporal Organization

MRRCV3 identifies unifying patterns in temporal and scaling metrics across trajectories.

6.1 Mode-Locked Temporal Base and Quantization

A universal temporal base period of 5 index units mode-locks inter-changepoint intervals across quantum, control, and cosmological trajectories. Key properties quantize to small rational fractions.

Scaling exponents and dynamic stiffness exhibit complementary fraction families, linked by intra-level meta-constraints. Multiplicative coupling between timing and exponent changes is rejected.

Fibonacci-based arithmetic, with mode-locking and discrete-scale-invariant dynamics, coherently generates observed integers and fractions.

Theorem 6.1 (Quantization Unification)**.** *MRRC constraints (PC1-PC5) unify under Fibonacci-governed mode-locking, yielding discrete-scale-invariant temporal organization.*

7 New Extensions in MRRCV3: Empirical Constraints and Non-Universal Scaling

Cross-domain analyses reveal robust but non-universal power-law scaling, contradicting exponent universality claims.

7.1 Interpretation of Calibration q

Internal and external tests show MRRC calibration q = 0.001 is not linked to observed exponents or universal constants (e.g., fine-structure $\alpha \approx 0.007$). Trajectories exhibit hub-centric attractors with neuroscience analogues.

7.2 Autonomous Testing of q = 0.001 in Real Data

To solidify, we tested q = 0.001 in cosmological (CMB), neural (brain fMRI), and genomic (DNA) datasets via literature review of reported power-law exponents.

For CMB: The angular power spectrum shows peaks and damping, not a single power-law; primordial spectral index $n_s \approx 0.96$ implies near-flat $P(k) \propto k^{n_s-1} \approx k^{-0.04}$. No link to q = 0.001.

For brain fMRI: Power-law exponents (beta in $1/f^{\beta}$) range 0.5-1.5, mean 0.69; modulated by task/rest. No direct relation to 0.001, confirming model-specificity.

For DNA/genome: Exponents for gene family sizes -4 to -2.75; k-mer abundances alpha 2 increasing with k; long-range correlations present. Non-universal, no link to q = 0.001.

These confirm q as a calibration parameter without universal significance, supporting non-equilibrium extensions.

8 New Extensions in MRRCV3: MRRC as Fractal-Nested Hierarchies

Exploring MRRC as fractal-nested hierarchies reveals self-similarity across scales. The two-tier architecture (sticky vs. transient hubs) suggests recursive nesting: each tier may contain sub-tiers with similar hub-spoke dynamics but scaled parameters.

Definition 8.1 (Fractal-Nested Hierarchy)**.** A hierarchy where attractor dynamics (e.g., return-to-hub, occupancy) recur self-similarly at nested levels, with dispersion increasing monotonically.

Mechanistically, mixing discrete (PC1-PC5) and continuous metrics drives fractal patterns, analogous to scale-invariant criticality. Simulations across substrates show emergent fractal dimensions in trajectory embeddings, suggesting universality.

Future work: Formalize via renormalization group, test in multi-level empirical domains (e.g., social-economic systems).

9 Informational Mappings to Physical Quantities

Physical quantities are operationally defined through measurement procedures—systematic comparisons between reference and observed states. MRRC makes this information-processing nature explicit by analyzing what these measurements structurally require. We explore how MRRC constraints map onto familiar physical quantities in our universe, with the caveat that these are interpretive connections rather than derivations.

9.1 Temporal Structure

In MRRC terms, temporal experience emerges from the indexing of successful comparison and recording operations. For any subsystem S:

$$T_S := |\{\mathrm{MRRC}_0, \mathrm{MRRC}_1, \ldots, \mathrm{MRRC}_n\}_S|$$

This operational definition explains temporal phenomena: systems with higher maintenance costs (larger β) execute fewer MRRC operations per unit substrate evolution, experiencing slower internal temporal progression relative to systems with lower costs.

9.2 Spatial Structure

Spatial relationships emerge from communication costs between MRRC-capable subsystems. The MRRC-distance between subsystems u and v is:

$$d(u, v) := \inf\{\text{MRRC hops required for reliable record transfer}\}$$

This metric structure provides a foundation for emergent spatial geometry based on information transfer costs rather than pre-existing spatial containers.

9.3 Energy and Mass Interpretations

The following represent interpretive analogies rather than formal derivations.

Energy maps to the operational capacity to alter correlation structures:

$$E_{\text{available}} \geq k_B T \ln 2 \cdot \mathbb{E}[\text{required erasures}]$$

Informational mass corresponds to resistance against reconfiguration:

$$m_{\text{inf}} \propto \left. \frac{\partial^2 W_{\min}}{\partial v^2} \right|_{v=0}$$

where $W_{\min}$ is the minimal work to change correlation structure at rate v.

Speed limits emerge from finite costs of correlation updates under noise constraints, yielding a maximum sustainable update rate c.

9.4 Important Limitations

These mappings represent interpretive connections between MRRC operations and measurement procedures in physics. Physical constants like c, G, and α have specific numerical values that arise from the particular geometry and dynamics of our universe's substrate, not from MRRC logic alone.

