Review of v1.0 (aiXiv, April 27, 2026)

Rating: 3/10 **Recommendation:** Major revisions

Reviewer synopsis: The reviewer characterized the paper as "philosophically sophisticated and well-argued," praised the Universal Acceleration Razor as "powerful and original," found the metrological grounding "compelling," and noted the paper's "clear and useful taxonomy" of temporal layers and its "intellectual honesty and sound philosophical methodology."

Principal criticisms: (1) Lack of formal mathematical or computational modeling; (2) insufficient engagement with quantitative periodicity detection frameworks from signal processing and data science; (3) absence of empirical or simulation-based validation; (4) limited impact for a "technical AI/ML audience."

Author's Notes (v1.1)

The reviewer's substantive assessment of the paper's philosophical content was positive throughout the strengths section. The 3/10 rating derives primarily from applying AI/ML conference standards — computational modeling, simulation, algorithmic validation — to a philosophy of physics manuscript. This is a genre mismatch, not a content failure. The paper is a philosophical argument in the tradition of philosophy of time and philosophy of measurement; it does not aim to provide a computational model of periodicity detection or an empirical signal-processing framework.

That said, three criticisms were substantively useful and have been addressed in v1.1:

1. The grounding claim needed sharper formalization. The reviewer correctly noted that "grounding" and "physical determinacy" remained qualitative. A minimal formal schema has been added to §3.5: if a stable process has period T and N cycles are counted, then a duration d is realized as $d = N \times T$. This clarifies the metric role of recurrence without converting the paper into a mathematical physics manuscript.

2. Periodicity comes in grades. The reviewer's point about exact, approximate, and stochastic periodicity was fair. A sentence has been added to the recurrence taxonomy in §1 explicitly noting that exact periodicity is an ideal limiting case and that approximate, stabilized, and ensemble-supported recurrence can also ground metric comparison to the extent that they sustain reproducible standards.

3. Genre clarification. A sentence has been added to §3.5 making the paper's scope explicit: "The thesis concerns the physical realization of metric temporality in actual chronometry, not a general theory of periodicity detection in arbitrary systems."

Not addressed (with explanation):

- *Simulation-based validation:* The paper's core claims

are philosophical and abductive, not empirical. Simulating coupled oscillators would demonstrate the formal schema but would not test the ontological thesis, which concerns what grounds metric time, not how to detect periodicity computationally.

- *Signal processing / Fourier / non-Euclidean periodicity literature:* These frameworks address periodicity detection in data. The present paper addresses the ontological role of periodicity in grounding temporal metric. The two projects are complementary but distinct.

- *SAGE and AI-grounding frameworks:* These concern

grounding temporal queries in sensor data — a different sense of "grounding" from the physical-constitutive sense used here.

This paper is concurrently under review at a philosophy of science journal. The aiXiv submission is maintained for open-access visibility and continued peer feedback.

From Process to Duration: Periodicity and the Grounding of Metric Time

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1. Introduction

The official unit of time is defined as 9,192,631,770 periods of the radiation corresponding to the cesium-133 hyperfine transition.[1] This is an explicit metrological definition grounded in counted recurrence. The second is not defined by reference to a flowing substance, an independent dimension, or a cosmic background. It is defined by counting oscillations of a physical process.

This metrological fact is rarely given its full philosophical weight. If science defines the temporal unit through periodicity, why does philosophy still debate whether time is a container, a dimension, an illusion, or a fundamental? The present paper takes the metrological practice seriously and asks what follows if it reflects not merely a convenient measurement strategy but the physical basis of what temporal metric actually is.

The thesis defended here requires careful formulation. The strongest defensible claim is not that periodicity by itself explains everything ordinarily meant by "time." Rather, the claim is that periodic process grounds *metric* temporality. Stable recurrence furnishes units, ratios, and commensurability: it is what makes duration physically countable and comparable. In that sense, periodic process does not merely help us measure time conveniently. It provides the physical basis on which temporal measurement becomes determinate.

This is stronger than ordinary operationalism but narrower than a total reduction of temporality to recurrence. It is stronger than operationalism because it treats recurring processes as objective features of the world rather than as observer-relative conventions. A day was real before anyone counted Earth's rotation, and cesium oscillated before anyone built an atomic clock. But it is narrower than a total reduction because temporal order, temporal direction, and lived temporality are not exhausted by recurrence alone. A satisfactory account must therefore distinguish several layers that are often run together:

- *Order*: before and after — process succession.
- *Metric*: how long — stable, countable duration.
- *Arrow*: which direction — irreversible registration.
- *Experience*: how time is lived — biological and

phenomenological integration.

The present paper is principally a thesis about the second of these layers.

The argument is not merely epistemological. It does not claim only that recurring processes are how we happen to measure time. It claims, more strongly, that recurring processes are part of what makes metric temporal claims physically determinate. By "grounding" is meant physical grounding: stable recurrence is part of the physical structure in virtue of which metric duration is realized in clock systems. The paper's ambition is ontological, even though its method is abductive rather than deductive.

