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Peer Review

Review of: "The Information Theory of Self-Organization Phenomena in Thermal Systems"

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This work presents an interesting attempt to bridge information theory and thermodynamics by proposing a novel framework. The authors revisit SPBM and MPBM from an information-theoretic perspective, aiming to uncover deeper connections between these fields.

The paper is potentially valuable and introduces some new ideas worthy of consideration for publication. However, I recommend major revisions to address several key issues:

1. **Missing Citations:** Sections 3 and 4 are significantly lacking in citations. Several concepts presented as novel appear to be well-established in the field, and failing to acknowledge prior work weakens the paper's contribution and raises serious concerns about the authors' awareness of the existing literature. Examples include equation 23, the Casimir effect, equation 28 (Fermi-Dirac distribution), self-organizing behavior during LLM training, and the concept of "Equilibrium Flow" in complex systems. The authors should thoroughly review the literature and provide appropriate citations to give credit to original sources and accurately contextualize their work. Failing to do so is a major deficiency.
2. **Novelty Issues:** Closely related to the above point, the authors sometimes claim to introduce concepts that are already well-known. For example, the concept of "Equilibrium Flow" has been explored extensively in complex systems research. The authors should clearly differentiate their specific contributions from existing work and acknowledge the relevant literature.
3. **Fermi-Dirac distribution:** The statement of Theorem 3, regarding the Fermi-Dirac distribution under negative information temperature, requires either a proper citation to a reliable source or a proof within the paper.

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4. **Overstated Claims Regarding LLM Training:** The application of the framework to LLM training, while conceptually intriguing, currently lacks sufficient empirical support. The claim in the introduction that "we apply our framework to the training process of LLMs" is overstated. The authors should either remove this claim or provide substantial evidence (e.g., training results, simulations, or detailed analysis) to support it.
    1. Results demonstrating that the distribution of weights or activations within the LLM actually approaches a Fermi-Dirac distribution under certain conditions.
    2. A comparison of their framework's predictions with empirical observations of LLM training dynamics.
5. **Limitations of the SPBM Model:** The authors need to explicitly address the limitations of the simplified SPBM model and discuss how the theoretical framework can be extended to more complex systems with multiple interacting particles in higher-dimensional spaces.
6. **Appendix with Mathematical Details:** The authors should provide complete mathematical formulations and derivations, preferably in an appendix, to allow readers to fully evaluate the rigor of their arguments.
7. **Clarity of Mathematical Sections:** The mathematical sections require significant improvement in clarity. The authors should:
    1. Ensure consistent notation (e.g., `X(t ± ΔX)`)
    2. Provide step-by-step derivations for theorems (at least in the appendix).
    3. Separate the discussion of necessary and sufficient conditions into distinct sections.
    4. Better connect mathematical expressions to their physical or informational interpretations.
    5. Define all symbols upon first use.
    6. Clarify how the "adjacent displacement principle" generates probability distributions.
8. **Introduction:** The introduction should include a paragraph that explicitly positions the paper's contribution within the established fields of Classical Theory of Brownian Motion, Integration of Information Theory and Statistical Mechanics, Relationship Between Energy and Information, and Self-Organization and Non-Equilibrium Thermodynamics. This paragraph should clarify how the authors' framework extends, challenges, or reconciles competing perspectives.
9. The repeated presentation of theorems in section 4.3 ("Equilibrium Flow") is confusing. The authors should present each theorem only once, in the context of its proof, to avoid unnecessary redundancy and improve readability.

10. **Inconsistent Capitalization:** The paper exhibits inconsistent capitalization (e.g., "Self Organisation" instead of "self-organization"). A careful review and correction of capitalization throughout the manuscript is needed to adhere to standard writing conventions.

Addressing these points would significantly improve the quality and credibility of the manuscript and make a stronger contribution to the scientific community.

Declarations

Potential competing interests: No potential competing interests to declare.