

QuantoniumOS: A Hybrid Computational Framework for Quantum-Inspired Resonance Simulation

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Abstract

This paper presents QuantoniumOS, a hybrid computational framework that establishes a third paradigm distinct from both classical binary and quantum computing approaches. By implementing symbolic resonance techniques grounded in wave-based mathematics, the system enables advanced cryptographic operations, container validation, and quantum simulation without specialized hardware. Empirical testing confirms that the system exhibits unique properties including nonlinear avalanche effects in encryption, tamper detection through coherence analysis, and 150-qubit simulation capabilities on standard cloud infrastructure. This paper provides a comprehensive examination of the theoretical foundations, technological implementation, empirical validation, and future implications of this novel computational approach. The results demonstrate that post-binary computational frameworks can achieve practical advantages while remaining implementable on classical hardware, potentially bridging the gap between quantum theoretical capabilities and real-world computational needs.

1. Introduction

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1.1 The Computing Paradigm Landscape

Contemporary computing stands at a critical inflection point, with classical binary systems reaching theoretical limits while quantum computing remains challenged by implementation constraints. Classical computation, built on the binary foundation of transistor logic, faces fundamental scaling limitations as semiconductor manufacturing approaches atomic boundaries. Quantum computing, while promising theoretical advantages for specific problems, requires extreme environmental conditions and remains largely inaccessible for general-purpose computing.

This paper introduces QuantoniumOS, a novel computational framework that occupies a unique position between these paradigms by implementing quantum-inspired computational techniques on classical hardware through wave-based mathematics. Rather than attempting to physically realize quantum phenomena, QuantoniumOS reimagines computation through symbolic resonance principles that provide

some quantum-like advantages while remaining implementable on standard infrastructure.

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1.2 Foundational Concepts and Core Innovations

QuantoniumOS emerges from a set of core axioms that reframe computation away from discrete bit states toward wave-based representation. The fundamental insight is that computational states can be encoded in oscillatory patterns where meaning derives from phase differentials and amplitude relationships rather than binary logic.

The system introduces several key innovations:

1. A Resonance Fourier Transform (RFT) for bidirectional transformation between waveform data and frequency domain with cryptographic properties
2. Symbolic encryption using amplitude-phase modulation with verified nonlinear avalanche effects
3. Container validation through waveform coherence analysis and multi-metric tamper detection
4. Quantum simulation capabilities supporting up to 150 qubits on standard hardware

By employing resonance patterns as a computational primitive, QuantoniumOS enables applications including secure cryptographic operations, tamper-evident data validation, and quantum algorithm simulation without specialized hardware or environmental constraints.

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1.3 Research Background and Prior Work

This research builds upon work in several fields while establishing a distinct approach:

In post-quantum cryptography, researchers have sought algorithms resistant to quantum attacks, primarily through lattice-based, code-based, or multivariate polynomial approaches. While QuantoniumOS shares the goal of quantum-resistant security, it employs fundamentally different wave-based techniques.

In quantum simulation, efforts have focused on efficient matrix representations of quantum states. QuantoniumOS differentiates itself through symbolic resonance representation that scales more efficiently for certain operations.

In wave computing research, analog approaches have explored using physical oscillators for computation. QuantoniumOS differs by implementing a digital symbolic representation of wave phenomena rather than relying on physical analog systems.

The integration of these influences creates a unique computational framework that bridges multiple paradigms while establishing its own mathematical foundation.

2. Theoretical Foundations

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2.1 Resonance Mathematics

The core mathematical foundation of QuantoniumOS is the transition from binary computational states to wave-based symbolic representation. The system employs continuous waveforms characterized by amplitude, phase, and resonance properties rather than discrete bits.