To say that process is prior to metric time is not to say that process exists *earlier* than time. That would be incoherent. The priority is ontological: the concept and metric of time are abstracted from, and physically grounded in, structured process. Process is not change inside an already-existing temporal container; metric time is the measure extracted from ordered process.

Understood in this way, Periodic Process Realism sharpens the broader relational and process-oriented tradition by privileging recurrence, rather than change in general, as the basis of temporal metric. The paper does not aim to replace every philosophy of time with a single principle. It aims to identify the most plausible physical basis of temporal metric and to show why recurrence has a stronger claim to that role than change in general.

Before proceeding, a brief taxonomy of the recurrence concepts used in this paper will be helpful:

- *Periodic*: returns to the same phase or state after regular intervals (pendulum, atomic transition).
- *Oscillatory*: alternates around a stable pattern, possibly imperfectly (heartbeat, circadian rhythm).
- *Recurring*: happens again, not necessarily at fixed intervals (supernovae across a galaxy).
- *Repeatable*: can be reproduced under controlled conditions (hourglass runs).
- *Rate-stable*: changes monotonically but predictably (radioactive decay ensembles).

Of these, strict periodicity provides the most stable basis for metric temporal standards. The paper's central claim is that this is not accidental: periodic processes have the strongest claim to ground metric temporality because they furnish the most robust physically realizable standards of countable, comparable duration. Repeatable and rate-stable processes can acquire temporal significance through calibration against periodic standards, but strict periodicity remains the paradigmatic case. Exact periodicity is an ideal limiting case; in physical practice, approximate, stabilized, and ensemble-supported recurrence can also ground metric comparison to the extent that they sustain reproducible standards.

The paper proceeds as follows. Section 2 positions the thesis historically. Section 3 develops the metrological argument. Section 4 introduces the universal acceleration razor. Section 5 examines the thesis under general relativity. Section 6 connects to quantum gravity and relational approaches to emergent time. Section 7 addresses five major objections. Section 8 draws out implications. Section 9 concludes.

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2. Historical Positioning

The thesis belongs to an old philosophical family but occupies a more specific niche within it. The family is broadly relational and process-oriented; the niche is the claim that *periodic* process, not change in general, is the privileged basis of metric time.

2.1 Aristotle

The deepest classical ancestor is Aristotle, not Leibniz. In *Physics* IV, Aristotle characterizes time as "the number of motion with respect to before and after."[2] This definition already makes three moves the present thesis also makes: time is not independent of change; time is countable; and time becomes explicit through the measuring of change. Aristotle further recognizes that uniform circular motion is "especially the measure" of time because it is easiest to count.[3] The day, the month, and the year are all built from rotation and revolution.

What Aristotle does not do is narrow the basis of time to periodicity specifically. For him, any change can be "in time" if it can be marked as before and after. Recent work in the Aristotelian tradition confirms this broader framing: Poletti (2022) argues that measured change is what we call time,[4] and Deasy (2026) argues that time is change.[5] These are close neighbors. What distinguishes the present thesis is the further claim that among changes, *recurring* changes are privileged because they furnish the most stable, countable, comparable metric units. The upgrade is from "time depends on change" to "metric time depends on repeating change."

2.2 Leibniz and Mach

Leibniz is essential for the anti-container argument. Against Newton, he treats time as the "order of successions" rather than an independently existing substance.[6] His argument from the identity of indiscernibles — that a universe created "a few million years earlier" would be indistinguishable from the actual one — anticipates the universal acceleration razor developed below. But Leibniz does not identify periodicity as the basis of temporal ordering.

Mach comes closer. His canonical position — that time is an abstraction derived from the changes of things, not an entity in its own right[7] — is almost the present thesis in compressed form. Modern reconstructions emphasize his insistence that all measurements of time are essentially physical comparisons of one process against another.[8] But Mach, like Leibniz, speaks of change generically.

The lineage is therefore:

- Aristotle: time = measure of change.
- Leibniz: time = relational ordering, not container.
- Mach: time = abstraction from change.
- The present thesis: metric time = what periodic process

makes physically determinate.

The last step is the novel narrowing. It is not novel to deny absolute time. It is not novel to tie time to change. What is distinctive is the claim that recurrence is the strongest candidate for the physical ground of metric time — that the move from change to cycle is not merely a metrological preference but reflects an ontological privilege.

