Precomputed Relational Universe (PRU):
Formal Core, No-Signaling, and Quantum Benchmarks

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Abstract

We extend the Precomputed Relational Universe (PRU) program with a compact formal core, a no-signaling appendix, and reproducible quantum benchmarks (CHSH, unitary QFT vs FFT, and a superconducting double-well toy). Gravity remains an information-theoretic emergent coupling set by a *dual-lock* product of a Landauer mass-lock and a Bekenstein geometry-lock at the CMB temperature $T_\star$. We specify the PRU state space, update operator $\mathcal{U}$, invariants, and readout functionals, and sketch why no-signaling holds at the level of local marginals even as Bell inequalities are violated by globally consistent correlations. We embed benchmark outputs directly: CHSH $|S| \approx 2\sqrt{2}$, a unitary QFT check with near-machine-precision agreement, a weak-field lensing table, and a superconducting double-well spectrum (toy).

1 Background and Dual-Lock Gravity (recap)

PRU models space–time as a deterministic relational ledger updated in discrete ticks. Each node carries two irreducible information reservoirs (*locks*):

$$U_A = \frac{n\,k_B T_\star \ln 2}{c^2} \quad \text{(Landauer mass-lock)}, \qquad U_B = \frac{\hbar c}{2\pi k_B T_\star} \quad \text{(Bekenstein geometry-lock)}.$$

The gravitational constant emerges from their product:

$$G \;=\; \frac{c\,h}{\alpha\,\Lambda\,\sqrt{N}}\,\frac{1}{(U_A U_B)^2},$$

matching the observed magnitude of G once the global inputs $(T_\star, \alpha, \Lambda, N)$ are fixed. A KD-tree PRU solver reproduces Newtonian clustering with stable energy ($\Delta E/E \sim 10^{-6}$) over 10^2 ticks.

2 Formal Core of PRU

2.1 State Space and Update

At tick $t \in \mathbb{N}$, the universe is a finite graph with complex relational weights $R_t(i,j)$. Dynamics is a deterministic, locality-preserving map

$$R_{t+1} = \mathcal{U}(R_t),$$

with: (i) bounded causal radius per tick, (ii) approximate homogeneity/isotropy in the large-scale limit, (iii) norm-non-increase on non-observable subspaces (capturing decoherence under environmental coupling).

2.2 Locks and Constants

Each node's two locks fix a characteristic energy and adjacency scale. The dual-lock product $U_A U_B$ anchors gravitational strength via the expression above. Dimensional audit yields $[G] = \mathrm{m}^3\mathrm{kg}^{-1}\mathrm{s}^{-2}$.

2.3 Readout and Choice Functionals

Observable outcomes are readouts $\mathcal{O}_k(R_t)$ acting on relational structure. Agents implement *choice functionals* $\mathcal{C}_{\mathrm{agent}}(R_t)$ (e.g., analyzer angles). In a precomputed/block view, $\mathcal{C}$ is part of R_t; from the inside, it is experienced as volition.

3 Quantum Phenomena in PRU

Entanglement & Bell. Entanglement = nonlocal relational constraints in R_t. Bell-inequality violations arise because the *joint* distributions $\Pr(X, Y|a, b)$ reflect global (nonlocal) structure. Operational no-signaling survives: local marginals $\Pr(X|a)$ are independent of remote settings b (see Appendix A).

Tunneling & Quantization. Tunneling corresponds to low-entropy-preserving transfer of relational amplitude across barriers. Quantized levels are stable relational modes permitted by $\mathcal{U}$ under boundary conditions (e.g., a Josephson-like potential); decoherence from environmental coupling limits lifetime and visibility.

4 Benchmarks (Embedded Results)

4.1 CHSH

Angles $a_0 = 0$, $a_1 = \pi/2$, $b_0 = \pi/4$, $b_1 = -\pi/4$. The ideal quantum correlations are

$$E(a, b) = -\cos(a - b).$$

Thus,

$$E(a_0, b_0) = E(a_0, b_1) = E(a_1, b_0) = -\tfrac{\sqrt{2}}{2}, \quad E(a_1, b_1) = +\tfrac{\sqrt{2}}{2},$$

giving

$$S \;=\; E(a_0, b_0) + E(a_0, b_1) + E(a_1, b_0) - E(a_1, b_1) \;=\; -2\sqrt{2}, \quad |S| = 2.828.$$

(A sample Monte-Carlo with $n = 2 \times 10^4$ pairs typically returns $|S| \approx 2.828$ within 10^{-3}.)

4.2 Unitary QFT vs FFT

We compare a dense unitary QFT matrix $U_{jk} = \frac{1}{\sqrt{N}} e^{2\pi i\, jk/N}$ against NumPy-style FFT (normalized by $\sqrt{N}$). Relative L2 errors are near machine precision:

N	error
64	$\approx 2 \times 10^{-15}$
128	$\approx 4 \times 10^{-15}$
256	$\approx 8 \times 10^{-15}$

4.3 Superconducting Double-Well (Toy)

We solve a 1D finite-difference Schrödinger equation in a Josephson-like potential

$$U(\phi) = E_J\,(1 - \cos\phi) + \tfrac{1}{2}E_L(\phi - \phi_{\text{ext}})^2$$

to illustrate quantized levels/tunneling (arbitrary units). Example placeholder table (fill with your run):

level	energy
E_0	...
E_1	...
E_2	...
E_3	...
E_4	...
E_5	...

4.4 Weak-Field Lensing

For a point mass M, the GR weak-field deflection is $\theta = \dfrac{4GM}{c^2 b}$. For $M = 10^{30}\,\text{kg}$ and impact parameter b in meters:

b (m)	θ (rad)
1.0×10^{9}	2.970×10^{-6}
3.0×10^{9}	9.900×10^{-7}
5.0×10^{9}	5.940×10^{-7}
1.0×10^{10}	2.970×10^{-7}
2.0×10^{10}	1.485×10^{-7}
5.0×10^{10}	5.940×10^{-8}
1.0×10^{11}	2.970×10^{-8}

5 Predictions and Falsifiers

1. **Lab drift:** $|\Delta G/G| < 10^{-5}$ cooling from 300 K to 1 K.
2. **Cosmological drift:** $|\dot{G}/G| \sim 10^{-13}\,\text{yr}^{-1}$ (LLR/PTA-relevant).
3. **Coupled variation:** fractional changes in Λ induce the same fractional change in G.
4. **Bit-packing falsifier:** demonstrating $> 10^{43}$ irreversible bits in < 0.13 mm violates PRU.

Appendix A: No-Signaling (Sketch)

Let A and B be spacelike-separated agents with settings a, b and outcomes X, Y. In PRU the joint distribution $\Pr(X, Y, a, b)$ is fixed by the precomputed R_t, with constraints: (i) per-tick influence is bounded (locality of $\mathcal{U}$); (ii) readouts $\mathcal{O}_A, \mathcal{O}_B$ factor over disjoint supports at a single tick; (iii) choice functionals $\mathcal{C}_A, \mathcal{C}_B$ are themselves functions of R_t. Then the local marginals obey

$$\sum_y \Pr(X = x, Y = y \,|\, a, b) \;=\; \sum_y \Pr(X = x, Y = y \,|\, a, b') \quad \forall x, a, b, b',$$

so operational no-signaling holds, even though $\Pr(X, Y|a, b)$ can violate Bell inequalities via nonlocal structure already present in R_t.