

****Tri-Axial Semantic Reconstruction:**

An Orthogonal Model Integrating Historical, Dynamic, and Algorithmic Structure in Lexical Semantics**

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Abstract

This paper introduces *Tri-Axial Semantic Reconstruction* (TSR), a novel model for representing lexical meaning as a point in a three-dimensional semantic coordinate system. Each axis encodes a distinct and irreducible dimension of semantic information. *Axis A* captures historical-linguistic structure, including etymology, morphological evolution, and documented polysemy. *Axis B* models dynamic semantic structure using a force-dynamic and mechanical-action framework that identifies a root action unifying a word's multiple senses. *Axis C* encodes algorithmic structural organization using the recently defined *Median–Extremes Alternation* (MEA) permutation, which produces a reversible, deterministic ordering for polysemous senses based on center–edge alternation.

Because these axes are mutually orthogonal—neither predictable from nor reducible to each other—the TSR model yields a multi-dimensional, lossless reconstruction of lexical meaning. The resulting coordinate system enables geometric visualization of sense relationships, interpretable embeddings for NLP, models of semantic drift, and a structural approach to cross-linguistic comparison. TSR provides a bridge between historical linguistics, cognitive semantics, and computational modeling, offering a new framework for meaning representation grounded in mathematical structure and linguistic theory.

1. Introduction

Representing word meaning remains a central challenge in linguistics, philosophy of language, and natural language processing (NLP). Existing approaches fall into distinct disciplinary traditions that rarely interact. Historical linguistics documents diachronic change and etymological lineage. Cognitive linguistics identifies conceptual metaphors and dynamic patterns underlying usage. Computational linguistics constructs vector embeddings that encode distributional similarity.

However, these approaches are neither mutually compatible nor mutually explanatory. They produce *parallel* models of meaning that cannot be integrated without loss. Recent work in interpretable embeddings highlights the limitations of purely distributional models, while traditional semantic theory struggles to provide formal, algorithmic representations usable in computation.

This paper proposes a unifying framework: **Tri-Axial Semantic Reconstruction (TSR)**. TSR treats lexical meaning as a point in a three-dimensional coordinate system defined by three orthogonal meaning axes: historical-linguistic, dynamic-semantic, and algorithmic-structural. Each axis captures a category of information that the others cannot predict or explain. Together, these axes produce a multi-perspective, lossless representation of meaning.

The model also introduces the **Median–Extremes Alternation (MEA)** permutation as a structural backbone for polysemy. MEA provides the first fully reversible, deterministic alternation-based ordering with linear complexity, enabling a formal treatment of “central” vs. “peripheral” senses.

By integrating linguistic evidence, cognitive dynamics, and formal algorithmic structure, TSR provides a framework for analyzing meaning that is simultaneously interpretive, historical, and computational.

2. Background and Related Work

2.1 Historical Linguistic Structure

Historical linguistics provides etymological chains, sound-change pathways, and documented sense evolution. These resources describe how meanings emerge and diverge but do not formalize underlying conceptual structure. They also lack predictive models for semantic drift.

2.2 Cognitive Linguistics and Force-Dynamic Models

Cognitive linguistics (Lakoff, Talmy) emphasizes conceptual metaphor and force dynamics, noting that abstract meanings often map onto mechanical or embodied schemas (e.g., “argument as war,” “support as upward force”). However, cognitive models rarely produce formal mathematical structures or algorithmic representations.

2.3 Computational Semantics and Word Embeddings

Modern NLP uses high-dimensional vector embeddings derived from co-occurrence statistics. While effective, these vectors are uninterpretable, conflate unrelated senses, and lack grounding in linguistic structure.

2.4 Polysemy and Sense Ordering

No existing framework provides a formal definition for “central” senses or their relation to peripheral metaphoric extensions. Dictionary ordering is inconsistent and non-algorithmic.

3. Tri-Axial Semantic Reconstruction (TSR)

TSR defines meaning using three independent semantic axes:

1. Axis A — Historical-Linguistic Structure
2. Axis B — Dynamic-Semantic Structure (Force Dynamics)

3. Axis C — Algorithmic Structural Ordering (MEA)

These axes are mutually orthogonal: information on one axis cannot be derived from the others.