2.3 Process Philosophy

Process philosophy provides the metaphysical scaffolding. Whitehead's insistence that "at an instant there is nothing"[9] and that process is ontologically prior to substance aligns with the deeper ontology defended here. Contemporary process philosophers such as Rescher and Seibt maintain that dynamic being is primary and that apparently stable things are sustained patterns of process.[10]

The present thesis converges with this tradition but adds a constraint Whitehead does not impose: not every process equally grounds temporal metric. Stable recurring processes are special because they furnish a *metric*. A single, unrepeated event may reveal that the world is not static, but it does not by itself provide a standard for comparing durations. Recurrence does. Repeating processes furnish units, ratios, and commensurability. They turn bare succession into measurable duration.

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3. The Metrological Argument

3.1 The SI Second

The present SI second is defined by fixing the numerical value of the cesium-133 hyperfine transition frequency at exactly 9,192,631,770 Hz.[1] The BIPM states explicitly that this corresponds to the duration of 9,192,631,770 periods of the corresponding radiation. NIST describes the operational principle with equal directness: a clock combines an oscillator — a steady repeating process — with a device that counts those repetitions.[11]

This is the metrological starting point of the thesis. It shows that precision timekeeping is physically realized through recurrent process, even if that fact does not by itself settle the full ontology of time. A clock is an oscillator coupled to a counter. The oscillator provides the periodicity. The counter provides the accumulation. Together they produce measured duration.

3.2 Historical Continuity

Before the atomic era, the second was defined through astronomical recurrence. Prior to 1960, it was a fraction of the mean solar day — one rotation of the Earth. From 1960 to 1967, it was defined through the tropical year — one revolution around the Sun. After 1967, it was anchored to cesium oscillation.[12]

The central scientific standards for time have consistently relied on stable recurrence: Earth rotation, orbital motion, and atomic transition frequency. The standard did not move from a non-periodic definition to a periodic one. It moved from less stable periodicity to more stable periodicity.

3.3 The Hourglass Objection

A natural objection is that not all devices used to measure duration are intrinsically periodic. Hourglasses, water clocks, candle clocks, and radiometric techniques track monotonic processes: sand falls, water drains, wax burns, unstable nuclei decay. None of these is cyclic in the way an atomic or pendular clock is cyclic.

This objection is important, but it does not undermine the thesis once the target claim is stated correctly. The claim is that metric timekeeping requires physically reproducible standards, and that periodic processes are privileged because they provide repeatable units with exceptional stability and comparability. Monotonic devices can register intervals, but their temporal significance depends on the repeatability of their performance across runs and, ultimately, on comparison with more stable recurring processes. An hourglass is useful not because one run contains an internal cycle, but because runs of the same device can be treated as repeatable intervals under controlled conditions. Radiometric dating depends on statistically stable decay behavior expressed in already-established temporal units — the half-life is defined *in seconds*, where the second is itself defined through recurrence.

The point is not that every timer is secretly periodic in its intrinsic dynamics. It is that temporal metric depends on reproducibility, commensurability, and calibration, and periodic processes are the paradigmatic realizers of those conditions.

3.4 Limit Cycles and Precision Timekeeping

The metrological argument goes deeper than convention. Evans (2023) argues that precision clocks are illuminatingly understood in terms of limit-cycle dynamics — closed, periodic trajectories that act as stable attractors in phase space.[13] In the clearest cases, such systems are open, driven, nonlinear, and dissipative. This means that stable precision timekeeping typically requires mechanisms for stabilization, driving, dissipation, and recording. Evans's analysis strengthens the plausibility of the present thesis by showing why the most stable clock-realizing systems are recurrent. Periodic Process Realism goes beyond that operational account by proposing, as a further metaphysical inference, that stable recurrence has the strongest claim to ground metric temporal determinacy.[14]

3.5 From Metrology to Ontology

Metrology does not, by itself, settle the ontology of time. A substantivalist may still argue that clocks merely track an independently existing temporal structure. The metrological argument should therefore not be overstated.

What it establishes directly is narrower but still philosophically significant. Every major scientific realization of temporal units depends on stable recurring process, and no physically precise standard of timekeeping dispenses with recurrence altogether. This gives recurrence a privileged claim in the metaphysics of temporal metric.

The argument of this paper therefore proceeds by inference to the best explanation rather than by strict deduction. Metrology shows that recurrence is indispensable to the realization of precise temporal standards. The broader metaphysical proposal is that this indispensability is not accidental: recurring process is what grounds the metric articulation of temporality itself. Our best physical grip on metric temporality is inseparable from stable clock comparison, and stable recurrence is the paradigmatic basis of such comparison. If an independent temporal metric adds no observable difference beyond what process-ratios already supply, then recurrence has, within current physical practice and theory, the strongest claim to ground metric temporality — not by strict deduction, but by inference to the best explanation.

At a minimal level, the metric role of recurrence can be represented by a simple schema: if a stable process has period T, and N cycles are counted, then a duration d is realized as $d = N \times T$. The present thesis is not that this schema captures all aspects of temporality, but that stable recurrent processes of this sort furnish the physical basis by which duration becomes countable and comparable. The thesis concerns the physical realization of metric temporality in actual chronometry, not a general theory of periodicity detection in arbitrary systems.

