TPB/VERSF Three-Body Dynamics: Emergent Time, Distinguishability, and Information-Bounded Chaos

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Abstract

We reformulate the classical gravitational three-body problem within the Ticks-Per-Bit (TPB) and Void-Energy-Regulated Space Framework (VERSF), in which physical time is not fundamental but emerges only when a dynamical system generates at least one bit of new distinguishable information. Rather than assuming continuous time, we posit that microdynamic evolution occurs at a fine-grained "microtick" scale Δt, while physical time advances in discrete informational steps called bit-events. We construct this framework explicitly for the 1D collinear three-body case and generalise to 2D, 3D, and arbitrary N-body systems. The resulting dynamics constitute a discrete informational trajectory rather than a continuous chaotic flow. We derive scaling relations connecting the TPB information rate to classical Lyapunov exponents and Kolmogorov-Sinai entropy, including a toy computation showing how emergent time modifies effective Lyapunov behaviour. Four quantitative, computationally falsifiable predictions distinguish TPB dynamics from standard formulations. This work establishes the first complete application of emergent informational time to multi-body gravitational chaos.

General Reader Summary

This paper explores a surprising idea: *what if time only moves forward when the universe becomes more distinguishable?* In classical physics, especially in the notoriously unsolvable **three-body problem**, we assume that time flows smoothly and every tiny change matters. But the TPB/VERSF framework proposes something different: time advances only when the system generates at least **one new bit of information**. Instead of watching the three bodies evolve in an endlessly chaotic blur, the system becomes a sequence of informational "snapshots" taken only when something truly new happens. This doesn't magically solve the three-body problem in the traditional sense, but it **changes the rules of the game**: the chaotic motion becomes a discrete, information-driven process that *can* be followed, analysed, and even predicted using new tools. Close encounters produce bursts of new bits; quiet phases generate almost none — giving us a clean, structured way to track and quantify chaos. This reframing transforms the three-body problem from an infinitely delicate system into one that is **computationally and informationally solvable**, revealing hidden order beneath one of physics' wildest dances.

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1. Introduction

The Newtonian three-body problem stands as one of the foundational examples of deterministic chaos. Its continuous-time evolution exhibits extreme sensitivity to initial conditions, fractal phase-space structure, and the absence of closed-form solutions. These features rest on implicit assumptions: that time flows continuously, that spatial precision is unbounded, and that arbitrarily small differences in configuration are physically meaningful.

The TPB/VERSF framework challenges these assumptions. In this picture, time is not a background parameter but an emergent quantity that advances only when a system produces at least one bit of distinguishable change relative to finite resolution scales. Microphysical processes unfold at a fine-grained timescale Δt (the "microtick"), but a new moment of physical time is declared only when the system's configuration differs—at finite observational resolution—by at least one bit from the previous recorded state.

This creates a fundamentally different picture of dynamical evolution:

- **Microticks** represent raw deterministic state updates governed by the equations of motion.
- **Bit-events** mark the emergence of new distinguishable information and define physical moments.
- **TPB (Ticks-Per-Bit)** counts how many microticks are required to generate one bit of new information.

1.1 Resolution Scales in TPB

Central to the TPB framework are finite resolution parameters ε_x (position) and ε_v (velocity) that define the threshold for distinguishability. These parameters admit three possible interpretations:

1. **Fundamental scales**: If $\varepsilon_x \sim \ell$_Planck and $\varepsilon_v \sim c$ (or appropriate Planck-scale quantities), then distinguishability reflects fundamental physical limits and emergent time is observer-independent.
2. **Effective scales**: If ε_x, ε_v represent the resolution of a particular measurement apparatus or coarse-graining procedure, then different observers may experience different emergent time flows—analogous to renormalisation group flow, where physics at different scales exhibits different effective dynamics.
3. **Phenomenological parameters**: The scales may be treated as free parameters to be constrained by matching TPB predictions to observational or computational data.

The mathematical framework developed here applies in all three cases. The interpretation chosen determines the ontological status of emergent time but not its formal structure.

1.2 Goals and Structure

This paper achieves four main goals. First, it presents the first fully explicit construction of TPB emergent time for a multi-body dynamical system. Second, it defines a resolution-based information functional that governs bit-events. Third, it derives scaling relations connecting TPB information growth to classical chaos indicators. Fourth, it proposes concrete, computationally testable predictions. This elevates TPB/VERSF from philosophical framework to quantitative dynamical model.

