Art Motif Similarity Measure Analysis: Fertile Crescent, Old European, Scythian and Hungarian Elements in Minoan Culture

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Abstract: - This paper presents distance and similarity measures for art motifs that can be applied to any pair of archaeological artifacts that contain complex art motifs. An art motif similarity analysis shows particularly strong connections of Minoan art with Fertile Crescent, Old European, Scythian and traditional Hungarian art.

Key-Words: - distance metric, feature set, motif, motif similarity, pattern, spiral, similarity measure.

1 Introduction

Archaeologists, geneticists and linguists are sharply divided on the origin of the Minoan civilization. Based on archaeological data, Evans [14] argued for an African origin, Marinatos [26] supported a Near Eastern origin, while Gimbutas [18] considered Minoan culture to be a continuation of the Old European culture. Linguistic considerations led Bernal [4] to propose an Afro-Asiatic origin, Campbell-Dunn [6] an African origin, Gordon [20] a Semitic origin, Owens [30, 31] an Indo-European, and Revesz [38] a Finno-Ugric origin. In general, linguists at least agree that Minoan was a greatly different language than Mycenaean, which was an early form of Greek [44]. In contrast, Lazaridis et al. [24] shows a great genetic similarity between Minoans and Mycenaeans. In this paper, we use data science and a novel art motif similarity analysis to clarify Minoan origins.

Data science is an emerging discipline that uses *generally applicable data analysis tools* to various fields. Data science has an utmost respect for data and can make significant contribution to various fields where the accumulated data is too difficult to analyze using traditional methods.

A common data analysis tool in data science is the mathematical notion of a *distance metric*. In Section 3, we propose a novel distance metric for art motifs. Once a distance metric is established, it enables us to answer the question: “Given a set of art objects, which cluster together?” Intuitively, the art objects within the same cluster exhibit the same art motif. In Section 2, we identify twenty different art motifs that seem to be ancient and shared across various cultures, including the Minoan culture.

By considering art objects from many cultures, and analyzing the cluster distributions, data science can answer the question: “Is culture A or B closer related to culture C?” The ability to answer such questions leads to an algorithmically generated *art motif inheritance tree*. Such a tree is the analogue of a phylogenetic tree in genomics or a language family tree in linguistics. The art motif inheritance tree explains which cultures had common ancestors where some common art motifs likely originated.

Hence the similarity of the motifs repertoires of cultures could be as indicative of their relatedness as the similarity of their genome sets. While population genetics has developed mathematical measures for comparing the relatedness of populations, art is usually compared subjectively without the use of data science. This paper shows that the comparison of the art of various cultures can be approached using data science.

Current comparative art history is exposed to endless subjective argumentation, like on the subject of Minoan origins. In contrast, our data science method develops *computational art history* as a scientific subject that provides firm answers and can join archaeogenetics and comparative linguistics on an equal basis in the study of human prehistory.

The previous proposals of Minoan origins mentioned above all advocate mono-origins. In contrast, our data science methods can deal with cases where cultures have multiple origins. In fact, as is shown later, our data science analysis supports a multiple-origin for the Minoan culture.

The multiple-origin of Minoan culture may be surprising at first, but let us recall that archaeologists have found various well-defined and markedly distinguishable periods in Minoan history. Table 1 is a summary of Minoan chronology based on Evans [14].

Table 1. Minoan chronology

Period	Events
Early Minoan (EM) (3000-2200)	• Egyptian style seals • Cretan hieroglyphs
Middle Minoan (MM) (2200-1500)	• potter's wheel • Linear A
Late Minoan (LM) (1500-1000)	• Thera eruption, Cretan hieroglyphs and Linear A ends • Linear B

Each of the Minoan periods is further divided into three layers (I, II and II) and each of those into two smaller layers (A and B). For example, the big Thera volcanic eruption is more precisely dated to LM IA, that is, at the earliest layer of the Late Minoan period. Using tree ring data, Pearson et al. [33] recently dated the Thera eruption to 1597, 1560, 1546 or 1544. At around that time Cretan Hieroglyph and Linear A writing ended. Linear B writing appeared in LM IIIA.

The striking panoply of different writings introduced in different periods and replacing earlier ones is a strong suggestion of major cultural change. When he set up the chronology in Table 1, Evans did not know that Linear B is an early form of Greek writing [7, 44]. On the other hand, Beekes [2, 3] claims that Linear A is not an Indo-European language. Hence, Mycenaean Greeks likely came to Crete after the Thera volcanic eruption. They brought a new culture that mixed with the inherited pre-eruption culture (MM and LM IA).

Similarly, the significant cultural changes at the beginning of MM, for example the introduction of the potter's wheel, suggest new cultural influences. That means that MM could be another mixture of EM and some other culture. Therefore, in our data science analysis, we keep a careful track of the period of first appearance of any Minoan art motif.

The rest of this paper is organized as follows. Section 2 describes some features and art motifs used in our data science analysis. Sections 3 and 4 define, respectively, two different distance measures, with the first based purely on features and the second on transformations of features into each other. Section 5 presents some experimental results using the distance and associated similarity measures. Section 6 discusses the results. Finally, Section 7 gives some conclusions and directions for future work.

2 Definitions of Features and Motifs

Below we describe a set of features that we found frequently and can be easily evaluated as being either present or absent in any art.

Definition 1. The art contains:

1. (A) a simple spiral or concentric circles or
   (B) a complex spiral (spirals with one center).
2. a central spiral or concentric circles.
3. a spiral enclosed in a circle or circles.
4. a center with emanations from it in the form of (A) straight lines, (B) zigzag lines, (C) trees or tree branches (D) wheat or other grains. (The center may be a central spiral.)
5. small dots, spirals or mini worlds in separate quarters/wedges created by lines that run from a center to outwards. (Here the center is not necessarily the center of the entire design.)
6. three or more spirals that are arranged
   (A) in a fan-shape, originating from same point.
   (B) to connect with their neighbors to their right and left or above and below.
   (C) in a row and originate from a line segment.
7. at least two symmetric spirals:
   (A) on the left and right sides, or
   (B) in a circular arrangement.
8. spirals that are decorated with:
   (A) small circles, which we call bubbles,
   (B) several parallel lines, which we call waves.
9. interlocked, connected spirals that fill in space.
10. a series of spirals that are connected by a vine and alternately swirl left and right. The vine is a connection that shows leaves.
11. a star, rosette or other flower:
    (A) within the center of spirals,
    (B) under an altar or
    (C) within a circle of spirals.
12. an altar.
13. two joint spirals, with a crosshatched object (diamond, heart shape, etc.) between them.
14. a series of spirals that forms a headdress.
15. (A) a dragon, snake or serpent,
    (B) a person without hands or legs, or
    (C) a bull, cow or bullhorns.
16. a cross (A) within or top of bullhorns, semicircle or a circle, (B) within a square or (C) as a punctuation mark.
17. a cross in the form of a series of small squares or staircases.
18. dotted triangles with alternating up and down orientation. Little diamonds can be used instead of dots when the triangles are hatched.
19. dotted contours of an object.
20. a central tree:
    (A) around which there are angels, goddesses or flying animals indicating a spiritual realm, which may be also indicated by the tree standing on a hill or on an island, or
    (B) the sun or a representative of the sun, such as a dove, dwells on a tree branch.

Altogether we consider thirty-five features, when we count all the subfeatures. Art objects do not just combine the listed features in some random fashion. Instead they can be naturally grouped according to the features that they contain.

Definition 2. A *motif* is a regularly co-occurring set of features with a common meaning.

