Quasi-Delay-Insensitive Architecture of the Intellecton: Dual-Rail Encoding and Saddle-Point Decay

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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. Because the network contains Mutual Exclusion (MUTEX) arbiters, we prove network liveness and safeness dynamically via McMillan's finite prefix unfolding. Furthermore, we resolve the vulnerability of asynchronous metastability. By modeling the Markov kernel's inherent stochasticity via the Langevin equation, we derive the saddle-point decay time. We prove that while metastability resolution is not instantaneous, thermal fluctuations ensure the escape time is vastly shorter than biological timescales. Because the architecture is strictly QDI, agents simply delay their handshakes until stochastic resolution completes, ensuring zero hardware failure and only variable latency.

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 dynamics of the network form a Petri Net. Because the network must resolve non-deterministic conflicting choices (such as multiple agents vying for identical environmental resources), the STG inherently contains Mutual Exclusion (MUTEX) arbiters. This strictly violates the Free-Choice property.

Consequently, structural liveness cannot be established via Commoner's theorem (siphons and traps). Instead, we prove liveness and safeness (no state overwriting) dynamically via state-space reachability using McMillan's complete finite prefix unfolding, provided all forks are isochronic.

2 Saddle-Point Decay and Variable Latency

Classical asynchronous arbiters suffer from metastability when independent conflicting requests arrive within an infinitesimal window $\Delta t \to 0$. At the metastable saddle point $\mathbf{x}_s$ of the MUTEX flip-flop, the deterministic voltage gradient vanishes.

However, conscious agents are defined by stochastic Markov kernels. We model the metastable saddle point using a Langevin equation: $d\mathbf{x} = -\nabla V(\mathbf{x})dt + \sqrt{2D}dW_t$ [3], where D is proportional to the classical thermal noise of the environment. Rather than hanging indefinitely, an initial stochastic fluctuation provides an infinitesimal displacement, after which the deterministic gradient forces the state downhill. The exact resolution time from the unstable equilibrium scales logarithmically with the inverse noise intensity:

$$\tau_{\text{escape}} \sim \frac{1}{\lambda} \ln \left(\frac{1}{D} \right) \tag{2}$$

where λ is the positive eigenvalue of the saddle. 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.

Crucially, because the network utilizes a strictly QDI 4-phase protocol, it lacks a synchronous temporal deadline. The conscious agent simply delays the subsequent acknowledgment until the metastable state fully resolves. Therefore, metastability never produces an illegal logic state or hardware failure; it merely manifests as a variable latency. Stochastic noise provides the infinitesimal kick, and the QDI handshake guarantees absolute physical robustness.

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).