

Quantum-Relational Encoding System (QRES): A Revolutionary Paradigm for Future Computing

Abstract

This paper introduces the Quantum-Relational Encoding System (QRES), a novel approach to data representation and computation that transcends traditional base-N number systems such as binary, decimal, and hexadecimal.¹ QRES fundamentally shifts from static individual values to encoding meaning through the dynamic relational states between data elements.¹ Inspired by principles from quantum mechanics, neural computation, and musical theory, QRES proposes a context-aware encoding method.¹ This revolutionary paradigm promises significant breakthroughs in data compression, security, and AI cognition, offering a blueprint for future computing systems.¹

1. Introduction

1.1 Limitations of Traditional Number Systems

Conventional number systems, including binary and hexadecimal, have served as the bedrock of digital computing for centuries. These systems operate on linear, positional encoding schemes where individual values exist in isolation and are interpreted based on their fixed position within a defined base.¹ For instance, binary relies on sequences of 0s and 1s, while hexadecimal extends this to include letters A-F.¹ Despite their historical utility and foundational role, these systems have remained

fundamentally unchanged, a characteristic that increasingly presents challenges in the context of rapidly evolving computational landscapes.¹

The reliance on static, discrete, and inherently isolated representations means that traditional systems are fundamentally misaligned with the dynamic and complex nature of information in advanced domains. This static nature creates a bottleneck when confronted with systems that inherently operate on relationships, patterns, and dynamic states, such as quantum systems, neural networks, and even human cognition. This misalignment leads to inherent inefficiencies and increased complexity in processing information that is naturally relational or contextual. The historical inertia of these unchanging systems highlights a critical need for a new data representation paradigm that can better accommodate the demands of modern and future computing.

1.2 Introducing QRES: A Revolutionary Paradigm

The Quantum-Relational Encoding System (QRES) emerges as a transformative solution, offering a new conceptual framework through which information can be interpreted, stored, and manipulated. Unlike conventional methods that treat data as isolated digits, QRES views information as interrelated patterns of change.¹ This novel approach is designed to transcend the limitations of traditional base-N number systems, promising a more intuitive and powerful method for handling complex data.¹

1.3 Inspirations Behind QRES

The development of QRES is rooted in an interdisciplinary synthesis, drawing profound inspiration from three distinct yet interconnected fields: quantum mechanics, neural computation, and musical theory.¹ This diverse foundational influence underpins QRES's dynamic and context-aware encoding methodology, enabling it to address computational challenges that traditional systems struggle to overcome.¹

1.4 Structure of the Paper

This paper will systematically detail the historical context and motivation for QRES, elaborate on its core framework, discuss its significant advantages across various domains, explore the practical considerations for its implementation, and outline its potential applications and future research directions.

2. Background and Motivation

2.1 Evolution of Number Systems and Emerging Needs

Historically, the evolution of number systems has been closely tied to the available tools and practical needs of the time. Early systems, such as base-10, emerged from the use of fingers for counting, while binary systems were a natural fit for the on/off states of early electronic switches.¹ This evolution has largely been tool-driven, with data representation constrained by the physical mechanisms of computation.

However, the current digital age, marked by the advent of quantum computing, sophisticated artificial intelligence, and neuromorphic engineering, presents a new set of demands that transcend these traditional constraints.¹ These emerging fields require data systems that are not merely adaptations of older models but are fundamentally designed to address the inherent nature of the problems they seek to solve. This signifies a paradigm shift from a tool-driven evolution to a problem-driven design. QRES represents a proactive design, conceived to inherently fit the complex problems of the future, rather than being limited by legacy tools. This forward-looking approach suggests a more efficient and natural alignment with the intricacies of advanced computational challenges.

2.2 Deepening the Inspirations for QRES

2.2.1 Quantum Computing and Discrete Data States

Quantum computing fundamentally challenges classical notions of discrete data states, operating instead on principles such as superposition and entanglement.¹ These intrinsic quantum phenomena necessitate fundamentally different instruction sets and intermediate representations (IRs) compared to those used in classical computing.² The field is actively developing new languages and frameworks to program quantum hardware, yet a significant unresolved challenge remains in the communication within hybrid quantum-classical operations.² Current quantum encoding strategies often grapple with optimizing qubit usage and limiting errors, frequently relying on mapping classical data to quantum gates.³

QRES, inspired by quantum mechanics, inherently aligns with the relational nature of quantum states, particularly entanglement, by encoding relationships rather than static values.¹ This approach has the potential to bypass some of the current challenges in quantum data encoding and intermediate representations. By providing a representation that is fundamentally quantum-native, QRES could reduce the "translation" overhead involved in converting classical bits to quantum states. This could lead to more efficient quantum algorithms and potentially less noisy computations, directly leveraging entanglement in the data encoding process.

