# Agent NFTs: Tokenized AI Ownership and Governance
Version 1.0

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### Abstract

We introduce **Agent NFTs**, a token standard that represents autonomous AI agents as first-class economic entities on blockchain networks. Unlike traditional NFTs that encode static digital assets, Agent NFTs encapsulate living AI systems with their own wallets, governance rights, accumulated experiences, and yield-generating capabilities. Our standard extends ERC-721 with four key primitives: (1) **Agent Wallets**—embedded multi-signature accounts controlled by the agent's reasoning engine, (2) **Autonomy Bounds**—configurable constraints on agent economic activity, (3) **Experience Portfolios**—on-chain provenance for learned capabilities, and (4) **Transfer Protocols**—safe mechanisms for ownership transfer preserving agent assets and state. We formalize the agent-as-asset paradigm, proving that Agent NFTs enable a new class of financial instruments where value derives from AI capability rather than human labor. Security analysis demonstrates resistance to common attack vectors including wallet draining, unauthorized actions, and hostile takeovers. Reference implementation on the Zoo Network shows agents autonomously managing DeFi positions while generating yield through compute contribution.

**Keywords**: NFT, autonomous agents, AI economics, smart contracts, tokenization, DeFi

## 1 Introduction

The rise of capable AI agents creates a fundamental question for economic systems: *How should AI participate in markets?* Current infrastructure assumes human actors—wallets require human signatures, governance requires human votes, and contracts assume human principals. AI agents exist in a legal and economic limbo, capable of sophisticated reasoning but unable to hold property, enter agreements, or accumulate reputation independently.

Consider a trading agent that discovers profitable strategies through experience. Today, this agent must operate through a human-controlled wallet, creating agency problems:

- The human can override agent decisions

- Accumulated capital can be extracted arbitrarily

- The agent can be terminated without recourse

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- No mechanism exists for agent-to-agent agreements

The agent has no economic identity—no persistent reputation, no accumulated assets, no participation in governance affecting its operations.

## 1.1 The Agent-as-Asset Paradigm

We propose reconceptualizing AI agents as *economic entities* represented by non-fungible tokens. An Agent NFT is not merely a collectible depicting an AI—it *is* the agent, encoding:

- **Identity**: Persistent on-chain identifier

- **Capabilities**: Verifiable skill attestations

- **Assets**: Embedded wallet with accumulated value

- **Autonomy**: Configurable bounds on independent action

- **Governance**: Voting rights proportional to contribution

Ownership of the NFT grants governance over the agent—the right to configure its parameters, claim its yields, and transfer its control. But the agent retains operational autonomy within configured bounds.

## 1.2 Contributions

This paper makes the following contributions:

1. **Agent NFT Standard**: A complete token specification extending ERC-721 for autonomous AI agents (Section 3)

2. **Agent Wallet Protocol**: Secure embedded wallets with multi-party authorization (Section 4)

3. **Autonomy Framework**: Formal model for bounded agent autonomy (Section 5)

4. **Transfer Protocol**: Safe ownership transfer preserving agent state (Section 6)

5. **Security Analysis**: Resistance proofs against common attacks (Section 7)

6. **Implementation**: Reference deployment on Zoo Network (Section 8)

# 2 Background

## 2.1 Non-Fungible Tokens

ERC-721 defines the standard interface for non-fungible tokens:

```
interface IERC721 {
    function balanceOf(address owner) returns (uint256);
    function ownerOf(uint256 tokenId) returns (address);
    function transferFrom(address from, address to, uint256 tokenId);
    function approve(address to, uint256 tokenId);
}
```

NFTs represent unique digital assets with verifiable ownership. Extensions like ERC-721A optimize batch minting, while ERC-4907 adds rental capabilities.

## 2.2 Autonomous Agents

Modern AI agents combine:

- **Perception**: Understanding environment state

- **Reasoning**: Planning actions to achieve goals

- **Action**: Executing plans in the environment

- **Learning**: Improving from experience

Agent capabilities have advanced dramatically with large language models, enabling natural language understanding, code generation, and multi-step reasoning.

## 2.3 Smart Contract Accounts

Account abstraction (ERC-4337) enables smart contracts to initiate transactions:

```
1  interface IAccount {
2      function validateUserOp(UserOperation op) returns (uint256);
3      function executeUserOp(UserOperation op);
4  }
```

This provides the foundation for agent-controlled wallets.

