Binocular: A Decentralized Bitcoin Oracle on Cardano

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Abstract

Binocular is a Bitcoin oracle for Cardano that enables smart contracts to verify Bitcoin blockchain state. Anyone can submit Bitcoin block headers to a single on-chain Oracle without registration or bonding. The Cardano smart contract validates all blocks against Bitcoin consensus rules (proof-of-work, difficulty, timestamps) and automatically selects the canonical chain. Blocks with 100+ confirmations and 200+ minutes on-chain aging are promoted to confirmed state, enabling transaction inclusion proofs. Security relies on a 1-honest-party assumption and Bitcoin's proof-of-work, with attack costs exceeding $46 million.

Introduction

Cardano smart contracts cannot directly observe Bitcoin transactions, limiting cross-chain applications like bridges, Bitcoin-backed assets, and decentralized exchanges. Binocular solves this by implementing a Bitcoin oracle that validates block headers on-chain.

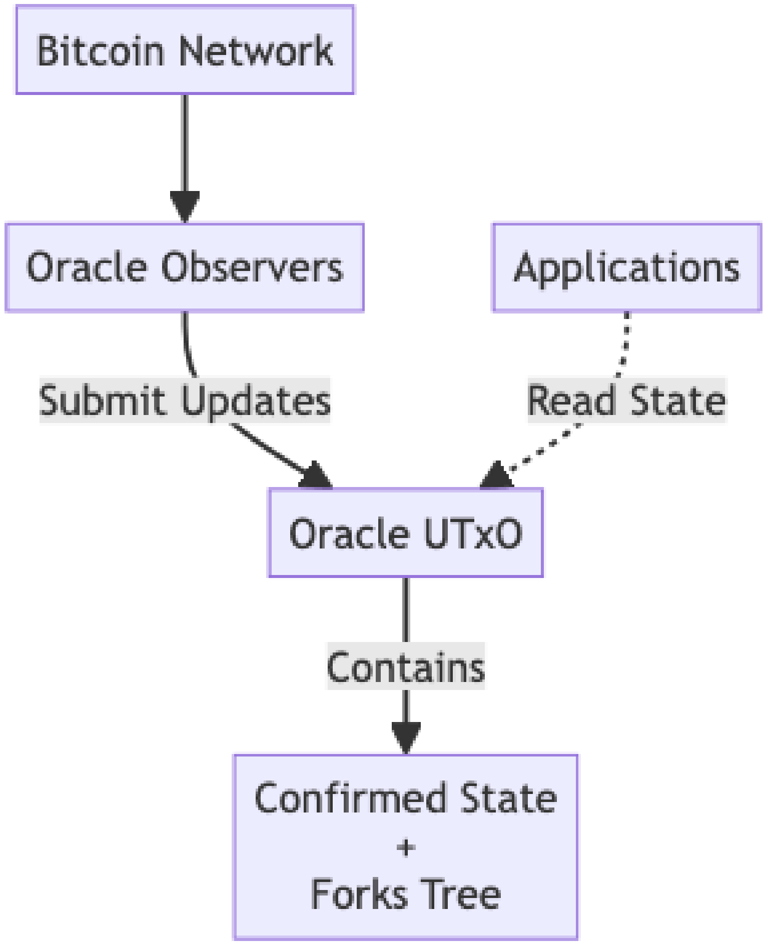
The protocol uses a single Oracle UTxO containing both confirmed Bitcoin state and a tree of competing unconfirmed forks. Anyone can submit updates without permission. The on-chain validator enforces Bitcoin consensus rules and automatically promotes qualified blocks. With at least one honest party monitoring Bitcoin, the Oracle progresses with bounded latency (~17 hours for 100 confirmations).

Binocular enables applications to verify Bitcoin transaction inclusion proofs, opening possibilities for secure cross-chain interoperability.

Protocol Overview

Note: See the Whitepaper for full technical details.

