

Observations on Time, Information Compression, and Observer Interfaces

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Abstract

This note records a sequence of observations concerning time, causality, and quantum phenomena, framed through the concept of *observer interfaces*. Rather than proposing a finalized physical theory, we treat time as an emergent structural effect arising from information compression, decoherence, and observer-limited interaction. Classical continuity, quantum discontinuity, and apparent violations of causality are examined under a unified interface-based perspective.

1 Motivation

Several foundational puzzles motivate this exploration:

- Why does the speed of light appear as a universal limit?
- Why do quantum processes appear to exhibit “superluminal” correlations without enabling communication?
- Why does the present moment seem to possess a finite “thickness”?
- Why is the classical world continuous, while the quantum world appears discrete or jump-like?
- What role does observation play in the generation of time?

We treat these not as isolated questions, but as different projections of a single structural phenomenon.

2 Time as an Emergent Effect

Observation 1 (Time as Information Compression). *Time may be interpreted not as a primitive dimension, but as a byproduct of information compression performed by an observer-limited interface.*

Under this view, temporal ordering emerges when a system compresses a large state space into a sequence of admissible, recordable states. What is experienced as “flow of time” corresponds to the rate at which distinguishable information can be stably externalized.

Remark 1. *This perspective aligns with the intuition that entropy increase and irreversibility are observer-relative rather than absolute.*

3 Speed of Light as an Interface Constraint

Observation 2 (Light-Speed as Interface Bandwidth). *The speed of light represents a maximal bandwidth constraint of spacetime interfaces, rather than a fundamental limit on all physical processes.*

Information cannot be transmitted faster than this limit because doing so would require bypassing the observer's causal interface. Quantum correlations may exceed this limit internally, but cannot be externalized into communicable signals.

Observation 3 (Interface-Induced Gravity). *Let $\Phi : \Omega \rightarrow \mathcal{I}$ be a non-invertible interface map from a space of generative states Ω to an observer-accessible space \mathcal{I} , induced by a fixed rule system Θ .*

Assume that:

- Ω contains multiple realizations corresponding to identical interface data $i \in \mathcal{I}$;
- system evolution preserves admissibility under Θ ;
- observers are restricted to dynamics expressible solely in terms of \mathcal{I} .

Then the induced effective dynamics on \mathcal{I} necessarily include non-recoverable aggregation tendencies, corresponding to motion toward equivalence classes of lower informational resolution.

In physical spacetime realizations, this aggregation tendency manifests as a universal attractive interaction among energy-localized configurations. We interpret gravitational attraction as the macroscopic signature of interface non-invertibility under information-compressing observation.

3.1 Interface Extremes: Gravity and Black Holes

Observation 4 (Interface-Induced Gravity and Interface Collapse). *Let $\Phi : \Omega \rightarrow \mathcal{I}$ be a non-invertible interface map induced by a fixed rule system Θ , and suppose that observer-accessible dynamics are restricted to \mathcal{I} .*

Non-invertibility of Φ induces effective aggregation tendencies on \mathcal{I} , corresponding to motion toward equivalence classes of reduced informational resolution. At macroscopic scales, this manifests as a universal attractive interaction among localized energy configurations, interpreted as gravitational attraction.

A black hole corresponds to an extreme regime of this same mechanism, in which Φ collapses large regions of Ω onto minimal interface representations, rendering further externalization of internal state information impossible.

In this unified view, gravity and black holes are not distinct physical phenomena, but different regimes of interface non-invertibility. Gravity reflects a *gradient of informational compression*, while a black hole represents a limit point at which interface-mediated time and state differentiation cease to function.

Remark 2 (Consistency with the Equivalence Principle). *This interpretation does not violate the equivalence principle. Locally, an observer embedded within an interface-defined equivalence class cannot distinguish between aggregation induced by interface compression and uniform acceleration.*

The equivalence principle thus arises naturally from observer confinement to \mathcal{I} : locally accessible dynamics remain invariant under transformations that preserve interface-level admissibility. Apparent gravitational effects reflect global properties of Φ , while local experiments remain insensitive to the underlying informational gradient.