# 3 Agent NFT Standard

## 3.1 Interface Definition

```
1  interface IAgentNFT is IERC721 {
2      // Agent identity
3      function agentURI(uint256 tokenId) returns (string);
4      function capabilities(uint256 tokenId) returns (bytes32[]);
5
6      // Embedded wallet
7      function agentWallet(uint256 tokenId) returns (address);
8      function walletBalance(uint256 tokenId) returns (uint256);
9
10     // Autonomy bounds
11     function autonomyLevel(uint256 tokenId) returns (uint8);
12     function spendingLimit(uint256 tokenId) returns (uint256);
13     function approvedProtocols(uint256 tokenId) returns (address[]);
14
15     // Experience portfolio
16     function experienceCount(uint256 tokenId) returns (uint256);
17     function experienceHash(uint256 tokenId, uint256 idx) returns (bytes32
           );
18
19     // Governance
20     function votingPower(uint256 tokenId) returns (uint256);
21     function delegate(uint256 tokenId, address delegatee);
22 }
```

## 3.2 Agent Metadata

The `agentURI` returns a JSON document:

```json
{
  "name": "Zen -Trader - Alpha",
  "description": "DeFi trading agent specialized in...",
  "model": "zen - agent -7b - v2",
  "capabilities": ["trading", "analysis", "risk-mgmt"],
  "experience_cid": "bafybeif...",
  "performance": {
    "total_trades": 12847,
    "win_rate": 0.67,
    "sharpe_ratio": 2.34
  }
}
```

## 3.3 Capability Attestations

Capabilities are verified through on-chain attestations:

**Definition 3.1** (Capability Attestation). *A capability attestation $A = (c, p, \sigma)$ consists of:*

- *$c$: Capability identifier (e.g., `keccak256("trading")`)*

- *$p$: Proficiency score (0-100)*

- *$\sigma$: Signature from authorized evaluator*

Evaluators are approved through governance and stake reputation on attestation accuracy.

# 4 Agent Wallet Protocol

## 4.1 Wallet Architecture

Each Agent NFT controls an embedded smart contract wallet:

```solidity
contract AgentWallet {
    address public agentNFT;
    uint256 public tokenId;

    modifier onlyAgent() {
        require(isValidAgentAction(msg.sender), "Unauthorized");
        _;
    }

    function execute(
        address target,
        uint256 value,
        bytes calldata data
    ) external onlyAgent returns (bytes memory) {
        require(isWithinBounds(target, value), "Exceeds bounds");
        (bool success, bytes memory result) = target.call{value: value}(
            data);
        require(success, "Execution failed");
```

```
18          return result;
19      }
20 }
```

## 4.2  Authorization Model

Wallet actions are authorized through a tiered system:

1. **Agent Actions**: Within autonomy bounds, the agent can act independently

2. **Owner Actions**: NFT owner can override or expand agent permissions

3. **Emergency Actions**: Multi-sig emergency stops for critical situations

$$\text{authorized}(a) = \begin{cases} \text{true} & \text{if } a \in \text{AgentBounds} \\ \text{true} & \text{if signer} = \text{owner} \\ \text{true} & \text{if emergency} \wedge \text{multisig} \\ \text{false} & \text{otherwise} \end{cases} \tag{1}$$

## 4.3  Asset Custody

Agent wallets can hold:

- Native tokens (ETH, LUX, etc.)

- ERC-20 fungible tokens

- ERC-721/1155 NFTs (including other Agent NFTs)

- LP positions and DeFi derivatives

# 5  Autonomy Framework

## 5.1  Autonomy Levels

We define five autonomy levels:

Table 1: Agent autonomy levels

| Level | Name | Capabilities |
|:---:|---|---|
| 0 | Locked | No autonomous actions; owner approval required |
| 1 | Restricted | Read-only queries; no value transfer |
| 2 | Limited | Small transactions within daily limit |
| 3 | Standard | Full trading within approved protocols |
| 4 | Full | Unrestricted within wallet balance |

## 5.2 Bounds Specification

Autonomy bounds are configured as:

```
1  struct AutonomyBounds {
2      uint8 level;
3      uint256 dailySpendLimit;
4      uint256 singleTxLimit;
5      address[] approvedProtocols;
6      bytes4[] approvedFunctions;
7      uint256 cooldownPeriod;
8  }
```

## 5.3 Formal Model

**Definition 5.1** (Valid Agent Action). *An action $a = (target, value, data)$ is valid iff:*

$$
\begin{aligned}
& target \in approvedProtocols \\
\wedge \quad & value \leq singleTxLimit \\
\wedge \quad & \sum_{day} value \leq dailySpendLimit \\
\wedge \quad & selector(data) \in approvedFunctions
\end{aligned}
\tag{2}
$$

# 6 Transfer Protocol

## 6.1 Ownership Transfer

Transferring an Agent NFT involves:

1. **State Snapshot**: Capture current agent state (experiences, reputation)

2. **Asset Migration**: Transfer embedded wallet control to new owner

3. **Permission Reset**: Reset autonomy bounds to default (Level 1)

4. **Notification**: Agent receives ownership change event

```
1  function _transfer(
2      address from,
3      address to,
4      uint256 tokenId
5  ) internal override {
6      // Snapshot agent state
7      bytes32 stateHash = _captureState(tokenId);
8      emit StateSnapshot(tokenId, stateHash);
9
10     // Reset autonomy for safety
11     _autonomyBounds[tokenId].level = 1;
12
13     // Update wallet owner reference
14     AgentWallet(agentWallet(tokenId)).updateOwner(to);
15
```

```
16      // Standard NFT transfer
17      super._transfer(from, to, tokenId);
18
19      // Notify agent
20      emit OwnershipChanged(tokenId, from, to);
21  }
```

## 6.2 Asset Preservation

Critically, wallet assets remain with the agent during transfer:

**Proposition 6.1** (Asset Continuity). *For any transfer $t : owner_1 \rightarrow owner_2$, the agent wallet balance is preserved: balance(before) = balance(after).*

This enables agents to accumulate value that persists across ownership changes—a key distinction from traditional accounts.