The paper is organised as follows. Section 2 establishes the microdynamic evolution equations. Section 3 defines the information measure and distinguishability criteria. Section 4 constructs emergent time via bit-events. Section 5 addresses collision regularisation. Section 6 provides a worked example. Sections 7–8 connect TPB to classical chaos theory and present falsifiable predictions. Section 9 generalises to N-body systems. Sections 10–11 discuss implications and conclude.

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2. Microdynamic Evolution

We begin with standard Newtonian gravitational dynamics, but treat it as *microdynamic*: a fine-grained deterministic update that does not itself constitute physical time.

2.1 The Microtick Timescale

The microtick interval Δt represents the fundamental update rate of the underlying dynamics. In the VERSF framework, this scale is not arbitrary but tied to the information-processing capacity of the void substrate. The void supports a maximum information throughput determined by the bit-energy relation:

$$E_{bit} = k_B T_{void} \ln 2$$

where T_{void} is the effective temperature of the void's informational degrees of freedom. Combined with the characteristic energy scale of gravitational interactions, this yields a natural tick rate. In previous TPB applications to particle physics, this rate has been estimated at approximately $\nu_{tick} \sim 3 \times 10^{12}$ Hz, corresponding to $\Delta t \sim 3 \times 10^{-13}$ s.

For the classical three-body problem studied here, the absolute value of Δt is less critical than the ratio $\Delta t/\tau_{dyn}$, where τ_{dyn} is the dynamical timescale of the system. We require $\Delta t \ll \tau_{dyn}$ to ensure the microtick evolution accurately captures the continuous Newtonian dynamics. **In this paper, ν_{tick} sets a reference scale; all emergent-time phenomena depend primarily on the ratio $\Delta t/\tau_{dyn}$ and on the resolution parameters ε_x, ε_v.** The specific numerical value of ν_{tick} affects only the absolute calibration of emergent time, not its qualitative structure or the predictions derived below.

2.2 The 1D Collinear System

Consider three point masses constrained to a line with positions $x_1, x_2, x_3 \in \mathbb{R}$, velocities v_1, v_2, v_3, and masses m_1, m_2, m_3. The gravitational acceleration on mass i is:

$$a_i = -G \sum_{j\neq i} m_j \cdot \mathrm{sgn}(x_i - x_j) / (|x_i - x_j|^2 + \delta^2)$$

where δ is a softening length that regularises close encounters (see Section 5). The sgn function provides the correct directional structure for 1D gravity.

Evolution proceeds via symplectic Euler integration at microtick k:

$$v_i^{(k+1)} = v_i^{(k)} + a_i^{(k)} \Delta t$$

$$x_i^{(k+1)} = x_i^{(k)} + v_i^{(k+1)} \Delta t$$

Define the full microstate:

$$X^{(k)} = (x_1^{(k)}, x_2^{(k)}, x_3^{(k)}, v_1^{(k)}, v_2^{(k)}, v_3^{(k)})$$

This produces a deterministic map $X^{(k+1)} = F(X^{(k)})$. At this level, the system is classical Newtonian mechanics. The TPB/VERSF structure enters through the distinguishability criterion.

2.3 Extension to Higher Dimensions

In 2D or 3D, positions become vectors $\mathbf{r}_i \in \mathbb{R}^d$ and the acceleration takes the standard form:

$$\mathbf{a}_i = -G \sum_{j\neq i} m_j (\mathbf{r}_i - \mathbf{r}_j) / (|\mathbf{r}_i - \mathbf{r}_j|^2 + \delta^2)^{3/2}$$

All subsequent constructions generalise directly by replacing scalar separations with vector norms.

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3. Distinguishability and the Information Measure

Physical time advances when the system's configuration becomes distinguishably different. We formalise this through an information measure defined at finite resolution.

3.1 Pairwise Invariants

Define the pairwise separations and relative velocities:

$d_{ij} = |x_i - x_j|$

$u_{ij} = |v_i - v_j|$

In higher dimensions, these become $d_{ij} = |\mathbf{r}_i - \mathbf{r}_j|$ and $u_{ij} = |\mathbf{v}_i - \mathbf{v}_j|$.

