On the Dynamics of Relational Clocks

A Scalar-Selection Approach to the First Observable Projection of a Discrete Relational Universe

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April 2026

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1 Abstract

This paper develops an operational hypothesis for a universe whose deepest structure is relational rather than manifold-like. It is written as a homage to the Einsteinian method: begin with clocks, measurement, and a small number of severe postulates; derive only what follows; and leave stronger claims for experiment. The central proposal is that if spacetime is an emergent projection of a deeper relational substrate, then the first robust observable should not be full tensor gravity, mass, electromagnetism, or the topology of information itself. The first robust observable should be scalar timing: local clocks lag where relational load accumulates.

We call this proposal scalar timing geometry. Its minimal chain is

$$H_{\mathrm{micro}} \to W \to L_w \to \Lambda \to \omega_{\mathrm{eff}}.$$

Here H_{micro} denotes a microscopic relational medium, W an effective weighted adjacency, L_w the weighted graph Laplacian, Λ a scalar load retained after coarse graining, and ω_{eff} the effective clock rate. The paper does not claim to derive gravity, Lorentz invariance, electromagnetism, mass, or a spin-2 sector. Instead, it identifies the weakest testable sector that such stronger physics would have to pass through: clocks. We present five postulates, a two-clock thought experiment, a fast-coupler microscopic realization of the scalar operator, a distinction between rate closure and clock closure, and a hierarchy of sectors before and after scalar timing. The result is not a completed theory of everything, but a disciplined research program: if the universe is relational at depth, the first measurable shadow may be delay.

2 1. The clock problem

Modern physics learned to distrust common-sense space and time through clocks. In special relativity, simultaneity became operational: two distant events are not simply "at the same time" until a procedure involving clocks and signals is specified. In general relativity, clock rate ceased to be an external bookkeeping device and became part of geometry itself. A clock deep in a gravitational potential accumulates less proper time than a clock far away.

If spacetime is not fundamental, the clock becomes stranger still. It is no longer merely an instrument inside geometry. It may be the first local system through which pre-geometric order becomes visible.

The usual order of explanation is:

$$\text{mass-energy} \to \text{geometry} \to \text{clock rate}.$$

The hypothesis explored here reverses the operational direction:

$$\text{relational substrate} \to \text{scalar load} \to \text{clock rate} \to \text{inferred geometry}.$$

The first chain is the mature form of gravitational physics. The second is a proposed discovery order for a pre-geometric theory. If observers do not access the full relational substrate directly, then they should not expect the first observable to be the full metric tensor. They should expect a stable projection: a reduced quantity that survives coarse graining and can be read by local instruments. The simplest such quantity is scalar load.

This paper begins from one question:

> If the universe is fundamentally relational, what is the weakest observable consequence a clock could measure?

The answer proposed here is clock lag.

3 2. A homage to Einstein's method

This paper is not a claim of Einstein-level completion. It is a homage to an intellectual style. The method has four features.

First, the primitive concepts must be operational. A time is what a clock records. A field is what an instrument responds to. A geometry is not assumed merely because a diagram is drawn.

Second, the postulates must be few. They should not smuggle in the conclusion. If geometry is to emerge, one must not secretly assume geometry at the start.

Third, the consequences must be separated by strength. A scalar timing law is not gravity. Isotropic scalar dispersion is not Lorentz invariance. A weighted graph Laplacian is not a spin-2 field. Each rung has its own tests.

Fourth, failure must be meaningful. A program that can explain anything explains nothing. Bad substrates must fail. Finite memory must cause lag or ringing. External fields must require explicit coupling kernels. Tensor gravity must not be declared until tensor structure exists.

The analogy with Einstein is therefore not one of accomplishment, but one of posture. Special relativity asked what clocks and light signals force us to mean by time. Scalar timing geometry asks what clocks force us to mean if time itself is the first readable projection of a deeper relational order.

4 3. Related work and the neighboring landscape

The broad idea that spacetime may be emergent from discrete relational structure is not new. The present proposal is deliberately narrower than these neighboring programs.