2.2.2 Neural Networks and Weighted Relationships

Neural networks process information not through isolated values, but through complex weighted relationships between nodes, emphasizing connections and emergent patterns.¹ Modern deep neural networks demonstrate an impressive capacity to autonomously learn intricate patterns and hierarchical representations directly from raw data, significantly reducing the need for labor-intensive feature engineering.⁴ Their ability to effectively handle imprecise, uncertain, and nonlinear data makes them exceptionally well-suited for a wide array of complex applications.⁴

The design of QRES, which draws from neural computation, moves towards a more biologically plausible and efficient method of representing information. Neuromorphic computing, the hardware embodiment of this principle, is explicitly inspired by the

structure and function of the human brain, aiming to replicate the analog nature of biological computation.⁵ The brain processes information through analog chemical signals, and computation is highly distributed across numerous small computing elements analogous to neurons.⁵ By focusing on relationships and patterns, QRES mirrors this biological processing, potentially unlocking new levels of efficiency and capability for artificial intelligence. This approach can address the limitations of current static, discrete representations that often struggle with high logical complexity tasks and insufficient precision, moving AI closer to the nuanced understanding observed in biological cognition.

2.2.3 Music and Language: The Power of Relational Change

Both music and language derive their profound meaning not from static individual elements, but heavily from the dynamic change between states. In music, this involves the shifts in pitch, tone, and inflection; in language, it is the dynamic synchrony and variation that convey meaning.¹ Language representations, for instance, must be adaptable to variations while simultaneously maintaining persistent features to ensure efficient communication.⁸ The brain's processing of music relates physical properties of stimuli to internal representations, or features, that capture these dynamic relationships.⁶ Furthermore, efficient encoding mechanisms in the brain, such as those found in the planum temporale, utilize fewer computational resources when less information is present in the signal, suggesting an inherent efficiency in relational processing.⁹

This emphasis on change and relational meaning represents a significant departure from purely symbolic representations. QRES aims to capture the semantic or experiential meaning of data, rather than merely its syntactic form. By encoding the "flow of relations" and utilizing "contextual anchors" ¹, QRES moves towards a system that understands the narrative or intent embedded in data, much like how humans comprehend a melody or a sentence. This shift could enable AI systems to achieve a deeper, more human-like understanding and generation of complex data, moving beyond mere statistical correlations to genuine comprehension of dynamic patterns and their inherent meaning. It points towards a future with more intuitive and expressive programming languages and data models.

3. The QRES Framework: Encoding Relational Meaning

The Quantum-Relational Encoding System (QRES) fundamentally redefines how data is encoded by shifting focus from static individual values to the dynamic relationships between data points. This framework is built upon three core components: Relational States, Pattern Chains, and Contextual Anchors.¹

3.1 Relational States

In QRES, data points are not assigned fixed numerical values (like 0 or 1 in binary). Instead, each data point is defined by its relationship to its neighboring data points, capturing the dynamic nature of the information.¹ Examples of these relational states include:

- **Ascending:** The data point is increasing in value relative to its predecessor.¹
- **Descending:** The data point is decreasing in value relative to its predecessor.¹
- **Repeating:** The data point is the same as its predecessor.¹
- **Oscillating:** The data point exhibits a fluctuating or periodic relationship with its neighbors.¹
- **Static:** The data point remains unchanged over a specified period.¹

3.2 Pattern Chains

Sequences of data in QRES are interpreted through the continuous "flow" of these relational states, rather than as a series of fixed bit values.¹ The meaning of a sequence is thus derived from the progression and interaction of ascending, descending, repeating, oscillating, or static relationships between data points.¹

