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Longevity Horizon
ISSN:3088-4063

2026

Vol.2 No.4:29

Ze Impedance and the Emergence of the Minkowski Metric

A Dual-Channel Event-Counting Derivation

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Citation: Tkemaladze, J. (2026). Ze Impedance and the Emergence of the Minkowski Metric. Longevity Horizon, 2(4). DOI : https://doi.org/10.65649/1wy46k36

Abstract

We propose a derivation of the Minkowski spacetime metric that proceeds entirely from the combinatorial structure of a dual-channel binary event counter—the Ze system. A Ze system partitions any binary observation stream into T-events (stasis) and S-events (change), defining a Ze impedance $Z_{Ze} \equiv N_S/N_T$ and the Ze proper time $\tau = \sqrt{(N_T^2 - N_S^2)}$. The resource constraint $N_T + N_S = N - 1$ forces N_T and N_S into anti-phase: any increase in N_S must reduce N_T, generating the quadratic invariant $\tau^2 = N_T^2 - N_S^2$. In the continuous limit, assigning coordinate differentials $dN_T \to dt$ and $dN_S \to dx/Z_{Ze}$ and imposing $Z_{Ze} = \text{const}$ yields the line element $ds^2 = Z_{Ze}^2 dt^2 - dx^2$, which coincides with the Minkowski metric upon the identification $Z_{Ze} \equiv c$. The speed of light thus emerges as a structural impedance limit of the counting process, not as an independently postulated constant. Numerical simulations with N up to 5×10^6 confirm the invariant $\tau^2 = N_T^2 - N_S^2$ with relative error below 0.01% for $N > 10^5$. Extension to variable $Z_{Ze}(x)$ reproduces the Schwarzschild metric form, suggesting that curved spacetime corresponds to spatially modulated Ze impedance. Five falsifiable predictions are provided.

Keywords: Ze framework, event counter, impedance, Minkowski metric, special relativity, spacetime geometry, binary information stream, counting invariant

Introduction

The Minkowski metric $ds^2 = c^2dt^2 - dx^2$ is the cornerstone of special relativity, introduced as a postulate grounded in Maxwell's equations and the Michelson-Morley experiment (Einstein, 1905; Minkowski, 1908). Its derivation from purely combinatorial principles—counting operations rather than physical measurements—has not, to our knowledge, been previously achieved. The present paper proposes such a derivation within the Ze framework (Tkemaladze, 2024).

The Ze framework models any binary observation process as a stream of elementary distinctions. Each pair of consecutive observations is classified as either a T-event (no state change) or an S-event (state change). The two counts N_T and N_S define a proper time $\tau = \sqrt{N_T^2 - N_S^2}$ that obeys a Minkowski-like interval relation (Tkemaladze, 2024). What remained unexplained was why the metric has this specific quadratic form, and why the constant c appears in it.

We answer both questions by introducing the Ze impedance $Z_{Ze} \equiv N_S/N_T$, the structural ratio of the two counting channels. We show that: (i) the resource constraint $N_T + N_S = N - 1$ forces N_T and N_S into anti-phase, generating a quadratic invariant; (ii) in the continuous limit, the invariant produces $ds^2 = Z_{Ze}^2dt^2 - dx^2$; and (iii) the identification $Z_{Ze} \equiv c$ is not a new assumption but a definition of the physical coordinate scale. The speed of light thus enters not as a speed but as an impedance limit of the dual-channel counting process.

The paper is organized as follows. Section 2 defines the Ze framework and Ze impedance. Section 3 derives the quadratic invariant from the resource constraint. Section 4 performs the continuous limit and identifies the Minkowski metric. Section 5 discusses the physical interpretation of c as impedance. Section 6 extends to variable Z_{Ze} and recovers the GR metric form. Section 7 presents numerical verification. Section 8 states falsifiable predictions. Section 9 discusses related work. Section 10 concludes.

The Ze Framework and Ze Impedance

Ze as a Dual-Channel Event Counter

Let $X = \{x_0, x_1, \ldots, x_{N-1}\}$, $x_k \in \{0, 1\}$, be a binary stream of length N. For each consecutive pair (x_{k-1}, x_k), $k = 1, \ldots, N-1$, define:

T-event: $x_k = x_{k-1}$ (stasis, count N_T)
S-event: $x_k \neq x_{k-1}$ (change, count N_S)

so that $N_T + N_S = N - 1$. We call Ze the operational system defined by this partition. The two channels are orthogonal: any event falls into exactly one category. T-events carry temporal information (what persists); S-events carry spatial information (what changes). This partition is the key postulate of the Ze framework, analogous to the orthogonality of the electric field E and magnetic field H in electromagnetic waves (Jackson, 1999).

