BYPASSING THE EYE OF THE BEHOLDER:
AUTOMATED OSTRACA FACSIMILE EVALUATION*

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INTRODUCTION

Studies of Iron Age ostraca such as the Samaria,1 Lachish2 and Arad3 corpora rely on manually drawn facsimiles.4 Facsimiles crafted by hand may unintentionally mix up documentation with interpretation.

Despite their great importance for the field of epigraphy, to the best of our knowledge no attention has thus far been devoted to facsimile quality evaluation that is independent of the human eye. By quality evaluation we mean an assessment of how well a given facsimile represents the original ostracon. The currently established publication standard includes

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4 By “manually drawing” we refer to both traditional pen-on-paper hand facsimiles, and digital drawings created using utilities such as Adobe Photoshop.
superimposing the facsimile over the inscription image, but this is performed manually with no attempt at measuring the quality of the fit.\(^5\)

In what follows we attempt to:

- Establish a simple, straightforward mathematical procedure to be used for facsimile quality evaluation.
- Test the proposed procedure in order to assess its reliability.
- Establish the foundations for an iterative procedure, in order to allow for improving the drawing of new facsimiles.

As a future development (not to be elaborated in this paper) we envision the deployment of similar procedures for the creation of fully computerized facsimiles.

PRELIMINARY ANALYSIS

Our facsimile evaluation is carried out with respect to an image of the inscription. To compare a facsimile to an ostracon image one needs to align them to one another. We propose to keep the computerized image of the ostracon unchanged, while the computerized facsimile is slightly rotated/squeezed/stretched (operations we refer to collectively as geometrical transformations) in order to receive the best fit. In image processing terms, finding the best fit of one image to another, utilizing allowed geometrical transformations, is denoted as “registration.”\(^6\)

For instance, in the example on the following page (an image of an Egyptian scarab from Megiddo\(^7\), fig. 2 is distorted in relation to fig. 1. Using digital imaging tools, the dimensions of fig. 2 can be altered and the image slightly rotated in order to align with fig. 1.

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\(^6\) In what follows, only relatively simple types of geometric transformations are used. A fairly recent and complete survey of more sophisticated registration techniques can be found in B. Zítova and J. Flusser, “Image Registration Methods: A Survey,” *Image and Vision Computing* 21 (2003): 977–1000.

\(^7\) Courtesy Tel Aviv University and Arie Shaus.
The procedure of registration is demonstrated on Arad Ostracon No. 1. The handwritten facsimile, the image and the registered facsimile are shown in figs. 3, 4 and 5 respectively. As the facsimile deformation should be kept minimal, only slight rotations (up to ±5 degrees), proportional rescalings and small height/width ratio adjustments (up to ±10%), were performed.

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8 Facsimilies: Aharoni (n 3), courtesy the Israel Exploration Society; the ostracon image: courtesy Tel Aviv University.

9 The greatest height/width ratio adjustment achieved in our experiments was 3.3%.
It is quite difficult to observe how well the original and registered facsimiles fit the ostracon image. To show this, we combined the facsimiles with the ostracon image (figs. 6–7). The facsimile images (in white) are overlaid on the ostracon image.

Using the overlaid images, the difference between the registered and the unregistered facsimiles can clearly be seen. The most noticeable features in the unregistered facsimile are the “shadows” surrounding the facsimile silhouette. They occur because the ink of the ostracon image is not obstructed completely by the facsimile as it should be in the case of perfect registration.

**INTRODUCING THE METRIC**

As shown above, given an acceptable registration, the “shadows” are useful for facsimile quality assessment. One needs to find a way to quantify their size, so that different facsimiles can be compared. The mere existence of ink areas not obstructed by the facsimile may be a sign of either inaccurate registration, or inadequate depiction of the ostracon by the facsimile. Following similar reasoning, if the facsimile corresponds perfectly to the ostracon image, no bright = “clay” areas underneath the facsimile will be present; the facsimile will simply fit.
In computerized (grayscale) imagery, each element (pixel) has a numeric value (representing a gray level), with black coded as 0 and white as 255. One can use this numeric value in order to quantify the fit between the ostracon image and the facsimile.

