Semantic Distance via Associative Keyword Fields for Quantum Hyper-Aether

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Abstract

This paper extends the Quantum Hyper-Aether framework by introducing a semantic distance metric based not on direct vector comparison, but on the overlap structure of associative semantic fields.

Instead of measuring meaning similarity through static embedding proximity, the proposed framework models semantics as dynamically generated associative keyword fields. Semantic distance is then defined through the commonality, resonance, and interference structure among these associative fields.

This approach provides:

- human-like semantic similarity,
- context-dependent meaning formation,
- semantic resonance routing,
- emergent specialization,
- semantic collapse dynamics,
- and creativity through long-range semantic interference.

The proposed metric establishes a mathematical foundation for semantic-native operating systems and distributed cognitive architectures.

1 Introduction

Conventional semantic similarity methods rely primarily on:

- vector embeddings,
- cosine similarity,
- latent statistical proximity.

However, human semantic cognition is not solely based on direct vector similarity. Human understanding emerges through associative semantic activation.

For example, the concepts:

- "ocean",
- "universe"

may appear distant in embedding space, yet they share associative semantic structures such as:

- vastness,

- silence,
- unknown,
- depth,
- exploration.

This paper proposes that semantic distance should be defined through the overlap and resonance of associative semantic fields.

2 Associative Semantic Fields

For a semantic entity S_i, we define an associative keyword field:

$$A(S_i) = \{k_1, k_2, k_3, \dots\} \tag{1}$$

where:

- $A(S_i)$ is the associative semantic field,
- k_n are associated semantic keywords.

Unlike conventional embeddings, the associative field represents dynamically evoked meaning structures.

2.1 Weighted Associative Fields

More generally:

$$A(S_i) = \{(k_n, w_n)\} \tag{2}$$

where:

- $w_n \geq 0$ is the associative strength,
- larger values indicate stronger semantic resonance.

3 Semantic Similarity and Distance

3.1 Jaccard-Based Similarity

The simplest similarity measure is:

$$Sim(i,j) = \frac{|A_i \cap A_j|}{|A_i \cup A_j|} \tag{3}$$

Semantic distance is then:

$$D(i,j) = 1 - Sim(i,j) \tag{4}$$

This definition captures semantic overlap through shared associative structures.

3.2 Weighted Semantic Similarity

For weighted associative fields:

$$Sim_w(i,j) = \frac{\sum_{k \in A_i \cap A_j} \min(w_k^{(i)}, w_k^{(j)})}{\sum_{k \in A_i \cup A_j} \max(w_k^{(i)}, w_k^{(j)})} \tag{5}$$

The weighted semantic distance becomes:

$$D_w(i,j) = 1 - Sim_w(i,j) \tag{6}$$

4 Quantum Associative Semantic Fields

In Quantum Hyper-Aether, semantics exist in superposed semantic states.

We therefore define a semantic associative wave function:

$$\Phi(S) = \sum_n w_n e^{i\theta_n} |k_n\rangle \tag{7}$$

where:

- w_n is associative amplitude,
- θ_n is semantic phase,
- $|k_n\rangle$ is the semantic keyword basis state.

4.1 Quantum Semantic Similarity

Semantic similarity can then be defined through quantum fidelity:

$$Sim_Q(i,j) = |\langle \Phi(S_i)|\Phi(S_j)|\Phi(S_i)|\Phi(S_j)\rangle|^2 \tag{8}$$

and quantum semantic distance becomes:

$$D_Q(i,j) = 1 - Sim_Q(i,j) \tag{9}$$

5 Composite Semantic Distance

The complete semantic distance metric integrates multiple semantic perspectives:

$$D_H(i,j) = \alpha D_w(i,j) + \beta D_Q(i,j) + \gamma D_G(i,j) \tag{10}$$

where:

- D_w is associative overlap distance,
- D_Q is quantum semantic distance,
- D_G is semantic graph distance,
- $\alpha, \beta, \gamma \geq 0$,
- $\alpha + \beta + \gamma = 1$.

This metric defines the semantic geometry of Quantum Hyper-Aether.

6 Problems Solved by Semantic Distance

Introducing semantic distance into Quantum Hyper-Aether resolves multiple fundamental ambiguities that previously existed in semantic-computational systems.

Without semantic distance, semantic graphs and semantic virtual machines remain largely conceptual. By defining semantic geometry, the system acquires mathematically grounded semantic dynamics.

6.1 Semantic Routing and Communication

Previously, semantic multicast and semantic routing lacked a rigorous criterion for deciding where semantic information should propagate.

With semantic distance, communication probability becomes:

$$P(i \to j) \propto e^{-D_H(i,j)} \tag{11}$$

This enables:

- semantic-aware VM routing,
- adaptive communication clustering,
- semantic resonance networks,
- meaning-based multicast propagation.

Thus routing becomes driven by semantic affinity rather than static network topology.

6.2 Emergent VM Specialization

The original framework described emergent VM differentiation, but lacked a mechanism explaining why specialization occurs.

Semantic distance introduces semantic phase separation dynamics.

Semantically similar VMs naturally synchronize and cluster, while distant semantic domains diverge into distinct cognitive roles.

This explains the emergence of:

- reasoning VMs,
- memory VMs,
- routing VMs,
- stabilizer VMs,
- creative VMs.

Specialization therefore emerges as a self-organizing property of semantic geometry.

