Computational Space Theory (CST): An Axiomatic Framework

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Abstract

We present an axiomatic formulation of Computational Space Theory (CST), a framework in which gravity, energy, space, time, and quantum phenomena emerge from a fundamental principle: gravity as local delay of time and energy as the potential associated with this delay. CST unifies geometry, dynamics, and information by postulating that the universe is a discrete computational process without archival memory. The formalism connects the slowing of local computational rates to gravitational potential, derives energy as its associated interaction term, and recovers fundamental physical laws as emergent structures.

1 Foundational Axioms

A1 **Gravity as Delay of Time**: The local lapse of time is reduced in regions of high density:

$$N(x) \equiv \frac{d\tau}{dt} = \sqrt{1 - \frac{\rho(x)}{\rho_0}} \in (0,1],$$

where $\rho(x)$ is the emergent density, ρ_0 a reference density, and $N(x)$ the fractional rate of proper to coordinate time.

A2 **Time as Computation**: Local time is equivalent to computational cycles. The computational rate is:

$$R(x) = \frac{c^3}{8\pi G\rho(x)\ell^3},$$

where ℓ is the characteristic length scale of computational nodes.

A3 **Energy as Potential of Delay**: Energy is the stored potential of temporal delay:

$$E_{\text{grav}} = -Gm\ell \int \rho(x)\, dV.$$

A4 **Emergent Space**: Spatial distances arise as shortest paths in the network:

$$d_{ij} = \min(\text{edges along path from } i \text{ to } j).$$

The emergent density is proportional to local connectivity:

$$\rho_i = \frac{E_i}{N_i},$$

where E_i is the number of edges and N_i the neighboring nodes.

A5 **No Archival Memory**: The universe retains no permanent record. State evolution is given by:

$$\sigma_i(t+\delta t) = F(\sigma_i(t), \sigma_j(t), \dots),$$

with no storage of past states beyond their computational role.

A6 **Quantum Uncertainty as Cycle Limit**: The uncertainty principle emerges from finite information per cycle:

$$\Delta t \sim \frac{1}{R(x)} \implies \Delta E \gtrsim \frac{\hbar}{2R(x)}.$$

A7 **Gauge Interactions as Symmetries of Update Rules**: Gauge fields arise from invariances of the update function F:

- $U(1)$: electromagnetism,
- $SU(2)$: weak interaction,
- $SU(3)$: strong interaction.

Their effective dynamics are locally modulated by $N(x)$.

2 Emergent Geometry

The line element is defined by lapse-modulated time and emergent spatial metric:

$$ds^2 = -N(x)^2 c^2 dt^2 + h_{ij}(x) dx^i dx^j.$$

Here, h_{ij} arises from quasi-metric mapping of shortest-path distances in the graph. Acceleration is interpreted as motion along gradients of $N(x)$.

3 Total Energy Formulation

CST defines the total energy as:

$$E = \hbar R(x) S + \frac{1}{2} m \ell^2 \left(\frac{dS}{dt}\right)^2 - Gm\ell \int \rho(x)\, dV,$$

with contributions from computational, kinetic, and gravitational components.

4 Quantum Framework

- **Uncertainty**: Derived from finite cycles.
- **Entanglement**: Global correlations of node states represented by density operator ρ_{CST}.
- **Wavefunction collapse**: Reinterpretation as irreversible reconfiguration within cycle constraints.

5 Constants and Scaling

The gravitational constant emerges naturally:

$$G = \frac{\hbar c^3}{\ell_p^2},$$

linking Planck scale ℓ_p to the computational substrate.

6 Predictions and Tests

(P1) **Universal coupling**: All processes, including gauge fields, are slowed by $N(x)$, not just clocks.

(P2) **Strong-field quantum effects**: Lower $R(x)$ reduces ΔE, testable in neutron stars or near black holes.

(P3) **Cosmology without archival memory**: Large-scale fluctuations of CMB may deviate from gaussianity due to continuous regeneration.

(P4) **Black hole information**: No paradox believe, as no global memory exists; emitted photons remain the only relics.

7 Conclusion

CST achieves unification by reducing physics to the dynamics of local temporal delays. Gravity is the modulation of computational pace, energy is its potential, space emerges as relational structure, and quantum limits reflect finite-cycle constraints. By starting from two axioms-gravity as delay of time and energy as potential of delaythe theory integrates general relativity, quantum mechanics, gauge interactions, and phenomenology into a single computational ontology.