The Nonexistence of the Instantaneous Present

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Much of theoretical physics rests on the idealization that a physical system possesses a complete state at each instant of time—a state sufficient to determine all future evolution. We present independent arguments that this idealization is physically unjustified. First, the state at a temporal point is constructed as the limit of states over intervals; the ε-δ definition of a limit explicitly excludes the limit point from its own construction, guaranteeing convergence of the value in the neighborhood of the point while remaining formally silent on what properties the point itself carries. Second, the joint application of quantum mechanics and general relativity guarantees that the limiting process $\delta t \to 0$ physically self-destructs at the Planck scale; quantum-mechanical clock bounds independently constrain the measurability of time intervals from below; and special relativity independently requires infinite energy to compress proper time to zero—three distinct mechanisms by which established physics prevents the temporal point from being physically realized. Third, quantum field theory has known since the 1940s that physics evaluated at a spacetime point is pathological—a fact encoded in ultraviolet divergences, systematized by the renormalization program, and given physical interpretation by Wilson's demonstration that the divergences reflect the finite domain of validity of any effective description, not a deficiency of any particular calculational method. These lines of evidence converge on a single conclusion: the instantaneous present—a temporal point carrying complete dynamical information—does not exist. Any dynamical framework that presupposes it, including the Chapman-Kolmogorov factorization condition central to the theory of stochastic processes, rests on an assumption that established physics contradicts.

INTRODUCTION

The assumption that a physical system possesses a complete state at each instant of time is so deeply embedded in theoretical physics that it is rarely stated as an assumption at all. In classical mechanics, the state is specified by positions and momenta at a time t; in quantum mechanics, by a vector in Hilbert space or equivalently a density matrix; in classical field theory, by field configurations and their conjugate momenta on a Cauchy surface. In every case, the formalism presupposes that the state at a temporal point carries the full kinematic specification of the system—all degrees of freedom, all constraints, all information required to determine the system's future evolution.

We argue that this presupposition is physically unjustified. Independent arguments—from pure mathematics, established gravitational and relativistic physics, and quantum field theory—show that the instantaneous present, understood as a temporal point carrying complete dynamical information, is not delivered by the mathematical constructions that define it and is not accessible to the physical processes that would be required to reach it.

The question is not whether the state at a temporal point can be *defined*. It can. The question is whether the mathematical object so defined inherits the properties that physics demands of it—in particular, whether it carries the complete kinematic information that dynamical frameworks require. We show that nothing in the construction guarantees this, and that established physics provides independent reasons to doubt it.

This conclusion has immediate consequences for any dynamical framework that requires a complete state at a temporal point. The Chapman-Kolmogorov (CK) factorization condition for stochastic processes,

$$\Gamma(t_2 \leftarrow t_1) = \Gamma(t_2 \leftarrow t) \cdot \Gamma(t \leftarrow t_1), \tag{1}$$

for every intermediate time $t_1 < t < t_2$, is one such framework: it requires the state at t to function as a complete relay, encoding everything the future evolution needs. When this factorization fails, the process is *indivisible*: the transition matrix over the whole interval is a primitive dynamical object, not decomposable through intermediate times. Barandes [1–3] has established an exact correspondence between indivisible stochastic processes and quantum mechanics, showing that interference, entanglement, decoherence, and the Born rule all arise from stochastic indivisibility. If the instantaneous present does not carry complete dynamical information, then indivisibility is the expected condition and divisibility the idealization. But this stochastic consequence is downstream of the core claim, which concerns the nature of temporal points themselves.

ARGUMENT FROM LIMITS

The state of a physical system at a temporal point is not directly observable [8]: every physical measurement ever performed has yielded an average over a nonzero interval. The "state at time t" is a mathematical extraction: the limit of interval-averaged states as the interval shrinks to zero. In standard analysis, the infinitesimal interval has no existence; one has either finite intervals or the point, with nothing in between. The question is therefore what the point inherits from the intervals that define it.

The ε-δ definition of this limit is mathematically rigorous [4]. The limit value exists and is well-defined. This is not in dispute.

What is in dispute is whether the limit point inherits the properties that dynamical frameworks demand of it. Consider what the ε-δ definition actually guarantees. For a function f and a point a, the statement $\lim_{x\to a} f(x) = L$ means: for every $\varepsilon > 0$, there exists $\delta > 0$ such that for all x with $0 < |x - a| < \delta$, we have $|f(x) - L| < \varepsilon$. The condition $0 < |x-a|$ is essential: the definition explicitly excludes the point a itself. The limit characterizes the behavior of f in every punctured neighborhood of a while making no assertion about a itself.