Binocular uses a **single Oracle UTxO** containing the complete protocol state:



The Oracle UTxO contains:

- **Confirmed State**: Bitcoin blocks with 100+ confirmations (Merkle tree root)
- **Forks Tree**: Competing unconfirmed Bitcoin chains indexed by block hash

How it works:

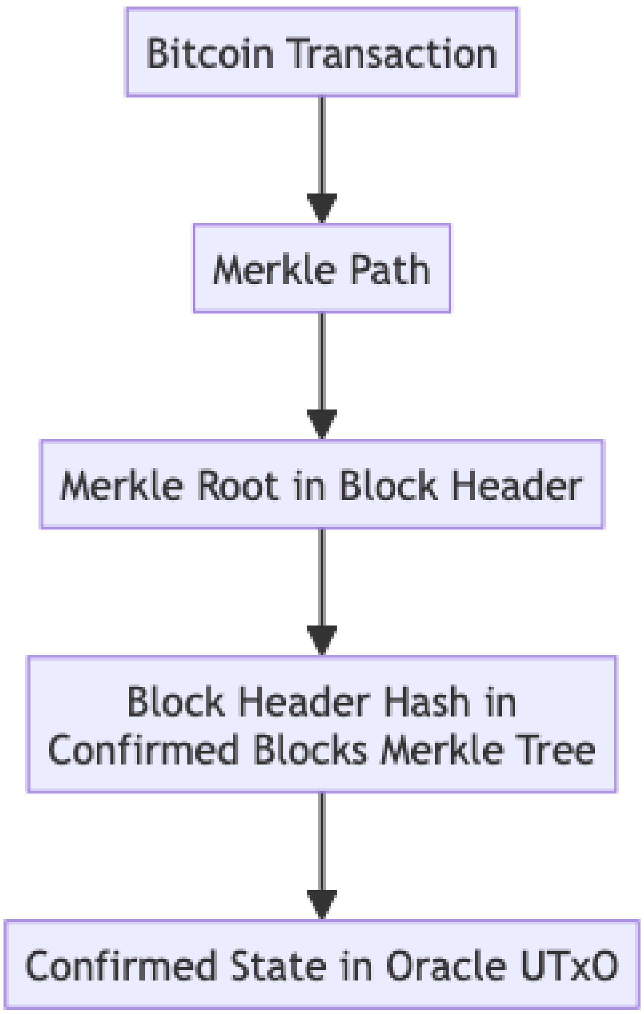
1. Anyone submits Bitcoin block headers to the Oracle (no registration needed)
2. The on-chain validator validates each block (PoW, difficulty, timestamps)
3. Valid blocks are added to the forks tree
4. The validator automatically selects the canonical chain (highest chainwork)
5. Blocks meeting criteria (100+ confirmations AND 200+ minutes old) are promoted to confirmed state
6. All operations happen atomically in a single transaction

Fork Competition: Multiple forks coexist in the tree. The validator automatically selects the canonical chain following Bitcoin's longest chain rule (highest cumulative chainwork).

Challenge Period: The 200-minute on-chain aging requirement prevents pre-computed attacks. Attackers cannot mine 100+ blocks offline and immediately promote them - blocks must exist on-chain for 200 minutes, giving honest parties time to submit the real Bitcoin chain.

Transaction Inclusion Proofs

With verified Bitcoin block headers in confirmed state, applications can prove a Bitcoin transaction exists:



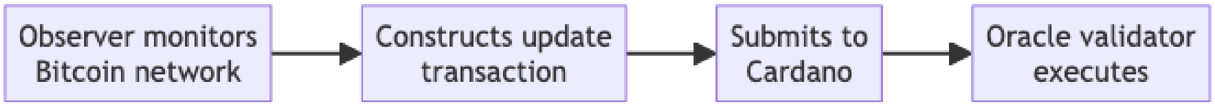
Key Concepts

- **Oracle UTxO**: Single on-chain UTxO holding all protocol state
- **Confirmed State**: Bitcoin blocks with 100+ confirmations and 200+ min aging
- **Forks Tree**: Tree data structure holding competing unconfirmed chains
- **Canonical Chain**: Automatically selected fork with highest chainwork
- **Block Promotion**: Automatic move of qualified blocks to confirmed state
- **Challenge Period**: 200-minute on-chain aging before blocks can be promoted
- **Chainwork**: Cumulative proof-of-work used for canonical chain selection

How It Works

1. Submitting Bitcoin Blocks

Anyone can submit an update transaction containing new Bitcoin block headers:

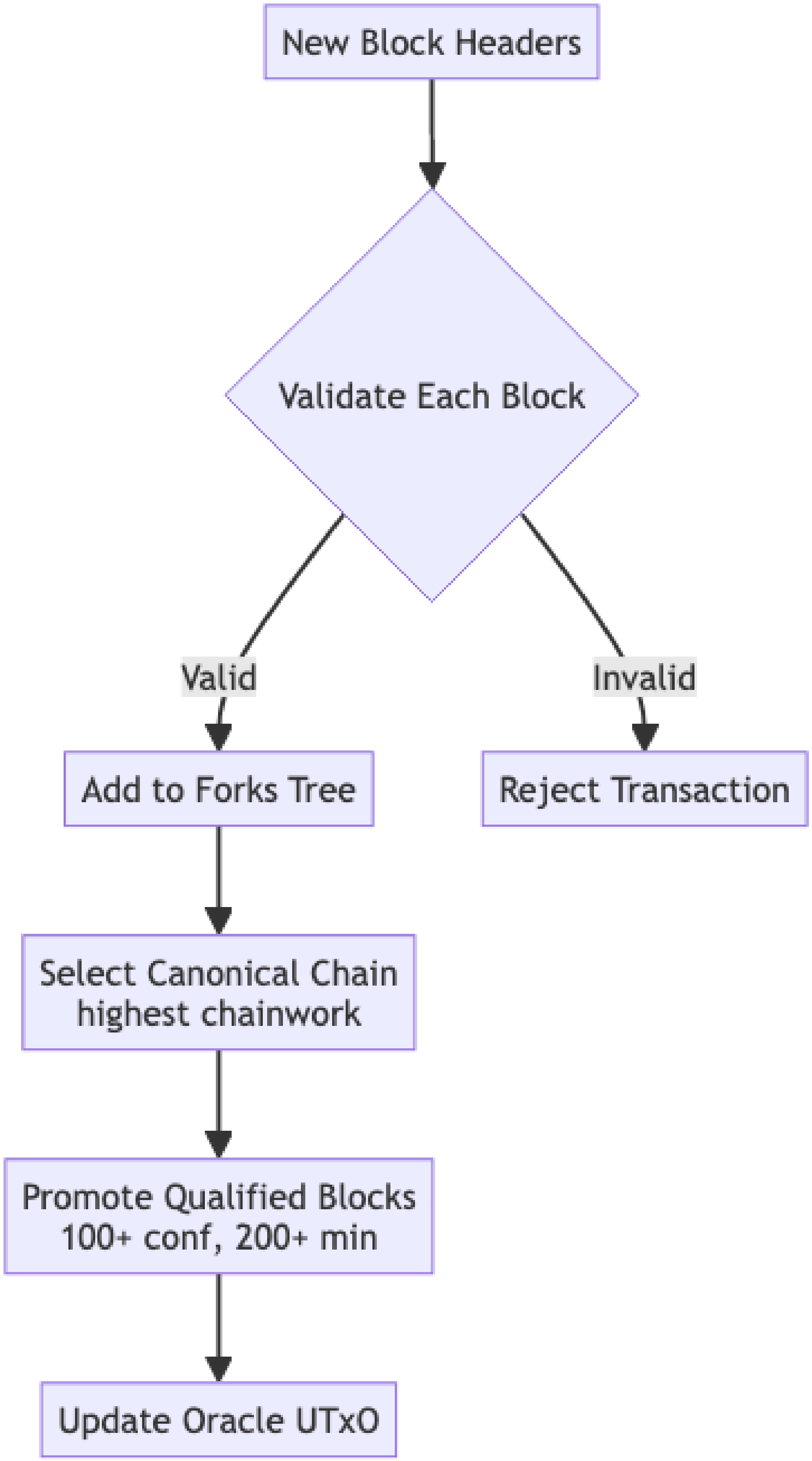


No registration or bonding required. The transaction includes:

- One or more Bitcoin block headers
- Fork point (which block these extend from)

2. On-Chain Validation & Processing

The Oracle validator performs all operations atomically in a single transaction:

