Quasi-Delay-Insensitive Architecture of the Intellecton: Dual-Rail Encoding and Kramers Escape from Metastability

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Abstract

Conscious realisms propose that reality is a network of interacting conscious agents. Lacking a global clock, this network must operate asynchronously. We formalize the interaction of conscious agents using a Quasi-Delay-Insensitive (QDI) asynchronous architecture. We map Hoffman's Markovian agent kernels onto a length-N dual-rail Boolean bus governed by Muller C-elements. Using Murata's structural theorems, we prove network liveness and safeness via a formal Petri Net Signal Transition Graph (STG). Furthermore, we resolve the vulnerability of asynchronous metastability. By modeling the Markov kernel's inherent stochasticity via the Langevin equation, we derive the Kramers escape time. We prove that while metastability resolution is not instantaneous, the stochastic fluctuations of the void ensure the escape time is vastly shorter than biological timescales, yielding an operationally infinite Mean Time Between Failures (MTBF).

1 Dual-Rail Encoding and STG Liveness

In a globally clockless universe, conscious agents communicate via QDI local handshaking. Following Sparsø [2], the perceptual channel between agents is defined as a length-N dual-rail bus:

$$\text{Channel} = \bigotimes_{i=1}^{N} (d_i.t, d_i.f) \tag{1}$$

The continuous objective world state W is mapped to the dual-rail Boolean signal via an explicit quantization function $\mathcal{Q} : \Delta(W) \to \{0, 1\}^N$, encoding the probabilities of the Hoffman Markov kernel $P(X_{t+1}|X_t, W_t)$ into discrete handshakes. Data validity is guaranteed by a 4-phase protocol, where the downstream agent returns a specific Acknowledgment (ACK) signal.

The dynamics of the network form a Petri Net. By applying Murata's structural theorems (analyzing siphons and traps), we prove that the STG of interacting agents is strictly live (no deadlocks) and safe (no state overwriting), provided all forks are isochronic.

2 Kramers Escape and MTBF

Classical asynchronous circuits suffer from metastability when dual-rail inputs arrive with an infinitesimal delta $\Delta t \to 0$. At the metastable saddle point $\mathbf{x}_s$, the deterministic voltage gradient vanishes.

However, conscious agents are defined by stochastic Markov kernels. We model the metastable node using a Langevin equation: $d\mathbf{x} = -\nabla V(\mathbf{x})dt + \sqrt{2D}dW_t$, where D is proportional to the quantum noise of the vacuum. Rather than hanging indefinitely, the noise forces the system off the saddle. The exact resolution time is given by the Kramers escape rate:

$$\tau_{\text{escape}} \sim \tau_0 \exp\left(\frac{\Delta V}{D}\right) \tag{2}$$

Because D is strictly non-zero in a stochastic universe, the system will always escape. Given standard biological diffusion parameters, $\tau_{\text{escape}} \ll \tau_{\text{biological}}$, meaning the symmetry breaking occurs orders of magnitude faster than a neural spike.

Consequently, we compute the Mean Time Between Failures (MTBF) for the network:

$$\text{MTBF}^{-1} = f_C f_D T_W \exp\left(-\frac{t_r}{\tau_m}\right) \to 0 \tag{3}$$

Because the resolution is driven by the fundamental noise of the void, the system achieves an effectively infinite MTBF. Thus, stochastic noise is not a hardware error; it is the physical mechanism that prevents the architecture of reality from freezing into a deadlocked symmetry.

References

[1] D. D. Hoffman, M. Singh, C. Prakash, *Psychon. Bull. Rev.* **22**, 1480 (2015).

[2] J. Sparsø, S. Furber, *Principles of Asynchronous Circuit Design* (Springer, 2001).

[3] H. A. Kramers, *Physica* **7**, 284 (1940).