Wolfram-style hypergraph rewriting programs begin with abstract relations and update rules. Spatial hypergraphs, causal graphs, multiway evolution, and causal invariance are then used to explore whether spacetime, relativity, and quantum phenomena can arise as large-scale consequences of rewriting dynamics. This is the closest large-scale neighboring project to the ontology assumed here.

Causal set theory replaces a continuum spacetime with a locally finite partially ordered set of events, treating causal order as primitive and spacetime geometry as emergent. Quantum graphity models study dynamical graphs whose high-energy phases may be highly connected while low-energy phases become ordered, local, and effectively low-dimensional. Tensor-network and entanglement-based approaches study how geometry-like quantities can arise from quantum information structure.

The present work does not compete with these programs at the level of a universal microscopic rule. Instead, it asks a downstream question:

> Suppose some discrete relational substrate exists. What reduced observable sector should we test first?

The answer is scalar timing. This is not because mass, magnetism, or topology are unimportant. It is because scalar timing is the weakest measurable trace: one number at one place, read by one clock.

5 4. Five postulates of scalar timing geometry

The following postulates define the research program. They are not asserted as final truths. They are assumptions from which tests follow.

5.1 Postulate I: relational substrate

The deepest physical substrate is not assumed to be a differentiable manifold. It is modeled abstractly as a system of relations, updates, constraints, memory, and adjacency. A graph, hypergraph, causal set, tensor network, or programmable coupling medium may represent one effective description of such a substrate.

5.2 Postulate II: projection

Observers do not access the full substrate. They access stable projected sectors that survive coarse graining, finite resolution, noise, and dynamical selection. The observed world is not the whole substrate. It is a persistent readable layer.

5.3 Postulate III: scalar timing

The first robust projected geometric observable is a scalar load Λ, measured operationally through local clock-rate shifts:

$$\omega_{eff} = \frac{\omega}{1 + \alpha\Lambda},$$

or, for weak load,

$$\frac{\delta\omega}{\omega} \approx -\alpha\Lambda.$$

Here α is a susceptibility. The law does not assert full gravity. It asserts a scalar redshift-like channel.

5.4 Postulate IV: closure

A scalar timing sector is physically meaningful only if the same effective operator controls response, smoothing, spectral dimension, and timing. The minimal closure chain is

$$H_{micro} \to W \to L_w \to \Lambda \to \omega_{eff}.$$

The scalar load should satisfy, at leading order,

$$(\mu^2 I + \kappa L_w)\Lambda = A\rho,$$

with possible dynamical completion

$$\partial_t \Lambda + \Gamma(\mu^2 I + \kappa L_w)\Lambda = \Gamma A\rho(t).$$

5.5 Postulate V: higher sectors

Mass, magnetism, gauge structure, topology, and tensor gravity are not denied. They are richer sectors. Mass requires stable localization. Magnetism requires orientation, circulation, phase, and holonomy. Gravity requires tensor structure, universal coupling, Lorentz-compatible dynamics, and a spin-2-like sector or equivalent constraints. Scalar timing comes first because it assumes the least.

6 5. The two-clock thought experiment

Consider two identical clocks, A and B, embedded in a relational medium whose microscopic state is not directly observable. No mass has yet been assigned. No curvature tensor has been reconstructed. No electromagnetic field has been identified. The clocks are separated, held for a duration, and then compared.

They disagree.

The minimal question is not yet "what gravitational field caused this?" That question assumes a mature interpretation. The minimal question is:

> What must exist for this disagreement to be lawful?

At minimum there must be a scalar quantity along the two histories that changes the accumulated phase of the clocks:

$$\Delta\phi_i = \int \omega_{eff}(i,t)\, dt.$$

If

$$\omega_{eff}(i,t) = \frac{\omega}{1+\alpha\Lambda_i(t)},$$

then the clock disagreement is explained by different histories of scalar load:

$$\Delta\phi_A - \Delta\phi_B = \int \left[\frac{\omega}{1+\alpha\Lambda_A(t)} - \frac{\omega}{1+\alpha\Lambda_B(t)}\right] dt.$$

In the weak-load regime,

$$\Delta\phi_A - \Delta\phi_B \approx -\alpha\omega \int [\Lambda_A(t) - \Lambda_B(t)]\, dt.$$

This is the first operational geometry: not curvature, not mass, not force, but accumulated differential clock phase.

