2 New Technologies for Tracing Magical Texts and Drawings: Experience with Automatic Binarization Algorithms

Raquel Martín Hernández and Arie Shaus

Many issues faced by paleographers and philologists in their study of the materiality of the objects at hand might provide obstacles that can literally make or break our ability to interact with a given text. The essays in this book show how new technologies are significantly helping in the tasks of deciphering, understanding, and restoring ancient texts written on different materials.

Philological editions of ancient texts, and articles in which ancient artifacts are studied, sometimes require facsimiles of the discussed finds: tablets, gemstones, and papyri. The facsimiles are especially important for certain objects when a normal photograph cannot fully capture or elucidate the writing (e.g., texts written on metal lamellae). In these and other cases, as we explore below, the production of facsimiles provides a great tool in the advancement of interacting with and understanding texts.

In this chapter we examine some possible methods of producing facsimiles of ancient objects, specifically those that have been studied within the projects led by Christopher A. Faraone and Sofía Torallas Tovar at the University of Chicago. These projects focus on Greco-Egyptian magical formularies and curse tablets written in Greek and Latin. Here we make an initial assessment of the material particularities of individual fragments and then describe different methods that can be used to produce black-and-white facsimiles of these artifacts. Finally, we explore the possibility of using automatic binarization algorithms and analyze the results obtained across different materials.

FRAMEWORK

The University of Chicago's Transmission of Magical Knowledge in Antiquity: The Papyrus Magical Handbooks in Context[1] is an ambitious project aiming to reedit, translate, and study the preserved magical formularies of Greco-Roman Egypt (first century BCE to fifth century CE). One of the primary goals of the project is to focus on the materiality of the papyri. The study includes not only the texts but also magical drawings that appear within the texts—mainly figural representations of gods and demons, victims, and magical

1 The project, directed by Christopher A. Faraone and Sofía Torallas Tovar, has been funded by the Neubauer Collegium for Culture and Society. See https://papyrusmagicalhandbook.wordpress.com.

symbols. These images will be integrated with the edited texts in black-and-white facsimiles, placed in the same position in which they appear in the original document. In this way, the reader will have a clear picture of the layout of the text without having to turn to the image of the papyrus itself, which is sometimes difficult to access. This project proposes a promising new methodology that looks to provide a more accurate understanding of the peculiarities of these specific texts and their transmission.[2]

On the other hand, the project Curses in Context, also funded by the Neubauer Collegium for Culture and Society, aims at a more intensive and contextualized study of ancient curse tablets written in Greek and Latin. Texts written on lead are usually edited without using a photograph of the tablet, mainly because normal captures do not provide a sufficient contrast of light and shadow to allow the reader to examine the document thoroughly. Sometimes, however, the edited text is accompanied by a drawing or a black-and-white facsimile. In the past, drawings by hand were the only option. This technique, though extremely useful, is not within the reach of everyone's artistic abilities. In addition, such facsimiles usually involve a higher degree of inaccuracy because they are often biased by the text-editor's interpretation.[3] Today, the use of high-resolution photographs and technological advances in facsimile production can better meet the demands of production and enhance the reliability of these drawings. Furthermore, the use of automatic binarization algorithms allows us to produce facsimiles of great precision after only a brief investment of time.

Depending on the scholar's degree of intervention in the creation of the facsimile, the techniques employed can be categorized as manual, semiautomatic, and automatic. As we point out below, all of these techniques have their respective advantages and disadvantages. In addition, the effectiveness of automatic binarization algorithms depends on the material on which the text was written.

MATERIALITY OF MAGICAL TEXTS AND PROBLEMS OF LEGIBILITY

Papyrus is probably the material surface that offers the least number of issues for facsimile creation, thanks to the high contrast between the black ink and the papyrus's light-yellow fibers. In most cases, the ink is well fixed to the fibers and clearly legible, unless superficial problems are present—for example, carbonization of the papyrus,[4] deterioration of the surface by external agents, or instability of the ink itself. Subsequently, given the papyri we are working on (mainly Greco-Egyptian magical formularies), infrared, multispectral, or reflectance transformation imaging (RTI) captures[5] are not normally required.