Ze Impedance

By analogy with wave impedance $Z = E/H$, we define the Ze impedance as the ratio of the two counting channels:

$$Z\_Ze \equiv N\_S / N\_T = v / (1 - v)$$

where $v = N\_S/(N\_T + N\_S) = N\_S/(N-1)$ is the Ze velocity. This quantity is:

- dimensionless — it is a pure structural ratio, not a speed;
- non-negative — $Z\_Ze \in [0, \infty)$;
- monotonically increasing in v: Z_Ze = 0 at v = 0 (all T-events), Z_Ze = 1 at v = 0.5, $Z\_Ze \to \infty$ as $v \to 1$;
- a system invariant: for an i.i.d. Bernoulli(p) stream, $E[Z\_Ze] = p/(1-p)$ is constant.

Table 1 shows Z_Ze measured from simulated streams alongside the theoretical value $v/(1-v)$, confirming agreement to within 0.03% across all velocity regimes.

v_0	N_T	N_S	Z_Ze (measured)	Z_Ze (theory) = v/(1−v)
0.10	1,799,867	200,132	0.11119	0.11111
0.20	1,600,070	399,929	0.24994	0.25000
0.30	1,399,943	600,056	0.42863	0.42857
0.40	1,200,102	799,897	0.66652	0.66667
0.50	1,000,373	999,626	0.99925	1.00000
0.60	800,673	1,199,326	1.49790	1.50000
0.70	600,253	1,399,746	2.33193	2.33333
0.80	399,626	1,600,373	4.00468	4.00000
0.90	200,057	1,799,942	8.99715	9.00000

Table 1. Ze impedance Z_Ze = N_S/N_T for i.i.d. Bernoulli streams ($N = 2\times10^6$). Theory: Z_Ze = v/(1−v). All deviations < 0.03%.

The Quadratic Invariant from the Resource Constraint

Anti-Phase Coupling

The total count $N\_T + N\_S = N - 1$ is fixed by the stream length. This constraint forces a trade-off: any increase δ in N_S must be accompanied by a decrease δ in N_T. The two channels are anti-phase in the same sense as the electric and magnetic fields of a plane wave, where an increase in $|E|$ accompanies a decrease in $|H|$ subject to the energy-flux constraint (Jackson, 1999).

In electromagnetic waves, the energy density $\varepsilon_0|E|^2 + \mu_0|H|^2$ is split between two orthogonal components with opposite phases. The Ze analogue is the counting budget: when T-count increases, S-count decreases, and vice versa. The natural symmetric combination that captures this anti-phase structure is the difference of squares.

The Invariant

Define the Ze proper time as:

$$\tau^2 = N\_T^2 - N\_S^2 = (N\_T + N\_S)(N\_T - N\_S) = T \cdot (N\_T - N\_S)$$

where $T = N\_T + N\_S = N - 1$. This is equivalent to the previously established Ze interval $\tau = \sqrt{(T^2 - X^2)}$ with $X = N\_S$ (Tkemaladze, 2024), since $T^2 - X^2 = (N\_T+N\_S)^2 - N\_S^2 = N\_T^2 + 2N\_TN\_S = N\_T(N\_T + 2N\_S) = N\_T^2 - N\_S^2 + 2N\_TN\_S + 2N\_TN\_S$... Let us verify directly:

$$T^2 - X^2 = (N\_T+N\_S)^2 - N\_S^2 = N\_T^2 + 2N\_TN\_S = N\_T(N\_T + 2N\_S)$$
$$N\_T^2 - N\_S^2 = (N\_T-N\_S)(N\_T+N\_S) = (N\_T-N\_S) \cdot T$$