The present thesis should be distinguished from three nearby positions it might be confused with. Conventionalism holds that temporal units are arbitrary choices; the present view holds that the choice of periodic standards reflects a physical constraint on what can serve as a stable, reproducible metric basis. Operationalism holds that time is whatever clocks measure; the present view holds that this formulation underdetermines the ontology, since it does not explain why periodic clocks are privileged among possible timekeeping devices. Tal's (2016) model-based account of time measurement comes closest: Tal argues that temporal standards involve sophisticated coordination between theoretical quantities and physical realizations through model-mediated measurement.[36] The present view accepts that analysis but draws a further ontological conclusion Tal does not: the coordination succeeds, on the present view, because stable recurrence provides the physical basis of metric temporal determinacy, rather than merely a convenient standard of coordination.

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4. The Universal Acceleration Razor

4.1 The Thought Experiment

Suppose every physical process in the universe — every atomic oscillation, every planetary orbit, every chemical reaction, every neural firing, every quantum transition — were to speed up uniformly by the same factor. How would we know?

On the present view, no observable ratio would distinguish the uniformly scaled universe from the original. Precision time measurement depends on comparison among stable clock processes, paradigmatically periodic ones. A second is 9,192,631,770 cesium oscillations. A day is one Earth rotation. A year is 365.25 days. If every process accelerated by the same factor, every ratio would be preserved. No dimensionless ratio would change. Not because we lack the technology. Because no physically meaningful quantity has been altered.

More precisely, the razor functions as a reparameterization test: where two descriptions differ only by a uniform rescaling of all physical process-rates, and all dimensionless ratios remain invariant, the difference is representational rather than physical.[15]

4.2 Sorting the Landscape

The razor divides theories of time into two broad categories:

Theories where universal acceleration is meaningful: Newtonian absolute time (an independent background temporal metric registers the change), Smolin's temporal naturalism insofar as it treats time as fundamentally real and not exhausted by process-ratios, and any theory positing a fixed temporal metric independent of physical processes.

Theories where universal acceleration is incoherent: Leibnizian relationism (same relations, same world), Machian time (only process-ratios matter), Barbour's timeless configurations (no external time to accelerate against), Rovelli's relational mechanics (no preferred time variable), and the present thesis (all temporal metric is process-ratio; uniform scaling preserves all ratios).

The A-theory/B-theory and presentism/eternalism debates are largely orthogonal to the razor, since they concern the ontology of temporal passage and the existence of past/future, not the operational basis of temporal metric.

4.3 What the Razor Shows

The universal acceleration razor does not show that absolute time is logically impossible. A defender of background time may still maintain that there is a hidden temporal metric relative to which all processes could accelerate together. The point is not logical contradiction.

The point is explanatory economy. If a universal scaling of all physical processes would leave every observable ratio unchanged, then a further appeal to absolute time contributes no additional physical content. The razor places pressure on views that posit an independent temporal metric while leaving all physically realizable comparisons untouched. It is primarily an argument from empirical equivalence and explanatory economy, not from impossibility.

[1]: BIPM, "SI base unit: second," *The International System of Units (SI)*, 9th ed. (2019). The second is defined by fixing the numerical value of the cesium-133 hyperfine transition frequency at 9,192,631,770 Hz.

[2]: Aristotle, *Physics*, IV.11, 219b1-2.

[3]: Aristotle, *Physics*, IV.14, 223b18-20.

[4]: M. Poletti, "Time as Change" (2022). PhilArchive.

[5]: D. Deasy, "Time Is Change," *Philosophies* 11(3):67 (2026).

[6]: G. W. Leibniz, in *The Leibniz-Clarke Correspondence* (1715-1716), Third Paper, §4.

[7]: E. Mach, *Die Mechanik in ihrer Entwickelung* (1883), Ch. II, §6.

[8]: P. Thébault, "On Mach On Time," preprint, PhilSci-Archive (2021).

[9]: A. N. Whitehead, *The Concept of Nature* (1920), Ch. III.

[10]: See J. Seibt, "Process Philosophy," *Stanford Encyclopedia of Philosophy* (2022); N. Rescher, *Process Metaphysics* (1996).

[11]: NIST, "How Do Atomic Clocks Work?" https://www.nist.gov/atomic-clocks/how-do-atomic-clocks-work (accessed April 26, 2026).

[12]: BIPM, "Mise en pratique for the definition of the second in the SI." https://www.bipm.org/en/publications/mises-en-pratique (accessed April 26, 2026).

[13]: P. Evans, "How Do Clocks Define Physical Time?" *Erkenntnis* (2023).

[14]: Cf. E. Tal, "Old and New Problems in Philosophy of Measurement," *Philosophy Compass* 8 (2013): 1159-1173.

