Coherence–Rupture–Regeneration (CRR):

A Process Account of Active Inference at Criticality

Response to Tucker, Luu & Friston, 'The Criticality of Consciousness' (Entropy, 2025)

Overview

Thank you for your talk. Your paper (above) establishes that consciousness emerges when excitatory (E) and inhibitory (I) systems achieve balance at criticality. I present here an idea for how a *process* account: Coherence–Rupture–Regeneration (CRR); that aims to describe *how* this balance is achieved and maintained through iterative variational inference. CRR formalises the temporal dynamics of active inference using a single parameter Ω (temporal integration depth = 1/precision), and maps these dynamics onto the oscillatory signatures (theta, gamma, beta) you identify.

1. CRR Formalised in Active Inference

1.1 The Three Phases

CRR proposes that conscious experience unfolds through three iterating phases, each interpretable in terms of variational free energy minimisation:

Coherence (C): Evidence accumulates as the system minimises free energy through iterative inference. Formally, $C(t) = \int L(x,\tau)d\tau$, where $L(x,\tau)$ represents the pattern density (prediction errors and their resolution) across the cortical hierarchy. This corresponds to the *evidence accumulation* phase of Bayesian belief updating.

Rupture (δ): When accumulated coherence reaches a threshold Ω, the system undergoes a discrete belief-updating event; idealised here as a Dirac delta δ(now). This is the moment when the posterior is committed: the *decision point* in variational inference where accumulated evidence triggers model updating. The scale-invariance of δ ensures this occurs simultaneously across hierarchical levels.

Regeneration (R): Following rupture, the generative model reconstitutes with updated posteriors. The regeneration integral $R = \int \varphi(x,\tau)\cdot\exp(C/\Omega)\cdot\Theta(C-\Omega)d\tau$ weights historical states by their coherence, ensuring that high-evidence moments contribute more to the reconstituted model. This is *posterior reconstitution*; the new generative model q(s) that will guide the next cycle.

1.2 The Single Parameter Ω

The key theoretical move is that your two control parameters (E and I) collapse into a single parameter Ω (temporal integration depth) defined as the inverse of precision: $\Omega = 1/\pi$. The relationships are:

> **$E \propto \Omega$:** Excitation scales with integration depth. Higher Ω means broader temporal integration, more reliance on accumulated structure (priors), and expanded conceptual scope - your dorsal limbic, REM-like processing.

$I \propto 1/\Omega = \pi$: Inhibition scales with precision. Lower Ω (higher precision) means narrower integration, sharper selection, more reliance on immediate sensory evidence; your ventral limbic, NREM-like processing.

Criticality at Ω = 1: E–I balance obtains when $\Omega = 1/\Omega$, i.e., when $\Omega = 1$. At this point, precision equals integration depth, and the system achieves the optimal balance for belief updating.

