Facts as Structural Necessities: On the Co-Dependence of Physical Time and Physical Law on Irreversible Fact Formation

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For the General Reader

Every moment something definite happens in the physical world — a particle is detected, a chemical reaction completes, a photon is absorbed — the universe crosses a threshold from which it cannot return. These definite, irreversible events are what this paper calls *physical facts*: moments at which the universe commits to one outcome out of several possibilities, and that commitment is irreversibly recorded in the surrounding environment.

Physics usually takes such facts for granted, treating them as the natural output of its equations. This paper argues the opposite: physical facts are not products of physics but its prerequisites. Without them, time itself could not exist — there would be no "before" and "after", no direction of change, no way to measure how long anything takes. Without them, physical laws could not exist either — there would be nothing definite to predict, nothing definite to test against, no way to say whether a prediction was right or wrong.

We prove this claim in two independent ways. First, we show that the arrow of time — the fact that time runs in one direction and not the other — requires that at least some events in the universe are genuinely irreversible. Those irreversible events are facts. A universe in which everything is reversible has no arrow of time at all. Second, we show that any physical law, whether it governs particles, fields, or quantum systems, must ultimately be testable against definite outcomes. Testing requires definiteness; definiteness means facts.

The joint conclusion — that any universe with both time and physical laws must contain facts — is what we call the Joint Necessity Theorem. We go further and show that this is not merely necessary but uniquely necessary: every proposed alternative to a fact-based picture either secretly contains facts at some boundary, or reduces to pure mathematics with no physical content whatsoever.

Three structural features follow for any universe that contains facts: it must have a minimum scale below which no two distinct states can be told apart; every fact must be accompanied by an irreversible trace in its environment; and any bounded region can contain only a finite number of facts. These three features are precisely the foundational axioms of the Void Energy-Regulated Space Framework (VERSF) — a theoretical programme developed by the author. This paper shows that those axioms are not assumptions of VERSF but necessary consequences of the simple requirement that physics must deal in definite facts.

Abstract

Physics standardly treats physical facts — stable, irreversible, finitely distinguishable outcomes — as contingent products of physical processes. We argue that this order of explanation must be reversed: facts are not produced by a pre-existing physics but are the structural preconditions that make physics possible at all. We formalise this claim along two independent lines. First, the *temporal line*: we prove that both the arrow of time and the measurability of temporal duration logically require the existence of physical facts, so that a fact-free universe necessarily lacks physical time. Second, the *nomological line*: we prove that every physical law, in any formulation satisfying our operational definition of physical law, presupposes physical facts as the definite states on which its operations are defined and against which its predictions are tested, so that a fact-free universe admits no physical law.

The conjunction of these two results yields the **Joint Necessity Theorem**: any universe possessing physical time and governed by physical laws is necessarily fact-producing. We further prove a **Uniqueness Corollary**: any ontological alternative to facts — continuous-only evolution, globally reversible processes, permanently superposed states — either secretly contains facts at some boundary or interface, or is physically indistinguishable from the null case, a universe with no physics at all. Facts are therefore not merely necessary for physics; their absence eliminates physics entirely, leaving only formal mathematics.

Three structural corollaries follow immediately: any fact-producing universe must exhibit (i) a positive minimum distinguishability scale, (ii) irreversible environmental commitment at each fact-formation event, and (iii) a finite upper bound on fact-density within any bounded region. These three conditions are precisely the foundational axioms of the Void Energy-Regulated Space Framework (VERSF), establishing that VERSF's foundational structure is not assumed but derived from the prior necessity of facts.

Keywords: physical facts, arrow of time, physical law, irreversibility, finite distinguishability, VERSF, foundations of physics, fact-producing universe, information-theoretic constraints

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Table of Contents

1. Introduction
2. Formal Framework
    - 2.1 Defence of the Definitions: Why Weaker Alternatives Fail
    - 2.2 On Realisation and World-Directedness
3. The Temporal Line: Physical Time Requires Facts
4. The Nomological Line: Physical Laws Require Facts
5. The Joint Necessity Theorem
    - 5.1 The Uniqueness Corollary: Facts as the Only Foundation
6. Structural Corollaries and the VERSF Connection
    - 6.1 Connection to VERSF
7. Discussion and Relation to Existing Work
    - 7.5 Clarifications and Scope of the Result
8. Conclusion

- References

Theorems and Key Results

Result	Content	Section
Proposition 0	Necessity of the Realised/Possible Distinction	§2.2
Corollary 0.1	Realisation Requires Facts	§2.2
Theorem 1	Temporal Arrow Requires Facts	§3
Theorem 2	Temporal Duration Requires Facts	§3
Corollary 1	Fact-Free Universes Lack Physical Time	§3
Theorem 3	Physical Laws Require Facts: Testability	§4
Theorem 4	Physical Laws Require Facts: Mathematical Presupposition	§4
Corollary 2	Fact-Free Universes Admit No Physical Law	§4
Theorem 5	Joint Necessity Theorem	§5
Corollary 3	Uniqueness of Fact-Based Foundations	§5.1
Proposition 1	Finite Distinguishability is Necessary	§6
Proposition 2	Irreversible Commitment is Necessary	§6
Proposition 3	Finite Localisation Capacity is Necessary	§6

The concept of a physical fact is so basic to physics that it is almost never examined. When a quantum measurement yields a definite outcome, when a thermodynamic process crosses an irreversibility threshold, when a particle detector fires — each of these is an instance of fact formation: the universe commits to one outcome from a set of previously open alternatives, and that commitment is stably recorded in the state of the wider environment. Yet physics typically proceeds as though facts were products of the laws and time it already has in hand, rather than preconditions for those laws and that time to be meaningful at all.

This paper argues that the order of explanation must be reversed. Facts are not generated by an antecedently given physics operating in an antecedently given time. Rather, the very possibility of physical time and the very meaningfulness of physical law both require that physical facts exist. Time without facts has neither direction nor duration. Law without facts has neither testability nor a determinate domain of application. A universe in which nothing ever becomes definitively settled — in which all alternatives remain permanently open — is a universe in which physics, in any recognizable sense, cannot exist.

We develop this claim through a fully formal argument in two parallel and independent strands, which we call the temporal line and the nomological line. The temporal line proceeds from the phenomenological and operational structure of time: we prove that the temporal arrow and the measurability of duration each imply the existence of physical facts, so that physical time presupposes facts rather than generating them. The nomological line proceeds from the structure of physical law: we prove that both the testability and the mathematical definiteness required by any physical law presuppose facts as their indispensable substrate.

The two lines converge in the Joint Necessity Theorem (§5): any universe that (a) possesses physical time and (b) is governed by physical laws is necessarily fact-producing. This is a structural, not an empirical, conclusion. It does not depend on the specific dynamical laws of our universe but on what any physical universe must be like in order to qualify as physical at all. We reinforce this result with a Uniqueness Corollary (§5.1): we show that every proposed alternative to a fact-based ontology either collapses into fact-production at some boundary or collapses into physics-free pure mathematics. Facts are not just necessary; they are the *only* foundation from which physics can be built.

From the Joint Necessity Theorem, three structural corollaries follow immediately (§6). Any fact-producing universe must exhibit: (i) a positive minimum distinguishability scale $\delta_{min} > 0$; (ii) irreversible environmental commitment accompanying each fact-formation event; and (iii) a finite upper bound on the density of facts that can form within any bounded spatial region. These three conditions are precisely the foundational axioms of the Void Energy-Regulated Space Framework (VERSF) [Taylor 2024–2026]. The present paper therefore establishes that those axioms are not assumptions of VERSF but necessary consequences of the structural requirement that facts must exist in any physically meaningful universe.

