AFET: Entropically Coupled Threshold Dynamics Formal Extension of UTAC as an InformationSystem Interaction Framework

Abstract

We formalize the Adaptive FieldEntropic Threshold (AFET) framework as an entropically coupled extension of the Universal Threshold Activation Criticality (UTAC) model. UTAC provides a nonlinear information-theoretic activation structure. AFET introduces entropy production as a necessary dynamical constraint governing parameter evolution within UTAC. We demonstrate that entropy production acts as a modulation operator over threshold position, coupling steepness, and damping. The resulting formulation describes a hierarchical, domain-dependent threshold system capable of modeling multi-scale dynamical transitions.

1 Foundations

1.1 UTAC: Nonlinear Threshold Activation

UTAC defines the activation probability of a system state transition as:

$$A(t) = \sigma\left(\beta(R - \Theta)\right) \tag{1}$$

with logistic activation:

$$\sigma(x) = \frac{1}{1 + e^{-x}} \tag{2}$$

Parameters:

- R system response variable
- Θ activation threshold
- β coupling/steepness parameter
- A activation state probability

The width of the transition region is:

$$\Delta R \propto \frac{1}{\beta} \tag{3}$$

Thus β controls sensitivity and critical sharpness.

2 Entropy as Dynamical Driver

We define thermodynamic entropy:

$$S = k_B \ln \Omega \tag{4}$$

Information-theoretic entropy:

$$H = -\sum_i p_i \ln p_i \tag{5}$$

Entropy production rate (crucial quantity):

$$\Pi = \frac{dS}{dt} \tag{6}$$

Key principle:

> No entropy production ($\Pi = 0$) implies no sustained dynamical state transitions.

Thus entropy production acts as an enabling condition for UTAC dynamics.

3 AFET: Entropically Coupled UTAC

AFET introduces entropy-dependent modulation of UTAC parameters.

3.1 General Coupled Form

$$A(t) = \sigma\left(\beta_{\text{eff}}(t)\left(R(t) - \Theta_{\text{eff}}(t)\right)\right) \tag{7}$$

with:

$$\beta_{\text{eff}}(t) = \beta_0 + f_\beta(\Pi, \kappa_{\text{int}}, \kappa_{\text{ext}}) \tag{8}$$

$$\Theta_{\text{eff}}(t) = \Theta_0 + f_\Theta(\Pi, \rho) \tag{9}$$

$$\zeta_{\text{eff}}(t) = \zeta_0 + f_\zeta(\Pi) \tag{10}$$

where:

- Π entropy production rate
- κ internal/external coupling strength
- ρ system order parameter
- ζ damping coefficient

4 Hierarchical Beta Structure

We define β as a hierarchical stochastic field:

$$\beta_{d,t,i}(t) = \mu_d + \delta_{d,t} + \delta_{d,t,i} + g(\Pi_{d,t,i}(t)) + \epsilon \tag{11}$$

Indices:

- d domain
- t system type
- i individual system

This defines:

- Domain-level band
- System-type band
- System-specific variation
- State-dependent drift

5 Necessary Conditions for Dynamical Universality

A functioning dynamical system requires:

$$\Pi > 0 \tag{12}$$

and

$$\exists\, \beta, \Theta \text{ such that } \frac{dA}{dR} \neq 0 \tag{13}$$

Thus:

$$\text{Dynamical viability} \iff (\Pi > 0) \wedge (\text{Nonlinear threshold structure}) \tag{14}$$

6 Falsifiability Criteria

The AFET framework is falsified if:

1. No measurable covariance exists between entropy production Π and threshold dynamics.
2. β remains invariant across domain perturbations.
3. Transition widths remain constant under dissipative shifts.
4. Systems sustain transitions at $\Pi \to 0$.

7 Conclusion

UTAC defines informational activation structure. AFET defines entropic governance over activation parameters.

Entropy production enables state change. UTAC structures state change.

Together they form a minimal dynamical architecture capable of modeling multi-domain threshold systems.