Relevance Activation Theory in the RSVP Framework: A Derived Field-Theoretic Model of Cognition

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Abstract

This paper presents a field-theoretic model of cognition, integrating **Relevance Activation Theory (RAT)** within the **Relativistic Scalar Vector Plenum (RSVP)** framework. Cognition is modeled as recursive associative trajectories through a derived semantic manifold $\mathcal{M}$, governed by a scalar potential Φ, vector flow $\vec{v}$, and entropy density S. These fields evolve according to coupled differential equations, with relevance defined as vector alignment $\vec{v} \cdot \nabla\Phi$. The framework generalizes predictive processing, global workspace theory, and embodied cognition, while providing diagnostic metrics (e.g., semantic torsion, entropy descent) for reasoning failures in large reasoning models (LRMs). We formalize the dynamics, geometry, and neurocognitive mappings, proposing empirical and computational pathways for validation.

1 Introduction

Recent empirical findings (e.g., [**?**]) reveal that large reasoning models (LRMs) often produce shallow outputs under high-complexity conditions, suggesting that chain-based reasoning is locally plausible but globally brittle. We propose a novel model of cognition that reframes reasoning as recursive vectorial descent through a semantic field. **Relevance Activation Theory (RAT)** posits that cognition involves feedback-mediated alignment of latent semantic cues with internal goals, formalized as vector flows on a derived manifold. The **Relativistic Scalar Vector Plenum (RSVP)** provides a geometric and thermodynamic substrate, modeling cognition as trajectories governed by scalar potential Φ, vector flow $\vec{v}$, and entropy S. This paper formalizes the RSVP-RAT framework, addressing its mathematical structure, neurocognitive mappings, and implications for cognitive science and artificial intelligence.

2 Relevance Activation Theory

RAT conceptualizes cognition as a control system over semantic affordances, where relevance is dynamically activated through feedback between internal reference signals and perceptual inputs. For a semantic manifold $\mathcal{M}$, relevance is defined as:

$$R(x) = \vec{v}(x) \cdot \nabla\Phi(x),$$

where $\vec{v}$ is the vector flow, $\nabla\Phi$ is the gradient of the scalar potential, and $x \in \mathcal{M}$. Cognitive trajectories $\gamma(t) \subset \mathcal{M}$ evolve according to:

$$\frac{d\gamma}{dt} = \vec{v}(\gamma(t)) - \lambda\nabla S(\gamma(t)),$$

where λ modulates entropy-based correction, ensuring recursive descent toward high-relevance, low-entropy configurations.

3 RSVP Field Framework

The RSVP framework models cognition as the evolution of three coupled fields on a Lorentzian manifold (M, g):

- $\Phi : M \times \mathbb{R} \to \mathbb{R}$, a scalar potential encoding value or goal alignment.
- $\vec{v} : M \times \mathbb{R} \to TM$, a vector field encoding semantic flow or agency.
- $S : M \times \mathbb{R} \to \mathbb{R}_{\geq 0}$, an entropy density encoding uncertainty or cognitive load.

The fields obey coupled evolution equations:

$$\begin{aligned}
\partial_t \Phi + \vec{v} \cdot \nabla \Phi &= -\delta S, \\
\partial_t \vec{v} + (\vec{v} \cdot \nabla)\vec{v} &= -\nabla \Phi + \eta \nabla S + \tau(\gamma), \\
\partial_t S + \nabla \cdot (S \vec{v}) &= \sigma(\Phi, \vec{v}),
\end{aligned}$$

where δ, η are dissipation coefficients, $\tau(\gamma)$ is semantic torsion, and σ captures entropy generation. The Lagrangian governing these dynamics is:

$$\mathcal{L} = \frac{1}{2}\|\vec{v}\|^2 - \Phi - \delta S + \eta \langle \vec{v}, \nabla \Phi \rangle.$$

4 Semantic Manifold $\mathcal{M}$

The manifold $\mathcal{M}$ is a differentiable stack $\mathrm{Map}(C, X)$, where C is a sensorimotor configuration space and X encodes conceptual affordances. Its Riemannian metric $g_{\mathcal{M}}$ is induced by semantic similarity, with curvature R^l_{ijk} reflecting conceptual clustering. The dimensionality is determined by the effective rank of the Jacobian $J_f : \mathbb{R}^{n_{\text{input}}} \to \mathcal{M}$. Dynamic patching (e.g., via TARTAN-like tiling) allows $\mathcal{M}$ to adapt during learning or reasoning.

5 Neurocognitive Mappings

The fields map to neurobiological substrates:

- Φ: Dopaminergic reward signals or vmPFC BOLD activity, modeled as:

$$\partial_t \Phi = D_\Phi \Delta \Phi + f_{\text{reward}}(x, t).$$

- $\vec{v}$: Phase-coupled oscillations or neural vector fields, quantifiable via MEG/EEG phase-locking values.
- S: Neural entropy, computed as Shannon entropy of population codes or transformer softmax outputs.

6 Recursive Associative Trajectories

Cognitive processes are modeled as recursive associative trajectories $\gamma(t) \subset \mathcal{M}$, governed by:

$$\frac{d\gamma}{dt} = \vec{v}(\gamma(t)) - \lambda \nabla S(\gamma(t)).$$

Semantic torsion is defined as:

$$\tau(\gamma) = \|\vec{v} \wedge \nabla \Phi\| + \|\nabla S \cdot \vec{v}\|.$$

These trajectories explain phenomena such as:

- **Insight**: Rapid torsion resolution ($\tau \to 0$) with entropy drop ($\Delta S < 0$).
- **Confusion**: Stagnation in high-torsion regions ($\tau \gg 0$, $\nabla \Phi \approx 0$).
- **Shortcutting**: Geodesic projection in flat regions of $\mathcal{M}$ ($\ker(\nabla \Phi)$).

7 Contrast with Large Reasoning Models

LRMs fail in high-complexity tasks due to:

- Shallow Φ minima, leading to premature convergence.
- Flat ∇S, indicating lack of entropic resolution.
- Misalignment $\vec{v} \perp \nabla\Phi$, reflecting semantic drift.

Diagnostic invariants include:

- Alignment functional: $\mathcal{A} = \int_\gamma \frac{\vec{v}\cdot\nabla\Phi}{\|\vec{v}\|\|\nabla\Phi\|} dt$.

- Entropy descent rate: $\mathcal{E} = \frac{d}{dt} S(\gamma(t))$.

8 Relation to Cognitive Theories

RSVP-RAT generalizes existing theories:

- **Predictive Processing**: $\vec{v} \sim -\nabla S$ embeds free-energy minimization.
- **Global Workspace Theory**: Low-S states correspond to broadcast trajectories.
- **Embodied Cognition**: Fields extend over sensorimotor manifolds $M_{\text{body}} \subset \mathcal{M}$.

9 Future Work

Future research will:

- Simulate RSVP dynamics using neural field models (e.g., in NEST or Brian2).
- Test field mappings using fMRI/EEG during insight or multitasking tasks.
- Develop TARTAN, a platform for dynamic manifold patching and trajectory simulation.
- Explore BV-BRST quantization for symbolic-to-geometric transitions.

10 Conclusion

RSVP-RAT reframes cognition as recursive descent through a derived semantic field, offering a geometric and thermodynamic alternative to symbolic or token-based models. By modeling reasoning as trajectories governed by Φ, $\vec{v}$, and S, the framework captures the dynamic, adaptive nature of thought, providing a foundation for cognitive science and next-generation AI.