Entropy Transfer Constraint in Cognitive Compression Systems

I. Theorem Statement

A cognitive or computational system engaged in semantic compression will experience representational degradation or collapse if the rate of entropy intake $E_T(t)$ persistently exceeds the sum of entropy dissipation $E_D(t)$ and available internal buffering capacity $\delta(t)$, such that the cumulative overload passes a system-specific threshold Θ.

Formal Condition

For all time t:

$$E_T(t) \leq E_D(t) + \delta(t)$$

And if:

$$\int_{t_0}^{t_n} (E_T(t) - E_D(t))\, dt > \Theta \quad \Rightarrow \quad \text{System Collapse}$$

Where:

- $E_T(t)$: Entropy Intake — rate of incoming data or noise
- $E_D(t)$: Entropy Dissipation — processing, integration rate
- $\delta(t)$: Buffering Capacity — temporary memory or cache
- Θ: Collapse Threshold — architecture-specific tipping point

II. Scientific Foundation

Thermodynamics: Based on Landauer's Principle (minimum entropy for erasure).

Information Theory: Collapse occurs when entropy input exceeds dissipation capacity (Shannon entropy overload).

Cognitive Science: Mirrors stress-induced cognitive breakdowns.

AI Transformers: Attention saturation or hallucination under overload.

III. Mechanistic Explanation

- $E_T(t)$: Entropy inflow — rate of information/data input
- $E_D(t)$: Internal feedback processing and entropy reduction
- $\delta(t)$: Finite buffering storage — decays under prolonged load
- Θ: Collapse point — empirically observable for each architecture

IV. Testable Predictions

Transformers & LLMs

- High-entropy input leads to semantic drift and incoherence. - BLEU/BERT scores degrade near collapse thresholds.

Spiking Neural Networks

- Overload without feedback leads to signal collapse or chaos.

Human Cognition

- Working memory and feedback exhaustion causes recall failure.

V. Simulation Design Proposal

Model: Transformer with entropy gating or depth controls. **Procedure:** Increase input entropy (shuffled syntax, noise). **Measures:** Track perplexity, embedding divergence, coherence. **Outcome:** Identify Θ, observe $\delta(t)$ depletion pattern.

VI. Practical Implications

- **AI Safety:** Design feedback/regulation to prevent overload collapse.
- **Neuroscience:** Model stress-based failures and memory exhaustion.
- **Compression Theory:** Build adaptive encoders with entropy bypass.
- **Human Factors:** Limit cognitive load in interface and system design.