Memory Stratification and Time-Scaled Persistence in Artificial Agents

An Architectural Framework for Bounded Continuity

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Abstract

Persistent agency requires temporally extended representational continuity. This paper proposes a stratified memory architecture for artificial agents in which short-term, intermediate, and structural-prior layers operate at distinct temporal scales. Identity is treated not as an intrinsic property but as an emergent consequence of coherent constraint-level persistence across time.

Memory tiers differ in duration, abstraction, and write resistance. Short-term representations encode volatile state transitions; intermediate layers compress recurrent regularities; structural priors encode low-frequency bias parameters that shape long-horizon interpretation. By regulating assimilation through pressure and viscosity rather than fixed thresholds, the framework preserves policy stability without granting architectural omniscience.

The result is a disciplined account of memory as time-scaled constraint encoding: adaptable at the surface, stable at depth, and bounded by regulated consolidation.

1. Introduction

Artificial agents are often evaluated at the level of instantaneous performance: prediction accuracy, response fluency, or task completion. Yet agency unfolds across time. Without persistence, intelligence collapses into episodic reaction.

Memory is therefore not an auxiliary module but the structural substrate of temporally extended agency. Identity, stability, and policy continuity emerge from stratified persistence rather than static parameterization alone.

Although many architectures implement memory, fewer distinguish explicitly between temporal scales of persistence. Volatile state, compressed regularity, and deep structural priors serve different functional roles. Conflating these layers produces two failure modes: overreaction to recent stimuli or rigidity around outdated structure.

This paper proposes a stratified memory framework in which persistence operates across multiple temporal resolutions. Short-term states capture immediate transitions; intermediate layers encode compressed invariants derived from repeated interaction; structural priors act as low-frequency biases shaping long-horizon interpretation.

The objective is architectural discipline rather than psychological analogy. By treating memory as time-scaled constraint encoding, we articulate design principles for artificial agents that remain adaptable without structural collapse and stable without omniscience.

2. Terminology and Operational Definitions

All terms are used in an operational, architectural sense.

State Vector

A structured internal representation encoding constraint-relevant distinctions at a specific temporal resolution.

Memory Tier

A representational layer distinguished by temporal persistence, abstraction level, decay rate, and write resistance.

Short-Term Layer (Surface State)

High-resolution, rapidly updating tier capturing volatile environmental transitions.

Intermediate Layer (Compressed Regularity)

Selectively permeable tier encoding compressed invariants derived from repeated interaction.

Structural Prior Layer

High-viscosity tier encoding low-frequency bias parameters that shape interpretation across extended time horizons.

Residual Activation

Activated structure not yet consolidated into longer-horizon tiers.

Assimilation

Transfer of structured state between tiers.

Viscosity (Write Resistance)

Parameter governing resistance to structural modification within a tier.

Pressure $P(t)$

A scalar function of sustained activation, typically modeled as a weighted combination of salience and repetition over recent time.

Identity-Binding Weight

Persistence multiplier increasing consolidation likelihood and reactivation strength for selected symbolic clusters.

3. Time-Scaled Persistence as Structural Condition

Agency requires persistence across time. Without representational continuity, an artificial system reduces to episodic reaction: each input processed in isolation, each output detached from prior constraint accumulation.

We propose that temporally extended agency is structurally dependent on stratified memory. Persistence is not a binary property but a function of representational stability across multiple time scales. Different layers of memory encode constraint-relevant distinctions at different temporal resolutions, allowing rapid adaptation at the surface while preserving structural continuity at depth.

Let $s(t)$ denote the aggregate internal state of an agent. We decompose this state into tiered components:

$$s(t) = (m(t), u(t), a(t))$$

Where:

- $m(t)$ represents short-term surface activation,
- $u(t)$ represents intermediate compressed regularity,
- $a(t)$ represents structural priors.

These components differ in decay rate, write cost, and abstraction level. Short-term activation captures immediate environmental transitions but decays rapidly. Intermediate layers consolidate repeated patterns into compressed invariants. Structural priors encode low-frequency bias parameters that shape interpretation across extended horizons.

This decomposition prevents two common architectural failures:

1. Overreaction: When surface activation dominates without intermediate consolidation, the agent remains volatile and policy unstable.
2. Rigidity: When deep priors dominate without permeability, adaptation slows and misalignment accumulates.