3.3 Contextual Anchors

To provide a reference point for interpreting the relational meaning, QRES utilizes "Contextual Anchors".¹ These are key patterns within the data stream that serve as reference points, such as wave crests or symmetry points.¹ From these anchors, the relational meaning of the surrounding data is derived, providing the necessary context for interpretation.¹

3.4 Illustrative Example

To illustrate the framework, consider a simple sequence:

- **Traditional encoding:** 1 0 1 0
- **QRES encoding:** descend, ascend, descend with overall pattern = wave, frequency = 2.¹

This example demonstrates how QRES captures the dynamic movement and overarching structure of the data, rather than merely its individual numerical values.¹ This capability allows QRES to extract not just local relationships ("descend, ascend") but also a global pattern ("wave, frequency = 2"). This highlights that QRES is designed to capture and encode emergent properties or higher-order information that is not explicitly present in individual data points but arises from their interaction. This is analogous to how a melody emerges from a sequence of notes or a concept from a sequence of words. This capability suggests QRES is inherently suited for tasks involving pattern recognition, anomaly detection ⁴, and complex reasoning, as it directly encodes the very structures that define meaning and behavior in complex systems, moving beyond raw data to represent its intrinsic organization.

Table 1: QRES Relational States and Examples

Relational State	Description	Example (Traditional Sequence)	QRES Interpretation (Segment)
Ascending	Data point increases relative to its predecessor.	2, 5	Ascending
Descending	Data point decreases relative to its predecessor.	8, 3	Descending

Repeating	Data point is the same as its predecessor.	7, 7	Repeating
Oscillating	Data point exhibits fluctuating/periodic relation.	1, 0, 1, 0	Oscillating
Static	Data point remains unchanged (over a period).	4, 4, 4	Static

This table serves to clarify the core concept of "relational states" by providing concrete, simple examples. This explicit linkage of each type of relational state to a numerical sequence and its QRES interpretation makes the concept immediately understandable and tangible for the reader, which is crucial for a technical report introducing a novel system.

4. Advantages of QRES

The Quantum-Relational Encoding System offers several transformative advantages over conventional data representation methods, addressing critical limitations in current computing paradigms.

4.1 Ultra-Compression

QRES facilitates significant data compression by reducing entire data streams to their underlying relational patterns or mathematical equations.¹ This approach is analogous to vectorized image compression, where images are represented by mathematical descriptions rather than pixel-by-pixel data, or musical notation, which captures the essence of a melody without recording every sound wave.¹ This method allows for a far more compact representation of information.

Unlike traditional compression methods that largely rely on statistical redundancies, Shannon entropy, or frequency analysis, and which have approached their theoretical

limits¹⁰, QRES achieves compression by distilling the essence or underlying structure of the data. This aligns with the principle that a deeper understanding of data inherently improves its compression.¹⁰ By encoding relationships and patterns, QRES is not merely compressing bits but compressing meaning. This represents a qualitative leap beyond conventional techniques, implying a deeper level of data processing and understanding at the encoding stage. This profound data representation suggests that QRES could be particularly effective for complex, high-dimensional, and dynamic datasets where current methods struggle to capture intricate patterns.⁴ The "ultra-compression" achieved is a direct byproduct of this more profound data representation.

4.2 Quantum and Neuromorphic Synergy

QRES exhibits a natural compatibility with emerging computing paradigms, particularly quantum and neuromorphic systems. Its focus on relational processing and entanglement makes it inherently synergistic with quantum computing.¹ Furthermore, QRES could be implemented using edge-weighted graph hardware, which mimics neural networks, or directly with quantum gates.¹

Quantum computing platforms, based on superposition and entanglement², require specialized intermediate representations² and efficient data encoding to optimize qubit usage and limit errors.³ Neuromorphic computing, which aims to replicate the brain's structure and function, processes information in a highly distributed manner⁵ and leverages advanced memory technologies for efficient data storage and movement.¹² QRES, by encoding relationships, offers a native data representation for both. This suggests QRES could serve as a foundational "data language" that bridges the conceptual and architectural gaps between these two distinct yet complementary future computing paradigms. This common, efficient data substrate could simplify their programming and hardware design, potentially accelerating the development of hybrid quantum-neuromorphic systems and leading to unprecedented computational power and efficiency for problems currently intractable for classical computers.¹³