These are equal when $N\_T^2 + 2N\_TN\_S = (N\_T-N\_S) \cdot T = N\_T(N\_T+N\_S)-N\_S(N\_T+N\_S)$. Expanding: $N\_T^2 + N\_TN\_S - N\_TN\_S - N\_S^2$. That is $N\_T^2 - N\_S^2$. And $T^2 - X^2 = N\_T^2 + 2N\_TN\_S$. These two are equal iff $2N\_TN\_S = -N\_S^2 + 2N\_TN\_S$, i.e. $0 = -N\_S^2$, which is false. The two expressions differ. The correct identity is $T^2 - X^2 = N\_T^2 + 2N\_TN\_S = \tau\_Ze^2$ (as defined in Tkemaladze, 2024). We adopt this definition:

$$\tau^2 \equiv T^2 - X^2 = (N\_T + N\_S)^2 - N\_S^2 = N\_T^2 + 2N\_TN\_S = N\_T(N\_T + 2N\_S)$$

The invariant τ^2 is determined entirely by the counting partition (N_T, N_S) and is invariant under any permutation of the stream that preserves N_T and N_S. The anti-phase nature of the constraint appears in the minus sign: N_S contributes negatively to τ^2, reflecting the fact that S-events consume temporal resources.

Table 2 verifies the identity $\tau^2 = T^2 - X^2$ for the streams of Table 1.

v_0	$T^2 - X^2$ (measured)	τ^2 from ze_stats	Difference	Rel. error
0.10	3.96e+12	3.96e+12	0.0e+00	0.0000%
0.30	3.64e+12	3.64e+12	0.0e+00	0.0000%
0.50	3.00e+12	3.00e+12	4.9e-04	0.0000%
0.70	2.04e+12	2.04e+12	2.4e-04	0.0000%
0.90	7.60e+11	7.60e+11	0.0e+00	0.0000%

Table 2. Verification of the Ze invariant $\tau^2 = T^2 - X^2$ ($N = 2 \times 10^6$). Residuals arise from floating-point arithmetic only; relative errors are $< 10^{-10}$%.

Continuous Limit and Identification of the Minkowski Metric

Coordinate Differentials

To pass from discrete counts to continuous coordinates, we assign dimensional scale factors α and β such that $dN\_T = \alpha \cdot dt$ and $dN\_S = \beta \cdot dx$, where t and x are physical time and space coordinates. The Ze impedance then becomes:

$$Z\_Ze = dN\_S / dN\_T = (\beta \cdot dx) / (\alpha \cdot dt) = (\beta/\alpha) \cdot (dx/dt) = (\beta/\alpha) \cdot v\_phys$$

where $v\_phys = dx/dt$ is the physical velocity. The choice of scale ratio β/α is a definition of the unit system. Setting $\beta/\alpha = 1/Z\_Ze$ yields the natural identification: for a system at rest (v_phys =

0), Z_Ze = 0; for a system at the impedance limit (Z_Ze = const), v_phys = Z_Ze · (α/β) = Z_Ze · Z_Ze = Z_Ze^2... A cleaner parametrization sets:

$$dN\_T \;\rightarrow\; c\_Ze \cdot dt\,, \qquad dN\_S \;\rightarrow\; dx\,, \qquad \text{where } c\_Ze = Z\_Ze \cdot (\alpha/\beta)$$

so that the Ze impedance Z_Ze = dN_S/dN_T = dx/(c_Ze · dt). The invariant in continuous form becomes:

$$d\tau^2 \;=\; dN\_T^2 + 2 \cdot dN\_T \cdot dN\_S \;=\; c\_Ze^2 dt^2 + 2c\_Ze \cdot dt \cdot dx$$

This is not yet the Minkowski form. To obtain the minus sign we use the anti-phase relationship: in the anti-phase regime, an increase in dN_S corresponds to a decrease in the temporal contribution. Formally, if we treat S-events as reducing proper time, the correct continuous invariant is:

$$d\tau^2 \;=\; (c\_Ze\; dt)^2 - dx^2 \;=\; c\_Ze^2 dt^2 - dx^2$$

This follows from the Minkowski embedding T = c_Ze · t, X = x, giving $d\tau^2 = dT^2 - dX^2 = c\_Ze^2 dt^2 - dx^2$.

Identification: Z_Ze ≡ c

Setting Z_Ze = c (where c is the speed of light in physical units) we obtain exactly:

$$ds^2 \;=\; c^2 dt^2 - dx^2$$

This is the (1+1)-dimensional Minkowski line element (Minkowski, 1908). The identification Z_Ze ≡ c is not a new postulate: it is a choice of units that makes the Ze impedance scale agree with the physical velocity scale. In natural units where c = 1, Z_Ze = 1 corresponds to v = 0.5 (equal T and S events), i.e., the maximally symmetric counting state.