2 The first volume of the project has been published; see Faraone and Torallas Tovar 2022.

3 For an analysis of the degree of interpretation, see Shaus, Finkelstein, and Piasetzky 2010.

4 On the use of new technologies employed to read carbonized or deteriorated papyri, see, e.g., Kleve and Del Mastro 2000; Chabries, Booras, and Bearman 2003; Bülow-Jacobsen 2008; Bay et al. 2010; Macfarlane 2010; Alexopoulou et al. 2013; Kotoula and Earl 2015; and Janko 2016.

5 On RTI, see Earl et al. 2011; https://culturalheritageimaging.org; and chapter 1 in this volume.

In antiquity, potsherds were commonly used as writing material for private use and are particularly linked to aggressive magic, according to the procedures preserved in formularies and the content of the actual curses themselves (Martín Hernández and Torallas Tovar 2014b). Texts and drawings produced on potsherds (resulting in "ostraca," sing. "ostracon") were usually made with ink, since it adheres well to the surface of earthenware, though not quite as well as to papyrus. In the case of ostraca that have been exposed to deleterious external agents, the ink is often erased and the reading more challenging.

In cases where the surface of the ostracon has been effaced and the text is practically illegible, both infrared and multispectral photography may be useful (Bearman and Christens-Barry 2009; Faigenbaum et al. 2012, 2014; Sober et al. 2014). A successful capture of the object using these techniques with the added assistance of photo-retouching programs may offer a high-quality image that reveals more than the naked human eye can see (Faigenbaum-Golovin et al. 2017; Mendel-Geberovich et al. 2017).

Finally, in antiquity, metals—particularly lead—comprised the most common surfaces on which curse tablets were produced. The ductility of lead, together with its low economic cost and the multiple ritual analogies that were established between its color and coldness, made it the ideal material to carry out such aggressive ritual acts. The tablets were usually very thin and of small dimensions. Texts, symbols, and images were engraved with very sharp objects and are sometimes very small. To complicate matters, the tablets were often folded, pierced by nails, or deposited in bodies of water. Consequently, the small size of the text, the folding marks, the holes, and the degenerating effects of external agents on the tablet can turn the reading process into a significant ordeal. In such cases, new imaging technologies may offer great help for reading the texts.[6]

THE CREATION OF FACSIMILES OF MAGICAL TEXTS AND THE PROMISE OF NEW TECHNOLOGIES

MANUAL FACSIMILES

Publications of magical texts from antiquity often include black-and-white drawings or a high-quality image of the text to provide the reader with a clear image with which the proposed readings can be collated.[7] This provision is especially important for texts with magical images. Older editions of these texts, however, usually did not include such images (e.g., Wessely 1893; Audollent 1904),[8] though in some cases the edited texts were accompanied by freehand drawings (e.g., Kenyon 1893; Wünsch 1898). For example, the corpus of Greek Magical Papyri (*Papyri Graecae Magicae*), edited in 1928 (Preisendanz 1928–31), does not make any attempt at introducing high-quality drawings. Only some of the magical symbols were sporadically drawn in freehand and included in the publication. Small black-and-white photographs of some of the drawings of the papyri were included at the

6 See chapter 3 in this volume.

7 Bülow-Jacobsen 2020.

8 The drawings by Audollent, not included in his edition of the curse tablets, have been recently published in Németh 2013.

end of each volume. The publication itself included only a description of the drawing (either in the edited text or in its critical apparatus). The English translation of this corpus by Hans Dieter Betz, published in 1986, made an effort to supplement the texts with their corresponding images by including freehand drawings.