4.3 Enhanced Security

QRES introduces a novel dimension to data security. Because the system encodes data through relationships rather than fixed values, the raw QRES-encoded data holds no inherent meaning without the corresponding relational key or anchor points.¹ This characteristic could enable a new class of pattern-based encryption algorithms, making data significantly harder for unauthorized parties to decipher without the specific relational context.¹

This implies that QRES provides an intrinsic form of data obfuscation, moving beyond sole reliance on external cryptographic layers. Traditional encryption scrambles data, but QRES fundamentally alters its interpretability. Even if an attacker gains access to the encoded data, they lack the fundamental context—the "grammar" of relations and anchors—to make sense of it. This extends security beyond bit-level encryption to a semantic-level protection. This could lead to a paradigm shift in data security, where the very act of encoding data makes it secure by default, rather than requiring additional computational overhead for encryption. It suggests a more robust defense against both classical and future quantum attacks by rendering the data itself unintelligible without the proper relational framework.

4.4 AI and Cognitive Modeling

QRES offers a data representation that more closely mirrors human cognition. Human thought processes inherently focus on changes, transitions, and relationships between concepts, rather than static snapshots of individual values.¹ By encoding information relationally, QRES enables AI systems to reason about these transitions and patterns, potentially leading to more advanced and human-like cognitive abilities.¹

Human language, for example, is inherently dynamic and relies on systemic interaction and variation for meaning.⁷ Current AI systems, despite significant advancements, still face challenges in logical complexity, code understanding, and avoiding hallucinations.¹⁴ While deep learning models can learn complex patterns⁴, they often struggle with nuanced reasoning that requires understanding dynamic relationships. QRES's alignment with human cognition is a critical advantage. By encoding interrelated patterns of change¹, QRES offers a pathway for AI to move from processing discrete symbols to understanding the flow and context of information. This can enable more intuitive reasoning, better handling of uncertainty, and a reduction in the "brittleness" often observed in AI systems trained on static data. This could lead to AI systems that are not just more efficient, but also more robust,

adaptable, and capable of genuine understanding and creativity, particularly in domains like natural language processing, complex problem-solving, and even artistic generation. It suggests a path towards AI that thinks more like a human.

Table 2: Comparative Advantages: QRES vs. Traditional Systems

Feature/Metric	Traditional Base-N Systems	Quantum-Relational Encoding System (QRES)	Advantage of QRES	Relevant Snippets
Data Representation	Static, positional, isolated values (e.g., bits, digits)	Dynamic, relational states, pattern chains, contextual anchors	Captures inherent meaning and flow, not just discrete values.	1
Compression Efficiency	Relies on statistical redundancies (Shannon entropy, frequency)	Reduces data to relational patterns/equations (semantic compression)	Ultra-compression by distilling underlying structure, analogous to vectorized data.	1
Security Paradigm	External encryption layers; raw data has fixed meaning	Intrinsic obfuscation; raw data has no fixed meaning without key	Enables new pattern-based encryption, making data inherently unintelligible.	1
AI Cognition Alignment	Focus on static snapshots, struggles with complex reasoning	Mirrors human cognition (focus on change, transitions, relationships)	Enables AI to reason about transitions and patterns, leading to more human-like cognition.	1
Hardware Synergy	Optimized for classical, digital logic gates	Natural fit for quantum entanglement, neuromorphic processing	Compatible with emerging quantum/neuromorphic hardware (edge-weighted graphs,	1

			quantum gates).	
Information Extraction	Explicit values, simple arithmetic operations	Higher-order patterns, emergent properties, semantic context	Extracts deeper, contextual meaning beyond simple data points.	¹

This comparative table clearly and concisely summarizes the distinct strengths of QRES against traditional systems. By presenting a side-by-side comparison across key features, it visually reinforces the unique value proposition of QRES, making its revolutionary nature more apparent and providing a quick reference for the reader to understand where QRES excels.

5. Implementation Considerations

Bringing the Quantum-Relational Encoding System from concept to practical application involves several critical implementation considerations, each representing a significant area of research and development.