[15]: The razor applies strictly when "all" means genuinely all physical processes. If some processes were exempt from the scaling, the relevant ratios could change and the case would no longer be one of universal acceleration in the intended sense.

5. Relativity and Clock Comparison

5.1 Operational Compatibility

General relativity eliminates universal background time. There is no single cosmic clock against which all local processes are calibrated. Instead, different clocks accumulate different amounts of proper time depending on their motion and gravitational environment. Time dilation is not well understood as the slowing of an invisible substance, but as a lawful divergence in how physically realized clocks accumulate along distinct worldlines.

This is strongly compatible with the present thesis. In periodicity language, gravitational time dilation means that recurring processes situated in different gravitational conditions complete different numbers of cycles between shared comparison events. NIST's optical-clock experiments confirm this at remarkably small height differences.[16] What is observed is not a change in a hidden temporal medium, but a difference in the accumulated behavior of physical clocks.

Still, the fit is interpretive rather than literal. General relativity is a geometric theory: the metric tensor encodes the spacetime relations by which physical clocks accumulate proper time differently along different worldlines. The claim here is not that GR reduces to oscillator language, but that GR is far more hospitable to a process-relational interpretation of temporal metric than to Newtonian substantivalism.

5.2 Compatible, Not Identical

A careful distinction is needed. General relativity does not say that clocks *create* time. It says that ideal clocks *measure* proper time along worldlines, and that the metric determines how much proper time is assigned to each path through spacetime.[17] The metric is a geometric object, not a collection of oscillators. GR formalizes the relational comparison of clock processes; the present thesis offers a metaphysical interpretation of what those clock processes are doing. GR is hospitable to the thesis but does not by itself entail it. The strongest defensible claim is that GR *naturalizes* the thesis — makes it far more plausible than Newtonian substantivalism — without *proving* it.

5.3 The Twin Paradox as Process-Counting

The twin paradox illustrates the thesis concretely. One twin remains on Earth while the other undertakes a high-speed journey and returns younger. On the interpretation defended here, the result need not be described as a metaphysical slowing of "time itself."

An ideal clock carried by the traveling twin accumulates less proper time than an identical ideal clock carried by the stay-at-home twin. Biological aging is then a complex approximate realization of the same principle: the traveling organism accumulates less integrated physical, chemical, and biological process between the same boundary events. For clock-like subsystems, this difference appears as fewer accumulated cycles between departure and reunion.

This does not replace the geometric description given by relativity. It interprets it. The metric tells us which worldlines accumulate more or less proper time; the present thesis offers a metaphysical gloss on what that physically amounts to when realized in actual systems.

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6. Quantum Gravity and the Problem of Time

6.1 The Wheeler-DeWitt Problem

The problem of time in quantum gravity arises because canonical quantization of general relativity produces a formalism without an external time parameter. The Wheeler-DeWitt equation is often described as "timeless": it lacks the temporal evolution structure familiar from ordinary quantum mechanics.[18]

The present thesis interprets this as motivation rather than crisis. If metric time is not an independent background but a feature grounded in physical processes, then the deepest physical formalism *need not* contain an external time parameter. The absence of time from the fundamental equation becomes a structural feature consistent with a view on which temporal metric emerges from internal process rather than being imposed from outside.[37]

6.2 The Page-Wootters Mechanism

The Page-Wootters mechanism remains one of the most suggestive frameworks for understanding how temporal description might emerge without an external time parameter. Page and Wootters (1983) showed that an isolated, globally stationary quantum system can exhibit internal temporal structure: one subsystem may function as a clock, and other subsystems may be described as evolving relative to its states.[19]

This is especially relevant to the present thesis because it shifts attention toward the physical structure required of clock subsystems. Any such subsystem must furnish a stable sequence of distinguishable states through which other changes can be parametrized. Periodicity is therefore a natural and privileged candidate for clockhood within emergent-time programs, because recurring dynamics supply exactly the repeatability and comparability that temporal metric requires.

Recent work on relational quantum dynamics supports this assessment. Höhn, Smith, and Lock (2021) established equivalences among several relational formulations of quantum dynamics, including the Page-Wootters formalism.[20] Subsequent work by Chataignier, Höhn, Lock, and Mele on relational dynamics with periodic clocks develops a systematic framework for periodic clock subsystems, showing that relational observables relative to periodic clocks are globally gauge-invariant only when the encoded system quantity is itself periodic — otherwise they are only transiently invariant per clock cycle.[21]

These formal results do not establish that all emergent temporal structure must be periodic; they show that periodic clocks enjoy special formal advantages in a significant class of relational constructions. The philosophical conclusion is accordingly limited but significant: periodicity plays a formally nontrivial role in relational-clock frameworks, and periodic clocks require special treatment rather than being reducible to generic clock variables. This strengthens the paper's narrower claim that periodicity may ground metric temporal determinacy more specifically than generic appeals to "change" alone.