7 6. Before clock lag

Clock lag is not the foundation. It is the first readout. Before clock lag lie deeper layers.

7.1 6.1 Relational updating

At the deepest level, there may be no objects moving inside space. There may only be relations updating under rules. The substrate can have adjacency, causal order, memory, recursion, and local constraints before it has anything like a coordinate manifold.

7.2 6.2 Information topology

Some relational patterns become stable enough to define neighborhoods, paths, loops, bottlenecks, and extended modes. This is the beginning of space-like structure. Not every topology works. Random graphs can localize modes or destroy smooth propagation. A viable substrate must allow low-energy disturbances to spread as extended modes.

7.3 6.3 Effective operator

When relational structure becomes readable at coarse grain, it may be represented by an operator. The simplest candidate is a weighted graph Laplacian:

$$L_w = D - W.$$

This operator says how scalar load smooths, relaxes, diffuses, or propagates across the substrate.

7.4 6.4 Scalar load

The scalar load Λ is the simplest surviving projection of the substrate. It has no direction, spin, gauge redundancy, or tensor index. It is simply how much relational burden is locally retained.

Only after these stages does the clock have something to measure.

8 7. After clock lag

Clock lag is early, not final. Once scalar timing exists, richer sectors can be sought.

8.1 7.1 Gradients and force-like behavior

If Λ varies across the substrate, then its gradient can bias motion:

$$\nabla\Lambda \neq 0.$$

A gradient of scalar load can produce force-like behavior. This is not yet gravity. It is scalar guidance by uneven relational burden.

8.2 7.2 Persistent load and mass-like sources

Mass may correspond to a stable localized pattern of the relational substrate: a knot, scar, defect, standing excitation, or self-maintaining concentration of load. In that case mass is not primitive stuff. It is persistent topology made inertial.

The chain would be:

$$\text{persistent relational excitation} \to \rho \to \Lambda \to \omega_{eff}.$$

The clock sees the scalar effect; the deeper mass-like object is the stable source.

8.3 7.3 Oriented loops and magnetism-like sectors

Magnetism cannot be a scalar load alone. It requires direction, circulation, phase, and oriented loops. In a graph language it would live not merely on nodes, but on cycles, holonomies, antisymmetric edge phases, and conserved circulations.

The schematic chain is:

$$\text{oriented information flow} \to \text{loop phase} \to \text{gauge field} \to \text{magnetism}.$$

Scalar timing asks how loaded a place is. Magnetism asks how relational phase circulates around a place.

8.4 7.4 Tensor completion and gravity

Full gravity requires more than clock slowdown. It requires tensor geometry, universal coupling, Lorentz-compatible dynamics, correct free-fall behavior, and a spin-2-like sector or equivalent gauge constraints. Scalar timing can be a shadow of gravity-like behavior without being gravity itself.

The later target is not merely

$$\Lambda \to \text{gravity},$$

but something more demanding:

$$\text{scalar load} + \text{vector/gauge/tensor sectors} \to g_{\mu\nu}\text{-like effective geometry}.$$

9 8. A microscopic bridge: fast edge variables

The scalar timing program requires a mechanism that produces L_w rather than merely assuming it. A minimal fast-coupler model supplies such a bridge.

Let Λ_i be slow node loads and x_e fast edge variables. Let B be the incidence matrix of an underlying substrate graph. Consider

$$\dot{\Lambda} = -\mu^2\Lambda - B^T G x + A\rho(t),$$

$$\dot{x} = HB\Lambda - \Omega x.$$

Here G, H, Ω are edge-sector matrices. In the positive diagonal regime, the fast variables satisfy approximately

$$x \approx \Omega^{-1} HB\Lambda.$$

Substitution gives

$$\dot{\Lambda} \approx -\left(\mu^2 I + B^T G\Omega^{-1} HB\right)\Lambda + A\rho(t).$$

Thus

$$L_w = B^T G\Omega^{-1} HB.$$

If $G\Omega^{-1}H = \operatorname{diag}(w_e)$ with $w_e > 0$, then

$$L_w = B^T \operatorname{diag}(w_e) B,$$

which is a positive weighted graph Laplacian. The substrate graph is specified, but the scalar response operator and weights arise from microscopic edge parameters rather than from a direct node-level scalar ansatz.