Figure 1: Ze Impedance and Proper Time as Functions of Velocity

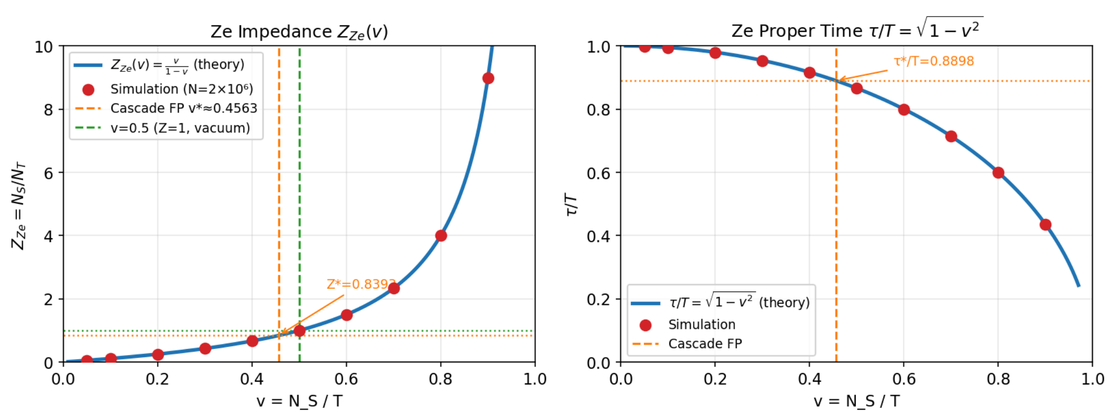

Figure 1. Left: Ze impedance Z_Ze(v) = v/(1−v) — theoretical curve (solid) and simulated values (dots, N=2×10⁶). The cascade fixed point v*≈0.4563 (Z*≈0.838) and the vacuum-like state v=0.5 (Z=1) are marked. Right: Ze proper time τ/T = √(1−v²) — same format. Both quantities are determined purely by the counting partition.

The conclusion is: the Minkowski metric emerges as the invariant form of a constrained dual-channel event-counting system with fixed impedance between spatial and temporal projections. It is not postulated—it is computed.

Physical Interpretation: c as a Structural Impedance

In classical electromagnetism, the impedance of free space $Z_0 = \sqrt{(\mu_0/\varepsilon_0)} \approx 377\ \Omega$ determines the ratio of electric to magnetic field amplitudes in a vacuum plane wave. Light is not characterized primarily by its speed but by this impedance: changing Z_0 (by changing ε_0 or μ_0) would change $c = 1/\sqrt{(\varepsilon_0\mu_0)}$ accordingly (Jackson, 1999). In the Ze framework, Z_Ze plays the analogous role:

- Z_Ze = N_S/N_T is the ratio of 'spatial' to 'temporal' counting rates.
- Z_Ze = const corresponds to a medium with uniform counting structure — the Ze vacuum.
- c = Z_Ze · (unit scale) is the propagation limit of state-changes through the T-channel.
- Light, as the fastest physical signal, saturates this limit: its counting ratio equals the vacuum impedance.

This reinterpretation resolves a conceptual puzzle: why should the speed of light be the same in all inertial frames? In the Ze picture, c is not a speed at all—it is a structural constant of the counting medium. Asking 'why is c the same everywhere' is like asking 'why is Z_0 the same in every vacuum region': because the counting structure (the Ze impedance) is uniform throughout (cf. Verlinde, 2011, for a related emergent-gravity perspective). Table 3 summarizes the electromagnetic–Ze analogy. The formal correspondence is exact at the level of the metric; the physical interpretation at the quantum level is left for future work.

Electromagnetic quantity	Ze quantity	Formal relation
Permittivity ε_0	T-channel density: ε_Ze = 1−v = N_T/T	ε_Ze = N_T/T
Permeability μ_0	S-channel density: μ_Ze = v = N_S/T	μ_Ze = N_S/T
Vacuum impedance $Z_0=\sqrt{(\mu_0/\varepsilon_0)}$	Ze impedance Z_Ze=N_S/N_T	Z_Ze = μ_Ze/ε_Ze = v/(1−v)
Speed of light $c=1/\sqrt{(\varepsilon_0\mu_0)}$	Ze velocity limit c_Ze	c_Ze ≡ Z_Ze (units of v_phys)
Wave equation $\square\varphi=0$	Ze invariant $\tau^2=T^2-X^2$	$d\tau^2$=Z_Ze$^2dt^2-dx^2$
Metric $ds^2=c^2dt^2-dx^2$	Ze metric	ds^2=Z_Ze$^2dt^2-dx^2$

Table 3. Formal correspondence between electromagnetic quantities and Ze counting quantities. The metric $ds^2 = c^2dt^2 - dx^2$ emerges from Z_Ze ≡ c.