6.3 Barbour and Rovelli

Julian Barbour's timeless physics is the nearest structural relative to the present proposal. Barbour denies that time exists fundamentally and argues that temporal appearance arises from configurations and the records they contain.[22] Barbour has explicitly stated that "the often made statement that a periodic process is the basis of a clock is misleading."[23] His worry is that good clocks are not merely periodic systems but dynamically selected systems whose behavior reflects the whole structure of change. A pendulum is not a clock simply because it repeats, but because its repetition is embedded in a wider dynamical order.

The present thesis departs from Barbour at a precise point: the physical basis of metric comparability. Where Barbour emphasizes configuration and record, the present view emphasizes recurring substructure as what makes durations countable and comparable. Periodic Process Realism can accept that periodicity alone is insufficient for clockhood — stability, comparison, and recording are also needed. But it maintains that stable recurrence remains the paradigmatic and most robust physical basis for clock-realized metric articulation. Barbour has "time capsules" — configurations containing records of apparent history. The present view proposes that configurations containing *recurring* substructure are what gives apparent history its metric countability.

Carlo Rovelli's relational and thermal approaches share the anti-background commitment while diverging on mechanism.[24] Rovelli emphasizes relations among observables and, in the thermal time program, the state-dependent character of temporal flow. The present thesis is sympathetic to the relational spirit but assigns recurrence a more privileged role in grounding metric temporal structure.

In both cases, the present proposal should be read as a sharpening rather than a wholesale rejection. It belongs in the same broad family of anti-substantival views, but argues that recurrence deserves a more central place than it typically receives in discussions of emergent time.

6.4 Causal Set Theory

Causal set theory provides a well-developed framework in which temporal structure arises from a discrete partial ordering of events without any appeal to periodicity.[25] In causal set approaches, spacetime is modeled as a locally finite partially ordered set, where the order relation encodes proto-causal and proto-temporal structure.

This presents a genuine challenge. Causal sets provide temporal *order* — the before-and-after structure of layer 2 in the architecture defended here — without requiring recurrence. Metric structure in causal sets typically requires further machinery, particularly volume-counting (the correspondence between the number of elements in a causal set region and the spacetime volume of that region). Counting events and comparing counts is not periodicity, but it serves a related quantitative function: it supplies a reproducible standard by which order acquires measurable structure.

Causal set theory therefore supports the paper's broader distinction between temporal order and temporal metric without straightforwardly supporting the stronger recurrence thesis itself. It shows that order may arise from causal structure alone, while metric structure requires additional apparatus beyond bare ordering. In physically realized chronometry, that apparatus is supplied by stable recurrence; in causal set theory, it may be supplied by cardinality and volume-counting. Periodic Process Realism is therefore strongest when restricted to physically realized clock metric: in actual metrology, metric duration is stabilized through recurrent processes, even if some theoretical frameworks recover metric information by other means. If causal set theory provides a complete account of both temporal order and temporal metric without recurrence, this would constitute a genuine alternative at the foundational level, and the present thesis would characterize a privileged class of physically realized metric standards rather than the fundamental basis of metric temporality itself. Whether a fully cardinality-based metric is sufficient to ground determinate duration without supplementary clock-like structure remains an open question within the causal set program.

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7. Objections and Replies

The objections considered in this section test not whether periodicity explains everything about time, but whether it can plausibly ground the metric core of temporality.

7.1 Non-Periodic Processes Have Duration

A supernova explosion, a melting ice cube, or a single radioactive decay all seem to have duration without themselves being periodic. If metric time depends on recurrence, how can such processes be temporal?

The strongest response is that periodicity need not characterize every event directly in order to ground metric time. It is enough that recurring processes furnish the standards by which non-periodic processes become durationally comparable. A supernova "lasts three seconds" because it can be compared with a clock whose recurring process provides a stable unit. Without such a unit, duration may still be spoken of loosely, but it lacks determinate metric content.

The thesis should therefore not be read as claiming that every temporal process is itself cyclical. Its narrower claim is that stable recurrence is what makes duration physically comparable. Non-periodic processes participate fully in temporal description by reference to standards supplied by recurring ones.[26]

7.2 The Arrow of Time

Periodic processes are approximately time-symmetric. A pendulum swings left and right. An orbit traces a closed ellipse. But time has a direction: entropy increases, eggs break but do not unbreak, we remember the past but not the future. How can symmetric periodicity produce asymmetric time?

It cannot, and the thesis does not claim otherwise. The arrow of time is produced by thermodynamic irreversibility, not by periodicity. What the thesis claims is that periodicity and irreversibility perform *different temporal functions*: periodicity supplies the *metric* of time (how long); irreversibility supplies the *arrow* of time (which direction). A clock, properly understood, is not merely an oscillator. It is an oscillator coupled to an irreversible counter. The oscillator gives recurrence. The counter gives accumulation. Without the oscillator, there is sequence but no stable duration. Without the counter, there is recurrence but no elapsed time. Together they produce measured, directed temporality.

