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Editorial Office
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Dear Editors,

I am pleased to submit the manuscript entitled **"Thermodynamic Scaling Limits of Algorithmic Oscillatory Synchronization: Why Physical Coupling is Required for Large-Scale Oscillatory Neural Networks"** for consideration as a Letter in *Neuromorphic Computing and Engineering*.

Recent work, notably Dan et al.'s HoloGraph architecture (*Nature Communications*, 2025), has validated oscillatory synchronization as a powerful mechanism for graph neural networks. However, a critical question remains unaddressed: can these approaches scale on conventional hardware?

This manuscript establishes fundamental thermodynamic limits on software-based oscillatory neural networks. We demonstrate that digital simulation of continuous coupling dynamics incurs $O(N^2)$ computational cost per timestep, rendering large-scale implementations thermodynamically intractable on GPUs/TPUs. By contrast, physical instantiation of oscillator coupling—where coupling emerges from substrate physics rather than algorithmic computation—eliminates this barrier entirely.

Our numerical experiments show 86–224× power reduction for physical implementations, with advantages scaling as $O(N^2/K)$. We introduce the **Coherence Gate** as a minimal hardware primitive for energy-efficient oscillatory computing.

This work is timely and directly relevant to NCE's readership:

- It identifies a fundamental scaling barrier that affects the entire oscillatory GNN field
- It provides concrete numerical evidence for the physical-coupling advantage
- It proposes a well-defined hardware primitive (Coherence Gate) that could guide neuromorphic implementations
- It positions oscillatory approaches within the broader thermodynamic computing movement

The manuscript has not been published elsewhere and is not under consideration by any other journal. All simulation code and data are publicly available at `https://github.com/todd866/coherence-gate`.

Thank you for considering this submission.

Sincerely,

Ian Todd
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