Computer image-editing software, such as Adobe Photoshop or Adobe Illustrator, may be extremely useful in creating accurate facsimiles. Producing "manual" facsimiles using these programs is an easy task, as the scholar needs only a high-quality digital image of the text, an image-editing program, a drawing tablet,[9] and a steady hand. With the image open in Adobe Photoshop, a new layer must be added to the image. The letters and drawings of the original inscription may be tracked in this new layer by using a different color for better contrast of parts of the image or text that are already tracked. When the work is complete, the background image is removed and the tracked layer saved. Changing the tracking color to black results in a black-and-white facsimile.

Recently, applications ("apps") developed for tablet computers have been improved, and now there exist convenient tools for performing the task of facsimile creation. Adobe apps such as Adobe Sketch, Adobe Draw, and Astropad[10] are all interesting choices. These apps make it possible to trace drawings by using a digital pen directly on one's screen, thus facilitating great precision.

All these manual processes can provide accurate facsimiles. Still, they require spending a great deal of time on deciphering strange symbols and complicated drawings, especially when the text is long or contains additions, as is usually the case in our projects.

SEMIAUTOMATIC FACSIMILES

Image-editing programs provide sophisticated tools that assist in editing images and producing semiautomatic facsimiles. Using contrast manipulation, color correction, noise removal, and mechanisms to separate the foreground from the background, a provisional facsimile can be created in relatively little time. These kinds of tools work well for black text written on papyrus and potsherds but are more difficult to apply with good results on other materials, such as lead. In this case, RTI images and viewers are of great help. This approach offers a good alternative to manual facsimiles, but the user must be aware of the possible loss of information during the process, since the writing is sometimes faded and can be completely lost when using color correction.

AUTOMATIC BINARIZATION ALGORITHMS

In projects such as the ones we are referring to—projects in which large numbers of facsimiles must be produced—alternatives that make the work both easier and faster without losing accuracy must be investigated. For that reason, we have explored the advantages of using automatic binarization algorithms. These methods allow for very fast, automatic production of black-and-white (binarized) versions of digital images. Often, such binarized

9 If only a personal computer is available, see Shaus et al. 2016.

10 This app uses the tablet as though it were a drawing tablet. The program is available and fully supported for use on Windows and Mac.

images are used as a first step toward further image-processing and text analysis tasks, such as optical character recognition, text digitization, and identification and comparison of scribes (Faigenbaum-Golovin et al. 2016, 2020; Shaus et al. 2020), but they can also be used alone for publication purposes.

Binarization algorithms (for a survey and examples, see Shaus, Turkel, and Piasetsky 2012) are performed on grayscale digital images. If several channels are present in the image, as in RGB (red-green-blue) images, they are usually averaged in advance on a per-pixel basis. Automatic binarization algorithms can be roughly divided into the two most common types: global and local.

Global algorithms partition the image into foreground (black) and background by setting a single binarization threshold for the whole image based on a certain logic. For example, if colors from 0 (black) to 255 (white) are present, an algorithm may set a threshold to 100, turning all the pixels with values 0–100 into 0 and pixels with values 101–255 into 255. The threshold can be predetermined or chosen by a method that takes into account the image's specific information; the most common such algorithm was suggested by Nobuyuki Otsu (1979).

Local algorithms are another, slightly more sophisticated option for producing a binarization. Typically, a binarization threshold would be computed for each pixel in the image individually based on its surrounding pixels—a "sliding window." The size of the window is important and may greatly influence the binarization results; a window size is typically chosen based on the resolution of the image, the size of the characters or drawings, and the distance between the lines. Local algorithms propose a natural technique of dealing with issues such as differential preservation of ink or uneven illumination of the artifact, though at the cost of higher computational burden and lack of "whole image" information when calculating the local thresholds. Numerous local binarization methods have been suggested, the most prominent being those by Wayne Niblack (1986) and Jaako Jari Sauvola (Sauvola and Pietikainen 2000).

