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Structured α-Neutrosophic Symbolic Conformance: A Formal Design Quality Evaluation Model for Digital Cultural and Creative Products Based on Paper Cutting Art

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Abstract: This paper proposes a new mathematical model to evaluate symbolic accuracy and cultural integrity in digital creative works inspired by traditional paper-cutting art. The model is based on a structured neutrosophic framework that combines aesthetic consistency, symbolic meaning, and cultural alignment into a unified quantitative system. Using a novel α-weighted approach, we define symbolic conformance functions that integrate the levels of geometric similarity, interpretive ambiguity, and semantic distortion. These components are mapped into structured neutrosophic equations that allow precise measurement of symbolic deviation from cultural references. A matrix-based representation is introduced to compute multi-element conformity, followed by fully solved examples demonstrating the model's functionality. This work offers a practical, rigorous tool for artists, designers, and digital humanities researchers to assess and improve cultural faithfulness in creative digitization processes.

Keywords: Neutrosophic Modeling, α-weighted Evaluation, Symbolic Conformance, Cultural Integrity, Paper-Cutting Art, Digital Aesthetics, Semantic Deviation.

1. Conceptual Background and Cultural Motivation

Paper-cutting art is a time-honored craft that transforms simple materials, like paper, into intricate designs rich with historical, spiritual, and social meaning [1]. Rooted in cultural traditions worldwide, from Chinese Jianzhi to Mexican Papel Picado, this art form serves as a powerful medium for storytelling and symbolic expression [1]. As societies embrace digital technologies, artists are increasingly creating digital versions of paper-cutting art, blending traditional aesthetics with modern computational tools. These digital creations are more than visual reproductions; they act as contemporary carriers of cultural heritage, merging age-old symbolism with innovative design [2].

However, transitioning from physical to digital art poses a significant challenge: how can we ensure that digital representations preserve the cultural and symbolic integrity of the original works? Traditional evaluation methods, which often focus on visual or geometric similarity, fail to capture the deeper symbolic fidelity of these artworks [3]. For example, a digital piece might look similar to its traditional counterpart but convey altered meanings due to design choices, software limitations, or intentional reinterpretation [3]. This gap highlights the need for a new approach to evaluate the symbolic alignment of digital paper-cutting-inspired products.

To address this challenge, we propose a structured mathematical model to assess the symbolic conformance of digital artworks inspired by paper-cutting traditions. Drawing on neutrosophic logic, which accounts for truth, indeterminacy, and falsity, our model introduces an innovative α-weighted symbolic evaluation system [4]. This system quantifies how closely a digital design aligns with the cultural and symbolic meanings of the original artwork while allowing for artistic innovation and reinterpretation [4]. Unlike rigid frameworks, our model recognizes that not all deviations from tradition are negative; instead, it measures symbolic transformation using logical rules and numerical metrics [5].

The proposed model employs conformance functions, conformance matrices, and cumulative deviation metrics to provide a rigorous framework for analysis. These tools enable designers and cultural scholars to evaluate the extent of creative divergence in digital works while respecting their traditional roots [5]. By combining cultural sensitivity with mathematical precision, this approach bridges the gap between traditional paper-cutting art and its digital evolution.

In the following sections, we will define the components of this model, present the mathematical equations underpinning it, and provide practical examples to illustrate its application. Our aim is to offer a clear and systematic framework that supports artists and researchers in preserving cultural heritage while embracing digital creativity.

2. Formal Definitions and Evaluation Components

To build a mathematically valid model for symbolic conformance, we must first define the core components of our system. Each digital artwork inspired by paper-cutting is treated as a collection of discrete symbolic units-shapes, patterns, motifs, or symbols-each of which can be independently analyzed for its alignment with a cultural reference.

Let us consider an artwork A composed of n symbolic elements:

$$A = \{S_1, S_2, \dots, S_n\}$$

Each symbolic element S_i will be evaluated along three axes:

1. Geometric or Structural Fidelity - Denoted T_i, this reflects how closely the shape matches its traditional form.

2. Interpretive Ambiguity - Denoted I_i, this represents uncertainty in meaning caused by transformation, abstraction, or reinterpretation.
3. Symbolic Distortion - Denoted F_i, this captures cultural misalignment, confusion, or loss of symbolic meaning.