The paper is organised as follows. Section 2 introduces the formal definitions and defends their minimality by testing weaker alternatives. Sections 3 and 4 develop the temporal and nomological lines respectively. Section 5 states and proves the Joint Necessity Theorem and the Uniqueness Corollary. Section 6 derives the three structural corollaries and connects them to VERSF. Section 7 situates the argument in relation to existing work. Section 8 concludes.

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2 Formal Framework

We introduce seven definitions that establish the formal setting for the theorems that follow. The framework is deliberately theory-neutral: it does not presuppose any specific dynamical formalism (Hamiltonian, path-integral, spinfoam, or otherwise) but is stated at a level of generality sufficient to encompass all standard physical theories.

Definition 1 *(Physical State Space).* A physical state space is a pair $(\Omega, \mathscr{F})$ where Ω is a non-empty set whose elements represent possible configurations of a physical system, and $\mathscr{F}$ is a σ-algebra of subsets of Ω representing measurable events. No element of Ω is assumed to be actualised; Ω is the space of possibilities, not of actualities.

Definition 2 *(Distinguishability Structure).* A distinguishability structure on $(\Omega, \mathscr{F})$ is a symmetric function $d : \Omega \times \Omega \to [0,\infty)$ satisfying $d(\omega,\omega) = 0$ for all $\omega \in \Omega$ and the triangle inequality $d(\omega_1,\omega_3) \leq d(\omega_1,\omega_2) + d(\omega_2,\omega_3)$. A positive minimum distinguishability scale $\delta_{min} > 0$ is a constant such that any two physically distinct states $\omega_1 \neq \omega_2$ that are operationally separable satisfy $d(\omega_1,\omega_2) \geq \delta_{min}$.

Definition 3 *(Environmental Record).* Given $(\Omega, \mathscr{F}, d)$ and a state $\omega^* \in \Omega$, a record of ω^* is a state R of an environmental system Ω_{env} distinct from the primary system, such that: (i) R is correlated with ω^* in a manner that distinguishes ω^* from any ω' with $d(\omega',\omega^*) \geq \delta_{min}$; and (ii) R is not erasable by any local operation acting only on the primary system.

Definition 4 *(Physical Fact).* A physical fact is a triple $F = (\omega^*, R, \tau)$ where: $\omega^* \in \Omega$ is a realised state; R is a record of ω^* in the sense of Definition 3; and τ is a *commitment index* — a logical marker of the state-space transition from open alternatives to a determinate committed state — such that:

- (i) $d(\omega^*, \omega') \geq \delta_{min}$ for all alternatives ω' that were operationally live before τ *(finite distinguishability)*;
- (ii) R is irreversibly established at τ — no physical operation on the system at any subsequent commitment index $t > \tau$ can return the system to its pre-τ state and simultaneously erase R from the environment *(irreversible commitment)*; and
- (iii) R remains stably accessible for all $t > \tau$ *(persistence)*.

Operational grounding of Definition 4. Definition 4 is not an ontological stipulation about the nature of reality, nor does it assume the conclusion of the theorems that follow. It is a *constraint-derived* definition: it specifies the minimal structure capable of supporting temporal ordering (Definition 6) and law testability (Definition 7). The conditions of clauses (i)–(iii) are therefore not assumed properties of the world but the weakest constraints under which Definitions 6 and 7 remain satisfiable. This is confirmed constructively in §2.1, where we show that relaxing any single clause renders the remaining structure insufficient to ground either physical time or physical law. The irreversibility of clause (ii) in particular is not presupposed as a feature of reality — it is derived as the minimum condition without which no record can be stable enough to serve as a temporal marker or a test outcome. A referee who objects that irreversibility is "built in" is correct that it is present in the definition; the point of §2.1 is to show that any definition from which irreversibility is absent cannot do the required structural work.

Remark on Definition 4 — the τ-ordering. The index τ in this definition is a *logical commitment index*, not yet the physical time $(T, <, \mu)$ of Definition 6. We formalise its structure precisely to forestall the objection that τ is simply time under another name.

Let $\mathcal{C}$ be the set of all commitment events in U. We define a binary relation $\prec$ on $\mathcal{C}$ as follows: $\tau_1 \prec \tau_2$ if and only if the state realised at τ_1 is a causal or logical precondition for the alternatives available at τ_2 — that is, if the commitment at τ_1 influences which alternatives are operationally live before τ_2. This relation satisfies:

- *Irreflexivity*: no commitment event is a precondition of itself;
- *Transitivity*: if $\tau_1 \prec \tau_2$ and $\tau_2 \prec \tau_3$ then $\tau_1 \prec \tau_3$;
- *Asymmetry*: if $\tau_1 \prec \tau_2$ then $\neg(\tau_2 \prec \tau_1)$.

Thus $(\mathcal{C}, \prec)$ is a strict partial order. Critically, $(\mathcal{C}, \prec)$ differs from the physical time structure $(T, <, \mu)$ of Definition 6 in two precise respects: (a) $\prec$ carries no duration measure — there is no analogue of μ assigning a magnitude to the interval between commitment events; and (b) $\prec$ is only a partial order — it does not require all commitment events to be comparable. The ordering $(\mathcal{C}, \prec)$ is not temporal succession but logical dependence: it encodes constraints on admissible transitions rather than durations or rates. In particular, $\prec$ does not define simultaneity, metric structure, or continuous parameterisation. These additional structures are precisely what Definition 6 introduces and what the temporal line establishes must arise from fact structure. The temporal line (§3) then establishes that any universe in which $\mathcal{C}$ is non-empty must additionally possess a full physical time structure $(T, <, \mu)$: the ordering $\prec$ on commitment events generates the asymmetric relation $<$ on T, and the distinguishability of successive facts grounds a non-zero duration measure μ. The argument is therefore not circular: it proceeds from the weaker structure $(\mathcal{C}, \prec)$ to the stronger structure $(T, <, \mu)$, not the reverse. Logical ordering ($\prec$) constrains the admissibility of transitions but does not define temporal metric, simultaneity, or rate. Physical time requires additional structure — in particular, a measure over distinguishable transitions. The temporal line demonstrates that such structure arises only when facts exist, converting the partial logical ordering of commitment events into the full temporal structure of Definition 6.

Definition 5 *(Fact-Producing Universe).* A universe U is fact-producing if the collection $\mathscr{F}_u = \{F_1, F_2, \ldots\}$ of all physical facts in U is non-empty: $\mathscr{F}_u \neq \emptyset$.

Definition 6 *(Physical Time).* Physical time in U is a structure $(T, <, \mu)$ where: T is the set of temporal indices associated with physical processes in U; $<$ is a binary relation on T; and $\mu : T \times T \to \mathbb{R}_{\geq 0}$ is a duration measure. We say: (a) U has a temporal arrow if $<$ is not symmetric, i.e., there exist $t_1, t_2 \in T$ with $t_1 < t_2$ but $\neg(t_2 < t_1)$; (b) U has measurable duration if $\mu(t_1, t_2) > 0$ for some $t_1 \neq t_2$.

Definition 7 *(Physical Law).* A physical law in U is a map L satisfying:

- (i) *Testability*: for any input states $s_1,\ldots,s_n$ and any predicted output of L given those inputs, there exists a physical procedure Π that returns a definite result confirming or disconfirming whether the actual system output matches the prediction;

- (ii) *Reproducibility*: repeated application of L to identically prepared initial states yields outputs that agree up to the minimum distinguishability scale — either the same definite output (deterministic case) or the same probability distribution over outputs (stochastic case), with individual realisations that can be jointly compared;
- (iii) *Predictive determinacy*: L maps definite input states to determinate outputs, where:
  - (a) *Deterministic case*: $L : \Omega^n \to \Omega$ maps definite input states to a single definite output state ω^*;
  - (b) *Stochastic case*: $L : \Omega^n \to \mathcal{P}(\Omega)$ maps definite input states to a probability measure over Ω, with the requirement that each individual realised outcome ω^*, once obtained, constitutes a physical fact in the sense of Definition 4 — a definite, stably recorded, irreversibly committed state.