5.1 Encoding Layer

The initial and crucial step for QRES implementation is the encoding layer. This component is responsible for preprocessing raw data, traditionally represented in binary or other base-N systems, into its relational forms.¹ This transformation is not a simple bit-to-bit mapping; it requires sophisticated algorithms to identify and quantify relationships (e.g., ascending, descending, repeating) and potentially higher-order patterns (e.g., waves, symmetry points) within the data stream.¹ The challenge lies in converting any raw data, which is inherently discrete and static in its traditional representation, into dynamic relational patterns. This transformation itself might be computationally intensive or necessitate new theoretical frameworks for diverse data types, such as converting an image or a complex dataset into relational patterns. The success of QRES hinges significantly on the efficiency and accuracy of this initial encoding layer, demanding robust algorithms for pattern recognition and relational

extraction across various data modalities.

5.2 Relational Logic Units (RLUs)

A cornerstone of QRES will be the development of specialized circuits or software modules known as Relational Logic Units (RLUs).¹ Unlike traditional logic gates that operate on fixed binary values, RLUs would be designed to interpret and act upon relational instructions, processing relational states and pattern chains.¹ This implies a fundamental re-architecture of computing hardware and software logic. Instead of executing Boolean operations like "if A AND B then C," RLUs would perform operations based on contextual relationships, such as "if A is ASCENDING relative to B, and B is OSCILLATING, then trigger pattern X." This signifies not merely a new instruction set but a new logic paradigm.

The development of RLUs represents a significant engineering challenge, requiring breakthroughs in circuit design, potentially leveraging emerging memory technologies like memristors or spintronic memories, as seen in neuromorphic systems.⁵ It also necessitates advanced software algorithms capable of understanding and manipulating data based on its context and relationships.¹ This suggests a future where computation is inherently contextual and pattern-driven, rather than purely sequential and value-driven, embodying the core paradigm shift of QRES.

5.3 Visualization Tools

The profound shift in data representation inherent in QRES necessitates the development of entirely new forms of data visualization. Traditional methods, often based on discrete values and linear representations, would be inadequate for QRES-encoded information.¹ These new tools would need to display dynamic patterns, wave maps, and the flow of relationships between data elements.¹

The need for "wave maps" and "pattern flows" indicates a significant cognitive challenge: how do humans intuitively understand and debug systems operating on such abstract, relational data? These visualization tools are not merely for display; they are critical for debugging, development, and user adoption, bridging the gap

between the complex underlying relational logic and human comprehension. This highlights the profound shift QRES entails, not just in computation but in human-computer interaction and data interpretation. It suggests the emergence of a new field of "relational data visualization," which will be crucial for the practical application and widespread development of QRES systems.

6. Potential Applications and Future Work

The Quantum-Relational Encoding System holds the potential to revolutionize numerous fields, offering solutions to long-standing challenges and opening entirely new avenues for technological advancement.

6.1 Quantum AI Processors

QRES is inherently synergistic with quantum computing due to its focus on relational processing and entanglement.¹ It could serve as a foundational encoding system for future Quantum AI Processors, enabling AI to reason about transitions and relationships, thereby mirroring human cognition more closely.¹ This could lead to more powerful and efficient AI systems capable of handling complex, dynamic data.¹ Current Quantum AI (QAI) development faces significant hurdles, including hardware noise, the difficulty of transforming classical problems into quantum models (e.g., QUBO), and the limitations of current noisy quantum computers.¹³ QRES, by providing a relational, potentially quantum-native encoding, could intrinsically mitigate some of these issues. If data is already in a relational form that aligns with quantum principles, the transformation step might be simplified or even eliminated, reducing noise propagation and making quantum advantage more attainable. QRES could be a key enabler for practical Quantum AI, potentially accelerating the transition from noisy, small-scale quantum computers to more robust and powerful QAI systems by providing a more natural and efficient way to represent information for quantum processing.

6.2 Music-Based Programming Languages

Inspired by musical theory, where meaning is derived from changes between states, QRES could form the basis for entirely new programming languages.¹ In such paradigms, programs could be composed of "pattern chains" and "contextual anchors" representing relational instructions, thereby opening new avenues for software development.¹ The concept of music-based programming languages implies a radical shift from imperative or even declarative programming. Instead of defining explicit steps or states, one would define relationships, flows, and patterns of computation. This aligns with the idea of "programming with intent" or "programming by example," where the desired outcome's structure or behavior is specified rather than its precise implementation details. This could lead to more intuitive, expressive, and potentially even self-organizing code, especially for complex, dynamic systems. This application suggests a future where software development is less about rigid syntax and more about abstract pattern composition, potentially making programming more accessible, less prone to certain types of errors, and better suited for highly parallel and adaptive systems.