This exclusion is not a technicality. It is the reason limits are useful: they allow us to assign a value at a point where the function may not be defined, or where its value may differ from the limiting behavior. The limit of $\sin(x)/x$ as $x \to 0$ is 1, but the function is undefined at $x = 0$. The limit construction delivers the value; it does not deliver the function's other properties at the point, because the point is excluded from the construction.

That the $\delta t \to 0$ limit can fail to deliver physically expected quantities is not a new observation. As Landau and Lifshitz emphasized [7], in quantum mechanics the ratio $\Delta x/\Delta t$ does not converge as $\Delta t \to 0$: successive position measurements become more erratic, not less, and velocity—defined as the limit of this ratio—does not exist. The limiting process fails to deliver even a derived kinematic quantity. The present argument extends this logic to the state itself: if the limit already fails for the derivative, the assumption that it delivers the full kinematic specification at the point requires justification.

The physical consequence is direct. The state at a temporal point is constructed as a limit of interval-averaged states. The ε-δ definition guarantees that these interval-averaged states converge to a well-defined value. But the full kinematic specification of a physical system—the complete set of degrees of freedom, their interrelations, and the constraints that govern their evolution—is a richer structure than a single value. The definition of a limit is silent on whether this richer structure survives at the limit point, because the limit point is excluded from the construction that defines it.

This argument applies within the standard continuum topology of the real line. Alternative topological structures—non-Hausdorff spacetimes in which limits need not be unique [5], or causal set theory in which the continuum is replaced by a discrete partial order [6]—would modify the analysis in ways specific to each framework. The present argument targets the standard idealization.

This does not prove that the limit point lacks the required kinematic information. It establishes that nothing in the mathematical construction guarantees it has that information. The completeness of the state at a temporal point is therefore not a consequence of how such states are constructed. It is an additional assumption—one that, as the following sections show, contradicts established physics.

ARGUMENTS FROM RELATIVITY

General relativity and quantum mechanics are among the most precisely confirmed theories in the history of science. Applied jointly, they yield a concrete prediction about the limits of spatial measurement through two independent lines of argument.

Mead [9] and Garay [10] establish that a fundamental minimal spatial length must exist as a consequence of the joint requirements of quantum mechanics and general relativity: increasing the precision of a spatial measurement demands concentrating energy within a region whose Schwarzschild radius eventually exceeds the region itself. The Planck length $l_P = \sqrt{\hbar G/c^3} \approx 1.6 \times 10^{-33}$ cm is the unique length scale constructible from the three constants governing the relevant physics ($\hbar$, G, c), and both analyses yield bounds consistent with this scale, though neither derives it as a sharp numerical threshold. The existence of this fundamental length in turn limits the precision with which clocks can be synchronized, as Mead shows [9]—an observation originally motivated by the problem of infinities in quantum field theory arising from point-particle idealizations, connecting the gravitational argument directly to the renormalization evidence of Sec. IV.

't Hooft's analysis of trans-Planckian scattering [11] arrives at the same spatial obstruction by a route that is arguably more direct: when two particles collide at sufficiently high center-of-mass energy, general relativity requires that the interaction region undergo gravitational collapse. This conclusion depends only on the particle kinematics and the Einstein equations, without recourse to quantum interference effects, and therefore rests on fewer assumptions than the Mead-Garay derivation.

A third, independent route to a temporal limitation is provided by Salecker and Wigner [12], who show that quantum mechanics imposes fundamental bounds on the precision of any clock used to measure spacetime intervals. Their argument proceeds from the quantum-mechanical properties of the clock itself—its mass, spatial extent, and the uncertainty principle—without invoking gravitational collapse, and establishes that the measurability of time intervals is bounded from below on physical grounds distinct from those of either Mead or 't Hooft.

The temporal consequence follows from these spatial results together with the Salecker-Wigner clock bounds.

Since the Planck time

$$t_P = \frac{l_P}{c} = \sqrt{\frac{\hbar G}{c^5}} \approx 5.4 \times 10^{-44} \text{ s} \quad (2)$$

is the light-crossing time of the Planck length, probing temporal intervals shorter than t_P requires concentrating energy at the same densities that trigger gravitational self-collapse in the Mead and 't Hooft analyses. This temporal extension is not stated by Mead, Garay, or 't Hooft, but is a direct physical inference from their spatial results: the energy scales are identical, related by the factor c. The interaction region collapses into a black hole before the temporal measurement completes. The Salecker-Wigner argument corroborates this conclusion from an independent direction: the quantum-mechanical properties of the clock itself prevent arbitrarily fine temporal resolution, without any appeal to gravitational collapse.