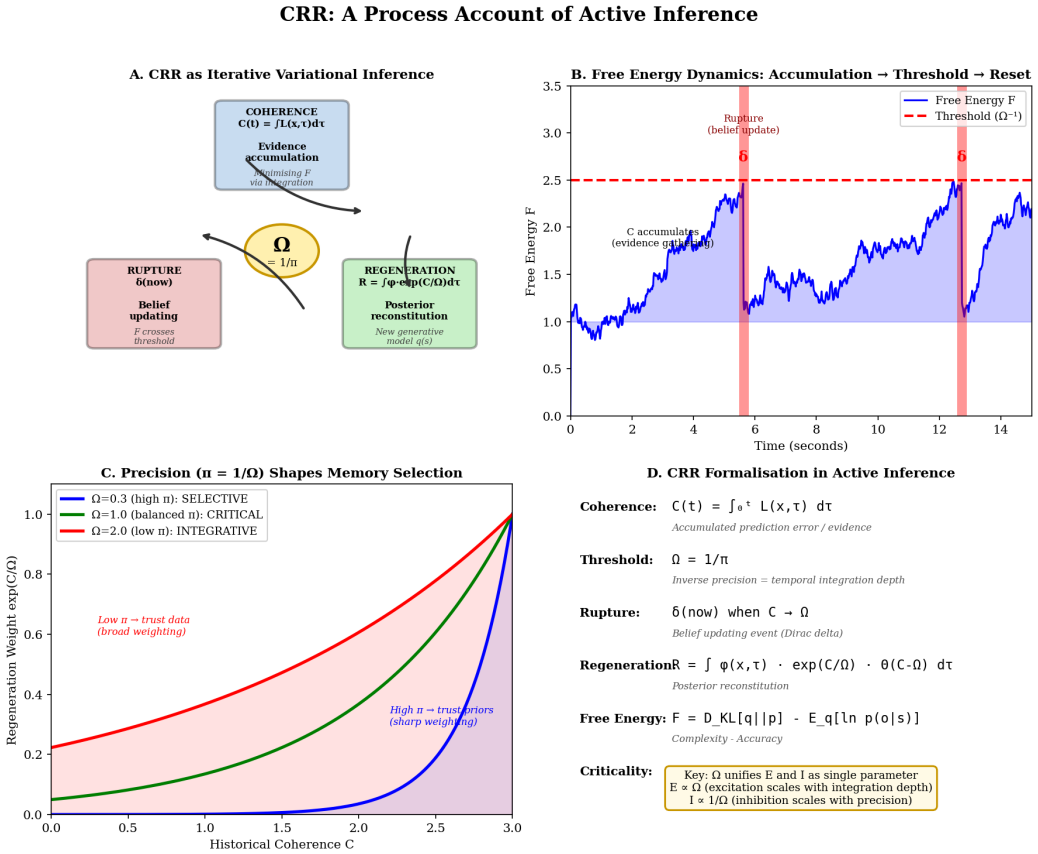

Figure 1. CRR as iterative variational inference. (A) The three-phase cycle with Ω at centre. (B) Free energy dynamics showing accumulation, threshold-crossing, and reset. (C) The exp(C/Ω) weighting function under different precision regimes. (D) Formal definitions.

2. Oscillatory Implementation

Your paper identifies theta-gamma coupling (excitatory, dorsal limbic) and alpha-beta modulation (inhibitory, ventral limbic) as key oscillatory signatures. CRR proposes a specific functional mapping:

2.1 Theta (θ, ~7 Hz): The Accumulation Clock

Theta rhythm sets the timescale for evidence accumulation. Each theta cycle (~143 ms) represents one iteration of variational inference; one step of coherence integration. In FEP terms, theta determines the *rate* at which the system samples and integrates prediction errors. The dorsal limbic (Papez) regulation of theta, via the lemnothalamic pathway, aligns with your proposal that phasic arousal controls the excitatory, predictive processing stream.

2.2 Gamma (γ, 30–100 Hz): The Content of Coherence

Gamma oscillations, nested within theta, carry the *content* being integrated - the L(x,τ) pattern density in the coherence integral. Local gamma bursts at theta peaks represent the prediction errors and predictions exchanged between cortical levels. In CRR, gamma is what *fills* each theta cycle with meaningful structure. The theta-gamma coupling your paper emphasises is, in CRR terms, the mechanism by which coherence *accumulates*.

2.3 Beta (β, ~20 Hz): The Threshold Enforcer

Beta oscillations implement the threshold Ω - the **precision** that determines when rupture occurs. Your characterisation of beta as the 'status quo' signal aligns precisely: beta maintains the current model, resisting belief updating until accumulated evidence warrants it. The ventral limbic (Yakovlev) regulation of beta, via collothalamic projections from the midbrain, corresponds to the inhibitory, corrective processing that enforces precision. When C approaches Ω, beta power increases (defending the current model); at rupture, beta releases, allowing the transition.