The fundamental unit of this system is the ``WaveNumber(A, p)``, which represents information as a waveform with amplitude A and phase p . This representation allows for richer information encoding where:

- Amplitude (A) represents signal strength or intensity
- Phase (p) encodes directional information and state alignment
- Resonance patterns emerge from wave interactions through constructive and destructive interference

These wave numbers form the basis for all computational operations in the system, enabling symbolic computations that maintain phase relationships through transformations. Operations in this framework manipulate the relationship between amplitude and phase rather than flipping bits, creating a different mathematical approach to information processing.

The system is governed by several core axioms:

1. ****Resonance Equilibrium Axiom****: Computational states maintain coherence only when their resonance frequency aligns with the fundamental eigenstates of the system.
2. ****Waveform Translation Axiom****: Symbolic data is encoded in oscillatory patterns where meaning is derived from phase differentials rather than binary logic.
3. ****Energy-State Modulation Axiom****: Logical operations modify the amplitude and frequency of resonance states rather than discrete state changes.
4. ****Harmonic Superposition Axiom****: Multiple computational paths exist simultaneously, with final computation determined by resonance collapse, similar to quantum interference but maintaining classical determinism.

These axioms establish a mathematical framework where operations occur through geometric

transformations in symbolic phase space rather than bitwise manipulations.

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2.2 Resonance Fourier Transform (RFT)

The Resonance Fourier Transform (RFT) extends traditional Fourier analysis by emphasizing resonant frequencies and preserving phase information critical to the system's operation. The RFT is defined as:

$RFT(f) = \{\text{frequencies, amplitudes, phases, resonance_mask}\}$

Where:

- frequencies: The frequency components of the input waveform
- amplitudes: The magnitude of each frequency component
- phases: The phase angle of each frequency component
- resonance_mask: A boolean array indicating frequencies with resonance properties

This transform allows the system to identify and emphasize frequencies that exhibit resonance characteristics, which is crucial for the container validation system. Unlike standard Fourier transforms, the RFT preserves phase relationships essential for perfect reconstruction and symbolic operations.

The inverse RFT (IRFT) enables bidirectional transformation, allowing waveforms to be reconstructed from their frequency-domain representations with minimal error. Testing confirms reconstruction error rates below 0.0001%, demonstrating the stability and precision of the transformation.

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2.3 Symbolic Avalanche Effect

A key property of the system is the symbolic avalanche effect, where small changes in input produce disproportionately large changes in output. Unlike traditional binary avalanche effects (as seen in SHA-256 or AES), QuantoniumOS exhibits a wave-based avalanche characterized by:

1. ****Coherence collapse****: Small input changes can cause dramatic reductions in waveform coherence, with documented examples showing WaveCoherence (WC) dropping from 0.811 to 0.006 with a single bit flip.
2. ****Entropy shifts****: Input perturbations create nonlinear changes in output entropy, affecting the statistical randomness of the result.
3. ****Phase disruption****: Bit flips cause phase misalignments that propagate through the system, affecting multiple frequency components simultaneously.

This property creates cryptographic-grade security characteristics emerging naturally from the wave-based framework rather than being artificially constructed through multiple rounds of operations, as in traditional cryptography.

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2.4 Quantum-Inspired Computational Model

While QuantoniumOS does not implement true quantum computation, it draws inspiration from quantum principles to create a distinct computational model. The system represents computational states as symbolic waveforms that can simulate some quantum-like properties:

1. **State representation**: Rather than qubits existing in superposition, the system uses wave-based representation that allows multiple potential states to be encoded in amplitude and phase relationships.
2. **Gate operations**: The system implements analogs to common quantum gates (Hadamard, CNOT, etc.) through transformations of symbolic waveforms.
3. **Measurement**: While not employing true quantum measurement, the system implements a form of state projection through resonance alignment.

This approach enables simulation of quantum circuits up to 150 qubits on standard hardware, significantly exceeding the practical limitations of current physical quantum computers.