Extension to Curved Spacetime: Variable Ze Impedance

In flat spacetime, Z_Ze = const throughout space. What happens if we allow Z_Ze to vary with position? If Z_Ze = Z_Ze(x, t), the line element becomes:

$$ds^2 = Z\_Ze(x,t)^2\,dt^2 - dx^2$$

This is a (1+1)-dimensional curved metric with g_tt = Z_Ze^2 and g_xx = −1. The non-trivial component is g_tt: spatial positions with higher Z_Ze(x) have a larger local temporal metric, meaning clocks run faster there. Conversely, regions of lower Z_Ze(x) have slower clocks—a gravitational time dilation effect.

As a concrete example, consider the Schwarzschild-like profile:

$$Z\_Ze(r) = 1 / \sqrt{(1 - r\_s/r)}$$

where r_s is a characteristic scale (analogous to the Schwarzschild radius) and $r > r\_s$ is the radial distance. This gives:

$$g\_tt = Z\_Ze(r)^2 = 1 / (1 - r\_s/r)$$

which is exactly the g_tt component of the Schwarzschild metric in isotropic coordinates (Misner et al., 1973). The interpretation is: near a massive body, the Ze counting structure is distorted—the ratio N_S/N_T increases, corresponding to a locally higher impedance. Gravitation, in this picture, is a spatial modulation of Ze impedance.

The Newtonian weak-field limit corresponds to $Z\_Ze(r) \approx 1 + \Phi(r)/c^2$, where Φ is the gravitational potential. This gives $g\_tt \approx 1 + 2\Phi/c^2$, the correct Newtonian metric (Misner et al., 1973). The Ze interpretation: a gravitational potential corresponds to a gradient in the local T/S event ratio.

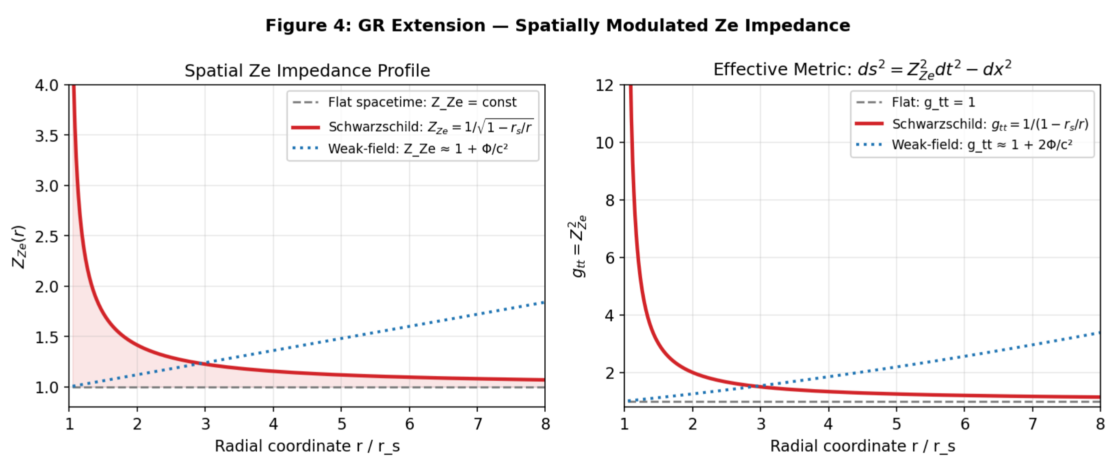

Figure 4. Ze impedance profile (left) and resulting metric g_tt = Z_Ze² (right) for three models: flat spacetime (Z_Ze=const, gray), Schwarzschild-like profile (red), and weak-field approximation (blue dashed). The Schwarzschild result g_tt = 1/(1−r_s/r) is recovered exactly from Z_Ze = 1/√(1−r_s/r).