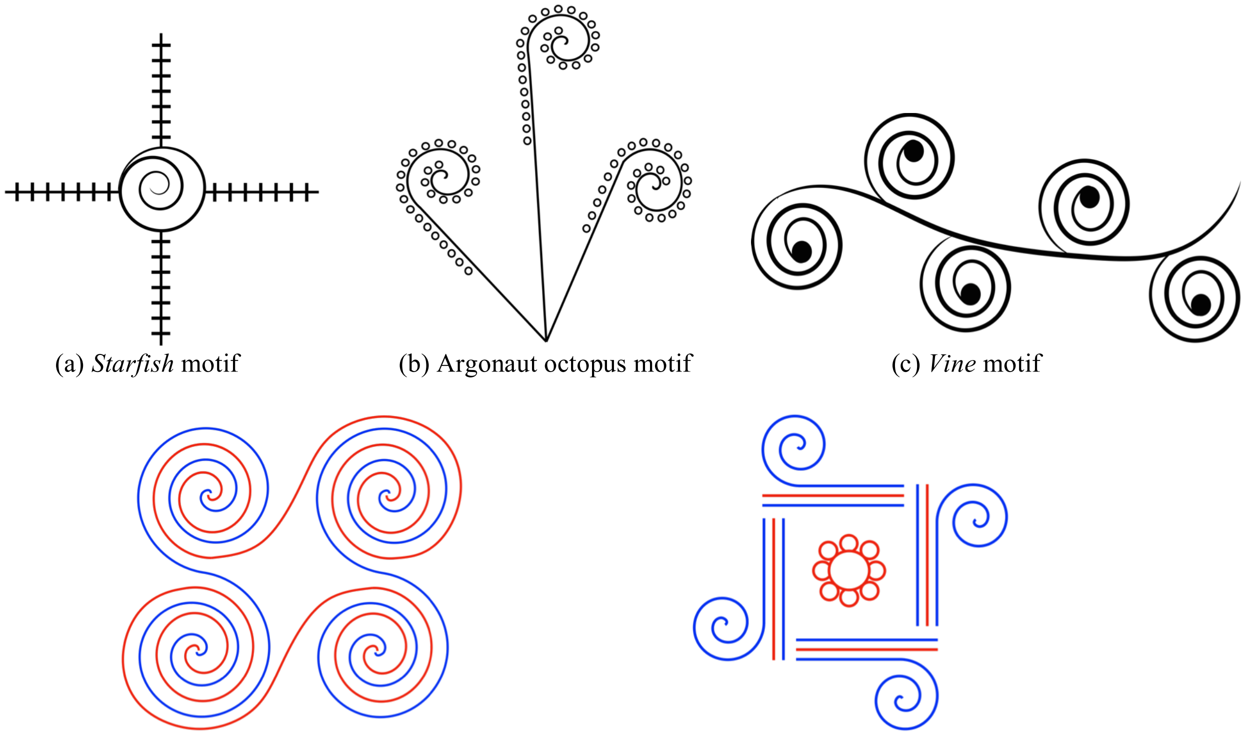
Definition 3. We define the following motifs as a set of features, which are listed in parentheses:
1. *Sun motif*: Contains a simple spiral (1A) or a complex spiral (1B) that is central (2), usually enclosed in a circle (3), and has various emanations from its center in the form of parallel lines (4A) or trees (4C).
2. *Starfish motif*: Contains a simple spiral or concentric circles (1A) that is central (2), and has emanations from its center that looks like wheat or some grain (4D).
3. *Argonaut octopus motif*: Contains simple spirals (1A) with fan arrangements into threes (6A), and bubbles on the spirals (8A). The inspiration for this motif seems to be the suckers of an *Argonauta argo* octopus, which seeks shelter in the empty shells of other animals.
4. *Dragon motif*: Contains simple spirals (1A), arranged in a pair (7A), and a dragon, serpent or snake (15A) between which there is usually a tree.
5. *Embroidery motif*: Contains complex spirals (1B) that connect with their left and right or above or below neighbors (6B) and fill in the entire space (9).
6. *Vine motif*: Contains simple spirals (1A) that are connected by a vine that alternatively swirl left and right (10) and have in the centers a rosette or some other flower (11).
7. *Crown motif*: Contains simple spirals (1A) that are arranged in a row and stemming form a short line (6C) and appear as a headdress (14).
8. *Fertility motif*: Contains simple spirals (1A) that with at least one pair symmetrically arranged (7A) and joint with a crosshatched object between them (13).
9. *Whirl motif*: Contains simple spirals (1A) that have a circular arrangement (7B) and have several parallel lines extending each spiral (8B). The advanced forms of this motive also usually have in the center of the circle of spirals a rosette or some other flower (11C).
10. *Snake goddess motif*: Contains simple spirals (1A) in the form of a dragon, serpent or snake (15A) and a person without hands (15B).
11. *Sacrifice motif*: Contains a bull or a cow (15C) and a cross within a bullhorn (16A).
12. *Water motif*: Contains dotted triangles with alternating up and down orientation (18).
13. *Well motif*: Contains a cross within a square (16B) and in the form of squares or staircases (17) and dotted triangles with up and down orientation (18) or diamonds around the square. (Note that below and above the diamonds we have a series of up and down triangles.)
14. *Serrated leaf motif*: Contains dotted contours of objects (19).
15. *Divided sun motif*: Contains a dividing line with a dot on each side (5) and half a sun on the left and half a sun on the right. Together the two halves form a circular center with straight lines emanating from it (4A) suggesting sunrays.
16. *Heaven's gate motif*: Contains in the center a tree on top of a gate on a hilltop (20A).
17. *World tree motif*: Contains a center with tree branch emanations from it (4c), two dividing lines (in the form of tree branches) from the center with a mini world in each quarter (5), and there is the sun perching on a tree branch non-tree dwelling animals on the branches (20B).
18. *Four suns motif*: Contains a center with straight line emanations from it (4A), in each quarter there is a circle with a dot inside (5), and also contains a cross within a circle (16A).
19. *Altar motif*: Contains a star or rosette below an altar (11B) and an altar (12), which has bullhorns on it or its shape imitates a bullhorn (15C).
20. *Punctuation motif*: Contains some writing with punctuation marks in the form of small crosses (16C) and dots.

For example, Fig. 21 (a) is a starfish motif because it contains a simple spiral (1A) that is central (2) and enclosed in a circle (3) and contains a center with wheat or grain emanations from it (4D).

Fig. 21 (b) is an Argonaut octopus motif because it contains three simple spirals (1A) that are arranged in a fan shape (6A) and have bubbles on the spirals (8A).

Fig. 21 (c) is a vine motif because it contains simple spirals (1A) that are connected by a vine that alternatively swirls left and right (10), and the spirals have in their centers a flower (11).

Fig. 21 (d) is an embroidery motif because it contains complex spirals (1B) that connect with their left and right or above and below neighbors (6B) and fill in the entire space (9), the square.



(a) *Starfish* motif (b) Argonaut octopus motif (c) *Vine* motif

(d) *Embroidery* motif (e) *Whirl* motif

Fig. 21. Illustrations of four motifs that contain spirals.

Finally, Fig. 21 (e) is an example of the whirl motif because it contains simple spirals (1A) that have a circular arrangement (7B) and have several parallel lines extending each spiral (8B). The center contains a rosette (11C).

3 A Features-Based Distance Metric

Based on the features listed in Section 2, we can define a motif similarity measure:

$$sim : X \times X \rightarrow [0, n]$$

where X is any set of motifs and n is the number of features considered as follows:

Definition 1. The similarity of two motifs is the number of common features that they contain.

For example, similarity between the two dishes in Figs. 1 (a) and 1 (b) (see Appendix), abbreviated as 1a and 1b, respectively, is:

$$sim(1a, 1b) = 2$$

because they have three features in common as shown in Table 3. We simply counted as one similarity the fact that they both had something emanating from the center. A more refined measure may count separately that they both have emanating from the center both straight lines and zigzags. Moreover, there are several parallel straight lines. However, we wanted to keep the spiral motif similarity measure simple as a first approximation of similarity.

Next we give a mathematical analysis of the *sim* function. To help the analysis, let X be a set of motifs and F a set of features, and let us define the contains function:

$$cont : X \times F \rightarrow [true, false]$$

as the function that given a motif and a feature returns *true* if the motif contains the feature and otherwise returns false.

We say that the set of motifs X is discernible by a feature set $F = \{f_1, \dots, f_n\}$ if and only if the following holds:

$$\forall\, x, y \in X \;\exists\, f_i : cont(x, f_i) \neq cont(y, f_i)$$

Note that our set of motifs is not discernible by our feature set because Figs. 4 (a) and 4 (b) contain exactly the same set of features. That may give rise to certain problems on occasion. However, intuitively, every set of motifs can be made discernible by adding suitable features to the feature set.

As a complement of the similarity function, we also define a distance function:

$$dist : X \times X \rightarrow [0, n]$$

Definition 2. The distance function *dist* of two motifs is the number of different features that they contain, that is:

$$dist(x, y) = n - sim(x, y)$$

where the feature set *F* has *n* number of elements.

Next we prove that the distance function is a mathematical metric if the set of motifs *X* is discernable by the feature set *F*. First, the equation:

$$dist(x, x) = 0 \qquad (1)$$

obviously holds. Second,

$$dist(x, y) = 0 \leftrightarrow x = y \qquad (2)$$

also holds because otherwise motifs x and y would have the same features and hence *X* would not be discernible by *F*. Third, the distance function is obviously symmetric by definition. That is,

$$dist(x, y) = dist(y, x) \qquad (3)$$

Fourth, the triangle inequality:

$$dist(x, z) \leq dist(x, y) + dist(y, z) \qquad (4)$$

also holds because if *x* and *z* differ on any feature f_i, then either *x* and *y* differ on f_i or *y* and *z* differ on f_i because if neither *x* and *y* nor *y* and *z* would differ on f_i, it would mean that both *x* and *y* agree on f_i and *y* and *z* agree on f_i. However, that would imply by transitivity that *x* and *z* also agree on f_i, which would be a contradiction.