4. Axis A: Historical-Linguistic Structure

Axis A encodes all empirically documented historical information about a word:

- etymology and proto-forms
- morphological decomposition
- historical semantic drift
- attested senses over time
- frequency data
- register and regional variation

This axis reflects the *horizontal* movement of meaning across time and cultures. It is inherently empirical and corpus-dependent. Data may be represented through:

- tree structures (etymological lineage)
- distributional vectors
- clustering of senses
- diachronic trajectories

Axis A provides the grounding context for a word's evolution but does not explain conceptual unity among its senses.

5. Axis B: Dynamic-Semantic Structure

Axis B formalizes the *root action* underlying a word's multiple senses using a force-dynamic and mechanical-action model (e.g., push, pull, join, divide, rotate, stabilize, resist).

This axis captures:

- the unifying mechanical metaphor
- the directionality and tension in meaning
- internal dynamics across senses
- conceptual torque (e.g., break = “separate under tension”)
- continuity between literal and figurative senses

Unlike Axis A:

- it does not care about historical accidents
- it identifies the conceptual *mechanism* governing meaning
- it compresses polysemy into a single dynamic schema

This is the cognitive/structural backbone of meaning.

6. Axis C: Algorithmic Structural Ordering via MEA

Axis C provides a formal ordering of polysemous senses using the **Median–Extremes Alternation (MEA)** permutation:

- For a list of senses ordered by frequency or historical priority,
- MEA selects the median (or median pair) first,
- Then alternates between central and peripheral senses:
median → extremes → near-median → near-extremes → etc.

MEA is:

- deterministic
- reversible
- $O(n)$ in complexity
- length-preserving
- applicable to any sequence

When applied to semantic senses, MEA reveals:

- structural prioritization

- center–edge dynamics
- sense symmetry
- conceptual clustering
- a canonical ordering free of editorial choice

This axis cannot be derived from force dynamics or etymology; it is purely algorithmic.

7. Orthogonality of the Axes

Orthogonality is the central theoretical claim:

- Axis A: historical contingency
- Axis B: cognitive action-structure
- Axis C: algorithmic ordering

No axis can be predicted or inferred from the other two.

For example:

- A word's history does not reveal its root mechanical action.
- Its root action does not determine its MEA structure.
- MEA structure does not predict etymological lineage.

This independence allows *lossless reconstruction* of meaning through triangulation.

8. Mathematical Representation

A word w becomes a point in a three-dimensional semantic space:

$$w = (Aw, Bw, Cw) \quad w = (A_w, B_w, C_w) \quad w = (Aw, Bw, Cw)$$

Where:

- Aw is the historical-linguistic vector
- Bw is the dynamic-semantic vector

- CwC_w is the MEA structural vector

Distance metrics may include:

- Euclidean distance
- Manhattan distance
- cosine similarity
- hybrid geometric measures

Clusters in this space correspond to:

- semantic domains
- conceptual families
- metaphor networks
- cross-linguistic equivalences

This provides a mathematically grounded framework for semantic geometry.

9. Applications

9.1 Interpretable Word Embeddings

TSR produces embeddings with explicit semantic meaning along each axis, unlike opaque high-dimensional NLP vectors.

9.2 Semantic Drift Modeling

Words shift position along Axis A over time; drift can be visualized as trajectories.

9.3 Polysemy Analysis

Axis C reveals structural distribution of senses, identifying:

- central meanings
- metaphorical extensions

- emerging peripheral senses

9.4 Cross-Linguistic Comparison

Words in different languages can be projected into the same 3D semantic space for structural comparison.

9.5 Ontology Engineering

TSR may underpin next-generation semantic ontologies with geometric foundations.

9.6 Information Retrieval

Concepts can be searched using geometric proximity rather than keyword matching.

10. Discussion

TSR provides a unified, multi-perspective framework for lexical meaning that neither duplicates nor replaces existing models. Instead, it integrates and formalizes relationships across fields long treated as separate.

The framework invites interdisciplinary collaboration:

- linguists to refine Axis A
- cognitive semanticists to model Axis B
- mathematicians and computer scientists to analyze Axis C
- NLP practitioners to map TSR coordinates into large corpora

TSR is not a complete theory of meaning but a **coordinate architecture** capable of housing multiple theoretical models under a unified geometric schema.

11. Conclusion

This paper introduces Tri-Axial Semantic Reconstruction, a three-dimensional model for representing lexical meaning using orthogonal axes of historical-linguistic structure, dynamic-semantic action, and algorithmic structural ordering. The model provides a lossless, interpretable, mathematically grounded space for analyzing meaning, polysemy, and semantic drift.

Future work will involve formalizing measurement methods for each axis, developing computational embeddings, and validating TSR through empirical analysis across languages and corpora.