A Computational Framework for Quantum Mechanics

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We propose a speculative framework in which the underlying structure of reality is modeled as a densely connected neural network, with reality emerging from a computational substrate. In this approach, wave phenomena arise from subthreshold activations across many nodes, while particle phenomena occur when individual nodes exceed a threshold and "spike." We suggest that this model can capture key features of quantum mechanics, including wave-particle duality, measurement-induced collapse, and the generation of virtual particles when local energy surpasses threshold. Furthermore, a high concentration of spikes in one region may slow the local "computational speed," suggesting an interpretation of gravitational time dilation and space-time curvature. Though conceptual, the framework could be tested by scenarios in which a single photon or electron sometimes yields no detection (lost to sub-threshold dissipation) or multiple detections (leftover activation combining with new signals). We conclude by discussing open challenges, especially regarding entanglement, non-local correlations, Lorentz invariance, and the full embedding of this idea into known gauge symmetries.

I. INTRODUCTION

Modern physics comprises two exceptionally successful theories: quantum field theory (QFT), which describes the subatomic realm, and general relativity (GR), which treats gravity as the curvature of space-time. The unification of these frameworks has proven elusive. We introduce a speculative but potentially unifying approach: *the universe as a neural network*, where spacetime and fields emerge from a discrete computational substrate of nodes and connections.

This proposal draws inspiration from cellular automata [1] and information-theoretic interpretations of quantum phenomena [3]. In our model:

- **Wave-like behavior** arises from subthreshold activations spreading across nodes.
- **Particle-like behavior** emerges when a node's total activation crosses a threshold, producing a "spike."
- **Gravity** is interpreted as a local computational slowdown to process spikes—the more spikes in a region, the more "compute power" consumed, effectively slowing local time.

We further consider how entanglement might arise as multiple particles collectively share a common "wavefunction" in the network, although genuine nonlocal correlations (Bell inequalities) remain a significant open question.

II. BASIC NEURAL-NETWORK MODEL

A. Discrete Nodes and Connections

We posit a discrete set of nodes (or "neurons") $\{N_j\}$ arranged in layered or higher-dimensional structures. Each node N_j has connections from one or more upstream nodes N_i. Denote the connection weight from node i to node j by w_{ij}. In discrete time steps $t, t+\Delta t, \ldots$, each node j receives inputs from its upstream neighbors.

B. Sub-threshold Activation with Threshold and Inhibition

Let $\psi_j(t)$ denote the *sub-threshold activation* at node j at time t. We write its update rule schematically as

$$\psi_j(t+\Delta t) \;=\; \sum_i w_{ij}\, \psi_i(t) \;-\; \Theta_j(t)\,. \tag{1}$$

Here, $\Theta_j(t)$ is a term enforcing threshold-related or **inhibitory** effects, which might include:

- A *leak* or *decay* term, ensuring that activations do not accumulate indefinitely. In a realistic physical theory, one might set this term to zero or extremely small to preserve total energy or probability over time.
- A *reset* after spiking, preventing the node from continually firing.

When $\psi_j(t+\Delta t)$ remains below some threshold ε_j, no spike occurs, so the signal remains *subthreshold.* If it *exceeds* ε_j, we say node j *spikes* at time $t+\Delta t$, emitting a discrete signal (or "particle event") to its downstream connections.

C. Wave-Like vs. Particle-Like Phenomena

- **Wave-like:** In the subthreshold regime, $\psi_j(t)$ can spread over many nodes in superposition, mirroring continuous wave interference in optics or quantum mechanics. Leftover subthreshold activation from *previous* time steps ($\psi_j(t-\Delta t)$, etc.) can persist, providing a memory effect of previous signals.

- **Particle-like:** A spike is a localized event at node j, similar to the detection of a photon or electron. This spike typically resets or alters ψ_j (e.g., sets it to zero).

III. WAVE-PARTICLE DUALITY

A. Single Signal as a Wave

Consider a single node N_S (a source) spiking at time $t=0$. For $t>0$, its downstream nodes $\{N_i\}$ receive partial activations:

$$\psi_i(t+\Delta t) \;=\; w_{iS}\,\delta_{S,\mathrm{spike}}(t) \;+\; \alpha\,\psi_i(t)\,, \tag{2}$$

where $\delta_{S,\mathrm{spike}}(t)$ encodes the amplitude of the new spike from N_S, and $\alpha\,\psi_i(t)$ is the fraction α of ψ_i persisted from previous signals (a memory effect). As long as $\psi_i(t+\Delta t)<\varepsilon_i$, no secondary spike occurs, and these partial activations form a broad, wave-like pattern across the network.

B. Single-Slit Diffraction (Huygens-like)

If a subset of nodes N_k represent a "slit" (i.e., they allow efficient signal transmission to the next layer), each node N_k in that slit region becomes a secondary source of wavelets:

$$\psi_j(t+\Delta t) \;=\; \sum_{k\in\mathrm{slit}} w_{jk}\,\psi_k(t) \;+\; \beta\,\psi_j(t)\,, \tag{3}$$

where β again allows leftover (memory) activation to remain. This mimics Huygens' principle, generating a diffraction pattern downstream from constructive and destructive interference of partial signals.

C. Particle-like Detection

Eventually, if the activations converge in amplitude at some node N_D such that

$$\psi_D(t) \;\geq\; \varepsilon_D,$$

node N_D spikes. This event is interpreted as a *localized detection* of a quantum-like "particle." Over many such runs/nodes, the accumulated spiking distribution reproduces an interference pattern—even though each detection is discrete.