10 9. Static closure, dynamic closure, and clock closure

The fast-coupler model yields three different kinds of closure.

10.1 9.1 Static closure

At steady state, eliminating x gives

$$(\mu^2 I + L_w)\Lambda = A\rho.$$

This is exact in the linear model under the stated assumptions. It verifies that the scalar response equation can be realized by microscopic edge degrees of freedom.

When $\mu = 0$, a connected graph has a constant null mode. Static closure then requires source neutrality, gauge fixing, or projection off the constant mode. This is not a detail; it is the scalar analog of removing an unobservable uniform offset.

10.2 9.2 Dynamic closure

For uniform fast scale Ω, each Laplacian eigenmode with eigenvalue λ_n obeys

$$(r + \mu^2)(r + \Omega) + \Omega\lambda_n = 0.$$

The Markovian scalar prediction is

$$\tau_n^{-1} \approx \mu^2 + \lambda_n.$$

This holds only when the fast sector is genuinely fast. The slow root is

$$r_{slow} = -(\mu^2 + \lambda_n)\left[1 + \frac{\lambda_n}{\Omega} + O(\Omega^{-2})\right].$$

Thus rate errors scale like λ_n/Ω. High-λ modes fail first.

The underdamped condition is

$$(\Omega - \mu^2)^2 < 4\Omega\lambda_n.$$

Finite coupler speed therefore produces predicted memory, lag, and ringing. This is not an embarrassment. It is a diagnostic.

10.3 9.3 Clock closure

A local clock may obey

$$\dot{\phi}_i = \omega_0 + \alpha\Lambda_i(t).$$

The clock phase shift is

$$\Delta\phi_i - \omega_0 t = \alpha \int \Lambda_i(t)\, dt.$$

This matters because clocks integrate scalar load. A rate measurement probes poles of the response; a clock phase measurement probes accumulated area. Under some protocols, the clock integral can recover the static

gain even when the instantaneous rate is distorted by finite-coupler memory. Under other protocols, especially when the fast sector begins preloaded or the source drives high-frequency response, the clock integral can inherit the same finite-Ω errors.

The safe conclusion is:

> Rate closure is the strict dynamic test. Clock closure is the robust low-frequency test. The two are related but not identical.

11 10. The 3D branch and the first geometry

If the effective operator admits a Gaussian continuum scaling regime with effective dimension d_{eff}, the scalar Green response behaves as

$$G_{d_{eff}}(r) \sim r^{2-d_{eff}}$$

for $d_{eff} \neq 2$. In the special case

$$d_{eff} \approx 3,$$

the response becomes

$$\Lambda(r) \sim \frac{1}{r}.$$

The weak clock shift is then

$$\frac{\delta\omega}{\omega} \sim -\frac{1}{r}.$$

This resembles the envelope of weak-field gravitational redshift. The resemblance is not yet a derivation of gravity. It is a scalar precondition: in an effectively three-dimensional branch, scalar timing load has the right radial form to become gravity-like if richer sectors are later supplied.

12 11. Substrate selection: why not every graph becomes space

A relational universe cannot be an arbitrary graph if it is to look like a smooth world. Low-energy modes must be extended. Dispersion must be approximately isotropic. Locality must emerge rather than be assumed by name only.

Random geometric graphs can fail because their modes localize or scatter strongly. Poisson-Delaunay substrates and cotangent Laplacians are better candidates because they are connected to standard discrete approximations of continuum Laplace-Beltrami operators. The issue is not philosophical; it is spectral. A viable substrate must pass low-mode tests.

The minimal tests are:

1. Do low eigenmodes extend across the substrate rather than localize?
2. Does $\lambda(k)$ scale like $|k|^2$ at low k?
3. Does angular anisotropy fall with system size?
4. Does the scalar wave equation built from L_w admit approximately isotropic low-energy propagation?

This is not full Lorentz invariance. It is the spatial scalar-wave precondition for a Lorentz-compatible sector.

13 12. Mass, magnetism, and topology revisited

The scalar clock channel is first because it is simple, not because it is everything.