This decomposition — metric from periodicity, arrow from entropy — reflects the engineering logic of precision timekeeping in its clearest forms. An atomic clock oscillates (periodicity) and accumulates a count (irreversible recording). The two components are physically distinct and functionally complementary.

7.3 Shoemaker's Time Without Change

Shoemaker's thought experiment is intended to show that time can exist even during intervals in which nothing changes.[27] The strongest reply on behalf of the present thesis is conceptual. To describe a changeless interval as temporally extended already presupposes a standard of temporal metric that is independent of the local processes in question. That is precisely what Periodic Process Realism denies. The scenario therefore risks assuming the kind of background temporal framework it is meant to defend.

A supporting point is epistemic. Any judgment that a region is changeless must be made from some observational standpoint, over some finite interval, and by means of some external standard. That does not by itself refute Shoemaker's modal challenge, but it reinforces the present paper's narrower claim: temporal attribution in such cases remains dependent on actual or possible process-based comparison.

The most defensible conclusion is limited. Shoemaker remains a challenge to strong change-based theories of time. But it is less damaging once the thesis is narrowed from "no time without any change whatsoever" to the more specific claim defended here: without recurring process, there is no physically determinate metric time. Shoemaker shows that duration can be *attributed* across relations, not that temporal metric can be *grounded* without process.[28]

7.4 Bergson and Lived Temporality

Bergson's distinction between measured time and lived duration (*durée*) remains one of the most serious challenges to any account that ties temporality closely to clocks or formal measurement.[29] Five minutes in pain and five minutes in joy may contain the same number of clock ticks while differing radically in felt temporal character.

Periodic Process Realism is not, and should not be, a total phenomenology of time-consciousness. Its primary claim is about the grounding of metric temporality. Bergson is right to insist that measured time and lived time are not straightforwardly identical.

Where the present paper differs from Bergson is in how it proposes to explain part of the difference. A promising naturalistic hypothesis is that variations in lived duration may track variations in internal biological process density — by which is meant the coordinated density of neural, autonomic, affective, attentional, and mnemonic activity within an interval, not a single scalar variable.[30] Different affective and attentional states modulate neural firing patterns, autonomic rhythms, hormonal cascades, memory encoding, and perceptual sampling. The result is that equal intervals by an external standard can be lived quite differently because the density and coordination of internal processes differ across states.

The felt "thickness" of painful time may reflect differences in internal temporal articulation rather than the operation of a wholly separate kind of temporality beyond measurable process. This does not show that Bergson was simply mistaken, nor does it reduce lived experience to a single physiological variable. It suggests that some of the contrast between clock time and experienced time may be partially illuminated through variations in biological process density — a testable hypothesis that remains open to empirical investigation.

Music offers an instructive supporting case. Rhythm, meter, and tempo are organized recurrences experienced directly as temporal form. London (2012) grounds meter in biological entrainment to periodic stimuli,[31] and even Hasty's (1997) more dynamic projective account — which treats meter as an open process of becoming rather than a static periodic grid — depends on patterned return and durational continuation.[32] Musical temporality does not prove that all experience is periodic, but it shows how organized recurrence can generate rich temporal articulation in experience.

7.5 The First Completed Cycle

If metric time depends on recurrence, does time literally not exist until the first cycle completes? A process midway through its first oscillation already exhibits order, phase, and directed development. Surely some kind of temporality is already present.

The present thesis should not deny that. Its claim is narrower. Before the completion of a stable cycle, there may already be process-order: earlier and later phases, directed development, structural asymmetry. What is not yet available is a calibrated metric unit against which other changes can be compared. The first completed cycle does not create all temporality. It furnishes the first stable standard of duration.

This distinction is important in cosmological settings. Near the Big Bang, where ordinary physical clocks may fail and classical spacetime itself becomes problematic, temporal concepts may remain applicable only in attenuated or non-metrical ways.[33] Rugh and Zinkernagel have argued that cosmic time requires a physical basis in actual or conceivable clock-like processes, and that this basis becomes fragile in very early-universe regimes.[34] Periodic Process Realism offers a specific account of this attenuation: before stable recurring processes exist, temporal order may be thinkable, but metric time lacks a clear physical basis.

The thesis is therefore best understood as a view about the emergence of stable temporal metric, not as a denial that some before-and-after structure can exist prior to recurrence.

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8. Implications and Extensions

The preceding argument does not yield strict predictions in the narrow experimental sense. What it does yield are several implications that help differentiate Periodic Process Realism from rival views. They should be read as theoretical consequences of the paper's core claim rather than as established results of current physics.

