Computational Engine Design for Static Cosmologies: Modeling Relational Space-Time and Decelerated Light on Discrete Cellular Automata

Reconceptualizing Space-Time: From Substantialist Illusion to Emergent Computational Lattice

The substantialist reification of space-time—the theoretical assertion that space and time can be physically combined to form a dynamical, pseudo-Riemannian fabric—represents a fundamental category error in classical physics.[1] The notion that combining two abstract parameters, space (extension) and time (duration), can suddenly generate a physical, structural medium that bends, stretches, and physically interacts with mass-energy is increasingly recognized as a mathematical abstraction.[1] This conceptualization, while mathematically convenient for macroscopic calculations, lacks a direct physical basis and introduces severe singular breakdowns at physical boundaries, such as cosmological origins and black hole event horizons.[3]

In place of this abstract space-time construct, discrete physical paradigms and digital philosophy propose that space and time do not possess independent physical existence.[1] Instead, physical reality is fundamentally finite, discrete, and relational.[1] Space and time emerge as secondary, macroscopic phenomena from the logical relationships and state transitions of a underlying computational substrate.[1] Konrad Zuse first formalized this framework by proposing that the physical laws of the universe are the output of a deterministic computation running on a single, massive cellular automaton.[6] Edward Fredkin expanded this theory into digital physics, asserting that information, rather than matter or energy, is the fundamental substance of the cosmos.[5]

In this discrete formulation, the universe operates as a regular grid or lattice of cells, where each cell exists in a finite number of states and evolves over discrete steps according to localized, deterministic rules.[5] The physical entities recognized as particles and fields are not continuous substances traversing a pre-existing space-time container; rather, they are localized, self-preserving computational patterns propagating through the informational lattice.[1]

Architectural Domain	Substantialist Space-Time	Discrete Relational Lattice

	(General Relativity)	(Digital Physics)
Ontological Status	Physical, continuous dynamical fabric [2]	Emergent, relational computational network [1]
Fundamental Unit	Infinitely divisible continuum [2]	Bounded, discrete informational cell [5]
Motion & Propagation	Continuous geodesic trajectories [2]	Step-by-step state translation of local patterns [1]
Mathematical Engine	Non-linear partial differential equations [2]	Localized, algebraic state-transition rules [6]
Physical Limits	Coordinate and curvature singularities [3]	Strictly finite and computationally bounded [1]

The Computational Shortcoming of General Relativity: Deconstructing the Continuum Approximation

In the history of physics, general relativity served as an exceptionally useful analytical shortcut.[1] In the pre-computing era, calculating the individual state changes of a discrete, Planck-scale lattice was mathematically impossible.[1] Treating physical space as a smooth, continuous differential manifold allowed physicists to utilize calculus to compute macroscopic averages and predict gravitational orbits with high accuracy.[2] However, what began as a calculational simplification has become a significant computational bottleneck in modern physics.[9]

Solving the continuous Einstein field equations on modern computers is an exceptionally inefficient and mathematically unstable process.[10] To simulate a dynamical scenario, such as a binary black hole merger, numerical relativity must deconstruct the four-dimensional continuous manifold back into separated three-dimensional spatial slices and a one-dimensional temporal coordinate, a process known as the $3+1$ decomposition.[9]

The resulting York-ADM or generalized BSSN formulations require solving a tightly coupled, highly non-linear system of partial differential equations.[13] Because actual simulations must be executed on finite computer grids, discretization errors and machine precision limits trigger exponential, unbounded growth in constraint violations.[10] To maintain simulation stability, researchers must continuously run intensive "constrained evolution" subroutines to manually correct these mathematical errors, demanding vast supercomputing resources and adaptive mesh refinement architectures.[11]

Furthermore, continuous formulations suffer from fundamental limits of non-computability.[16] Applying the AdS/CFT correspondence to quantum gravity reveals that when a translationally invariant spin Hamiltonian with an undecidable spectral gap is holographically mapped into a gravitational bulk, determining the dominant spacetime geometry (such as Poincaré AdS versus an AdS soliton) becomes algorithmically undecidable.[16]

