Pauli Exclusion as Emergent Antisymmetry via MDL

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2025

Abstract

TODO

Keywords: Spinor, Spectral Complexity, Minimal Description Length

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1.1 Motivation

We began with the goal of constructing a minimal, observer-centric framework in which physical laws are not imposed but *emerge* from information-theoretic principles. The initial attempt relied on hardcoding fermionic behavior, specifically Pauli's exclusion principle, through antisymmetric wavefunctions (e.g., Slater determinants).

While this approach reproduced desired phenomenology, it violated the guiding principle: *all structure should emerge from a compression principle rather than be assumed.*

1.2 Initial Assumptions and Limitations

The initial model assumed:

- Point-like particles with positional degrees of freedom.

- Gaussian wavepackets representing localized "blobs."
- Explicit antisymmetry to enforce fermionic behavior.

These assumptions were sufficient to produce stable, inertial-like dynamics, but they imposed:

- Hard constraints (e.g., exclusion) rather than emergent behavior.
- A fixed particle ontology rather than a representation-based one.

1.3 Shift in Perspective: Observer-Centric MDL

We replaced the ontological perspective with an *observer-centric Minimum Description Length (MDL)* framework:

- The fundamental object is not a particle, but a *description of observations.*
- The observer selects representations that minimize encoding cost.

We identified three key principles:

1. **Observer existence:** Observers correspond to consistent sequences of encoded states.
2. **Compression:** Descriptions are minimized in spectral complexity (low-frequency dominance).
3. **Symmetry:** Equivalent configurations must not be redundantly distinguished.

1.4 Key Insight: Compression is a Collective Property

A critical realization was that:

> *Compression is not a property of individual objects, but of the entire configuration.*

This implies:

- Physical statistics (bosonic vs fermionic) cannot be assigned locally.
- Instead, they emerge from global encoding constraints.

1.5 The Trade-Off: Compression vs. Distinguishability

We identified two competing encoding strategies:

1. **Symmetric (bosonic) encoding:**
$$A + B$$
    - Minimizes spectral complexity.
    - Merges identities, increasing ambiguity.
2. **Antisymmetric (fermionic) encoding:**
$$A - B$$
    - Preserves distinguishability.
    - Introduces structural cost (higher frequencies).

1.6 Ambiguity as a Cost Function

We introduced a new term into the MDL framework:

$$\text{Total Cost} = C_{\text{spectral}} + \lambda \cdot C_{\text{ambiguity}}$$

where:

- C_{spectral} measures the frequency-weighted energy of the signal.
- $C_{\text{ambiguity}}$ penalizes indistinguishability between configurations.

This ambiguity cost becomes large when two states overlap and cannot be uniquely reconstructed.

1.7 Emergence of Pauli Exclusion

With this modified cost function, we observe:

- When particles are well separated:
  - Symmetric encoding is cheaper.
  - Bosonic behavior emerges.
- When particles overlap:
  - Ambiguity cost diverges.
  - Antisymmetric encoding becomes cheaper.
  - Effective exclusion emerges.

Thus:

> *Pauli exclusion is not a fundamental rule, but a consequence of minimizing description length under a distinguishability constraint.*

1.8 Role of Gaussian States

Gaussian wavepackets naturally arise because they minimize joint uncertainty in position and frequency domains. They are therefore:

- The optimal localized representation under spectral compression.
- The natural "atoms" of the observer's encoding.

1.9 Spinors as Minimal Representations

Spinors were reinterpreted not as fundamental physical entities, but as:

> *minimal representations that encode rotational and exchange symmetries in a compressed form.*

Their defining feature:

- A 2π rotation introduces a sign change.
- This sign structure enables antisymmetric encoding.

Thus, spin-$\frac{1}{2}$ behavior is not assumed, but emerges as the minimal structure supporting antisymmetric distinguishability.

1.10 Phase Transition Perspective

The physical universe is hypothesized to exist at a critical point:

- Pure bosonic regime: maximal compression, but loss of information.
- Pure fermionic regime: maximal distinguishability, but rigid structure.

The observed universe corresponds to a balance between these extremes:

> *A phase transition between compression and distinguishability.*

1.11 Conclusion

The key result of this progression is the replacement of hardcoded physical laws with emergent constraints:

- Pauli exclusion emerges from an ambiguity penalty.
- Bosons and fermions correspond to different optimal encoding strategies.
- Spinors arise as minimal representations of symmetry under compression.

This leads to a unified view:

> *Physics is the minimal description of observer-consistent data under competing pressures of compression and distinguishability.*