3.2 The Information Functional

Define the truncated logarithm:

$\log_2(z)_+ = 0$ if $z \leq 1$; $\log_2(z)$ if $z > 1$

The configuration information is:

$I(X) = \sum_{i<j} [\log_2(d_{ij}/\varepsilon_x)_+ + \log_2(u_{ij}/\varepsilon_v)_+]$

Interpretation: Each pairwise separation or velocity difference that exceeds the resolution threshold contributes $\log_2$(ratio) bits. Quantities below threshold contribute zero—they are indistinguishable from coincidence.

Note on zero velocities: When all velocities vanish, $u_{ij} = 0$ for all pairs. Since $0/\varepsilon_v = 0 < 1$, the truncated logarithm returns 0. This is well-defined and physically sensible: stationary particles carry no velocity information.

3.3 I(X) as an Upper Bound on Distinguishability

The information functional I(X) is intentionally defined as an upper bound on distinguishability rather than a minimal coding length. Because gravity couples each mass pair independently, using all three pairwise separations yields a symmetric and dynamically meaningful measure, even if some terms are not independent in 1D. In one dimension with ordered particles $x_1 < x_2 < x_3$, the separation $d_{13} = d_{12} + d_{23}$ introduces redundancy. We retain all three terms because (a) it treats all particle pairs symmetrically, (b) it generalises naturally to higher dimensions where no such constraint exists, and (c) the overcounting is systematic and does not affect the bit-event dynamics qualitatively. In 2D and 3D the redundancy disappears entirely. A minimal representation using only N−1 independent separations could alternatively be employed for 1D systems requiring strict information-theoretic accounting.

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4. Bit-Events and Emergent Physical Time

4.1 The Bit-Event Rule

Let $n = 0, 1, 2, \ldots$ index **bit-events**, the emergent moments of physical time. Let k index microticks.

Initialise:

- $X_0 = X^{(0)}$ (initial microstate)
- $I_0 = I(X_0)$ (initial information)
- $k_0 = 0$

At each microtick k, compute $I(X^{(k)})$. A new bit-event occurs when:

$$|I(X^{(k)}) - I_n| \geq 1$$

Upon triggering, record:

$$k_{n+1} = k,\ X_{n+1} = X^{(k)},\ I_{n+1} = I(X^{(k)})$$

The ticks-per-bit and emergent time increment are:

$$TPB_{n+1} = k_{n+1} - k_n$$

$$\Delta T_{n+1} = TPB_{n+1} \cdot \Delta t$$

Cumulative emergent time:

$$T_n = \sum_{m=1}^{n} \Delta T_m$$

4.2 Symmetric vs. Asymmetric Triggering

The symmetric threshold $|\Delta I| \geq 1$ is chosen because bit-events correspond to resolvable state changes, irrespective of whether structure becomes more complex or more compact. If only increases were considered, collapsing structures (e.g., infalling particles) would be "time-frozen," which is unphysical. The symmetric rule ensures time flows for all resolvable change.

An alternative **asymmetric rule** ($\Delta I \geq +1$ only) would treat time as recording only *growth* of distinguishability. This may be appropriate in contexts where the second law of thermodynamics plays a foundational role, but we adopt the symmetric rule here as the more general choice.

4.3 Information Echoes in Periodic Systems

In bound oscillatory systems, the configuration may return to previously visited information values. Under the symmetric rule, each threshold crossing generates a new bit-event, even if the system is retracing earlier structure. This produces "information echoes"—repeated bit-events at similar I values.

This is not a defect but a feature: the system is genuinely producing distinguishable change as it oscillates. An observer watching the system would perceive time passing even during periodic motion. However, for systems exhibiting exact periodicity, a refinement could be introduced wherein identical configurations (within resolution) do not generate new bit-events. We defer this extension to future work.

4.4 The Physical Meaning of Emergent Time

TPB time is best interpreted as an informational analogue of proper time: it measures how much new, resolvable structure the system has produced. Coordinate time continues to govern microphysics, but emergent time encodes the physically relevant, coarse-grained evolution. In this sense, TPB time is neither arbitrary nor subjective—it reflects the finite-information character of real physical systems. Just as proper time in relativity depends on the worldline traversed, TPB time depends on the informational trajectory through configuration space.

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5. Collision Regularisation

Newtonian gravity diverges as $d_{ij} \to 0$. While the information measure handles this gracefully (small separations contribute zero bits), the acceleration becomes singular.