All values are normalized on the interval [0,1], where $T_i = 1$ means perfect visual alignment, $I_i = 1$ indicates maximum ambiguity, and $F_i = 1$ reflects complete symbolic contradiction or loss.

2. 1 α-Weighted Symbolic Score

We introduce α-parameters to control the weight of each component in the evaluation, based on the complexity or sensitivity of the symbolic element.

Let $\alpha_i \in (0,1]$ be a symbolic weight assigned to element S_i, with higher values for elements of greater cultural importance.

We define the Symbolic Conformance Score R_i for each symbolic element S_i as:

$$R_i = \alpha_i \cdot T_i + (1 - \alpha_i) \cdot (1 - |I_i + F_i|)$$

Let:

T_i reinforces the shape similarity,

$I_i + F_i$ penalizes distortion and ambiguity jointly,

$1 - |I_i + F_i|$ ensures the conformance score is reduced if ambiguity or distortion increases.

2.2 Ideal Reference Vector

Let the ideal symbolic reference be:

$$\vec{R}_{\text{ideal}} = [1,1, \dots ,1] \in \mathbb{R}^n$$

This vector assumes perfect conformance in all symbolic dimensions (no ambiguity or distortion, full geometric match).

2.3 Conformance Matrix

To represent the evaluation across multiple artworks or motifs, we define the Conformance Matrix R :

$$\mathrm{R} = \begin{bmatrix} R_{11} & R_{12} & \dots & R_{1n} \\ R_{21} & R_{22} & \dots & R_{2n} \\ \vdots & \vdots & & \vdots \\ R_{m1} & R_{m2} & \dots & R_{mn} \end{bmatrix}$$

Where R_{ij} is the symbolic conformance score for motif j in artwork i.

2.4 Symbolic Divergence Function

To measure the deviation of a digital artwork from cultural expectations, we define the symbolic divergence as:

$$\delta_i = \frac{1}{n}\sum_{j=1}^{n} \left|R_{ij} - 1\right|$$

This scalar value represents the average deviation of artwork i from the ideal cultural reference. Smaller values indicate higher symbolic fidelity.

2.5 Weighted Divergence Score

If some symbols are more important than others, we introduce weights w_j for each symbol S_j, and define:

$$\Delta_i = \sum_{j=1}^{n} w_j \cdot \left|R_{ij} - 1\right| \text{ subject to } \sum_{j=1}^{n} w_j = 1$$

This offers more culturally sensitive evaluation by emphasizing the most critical symbolic elements.

3. Numerical Examples

In this section, we apply the structured α-neutrosophic symbolic conformance model (SαNSCM) to a concrete example. All variables are defined, all steps are shown, and calculations are complete and logically sound.

3.1 Scenario

A designer creates a digital version of a traditional paper-cutting artwork. The artwork includes three symbolic elements:

1. A lotus flower (symbol of purity)
2. A dragon (symbol of strength)
3. A double-fish motif (symbol of prosperity)

The cultural reviewers assess each symbol along three axes:

1. T_i : How well the shape matches the traditional structure
2. I_i : How much symbolic ambiguity exists due to style or abstraction
3. F_i : How much cultural distortion occurred (e.g., incorrect usage)

The designer also assigns an importance weight α_i to each symbol based on cultural sensitivity.

Step 1: Given Data as presnnted in Table 1 below.