This result follows from the gravitational self-collapse of the localized energy at the required densities. It is not a prediction of any particular quantum gravity program. It does not depend on whether spacetime is discrete, noncommutative, or continuous at the Planck scale. It does not rely on the time-energy uncertainty relation, whose interpretation is complicated by the fact that time is not an observable in standard quantum mechanics. It is a consequence of applying two established theories simultaneously. The specific physics below t_P is unknown. What is known is that the limiting process $\delta t \to 0$ cannot be physically completed. The temporal point is a limit that established physics prevents from being physically realized.

Special relativity provides an independent obstruction to the same limit. For a massive system, the Lorentz factor $\gamma = (1 - v^2/c^2)^{-1/2}$ diverges as $v \to c$. The proper time interval experienced by the system, $\Delta\tau = \Delta t/\gamma$, goes to zero in this limit—but reaching it requires infinite energy. The zero-duration limit is a mathematical boundary that established physics prevents from being physically attained, not through gravitational collapse but through the divergence of the energy required to compress proper time to zero. The argument applies to proper time, which is the physically meaningful temporal quantity; coordinate time is a gauge choice that can be freely redefined without altering any measurable prediction. That three independent sectors of established physics—gravitation, quantum clock bounds, and relativistic kinematics—all prevent the same limit from being reached strengthens the conclusion beyond what any single argument achieves alone.

One might object that a discrete spacetime structure at the Planck scale could support well-defined states at its lattice points. But this objection concedes the core claim: it abandons the continuum temporal point, which is the object under scrutiny. A theory positing discrete dynamics at the Planck scale is no longer working with the instantaneous present as standardly conceived—it has replaced the continuum idealization with a fundamentally different mathematical structure.

The preceding section established that the mathematical construction of the point-state does not guarantee dynamical completeness at the point. This section establishes that the physical processes required to reach the point cannot be carried out: gravitational self-collapse, quantum clock bounds, and relativistic energy divergence each independently prevent the limiting process from being physically completed.

ARGUMENT FROM RENORMALIZATION

Quantum field theory provides corroboration from an independent direction. When interactions in QFT are evaluated at a spacetime point—taking the separation between interacting fields to zero—the result is infinite. These ultraviolet divergences are well understood: they arise whenever the formalism is pushed to the point-valued limit [13].

The renormalization program [14–19], given conceptual foundation by Wilson [17–19], extracts finite physical predictions by introducing a regulator that prevents the theory from reaching the spacetime point. The physical content is obtained at finite resolution and shown to be independent of the specific regulator. But the point-valued limit is never taken. The resulting predictions agree with experiment to extraordinary precision [22]—not because the point-valued limit is well-behaved, but because the physics at finite resolution is sufficient and self-consistent without it.

It is essential to distinguish the Wilsonian understanding of renormalization from the earlier view in which divergences were regarded as computational artifacts of perturbative methods. Wilson's framework demonstrates that the need for renormalization is not an artifact of perturbation theory. Lattice quantum field theory, which is a fully non-perturbative formulation, requires renormalization for the same structural reasons [20]. The running of coupling constants with energy scale—for instance, the running of the strong coupling α_s in quantum chromodynamics—is an experimentally measured phenomenon [21], not a calculational convenience. In Wilson's picture, a theory at energy scale μ is an effective description whose parameters run with the scale, obtained by integrating out degrees of freedom above that scale. The "bare" theory at a spacetime point is not a physically meaningful object that we have failed to calculate correctly, but the boundary where the effective description ceases to be valid. This is why even the lattice formulation—which replaces the continuum with a finite number of degrees of freedom—still requires renormalization: physical quantities depend on how those degrees of freedom are coarse-grained, regardless of whether the underlying structure is continuous or discrete. The renormalization group is the systematic expression of this fact.

Physics at a spacetime point is where the formalism breaks down. Physical content is extracted at finite resolution. Whether a future theory could render the spacetime point well-defined is an open question; but the argument here is evidential, not deductive. Our best established theories—the very theories whose predictions have been confirmed to extraordinary precision—provide no basis for assuming that the point carries complete physical information, and positive grounds for doubting it. This conclusion finds independent support in algebraic quantum field theory, where the Haag-Kastler axioms assign observable algebras to open spacetime regions and the algebra at a point is provably trivial [24]; a rigorous, non-perturbative result that merits separate treatment. The parallel with the preceding arguments is not analogical but structural: in all three cases, the temporal or spacetime point is where the physics fails, and the meaningful content lives at finite resolution.