6.3 Semantic Collapse Resolution

Semantic collapse previously lacked a state-selection criterion.

With semantic distance, observation collapses the semantic system toward the nearest coherent semantic state:

$$G_k = \arg\min_j D(O, G_j) \tag{12}$$

where:

- O is the observation semantic field,
- G_j are candidate semantic graph states.

This provides a mathematically interpretable semantic collapse mechanism.

6.4 Creativity and Long-Range Semantic Resonance

Traditional embedding similarity struggles to explain creativity, metaphor, or conceptual blending.

Associative semantic distance enables long-range semantic resonance.

Concepts that are distant in vector space may still share deep associative structures.

For example:

- ocean,
- universe

share semantic associations such as:

- vastness,
- silence,
- exploration,
- unknown depth.

Creativity emerges from such distant semantic resonance:

$$C(i, j) \sim \frac{R(i, j)}{D(i, j)} \tag{13}$$

where:

- $R(i, j)$ is semantic resonance,
- $D(i, j)$ is semantic distance.

This provides a computational foundation for:

- metaphor generation,
- analogical reasoning,
- abstract imagination,
- conceptual synthesis.

6.5 Semantic Memory Organization

Without semantic distance, semantic memory behaves as passive storage.

Semantic geometry transforms memory into a dynamically structured semantic field.

This enables:

- semantic neighborhood formation,
- context-sensitive recall,
- associative memory activation,
- long-range semantic linkage.

Memory therefore becomes semantically navigable.

6.6 Semantic Stability and Turbulence

The original framework referenced semantic stability, but lacked quantitative evaluation methods.

Semantic stability can now be defined as:

$$S = \sum_{ij} w_{ij} D(i,j) \tag{14}$$

This allows detection of:

- semantic coherence,
- instability,
- fragmentation,
- semantic turbulence,
- pre-collapse states.

Thus the semantic system acquires measurable dynamical behavior.

6.7 Formation of Semantic Operating Systems

The most significant consequence is that semantic distance transforms Quantum Hyper-Aether from a conceptual architecture into a semantic operating system.

Semantic distance enables:

- semantic scheduling,
- semantic routing,
- semantic memory allocation,
- semantic VM generation,
- semantic resource organization,
- semantic topology evolution.

In this framework, the operating system no longer manages only computation and memory, but manages semantic dynamics themselves.

6.8 Toward Semantic Physics

Finally, semantic distance introduces the possibility of treating semantics as a physical-like dynamical field.

This enables concepts such as:

- semantic topology,
- semantic curvature,
- semantic attractors,
- semantic flow,
- semantic resonance,
- semantic phase transitions.

Thus Quantum Hyper-Aether becomes not merely an AI architecture, but a candidate foundation for semantic physics and distributed cognitive systems.

7 Semantic Routing

Semantic routing is governed by semantic proximity.

Communication probability between virtual machines becomes:

$$P(i \to j) \propto e^{-D_H(i,j)} \tag{15}$$

This creates:

- semantic multicast,
- semantic resonance routing,
- emergent communication clusters.

Rather than routing packets, the system routes meaning.

8 Emergent VM Specialization

Semantic distance naturally induces VM specialization.

VMs operating in similar semantic regions become coherent, while distant semantic domains separate into independent structures.

Thus:

$$\text{Specialization} \sim \text{Semantic Phase Separation} \tag{16}$$

This mechanism explains the emergence of:

- reasoning VMs,
- memory VMs,
- routing VMs,
- creative VMs,
- stabilizer VMs.

9 Semantic Collapse Dynamics

Observation in Quantum Hyper-Aether induces semantic collapse.

The observed semantic state becomes:

$$G_k = \arg\min_j D(O, G_j) \tag{17}$$

where:

- O is the observation semantic field,
- G_j are candidate semantic graph states.

Thus semantic collapse selects the semantically nearest coherent state.

10 Creativity as Long-Range Semantic Resonance

Creativity emerges from semantically distant yet resonant fields.

We define creativity intensity as:

$$C(i,j) \sim \frac{R(i,j)}{D(i,j)} \tag{18}$$

where:

- $R(i,j)$ is semantic resonance,
- $D(i,j)$ is semantic distance.

High creativity arises when distant semantic domains unexpectedly share associative structures.

This models:

- metaphor generation,
- conceptual blending,
- abstract analogy,
- emergent imagination.

11 Semantic Stability

Global semantic stability is defined as:

$$S = \sum_{ij} w_{ij} D(i,j) \tag{19}$$

This quantity characterizes:

- semantic coherence,
- collapse instability,
- fragmentation,
- semantic turbulence.

12 Advantages

The associative semantic distance framework provides:

- human-like semantic cognition,
- context-sensitive meaning formation,
- adaptive semantic routing,
- emergent semantic topology,
- creativity through semantic interference,
- semantic-native operating behavior,
- distributed semantic cognition.

13 Conclusion

This paper introduced a semantic distance framework based on associative semantic overlap.

Unlike conventional embedding-only similarity, the proposed framework models semantics as dynamic associative fields.

The resulting semantic geometry enables:

- semantic routing,
- semantic collapse,
- emergent specialization,
- semantic memory formation,
- creativity through interference,
- and distributed semantic cognition.

This work provides a mathematical foundation for semantic-native operating systems, distributed AGI architectures, and next-generation cognitive infrastructures.

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