Collective Reference Shift and Constraint-Field Dynamics in Multi-Agent Systems

An Architectural Framework for Bounded Collective Stability

Stephen A. Putman
putmanmodel@pm.me
Version 0.2 — February 2026

Abstract

Collective dynamics in artificial agent systems are often modeled through averaged affective states or belief propagation. This paper argues that systemic instability is more reliably predicted by reference shift within shared constraint fields than by mean activation alone. Multi-agent interaction is formalized as propagation across coupled constraint surfaces, where transitions from distributed to concentrated reference states alter feedback symmetry and dissipation capacity. Two cascade regimes—amplification-dominant and inhibition-dominant—emerge as structural phase transitions contingent on coupling asymmetry and bounded dissipation rather than emotional magnitude. By grounding crowd dynamics in constraint-mediated interaction rather than narrative contagion, this framework provides measurable criteria for instability, recovery, and bounded adaptation in scalable, non-omniscient multi-agent simulations.

1. Introduction

Multi-agent simulations frequently model collective behavior through aggregated variables such as mean affect, belief distribution, or consensus convergence. While these measures capture surface-level trends, they often fail to anticipate abrupt phase transitions, cascade instability, or coordinated shifts in behavior.

This paper proposes a constraint-field account of collective dynamics in which systemic instability is better predicted by shifts in reference alignment than by activation magnitude alone. Agents do not merely transmit state; they operate within shared constraint fields where coupling strength, feedback symmetry, and dissipation capacity determine systemic stability.

Building upon prior analyses of dimensional inference and stratified memory, we extend the architectural framework to distributed systems. Collective behavior is treated as structured propagation across coupled agents bounded by constraint access, persistence architecture, and field-mediated interaction.

The objective is architectural discipline. By formalizing reference state transitions, cascade regimes, and stability boundaries, we articulate design principles for scalable multi-agent systems that remain adaptive without requiring omniscient coordination.

2. Terminology and Operational Definitions

The following terms are used in an architectural and operational sense:

Agent

A bounded system possessing stratified memory and representational mediation, capable of state update through interaction.

Constraint Field

The structured interaction surface within which agents exchange influence. A constraint field encodes coupling rules, feedback symmetry, and dissipation channels.

Coupling Coefficient (κ_{ij})

A scalar parameter governing influence strength from agent j to agent i within a shared field.

Reference State (r_i)

A continuous scalar alignment parameter representing an agent's dominant interpretive orientation.

- $r_i \approx 0 \rightarrow$ distributed reference (shared constraint orientation).
- $r_i \rightarrow 1 \rightarrow$ concentrated reference (internally aligned orientation with reduced reciprocity).

Distributed Reference

A configuration in which agents orient primarily to shared constraint surfaces and reciprocal feedback.

Concentrated Reference

A configuration in which agents orient primarily to internal activation pressure with diminished reciprocity.

Dissipation Channel (*D*)

A structural pathway allowing activation pressure to discharge without amplifying systemic coupling.

Cascade

A rapid, nonlinear propagation of state change across agents resulting from coupling asymmetry and reduced dissipation.

Phase Transition

A qualitative shift in systemic behavior resulting from incremental changes in coupling strength, reference distribution, or dissipation capacity.

Reciprocity

The symmetry of feedback exchange between agents. High reciprocity stabilizes distributed reference; asymmetric feedback increases instability risk.

Reciprocity may be approximated by coupling symmetry. For example, a simple reciprocity index may be defined as

$$R = \frac{1}{N} \sum_{i,j} \frac{1}{|\kappa_{ij} - \kappa_{ji}| + \varepsilon},$$

where $\varepsilon > 0$ is a small constant preventing singularity when $\kappa_{ij} = \kappa_{ji}$, Equivalently, as $|\kappa_{ij} - \kappa_{ji}| \to 0$, reciprocity increases and effective dissipation strengthens.

3. Reference Distribution and Systemic Stability

Let each agent *i* possess a reference alignment scalar $r_i \in [0,1]$. Reference alignment is continuous and state-dependent.

Activation a_i and reference alignment r_i evolve on different timescales. Activation responds rapidly to field perturbation, whereas reference alignment shifts under sustained activation and coupling asymmetry. This timescale separation allows transient spikes to dissipate without immediately restructuring reference orientation.

Collective stability depends not solely on mean activation, but on the distribution of r_i across the population.

Define concentration density:

$C = (1/N) \Sigma_i r_i$

A system may exhibit moderate activation while remaining stable if *C* remains low and dissipation channels are strong.

Conversely, instability may arise under modest activation if *C* increases while dissipation capacity remains constant or declines.

Systemic risk therefore depends on reference orientation rather than affect amplitude alone.

Concentrated reference reduces effective reciprocity. As r_i increases across agents, dissipation pathways weaken and activation becomes locally self-reinforcing. Distributed reference increases feedback symmetry and expands dissipation channels.

This transition is structural rather than psychological. Concentration is not inherently destabilizing; instability arises when coupling strength remains high while reciprocity declines.

