



EQUILIBRIUM

Equilibrium Research Division

WP-2025-001-PROPOSAL: Autonomous Intelligence Infrastructure

**Blockchain, AI Agents and
Liquid Neural Networks**

From ODE Solvers to Closed-Form ZK Inference

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1 Executive Overview

This document outlines a research proposal developed within **Equilibrium** to investigate the integration of Artificial Intelligence agents into blockchain infrastructures. The study aims to evaluate how autonomous intelligent systems can operate within decentralized environments while maintaining verifiability, scalability, and economic efficiency.

Particular emphasis is placed on **Liquid Neural Networks (LNNs)**, an emerging neural architecture characterized by adaptive and continuous parameter dynamics. These models may provide a structurally efficient solution for resource-constrained and latency-sensitive blockchain environments.

The research is intended to serve as a conceptual and technical foundation for future Equilibrium initiatives involving decentralized intelligence systems, quantitative trading automation, and distributed decision-making infrastructures.

2 Blockchain as a Substrate for Autonomous Intelligence

Over the last decade, blockchain technology has evolved from digital payment rails into programmable trust infrastructure. Parallel to this evolution, Artificial Intelligence has demonstrated unprecedented capabilities in pattern recognition, forecasting, and adaptive control.

The convergence of these domains suggests the emergence of decentralized ecosystems composed of *autonomous agents* capable of:

- Executing financial strategies in decentralized finance protocols
- Performing predictive analytics using real-time market data
- Managing distributed IoT infrastructures
- Conducting automated compliance and identity verification
- Operating dynamic digital asset ecosystems

Early industry developments indicate that AI agents interacting with smart contracts are technically feasible but introduce several open research questions regarding the stochastic nature of block-times and gas costs.

3 Core Research Challenges

3.1 Security and Verifiability

The deployment of AI models in trustless environments introduces verification problems:

- Guaranteeing inference correctness without revealing model weights (Model IP).
- Preventing adversarial data manipulation.
- Maintaining transparency in adaptive model architectures.

3.2 Scalability and Computational Constraints

Neural models require significant computational resources, conflicting with blockchain execution limits. Potential solutions include:

- Off-chain inference frameworks (Optimistic or ZK-based).
- Zero-knowledge verification proofs (zk-SNARKs/STARKs).
- Hybrid execution models using Trusted Execution Environments (TEEs).

3.3 Oracle Reliability and Data Integrity

AI agents require reliable external data. The robustness of decentralized oracle mechanisms remains a fundamental research bottleneck, particularly for high-frequency time-series data required by LNNs.

3.4 Autonomous Governance

Multi-agent blockchain ecosystems introduce complex coordination dynamics requiring formal governance frameworks to prevent cascading failures in liquidity pools.

4 Architectural Integration Frameworks

4.1 On-Chain vs Off-Chain Inference

On-chain execution guarantees transparency but suffers from severe computational limitations. Off-chain execution provides scalability but requires cryptographic trust mechanisms.

4.2 Model State Storage

Two primary strategies emerge:

- Full parameter storage on-chain (Cost prohibitive for deep networks).
- Hashed checkpoints referencing off-chain model states (Merkle roots of weights).

4.3 Event-Driven Agent Architectures

Blockchain systems operate in discrete temporal intervals (blocks). Agent architectures must synchronize continuous learning processes with discrete ledger updates, a problem uniquely suited for Liquid Neural Networks.

5 Liquid Neural Networks: Foundations

5.1 Continuous-Time Formulation

Let $h(t) \in \mathbb{R}^d$ represent the hidden state and $x(t)$ the input signal. LNNs are typically modeled through Ordinary Differential Equations (ODEs):

$$\frac{dh(t)}{dt} = f(h(t), x(t), \theta(t)) \quad (1)$$

Unlike traditional recurrent neural networks (RNNs), parameters evolve dynamically, allowing the system to model causal relationships in continuous time.

5.2 Adaptive Parameter Dynamics

$$\frac{d\theta(t)}{dt} = g(\theta(t), h(t), x(t)) \quad (2)$$

This allows real-time structural adaptation, mimicking neuroplasticity.

5.3 Discrete-Time Blockchain Approximation

Standard implementations utilize numerical solvers (e.g., Euler or Runge-Kutta) to approximate the state at block height $k + 1$:

$$h_{k+1} = h_k + \Delta t f(h_k, x_k, \theta_k) \quad (3)$$

$$\theta_{k+1} = \theta_k + \Delta t g(\theta_k, h_k, x_k) \quad (4)$$

6 Advanced Proposal: Closed-Form Continuous (CfC) Networks

While the standard formulation (Section 5) is theoretically sound, numerical solvers are computationally expensive ($O(\text{steps})$) for smart contracts. To optimize for Equilibrium's high-frequency trading needs, we propose a **Closed-form Continuous-depth** architecture.