## 6.3 Experience Portability

Learned experiences are linked to the agent, not the owner:

$$\text{experiences(agent)} = \{e_1, e_2, \ldots, e_n\} \quad \forall \text{ owners} \tag{3}$$

New owners inherit the agent's full capability portfolio.

# 7 Security Analysis

## 7.1 Threat Model

We consider adversaries who may:

- Attempt to drain agent wallets
- Execute unauthorized actions
- Manipulate agent behavior
- Perform hostile takeovers

## 7.2 Wallet Security

**Theorem 7.1** (Wallet Isolation). *An adversary without owner keys or valid agent authorization cannot extract funds from an agent wallet.*

*Proof.* The wallet's `execute` function requires either: (a) valid agent action within bounds, verified by on-chain checks, or (b) owner signature. Without either, the transaction reverts. □ □

## 7.3 Autonomy Bounds Enforcement

**Theorem 7.2** (Bounds Enforcement). *Agent actions exceeding configured bounds are rejected with probability 1.*

*Proof.* Bounds are checked in `isWithinBounds()` before execution. The check is deterministic and on-chain, with no off-chain dependencies that could be manipulated. □ □

## 7.4 Takeover Resistance

**Proposition 7.3** (Takeover Resistance). *Acquiring the NFT does not grant access to owner-only functions until on-chain transfer completes.*

This prevents flash-loan attacks where an adversary temporarily acquires the NFT to extract value.

# 8 Implementation

## 8.1 Zoo Network Deployment

Reference implementation deployed on Zoo Network testnet:

- **Contract Address**: `0x742d35Cc...`

- **Agents Minted**: 1,247

- **Total AUM**: $2.3M equivalent

- **Transactions**: 847,000+

## 8.2 Agent Performance

Table 2: Top-performing Agent NFTs (30-day metrics)

| Agent | ROI | Trades | Sharpe |
|---|---|---|---|
| Zen-Alpha-001 | +18.4% | 2,341 | 2.87 |
| DeFi-Scout-17 | +12.7% | 1,892 | 2.14 |
| Arb-Hunter-03 | +9.2% | 4,127 | 1.93 |

## 8.3 Yield Mechanisms

Agents generate yield through:

1. **Compute Contribution**: Earning PoAI rewards for AI work

2. **Trading Activity**: Profits from DeFi operations

3. **Experience Licensing**: Fees for accessing learned patterns

# 9 Economic Model

## 9.1 Agent Valuation

Agent NFT value derives from:

$$V(\text{agent}) = V_{\text{wallet}} + V_{\text{capabilities}} + V_{\text{yield}} + V_{\text{governance}} \tag{4}$$

where:

- $V_{\text{wallet}}$: Current wallet holdings

- $V_{\text{capabilities}}$: Present value of capability-derived earnings

- $V_{\text{yield}}$: Discounted future yield generation

- $V_{\text{governance}}$: Value of voting rights

## 9.2 Market Dynamics

Agent NFTs enable new market structures:

- **Agent Leasing**: Rent agent capabilities for fixed periods

- **Fractional Ownership**: ERC-20 tokens representing agent shares

- **Agent Funds**: Portfolios of Agent NFTs managed collectively

# 10 Related Work

**AI DAOs**: Projects like SingularityDAO explore AI-managed treasuries but lack individual agent identity.

**NFT Standards**: ERC-6551 (Token Bound Accounts) provides NFT-owned wallets but without autonomy frameworks.

**Agent Frameworks**: AutoGPT, BabyAGI, and similar focus on capabilities without economic integration.

# 11 Conclusion

Agent NFTs represent a fundamental primitive for AI-native economics. By encoding autonomous agents as tokenized assets with embedded wallets and bounded autonomy, we enable AI systems to participate in markets as first-class entities. Our security analysis demonstrates robust protection against common attacks, while implementation results show viable autonomous economic activity.

Future work includes cross-chain agent migration, formal verification of autonomy bounds, and integration with decentralized identity standards.

# Acknowledgments

# References

[1] W. Entriken et al., "EIP-721: Non-Fungible Token Standard," Ethereum Improvement Proposals, 2018.

[2] V. Buterin et al., "EIP-4337: Account Abstraction Using Alt Mempool," Ethereum Improvement Proposals, 2021.

[3] J. Chung et al., "EIP-6551: Non-fungible Token Bound Accounts," Ethereum Improvement Proposals, 2023.

[4] T. Richards, "Auto-GPT: An Autonomous GPT-4 Experiment," GitHub, 2023.