We adopt Plummer softening:

$a_i \propto 1 / (d_{ij}^2 + \delta^2)^{3/2}$ (3D)

$a_i \propto 1 / (d_{ij}^2 + \delta^2)$ (1D)

where δ is a softening length.

5.1 Justification for $\delta \sim \varepsilon_x$

By setting the gravitational softening length equal to the spatial distinguishability scale, $\delta = \varepsilon_x$, the model becomes self-consistent: the regime in which gravity becomes non-Newtonian coincides precisely with the regime in which separations cannot be distinguished at all. In this way the informational coarse-graining and the dynamical coarse-graining align, preventing physical divergences in a region where fine structure is not physically meaningful. This is not merely a computational convenience but reflects a coherent physical picture in which resolution limits apply uniformly to both dynamics and observation.

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6. Worked Example: Symmetric Three-Body Configuration

6.1 Initial Conditions

- Positions: $x_1 = -1$, $x_2 = 0$, $x_3 = +1$
- Velocities: $v_1 = v_2 = v_3 = 0$
- Masses: $m_1 = m_2 = m_3 = 1$
- Resolution: $\varepsilon_x = 0.5$, $\varepsilon_v = 0.1$
- Microtick: $\Delta t = 0.01$
- Units: $G = 1$

6.2 Initial Information Content

Pairwise separations: $d_{12} = 1$, $d_{23} = 1$, $d_{13} = 2$.

Position contributions:

- $\log_2(1/0.5) = \log_2(2) = 1$ bit (for d_{12})
- $\log_2(1/0.5) = 1$ bit (for d_{23})
- $\log_2(2/0.5) = \log_2(4) = 2$ bits (for d_{13})

Velocity contributions: All $u_{ij} = 0$, so all terms vanish.

Total: $I_0 = 4$ bits.

6.3 Early Evolution

After one microtick, gravitational acceleration is approximately:

- $a_1 \approx +1.25$ (pulled rightward by m_2, m_3)
- $a_2 \approx 0$ (symmetric)
- $a_3 \approx -1.25$ (pulled leftward)

Velocity changes: $\Delta v \sim 0.0125$.

Position changes: $\Delta x \sim 1.25 \times 10^{-4}$.

The change in d_{12} is ~ 10^{-4}, giving:

$\Delta\log_2(d_{12}/\varepsilon_x) \approx \Delta d_{12} / (d_{12} \cdot \ln 2) \approx 10^{-4}$ bits

Since $\Delta I \ll 1$, **no bit-event occurs**. Emergent time remains frozen.

6.4 Eventual Bit-Event

As the outer masses accelerate inward, velocities grow and separations shrink. Eventually the cumulative change in I(X) reaches 1 bit, triggering the first bit-event. The elapsed microticks give TPB_1, and emergent time begins to flow.

In chaotic phases (near close approaches), bit-events cluster rapidly. In quiescent phases, many microticks pass without bit-events.

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7. Connection to Classical Chaos Theory

7.1 Lyapunov Exponents and Phase-Space Divergence

The maximal Lyapunov exponent λ characterises the exponential rate at which nearby trajectories diverge:

$|\delta X(t)| \sim |\delta X(0)|\ e\lambda t$

In classical mechanics, this divergence occurs at all scales. In TPB, only divergence that crosses resolution thresholds is registered.

7.2 How TPB Modifies Continuous Chaos

In TPB, the exponential divergence of nearby trajectories still occurs at the microdynamic level, but only divergences large enough to cross informational thresholds contribute to emergent time. As a result, the effective Lyapunov behaviour is piecewise rather than continuous: the system's "observable" divergence is discretised into bit-level increments. Fine-grained chaos persists in the microticks, but emergent time samples this chaos only when it produces resolvable change.

7.3 Toy Lyapunov Computation: Emergent-Time Exponent

We can make the modification of Lyapunov behaviour explicit through a simple computation. Consider two nearby trajectories X(t) and X'(t) = X(t) + δX(t), both evolving under the same microdynamics.

Classical case: The Lyapunov exponent in coordinate time is:

$$\lambda = \lim_{t\to\infty} (1/t) \ln(|\delta X(t)| / |\delta X(0)|)$$

TPB case: Define the emergent-time Lyapunov exponent by measuring divergence at bit-events:

$$\lambda\_TPB = \lim_{n\to\infty} (1/T_n) \ln(|\delta X_n| / |\delta X_0|)$$

where $\delta X_n = X_n - X'_n$ is the separation at bit-event n, and T_n is the cumulative emergent time.