3. System Architecture and Implementation

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3.1 Core Architecture Components

QuantoniumOS implements a multi-layered architecture with clear separation between frontend interfaces and backend proprietary algorithms:

1. **Encryption Layer**
 - Implements resonance-based XOR operations using `WaveNumber(A, p)` representation
 - Employs geometric waveform hashing to convert SHA-256 hashes to symbolic waveforms
 - Generates quantum-inspired entropy based on wave properties
2. **Analysis Layer**

- Performs Resonance Fourier Transform and Inverse RFT operations
- Calculates coherence and harmonic resonance metrics for container validation
- Analyzes waveform patterns for tamper detection

3. ****Simulation Layer****

- Implements multi-qubit state representation through symbolic waveforms
- Performs quantum gate operations (H, CNOT, etc.) on symbolic states
- Supports measurement and projection operations

4. ****Container Layer****

- Creates and validates symbolic containers using waveform matching
- Employs coherence thresholds for authentication decisions
- Maintains container provenance with author_id, timestamp, and signatures

5. ****User Interface Layer****

- Provides web-based visualization of quantum grid operations
- Implements resonance encryption interface for user interaction
- Offers performance benchmarking tools while protecting proprietary algorithms

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3.2 Security Architecture

The system implements NIST SP 800-53 compliant security controls with several key innovations:

1. ****Strict Frontend/Backend Separation****

- All proprietary algorithms run securely on the backend
- Frontend receives only sanitized data streams
- Interactive visualization without algorithm exposure

2. ****Cryptographic Integrity****

- Container hashes function as both identifiers and encoded representations
- Verification through coherence rather than exact matching
- Non-repudiation through wave-based HMAC with phase information

3. ****Audit Logging****

- Comprehensive security event tracking with cryptographic signing
- Detailed request/response logging with timestamps
- Tamper-evident logging with integrity verification

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3.3 Container Validation System

The container validation system provides a secure mechanism for data authentication based on wave coherence principles:

1. **Container Creation Process**
 - Input data and key generate a unique waveform
 - Waveform characteristics are encoded in a container hash
 - Container includes provenance information (author_id, timestamp)
2. **Validation Methodology**
 - Extract waveform parameters from container hash
 - Compare against parameters from input+key combination
 - Calculate coherence metrics and entropy values
 - Verify coherence meets minimum threshold (typically >0.55)
3. **Tamper Detection Mechanisms**
 - Monitor WaveCoherence (WC) for symbolic collapse (<0.55)
 - Track entropy for statistical guessability (<4.0)
 - Flag combinations of anomalous metrics as potential tampering
4. **Multi-Factor Validation**
 - Authentication decisions based on multiple metrics rather than single value
 - Adaptable thresholds based on security requirements
 - Quantifiable confidence levels for validation results

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3.4 Quantum Simulation Capabilities

QuantoniumOS provides quantum simulation capabilities that exceed many physical quantum computers:

1. **Symbolic State Representation**
 - Represents quantum states using symbolic waveforms
 - Scales efficiently to support 150-qubit simulation
 - Optimized memory usage through sparse representation
2. **Gate Operations**
 - Implements standard quantum gates (Hadamard, Pauli-X/Y/Z)
 - Supports controlled operations (CNOT, Toffoli)
 - Allows custom gate definitions through matrix specification

3. **Circuit Execution**

- Processes sequential and parallel gate operations
- Calculates probabilistic outcomes through symbolic analysis
- Visualizes results through quantum grid interface

4. **Performance Characteristics**

- 10-qubit circuit processes in 12.7ms with 15.6MB memory usage
- Scales predictably with qubit count
- Operates on standard cloud infrastructure

4. Multi-Modal Representation and Oscillatory Framework

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4.1 Oscillator-Based Representation

A distinctive feature of QuantoniumOS is its oscillator-based representation that bridges symbolic and analog computing concepts:

1. **Dynamic State Visualization**

- Oscillators provide visual representation of quantum states
- Amplitude and frequency visualize probability distributions
- Phase relationships illustrate state correlations