Noting the promising results that such algorithms have offered for texts written on potsherds (Shaus, Turkel, and Piasetsky 2012), we began a collaboration and applied the various algorithms to texts written on other materials, such as papyrus, parchment, and metal. In addition, we tested the algorithms on drawings and symbols, frequently featured on documents.

EXPERIMENTS

EXPERIMENTAL SETTING

We developed a program allowing for the fast creation of several binarizations for each document, a program to be utilized and evaluated by the paleographer. The following algorithms were applied: predetermined threshold values of 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200, 210, 220, 230, and 240; Otsu automatic global threshold selection algorithm; Niblack local threshold selection algorithm with half-window sizes of 50, 100, 150, 200, and 250 pixels; Sauvola local threshold selection algorithm with half-window sizes of 50, 100, 150, 200, and 250 pixels (the real window is of the size 2 × half + 1 pixels).

AUTOMATIC FACSIMILES OF MAGICAL TEXTS ON OSTRACA

Unsurprisingly, the program produces quite good black-and-white binarizations for texts and images written on potsherds. Here we have chosen an aggressive Coptic magical text (edition in Martín Hernández and Torallas Tovar 2014a) to demonstrate the automatic facsimile created by the algorithm. For an example of the program's run, see figure 2.1; for results, see figure 2.2.

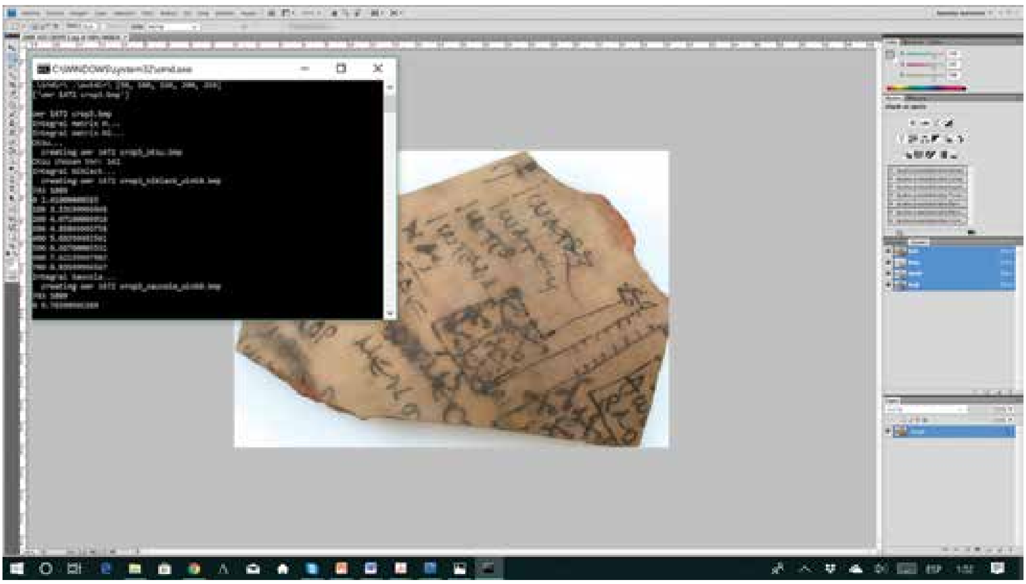


Figure 2.1. Capture of the original image of the piece and the program's run. Image ©Abadía de Montserrat.