The stochastic clause (iii)(b) is essential. For a probabilistic law, the output of L in the abstract is a distribution; but physics requires that the distribution be tested against *individual definite outcomes*. Each such outcome — a click, a pointer position, a decay event — is a physical fact. The probability measure describes the statistical pattern of fact-formation; it does not replace the facts themselves. The scope of all theorems that follow is precisely those formalisms qualifying as physical laws under this definition, covering both the deterministic and stochastic cases.

2.1 Defence of the Definitions: Why Weaker Alternatives Fail

One might object that Definition 4 builds irreversibility into the definition of a fact, making the subsequent theorems trivially true by definitional fiat. We address this directly by showing that no weaker definition supports Definitions 6 or 7, establishing that Definition 4 is minimal and necessary rather than question-begging.

Test 1: Reversible facts. Suppose we weaken Definition 4 by dropping clause (ii), permitting reversible commitments. Then a "fact" $F = (\omega^*, R, \tau)$ could be undone: some operation O at $t > \tau$ restores the pre-τ state and erases R. But then R is not stably accessible for all $t > \tau$, violating clause (iii). Moreover, the temporal ordering $<$ between τ and the erasure event becomes symmetric — the system has genuinely returned to its prior state — undermining the asymmetric structure required by Definition 6(a). Reversible facts cannot support a temporal arrow.

Test 2: Non-persistent facts. Suppose we drop clause (iii), permitting facts whose records fade. A non-persistent record cannot serve as a stable temporal marker, cannot be reproducibly compared across applications of a law (violating Definition 7(ii)), and cannot anchor the duration measure μ (since the events it marks are not stably accessible). Non-persistent facts cannot support measurable duration or law reproducibility.

Test 3: Non-distinguishable facts. Suppose we drop clause (i) and the minimum scale δ_{min}, permitting arbitrarily close states to count as distinct facts. Then any physical record R would need to distinguish ω^* from states at arbitrarily fine resolution. No finite physical system can encode infinite-precision information; R would be unstable against arbitrarily small perturbations, violating clause (iii). As we prove formally in Proposition 1, a universe with $\delta_{min} = 0$ admits no stable facts.

In each case, the weakened definition fails to support Definition 6 or Definition 7. We therefore conclude that Definition 4 is *a* minimal definition — one that shares the structural features any adequate fact-definition must possess. We do not claim it is the uniquely minimal definition: an alternative formalisation that encodes irreversibility differently (e.g., via entropy production rather than record stability) might serve equally well. What the three tests establish is that *whatever form a workable fact-definition takes, it must incorporate* (a) some minimum distinguishability scale, (b) some form of non-local or non-erasable commitment, and (c) some persistence condition. Any definition lacking these features cannot ground both Definition 6 and Definition 7. The particular form of Definition 4 is chosen for its formal tractability; the structural features it encodes are necessary regardless of formalism.

2.2 On Realisation and World-Directedness

Before proceeding to the temporal and nomological lines, we establish a more primitive result that undergirds everything that follows: any framework that counts as a theory of a physical world must distinguish between physically realised states and merely possible states. This distinction is not an operational convenience, not an epistemic demand, and not a feature of any particular formalism — it is the minimal ontological condition under which a formal structure can count as a theory of an actual world rather than a space of abstract alternatives. Definitions 4 and 7 then formalise, at the levels of fact and law respectively, the structure that this distinction requires.

Proposition 0 *(Necessity of the Realised/Possible Distinction).* Any framework that qualifies as a theory of a physical world must distinguish between physically realised states and merely possible states.

Proof. Let a framework $\mathcal{T}$ be proposed as a theory of a physical world. Then $\mathcal{T}$ must do more than specify a set Ω of admissible configurations; it must purport to describe which configuration, history, or class of histories actually obtains.

Suppose, for contradiction, that $\mathcal{T}$ makes no distinction between realised and merely possible states. Then every element of Ω stands on equal ontological footing: none is selected, privileged, or identified as the state of the world. In that case, $\mathcal{T}$ does not describe a world, but only a possibility space. It cannot determine what is the case, and therefore cannot distinguish a world from an abstract space of admissible configurations. A framework that specifies only possibilities without any principle of realisation lacks world-directed content: it cannot assign truth conditions to claims about the world, since no state of affairs is identified as obtaining rather than merely being admissible. Such a framework may be mathematically meaningful, but it is not a physical theory of an actual universe. This contradicts the assumption that $\mathcal{T}$ qualifies as a theory of a physical world.

Therefore any framework that qualifies as a theory of a physical world must distinguish realised from merely possible states. □

Corollary 0.1 *(Realisation Requires Facts).* If a framework distinguishes realised from merely possible states, then it must contain structures functionally equivalent to physical facts.

Proof. A realised state must be sufficiently definite to be distinguished from alternative possible states. It must therefore possess at least: (i) *distinguishability*, so that it differs from alternatives by at least a minimum scale; (ii) *commitment*, so that one alternative is selected rather than all remaining equally open; and (iii) *persistence*, so that the realised state can function as a stable part of a world rather than as an uninstantiated abstraction. These are precisely the structural features encoded by Definition 4. Hence any physically instantiated realised/possible distinction requires fact-like structures. □

Proposition 0 and Corollary 0.1 together establish that physical facts are not introduced by convention or by the operational requirements of Definition 7. They arise as the necessary form taken by realisation in any theory of an actual universe. The remainder of the paper demonstrates, through the temporal and nomological lines, that the specific structures of physical time and physical law further require these fact-like structures to satisfy the full conditions of Definition 4.

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3 The Temporal Line: Physical Time Requires Facts

We develop the first strand of the argument. The goal is to show that both structural features of physical time — the arrow (asymmetric ordering of events) and duration (measurable interval between events) — require the existence of physical facts. It will follow that a fact-free universe is also a timeless universe in every operational sense of that word.

Theorem 1 *(Temporal Arrow Requires Facts).* If U has a temporal arrow, then U is fact-producing.

Proof. Suppose U has a temporal arrow. By Definition 6(a), there exist temporal indices $t_1, t_2 \in T$ such that $t_1 < t_2$ and $\neg(t_2 < t_1)$. This asymmetry in the temporal ordering requires that at least one physical process in U is structurally irreversible. We establish this by contradiction.

Suppose every physical process in U is reversible: for every physical transition $T : s_1 \rightarrow s_2$ occurring between t_1 and t_2, there exists an admissible physical process $T^{-1} : s_2 \rightarrow s_1$ that is also realisable in U. Under this assumption, the physical history of U is symmetric under time-reversal. This symmetry implies that for any pair of temporal indices t_1, t_2 with $t_1 < t_2$, the reverse relation $t_2 < t_1$ is equally physically grounded, making $<$ symmetric and contradicting the assumption that U has a temporal arrow. Therefore U must contain at least one structurally irreversible physical process P.

Addressing the statistical objection. One might propose, following Boltzmann, that a macroscopic temporal arrow could emerge statistically from microscopically reversible dynamics under special initial conditions, without requiring structural irreversibility at any individual event. A sharper version of this objection holds that macrostates — the operationally relevant records of past configurations — are merely convenient coarse-grained descriptions of reversible microstates, not genuine irreversible commitments in the sense of Definition 3. We address both versions.

Lemma (Macrostate Detectability Requires Definition-3 Records). Any operationally detectable macrostate distinction requires at least one environmental encoding satisfying Definition 3(ii) — that is, an encoding not erasable by local operations on the primary system.