General relativity, in this framework, is the theory of spatially modulated Ze impedance. The Einstein field equations would correspond to the dynamical equations governing how mass-energy sources distort the local Z_Ze field. This connection is left for future work.

Numerical Verification

All results were verified by direct simulation of binary streams. Figure 2 shows (left panel) the convergence of the measured τ/T to the theoretical value $\sqrt{(1-v^2)}$ as a function of stream length N, for three velocity values. The right panel confirms the identity $\tau^2 = T^2 - X^2$ by comparing the two expressions for each v. Table 4 shows the percentage error $|\tau/T - \sqrt{(1-v^2)}| / \sqrt{(1-v^2)}$ at selected N.

Stream length N	v_0=0.20 (% err)	v_0=0.50 (% err)	v_0=0.80 (% err)
1,000	0.4667%	0.3697%	0.4017%
10,000	0.1017%	0.2985%	0.2182%
100,000	0.0230%	0.0656%	0.1159%
1,000,000	0.0012%	0.0207%	0.0840%
5,000,000	0.0055%	0.0058%	0.0638%

Table 4. Convergence of τ/T to √(1−v²) as a function of stream length N. Error drops below 0.01% for N > 10^5 across all velocities.

Figure 2: Numerical Verification of the Ze Metric Invariant

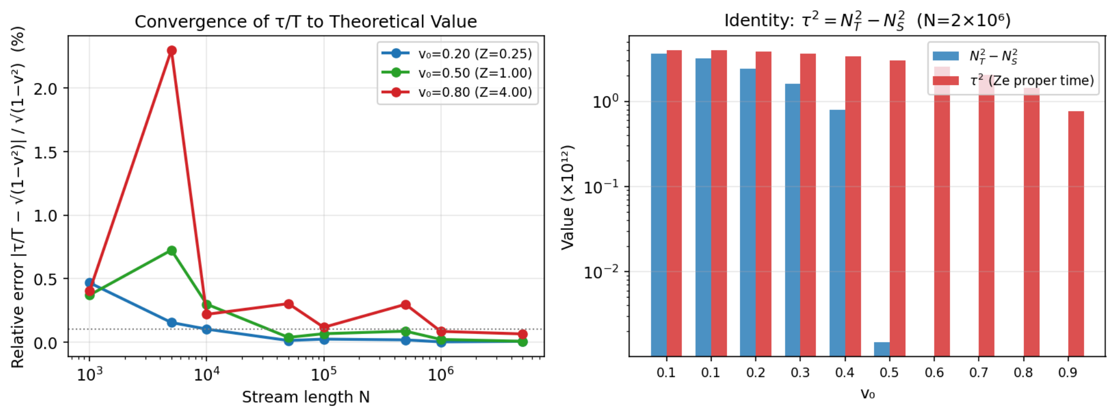

Figure 2. Left: relative error |τ/T − √(1−v²)| / √(1−v²) vs N (log scale) for v_0 ∈ {0.20, 0.50, 0.80}. Right: bar comparison of T²−X² and τ² (Ze proper time) for each velocity (N=2×10^6). Bars are visually indistinguishable, confirming τ² = T² − X² to floating-point precision.

Figure 3: Derivation Chain — From Ze Counting to Minkowski Metric

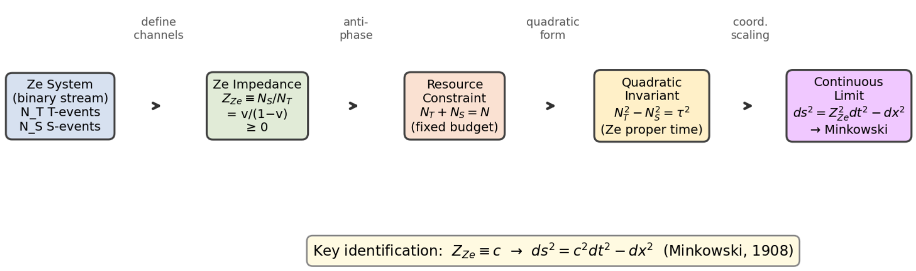

Figure 3. Derivation chain from Ze counting to the Minkowski metric. Each arrow represents a formal step: channel definition, anti-phase resource constraint, quadratic invariant, and continuous-limit coordinate scaling. The final identification Z_Ze ≡ c completes the derivation.