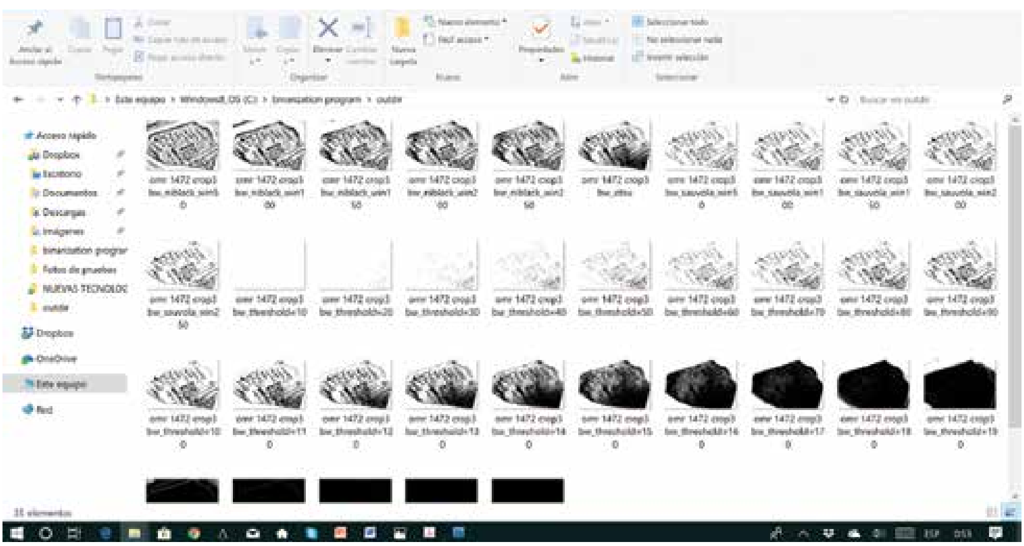


Figure 2.2. Example of results provided by the automatic binarization algorithm.

Some problems with shading on the edges due to the curved surface were detected. Such issues can be resolved by combining two or three resulting binarizations in Photoshop or another image-editing program to obtain an accurate image of the whole artifact. With just some slight adjustments using the editing tools, a rather accurate facsimile can be produced in a short time, as exemplified in figure 2.3.

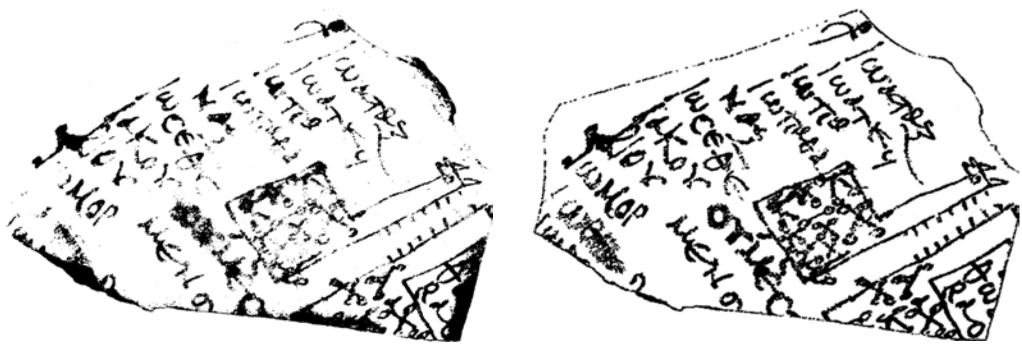


Figure 2.3. Example of binarization and facsimile creation of a Coptic magical text. *Left:* The best image produced by automatic binarization (sauvola_win50). *Right:* The final product—a combination of different images produced by the program with a little image retouching in Photoshop.

AUTOMATIC FACSIMILES OF MAGICAL TEXTS ON PAPYRUS AND PARCHMENT

The program produced a less efficient binarization with papyrus than it did with potsherds, mainly because the surface of papyrus presents more shades, and its color scheme is larger than that on ostraca. Using a multispectral or infrared capture of the object, however, could certainly improve the outcome. The results of the first tests were promising but, again, not as distinct as the results obtained with ostraca. One of the issues is that if one saves the image of the papyrus in the CMYK (cyan-magenta-yellow-key) color mode instead of RGB, the algorithm produces a binarization in which the colors are inverted: the ink is in white and the papyrus surface is in black. To produce a more accurate black-and-white facsimile, only a color inversion is needed. Some minor retouching and a bit of erasing reduces the difference between the automatic facsimile and the manual facsimile. An example of the result can be seen in figure 2.4.