Proof of Lemma. An operationally detectable macrostate M is one that a physical procedure Π can distinguish from other macrostates M'. For Π to accomplish this, it must become correlated with M in a way that is (a) stable against perturbations of the primary system and (b) accessible without reversing all environmental interactions. We now show that any mechanism achieving this must produce a Definition-3 record — the decoherence argument is not an additional empirical premise but a demonstration that any mechanism capable of producing stable, non-erasable records must instantiate the structural features captured by Definition 3, regardless of its underlying dynamics.

Suppose, for contradiction, that a macrostate M were operationally detectable without any environmental encoding satisfying Definition 3(ii) — that is, suppose its detection record R could be erased by local operations on the primary system. Then R would be a local correlation between the primary system and the detector alone, with no spread into environmental degrees of freedom. But a purely local two-body correlation is not stable against environmental perturbation, and this is not a probabilistic claim but a physical necessity. No physically realisable macroscopic system can be isolated from all environmental degrees of freedom: vacuum fluctuations, gravitational coupling, and thermal radiation provide irreducible channels of environmental interaction that are frame-invariant and cannot be screened by any physical shielding. A macrostate record R that is stable only under conditions of perfect environmental isolation — conditions no physical system can achieve — is not stably accessible in the operational sense of Definition 3(ii). Therefore any interaction between the primary system and its unavoidable environmental degrees of freedom would disturb a purely local R, and recovery would require precisely reversing that interaction. Such a purely local R is therefore not stable against perturbations in the sense required by (a). Therefore R cannot be purely local — it must extend into environmental degrees of freedom in a way that is not erasable by local operations on the primary system.

The decoherence programme [Zurek 2003] and quantum Darwinism [Zurek 2009] provide the dynamical account of how this spreading occurs: macrostates become classically distinguishable by developing redundant entanglement across many independent environmental sub-systems. This redundant encoding is excluded from erasure by any local operation not merely practically but as a matter of principled physical limitation — coherently reversing macroscopic environmental entanglement requires control over degrees of freedom that are, by the structure of system–environment interaction, causally decoupled from the primary system after decoherence. The decoherence framework is therefore not an independent empirical assumption layered onto the argument; it is the mechanistic demonstration that the only available route to stable macrostate detectability is one that produces Definition-3 records. Therefore any operationally detectable macrostate M is backed by a record R in Ω_{env} satisfying Definition 3(ii). □

Returning to the statistical objection: a Boltzmannian arrow grounds temporal asymmetry in the statistical tendency of macrostates to encode past configurations in a particular direction. But the Lemma shows that any *operationally detectable* macrostate encoding — any record that can in principle be read, compared, or used to anchor a temporal index — must satisfy Definition 3. And any such record, combined with the committed state ω^* it encodes and the commitment index τ at which it became environmentally entangled, constitutes a physical fact in the sense of Definition 4. The statistical machinery explains the *distribution* of facts across time and the tendency of their records to point in a particular temporal direction; it does not explain away the existence of the records themselves. The arrow and the fact are co-constitutive: any operationally detectable temporal asymmetry presupposes at least one fact.

Returning to the proof: at commitment index τ, the state of a physical system transitions from a space of pre-committed alternatives to a definite realised state ω^*, and this transition is not undoable by any subsequent local operation. The information distinguishing ω^* from the alternatives is transferred into environmental degrees of freedom beyond local control. By Definition 4, the triple (ω^*, R, τ) constitutes a physical fact, where R is the environmental record established by the irreversible commitment. Therefore U contains at least one physical fact, making it fact-producing in the sense of Definition 5. □

Theorem 2 *(Temporal Duration Requires Facts).* If U has measurable duration, then U is fact-producing.

Proof. Suppose U has measurable duration. By Definition 6(b), there exist $t_1, t_2 \in T$ with $t_1 \neq t_2$ and $\mu(t_1, t_2) > 0$. For $\mu(t_1, t_2) > 0$ to be physically meaningful — for there to be a non-zero duration between t_1 and t_2 that is in principle observable or operationally definable — the indices t_1 and t_2 must correspond to physically distinguishable events e_1 and e_2 satisfying $d(e_1, e_2) \geq \delta_{min} > 0$. This is a necessary condition: if e_1 and e_2 were not physically distinguishable, no physical clock, counting procedure, or dynamical equation could assign a non-zero duration to the interval between them, since all operational definitions of duration reduce ultimately to counting or comparing distinguishable physical configurations.

For e_1 and e_2 to be physically distinguishable events, each must be realised as a definite physical configuration with a stable environmental record. An event that has not committed to a definite state — that remains entirely in a superposition of alternatives without any irreversible record — cannot serve as a determinate temporal marker. It corresponds to a smeared-out distribution of possible times rather than a definite moment, making it impossible to assign a determinate duration from it. Therefore both e_1 and e_2 must be physically realised as definite states with stable records. By Definition 4, each constitutes a physical fact. Therefore U contains at least two physical facts, making it fact-producing. □

Corollary 1 *(Fact-Free Universes Lack Physical Time).* A universe U in which no physical fact obtains possesses neither a temporal arrow nor a measurable duration between any two events.

Proof. Immediate from the contrapositives of Theorems 1 and 2. □

Corollary 1 has a sharp interpretive upshot. An empty universe — one with no physical facts — has no arrow and no duration. It is not that such a universe has time but nothing happens within it; rather, it has no time in any operationally or structurally meaningful sense. This aligns with the relational view of time [Leibniz 1715/1716; Mach 1883; Barbour 1994], but the present argument does not depend on relationalism as a philosophical commitment — it follows from the formal structure of Definitions 4–6 alone.

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4 The Nomological Line: Physical Laws Require Facts

We now develop the second strand of the argument, independent of the temporal line. The goal is to show that physical laws, in any formulation satisfying Definition 7, cannot exist in a fact-free universe. We pursue this along two sub-arguments: the testability argument and the mathematical presupposition argument. These are logically independent; either alone is sufficient to establish the main conclusion of this section.

Theorem 3 *(Physical Laws Require Facts: Testability).* If U contains a physical law L satisfying Definition 7(i), then U is fact-producing.

Proof. By Definition 7(i), L is testable: there exists a physical procedure Π that returns a definite result confirming or disconfirming whether the actual system output matches L's prediction ω^*. We consider what Π requires.

First, Π must produce a definite result. A procedure that returns only a further superposition of "confirmed" and "disconfirmed" without committing to one of them is not a test in any operationally meaningful sense: it provides no information about whether L is satisfied. Therefore the outcome of Π must be a definite, committed result — a physical fact in the sense of Definition 4.

Second, even granting that Π produces a definite result, the comparison between that result and the prediction ω^* requires that ω^* itself corresponds to a physical configuration that is sufficiently definite to be compared. A prediction that is entirely non-committal — compatible with all possible outcomes — is vacuously satisfied and constitutes no law at all. Therefore L's predictions must be over definite states.

Third, reproducibility (Definition 7(ii)) requires that repeated preparations of the same initial state yield results that can be compared. Comparison requires that each individual result is definite. An ensemble of results that are individually indeterminate cannot be reproducibly compared. In all cases, testability and reproducibility require at least one physical fact in U, making U fact-producing. □

Theorem 4 *(Physical Laws Require Facts: Mathematical Presupposition).* Every formalism qualifying as a physical law under Definition 7 presupposes that physical states are sufficiently definite to serve as determinate elements of the relevant mathematical structures.

Proof. We consider the three main dynamical formalisms in turn.

(a) Hamiltonian/operator formalism. The Schrödinger equation $d\psi/dt = -i\hbar^{-1}H\psi$ is well-defined physically only when $\psi(t)$ is a determinate element of the state space at each t. Physical predictions require that at least the initial state s_0 is definite: the initial value problem has physical meaning only when s_0 has been physically prepared, i.e., when s_0 is the output of at least one physical fact.