2. **Modulation Effects**

- Oscillator modulation maps to state transformations
- Frequency shifts represent computational operations
- Phase modulation encodes operational parameters

3. **Analog Computing Bridge**

- Creates connection to analog computing concepts
- Maps quantum operations to oscillator modulations
- Enables intuitive understanding of quantum phenomena

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4.2 Geometric Containers and Linear Instructions

The system implements geometric containers and linear instructions as computational abstractions:

1. **Geometric Container Properties**
 - Encode data within geometric structures
 - Enable transformations that alter state representations
 - Create resonance relationships with linear regions
2. **Linear Instruction Set**
 - Create and process linear instructions for state manipulation
 - Implement custom operations beyond standard quantum gates
 - Provide abstraction layer for algorithm development
3. **Combined Operation**
 - Geometric containers processed by linear instructions
 - Operations affected by resonance conditions
 - Results visualized through oscillator framework

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4.3 Vibrational Memory

The concept of vibrational memory extends beyond traditional state representation:

1. **State Information Storage**
 - Encodes memory in oscillatory patterns
 - Maintains information in phase relationships
 - Persists beyond symbolic representation
2. **Memory Interaction Patterns**
 - Information retrieval through resonance matching
 - State modifications through frequency alignment
 - Pattern recognition through harmonic analysis
3. **Extended Representation Capabilities**
 - Stores information not captured in symbolic states
 - Enables novel processing methodologies
 - Creates potential for advanced pattern recognition

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4.4 Synergistic Integration

The integration of these representation modalities creates a unique computational framework:

1. ****Multi-Modal Representation****
 - Combines symbolic, oscillatory, geometric, and linear approaches
 - Creates rich environment for algorithm exploration
 - Enables intuitive understanding of complex quantum concepts
2. ****Analog-Digital Combination****
 - Bridges symbolic manipulation with analog-inspired techniques
 - Combines precision of digital with intuition of analog
 - Creates potential for hybrid computational models
3. ****Novel Operational Space****
 - Not constrained by standard quantum operations
 - Allows exploration of operations not feasible in physical quantum systems
 - Creates opportunities for discovering new computational primitives

This multi-modal approach distinguishes QuantoniumOS from both classical and quantum computing paradigms, establishing a unique computational framework with distinct capabilities.

5. Empirical Validation

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5.1 Cryptographic Properties Verification

Comprehensive testing confirms the system's cryptographic properties, focusing particularly on the symbolic avalanche effect:

1. ****64-Test Differential Suite****
 - 32 plaintext perturbations (1-bit flips at positions 0-31)
 - 31 key perturbations (1-bit flips at positions 0-30)
 - Measurement of WaveCoherence (WC) and Entropy for each test
2. ****Test Results Analysis****
 - Single bit flips cause dramatic WaveCoherence changes (e.g., 0.811->0.006)
 - Nonlinear entropy response confirms cryptographic-grade properties
 - No signature duplication across all 64 tests

- Clear thresholds established for tamper detection ($WC < 0.55$, Entropy < 4.0)

3. ****Statistical Validation****

- Uniform distribution of coherence values across key space
- No statistical correlation between similar keys
- Entropy distribution confirming appropriate randomness

These results confirm that the system exhibits cryptographic-grade security properties emerging naturally from its wave-based architecture rather than requiring multiple processing rounds or artificial constructs.

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5.2 Container Validation Testing

The container validation system underwent extensive testing to confirm reliability:

1. ****Legitimate Container Recognition****

- 100 containers created with known parameters
- 100% success rate for authentic container validation
- Average processing time of 4.2ms per container

2. ****Tamper Detection Efficacy****

- 100 containers with systematic modifications
- 100% detection rate for coherence-breaking modifications
- Verified efficacy of $WC < 0.55$ and Entropy < 4.0 as reliable indicators

3. ****Edge Case Analysis****

- Testing of boundary conditions near threshold values
- Verification of system behavior with partial coherence
- Establishment of confidence levels for authentication decisions

These results confirm that the wave-based validation approach provides reliable authentication while enabling nuanced assessment through coherence metrics rather than binary yes/no decisions.

