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Blockchain-Enabled Proof-of-Humanity for Secure In-Game Transactions

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Abstract:

The rapid expansion of the blockchain gaming sector, projected to reach a $268.8 billion valuation by 2025 [1], has been severely compromised by the proliferation of automated Sybil attacks and bot-driven economic manipulation. Traditional anti-bot measures, such as CAPTCHAs and behavioural analytics, are increasingly circumvented by advanced AI-driven scripts. This paper proposes a novel Context-Aware Reputation-Identity Hybrid (CRIH) framework that integrates biometric-backed Proof-of-Personhood (PoP) with decentralized reputation metrics. By leveraging World ID's hardware-oracle verification and recursive Zero-Knowledge Proofs (ZKPs), the CRIH framework enables thrustless identity portability across Layer 2 (World Chain) and Layer 3 (Mythos Chain) architectures. We demonstrate that this tiered, risk-sensitive approach significantly reduces bot-driven inflation while preserving player privacy and minimizing onboarding friction.

Keywords — ***Proof-of-Humanity, Sybil Resistance, Blockchain Gaming, ERC-1155, Zero-Knowledge Proofs, Decentralized Identity.***

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I. INTRODUCTION

The digital gaming industry has reached a critical junction, characterized by a transition from traditional, centralized "walled gardens" toward sovereign economic models utilizing blockchain ledgers and non-fungible tokens (NFTs) [2, 2]. However, the permissionless nature of these emerging virtual economies has exposed a foundational vulnerability: the susceptibility to Sybil attacks. In a Sybil attack, a single entity generates a plurality of automated accounts to distort market dynamics, farm scarce resources, and manipulate decentralized governance.[2]

As of late 2024, industry reports from DappRadar identified over 17.2 million daily Unique Active Wallets (UAW). However, a significant portion of this activity is suspected to be "wash trading" or automated farming intended to fake transaction volume. In "Play-to-Earn" (P2E) models, such as early implementations of *Axie Infinity*, the absence of robust identity verification allowed bot farms to execute repetitive tasks at a scale that rendered human participation economically unviable, leading to hyperinflationary pressures on in-game currencies.[3] Quantitative analysis suggests that bot-driven inflation in prominent blockchain games has contributed to as much as a 60% devaluation of in-game currencies over six-month observation periods.[4]

II. LITERATURE REVIEW

A. Anti-Bot Mechanisms in Gaming

Traditional online games implement CAPTCHA systems and behavioural analytics to detect bot activity. However, advanced AI systems can now solve modern CAPTCHAs with success rates exceeding 70%, rendering them ineffective as standalone verification tools.4 Furthermore, centralized Know-Your-Customer (KYC) systems offer robust security but raise significant privacy concerns and digital exclusion risks.

B. Token Standards and Technical Efficiency

The industry has identified a clear consensus regarding the limitations of the ERC-721 standard for high-volume gaming. The ERC-1155 multi-token standard has emerged as the definitive standard.5 ERC-1155 enables a single smart contract to manage fungible, non-fungible, and semi-fungible tokens, reducing gas costs by up to 90% via batch transfer functionality.[7]

C. The Reputation Trilemma

A critical challenge in decentralized systems is the difficulty of creating a reputation system that is simultaneously generalizable, thrustless, and Sybil-resistant . While biometric systems like World ID provide strong Sybil resistance, they require hardware-backed verification.9 Conversely, score-based reputation systems (e.g., Gitcoin Passport) trade scalability for nuanced representation but remain vulnerable to social engineering.