(b) Symmetry groups. Physical symmetry groups G act on the state space Ω by maps $\varphi : \Omega \to \Omega$ that preserve physical structure. For such an action to have physical content — for the symmetry to be a symmetry of the physics rather than merely of the mathematics — G must map physically realisable states to physically realisable states. If no states in Ω are ever realised as physical facts, then G acts only on a formal mathematical space with no physical interpretation. The symmetry is physically vacuous. Therefore the physical content of symmetry laws requires a non-empty set of physical facts.

(c) Variational principles and path integrals. These formalisms define physical evolution by extremising an action functional over spaces of paths or field configurations. For the physical trajectory to be selected — for the path integral to localise around the classical solution — boundary conditions must be specified at definite initial and final times. Those boundary conditions are physical facts: definite, stably recorded states of the system at the relevant temporal boundaries. Without boundary-condition facts, the variational principle selects no physical path; the formalism is mathematically well-defined but physically contentless. While path-integral and ensemble formalisms are defined over spaces of possibilities, their physical interpretation requires the specification of realised configurations — either through boundary conditions, measurement outcomes, or statistical sampling. The formalism alone does not eliminate the need for definiteness; it relocates it to the interface between formal description and physical instantiation.

The Everettian objection. A referee might object that Everettian quantum mechanics avoids singular facts entirely: Born-rule probabilities are confirmed via relative frequencies across branches, and no meta-level observer is required beyond ordinary quantum systems entangling with apparatus. Branch-relative definiteness, on this view, is all the definiteness physics needs.

The correct response to this objection is that it does not threaten the Joint Necessity Theorem — it confirms it. We take the scope argument as primary; the reproducibility argument follows as supplementary.

Primary — the scope argument. Even granting the most permissive reading of the Everettian framework, the picture requires that individual branch outcomes be definite relative to branch observers. Those branch-relative outcomes are physically real states of the observer-apparatus systems: they are correlated with measurement results, distinguish those results from alternatives, and are stably encoded in the observer's physical state in a way not erasable by local operations on the measured system. They therefore satisfy Definition 4 relative to each branch's state space. Either these branch-local states are physically real, in which case they are physical facts and the Everettian universe is fact-producing — massively so, with a separate branch-local fact at every branching event — or they are not physically real, in which case the theory makes no physical predictions in any branch, violating Definition 7(i). There is no middle ground. Everett does not eliminate facts; it multiplies them. The Everettian objection, correctly parsed, is not a counterexample to the Joint Necessity Theorem but a further instance of it.

Supplementary — the reproducibility argument. The scope argument establishes that Everett is fact-producing. A separate question is whether branch-relative definiteness can serve as the sole confirmation standard for a physical law. It cannot. Definition 7(ii) requires reproducibility: results must be jointly evaluable across applications of L. Two observers in distinct branches each obtain definite branch-relative outcomes, but those outcomes cannot be jointly compared across branches — no procedure Π can access both simultaneously. Cross-branch outcomes are not jointly evaluable. Any reproducibility claim within the Everettian framework must therefore locate its comparison procedure within a single branch — and that comparison's output is a branch-local fact satisfying Definition 4. The reproducibility argument reinforces what the scope argument already establishes: branch-local facts are the unit of physical confirmation, and their existence is what the Joint Necessity Theorem asserts.

In all three formalisms, the mathematical apparatus of physical law requires physical facts as the definite states on which it operates and against which it is tested. Therefore any universe in which physical laws have determinate mathematical and physical content is fact-producing. □

Corollary 2 *(Fact-Free Universes Admit No Physical Law).* A universe U in which no physical fact obtains cannot contain any testable, reproducible, or mathematically determinate physical law.

Proof. Immediate from the contrapositives of Theorems 3 and 4. □

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5 The Joint Necessity Theorem

The two lines of argument converge in the following central result.

Theorem 5 *(Joint Necessity Theorem).* Any universe U that (a) possesses physical time and (b) is governed by at least one physical law in the sense of Definition 7 is necessarily fact-producing.

Proof. Condition (a): U possesses physical time. By Definition 6, physical time in U is non-trivial if U has a temporal arrow or measurable duration, or both. By Theorem 1, a temporal arrow implies U is fact-producing. By Theorem 2, measurable duration implies U is fact-producing. Therefore condition (a) alone is sufficient to establish the conclusion.

Condition (b): U is governed by a physical law L. By Theorem 3, the testability of L implies U is fact-producing. By Theorem 4, the mathematical definiteness required by L implies U is fact-producing. Therefore condition (b) alone is independently sufficient to establish the conclusion.

Since either condition is independently sufficient, and both are jointly satisfied by assumption, U is fact-producing. The necessity is double: facts are required both by the existence of time and by the existence of physical law. These two requirements are, moreover, logically independent in the sense that neither is derived from the other within the argument; they converge on the same conclusion from different structural directions. □

We pause to characterise the sense of necessity at work in Theorem 5. The necessity is *structural*: it follows from the formal definitions of physical time (Definition 6) and physical law (Definition 7) together with the definition of a physical fact (Definition 4). It is not empirical necessity (dependent on the specific laws of our universe), not metaphysical necessity in the modal sense (dependent on possible-world semantics), and not merely nomological necessity (dependent on the contingent laws of physics). It is the necessity that attaches to the formal conditions of possibility of physics itself.

5.1 The Uniqueness Corollary: Facts as the Only Foundation

The Joint Necessity Theorem establishes that facts are *necessary* for physics. We now show that they are, in a precise sense, *the only* possible foundation for physics. This turns the necessity result into a uniqueness result.

Operational scope of "physics". Throughout this section, *physics* denotes a framework capable of generating testable, reproducible, and operationally meaningful predictions in the senses of Definition 7. Structures that are mathematically well-defined but lack these properties — smooth dynamical systems with no observable outputs, formal Hilbert spaces with no measurement interface, globally symmetric theories with no testable asymmetry — may be of mathematical or philosophical interest, but they do not constitute physics in the empirical sense this paper is concerned with. This clarification pre-empts a class of semantic objections: we are not claiming that fact-free formal structures are incoherent or impossible as mathematical objects, but that they fail to qualify as physical theories under the operational criterion of Definition 7. The Uniqueness Corollary is therefore a claim about physics, not about mathematics.

Corollary 3 *(Uniqueness of Fact-Based Foundations).* Any ontological alternative to physical facts — any framework that eliminates commitment events, irreversible records, or minimum distinguishability — either (i) covertly reintroduces facts at some boundary or interface, or (ii) reduces to a purely mathematical structure with no physical content.

Proof. Let U' be a universe proposed as a physical universe that eliminates physical facts. We consider the three main categories of proposed alternatives:

Case A: Continuous-only ontologies. Suppose U' contains only continuously evolving fields or wavefunctions with no commitment events (no τ-indexed transitions to definite states). By Corollary 1, U' has neither a temporal arrow nor measurable duration. By Corollary 2, U' admits no testable or reproducible law. The formalism of U' is mathematically well-defined — a smooth manifold with dynamics — but it makes no physical predictions, has no operational content, and cannot be distinguished from any other smooth dynamical system by any physical procedure. U' has mathematics but no physics. This is outcome (ii).

Case B: Globally reversible ontologies. Suppose U' contains physical processes but all are globally reversible: for every physical trajectory, the time-reversed trajectory is also physically admissible, and the system eventually returns arbitrarily close to its initial state. We consider two sub-cases.

Sub-case B1: No locally stable records exist. If no record-like structure in U' is stable against eventual global reversal, then by Definition 4(iii) no physical facts exist — persistence for all $t > \tau$ fails because the global dynamics eventually erases every local correlation. By Corollary 1, U' has no temporal arrow (since the ordering $<$ is symmetric under global reversibility). U' has no physics in the sense of Definition 7. This is outcome (ii).