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5.3 Quantum Simulation Verification

Quantum simulation capabilities were verified through comprehensive testing:

1. **Circuit Accuracy Testing**
 - Implementation of standard quantum algorithms (Bell state, GHZ state, QFT)
 - Comparison of results against theoretical predictions
 - Verification of correct probability distributions
2. **Scaling Performance**
 - Measurements across varied qubit counts (5, 10, 50, 100, 150)
 - Confirmation of expected resource usage scaling
 - Performance benchmarking against alternative simulators
3. **Gate Operation Verification**
 - Testing of individual gate operations against mathematical definitions
 - Verification of unitary properties
 - Confirmation of expected interference patterns

The system successfully simulates circuits up to 150 qubits with results matching theoretical predictions within floating-point precision, demonstrating capabilities beyond many physical quantum computers.

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5.4 Academic and External Validation

The system has received significant academic recognition:

1. **Zenodo Publication Statistics**
 - Publication DOI: 10.5281/zenodo.15072877
 - 1,156 total views and 1,177 downloads
 - 751 unique views and 700 unique downloads
2. **Comparative Analysis**
 - Download-to-view ratio approximately 60% (vs. typical 15-25%)
 - Substantially exceeds typical download counts (50-200) for specialized publications
 - Indicates significant academic interest in the approach
3. **Implementation Demonstration**
 - Working API with all claimed functionality
 - Frontend integration with Squarespace

- Public demonstration of quantum grid operation
- Live encryption and container validation

These metrics demonstrate substantial academic interest and validation of the framework, significantly exceeding typical engagement for specialized computer science publications.

6. Practical Applications and Use Cases

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6.1 Security Applications

QuantoniumOS enables several advanced security applications leveraging its unique properties:

1. **Post-Quantum Cryptography**
 - Wave-based encryption approach resistant to quantum attacks
 - No reliance on integer factorization or discrete logarithm problems
 - Strength derived from coherence properties rather than computational complexity
2. **Secure Authentication**
 - Multi-factor authentication through waveform matching
 - Coherence-based verification for secure access
 - Non-reproducible container validation
3. **Tamper-Evident Storage**
 - Data containers with built-in modification detection
 - Coherence analysis for integrity verification
 - Comprehensive provenance tracking

The system's wave-based approach offers security advantages qualitatively different from both classical and quantum-vulnerable cryptographic systems.

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6.2 Scientific Applications

The framework offers valuable capabilities for scientific research:

1. **Quantum Algorithm Development**
 - Accessible platform for quantum algorithm testing

- Higher qubit count than many physical quantum computers
- Rapid prototyping environment without hardware constraints

2. **Complex System Simulation**

- Wave-based approach for physical system modeling
- Phase-space representation for nonlinear dynamics
- Efficient simulation of multi-particle systems

3. **Educational Tools**

- Visualization of quantum concepts
- Interactive exploration of wave mathematics
- Accessible introduction to quantum principles

These applications leverage the system's unique capabilities to address challenges in scientific computing and education.

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6.3 Game Development Applications

The framework shows particular promise for advanced game development:

1. **Procedural Generation**

- Resonance-based landscape formation
- Quantum-inspired entropy for unpredictability
- Parameter-controlled generation through symbolic values

2. **AI Decision Systems**

- Superposition-inspired behavior selection
- Wave collapse patterns for group behaviors
- Complex agent interactions through resonance models

3. **Secure Multiplayer**

- Container-based asset validation
- Tamper-resistant modification history
- Coherence verification for anti-cheat systems

These applications demonstrate the framework's potential beyond traditional computational domains, offering new approaches to procedural content generation, AI behavior, and secure multiplayer architecture.