![Grayscale Levels](image)

Fig. 8: The nominal grayscale levels

Following our analysis above, the requirements from a facsimile should be:

1. The pixel values “below” the facsimile should be as small (dark) as possible. The average of these values is denoted here as “inkness.”
2. The pixel values outside the facsimile ought to be as large (bright) as possible. The average of these values is denoted here as “clayness.”

![Facsimile Comparison](image)

Fig. 9: (Above) An enlarged fragment of the ostracon image (fig. 4, last line, left). (Below) The same fragment, compared with a registered facsimile. Note that the depiction of the leftmost character is problematic; this causes the “inkness” to be somewhat higher (thus less satisfactory).

Merging the “inkness” and the “clayness” averages is desirable.
The simplest formula combining the two is the CMI ("clayness minus inkness") metric:

\[ \text{CMI} = \text{clayness} - \text{inkness} \]

As the objective is to maximize "clayness" and minimize "inkness," the goal is to maximize the CMI index.

Taking as an input the facsimile and an ostracon image after applying the registration procedure discussed above, both the "inkness" and the "clayness" averages can be calculated, leading to a simple CMI metric calculation. The CMI indexes depend on the given ostracon image. For example, an image with different illumination may produce different numbers. Furthermore, the CMI index magnitude by itself is of little importance for the evaluation of the facsimile quality. Only the difference (or the ratio) between indexes of different facsimiles can allow comparison of their qualities. In what follows we put this idea to a test.

**METHODOLOGY VERIFICATION 1**

Arad Ostracon No. 34\(^{10}\) (which contains hieratic numerals), is evaluated below (figs. 10–18). A comparison of several facsimiles of the same ostracon, drawn by different individuals, was performed. Two of the facsimiles were drawn by epigraphers and one by an artist. In order to avoid identifying these illustrators, they are denoted below as A, B and C.

- In the first stage, utilizing the registration program,\(^{11}\) the best registration of the facsimiles to the ostracon image was obtained.
- In the second stage, the registration outputs and the CMI indexes for the different facsimiles were compared in order to identify the best facsimile.

Figs. 10–13 show the ostracon image and the 3 facsimiles\(^{12}\) after the registration procedure:

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\(^{10}\) Aharoni (n 3).

\(^{11}\) Which is also guided by the CMI metric.

Fig. 10: Arad Ostracon No. 34

Fig. 11: Registered Facsimile A
Fig. 12: Registered Facsimile B

Fig. 13: Registered Facsimile C
Figs. 11–13 show that the relative evaluation of the different facsimiles is quite difficult. The results of the CMI-based evaluation follow.

**Fig. 14: Overlaid Facsimile A  CMI = 71.1**

The overall fit of overlaid Facsimile A is good. Nevertheless, the facsimile characters are not always correlated with the ostracon image characters (e.g., fig. 14, lower left); the characters themselves are somewhat oversized.

**Fig. 15: Overlaid Facsimile B  CMI = 82.6**
The overlaid Facsimile B fit is good and the facsimile characters seem to be in better correlation with the ostracon image. On the other hand, the character strokes are sometimes a bit too wide (e.g., fig. 15, upper left) and the fit is not always perfect. Also notice cases where the strokes are not long enough (e.g., fig. 15, upper left and lower right).

In the case of overlaid Facsimile C the characters are narrow and “crisp”; they seem to be a good fit. The CMI index is justifiably high, despite one possibly missing character, taken for a scratch or stain (fig. 18, upper right). Still, due to the overall high quality of the facsimile, the CMI score remains high.

Another look at the four different image fragments shows that the scores are indeed founded on the facsimiles’ relative merits (figs. 17–20).