DISSOLUTION OF THE MEASUREMENT PROBLEM

The measurement problem is standardly formulated as the tension between the deterministic, unitary evolution of the quantum state and the occurrence of definite, stochastic outcomes upon measurement [26]. This tension presupposes that both sides of the measurement event—the unitarily evolving superposition before and the definite outcome after—are complete states at temporal points, where "complete" means carrying sufficient dynamical information to determine future evolution (whether pure or mixed). The demand is that the timeline can be cut at "the moment of collapse" with a fully specified state on either side. This is precisely the demand that the instantaneous present carry complete dynamical information, applied to the measurement event.

Measurement is a physical interaction between system and apparatus. Every stage—photons hitting detectors, electrons cascading through amplifiers, pointers moving on dials—takes nonzero time. There is no instant at which the measurement happens. There is an interval over which system and apparatus become correlated—a picture independently supported by decoherence theory, which models the finite timescale over which system-environment entanglement suppresses interference [25, 26]. At the beginning, they are uncorrelated. At the end, the apparatus registers a definite outcome.

Asking "at which point in between did the transition occur?" is demanding dynamical completeness at intermediate temporal points within the measurement interval. The preceding arguments show this demand is unjustified: the mathematical construction does not guarantee completeness at the point, the physical limit to the point cannot be reached, and the point-valued limit is where known physics becomes pathological.

The measurement problem is thereby dissolved rather than solved. The apparent conflict between unitary evolution and definite outcomes depends on both being complete descriptions at temporal points; if temporal points do not carry complete dynamical information, the conflict has no well-defined terms in which to arise.

The specific outcome of a measurement—why *this* result rather than *that* one—is not addressed by this dissolution, nor does it need to be. Within the framework of indivisible stochastic processes [1–3], the outcome is a stochastic draw from the transition matrix over the measurement interval. It is irreducibly stochastic, no more requiring a deterministic explanation than the decay of a radioactive atom at one moment rather than another. In the standard Hilbert space formulation, the Schrödinger equation is deterministic, making stochastic outcomes appear to require a mechanism—collapse—that violates the governing equation. In the indivisible stochastic formulation, the dynamics are stochastic from the start; the transition matrix yields probabilities and outcomes are draws from those probabilities, with no deterministic equation being violated. The Schrödinger equation, in this light, deterministically governs the evolution of the transition matrix—the probability law itself—not the realization of individual outcomes, which was never deterministic in either formulation. The two formulations are empirically equivalent—they produce identical predictions. But the conceptual puzzle is an artifact of the Hilbert space formulation's mathematical structure, not of the physics.

CONSEQUENCES

If the instantaneous present does not carry complete dynamical information, then any factorization condition that presupposes it—including the Chapman-Kolmogorov condition, Eq. (1)—is an idealization rather than a physical fact. Through Barandes's stochastic-quantum correspondence [1–3], this means indivisibility is the generic dynamical condition and quantum behavior is the default, not the exception.

Classical behavior emerges when the observer's temporal integration window δt_{obs} satisfies $\delta t_{\text{obs}} \gg \tau_{\text{coh}}$, where τ_{coh} is the system's coherence time—the timescale over which indivisibility is manifest. In this regime, violations of the factorization condition are integrated out and the process appears divisible. The quantum-to-classical transition is a consequence of finite temporal resolution, not an ontological boundary.

This yields a falsifiable prediction: any stochastic system observed at sufficiently fine temporal resolution relative to its coherence time should exhibit measurable violations of the CK condition. Recent work [23] reports CK violations in financial time series, consistent with this prediction, though the authors interpret the violations as memory effects rather than indivisibility. Systematic measurements across multiple physical systems—mesoscopic devices, turbulent flows, biological processes—would constitute a direct test.

DISCUSSION

The arguments presented here arrive at the same conclusion from premises that share no common assumptions. The first requires only the ε-δ definition of a mathematical limit. The second requires the established validity of quantum mechanics and general relativity, corroborated by the Salecker-Wigner quantum clock bounds. The third requires only the kinematic structure of special relativity. The fourth requires only the existence of ultraviolet divergences in quantum field theory and their physical interpretation through Wilson's renormalization group. No argument invokes a particular interpretation of quantum mechanics, proposes new axioms, or modifies existing theory.

Their convergence on a single conclusion—that the instantaneous present does not carry complete dynamical information—establishes that any framework presupposing such completeness rests on an idealization. When this idealization is removed, indivisibility emerges as the expected dynamical condition, divisibility as the approximation. The measurement problem, built on the presupposition of dynamical completeness at the collapse event, dissolves when the presupposition is removed.

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