

# RCA–CID–WSIG–EBOC Unified Theory: Reversible Automata $\times$ Closed Introspective Decoder $\times$ Windowed Scattering/Information Geometry $\times$ Eternal Block Causal Network

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## Abstract

From standpoint that “eternal graph (EBOC-Graph) is **static measure structure**, ‘time’ produced only by observer (decoder) filtration and commitment of leaves”, establish unified theory with **four layers**, provable, checkable and engineerable:

**(I) Dynamics Layer (RCA):** Reversible cellular automaton describes reversible evolution of entire system, ensuring **joint information conservation** and **erasure-free implementation**; reversibility evidenced by Hedlund–Moore–Myhill Garden-of-Eden criterion and Toffoli–Margolus block-reversible construction.

**(II) Recording/Inference Layer (CID):** Closed introspective decoder records self-changes via **append-only log**; under minimal recording strategy its “recording entropy” **monotonically (usually strictly) increases** along time filtration, equivalent to “**halting/I-projection fixed point/KL no longer decreases**” (Csiszár I-geometry and Pythagorean identity).

**(III) Measurement Layer (WSIG):** Unify all readouts as **windowed integral** of “phase derivative = Wigner–Smith delay trace =  $-2\pi \cdot$  spectral shift density”; give **non-asymptotic error closure** via Nyquist–Poisson–Euler–Maclaurin three-term decomposition.

**(IV) Graph Spectral Layer (EBOC-Graph):** Use graph Laplacian spectrum as frequency domain, implement localized filtering with **Chebyshev polynomials** and exponential tail bounds; non-backtracking spectrum via Ihara–Hashimoto–Bass determinant isomorphic to closed-path counting, supporting “leaf-readout/commitment” engineering implementation.

Key claims with **refutable criteria** and **engineering blueprints**:

1. Modeling  $R_t$  as sequence of codewords of length  $t$  with prefix codes ensuring concatenation reversibility, update  $R_{t+1} = (R_t, C_t)$  gives  $S_{t+1} - S_t = H(C_t | R_t) \geq 0$
2. “No entropy increase”  $\Leftrightarrow$  “halting”  $\Leftrightarrow$  “I-projection fixed point”
3. Unique canonical form requires “adjacent scale reorganizable + prefix decodable”; one natural and sufficient realization is Zeckendorf decomposition with prefix codes (Kraft), not unique option; eliminates exponential recording explosion from “same object multiple representations”

# 1 Setup and Notation

- **Static block universe:** Given probability space  $(\Omega, F, \mathbb{P})$ , “time” induced only by decoder **filtration–commitment** of leaves
- **RCA:** Global map  $F : \Sigma^{\mathbb{Z}^d} \rightarrow \Sigma^{\mathbb{Z}^d}$  on lattice  $\mathbb{Z}^d$  **reversible** with  $F^{-1}$  also CA (finite radius inverse local rule exists)
- **CID:** Internal record  $R_t \in \mathcal{C}^*$  updates **append-only**  $R_{t+1} = R_t \circ C_t$ ; total state  $X_t = (Z_t, R_t)$  reversibly evolves under bijection  $U$ ; encoder Enc is **prefix code**
- **Encoding canonical form:** Size payload  $n$  uses **Zeckendorf unique decomposition** (no adjacent 1s); trailing “11” gives Fibonacci prefix code
- **I-geometry:** Belief family is exponential family, update via **I-projection (minimal KL)**, satisfying KL Pythagorean decomposition
- **WSIG:** Scattering matrix  $S(\lambda)$  determinant phase gives **spectral shift**  $\xi$ , with  $\partial_\lambda \arg \det S(\lambda) = \text{tr } Q_{\text{WS}}(\lambda) = -2\pi \xi'(\lambda)$ ; adopt convention  $\det S(\lambda) = e^{-2\pi i \xi(\lambda)}$ , where  $Q_{\text{WS}} = -iS^\dagger \partial_\lambda S$  is Wigner–Smith delay matrix
- **EBOC-Graph:** Use graph Laplacian  $L$  spectrum as frequency domain,  $\phi(L)$  approximated by Chebyshev series (degree  $m$  gives error  $O(\varrho^{-m})$ )

## 2 Reversible Cellular Automaton (RCA)

**Definition 2.1** (Reversible CA). *If  $F$  bijective and  $F^{-1}$  also CA, call  $F$  **reversible cellular automaton**.*

**Theorem 2.2** (Moore–Myhill Garden-of-Eden Criterion). *On  $\mathbb{Z}^d$ , **surjective** if and only if **pre-injective**; thus “injective + surjective”  $\Leftrightarrow$  **reversible**.*

## 3 Closed Introspective Decoder (CID)

**Definition 3.1** (CID). *System with internal record  $R_t$  updating append-only, encoder using prefix codes, total state evolving reversibly.*

**Theorem 3.2** (Recording Entropy Monotonicity). *Under minimal recording strategy, recording entropy  $S(R_t)$  strictly increasing unless system halted.*

## 4 Windowed Scattering and Information Geometry (WSIG)

Core identity:

$$\frac{\varphi'(\lambda)}{\pi} = \frac{1}{2\pi} \text{tr } Q_{\text{WS}}(\lambda) = -\xi'(\lambda) = \rho(\lambda)$$

All readouts unified as windowed integrals of spectral shift density.

## 5 EBOC Graph Spectral Layer

Use Chebyshev polynomials on graph Laplacian spectrum for localized filtering. Non-backtracking spectrum via Ihara–Hashimoto–Bass formula.

## 6 Unified Framework

Four layers integrated:

- RCA: reversible dynamics, information conservation
- CID: append-only logs, entropy monotonicity
- WSIG: windowed readout, NPE error closure
- EBOC-Graph: spectral filtering, leaf commitment

**Main equivalence:**

$$\text{Halting} \iff \text{No entropy increase} \iff \text{I-projection fixed point}$$