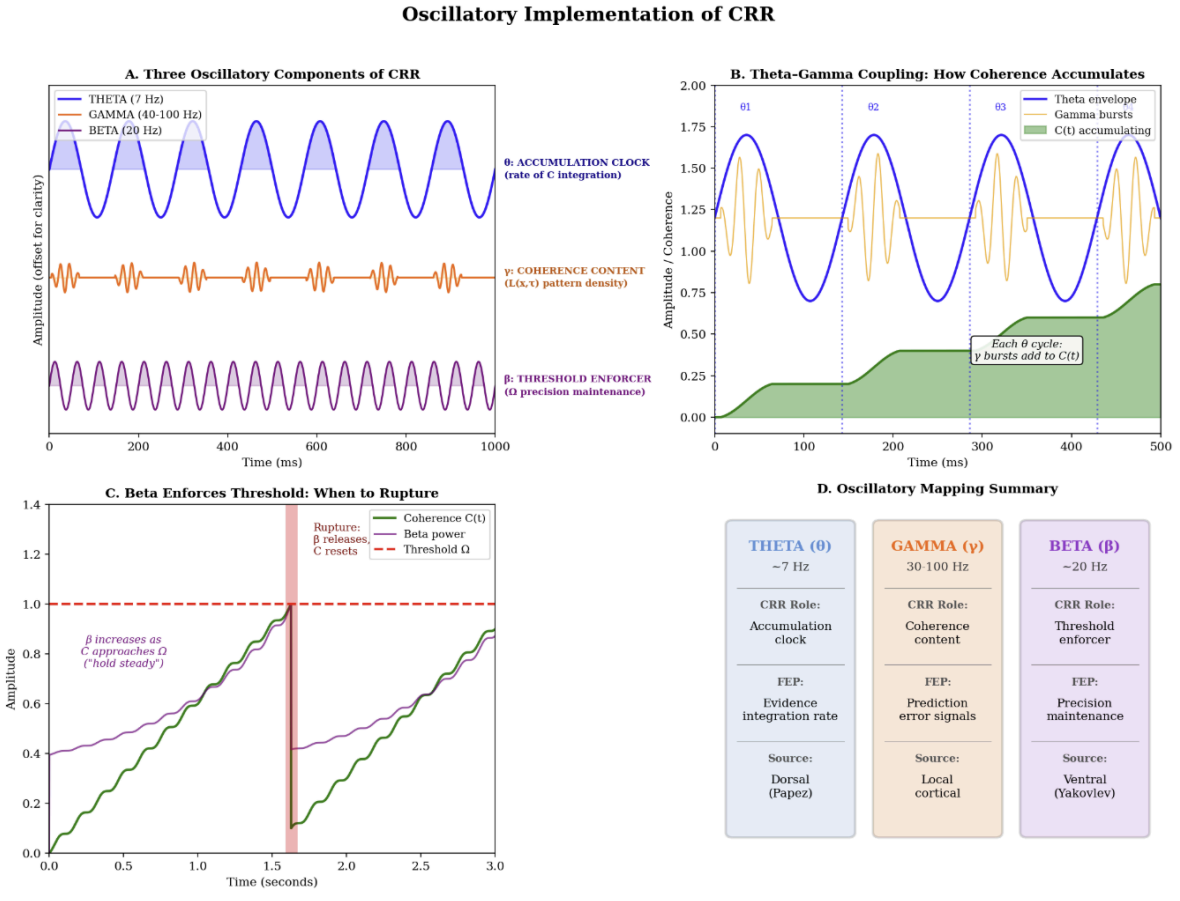

Figure 2. Oscillatory implementation of CRR. (A) The three oscillations and their functional roles. (B) Theta–gamma coupling as the mechanism of coherence accumulation. (C) Beta as threshold enforcement, increasing as C approaches Ω. (D) Summary mapping.

3. Derivations and Predictions

3.1 The Specious Present

Your paper cites James's observation of ~15-second 'perchings' but does not derive this duration. CRR offers a derivation: if approximately 90 theta cycles are required for coherence to reach threshold at criticality (Ω = 1), then:

Specious Present Duration = Ω × (cycles to threshold) / θ-frequency ≈ 1 × 90 / 7 Hz ≈ 13 seconds

This yields a testable prediction: manipulations that alter Ω should systematically alter the duration of the specious present. Anxious states (high precision, low Ω) would compress experienced duration; elated states (low precision, high Ω) would expand it. The phenomenology of time dilation under different affective states (which your paper notes but does not formalise) emerges naturally from Ω modulation.