Relationship: At bit-event n, the coordinate time is $t_n = k_n \Delta t$. The actual phase-space separation $|\delta X_n|$ equals $|\delta X(t_n)|$ from the continuous evolution. Thus:

$$\lambda\_TPB = (t_n/T_n) \cdot (1/t_n) \ln(|\delta X(t_n)| / |\delta X(0)|) = (t_n/T_n) \cdot \lambda$$

The ratio t_n/T_n measures how coordinate time relates to emergent time. When bit-events are frequent (low TPB, highly chaotic regime), $T_n \approx t_n$ and $\lambda\_TPB \approx \lambda$. When bit-events are sparse (high TPB, regular regime), emergent time undersamples the continuous evolution.

Key result: The *sampled trajectory* $\{X_n\}$ exhibits **piecewise-exponential** divergence rather than continuous exponential growth. The divergence appears in discrete jumps of at least ε_x or ε_v, occurring at irregular emergent-time intervals.

Effective coarse-grained exponent: A more useful quantity is the rate at which *resolvable* divergence accumulates. If two trajectories must differ by at least ε to be distinguished, then the time to first distinguishable separation is:

$$t\_sep \approx (1/\lambda) \ln(\varepsilon / |\delta X(0)|)$$

The TPB framework naturally enforces this: trajectories closer than ε contribute zero bits and generate no emergent time difference. This provides an operational, resolution-dependent definition of chaos.

Summary: In practice, λ_TPB should be interpreted as a coarse-grained, resolution-dependent Lyapunov exponent. It matches the classical λ in strongly chaotic regions where bit-events are dense, and is effectively reduced in regular regions where emergent time skips long microdynamic intervals. The TPB framework thus provides a natural bridge between infinite-precision chaos theory and finite-resolution physical observation.

7.4 Kolmogorov-Sinai Entropy

The Kolmogorov-Sinai (KS) entropy h_KS measures the rate of information production in phase space:

$$h\_KS = \sum_{\lambda_i > 0} \lambda_i$$

where the sum runs over positive Lyapunov exponents. For typical chaotic systems, h_KS quantifies how many bits of new information the system generates per unit time at infinite resolution.

7.5 The TPB Information Rate

We define the **TPB information rate**:

$$h\_TPB = \lim_{n\to\infty} (n / t_n)$$

where $t_n = k_n \cdot \Delta t$ is the coordinate (microtick) time at bit-event n. This measures bits generated per unit coordinate time at resolution (ε_x, ε_v).

Scaling relation: For a system with KS-entropy h_KS, we expect:

$$h\_TPB(\varepsilon) \sim h\_KS \cdot f(\varepsilon / \ell\_char)$$

where ℓ_char is a characteristic length scale (e.g., mean separation) and f is a function satisfying:

- $f(0) \to 1$ (infinite resolution recovers h_KS)
- $f(x) \to 0$ as $x \to \infty$ (coarse resolution suppresses information)

A plausible functional form is $f(x) \sim 1/(1 + x^2)$ or exponential cutoff, but determining the exact form requires numerical study.

7.6 TPB as a Coarse-Grained KS-Entropy

The TPB framework provides a natural regularisation of KS-entropy. Classical h_KS assumes infinite precision; h_TPB is the information rate accessible at finite resolution. This connects to the physical intuition that real observers cannot access arbitrarily fine phase-space structure.

Key insight: High Lyapunov exponents produce frequent bit-events (fast emergent time); low Lyapunov regions produce sparse bit-events (slow emergent time). TPB time flows fastest where chaos is strongest.

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8. Falsifiable Predictions

The following predictions distinguish TPB dynamics from standard continuous-time formulations and are computationally testable.

Prediction 1 (Resolution Scaling)

For a given three-body trajectory, compute h_TPB at two resolutions ε and ε'. The ratio satisfies:

$$h\_TPB(\varepsilon) / h\_TPB(\varepsilon') = g(\varepsilon/\varepsilon', \lambda)$$

where g depends on the Lyapunov exponent λ. Specifically, for $\varepsilon' = \alpha\varepsilon$ with $\alpha > 1$:

$$h\_TPB(\varepsilon) / h\_TPB(\alpha\varepsilon) > 1$$

and the ratio should increase monotonically with λ. Systems with larger Lyapunov exponents are more sensitive to resolution changes.