Sub-case B2: Locally stable records exist over finite intervals. Suppose U' contains record-like structures that are stable over some finite window $[\tau, \tau + \Delta]$ before eventually being erased by the global dynamics. Such records are *not* physical facts in the sense of Definition 4. Clause (ii) of Definition 4 requires that R is irreversibly established — meaning no operation at *any* subsequent time can erase R. Finite-window stability does not satisfy this: the global reversal at time $\tau + \Delta + \varepsilon$ is precisely the operation that erases R. These locally stable, eventually erased records are better termed *approximate facts* or *transient records*; they do not satisfy Definition 4(ii). A universe populated only by transient records admits no physical law: reproducibility (Definition 7(ii)) requires that repeated applications of L yield results that can be jointly compared, but transient records cannot be stably accumulated or compared across trials if they are eventually erased. Therefore U' has no facts in the sense of Definition 4 and no physics in the sense of Definition 7. This is also outcome (ii).

In both sub-cases, a globally reversible universe collapses to outcome (ii): it may have transient record-like structures, but these do not constitute physical facts and cannot support physical laws. The apparent possibility of "approximate facts" in globally reversible systems is not a third option — it is a failure mode that reveals the necessity of strict persistence.

Remark on the idealization in Definition 4(iii). A careful reader will note that records in our own universe are not literally eternal: they will eventually be erased by heat death, Poincaré recurrence, or black hole evaporation. If "persistence for all $t > \tau$" is taken as a literal requirement with no qualification, then no record in a finite or recurrent universe satisfies Definition 4(iii), and the framework would imply — incorrectly — that our universe contains no physical facts.

We clarify that Definition 4(iii) is a structural idealization, not a literal chronological demand. A record R satisfies the persistence clause when it is stably accessible for all $t > \tau$ within the *operational stability horizon* relevant to the physical law or temporal structure it is invoked to ground — that is, for all times at which any physically realizable procedure could in principle access R to test a law or anchor a temporal index. This operationalisation has two consequences. First, it correctly classifies records in our universe as physical facts: a detector click that is stable for cosmological timescales far exceeding any experimental timescale satisfies persistence in the relevant sense, even if a Poincaré recurrence at t = 10^(10^120) years could in principle erase it. Second, Sub-case B2 applies precisely when the reversal timescale Δ is comparable to or shorter than the operational timescale of law-testing — the regime where transient records genuinely fail to support reproducibility. The distinction between our universe and a globally reversible one is therefore not that our universe has literally eternal records, but that its records are stable on timescales that are astronomically longer than any operational timescale, whereas globally reversible systems have reversal timescales comparable to or shorter than the very processes they would need to ground.

Case C: Permanently superposed ontologies. Suppose U' contains only quantum superpositions with no wavefunction reduction and no decoherence-driven commitment to definite outcomes. Any measurement-like interaction in U' produces only further entanglement without any definite output. As established in the proof of Theorem 4(c) (the Everettian objection), such a universe either (i) produces definite outcomes at some meta-level observer interface — covertly introducing facts — or (ii) produces no testable predictions, reducing to outcome (ii).

In all three cases, the elimination of facts either conceals facts at an interface or eliminates physical content entirely. No third option is known that satisfies Definitions 1–7 without either reintroducing facts or losing physical content. Therefore facts are not merely necessary for physics; they are the unique structural foundation from which physics can be built. □

Corollary 3 has the following interpretive significance: the question is not whether physics can dispense with facts, but how and where facts enter any viable physical framework. Theories that appear fact-free — pure state-space evolution, many-worlds, timeless quantum gravity — must, upon analysis, either locate their factual commitments at a boundary (initial conditions, observer registration, decoherence events) or else accept that they are providing mathematics rather than physics. The choice is not between fact-based and fact-free physics; it is between physics that is explicit about its facts and physics that conceals them.

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6 Structural Corollaries and the VERSF Connection

From the Joint Necessity Theorem, three structural corollaries follow that characterise what any fact-producing universe must be like.

Proposition 1 *(Finite Distinguishability is Necessary).* In any fact-producing universe, the distinguishability structure must have a positive minimum scale $\delta_{min} > 0$.

Proof. Suppose for contradiction that $\delta_{min} = 0$. Consider any physical fact $F = (\omega^*, R, \tau)$. The record R must encode ω^* in a way that distinguishes ω^* from all alternatives (Definition 3(i)). But if $\delta_{min} = 0$, then for any $\varepsilon > 0$ there exists a state ω' with $d(\omega', \omega^*) < \varepsilon$. The record R would then need to distinguish ω^* from states arbitrarily close to it in Ω. Any physical perturbation of the environment of size ε could transform R into a record consistent with ω' rather than ω^*. For R to be stable against all such perturbations — no matter how small — it would need to encode information at arbitrarily fine resolution, requiring infinite precision in its physical realisation. But any physical record is a finite physical system; it cannot encode information at infinite precision. Therefore no stable record can exist when $\delta_{min} = 0$, contradicting Definition 4(iii). Therefore any fact-producing universe must have $\delta_{min} > 0$. □

Proposition 2 *(Irreversible Commitment is Necessary).* In any fact-producing universe, every physical fact $F = (\omega^*, R, \tau)$ is accompanied by irreversible transfer of distinguishing information to environmental degrees of freedom beyond local control of the system.

Proof. This follows directly from Definition 4(ii). Suppose the commitment at τ were reversible: there exists a physical operation O acting on the system–environment composite at some $t > \tau$ such that O restores the system to its pre-τ state and erases R from the environment. Then R is not stably accessible for all $t > \tau$ — it can be erased by O — contradicting Definition 4(iii). Therefore no reversible commitment can constitute a physical fact.

The physical mechanism by which irreversibility is enforced is well-understood: Landauer's principle establishes that logically irreversible operations are accompanied by dissipation of at least k_B T ln 2 of energy into the thermal environment [Landauer 1961; Bennett 1982]. More generally, information-theoretic irreversibility corresponds to the spreading of distinguishing information into environmental degrees of freedom that are too numerous and too entangled with the wider environment to be recovered by any local operation — the process of einselection described by Zurek [2003]. The irreversibility required for fact formation is consistent with, and may be formalised through, entropy-increasing processes as described in statistical mechanics; a detailed connection between fact-formation events and entropy flow in the sense of Jaynes [1957] and Shannon [1948] is left for future work. □

Proposition 3 *(Finite Localisation Capacity is Necessary).* In any fact-producing universe, for any bounded physical region B and any fixed boundary width $\xi > 0$, there exists a finite upper bound $N(B, \xi) < \infty$ on the number of distinct physical facts whose primary states ω^*_i are localised within B.

Proof. From Proposition 2, each fact $F = (\omega^*, R, \tau)$ requires an environmental record R residing in Ω_{env} distinct from the primary system. Since R by Definition 3(ii) must be non-erasable by local operations on the primary system, R may extend beyond B — indeed, effective decoherence requires R to be encoded in environmental degrees of freedom outside the region supporting ω^*. We therefore introduce an explicit *localisation premise*: we say fact F is localised within B if $\omega^* \in B$ and R is localised within the boundary shell $B' = B \cup \partial B(\xi)$, where $\partial B(\xi)$ denotes the boundary region of width ξ surrounding B. This localisation premise is not a specific geometric assumption but a minimal physical requirement: if the record of a fact were delocalised across arbitrarily distant degrees of freedom, it would fail Definition 3(ii), as its stability would then depend on inaccessible global correlations rather than physically accessible environmental encoding. A record that can only be stabilised by correlations spread across the entire universe is not stable against local operations in any physically meaningful sense. This connection to Definition 3(ii) is reinforced by the physics of decoherence: the environmental degrees of freedom that cause decoherence — and therefore that encode the distinguishing information of a fact — are generically local to the system, being the immediately adjacent degrees of freedom (neighbouring atoms, nearby photons, local phonon modes) that interact with the system at the moment of commitment. Decoherence-induced records are therefore naturally localised within a finite neighbourhood of the fact's primary state, not spread arbitrarily across the universe. The boundary shell $\partial B(\xi)$ represents the minimal environmental neighbourhood within which a physically accessible, Definition-3-compliant record can reside.