3.2 Sleep Stages as Precision Oscillation

Your account of NREM (inhibitory, corrective) and REM (excitatory, generative) sleep maps directly onto Ω oscillation:

> **NREM (Low Ω, High Precision):** The exp(C/Ω) weighting function becomes sharply peaked. Only high-coherence moments - the salient, unpredicted events you describe—survive into consolidation. This is selective memory: precision-weighted pruning of the day's experiences.
>
> **REM (High Ω, Low Precision):** The exp(C/Ω) weighting becomes broadly uniform. All of history contributes to regeneration - the 'running free' of your Hinton-inspired account. This is integrative memory: low-precision replay that reorganises the generative model.

The nightly cycling of Ω between these extremes recalibrates the system for next-day criticality. Rather than two separate systems alternating, CRR proposes a single parameter undergoing controlled oscillation.

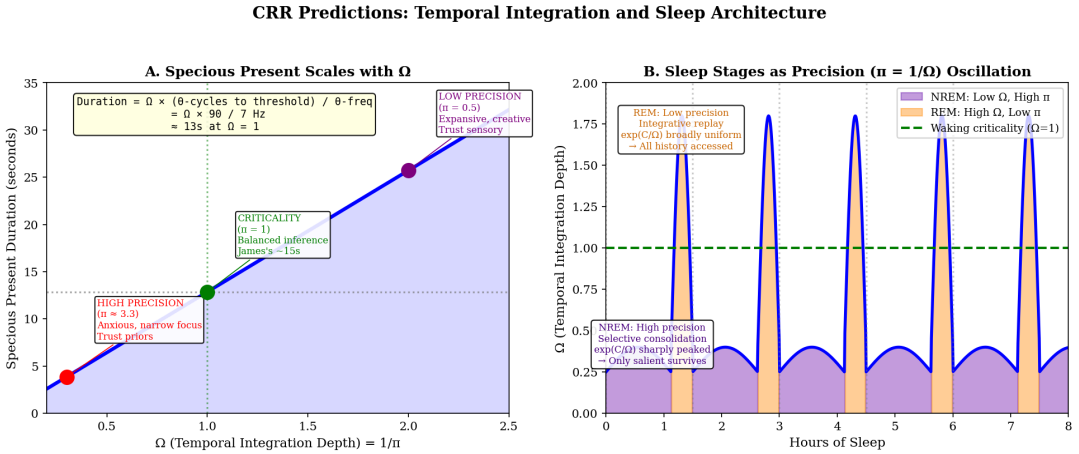

Figure 3. CRR predictions. (A) Specious present duration as a function of Ω, with high/low precision states annotated. (B) Sleep architecture as Ω oscillation between NREM minima (high π) and REM maxima (low π).

4. What CRR Potentially Adds

Your paper describes the conditions for consciousness (E–I balance at criticality). CRR attempts to describe the process by which these conditions are met and maintained:

> **Temporal dynamics:** CRR makes explicit how the system moves through time (accumulating, punctuating, regenerating) rather than treating criticality as a static condition.
>
> **Parameter parsimony:** Collapsing E and I into Ω provides a single control variable, potentially simplifying experimental prediction and theoretical analysis.
>
> **Quantitative derivations:** The specious present duration, the shape of memory selection in sleep, and the relationship between oscillatory parameters become derivable rather than observed.
>
> **The rupture event:** Modelling the transition between James's 'perchings' and 'flightings' as a Dirac delta provides a formal account of the experienced 'now' - the moment of belief commitment.

5. Open Questions

Several questions remain unresolved:

> Does collapsing E and I into High/Low Ω lose important information about the distinct neuroanatomical substrates (dorsal vs. ventral limbic) you have identified? Or does the mapping preserve the essential functional distinctions?
>
> What neural mechanism could implement the Dirac-like “rupture”? Is this an idealisation, or might EEG/MEG signatures reveal discrete transition events consistent with this form?
>
> How precisely does exp(C/Ω) relate to the precision weighting in standard active inference formulations? Is there a formal equivalence, or merely an analogy?
>
> Can the ~90 theta cycles to threshold be derived from first principles, or is this an empirical parameter that must be measured?

6. Conclusion

The CRR framework proposes that consciousness is not something the brain *achieves* at criticality but something it *does* - a continuous process of accumulating coherence, rupturing into nowness, and regenerating with the weight of history. The feeling of consciousness, on this account, is the feeling of this very process: anticipation as C approaches Ω, presence at the moment of δ, continuation through R.

With respect and interest in your response.