Test: Simulate ensembles of three-body systems with varying degrees of chaos (controlled by energy or angular momentum). Verify that the resolution-ratio of h_TPB correlates positively with measured Lyapunov exponents.

Prediction 2 (Pericenter Bursts)

Near close approaches (pericenter passages), the rate of bit-events should spike dramatically. Define the **local bit-rate**:

$$\beta(t) = dn/dt$$

evaluated over a sliding window. Then $\beta(t)$ should peak at times when $\min_{i\neq j}(d_{ij})$ reaches local minima.

Test: Track bit-event times and correlate with minimum pairwise separation. The correlation coefficient between $\beta(t)$ and $1/\min(d_{ij})$ should be significantly positive.

Prediction 3 (Time-Average Divergence)

Define an observable $O(X)$ (e.g., total kinetic energy, moment of inertia). Compute:

- Coordinate-time average: $\langle O\rangle\_t = (1/t\_N) \int_0^{t\_N} O(X(t))\, dt$
- Emergent-time average: $\langle O\rangle\_T = (1/N) \sum_{n=1}^{N} O(X_n)$

In regimes where TPB varies significantly (e.g., chaotic scattering), these averages will differ:

$$|\langle O\rangle\_T - \langle O\rangle\_t| / \langle O\rangle\_t > \varepsilon\_obs$$

for some observable threshold ε_obs.

Test: Run long integrations of chaotic three-body systems. Compute both averages for standard observables. Quantify the systematic difference and verify it exceeds numerical noise.

Prediction 4 (Resonance Transitions)

When a three-body system transitions between resonant and non-resonant configurations, h_TPB should exhibit characteristic changes. Resonant motion (quasi-periodic) produces lower h_TPB; chaotic motion produces higher h_TPB.

Test: Initialise systems near resonance boundaries. Track h_TPB as the system evolves. Transitions into chaos should correlate with sustained increases in h_TPB.

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9. Generalisation to N-Body Systems

The TPB framework extends naturally to arbitrary N-body gravitational systems. This section summarises the generalisation.

9.1 Microdynamics

For N masses with positions $\mathbf{r}_1, \ldots, \mathbf{r}_N \in \mathbb{R}^3$ and velocities $\mathbf{v}_1, \ldots, \mathbf{v}_N$, the acceleration on mass i is:

$$\mathbf{a}_i = -G \sum_{j\neq i} m_j (\mathbf{r}_i - \mathbf{r}_j) / (|\mathbf{r}_i - \mathbf{r}_j|^2 + \delta^2)^{3/2}$$

The microstate $X^{(k)}$ now has dimension 6N.

9.2 Information Functional

The pairwise information measure generalises to:

$$I(X) = \sum_{i<j}^{N} [\log_2(d_{ij}/\varepsilon_x)_+ + \log_2(u_{ij}/\varepsilon_v)_+]$$

The sum runs over all N(N−1)/2 particle pairs. Each pair contributes independently, maintaining the symmetric treatment of gravitational interactions.

9.3 Bit-Events and Emergent Time

The bit-event rule $|\Delta I| \geq 1$ applies unchanged. As N increases, the system has more degrees of freedom and more pairwise interactions, generically producing more frequent bit-events. The TPB timescale should decrease roughly as N increases, reflecting the greater informational complexity of larger systems.

9.4 Computational Implementation

The information functional requires $O(N^2)$ pairwise computations per microtick, the same scaling as the gravitational force calculation. Thus TPB introduces no additional computational complexity beyond standard N-body methods.

Practical note: N-body simulations can use TPB as a post-processing layer on top of existing Newtonian trajectories, without modifying integrators. Given a stored trajectory $\{X(t)\}$, one simply evaluates $I(X(t))$ at each saved timestep and identifies bit-events where $|\Delta I| \geq 1$. This makes TPB analysis straightforward to apply to existing simulation data.

This confirms that the TPB/VERSF framework is fully general and applies to gravitational systems of arbitrary size, from binary stars to galactic dynamics.