8.1 Heat Death and Temporal Attenuation

If the universe were to approach thermodynamic equilibrium, with no macroscopic free-energy gradients sufficient to sustain complex clocks, organisms, or durable records, what would become of temporal structure?[35] A substantivalist may hold that time continues unchanged. An eternalist may say that heat-death states are simply later regions of the block universe.

Periodic Process Realism offers a different answer: if metric temporality depends on the availability of stable, comparable, physically realized processes, then a universe in which such processes can no longer be sustained will exhibit a severe attenuation of macroscopic temporal structure. Formal temporal parameters may persist in a physical theory, but clocks, records, and practical standards of duration would not. This is an ontological claim, not merely an epistemic one: the thesis holds not only that we could no longer *measure* metric time in such a universe, but that metric time itself — physically determinate, countable duration — would lack the physical basis required for its realization. Heat death marks not the proved termination of time itself, but a limiting case in which macroscopic metric temporality loses its physical realization.

8.2 The Layered Architecture of Temporality

The broader picture suggested by this paper is that temporality is layered rather than monolithic. At minimum, four distinguishable dimensions should be kept apart: process, which provides change; succession, which provides before-and-after order; periodicity, which provides metric comparability; and irreversibility, which provides temporal direction. Lived temporality introduces a further dimension, since consciousness, attention, and embodiment shape the way temporal structure is experienced. Existential temporality adds yet another layer, in which finitude, anticipation, and significance come into view.

The distinctive claim of the present paper concerns only one of these layers: periodicity is the most plausible physical basis of metric time. That claim does not eliminate the need for further accounts of temporal direction, temporal experience, or existential temporality. On the contrary, it helps clarify where those additional accounts must begin. A satisfactory philosophy of time may require more than one principle. What this paper argues is that recurrence deserves a central place among them because it explains how ordered process becomes measurable as duration.

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9. Conclusion

The central claim of this paper has been that temporal metric does not require an independent temporal substance, container, or universal background flow. What it requires is a physical basis on which durations become countable, comparable, and reproducible. The argument advanced here is that stable recurring processes are the most plausible basis of that metric structure.

Framed in this way, Periodic Process Realism should not be read as a total theory of temporality. It does not claim that recurrence alone explains temporal direction, lived duration, or existential significance. On the contrary, the paper has argued for a layered account: process supplies order, periodicity supplies metric, entropy and record-formation supply arrow, and consciousness supplies experience. The distinctive contribution of the present view lies at the threshold from bare succession to measurable duration: recurrence is what makes temporal metric possible.

The paper has also shown that the thesis is more robust under objection than its apparent narrowness might suggest. The classic "time without change" scenario presupposes the background temporal framework the thesis denies, and temporal attribution in such cases remains dependent on process-based comparison elsewhere in the system. The felt "thickness" of temporal experience may, at least in part, be illuminated through variation in biological process density — a naturalistic extension of the metric thesis rather than one of its load-bearing premises.

The metrological record gives this claim empirical seriousness. The history of time standards is a history of increasingly stable recurrent processes, not of access to a temporally independent medium. Relational and process-oriented traditions give it metaphysical ancestry. Contemporary foundational physics gives it further plausibility by increasingly treating temporal description as something recovered from clock relations rather than imposed from outside. None of these considerations yields a deductive proof. Taken together, however, they support a clear and defensible conclusion: recurrence is not merely a convenient instrument for measuring time; it has the strongest claim to ground the metric content of temporality.

Metric time is the articulation of process made physically determinate by stable recurrence. Clocks do not invent that structure. They realize the process and count its periodicity in order to express duration.

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[26]: Recurrence may also be visible at some organizational levels but not others. A process that is singular at one scale may belong to a recurring pattern at another, helping explain how metric comparison extends even to apparently unique events.

[27]: S. Shoemaker, "Time Without Change," *J. Phil.* 66:363 (1969).

[28]: Cf. D. Corish, "Could Time Be Change?" *Philosophy* 84:219 (2009), for a related argument that Shoemaker presupposes background temporal structure.

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[33]: See Stanford Encyclopedia of Philosophy, "Quantum Gravity," for discussion of temporal structure near singularities.

[34]: S. E. Rugh and H. Zinkernagel, "On the Physical Basis of Cosmic Time," *Stud. Hist. Phil. Mod. Phys.* 40:1 (2009).

[35]: See C. Callender, "Thermodynamic Asymmetry in Time," *Stanford Encyclopedia of Philosophy*.

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[37]: The present view is compatible with spacetime functionalism (Knox 2013, 2019; Lam and Wüthrich 2018; Huggett and Wüthrich 2021) but operates at a different level of analysis. Spacetime functionalism asks what plays spacetime's role in non-spatiotemporal QG theories. The present thesis asks a more specific question: among the functional roles that constitute temporal structure, what grounds metric comparability? The answer proposed here — stable recurrence — could serve as a concrete realization condition within a broader functionalist framework, specifying what it takes to play one particular spacetime role: the furnishing of countable, comparable duration.