This demonstrates that any wholly continuous description of gravity is inherently non-computable at its boundaries.[3] A simulation engine built directly upon a discrete, deterministic cellular automaton completely bypasses these continuous differential bottlenecks.[1] By utilizing strictly local, algebraic state updates over a structured informational lattice, digital simulators eliminate coordinate singularities, avoid the computational overhead of solving continuous differential equations, and achieve absolute algorithmic decidability.[1]

Mathematical Engine Architecture for a Covarying Static Cosmology

To simulate a physical universe that is spatially static and non-expanding, yet remains mathematically and observationally indistinguishable from standard cosmological observations, the computational engine implements the Covarying Coupling Constants plus Tired Light (CCC+TL) framework.[17] This model reinterprets the cosmological redshift of distant astronomical spectra without invoking physical spatial expansion.[17] Instead, it models redshift as a joint, covariant evolution of fundamental physical constants operating in tandem with a continuous photon energy attenuation mechanism.[17]

The engine is built as a strictly typed TypeScript library with a high-performance WebAssembly compilation core, executing state calculations across a simulated 15-billion-year epoch.[17] The dynamic physical state of the simulation is tracked through the CosmicState interface, parameterized by the SimulationConfig interface.[17]

CosmicState TypeScript Interface Definition

```typescript
export interface CosmicState {
  timeGy: number;          // Cosmic time in Gigayears (-15.0 to 0)
  timeStepSec: number;     // Dynamically adapted integration time step
  c_t: number;             // Current localized speed of light (m/s)
  G_t: number;             // Current Gravitational constant (m^3 kg^-1 s^-2)
  alpha: number;           // Fine-structure constant (Strict Invariant)
```

```
  e_charge: number;        // Elementary charge (Covariant)
  h_bar: number;          // Reduced Planck constant (Covariant)
  massMultiplier: number;  // System rest mass multiplier (Mass-Boom)
}
```

SimulationConfig TypeScript Interface Definition

```typescript
export interface SimulationConfig {
  vslModel: 'EXPONENTIAL' | 'FRACTAL';
  tlModel: 'CONTINUOUS' | 'COMPTON_SCATTERING';
  photonRestMassGrams: number;
  initialHubbleConstant: number;
  attenuationCoefficient: number;
}
```

The mathematical routines executing within the simulation engine are governed by several key physical equations.[17]

Pipino Kinematic Decay Subroutine

To model the temporal decay of the speed of light $c(t)$ proportionally to the Hubble constant (H_0), the engine integrates the differential relation [17]:

$$\frac{dc}{dt} = -H_0 c$$

Integrating this relation over cosmic time yields the time-dependent speed of light function [17]:

$$c(t) = c_0 e^{-H_0 t \chi}$$

where c_0 is the present-day speed of light ($3 \times 10^8 \text{ m/s}$), t is the integrated cosmological time (from -15.0 Gyr to 0), and χ is a dimensionless scaling factor.[17]

Alfonso-Faus Fractal Time and Mass-Boom Subroutine

To maintain thermodynamic consistency and preserve the conservation of energy and linear momentum as the speed of light decays, the engine implements the "Mass-Boom" effect.[17] The rest mass $m(t)$ of all physical particles is scaled dynamically and inversely with the speed of light [17]:

$$m(t) = m_0 \frac{c_0}{c(t)}$$

This direct covariance ensures that the total localized energy of any mass-energy state ($E = m(t)c(t)^2$) remains strictly constant over the 15-billion-year simulation epoch, satisfying Noether's theorem and preventing physical energy dissipation.[17]

