Semantic Constraints for Compositional Meaning

A Working Framework

Joel Ellingson — January 2025

1. Problem Statement: Why Unconstrained Semantics Fails

Meaning composition is not arbitrary. Some combinations work ("the red ball"), some fail categorically ("*the very existence"), and some succeed only through systematic reinterpretation ("the loud car" → the car with a loud engine, not a car that is itself loud).

Standard distributional approaches (word2vec, BERT embeddings) capture statistical regularities but cannot explain why:

- "The cat devoured the fish" is well-formed
- "*The idea devoured the fish" is anomalous
- "The company devoured its competitors" succeeds through metaphorical extension

These patterns recur systematically across languages, domains, and speakers. This suggests that semantic units carry **constraints** that determine compositional legality independent of context.

The core question: What properties must a semantic unit carry for composition to succeed or fail in principled ways?

2. The Central Reframe: Atoms Are Constraints, Not Meanings

A critical insight emerges from synthesizing multiple independent research traditions: **semantic atoms are not meanings themselves—they are constraint-bearing property bundles that determine how meaning can compose, fail, stabilize, and generalize.**

The goal is not to represent the meaning of "dog" but to encode *why "dog" can fill the subject slot of "eat" while "justice" cannot* (without coercion).

3. Five Constraint Dimensions

For composition to succeed predictably, every semantic unit must answer certain questions. These map to five candidate dimensions along which constraints manifest:

Axis 1: Ontological Type — *What kind of thing is this?*

A unit must declare whether it denotes an entity, event, state, property, or relation. This determines what roles it can fill, what modifications it accepts, and what inferences it licenses. Jackendoff's categories (Thing, Event, State, Place, Path, Property, Time, Amount) recur across formal semantics, cognitive linguistics, and computational ontologies (SUMO, DOLCE).

Axis 2: Valence Structure — *How can this combine with others?*

Without combinatorial rules, language collapses into unstructured association. A unit must specify how many arguments it requires, what types are permitted, and what roles they play. VerbNet's 300+ verb classes, FrameNet's 1,200+ frames, and type-logical grammar all converge on finite, systematic argument structures. The same thematic role inventory (Agent, Patient, Theme, Experiencer, Instrument, Goal, Source, Location) appears across unrelated theoretical traditions.

Axis 3: Internal Decomposition (Qualia) — *Which aspects are accessible?*

Without selective access to internal structure, polysemy explodes into homonymy. "Fast car" accesses motion capability; "fast food" accesses preparation time; "fast driver" accesses behavioral tendency. Pustejovsky's Generative Lexicon identifies four qualia roles (Constitutive, Formal, Telic, Agentive) that govern coercion and aspect selection—explaining systematic polysemy without multiplying lexical entries.

Axis 4: Force Dynamics — *Does this participate in change or causation?*

Without force/causation encoding, event semantics fails. Units must declare whether they cause, enable, or prevent change; resist or yield to external forces; participate in directed processes. Talmy's force dynamics explains systematic patterns in causative alternations, aspect, and modality across languages. The same primitives (Agonist, Antagonist, tendency toward motion/rest) recur in unrelated language families.

Axis 5: Geometric Position — *How does this relate to others?*

Without metric structure, generalization and categorization fail. Units must occupy positions where proximity encodes similarity, depth encodes abstraction level, and regions encode category boundaries. Gärdenfors' Conceptual Spaces demonstrate that natural categories correspond to convex regions; hyperbolic embeddings (Nickel & Kiela 2017) dramatically outperform Euclidean for hierarchical structure; Berlin-Kay color universals show cross-linguistic constraints on boundaries.

Dimension	Governs	Key Sources
Ontological Type	Category membership	Jackendoff, SUMO
Valence Structure	Argument slots and roles	VerbNet, FrameNet, Lambek
Internal Decomposition	Accessible qualia	Pustejovsky (1995)
Force/Causation	Dynamic participation	Talmy (2000)
Geometric Position	Similarity and hierarchy	Gärdenfors, Hyperbolic

Note: These dimensions appear orthogonal, but orthogonality is hypothesized, not proven. Empirical work may reveal dependencies or require axis splitting/merging. A potential sixth axis—**Boundedness** (count/mass, telic/atelic)—may warrant separate treatment or reduce to a feature within Ontological Type.