Our claim is more modest: the functional roles served by physical quantities (temporal ordering, spatial metrics, energy capacity, mass resistance) may reflect deeper information-processing requirements. Like how thermodynamics reveals statistical mechanics beneath heat phenomena, MRRC may reveal information-processing constraints beneath physical measurement operations.

10 Complexity Emergence Hierarchy

We define emergence as the appearance of novel correlation structures under coarse-graining that exhibit predictive regularities not reducible to component statistics without loss of descriptive accuracy.

10.1 Hierarchy Structure

The emergence hierarchy represents increasing complexity and persistence of correlation structures:

Level 0 — Isolated MRRC Events: Single comparison-record operations with no persistent inter-event correlations.

Level 1 — Stable Records: MRRC operations that maintain local information across multiple cycles.

Level 2 — Bound Structures: Collections of stable records forming persistent aggregates with internal correlation cycles.

Level 3 — Interacting Assemblies: Bound structures that exchange correlations to form composite states.

Level 4 — Self-Maintaining Systems: Structures that actively channel resources to maintain identity against environmental degradation.

Level 5 — Replicating Systems: Self-maintaining systems that produce copies of their correlation structure.

Level 6 — Adaptive Replicators: Replicating systems that modify their structure to improve persistence in changing environments.

Level 7 — Symbolic Systems: Adaptive systems that develop abstract reference systems for internal coordination and environmental manipulation.

Level 8 — Meta-Level Engineers: Symbolic systems that explicitly model their own constraints and design new operational substrates.

10.2 Transition Dynamics

Each transition in the hierarchy requires overcoming specific informational and energetic barriers. Higher levels generally exhibit:

- Increased correlation persistence
- Greater resource requirements for maintenance
- Enhanced capacity for environmental manipulation
- More sophisticated information processing capabilities

The hierarchy appears substrate-independent, suggesting universal patterns in complexity emergence under MRRC constraints. V3.0 extensions link this to two-tier attractors and fractal nesting.

11 Framework Validation and Testing

11.1 Conditional Falsifiability

MRRC makes testable predictions within its domain of applicability. The framework would be invalidated for specific substrates if:

- **Zero-cost persistence:** Stable correlations maintained indefinitely without measurable resource expenditure in noisy finite-temperature environments
- **Unbounded complexity growth:** Indefinite complexity increase in closed systems with fixed resource budgets
- **Infinite-speed correlation updates:** Reliable information transfer at arbitrarily high speeds with finite energy costs
- **Costless temporal reversibility:** Perfect reconstruction of arbitrary past states without resource expenditure proportional to temporal distance

Note that these falsifiability conditions follow the normal pattern in physics—theories specify their domains of applicability and make predictions within those domains.

11.2 Empirical Tests

Memory Refresh Costs: Measure minimum energy required to maintain bit fidelity in physical memory systems under thermal noise. MRRC predicts costs approaching $\beta k_B T \ln 2$ asymptotically, where β is empirically determined for each system (like measuring the mass of an electron).

Implementation example: Use a superconducting qubit or trapped ion as a single-bit memory. Apply controlled thermal noise and measure the minimum energy required to maintain 99% fidelity over increasing time intervals. Plot energy cost vs. time to verify linear scaling.

Complexity Saturation: Evolve computational organisms under fixed resource budgets. MRRC predicts complexity plateauing when maintenance costs equal available resources.

Implementation example: Create a digital evolution environment (similar to Avida) with:

- Fixed CPU cycles per generation (resource budget)
- Organisms that must allocate cycles between replication and maintenance
- Complexity measured as genome length or functional diversity
- Prediction: $C(t)$ grows then plateaus when $W_{\text{maint}}(C) = W_{\text{budget}}$

Correlation Propagation Limits: Test maximum sustainable information transfer rates in optional physical channels. MRRC predicts finite bounds related to refresh costs, with system-specific parameters.

Hierarchical Emergence: Examine whether systems satisfying MRRC constraints spontaneously develop the predicted complexity hierarchy.

V3.0 adds tests for non-universal scaling and q = 0.001 (see Section 7.3), confirming predictions.

11.3 Integration with Existing Theory

MRRC integrates with established frameworks as a constraint meta-layer, extending rather than replacing existing approaches:

Thermodynamics: MRRC's entropy costs align with thermodynamic principles while extending them to general information processing systems. Like how statistical mechanics explains thermodynamics at a deeper level [1].

Information Theory: MRRC generalizes Landauer's principle and extends Shannon's framework to evolving systems with memory constraints.

Complexity Science: MRRC provides formal foundations for understanding emergence hierarchies observed across multiple domains.

Quantum Mechanics: MRRC interprets measurement as environmental recording with associated entropy costs, compatible with decoherence theory [2].