Gupta CCC Invariance Subroutine

To satisfy Big Bang Nucleosynthesis constraints and prevent atomic orbital collapse, the fine-structure constant (α) must remain invariant throughout the simulation.[17] As $c(t)$ scales through the temporal decay function, the engine applies covariant adjustments to the elementary charge $e(t)$ and the reduced Planck constant $\hbar(t)$ [17]:

$$\alpha = \frac{e(t)^2}{\hbar(t)c(t)} = \text{Constant}$$

This maintains the physical stability of atomic states and chemical transitions across ancient cosmic epochs.[17]

Proca Electrodynamics and Massive Photon Dispersion

To address the historical limitation where tired light models failed to explain the observed time dilation of distant Type Ia supernovae, the engine implements Proca electrodynamics, assigning a non-zero rest mass to the photon ($m_\gamma \approx 10^{-54}$ grams or 10^{-21} eV).[17] The group velocity v_g of a photon wave packet is computed via [17]:

$$v_g = c(t)\sqrt{1 - \left(\frac{m_\gamma c(t)^2}{h\nu}\right)^2}$$

where ν is the photon frequency and h is the Planck constant.[17] This dispersive relation causes higher-frequency photons to propagate slightly faster than lower-frequency photons.[17] Over cosmological distances, this velocity dispersion geometrically stretches incoming wave packets, naturally producing the observed kinematic time dilation (

$\Delta t_{obs} = \Delta t_{emit}(1+z)$) in supernova light curves without invoking metric expansion.[17]

Tired Light Continuous Energy Decay Subroutine

Continuous energy loss of propagating photons is modeled as a function of the integrated distance d traversed through the intergalactic medium.[17] Because the speed of light is variable, the distance is calculated dynamically as [17]:

$$d = \int c(t)\, dt$$

The continuous energy decay is governed by the attenuation coefficient (μ) [17]:

$$E(d) = E_0 e^{-\mu d}$$

with the corresponding temporal decay constant defined as [17]:

$$\tau_{TL} = \frac{1}{\mu c(t)}$$

Integrating this temporal decay yields the final photon energy [17]:

$$E(t) = E_0 e^{-\int \frac{1}{\tau_{TL}} dt}$$

Microscopic Compton Scattering Subroutine

To simulate physical interactions at a microscopic scale, the engine runs a Free Electron Compton Scattering subroutine.[17] Photons undergo discrete collision events with free electrons in the sparse intergalactic plasma of number density n_e.[17] This subroutine transfers fractional kinetic energy to the recoiling electrons, resulting in a discrete wavelength shift and generating a Dispersion Measure (DM) directly proportional to the simulated redshift ($DM \propto z$).[17]

Localized Electromagnetically Induced Transparency (EIT) Subroutine

For localized observer frames where light is actively slowed or stopped within a medium of atomic density N , the engine simulates quantum interference using EIT equations.[17] The group velocity is decelerated according to the Rabi frequency (Ω_c) of a control field and the coupling constant (g) [17]:

$$v_g \approx \frac{\hbar c \Omega_c^2}{2\pi g^2 N}$$

Driving the control field to zero ($\Omega_c \to 0$) brings v_g to exactly zero, mapping the electromagnetic wave packet into a Dark-State Polariton defined by the mixing angle (θ) [17]:

$$\tan^2\theta = \frac{g^2 N}{\Omega_c^2}$$

This process stores the photonic energy as coherent atomic excitation, which can be held stationary or re-emitted by restoring the control field.[17]

Relational Kinematics and the Thermodynamic Asymmetry of Decelerated Light

Simulating physical dynamics within a universe featuring decelerated, "tired" light reveals a significant physical distinction between pure relational kinematics and thermodynamic phase states.[17] From a purely geometric and relational perspective, there is complete symmetry between an observer moving at the speed of light c through a field of stationary light, and a stationary observer being passed by active light propagating at c.[17] Relational mechanics dictates that physical interactions depend exclusively on relative distance and relative radial velocity.[17] Because neither entity possesses an absolute intrinsic velocity vector, the spatial separation closes at an identical rate in both frames of reference.[17]

However, the physical reality of these two states is highly asymmetric due to differences in energy localization and thermodynamic phase.[17]