A *mathematical metric* is a distance function that satisfies Equations (1)-(4). We can prove the following:

Theorem 1. Let *X* be a set of motifs that is discernible by a feature set *F*. Then distance function *dist* built on the feature set *F* is a mathematical metric. ■

Next we show the following about *sim*:

Theorem 2. Let *X* be a set of motifs that is discernible by a feature set *F* with $n \geq 0$ elements. Let *dist* be a distance function built on the feature set *F* and *sim* be a similarity function defined as:

$$sim(x, y) = n - dist(x, y)$$

where $x, y \in X$. Then the *sim* function satisfies the following properties:

$$sim(x, x) = n \qquad (5)$$
$$sim(x, y) = n \leftrightarrow x = y \qquad (6)$$
$$sim(x, y) = sim(y, x) \qquad (7)$$
$$sim(x, z) \geq sim(x, y) + sim(y, z) - n \qquad (8)$$

Proof: Here Equation (5) follows from the definition of *sim* and that $dist(x, y) = 0$ by Equation (1). For Equation (6), the only if direction (←) follows from Equation (5), while the if direction (→) follows from the fact that if $sim(x, y) = n$, then $dist(x, y) = 0$ must hold by the definition of *sim,* and then by Equation (2), $x = y$ is true.

Equation (7) can be shown by the definition of similarity as the set of common features, which is a symmetric notion.

Finally, Equation (8) can be rewritten using the definition of *sim* as follows:

$$n - dist(x, z) \geq \left(n - dist(x, y)\right) + (n - dist(y, z)) - n$$

Rearranging, we get:

$$0 \geq dist\ (x, z) - dis(x, y) - dist\ (y, z) \qquad (9)$$

We need to prove the above inequality, which is equivalent to Equation (8). To prove that, we note that from Equation (4), we have:

$$dist(x, z) - dist(x, y) - dist(y, z) \leq 0$$

which is equivalent to Equation (9) above.

The intuition behind Equation (8) is that suppose that sim(x, z) = k, that is, motifs x and z agree on k features. Now consider any motif *y*. For each feature $f_i \in F$, one of the following has to hold:

1. f_i is one of the *k* features that *x* and *z* share. Then it adds one to the left hand side and two to the right hand side.
2. f_i is not one of the *k* features that *x* and *z* share, but it is shared between *x* and *y*. Then it adds zero to the left side and one to the right side.
3. f_i is not one of the *k* features that *x* and *z* share, but it is shared between *y* and *z.* Then it adds zero to the left side and one to the right side.
4. f_i is not one of the *k* features that *x* and *z* share, and *y* shares it with neither *x* nor *z*. Then it adds zero to both the left and the right side.

We can see that as we consider each of the n features, we get the k on the left side and $2k$ on the right side because of case 1 above due to the k features shared by x and z. In addition, we get zero on the left side and at most n - k on the right side because of the features that are not shared by x and z. In total, considering only the feature similarities, we get k on the left side and at most

$$2k + (n - k) = n + k$$

on the right side. After we subtract n from the right side value, we clearly can get only at most k on the right side, while we always have exactly k on the left side. Therefore, Equation (8) has to hold.

4 A Transformations-Based Distance Metric

Theorems 1 and 2 showed a set of properties for the similarity and distance functions. Below we outline another distance function that is suitable for *linear motifs*, which are motifs that are composed of line segments and dots. The line segments all are straight and the lines have the same width and the dots have the same diameter. We also assume that the lines and dots are black on a white background, that is, we ignore the colors of the lines and the dots. In the following discussion of linear motifs, we use interchangeably the terms dot and point.

A linear motif can be *transformed* into another linear motif by repeatedly applying the following types of changes:

1. Adding or deleting some line segment.
2. Adding or deleting some dot.
3. Extending or shortening some line segment.
4. Shifting in parallel some line segment.

In the following, we will refer to changes of Type 3 as *resizing*. Note that a Type 4 change cannot be a shift that exactly overlays either completely or partially another line segment because completely overlaying would be deleting one line segment, which is a Type 1 change, and partially overlaying would be extending a line segment, which is a Type 3 change. In addition, we do not consider moving any dot as a separate type of change. Instead, moving a dot is considered the deletion of one dot and the addition of another dot.

Definition 3. Let x and y be motifs that are composed of line segments and dots. Let t be any transformations from x to y with o number of lines added or omitted, p number of dots added or omitted, r number of lines resized, and s number of lines shifted in parallel. Then the cost of the transformation by t from x to y is the following:

$$cost(t, x, y) = c_1\, o + c_2\, p + c_3\, r + c_4\, s \quad (10)$$

where c_1, c_2, c_3 and c_4 are positive constants. Further, let T be the set of possible transformations from x to y. Then the linear distance between x and y is the following:

$$dist_2(x, y) = Min_{t \in T}\, cost(t, x, y)$$

Note: Intuitively, a slight shift in parallel of a line segment is visually less of a change than adding or deleting a line segment. Hence in Equation (10), it is sensible for practical applications to choose the coefficient values such that $c_1 \geq c_4$. If the values are chosen such that $c_1 < 0.5\, c_4$, then instead of shifting a line segment parallel to itself, it would be less costly to delete the line segment and add a new line segment that is parallel to the deleted line.

Similarly, resizing a line segment is also visually less of a change than adding or deleting a line segment. Hence $c_1 \geq c_3$ is expected. In addition, if we choose $c_1 < 0.5\, c_3$, then instead of resizing a line segment it would be less costly to delete a line segment and add a new line segment.

Next we give some examples of transformations

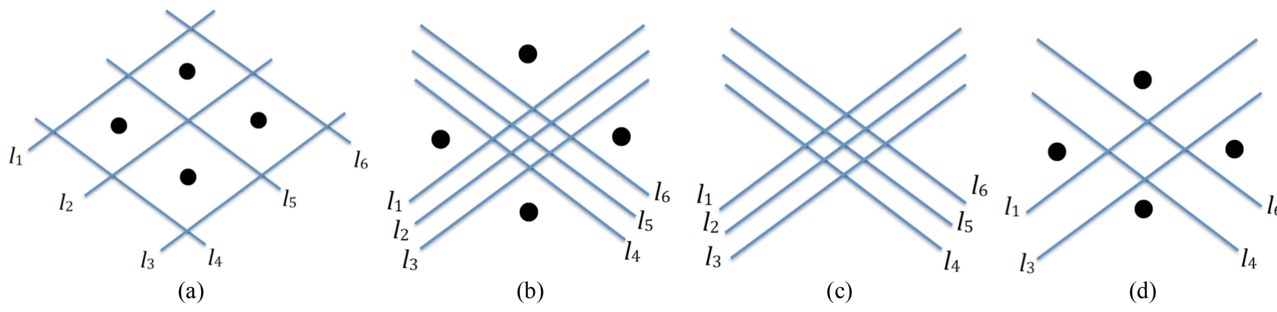


Fig. 22. Four linear motifs such that (a) is a transformed into (b) by shifting in parallel lines l_1, l_3, l_4 and l_6, while (b) is transformed into (c) by omitting the four dots, and (b) is transformed into (d) by omitting the lines l_2 and l_5.

using the linear motifs in Fig. 22, where we added the line numberings only for the ease of discussion.

Example 1. Let us assume that the coefficients in Equation (10) are $c_1 = c_2 = 1$ and $c_3 = c_4 = 0.5$. Then consider the four motifs in Fig. 22. Clearly, we can transform Fig. 22 (a) into Fig. 22 (b) shifting lines l_1 and l_3 in parallel closer to line l_2 and simultaneously shifting lines l_4 and l_6 in parallel closer to line l_5. Hence we have:

$$dist_2(22a, 22b) = 2$$

Since it is also clear that Fig. 22 (b) can be transformed to Fig. 22 (c) by omitting the four dots:

$$dist_2(22b, 22c) = 4$$

Moreover, the above two transformations can be composed to obtain a composite transformation from Fig. 22 (a) to Fig. 22 (c). Hence:

$$dist_2(22a, 22c) = 6$$

Fig. 22 (b) can be transformed also into Fig. 22 (d) by eliminating lines l_2 and l_5. Hence:

$$dist_2(22b, 22d) = 2$$

Finally, the transformation from Fig. 22 (a) to Fig. 22 (b) can be composed with the above transformation to give a new transformation, which is also optimal. Hence:

$$dist_2(22a, 22d) = 4$$

Therefore, according to the distance metric that we use, Fig. 22 (d) is closer than Fig. 22 (c) to Fig. 22 (a), the initial figure.