Table 1. Dataset

Symbol	T_i	I_i	F_i	α_i
Lotus Flower	0.90	0.10	0.05	0.85
Dragon	0.75	0.20	0.25	0.95
Double-Fish	0.80	0.15	0.10	0.60

Step 2: Compute Conformance Score R_i
Using the formula:

$$R_i = \alpha_i \cdot T_i + (1 - \alpha_i) \cdot (1 - |I_i + F_i|)$$

Symbol 1: Lotus Flower

$$\begin{aligned} I_1 + F_1 &= 0.10 + 0.05 = 0.15 \\ 1 - |I_1 + F_1| &= 0.85 \\ R_1 &= 0.85 \cdot 0.90 + 0.15 \cdot 0.85 \\ &= 0.765 + 0.1275 = 0.8925 \end{aligned}$$

Symbol 2: Dragon

$$\begin{aligned} I_2 + F_2 &= 0.20 + 0.25 = 0.45 \\ 1 - |I_2 + F_2| &= 0.55 \\ R_2 &= 0.95 \cdot 0.75 + 0.05 \cdot 0.55 \\ &= 0.7125 + 0.0275 = 0.74 \end{aligned}$$

Symbol 3: Double-Fish

$$\begin{aligned} I_3 + F_3 &= 0.15 + 0.10 = 0.25 \\ 1 - |I_3 + F_3| &= 0.75 \\ R_3 &= 0.60 \cdot 0.80 + 0.40 \cdot 0.75 \\ &= 0.48 + 0.30 = 0.78 \end{aligned}$$

Final Conformance Vector

$$\vec{R} = [0.8925, 0.74, 0.78]$$

Step 3: Compute Symbolic Divergence

$$\delta = \frac{1}{3}\sum_{i=1}^{3} |R_i - 1|$$

$$|0.8925 - 1| = 0.1075$$
$$|0.74 - 1| = 0.26$$
$$|0.78 - 1| = 0.22$$
$$\delta = \frac{1}{3}(0.1075 + 0.26 + 0.22)$$
$$= \frac{0.5875}{3} = 0.1958$$

This indicates a moderate symbolic deviation from cultural perfection.

Step 4: Weighted Symbolic Divergence (Optional)
Assume the following cultural importance weights:

Lotus Flower: $w_1 = 0.4$

Dragon: $w_2 = 0.4$

Double-Fish: $w_3 = 0.2$

$$\Delta = \sum_{i=1}^{3} w_i \cdot |R_i - 1|$$

$$\Delta = 0.4 \cdot 0.1075 + 0.4 \cdot 0.26 + 0.2 \cdot 0.22$$
$$= 0.043 + 0.104 + 0.044 = 0.191$$

This confirms that even with cultural weighting, the symbolic deviation remains around 0.19 , signaling a strong-but not perfect-alignment.

The lotus flower showed a high level of alignment, as it exhibited minimal ambiguity and distortion. In contrast, the dragon symbol was more distorted, which led to a lower conformance score. The double-fish symbol fell somewhere in between, being moderately preserved but still displaying some degree of ambiguity.

4. Matrix-Based Evaluation and Comparative

This section scales the individual symbolic evaluation from the previous example to a matrix form. This enables comparison across multiple artworks or multiple versions of the same digital design.

4.1 Matrix Construction

Let us suppose we evaluate two digital artworks, each consisting of the same three symbolic elements:

A_1 : Artwork 1

A_2 : Artwork 2

We reuse the symbolic components from Section 3:

1. Lotus Flower
2. Dragon
3. Double-Fish

Table 2 presents the raw symbolic evaluation data-structural similarity T_i, ambiguity I_i, distortion F_i, and cultural weight α_i-used to compute conformance scores for each symbolic element across two artworks.

Table 2. Symbolic Input Parameters for Two Digital Artworks

Artwork	Symbol	T_i	I_i	F_i	α_i
A_1	Lotus Flower	0.90	0.10	0.05	0.85
A_1	Dragon	0.75	0.20	0.25	0.95
A_1	Double-Fish	0.80	0.15	0.10	0.60
A_2	Lotus Flower	0.70	0.30	0.20	0.85
A_2	Dragon	0.90	0.10	0.10	0.95
A_2	Double-Fish	0.85	0.15	0.05	0.60

As seen in Table 2, the same symbols are evaluated differently across artworks, depending on their stylistic treatment and digital interpretation.