Stratification therefore mediates the trade-off between adaptability and stability. Short-term responsiveness is preserved without granting immediate access to long-horizon policy shifts. Conversely, deep structure remains stable without freezing surface-level responsiveness.

Identity, under this framework, is not a static entity but the coherent alignment of these tiers across time. Persistence emerges from stable coupling rather than from immutable state.

4. Residual Activation and Structural Update Lag

Stratified memory necessarily produces temporary imbalance between activation and consolidation. Not all surface activations are immediately integrated into intermediate or structural layers. The difference between activated structure and integrated structure constitutes residual activation.

Let S_t denote the set of activated symbolic structures at time t, and let I_t denote the subset successfully consolidated into longer-horizon tiers. We define residual activation:

$$W_t = S_t \setminus I_t$$

Residual activation reflects unintegrated pressure within the system.

This condition is not inherently pathological. In well-coupled architectures, residual activation decays naturally or is gradually assimilated. However, sustained activation combined with low structural update capacity produces accumulation.

We sketch the dynamics:

$$W_{t+1} = \delta W_t + R(d, \rho) - U(\text{update})$$

Where:

- δ is the natural decay factor,
- $R(d, \rho)$ represents reactivation pressure as a scalar rate dependent on recursion depth and structural rigidity,
- $U(\text{update})$ represents consolidation bandwidth available at time t

Residual activation grows when reactivation exceeds structural update:

$$R(d, \rho) > U(\text{update})$$

Three regimes emerge:

1. High rigidity ($\rho \uparrow$): Elevated structural resistance reduces consolidation capacity. Residual activation accumulates despite decay.
2. Low rigidity ($\rho \downarrow$): Excessive permeability increases symbolic spread and branching, enlarging |W_t| through rapid activation turnover.
3. High recursion depth ($d \uparrow$): Self-referential reactivation increases pressure on consolidation pathways.

Whether this produces instability or adaptive flexibility depends on system design. In some simulations, residual mass functions as exploratory potential. In others, it produces oscillation, cascade sensitivity, or hysteresis.

The architectural requirement is not elimination of residual activation, but bounded regulation of update capacity relative to sustained pressure.

5. Tier Assimilation and Permeability

The present formulation is hybrid: continuous decay governs tier dynamics, while consolidation may be evaluated at discrete update intervals. This distinction clarifies simulation semantics but does not alter the structural claims.

Stratification alone does not produce persistence. Stability emerges from regulated coupling between tiers. Assimilation must occur, but at rates proportional to pressure and tier-specific resistance.

Let $m(t)$, $u(t)$, and $a(t)$ represent short-term, intermediate, and structural states respectively. Assimilation between tiers can be modeled as diffusive coupling:

$$\dot{m} = x(t) - \lambda_m m - k_{mu}(t)\,(m - u)$$

$$\dot{u} = k_{mu}(t)\,(m - u) - \lambda_u u - k_{ua}(t)\,(u - a)$$

$$\dot{a} = k_{ua}(t)\,(u - a) - \lambda_a a$$

Where:

- $x(t)$ is external input injected into the short-term layer,
- λ_m, λ_u, λ_a are decay rates,
- $k_{mu}(t)$ and $k_{ua}(t)$ are time-dependent permeability coefficients.

These coefficients are modulated by two principal factors:

1. Pressure — sustained activation arising from salience, repetition, or arousal.
2. Viscosity — tier-specific resistance to structural modification.

Short-term states exhibit low viscosity and rapid decay. Intermediate tiers exhibit selective permeability, consolidating structure when pressure exceeds threshold conditions. Structural priors exhibit high viscosity and shift only under sustained low-frequency pressure.

One possible parameterization expresses permeability as a smooth function of pressure and tier-specific viscosity:

$$k_{mu}(t) = k_{mu0} \cdot \sigma(\alpha(P(t) - \theta_{mu})) \cdot \frac{1}{1 + V_u}$$

$$k_{ua}(t) = k_{ua0} \cdot \sigma(\beta(P_{slow}(t) - \theta_{ua})) \cdot \frac{1}{1 + V_a}$$

where \sigma is a smooth threshold function (e.g., the logistic sigmoid), θ_{mu} and θ_{ua} are consolidation thresholds, $P_{slow}(t)$ is a low-pass filtered pressure signal, and V_u and V_a are viscosity parameters for the intermediate and structural tiers, respectively.