Systemic stability is therefore governed by interaction among:

- Coupling strength (κ),
- Dissipation capacity (*D*),
- Concentration density (*C*).

Abrupt transitions occur when incremental parameter shifts push the system across a stability boundary.

4. Field Coupling and Endogenous Amplification

Agents influence one another through field-mediated coupling.

Let each agent j possess activation magnitude a_j and reference alignment r_j. Influence exerted on agent i may be expressed as:

$$\Delta a_i \propto \Sigma_j \ \kappa_{ij} \cdot a_j \cdot r_j$$

Influence is therefore asymmetric: agents with high activation and concentrated reference exert disproportionate perturbation on the field.

However, isolated concentrated agents do not necessarily produce instability. In a predominantly distributed field (low *C*), reciprocal damping dissipates localized perturbations.

Instability emerges when concentration density exceeds a critical threshold relative to dissipation capacity. To compare amplification against dissipation formally, we define effective amplification at the agent level:

$$A_{\mathrm{eff},i} = \sum_{j=1}^{N} \kappa_{ij} a_j r_j$$

Cascade probability increases nonlinearly as A_eff approaches or exceeds D.

Three regimes emerge:

- Low $C \rightarrow$ perturbations dissipate.
- Moderate $C \rightarrow$ localized oscillations.
- High $C \rightarrow$ systemic phase transition.

Resonance is endogenous. Internal reference alignment modulates the field itself. Local clusters of concentrated agents act as amplification nodes capable of shifting systemic equilibrium.

These dynamics arise from structural asymmetry and bounded dissipation—not narrative contagion.

5. Cascade Regimes and Stability Boundaries

Instability occurs when amplification exceeds dissipation:

Let dissipation capacity be denoted D, representing the aggregate strength of reciprocal feedback and structural damping mechanisms within the constraint field.

The instability condition is therefore:

$A_{\mathrm{eff},i} > D$

Dissipation capacity may decrease as concentration density increases due to erosion of reciprocal feedback pathways. A minimal functional approximation may be expressed as

$D(C) = D_0(1 - \alpha C)$,

where $\alpha \in [0,1]$ modulates the sensitivity of damping to concentration density.

In linearized form, instability may be approximated by the spectral radius of the effective coupling operator $\mathbf{K} \cdot \mathrm{diag}(r)$. When its largest eigenvalue exceeds dissipation capacity, distributed reference becomes unstable.

Two cascade regimes follow.

Amplification-Dominant Cascade

If amplification exceeds dissipation while coupling remains strong and reciprocity is partially intact, agents synchronize around concentrated reference. Coordination increases, producing cohesive and rapid phase transitions.

Inhibition-Dominant Cascade

If rising instability reduces reciprocity or fragments coupling symmetry, agents withdraw into localized concentration. Coordination declines, and the field fragments into partially isolated clusters.

Both regimes arise from the same inequality but differ in coupling evolution during transition.

Importantly, cascade is not a function of activation magnitude alone. Moderate activation remains stable under strong reciprocity and sufficient dissipation.

Stability boundaries depend on:

- Concentration density (C),
- Coupling strength (κ),
- Dissipation capacity (D).

Nonlinear systemic transitions occur when small parameter shifts alter the balance among these quantities.

The architectural objective is bounded adaptation: agents must be capable of temporary concentration without irreversible collapse of reciprocity.

6. Architectural Implications

This framework imposes several design constraints for multi-agent systems.

1. Mean activation is insufficient for stability prediction. Monitoring concentration density and dissipation capacity is required.
2. Coupling must be regulated relative to dissipation. Strong coupling without adequate damping increases cascade probability.
3. Asymmetric influence must be modeled explicitly. Highly concentrated agents function as endogenous amplification sources.
4. Dissipation channels must remain structurally available. Agents require mechanisms for re-entry into distributed reference following concentration.

These principles define architectural boundaries for scalable, non-omniscient distributed systems.

7. Falsifiability and Empirical Testing

This framework may be empirically challenged.

If collective instability can be predicted reliably using mean activation alone, without tracking reference distribution or dissipation parameters, the central thesis is weakened.

If symmetric coupling models reproduce cascade thresholds more accurately than asymmetric formulations incorporating r_i weighting, endogenous amplification may be overstated.

A minimal empirical test would simulate identical agent populations under two monitoring regimes:

1. Mean activation–based prediction.
2. Reference-distribution and dissipation–based prediction.

Comparative evaluation would measure:

- Prediction accuracy for phase transitions,
- Time-to-instability under controlled perturbations,
- Recovery latency following cascade events.

Consistent superiority of reference-distribution monitoring would provide measurable support for the framework.

8. Conclusion

Collective instability in artificial agent systems arises not merely from activation magnitude, but from shifts in reference alignment within shared constraint fields.

By formalizing concentration density, asymmetric amplification, and dissipation-bounded stability, this paper provides architectural principles for multi-agent simulations capable of bounded adaptation without omniscient control.

The contribution is structural: a disciplined account of collective dynamics grounded in constraint-mediated interaction rather than narrative abstraction.