Under this localisation premise, the number of distinct facts localised within B is bounded as follows. From Proposition 1, each ω_i *is separated from all other* ω_j by at least $\delta_{min} > 0$. The primary states ω^*_i within B are therefore bounded by the packing number $N(B, \delta_{min}) < \infty$ (since B is bounded and $\delta_{min} > 0$). Each record R_i within the boundary shell $B' \cup \partial B(\xi)$ must encode at least one distinguishable bit per fact; the boundary shell is a bounded region with packing number $N(\partial B(\xi), \delta_{min}) < \infty$. The combined constraint — finite packing of primary states within B, finite bit-capacity of boundary shell — yields a finite total bound $N(B, \xi) < \infty$ on simultaneously localisable distinct facts.

Connection to holographic bounds. This result has a precise structural parallel with the Bekenstein–Hawking bound [Bekenstein 1973; Hawking 1975], which states that the entropy — equivalently, the maximum information — of a spatial region scales with the *area* of its boundary, not its volume. The structure of our proof reflects this: the limiting resource is not the volume of B but the boundary capacity of $\partial B(\xi)$. We do not here derive the specific area-scaling of the Bekenstein–Hawking bound, which requires additional assumptions about the geometry of spacetime; but the qualitative result — that the information capacity of a bounded region is finite and governed by boundary constraints — follows from the structure of Definition 4 alone. □

6.1 Connection to VERSF

Propositions 1–3 establish the three foundational constraints of the Void Energy-Regulated Space Framework as necessary consequences of fact-producing universes rather than as independent assumptions.

Proposition 1 corresponds to the VERSF axiom of finite distinguishability — the requirement that the void-to-universe interface can only generate distinctions at or above a minimum scale set by the Planck regime. Proposition 2 corresponds to the VERSF axiom of irreversible commitment — the requirement that each fold event at the void boundary transfers information irreversibly into the physical record. Proposition 3 corresponds to the VERSF axiom of bounded localisation capacity — the requirement that any bounded spatial region can carry only a finite informational load, which in VERSF is connected to the Bekenstein–Hawking bound on entropy [Bekenstein 1973; Hawking 1975].

The significance of this derivation is structural. VERSF has previously postulated these three axioms as the foundational conditions under which physics is possible. The present paper shows that they are not postulates — they are theorems. Any universe that has time and is governed by laws must exhibit them. VERSF thereby represents one rigorous theoretical expression of what any physically meaningful universe must structurally be, with its foundational axioms now demonstrated to be necessary consequences of the prior requirement that physical facts exist.

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7 Discussion and Relation to Existing Work

Relation to relational approaches to time. The temporal line of the argument shares structural features with the relational tradition in the philosophy of time [Leibniz 1715/1716; Mach 1883] and with Barbour's timeless quantum gravity [Barbour 1994]. Barbour argues that time is not fundamental but emerges from the structure of "nows" — configurations of the universe at a moment. Our argument is compatible with this but more general: we do not require the entire configuration of the universe as the relevant relatum, only the existence of at least one physical fact. Conversely, our argument is stronger in that it derives the necessity of fact-existence from the structural requirements of time and law, rather than positing an ontology of configurations.

Relation to Wheeler and information-theoretic physics. Wheeler's "it from bit" programme [Wheeler 1990] proposed that every physical entity derives its existence from binary alternatives posed by observers. The technical foundation for treating physical entropy in information-theoretic terms was established by Shannon [1948] and Jaynes [1957], whose work showed that the entropy of a physical system can be identified with the information required to specify its microstate — a connection that underpins the information-theoretic reading of fact-formation developed in §§3–4. The present argument may be seen as a formal development of one strand of Wheeler's vision: the claim that the physical world is constituted by definite answers to physical questions — i.e., by facts. However, we do not require observers in any anthropocentric sense; the irreversible environmental record in Definition 4 plays the role of the observer without requiring consciousness or intentionality. The Uniqueness Corollary (§5.1) gives this programme additional force: it is not merely that facts are a natural starting point for physics, but that no alternative starting point avoids facts entirely. Structural realists who identify mathematical and physical structure may resist the distinction between physics and mathematics on which the Uniqueness Corollary depends; we note that the argument is explicitly operationalist in its commitments, and that the choice between operationalism and structural realism is orthogonal to the internal validity of the theorems proved in §§3–5.

Relation to decoherence and einselection. Zurek's programme of einselection [Zurek 2003] provides a dynamical account of how definite outcomes emerge from quantum superpositions through interaction with an environment. The present paper operates at a different level: we are not asking how facts dynamically emerge within an existing physical framework but why any physical framework must contain facts at all. Decoherence theory presupposes a pre-given physical time and a pre-given Hamiltonian governing the system-environment interaction; the present argument shows that these presuppositions themselves require facts to be meaningful.

Relation to the problem of the arrow of time. A substantial literature addresses the asymmetry between thermodynamic and cosmological arrows of time [Penrose 1979; Price 1996; Carroll 2010]. The standard approach treats the arrow as a dynamical consequence of special initial conditions (low entropy at the Big Bang) or of cosmological expansion. Theorem 1 of the present paper cuts in a different direction: the arrow of time is not merely a consequence of special conditions but is structurally equivalent to the existence of physical facts, even after the statistical objection (§3) is considered. A universe without facts has no arrow; the arrow and facts are two descriptions of the same structural phenomenon. This suggests that cosmological explanations of the arrow must ultimately account for why facts exist in the first place, rather than assuming a pre-given time structure within which the arrow emerges.

Quantum mechanics and superposition. Quantum mechanics operates on superpositions of states that are not definite outcomes, and yet quantum mechanics is a physical law in any reasonable sense. Does this contradict Theorem 4? The response is that the superposition principle operates at the level of the wavefunction — the pre-factual state space Ω — while physical facts correspond to the outputs of measurements: the definite outcomes selected from Ω by the Born rule. The Born rule itself is a law in the sense of Definition 7, and it is tested against definite measurement outcomes (physical facts). The mathematical machinery of quantum mechanics is perfectly consistent with Theorem 4: it operates on a formal Hilbert space and connects to physics precisely at the point where definite outcomes — facts — are produced. The Everettian case is addressed directly in the proof of Theorem 4.

7.5 Clarifications and Scope of the Result

The claims of this paper are structural and operate within a clearly defined operational framework. We address here several potential points of interpretation or objection, clarifying the scope and limits of the results.

(i) On the Definition of Physical Law and the Operational Criterion. A natural concern is that Definition 7 adopts an operational notion of physics — requiring testability, reproducibility, and definite outcomes — and therefore risks excluding non-operational or realist formulations a priori. We address this concern by showing that the operational criterion is not a philosophical preference but a structural necessity for any framework that claims to function as a physical theory.

Consider a putative realist theory that aims to describe reality independently of observation. For such a theory to qualify as physics rather than pure metaphysics, it must satisfy at least one — and in practice all — of the following conditions: (1) it specifies conditions under which its claims are correct or incorrect; (2) it distinguishes physically realised states from merely possible ones; or (3) it allows comparisons between different physical situations or histories. Each of these requirements implicitly demands the existence of determinate states — states sufficiently definite to serve as the truth-makers of the theory's claims.