Theorem 3. Let X be a set of linear motifs. Suppose we allow only transformations that add or omit lines and points, or resize or shift lines. Then the distance function $dist_2$ function is a mathematical metric.

Proof: To show that the $dist_2$ function is a mathematical metric, we have to prove that for any motif x and y in X, the following equations hold:

$$dist_2(x, x) = 0 \quad (11)$$
$$dist_2(x, y) = 0 \leftrightarrow x = y \quad (12)$$
$$dist_2(x, y) = dist_2(y, x) \quad (13)$$
$$dist_2(x, z) \leq dist_2(x, y) + dist_2(y, z) \quad (14)$$

Show Equation (11): The trivial transformation of doing no addition, omission, resizing and shift will yield a transformation with a total cost of zero, which is optimal. Hence the distance between any motif and itself is always zero.

Show Equation (12): If $x \neq y$, then there must be some transformation that involves omission or addition of lines or points, or resizing or shifting lines. The distance between x and y must be greater than zero because all of these transformations have positive constant coefficients in Equation (10). If $x = y$, then the trivial transformation of doing no addition, omission, resizing nor shift will yield a total cost of zero.

Show Equation (13): Clearly, if t is any transformation from x to y, then the reverse transformation t', which does exactly the opposite of t in each step and in reverse order, will have the same cost because the cost of each addition of a line is the same as the cost of deletion of a line, the cost of addition of a point is the same as the cost of deletion of a point, the cost of resizing a line is also the same whether the line is extended or shortened, and the cost of shifting a line parallel to itself is the same whether it is shifted upward or downward or left or right. Further, if transformation t is optimal from x to y, then t' is also optimal from y to x.

Show Equation (14): Clearly, if we have an optimal transformation t_1 from x to y and another optimal transformation t_2 from y to z, then a composition of the two yields a transformation t_3 from x to z. We also know that:

$$cost(t_3, x, z) = cost(t_1, x, y) + cost(t_2, y, z) \quad (15)$$

The transformation t_3 from x to z may not be optimal. Suppose that t_4 is an optimal transformation from x to z, where t_4 may be the same as t_3 or some other transformation. Since t_4 is optimal, we know that:

$$dist_2(x, z) = cost(t_4, x, z) \leq cost(t_3, x, z)$$

Hence we have the inequality:

$$dist_2(x, z) \leq cost(t_3, x, z) \quad (16)$$

Further, since t1 and t2 are optimal transformations, we also know that:

$$dist_2(x, y) = cost(t_1, x, y)$$

and

$$dist_2(y, z) = cost(t_2, y, z)$$

By adding the above two equalities, we obtain:

$$cost(t_1, x, y) + cost(t_2, y, z) = dist_2(x, y) + dist_2(y, z)$$

Substituting the above into the right side of Equation (15) and combining with Equation (16), we obtain the following:

$$dist_2(x, z) \leq cost(t_3, x, z) = dist_2(x, y) + dist_2(y, z)$$

Finally, Equation (14) follows from the above by eliminating the intermediate term. ■

When we have linear motifs with at most n line segments and m dots, then we can always change one linear motif to another linear motif with at most n deletions and n additions of line segments, and m deletions and m additions of dots. Therefore:

$$N = c_1 2n + c_2 2m$$

is a natural upper bound on the distance between any two linear motifs with as most n line segments and m dots.

The above motivates the following definition:

Definition 4. Let X be a set of linear motifs that are each composed of at most n line segments and m dots, let $dist_2$ be as in Definition 3, and let N be as above. Then we define the similarity function sim_2 as follows:

$$sim_2(x, y) = N - dist_2(x, y)$$

Example 2. Consider again the same $dist_2$ function as in Example 1 and the set of linear motifs shown in Fig. 19. Since each linear motif has at most six line segments and four dots, $N = 20$. Hence we have the following similarity function:

$$sim_2(x, y) = 20 - dist_2(x, y)$$

Theorem 4. Let X be a set of linear motifs satisfying the conditions in Definition 4. Then the sim_2 function satisfies the following properties:

$$sim_2(x, x) = N \quad (17)$$
$$sim_2(x, y) = N \leftrightarrow x = y \quad (18)$$
$$sim_2(x, y) = sim_2(y, x) \quad (19)$$
$$sim_2(x, z) \geq sim_2(x, y) + sim_2(y, z) - N \quad (20)$$

Proof: Equations (17)-(19) trivially follow from Equations (11)-(13) and Definition 4. To show Equation (20), first rewrite the equation in Definition 4 as follows:

$$dist_2(x, y) = N - sim_2(x, y)$$

Second, substitute the above into Equation (14) to obtain:

$$N - sim_2(x, z) \leq 2N - sim_2(x, y) - sim_2(y, z)$$

Subtracting N from both sides and then multiply by -1 we obtain Equation (20). ■

5 Experimental Results

We investigated thousands of art objects, including all Minoan and Mycenaean art objects found in Evans [13, 14], Marinatos [26], and the *Corpus der Minoischen und Mykenischen Siegel (CMS)* [28], all Neolithic Old European art objects found in Gimbutas [18], all Bronze Age European art objects found in Keszi [22], Patay [32], all Scythian art objects found in Borovka [5], and all Hungarian art works found in Varga [43]. In addition, the author's decades long art collection and photos from museum visits in Greece and Hungary were also used. Finally, the Internet webpages on relevant art objects were also investigated.

After the above extensive search, only 56 sample art objects were selected as shown in Figs. 1-20 of the Appendix. These art objects were selected because they illustrate the motifs listed in Section 2. We did not select art objects that were not illustrating one of the motifs or were repeatedly illustrating the same motif. When several Minoan or Mycenaean art objects illustrated the same motif, we always choose the one that had an earlier date. For example, we did not select the famous *Tiryns Signet Ring*, which had a divided sun motif, also called a half-rosette motif in Evans [14], because we found an earlier Middle Minoan art object with the same motif. With the other cultures, we did not aim for the earlier but for the best example that we could find. For example, the water motif can be found on a Neolithic (early 7th millennium BC) mural excavated at Çatalhöyük, Turkey as shown in Gimbutas [18] Fig. 286. However, the bowl from Iran in Fig. 12 (a) seems a better illustration of the water motif, although it is from a later period and culture that is likely a successor of the original Fertile Crescent culture.

We avoided using art objects that are considered fake by serious scholars. Hence, we did not use the controversial *Ring of Nestor* because of its unclear provenance. Marinatos and Jackson [27] consider it fake, while Eliopoulos [12] defends its authenticity.

Table 2. A feature analysis of the art objects shown in Figs. 1-20 (see Appendix).
Legend: Fertile Crescent green, Old European blue, Minoan and Mycenaean purple, Scythian orange, and Hungarian pink.

Fig	1		2	3	4				5	6			7		8		9	10	11			12	13	14	15			16			17	18	19	20	
	A	B			A	B	C	D		A	B	C	A	B	A	B			A	B	C				A	B	C	A	B	C				A	B
1a	✔		✔	✔	✔	✔																													
1b		✔	✔		✔		✔																												
1c	✔		✔	✔	✔	✔	✔																												
2a	✔		✔			✔		✔	✔																										
2b	✔		✔	✔				✔																											
3a	✔									✔					✔																				
3b	✔		✔	✔						✔					✔																				
4a	✔												✔		✔										✔										
4b	✔												✔		✔										✔										
4c	✔												✔												✔										
5a		✔									✔						✔																		
5b		✔									✔						✔																		
5c		✔									✔						✔																		
6a	✔																	✔	✔																
6b	✔												✔					✔	✔																
6c	✔																	✔	✔																
7a	✔											✔												✔											
7b	✔											✔												✔											
7c	✔											✔												✔											
8a	✔								✔				✔										✔												
8b	✔												✔										✔												
8c	✔												✔										✔												
8d	✔												✔										✔												
8e	✔												✔										✔												
9a	✔													✔		✔																			
9b	✔													✔		✔					✔														
9c	✔													✔		✔					✔														
10a	✔																								✔	✔									
10b	✔																								✔	✔									
11a																											✔	✔							
11b																											✔	✔							
11c	✔		✔	✔	✔				✔				✔					✔										✔					✔		
12a																																✔			
12b																																✔			
12c																																✔			
12d																																✔	✔		
13a																											✔		✔		✔	✔			
13b																											✔		✔		✔	✔			
13c																													✔		✔	✔			
14a																																	✔		
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15a					✔				✔																										
15b					✔				✔																										
15c					✔				✔																										
16a																																		✔	
16b																																		✔	
16c																																		✔	✔
17a							✔		✔																		✔								✔
17b							✔		✔																		✔								✔
18a					✔				✔																			✔							
18b					✔				✔																			✔							
19a																				✔	✔						✔								
19b																				✔	✔						✔								
20a																														✔					
20b					✔																							✔		✔					

Table 3. *Sim* scores of three or greater between motifs of different cultures are highlighted in green. Legend: See Table 2.