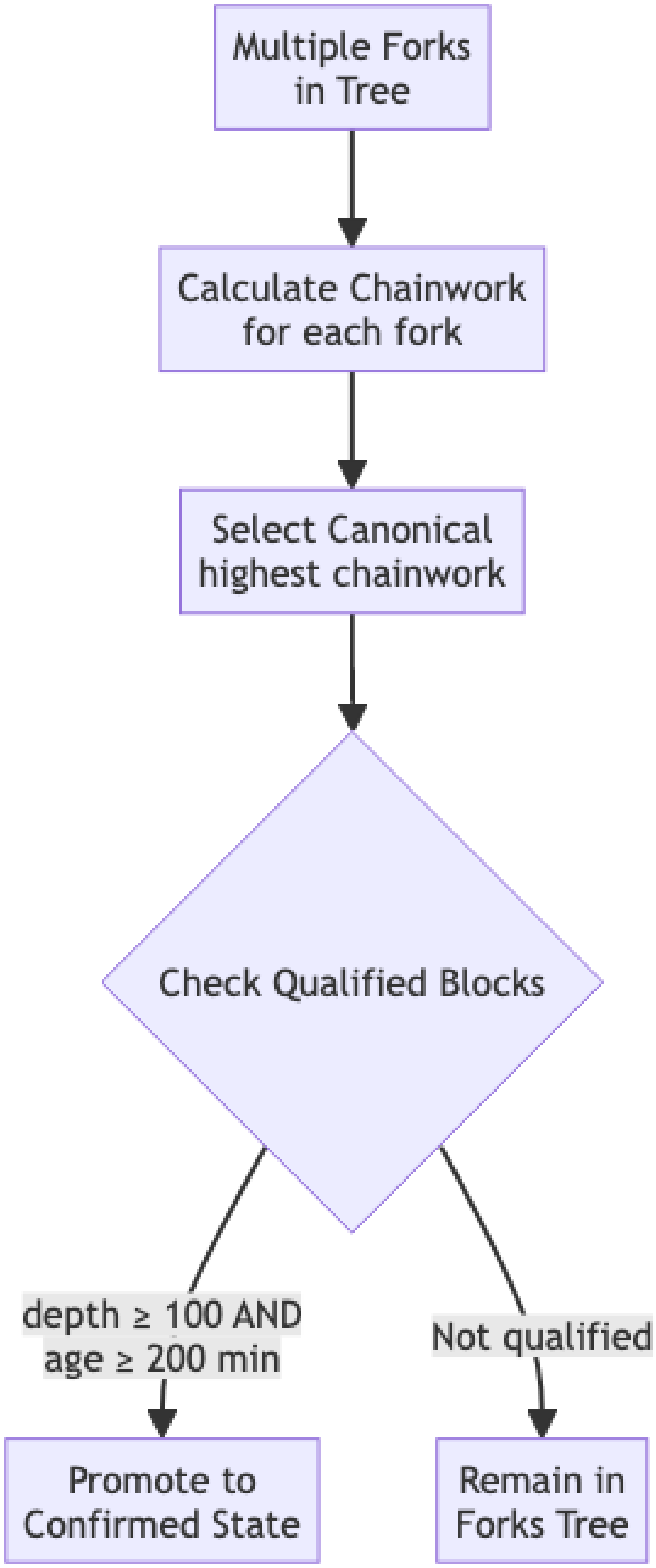

New Block Headers
Validate Each Block
Valid
Invalid
Add to Forks Tree
Reject Transaction
Select Canonical Chain highest chainwork
Promote Qualified Blocks 100+ conf, 200+ min
Update Oracle UTxO

Validation checks for each block:

- **Proof-of-Work**: Block hash ≤ difficulty target
- **Difficulty**: Matches expected retarget (every 2016 blocks)
- **Timestamps**: Greater than median of last 11 blocks, not too far in future
- **Chain Continuity**: Previous block hash exists in forks tree or confirmed state
- **Version**: Block version ≥ 4

3. Automatic Fork Resolution & Promotion

Fork Competition: Multiple forks coexist in the tree, but only one is canonical at any time.


Multiple Forks in Tree
Calculate Chainwork for each fork
Select Canonical highest chainwork
Check Qualified Blocks
depth ≥ 100 AND age ≥ 200 min
Not qualified
Promote to Confirmed State
Remain in Forks Tree

Block Promotion: Blocks are automatically promoted when:

- On the canonical chain (highest chainwork)
- At least 100 blocks deep from tip
- At least 200 minutes old (since added to forks tree)

The promoted block's hash is added to the confirmed blocks Merkle tree, enabling transaction inclusion proofs.

Security

Economic Security: Attack Cost Analysis

To attack the Oracle and confirm invalid Bitcoin blocks, an adversary must mine 100+ Bitcoin blocks. This is economically infeasible:

Cost Breakdown (2025 estimates):

- Bitcoin network hashrate: ~600 EH/s
- Mining 100 blocks requires >50% hashrate control
- Time: ~16.7 hours (1000 minutes)

Direct Costs:

- **Energy**: 300 million kWh × $0.05/kWh = **$15 million**
- **Opportunity cost**: Lost block rewards from honest mining = **$31 million** (100 blocks × 3.125 BTC × $100k)
- **Total: $46 million minimum**

Alternative (Hardware Purchase):

- Required hashrate: 600 EH/s = 600 million TH/s
- ASIC cost: $30/TH
- **Hardware cost: $18 billion** (plus energy)

Realistic Attack Rewards:

- Oracle manipulation for DApp exploit: < $10M
- Attack destroys Bitcoin value, making reward worthless

Conclusion: Attack cost ($46M - $18B) far exceeds any realistic reward (< $10M).