4. Formal Grounding: Type-Logical Grammar

The constraint-based view has formal mathematical grounding in type-logical grammar (Lambek 1958, Moortgat 2012). This framework treats syntax as type inference—words have types, and combination is type-valid function application.

Each word is assigned a **type** specifying what it combines with:

Word	Type	Meaning
John	NP	Noun phrase (saturated)
runs	NP\S	Takes NP on left, yields S
the	NP/N	Takes N on right, yields NP
quickly	(NP\S)\(NP\S)	Modifies verb phrase

Composition follows logical rules: **Forward Application** (A/B + B → A) and **Backward Application** (B + B\A → A). Via the Curry-Howard correspondence, types are propositions, derivations are proofs, and composition is computation. This means syntactic derivation *is* semantic computation—compositionality is built into the grammar, not learned.

"Frege in Space" — Compositional Distributional Semantics

Baroni et al. (2014) extend this insight: different word classes have different **algebraic types**. Nouns are vectors (points in semantic space). Adjectives are matrices (linear transformations on nouns). Transitive verbs are order-3 tensors (taking two noun arguments). This respects grammatical types while preserving geometric structure—and aligns directly with VerbNet's thematic role structure.

The implication: composition operations can be **derived from linguistic theory** rather than learned from data. Type compatibility predetermines which combinations are well-formed.

5. Empirical Anchors

These constraint dimensions are grounded in multiple independent research programs:

Cross-Linguistic Validation

• **NSM (Natural Semantic Metalanguage):** 65 semantic primes verified across 30+ languages from 16+ families, organized into categories: Substantives (I, YOU, SOMEONE, THING), Mental Predicates (THINK, KNOW, WANT, FEEL), Speech (SAY, WORDS, TRUE), Actions (DO, HAPPEN, MOVE), Space/Time, Logical operators, Evaluators, Quantifiers

- **Berlin-Kay color universals:** Constrained progression of basic color terms across languages
- **Thematic role inventories:** Converge on 8-12 roles regardless of theoretical framework

Computational Validation

- **VerbNet:** 6,800 verbs in ~300 classes organized by syntactic-semantic properties
- **FrameNet:** 1,200+ frames with explicit role structures and frame-to-frame relations (Inheritance, Causative_of, Perspective, Precedes)

- **WordNet-SUMO mapping:** Taxonomic organization validated against formal ontology

Geometric & Neural Validation

- **Hyperbolic embeddings:** 5D hyperbolic matches 200D Euclidean for hierarchical data
- **Binder et al. (2016):** 65 brain-based experiential attributes clustering compatibly with the proposed axes

6. What Is Explicitly Out of Scope

The atomic constraint layer does **not** include: pragmatics, information structure, epistemic/modal status, definiteness, social meaning, or discourse coherence. These operate *above* the constraint layer—they take constraint-bearing units as input and produce context-sensitive interpretations as output.

Key distinction: Atomic constraints are stable across contexts; interface layers modulate interpretation contextually.

7. Application: Predetermined Attention Sparsity

One motivation for this framework is computational: standard transformer attention computes all $O(n^2)$ token pairs, then softmax suppresses most of them. If semantic constraints can predetermine which pairs are compatible, we can skip the incompatible pairs entirely.

Early experiments using constraints derived from POS compatibility, VerbNet selectional restrictions, and WordNet hypernyms suggest this is viable:

- ~74% of baseline transformer attention mass lands on linguistically-predicted compatible pairs (vs. ~47% for random masks with same sparsity)
- 21-30% faster convergence to equivalent perplexity
- ~31% sparsity with no quality degradation

This validates that constraint-based structure captures something real. Extending coverage to Qualia and Force dynamics should improve these results—and would test the full five-axis framework.

8. Summary Position

What I claim:

- Semantic composition is governed by constraints, not arbitrary associations
- These constraints can be organized along a small number of independent dimensions
- Multiple independent research traditions converge on similar dimensional structure

What I do not claim:

- That the current five axes are final or complete
- That I have derived them deductively from first principles
- That they exhaust semantic structure

The axes are current best hypotheses—to be tested, not defended. I would welcome feedback on where this framework is sound, where it oversimplifies, and what distinctions I may be missing.

—

This memo synthesizes research from linguistics, cognitive science, formal semantics, typology, and neuroscience. It is intended as a working document for developing a principled "periodic table" of semantic properties.