3.2 A Minimal Discrete Toy Model

Let $\Omega = \{\omega_1, \omega_2, \dots, \omega_N\}$ be a finite set of generative states. Let the interface space be $\mathcal{I} = \{i_1, i_2, \dots, i_M\}$ with $M < N$.

Define a non-invertible interface map

$$\Phi : \Omega \rightarrow \mathcal{I}$$

such that multiple $\omega \in \Omega$ map to the same $i \in \mathcal{I}$.

Let Θ be a rule system enforcing admissible transitions $\omega \rightarrow \omega'$ that preserve Φ -consistency. Observers have access only to transitions expressible on \mathcal{I} .

For each $i \in \mathcal{I}$, define an equivalence class

$$[\omega]_i = \{\omega \in \Omega \mid \Phi(\omega) = i\}.$$

Suppose transition probabilities on Ω are uniform among admissible states. Then interface-level dynamics induce an effective bias toward equivalence classes with larger cardinality $|[\omega]_i|$.

Observation 5 (Emergent Attraction from State Degeneracy). *Given observer restriction to \mathcal{I} , any region corresponding to a larger preimage under Φ induces an effective attractive tendency in interface-level dynamics.*

This attraction is not a fundamental force, but a statistical consequence of state degeneracy under non-invertible observation.

In this model, a black-hole-like regime corresponds to an interface state $i^* \in \mathcal{I}$ such that

$$|[\omega]_{i^*}| \gg |[\omega]_i| \quad \forall i \neq i^*,$$

and transitions out of $[\omega]_{i^*}$ are disallowed by Θ .

From the interface perspective, dynamics appear frozen, while internal micro-dynamics in Ω may continue unrestricted.

3.3 Energy as Interface Occupancy Density

Definition 1 (Interface Occupancy). *Given a non-invertible interface map $\Phi : \Omega \rightarrow \mathcal{I}$, define the interface occupancy density of an interface state $i \in \mathcal{I}$ as*

$$\rho(i) := |\Phi^{-1}(i)|,$$

the cardinality of its preimage in the generative space Ω .

Observation 6 (Energy as Occupancy Density). *Energy may be interpreted as a measure of interface occupancy density. Regions of high energy correspond to interface states with large degeneracy in Ω , i.e., high $\rho(i)$.*

Under observer-restricted dynamics on \mathcal{I} , transitions preferentially enter and remain within regions of higher occupancy density. From the interface perspective, such regions behave as persistent, inertia-bearing configurations.

Observation 7 (Inertia from Occupancy Persistence). *Interface states with high occupancy density exhibit resistance to change in interface-level dynamics, as transitions out of large equivalence classes are statistically suppressed.*

This persistence manifests as inertial behavior.

Remark 3 (Inevitability of Large-Scale Structure Formation). *At cosmological scales, any non-invertible interface map Φ combined with observer-restricted dynamics on \mathcal{I} necessarily induces uneven occupancy distributions.*

Even from initially homogeneous conditions in Ω , stochastic fluctuations produce interface regions with slightly higher occupancy density. These regions subsequently attract further interface-level trajectories, amplifying density contrast over time.

Thus, large-scale structure formation is not contingent on fine-tuned initial conditions, but is a generic consequence of interface non-invertibility and information compression.

4 Interface Compression and Emergent Attraction

4.1 Setup

Let Ω be a space of microstates (generative states). Let \mathcal{I} be a space of observer-accessible interface data (records, observations, transcripts, measurement outcomes).

Definition 2 (Interface map). *An interface map is a (possibly stochastic) map*

$$\Phi : \Omega \rightarrow \mathcal{I},$$

induced by a fixed rule system Θ specifying what can be observed, queried, or verified.