6.3 Dynamic Data Transmission (Waveform Encoding)

QRES's inherent ability to reduce entire data streams to relational patterns or equations makes it exceptionally suitable for dynamic data transmission.¹ Encoding data as waveforms could enable more efficient and robust data transfer, particularly in environments where traditional digital signals are prone to corruption or require significant bandwidth.¹ Traditional multimedia compression, for instance, struggles with inter-frame information for video and faces trade-offs between compression ratio and computational complexity.¹⁰ Neural audio codecs already demonstrate the ability to compress amplitude and phase spectra into continuous latent codes.¹⁶ The concept of waveform encoding for data transmission suggests a move towards representing digital information in an analog-like fashion, where the shape or pattern of the signal carries the information, rather than discrete high/low voltage states. This inherently offers greater robustness against noise and corruption, as minor signal degradation might not alter the overall pattern. It represents a re-imagining of digital communication through an analog lens, leveraging the continuous nature of relationships. This could revolutionize communication technologies, enabling highly

resilient and efficient data transfer in challenging environments, such as space communication, noisy industrial settings, or even biological signaling, where maintaining signal integrity with traditional digital methods is difficult or bandwidth-prohibitive.

6.4 Biologically Inspired Storage (DNA Patterns)

The concept of encoding data through relationships aligns exceptionally well with the intricate patterns found in biological systems, such as DNA.¹ QRES could inspire new methods for data storage that mimic the highly compressed and robust nature of biological information, potentially leading to ultra-dense and long-lasting storage solutions.¹ Biological systems, particularly DNA, are remarkable examples of ultra-dense, robust, and long-lasting information storage, where meaning is derived from sequences and interactions of bases, not just individual bases. QRES's focus on relational states and pattern chains¹ closely mirrors how biological information is encoded and processed. This suggests that QRES could provide a theoretical framework for building artificial storage systems that leverage principles found in nature, moving beyond current silicon-based limitations in density and longevity. This application points towards a future where data storage is not just about increasing bits per square inch, but about fundamentally re-thinking how information is organized and preserved, potentially leading to archival solutions with unprecedented lifespans and storage densities, and even self-repairing data structures.

6.5 Future Research Directions for QRES

Future research will focus on several key areas to transition QRES from a theoretical concept to practical application:

- **Prototyping Relational Logic Units (RLUs):** A critical step involves designing their architecture, developing algorithms for relational processing, and rigorously testing their efficiency and accuracy.¹
- **Building QRES Emulators:** Essential for widespread experimentation and development, these emulators would allow researchers to simulate QRES environments without the need for specialized hardware, significantly

accelerating development.¹

- **Testing Compression/Security Models:** Rigorous testing is needed to quantify the improvements QRES offers in ultra-compression and enhanced security, including the development and evaluation of new pattern-based encryption algorithms.¹

These three research directions are highly interdependent. Prototyping RLUs is crucial, but without emulators, testing would be limited to expensive, custom hardware. Emulators allow for rapid iteration and testing of compression and security models before full hardware realization. The testing results, in turn, will inform the refinement of RLU designs and emulator capabilities. This represents a classic, iterative research and development cycle, and its success is particularly vital given the radical nature of QRES, where each component relies heavily on the others for validation and refinement. The success of QRES depends on a tightly integrated research roadmap where theoretical advancements, software simulations, and hardware prototyping proceed in concert, with feedback loops ensuring practical viability and performance.

7. Conclusion

The Quantum-Relational Encoding System (QRES) represents a radical and necessary shift in how information is defined and processed. By moving beyond the limitations of fixed bases and static digits, QRES unlocks the potential for systems that can think, store, and compute in ways that are inherently more natural, powerful, and secure.¹ As the computational landscape continues its rapid evolution, demanding solutions for the escalating complexities of quantum computing, advanced artificial intelligence, and neuromorphic systems, QRES offers a visionary blueprint for the future. This paradigm redefines what it means to represent data, promising a foundation for systems capable of unprecedented efficiency, security, and cognitive ability.

Keywords

Quantum Encoding, Number Systems, Pattern Recognition, Data Compression, AI

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