#	Figure																												
	1			2		3		4			5			6			7			8					9			10	
	a	b	c	a	b	a	b	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	d	e	a	b	c	a	b
1a	5	2	5	3	3	1	3	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1b	2	4	3	1	1	0	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1c	5	3	6	4	4	1	3	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2a	3	1	4	5	3	1	2	1	1	1	0	0	0	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1
2b	3	1	4	3	4	1	3	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3a	1	0	1	1	1	3	3	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3b	3	1	3	2	3	3	5	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4a	1	0	1	1	1	2	2	4	4	3	0	0	0	1	2	1	1	1	1	2	2	2	2	2	1	1	1	2	2
4b	1	0	1	1	1	2	2	4	4	3	0	0	0	1	2	1	1	1	1	2	2	2	2	2	1	1	1	2	2
4c	1	0	1	1	1	1	1	3	3	3	0	0	0	1	2	1	1	1	1	2	2	2	2	2	1	1	1	2	2
5a	0	1	0	0	0	1	1	0	0	0	3	3	3	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
5b	0	1	0	0	0	1	1	0	0	0	3	3	3	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
5c	0	1	0	0	0	1	1	0	0	0	3	3	3	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
6a	1	0	1	1	1	1	1	1	1	1	1	1	1	3	3	3	1	1	1	1	1	1	1	1	1	1	1	1	1
6b	1	0	1	1	1	1	1	2	2	2	0	0	0	3	4	3	1	1	1	2	2	2	2	2	1	1	1	1	1
6c	1	0	1	1	1	1	1	2	2	2	0	0	0	3	3	3	1	1	1	2	2	2	2	2	1	1	1	1	1
7a	1	0	1	1	1	1	1	1	1	1	0	0	0	1	1	1	3	3	3	1	1	1	1	1	1	1	1	1	1
7b	1	0	1	1	1	1	1	1	1	1	0	0	0	1	1	1	3	3	3	1	1	1	1	1	1	1	1	1	1
7c	1	0	1	1	1	1	1	1	1	1	0	0	0	1	1	1	3	3	3	1	1	1	1	1	1	1	1	1	1
8a	1	0	1	2	1	1	1	2	2	2	0	0	0	1	2	1	1	1	1	4	3	3	3	3	1	1	1	1	1
8b	1	0	1	1	1	1	1	2	2	2	0	0	0	1	2	1	1	1	1	3	3	3	3	3	1	1	1	1	1
8c	1	0	1	1	1	1	1	2	2	2	0	0	0	1	2	1	1	1	1	3	3	3	3	3	1	1	1	1	1
8d	1	0	1	1	1	1	1	2	2	2	0	0	0	1	2	1	1	1	1	3	3	3	3	3	1	1	1	1	1
8e	1	0	1	1	1	1	1	2	2	2	0	0	0	1	2	1	1	1	1	3	3	3	3	3	1	1	1	1	1
9a	1	0	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	3	3	3	1	1
9b	1	0	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	3	4	4	1	1
9c	1	0	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	3	4	4	1	1
10a	1	0	1	1	1	1	1	2	2	2	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3
10b	1	0	1	1	1	1	1	2	2	2	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3

#	Figure																										
	11			12				13			14			15			16			17		18		19		20	
	a	b	c	a	b	c	d	a	b	c	a	b	c	a	b	c	a	b	c	a	b	a	b	a	b	a	b
11a	2	2	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	1
11b	2	2	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	1
11c	1	1	9	0	0	0	1	0	0	0	1	1	1	2	2	2	0	0	0	1	1	3	3	0	0	0	2
12a	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12b	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12c	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12d	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13a	1	1	0	1	1	1	1	4	4	3	0	0	0	0	0	0	0	0	0	1	1	0	0	1	1	0	0
13b	1	1	0	1	1	1	1	4	4	3	0	0	0	0	0	0	0	0	0	1	1	0	0	1	1	0	0
13c	0	0	0	1	1	1	1	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14a	0	0	1	0	0	0	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14b	0	0	1	0	0	0	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14c	0	0	1	0	0	0	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15a	0	0	2	0	0	0	0	0	0	0	0	0	0	2	2	2	0	0	0	1	1	2	2	0	0	0	1
15b	0	0	2	0	0	0	0	0	0	0	0	0	0	2	2	2	0	0	0	1	1	2	2	0	0	0	1
15c	0	0	2	0	0	0	0	0	0	0	0	0	0	2	2	2	0	0	0	1	1	2	2	0	0	0	1
16a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
16b	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
16c	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	1	1	0	0	0	0	0	0
17a	1	1	1	0	0	0	0	1	1	0	0	0	0	1	1	1	0	0	1	4	4	1	1	1	1	0	0
17b	1	1	1	0	0	0	0	1	1	0	0	0	0	1	1	1	0	0	1	4	4	1	1	1	1	0	0
18a	1	1	3	0	0	0	0	0	0	0	0	0	0	2	2	2	0	0	0	1	1	3	3	0	0	0	2
18b	1	1	3	0	0	0	0	0	0	0	0	0	0	2	2	2	0	0	0	1	1	3	3	0	0	0	2
19a	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	3	3	0	0
19b	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	3	3	0	0
20a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
20b	1	1	2	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	2	2	0	0	1	3

Table 4. Fertile Crescent, Old European and successors, Minoan, Scythian and Hungarian motifs. Legend: See Table 1.

#	Motif	Fertile Crescent	Old European and successors	Minoan first appearance: Early Minoan	Minoan first appearance: Middle Minoan	Minoan first appearance: Late Minoan	Scythian	Hungarian
1	Sun		✔		✔			✔
2	Starfish			✔				✔
3	Argonaut octopus				✔			✔
4	Dragon					✔	✔	✔
5	Embroidery		✔		✔			✔
6	Vine					✔	✔	✔
7	Crown					✔	✔	✔
8	Fertility		✔		✔			✔
9	Whirl		✔		✔			✔
10	Snake goddess			✔				✔
11	Sacrifice		✔		✔			✔
12	Water	✔	✔	✔				✔
13	Well		✔		✔			✔
14	Serrated leaf	✔	✔	✔				✔
15	Divided sun		✔		✔			✔
16	Heaven's gate					✔	✔	✔
17	World tree				✔			✔
18	Four suns				✔			✔
19	Altar				✔			✔
20	Punctuation				✔			✔

On the other hand, the balance of opinion seems to accept as genuine the *Ring of Minos*, which we used in Fig. 16 (a). The authenticity of that ring was enhanced by a recent find of a similar gold signet ring in the *Griffin Warrior Tomb* near the ancient town of Pylos, Greece (see Davis and Stocker [10]).

Figs. 1-20 are arranged to group the art objects according to the twenty motifs in Section 2. Sometimes an art object exhibits something close to the defined motif. For example, some Old European art objects depicted a type of snake goddess that had hands. Since those did not fit our definition of a snake goddess motif, they were not selected. The art objects selected had to exhibit all the required features of at least one motif.