For $i \in \mathcal{I}$ define the fiber (preimage)

$$\Omega_i := \Phi^{-1}(i) \subseteq \Omega.$$

Definition 3 (Interface indistinguishability). *Two microstates $\omega, \omega' \in \Omega$ are interface-equivalent if $\Phi(\omega) = \Phi(\omega')$.*

4.2 Information under an interface

Assume a prior measure μ on Ω (or a family μ_λ indexed by scale λ). This induces a distribution on \mathcal{I} :

$$P(i) := \mu(\Omega_i).$$

Definition 4 (Interface surprisal / compressed description length). *Define the interface description length*

$$\ell(i) := -\log P(i),$$

and the interface entropy

$$H(\Phi) := \mathbb{E}_{i \sim P}[\ell(i)] = -\sum_{i \in \mathcal{I}} P(i) \log P(i).$$

Intuition: $\ell(i)$ measures how many bits are required to specify the observed interface datum i , given the rule-limited access encoded by Φ .

4.3 Coarse-grained geometry and effective dynamics

Let $x \in \mathbb{R}^3$ denote a coarse-grained spatial descriptor extracted from i , written $x = \pi(i)$ for some projection $\pi : \mathcal{I} \rightarrow \mathbb{R}^3$ (e.g., center-of-mass record).

Define an *effective free-energy functional* on interface data:

$$\mathcal{F}(i) := \mathbb{E}[E \mid i] - T \ell(i),$$

where E is the microstate energy and T is an effective temperature/scale parameter (used only as a Lagrange multiplier controlling information contribution).

We posit an induced drift (gradient flow) on accessible coordinates:

$$\dot{x} \propto -\nabla_x \mathbb{E}[\mathcal{F}(i) \mid \pi(i) = x].$$

In regimes where the $\ell(i)$ term dominates the spatial dependence, the drift is toward configurations minimizing description length (maximizing compressibility).

4.4 Observation (Interface Compression \Rightarrow Emergent Attraction)

Observation 8 (Gravity as an interface-level effect). *If the interface map Φ is non-invertible and the induced description length $\ell(i)$ strictly decreases under aggregation of energy-localized configurations (in the sense that merging two separated lumps yields lower $\ell(i)$ at fixed total energy), then the induced effective dynamics on coarse-grained coordinates exhibit a systematic attractive drift between those lumps.*

4.5 Conjectures

Conjecture 1 (Generic non-invertibility of physical interfaces). *For physically realizable rule systems Θ with bounded observation bandwidth, the induced interface map $\Phi : \Omega \rightarrow \mathcal{I}$ is generically non-invertible:*

$$\exists \omega \neq \omega' \in \Omega \text{ s.t. } \Phi(\omega) = \Phi(\omega').$$

Conjecture 2 (Compression monotonicity under aggregation). *In spatially extended closed systems with conserved energy-momentum, the interface description length $\ell(i)$ is generically aggregation-subadditive:*

$$\ell(i_{\text{together}}) \leq \ell(i_{\text{separate}}) - c(d),$$

where d is separation distance and $c(d) > 0$ increases with d in the regime where the interface cannot resolve full microstructure.

Conjecture 3 (Entropic-force form of attraction). *In the aggregation-subadditive regime, the induced drift admits an entropic-force form:*

$$F_{\text{eff}}(d) = -\frac{\partial}{\partial d} \left(T \mathbb{E}[\ell(i) \mid d] \right),$$

which is attractive whenever $\mathbb{E}[\ell(i) \mid d]$ increases with separation d .

Conjecture 4 (Newtonian scaling as a universal low-resolution limit). *Assume (i) translation/rotation invariance at the interface level, (ii) locality of interface resolution, and (iii) far-field dominance of a single scalar “compressibility potential”. Then, in the long-distance limit, the leading attractive term satisfies*

$$F_{\text{eff}}(d) \approx -G_{\text{eff}} \frac{m_1 m_2}{d^2},$$

for some interface-dependent constant G_{eff} determined by Θ and the coarse-graining scale.

