

Kimera SWM Architecture (Geoid, Entropy, and EchoForm)

The **Kimera SWM** is structured around three foundational components – **Geoids**, **Semantic-Thermodynamic Entropy**, and **EchoForm** – which together govern its knowledge representation and processing pipeline. A **Geoid** is a core semantic unit (akin to a frame or concept node) that combines structural, symbolic, and meaning content. Geoids may be implemented as structured records or graph nodes containing slot-value pairs, predicates, and links to other geoids. In effect, each geoid represents a “stereotyped situation” or concept schema ¹ ². Geoids carry symbolic identifiers (names or URIs) plus semantic features (attributes or embeddings) and relational links (edges to other geoids). They form a large semantic network or ontology (as in semantic frames or network structures ¹ ²).

Data Structures – Geoids and EchoForm: Geoids are stored in a knowledge base (e.g. a graph database) where each node has fields (similar to AI “frames” ¹) and relations to other nodes. For example, a geoid for “Purchase” might include slots for *buyer*, *seller*, *item*, *price*, *time* etc. Underlying these is a formal schema (e.g. RDF/OWL or JSON) that defines the allowed slots and types, ensuring consistency across geoids. **EchoForm** is the representational grammar or schema used to encode incoming events as structured data. EchoForm frames events in terms of their participants and relations (subject, action, object, time, location, etc.), much like an event ontology or a semantic frame ³ ¹. For instance, an EchoForm entry could take the form:

```
Event {  
  actor: X, action: Y, object: Z, time: T, location: L, context: C  
}
```

This EchoForm schema maps an event into a tuple of semantic fields; it effectively produces the data structure that is matched against geoids. The design of EchoForm draws on frame semantics (as in cognitive AI) and event ontologies: events are encoded as relations among entities ³ ⁴.

Semantic-Thermodynamic Entropy: The system maintains a quantitative measure of uncertainty or “meaning tension” among active geoids, called *Semantic-Thermodynamic Entropy*. Formally, this is analogous to Shannon entropy: it quantifies the average uncertainty of the current semantic state ⁵. Practically, one can compute entropy over a distribution of active geoids or feature vectors, e.g.

$$H_{\text{semantic}} = - \sum_i p_i \log p_i,$$

where p_i reflects the normalized strength (activation) or probability of geoid i being relevant to current inputs. In Wang et al.’s formalism, “semantic entropy” $H(Y_\theta)$ is defined similarly to Shannon entropy ⁶. High semantic entropy indicates a diffuse or conflicted state with many competing interpretations (high unpredictability of meaning), while low entropy indicates concentrated, coherent knowledge. By analogy

with thermodynamics, this entropy serves as a **pressure metric**: the system “prefers” to minimize free energy/entropy over time ⁷ ⁸, driving processes like hypothesis selection, learning, and knowledge reorganization.

Processing Pipeline and Logic

The Kimera SWM operates via an event-driven pipeline. Below is the stepwise logical flow:

- **1. Event Input and EchoForm Encoding:** Raw input data (text, sensor data, etc.) is parsed into an EchoForm event structure. A dedicated parser or extractor fills the EchoForm schema fields for each event. This structured event record encodes the event’s semantics in a formal way. For example, a sentence like “Alice buys a car from Bob” might yield

Event { actor: Alice, action: buy, object: car, agent: Bob }

. EchoForm ensures that events are consistently represented so they can be matched against geoids.
- **2. Geoid Matching and Activation:** The EchoForm event is used to query and activate relevant geoids. Each geoid contains a pattern or prototype (symbolic and semantic features) describing a category of events. The system compares the EchoForm tuple against geoids (e.g. via unification, semantic similarity, or embedding distance). Matching geoids receive an **activation** score based on similarity. These activations are then **spread** across the geoid network according to the connectivity (similar to spreading activation in semantic networks ⁹). Concretely, labeled source nodes (initially the geoids most directly matching the event) propagate weighted activation to neighbors in the graph ⁹. Activation decays with distance or inhibitory thresholds, so only closely related geoids become significantly active. This mechanism is analogous to cognitive spreading activation: it retrieves associated concepts and assesses which semantic clusters are most relevant.
- **3. Resonance (Recognition) vs. Novelty:** Activated geoids compete via a *resonance* mechanism (inspired by Adaptive Resonance Theory ¹⁰). A geoid “resonates” with the event if its stored template closely matches the input (the difference is below a vigilance threshold ¹⁰). If resonance occurs, the event is recognized as an instance of that geoid’s category. Otherwise, if all matches are poor (all activations below threshold), the system may invoke a *search/reset* akin to ART: suppressing poor matches and seeking another candidate, or prepare to form a new geoid. Thus, resonance signals successful categorization; failure to resonate signals novelty.
- **4. Belief Revision / Contradiction Handling:** When the new event content contradicts existing geoids (e.g. it asserts a fact that conflicts with stored facts), a **belief revision** process is triggered ¹¹. This involves identifying conflicting geoids and updating or retracting information to restore consistency. For example, if geoids imply “X is true” and the new event states “X is false,” the system must revise one of these beliefs ¹¹. Formal belief revision logic guides which geoids to modify or remove. This ensures the KB remains coherent, preventing unsatisfiable contradictions from persisting.
- **5. Learning and Mutation:** If the event could not be adequately captured by existing geoids (e.g. resonance failed and no suitable category exists), the system undergoes **mutation**: it creates or adapts geoids to incorporate the novel structure. Mutation can mean instantiating a new geoid node for this event type, or splitting an existing geoid into finer categories. This process updates the KB