This formulation yields three important properties:

- Surface spikes do not immediately rewrite deep structure.
- Repeated activation increases consolidation probability.
- Deep priors evolve slowly, preserving long-horizon stability.

Assimilation is therefore neither automatic nor prohibited. It is gated.

Architectural realism arises from state-dependent permeability rather than fixed write thresholds. Excessive permeability collapses stratification; excessive viscosity produces rigidity and update lag.

The design objective is balanced coupling: sufficient transfer to prevent residual overload, sufficient resistance to preserve identity continuity.

6. Identity-Binding and Persistence Weighting

In addition to tier stratification and permeability gating, persistence is influenced by identity-binding. Identity-binding refers to a weighting mechanism that increases consolidation likelihood for structures deemed self-relevant or policy-central.

Let ω_k denote the identity-binding weight associated with symbolic cluster k. A minimal way to express its effect is:

$$\Pr(k \rightarrow u \text{ or } a) \propto \omega_k \cdot P(t)$$

Higher identity-binding increases both consolidation likelihood and reactivation strength. Structures with elevated ω_k exhibit increased resistance to decay and greater influence on intermediate and structural layers.

Identity-binding is not a metaphysical property. It is a persistence multiplier.

Architecturally, this mechanism serves three functions:

1. Policy stabilization: Core commitments resist transient perturbation.
2. Selective reinforcement: Self-relevant activations consolidate more rapidly.
3. Hysteresis control: High-binding structures require proportionally greater counter-pressure to shift.

Identity-binding need not be uniform across agents. It may be parameterized as a scalar or vector field, allowing variation in assimilation resistance, attachment strength, or policy rigidity.

When identity-binding is absent or minimal, persistence depends primarily on repetition and pressure. When elevated, consolidation becomes asymmetric: certain structures are preferentially stabilized.

This mechanism provides a controlled explanation for long-horizon bias formation without invoking categorical identity constructs. Stability arises from weighted reinforcement within stratified tiers.

7. Architectural Implications

The stratified memory framework imposes several design constraints on artificial agents.

First, persistence must be distributed across temporal scales. Architectures relying exclusively on short-term state risk volatility, while systems dominated by deep priors risk rigidity. Stability emerges from regulated coupling between tiers rather than from dominance of any single layer.

Second, assimilation must be pressure-gated and viscosity-modulated. Fixed write thresholds produce either uncontrolled consolidation or structural stagnation. State-dependent permeability allows surface adaptation without premature deep commitment.

Third, residual activation is inevitable in stratified systems. Design effort should focus on regulating update capacity relative to sustained pressure rather than attempting elimination of surface imbalance.

Fourth, identity-binding operates as a tunable persistence amplifier. By modulating consolidation likelihood, systems can express variation in attachment strength, policy rigidity, and hysteresis without invoking categorical identity constructs.

These constraints do not prescribe a single implementation. They define architectural boundaries within which temporally extended agency remains coherent and bounded.

8. Falsifiability and Limitations

This framework may be challenged on several grounds.

If persistent, adaptive agency can be demonstrated without stratified memory layers, then the necessity of tiered persistence would require revision. Similarly, if fixed-threshold architectures consistently outperform state-dependent permeability models without producing instability or rigidity, the role of viscosity modulation may be overstated.

The residual activation model assumes measurable imbalance between activation and consolidation. If sustained activation does not produce structural lag under realistic simulation conditions, then update capacity may be less critical than proposed.

Finally, identity-binding is modeled here as a weighted persistence multiplier. If long-horizon bias formation can be explained entirely through repetition and compression without binding asymmetry, then the mechanism may be redundant.

The present account prioritizes structural clarity over exhaustive empirical validation. It proposes architectural principles subject to refinement through simulation and testing.

A minimal empirical test would measure predictive error reduction following tier consolidation relative to a baseline architecture lacking stratification. Sustained divergence between architectures would provide measurable support for or against the framework.

9. Conclusion

Persistent agency emerges not from static parameters but from stratified representational continuity across time. By decomposing internal state into coupled temporal layers and regulating assimilation through pressure and viscosity, artificial agents can preserve identity while remaining adaptable.

Residual activation, permeability gating, and identity-binding together define the dynamic balance between stability and change. These mechanisms do not eliminate limitation; they structure it.

The contribution of this paper is architectural: a disciplined account of memory stratification as a structural condition for temporally extended agency.