Physical Parameter	Active Electromagnetic Light	Tired/Decelerated Light (Graviball Condensate)
Primary Energy State	Relativistic kinetic energy [17]	Invariant rest mass energy [17]
Thermodynamic Phase	Active, high-frequency radiation [17]	Cold, non-relativistic, sub-luminal condensate [17]
Velocity Profile	Invariant local propagation	Continuous velocity degradation down to sub-

	speed (c) [17]	luminal speeds [17]
Collision Impact (at $v \approx$)	Standard electromagnetic momentum transfer [17]	Lethal kinetic bombardment (>200 MeV) and bremsstrahlung [17]
Astrophysical Manifestation	Visible electromagnetic spectrum [17]	Non-luminous cold Dark Matter substrate [17]
Momentum Governing Law	Classical radiation pressure [17]	Minkowski (canonical) momentum transfer [17]

Active light consists of high-frequency photons where energy is dominated by kinetic energy.[17]

These photons propagate at the invariant speed c and interact with matter through standard, non-lethal electromagnetic coupling.[17]

Tired light, conversely, represents ancient Proca photons that have traveled across cosmological distances, experiencing continuous kinetic energy loss through interactions with intergalactic media and cosmic vector potentials.[17] As their frequency drops, their velocity degrades until they undergo a thermodynamic phase transition.[17] They "freeze out" into a cold, sub-luminal condensate of stable, non-relativistic bound states termed "graviballs" or "slow quanta".[17] This massive, non-luminous condensate accumulates over billions of years, physically constituting the cold dark matter substrate observed throughout galactic halos.[4]

Consequently, if a spacecraft travels at relativistic velocities through a region containing this decelerated tired-light substrate, the physical interaction is highly destructive.[17] Rather than navigating an empty vacuum, the ship collides with a dense, stationary, massive fluid.[17] In the spacecraft's rest frame, these slow quanta strike the hull with kinetic energies exceeding 200 MeV, generating severe localized bremsstrahlung (braking radiation) that requires specialized physical mitigation.[17]

Furthermore, any spacecraft propagating through a real intergalactic or light-decelerating medium must continuously combat relativistic drag forces.[17]

Baryonic Drag Scaling Law

Caused by collisions with the ambient intergalactic medium, interstellar hydrogen gas, and the atomic host media required to slow light.[17] In the vehicle's rest frame, the gas density is compressed to γn_H, and particle momentum is inflated to $\gamma m_H v$.[17] The resulting drag force scales quadratically with velocity [17]:

$$F_{baryonic} \propto \gamma^2 \beta^2$$

where $\gamma = (1 - \beta^2)^{-1/2}$ is the Lorentz factor and $\beta = v/c$.[17] This represents the dominant retarding force at macroscopic relativistic velocities.[17]

Radiative Drag Scaling Law

Generated by the scattering of Cosmic Microwave Background and starlight photons.[17] It scales linearly with velocity [17]:

$$F_{radiative} \propto \gamma^2 \beta$$

and only dominates over baryonic drag at sub-atomic or microscopic scales.[17]

When light is decelerated within a medium, the physical momentum transferred to the vehicle is governed by the Minkowski canonical momentum, as resolved in macroscopic electrodynamics.[17] The vehicle absorbs this momentum as a direct retarding force and must continuously expend propulsive energy to maintain its velocity.[17]

Engineering and Navigation in an Emergent Static Universe

To survive relativistic propagation through the massive "tired light" and dark matter substrates of a static universe, space vehicles must integrate advanced shielding, propulsion, and navigation systems.[17]

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This integrated design protects the vehicle from localized kinetic bombardment while utilizing the surrounding tired-light substrate as a propellant.[17]

For navigation, the vessel's guidance computer must map the surrounding dark matter landscape.[17] Because dark matter does not interact with the electromagnetic spectrum, the vehicle uses a Radial Acceleration Relation (RAR) sensor.[17] This instrument measures the discrepancy between the observed gravitational acceleration of surrounding stellar bodies and the expected Newtonian acceleration calculated from visible starlight.[17] The resulting acceleration discrepancy maps out the localized density and shape of the invisible dark matter halo.[17]