4.2 Conformance Matrix Computation

We now compute R_{ij} for each artwork A_i and each symbol j using the same formula:

$$R_{ij} = \alpha_{ij} \cdot T_{ij} + (1 - \alpha_{ij}) \cdot (1 - |I_{ij} + F_{ij}|)$$

Table 3 presents the symbolic conformance scores R_{ij} computed for each symbol in two digital artworks. Higher values indicate closer alignment to cultural expectations.

Table 3. Symbolic Conformance Matrix R for Two Artworks

Symbol	R_{1j} (Artwork 1)	R_{2j} (Artwork 2)
Lotus Flower	0.8925	0.7225
Dragon	0.74	0.8875
Double-Fish	0.78	0.825

Each row in Table 3 corresponds to the same symbolic motif across the two artworks. We observe that Artwork 1 performs better on the lotus flower, while Artwork 2 shows better fidelity in the dragon and double-fish motifs.

4.3 Divergence Review

We compute total symbolic divergence per artwork:

$$\delta_i = \frac{1}{3}\sum_{j=1}^{3} |R_{ij} - 1|$$

Artwork 1 Divergence:

$$\delta_1 = \frac{1}{3}(0.1075 + 0.26 + 0.22) = 0.1958$$

Artwork 2 Divergence:

$$\delta_2 = \frac{1}{3}(0.2775 + 0.1125 + 0.175) = 0.1883$$

Table 4 compares the overall deviation from symbolic perfection for each artwork. Lower values indicate closer cultural alignment.

Table 4 Overall Symbolic Divergence Comparison

Artwork	δ (Avg. Deviation)
A_1	0.1958
A_2	0.1883

From Table 4, we conclude that Artwork 2 achieves slightly better symbolic fidelity overall, despite having a lower lotus match. This suggests that a well-balanced design may outperform a partially accurate one, emphasizing the need for complete symbolic assessment.

5. Analysis and Explanation

The symbolic conformance scores calculated in the previous section give us useful insight into the quality and cultural alignment of the two digital artworks. These scores help explain how well each symbol has been preserved or transformed in the digital environment.

a) Lotus Flower:
Artwork 1 preserved the lotus shape and meaning more clearly than Artwork 2. Its higher score (0.8925) reflects minimal distortion and low ambiguity. Artwork 2's lotus showed more symbolic confusion and visual deviation, lowering its score to 0.7225.

b) Dragon:
In Artwork 2, the dragon symbol had strong visual clarity and cultural correctness,

scoring 0.8875. Artwork 1's dragon, by contrast, suffered from both visual and symbolic inconsistencies, dropping its score to 0.74.

c) Double-Fish:
Both artworks did moderately well on this motif. However, Artwork 2 slightly outperformed with a score of 0.825 versus 0.78 in Artwork 1. This indicates a clearer rendering and less symbolic ambiguity.

5.1 Overall Evaluation

The divergence values (δ) summarize the symbolic deviation for each artwork. Artwork 2 had a slightly better average deviation score (0.1883), showing that even small improvements in symbolic clarity can affect the overall cultural perception.

This result also shows that focusing on one well-rendered symbol is not enough. Instead, a consistent treatment across all symbolic elements gives a stronger cultural outcome.

5.2 Cultural Implications

These calculations highlight how mathematical models can support cultural analysis.
The structured scores:

a) Show which parts of an artwork need improvement
b) Help designers maintain symbolic faithfulness
c) Provide a measurable standard for cultural evaluation

6. Conclusion

This paper introduced a new mathematical model to evaluate the cultural accuracy of digital artworks inspired by paper-cutting traditions. The model uses a structured neutrosophic approach, combining shape similarity, symbolic clarity, and cultural correctness into a single conformance score.

We showed how the model uses weighted values through α to reflect the importance of each symbol. We also demonstrated how ambiguity and distortion reduce the overall symbolic quality, even when the visual appearance seems correct.

By applying the model to two sample artworks, we saw how scores reveal specific strengths and weaknesses in symbolic design. This method can help artists, designers, and reviewers make informed improvements and preserve traditional meanings in digital formats.

The proposed system offers a practical way to connect cultural evaluation with logical analysis, especially for visual art forms that carry deep symbolic meaning.

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