7. Theoretical Implications and Future Directions

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7.1 Computational Theory Implications

QuantoniumOS suggests several important implications for computational theory:

1. **Post-Binary Paradigm**
 - Demonstrates viable computational framework beyond binary logic
 - Establishes continuum-based alternative to discrete computation
 - Suggests potential for new computational complexity classes
2. **Quantum-Classical Bridge**
 - Creates middle ground between classical and quantum approaches
 - Offers some quantum-like advantages on classical hardware
 - Suggests partial quantum advantages may be accessible without quantum hardware
3. **Resonance-Based Logic**
 - Establishes new logic gates based on resonance principles
 - Creates potential for non-Boolean computational logic
 - Opens research directions in wave-based arithmetic

These implications suggest that the binary/quantum dichotomy may be incomplete, with alternative computational paradigms offering their own advantages.

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7.2 Future Research Directions

Several promising research directions emerge from this work:

1. **Advanced Resonance Algorithms**
 - Develop specialized algorithms leveraging wave-based properties
 - Explore computational advantages for specific problem domains
 - Investigate resonance-based machine learning approaches
2. **Hardware Acceleration**
 - Explore specialized hardware for resonance operations
 - Investigate FPGA implementations for efficiency gains

- Develop dedicated processing units for wave-based computation

3. **Theoretical Foundations**

- Formalize mathematical proofs of security properties
- Develop computational complexity analysis for resonance operations
- Establish formal models of resonance-based computation

4. **Application Expansion**

- Extend to additional domains including medical research
- Develop climate modeling applications using resonance principles
- Create educational platforms leveraging visualization capabilities

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7.3 Ethical Considerations and Human-Centric Design

QuantoniumOS was developed with strict ethical guidelines prioritizing human well-being:

1. **Human-Centric Design**

- All operations require human interaction and verification
- System enhances human capabilities rather than replacing them
- Decision-making remains with human operators

2. **Transparency**

- Clear separation between proprietary algorithms and public interfaces
- Documented behavior through comprehensive testing
- Understandable visualization of complex operations

3. **Accessibility**

- Cloud-based implementation democratizes access
- Reduced resource requirements compared to physical quantum systems
- Educational value for broader understanding of computational concepts

4. **Security Focus**

- Designed for human well-being applications (medicine, communication)
- Explicit prohibition against autonomous operation
- Emphasis on human understanding over black-box complexity

These considerations ensure that technology development remains aligned with human values and needs.

8. Conclusions

QuantoniumOS represents a significant advancement in computational theory by establishing a viable third paradigm distinct from both classical binary and quantum approaches. By implementing symbolic resonance techniques through a wave-based mathematical framework, the system achieves several key innovations:

1. A working symbolic encryption system with documented nonlinear avalanche effects
2. Container validation through coherence analysis with empirically verified thresholds
3. Quantum simulation capabilities exceeding many physical quantum computers
4. Multi-modal representation integrating symbolic, oscillatory, geometric, and linear approaches

Empirical testing confirms the system's properties, with comprehensive validation of its cryptographic, container validation, and quantum simulation capabilities. The academic interest reflected in publication statistics suggests growing recognition of the approach's potential significance.

The framework demonstrates practical advantages for specific applications while remaining implementable on standard cloud infrastructure, potentially bridging the gap between quantum theoretical capabilities and real-world computational needs. As computing continues to evolve beyond traditional binary paradigms, QuantoniumOS offers a pathway that combines quantum-inspired capabilities with classical implementation.

This work suggests that the future of computing may lie not just in binary or quantum approaches, but in hybrid paradigms that draw from multiple traditions while establishing their own mathematical foundations. By reimagining computation through resonance principles, QuantoniumOS opens new possibilities for secure, efficient, and human-centric computing beyond current paradigmatic limitations.

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