Conjecture 5 (Equivalence principle as interface universality). *If Φ erases internal labels beyond total energy–momentum, then the induced acceleration depends only on the interface-relevant energy localization and not on micro-composition:*

$a_{\text{eff}}(x)$ is independent of microstate species given fixed coarse energy profile.

Conjecture 6 (Rule-external augmentation changes “gravity”). *Augmenting the rule system Θ with rule-external structure (higher-resolution access) refines Φ and reduces fiber sizes $|\Omega_i|$, thereby weakening the compression term and altering the effective attraction:*

$$\Theta \subset \Theta' \Rightarrow \ell_{\Theta'}(i) \leq \ell_{\Theta}(i) \quad \text{and} \quad |F_{\text{eff}}^{\Theta'}| \leq |F_{\text{eff}}^{\Theta}| \text{ in comparable regimes.}$$

5 Quantum Superposition and Apparent Atemporality

Definition 5 (Pre-Temporal State). *A system is in a pre-temporal state if its internal evolution is not yet projected onto an observer-defined temporal ordering.*

Observation 9 (Quantum Superposition as Pre-Temporal). *Quantum superposition may be understood as a state that has not yet entered observer-generated time.*

Measurement is not merely a passive readout, but an active interface event that projects the system into a temporal sequence.

6 Measurement as a Local Time-Generation Event

Observation 10 (Measurement Generates Local Time). *Each quantum measurement event constitutes a localized generation of time, establishing a before-and-after relation relative to the observer.*

This explains why time appears continuous at macroscopic scales (due to dense, overlapping measurement events), yet discontinuous at microscopic scales.

7 The Thickness of “Now”

Observation 11 (Finite Present Interval). *The “present” is not a mathematical instant, but a finite interval required for information stabilization and interface registration.*

The thickness of “now” corresponds to the minimum temporal window necessary for coherent observation.

8 Classical Continuity vs Quantum Discreteness

Observation 12 (Continuity as High-Frequency Averaging). *Classical continuity emerges from the averaging of an enormous number of microscopic, discrete interface events.*

Observation 13 (Interface-Induced Electric Interaction). *If an interface map $\Phi : \Omega \rightarrow \mathcal{I}$ selectively preserves certain signed or oriented degrees of freedom while compressing others, then asymmetries in interface occupancy may persist under aggregation.*

Such persistent interface-level asymmetries induce effective long-range interactions that are not universally attractive. In physical realizations, these interactions manifest as electric charge and electromagnetic forces.

In contrast to gravity, which arises from scalar compression of interface occupancy, electric interactions arise from vector- or sign-sensitive interface constraints, allowing both attraction and repulsion.

Quantum jumps are visible only when the observer interface has insufficient resolution or insufficient averaging depth.

9 Black Holes as Interface Collapse

Observation 14 (Black Holes as Temporal Compression Extremes). *A black hole may be viewed as a region where time is maximally compressed, and observer interfaces fail to externalize internal states.*

From the external perspective, information appears frozen; from the internal perspective, standard temporal notions may cease to apply.

10 Free Will and Interface Choice

Observation 15 (Free Will as Path Selection Freedom). *Free will may be interpreted as residual freedom in selecting among admissible compression paths within an observer interface.*

This freedom does not violate physical law, but operates within underdetermined regions of the interface.

11 The Universe Before Time

Observation 16 (Atemporal Universe Hypothesis). *Prior to global decoherence, the universe may be regarded as effectively atemporal, with no observer-relative time ordering.*

Under this view, the “origin” of the universe is not a temporal event, but a transition into a regime where observation and time become meaningful.

12 Stronger Observers

Observation 17 (Observer Hierarchy). *An observer with a more expressive interface would perceive a richer causal structure, potentially accessing relations that appear acausal or paradoxical to weaker observers.*

Causality itself may therefore be observer-relative.