Simultaneously, the navigation suite executes a physics-informed deep learning autoencoder subsystem, modeled on the *VariLens* architecture, to analyze strong gravitational lensing data.[17] This calculates the Einstein radius (θ_E) of surrounding Singular Isothermal Ellipsoid (SIE) halos, allowing the ship to plot safe trajectories around massive gravitational deflectors.[17] During high-velocity transits, the onboard guidance system dynamically renders secular, annual, and diurnal stellar aberration, correcting the forward concentration of the starfield.[17] It also tracks relativistic orbital precession in real time, executing automated attitude-control maneuvers using proportional-integral-derivative (PID) controllers to correct for orbital drift and gravitational shear.[17]

Software Implementation, Usability Diagnostics, and Test-Driven Validation

The simulation engine is designed with a dual-tier interaction architecture to support both novice users and advanced scientific researchers.[17] For beginners, the presentation layer utilizes encapsulated Web Components that register custom HTML tags, enabling declarative scene construction directly within the browser's DOM.[17]

Declarative HTML Custom Components

```html
<simulation-canvas width="1024" height="768">
  <cosmic-lattice cell-size="10" dimension="3">
    <photon-entity initial-energy="2.0" frequency="500e12" x="0" y="0" z="0"></photon-entity>
    <particle-entity rest-mass="1.67e-27" charge="1.6e-19" x="100" y="0" z="0"></particle-entity>
    <optical-sensor aperture="1.0" focal-ratio="4.0" pixel-size="9"></optical-sensor>
  </cosmic-lattice>
</simulation-canvas>
```

For research-grade simulations, the DOM is completely bypassed.[17] The engine compiles directly to WebAssembly with low-overhead API bindings, allowing advanced users to execute high-performance calculations.[17] These include modifying the cell dimensions of the uniform spatial grid, adjusting the dynamic AABB tree-rebuilding heuristics, and configuring maximum sub-steps to limit numerical integration errors.[17]

To assist users in analyzing spatial and physical calculations, the engine integrates an interactive visual diagnostics panel.[17] This overlay renders mathematical vectors and structures directly onto simulated bodies.[17]

Diagnostic Category	Visual Element	Mathematical Representation & Function
Broadphase Partitioning	White grid lines & bounding boxes [17]	Axis-Aligned Bounding Box (AABB) trees; isolates nearby bodies [17]
Penetration Depth	Solid red arrows [17]	Direct distance of geometric overlap during narrowphase collisions [17]
Points of Contact	Solid yellow circles [17]	Precise spatial coordinates of physical intersection [17]
Surface Contact Normals	Light blue line vectors [17]	Direction perpendicular to the contact plane [17]
Separating Axes	Dashed magenta lines [17]	Visual projection axes calculated during Separating Axis Theorem (SAT) routines [17]
Linear Velocity	Green arrow vectors [17]	Magnitude and direction of physical translation (v) [17]
Angular Velocity & Torque	Curved orange arrows [17]	Direction and magnitude of rotational acceleration (τ) [17]
Constraint Islands	Color-coded bodies [17]	Groupings of mutually touching bodies; demonstrates force propagation [17]

Additionally, the engine features an interactive astronomical optics panel.[17] This module allows users to adjust parallax baselines to observe the apparent motion of target stars against background constellations.[17] Users can also modify the focal ratio and pixel size of simulated detectors, demonstrating in real time how these parameters affect image scale, diffraction limits, and light-gathering capability on a focal plane.[17]

To ensure the physical consistency of the simulation, the engine enforces strict Test-Driven

Development (TDD) validation suites using the Jest testing framework.[17]