Table 2 shows a feature analysis of the 56 selected art objects, where a checkmark symbol indicates the presence of a feature. Table 3 shows a similarity matrix of the 56 art objects with some omissions, where the similarity would be below 3. The similarity measure used was the *sim* function of Section 3 with a weight of one for each feature. There were many art object pairs from different cultures with a similarity score of three or more, suggesting a significant interaction among the selected cultures. The Table 3 entries corresponding to these pairs are highlighted in green. Table 4 summarizes where the seventeen motifs were found. Those motifs that were already found in the fertile crescent are highlighted in green, those that were first found in the Old European culture or its successor Bronze Age cultures are highlighted in

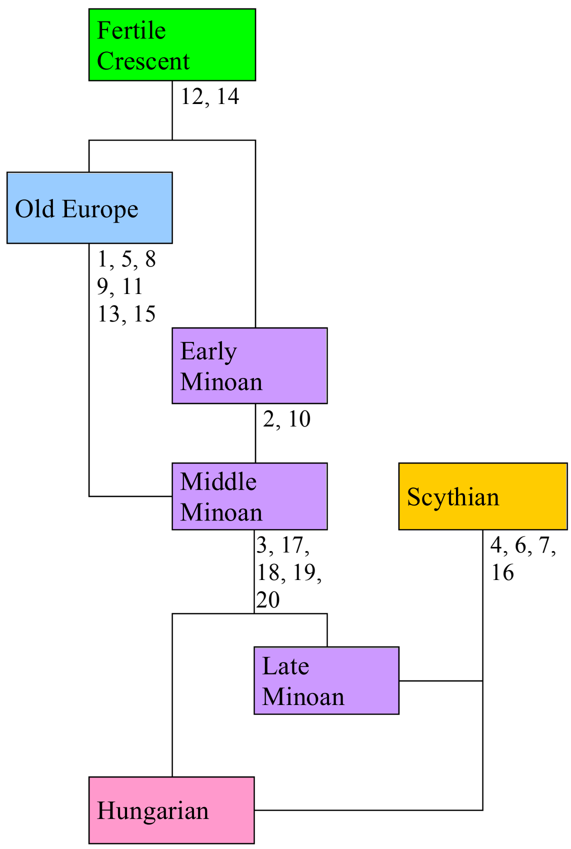

Fig. 23. A possible motif inheritance diagram.

blue, those that were apparently Early Minoan or Middle Minoan innovations are highlighted in purple, and those that were also found in Scythian art are highlighted in orange.

Scythian art can be used as a proxy of Eurasian Steppe art. According to Gimbutas [18], the Indo-European homeland was on the Eurasian Steppe. Hence it is likely that the Mycenaean people also came from the North Black Sea area via the western shores of the Black Sea into the Aegean Sea area. They could have shared same art motifs with the Scythians and brought them to Crete, which they probably conquered sometime in 1450 BC. The subsequent era, while it is classified as some layers of Late Minoan, shows a mixture of Eurasian Steppe origin art motifs and continuing Early and Middle Minoan art motifs. That is a more logical direction of motif inheritance than the reverse direction, that is, the assumption that these were Late Minoan-Mycenaean innovations transmitted to the Scythians because Scythian art lacks the thirteen features that all occur in Middle Minoan art.

Based on Table 4, we can build a possible motif inheritance diagram as shown in Fig. 23. The diagram suggests that the water motif (12) and the serrated leaf motif (14) are the oldest surviving motifs. The four Scythian motifs (4, 6, 7, and 16) may be equally ancient motifs from a Eurasian Steppe or Asian origin. The dragon motif (4) may go back to China. It would be interesting to investigate the origin of these motifs by extending the comparison to other Eurasian Steppe and Asian cultures. The sun motif with its center spiral may hark back to the center of Old European spindle whorls such as the ones found at the Dikilitash and the Vinca archaeological sites.

The starfish and the Argonaut octopus motifs are Minoan innovations as can be expected because of the maritime culture of the Minoans, while the vine motif may be an innovation in the eastern Black Sea region, which is an ancient vine growing area. The Scythians lived in those areas and may have become familiar with viniculture and with it the vine motif.

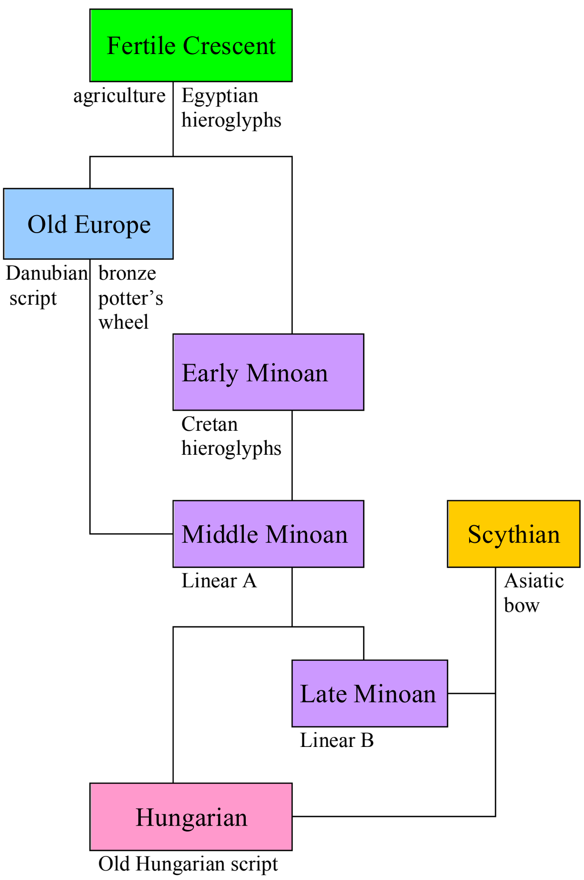

Fig. 24. Other possible cultural transmissions.

In our second experiment, we applied the distance function $dist_2$ to the following four art objects:

1. The "quartered diamond with four dots" motif, which is a central part of the fertility motif in Fig. 8 (a), and is similar to Fig. 22 (a).
2. The Majiayao culture (upper Yellow River region in China, 3300 – 2000 BC) bowl that is shown in Varga [43] page 468. This bowl has a motif similar to that of Fig. 22 (b).
3. The Cucuteni bowl in Fig. 11 (a) with a triple-cross linear motif similar to that of Fig. 22 (c).
4. The Hungarian jug in Fig. 11 (c), which has a linear motif (see the detail in the top-left) matching that of Fig. 22 (d).

For the above four objects, Table 5 shows the sim_2 simiarity scores as defined in Example 2.

Table 5. Sim_2 function similarity scores of sixteen or greater between motifs of different cultures are highlighted in green. Legend: Old European blue, Majiayao orange, and Hungarian pink.

Figure	Figure			
	8a/22a	22b	11a/22c	11c/22d
8a/22a	20	18	14	16
22b	18	20	16	18
11a/22c	14	16	20	14
11c/22d	16	18	14	20

6 Discussion of the Results

The most important result of our study is that the Minoans are not a simple homogeneous group but were composed of several groups that came to the island of Crete in separate waves as shown in Figs. 24 and 25.

Early Minoan Civilization: The earliest group that we can identify using art motifs likely came from the Fertile Crescent via Anatolia. The Fertile Crescent settlers brought with them agriculture. In a later wave of expansion from the Fertile Crescent the idea of hieroglyph writing may have spread from Egypt to Crete. Evans [14] also found several similarities between the Cretan hieroglyph [29, 45-47] and the Egyptian hieroglyph scripts.

Middle Minoan Civilization: Agriculture spread from Anatolia to Old Europe, which Gimbutas [18] defined as the areas of South-Eastern Europe consisting of early farmers settled along the major rivers, such as the Danube. These Old European settlers initially kept separate from the native hunter-gatherer populations, but eventually the two populations merged together.

The Middle Minoan culture was clearly influenced by Old European culture as is revealed by the common art motifs in Old Europe and the Middle Minoan culture. This results is in agreement with Childe [8], who noted that bronze metallurgy developed earlier in Old Europe than in Crete, where it was only introduced from the former in the Middle Minoan period. According to Haarmann [21], the potter's wheel was also used in the late Old European culture, more specifically the Cucuteni culture. The use of the potter's wheel also appears in Crete during the early layers of Middle Minoan (MM I). Hence it may have been transmitted from Old Europe to Crete in the same period.

Finally, the Old European culture also developed a writing, which is called the Danubian script, [21]. Several authors noted the similarities between the Danubian script and Linear A and also between Linear A [15, 19] and the Old Hungarian script that was used by Hungarians before the adoption of the Latin alphabet [9, 34-38]. Hence the Danubian script may have influenced the development of the Linear A script, which also appears during MM.

Late Minoan Civilization: Our results indicate that the art of the late Minoan civilization was influenced by Scythian culture as many typically Scythian art motifs are adopted during that period. In addition, Evans [14] made the observation that the Asiatic bow seems to appear first in the Aegean area during Late Minoan times, such as on the Mycenaean Thisbe seal-stone (Evans [14], Vol. 4, Fig. 561). Linear B also appears only during Late Minoan and was deciphered by Chadwick and Ventris [44] as an early form of Greek. The origin of Greeks is supposed to be also from the Proto-Indo-European homeland, which was according to Gimbutas somewhere on the Eurasian Steppe. Therefore culturally if not necessarily linguistically the Mycenaean Greeks and the Scythians were related, including in their common use of the Asiatic bow and the art motifs that we found to be common in Late Minoan and Scythian art.