Fig 16: Overlaid Facsimile C  CMI = 84.0

Fig. 17: Upper left fragment (clockwise, original image, A, B, C)
Fig. 18: Lower left fragment (clockwise, original image, A, B, C)

Fig. 19: Upper right fragment (clockwise, original image, A, B, C)

Fig. 20: Upper right fragment (clockwise, original image, A, B, C)
The procedure we used indicates that Facsimile C is the best of the three. It also indicates that providing the person who draws the facsimile with the CMI tool may improve the accuracy of the facsimile.

**METHODOLOGY VERIFICATION 2**

As stated above, the CMI index depends on the ostracon image. Camera position and angle (vis-à-vis the object) as well as illumination characteristics are critical factors in obtaining the image. They can change the CMI as stated above. However, the procedure we propose should allow us to maintain the CMI ranking of the three facsimiles independent of the ostracon image. To demonstrate this we compare the same facsimiles with a different image of the same hieratic ostracon (Arad No. 34).\(^\text{13}\)

![Fig 21: Another image of Arad Ostracon 34.](image)

Comparing figs. 10 and 21, it is obvious that the latter image is markedly different from the former: it is viewed from a different angle, it is slightly rotated, the background is brighter and lacks shadows, and the ostracon itself is darker.

\(^{13}\) Courtesy of the Israel Antiquities Authority.
Table 1 summarizes the results of the first and second comparisons. The protocol (applying a registration to the input facsimiles and calculating the resulting CMI metric) is the same in both cases.

Table 1: CMI Results for two attempts to compare the facsimiles to Arad Ostracon 34

<table>
<thead>
<tr>
<th>Facsimile</th>
<th>CMI score using Image #1</th>
<th>CMI score using Image #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>71.1</td>
<td>64.5</td>
</tr>
<tr>
<td>B</td>
<td>82.6</td>
<td>71.6</td>
</tr>
<tr>
<td>C</td>
<td>84.0</td>
<td>75.1</td>
</tr>
</tbody>
</table>

The change in the magnitude of the score is hardly surprising, as the image has a different grayscale level distribution. What is important is the fact that the order of the CMI scores is maintained despite the utterly different ostracon images: the A score is lower than the B score, with the C index higher than both A and B. In other words, despite using substantially different ostracon images, the relative results of the facsimile evaluation remain effectively the same.

**SHORTCOMINGS**

Several shortcomings in the method and its verification are worth mentioning:

1. In any given quality assessment metric, some cases can lead to misleading results. The CMI index is no exception. As an illustration, let us assume an extremely faint character, with gray levels comparable to typical clay gray levels. In such a case, omitting the character from the facsimile might be preferable from the CMI index point of view. A compromise could be to draw only a silhouette of such a faint character. Another example may be that of a dark stain; from the CMI index perspective it may be better to record it on the facsimile as if it were a character.

2. The CMI-based evaluation depends on registration of the facsimile to the ostracon image. It can be claimed that the currently used registration is excessively simple, only allowing for small rotation and subsequent minor rescalings. A more delicate registration can be considered; registering on a per-
character basis, for instance, may lead to another quality measure and allow for low scale correction of the drawing. Such a method of registration may also compensate for nonlinear camera distortions.

3. The results presented here were obtained from a limited number of test cases. Additional research is expected to strengthen the confidence in this methodology.

CONCLUSIONS AND FUTURE DIRECTIONS

Our technique for evaluating different facsimiles of the same ostracon was tested on three facsimiles and two different images of the same ostracon (Arad No. 34). The CMI (“clayness minus inkness”) grades received for the facsimiles reflect their relative merits. Based on the CMI scores, the ranking of the facsimiles are minimally influenced by the ostracon image. It can therefore be concluded that the proposed technique is sound and can be used in order to evaluate the accuracy of a facsimile in relation to the original ostracon. Our method can also be used as a facsimile-drawing aid, allowing for iterative improvements of the facsimile drawing.

It is possible to extend the methodology for the use of a computer-based binarization (automatic facsimile production). In other words, although the facsimiles cannot be regarded as a perfect representation of the ostracon, they may be used as a “first draft” for a new facsimile, produced by a computer. Non-ostraca inscriptions (along with their facsimiles) can also be dealt with, given some minor adaptations.