topology. In ANN terms, it is akin to forming a new cluster or performing structural learning. The criteria for mutation are influenced by entropy (see below) and by thresholds on activation novelty: rarely matched events accumulate until a trigger for learning occurs.

- **6. Entropy Monitoring:** Throughout processing, the system computes the **semantic entropy** of the active-geoid distribution ⁶ ⁵. This captures the “spread” of activation. For instance, if a single geoid dominates (low uncertainty), entropy is low; if many geoids share activity roughly equally (high uncertainty), entropy is high. Conceptually, this entropy reflects the amount of “cognitive pressure” or information discrepancy in the system at that moment.
- **7. Entropy-Based Triggers and Dynamics:** The semantic entropy guides higher-level behavior. Key triggers include:
 - **Drift:** When entropy is moderate to high, the system enters a “drift” mode, exploring related concepts more freely. For example, if no strong resonance occurs, meanings may drift until a coherent pattern emerges. This resembles concept drift adaptation in learning systems.
 - **Collapse / Pruning:** If entropy exceeds a high threshold, the system performs a **collapse** or pruning of low-importance geoids. Much as high thermodynamic entropy can induce phase transitions, high semantic entropy triggers consolidation: weak or peripheral geoids (with low activation or inconsistent data) are merged or eliminated to simplify the model. This is akin to forgetting in cognitive models or pruning in neural networks, and it serves to reduce complexity.
 - **Echo Loops:** Under certain entropy conditions, activation may enter feedback loops (“echo loops”), repeatedly reinforcing particular patterns. For example, a self-reinforcing chain of related geoids can sustain activation internally. The system monitors for such loops and eventually dampens them (e.g. via decay or thresholding) unless they reflect a valid recurrent pattern.
 - **Learning/Motif Mutation:** Extremely low entropy (overly rigid state) may trigger increased mutation pressure: if the model is too certain but new data still arrives, the system is compelled to create new variants. Conversely, high entropy can also trigger creative mutation to split ambiguous geoids. In short, entropy acts as a **cognitive pressure**: much as free-energy minimization drives the brain ⁷, the system seeks to reduce semantic entropy. When it cannot immediately minimize entropy by simple adjustment, it resorts to structural changes (mutation) that can lower the entropy in future states.

These dynamic responses ensure that the knowledge base reorganizes adaptively. Over time, frequent echo loops that reduce entropy become entrenched, while unstable configurations are pruned. The interplay of activation spreading and entropy-based adaptation is analogous to **predictive coding**: the system continually predicts event structure (via geoids) and adjusts until the “surprise” (entropy) is minimized ⁷ ⁸.

Formal Architecture Mapping

Modules and Data Flow: The Kimera SWM can be decomposed into submodules in a data pipeline. For example:

- **Input Interface:** Receives raw event data (text, signals) and forwards it to the EchoForm Parser.
- **EchoForm Parser:** Converts raw input into the structured EchoForm schema (event frame). Internally it uses grammars or ML models to extract entities and actions.