IV. DOUBLE-SLIT EXPERIMENT

When two slits are open (modeled by two distinct regions of transmitting nodes), partial activations from each slit overlap in subsequent layers. This superposition yields the classic interference fringes. Crucially, each *individual* run (or single-photon/electron emission) leads to exactly one spike in the final detector layer, but many runs build up a wave-like interference pattern.

A. Single-Photon/Electron Double-Slit Experiment

Let N_S emit exactly one "photon/electron spike" at $t=0$. The wave of sub-threshold activations passes through both slits, summing at intermediate layer nodes:

$$\psi_j(t) \;=\; \psi_j^{(1)}(t) \;+\; \psi_j^{(2)}(t-\Delta t)\,, \tag{4}$$

where the second term explicitly accounts for leftover activation $\psi_j^{(2)}$ from a previous step $(t-\Delta t)$. If eventually $\psi_j(t)$ crosses threshold, node j spikes, yielding a single detection event.

This memory aspect means prior waves can persist, effectively combining with newly arriving activation and possibly affecting future detections. Such a mechanism allows for the build-up of an interference pattern *over time.*

V. GRAVITY AS A LOCAL SLOWDOWN IN SPIKE PROCESSING

A. Conceptual Mechanism

In general relativity, mass-energy concentrations curve space-time, resulting in gravitational time dilation. We propose that when a node in a region fire spikes, the "universe computer" computational resources are used to handle those spikes, effectively slowing local updates.

Thus, each spike requires finite processing power. Regions with high spike rate experience a relative slowdown (larger $\Delta t_{\mathrm{local}}$) compared to regions with fewer spikes. This slowdown is analogous to gravitational time dilation near massive bodies in GR.

B. Time Dilation and Spatial Curvature

1. **Local Slowing:** A region with intense spike activity might require $\Delta t_{\mathrm{local}}>\Delta t_{\mathrm{far}}$ from an external observer's vantage.

2. **Curvature:** If signals traverse layers more slowly or follow altered paths in high-density (high spike) regions, the emergent geometry is akin to curved space-time. Demonstrating a full equivalence with Einstein's field equations is left for future work.

VI. ENTANGLEMENT AND COMBINED WAVEFUNCTIONS

A. Multiple Spikes, One Wavefunction

In quantum mechanics, two particles can share a joint wavefunction, e.g., $|\Psi_{AB}\rangle$. Here, if two source neurons N_A and N_B spike such that they have common interacting nodes, their partial (subthreshold) activations can overlap across these nodes. The resulting pattern

$$\psi_j(t) = \psi_j^{(A)}(t) + \psi_j^{(B)}(t)$$

acts as a combined wavefunction, so long as no threshold event collapses it.

B. Entangled States

If the partial activations are inseparable (i.e., cannot be factored into distinct wavefronts for A and B), we label the system "entangled" in analogy to standard QM. Measuring one region by forcing a spike in a subset of nodes influences the global network's activation, effectively "collapsing" the shared wavefunction.

C. Nonlocality and Bell Inequalities

To replicate the exact statistical violations of Bell's inequalities, the model may require additional nonlocal or global-update rules. Simple, purely local updates with finite speed c may not reproduce strong quantum correlations, so the entanglement picture here remains partial.

VII. POSSIBLE EXPERIMENTAL SIGNATURES

A. Zero or Multiple Detections from a Single Emission

We speculate that if leftover sub-threshold activations remain in certain neurons from previous runs, a single electron or photon emission might either:

- **yield no detection** (absorbed or dissipated in the substrate), or
- **yield multiple detections** if new and leftover activations sum above threshold in more than one node.

Such outcomes would deviate from standard quantum mechanics, which conserves particle number in typical experiments. Observing such anomalies would suggest new physics or confirm a memory-based substrate mechanism.

VIII. OPEN CHALLENGES AND FUTURE WORK

Despite the appeal of a discrete neural-network substrate, several major challenges remain:

- **Lorentz Invariance:** Ensuring local observers always measure light-speed c and that no preferred frame emerges from discrete updates.
- **Exact Mapping to GR:** Demonstrating how $\Delta t_{\mathrm{local}}$ scales as per the Schwarzschild or Kerr metric, matching all known gravitational tests.
- **Gauge Invariance and Spin:** Embedding the full Standard Model fields, including spin-$\frac{1}{2}$ fermions and gauge bosons, may require specialized connectivity rules or thresholds.
- **Bell Test Correlations:** Showing how strong quantum correlations can arise without explicit superluminal signals.

Nevertheless, this model offers a novel perspective: wave-particle duality, gravitational time dilation, and partial entanglement might be interpretable as consequences of a threshold-based neural substrate, coupled with memory-driven subthreshold activation.

IX. CONCLUSION

We have outlined a speculative *neural-network framework* in which subthreshold activations behave like continuous wavefunctions, and threshold-crossing nodes yield discrete particle detections. Incorporating leftover (memory) activation allows old wavefronts to combine with new signals, mirroring interference phenomena. Interpreting gravitational time dilation as a local slowdown in update cycles offers a route to analogize curvature of space-time.

Key predictions—such as multi-detections from single emissions or complete non-detections—offer a tentative route to falsify or refine the hypothesis. While reproducing exact Bell correlations, full Lorentz invariance, and gauge symmetries remains formidable, these ideas may inspire further inquiry into computational or discrete underpinnings of quantum gravity.

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[3] J.A. Wheeler, "Information, Physics, Quantum: The Search for Links," in *Complexity, Entropy, and the Physics of Information*, edited by W.H. Zurek (Addison-Wesley, 1990).