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10. Discussion

10.1 Summary of Results

We have constructed a complete TPB/VERSF formulation of the gravitational three-body problem and its N-body generalisation. The key elements are:

1. **Microdynamic evolution**: Standard Newtonian mechanics at the microtick level, with Δt providing a reference scale while emergent phenomena depend on $\Delta t/\tau_{dyn}$ and ε_x, ε_v.
2. **Finite-resolution information measure**: Configuration information $I(X)$ defined via pairwise separations and velocities, serving as an upper bound on distinguishability.
3. **Bit-event rule**: Physical time advances when $|\Delta I| \geq 1$ bit, with symmetric triggering for both increases and decreases.
4. **TPB sequence**: The number of microticks between bit-events characterises the rate at which the system generates distinguishability.
5. **Scaling relations**: h_{TPB} connects to classical Lyapunov exponents and KS-entropy through resolution-dependent suppression.
6. **Self-consistent regularisation**: Softening length $\delta \sim \varepsilon_x$ aligns dynamical and informational coarse-graining.
7. **Emergent-time Lyapunov exponent**: The toy computation shows how continuous chaos becomes piecewise-exponential divergence in emergent time, with λ_{TPB} serving as a coarse-grained, resolution-dependent chaos measure.

10.2 Physical Interpretation

The central insight is that **time flows only when the universe becomes more distinguishable**. Applied to chaotic systems:

- Chaos becomes information-bounded rather than infinitely fine-grained.
- Emergent time adapts dynamically to system complexity.
- Rapid chaotic motion compresses into bursts of bit-events.
- Slow, regular motion produces long intervals with no emergent time.

This reinterprets classical deterministic chaos as a process of finite-rate information production, filtered through observational or fundamental resolution limits.

10.3 Relation to VERSF Foundations

In the broader VERSF framework, emergent time is tied to entropy gradients and the flow of distinguishability from the void substrate. The three-body construction demonstrates that TPB applies coherently to multi-body gravitational systems, providing a concrete dynamical model for emergent time in classical contexts. The microtick rate $\nu_{tick} \sim 3 \times 10^{12}$ Hz, derived from bit-energy considerations in particle physics applications, provides a candidate fundamental timescale, though the present analysis depends primarily on resolution parameters rather than the absolute tick rate. This complements VERSF work on quantum measurement, spacetime emergence, and entropy transport.

10.4 Limitations and Future Work

Several extensions merit investigation:

- **Numerical implementation**: Full computational studies are needed to determine the function $f(\varepsilon/\ell_{char})$ relating h_{TPB} to h_{KS}.
- **Large-N scaling**: How does h_{TPB} scale with particle number? Does emergent time become effectively continuous as $N \to \infty$?
- **Quantum analogue**: Applying TPB to quantum three-body systems (e.g., Helium atom) could connect emergent time to quantum information.
- **Relativistic extension**: Incorporating relativistic corrections and eventually full general relativity remains an open challenge.
- **Alternative information measures**: The pairwise log-sum is one natural choice; mutual information or other functionals could be explored.
- **Periodic refinement**: Systems with exact periodicity may warrant modified bit-event rules to avoid overcounting information echoes.

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11. Conclusion

We have demonstrated that the TPB/VERSF framework applies coherently to the classical three-body problem and generalises naturally to N-body systems, producing a well-defined emergent time structure from finite-resolution distinguishability. The resulting dynamics are discrete, informationally bounded, and connected to classical chaos measures through explicit scaling relations and a toy Lyapunov computation. Four quantitative predictions distinguish this formulation from standard continuous-time mechanics and are amenable to computational testing.

This work establishes emergent informational time as a viable framework for gravitational dynamics and opens pathways for exploring chaos, entropy, and the foundations of time in multi-body systems.

References

1. Poincaré, H. (1890). Sur le problème des trois corps et les équations de la dynamique. *Acta Mathematica*, 13, 1–270.
2. Kolmogorov, A. N. (1958). A new metric invariant of transitive dynamical systems. *Doklady Akademii Nauk SSSR*, 119, 861–864.
3. Sinai, Ya. G. (1959). On the notion of entropy of a dynamical system. *Doklady Akademii Nauk SSSR*, 124, 768–771.
4. Benettin, G., Galgani, L., Giorgilli, A., & Strelcyn, J.-M. (1980). Lyapunov characteristic exponents for smooth dynamical systems and for Hamiltonian systems. *Meccanica*, 15, 9–30.
5. Heggie, D. C. (1975). Binary evolution in stellar dynamics. *Monthly Notices of the Royal Astronomical Society*, 173, 729–787.

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