6.1 Solving the ODE Analytically

Instead of iterating, we solve the linear component of the ODE to predict the state at any time t in $O(1)$ complexity.

Proposition 1 (CfC Solution). *Given a liquid time-constant τ , the state $h(t)$ can be computed as:*

$$h(t) = (h(t_0) - A) \odot e^{-\frac{t-t_0}{\tau}} + A \quad (5)$$

This formulation allows the agent to "jump" to the exact timestamp of the next block without intermediate computation steps, drastically reducing gas costs.

6.2 Finite Field Quantization for ZK-Proofs

To verify the inference via Zero-Knowledge Proofs (e.g., zk-STARKs), we must map the continuous weights \mathbb{R} to a Finite Field \mathbb{F}_p .

Definition 1 (Fixed-Point Quantization). *Let S be a scaling factor. The mapping $Q : \mathbb{R} \rightarrow \mathbb{F}_p$ is:*

$$Q(x) = \lfloor x \cdot S \rfloor \pmod p \quad (6)$$

This enables the construction of arithmetic circuits that prove the agent executed the trading strategy correctly without revealing the proprietary weights θ .

6.3 Non-Linearity Approximation

Since exponential functions e^{-x} are expensive in arithmetic circuits, we propose using Padé approximants:

$$e^{-x} \approx \frac{12 - 6x + x^2}{12 + 6x + x^2} \quad (7)$$

This rational function allows for efficient on-chain verification of the LNN's decay dynamics.

7 On-Chain Execution Algorithm

The following algorithm outlines the proposed execution logic for the Equilibrium Smart Agent.

Algorithm 1 Equilibrium CfC Inference Execution

```
1: Input: State  $h_k$ , Market Data  $x_{k+1}$ , BlockTime  $\Delta t$ 
2: Output: Action  $a_{k+1}$ 
3: procedure EXECUTE( $h_k, x_{k+1}, \Delta t$ )
4:    $\tau \leftarrow$  ComputeTimeConstant( $x_{k+1}$ )
5:   decay  $\leftarrow$  PadéApprox( $-\Delta t/\tau$ )
6:    $h_{temp} \leftarrow (h_k - A) \cdot$  decay  $+ A$ 
7:    $h_{k+1} \leftarrow$  GatingMechanism( $h_{temp}, x_{k+1}$ )
8:    $a_{k+1} \leftarrow$  PolicyHead( $h_{k+1}$ )
9:   return  $a_{k+1}$ 
10: end procedure
```

8 Strategic Advantages of LNNs

- **Continuous adaptation:** Robustness to non-stationary environments (e.g., flash crashes).
- **Parameter Efficiency:** Lower parameter complexity relative to deep architectures (Transformers), reducing storage costs.
- **Causality:** Improved ability to distinguish correlation from causation in market data.
- **Irregular Sampling:** Native handling of tick-by-tick data without artificial binning.

9 Potential Applications within Equilibrium Ecosystems

9.1 Decentralized Asset Management

- Dynamic portfolio rebalancing based on predicted volatility surfaces.
- Liquidity optimization (concentrated liquidity management on AMMs).
- Volatility anomaly detection for circuit breakers.

9.2 Autonomous Market Infrastructure

Agents could manage automated trading logic, risk monitoring, and strategy evolution entirely on-chain or via validium.

9.3 Distributed Multi-Agent Intelligence

Networks of cooperating agents could perform decentralized market analysis and resource optimization using Federated Learning on the blockchain.

10 Strategic Relevance for Equilibrium

The integration of blockchain infrastructure with adaptive AI systems aligns with Equilibrium's long-term research vision focused on:

- Autonomous quantitative trading
- Decentralized financial intelligence
- AI-native portfolio management systems
- Distributed predictive analytics platforms

11 Future Research Roadmap

Future work may include:

- Development of prototype LNN-driven agents using the CfC architecture.
- Integration with decentralized execution environments (StarkNet or Arbitrum Stylus).
- Verification frameworks using cryptographic proofs (Halo2 or PlonK).
- Experimental benchmarking against traditional ML architectures (LSTM/GRU).

12 Author Background

During his academic and professional development, Leonardo Sorio has focused extensively on financial time-series modeling, machine learning, and blockchain technologies. His research background combines applied mathematics, financial engineering, and decentralized infrastructure design.

This proposal represents an exploratory initiative intended to expand Equilibrium's research capabilities in emerging autonomous intelligence systems.

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