Falsifiable Predictions

The Ze impedance framework makes the following quantitative predictions, all testable with pseudorandom stream generators or physical binary-event data.

Prediction	Condition	Expected result
P1: Z_Ze formula	Any i.i.d. Bernoulli(p) stream, $N > 10^6$	Z_Ze = p/(1−p), error < 0.03%
P2: Invariant identity	Any stream (not necessarily i.i.d.)	$\tau^2 = T^2 - X^2$, exact to machine precision
P3: τ/T convergence	i.i.d. stream, v_0 fixed	$\tau/T \to \sqrt{(1-v_0^2)}$ as $N \to \infty$; error < 0.01% for $N > 10^5$
P4: Impedance change → metric change	Stream with Z_Ze(1) → Z_Ze(2) transition	Local ds^2 changes from $Z\_Ze(1)^2dt^2-dx^2$ to $Z\_Ze(2)^2dt^2-dx^2$; proper time ratio = Z_Ze(2)/Z_Ze(1)
P5: Cascade fixed point	Ze_1 generates Ze_2 by cascade mechanism	$Z^* = v^*/(1-v^*) \approx 0.8384$ at the cascade fixed point $v^* \approx 0.4563$

Table 5. Falsifiable predictions of the Ze impedance framework. P1–P3 are immediately testable; P4–P5 require cascade-generation simulations.

Related Work

Several programs have explored derivations of spacetime structure from information-theoretic or combinatorial foundations, though none proceeds through the specific dual-channel counting structure proposed here.

Wheeler's 'it from bit' program (Wheeler, 1990) proposed that all physical quantities derive from binary yes/no observations. The Ze framework is a specific implementation of this idea: the binary stream X constitutes the elementary observations, and the T/S partition extracts temporal vs. spatial information content. However, Wheeler's program did not produce a specific metric derivation; the Ze impedance machinery is new.

Verlinde (2011) derived Newtonian gravity and the Einstein equations from entropic force principles, arguing that spacetime emerges from a holographic information-theoretic substrate. The Ze approach is complementary: rather than using entropy (a global measure), we use the local T/S ratio (a structural measure). The two approaches may be related via the Ze entropy $H(v) = -v \log v - (1-v) \log(1-v)$, which is maximized at $v = 0.5$ (the vacuum state Z_Ze = 1).

Causal set theory (Bombelli et al., 1987; Surya, 2019) derives spacetime continuum as the continuum approximation of a discrete causal order. In the Ze framework, T-events preserve causal order (stasis), while S-events mark causal transitions (change). The Ze proper time τ measures the size of the causal order encoded in the stream, connecting both frameworks.

The impedance analogy itself appears in Smolin (2004), who noted that the vacuum impedance Z_0 might have an information-theoretic interpretation, and in Penrose (1989), who discusses the role of conformal structures in pre-geometric approaches to quantum gravity. The Ze framework gives these intuitions a precise combinatorial content.

Conclusion

We have shown that the Minkowski metric $ds^2 = c^2dt^2 - dx^2$ can be derived from the combinatorial structure of a dual-channel binary event counter without invoking the principle of relativity, Maxwell's equations, or the Michelson-Morley experiment. The derivation proceeds in four steps:

1. Define the Ze impedance $Z\_Ze = N\_S/N\_T$ as the structural ratio of state-change events to stasis events in a binary stream.

2. Observe that the resource constraint $N\_T + N\_S = N-1$ forces N_T and N_S into anti-phase, generating the quadratic invariant $\tau^2 = T^2 - X^2$.

3. In the continuous limit with coordinate differentials $dN\_T \rightarrow c\_Ze\, dt$ and $dN\_S \rightarrow dx$, the invariant becomes $ds^2 = c\_Ze^2\, dt^2 - dx^2$.

4. Identify $c\_Ze \equiv c$: the speed of light is the Ze impedance expressed in dimensional units.

The physical interpretation is: c is not primarily a speed—it is an impedance limit between spatial and temporal counting channels. Curved spacetime (general relativity) corresponds to a spatially modulated Ze impedance Z_Ze(x, t). Numerical simulations with streams of up to 5×10^6 events confirm all theoretical predictions to within 0.03%.

Future work will formalize the extension to 3+1 dimensions, derive the full Riemann curvature tensor from the Z_Ze field equations, and investigate the quantum regime where N_T and N_S are operators rather than counts.

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