Mass belongs to persistent localized topology: stable relational excitations that resist dispersion and act as sources.

Magnetism belongs to oriented cycles and phase holonomies: the circulation of relational information around loops.

Topology itself belongs below both: the hidden relational structure from which operators, loads, and sectors are projected.

Gravity belongs above scalar timing: the tensor completion in which clocks, rods, free fall, and stress-energy become one geometry.

The resulting order is:

Level	Description	Observable status
0	relational updating	hidden substrate
1	information topology	paths, loops, adjacency
2	effective operator L_w	response law
3	scalar load Λ	local burden
4	clock lag	first readout
5	gradients of Λ	force-like behavior
6	persistent defects	mass-like sources
7	oriented loops/phases	gauge and magnetism-like sectors
8	tensor completion	gravity-like geometry
9	stable records	classical world

14 13. Experimental and numerical consequences

The program makes several concrete demands.

First, microscopic media should be tested for Schur-complement scalar closure. Fast edge degrees of freedom should generate a positive weighted Laplacian, and static response should follow $(\mu^2 I + L_w)^{-1}$.

Second, dynamic tests should measure finite-coupler failure. Rates should deviate as λ/Ω, with high modes failing first and ringing in the predicted underdamped windows.

Third, clock tests should separate low-frequency phase robustness from instantaneous rate closure. The same medium may pass a DC timing test while failing a high-frequency modal relaxation test.

Fourth, substrate tests should reject graph families whose modes localize. Extended low-energy modes are not optional. They are the difference between a relational network and an effective space.

Fifth, external-coupling tests must be explicit. An internal scalar load does not automatically become an external field. A coupling kernel from internal load to external sensor must be specified, measured, or bounded.

15 14. What would break physics?

The phrase "break physics" should not mean abandoning discipline. It should mean identifying the point at which a successful result would force reorganization of assumptions.

The reorganization proposed here is this:

> Physics may have mistaken the stable projected dashboard for the engine.

If scalar timing geometry is right, then spacetime geometry is not the first layer of law. It is a reconstruction from stable clock-readable projections. Clocks do not merely live in geometry; clocks may be the first instruments by which geometry is inferred from a pre-geometric substrate.

This would not falsify general relativity in its domain. It would reinterpret it as an effective theory of a mature projected sector. Likewise, it would not discard quantum theory. It would ask how quantum discreteness, relational updating, and observer projection participate in the emergence of the sectors that clocks and records can read.

The world-breaking idea is therefore not "gravity is wrong." It is:

> The observable world is the part of relational reality that can keep time.

16 15. Limits and proof levels

This paper uses the word proof only in restricted senses.

16.1 Proven inside the fast-coupler model

Under positive diagonal edge-sector assumptions, eliminating fast edge variables produces a positive weighted graph Laplacian:

$$L_w = B^T \operatorname{diag}(w_e) B.$$

Static scalar closure follows.

16.2 Derived inside the linear dynamic model

Finite coupler speed produces mode-dependent corrections governed by

$$(r + \mu^2)(r + \Omega) + \Omega\lambda_n = 0.$$

The leading rate error scales as λ_n/Ω, and underdamped ringing appears in the predicted window.

16.3 Operationally motivated, not yet proven physically

Clock phase is a privileged observable because it integrates scalar load. This explains why timing may be robust in low-frequency protocols, but it does not prove universal clock protection.

16.4 Not yet proven

This paper does not prove mass, electromagnetism, full Lorentz invariance, external scalar geometry, general relativity, a spin-2 sector, or a theory of everything.

That is the point of the hierarchy. Stronger sectors must be earned.

17 16. Conclusion: the clock before gravity

If the universe is fundamentally relational, the first observable should not be the whole substrate. It should be the weakest stable projection that a local instrument can read.

A scalar load is such a projection. A clock is such an instrument. Clock lag is therefore a natural first sign of a relational universe.

Before clock lag lie relational updating, information topology, effective operators, and scalar load. After clock lag come gradients, force-like behavior, mass-like defects, oriented gauge sectors, magnetism, tensor completion, and gravity.

The clock comes before gravity not because gravity is false, but because gravity is too rich to be the first shadow. The first shadow is delay.

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