- **Geoid Knowledge Base:** A database of geoid records (e.g. triple store or object store), indexed by attributes and relations. Supports queries by pattern.
- **Activation Engine:** Implements matching and spreading activation. It takes an EchoForm frame, retrieves candidate geoids, computes activation scores, and propagates activation through the geoid graph ⁹.
- **Resonance/Recognition Unit:** Applies thresholds (vigilance) to determine recognition. It triggers learning if no stable match is found ¹⁰.
- **Revision/Conflict Handler:** Monitors for contradictory information and invokes belief revision protocols to maintain consistency ¹¹.
- **Entropy Monitor:** Continuously computes the semantic entropy of the active geoid set ⁶ ⁵ and signals when thresholds are crossed.
- **Adaptation Controller:** On entropy triggers, it orchestrates pruning, mutation, or loop-damping. It updates the geoid KB (e.g. merging or deleting nodes) and may refine EchoForm mappings.
- **Output/Action Module:** The resulting high-level interpretation or decision (e.g. categorized event, updated KB, or downstream command) is emitted for further use.

Data Schemas: EchoForm events and geoids both follow defined schemas. For EchoForm, the schema might be a JSON Schema or OWL ontology specifying that each event has fields like {actor, predicate, object, time, location, context}. Geoids are likewise structured: for instance, a geoid record could look like

```
Geoid {
  id: G123,
  type: "PurchaseEvent",
  slots: { buyer: Person, seller: Person, item: Product, price: Number, ... },
  relations: [...],
  prototypeVector: [...]
}
```

This formalization allows algorithmic matching: the EchoForm event is matched against slots and relations of geoids. Semantic features (e.g. word embeddings or symbolic categories) can be stored in fields like prototypeVector for fuzzy comparison.

EchoForm Encoding Logic: When encoding an event, EchoForm identifies frame elements (roles) and fills the corresponding slots. This may rely on a natural language or sensor processing subsystem (not detailed here), but the key is that all events are expressed in the same schema so they can be uniformly integrated. In practice, EchoForm can be implemented via a schema mapping (e.g. RDF triples: <Actor> --[Action]--> <Object> plus metadata), or via predicate logic form. This ensures events are graph-structured data compatible with the geoid graph.

Integration and System Evolution

The **Geoid-Entropy-EchoForm** interplay drives system evolution. As events stream in, geoids accumulate evidence and their statistical associations change. Activation patterns adjust geoid weights; entropy calculations summarize the health of representations. Over time, well-used geoids stabilize (low entropy,

strong resonance), while fringe concepts may drift or be culled. This dynamic is analogous to a learning neural network that reinforces some pathways and prunes others based on error/surprise.

Formally, one can view the system as alternating between *inference* (recognition via activation/resonance) and *learning* (updating geoids and network topology). In the inference phase, low entropy is the goal (clear categorization); in learning, sudden entropy spikes indicate model inadequacy, prompting structural changes. The cyclic process – encode event (EchoForm), activate geoids, measure entropy, adapt structures – constitutes the logical pipeline of Kimera SWM.

Citations: The design draws on cognitive-semantic principles: semantic networks and frames as knowledge structures ¹ ², spreading-activation inference ⁹, adaptive resonance matching ¹⁰, and belief revision for consistency ¹¹. The entropy concept is rooted in information theory ⁵ and predictive coding (free-energy) frameworks ⁷ ⁸. Together, these components form a coherent architecture that encodes events (via EchoForm), represents knowledge (via Geoids), and self-organizes under semantic–thermodynamic pressures (via entropy-driven adaptation).

¹ ⁴ Frame (artificial intelligence) - Wikipedia

[https://en.wikipedia.org/wiki/Frame_\(artificial_intelligence\)](https://en.wikipedia.org/wiki/Frame_(artificial_intelligence))

² Knowledge representation and reasoning - Wikipedia

https://en.wikipedia.org/wiki/Knowledge_representation_and_reasoning

³ Mechanisms Meet Content: Integrating Cognitive Architectures and Ontologies

<https://cdn.aaai.org/ocs/4161/4161-17767-1-PB.pdf>

⁵ ⁸ Entropy (information theory) - Wikipedia

[https://en.wikipedia.org/wiki/Entropy_\(information_theory\)](https://en.wikipedia.org/wiki/Entropy_(information_theory))

⁶ A Semantic Generalization of Shannon's Information Theory and Applications

<https://www.mdpi.com/1099-4300/27/5/461>

⁷ Predictive coding under the free-energy principle - PMC

<https://pmc.ncbi.nlm.nih.gov/articles/PMC2666703/>

⁹ Spreading activation - Wikipedia

https://en.wikipedia.org/wiki/Spreading_activation

¹⁰ Adaptive resonance theory - Wikipedia

https://en.wikipedia.org/wiki/Adaptive_resonance_theory

¹¹ Belief revision - Wikipedia

https://en.wikipedia.org/wiki/Belief_revision