Without such states, correctness is undefined, as no outcome can be identified as having occurred; realisation is undefined, as all possibilities remain equally uncommitted; and comparison is undefined, as no stable records exist to relate one situation to another. A framework lacking determinate states may be mathematically well-defined, but it cannot support truth conditions, empirical distinction, or physical content. It therefore fails to qualify as a physical theory in any meaningful sense, whether operationalist or realist. In particular, a framework that defines physical law purely as dynamical evolution over a space of possibilities, without any mechanism for selecting or identifying realised states, fails to distinguish between physically realised and merely possible histories. Such a framework cannot assign truth values to its own claims and therefore does not constitute a theory of a physical world, but a description of a space of possible worlds. More generally, a framework that specifies only global structure without any procedure for identifying or distinguishing realised configurations cannot assign physical meaning to its own states: it may describe a space of mathematically possible histories, but without a mechanism for identifying which history is realised, it lacks physical content in any world-directed sense.

Definition 7 should therefore not be read as imposing an operationalist philosophy on physics, but as formalising, at the level of law, the more primitive ontological requirement established in §2.2: that any theory of a physical world must distinguish realised from merely possible states. Definition 7 is not the starting point for that requirement — it is one of its formal consequences. The requirement of definiteness is not epistemic but ontological: it concerns the existence of states that are actual rather than merely possible, and does not depend on observation or knowledge, but on the existence of physical states that can serve as the bearers of truth. The argument does not require that physical states be accessible to observers, but only that they be determinate. A universe in which all states remain equally possible, with no mechanism selecting realised configurations, does not constitute a physical reality but a space of possibilities. The distinction is ontological, not epistemic. The results of this paper therefore do not depend on adopting operationalism over realism. Rather, they show that any framework capable of functioning as physics — including realist frameworks — must implicitly contain structures satisfying Definition 7, and must therefore be fact-producing in the sense of Definition 4. The argument does not assume a specific formalism, but only that a physical theory distinguishes between possible and realised configurations. Any framework — algebraic, categorical, or relational — that does not admit such a distinction fails to define a physical world, as it cannot specify which configurations obtain. The results therefore apply not to a particular representation of physics, but to any framework that claims to describe a realised universe.

(ii) On the Role of Irreversibility. Definition 4 incorporates irreversibility as a condition on physical facts. Section 2.1 addresses the potential circularity concern directly: irreversibility is not assumed arbitrarily, but shown to be required for the stability of records. Without irreversible environmental encoding, no record can remain accessible under perturbations, and therefore cannot function as a temporal marker or as the outcome of a test procedure. The role of irreversibility is constraint-derived: it is the minimal condition under which Definitions 6 and 7 can be satisfied simultaneously. Stability alone is insufficient to ground facthood: a metastable state that can be reversed without loss of environmental encoding does not constitute a physical fact. What distinguishes facts is not longevity but the irreversible dispersal of distinguishing information into degrees of freedom beyond local recovery.

(iii) On the Dependence on Decoherence. The argument in Section 3 makes use of decoherence theory. A potential concern is that this introduces empirical assumptions into an otherwise structural argument. We emphasise that decoherence is not used as an independent premise but as a demonstration of uniqueness. The Lemma establishes that any operationally stable record must extend beyond local system degrees of freedom. Decoherence provides the known physical mechanism by which such records are produced, and the argument demonstrates that any mechanism capable of producing stable, non-erasable records must instantiate the structural features captured by Definition 3, regardless of its underlying dynamics. The conclusions therefore do not depend on decoherence specifically, but on the structural necessity of stable, non-erasable environmental encoding — any mechanism capable of producing such encoding would satisfy Definition 3 equally. Coarse-grained irreversibility is insufficient to ground facthood, as it depends on a choice of description rather than on physical state structure. In a strictly reversible universe, all information remains recoverable in principle: such a universe admits no non-erasable records and therefore no structures satisfying Definition 3(ii). Apparent irreversibility arising from coarse-graining does not alter this, as it reflects description rather than physical state structure. The argument therefore excludes reversible universes at the level of ontology, not observation.

(iv) On Everettian Quantum Mechanics. Everettian formulations are sometimes presented as eliminating definite outcomes. The analysis in Section 4 shows that this is not the case. Branch-relative outcomes are physically real states of observer–apparatus systems that satisfy the conditions of Definition 4 within each branch: they are distinguishable, stably encoded, and not erasable by local operations on the measured system. The Everettian framework therefore does not provide a counterexample to the Joint Necessity Theorem, but an instance in which fact production occurs in a distributed, branch-local manner. The question is not whether facts exist in Everettian quantum mechanics — they do — but how they are indexed.

(v) On Persistence and Idealisation. Definition 4 requires that records remain accessible for all $t > \tau$. Taken literally, this would exclude any universe in which records are eventually erased by long-timescale processes such as heat death or Poincaré recurrence. As clarified in the remark following Case B of Corollary 3, this condition is an operational idealisation: persistence is required over the timescales relevant to law-testing and temporal ordering. Records that remain stable over all physically accessible timescales satisfy this condition, even if they are not literally eternal. The operative distinction is between systems in which records are stable over operational timescales and those in which records are erased on timescales comparable to the processes they are intended to support. Persistence within the operational stability horizon excludes systems in which reversal occurs on timescales comparable to or shorter than the processes being described, ensuring that reversible dynamics cannot masquerade as fact formation.

(vi) On the Scope of the Uniqueness Corollary. The Uniqueness Corollary establishes that fact-free frameworks fail to qualify as physical theories within the operational scope of Definition 7. This is not a claim about all conceivable mathematical structures. It remains logically possible to construct formal systems in which no definite outcomes occur; such systems may be of genuine mathematical interest. While we do not claim to exhaust all conceivable formalisms, any framework that (i) distinguishes realised from possible states, (ii) supports comparison between configurations, and (iii) admits stable records, must instantiate structures equivalent to Definition 4. No known alternative satisfying these conditions avoids fact-like structures. The uniqueness claim is therefore strong but open: it holds for all frameworks presently known to satisfy Definitions 1–7, and we know of no principled route to constructing one that does not.

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8 Conclusion

We have argued, through a formally structured chain of definitions, theorems, and corollaries, that physical facts are structural necessities of any universe that possesses physical time and is governed by physical laws. The argument proceeds along two independent lines — the temporal and the nomological — each of which is sufficient on its own to establish that fact-free universes are impossible as physical universes. Their conjunction in the Joint Necessity Theorem gives the result double grounding.

We have further established, through the Uniqueness Corollary, that facts are not merely necessary but uniquely necessary: every proposed alternative either covertly contains facts at some interface or collapses into physics-free mathematics. This moves the result from necessity to uniqueness: the question for physics is not whether to build on facts, but where and how its facts are located.

Three structural corollaries characterise any fact-producing universe: it must have a minimum distinguishability scale, it must feature irreversible environmental commitment at each fact-formation event, and it must have finite fact-localisation capacity in any bounded region. These three conditions are precisely the foundational axioms of VERSF. The paper therefore establishes that those axioms are not posited but necessitated: they hold in any universe worthy of the name physical.

The broader implication is a reversal of the standard explanatory order. The analysis suggests that physical facts function as structural preconditions of any framework qualifying as physics in the operational sense defined herein. Time is not the backdrop against which facts occur; facts are the structure from which time is made. Laws do not govern a world that facts happen to populate; facts are what laws require in order to be laws at all. This reversal has consequences for how we think about the deepest structure of physical reality: the question is not what laws govern the universe, but what conditions allow laws — and time, and fact — to exist at all. That question, we suggest, is the true foundational question of physics, and the VERSF programme is directed at answering it.

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