The binarizations for texts written on parchment are similar to those on papyrus. Depending, however, on the preservation of the ink and the thinness of the parchment, which can make the ink on the back visible on the front (a "bleed-through" effect), the results are very different. The use of infrared or multispectral images can be of great help in the most difficult cases. An example of the result is shown in figure 2.5.

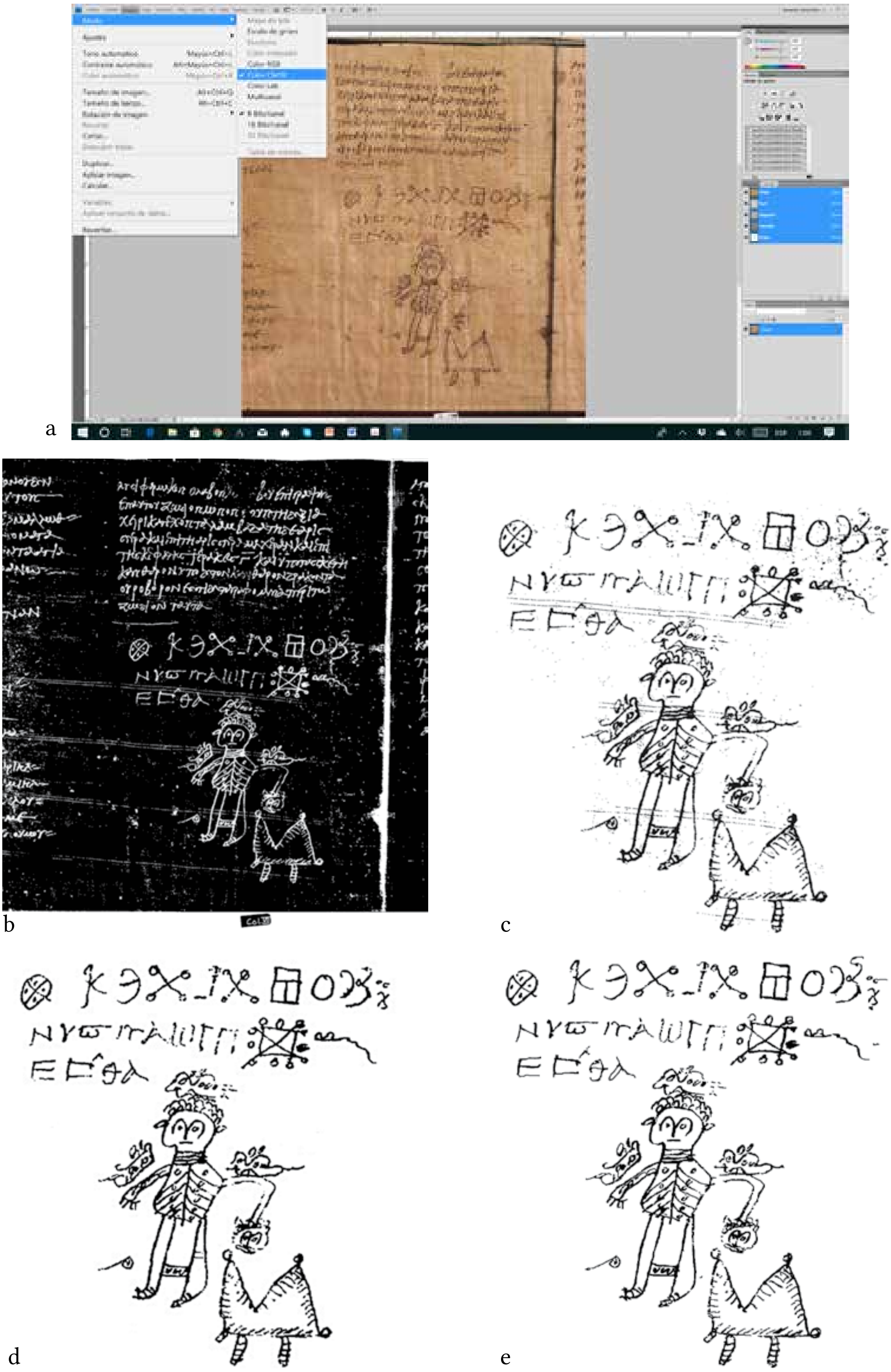
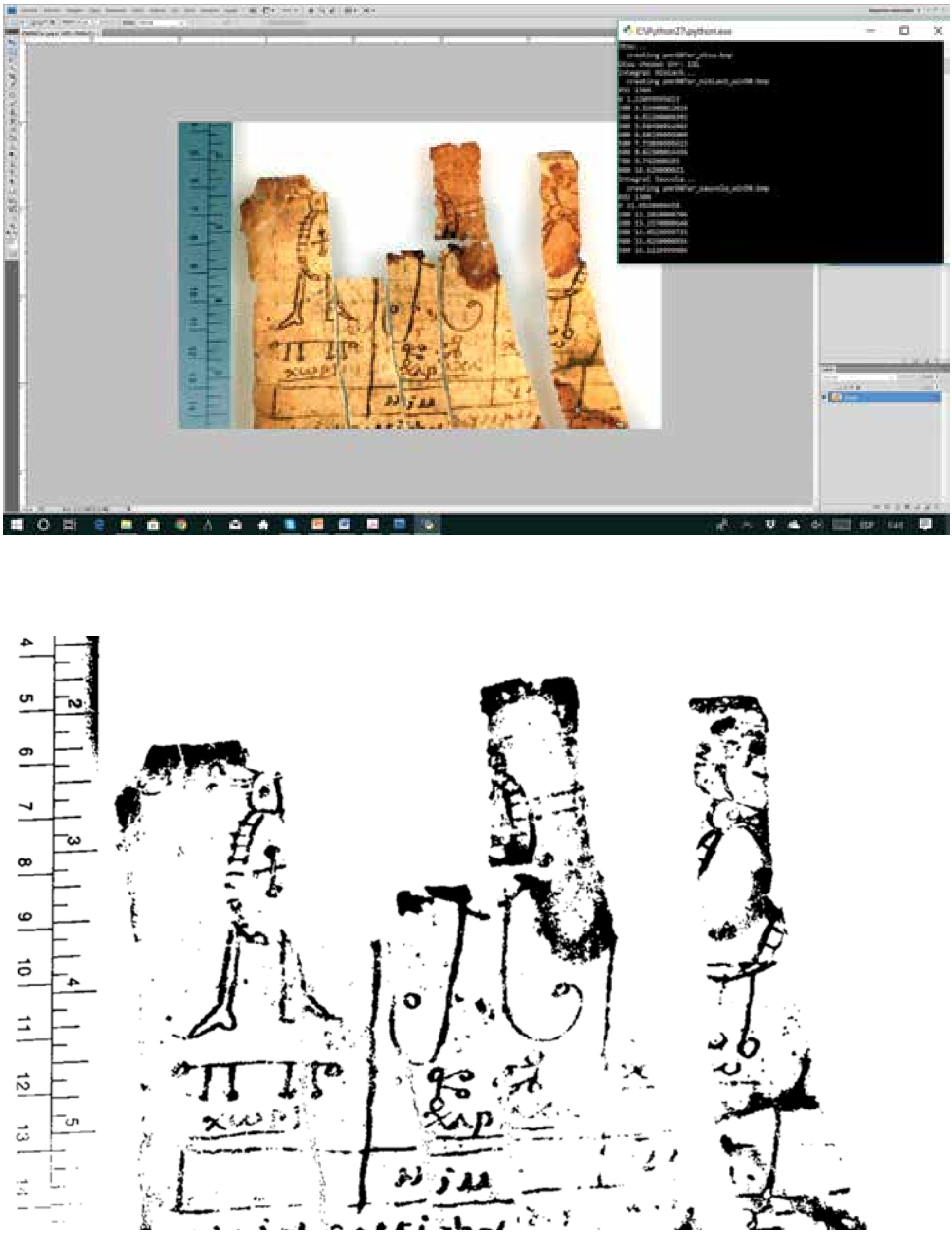