Challenge Period Defense

The 200-minute on-chain aging requirement prevents pre-computed attacks:

Attack Timeline:

1. Attacker mines 100+ blocks offline (takes weeks/months)
2. Publishes to Oracle at time t_0
3. Cannot be promoted until t_0 + 200 minutes

Honest Party Response:

- Detects attack within monitoring interval (typically < 60 minutes)

- Submits real Bitcoin chain to Oracle
- Real chain has higher chainwork (continues from actual Bitcoin)
- Oracle automatically selects real chain as canonical
- Attack blocks become orphaned

Response Window: 200 - 60 - 5 (Cardano finality) = **135 minutes to spare**

1-Honest-Party Assumption

The protocol requires **at least one honest participant** who:

- Monitors the Bitcoin network
- Submits valid Bitcoin blocks to the Oracle
- Has access to canonical Bitcoin blockchain data

This is a minimal assumption - requires only that someone, somewhere, runs the freely available observer software. Applications depending on the Oracle have natural incentives to ensure freshness.

Key Features

Permissionless Participation

- Anyone can submit Bitcoin blocks to the Oracle
- No registration, bonding, or special privileges required
- Only requirement: valid block headers and transaction fees

On-Chain Bitcoin Validation

- Complete Bitcoin consensus validation in Plutus smart contract
- Enforces proof-of-work, difficulty adjustment, timestamp rules
- Efficient storage: only essential block data stored on-chain after validation
- No trusted authorities or off-chain dependencies
- Invalid blocks automatically rejected by validator

Simplified Single-UTxO Architecture

- One Oracle UTxO contains all protocol state
- Atomic updates: validation, fork selection, and promotion in single transaction
- No coordination between multiple UTxOs
- Predictable transaction costs

Automatic Processing

- **Canonical Selection**: Validator automatically picks highest chainwork fork
- **Block Promotion**: Qualified blocks automatically move to confirmed state
- **Fork Resolution**: Competition resolved through on-chain chainwork calculation
- No manual intervention or separate maturation transactions needed

Security Properties

- **Safety**: Confirmed state never contains invalid Bitcoin blocks (enforced by validator)
- **Liveness**: Oracle progresses under 1-honest-party assumption (~17 hour latency)
- **Economic Security**: Attack costs $46M+ far exceed realistic rewards
- **Challenge Defense**: 200-minute aging prevents pre-computed attacks

Future Work

BiFROST Protocol Integration

Binocular will be further developed and integrated into the BiFROST cross-chain bridge protocol, which aims to provide secure, decentralized asset bridges between Bitcoin and Cardano. Binocular's trustless Bitcoin state verification serves as a foundational component for cross-chain bridges, Bitcoin-backed stablecoins, and other interoperability applications.

Planned Enhancements

Participation Incentives: Design explicit economic rewards for Oracle observers to strengthen liveness guarantees beyond the minimal 1-honest-party assumption.

Enhanced Tooling: Build open-source observer infrastructure, monitoring dashboards, and multi-platform support for running Oracle observers.

Design Decisions

Direct Block Validation vs NIPoPoWs: Non-Interactive Proofs of Proof-of-Work (NIPoPoWs) were considered for efficient light client support but rejected after research. Direct block validation provides stronger security guarantees and simpler implementation, while NIPoPoW verification adds significant on-chain complexity without clear benefits for the primary use case of transaction inclusion proofs.

No On-Chain Governance: Protocol parameters (100 confirmations, 200-minute challenge period) are fixed by design. Anyone can deploy an independent Oracle UTxO with different parameters if needed, enabling experimentation without governance complexity.

Conclusion

Binocular provides a Bitcoin oracle for Cardano with complete on-chain validation of Bitcoin consensus rules. The protocol's single-UTxO architecture enables atomic updates with automatic canonical chain selection and block promotion.

Key achievements:

- **Permissionless**: Anyone can submit blocks without registration or bonding
- **Secure**: $46M+ attack costs far exceed realistic rewards

- **Validated**: All Bitcoin consensus rules enforced on-chain (PoW, difficulty, timestamps)
- **Minimal Trust**: Requires only 1-honest-party assumption with ~17 hour latency

By enabling transaction inclusion proofs, Binocular opens possibilities for cross-chain bridges, Bitcoin-backed assets, and decentralized exchanges between Bitcoin and Cardano ecosystems.

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