These phenomena are therefore not absolute laws, but stable interface-level regularities that persist only under fixed observational constraints.

13 Clarification: Beyond Reductionism and Informationism

The interface-based perspective adopted in this work should not be interpreted as a form of reductionism, nor as an ontological claim that reality is fundamentally “made of information.”

First, this framework does not reduce physical phenomena to a single primitive substance or microphysical mechanism. Microstates in Ω are not eliminated, replaced, or declared irrelevant.

Phenomenon	Structural Cause (Interface Perspective)	Effect of Interface Enhancement
Gravity	Information compression across spatial degrees of freedom due to interface non-invertibility	Effective attraction weakens; trajectories become less biased as finer spatial distinctions are resolved
Energy	Interface occupancy density (cardinality of microstate equivalence classes)	Effective mass or inertia decreases as degeneracy is resolved into distinguishable microstates
Speed of light limit	Finite causal bandwidth of the observer interface	Maximum signal speed increases only if interface bandwidth is fundamentally expanded
Arrow of time	Irreversible information compression under observation	Temporal asymmetry diminishes as reversible microdynamics become externally accessible
Quantum nonlocal correlations	Projection of generative-level nonlocality through a constrained interface	Correlations appear less paradoxical as intermediate generative structure becomes observable
No superluminal communication	Inability to control or steer interface fibers	Limited signaling may emerge only if the interface allows directed control of microstate selection

Table 1: Physical phenomena interpreted as consequences of interface structure, together with their expected modification under enhanced interface resolution or access.

Rather, the analysis concerns how observer-accessible regularities arise when dynamics are necessarily expressed through a constrained interface \mathcal{I} . The focus is structural, not eliminative.

Second, the present approach is not informationism. Information here is not treated as an intrinsic substance or universal currency of reality. Instead, informational quantities such as description length or entropy are explicitly interface-relative: they are defined only with respect to a rule system Θ that governs what can be observed, recorded, or externalized. No claim is made that information exists independently of such interfaces.

In this sense, the framework is neither bottom-up reductionist nor top-down informational. It is relational and operational: physical phenomena are understood as emergent constraints on dynamics induced by the necessity of observation under limited, non-invertible interfaces. Gravity, time, and causality are not reduced to information, but arise as stable interface-level regularities that persist across a wide range of underlying microphysical realizations.

Observation 18 (Existence of Stronger Interfaces). *If observable reality is mediated by a non-invertible interface that induces irreversible information compression, and if interface fidelity admits a partial ordering, then the existence of interfaces with strictly greater information retention than*

Interaction	Interface-Retained Structure	Compression Type	Characteristic Interface Behavior
Gravitational	Scalar occupancy density (total degeneracy)	Fully scalar, sign-erasing compression	Universally attractive; unscreenable; acts on all energy-localized configurations
Electromagnetic	Signed or vector-valued interface attributes (charge, orientation)	Partial compression preserving sign and direction	Attractive or repulsive; screenable; long-range due to retained vector structure
Weak	Chiral and flavor-asymmetric interface labels	Selective compression violating parity symmetry	Short-range; non-universal; induces irreversible transmutations at the interface level
Strong	Color-like multi-component relational constraints	Minimal compression of internal relational structure	Confining; saturating; prevents isolation of interface-incomplete states

Table 2: The four fundamental interactions interpreted as consequences of which structural features are retained or erased by the observer interface under information compression.

the human-observer interface cannot be excluded and is generically expected.

Such interfaces need not correspond to entities within the observable domain, as any interaction with them would necessarily be projected through the weaker interface and thereby lose its distinguishing structure.

14 Conclusion

These observations suggest that time, causality, and physical law are not absolute primitives, but emergent structures arising from observer interfaces, information compression, and decoherence. This framework does not negate existing physical theories, but offers an interpretive layer that may unify classical, quantum, and cosmological phenomena.