Relationship to Existing Frameworks: MRRC complements rather than competes with established approaches:

- *Free Energy Principle [3]:* MRRC provides the constraint logic underlying systems that minimize free energy through environmental interaction
- *Constructor Theory [4]:* MRRC specifies minimal conditions for systems capable of supporting constructor operations
- *Computational Universe [5]:* MRRC analyzes the information-processing constraints that limit computational capacity in physical substrates

12 Illustrative Example: Cellular Automaton Implementation

To demonstrate MRRC principles concretely, consider a simple cellular automaton that satisfies PC1–PC5:

Setup: 1D cellular automaton with cells $c_i \in \{0, 1\}$, update rule R, and a designated "recorder" region that tracks pattern changes.

MRRC Implementation:

- σ_k: Current configuration of observed region
- r_{k-1}: Reference configuration used for comparison
- Δ_k: XOR comparison between σ_k and r_{k-1}
- m_k: Updated recorder state incorporating Δ_k

Constraint Satisfaction:

- PC1: 4-tuple operations implement minimal recorded change
- PC2: Discrete time steps provide temporal indexing through distinction-making
- PC3: Cellular automaton rules are deterministic and reversible
- PC4: Finite recorder region limits memory capacity M
- PC5: Each operation requires computational resources (CPU cycles)

Predicted Behaviors:

- Temporal asymmetry: Reconstructing past configurations requires exponentially more computation as information is lost
- Complexity saturation: Pattern complexity plateaus when maintenance costs equal available update budget
- Hierarchy emergence: Complex patterns should form from simple rules following MRRC dynamics

V3.0 extensions predict two-tier attractors in CA trajectories, with Fibonacci quantization in changepoint intervals.

13 Discussion and Future Directions

13.1 Framework Contributions

The MRRC framework provides several novel contributions:

- A unified constraint-logic foundation for analyzing order and complexity across substrates
- Formal derivation of temporal asymmetries from information processing requirements
- A structured approach to understanding complexity emergence hierarchies
- Integration of thermodynamic, computational, and complexity-theoretic perspectives
- Testable predictions for information processing in evolving systems
- V3.0: Hierarchical attractors, quantization unification, non-universal scaling, fractal nesting

13.2 Limitations and Scope

MRRC's applicability is conditional on systems satisfying the primitive constraints. It does not:

- Derive physical laws from pure logic
- Claim universal applicability to all possible systems
- Replace or contradict established physical theories
- Explain why our particular universe has its specific constants and structures

The framework operates as a meta-theoretical tool that analyzes structural requirements for information processing, much like how thermodynamics analyzes energy constraints without specifying particular mechanical implementations.

13.3 Future Research Directions

Experimental Validation: Systematic testing of MRRC predictions in controllable physical and computational systems, expanding beyond computational substrates to biological and social-economic.

Mathematical Development: Formal development of the constraint system using category theory or other advanced mathematical frameworks; quantify attractor transitions.

Cross-Domain Applications: Application to specific domains including biology, artificial intelligence, and materials science; develop predictive models for oscillatory regimes.

Collaboration Opportunities: Integration with research groups working on foundations of physics, complexity science, and information theory.

14 Conclusion

The MRRC framework (V3.0) provides a constraint-logic foundation for analyzing information processing in evolving systems. By identifying minimal structural requirements for recordable change under finite resources, it offers insights into temporal asymmetries, complexity emergence, hierarchical attractors, quantization, and non-universal scaling.

While developed independently, the framework's convergence with established principles in thermodynamics, information theory, and complexity science suggests it may capture fundamental constraints on evolving systems. The framework operates as a meta-theoretical tool that can analyze structural preconditions for order and memory across various substrates while complementing existing physical theories.

Future work should focus on experimental validation, mathematical formalization, and application to specific domains. The framework's testable predictions and clear scope limitations position it as a scientific tool rather than speculative metaphysics.

This work demonstrates how logical analysis of minimal structural requirements can yield insights into complex phenomena, suggesting that constraint-based approaches may provide valuable perspectives on fundamental questions about order, complexity, and temporal experience in evolving systems.

References

[1] R. Landauer, "Irreversibility and heat generation in the computing process," *IBM Journal of Research and Development*, vol. 5, no. 3, pp. 183–191, 1961.

[2] W. H. Zurek, "Decoherence, einselection, and the quantum origins of the classical," *Reviews of Modern Physics*, vol. 75, no. 3, pp. 715–775, 2003.

[3] K. Friston, "The free-energy principle: a unified brain theory?" *Nature Reviews Neuroscience*, vol. 11, pp. 127–138, 2010.

[4] D. Deutsch, "Constructor theory," *Synthese*, vol. 190, pp. 4331–4359, 2013.

[5] S. Lloyd, "Computational capacity of the universe," *Physical Review Letters*, vol. 88, no. 23, 237901, 2002.

[6] J. Biamonte et al., "Quantum machine learning," *Nature*, vol. 549, pp. 195–202, 2017.

[7] S. Wolfram, *A New Kind of Science*. Wolfram Media, 2002.

[8] S. A. Kauffman, *The Origins of Order: Self-Organization and Selection in Evolution*. Oxford University Press, 1993.