The above complex picture is possible only by a careful layer analysis of the changing art motifs within the Minoan civilization. The language of the Minoan civilization also may have changed, but we need to be cautious in our approach. The languages in which Linear A and Linear B were written may or may not reflect the common language of the Minoan people. Instead, they may reflect the language of the power class, the political and religious leaders. As an analogy, one can think of Medieval Europe, where Latin was commonly used as the written language even in countries where the vernacular was entirely different.

Nevertheless, the numerous cultural transmissions from art motifs to bronze metallurgy, the potter's wheel, and writing scripts suggest not only trade relations but also population movements among the mentioned areas as shown in Fig. 25.

The exact route taken by Old Europeans to Crete is unknown. The Morava-Vardar path provided a convenient land connection between the Thessaly plains and the Carpathian Basin. It could have been taken before the arrival of the Mycenaeans to the Greek mainland. A sea route is also possible from the Black Sea costal areas of present day Moldova [17], where the Cucuteni culture has expanded in later times, via the Bosporus Strait and the Sea of Marmara to the Aegean islands. On the other side, there was also a convenient sea route from the Danilska culture on the Adriatic Sea to Crete. Both the Cucuteni and the Danilska cultures are part of the Old European culture according to Gimbutas [18].

Some of the seemingly contradictory results can be explained in terms of Fig. 25. Evans' examples of Egyptian-Minoan similarities [14] come from the Early Minoan layer. Gimbutas' examples, including Fig. 1 (b) [18], come from the Middle Minoan layer. Marinatos' examples [26] come from the Late Minoan and Mycenaean period, when the Minoan culture already expanded to the Near East as evidenced by the Cypro-Minoan script on Cyprus and Late Minoan I style frescos at Alalakh, Turkey, el-Dab'a, Egypt, Qatna, Syria, and Tel Kabri, Israel. These imply considerable interactions, perhaps involving also population movements, between Crete and the Near East in Late Minoan times. The Minoan culture's successors include the Mycenaean culture and some

Fig. 25. The art motif similarity analysis leads to a complex picture of Minoan origins, where the Early Minoan was influenced by the Fertile Crescent, Middle Minoan by the Old European civilization, and Later Minoan by Steppe origin people related to Scythians.

part of Hungarian folk art culture.

Hungarian folk art seems to reflect some survival of a Bronze Age culture as well as the art of later arriving groups. Finno-Ugric linguistics has long connected Hungarian with the Khanty and the Mansi languages, which are currently spoken only by a few ten thousand people in Siberia [48]. However that connection arose, it is worth noting that some of the Khanty embroidery contains an elaborated but still recognizable water motif and a fertility motif as shown in Figs. 26 (a) and (b), respectively.

In Fig. 23 (a), the blue color of the wavy line helps to recognize the water motif. In Fig. 23 (b), the central diamond is surrounded by somewhat squared version of double spirals on the top and the bottom. Further, instead of pairing two deer as in Fig. 8 (e), two birds are paired on the top, and those are mirrored on the bottom.

Another interesting cultural similarity can be found between some Khanty and Mansi musical

(a) *Water* motif

(b) *Fertility* motif

Fig. 26. Khanty art motifs.
http://folkcostume.blogspot.com/2016/09/south-khanty-costume-and-embroidery.html

(a) Harp player Keros (c. 2600-2300 BC)
Photo: en.wikipedia.org/wiki/Cycladic_art
(by Robur.q – own work CC BY-SA 3.0)

(b) Harp and lyre, Knossos (MM II)
CMS [28] Vol. 2, Fig. 90

(c) Khanty harp
Photo: www.nba.fi/hanti/en/a4_s1_as6_2.php

Fig. 27. Harps with swan or other animal figureheads.

instruments shown in Fig. 27 (c) and the Cycladic harp in Fig. 27 (a) and the Middle Minoan harp in Fig. 27 (b). The Khanty and Mansi call their harp a *khutang*, which means swan, and commonly have a swan's head on their instrument, although other animal heads are also used occasionally. For example, the Khanty harp in Fig. 27 (c) has a fox head. The Khanty and the Mansi harps are the only harps in Northern Siberia.

In addition to our observations above, we also mention Varga [43]'s recent book, which presents numerous examples of art similarities from the Carpathian Basin through Eurasia. His book adds to the idea that whenever humans spread through the Eurasian continent, they already had a developed culture that may survive in part even today.

7 Conclusions and Future Work

Our results may disappoint those who looked for a simple answer to the origins of the Minoans. However, the complex picture that emerges from our study agrees well with what Homer (in *Odyssey* 19: 175-77) wrote about of Crete in his time:

Language with language is mingled together. There are Akhaians, there are great-hearted Eteocretans, there are Kydones, and Dorians in their three clans, and noble Pelasgians.

Homer paints a complex, multicultural picture of Crete. The Akhaians can be associated with the Mycenaeans, who arrived by Late Minoan times. The Dorians were Greeks, who arrived around 1200 BC. The other three names may refer to three earlier layers of settlers. The Pelasgians may be the earliest Neolithic settlers, who could be found also on the mainland and many other Aegean islands in Homer's time. The Eteocretans may be Early Minoans, who came from the Near East or Egypt and settled mainly in eastern Crete. Finally, the Kydones may be Middle Minoans, who came from Old Europe perhaps via the Adriatic Sea and settled mainly in western Crete. More archeological, genetic, linguistic and art comparison work is needed to explore these possibilities.

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APPENDIX

(a) Dimini, Greece (4500-4000 BC) Gimbutas [18] Fig. 156 (b) Minoan seal, Vorou, Crete (MM I) CMS [28] Vol. II, Fig. 377 (c) Magyarszombatfa, Hungary (1950) author's collection

Fig. 1. *Sun* motif

(a) Minoan lid of a box. EM, (author's photo) Archaeological Museum in Heraklion (b) Magyarszombatfa, Hungary Varga [43]

Fig. 2. *Starfish* motif

(a) Minoan jug detail, Poros, Crete (MM III) Photo from: https://en.wikipedia.org/wiki/Minoan_pottery] (b) Magyarszombatfa, Hungary Varga [43]

Fig. 3. *Argonaut octopus* motif

(a) Central Crete (LM I) Evans [14], Vol. 4, Fig. 377 (b) Scythian earring (1^{st} cent. BC) en.wikipedia.org/wiki/Scythians (c) Sopron, Hungary (13^{th} cent.) [drawing by Szaniszló Bérczi] hu.wikipedia.org/wiki/Szent_Mihály-templom_(Sopron)

Fig. 4. *Dragon* motif

(a) Butmir (near Sarajevo) vase (4900-4700 BC) Gimbutas [18], Fig. 439 (b) Minoan bowl, Platanos, (EM III-MM I) Evans [14], Vol. 2, Fig. 104 (a) (c) embroidery (c. 1900) Tótkomlós, Hungary
Photo (c): http://emf-kryon.blogspot.com/2013/03/a-magyar-nepviselet-es-szakralis.html used with Kati Gábor's permission

Fig. 5. *Embroidery* motif

(a) Minoan vase (detail), Isopata near Knossos, Greece, (LM III), Evans [13], Fig. 75

(b) Hungarian (Székely) wooden gate, Csíksomlyó, Transylvania, Romania (detail, author's photo, 2017)

(c) Scythian bow and arrow case, Chertomlyk Barrow, Ukraine, 4th century BC
Photo from: www.hermitagemuseum.org/wps/portal/hermitage/digital-collection

Fig. 6. *Vine* motif

(a) Minoan griffin, Knossos (LM III) (b) Hungarian hunter, Sânnicolau Mare, Romania (c) Scythian stag, western Asia
en.wikipedia.org/wiki/Throne_Room,_Knossos en.wikipedia.org/wiki/Scythian_art
hu.wikipedia.org/wiki/Nagyszentmiklósi_kincs [drawing after original by J. Hampel]

Fig. 7. *Crown* motif



(a) Cucuteni figurine (4800 – 3000 BC) (b) Minoan seal, Zakros, Crete (MM) (c) fibula, Zemplénagárd, Hungary (10th cent.)
Cucuteni figurines of this type usually contain spirals on the buttocks, which are not visible.
(a): https://en.wikipedia.org/wiki/Cucuteni–Trypillia_culture (b) Evans [14], Vol. 2, Fig. 110a,
(c) by permission of Otto Herman museum, Miskolc, Hungary


(d) Mycenaean stag figurine (e) Detail of a traditional Hungarian (Székely) design embroidery by Zsuzsa Ligeti
Gimbutas [18] (e) by Zsuzsa Ligeti's permission from ligetizsuzsa.5mp.eu/web.php?a=ligetizsuzsa&o=XIb2pzVdeo