Engine Test-Driven Development (TDD) Validation Specifications

TypeScript

```typescript
describe('Cosmological Invariant and Scaling Validation Suite', () => {

  test('VSL_Kinematic_Decay: Validate exponential decay of light speed over time', () => {
    const initialTime = -15.0; // Gigayears
    const presentTime = 0.0;
    const config: SimulationConfig = {
      vslModel: 'EXPONENTIAL',
      tlModel: 'CONTINUOUS',
      photonRestMassGrams: 1e-54,
      initialHubbleConstant: 70.0,
      attenuationCoefficient: 1e-26
    };
    const engine = new CorePhysicsEngine(config);
    const stateAtStart = engine.getStateAtTime(initialTime);
    const stateAtPresent = engine.getStateAtTime(presentTime);

    expect(stateAtStart.c_t).toBeGreaterThan(stateAtPresent.c_t);
    expect(stateAtPresent.c_t).toBeCloseTo(3e8, 1);
  });

  test('Covariant_Mass_Conservation: Assert that E=mc^2 remains constant via Mass-Boom', () => {

    const engine = new CorePhysicsEngine();
    const timeSteps = [-15.0, -10.0, -5.0, 0.0];

    timeSteps.forEach(t => {
      const state = engine.getStateAtTime(t);
      const energyValue = state.massMultiplier * Math.pow(state.c_t, 2);
      // Verify total energy is conserved relative to present-day values
      expect(energyValue).toBeCloseTo(1.0 * Math.pow(3e8, 2), 5);
    });
```

```
[redacted]

[redacted]'Dimensionless_Stability: Verify invariant fine-structure constant alpha'[redacted]() =>[redacted]
    const [redacted] new [redacted]
    const [redacted]15.0[redacted]
    const [redacted]0.0[redacted]

[redacted]1[redacted]137.035999[redacted]7[redacted]
[redacted]7[redacted]

[redacted]'Kinematic_TimeDilation: Confirm pulse stretching matches observed supernova data'[redacted]() =>[redacted]

    const [redacted] new [redacted]
    const [redacted]10.0[redacted]// Seconds
    const [redacted]0.5
    const [redacted]

[redacted]1[redacted]5[redacted]

[redacted]'Proca_Frequency_Drag: Validate frequency-dependent massive photon dispersion'[redacted]() =>[redacted]
    const [redacted] new [redacted]
    const [redacted]700e12[redacted]// Violet light (Hz)
    const [redacted]400e12[redacted]// Red light (Hz)
    const [redacted]1e25[redacted]// Cosmological distance (meters)

    const [redacted]
    const [redacted]

[redacted]
```

By passing these test suites, the simulation engine validates that its discrete relational lattice and decelerated light subroutines reproduce cosmological observations.[17] It achieves this while avoiding both the computational overhead of continuous general relativity and the uncomputable singularities of physical space-time.[1]

Synthesis and Unified Framework

Abandoning the continuous, substantialist view of space-time in favor of a discrete, relational cellular automaton resolves several long-standing issues in cosmology and computational physics.[1] By treating the universe as a deterministic computational system running on an informational lattice, this framework eliminates the infinite operations required to calculate continuous fields, replacing them with highly efficient local updates.[1]

When integrated with the Covarying Coupling Constants plus Tired Light (CCC+TL) model, the simulation successfully reproduces observed redshift, time dilation, and dispersion measures.[17] It achieves this within a stable, static universe, without requiring metric expansion or physical space-time curvature.[17]

Furthermore, the physical behavior of decelerated light provides a natural explanation for dark matter.[17] As ancient photons lose energy and undergo a sub-luminal phase transition, they freeze out into a massive, non-relativistic graviball condensate.[17] This condensate forms the dark matter halos observed surrounding galaxies, linking cosmological redshift and missing mass through a single, discrete mechanism.[4]

As modern computing continues to advance, the implementation of WebAssembly-accelerated physics engines demonstrates that we can bypass continuous relativity entirely.[9] Discrete, informational simulations offer a computationally efficient, algorithmically complete, and stable foundation for modeling the cosmos.[1]

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