Chaos Spike Detection (CSD): Real-Time Instability Flags for R-TFT

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Overview

Chaos Spike Detection (CSD) is a diagnostic layer that identifies when a system exits resonance and enters chaotic behavior. It complements Real-Time Fractional Tracking (R-TFT) by offering a lightweight signal monitor for structural breaks.

Core Detection Criteria

1. **Coherence Drop**
   A sustained decrease in resonance magnitude:
   $$\|R(t)\| < \alpha \cdot \text{mean}(\|R(t-\tau) : R(t)\|)$$
2. **Gradient Spike**
   A sudden jump between time steps:
   $$|R(t) - R(t - \Delta t)| > \epsilon$$
3. **Memory Divergence (RME)**
   Deviation from a stored memory vector:
   $$\cos\theta(R(t), M(t)) < \beta$$

Each trigger is evaluated independently and can be tuned per system or domain.

R-TFT Integration Modes

Basic Mode

CSD runs on the single-vector $R(t)$ signal output from R-TFT. Suitable for 1D or 2D systems using a single resonance vector $\boldsymbol{P}$.

Multi-Vector Mode

For systems with multiple competing resonance vectors, CSD can be applied separately to each $R_i(t)$ or to a combined metric:
$$R_{\text{total}}(t) = \sum_i w_i R_i(t)$$
with weightings w_i based on coherence or priority.

Memory Mode (RME)

When RME is active, CSD uses stored reference vectors $M(t)$ from earlier stable resonance epochs to detect phase drift. A divergence is flagged when the cosine similarity between the current $R(t)$ and its memory vector falls below a threshold:

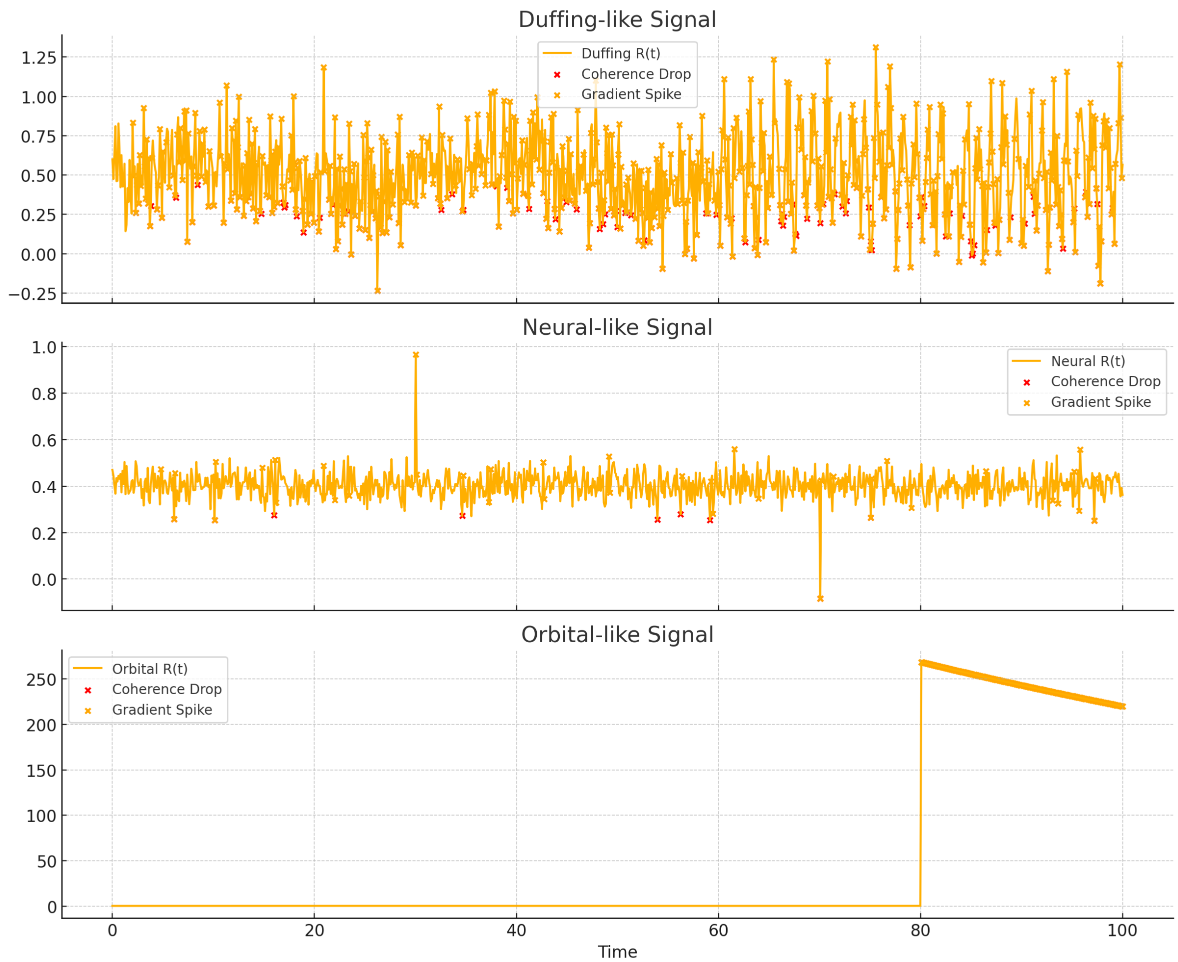
$$\cos\theta\left(R(t), M(t)\right) = \frac{R(t)\cdot M(t)}{\|R(t)\|\|M(t)\|} < \beta$$

This form allows CSD to detect subtle structural deviations even when the resonance magnitude remains high, making it sensitive to attractor deformation rather than just loss of coherence.

System Compatibility Matrix

Domain	CSD Usefulness	Notes
Orbital Mechanics	Recommended	Flags orbit instability, collision risk
Neural Oscillators	Recommended	Detects phase spikes, seizure precursors
Duffing / Chaotic Oscillators	Recommended	Captures bifurcations and chaotic onset
Quantum Systems	Partial	Requires smoothing or filtering
Cosmic Structure	Limited	High noise may trigger false positives
Planck-scale Foam	TBD	Depends on R(t) quantization viability

Validation Tests



To confirm that CSD operates reliably across different resonance systems, we simulated three representative $R(t)$ signals:

- **Duffing-like Oscillator:** A chaotic oscillator with slow noise followed by abrupt high-frequency transitions, mimicking bifurcation onset.
- **Neural-like Oscillator:** A stable background with abrupt spiking and inhibitory events, simulating neural firing or seizure onset.
- **Orbital-like System:** A slow resonance decay with no sharp phase transitions, reflecting a drifting orbital system.

Each signal was processed with the CSD triggers described earlier. The following results were observed:

- **Duffing:** Both coherence drops and gradient spikes were detected after the transition to chaos ($t > 60$), showing sensitivity to bifurcation onset.
- **Neural:** A sharp gradient spike and a coherence drop occurred exactly at simulated spike and inhibition points, validating event detection in biological signals.
- **Orbital:** A gradual loss of coherence was flagged near $t \approx 80$, with no false spikes, confirming effectiveness for slow-drift systems.

These tests confirm that CSD is applicable across orbital, biological, and chaotic oscillator domains, with minimal tuning required.

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