Fig. 8. *Fertility* motif



(a) Varna, Bulgaria (4569–4340 BC) (b) Minoan gold plaque, Aegina, (1850-1550 BC) (c) Hungarian plate (detail)
en.wikipedia.org/wiki/Varna_Necropolis en.wikipedia.org/wiki/Aegina_Treasure author's collection

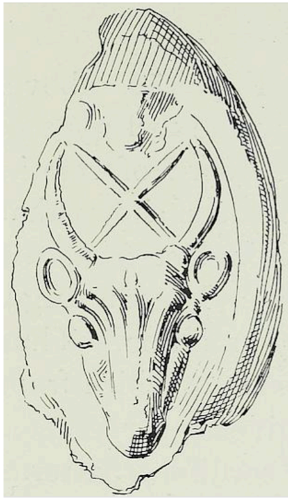
Fig. 9 *Whirl* motif

(a) Kumasa, snake coiling around head (EM II)
Evans [14], Vol. 4, Fig. 121

(b) Hungarian jug from Korond, Transylvania, Romania
(author's collection, 2017)

Fig. 10. *Snake goddess* motif

(a) Cucuteni vase with a triple cross within bullhorns
https://en.wikipedia.org/wiki/Cucuteni–Trypillia_culture



(b) Minoan seal impression, Knossos (MM III)
Evans [14] Vol. 1, Fig. 522

(c) Hungarian (Székely) jug from Korond, Transylvania, Romania (author's collection, 2017)

Fig. 11. *Sacrifice* motif

(a) Iranian bowl (c. 4000 BC)

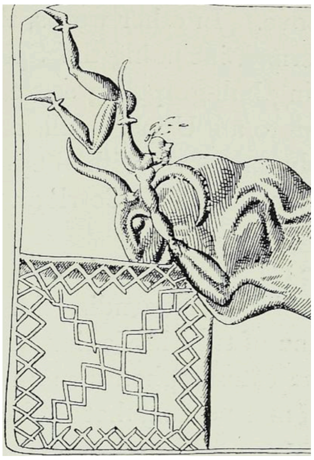
(c) Minoan pottery fragment (EM)
Evans [14], Vol. 4, Fig. 56

(b) Nagyrév culture, Szigetszentmiklós, Hungary
Patay [32]

(d) Hungarian jug, Pécs, Hungary, 1991
author's collection

Photo (a) www.christies.com/lotfinder/Lot/an-iranian-painted-pottery-bowl-with-basket-5903846-details.aspx

Fig. 12. *Water* motif

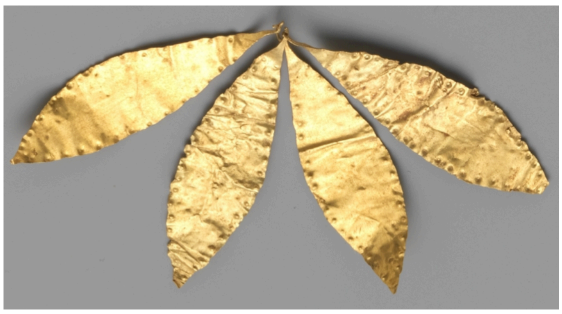


(a) Nagyrév cult., Szigetszentmiklós, Hungary
Patay [32]

(b) Minoan bull, (MM III)
Evans [14], Vol. 1, Fig. 274

(c) Hungarian carpet
www.jofogas.hu/budapest/Torontali

Fig. 13. *Well* motif



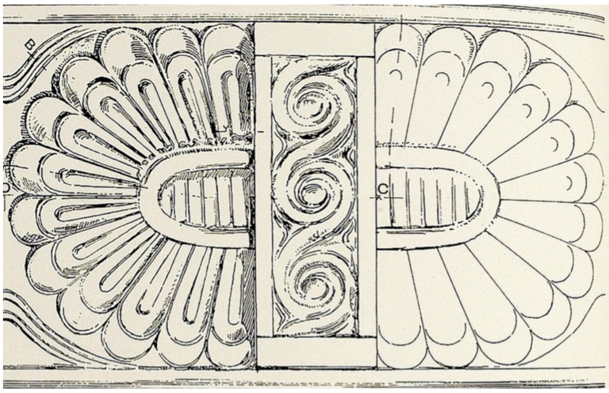
(a) Anatolian idol (3500 -2500 BC)
www.e-tiquities.com/anatolian

(b) Cucuteni, Cărbuna, Moldova
en.wikipedia.org/wiki/Cucuteni–Trypillia_culture

(c) Minoan gold leaf, Mochlos, Crete, Greece (EM II)
Metropolitan Museum of Art, NY
Placed by museum in public domain.

Fig. 14. *Serrated leaf* motif

(a) Cucuteni vase drawing, Valea Lupului, Romania, Gimbutas [18], Fig. 362

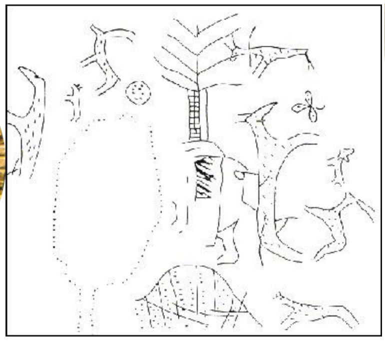


(b) Minoan "half-rosettes", Knossos, Greece (MM III)
Evans [14], Vol. 4, Fig. 173

(c) Salt shaker, Somogy County, Hungary (1856)
Varga [43], p. 210

Fig. 15. *Divided sun* motif

(a) Ring of Minos, Knossos, Greece (LM I-II)
Heraklion Archaeological Museum [CC0]

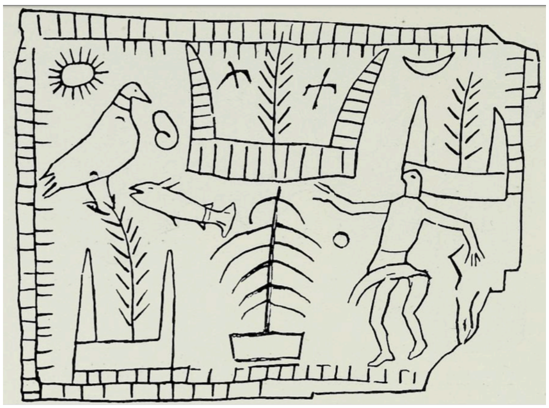


(b) Hungarian shaman tree
Diószegi [11]

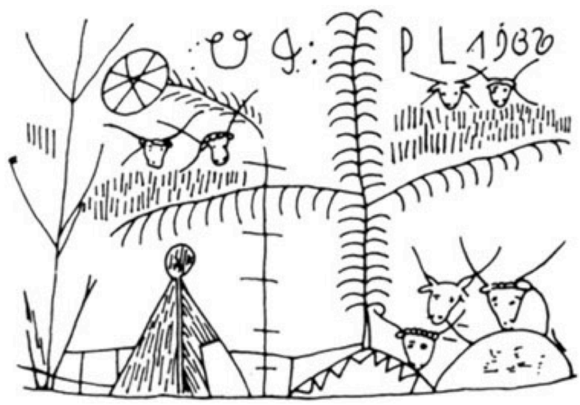
(c) Scythian winged horse
with tree (vase detail)

Photo (a) commons.wikimedia.org/wiki/File:Ring_of_Minos_archmus_Heraklion.jpg
Photo (c) commons.wikimedia.org/wiki/File:Vase_in_the_Scythian_style_01.jpg

Fig. 16. *Heaven's gate* motif



(a) Minoan votive tablet, Psychro Cave (MM III)
Evans [14], Vol. 1, Fig. 470



(b) Hungarian carving of a world tree
https://en.wikipedia.org/wiki/Hungarian_mythology

Fig. 17. *World tree* motif

(a) Minoan seal from Phaistos (MM II)
CMS [28] Vol. 2-5, Fig. 99

(b) bracteate of King Béla IV (1235-1270)
Coins of Hungary [42]

Fig. 18. *Four suns* motif

(a) Minoan seal, Idaean Cace (MM II)
Evans [14] Vol 2, Fig 167

(b) bracteate of King Béla IV (1235-1270)
Coins of Hungary [42]

Fig. 19. *Altar* motif

(a) Minoan Cretan Hieroglyphic seal (MM II)
Ashmolean, Oxford, UK, CMS [28] Vol. 6, Fig. 102

(b) Silver dinar of King St. Stephen I (997-1038)
Coins of Hungary [42]

Fig. 20. *Punctuation* motif