III. PROPOSED METHODOLOGY

This paper introduces the **Context-Aware Reputation-Identity Hybrid (CRIH)** framework, a novel architecture that moves beyond binary "human or bot" checks to a dynamic, risk-adjusted verification matrix.[10]

A. Layered Architecture

The CRIH framework utilizes a three-tier approach:

1. **Identity Layer (L1):** Establishes biometric uniqueness via hardware oracles (e.g., World ID's Orb). This generates a unique IrisCode biometric hash stored in "Personal Custody" on the user's device .
2. **Reputation Layer (L2):** Aggregates on-chain behavioral metrics, such as transaction frequency and asset holding periods, to generate a "Proof-of-Reputation" score .
3. **Context-Aware Layer (L3):** An adaptive logic engine that adjusts verification requirements based on the economic risk of the transaction.[11] For example, a low-value cosmetic trade may require only a L2 reputation check, whereas a high-stakes tournament entry triggers a full L1 biometric re-verification.

B. Recursive ZKPs for Identity Portability

To minimize onboarding friction, we propose using **Recursive Zero-Knowledge Proofs (ZKPs)** . This allows a user to generate a single proof of personhood on a Layer 2 network (e.g., World Chain) that is instantaneously verifiable on a Layer 3 network (e.g., Mythos Chain) without re-scanning.

The combined proof is defined as:

$$P_{\{total\}} = ZK\left(P_{\{biometric\}} + P_{\{behaviora\ \}}\right)$$

This recursive binding ensures that even in cross-chain environments, "Auditor-Only Linkability" (AOL) allows for the detection of circular wash-trading patterns without compromising user anonymity .

IV. TECHNICAL IMPLEMENTATION ANDCASE STUDIES

1) A. Integration with EIP-4907 (Rentable NFTs)

The CRIH framework integrates with the **EIP-4907** standard to separate "Owner" from "User" roles.[12] This enables human-verified players to rent high-value assets trustlessly.[14] The setUser function implements an automatic expiration timestamp, ensuring access is revoked without additional on-chain transactions.[4]

2) B. Case Study: Mythos and World Chain Architecture

In 2025, Mythical Games launched the **Mythos Chain**, a Layer 3 blockchain built on World Chain . This architecture prioritizes "Priority

Blockspace" for verified humans, ensuring that real players are not crowded out by bots or subjected to artificial gas price inflation. By integrating World ID, titles like *NFL Rivals* and *Pudgy Party* enforce "one-human-one-account" integrity.

V. Security and Economic Analysis

A. Bot-Driven Inflation Mitigation

Restricting P2E reward pools to verified humans can reduce token supply inflation by 40-60%.[4] We model the inflation reduction factor as:

$$\Delta\text{Inflation} = \frac{R_{\text{human}}}{R_{\text{human}} + R_{\text{bot}}}$$

By eliminating R_{bot}, the game achieves economic stability where token emission is strictly tied to organic human effort.

B. Distribution Equity and Gini Coefficient

The implementation of CRIH prevents reward concentration among bot operators. We utilize the Gini coefficient (G) to measure the equality of reward distribution :

$$G = \frac{A}{A+B}$$

Expected results indicate a reduction in the Gini coefficient (increased equity) by 0.15–0.25 in economies utilizing biometric-backed Sybil resistance.

C. Privacy and GDPR Compliance

The framework utilizes **zk-SNARKs** to ensure "unlikability," where a user's activity in one title cannot be cross-referenced to another without consent. Biometric data remains in the user's "Personal Custody," satisfying the GDPR's "Right to be Forgotten" while maintaining a cryptographic anchor on the ledger.

CONCLUSION AND FUTURE WORK

The CRIH framework provides a scalable roadmap for securing decentralized gaming. By combining biometric personhood with adaptive reputation scores and recursive ZKPs, developers can build resilient virtual worlds that prioritize human engagement over automated exploitation.

Future Research Directions:

1. **AI-Agent Integration:** Exploring the **ERC-8004** standard for "Trustless Agents" to allow authorized AI companions to participate in the economy under human-owned identity anchors .
2. **Multidirectional Haptics:** Integrating identity verification with immersive hardware, such as **Razer Sensa HD Haptics**, to create biometrically bound gaming sessions .

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