Figure 2.4. Example of binarization and facsimile creation with papyrus: P.Oslo I 1, © University of Oslo. *a:* Saving the image in CMYK mode. *b:* Result obtained by the algorithm (threshold at grayscale value of 150). *c:* Inversion of colors. *d:* Retouched automatic facsimile. *e:* Manual facsimile.



a

b

Figure 2.5. Example of binarization and facsimile creation with parchment.
a: Magical texts on parchment. P.Monts.Roca inv. 607a ©Abadía de Montserrat.
b: Automatic binarization (Sauvola algorithm with half-window size of 50 pixels).

AUTOMATIC FACSIMILES OF MAGICAL TEXTS ON METAL (LEAD)

Texts written on lead are typically the most challenging. Without an RTI image of the artifact, the results are very poor. Even with an RTI capture present, producing a facsimile of the whole object is difficult, mainly because of problems in its preservation, irregularities of its surface, and the visibility of its incisions.

An RTI image is created from multiple digital photographs taken from a stationary camera position. Every photograph is taken with light projected from a different direction using a lighting dome (in RTI) or a handheld flash (in H-RTI). This technique has greatly improved the visibility of texts written on lead using viewers of RTI images such as RTIViewer.[11] RTI viewers offer binarized images that, contingent on the light, can make the text more or less visible depending on the part of the surface on which the text is written. This technique may offer good visibility of specific artifacts, especially those where the contrast between light and shadow is greater. Tests with our program were performed to see how well the binarization algorithms work with RTI images of lead curse tablets, but unfortunately the results were poor.

FURTHER STEPS

Several future avenues of research can be proposed:

- All the binarizations may benefit from automatic speckle removal (for details, see Shaus, Turkel, and Piasetzky 2012), which can offer further improvement of processing speed.
- More sophisticated overall improvement may be achieved by using sparse methods in the binarization process (for an example, see Shaus et al. 2013).
- If specific characters or minor details require reconstruction, the use of a semiautomatic stroke reconstruction algorithm (see Sober and Levin 2017) may be advised.
- A combination of 3D scanning and pattern recognition algorithms can be beneficial for incised texts (for an example, see Rothacker et al. 2015).
- For documents written in ink, a hardware-based binarization can be attempted (see Shaus et al. 2019).

CONCLUSIONS

Given the great advances in technology that are easily accessible to scholars and the great ease of obtaining high-quality images of ancient texts, it is vitally important that philological editions take advantage of these advances to offer a more complete presentation of the texts. Increasingly, editions of ancient texts tend to take into account the data provided by the material study as well as other features generally left aside in past studies, when scholars were mainly interested in providing only an accurate reading of the text. In projects such as those described above, which aim to offer an edition as faithful to the original as

11 This free and open-source program is accessible at https://culturalheritageimaging.org/What_We_Offer/Downloads/.

possible, the production of facsimiles to be included in the published edition of the text is of vital importance. This study explores the possibilities of using automatic binarization algorithms to reach that goal. Such algorithms provide great help in creating accurate black-and-white images in record time, and their effectiveness has been shown for texts on papyrus, parchment, and potsherds. The results for engraved texts, especially on metal, are not as promising at the moment, but some ideas and desiderata have been suggested here. The results and proposals we have presented constitute the first steps in the effort to achieve, in the future, equal effectiveness in the binarization of ancient texts in metal.

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